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INTERNATIONAL STANDARD

IEEE Std 1076.1™

Behavioural languages –
Part 6: VHDL Analog and Mixed-Signal Extensions

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Behavioural languages – Part 6: VHDL Analog and Mixed-Signal Extensions

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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The text of this standard is based on the following documents:

IEEE Std	FDIS	Report on voting
1076.1 (2007)	93/280/FDIS	93/286/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

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IEEE Standard VHDL Analog and Mixed-Signal Extensions

Sponsor

Design Automation Standards Committee
of the
IEEE Computer Society

Approved 17 May 2007

IEEE SA-Standards Board

Abstract: This standard defines the IEEE 1076.1 language, a hardware description language for the description and the simulation of analog, digital, and mixed-signal systems. The language, also informally known as VHDL-AMS, is built on IEEE Std 1076™-2002 (VHDL) and extends it with additions and changes to provide capabilities of writing and simulating analog and mixed-signal models.
Keywords: analog design, computer, computer languages, hardware design, mixed-signal design, VHDL

IEEE introduction

The IEEE 1076.1 language, informally known as VHDL-AMS, is a superset of IEEE Std 1076-2002 (VHDL) that provides capabilities for describing and simulating analog and mixed-signal systems with conservative and nonconservative semantics for the analog portion of the system. The language supports many abstraction levels in electrical and non electrical energy domains. The modeled analog systems arelumped systems that can be described by ordinary differential equations and algebraic equations. The language does not specify any particular technique to solve the equations, but it rather defines the results that must be achieved. The solution of the equations may include discontinuities. Interaction between the digital part of a model and its analog part is supported in a flexible and efficient manner. Finally, support for frequency domain small-signal and noise simulation is provided.

The extension of VHDL to support analog and mixed-signal systems began in 1989, as part of the second revision of IEEE Std 1076 targeted for a 1993 release. A large number of requirements to support analog and mixed-signal systems were submitted, and it soon became apparent that the complexity of the topic required the formation of a separate working group. The design of the IEEE 1076.1 language formally began in 1993, when the IEEE 1076.1 Working Group was formed under the auspices of the Design Automation Standards Committee of the IEEE Computer Society, under Project Authorization Request (PAR) 1076.1. Its charter was to extend the IEEE 1076 (VHDL) language to support the requirements for the description and simulation of analog and mixed-signal systems. The IEEE 1076.1 Working Group approved the draft standard in June 1997. The first release of the draft of IEEE Std 1076.1-1999 was approved by the IEEE Standards Board on 18 March 1999.

The 2007 revision includes changes made to IEEE Std 1076-2002 since the first release of the IEEE 1076.1 standard. It also includes clarification of IEEE 1076.1 language definitions and corrections of typographical errors that were introduced in the 1999 version of the IEEE 1076.1 language reference manual. See the Annex D for a list of changes from the 1999 release.

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BEHAVIOURAL LANGUAGES –

Part 6: VHDL Analog and Mixed-Signal Extensions

0. Overview

This clause describes the purpose, scope, and organization of this standard.

0.1 Purpose and scope

This standard defines IEC 61691-6/IEEE 1076.1™ language, a hardware description language for the description and the simulation of analog, digital, and mixed-signal systems. The language, also informally known as VHDLAMS, is built on the IEC 61691-1-1/IEEE 1076™ (VHDL) language and extends it to provide capabilities of writing and simulating analog and mixed-signal models.

This document contains the complete reference of the IEC 61691-6/IEEE 1076.1 VHDL language, including the unchanged portions of the base language and the extensions. Formally, IEC 61691-6:2009/IEEE Std 1076.1-2007 defines the extensions only, and portions of text marked with change bars are either exclusively part of IEC 61691-6:2009/IEEE Std 1076.1-2007 or define changes compared to IEC 61691-1-1:2004/IEEE Std 1076-2002.[1] Portions of text not marked with change bars are identical in this document and in IEC 61691-1-1:2004/IEEE Std 1076-2002.

The primary audience of this document are implementers of tools supporting the language and advanced users of the language. The document is not intended to provide any introductory or tutorial information. It rather provides formal definitions of language elements and language constructs.

The IEC 61691-6/IEEE 1076.1 language is a superset of the IEC 61691-1-1/IEEE 1076 language (VHDL). As such, any legal IEC 61691-1-1/IEEE 1076 model is a IEC 61691-6/IEEE 1076.1 model, and any IEC 61691-6/IEEE 1076.1 tool shall provide the same simulation results as obtained with an IEC 61691-1-1/IEEE 1076 tool. IEC 61691-1-1:2004/IEEE Std 1076-2002 and IEC 61691-6:2009/IEEE Std 1076.1-2007 will remain separate standards. This means that when IEC 61691-1-1:2004/IEEE Std 1076-2002 is revised, IEC 61691-6:2009/IEEE Std 1076.1-2007 will not be automatically revised accordingly. A separate effort will be required to keep both standards synchronized and to avoid inconsistencies.

0.2 Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in the text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

This standard is dependent upon IEC 61691-1-1:2004/IEEE Std 1076-2002. In addition, certain definitions in this document depend on IEEE Std 1076.2-1996, which describes via standard packages and definitions mathematical functions that can be used within VHDL design units.

IEC 61691-1-1:2004 *Behavioural languages - Part 1-1: VHDL language reference manual*

IEEE Std 1076-2002, *IEEE Standard VHDL Language Reference Manual*.[2, 3, 4]

[1] Information on references can be found in 0.2.

[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/). IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/).'

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[4] IEEE Std 1076-2002 was adopted as IEC 61691-1-1:2004.

IEEE Std 1076.2-1996 (Reaff 2002), IEEE Standard VHDL Mathematical Packages.

0.3 Structure and terminology of this standard

This standard is organized into clauses, each of which focuses on some particular area of the language. Within each clause, individual constructs or concepts are discussed in each subclause.

Each subclause describing a specific construct begins with an introductory paragraph. Next, the syntax of the construct is described using one or more grammatical *productions*.

A set of paragraphs describing the meaning and restrictions of the construct in narrative form then follow.

In this document, the word *shall* is used to indicate a mandatory requirement. The word *should* is used to indicate a recommendation. The word *may* is used to indicate a permissible action. The word *can* is used for statements of possibility and capability.

Finally, each clause may end with examples, notes, and references to other pertinent clauses.

0.3.1 Syntactic description

The form of a VHDL description is described by means of context-free syntax using a simple variant of the Backus-Naur Form; in particular:

a) Lowercase words in roman font, some containing embedded underlines, are used to denote syntactic categories, for example:

    formal_port_list

    Whenever the name of a syntactic category is used, apart from the syntax rules themselves, spaces take the place of underlines [thus, "formal port list" would appear in the narrative description when referring to the syntactic category in item a)].

b) Boldface words are used to denote reserved words, for example:

    array

    Reserved words shall be used only in those places indicated by the syntax.

c) A *production* consists of a *left-hand side*, the symbol "::=" (which is read as "can be replaced by"), and a *right-hand side*. The left-hand side of a production is always a syntactic category; the right-hand side is a replacement rule. The meaning of a production is a textual-replacement rule: any occurrence of the left-hand side may be replaced by an instance of the right-hand side.

d) A vertical bar (|) separates alternative items on the right-hand side of a production unless it occurs immediately after an opening brace, in which case it stands for itself, as follows:

    letter_or_digit ::= letter | digit
    choices ::= choice { | choice }

    In the first instance, an occurrence of "letter_or_digit" can be replaced by either "letter" or "digit." In the second case, "choices" can be replaced by a list of "choice," separated by vertical bars [see item f) for the meaning of braces].

e) Square brackets [ ] enclose optional items on the right-hand side of a production; thus, the following two productions are equivalent:

    return_statement ::= **return** [expression] ;
    return_statement ::= **return** ; | **return** expression ;

    Note, however, that the initial and terminal square brackets in the right-hand side of the production for signatures (see 2.3.2) are part of the syntax of signatures and do not indicate that the entire right-hand side is optional.

f) Braces { } enclose a repeated item or items on the right-hand side of a production. The items may appear zero or more times; the repetitions occur from left to right as with an equivalent left-recursive rule. Thus, the following two productions are equivalent:

    term ::= factor { multiplying_operator factor }
    term ::= factor | term multiplying_operator factor

g) If the name of any syntactic category starts with an italicized part, it is equivalent to the category name without the italicized part. The italicized part is intended to convey some semantic information. For example, *type*_name and *subtype*_name are both syntactically equivalent to name alone.

h) The term simple_name is used for any occurrence of an identifier that already denotes some declared entity.

0.3.2 Semantic description

The meaning and restrictions of a particular construct are described with a set of narrative rules immediately following the syntactic productions. In these rules, an italicized term indicates the definition of that term and identifiers appearing entirely in uppercase letters refer to definitions in package STANDARD (see 14.2).

The following terms are used in these semantic descriptions with the following meanings:

erroneous: The condition described represents an ill-formed description; however, implementations are not required to detect and report this condition. Conditions are deemed erroneous only when it is impossible in general to detect the condition during the processing of the language.

error: The condition described represents an ill-formed description; implementations are required to detect the condition and report an error to the user of the tool.

illegal: A synonym for “error.”

legal: The condition described represents a well-formed description.

0.3.3 Front matter, examples, notes, references, and annexes

Prior to this subclause are several pieces of introductory material; following Clause 15 are some annexes and an index. The front matter, annexes, and index serve to orient and otherwise aid the user of this standard, but are not part of the definition of VHDL.

Some clauses of this standard contain examples, notes, and cross-references to other clauses of the standard; these parts always appear at the end of a clause. Examples are meant to illustrate the possible forms of the construct described. Illegal examples are italicized. Notes are meant to emphasize consequences of the rules described in the clause or elsewhere. In order to distinguish notes from the other narrative portions of this standard, notes are set as enumerated paragraphs in a font smaller than the rest of the text. Cross-references are meant to guide the user to other relevant clauses of the standard. Examples, notes, and cross-references are not part of the definition of the language.

1. Design entities and configurations

The *design entity* is the primary hardware abstraction in VHDL. It represents a portion of a hardware design that has well-defined inputs and outputs and performs a well-defined function. A design entity may represent an entire system, a subsystem, a board, a chip, a macro-cell, a logic gate, or any level of abstraction in-between. A *configuration* can be used to describe how design entities are put together to form a complete design.

A design entity may be described in terms of a hierarchy of *blocks*, each of which represents a portion of the whole design. The top-level block in such a hierarchy is the design entity itself; such a block is an *external* block that resides in a library and may be used as a component of other designs. Nested blocks in the hierarchy are *internal* blocks, defined by block statements (see 9.1).

A design entity may also be described in terms of interconnected components. Each component of a design entity may be bound to a lower-level design entity in order to define the structure or behavior of that component. Successive decomposition of a design entity into components, and binding those components to other design entities that may be decomposed in like manner, results in a hierarchy of design entities representing a complete design. Such a collection of design entities is called a *design hierarchy*. The bindings necessary to identify a design hierarchy can be specified in a configuration of the top-level entity in the hierarchy.

This clause describes the way in which design entities and configurations are defined. A design entity is defined by an *entity declaration* together with a corresponding *architecture body*. A configuration is defined by a *configuration declaration*.

1.1 Entity declarations

An entity declaration defines the interface between a given design entity and the environment in which it is used. It may also specify declarations and statements that are part of the design entity. A given entity declaration may be shared by many design entities, each of which has a different architecture. Thus, an entity declaration can potentially represent a class of design entities, each with the same interface.

entity_declaration ::=
    entity identifier **is**
        entity_header
        entity_declarative_part
    [**begin**
        entity_statement_part]
    end [**entity**] [*entity*_simple_name];

The entity header and entity declarative part consist of declarative items that pertain to each design entity whose interface is defined by the entity declaration. The entity statement part, if present, consists of concurrent statements that are present in each such design entity.

If a simple name appears at the end of an entity declaration, it shall repeat the identifier of the entity declaration.

1.1.1 Entity header

The entity header declares objects used for communication between a design entity and its environment.

entity_header ::=
    [*formal*_generic_clause]

[*formal*_port_clause]

generic_clause ::=
generic (generic_list) ;

port_clause ::=
port (port_list) ;

The generic list in the formal generic clause defines generic constants whose values may be determined by the environment. The port list in the formal port clause defines the ports of the design entity, and their direction, if any.

In certain circumstances, the names of generic constants and ports declared in the entity header become visible outside of the design entity (see 10.2 and 10.3).

Examples:

— An entity declaration with port declarations only:

```
entity Full_Adder is
   port (X, Y, Cin: in Bit; Cout, Sum: out Bit);
end Full_Adder;
```

— An entity declaration with generic declarations also:

```
entity AndGate is
   generic (N: Natural := 2);
   port (Inputs: in Bit_Vector (1 to N);
         Result: out Bit);
end entity AndGate;
```

— An entity declaration with neither:

```
entity TestBench is
end TestBench;
```

— An entity with both signal and quantity declarations:

```
entity Multiplier is
   generic (Bound: REAL);
   port (quantity Input1, Input2: in  REAL;
         quantity Output:         out REAL;
         signal   OutOfBound:     out BOOLEAN);
end entity multiplier;
```

1.1.1.1 Generics

Generics provide a channel for static information to be communicated to a block from its environment. The following applies to both external blocks defined by design entities and to internal blocks defined by block statements.

generic_list ::= *generic*_interface_list

The generics of a block are defined by a generic interface list; interface lists are described in 4.3.2.1. Each interface element in such a generic interface list declares a formal generic.

The value of a generic constant may be specified by the corresponding actual in a generic association list. If no such actual is specified for a given formal generic (either because the formal generic is unassociated or because the actual is **open**), and if a default expression is specified for that generic, the value of this expression is the value of the generic. It is an error if no actual is specified for a given formal generic and no default expression is present in the corresponding interface element. It is an error if some of the subelements of a composite formal generic are connected and others are either unconnected or unassociated.

NOTE—Generics may be used to control structural, data flow, or behavioral characteristics of a block, or may simply be used as documentation. In particular, generics may be used to specify the size of ports; the number of subcomponents within a block; the timing characteristics of a block; or even the physical characteristics of a design such as temperature, capacitance, or location.[4]

1.1.1.2 Ports

Ports provide channels for dynamic communication between a block and its environment. The following applies to both external blocks defined by design entities and to internal blocks defined by block statements, including those equivalent to component instantiation statements and generate statements (see 9.7).

port_list ::= *port*_interface_list

The ports of a block are defined by a port interface list; interface lists are described in 4.3.2.1. Each interface element in the port interface list declares a formal port. A formal port is a signal port, a quantity port, or a terminal port.

To communicate with other blocks, the signal ports, terminal ports, or quantity ports of a block can be associated with signals, terminals, or quantities, respectively, in the environment in which the block is used. Moreover, the signal ports and quantity ports of a block may be associated with an expression in order to provide these ports with constant driving values; such ports shall be of mode **in**. A signal port is itself a signal (see 4.3.1.2); a terminal port is itself a terminal (see 4.3.1.5); and a quantity port is itself a quantity (see 4.3.1.6); thus, a formal port of a block may be associated as an actual with a formal port of an inner block. The port, signal, quantity, terminal, or expression associated with a given formal port is called the *actual* corresponding to the formal port (see 4.3.2.2). The actual, if not an expression, shall be denoted by a static name (see 6.1). The actual, if an expression, shall be a globally static expression (see 7.4). A terminal port shall not be associated with an expression.

After a given description is completely elaborated (see Clause 12), if a formal port is associated with an actual that is itself a port, then the following restrictions apply depending upon the mode (see 4.3.2), if any, of the formal port:

a) For a formal port of mode **in**,
   - If the formal port is a signal port, the associated actual shall be a signal port of mode **in**, **inout**, or **buffer**.
   - If the formal port is a quantity port, the associated actual shall be a quantity port of mode **in** or **out**.

b) For a formal port of mode **out**,
   - If the formal port is a signal port, the associated actual shall be a signal port of mode **out**, **inout**, or **buffer**.
   - If the formal port is a quantity port, the associated actual shall be a quantity port of mode **out**.

c) For a formal port of mode **inout**, the associated actual shall be a port of mode **inout**, or **buffer**.

d) For a formal port of mode **buffer**, the associated actual shall be a port of mode **out**, **inout**, or **buffer**.

e) For a formal port of mode **linkage**, the associated actual may be a port of any mode.

If a formal port is associated with an actual port, signal, terminal, quantity, or expression, then the formal port is said to be *connected*. If a formal port is instead associated with the reserved word **open**, then the formal is said to be *unconnected*. It is an error if a signal or quantity port of mode **in** is unconnected or

[4]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

unassociated (see 4.3.2.2) unless its declaration includes a default expression (see 4.3.2). It is an error if a signal port or quantity port of any mode other than **in** is unconnected or unassociated and its type is an unconstrained array type. It is an error if a terminal port is unconnected or unassociated and its nature is an unconstrained array nature. It is an error if some of the subelements of a composite formal port are connected and others are either unconnected or unassociated. It is an error if any quantity is associated as an actual with more than one formal of mode **out**.

NOTE—Ports of mode linkage may be removed from a future version of the language (see Annex E).

1.1.2 Entity declarative part

The entity declarative part of a given entity declaration declares items that are common to all design entities whose interfaces are defined by the given entity declaration.

```
entity_declarative_part ::=
    { entity_declarative_item }

entity_declarative_item ::=
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | signal_declaration
    | shared_variable_declaration
    | file_declaration
    | alias_declaration
    | attribute_declaration
    | attribute_specification
    | disconnection_specification
    | step_limit_specification
    | use_clause
    | group_template_declaration
    | group_declaration
    | nature_declaration
    | subnature_declaration
    | quantity_declaration
    | terminal_declaration
```

Names declared by declarative items in the entity declarative part of a given entity declaration are visible within the bodies of corresponding design entities, as well as within certain portions of a corresponding configuration declaration.

The various kinds of declaration are described in Clause 4, and the various kinds of specification are described in Clause 5. The use clause, which makes externally defined names visible within the block, is described in Clause 10.

Example:

— An entity declaration with entity declarative items:

```
entity ROM is
   port (Addr: in  Word;
         Data: out Word;
         Sel:  in  Bit);
   type Instruction is array (1 to 5) of Natural;
```

```
        type Program is array (Natural range <>) of Instruction;
        use Work.OpCodes.all, Work.RegisterNames.all;
        constant ROM_Code: Program :=
           (
              (STM, R14, R12, 12, R13),
              (LD,  R7,  32,  0,  R1 ),
              (BAL, R14, 0,   0,  R7 ),
                    .
                    .    --  etc.
                    .
           ) ;
     end ROM;
```

NOTE—The entity declarative part of a design entity whose corresponding architecture is decorated with the 'FOREIGN attribute is subject to special elaboration rules. See 12.3.

1.1.3 Entity statement part

The entity statement part contains concurrent statements that are common to each design entity with this interface.

entity_statement_part ::=
    { entity_statement }

entity_statement ::=
    concurrent_assertion_statement
    | *passive*_concurrent_procedure_call
    | *passive*_process_statement

It is an error if any statements other than concurrent assertion statements, concurrent procedure call statements, or process statements appear in the entity statement part. All entity statements shall be passive (see 9.2). Such statements may be used to monitor the operating conditions or characteristics of a design entity.

Example:

— An entity declaration with statements:

```
     entity Latch is
        port (Din:  in  Word;
              Dout: out Word;
              Load: in  Bit;
              Clk:  in  Bit );
        constant Setup: Time := 12 ns;
        constant PulseWidth: Time := 50 ns;
        use Work.TimingMonitors.all;
     begin
        assert Clk='1' or Clk'Delayed'Stable (PulseWidth);
        CheckTiming (Setup, Din, Load, Clk);
     end;
```

NOTE—The entity statement part of a design entity whose corresponding architecture is decorated with the 'FOREIGN attribute is subject to special elaboration rules. See 12.4.

1.2 Architecture bodies

An architecture body defines the body of a design entity. It specifies the relationships between the inputs, outputs, quantities, and terminals of a design entity and may be expressed in terms of structure, data flow, equations, or behavior. Such specifications may be partial or complete.

```
architecture_body ::=
    architecture identifier of entity_name is
        architecture_declarative_part
    begin
        architecture_statement_part
    end [ architecture ] [ architecture_simple_name ] ;
```

The identifier defines the simple name of the architecture body; this simple name distinguishes architecture bodies associated with the same entity declaration.

The entity name identifies the name of the entity declaration that defines the interface of this design entity. For a given design entity, both the entity declaration and the associated architecture body shall reside in the same library.

If a simple name appears at the end of an architecture body, it shall repeat the identifier of the architecture body.

More than one architecture body may exist corresponding to a given entity declaration. Each declares a different body with the same interface; thus, each together with the entity declaration represents a different design entity with the same interface.

NOTE—Two architecture bodies that are associated with different entity declarations may have the same simple name, even if both architecture bodies (and the corresponding entity declarations) reside in the same library.

1.2.1 Architecture declarative part

The architecture declarative part contains declarations of items that are available for use within the block defined by the design entity.

```
architecture_declarative_part ::=
    { block_declarative_item }

block_declarative_item ::=
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | signal_declaration
    | shared_variable_declaration
    | file_declaration
    | alias_declaration
    | component_declaration
    | attribute_declaration
    | attribute_specification
    | configuration_specification
    | disconnection_specification
    | step_limit_specification
```

| use_clause
| group_template_declaration
| group_declaration
| nature_declaration
| subnature_declaration
| quantity_declaration
| terminal_declaration

The various kinds of declaration are described in Clause 4, and the various kinds of specification are described in Clause 5. The use clause, which makes externally defined names visible within the block, is described in Clause 10.

NOTE—The declarative part of an architecture decorated with the 'FOREIGN attribute is subject to special elaboration rules. See 12.3.

1.2.2 Architecture statement part

The architecture statement part contains statements that describe the internal organization and/or operation of the block defined by the design entity.

architecture_statement_part ::=
  { architecture_statement }

architecture_statement ::= simultaneous_statement | concurrent_statement

All of the statements in the architecture statement part are either concurrent or simultaneous statements, which execute asynchronously with respect to one another. The various kinds of concurrent statements are described in Clause 9; the various kinds of simultaneous statements are described in Clause 15.

Examples:

— A body of entity Full_Adder:

```
architecture DataFlow of Full_Adder is
   signal A,B: Bit;
begin
   A <= X xor Y;
   B <= A and Cin;
   Sum <= A xor Cin;
   Cout <= B or (X and Y);
end architecture DataFlow;
```

— A body of entity TestBench:

```
library Test;
use Test.Components.all;
architecture Structure of TestBench is
   component Full_Adder
      port (X, Y, Cin: Bit; Cout, Sum: out Bit);
   end component;
signal A,B,C,D,E,F,G: Bit;
   signal OK: Boolean;
begin
   UUT:        Full_Adder port map (A,B,C,D,E);
   Generator:  AdderTest  port map (A,B,C,F,G);
   Comparator: AdderCheck port map (D,E,F,G,OK);
end Structure;
```

— A body of entity AndGate:

```
architecture Behavior of AndGate is
begin
   process (Inputs)
      variable Temp: Bit;
   begin
      Temp := '1';
      for i in Inputs'Range loop
         if Inputs(i) = '0' then
            Temp := '0';
            exit;
         end if;
      end loop;
      Result <= Temp after 10 ns;
   end process;
end Behavior;
```

— A body of entity Multiplier:

```
architecture Sample of Multiplier
begin
   Output == Input1 * Input2;
   OutOfBound <= Output'Above(Bound) or not Output'Above(-Bound);
end architecture Sample;
```

NOTE—The statement part of an architecture decorated with the 'FOREIGN attribute is subject to special elaboration rules. See 12.4.

1.3 Configuration declarations

The binding of component instances to design entities is performed by configuration specifications (see 5.2); such specifications appear in the declarative part of the block in which the corresponding component instances are created. In certain cases, however, it may be appropriate to leave unspecified the binding of component instances in a given block and to defer such specification until later. A configuration declaration provides the mechanism for specifying such deferred bindings.

configuration_declaration ::=
  configuration identifier **of** *entity*_name **is**
    configuration_declarative_part
    block_configuration
  end [**configuration**] [*configuration*_simple_name] ;

configuration_declarative_part ::=
  { configuration_declarative_item }

configuration_declarative_item ::=
   use_clause
  | attribute_specification
  | group_declaration

The entity name identifies the name of the entity declaration that defines the design entity at the apex of the design hierarchy. For a configuration of a given design entity, both the configuration declaration and the corresponding entity declaration shall reside in the same library.

If a simple name appears at the end of a configuration declaration, it shall repeat the identifier of the configuration declaration.

NOTE 1—A configuration declaration achieves its effect entirely through elaboration (see Clause 12). There are no behavioral semantics associated with a configuration declaration.

NOTE 2—A given configuration may be used in the definition of another, more complex configuration.

Examples:

— An architecture of a microprocessor:

```
architecture Structure_View of Processor is
   component ALU port ( ··· ); end component;
   component MUX port ( ··· ); end component;
   component Latch port ( ··· ); end component;
begin
   A1: ALU port map ( ··· );
   M1: MUX port map ( ··· );
   M2: MUX port map ( ··· );
   M3: MUX port map ( ··· );
   L1: Latch port map ( ··· );
   L2: Latch port map ( ··· );
end Structure_View;
```

— A configuration of the microprocessor:

```
library TTL, Work;
configuration V4_27_87 of Processor is
   use Work.all;
   for Structure_View
      for A1: ALU
         use configuration TTL.SN74LS181;
      end for;
      for M1,M2,M3: MUX
         use entity Multiplex4 (Behavior);
      end for;
      for all: Latch
         -- use defaults
      end for;
   end for;
end configuration V4_27_87;
```

1.3.1 Block configuration

A block configuration defines the configuration of a block. Such a block is either an internal block defined by a block statement or an external block defined by a design entity. If the block is an internal block, the defining block statement is either an explicit block statement or an implicit block statement that is itself defined by a generate statement.

block_configuration ::=
    for block_specification
        { use_clause }
        { configuration_item }
    end for ;

block_specification ::=
    *architecture*_name

| *block_statement*_label
| *generate_statement*_label [(index_specification)]

index_specification ::=
discrete_range
| *static*_expression

configuration_item ::=
block_configuration
| component_configuration

The block specification identifies the internal or external block to which this block configuration applies.

If a block configuration appears immediately within a configuration declaration, then the block specification of that block configuration shall be an architecture name, and that architecture name shall denote a design entity body whose interface is defined by the entity declaration denoted by the entity name of the enclosing configuration declaration.

If a block configuration appears immediately within a component configuration, then the corresponding components shall be fully bound (see 5.2.1.1), the block specification of that block configuration shall be an architecture name, and that architecture name shall denote the same architecture body as that to which the corresponding components are bound.

If a block configuration appears immediately within another block configuration, then the block specification of the contained block configuration shall be a block statement or generate statement label, and the label shall denote a block statement or generate statement that is contained immediately within the block denoted by the block specification of the containing block configuration.

If the scope of a declaration (see 10.2) includes the end of the declarative part of a block corresponding to a given block configuration, then the scope of that declaration extends to each configuration item contained in that block configuration, with the exception of block configurations that configure external blocks. Similarly, if a declaration is visible (either directly or by selection) at the end of the declarative part of a block corresponding to a given block configuration, then the declaration is visible in each configuration item contained in that block configuration, with the exception of block configurations that configure external blocks. Additionally, if a given declaration is a homograph of a declaration that a use clause in the block configuration makes potentially directly visible, then the given declaration is not directly visible in the block configuration or any of its configuration items. See 10.3.

For any name that is the label of a block statement appearing immediately within a given block, a corresponding block configuration may appear as a configuration item immediately within a block configuration corresponding to the given block. For any collection of names that are labels of instances of the same component appearing immediately within a given block, a corresponding component configuration may appear as a configuration item immediately within a block configuration corresponding to the given block.

For any name that is the label of a generate statement immediately within a given block, one or more corresponding block configurations may appear as configuration items immediately within a block configuration corresponding to the given block. Such block configurations apply to implicit blocks generated by that generate statement. If such a block configuration contains an index specification that is a discrete range, then the block configuration applies to those implicit block statements that are generated for the specified range of values of the corresponding generate parameter; the discrete range has no significance other than to define the set of generate statement parameter values implied by the discrete range. If such a block configuration contains an index specification that is a static expression, then the block configuration applies only to the implicit block statement generated for the specified value of the corresponding generate parameter. If no index specification appears in such a block configuration, then it applies to exactly one of the following sets of blocks:

- All implicit blocks (if any) generated by the corresponding generate statement, if and only if the corresponding generate statement has a generation scheme including the reserved word **for.**
- The implicit block generated by the corresponding generate statement, if and only if the corresponding generate statement has a generation scheme including the reserved word **if** and if the condition in the generate scheme evaluates to TRUE.
- No implicit or explicit blocks, if and only if the corresponding generate statement has a generation scheme including the reserved word **if** and the condition in the generate scheme evaluates to FALSE.

If the block specification of a block configuration contains a generate statement label, and if this label contains an index specification, then it is an error if the generate statement denoted by the label does not have a generation scheme including the reserved word.

Within a given block configuration, whether implicit or explicit, an implicit block configuration is assumed to appear for any block statement that appears within the block corresponding to the given block configuration, if no explicit block configuration appears for that block statement. Similarly, an implicit component configuration is assumed to appear for each component instance that appears within the block corresponding to the given block configuration, if no explicit component configuration appears for that instance. Such implicit configuration items are assumed to appear following all explicit configuration items in the block configuration.

It is an error if, in a given block configuration, more than one configuration item is defined for the same block or component instance.

NOTE 1—As a result of the rules described in the preceding paragraphs and in Clause 10, a simple name that is visible by selection at the end of the declarative part of a given block is also visible by selection within any configuration item contained in a corresponding block configuration. If such a name is directly visible at the end of the given block declarative part, it will likewise be directly visible in the corresponding configuration items, unless a use clause for a different declaration with the same simple name appears in the corresponding configuration declaration, and the scope of that use clause encompasses all or part of those configuration items. If such a use clause appears, then the name will be directly visible within the corresponding configuration items except at those places that fall within the scope of the additional use clause (at which places neither name will be directly visible).

NOTE 2—If an implicit configuration item is assumed to appear within a block configuration, that implicit configuration item will never contain explicit configuration items.

NOTE 3—If the block specification in a block configuration specifies a generate statement label, and if this label contains an index specification that is a discrete range, then the direction specified or implied by the discrete range has no significance other than to define, together with the bounds of the range, the set of generate statement parameter values denoted by the range. Thus, the following two block configurations are equivalent:

```
for Adders(31 downto 0) ··· end for;
for Adders(0 to 31) ··· end for;
```

NOTE 4—A block configuration is allowed to appear immediately within a configuration declaration only if the entity declaration denoted by the entity name of the enclosing configuration declaration has associated architectures. Furthermore, the block specification of the block configuration shall denote one of these architectures.

Examples:

- A block configuration for a design entity:

```
for ShiftRegStruct                          --  An architecture name.
   --  Configuration items
   --  for blocks and components
   --  within ShiftRegStruct.
end for;
```

— A block configuration for a block statement:

```
for B1                                   --  A block label.
   --  Configuration items
   --  for blocks and components
   --  within block B1.
end for;
```

1.3.2 Component configuration

A component configuration defines the configuration of one or more component instances in a corresponding block.

```
component_configuration ::=
   for component_specification
      [ binding_indication ; ]
      [ block_configuration ]
   end for ;
```

The component specification (see 5.2) identifies the component instances to which this component configuration applies. A component configuration that appears immediately within a given block configuration applies to component instances that appear immediately within the corresponding block.

It is an error if two component configurations apply to the same component instance.

If the component configuration contains a binding indication (see 5.2.1), then the component configuration implies a configuration specification for the component instances to which it applies. This implicit configuration specification has the same component specification and binding indication as that of the component configuration.

If a given component instance is unbound in the corresponding block, then any explicit component configuration for that instance that does not contain an explicit binding indication will contain an implicit, default binding indication (see 5.2.2). Similarly, if a given component instance is unbound in the corresponding block, then any implicit component configuration for that instance will contain an implicit, default binding indication.

It is an error if a component configuration contains an explicit block configuration and the component configuration does not bind all identified component instances to the same design entity.

Within a given component configuration, whether implicit or explicit, an implicit block configuration is assumed for the design entity to which the corresponding component instance is bound, if no explicit block configuration appears and if the corresponding component instance is fully bound.

Examples:

— A component configuration with binding indication:

```
for all: IOPort
   use entity StdCells.PadTriState4 (DataFlow)
      port map (Pout=>A, Pin=>B, IO=>Dir, Vdd=>Pwr, Gnd=>Gnd);
end for;
```

— A component configuration containing block configurations:

```
for D1: DSP
   for DSP_STRUCTURE
      --  Binding specified in design entity or else defaults.
```

```
            for Filterer
               --  Configuration items for filtering components.
            end for;
            for Processor
               --  Configuration items for processing components.
            end for;
         end for;
      end for;
```

NOTE—The requirement that all component instances corresponding to a block configuration be bound to the same design entity makes the following configuration illegal:

```
architecture A of E is
   component C is end component C;
   for L1: C use entity E1(X);
   for L2: C use entity E2(X);
begin
   L1: C;
   L2: C;
end architecture A;

configuration Illegal of Work.E is
   for A
      for all: C
         for X        --  Does not apply to the same design entity in all instances of C.
            ...
         end for;     -- X
      end for; -- C
   end for; -- A
end configuration Illegal;
```

2. Subprograms and packages

Subprograms define algorithms for computing values or exhibiting behavior. They may be used as computational resources to convert between values of different types, to define the resolution of output values driving a common signal, or to define portions of a process. Packages provide a means of defining these and other resources in a way that allows different design units to share the same declarations.

There are two forms of subprograms: procedures and functions. A procedure call is a statement; a function call is an expression and returns a value. Certain functions, designated *pure* functions, return the same value each time they are called with the same values as actual parameters; the remainder, impure functions, may return a different value each time they are called, even when multiple calls have the same actual parameter values. In addition, *impure* functions can update objects outside of their scope and can access a broader class of values than can pure functions. The definition of a subprogram can be given in two parts: a subprogram declaration defining its calling conventions, and a subprogram body defining its execution.

Packages may also be defined in two parts. A package declaration defines the visible contents of a package; a package body provides hidden details. In particular, a package body contains the bodies of any subprograms declared in the package declaration.

2.1 Subprogram declarations

A subprogram declaration declares a procedure or a function, as indicated by the appropriate reserved word.

```
subprogram_declaration ::=
    subprogram_specification ;

subprogram_specification ::=
      procedure designator [ ( formal_parameter_list ) ]
    | [ pure | impure ] function designator [ ( formal_parameter_list ) ]
                return type_mark

designator ::=  identifier  |  operator_symbol

operator_symbol ::=  string_literal
```

The specification of a procedure specifies its designator and its formal parameters (if any). The specification of a function specifies its designator, its formal parameters (if any), the subtype of the returned value (the *result subtype*), and whether or not the function is pure. A function is *impure* if its specification contains the reserved word **impure**; otherwise, it is said to be *pure*. A procedure designator is always an identifier. A function designator is either an identifier or an operator symbol. A designator that is an operator symbol is used for the overloading of an operator (see 2.3.1). The sequence of characters represented by an operator symbol shall be an operator belonging to one of the classes of operators defined in 7.2. Extra spaces are not allowed in an operator symbol, and the case of letters is not significant.

NOTE 1—All subprograms can be called recursively.

NOTE 2—The restrictions on pure functions are enforced even when the function appears within a protected type. That is, pure functions whose body appears in the protected type body shall not directly reference variables declared immediately within the declarative region associated with the protected type. However, impure functions and procedures whose bodies appear in the protected type body may make such references. Such references are made only when the referencing subprogram has exclusive access to the declarative region associated with the protected type.

2.1.1 Formal parameters

The formal parameter list in a subprogram specification defines the formal parameters of the subprogram.

formal_parameter_list ::= *parameter*_interface_list

Formal parameters of subprograms may be constants, variables, signals, or files. In the first three cases, the mode of a parameter determines how a given formal parameter is accessed within the subprogram. The mode of a formal parameter, together with its class, also determines how such access is implemented. In the fourth case, that of files, the parameters have no mode.

For those parameters with modes, the only modes that are allowed for formal parameters of a procedure are **in**, **inout**, and **out**. If the mode is **in** and no object class is explicitly specified, **constant** is assumed. If the mode is **inout** or **out**, and no object class is explicitly specified, **variable** is assumed.

For those parameters with modes, the only mode that is allowed for formal parameters of a function is the mode **in** (whether this mode is specified explicitly or implicitly). The object class shall be **constant**, **signal**, or **file**. If no object class is explicitly given, **constant** is assumed.

In a subprogram call, the actual designator (see 4.3.2.2) associated with a formal parameter of class **signal** shall be a name denoting a signal. The actual designator associated with a formal of class **variable** shall be a name denoting a variable. The actual designator associated with a formal of class **constant** shall be an expression. The actual designator associated with a formal of class **file** shall be a name denoting a file.

NOTE—Attributes of an actual are never passed into a subprogram. References to an attribute of a formal parameter are legal only if that formal has such an attribute. Such references retrieve the value of the attribute associated with the formal.

2.1.1.1 Constant and variable parameters

For parameters of class **constant** or **variable**, only the values of the actual or formal are transferred into or out of the subprogram call. The manner of such transfers, and the accompanying access privileges that are granted for constant and variable parameters, are described in this subclause.

For a nonforeign subprogram having a parameter of a scalar type or an access type, the parameter is passed by copy. At the start of each call, if the mode is **in** or **inout**, the value of the actual parameter is copied into the associated formal parameter; it is an error if, after applying any conversion function or type conversion present in the actual part of the applicable association element (see 4.3.2.2), the value of the actual parameter does not belong to the subtype denoted by the subtype indication of the formal. After completion of the subprogram body, if the mode is **inout** or **out**, the value of the formal parameter is copied back into the associated actual parameter; it is similarly an error if, after applying any conversion function or type conversion present in the formal part of the applicable association element, the value of the formal parameter does not belong to the subtype denoted by the subtype indication of the actual.

For a nonforeign subprogram having a parameter whose type is an array or record, an implementation may pass parameter values by copy, as for scalar types. If a parameter of mode **out** is passed by copy, then the range of each index position of the actual parameter is copied in, and likewise for its subelements or slices. Alternatively, an implementation may achieve these effects by reference; that is, by arranging that every use of the formal parameter (to read or update its value) be treated as a use of the associated actual parameter throughout the execution of the subprogram call. The language does not define which of these two mechanisms is to be adopted for parameter passing, nor whether different calls to the same subprogram are to use the same mechanism. The execution of a subprogram is erroneous if its effect depends on which mechanism is selected by the implementation.

For a subprogram having a parameter whose type is a protected type, the parameter is passed by reference. It is an error if the mode of the parameter is other than **inout**.

For a formal parameter of a constrained array subtype of mode **in** or **inout**, it is an error if the value of the associated actual parameter (after application of any conversion function or type conversion present in the actual part) does not contain a matching element for each element of the formal. For a formal parameter whose declaration contains a subtype indication denoting an unconstrained array type, the subtype of the formal in any call to the subprogram is taken from the actual associated with that formal in the call to the subprogram. It is also an error if, in either case, the value of each element of the actual array (after applying any conversion function or type conversion present in the actual part) does not belong to the element subtype of the formal. If the formal parameter is of mode **out** or **inout**, it is also an error if, at the end of the subprogram call, the value of each element of the formal (after applying any conversion function or type conversion present in the formal part) does not belong to the element subtype of the actual.

NOTE—For parameters of array and record types, the parameter passing rules imply that if no actual parameter of such a type is accessible by more than one path, then the effect of a subprogram call is the same whether or not the implementation uses copying for parameter passing. If, however, there are multiple access paths to such a parameter (for example, if another formal parameter is associated with the same actual parameter), then the value of the formal is undefined after updating the actual other than by updating the formal. A description using such an undefined value is erroneous.

2.1.1.2 Signal parameter

For a formal parameter of class **signal**, references to the signal, the driver of the signal, or both, are passed into the subprogram call.

For a signal parameter of mode **in** or **inout**, the actual signal is associated with the corresponding formal signal parameter at the start of each call. Thereafter, during the execution of the subprogram body, a reference to the formal signal parameter within an expression is equivalent to a reference to the actual signal.

It is an error if signal-valued attributes 'STABLE, 'QUIET, 'TRANSACTION, and 'DELAYED of formal signal parameters of any mode are read within a subprogram; similarly, it is an error if quantity-valued attributes 'RAMP or 'SLEW are read within a subprogram.

A process statement contains a driver for each actual signal associated with a formal signal parameter of mode **out** or **inout** in a subprogram call. Similarly, a subprogram contains a driver for each formal signal parameter of mode **out** or **inout** declared in its subprogram specification.

For a signal parameter of mode **inout** or **out**, the driver of an actual signal is associated with the corresponding driver of the formal signal parameter at the start of each call. Thereafter, during the execution of the subprogram body, an assignment to the driver of a formal signal parameter is equivalent to an assignment to the driver of the actual signal.

If an actual signal is associated with a signal parameter of any mode, the actual shall be denoted by a static signal name. It is an error if a conversion function or type conversion appears in either the formal part or the actual part of an association element that associates an actual signal with a formal signal parameter.

If an actual signal is associated with a signal parameter of any mode, and if the type of the formal is a scalar type, then it is an error if the bounds and direction of the subtype denoted by the subtype indication of the formal are not identical to the bounds and direction of the subtype denoted by the subtype indication of the actual.

If an actual signal is associated with a formal signal parameter, and if the formal is of a constrained array subtype, then it is an error if the actual does not contain a matching element for each element of the formal. If an actual signal is associated with a formal signal parameter, and if the subtype denoted by the subtype indication of the declaration of the formal is an unconstrained array type, then the subtype of the formal in any call to the subprogram is taken from the actual associated with that formal in the call to the subprogram. It is also an error if the mode of the formal is **in** or **inout** and if the value of each element of the actual array does not belong to the element subtype of the formal.

A formal signal parameter is a guarded signal if and only if it is associated with an actual signal that is a guarded signal. It is an error if the declaration of a formal signal parameter includes the reserved word **bus** (see 4.3.2).

NOTE—It is a consequence of the preceding rules that a procedure with an **out** or **inout** signal parameter called by a process does not have to complete in order for any assignments to that signal parameter within the procedure to take effect. Assignments to the driver of a formal signal parameter are equivalent to assignments directly to the actual driver contained in the process calling the procedure.

2.1.1.3 File parameters

For parameters of class **file**, references to the actual file are passed into the subprogram. No particular parameter-passing mechanism is defined by the language, but a reference to the formal parameter shall be equivalent to a reference to the actual parameter. It is an error if an association element associates an actual with a formal parameter of a file type and that association element contains a conversion function or type conversion. It is also an error if a formal of a file type is associated with an actual that is not of a file type.

At the beginning of a given subprogram call, a file parameter is open (see 3.4.1) if and only if the actual file object associated with the given parameter in a given subprogram call is also open. Similarly, at the beginning of a given subprogram call, both the access mode of and external file associated with (see 3.4.1) an open file parameter are the same as, respectively, the access mode of and the external file associated with the actual file object associated with the given parameter in the subprogram call.

At the completion of the execution of a given subprogram call, the actual file object associated with a given file parameter is open if and only if the formal parameter is also open. Similarly, at the completion of the execution of a given subprogram call, the access mode of and the external file associated with an open actual file object associated with a given file parameter are the same as, respectively, the access mode of and the external file associated with the associated formal parameter.

2.2 Subprogram bodies

A subprogram body specifies the execution of a subprogram.

```
subprogram_body ::=
    subprogram_specification is
        subprogram_declarative_part
    begin
        subprogram_statement_part
    end [ subprogram_kind ] [ designator ] ;

subprogram_declarative_part ::=
    { subprogram_declarative_item }

subprogram_declarative_item ::=
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | variable_declaration
    | file_declaration
    | alias_declaration
    | attribute_declaration
    | attribute_specification
    | use_clause
    | group_template_declaration
    | group_declaration

subprogram_statement_part ::=
    { sequential_statement }

subprogram_kind ::=  procedure | function
```

The declaration of a subprogram is optional. In the absence of such a declaration, the subprogram specification of the subprogram body acts as the declaration. For each subprogram declaration, there shall be a corresponding body. If both a declaration and a body are given, the subprogram specification of the body shall conform (see 2.7) to the subprogram specification of the declaration. Furthermore, both the declaration and the body shall occur immediately within the same declarative region (see 10.1).

If a subprogram kind appears at the end of a subprogram body, it shall repeat the reserved word given in the subprogram specification. If a designator appears at the end of a subprogram body, it shall repeat the designator of the subprogram.

It is an error if a variable declaration in a subprogram declarative part declares a shared variable. (See 4.3.1.3.)

A *foreign subprogram* is one that is decorated with the attribute 'FOREIGN, defined in package STANDARD (see 14.2). The STRING value of the attribute may specify implementation-dependent information about the foreign subprogram. Foreign subprograms may have non-VHDL implementations. An implementation may place restrictions on the allowable modes, classes, and types of the formal parameters to a foreign subprogram; such restrictions may include restrictions on the number and allowable order of the parameters.

Excepting foreign subprograms, the algorithm performed by a subprogram is defined by the sequence of statements that appears in the subprogram statement part. For a foreign subprogram, the algorithm performed is implementation defined.

The execution of a subprogram body is invoked by a subprogram call. For this execution, after establishing the association between the formal and actual parameters, the sequence of statements of the body is executed if the subprogram is not a foreign subprogram; otherwise, an implementation-defined action occurs. Upon completion of the body or implementation-dependent action, if exclusive access to an object of a protected type was granted during elaboration of the declaration of the subprogram (see 12.5), the exclusive access is rescinded. Then, return is made to the caller (and any necessary copying back of formal to actual parameters occurs).

A process or a subprogram is said to be a *parent* of a given subprogram S if that process or subprogram contains a procedure call or function call for S or for a parent of S.

An *explicit* signal is a signal other than an implicit signal GUARD or other than one of the implicit signals defined by the predefined attributes 'ABOVE, 'DELAYED, 'STABLE, 'QUIET, or 'TRANSACTION. The *explicit ancestor* of an implicit signal is found as follows. All implicit GUARD signals and any signal defined by the predefined attribute 'ABOVE have no explicit ancestor. An explicit ancestor of an implicit signal defined by the predefined attributes 'DELAYED, 'STABLE, 'QUIET, or 'TRANSACTION is the signal found by recursively examining the prefix of the attribute. If the prefix denotes an explicit signal, a slice, or a member (see Clause 3) of an explicit signal, then that is the explicit ancestor of the implicit signal. Otherwise, if the prefix is one of the implicit signals defined by the predefined attributes 'DELAYED, 'STABLE, 'QUIET, or 'TRANSACTION, this rule is recursively applied. If the prefix is an implicit signal GUARD, or a signal defined by the predefined attribute 'ABOVE, then the signal has no explicit ancestor.

If a pure function subprogram is a parent of a given procedure and if that procedure contains a reference to an explicitly declared signal or variable object, or a slice or subelement (or slice thereof) of an explicit signal, then that object shall be declared within the declarative region formed by the function (see 10.1) or within the declarative region formed by the procedure; this rule also holds for the explicit ancestor, if any, of an implicit signal and also for the implicit signal GUARD. If a pure function is the parent of a given procedure, then that procedure shall not contain a reference to an explicitly declared file object (see 4.3.1.4) or to a shared variable (see 4.3.1.3).

Similarly, if a pure function subprogram contains a reference to an explicitly declared signal or variable object, or a slice or subelement (or slice thereof) of an explicit signal, then that object shall be declared within the declarative region formed by the function; this rule also holds for the explicit ancestor, if any, of an implicit signal and also for the implicit signal GUARD. A pure function shall not contain a reference to an explicitly declared file object.

A pure function shall not be the parent of an impure function.

The rules of the preceding three paragraphs apply to all pure function subprograms. For pure functions that are not foreign subprograms, violations of any of these rules are errors. However, since implementations cannot in general check that such rules hold for pure function subprograms that are foreign subprograms, a description calling pure foreign function subprograms not adhering to these rules is erroneous.

Example:

— The declaration of a foreign function subprogram:

```
package P is
   function F return INTEGER;
   attribute FOREIGN of F: function is
      "implementation-dependent information";
end package P;
```

NOTE 1—It follows from the visibility rules that a subprogram declaration shall be given if a call of the subprogram occurs textually before the subprogram body, and that such a declaration shall occur before the call itself.

NOTE 2—The preceding rules concerning pure function subprograms, together with the fact that function parameters shall be of mode **in**, imply that a pure function has no effect other than the computation of the returned value. Thus, a pure function invoked explicitly as part of the elaboration of a declaration, or one invoked implicitly as part of the simulation cycle, is guaranteed to have no effect on other objects in the description.

NOTE 3—VHDL does not define the parameter-passing mechanisms for foreign subprograms.

NOTE 4—The declarative parts and statement parts of subprograms decorated with the 'FOREIGN attribute are subject to special elaboration rules. See 12.3 and 12.4.5.

NOTE 5—A pure function subprogram shall not reference a shared variable. This prohibition exists because a shared variable cannot be declared in a subprogram declarative part and a pure function cannot reference any variable declared outside of its declarative region.

NOTE 6—A subprogram containing a wait statement shall not have an ancestor that is a subprogram declared within either a protected type declaration or a protected type body.

2.3 Subprogram overloading

Two formal parameter lists are said to have the same *parameter type profile* if and only if they have the same number of parameters, and if at each parameter position the corresponding parameters have the same base type. Two subprograms are said to have the same *parameter and result type profile* if and only if both have the same parameter type profile, and if either both are functions with the same result base type or neither of the two is a function.

A given subprogram designator can be used to designate multiple subprograms. The subprogram designator is then said to be overloaded; the designated subprograms are also said to be overloaded and to overload each other. If two subprograms overload each other, one of them can hide the other only if both subprograms have the same parameter and result type profile.

A call to an overloaded subprogram is ambiguous (and therefore is an error) if the name of the subprogram, the number of parameter associations, the types and order of the actual parameters, the names of the formal parameters (if named associations are used), and the result type (for functions) are not sufficient to identify exactly one (overloaded) subprogram.

Similarly, a reference to an overloaded resolution function name in a subtype indication is ambiguous (and is therefore an error) if the name of the function, the number of formal parameters, the result type, and the relationships between the result type and the types of the formal parameters (as defined in 2.4) are not sufficient to identify exactly one (overloaded) subprogram specification.

Examples:

— Declarations of overloaded subprograms:

```
procedure Dump (F: inout Text; Value: Integer);
procedure Dump (F: inout Text; Value: String);

procedure Check (Setup: Time; signal D: Data; signal C: Clock);
procedure Check (Hold: Time; signal C: Clock; signal D: Data);
```

— Calls to overloaded subprograms:

```
Dump (Sys_Output, 12);
Dump (Sys_Error, "Actual output does not match expected output");

Check (Setup=>10 ns, D=>DataBus, C=>Clk1);
Check (Hold=>5 ns, D=>DataBus, C=>Clk2);
Check (15 ns, DataBus, Clk) ;
   --  Ambiguous if the base type of DataBus is the same type
   --  as the base type of Clk.
```

NOTE 1—The notion of parameter and result type profile does not include parameter names, parameter classes, parameter modes, parameter subtypes, or default expressions or their presence or absence.

NOTE 2—Ambiguities may (but need not) arise when actual parameters of the call of an overloaded subprogram are themselves overloaded function calls, literals, or aggregates. Ambiguities may also (but need not) arise when several overloaded subprograms belonging to different packages are visible. These ambiguities can usually be solved in two ways: qualified expressions can be used for some or all actual parameters and for the result, if any; or the name of the subprogram can be expressed more explicitly as an expanded name (see 6.3).

2.3.1 Operator overloading

The declaration of a function whose designator is an operator symbol is used to overload an operator. The sequence of characters of the operator symbol shall be one of the operators in the operator classes defined in 7.2.

The subprogram specification of a unary operator shall have a single parameter, unless the subprogram specification is a method (see 3.5.1) of a protected type. In this latter case, the subprogram specification shall have no parameters. The subprogram specification of a binary operator shall have two parameters; unless the subprogram specification is a method of a protected type, in which case, the subprogram specification shall have a single parameter. If the subprogram specification of a binary operator has two parameters, for each use of this operator, the first parameter is associated with the left operand, and the second parameter is associated with the right operand.

For each of the operators "+" and "–", overloading is allowed both as a unary operator and as a binary operator.

NOTE 1—Overloading of the equality operator does not affect the selection of choices in a case statement in a selected signal assignment statement, nor does it affect the propagation of signal values.

NOTE 2—A user-defined operator that has the same designator as a short-circuit operator (i.e., a user-defined operator that overloads the short-circuit operator) is not invoked in a short-circuit manner. Specifically, calls to the user-defined operator always evaluate both arguments prior to the execution of the function.

NOTE 3—Functions that overload operator symbols may also be called using function call notation rather than operator notation. This statement is also true of the predefined operators themselves.

Examples:

```
type MVL is ('0', '1', 'Z', 'X');
function "and" (Left, Right: MVL) return MVL;
function "or" (Left, Right: MVL) return MVL;
function "not" (Value: MVL) return MVL;

signal Q,R,S: MVL;

Q <= 'X' or '1';
R <= "or" ('0','Z');
S <= (Q and R) or not S;
```

2.3.2 Signatures

A signature distinguishes between overloaded subprograms and overloaded enumeration literals based on their parameter and result type profiles. A signature can be used in an attribute name, entity designator, or alias declaration.

signature ::= [[type_mark { , type_mark }] [**return** type_mark]]

(Note that the initial and terminal brackets are part of the syntax of signatures and do not indicate that the entire right-hand side of the production is optional.) A signature is said to match the parameter and the result type profile of a given subprogram if, and only if, all of the following conditions hold:

— The number of type marks prior to the reserved word **return**, if any, matches the number of formal parameters of the subprogram.

— At each parameter position, the base type denoted by the type mark of the signature is the same as the base type of the corresponding formal parameter of the subprogram.

— If the reserved word **return** is present, the subprogram is a function and the base type of the type mark following the reserved word in the signature is the same as the base type of the return type of the function, or the reserved word **return** is absent and the subprogram is a procedure.

Similarly, a signature is said to match the parameter and result type profile of a given enumeration literal if the signature matches the parameter and result type profile of the subprogram equivalent to the enumeration literal defined in 3.1.1.

Example:

```
attribute BuiltIn of "or" [MVL, MVL return MVL]: function is TRUE;
   --  Because of the presence of the signature, this attribute
specification
   --  decorates only the "or" function defined in 2.3.1.
```

```
attribute Mapping of JMP [return OpCode] :literal is "001";
```

2.4 Resolution functions

A resolution function is a function that defines how the values of multiple sources of a given signal are to be resolved into a single value for that signal. Resolution functions are associated with signals that require resolution by including the name of the resolution function in the declaration of the signal or in the declaration of the subtype of the signal. A signal with an associated resolution function is called a resolved signal (see 4.3.1.2).

A resolution function shall be a pure function (see 2.1); moreover, it shall have a single input parameter of class **constant** that is a one-dimensional, unconstrained array whose element type is that of the resolved signal. The type of the return value of the function shall also be that of the signal. Errors occur at the place of the subtype indication containing the name of the resolution function if any of these checks fail (see 4.2).

The resolution function associated with a resolved signal determines the *resolved value* of the signal as a function of the collection of inputs from its multiple sources. If a resolved signal is of a composite type, and if subelements of that type also have associated resolution functions, such resolution functions have no effect on the process of determining the resolved value of the signal. It is an error if a resolved signal has more connected sources than the number of elements in the index type of the unconstrained array type used to define the parameter of the corresponding resolution function.

Resolution functions are implicitly invoked during each simulation cycle in which corresponding resolved signals are active (see 12.6.1). Each time a resolution function is invoked, it is passed an array value, each element of which is determined by a corresponding source of the resolved signal, but excluding those sources that are drivers whose values are determined by null transactions (see 8.4.1). Such drivers are said to be *off*. For certain invocations (specifically, those involving the resolution of sources of a signal declared with the signal kind **bus**), a resolution function may thus be invoked with an input parameter that is a null array; this occurs when all sources of the bus are drivers, and they are all off. In such a case, the resolution function returns a value representing the value of the bus when no source is driving it.

Example:

```
function WIRED_OR (Inputs: BIT_VECTOR) return BIT is
   constant FloatValue: BIT := '0';
begin
   if Inputs'Length = 0 then
      --  This is a bus whose drivers are all off.
      return FloatValue;
   else
      for I in Inputs'Range loop
         if Inputs(I) = '1' then
            return '1';
         end if;
      end loop;
      return '0';
   end if;
end function WIRED_OR;
```

2.5 Package declarations

A package declaration defines the interface to a package. The scope of a declaration within a package can be extended to other design units.

```
package_declaration ::=
    **package** identifier **is**
        package_declarative_part
    **end** [ **package** ] [ *package*_simple_name ] ;

package_declarative_part ::=
    { package_declarative_item }

package_declarative_item ::=
      subprogram_declaration
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | signal_declaration
    | *shared*_variable_declaration
    | file_declaration
    | alias_declaration
    | component_declaration
    | attribute_declaration
    | attribute_specification
    | disconnection_specification
    | use_clause
    | group_template_declaration
    | group_declaration
    | nature_declaration
    | subnature_declaration
    | terminal_declaration
```

If a simple name appears at the end of the package declaration, it shall repeat the identifier of the package declaration.

If a package declarative item is a type declaration (i.e., a full type declaration whose type definition is a protected type definition), then that protected type definition shall not be a protected type body.

Items declared immediately within a package declaration become visible by selection within a given design unit wherever the name of that package is visible in the given unit. Such items may also be made directly visible by an appropriate use clause (see 10.4).

NOTE—Not all packages will have a package body. In particular, a package body is unnecessary if no subprograms, deferred constants, or protected type definitions are declared in the package declaration.

Examples:

— A package declaration that needs no package body:

```
package TimeConstants is
   constant tPLH: Time := 10 ns;
   constant tPHL: Time := 12 ns;
   constant tPLZ: Time := 7 ns;
   constant tPZL: Time := 8 ns;
   constant tPHZ: Time := 8 ns;
   constant tPZH: Time := 9 ns;
end TimeConstants;
```

— A package declaration that needs a package body:

```
package TriState is
   type Tri is ('0', '1', 'Z', 'E');
```

```
        function BitVal (Value: Tri) return Bit;
        function TriVal (Value: Bit) return Tri;
        type TriVector is array (Natural range <>) of Tri;
        function Resolve (Sources: TriVector) return Tri;
    end package TriState;
```

2.6 Package bodies

A package body defines the bodies of subprograms and the values of deferred constants declared in the interface to the package.

package_body ::=
  package body *package*_simple_name **is**
    package_body_declarative_part
  end [**package body**] [*package*_simple_name] ;

package_body_declarative_part ::=
  { package_body_declarative_item }

package_body_declarative_item ::=
   subprogram_declaration
  | subprogram_body
  | type_declaration
  | subtype_declaration
  | constant_declaration
  | *shared*_variable_declaration
  | file_declaration
  | alias_declaration
  | use_clause
  | group_template_declaration
  | group_declaration

The simple name at the start of a package body shall repeat the package identifier. If a simple name appears at the end of the package body, it shall be the same as the identifier in the package declaration.

In addition to subprogram body and constant declarative items, a package body may contain certain other declarative items to facilitate the definition of the bodies of subprograms declared in the interface. Items declared in the body of a package cannot be made visible outside of the package body.

If a given package declaration contains a deferred constant declaration (see 4.3.1.1), then a constant declaration with the same identifier shall appear as a declarative item in the corresponding package body. This object declaration is called the *full* declaration of the deferred constant. The subtype indication given in the full declaration shall conform to that given in the deferred constant declaration.

Within a package declaration that contains the declaration of a deferred constant, and within the body of that package (before the end of the corresponding full declaration), the use of a name that denotes the deferred constant is only allowed in the default expression for a local generic, local port, or formal parameter. The result of evaluating an expression that references a deferred constant before the elaboration of the corresponding full declaration is not defined by the language.

Example:

```
package body TriState is
```

```
    function BitVal (Value: Tri) return Bit is
       constant Bits : Bit_Vector := "0100";
    begin
       return Bits(Tri'Pos(Value));
    end;

    function TriVal (Value: Bit) return Tri is
    begin
       return Tri'Val(Bit'Pos(Value));
    end;

    function Resolve (Sources: TriVector) return Tri is
       variable V: Tri := 'Z';
    begin
       for i in Sources'Range loop
          if Sources(i) /= 'Z' then
             if V = 'Z' then
                V := Sources(i);
             else
                return 'E';
             end if;
          end if;
       end loop;
       return V;
    end;

end package body TriState;
```

2.7 Conformance rules

Whenever the language rules either require or allow the specification of a given subprogram to be provided in more than one place, the following variations are allowed at each place:

— A numeric literal can be replaced by a different numeric literal if and only if both have the same value.

— A simple name can be replaced by an expanded name in which this simple name is the selector if, and only if, at both places the meaning of the simple name is given by the same declaration.

Two subprogram specifications are said to *conform* if, apart from comments and the preceding allowed variations, both specifications are formed by the same sequence of lexical elements and if corresponding lexical elements are given the same meaning by the visibility rules.

Conformance is likewise defined for subtype indications in deferred constant declarations.

NOTE 1—A simple name can be replaced by an expanded name even if the simple name is itself the prefix of a selected name. For example, Q.R can be replaced by P.Q.R if Q is declared immediately within P.

NOTE 2—The subprogram specification of an impure function is never conformant to a subprogram specification of a pure function.

NOTE 3—The following specifications do not conform since they are not formed by the same sequence of lexical elements:

```
procedure P (X,Y: INTEGER)
procedure P (X: INTEGER; Y: INTEGER)
procedure P (X,Y: in INTEGER)
```

3. Types and natures

This clause describes the various categories of types and natures that are provided by the language as well as those specific types that are predefined. The declarations of all predefined types are contained in package STANDARD, the declaration of which appears in Clause 14.

A type is characterized by a set of values and a set of operations. The set of operations of a type includes the explicitly declared subprograms that have a parameter or result of the type. The remaining operations of a type are the basic operations and the predefined operators (see 7.2). These operations are each implicitly declared for a given type declaration immediately after the type declaration and before the next explicit declaration, if any.

A *basic operation* is an operation that is inherent in one of the following:

— An assignment (in assignment statements and initializations)

— An allocator

— A selected name, an indexed name, or a slice name

— A qualification (in a qualified expression), an explicit type conversion, a formal or actual part in the form of a type conversion, or an implicit type conversion of a value of type *universal_integer* or *universal_real* to the corresponding value of another numeric type

— A numeric literal (for a universal type), the literal **null** (for an access type), a string literal, a bit string literal, an aggregate, or a predefined attribute

There are five classes of types. *Scalar* types are integer types, floating-point types, physical types, and types defined by an enumeration of their values; values of these types have no elements. *Composite* types are array and record types; values of these types consist of element values. *Access* types provide access to objects of a given type. *File* types provide access to objects that contain a sequence of values of a given type. *Protected types* provide atomic and exclusive access to variables accessible to multiple processes.

The set of possible values for an object of a given type can be subjected to a condition that is called a *constraint* (the case where the constraint imposes no restriction is also included); a value is said to satisfy a constraint if it satisfies the corresponding condition. A *subtype* is a type together with a constraint. A value is said to *belong to a subtype* of a given type if it belongs to the type and satisfies the constraint; the given type is called the *base type* of the subtype. A type is a subtype of itself; such a subtype is said to be *unconstrained* (it corresponds to a condition that imposes no restriction). The base type of a type is the type itself.

The set of operations defined for a subtype of a given type includes the operations defined for the type; however, the assignment operation to an object having a given subtype only assigns values that belong to the subtype. Additional operations, such as qualification (in a qualified expression) are implicitly defined by a subtype declaration.

The term *subelement* is used in this standard in place of the term element to indicate either an element, or an element of another element or subelement. Where other subelements are excluded, the term *element* is used instead.

A given type shall not have a subelement whose type is the given type itself. Similarly, a given nature shall not have a subelement whose nature is the given nature itself. Natures are introduced in 3.6.

A *member* of an object is one of the following:

— A slice of the object

— A subelement of the object

— A slice of a subelement of the object

The name of a class of types or natures is used in this standard as a qualifier for objects and values that have a type or nature of the class considered. For example, the term *array object* is used for an object whose type is an array type or whose nature is an array nature; similarly, the term *access value* is used for a value of an access type.

NOTE—The set of values of a subtype is a subset of the values of the base type. This subset need not be a proper subset.

3.1 Scalar types

Scalar types consist of *enumeration types, integer types, physical types*, and *floating-point types*. Enumeration types and integer types are called *discrete types.* Integer types, floating-point types, and physical types are called *numeric types.* All scalar types are ordered; that is, all relational operators are predefined for their values. Each value of a discrete or physical type has a position number that is an integer value.

```
scalar_type_definition ::=
     enumeration_type_definition
   | integer_type_definition
   | floating_type_definition
   | physical_type_definition
```

range_constraint ::= **range** range

```
range ::=
     range_attribute_name
   | simple_expression direction simple_expression
```

direction ::= **to** | **downto**

A range specifies a subset of values of a scalar type. A range is said to be a *null* range if the specified subset is empty.

The range L **to** R is called an *ascending* range; if L > R, then the range is a null range. The range L **downto** R is called a *descending range*; if L < R, then the range is a null range. The smaller of L and R is called the *lower bound*, and the larger, the *upper bound*, of the range. The value V is said to *belong to the range* if the relations (*lower bound* <= V) and (V <= *upper bound*) are both true and the range is not a null range. The operators >, <, and <= in the preceding definitions are the predefined operators of the applicable scalar type.

For values of discrete or physical types, a value V1 is said to be *to the left* of a value V2 within a given range if both V1 and V2 belong to the range and either the range is an ascending range and V2 is the successor of V1, or the range is a descending range and V2 is the predecessor of V1. A list of values of a given range is in *left to right order* if each value in the list is to the left of the next value in the list within that range, except for the last value in the list.

If a range constraint is used in a subtype indication, the type of the expressions (likewise, of the bounds of a range attribute) shall be the same as the base type of the type mark of the subtype indication. A range constraint is *compatible* with a subtype if each bound of the range belongs to the subtype or if the range constraint defines a null range. Otherwise, the range constraint is not compatible with the subtype.

The direction of a range constraint is the same as the direction of its range.

NOTE—Indexing and iteration rules use values of discrete types.

3.1.1 Enumeration types

An enumeration type definition defines an enumeration type.

enumeration_type_definition ::=
    (enumeration_literal { , enumeration_literal })

enumeration_literal ::= identifier | character_literal

The identifiers and character literals listed by an enumeration type definition shall be distinct within the enumeration type definition. Each enumeration literal is the declaration of the corresponding enumeration literal; for the purpose of determining the parameter and result type profile of an enumeration literal, this declaration is equivalent to the declaration of a parameterless function whose designator is the same as the enumeration literal and whose result type is the same as the enumeration type.

An enumeration type is said to be a *character type* if at least one of its enumeration literals is a character literal.

Each enumeration literal yields a different enumeration value. The predefined order relations between enumeration values follow the order of corresponding position numbers. The position number of the value of the first listed enumeration literal is zero; the position number for each additional enumeration literal is one more than that of its predecessor in the list.

If the same identifier or character literal is specified in more than one enumeration type definition, the corresponding literals are said to be *overloaded*. At any place where an overloaded enumeration literal occurs in the text of a program, the type of the enumeration literal is determined according to the rules for overloaded subprograms (see 2.3).

Each enumeration type definition defines an ascending range.

Examples:

```
type MULTI_LEVEL_LOGIC is (LOW, HIGH, RISING, FALLING, AMBIGUOUS);

type BIT is ('0','1');

type SWITCH_LEVEL is ('0','1','X');     --  Overloads '0' and '1'
```

3.1.1.1 Predefined enumeration types

The predefined enumeration types are CHARACTER, BIT, BOOLEAN, SEVERITY_LEVEL, FILE_OPEN_KIND, and FILE_OPEN_STATUS.

The predefined type CHARACTER is a character type whose values are the 256 characters of the ISO/IEC 8859-1:1998 [B7][5] character set. Each of the 191 graphic characters of this character set is denoted by the corresponding character literal.

The declarations of the predefined types CHARACTER, BIT, BOOLEAN, SEVERITY_LEVEL, FILE_OPEN_KIND, and FILE_OPEN_STATUS appear in package STANDARD in Clause 14.

[5]The numbers in brackets correspond to those of the bibliography in Annex F.

NOTE 1—The first 33 nongraphic elements of the predefined type CHARACTER (from NUL through DEL) are the ASCII abbreviations for the nonprinting characters in the ASCII set (except for those noted in Clause 14). The ASCII names are chosen as ISO/IEC 8859-1:1998 [B7] does not assign them abbreviations. The next 32 (C128 through C159) are also not assigned abbreviations, so names unique to VHDL are assigned.

NOTE 2—Type BOOLEAN can be used to model either active high or active low logic depending on the particular conversion functions chosen to and from type BIT.

3.1.2 Integer types

An integer type definition defines an integer type whose set of values includes those of the specified range.

integer_type_definition ::= range_constraint

An integer type definition defines both a type and a subtype of that type. The type is an anonymous type, the range of which is selected by the implementation; this range shall be such that it wholly contains the range given in the integer type definition. The subtype is a named subtype of this anonymous base type, where the name of the subtype is that given by the corresponding type declaration and the range of the subtype is the given range.

Each bound of a range constraint that is used in an integer type definition shall be a locally static expression of some integer type, but the two bounds need not have the same integer type. (Negative bounds are allowed.)

Integer literals are the literals of an anonymous predefined type that is called *universal_integer* in this standard. Other integer types have no literals. However, for each integer type there exists an implicit conversion that converts a value of type *universal_integer* into the corresponding value (if any) of the integer type (see 7.3.5).

The position number of an integer value is the corresponding value of the type *universal_integer*.

The same arithmetic operators are predefined for all integer types (see 7.2). It is an error if the execution of such an operation (in particular, an implicit conversion) cannot deliver the correct result (that is, if the value corresponding to the mathematical result is not a value of the integer type).

An implementation may restrict the bounds of the range constraint of integer types other than type *universal_integer*. However, an implementation shall allow the declaration of any integer type whose range is wholly contained within the bounds –2147483647 and +2147483647 inclusive.

Examples:

```
type TWOS_COMPLEMENT_INTEGER is range -32768 to 32767;

type BYTE_LENGTH_INTEGER is range 0 to 255;

type WORD_INDEX is range 31 downto 0;

subtype HIGH_BIT_LOW is BYTE_LENGTH_INTEGER range 0 to 127;
```

3.1.2.1 Predefined integer types

The only predefined integer type is the type INTEGER. The range of INTEGER is implementation dependent, but it is guaranteed to include the range –2147483647 to +2147483647. It is defined with an ascending range.

NOTE—The range of INTEGER in a particular implementation is determinable from the values of its 'LOW and 'HIGH attributes.

3.1.3 Physical types

Values of a physical type represent measurements of some quantity. Any value of a physical type is an integral multiple of the primary unit of measurement for that type.

```
physical_type_definition ::=
    range_constraint
        units
            primary_unit_declaration
            { secondary_unit_declaration }
        end units [ physical_type_simple_name ]

primary_unit_declaration ::=  identifier ;

secondary_unit_declaration ::= identifier = physical_literal ;

physical_literal ::=  [ abstract_literal ] unit_name
```

A physical type definition defines both a type and a subtype of that type. The type is an anonymous type, the range of which is selected by the implementation; this range shall be such that it wholly contains the range given in the physical type definition. The subtype is a named subtype of this anonymous base type, where the name of the subtype is that given by the corresponding type declaration and the range of the subtype is the given range.

Each bound of a range constraint that is used in a physical type definition shall be a locally static expression of some integer type, but the two bounds need not have the same integer type. (Negative bounds are allowed.)

Each unit declaration (either the primary unit declaration or a secondary unit declaration) defines a *unit name*. Unit names declared in secondary unit declarations shall be directly or indirectly defined in terms of integral multiples of the primary unit of the type declaration in which they appear. The position numbers of unit names need not lie within the range specified by the range constraint.

If a simple name appears at the end of a physical type declaration, it shall repeat the identifier of the type declaration in which the physical type definition is included.

The abstract literal portion (if present) of a physical literal appearing in a secondary unit declaration shall be an integer literal.

A physical literal consisting solely of a unit name is equivalent to the integer 1 followed by the unit name.

There is a position number corresponding to each value of a physical type. The position number of the value corresponding to a unit name is the number of primary units represented by that unit name. The position number of the value corresponding to a physical literal with an abstract literal part is the largest integer that is not greater than the product of the value of the abstract literal and the position number of the accompanying unit name.

The same arithmetic operators are predefined for all physical types (see 7.2). It is an error if the execution of such an operation cannot deliver the correct result (i.e., if the value corresponding to the mathematical result is not a value of the physical type).

An implementation may restrict the bounds of the range constraint of a physical type. However, an implementation shall allow the declaration of any physical type whose range is wholly contained within the bounds –2147483647 and +2147483647 inclusive.

Examples:

```
type DURATION is range -1E18 to 1E18
      units
         fs;                           --femtosecond
         ps     =   1000 fs;           --picosecond
         ns     =   1000 ps;           --nanosecond
         us     =   1000 ns;           --microsecond
         ms     =   1000 us;           --millisecond
         sec    =   1000 ms;           --second
         min    =   60 sec;            --minute
      end units;

type DISTANCE is range 0 to 1E16
      units
      -- primary unit:
         Å;                            --angstrom

      -- metric lengths:
         nm     =   10 Å;              --nanometer
         um     =   1000 nm;           --micrometer (or micron)
         mm     =   1000 um;           --millimeter
         cm     =   10 mm;             --centimeter
         m      =   1000 mm;           --meter
         km     =   1000 m;            --kilometer

      -- English lengths:
         mil    =   254000 Å;          --mil
         inch   =   1000 mil;          --inch
         ft     =   12 inch;           --foot
         yd     =   3 ft;              --yard
         fm     =   6 ft;              --fathom
         mi     =   5280 ft;           --mile
         lg     =   3 mi;              --league
      end units DISTANCE;

variable x: distance;
variable y: duration;
variable z: integer;

x := 5 Å + 13 ft - 27 inch;
y := 3 ns + 5 min;
z := ns / ps;
x := z * mi;
y := y/10;
z := 39.34 inch / m;
```

NOTE 1—The 'POS and 'VAL attributes may be used to convert between abstract values and physical values.

NOTE 2—The value of a physical literal, whose abstract literal is either the integer value zero or the floating-point value zero, is the same value (specifically zero primary units) no matter what unit name follows the abstract literal.

3.1.3.1 Predefined physical types

The only predefined physical type is type TIME. The range of TIME is implementation dependent, but it is guaranteed to include the range –2147483647 to +2147483647. It is defined with an ascending range. All specifications of delays and pulse rejection limits shall be of type TIME. The declaration of type TIME appears in package STANDARD in Clause 14.

By default, the primary unit of type TIME (1 femtosecond) is the *resolution limit* for type TIME. Any TIME value whose absolute value is smaller than this limit is truncated to zero (0) time units. An implementation may allow a given execution of a model (see 12.6) to select a secondary unit of type TIME as the resolution limit. Furthermore, an implementation may restrict the precision of the representation of values of type TIME and the results of expressions of type TIME, provided that values as small as the resolution limit are representable within those restrictions. It is an error if a given unit of type TIME appears anywhere within the design hierarchy defining a model to be executed, and if the position number of that unit is less than that of the secondary unit selected as the resolution limit for type TIME during the execution of the model, unless that unit is part of a physical literal whose abstract literal is either the integer value zero or the floating-point value zero.

NOTE—By selecting a secondary unit of type TIME as the resolution limit for type TIME, it may be possible to simulate for a longer period of simulated time, with reduced accuracy, or to simulate with greater accuracy for a shorter period of simulated time.

Cross-references: Delay and rejection limit in a signal assignment, 8.4; disconnection, delay of a guarded signal, 5.3; function NOW, 14.2; predefined attributes, functions of TIME, 14.1; simulation time, 12.6.2 and 12.6.3; type TIME, 14.2; updating a projected waveform, 8.4.1; wait statements, timeout clause in, 8.1; Elaboration of a declarative part, 12.3.

3.1.4 Floating-point types

Floating-point types provide approximations to the real numbers.

floating_type_definition ::= range_constraint

A floating type definition defines both a type and a subtype of that type. The type is an anonymous type, the range of which is selected by the implementation; this range shall be such that it wholly contains the range given in the floating type definition. The subtype is a named subtype of this anonymous base type, where the name of the subtype is that given by the corresponding type declaration and the range of the subtype is the given range. The tolerance group of the subtype (see 4.2) is a value of type STRING equal to an empty string literal.

Each bound of a range constraint that is used in a floating type definition shall be a locally static expression of some floating-point type, but the two bounds need not have the same floating-point type. (Negative bounds are allowed.)

Floating-point literals are the literals of an anonymous predefined type that is called *universal_real* in this standard. Other floating-point types have no literals. However, for each floating-point type there exists an implicit conversion that converts a value of type *universal_real* into the corresponding value (if any) of the floating-point type (see 7.3.5).

The same arithmetic operations are predefined for all floating-point types (see 7.2). A design is erroneous if the execution of such an operation cannot deliver the correct result (that is, if the value corresponding to the mathematical result is not a value of the floating-point type).

An implementation shall choose a representation for all floating-point types except for *universal_real* that conforms either to IEEE Std 754™-1985 [B2] or to IEEE Std 854™-1987 [B3]; in either case, a minimum representation size of 64 bits is required for this *chosen representation*.

An implementation may restrict the bounds of the range constraint of floating-point types other than type *universal_real*. However, an implementation shall allow the declaration of any floating-point type whose range is wholly contained within the bounds allowed by the chosen representation.

NOTE—An implementation is not required to detect errors in the execution of a predefined floating-point arithmetic operation, since the detection of overflow conditions resulting from such operations might not be easily accomplished on many host systems.

3.1.4.1 Predefined floating-point types

The only predefined floating-point type is the type REAL. The range of REAL is host-dependent, but it is guaranteed to be the largest allowed by the chosen representation. It is defined with an ascending range.

NOTE—The range of REAL in a particular implementation is determinable from the values of its 'LOW and 'HIGH attributes.

3.2 Composite types

Composite types are used to define collections of values. These include both arrays of values (collections of values of a homogeneous type) and records of values (collections of values of potentially heterogeneous types).

composite_type_definition ::=
    array_type_definition
  | record_type_definition

An object of a composite type represents a collection of objects, one for each element of the composite object. It is an error if a composite type contains elements of file types or protected types. Thus an object of a composite type ultimately represents a collection of objects of scalar or access types, one for each noncomposite subelement of the composite object.

3.2.1 Array types

An array object is a composite object consisting of elements that have the same subtype. The name for an element of an array uses one or more index values belonging to specified discrete types. The value of an array object is a composite value consisting of the values of its elements.

array_type_definition ::=
  unconstrained_array_definition | constrained_array_definition

unconstrained_array_definition ::=
  array (index_subtype_definition { , index_subtype_definition })
    of *element*_subtype_indication

constrained_array_definition ::=
  array index_constraint **of** *element*_subtype_indication

index_subtype_definition ::= type_mark **range** <>

index_constraint ::= (discrete_range { , discrete_range }) discrete_range ::= *discrete*_subtype_indication | range

An array object is characterized by the number of indices (the dimensionality of the array); the type, position, and range of each index; and the type and possible constraints of the elements. The order of the indices is significant.

A one-dimensional array has a distinct element for each possible index value. A multidimensional array has a distinct element for each possible sequence of index values that can be formed by selecting one value for each index (in the given order). The possible values for a given index are all the values that belong to the corresponding range; this range of values is called the *index range*.

An unconstrained array definition defines an array type and a name denoting that type. For each object that has the array type, the number of indices, the type and position of each index, and the subtype of the elements are as in the type definition. The *index subtype* for a given index position is, by definition, the subtype denoted by the type mark of the corresponding index subtype definition. The values of the left and right bounds of each index range are not defined, but shall belong to the corresponding index subtype; similarly, the direction of each index range is not defined. The symbol <> (called a *box*) in an index subtype definition stands for an undefined range (different objects of the type need not have the same bounds and direction).

A constrained array definition defines both an array type and a subtype of this type:

— The array type is an implicitly declared anonymous type; this type is defined by an (implicit) unconstrained array definition, in which the element subtype indication is that of the constrained array definition and in which the type mark of each index subtype definition denotes the subtype defined by the corresponding discrete range.
— The array subtype is the subtype obtained by imposition of the index constraint on the array type.

If a constrained array definition is given for a type declaration, the simple name declared by this declaration denotes the array subtype.

The direction of a discrete range is the same as the direction of the range or the discrete subtype indication that defines the discrete range. If a subtype indication appears as a discrete range, the subtype indication shall not contain a resolution function.

Examples:

— Examples of constrained array declarations:

```
type MY_WORD is array (0 to 31) of BIT;
   -- A memory word type with an ascending range.

type DATA_IN is array (7 downto 0) of FIVE_LEVEL_LOGIC;
   -- An input port type with a descending range.
```

— Example of unconstrained array declarations:

```
type MEMORY is array (INTEGER range <>) of MY_WORD;
   -- A memory array type.
```

— Examples of array object declarations:

```
signal DATA_LINE: DATA_IN;
   -- Defines a data input line.

variable MY_MEMORY: MEMORY (0 to 2**n-1);
   -- Defines a memory of 2^n 32-bit words.
```

NOTE—The rules concerning constrained type declarations mean that a type declaration with a constrained array definition such as

```
type T is array (POSITIVE range MINIMUM to MAX) of ELEMENT;
```

is equivalent to the sequence of declarations

```
subtype index_subtype is POSITIVE range MINIMUM to MAX;
type array_type is array (index_subtype range <>) of ELEMENT;
subtype T is array_type (index_subtype);
```

where *index_subtype* and *array_type* are both anonymous. Consequently, T is the name of a subtype and all objects declared with this type mark are arrays that have the same index range.

3.2.1.1 Index constraints and discrete ranges

An index constraint determines the index range for every index of an array type and, thereby, the corresponding array bounds.

For a discrete range used in a constrained array definition and defined by a range, an implicit conversion to the predefined type INTEGER is assumed if each bound is either a numeric literal or an attribute, and if the type of both bounds (prior to the implicit conversion) is the type *universal_integer*. Otherwise, both bounds shall be of the same discrete type, other than *universal_integer*; this type shall be determined independently of the context, but using the fact that the type shall be discrete and that both bounds shall have the same type. These rules apply also to a discrete range used in an iteration scheme (see 8.9) or a generation scheme (see 9.7).

If an index constraint appears after a type mark in a subtype indication, then the type or subtype denoted by the type mark shall not already impose an index constraint. The type mark shall denote either an unconstrained array type or an access type whose designated type is such an array type. In either case, the index constraint shall provide a discrete range for each index of the array type, and the type of each discrete range shall be the same as that of the corresponding index.

An index constraint is *compatible* with the type denoted by the type mark if, and only if, the constraint defined by each discrete range is compatible with the corresponding index subtype. If any of the discrete ranges defines a null range, any array thus constrained is a *null array*, having no elements. An array value *satisfies* an index constraint if at each index position the array value and the index constraint have the same index range. (Note, however, that assignment and certain other operations on arrays involve an implicit subtype conversion.)

The index range for each index of an array object is determined as follows:

a) For a variable, signal, or quantity declared by an object declaration, the subtype indication of the corresponding object declaration shall define a constrained array subtype (and thereby, the index range for each index of the object). The same requirement exists for the subtype indication of an element declaration if the type of the record element is an array type, and for the element subtype indication of an array type definition if the type of the array element is itself an array type.

b) For a terminal declared by an object declaration, the subnature indication of the corresponding object declaration shall define a constrained array subnature (and thereby, the index range for each index of the object). The same requirement exists for the subnature indication of an element declaration if the nature of the record element is an array nature, and for the element subnature indication of an array nature definition if the nature of the array element is itself an array nature.

c) For a constant declared by an object declaration, the index ranges are defined by the initial value if the subtype of the constant is unconstrained; otherwise, they are defined by this subtype (in which case the initial value is the result of an implicit subtype conversion).

d) For an attribute whose value is specified by an attribute specification, the index ranges are defined by the expression given in the specification if the subtype of the attribute is unconstrained; otherwise, they are defined by this subtype (in which case the value of the attribute is the result of an implicit subtype conversion).

e) For an array object designated by an access value, the index ranges are defined by the allocator that creates the array object (see 7.3.6).

f) For an interface object declared with a subtype or subnature indication that defines a constrained array subtype or subnature, the index ranges are defined by that subtype or subnature.

g) For a formal parameter of a subprogram that is of an unconstrained array type and that is associated in whole (see 4.3.2.2), the index ranges are obtained from the corresponding association element in the applicable subprogram call.

h) For a formal parameter of a subprogram that is of an unconstrained array type and whose subelements are associated individually (see 4.3.2.2), the index ranges are obtained as follows: The directions of the index ranges of the formal parameter are those of the base type of the formal; the high and low bounds of the index ranges are respectively determined from the maximum and minimum values of the indices given in the association elements corresponding to the formal.

i) For a formal generic or a formal port of a design entity or of a block statement that is of an unconstrained array type and that is associated in whole, the index ranges are obtained from the corresponding association element in the generic map aspect (in the case of a formal generic) or port map aspect (in the case of a formal port) of the applicable (implicit or explicit) binding indication.

j) For a local generic or a local port of a component that is of an unconstrained array type and that is associated in whole, the index ranges are obtained from the corresponding association element in the generic map aspect (in the case of a local generic) or port map aspect (in the case of a local port) of the applicable component instantiation statement.

k) For a local generic or a local port of a component that is of an unconstrained array type and whose subelements are associated individually, the index ranges are obtained as follows: The directions of the index ranges of the local generic or local port are those of the base type of the local; the high and low bounds of the index ranges are respectively determined from the maximum and minimum values of the indices given in the association elements corresponding to the local.

If the index ranges for an interface object or member of an interface object are obtained from the corresponding association element (when associating in whole) or elements (when associating individually), then they are determined either by the actual part(s) or by the formal part(s) of the association element(s), depending upon the mode of the interface object, as follows:

— For an interface object or member of an interface object whose mode is **in**, **inout**, or **linkage**, if the actual part includes a conversion function or a type conversion, then the result type of that function or the type mark of the type conversion shall be a constrained array subtype, and the index ranges are obtained from this constrained subtype; otherwise, the index ranges are obtained from the object or value denoted by the actual designator(s).

— For an interface object or member of an interface object whose mode is **out**, **buffer**, **inout**, or **linkage**, if the formal part includes a conversion function or a type conversion, then the parameter subtype of that function or the type mark of the type conversion shall be a constrained array subtype, and the index ranges are obtained from this constrained subtype; otherwise, the index ranges are obtained from the object denoted by the actual designator(s).

For an interface object of mode **inout** or **linkage**, the index ranges determined by the first rule shall be identical to the index ranges determined by the second rule.

Examples:

```
type Word is array (NATURAL range <>) of BIT;
type Memory is array (NATURAL range <>) of Word (31 downto 0);

constant A_Word: Word := "10011";
   --  The index range of A_Word is 0 to 4

entity E is
   generic (ROM: Memory);
   port (Op1, Op2: in Word; Result: out Word);
end entity E;
   --  The index ranges of the generic and the ports are defined by
   --  the actuals associated with an instance bound to E; these index
   --  ranges are accessible  via the predefined array attributes
   --  (see 14.1).

signal A, B: Word (1 to 4);
signal C: Word (5 downto 0);

Instance: entity E
   generic map (1 to 2 => (others => '0'))
   port map (A, Op2(3 to 4) => B(1 to 2), Op2(2) => B(3),
             Result => C(3 downto 1));
   --  In this instance, the index range of ROM is 1 to 2 (matching
   --  that of the actual), the index range of Op1 is 1 to 4 (matching
   --  the index range of A), the index range of Op2 is 2 to 4, and
   --  the index range of Result is (3 downto 1) (again matching the
   --  index range of the actual).
```

3.2.1.2 Predefined array types

The predefined array types are STRING, REAL_VECTOR, and BIT_VECTOR, defined in package STANDARD in Clause 14.

The values of the predefined type STRING are one-dimensional arrays of the predefined type CHARACTER, indexed by values of the predefined subtype POSITIVE:

```
subtype POSITIVE is INTEGER range 1 to INTEGER'HIGH;
type STRING is array (POSITIVE range <>) of CHARACTER;
```

The values of the predefined types BIT_VECTOR and REAL_VECTOR are one-dimensional arrays of the predefined type BIT and REAL, respectively, indexed by values of the predefined subtype NATURAL:

```
subtype NATURAL is INTEGER range 0 to INTEGER'HIGH;
type BIT_VECTOR is array (NATURAL range <>) of BIT;
type REAL_VECTOR is array (NATURAL range <>) of REAL;
```

Examples:

```
variable MESSAGE: STRING (1 to 17) := "THIS IS A MESSAGE";

signal LOW_BYTE: BIT_VECTOR (0 to 7);
```

3.2.2 Record types

A record type is a composite type, objects of which consist of named elements. The value of a record object is a composite value consisting of the values of its elements.

```
record_type_definition ::=
    **record**
        element_declaration
        { element_declaration }
    **end record** [ *record_type*_simple_name ]
```

```
element_declaration ::=
    identifier_list : element_subtype_definition ;
```

identifier_list ::= identifier { , identifier }

element_subtype_definition ::= subtype_indication

Each element declaration declares an element of the record type. The identifiers of all elements of a record type shall be distinct. The use of a name that denotes a record element is not allowed within the record type definition that declares the element.

An element declaration with several identifiers is equivalent to a sequence of single element declarations. Each single element declaration declares a record element whose subtype is specified by the element subtype definition.

If a simple name appears at the end of a record type declaration, it shall repeat the identifier of the type declaration in which the record type definition is included.

A record type definition creates a record type; it consists of the element declarations in the order in which they appear in the type definition.

Example:

```
type DATE is
   record
      DAY    : INTEGER range 1 to 31;
      MONTH  : MONTH_NAME;
      YEAR   : INTEGER range 0 to 4000;
   end record;
```

3.3 Access types

An object declared by an object declaration is created by the elaboration of the object declaration and is denoted by a simple name or by some other form of name. In contrast, objects that are created by the evaluation of allocators (see 7.3.6) have no simple name. Access to such an object is achieved by an *access value* returned by an allocator; the access value is said to *designate* the object.

access_type_definition ::= **access** subtype_indication

For each access type, there is a literal **null** that has a null access value designating no object at all. The null value of an access type is the default initial value of the type. Other values of an access type are obtained by evaluation of a special operation of the type, called an *allocator*. Each such access value designates an object of the subtype defined by the subtype indication of the access type definition. This subtype is called the *designated subtype* and the base type of this subtype is called the *designated type*. The designated type shall not be a file type or a protected type; moreover, it shall not have a subelement that is a file type or a protected type.

An object declared to be of an access type shall be an object of class variable. An object designated by an access value is always an object of class variable.

The only form of constraint that is allowed after the name of an access type in a subtype indication is an index constraint. An access value belongs to a corresponding subtype of an access type either if the access value is the null value or if the value of the designated object satisfies the constraint.

Examples:

```
type ADDRESS is access MEMORY;
type BUFFER_PTR is access TEMP_BUFFER;
```

NOTE 1—An access value delivered by an allocator can be assigned to several variables of the corresponding access type. Hence, it is possible for an object created by an allocator to be designated by more than one variable of the access type. An access value can only designate an object created by an allocator; in particular, it cannot designate an object declared by an object declaration.

NOTE 2—If the type of the object designated by the access value is an array type, this object is constrained with the array bounds supplied implicitly or explicitly for the corresponding allocator.

3.3.1 Incomplete type declarations

The designated type of an access type can be of any type except a file type or a protected type (see 3.3). In particular, the type of an element of the designated type can be another access type or even the same access type. This permits mutually dependent and recursive access types. Declarations of such types require a prior incomplete type declaration for one or more types.

incomplete_type_declaration ::= **type** identifier ;

For each incomplete type declaration there shall be a corresponding full type declaration with the same identifier. This full type declaration shall occur later and immediately within the same declarative part as the incomplete type declaration to which it corresponds.

Prior to the end of the corresponding full type declaration, the only allowed use of a name that denotes a type declared by an incomplete type declaration is as the type mark in the subtype indication of an access type definition; no constraints are allowed in this subtype indication.

Example of a recursive type:

```
type CELL;  --  An incomplete type declaration.

type LINK is access CELL;

type CELL is
   record
      VALUE : INTEGER;
      SUCC  : LINK;
      PRED  : LINK;
   end record CELL;
variable HEAD: LINK := new CELL'(0, null, null);
variable \NEXT\: LINK := HEAD.SUCC;
```

Examples of mutually dependent access types:

```
type PART;  --  Incomplete type declarations.
type WIRE;

type PART_PTR is access PART;
type WIRE_PTR is access WIRE;

type PART_LIST is array (POSITIVE range <>) of PART_PTR;
type WIRE_LIST is array (POSITIVE range <>) of WIRE_PTR;

type PART_LIST_PTR is access PART_LIST;
type WIRE_LIST_PTR is access WIRE_LIST;

type PART is
   record
      PART_NAME   : STRING (1 to MAX_STRING_LEN);
      CONNECTIONS : WIRE_LIST_PTR;
   end record;

type WIRE is
   record
      WIRE_NAME : STRING (1 to MAX_STRING_LEN);
      CONNECTS  : PART_LIST_PTR;
   end record;
```

3.3.2 Allocation and deallocation of objects

An object designated by an access value is allocated by an allocator for that type. An allocator is a primary of an expression; allocators are described in 7.3.6. For each access type, a deallocation operation is implicitly declared immediately following the full type declaration for the type. This deallocation operation makes it possible to deallocate explicitly the storage occupied by a designated object.

Given the following access type declaration:

```
type AT is access T;
```

the following operation is implicitly declared immediately following the access type declaration:

```
procedure DEALLOCATE (P: inout AT);
```

Procedure DEALLOCATE takes as its single parameter a variable of the specified access type. If the value of that variable is the null value for the specified access type, then the operation has no effect. If the value of that variable is an access value that designates an object, the storage occupied by that object is returned to the system and may then be reused for subsequent object creation through the invocation of an allocator. The access parameter P is set to the null value for the specified type.

NOTE—If an access value is copied to a second variable and is then deallocated, the second variable is not set to null and thus references invalid storage.

3.4 File types

A file type definition defines a file type. File types are used to define objects representing files in the host system environment. The value of a file object is the sequence of values contained in the host system file.

file_type_definition ::= **file of** type_mark

The type mark in a file type definition defines the subtype of the values contained in the file. The type mark may denote either a constrained or an unconstrained subtype. The base type of this subtype shall not be a file type, an access type, or a protected type. If the base type is a composite type, it shall not contain a subelement of an access type, a file type, or a protected type. If the base type is an array type, it shall be a one-dimensional array type.

Examples:

```
file of STRING          --  Defines a file type that can contain
                        --  an indefinite number of strings of
                        --  arbitrary length.
file of NATURAL         --  Defines a file type that can contain
                        --  only nonnegative integer values.
```

3.4.1 File operations

The language implicitly defines the operations for objects of a file type. Given the following file type declaration:

type FT **is file of** TM;

where type mark TM denotes a scalar type, a record type, or a constrained array subtype, the following operations are implicitly declared immediately following the file type declaration:

```
procedure FILE_OPEN (file F: FT;
                     External_Name: in STRING;
                     Open_Kind: in FILE_OPEN_KIND := READ_MODE);

procedure FILE_OPEN (Status: out FILE_OPEN_STATUS;
                     file F: FT;
                     External_Name: in STRING;
                     Open_Kind: in FILE_OPEN_KIND := READ_MODE);

procedure FILE_CLOSE (file F: FT);

procedure READ (file F: FT; VALUE: out TM);

procedure WRITE (file F: FT; VALUE: in TM);

function ENDFILE (file F: FT) return BOOLEAN;
```

The FILE_OPEN procedures open an external file specified by the External_Name parameter and associate it with the file object F. If the call to FILE_OPEN is successful (see below), the file object is said to be *open* and the file object has an *access mode* dependent on the value supplied to the Open_Kind parameter (see 14.2).

— If the value supplied to the Open_Kind parameter is READ_MODE, the access mode of the file object is *read-only*. In addition, the file object is initialized so that a subsequent READ will return the first value in the external file. Values are read from the file object in the order that they appear in the external file.

— If the value supplied to the Open_Kind parameter is WRITE_MODE, the access mode of the file object is *write-only*. In addition, the external file is made initially empty. Values written to the file object are placed in the external file in the order in which they are written.

— If the value supplied to the Open_Kind parameter is APPEND_MODE, the access mode of the file object is *write-only*. In addition, the file object is initialized so that values written to it will be added to the end of the external file in the order in which they are written.

In the second form of FILE_OPEN, the value returned through the Status parameter indicates the results of the procedure call:

— A value of OPEN_OK indicates that the call to FILE_OPEN was successful. If the call to FILE_OPEN specifies an external file that does not exist at the beginning of the call, and if the access mode of the file object passed to the call is write-only, then the external file is created.

— A value of STATUS_ERROR indicates that the file object already has an external file associated with it.

— A value of NAME_ERROR indicates that the external file does not exist (in the case of an attempt to read from the external file) or the external file cannot be created (in the case of an attempt to write or append to an external file that does not exist). This value is also returned if the external file cannot be associated with the file object for any reason.

— A value of MODE_ERROR indicates that the external file cannot be opened with the requested Open_Kind.

The first form of FILE_OPEN causes an error to occur if the second form of FILE_OPEN, when called under identical conditions, would return a Status value other than OPEN_OK.

A call to FILE_OPEN of the first form is *successful* if and only if the call does not cause an error to occur. Similarly, a call to FILE_OPEN of the second form is successful if and only if it returns a Status value of OPEN_OK.

If a file object F is associated with an external file, procedure FILE_CLOSE terminates access to the external file associated with F and closes the external file. If F is not associated with an external file, then FILE_CLOSE has no effect. In either case, the file object is no longer open after a call to FILE_CLOSE that associates the file object with the formal parameter F.

An implicit call to FILE_CLOSE exists in a subprogram body for every file object declared in the corresponding subprogram declarative part. Each such call associates a unique file object with the formal parameter F and is called whenever the corresponding subprogram completes its execution.

Procedure READ retrieves the next value from a file; it is an error if the access mode of the file object is write-only or if the file object is not open. Procedure WRITE appends a value to a file; it is similarly an error if the access mode of the file object is read-only or if the file is not open. Function ENDFILE returns FALSE if a subsequent READ operation on an open file object whose access mode is read-only can retrieve another value from the file; otherwise, it returns TRUE. Function ENDFILE always returns TRUE for an open file object whose access mode is write-only. It is an error if ENDFILE is called on a file object that is not open.

For a file type declaration in which the type mark denotes an unconstrained array type, the same operations are implicitly declared, except that the READ operation is declared as follows:

```
procedure READ (file F: FT; VALUE: out TM; LENGTH: out Natural);
```

The READ operation for such a type performs the same function as the READ operation for other types, but in addition it returns a value in parameter LENGTH that specifies the actual length of the array value read by the operation. If the object associated with formal parameter VALUE is shorter than this length, then only that portion of the array value read by the operation that can be contained in the object is returned by the READ operation, and the rest of the value is lost. If the object associated with formal parameter VALUE is longer than this length, then the entire value is returned and remaining elements of the object are unaffected by the READ operation.

An error will occur when a READ operation is performed on file F if ENDFILE(F) would return TRUE at that point.

At the beginning of the execution of any file operation, the execution of the file operation *blocks* (see 12.5) until exclusive access to the file object denoted by the formal parameter F can be granted. Exclusive access to the given file object is then granted and the execution of the file operation proceeds. Once the file operation completes, exclusive access to the given file object is rescinded.

NOTE—Predefined package TEXTIO is provided to support formatted human-readable I/O. It defines type TEXT (a file type representing files of variable-length text strings) and type LINE (an access type that designates such strings). READ and WRITE operations are provided in package TEXTIO that append or extract data from a single line. Additional operations are provided to read or write entire lines and to determine the status of the current line or of the file itself. Package TEXTIO is defined in Clause 14.

3.5 Protected types

A protected type definition defines a protected type. A protected type implements instantiatiable regions of sequential statements, each of which are guaranteed exclusive access to shared data. Shared data is a set of variable objects that may be potentially accessed as a unit by multiple processes.

```
protected_type_definition ::=
    protected_type_declaration
  | protected_type_body
```

Each protected type declaration appearing immediately within a given declarative region (see 10.1) shall have exactly one corresponding protected type body appearing immediately within the same declarative region and textually subsequent to the protected type declaration. Similarly, each protected type body appearing immediately within a given declarative region shall have exactly one corresponding protected type declaration appearing immediately within the same declarative region and textually prior to the protected type body.

3.5.1 Protected type declarations

A protected type declaration declares the external interface to a protected type.

```
protected_type_declaration ::=
  protected
      protected_type_declarative_part
  end protected [ protected_type_simple_name ]

protected_type_declarative_part ::=
  { protected_type_declarative_item }

protected_type_declarative_item ::=
    subprogram_declaration
  | attribute_specification
```

| use_clause

If a simple name appears at the end of a protected type declaration, it shall repeat the identifier of the type declaration in which the protected type definition is included.

Each subprogram specified within a given protected type declaration defines an abstract operation, called a *method*, that operates atomically and exclusively on a single object of the protected type. In addition to the (implied) object of the protected type operated on by the subprogram, additional parameters may be explicitly specified in the formal parameter list of the subprogram declaration of the subprogram. Such formal parameters shall not be of an access type or a file type; moreover, they shall not have a subelement that is an access type or a file type. Additionally, in the case of a function subprogram, the return type of the function shall not be of an access type or file type; moreover, it shall not have a subelement that is an access type or a file type.

Examples:

```
type SharedCounter is protected
   procedure increment (N: Integer := 1);
   procedure decrement (N: Integer := 1);
   impure function value return Integer;
end protected SharedCounter;

type ComplexNumber is protected
   procedure extract (variable r, i: out Real);
   procedure add (variable a, b: inout ComplexNumber);
end protected ComplexNumber;

type VariableSizedBitArray is protected
   procedure add_bit (index: Positive; value: Bit);
   impure function size return Natural;
end protected VariableSizedBitArray;
```

3.5.2 Protected type bodies

A protected type body provides the implementation for a protected type.

protected_type_body ::=
  protected body
    protected_type_body_declarative_part
  end protected body [*protected_type*_simple name]

protected_type_body_declarative_part ::=
  { protected_type_body_declarative_item }

protected_type_body_declarative_item ::=
   subprogram_declaration
  | subprogram_body
  | type_declaration
  | subtype_declaration
  | constant_declaration
  | variable_declaration
  | file_declaration
  | alias_declaration
  | attribute_declaration

| attribute_specification
| use_clause
| group_template_declaration
| group_declaration

Each subprogram declaration appearing in a given protected type declaration shall have a corresponding subprogram body appearing in the corresponding protected type body.

NOTE—Subprogram bodies appearing in a protected type body not conformant to any of the subprogram declarations in the corresponding protected type declaration are visible only within the protected type body. Such subprograms may have parameters and (in the case of functions) return types that are or contain access and file types.

Examples:

```
type SharedCounter is protected body

   riable counter: Integer := 0;

   procedure increment (N: Integer := 1) is
   begin
      counter := counter + N;
   end procedure increment;

   procedure decrement (N: Integer := 1) is
   begin
      counter := counter - N;
   end procedure decrement;

   impure function value return Integer is
   begin
      return counter;
   end function value;
end protected body SharedCounter;

type ComplexNumber is protected body

   variable re, im: Real;

   procedure extract (r, i: out Real) is
   begin
      r := re;
      i := im;
   end procedure extract;

   procedure add (variable a, b: inout ComplexNumber) is
      variable a_real, b_real: Real;
      variable a_imag, b_imag: Real;
   begin
      a.extract (a_real, a_imag);
      b.extract (b_real, b_imag);
      re  := a_real + b_real;
      im := a_imag + b_imag;
   end procedure add;
end protected body ComplexNumber;
```

```
type VariableSizeBitArray is protected body
   type bit_vector_access is access Bit_Vector;

   variable bit_array: bit_vector_access := null;
   variable bit_array_length: Natural := 0;

   procedure add_bit (index: Positive; value: Bit) is
      variable tmp: bit_vector_access;
   begin
      if index > bit_array_length then
         tmp := bit_array;
         bit_array := new bit_vector (1 to index);
         if tmp /= null then
            bit_array (1 to bit_array_length) := tmp.all;
            deallocate (tmp);
         end if;
         bit_array_length := index;
      end if;
      bit_array (index) := value;
   end procedure add_bit;

   impure function size return Natural is
   begin
      return bit_array_length;
   end function size;
end protected body VariableSizeBitArray;
```

3.6 Natures

A *nature* defines values which may be accessed through the attributes of a terminal. These attributes include its compatibility with other terminals, the *reference terminal* of the nature, and its *across type* and *through type* (together, the *branch types* of the nature), which are used indirectly to define the types of branch quantities. It is an error if an object other than a terminal is declared as being of a given nature. Natures may be scalar or composite.

3.6.1 Scalar natures

A scalar nature definition defines a scalar nature and its branch types, and declares the name of the reference terminal, which is of the nature.

scalar_nature_definition ::=
   type_mark **across**
   type_mark **through**
   identifier **reference**

The two type marks define, respectively, the across type and through type of the scalar nature. The type marks shall denote floating-point types. The *simple nature* of a scalar nature is the nature itself.

Examples:

A nature declaration for electrical systems:

```
subtype Voltage is REAL tolerance "voltage";
subtype Current is REAL tolerance "current";
nature Electrical is
         Voltage across     -- across type is Voltage
         Current through    -- through type is Current
         Ground reference;  -- reference terminal is named Ground
```

A nature declaration for thermal systems:

```
subtype Temperature is REAL tolerance "temp";
subtype Heatflow is REAL tolerance "heat";
nature Thermal is
         Temperature across   -- across type is Temperature
         Heatflow through     -- through type is Heatflow
         Th_ref reference;    -- reference terminal is named Th_ref
```

3.6.2 Composite natures

Composite natures are used to define collections of terminals. These include arrays of terminals and records of terminals.

composite_nature_definition ::=
  array_nature_definition | record_nature_definition

A terminal of a composite nature represents a collection of scalar terminals, one for each scalar subelement of the composite nature. The scalar subelements of a composite nature shall all have the same simple nature, which is also the simple nature of the composite nature.

3.6.2.1 Array natures

An array nature is a composite nature. Terminal objects of an array nature consist of identical elements, each associated with some index value. The branch types defined by an array nature definition are array types. A terminal object of an array nature is referred to as an array object, just as is an object of an array type.

array_nature_definition ::=
  unconstrained_nature_definition | constrained_nature_definition

unconstrained_nature_definition ::=
  array (index_subtype_definition { , index_subtype_definition })
    of subnature_indication

constrained_nature_definition ::=
  array index_constraint **of** subnature_indication

The across type defined by an unconstrained nature definition is equivalent to a type defined by an unconstrained array definition. The list of index subtype definitions of the unconstrained array definition is the list of index subtype definitions of the unconstrained nature definition. The across type defined by a constrained nature definition is equivalent to the type defined by a constrained array definition. The index constraint of the constrained array definition is the index constraint of the constrained nature definition. In each case, the element subtype indication of the equivalent type definition is that of the across type defined by the nature of the subnature indication, together with the index constraint of the subnature indication.

The through type defined by an unconstrained nature definition is equivalent to a type defined by an unconstrained array definition. The list of index subtype definitions of the unconstrained array definition is the list of index subtype definitions of the unconstrained nature definition. The through type defined by a constrained nature definition is equivalent to the type defined by a constrained array definition. The index constraint of the constrained array definition is the index constraint of the constrained nature definition. In each case, the element subtype indication of the equivalent type definition is that of the through type defined by the nature of the subnature indication, together with the index constraint of the subnature indication.

Example:

A one-dimensional array nature:

```
nature Electrical_vector is
   array (NATURAL range <>) of Electrical;
```

3.6.2.2 Record natures

A record nature is a composite nature. Terminal objects of a record nature consist of named terminals. The branch types defined by a record nature definition are record types.

record_nature_definition ::=
  record
    nature_element_declaration
    { nature_element_declaration }
  end record [*record_nature*_simple_name]

nature_element_declaration ::=
  identifier_list : element_subnature_definition ;

element_subnature_definition ::=
  subnature_indication

Each nature element declaration declares an element of the record nature. All elements shall have the same simple nature. The identifiers of all elements of a record nature shall be distinct. The use of a name that denotes a record element is not allowed within the record nature definition itself.

A nature element declaration with several identifiers is equivalent to a sequence of single nature element declarations. Each single nature element declaration declares a record element whose subnature is specified by the element subnature definition.

The across type defined by a record nature definition is equivalent to the type defined by a record type definition in which there is a matching element declaration for each nature element declaration. For each element declaration of the record type definition, the identifier list is the same as the identifier list of the matching nature element declaration, and the subtype indication of the element subtype definition is the across type defined by the nature of the subnature indication of the nature element declaration, together with the index constraint of the subnature indication of the nature element declaration.

The through type defined by a record nature definition is equivalent to the type defined by a record type definition in which there is a matching element declaration for each nature element declaration. For each element declaration of the record type definition, the identifier list is the same as the identifier list of the matching nature element declaration, and the subtype indication of the element subtype definition is the through type defined by the nature of the subnature indication of the nature element declaration, together with the index constraint of the subnature indication of the nature element declaration.

Examples:

A record nature:

```
nature Electrical_bus is
   record
      Strobe: Electrical;
      Databus: Electrical_vector (0 to 7);
   end record;
```

A mixed record nature:

```
nature Mixed is
   record
      ElJunction: Electrical;
      ThJunction: Thermal;    -- Illegal: Thermal and Electrical do not
                              --          have the same simple nature.
   end record;
```

4. Declarations

The language defines several kinds of entities that are declared explicitly or implicitly by declarations.

```
declaration ::=
    type_declaration
  | subtype_declaration
  | object_declaration
  | interface_declaration
  | alias_declaration
  | attribute_declaration
  | component_declaration
  | group_template_declaration
  | group_declaration
  | entity_declaration
  | configuration_declaration
  | subprogram_declaration
  | package_declaration
  | primary_unit
  | architecture_body
  | nature_declaration
  | subnature_declaration
```

For each form of declaration, the language rules define a certain region of text called the *scope* of the declaration (see 10.2). Each form of declaration associates an identifier with a named entity. Only within its scope, there are places where it is possible to use the identifier to refer to the associated declared entity; these places are defined by the visibility rules (see 10.3). At such places the identifier is said to be a *name* of the entity; the name is said to *denote* the associated entity.

This clause describes type and subtype declarations, nature and subnature declarations, the various kinds of object declarations, alias declarations, attribute declarations, component declarations, and group and group template declarations. The other kinds of declarations are described in Clause 1 and Clause 2.

A declaration takes effect through the process of elaboration. Elaboration of declarations is discussed in Clause 12.

4.1 Type declarations

A type declaration declares a type.

```
type_declaration ::=
    full_type_declaration
  | incomplete_type_declaration
```

full_type_declaration ::=
  type identifier **is** type_definition ;

```
type_definition ::=
    scalar_type_definition
  | composite_type_definition
  | access_type_definition
  | file_type_definition
  | protected_type_definition
```

The types created by the elaboration of distinct type definitions are distinct types. The elaboration of the type definition for a scalar type or a constrained array type creates both a base type and a subtype of the base type.

The simple name declared by a type declaration denotes the declared type, unless the type declaration declares both a base type and a subtype of the base type, in which case the simple name denotes the subtype and the base type is anonymous. A type is said to be *anonymous* if it has no simple name. For explanatory purposes, this standard sometimes refers to an anonymous type by a pseudo-name, written in italics, and uses such pseudo-names at places where the syntax normally requires an identifier.

NOTE 1—Two type definitions always define two distinct types, even if they are lexically identical. Thus, the type definitions in the following two integer type declarations define distinct types:

```
type A is range 1 to 10;
type B is range 1 to 10;
```

This applies to type declarations for other classes of types as well.

NOTE 2—The various forms of type definition are described in Clause 3. Examples of type declarations are also given in that clause.

4.2 Subtype declarations

A subtype declaration declares a subtype.

subtype_declaration ::=
    subtype identifier **is** subtype_indication ;

subtype_indication ::=
    [*resolution_function*_name] type_mark [constraint] [tolerance_aspect]

type_mark ::=
      *type*_name
    | *nsubtype*_name

constraint ::=
      range_constraint
    | index_constraint

tolerance_aspect ::=
    tolerance *string*_expression

A type mark denotes a type or a subtype. If a type mark is the name of a type, the type mark denotes this type and also the corresponding unconstrained subtype. The base type of a type mark is, by definition, the base type of the type or subtype denoted by the type mark.

A subtype indication defines a subtype of the base type of the type mark.

If a subtype indication includes a resolution function name, then any signal declared to be of that subtype will be resolved, if necessary, by the named function (see 2.4); for an overloaded function name, the meaning of the function name is determined by context (see 2.3 and 10.5). It is an error if the function does not meet the requirements of a resolution function (see 2.4). The presence of a resolution function name has no effect on the declarations of objects other than signals or on the declarations of files, aliases, attributes, or other subtypes.

If the subtype indication does not include a constraint, the subtype is the same as that denoted by the type mark. The condition imposed by a constraint is the condition obtained after evaluation of the expressions and ranges forming the constraint. The rules defining compatibility are given for each form of constraint in the appropriate clause. These rules are such that if a constraint is compatible with a subtype, then the condition imposed by the constraint cannot contradict any condition already imposed by the subtype on its values. An error occurs if any check of compatibility fails.

If the subtype indication includes a tolerance aspect, then the string expression of the tolerance aspect shall be a static expression, and the tolerance group of each scalar subelement of the subtype is the value of the string expression of the tolerance aspect. It is an error if in this case the subtype is not a nature type (see 4.3.1.6 for the definition of a nature type). If a subtype indication does not include a tolerance aspect, and the base type of the subtype is a nature type, then the tolerance group of each scalar subelement of the subtype is the same as that of the matching scalar subelement of the type denoted by the type mark.

The direction of a discrete subtype indication is the same as the direction of the range constraint that appears as the constraint of the subtype indication. If no constraint is present, and the type mark denotes a subtype, the direction of the subtype indication is the same as that of the denoted subtype. If no constraint is present, and the type mark denotes a type, the direction of the subtype indication is the same as that of the range used to define the denoted type. The direction of a discrete subtype is the same as the direction of its subtype indication.

A subtype indication denoting an access type, a file type, or a protected type shall not contain a resolution function. Furthermore, the only allowable constraint on a subtype indication denoting an access type is an index constraint (and then only if the designated type is an array type).

A subtype indication denoting a subtype of a record type, a file type, or a protected type shall not contain a constraint.

NOTE 1—A subtype declaration does not define a new type.

NOTE 2—The tolerance group of a subtype is a string value that may be used by a model to group quantities that have similar requirements concerning the accuracy and tolerance of the quantity values.

4.3 Objects

An *object* is a named entity that is a terminal or that contains (has) a value of a type. An object is one of the following:

— An object declared by an object declaration (see 4.3.1)
— A loop or generate parameter (see 8.9 and 9.7)
— A formal parameter of a subprogram (see 2.1.1)
— A formal port (see 1.1.1.2 and 9.1)
— A formal generic (see 1.1.1.1 and 9.1)
— A local port (see 4.5)
— A local generic (see 4.5)
— An implicit signal GUARD defined by the guard expression of a block statement (see 9.1)

In addition, the following are objects, but are not named entities:

— An implicit signal defined by any of the predefined attributes 'ABOVE, 'DELAYED, 'STABLE, 'QUIET, and 'TRANSACTION (see 14.1)
— An implicit quantity defined by any of the predefined attributes 'DOT, 'INTEG, 'DELAYED, 'ZOH, 'LTF, 'ZTF, 'REFERENCE, 'CONTRIBUTION, 'RAMP, and 'SLEW (see 14.1)
— An element or slice of another object (see 6.3, 6.4, and 6.5)

— An object designated by a value of an access type (see 3.3)

There are six classes of objects: constants, signals, variables, quantities, terminals, and files. The variable class of objects also has an additional subclass: shared variables. The class of an explicitly declared object is specified by the reserved word that shall or may appear at the beginning of the declaration of that object. For a given object of a composite type or nature, each subelement of that object is itself an object of the same class and subclass, if any, as the given object. The value (if any) of a composite object is the aggregation of the values of its subelements.

Objects declared by object declarations are available for use within blocks, processes, subprograms, or packages. Loop and generate parameters are implicitly declared by the corresponding statement and are available for use only within that statement. Other objects, declared by interface declarations, create channels for the communication of values between independent parts of a description.

4.3.1 Object declarations

An object declaration declares an object of a specified type or nature. Such an object is called an *explicitly declared object*.

```
object_declaration ::=
      constant_declaration
    | signal_declaration
    | variable_declaration
    | file_declaration
    | quantity_declaration
    | terminal_declaration
```

An object declaration other than a branch quantity declaration is called a *single-object declaration* if its identifier list has a single identifier; it is called a *multiple-object declaration* if the identifier list has two or more identifiers. A multiple-object declaration is equivalent to a sequence of the corresponding number of single-object declarations. For each identifier of the list, the equivalent sequence has a single-object declaration formed by this identifier, followed by a colon and by whatever appears at the right of the colon in the multiple-object declaration; the equivalent sequence is in the same order as the identifier list. A branch quantity declaration can be a multiple object declaration; however, it is not governed by the transformation in this paragraph (see 4.3.1.6 for the rules governing the creation of objects by a branch quantity declaration).

A similar equivalence applies also for interface object declarations (see 4.3.2).

NOTE—The subelements of a composite declared object are not declared objects.

4.3.1.1 Constant declarations

A constant declaration declares a *constant* of the specified type. Such a constant is an *explicitly declared constant*.

constant_declaration ::=
  constant identifier_list : subtype_indication [:= expression] ;

If the assignment symbol ":=" followed by an expression is present in a constant declaration, the expression specifies the value of the constant; the type of the expression shall be that of the constant. The value of a constant cannot be modified after the declaration is elaborated.

If the assignment symbol ":=" followed by an expression is not present in a constant declaration, then the declaration declares a deferred constant. Such a constant declaration shall appear in a package declaration. The corresponding full constant declaration, which defines the value of the constant, shall appear in the body of the package (see 2.6).

Formal parameters of subprograms that are of mode **in** may be constants, and local and formal generics are always constants; the declarations of such objects are discussed in 4.3.2. A loop parameter is a constant within the corresponding loop (see 8.9); similarly, a generate parameter is a constant within the corresponding generate statement (see 9.7). A subelement or slice of a constant is a constant.

It is an error if a constant declaration declares a constant that is of a file type, an access type, a protected type, or a composite type that has a subelement that is a file type, an access type, or a protected type.

NOTE—The subelements of a composite declared constant are not declared constants.

Examples:

```
constant TOLER: DISTANCE := 1.5 nm;
constant PI: REAL := 3.141592;
constant CYCLE_TIME: TIME := 100 ns;
constant Propagation_Delay: DELAY_LENGTH;  -- A deferred constant.
```

4.3.1.2 Signal declarations

A signal declaration declares a *signal* of the specified type. Such a signal is an *explicitly declared signal.*

signal_declaration ::=
    signal identifier_list : subtype_indication [signal_kind] [:= expression] ;

signal_kind ::= **register** | **bus**

If the name of a resolution function appears in the declaration of a signal or in the declaration of the subtype used to declare the signal, then that resolution function is associated with the declared signal. Such a signal is called a *resolved signal*.

If a signal kind appears in a signal declaration, then the signals so declared are *guarded* signals of the kind indicated. For a guarded signal that is of a composite type, each subelement is likewise a guarded signal. For a guarded signal that is of an array type, each slice (see 6.5) is likewise a guarded signal. A guarded signal may be assigned values under the control of Boolean-valued *guard expressions* (or *guards*). When a given guard becomes False, the drivers of the corresponding guarded signals are implicitly assigned a null transaction (see 8.4.1) to cause those drivers to turn off. A disconnection specification (see 5.3) is used to specify the time required for those drivers to turn off.

If the signal declaration includes the assignment symbol followed by an expression, it shall be of the same type as the signal. Such an expression is said to be a *default expression*. The default expression defines a *default value* associated with the signal or, for a composite signal, with each scalar subelement thereof. For a signal declared to be of a scalar subtype, the value of the default expression is the default value of the signal. For a signal declared to be of a composite subtype, each scalar subelement of the value of the default expression is the default value of the corresponding subelement of the signal.

In the absence of an explicit default expression, an implicit default value is assumed for a signal of a scalar subtype or for each scalar subelement of a composite signal, each of which is itself a signal of a scalar subtype. The implicit default value for a signal of a scalar subtype T is defined to be that given by T'LEFT.

It is an error if a signal declaration declares a signal that is of a file type, an access type, a protected type, or a composite type having a subelement that is a file type, an access type, or a protected type. It is also an error if a guarded signal of a scalar type is neither a resolved signal nor a subelement of a resolved signal.

A signal may have one or more *sources*. For a signal of a scalar type, each source is either a driver (see 12.6.1) or an **out**, **inout**, **buffer**, or **linkage** port of a component instance or of a block statement with which the signal is associated. For a signal of a composite type, each composite source is a collection of scalar sources, one for each scalar subelement of the signal. It is an error if, after the elaboration of a description, a signal has multiple sources and it is not a resolved signal. It is also an error if, after the elaboration of a description, a resolved signal has more sources than the number of elements in the index range of the type of the formal parameter of the resolution function associated with the resolved signal.

If a subelement or slice of a resolved signal of composite type is associated as an actual in a port map aspect (either in a component instantiation statement, a block statement, or in a binding indication), and if the corresponding formal is of mode **out**, **inout**, **buffer**, or **linkage**, then every scalar subelement of that signal shall be associated exactly once with such a formal in the same port map aspect, and the collection of the corresponding formal parts taken together constitute one source of the signal. If a resolved signal of composite type is associated as an actual in a port map aspect, that is equivalent to each of its subelements being associated in the same port map aspect.

If a subelement of a resolved signal of composite type has a driver in a given process, then every scalar subelement of that signal shall have a driver in the same process, and the collection of all of those drivers taken together constitute one source of the signal.

The default value associated with a scalar signal defines the value component of a transaction that is the initial contents of each driver (if any) of that signal. The time component of the transaction is not defined, but the transaction is understood to have already occurred by the start of simulation.

Examples:

```
signal S: STANDARD.BIT_VECTOR (1 to 10);
signal CLK1, CLK2: TIME;
signal OUTPUT: WIRED_OR MULTI_VALUED_LOGIC;
```

NOTE 1—Signal ports of any mode are also signals. The term signal is used in this standard to refer to objects declared either by signal declarations or by signal port declarations (or to subelements, slices, or aliases of such objects). It also refers to the implicit signal GUARD (see 9.1) and to implicit signals defined by the predefined attributes 'ABOVE, 'DELAYED, 'STABLE, 'QUIET, and 'TRANSACTION. The term signal port is used to refer to objects declared by port declarations only.

NOTE 2—Signals are given initial values by initializing their drivers. The initial values of drivers are then propagated through the corresponding net to determine the initial values of the signals that make up the net (see 12.6.3).

NOTE 3—The value of a signal is indirectly modified by a signal assignment statement (see 8.4); such assignments affect the future values of the signal.

NOTE 4—The subelements of a composite, declared signal are not declared signals.

Cross-references: Disconnection specifications, 5.3; disconnection statements, 9.5; guarded assignment, 9.5; guarded blocks, 9.1; guarded targets, 9.5; signal guard, 9.1.

4.3.1.3 Variable declarations

A variable declaration declares a *variable* of the specified type. Such a variable is an *explicitly declared variable*.

variable_declaration ::=
  [**shared**] **variable** identifier_list : subtype_indication [:= expression] ;

A variable declaration that includes the reserved word **shared** is a *shared variable declaration*. A shared variable declaration declares a *shared variable*. Shared variables are a subclass of the variable class of objects. The base type of the subtype indication of a shared variable declaration shall be a protected type. Variables declared immediately within entity declarations, architecture bodies, packages, package bodies, and blocks shall be shared variables. Variables declared immediately within subprograms, processes, and simultaneous procedural statements shall not be shared variables. Variables may appear in protected type bodies; such variables, which shall not be shared variables, represent shared data.

If a given variable declaration appears (directly or indirectly) within a protected type body, then the base type denoted by the subtype indication of the variable declaration shall not be the protected type defined by the protected type body.

If the variable declaration includes the assignment symbol followed by an expression, the expression specifies an initial value for the declared variable; the type of the expression shall be that of the variable. Such an expression is said to be an *initial value expression*. A variable declaration, whether it is a shared variable declaration or not, whose subtype indication denotes a protected type shall not have an initial value expression (moreover, it shall not include the immediately preceding assignment symbol).

If an initial value expression appears in the declaration of a variable, then the initial value of the variable is determined by that expression each time the variable declaration is elaborated. In the absence of an initial value expression, a default initial value applies. The default initial value for a variable of a scalar subtype T is defined to be the value given by T'LEFT. The default initial value of a variable of a composite type is defined to be the aggregate of the default initial values of all of its scalar subelements, each of which is itself a variable of a scalar subtype. The default initial value of a variable of an access type is defined to be the value **null** for that type.

NOTE 1—The value of a variable that is not a shared variable is modified by a variable assignment statement (see 8.5); such assignments take effect immediately.

NOTE 2—The variables declared within a given procedure persist until that procedure completes and returns to the caller. For procedures that contain wait statements, a variable therefore persists from one point in simulation time to another, and the value in the variable is thus maintained over time. For processes, which never complete, all variables persist from the beginning of simulation until the end of simulation.

NOTE 3—The subelements of a composite, declared variable are not declared variables.

NOTE 4—Since the language guarantees mutual exclusion of accesses to shared data, but not the order of access to such data by multiple processes in the same simulation cycle, the use of shared variables can be both non-portable and non-deterministic. For example, consider the following architecture:

```
architecture UseSharedVariables of SomeEntity is
   subtype ShortRange is INTEGER range -1 to 1;
   type ShortRangeProtected is protected
      procedure Set (V: ShortRange);
      procedure Get (V: out ShortRange);
   end protected;

   type ShortRangeProtected is protected body
      variable Local: ShortRange := 0;
   begin
      procedure Set (V: ShortRange) is
      begin
         Local := V;
      end procedure Set;

      procedure Get (V: out ShortRange) is
      begin
         V := Local;
      end procedure Get;
   end protected body;

   shared variable Counter: ShortRangeProtected;

begin
   PROC1: process
      variable V: ShortRange;
   begin
      Counter.Get (V);
      Counter.Set (V+1);
      wait;
   end process PROC1;

   PROC2: process
      variable V: ShortRange;
   begin
      Counter.Get (V);
      Counter.Set (V-1);
      wait;
   end process PROC2;
end architecture UseSharedVariables;
```

In particular, the value of Counter after the execution of both processes is not guaranteed to be 0.

NOTE 5—Variables that are not shared variables may have a subtype indication denoting a protected type.

Examples:

```
variable INDEX: INTEGER range 0 to 99 := 0;
   -- Initial value is determined by the initial value expression

variable COUNT: POSITIVE;
   -- Initial value is POSITIVE'LEFT; that is,1

variable MEMORY: BIT_MATRIX (0 to 7, 0 to 1023);
   -- Initial value is the aggregate of the initial values of each
element

shared variable Counter: SharedCounter;
   -- See 3.5.1 and 3.5.2 for the definitions of SharedCounter

shared variable addend, augend, result: ComplexNumber;
   -- See 3.5.1 and 3.5.2 for the definition of ComplexNumber

variable bit_stack: VariableSizeBitArray;
   -- See 3.5.1 and 3.5.2 for the definition of VariableSizeBitArray;
```

4.3.1.4 File declarations

A file declaration declares a *file* of the specified type. Such a file is an *explicitly declared file*.

file_declaration ::=
    file identifier_list : subtype_indication [file_open_information] ;

file_open_information ::= [**open** *file_open_kind*_expression] **is** file_logical_name

file_logical_name ::= *string*_expression

The subtype indication of a file declaration shall define a file subtype.

If file open information is included in a given file declaration, then the file declared by the declaration is opened (see 3.4.1) with an implicit call to FILE_OPEN when the file declaration is elaborated (see 12.3.1.4). This implicit call is to the FILE_OPEN procedure of the first form, and it associates the identifier with the file parameter F, the file logical name with the External_Name parameter, and the file open kind expression with the Open_Kind parameter. If a file open kind expression is not included in the file open information of a given file declaration, then the default value of READ_MODE is used during elaboration of the file declaration.

If file open information is not included in a given file declaration, then the file declared by the declaration is not opened when the file declaration is elaborated.

The file logical name shall be an expression of predefined type STRING. The value of this expression is interpreted as a logical name for a file in the host system environment. An implementation shall provide some mechanism to associate a file logical name with a host-dependent file. Such a mechanism is not defined by the language.

The file logical name identifies an external file in the host file system that is associated with the file object. This association provides a mechanism for either importing data contained in an external file into the design during simulation or exporting data generated during simulation to an external file.

If multiple file objects are associated with the same external file, and each file object has an access mode that is read-only (see 3.4.1), then values read from each file object are read from the external file associated with the file object. The language does not define the order in which such values are read from the external file, nor does it define whether each value is read once or multiple times (once per file object).

The language does not define the order of and the relationship, if any, between values read from and written to multiple file objects that are associated with the same external file. An implementation may restrict the number of file objects that are associated at one time with a given external file.

If a formal subprogram parameter is of the class **file**, it shall be associated with an actual that is a file object.

Examples:

```
type IntegerFile is file of INTEGER;

file F1: IntegerFile;
   -- No implicit FILE_OPEN is performed during elaboration.

file F2: IntegerFile is "test.dat";
   -- At elaboration, an implicit call is performed:
   -- FILE_OPEN (F2, "test.dat");
   -- The OPEN_KIND parameter defaults to READ_MODE.

file F3: IntegerFile open WRITE_MODE is "test.dat";
   -- At elaboration, an implicit call is performed:
   -- FILE_OPEN (F3, "test.dat", WRITE_MODE);
```

NOTE—All file objects associated with the same external file should be of the same base type.

4.3.1.5 Terminal declarations

A terminal declaration declares a *terminal*, and also the reference quantity and contribution quantity of the terminal.

terminal_declaration ::=
    terminal identifier_list : subnature_indication ;

Each terminal of a scalar nature and each scalar subelement of a terminal of composite nature is a *scalar terminal*.

The across type implied by a terminal name is determined as follows. The across type implied by a name that denotes a terminal is the across type of the nature of the terminal. The across type implied by a terminal name that is a slice name is the base type of the across type of the nature of the terminal together with a constraint that is the range of the slice name. The across type implied by a terminal name that is a selected name denoting an element of a record or by a terminal name that is an indexed name is the across type of the nature of the denoted element.

The through type implied by a terminal name is determined as follows. The through type implied by a name that denotes a terminal is the through type of the nature of the terminal. The through type implied by a terminal name that is a slice name is the base type of the through type of the nature of the terminal together with a constraint that is the range of the slice name. The through type implied by a terminal name that is a selected name denoting an element of a record or by a terminal name that is an indexed name is the through type of the nature of the denoted element.

The simple nature of a terminal is identical to the simple nature of the nature of the terminal.

Each attribute name T'REFERENCE, where T is a terminal name, denotes the *reference quantity* of terminal T. T'REFERENCE is an across quantity of the across type implied by T whose plus terminal is T and whose minus terminal is the reference terminal of the simple nature of T. If T is composite, then each scalar subelement of T'REFERENCE is the reference quantity of the matching scalar subelement of T.

Each attribute name T'CONTRIBUTION, where T is a terminal name, denotes the *contribution quantity* of terminal T. T'CONTRIBUTION is a through quantity of the through type implied by T. If T is composite, then each scalar subelement of T'CONTRIBUTION is the contribution quantity of the matching scalar subelement of T. See 12.4.1 for more information on expressions of the form T'CONTRIBUTION.

Examples:

```
terminal Anode, Cathode: Electrical;
terminal T3, T4: Electrical_bus;
```

4.3.1.6 Quantity declarations

A quantity declaration declares one or more quantities.

quantity_declaration ::=
      free_quantity_declaration
    | branch_quantity_declaration
    | source_quantity_declaration

free_quantity_declaration ::=
    quantity identifier_list : subtype_indication [:= expression] ;

```
branch_quantity_declaration ::=
    **quantity** [ across_aspect ] [ through_aspect ] terminal_aspect ;

source_quantity_declaration ::=
    **quantity** identifier_list : subtype_indication source_aspect ;

across_aspect ::=
    identifier_list [ tolerance_aspect ] [ := expression ] **across**

through_aspect ::=
    identifier_list [ tolerance_aspect ] [ := expression ] **through**

terminal_aspect ::=
    *plus_terminal*_name [ **to** *minus_terminal*_name ]

source_aspect ::=
      **spectrum** *magnitude*_simple_expression , *phase*_simple_expression
    | **noise** *power*_simple_expression
```

Each quantity of a scalar type and each scalar subelement of a quantity of a composite type is a *scalar quantity*.

A free quantity declaration declares one or more quantities of the specified type. Similarly, a branch quantity declaration declares one or more quantities whose type(s) are determined by the rules given below. A *nature type* is a floating-point type or a composite type whose elements are of a nature type. The type of a quantity shall be a nature type.

It is an error if a branch quantity declaration includes neither an across aspect nor a through aspect.

A terminal aspect that does not include an explicit minus terminal name is equivalent to a terminal aspect with the given plus terminal name and the name of the reference terminal of the simple nature of its nature as the minus terminal name.

If the terminals denoted by the terminal names of a terminal aspect are both of composite natures, then they shall be of the same nature, and for each element of the plus terminal there shall be a matching element of the minus terminal. If one terminal is a terminal of a composite nature and the other of a scalar nature, then the scalar nature shall be the nature of the scalar subelements of the composite terminal. If both terminals are of a scalar nature then they shall be of the same scalar nature.

A quantity named in an across aspect is an *across quantity*, and similarly a quantity named in a through aspect is a *through quantity*. A *branch quantity* is either an across quantity or a through quantity.

The type of an across quantity is determined as follows. If both terminals denoted by the terminal aspect are of a scalar nature, then the type is the across type implied by the plus terminal name. If only one terminal denoted by the terminal aspect is of a composite nature, then the type is the across type implied by that terminal name. If both terminals denoted by the terminal aspect are of composite natures, then the type is the across type implied by the plus terminal name.

The type of a through quantity is determined as follows. If both terminals denoted by the terminal aspect are of a scalar nature, then the type is the through type implied by the plus terminal name. If only one terminal denoted by the terminal aspect is of a composite nature, then the type is the through type implied by that terminal name. If both terminals denoted by the terminal aspect are of composite natures, then the type is the through type implied by the plus terminal name.

The *plus terminal* and the *minus terminal* of a branch quantity are determined as follows:

a) If both terminals of the terminal aspect are scalar, then the plus and minus terminals of the quantity are, respectively, the plus and minus terminals of the terminal aspect.

b) If both terminals of the terminal aspect are composite, then the plus and minus terminals of each scalar subelement of the quantity are, respectively, the matching scalar subelements of the plus and minus terminals of the terminal aspect.

c) If the plus terminal is composite and the minus terminal is scalar, then the plus and minus terminals of each scalar subelement of the quantity are, respectively, the matching scalar subelement of the plus terminal and the scalar minus terminal of the terminal aspect.

d) If the plus terminal is scalar and the minus terminal is composite, then the plus and minus terminals of each scalar subelement of the composite quantity are, respectively, the scalar plus terminal and the matching scalar subelement of the minus terminal of the terminal aspect.

A source quantity declaration declares one or more source quantities. A source quantity whose source aspect includes the reserved word **spectrum** is a *spectral source quantity*. A source quantity whose source aspect includes the reserved word **noise** is a *noise source quantity*. The type of the magnitude simple expression, phase simple expression, and power simple expression in a source aspect shall be that of the source quantity. It is an error if the name of a source quantity appears in an expression in a source aspect.

If the quantity declaration includes the assignment symbol followed by an expression, the expression is said to be an initial value expression. The expression specifies an initial value for the declared quantity. The type of the expression shall be that of the quantity. The initial value of the quantity is determined by the expression when the quantity is elaborated. In the absence of an initial value expression, a default initial value applies. The default initial value for a quantity of a scalar type T is the value of the expression T(0.0). The default initial value of a quantity of composite type is the aggregate of the initial values of its scalar subelements.

The tolerance group of a scalar free quantity or a scalar source quantity is the tolerance group of its subtype. The tolerance group of a scalar across or through quantity is the tolerance group of its subtype or, if the across or through aspect respectively includes a tolerance aspect, the value of the string expression of the tolerance aspect.

Examples:

```
quantity Isense: Current;  -- A free quantity.

quantity Power: REAL tolerance "power";
   -- A free quantity whose tolerance group is "power".

quantity Vd across Id, Ic through Anode to Cathode;
   -- A scalar across quantity and two scalar through quantities
   -- with plus terminal Anode and minus terminal Cathode.
   -- The type of Vd is Voltage, the type of Id and Ic is Current.

quantity V2 across T3 to T4;
   -- A composite across quantity with plus terminal T3 and
   -- minus terminal T4. Its type is Electrical_bus'ACROSS,
   -- its elements are V2.Strobe and V2.Databus.

quantity I3 through T4;
   -- A composite through quantity with plus terminal T4 and minus
   -- terminal Ground. Its type is Electrical_bus'THROUGH.
   -- Its elements are I3.Strobe and I3.Databus.
```

```
quantity Ac: Voltage spectrum 1.0, 0.0;
   -- A spectral source quantity of type Voltage whose magnitude is 1.0
   -- and whose phase is 0.0 radians.

constant Kf: REAL := 1.0e-14;
quantity Flns: REAL noise Kf*Id/FREQUENCY;
   -- A noise source quantity describing flicker noise in a diode.
```

4.3.2 Interface declarations

An interface declaration declares an *interface object* of a specified type. Interface objects include *interface constants* that appear as generics of a design entity, a component, or a block, or as constant parameters of subprograms; *interface signals* that appear as signal ports of a design entity, component, or block, or as signal parameters of subprograms; *interface variables* that appear as variable parameters of subprograms; *interface files* that appear as file parameters of subprograms; and *interface terminals* and *interface quantities* that appear as ports of a design entity, a component, or a block.

interface_declaration ::=
  interface_constant_declaration
 | interface_signal_declaration
 | interface_variable_declaration
 | interface_file_declaration
 | interface_terminal_declaration
 | interface_quantity_declaration

interface_constant_declaration ::=
 [**constant**] identifier_list : [**in**] subtype_indication [:= *static*_expression]

interface_signal_declaration ::=
 [**signal**] identifier_list : [mode] subtype_indication [**bus**] [:= *static*_expression]

interface_variable_declaration ::=
 [**variable**] identifier_list : [mode] subtype_indication [:= *static*_expression]

interface_file_declaration ::=
 file identifier_list : subtype_indication

mode ::= **in** | **out** | **inout** | **buffer** | **linkage**

interface_terminal_declaration ::=
 terminal identifier_list : subnature_indication

interface_quantity_declaration ::=
 quantity identifier_list : [**in** | **out**] subtype_indication [:= *static*_expression]

If no mode is explicitly given in an interface declaration other than an interface file declaration, mode **in** is assumed.

For an interface constant declaration or an interface signal declaration, the subtype indication shall define a subtype that is neither a file type, an access type, nor a protected type. Moreover, the subtype indication shall not denote a composite type with a subelement that is a file type, an access type, or a protected type.

For an interface file declaration, it is an error if the subtype indication does not denote a subtype of a file type.

For an interface quantity declaration, the subtype indication shall define a subtype whose base type denotes a nature subtype. See 12.6.6 for a discussion of the effect of modes **in** and **out** in an interface quantity declaration.

If an interface signal declaration includes the reserved word **bus**, then the signal declared by that interface declaration is a guarded signal of signal kind **bus**.

If an interface declaration contains a ":=" symbol followed by an expression, the expression is said to be the *default expression* of the interface object. The type of a default expression shall be that of the corresponding interface object. It is an error if a default expression appears in an interface declaration and any of the following conditions hold:

— The mode is **linkage**
— The interface object is a formal signal parameter
— The interface object is a formal variable parameter of mode other than **in**
— The subtype indication of the interface declaration denotes a protected type

In an interface signal declaration appearing in a port list, the default expression defines the default value(s) associated with the interface signal or its subelements. In the absence of a default expression, an implicit default value is assumed for the signal or for each scalar subelement, as defined for signal declarations (see 4.3.1.2). The value, whether implicitly or explicitly provided, is used to determine the initial contents of drivers, if any, of the interface signal as specified for signal declarations.

An interface object provides a channel of communication between the environment and a particular portion of a description. The value of an interface object may be determined by the value of an associated object or expression in the environment; similarly, the value of an object in the environment may be determined by the value of an associated interface object. The manner in which such associations are made is described in 4.3.2.2.

The value of an object is said to be *read* when one of the following conditions is satisfied:

— When the object is evaluated, and also (indirectly) when the object is associated with an interface object of the modes **in**, **inout**, or **linkage.**
— When the object is a signal and a name denoting the object appears in a sensitivity list in a wait statement or a process statement.
— When the object is a signal and the value of any of its predefined attributes 'SLEW, 'RAMP, 'STABLE, 'QUIET, 'DELAYED, 'TRANSACTION, 'EVENT, 'ACTIVE, 'LAST_EVENT, 'LAST_ACTIVE, or 'LAST_VALUE is read.
— When the object is a quantity and its predefined attribute 'ABOVE is read.
— When one of its subelements is read.
— When the object is a file and a READ operation is performed on the file.
— When the object is a file of type STD.TEXTIO.TEXT and the procedure STD.TEXTIO.READLINE is called with the given object associated with the formal parameter F of the given procedure.

The value of an object is said to be *updated* when one of the following conditions is satisfied:

— When it is the target of an assignment, and also (indirectly) when the object is associated with an interface object of the modes **out**, **buffer**, **inout**, or **linkage**.
— When one of its subelements is updated.
— When the object is a file and a WRITE operation is performed on the file.

— When the object is a file of type STD.TEXTIO.TEXT and the procedure STD.TEXTIO.WRITE-LINE is called with the given object associated with the formal parameter F of the given procedure.
— When the object is a quantity and the analog solver determines an analog solution point.

It is an error if an object other than a signal, variable, quantity, or file object is updated.

An interface object of class signal, variable, or constant has one of the following modes:

— **in.** The value of the interface object is allowed to be read, but it shall not be updated. Reading an attribute of the interface object is allowed, unless the interface object is a subprogram signal parameter and the attribute is one of 'STABLE, 'QUIET, 'DELAYED, 'RAMP, 'SLEW, 'TRANSACTION, 'DRIVING, or 'DRIVING_VALUE.
— **out.** The value of the interface object is allowed to be updated, but it shall not be read. Reading the attributes of the interface element, other than the predefined attributes 'STABLE, 'QUIET, 'DELAYED, 'RAMP, 'SLEW, 'TRANSACTION, 'EVENT, 'ACTIVE, 'LAST_EVENT, 'LAST_ACTIVE, and 'LAST_VALUE, is allowed. No other reading is allowed.
— **inout.** Reading and updating the value of the interface object is allowed. Reading the attributes of the interface object, other than the attributes 'STABLE, 'QUIET, 'DELAYED, 'RAMP, 'SLEW, and 'TRANSACTION of a signal parameter, is also permitted.
— **buffer.** Reading and updating the value of the interface object is allowed. Reading the attributes of the interface object is also permitted.
— **linkage.** Reading and updating the value of the interface object is allowed, but only by appearing as an actual corresponding to an interface object of mode **linkage**. No other reading or updating is permitted.

NOTE 1—A subprogram parameter that is of a file type shall be declared as a file parameter.

NOTE 2—Since shared variables are a subclass of variables, a shared variable may be associated as an actual with a formal of class variable.

NOTE 3—Ports of mode linkage may be removed from a future version of the language. See Annex E.

NOTE 4—Interface file objects and interface terminal objects do not have modes.

4.3.2.1 Interface lists

An interface list contains the declarations of the interface objects required by a subprogram, a component, a design entity, or a block statement.

```
interface_list ::=
    interface_element { ; interface_element }

interface_element ::=  interface_declaration
```

A *generic* interface list consists entirely of interface constant declarations. A *port* interface list consists entirely of interface signal declarations, interface terminal declarations, interface quantity declarations, or any combination thereof. A *parameter* interface list may contain interface constant declarations, interface signal declarations, interface variable declarations, interface file declarations, or any combination thereof.

A name that denotes an interface object shall not appear in any interface declaration within the interface list containing the denoted interface object except to declare this object.

NOTE—The restriction mentioned in the previous sentence makes the following three interface lists illegal:

```
entity E is
   generic (G1: INTEGER; G2: INTEGER := G1);                 -- Illegal
   port (P1: STRING; P2: STRING(P1'RANGE));                   -- Illegal
   procedure X (Y1, Y2: INTEGER; Y3: INTEGER range Y1 to Y2);  -- Illegal
end E;
```

However, the following interface lists are legal:

```
entity E is
   generic (G1, G2, G3, G4: INTEGER);
   port (P1, P2: STRING (G1 to G2));
   procedure X (Y3: INTEGER range G3 to G4);
end E;
```

4.3.2.2 Association lists

An association list establishes correspondences between formal or local generic, port, or parameter names on the one hand and local or actual names or expressions on the other.

association_list ::=
    association_element { , association_element }

association_element ::=
    [formal_part =>] actual_part

formal_part ::=
    formal_designator
    | *function*_name (formal_designator)
    | type_mark (formal_designator)

formal_designator ::=
    *generic*_name
    | *port*_name
    | *parameter*_name

actual_part ::=
    actual_designator
    | *function*_name (actual_designator)
    | type_mark (actual_designator)

actual_designator ::=
    expression
    | *signal*_name
    | *variable*_name
    | *file*_name
    | *terminal*_name
    | *quantity*_name
    | **open**

Each association element in an association list associates one actual designator with the corresponding interface element in the interface list of a subprogram declaration, component declaration, entity declaration, or block statement. The corresponding interface element is determined either by position or by name.

An association element is said to be *named* if the formal designator appears explicitly; otherwise, it is said to be *positional*. For a positional association, an actual designator at a given position in an association list corresponds to the interface element at the same position in the interface list.

Named associations can be given in any order, but if both positional and named associations appear in the same association list, then all positional associations shall occur first at their normal position. Hence once a named association is used, the rest of the association list shall use only named associations.

In the following paragraphs, the term *actual* refers to an actual designator, and the term *formal* refers to a formal designator.

The formal part of a named association element may be in the form of a function call, where the single argument of the function is the formal designator itself, if and only if the mode of the formal is **out**, **inout**, **buffer**, or **linkage**, and if the actual is not **open**. In this case, the function name shall denote a function whose single parameter is of the type of the formal and whose result is the type of the corresponding actual. Such a *conversion function* provides for type conversion in the event that data flows from the formal to the actual.

Alternatively, the formal part of a named association element may be in the form of a type conversion, where the expression to be converted is the formal designator itself, if and only if the mode of the formal is **out**, **inout**, **buffer**, or **linkage**, and if the actual is not **open**. In this case, the base type denoted by the type mark shall be the same as the base type of the corresponding actual. Such a type conversion provides for type conversion in the event that data flows from the formal to the actual. It is an error if the type of the formal is not closely related to the type of the actual. (See 7.3.5.)

Similarly, the actual part of a (named or positional) association element may be in the form of a function call, where the single argument of the function is the actual designator itself, if and only if the mode of the formal is **in**, **inout**, or **linkage**, and if the actual is not **open**. In this case, the function name shall denote a function whose single parameter is of the type of the actual, and whose result is the type of the corresponding formal. In addition, the formal shall not be of class **constant** for this interpretation to hold (the actual is interpreted as an expression that is a function call if the class of the formal is **constant**). Such a conversion function provides for type conversion in the event that data flows from the actual to the formal.

Alternatively, the actual part of a (named or positional) association element may be in the form of a type conversion, where the expression to be type converted is the actual designator itself, if and only if the mode of the formal is **in**, **inout**, or **linkage**, and if the actual is not **open**. In this case, the base type denoted by the type mark shall be the same as the base type of the corresponding formal. Such a type conversion provides for type conversion in the event that data flows from the actual to the formal. It is an error if the type of the actual is not closely related to the type of the formal.

The type of the actual (after applying the conversion function or type conversion, if present in the actual part) shall be the same as the type of the corresponding formal, if the mode of the formal is **in**, **inout**, or **linkage**, and if the actual is not **open**. Similarly, if the mode of the formal is **out**, **inout**, **buffer**, or **linkage**, and if the actual is not **open**, then the type of the formal (after applying the conversion function or type conversion, if present in the formal part) shall be the same as the corresponding actual.

If the formal designator of a formal part is a terminal name, then the formal part shall be the formal designator itself (neither a conversion function nor a type conversion is allowed). Similarly, if the actual designator of an actual part is a terminal name, then the actual part shall be the actual designator itself.

The association of terminals is allowed only if the formal and actual are of the same nature or if the actual is **open**. The association of a formal of a given composite nature with an actual of the same nature is equivalent to the association of each scalar subelement of the formal with the matching scalar subelement of the actual.

For the association of signals or quantities with corresponding formal ports, association of a formal of a given composite type with an actual of the same type is equivalent to the association of each scalar subelement of the formal with the matching subelement of the actual, provided that no conversion function or type conversion is present in either the actual part or the formal part of the association element. If a conversion function or type conversion is present, then the entire formal is considered to be associated with the entire actual.

Similarly, for the association of actuals with corresponding formal subprogram parameters, association of a formal parameter of a given composite type with an actual of the same type is equivalent to the association of each scalar subelement of the formal parameter with the matching subelement of the actual. Different parameter passing mechanisms may be required in each case, but in both cases the associations will have an equivalent effect. This equivalence applies provided that no actual is accessible by more than one path (see 2.1.1.1).

A formal shall be either an explicitly declared interface object or member (see Clause 3) of such an interface object. In the former case, such a formal is said to be *associated in whole*. In the latter cases, named association shall be used to associate the formal and actual; the subelements of such a formal are said to be *associated individually*. Furthermore, every scalar subelement of the explicitly declared interface object shall be associated exactly once with an actual (or subelement thereof) in the same association list, and all such associations shall appear in a contiguous sequence within that association list. Each association element that associates a slice or subelement (or slice thereof) of an interface object shall identify the formal with a locally static name.

If an interface element in an interface list includes a default expression for a formal generic, for a formal signal port of any mode other than **linkage**, for a formal quantity port of mode **in**, or for a formal variable or constant parameter of mode **in**, then any corresponding association list need not include an association element for that interface element. For an interface element that is a formal generic, a formal signal port, or a formal variable or constant parameter, if the association element is not included in the association list, or if the actual is **open**, then the value of the default expression is used as the actual expression or signal value in an implicit association element for that interface element. For an interface element that is a formal quantity port, if the association element is not included in the association list, or if the actual is **open**, then the value of the default expression is used as the value of the quantity; this is equivalent to a simple simultaneous statement setting the quantity port to the value of the default expression.

It is an error if an actual of **open** is associated with a formal that is associated individually. An actual of **open** counts as the single association allowed for the corresponding formal, but does not supply a constant, signal, or variable (as is appropriate to the object class of the formal) to the formal.

NOTE 1—It is a consequence of these rules that, if an association element is omitted from an association list in order to make use of the default expression on the corresponding interface element, all subsequent association elements in that association list shall be named associations.

NOTE 2—In the case of a port of kind **signal**, although a default expression can appear in an interface element that declares a (local or formal) port, such a default expression is not interpreted as the value of an implicit association element for that port. Instead, the value of the expression is used to determine the effective value of that port during simulation if the port is left unconnected (see 12.6.2).

NOTE 3—Named association may not be used when invoking implicitly defined operators, since the formal parameters of these operators are not named (see 7.2).

NOTE 4—Since information flows only from the actual to the formal when the mode of the formal is in, and since a function call is itself an expression, the actual associated with a formal of object class constant is never interpreted as a conversion function or a type conversion converting an actual designator that is an expression. Thus, the following association element is legal:

```
Param => F (open)
```

under the conditions that Param is a constant formal and F is a function returning the same base type as that of Param and having one or more parameters, all of which may be defaulted. It is an error if a conversion function or type conversion appears in the actual part when the actual designator is **open**.

4.3.3 Alias declarations

An alias declaration declares an alternate name for an existing named entity.

alias_declaration ::=
    alias alias_designator [: alias_indication] **is** name [signature] ;

alias_designator ::= identifier | character_literal | operator_symbol

alias_indication ::= subtype_indication | subnature_indication

An *object alias* is an alias whose alias designator denotes an object (i.e., a constant, a variable, a signal, a quantity, a terminal, or a file). A *nonobject alias* is an alias whose alias designator denotes some named entity other than an object. An alias can be declared for all named entities except for labels, loop parameters, and generate parameters.

The alias designator in an alias declaration denotes the named entity specified by the name and, if present, the signature in the alias declaration. An alias of a signal denotes a signal; an alias of a variable denotes a variable; an alias of a constant denotes a constant; an alias of a quantity denotes a quantity; an alias of a terminal denotes a terminal; and an alias of a file denotes a file. Similarly, an alias of a subprogram (including an operator) denotes a subprogram, an alias of an enumeration literal denotes an enumeration literal, and so forth.

If the alias designator is a character literal, the name shall denote an enumeration literal. If the alias designator is an operator symbol, the name shall denote a function, and that function then overloads the operator symbol. In this latter case, the operator symbol and the function both shall meet the requirements of 2.3.1.

NOTE 1—Since, for example, the alias of a variable is a variable, every reference within this document to a designator (a name, character literal, or operator symbol) that requires the designator to denote a named entity with certain characteristics (e.g., to be a variable) allows the designator to denote an alias, so long as the aliased name denotes a named entity having the required characteristics. This situation holds except where aliases are specifically prohibited.

NOTE 2—The alias of an overloadable named entity is itself overloadable.

4.3.3.1 Object aliases

The following rules apply to object aliases:

a) A signature shall not appear in a declaration of an object alias.

b) The name shall be a static name (see 6.1) that denotes an object. The base type of the name specified in an alias declaration shall be the same as the base type of the type mark in the subtype indication (if the subtype indication is present); this type shall not be a multidimensional array type. When the object denoted by the name is referenced via the alias defined by the alias declaration, the following rules apply:

   1) If the subtype indication is absent or if it is present and denotes an unconstrained array type

      — If the alias designator denotes a slice of an object, then the subtype of the object is viewed as if it were of the subtype specified by the slice.

      — Otherwise, the object is viewed as if it were of the subtype specified in the declaration of the object denoted by the name.

   2) If the subtype indication is present and denotes a constrained array subtype, then the object is viewed as if it were of the subtype specified by the subtype indication; moreover, the subtype denoted by the subtype indication shall include a matching element (see 7.2.2) for each element of the object denoted by the name.

3) If the subtype indication denotes a scalar subtype, then the object is viewed as if it were of the subtype specified by the subtype indication; moreover, it is an error if this subtype does not have the same bounds and direction as the subtype denoted by the object name.

c) The same applies to attribute references where the prefix of the attribute name denotes the alias.

d) A reference to an element of an object alias is implicitly a reference to the matching element of the object denoted by the alias. A reference to a slice of an object alias consisting of the elements e_1, e_2, …, e_n is implicitly a reference to a slice of the object denoted by the alias consisting of the matching elements corresponding to each of e_1 through e_n.

The preceding rules apply to object aliases for terminals as well, with appropriate substitutions of nature for type and subnature for subtype.

4.3.3.2 Nonobject aliases

The following rules apply to nonobject aliases:

a) An alias indication shall not appear in a nonobject alias.

b) A signature is required if the name denotes a subprogram (including an operator) or enumeration literal. In this case, the signature is required to match (see 2.3) the parameter and result type profile of exactly one of the subprograms or enumeration literals denoted by the name.

c) If the name denotes an enumeration type, then one implicit alias declaration for each of the literals of the type immediately follows the alias declaration for the enumeration type; each such implicit declaration has, as its alias designator, the simple name or character literal of the literal and has, as its name, a name constructed by taking the name of the alias for the enumeration type and substituting the simple name or character literal being aliased for the simple name of the type. Each implicit alias has a signature that matches the parameter and result type profile of the literal being aliased.

d) Alternatively, if the name denotes a physical type, then one implicit alias declaration for each of the units of the type immediately follows the alias declaration for the physical type; each such implicit declaration has, as its alias designator, the simple name of the unit and has, as its name, a name constructed by taking the name of the alias for the physical type and substituting the simple name of the unit being aliased for the simple name of the type.

e) Finally, if the name denotes a type, then implicit alias declarations for each predefined operator for the type immediately follow the explicit alias declaration for the type and, if present, any implicit alias declarations for literals or units of the type. Each implicit alias has a signature that matches the parameter and result type profile of the implicit operator being aliased.

Examples:

```
variable REAL_NUMBER: BIT_VECTOR (0 to 31);

alias SIGN: BIT is REAL_NUMBER (0);
   -- SIGN is now a scalar (BIT) value

alias MANTISSA: BIT_VECTOR (23 downto 0) is REAL_NUMBER (8 to 31);
   -- MANTISSA is a 24bit value whose range is 23 downto 0.
   -- Note that the ranges of MANTISSA and REAL_NUMBER (8 to 31)
   -- have opposite directions. A reference to MANTISSA (23 downto 18)
   -- is equivalent to a reference to REAL_NUMBER (8 to 13).

alias EXPONENT: BIT_VECTOR (1 to 7) is REAL_NUMBER (1 to 7);
   -- EXPONENT is a 7-bit value whose range is 1 to 7.

alias STD_BIT   is STD.STANDARD.BIT;  -- explicit alias
```

```
-- implicit aliases ...
-- alias '0'    is STD.STANDARD.'0' [return STD.STANDARD.BIT];
-- alias '1'    is STD.STANDARD.'1' [return STD.STANDARD.BIT];
-- alias "and"  is STD.STANDARD."and"  [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "or"   is STD.STANDARD."or"   [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "nand" is STD.STANDARD."nand" [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "nor"  is STD.STANDARD."nor"  [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "xor"  is STD.STANDARD."xor"  [STD.STANDARD.BIT,
--                                          STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "xnor" is STD.STANDARD."xnor" [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "not"  is STD.STANDARD."not"  [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BIT];
-- alias "="    is STD.STANDARD."="    [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BOOLEAN];
-- alias "/="   is STD.STANDARD."/="   [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BOOLEAN];
-- alias "<"    is STD.STANDARD."<"    [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BOOLEAN];
-- alias "<="   is STD.STANDARD."<="   [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BOOLEAN];
-- alias ">"    is STD.STANDARD.">"    [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BOOLEAN];
-- alias ">="   is STD.STANDARD.">="   [STD.STANDARD.BIT,
--                                      STD.STANDARD.BIT
--                                         return STD.STANDARD.BOOLEAN];
```

NOTE—An alias of an explicitly declared object is not an explicitly declared object, nor is the alias of a subelement or slice of an explicitly declared object an explicitly declared object.

4.4 Attribute declarations

An attribute is a value, function, type, range, signal, quantity, or constant that may be associated with one or more named entities in a description. There are two categories of attributes: predefined attributes and user-defined attributes. Predefined attributes provide information about named entities in a description. Clause 14 contains the definition of all predefined attributes. Predefined attributes that are signals shall not be updated.

User-defined attributes are constants of arbitrary type. Such attributes are defined by an attribute declaration.

attribute_declaration ::=
    attribute identifier : type_mark ;

The identifier is said to be the *designator* of the attribute. An attribute may be associated with an entity declaration, an architecture, a configuration, a procedure, a function, a package, a type, a subtype, a nature, a subnature, a constant, a signal, a variable, a quantity, a terminal, a component, a label, a literal, a unit, a group, or a file.

It is an error if the type mark denotes an access type, a file type, a protected type, or a composite type with a subelement that is an access type, a file type, or a protected type. The denoted type or subtype need not be constrained.

Examples:

```
type COORDINATE is record X,Y: INTEGER; end record;
subtype POSITIVE is INTEGER range 1 to INTEGER'HIGH;
attribute LOCATION: COORDINATE;
attribute PIN_NO: POSITIVE;
```

NOTE 1—A given named entity E will be decorated with the user-defined attribute A if and only if an attribute specification for the value of attribute A exists in the same declarative part as the declaration of E. In the absence of such a specification, an attribute name of the form E'A is illegal.

NOTE 2—A user-defined attribute is associated with the named entity denoted by the name specified in a declaration, not with the name itself. Hence, an attribute of an object can be referenced by using an alias for that object rather than the declared name of the object as the prefix of the attribute name, and the attribute referenced in such a way is the same attribute (and therefore has the same value) as the attribute referenced by using the declared name of the object as the prefix.

NOTE 3—A user-defined attribute of a port, signal, variable, quantity, terminal, or constant of some composite type is an attribute of the entire port, signal, variable, quantity, terminal, or constant, not of its elements. If it is necessary to associate an attribute with each element of some composite object, then the attribute itself can be declared to be of a composite type such that for each element of the object, there is a corresponding element of the attribute.

4.5 Component declarations

A component declaration declares an interface to a virtual design entity that may be used in a component instantiation statement. A component configuration or a configuration specification can be used to associate a component instance with a design entity that resides in a library.

component_declaration ::=
    component identifier [**is**]
        [*local*_generic_clause]
        [*local*_port_clause]
    end component [*component*_simple_name] ;

Each interface object in the local generic clause declares a local generic. Each interface object in the local port clause declares a local port.

If a simple name appears at the end of a component declaration, it shall repeat the identifier of the component declaration.

4.6 Group template declarations

A group template declaration declares a *group template*, which defines the allowable classes of named entities that can appear in a group.

group_template_declaration ::=
    group identifier **is** (entity_class_entry_list) ;

entity_class_entry_list ::=
    entity_class_entry { , entity_class_entry }

entity_class_entry ::= entity_class [<>]

A group template is characterized by the number of entity class entries and the entity class at each position. Entity classes are described in 5.1.

An entity class entry that is an entity class defines the entity class that may appear at that position in the group type. An entity class entry that includes a box (<>) allows zero or more group constituents to appear in this position in the corresponding group declaration; such an entity class entry shall be the last one within the entity class entry list.

Examples:

```
group PIN2PIN is (signal, signal);  --  Groups of this type consist of
                                    --  two signals.
group RESOURCE is (label <>);       --  Groups of this type consist of
                                    --  any number of labels.

group DIFF_CYCLES is (group <>);    --  A group of groups.
```

4.7 Group declarations

A group declaration declares a group, a named collection of named entities. Named entities are described in 5.1.

group_declaration ::=
    group identifier : *group_template*_name (group_constituent_list) ;

group_constituent_list ::= group_constituent { , group_constituent }

group_constituent ::= name | character_literal

It is an error if the class of any group constituent in the group constituent list is not the same as the class specified by the corresponding entity class entry in the entity class entry list of the group template.

A name that is a group constituent shall not be an attribute name (see 6.6). Moreover, if such a name contains a prefix, it is an error if the prefix is a function call.

If a group declaration appears within a package body, and a group constituent within that group declaration is the same as the simple name of the package body, then the group constituent denotes the package declaration and not the package body. The same rule holds for group declarations appearing within subprogram bodies containing group constituents with the same designator as that of the enclosing subprogram body.

If a group declaration contains a group constituent that denotes a variable of an access type, the group declaration declares a group incorporating the variable itself, and not the designated object, if any.

Examples:

```
group G1: RESOURCE (L1, L2);                --  A group of two labels.
group G2: RESOURCE (L3, L4, L5);            --  A group of three labels.
group C2Q: PIN2PIN (PROJECT.GLOBALS.CK, Q);
                                  --  Groups may associate named
                                  --  entities in different declarative
                                  --  parts (and regions).
group CONSTRAINT1: DIFF_CYCLES (G1, G3);    --  A group of groups.
```

4.8 Nature declaration

A nature declaration declares a nature and defines the across and through types of the nature. A scalar nature declaration also declares the reference terminal of its simple nature denoted by the identifier of its scalar nature definition.

nature_declaration ::=
    nature identifier **is** nature_definition ;

nature_definition ::=
    scalar_nature_definition | composite_nature_definition

subnature_declaration ::=
    subnature identifier **is** subnature_indication ;

subnature_indication ::=
    nature_mark [index_constraint] [**tolerance** *string*_expression **across** *string*_expression **through**]

nature_mark ::=
    *nature*_name | *subnature*_name

For any nature name N, an attribute name of the form N'ACROSS denotes the across type of the nature denoted by N, and an attribute name of the form N'THROUGH denotes the through type of the nature denoted by N.

The natures created by the elaboration of distinct nature definitions are distinct natures. The elaboration of the nature definition for a scalar nature or a constrained array nature creates both a nature and a subnature of the nature.

The simple name declared by a nature declaration denotes the declared nature, unless the nature declaration declares both a nature and a subnature of the nature, in which case the simple name denotes the subnature and the nature is anonymous.

A subnature declaration declares a subnature. A condition imposed by an index constraint is said to be *compatible* with a nature if it is compatible with the across and through types of the nature. The condition imposed by the index constraint of a subnature indication shall be compatible with the nature denoted by the nature mark.

If a subnature indication includes a tolerance specification, then the tolerance group of the across type of the subnature is the value of the string expression preceding the reserved word **across**. Similarly, the tolerance group of the through type of the subnature is the value of the string expression preceding the reserved word **through**. Both string expressions in the tolerance specification shall be static expressions.

If the subnature indication does not include an index constraint, the subnature is the same as that denoted by the nature mark. The condition imposed by an index constraint is the condition obtained after the evaluation of the expressions and ranges forming the constraint. The rules defining compatibility are given in 3.2.1.1. These rules are such that if an index constraint is compatible with a subnature, then the condition imposed by the index constraint cannot contradict any condition already imposed by the subnature. An error occurs if any check for compatibility fails.

5. Specifications

This clause describes *specifications*, which may be used to associate additional information with a VHDL description. A specification associates additional information with a named entity that has been previously declared. There are four kinds of specifications: attribute specifications, configuration specifications, disconnection specifications, and step limit specifications.

A specification always relates to named entities that already exist; thus a given specification shall either follow or (in certain cases) be contained within the declaration of the entity to which it relates. Furthermore, a specification shall always appear either immediately within the same declarative part as that in which the declaration of the named entity appears, or (in the case of specifications that relate to design units or the interface objects of design units, subprograms, or block statements) immediately within the declarative part associated with the declaration of the design unit, subprogram body, or block statement.

5.1 Attribute specification

An attribute specification associates a user-defined attribute with one or more named entities and defines the value of that attribute for those entities. The attribute specification is said to *decorate* the named entity.

attribute_specification ::=
  attribute attribute_designator **of** entity_specification **is** expression ;

entity_specification ::=
  entity_name_list : entity_class

entity_class ::=
  entity
  | **architecture**
  | **configuration**
  | **procedure**
  | **function**
  | **package**
  | **type**
  | **subtype**
  | **constant**
  | **signal**
  | **variable**
  | **component**
  | **label**
  | **literal**
  | **units**
  | **group**
  | **file**
  | **nature**
  | **subnature**
  | **quantity**
  | **terminal**

entity_name_list ::=
  entity_designator { , entity_designator }
  | **others**
  | **all**

entity_designator ::= entity_tag [signature]

entity_tag ::= simple_name | character_literal | operator_symbol

The attribute designator shall denote an attribute. The entity name list identifies those named entities, both implicitly and explicitly defined, that inherit the attribute, described as follows:

- If a list of entity designators is supplied, then the attribute specification applies to the named entities denoted by those designators. It is an error if the class of those names is not the same as that denoted by the entity class.
- If the reserved word **others** is supplied, then the attribute specification applies to named entities of the specified class that are declared in the immediately enclosing declarative part, provided that each such entity is not explicitly named in the entity name list of a previous attribute specification for the given attribute.
- If the reserved word **all** is supplied, then the attribute specification applies to all named entities of the specified class that are declared in the immediately enclosing declarative part.

An attribute specification with the entity name list **others** or **all** for a given entity class that appears in a declarative part shall be the last such specification for the given attribute for the given entity class in that declarative part. It is an error if a named entity in the specified entity class is declared in a given declarative part following such an attribute specification.

If a name in an entity name list denotes a subprogram or package, it denotes the subprogram declaration or package declaration. Subprogram and package bodies cannot be attributed.

An entity designator that denotes an alias of an object is required to denote the entire object, not a member of an object.

The entity tag of an entity designator containing a signature shall denote the name of one or more subprograms or enumeration literals. In this case, the signature shall match (see 2.3.2) the parameter and result type profile of exactly one subprogram or enumeration literal in the current declarative part; the enclosing attribute specification then decorates that subprogram or enumeration literal.

The expression specifies the value of this attribute for each of the named entities inheriting the attribute as a result of this attribute specification. The type of the expression in the attribute specification shall be the same as (or implicitly convertible to) the type mark in the corresponding attribute declaration. If the entity name list denotes an entity declaration, architecture body, or configuration declaration, then the expression is required to be locally static (see 7.4).

An attribute specification for an attribute of a design unit (i.e., an entity declaration, an architecture, a configuration, or a package) shall appear immediately within the declarative part of that design unit. Similarly, an attribute specification for an attribute of an interface object of a design unit, subprogram, or block statement shall appear immediately within the declarative part of that design unit, subprogram, or block statement. An attribute specification for an attribute of a procedure, a function, a type, a subtype, a nature, a subnature, an object (i.e., a constant, a file, a signal, a quantity, a terminal, or a variable), a component, literal, unit name, group, or a labeled entity shall appear within the declarative part in which that procedure, function, type, subtype, nature, subnature, object, component, literal, unit name, group, or label, respectively, is explicitly or implicitly declared.

For a given named entity, the value of a user-defined attribute of that entity is the value specified in an attribute specification for that attribute of that entity.

It is an error if a given attribute is associated more than once with a given named entity. Similarly, it is an error if two different attributes with the same simple name (whether predefined or user-defined) are both associated with a given named entity. The single exception to this is the predefined attribute 'LAST_EVENT, where the two different attributes are disambiguated by the return type of the attribute.

An entity designator that is a character literal is used to associate an attribute with one or more character literals. An entity designator that is an operator symbol is used to associate an attribute with one or more overloaded operators.

If the entity tag is overloaded and the entity designator does not contain a signature, all named entities already declared in the current declarative part and matching the specification are decorated.

If an attribute specification appears, it shall follow the declaration of the named entity with which the attribute is associated, and it shall precede all references to that attribute of that named entity. Attribute specifications are allowed for all user-defined attributes, but are not allowed for predefined attributes.

An attribute specification may reference a named entity by using an alias for that entity in the entity name list, but such a reference counts as the single attribute specification that is allowed for a given attribute and therefore prohibits a subsequent specification that uses the declared name of the entity (or any other alias) as the entity designator.

An attribute specification whose entity designator contains no signature and identifies an overloaded subprogram or enumeration literal has the effect of associating that attribute with each of the designated overloaded subprograms or enumeration literals declared within that declarative part.

Examples:

```
attribute PIN_NO of CIN: signal is 10;
attribute PIN_NO of COUT: signal is 5;
attribute LOCATION of ADDER1: label is (10,15);
attribute LOCATION of others: label is (25,77);
attribute CAPACITANCE of all: signal is 15 pF;
attribute IMPLEMENTATION of G1: group is "74LS152";
attribute RISING_DELAY of C2Q: group is 7.2 ns;
```

NOTE 1—User-defined attributes represent local information only and cannot be used to pass information from one description to another. For instance, assume some signal X in an architecture body has some attribute A. Further, assume that X is associated with some local port L of component C. C in turn is associated with some design entity E(B), and L is associated with E's formal port P. Neither L nor P has attributes with the simple name A, unless such attributes are supplied via other attribute specifications; in this latter case, the values of P'A and X'A are not related in any way.

NOTE 2—The local ports and generics of a component declaration cannot be attributed, since component declarations lack a declarative part.

NOTE 3—If an attribute specification applies to an overloadable named entity, then declarations of additional named entities with the same simple name are allowed to occur in the current declarative part unless the aforementioned attribute specification has as its entity name list either of the reserved words **others** or **all**.

NOTE 4—Attribute specifications supplying either of the reserved words **others** or **all** never apply to the interface objects of design units, block statements, or subprograms.

NOTE 5—An attribute specification supplying either of the reserved words **others** or **all** may apply to none of the named entities in the current declarative part, in the event that none of the named entities in the current declarative part meet all of the requirements of the attribute specification.

5.2 Configuration specification

A configuration specification associates binding information with component labels representing instances of a given component declaration.

```
configuration_specification ::=
    for component_specification binding_indication ;

component_specification ::=
    instantiation_list : component_name

instantiation_list ::=
      instantiation_label { , instantiation_label }
    | others
    | all
```

The instantiation list identifies those component instances with which binding information is to be associated, defined as follows:

- If a list of instantiation labels is supplied, then the configuration specification applies to the corresponding component instances. Such labels shall be (implicitly) declared within the immediately enclosing declarative part. It is an error if these component instances are not instances of the component declaration named in the component specification. It is also an error if any of the labels denote a component instantiation statement whose corresponding instantiated unit does not name a component.
- If the reserved word **others** is supplied, then the configuration specification applies to instances of the specified component declaration whose labels are (implicitly) declared in the immediately enclosing declarative part, provided that each such component instance is not explicitly named in the instantiation list of a previous configuration specification. This rule applies only to those component instantiation statements whose corresponding instantiated units name components.
- If the reserved word **all** is supplied, then the configuration specification applies to all instances of the specified component declaration whose labels are (implicitly) declared in the immediately enclosing declarative part. This rule applies only to those component instantiation statements whose corresponding instantiated units name components.

A configuration specification with the instantiation list **others** or **all** for a given component name that appears in a declarative part shall be the last such specification for the given component name in that declarative part.

The elaboration of a configuration specification results in the association of binding information with the labels identified by the instantiation list. A label that has binding information associated with it is said to be *bound*. It is an error if the elaboration of a configuration specification results in the association of binding information with a component label that is already bound, unless the binding indication in the configuration specification is an incremental binding indication (see 5.2.1). It is also an error if the elaboration of a configuration specification containing an incremental binding indication results in the association of binding information with a component label that is already incrementally bound.

NOTE—A configuration specification supplying either of the reserved words **others** or **all** may apply to none of the component instances in the current declarative part. This is the case when none of the component instances in the current declarative part meet all of the requirements of the given configuration specification.

5.2.1 Binding indication

A binding indication associates instances of a component with a particular design entity. It may also associate actuals with formals declared in the entity declaration.

```
binding_indication ::=
    [ use entity_aspect ]
    [ generic_map_aspect ]
    [ port_map_aspect ]
```

The entity aspect of a binding indication, if present, identifies the design entity with which the instances of a component are associated. If present, the generic map aspect of a binding indication identifies the expressions to be associated with formal generics in the entity declaration. Similarly, the port map aspect of a binding indication identifies the signals, terminals, quantities, or values to be associated with formal ports in the entity declaration.

When a binding indication is used in an explicit configuration specification, it is an error if the entity aspect is absent.

A binding indication appearing in a component configuration shall have an entity aspect unless the block corresponding to the block configuration in which the given component configuration appears has one or more configuration specifications that together configure all component instances denoted in the given component configuration. The binding indications appearing in these configuration specifications are the corresponding *primary binding indications*. A binding indication need not have an entity aspect; in that case, either or both of a generic map aspect or a port map aspect shall be present in the binding indication. Such a binding indication is an *incremental binding indication*. An incremental binding indication is used to *incrementally rebind* the ports and generics of the denoted instance(s) under the following conditions:

— For each formal generic appearing in the generic map aspect of the incremental binding indication and denoting a formal generic that is unassociated or associated with **open** in any of the primary binding indications, the given formal generic is bound to the actual with which it is associated in the generic map aspect of the incremental binding indication.

— For each formal generic appearing in the generic map aspect of the incremental binding indication and denoting a formal generic that is associated with an actual other than **open** in one of the primary binding indications, the given formal generic is *rebound* to the actual with which it is associated in the generic map aspect of the incremental binding indication. That is, the association given in the primary binding indication has no effect for the given instance.

— For each formal port appearing in the port map aspect of the incremental binding indication and denoting a formal port that is unassociated or associated with **open** in any of the primary binding indications, the given formal port is bound to the actual with which it is associated in the port map aspect of the incremental binding indication.

It is an error if a formal port appears in the port map aspect of the incremental binding indication and it is a formal port that is associated with an actual other than **open** in one of the primary binding indications.

If the generic map aspect or port map aspect of a primary binding indication is not present, then the default rules as described in 5.2.2 apply.

It is an error if an explicit entity aspect in an incremental binding indication does not adhere to any of the following rules:

— If the entity aspect in the corresponding primary binding indication is of the first form (fully bound), as specified in 5.2.1.1, then the entity aspect in the incremental binding indication shall also be of the first form and shall denote the same entity declaration as that of the primary binding indication. An architecture name shall be specified in the incremental binding indication if and only if the primary binding indication also identifies an architecture name; in this case, the architecture name in the incremental binding indication shall denote the same architecture name as that of the primary binding indication.

— If the entity aspect in the primary binding indication is of the second form (that is, identifying a configuration), then the entity aspect of the incremental binding indication shall be of the same form and shall denote the same configuration declaration as that of the primary binding indication.

NOTE 1—The third form (**open**) of an entity aspect does not apply to incremental binding indications as this form cannot include either a generic map aspect or a port map aspect and incremental binding indications shall contain at least one of these aspects.

NOTE 2—The entity aspect of an incremental binding indication in a component configuration is optional.

NOTE 3—The presence of an incremental binding indication will never cause the default rules of 5.2.2 to be applied.

Examples:

```
entity AND_GATE is
   generic (I1toO, I2toO: DELAY_LENGTH := 4 ns);
   port (I1, I2: in BIT; O: out BIT);
end entity AND_GATE;

entity XOR_GATE is
   generic (I1toO, I2toO: DELAY_LENGTH := 4 ns);
   port (I1, I2: in BIT; O: out BIT);
end entity XOR_GATE;

package MY_GATES is
   component AND_GATE is
      generic I1toO, I2toO: DELAY_LENGTH := 4 ns);
      port (I1, I2: in BIT; O: out BIT);
   end component AND_GATE;

   component XOR_GATE is
      generic (I1toO, I2toO: DELAY_LENGTH := 4 ns);
      port (I1, I2: in BIT; O: out BIT);
   end component XOR_GATE;
end package MY_GATES;

entity Half_Adder is
   port (X, Y: in BIT; Sum, Carry: out BIT);
end entity Half_Adder;

use WORK.MY_GATES.all;
architecture Structure of Half_Adder is
   for L1: XOR_GATE use
      entity WORK.XOR_GATE(Behavior)     --  The primary binding
         generic map (3 ns, 3 ns)        --  indication for instance L1.
         port map (I1 => I1, I2 => I2, O => O);
   for L2: AND_GATE use
      entity WORK.AND_GATE(Behavior)     --  The primary binding
         generic map (3 ns, 4 ns)        --  indication for instance L2.
         port map (I1, open, O);
begin
   L1: XOR_GATE port map (X, Y, Sum);
   L2: AND_GATE port map (X, Y, Carry);
end architecture Structure;

use WORK.GLOBAL_SIGNALS.all;
configuration Different of Half_Adder is
   for Structure
      for L1: XOR_GATE
         generic map (2.9 ns, 3.6 ns);   --  The incremental binding
      end for;                           --  indication of L1; rebinds
                                         --  its generics.
      for L2: AND_GATE
```

```
            generic map (2.8 ns, 3.25 ns)  --  The incremental binding
            port map (I2 => Tied_High);    --  indication of L2; rebinds
         end for;                          --  its generics and binds
                                           --  its open port.
      end for;
   end configuration Different;
```

5.2.1.1 Entity aspect

An entity aspect identifies a particular design entity to be associated with instances of a component. An entity aspect may also specify that such a binding is to be deferred.

entity_aspect ::=
  entity *entity*_name [(*architecture*_identifier)]
  | **configuration** *configuration*_name
  | **open**

The first form of entity aspect identifies a particular entity declaration and (optionally) a corresponding architecture body. If no architecture identifier appears, then the immediately enclosing binding indication is said to *imply* the design entity whose interface is defined by the entity declaration denoted by the entity name and whose body is defined by the default binding rules for architecture identifiers (see 5.2.2). If an architecture identifier appears, then the immediately enclosing binding indication is said to *imply* the design entity consisting of the entity declaration denoted by the entity name together with an architecture body associated with the entity declaration; the architecture identifier defines a simple name that is used during the elaboration of a design hierarchy to select the appropriate architecture body. In either case, the corresponding component instances are said to be *fully bound*.

At the time of the analysis of an entity aspect of the first form, the library unit corresponding to the entity declaration denoted by the entity name is required to exist; moreover, the design unit containing the entity aspect depends on the denoted entity declaration. If the architecture identifier is also present, the library unit corresponding to the architecture identifier is required to exist only if the binding indication is part of a component configuration containing explicit block configurations or explicit component configurations; only in this case does the design unit containing the entity aspect also depend on the denoted architecture body. In any case, the library unit corresponding to the architecture identifier is required to exist at the time that the design entity implied by the enclosing binding indication is bound to the component instance denoted by the component configuration or configuration specification containing the binding indication; if the library unit corresponding to the architecture identifier was required to exist during analysis, it is an error if the architecture identifier does not denote the same library unit as that denoted during analysis. The library unit corresponding to the architecture identifier, if it exists, shall be an architecture body associated with the entity declaration denoted by the entity name.

The second form of entity aspect identifies a design entity indirectly by identifying a configuration. In this case, the entity aspect is said to *imply* the design entity at the apex of the design hierarchy that is defined by the configuration denoted by the configuration name.

At the time of the analysis of an entity aspect of the second form, the library unit corresponding to the configuration name is required to exist. The design unit containing the entity aspect depends on the configuration denoted by the configuration name.

The third form of entity aspect is used to specify that the identification of the design entity is to be deferred. In this case, the immediately enclosing binding indication is said to *not imply* any design entity. Furthermore, the immediately enclosing binding indication shall not include a generic map aspect or a port map aspect.

5.2.1.2 Generic map and port map aspects

A generic map aspect associates values with the formal generics of a block. Similarly, a port map aspect associates signals, quantities, terminals, or values with the formal ports of a block. The following applies to both external blocks defined by design entities and to internal blocks defined by block statements.

generic_map_aspect ::=
    generic map (*generic*_association_list)

port_map_aspect ::=
    port map (*port*_association_list)

Both named and positional association are allowed in a port or generic association list.

The following definitions are used in the remainder of this subclause:

— The term *actual* refers to an actual designator that appears either in an association element of a port association list or in an association element of a generic association list.

— The term *formal* refers to a formal designator that appears either in an association element of a port association list or in an association element of a generic association list.

The purpose of port and generic map aspects is as follows:

— Generic map aspects and port map aspects appearing immediately within a binding indication associate actuals with the formals of the entity declaration implied by the immediately enclosing binding indication. It is an error if a scalar formal may be associated with more than one actual. It is an error if a scalar subelement of any composite formal is associated more than once in the same association list.

  Each scalar subelement of every local port of the component instances to which an enclosing configuration specification or component configuration applies shall be associated as an actual with at least one formal or with a scalar subelement thereof. The actuals of these associations for a given local port shall be either the entire local port or any slice or subelement (or slice thereof) of the local port. The actuals in these associations shall be locally static names.

— Generic map aspects and port map aspects appearing immediately within a component instantiation statement associate actuals with the formals of the component instantiated by the statement. It is an error if a scalar formal is associated with more than one actual. It is an error if a scalar subelement of any composite formal is associated with more than one scalar subelement of an actual.

— Generic map aspects and port map aspects appearing immediately within a block header associate actuals with the formals defined by the same block header. It is an error if a scalar formal is associated with more than one actual. It is an error if a scalar subelement of any composite formal is associated with more than one actual or with a scalar subelement thereof.

An actual associated with a formal generic in a generic map aspect shall be an expression or the reserved word **open**; an actual associated with a formal port in a port map aspect shall be a signal, a quantity, a terminal, an expression, or the reserved word **open**.

Certain restrictions apply to the actual associated with a formal port in a port map aspect; these restrictions are described in 1.1.1.2.

A formal that is not associated with an actual is said to be an *unassociated* formal.

NOTE—A generic map aspect appearing immediately within a binding indication need not associate every formal generic with an actual. These formals may be left unbound so that, for example, a component configuration within a configuration declaration may subsequently bind them.

Example:

```
entity Buf is
   generic (Buf_Delay: TIME := 0 ns);
   port (Input_pin: in Bit; Output_pin: out Bit);
end Buf;

architecture DataFlow of Buf is
begin
   Output_pin <= Input_pin after Buf_Delay;
end DataFlow;

entity Test_Bench is
end Test_Bench;

architecture Structure of Test_Bench is
   component Buf is
      generic (Comp_Buf_Delay: TIME);
      port (Comp_I: in Bit; Comp_O: out Bit);
   end component;
   -- A binding indication; generic and port map aspects within a
   -- binding indication associate actuals (Comp_I, etc.) with
   -- formals of the entity declaration (Input_pin, etc.):
   for UUT: Buf
      use entity Work.Buf(DataFlow)
         generic map (Buf_Delay => Comp_Buf_Delay)
         port map (Input_pin => Comp_I, Output_pin=> Comp_O);

   signal S1,S2: Bit;
begin

   --  A component instantiation statement; generic and port map aspects
   --  within a component instantiation statement associate actuals
   --  (S1, etc.) with the  formals of a component (Comp_I, etc.):
   UUT: Buf
      generic map (Comp_Buf_Delay => 50 ns)
      port map (Comp_I => S1, Comp_O => S2);

   --  A block statement; generic and port map aspects within the
   --  block header  of a block statement associate actuals (in this
   --  case, 4) with the formals defined in the block header:
   B: block
      generic (G: INTEGER);
      generic map (G => 4);
   begin
   end block;
end Structure;
```

NOTE 1—A local generic (from a component declaration) or formal generic (from a block statement or from the entity declaration of the enclosing design entity) may appear as an actual in a generic map aspect. Similarly, a local port (from a component declaration) or formal port (from a block statement or from the entity declaration of the enclosing design entity) may appear as an actual in a port map aspect.

NOTE 2—If a formal generic is rebound by an incremental binding indication, the actual expression associated by the formal generic in the primary binding indication is not evaluated during the elaboration of the description.

Cross-references: Generics, 1.1.1.1; ports, 1.1.1.2; interface declarations, 4.3.2.

5.2.2 Default binding indication

In certain circumstances, a default binding indication will apply in the absence of an explicit binding indication. The default binding indication consists of a default entity aspect, together with a default generic map aspect and a default port map aspect, as appropriate.

If no visible entity declaration has the same simple name as that of the instantiated component, then the default entity aspect is **open**. A *visible entity declaration* is either

a) An entity declaration that has the same simple name as that of the instantiated component and that is directly visible (see 10.3),

b) An entity declaration that has the same simple name as that of the instantiated component and that would be directly visible in the absence of a directly visible (see 10.3) component declaration with the same simple name as that of the entity declaration, or

c) An entity declaration denoted by "L.C", where L is the target library and C is the simple name of the instantiated component. The *target library* is the library logical name of the library containing the design unit in which the component C is declared.

These visibility checks are made at the point of the absent explicit binding indication that causes the default binding indication to apply.

Otherwise, the default entity aspect is of the form

```
entity entity_name ( architecture_identifier )
```

where the entity name is the simple name of the instantiated component, and the architecture identifier is the same as the simple name of the most recently analyzed architecture body associated with the entity declaration. If this rule is applied either to a binding indication contained within a configuration specification or to a component configuration that does not contain an explicit inner block configuration, then the architecture identifier is determined during elaboration of the design hierarchy containing the binding indication. Likewise, if a component instantiation statement contains an instantiated unit containing the reserved word **entity** but does not contain an explicitly specified architecture identifier, this rule is applied during the elaboration of the design hierarchy containing a component instantiation statement. In all other cases, this rule is applied during analysis of the binding indication.

It is an error if there is no architecture body associated with the entity declaration denoted by an entity name that is the simple name of the instantiated component.

The default binding indication includes a default generic map aspect if the design entity implied by the entity aspect contains formal generics. The default generic map aspect associates each local generic in the corresponding component instantiation (if any) with a formal of the same simple name. It is an error if such a formal does not exist or if its mode and type are not appropriate for such an association. Any remaining unassociated formals are associated with the actual designator **open**.

The default binding indication includes a default port map aspect if the design entity implied by the entity aspect contains formal ports. The default port map aspect associates each local port in the corresponding component instantiation (if any) with a formal of the same simple name. It is an error if such a formal does not exist or if its mode and type are not appropriate for such an association. Any remaining unassociated formals are associated with the actual designator **open**.

If an explicit binding indication lacks a generic map aspect, and if the design entity implied by the entity aspect contains formal generics, then the default generic map aspect is assumed within that binding indication. Similarly, if an explicit binding indication lacks a port map aspect, and the design entity implied by the entity aspect contains formal ports, then the default port map aspect is assumed within that binding indication.

5.3 Disconnection specification

A disconnection specification defines the time delay to be used in the implicit disconnection of drivers of a guarded signal within a guarded signal assignment.

disconnection_specification ::=
  disconnect guarded_signal_specification **after** *time*_expression ;

guarded_signal_specification ::=
  *guarded*_signal_list : type_mark

signal_list ::=
  *signal*_name { , *signal*_name }
  | **others**
  | **all**

Each signal name in a signal list in a guarded signal specification shall be a locally static name that denotes a guarded signal (see 4.3.1.2). Each guarded signal shall be an explicitly declared signal or member of such a signal.

If the guarded signal is a declared signal or a slice thereof, the type mark shall be the same as the type mark indicated in the guarded signal specification (see 4.3.1.2). If the guarded signal is an array element of an explicitly declared signal, the type mark shall be the same as the element subtype indication in the (explicit or implicit) array type declaration that declares the base type of the explicitly declared signal. If the guarded signal is a record element of an explicitly declared signal, then the type mark shall be the same as the type mark in the element subtype definition of the record type declaration that declares the type of the explicitly declared signal. Each signal shall be declared in the declarative part enclosing the disconnection specification.

Subject to the aforementioned rules, a disconnection specification *applies* to the drivers of a guarded signal S of whose type mark denotes the type T under the following circumstances:

— For a scalar signal S, if an explicit or implicit disconnection specification of the form

```
disconnect S: T after time_expression;
```

exists, then this disconnection specification applies to the drivers of S.

— For a composite signal S, an explicit or implicit disconnection specification of the form

```
disconnect S: T after time_expression;
```

is equivalent to a series of implicit disconnection specifications, one for each scalar subelement of the signal S. Each disconnection specification in the series is created as follows: it has, as its single signal name in its signal list, a unique scalar subelement of S. Its type mark is the same as the type of the same scalar subelement of S. Its time expression is the same as that of the original disconnection specification.

The characteristics of the disconnection specification shall be such that each implicit disconnection specification in the series is a legal disconnection specification.

— If the signal list in an explicit or implicit disconnection specification contains more than one signal name, the disconnection specification is equivalent to a series of disconnection specifications, one for each signal name in the signal list. Each disconnection specification in the series is created as follows: It has, as its single signal name in its signal list, a unique member of the signal list from the original disconnection specification. Its type mark and time expression are the same as those in the original disconnection specification.

The characteristics of the disconnection specification shall be such that each implicit disconnection specification in the series is a legal disconnection specification.

— An explicit disconnection specification of the form

```
disconnect others: T after time_expression;
```

is equivalent to an implicit disconnection specification where the reserved word **others** is replaced with a signal list comprised of the simple names of those guarded signals that are declared signals declared in the enclosing declarative part, whose type mark is the same as T, and that do not otherwise have an explicit disconnection specification applicable to its drivers; the remainder of the disconnection specification is otherwise unchanged. If there are no guarded signals in the enclosing declarative part whose type mark is the same as T and that do not otherwise have an explicit disconnection specification applicable to its drivers, then the preceding disconnection specification has no effect.

The characteristics of the explicit disconnection specification shall be such that the implicit disconnection specification, if any, is a legal disconnection specification.

— An explicit disconnection specification of the form

```
disconnect all: T after time_expression;
```

is equivalent to an implicit disconnection specification where the reserved word **all** is replaced with a signal list comprised of the simple names of those guarded signals that are declared signals declared in the enclosing declarative part and whose type mark is the same as T; the remainder of the disconnection specification is otherwise unchanged. If there are no guarded signals in the enclosing declarative part whose type mark is the same as T, then the preceding disconnection specification has no effect.

The characteristics of the explicit disconnection specification shall be such that the implicit disconnection specification, if any, is a legal disconnection specification.

A disconnection specification with the signal list **others** or **all** for a given type that appears in a declarative part shall be the last such specification for the given type in that declarative part. It is an error if a guarded signal of the given type is declared in a given declarative part following such a disconnection specification.

The time expression in a disconnection specification shall be static and shall evaluate to a non-negative value.

It is an error if more than one disconnection specification applies to drivers of the same signal.

If, by the aforementioned rules, no disconnection specification applies to the drivers of a guarded, scalar signal S whose type mark is T (including a scalar subelement of a composite signal), then the following default disconnection specification is implicitly assumed:

```
disconnect S : T after 0 ns;
```

A disconnection specification that applies to the drivers of a guarded signal S is the *applicable disconnection specification* for the signal S.

Thus the implicit disconnection delay for any guarded signal is always defined, either by an explicit disconnection specification or by an implicit one.

NOTE 1—A disconnection specification supplying either the reserved words **others** or **all** may apply to none of the guarded signals in the current declarative part, in the event that none of the guarded signals in the current declarative part meet all of the requirements of the disconnection specification.

NOTE 2—Since disconnection specifications are based on declarative parts, not on declarative regions, ports declared in an entity declaration cannot be referenced by a disconnection specification in a corresponding architecture body.

Cross-references: Disconnection statements, 9.5; guarded assignment, 9.5; guarded blocks, 9.1; guarded signals, 4.3.1.2; guarded targets, 9.5; signal guard, 9.1.

5.4 Step limit specification

A step limit specification specifies a maximum amount of time that is permitted to elapse between the determination of the values of a quantity and the next determination of the value of that quantity.

step_limit_specification ::=
    limit quantity_specification **with** *real*_expression ;

quantity_specification ::=
    quantity_list : type_mark

quantity_list ::=
    *quantity*_name { , *quantity*_name }
    | **others**
    | **all**

Each quantity name in a quantity list in a step limit specification shall be a locally static name that denotes a quantity. Each quantity shall be an explicitly declared quantity or a member of such a quantity.

If the quantity is a declared quantity or a slice thereof, the type mark shall be the same as the type mark indicated in the quantity declaration for that quantity. If the quantity is an array element of an explicitly declared quantity, the type mark shall be the same as the element subtype indication in the (explicit or implicit) array type declaration that declares the base type of the explicitly declared quantity. If the quantity is a record element of an explicitly declared quantity, then the type mark shall be the same as the type mark in the element subtype definition of the record type declaration that declares the type of the explicitly declared quantity. Each quantity shall be declared in the declarative part enclosing the step limit specification.

Subject to the aforementioned rules, a step limit specification *applies* to a quantity Q whose type mark denotes the type T under the following circumstances:

— For a scalar quantity Q, if an explicit or implicit step limit specification of the form

```
limit Q: T with real_expression;
```

exists, then this step limit specification applies to Q.

— For a composite quantity Q, an explicit or implicit step limit specification of the form

```
limit Q: T with real_expression;
```

is equivalent to a series of implicit step limit specifications, one for each scalar subelement of the quantity Q. Each step limit specification in the series is created as follows: It has, as its single quantity name in its quantity list, a unique scalar subelement of Q. Its type mark is the same as the type of the same scalar subelement of Q. Its real expression is the same as that of the original step limit specification.

The characteristics of the step limit specification shall be such that each implicit step limit specification in the series is a legal step limit specification.

— If the quantity list in an explicit or implicit step limit specification contains more than one quantity name, the step limit specification is equivalent to a series of step limit specifications, one for each quantity name in the quantity list. Each step limit specification in the series is created as follows: It has, as its single quantity name in its quantity list, a unique member of the quantity list from the original step limit specification. Its type mark and time expression are the same as those in the original step limit specification.

The characteristics of the step limit specification shall be such that each implicit step limit specification in the series is a legal step limit specification.

— An explicit step limit specification of the form

```
limit others: T with real_expression;
```

is equivalent to an implicit step limit specification where the reserved word **others** is replaced with a quantity list comprised of the simple names of those quantities that are declared quantities declared in the enclosing declarative part, whose type mark is the same as T, and that do not otherwise have an explicit step limit specification applicable to it; the remainder of the step limit specification is otherwise unchanged. If there are no quantities in the enclosing declarative part whose type mark is the same as T and that do not otherwise have an explicit step limit specification applicable to them, then the preceding step limit specification has no effect.

The characteristics of the explicit step limit specification shall be such that the implicit step limit specification, if any, is a legal step limit specification.

— An explicit step limit specification of the form

```
limit all: T with real_expression;
```

is equivalent to an implicit step limit specification where the reserved word **all** is replaced with a quantity list comprised of the simple names of those quantities that are declared quantities declared in the enclosing declarative part and whose type mark is the same as T; the remainder of the step limit specification is otherwise unchanged. If there are no quantities in the enclosing declarative part whose type mark is the same as T, then the preceding step limit specification has no effect.

The characteristics of the explicit step limit specification shall be such that the implicit step limit specification, if any, is a legal step limit specification.

A step limit specification with the quantity list **others** or **all** for a given type that appears in a declarative part shall be the last such specification for the given type in that declarative part. It is an error if a quantity of the given type is declared in a given declarative part following such a step limit specification.

It is an error if more than one step limit specification applies to the same quantity.

If, by the aforementioned rules, no step limit specification applies to a scalar quantity Q whose type mark is T (including a scalar subelement of a composite quantity), then the following default step limit specification is implicitly assumed:

```
limit Q : T with X;
```

where X is the universal time corresponding to REAL'HIGH.

Thus the step limit expression for any quantity is always defined, either by an explicit step limit specification or by an implicit one. If the value of a quantity is determined at time T, its value is next determined at a time that is not greater than T plus the value of the step limit expression evaluated at time T (see 12.6.6 for the process by which the analog solver determines the values of quantities, and 12.6.4 for the role that the analog solver plays in the simulation cycle).

Example:

```
library IEEE;
use IEEE.Math_real.all;
entity source is
```

```
   generic (Amplitude: REAL; Freq: REAL);
   port (quantity Sine: out REAL);
   limit Sine: REAL with 0.05/Freq;  -- ensures that there are at least
                                     -- 20 analog solution points per
                                     -- period of the sine wave
end entity source;

architecture Sinusoid of source is
begin
   Sine == Amplitude * sin (Math_2_pi * Freq * NOW);
end architecture Sinusoid;
```

NOTE 1—A step limit specification supplying either the reserved words **others** or **all** may apply to none of quantities in the current declarative part, in the event that none of the quantities in the current declarative part meet all of the requirements of the step limit specification.

NOTE 2—Since step limit specifications are based on declarative parts, not on declarative regions, quantity ports declared in an entity interface cannot be referenced by a step limit specification in a corresponding architecture body.

Cross-references: Quantity declarations, 4.3.1.6; analog solver, 12.6.6.

6. Names

The rules applicable to the various forms of names are described in this clause.

6.1 Names

Names can denote declared entities, whether declared explicitly or implicitly. Names can also denote the following:

- Objects denoted by access values
- Methods (see 3.5.1) of protected types
- Subelements of composite objects
- Subelements of composite values
- Slices of composite objects
- Slices of composite values
- Attributes of any named entity

```
name ::=
      simple_name
    | operator_symbol
    | selected_name
    | indexed_name
    | slice_name
    | attribute_name

prefix ::=
      name
    | function_call
```

Certain forms of name (indexed and selected names, slice names, and attribute names) include a *prefix* that is a name or a function call. If the prefix of a name is a function call, then the name denotes an element, a slice, or an attribute, either of the result of the function call, or (if the result is an access value) of the object designated by the result. Function calls are defined in 7.3.3.

If the type of a prefix is an access type, then the prefix shall not be a name that denotes a formal parameter of mode **out** or a member thereof.

A prefix is said to be *appropriate* for a type or nature in either of the following cases:

- The type or nature of the prefix is the type or nature considered
- The type of the prefix is an access type whose designated type is the type considered

The evaluation of a name determines the named entity denoted by the name. The evaluation of a name that has a prefix includes the evaluation of the prefix, that is, of the corresponding name or function call. If the type of the prefix is an access type, the evaluation of the prefix includes the determination of the object designated by the corresponding access value. In such a case, it is an error if the value of the prefix is a null access value. It is an error if, after all type analysis (including overload resolution) the name is ambiguous.

A name is said to be a *static name* if and only if one of the following conditions holds:

- The name is a simple name or selected name (including those that are expanded names) that does not denote a function call, an object or value of an access type, or an object of a protected type and (in the case of a selected name) whose prefix is a static name.

— The name is an indexed name whose prefix is a static name, and every expression that appears as part of the name is a static expression.

— The name is a slice name whose prefix is a static name and whose discrete range is a static discrete range.

— The name is an attribute name whose prefix is a static signal name and whose suffix is one of the predefined attributes 'DELAYED, 'STABLE, 'QUIET, 'TRANSACTION, 'RAMP, or 'SLEW.

— The name is an attribute name whose prefix is a static quantity name and whose suffix is one of the predefined attributes 'ABOVE, 'DOT, 'INTEG, 'DELAYED, 'SLEW, 'LTF, 'ZOH, or 'ZTF.

Furthermore, a name is said to be a *locally static name* if and only if one of the following conditions hold:

— The name is a simple name or selected name (including those that are expanded names) that is not an alias and that does not denote a function call, an object or value of an access type, or an object of a protected type and (in the case of a selected name) whose prefix is a locally static name.

— The name is a simple name or selected name (including those that are expanded names) that is an alias, and that the aliased name given in the corresponding alias declaration (see 4.3.3) is a locally static name, and (in the case of a selected name) whose prefix is a locally static name.

— The name is an indexed name whose prefix is a locally static name, and every expression that appears as part of the name is a locally static expression.

— The name is a slice name whose prefix is a locally static name and whose discrete range is a locally static discrete range.

A *static signal name* is a static name that denotes a signal. The *longest static prefix* of a signal name is the name itself, if the name is a static signal name; otherwise, it is the longest prefix of the name that is a static signal name. Similarly, a *static variable name* is a static name that denotes a variable, and the longest static prefix of a variable name is the name itself, if the name is a static variable name; otherwise, it is the longest prefix of the name that is a static variable name. The terms *static quantity name* and its longest static prefix, and *static terminal name* and its longest static prefix are defined similarly.

Examples:

```
S(C,2)          --A static name: C is a static constant.
R(J to 16)      --A nonstatic name: J is a signal.
                --R is the longest static prefix of R(J to 16).

T(n)            --A static name; n is a generic constant.
T(2)            --A locally static name.
```

6.2 Simple names

A simple name for a named entity is either the identifier associated with the entity by its declaration or another identifier associated with the entity by an alias declaration. In particular, the simple name for an entity declaration, a configuration, a package, a procedure, or a function is the identifier that appears in the corresponding entity declaration, configuration declaration, package declaration, procedure declaration, or function declaration, respectively. The simple name of an architecture is that defined by the identifier of the architecture body.

simple_name ::= identifier

The evaluation of a simple name has no other effect than to determine the named entity denoted by the name.

6.3 Selected names

A selected name is used to denote a named entity whose declaration appears either within the declaration of another named entity or within a design library.

```
selected_name ::= prefix . suffix

suffix ::=
      simple_name
    | character_literal
    | operator_symbol
    | all
```

A selected name can denote an element of a record, an object designated by an access value, or a named entity whose declaration is contained within another named entity, particularly within a library, a package, or a protected type. Furthermore, a selected name can denote all named entities whose declarations are contained within a library or a package.

For a selected name that is used to denote a record element, the suffix shall be a simple name denoting an element of a record object or value. The prefix shall be appropriate for the type or nature of this object or value.

For a selected name that is used to denote the object designated by an access value, the suffix shall be the reserved word **all**. The prefix shall belong to an access type.

The remaining forms of selected names are called *expanded names*. The prefix of an expanded name shall not be a function call.

An expanded name denotes a primary unit contained in a design library if the prefix denotes the library and the suffix is the simple name of a primary unit whose declaration is contained in that library. An expanded name denotes all primary units contained in a library if the prefix denotes the library and the suffix is the reserved word **all**. An expanded name is not allowed for a secondary unit, particularly for an architecture body.

An expanded name denotes a named entity declared in a package if the prefix denotes the package and the suffix is the simple name, character literal, or operator symbol of a named entity whose declaration occurs immediately within that package. An expanded name denotes all named entities declared in a package if the prefix denotes the package and the suffix is the reserved word **all**.

An expanded name denotes a named entity declared immediately within a named construct if the prefix denotes a construct that is an entity declaration, an architecture body, a subprogram declaration, a subprogram body, a block statement, a process statement, a simultaneous procedural statement, a generate statement, or a loop statement, and the suffix is the simple name, character literal, or operator symbol of a named entity whose declaration occurs immediately within that construct. This form of expanded name is only allowed within the construct itself, or if the prefix denotes an entity declaration and the expanded name occurs within an architecture body corresponding to the entity declaration.

An expanded name denotes a named entity declared immediately within an architecture body if the prefix denotes the entity declaration corresponding to the architecture body and the suffix is the simple name, character literal, or operator symbol of a named entity whose declaration occurs immediately within the architecture body. This form of expanded name is only allowed within the architecture body.

An expanded name denotes a named entity declared immediately within a protected type if the prefix denotes an object of a protected type and the suffix is a simple name of a method whose declaration appears immediately within the protected type declaration.

If, according to the visibility rules, there is at least one possible interpretation of the prefix of a selected name as the name of an enclosing entity declaration, architecture, subprogram, block statement, process statement, simultaneous procedural statement, generate statement, or loop statement, or if there is at least one possible interpretation of the prefix of a selected name as the name of an object of a protected type, then the only interpretations considered are those of the immediately preceding three paragraphs. In this case, the selected name is always interpreted as an expanded name. In particular, no interpretations of the prefix as a function call are considered.

Examples:

```
-- Given the following declarations:

type INSTR_TYPE is
   record
      OPCODE: OPCODE_TYPE;
   end record;
signal INSTRUCTION: INSTR_TYPE;

-- The name "INSTRUCTION.OPCODE" is the name of a record element.

-- Given the following declarations:

type INSTR_PTR is access INSTR_TYPE;
variable PTR: INSTR_PTR;

-- The name "PTR.all" is the name of the object designated by PTR.

-- Given the following library clause:

library TTL, CMOS;

-- The name "TTL.SN74LS221" is the name of a design unit contained in
-- a library and the name "CMOS.all" denotes all design units contained
-- in a library.

-- Given the following declaration and use clause:

library MKS;
use MKS.MEASUREMENTS, STD.STANDARD;

-- The name "MEASUREMENTS.VOLTAGE" denotes a named entity declared in
-- a package and the name "STANDARD.all" denotes all named entities
-- declared in a package.

-- Given the following process label and declarative part:

P: process
   variable DATA: INTEGER;
begin
   -- Within process P, the name "P.DATA" denotes a named entity
   -- declared in process P.
end process;

counter.increment(5);          -- See 4.3.1.3 for the definition
counter.decrement(i);          -- of "counter."
if counter.value = 0 then ... end if;

result.add(sv1, sv2);          -- See 4.3.1.3 for the definition
                               -- of "result."
bit_stack.add_bit(1, '1');     -- See 4.3.1.3 for the definition
bit_stack.add_bit(2, '1');     -- of "bit_stack."
bit_stack.add_bit(3, '0');
```

NOTE 1—The object denoted by an access value is accessed differently depending on whether the entire object or a subelement of the object is desired. If the entire object is desired, a selected name whose prefix denotes the access value and whose suffix is the reserved word all is used. In this case, the access value is not automatically dereferenced, since it is necessary to distinguish an access value from the object denoted by an access value.

If a subelement of the object is desired, a selected name whose prefix denotes the access value is again used; however, the suffix in this case denotes the subelement. In this case, the access value is automatically dereferenced.

These two cases are shown in the following example:

```
type rec;

type recptr is access rec;

type rec is
   record
      value  : INTEGER;
      \next\ : recptr;
   end record;

variable list1, list2: recptr;
variable recobj: rec;

list2 := list1;             -- Access values are copied;
                            -- list1 and list2 now denote the same object.
list2 := list1.\next\;      -- list2 denotes the same object as list1.\next\.
                            -- list1.\next\ is the same as list1.all.\next\.
                            -- An implicit dereference of the access value occurs before the
                            -- "\next\" field is selected.
recobj := list2.all;        -- An explicit dereference is needed here.
```

NOTE 2—Overload resolution is used to disambiguate selected names. See rules a) and c) of 10.5.

NOTE 3—If, according to the rules of this clause and of 10.5, there is not exactly one interpretation of a selected name that satisfies these rules, then the selected name is ambiguous.

6.4 Indexed names

An indexed name denotes an element of an array.

indexed_name ::= prefix (expression { , expression })

The prefix of an indexed name shall be appropriate for an array type or nature. The expressions specify the index values for the element; there shall be one such expression for each index position of the array, and each expression shall be of the type of the corresponding index. For the evaluation of an indexed name, the prefix and the expressions are evaluated. It is an error if an index value does not belong to the range of the corresponding index range of the array.

Examples:

```
REGISTER_ARRAY(5)          -- An element of a one-dimensional array
MEMORY_CELL(1024,7)        -- An element of a two-dimensional array
```

NOTE—If a name (including one used as a prefix) has an interpretation both as an indexed name and as a function call, then the innermost complete context is used to disambiguate the name. If, after applying this rule, there is not exactly one interpretation of the name, then the name is ambiguous. See 10.5.

6.5 Slice names

A slice name denotes a one-dimensional array composed of a sequence of consecutive elements of another one-dimensional array. A slice of a signal is a signal; a slice of a variable is a variable; a slice of a constant is a constant; a slice of a value is a value; a slice of a quantity is a quantity; a slice of a terminal is a terminal.

slice_name ::= prefix (discrete_range)

The prefix of a slice shall be appropriate for a one-dimensional array object. The base type or nature of this array type or nature is the type or nature of the slice.

The bounds of the discrete range define those of the slice and shall be of the type of the index of the array. The slice is a *null slice* if the discrete range is a null range. It is an error if the direction of the discrete range is not the same as that of the index range of the array denoted by the prefix of the slice name.

For the evaluation of a name that is a slice, the prefix and the discrete range are evaluated. It is an error if either of the bounds of the discrete range does not belong to the index range of the prefixing array, unless the slice is a null slice. (The bounds of a null slice need not belong to the subtype of the index.)

Examples:

```
signal   R15:  BIT_VECTOR (0 to 31);
constant DATA: BIT_VECTOR (31 downto 0);

R15(0 to 7)            -- A slice with an ascending range.
DATA(24 downto 1)      -- A slice with a descending range.
DATA(1 downto 24)      -- A null slice.
DATA(24 to 25)         -- An error.
```

NOTE—If A is a one-dimensional array of objects, the name A(N **to** N) or A(N **downto** N) is a slice that contains one element; its type is the base type of A. On the other hand, A(N) is an element of the array A and has the corresponding element type.

6.6 Attribute names

An attribute name denotes a value, function, type, range, signal, quantity, or constant associated with a named entity.

attribute_name ::=
  prefix [signature] ' attribute_designator [(expression { , expression })]

attribute_designator ::= *attribute*_simple_name

The applicable attribute designators depend on the prefix plus the signature, if any. The meaning of the prefix of an attribute shall be determinable independently of the attribute designator and independently of the fact that it is the prefix of an attribute.

It is an error if a signature follows the prefix and the prefix does not denote a subprogram or enumeration literal, or an alias thereof. In this case, the signature is required to match (see 2.3.2) the parameter and result type profile of exactly one visible subprogram or enumeration literal, as is appropriate to the prefix.

If the attribute designator denotes a predefined attribute, the expressions either shall or may appear, depending upon the definition of that attribute (see Clause 14); otherwise, they shall not be present.

If the prefix of an attribute name denotes an alias, then the attribute name denotes an attribute of the aliased name and not the alias itself, except when the attribute designator denotes any of the predefined attributes 'SIMPLE_NAME, 'PATH_NAME, or 'INSTANCE_NAME. If the prefix of an attribute name denotes an alias and the attribute designator denotes any of the predefined attributes SIMPLE_NAME, 'PATH_NAME, or 'INSTANCE_NAME, then the attribute name denotes the attribute of the alias and not of the aliased name.

If the attribute designator denotes a user-defined attribute, the prefix cannot denote a subelement or a slice of an object.

Examples:

```
REG'LEFT(1)           -- The leftmost index bound of array REG

INPUT_PIN'PATH_NAME   -- The hierarchical path name of
                      -- the port INPUT_PIN

CLK'DELAYED(5 ns)     -- The signal CLK delayed by 5 ns
```

7. Expressions

The rules applicable to the different forms of expression, and to their evaluation, are given in this clause.

7.1 Expressions

An expression is a formula that defines the computation of a value.

```
expression ::=
      relation { and relation }
    | relation { or relation }
    | relation { xor relation }
    | relation [ nand relation ]
    | relation [ nor relation ]
    | relation { xnor relation }

relation ::=
    shift_expression [ relational_operator shift_expression ]

shift_expression ::=
    simple_expression [ shift_operator simple_expression ]

simple_expression ::=
    [ sign ] term { adding_operator term }

term ::=
    factor { multiplying_operator factor }

factor ::=
      primary [ ** primary ]
    | abs primary
    | not primary

primary ::=
      name
    | literal
    | aggregate
    | function_call
    | qualified_expression
    | type_conversion
    | allocator
    | ( expression )
```

Each primary has a value and a type. The only names allowed as primaries are attributes that yield values and names denoting objects (except terminals; the name of a terminal is not allowed as a primary) or values. In the case of names denoting objects other than objects of file types or protected types, the value of the primary is the value of the object. In the case of names denoting either file objects or objects of protected types, the value of the primary is the entity denoted by the name.

The type of an expression depends only upon the types of its operands and on the operators applied; for an overloaded operand or operator, the determination of the operand type, or the identification of the overloaded operator, depends on the context (see 10.5). For each predefined operator, the operand and result types are given in the following subclause.

NOTE—The syntax for an expression involving logical operators allows a sequence of **and**, **or**, **xor**, or **xnor** operators (whether predefined or user-defined), since the corresponding predefined operations are associative. For the operators **nand** and **nor** (whether predefined or user-defined), however, such a sequence is not allowed, since the corresponding predefined operations are not associative.

7.2 Operators

The operators that may be used in expressions are defined as follows. Each operator belongs to a class of operators, all of which have the same precedence level; the classes of operators are listed in order of increasing precedence.

logical_operator ::= **and** | **or** | **nand** | **nor** | **xor** | **xnor**

relational_operator ::= = | /= | < | <= | > | >=

shift_operator ::= **sll** | **srl** | **sla** | **sra** | **rol** | **ror**

adding_operator ::= + | – | &

sign ::= + | –

multiplying_operator ::= * | / | **mod** | **rem**

miscellaneous_operator ::= ** | **abs** | **not**

Operators of higher precedence are associated with their operands before operators of lower precedence. Where the language allows a sequence of operators, operators with the same precedence level are associated with their operands in textual order, from left to right. The precedence of an operator is fixed and cannot be changed by the user, but parentheses can be used to control the association of operators and operands.

In general, operands in an expression are evaluated before being associated with operators. For certain operations, however, the right-hand operand is evaluated if and only if the left-hand operand has a certain value. These operations are called *short-circuit* operations. The logical operations **and**, **or**, **nand**, and **nor** defined for operands of types BIT and BOOLEAN are all short-circuit operations; furthermore, these are the only short-circuit operations.

Every predefined operator is a pure function (see 2.1). No predefined operators have named formal parameters; therefore, named association (see 4.3.2.2) cannot be used when invoking a predefined operation.

NOTE 1—The predefined operators for the standard types are declared in package STANDARD as shown in 14.2.

NOTE 2—The operator **not** is classified as a miscellaneous operator for the purposes of defining precedence, but is otherwise classified as a logical operator.

7.2.1 Logical operators

The logical operators **and**, **or**, **nand**, **nor**, **xor**, **xnor**, and **not** are defined for predefined types BIT and BOOLEAN. They are also defined for any one-dimensional array type whose element type is BIT or BOOLEAN. For the binary operators **and**, **or**, **nand**, **nor**, **xor**, and **xnor**, the operands shall be of the same base type. Moreover, for the binary operators **and, or, nand, nor, xor**, and **xnor** defined on one-dimensional array types, the operands shall be arrays of the same length, the operation is performed on matching elements of the arrays, and the result is an array with the same index range as the left operand. For the unary operator **not** defined on one-dimensional array types, the operation is performed on each element of the operand, and the result is an array with the same index range as the operand.

The effects of the logical operators are defined in the following tables. The symbol T represents TRUE for type BOOLEAN, '1' for type BIT; the symbol F represents FALSE for type BOOLEAN, '0' for type BIT.

A	B	A **and** B	A	B	A **or** B	A	B	A **xor** B
T	T	T	T	T	T	T	T	F
T	F	F	T	F	T	T	F	T
F	T	F	F	T	T	F	T	T
F	F	F	F	F	F	F	F	F

A	B	A **nand** B	A	B	A **nor** B	A	B	A **xnor** B
T	T	F	T	T	F	T	T	T
T	F	T	T	F	F	T	F	F
F	T	T	F	T	F	F	T	F
F	F	T	F	F	T	F	F	T

A	**not** A
T	F
F	T

For the short-circuit operations **and**, **or**, **nand**, and **nor** on types BIT and BOOLEAN, the right operand is evaluated only if the value of the left operand is not sufficient to determine the result of the operation. For operations **and** and **nand**, the right operand is evaluated only if the value of the left operand is T; for operations **or** and **nor**, the right operand is evaluated only if the value of the left operand is F.

NOTE—All of the binary logical operators belong to the class of operators with the lowest precedence. The unary logical operator **not** belongs to the class of operators with the highest precedence.

7.2.2 Relational operators

Relational operators include tests for equality, inequality, and ordering of operands. The operands of each relational operator shall be of the same type. The result type of each relational operator is the predefined type BOOLEAN.

Operator	Operation	Operand type	Result type
=	Equality	Any type, other than a file type or a protected type	BOOLEAN
/=	Inequality	Any type, other than a file type or a protected type	BOOLEAN
< <= > >=	Ordering	Any scalar type or discrete array type	BOOLEAN

The equality and inequality operators (= and /=) are defined for all types other than file types and protected types. The equality operator returns the value TRUE if the two operands are equal and returns the value FALSE otherwise. The inequality operator returns the value FALSE if the two operands are equal and returns the value TRUE otherwise.

Two scalar values of the same type are equal if and only if the values are the same. Two composite values of the same type are equal if and only if for each element of the left operand there is a *matching element* of the right operand and vice versa, and the values of matching elements are equal, as given by the predefined equality operator for the element type. In particular, two null arrays of the same type are always equal. Two values of an access type are equal if and only if they both designate the same object or they both are equal to the null value for the access type.

For two record values, matching elements are those that have the same element identifier. For two one-dimensional array values, matching elements are those (if any) whose index values match in the following sense: the left bounds of the index ranges are defined to match; if two elements match, the elements immediately to their right are also defined to match. For two multidimensional array values, matching elements are those whose indices match in successive positions.

The ordering operators are defined for any scalar type and for any discrete array type. A *discrete array* is a one-dimensional array whose elements are of a discrete type. Each operator returns TRUE if the corresponding relation is satisfied; otherwise, the operator returns FALSE.

For scalar types, ordering is defined in terms of the relative values. For discrete array types, the relation < (less than) is defined such that the left operand is less than the right operand if and only if the left operand is a null array and the right operand is a non-null array.

Otherwise, both operands are non-null arrays, and one of the following conditions is satisfied:

a) The leftmost element of the left operand is less than that of the right, or
b) The leftmost element of the left operand is equal to that of the right, and the tail of the left operand is less than that of the right (the tail consists of the remaining elements to the right of the leftmost element and can be null).

The relation <= (less than or equal) for discrete array types is defined to be the inclusive disjunction of the results of the < and = operators for the same two operands. The relations > (greater than) and >= (greater than or equal) are defined to be the complements of the <= and < operators, respectively, for the same two operands.

7.2.3 Shift operators

The shift operators **sll**, **srl**, **sla**, **sra**, **rol**, and **ror** are defined for any one-dimensional array type whose element type is either of the predefined types BIT or BOOLEAN.

Operator	Operation	Left operand type	Right operand type	Result type
sll	Shift left logical	Any one-dimensional array type whose element type is BIT or BOOLEAN	INTEGER	Same as left
srl	Shift right logical	Any one-dimensional array type whose element type is BIT or BOOLEAN	INTEGER	Same as left
sla	Shift left arithmetic	Any one-dimensional array type whose element type is BIT or BOOLEAN	INTEGER	Same as left
sra	Shift right arithmetic	Any one-dimensional array type whose element type is BIT or BOOLEAN	INTEGER	Same as left
rol	Rotate left logical	Any one-dimensional array type whose element type is BIT or BOOLEAN	INTEGER	Same as left
ror	Rotate right logical	Any one-dimensional array type whose element type is BIT or BOOLEAN	INTEGER	Same as left

The index subtypes of the return values of all shift operators are the same as the index subtypes of their left arguments.

The values returned by the shift operators are defined as follows. In the remainder of this subclause, the values of their leftmost arguments are referred to as L and the values of their rightmost arguments are referred to as R.

— The **sll** operator returns a value that is L logically shifted left by R index positions. That is, if R is 0 or if L is a null array, the return value is L. Otherwise, a basic shift operation replaces L with a value that is the result of a concatenation whose left argument is the rightmost (L'Length – 1) elements of L and whose right argument is T'Left, where T is the element type of L. If R is positive, this basic shift operation is repeated R times to form the result. If R is negative, then the return value is the value of the expression L **srl** –R.

— The **srl** operator returns a value that is L logically shifted right by R index positions. That is, if R is 0 or if L is a null array, the return value is L. Otherwise, a basic shift operation replaces L with a value that is the result of a concatenation whose right argument is the leftmost (L'Length – 1) elements of L and whose left argument is T'Left, where T is the element type of L. If R is positive, this basic shift operation is repeated R times to form the result. If R is negative, then the return value is the value of the expression L **sll** –R.

— The **sla** operator returns a value that is L arithmetically shifted left by R index positions. That is, if R is 0 or if L is a null array, the return value is L. Otherwise, a basic shift operation replaces L with a value that is the result of a concatenation whose left argument is the rightmost (L'Length – 1) elements of L and whose right argument is L(L'Right). If R is positive, this basic shift operation is repeated R times to form the result. If R is negative, then the return value is the value of the expression L **sra** –R.

— The **sra** operator returns a value that is L arithmetically shifted right by R index positions. That is, if R is 0 or if L is a null array, the return value is L. Otherwise, a basic shift operation replaces L with a value that is the result of a concatenation whose right argument is the leftmost (L'Length – 1) elements of L and whose left argument is L(L'Left). If R is positive, this basic shift operation is repeated R times to form the result. If R is negative, then the return value is the value of the expression L **sla** –R.

— The **rol** operator returns a value that is L rotated left by R index positions. That is, if R is 0 or if L is a null array, the return value is L. Otherwise, a basic rotate operation replaces L with a value that is the result of a concatenation whose left argument is the rightmost (L'Length – 1) elements of L and whose right argument is L(L'Left). If R is positive, this basic rotate operation is repeated R times to form the result. If R is negative, then the return value is the value of the expression L **ror** –R.

— The **ror** operator returns a value that is L rotated right by R index positions. That is, if R is 0 or if L is a null array, the return value is L. Otherwise, a basic rotate operation replaces L with a value that is the result of a concatenation whose right argument is the leftmost (L'Length – 1) elements of L and whose left argument is L(L'Right). If R is positive, this basic rotate operation is repeated R times to form the result. If R is negative, then the return value is the value of the expression L **rol** –R.

NOTE 1—The logical operators may be overloaded, for example, to disallow negative integers as the second argument.

NOTE 2—The subtype of the result of a shift operator is the same as that of the left operand.

7.2.4 Adding operators

The adding operators + and – are predefined for any numeric type and have their conventional mathematical meaning. The concatenation operator & is predefined for any one-dimensional array type.

Operator	Operation	Left operand type	Right operand type	Result type
+	Addition	Any numeric type	Same type	Same type
–	Subtraction	Any numeric type	Same type	Same type
&	Concatenation	Any one-dimensional array type	Same array type	Same array type
		Any one-dimensional array type	The element type	Same array type
		The element type	Any one-dimensional array type	Same array type
		The element type	The element type	Any one-dimensional array type

For concatenation, there are three mutually exclusive cases, as follows:

a) If both operands are one-dimensional arrays of the same type, the result of the concatenation is a one-dimensional array of this same type whose length is the sum of the lengths of its operands, and whose elements consist of the elements of the left operand (in left-to-right order) followed by the elements of the right operand (in left-to-right order).

   If both operands are null arrays, then the result of the concatenation is the right operand. Otherwise, the direction and bounds of the result are determined as follows: Let S be the index subtype of the base type of the result. The direction of the result of the concatenation is the direction of S, and the left bound of the result is S'LEFT.

b) If one of the operands is a one-dimensional array and the type of the other operand is the element type of this aforementioned one-dimensional array, the result of the concatenation is given by the rules in case a), using in place of the other operand an implicit array having this operand as its only element. Both the left and right bounds of the index subtype of this implicit array is S'LEFT, and the direction of the index subtype of this implicit array is the direction of S, where S is the index subtype of the base type of the result.

c) If both operands are of the same type and it is the element type of some one-dimensional array type, the type of the result shall be known from the context and is this one-dimensional array type. In this case, each operand is treated as the one element of an implicit array, and the result of the concatenation is determined as in case a). The bounds and direction of the index subtypes of the implicit arrays are determined as in the case of the implicit array in case b).

In all cases, it is an error if either bound of the index subtype of the result does not belong to the index subtype of the type of the result, unless the result is a null array. It is also an error if any element of the result does not belong to the element subtype of the type of the result.

Examples:

```
subtype BYTE is BIT_VECTOR (7 downto 0);
type MEMORY is array (Natural range <>) of BYTE;

--  The following concatenation accepts two BIT_VECTORs and returns
--  a BIT_VECTOR [case a)]:

constant ZERO: BYTE := "0000" & "0000";

--  The next two examples show that the same expression can represent
--  either case a) or case c), depending on the context of
--  the expression.

--  The following concatenation accepts two BIT_VECTORS and returns
--  a BIT_VECTOR [case a)]:

constant C1: BIT_VECTOR := ZERO & ZERO;

--  The following concatenation accepts two BIT_VECTORs and returns
--  a MEMORY [case c)]:

constant C2: MEMORY := ZERO & ZERO;

--  The following concatenation accepts a BIT_VECTOR and a MEMORY,
--  returning a MEMORY [case b)]:

constant C3: MEMORY := ZERO & C2;

--  The following concatenation accepts a MEMORY and a BIT_VECTOR,
--  returning a MEMORY [case b)]:

constant C4: MEMORY := C2 & ZERO;

--  The following concatenation accepts two MEMORYs and returns
--  a MEMORY [case a)]:

constant C5: MEMORY := C2 & C3;

type R1 is range 0 to 7;
type R2 is range 7 downto 0;

type T1 is array (R1 range <>) of Bit;
type T2 is array (R2 range <>) of Bit;

subtype S1 is T1(R1);
subtype S2 is T2(R2);

constant K1: S1 := (others => '0');
constant K2: T1 := K1(1 to 3) & K1(3 to 4);  --  K2'Left = 0
```

```
                                                        --     and K2'Right = 4
constant K3: T1 := K1(5 to 7) & K1(1 to 2);            --  K3'Left = 0
                                                        --     and K3'Right = 4
constant K4: T1 := K1(2 to 1) & K1(1 to 2);            --  K4'Left = 0
                                                        --     and K4'Right = 1

constant K5: S2 := (others => '0');
constant K6: T2 := K5(3 downto 1) & K5(4 downto 3);  --  K6'Left = 7
                                                        --     and K6'Right = 3
constant K7: T2 := K5(7 downto 5) & K5(2 downto 1);  --  K7'Left = 7
                                                        --     and K7'Right = 3
constant K8: T2 := K5(1 downto 2) & K5(2 downto 1);  --  K8'Left = 7
                                                        --     and K8'Right = 6
```

NOTE 1—For a given concatenation whose operands are of the same type, there may be visible more than one array type that could be the result type according to the rules of case c). The concatenation is ambiguous and therefore an error if, using the overload resolution rules of 2.3 and 10.5, the type of the result is not uniquely determined.

NOTE 2—Additionally, for a given concatenation, there may be visible array types that allow both case a) and case c) to apply. The concatenation is again ambiguous and therefore an error if the overload resolution rules cannot be used to determine a result type uniquely.

7.2.5 Sign operators

Signs + and – are predefined for any numeric type and have their conventional mathematical meaning: they respectively represent the identity and negation functions. For each of these unary operators, the operand and the result have the same type.

Operator	Operation	Operand type	Result type
+	Identity	Any numeric type	Same type
–	Negation	Any numeric type	Same type

NOTE—Because of the relative precedence of signs + and – in the grammar for expressions, a signed operand shall not follow a multiplying operator, the exponentiating operator **, or the operators **abs** and **not**. For example, the syntax does not allow the following expressions:

```
A/+B          --  An illegal expression.
A**-B         --  An illegal expression.
```

However, these expressions may be rewritten legally as follows:

```
A/(+B)        --  A legal expression.
A ** (-B)     --  A legal expression.
```

7.2.6 Multiplying operators

The operators * and / are predefined for any integer and any floating-point type and have their conventional mathematical meaning; the operators **mod** and **rem** are predefined for any integer type. For each of these operators, the operands and the result are of the same type.

Operator	Operation	Left operand type	Right operand type	Result type
*	Multiplication	Any integer type	Same type	Same type
		Any floating-point type	Same type	Same type
/	Division	Any integer type	Same type	Same type
		Any floating-point type	Same type	Same type
mod	Modulus	Any integer type	Same type	Same type
rem	Remainder	Any integer type	Same type	Same type

Integer division and remainder are defined by the following relation:

A = (A/B) * B + (A **rem** B)

where (A **rem** B) has the sign of A and an absolute value less than the absolute value of B. Integer division satisfies the following identity:

(–A)/B = – (A/B) = A/(–B)

The result of the modulus operation is such that (A **mod** B) has the sign of B and an absolute value less than the absolute value of B; in addition, for some integer value N, this result shall satisfy the relation:

A = B * N + (A **mod** B)

In addition to the preceding table, the operators * and / are predefined for any physical type.

Operator	Operation	Left operand type	Right operand type	Result type
*	Multiplication	Any physical type	INTEGER	Same as left
		Any physical type	REAL	Same as left
		INTEGER	Any physical type	Same as right
		REAL	Any physical type	Same as right
/	Division	Any physical type	INTEGER	Same as left
		Any physical type	REAL	Same as left
		Any physical type	The same type	*Universal integer*

Multiplication of a value P of a physical type T_p by a value I of type INTEGER is equivalent to the following computation:

T_p'Val(T_p'Pos(P) * I)

Multiplication of a value P of a physical type T_p by a value F of type REAL is equivalent to the following computation:

T_p'Val(INTEGER(REAL(T_p'Pos(P)) * F))

Division of a value P of a physical type T_p by a value I of type INTEGER is equivalent to the following computation:

T_p'Val(T_p'Pos(P) / I)

Division of a value P of a physical type T_p by a value F of type REAL is equivalent to the following computation:

T_p'Val(INTEGER(REAL(T_p'Pos(P)) / F))

Division of a value P of a physical type T_p by a value P2 of the same physical type is equivalent to the following computation:

T_p'Pos(P) / T_p'Pos(P2)

Examples:

```
 5      rem    3      =  2
 5      mod    3      =  2
(-5)    rem    3      = -2
(-5)    mod    3      =  1
(-5)    rem   (-3)    = -2
(-5)    mod   (-3)    = -2
 5      rem   (-3)    =  2
 5      mod   (-3)    = -1
```

NOTE—Because of the precedence rules (see 7.2), the expression "–5 **rem** 2" is interpreted as "–(5 **rem** 2)" and not as "(–5) **rem** 2."

7.2.7 Miscellaneous operators

The unary operator **abs** is predefined for any numeric type.

Operator	Operation	Operand type	Result type
abs	Absolute value	Any numeric type	Same numeric type

The *exponentiating* operator ** is predefined for each integer type and for each floating-point type. In either case the right operand, called the *exponent,* is of the predefined type INTEGER.

Operator	Operation	Left operand type	Right operand type	Result type
**	Exponentiation	Any integer type	INTEGER	Same as left
		Any floating-point type	INTEGER	Same as left

Exponentiation with an integer exponent is equivalent to repeated multiplication of the left operand by itself for a number of times indicated by the absolute value of the exponent and from left to right; if the exponent is negative, then the result is the reciprocal of that obtained with the absolute value of the exponent. Exponentiation with a negative exponent is only allowed for a left operand of a floating-point type. Exponentiation by a zero exponent results in the value one. Exponentiation of a value of a floating-point type is approximate.

7.3 Operands

The operands in an expression include names (that denote objects, values, or attributes that result in a value), literals, aggregates, function calls, qualified expressions, type conversions, and allocators. In addition, an expression enclosed in parentheses may be an operand in an expression. Names are defined in 6.1; the other kinds of operands are defined in 7.3.1 through 7.3.6.

7.3.1 Literals

A literal is either a numeric literal, an enumeration literal, a string literal, a bit string literal, or the literal **null**.

```
literal ::=
      numeric_literal
    | enumeration_literal
    | string_literal
    | bit_string_literal
    | null
```

```
numeric_literal ::=
      abstract_literal
    | physical_literal
```

Numeric literals include literals of the abstract types *universal_integer* and *universal_real*, as well as literals of physical types. Abstract literals are defined in 13.4; physical literals are defined in 3.1.3.

Enumeration literals are literals of enumeration types. They include both identifiers and character literals. Enumeration literals are defined in 3.1.1.

String and bit string literals are representations of one-dimensional arrays of characters. The type of a string or bit string literal shall be determinable solely from the context in which the literal appears, excluding the literal itself but using the fact that the type of the literal shall be a one-dimensional array of a character type. The lexical structure of string and bit string literals is defined in Clause 13.

For a non-null array value represented by either a string or bit string literal, the direction and bounds of the array value are determined according to the rules for positional array aggregates, where the number of elements in the aggregate is equal to the length (see 13.6 and 13.7) of the string or bit string literal. For a null array value represented by either a string or bit string literal, the direction and leftmost bound of the array value are determined as in the non-null case. If the direction is ascending, then the rightmost bound is the predecessor (as given by the 'PRED attribute) of the leftmost bound; otherwise the rightmost bound is the successor (as given by the 'SUCC attribute) of the leftmost bound.

The character literals corresponding to the graphic characters contained within a string literal or a bit string literal shall be visible at the place of the string literal.

The literal **null** represents the null access value for any access type.

Evaluation of a literal yields the corresponding value.

Examples:

```
3.14159_26536      --  A literal of type universal_real.
5280               --  A literal of type universal_integer.
10.7 ns            --  A literal of a physical type.
O"4777"            --  A bit string literal.
"54LS281"          --  A string literal.
""                 --  A string literal representing a null array.
```

7.3.2 Aggregates

An aggregate is a basic operation (see the introduction to Clause 3) that combines one or more values into a composite value of a record or array type.

```
aggregate ::=
   ( element_association { , element_association } )

element_association ::=
   [ choices => ] expression

choices ::=  choice { | choice }

choice ::=
     simple_expression
   | discrete_range
   | element_simple_name
   | others
```

Each element association associates an expression with elements (possibly none). An element association is said to be *named* if the elements are specified explicitly by choices; otherwise, it is said to be *positional*. For a positional association, each element is implicitly specified by position in the textual order of the elements in the corresponding type declaration.

Both named and positional associations can be used in the same aggregate, with all positional associations appearing first (in textual order) and all named associations appearing next (in any order, except that it is an error if any associations follow an **others** association). Aggregates containing a single element association shall always be specified using named association in order to distinguish them from parenthesized expressions.

An element association with a choice that is an element simple name is only allowed in a record aggregate. An element association with a choice that is a simple expression or a discrete range is only allowed in an array aggregate: a simple expression specifies the element at the corresponding index value, whereas a discrete range specifies the elements at each of the index values in the range. The discrete range has no significance other than to define the set of choices implied by the discrete range. In particular, the direction specified or implied by the discrete range has no significance. An element association with the choice **others** is allowed in either an array aggregate or a record aggregate if the association appears last and has this single choice; it specifies all remaining elements, if any.

Each element of the value defined by an aggregate shall be represented once and only once in the aggregate.

The type of an aggregate shall be determinable solely from the context in which the aggregate appears, excluding the aggregate itself but using the fact that the type of the aggregate shall be a composite type. The type of an aggregate in turn determines the required type for each of its elements.

7.3.2.1 Record aggregates

If the type of an aggregate is a record type, the element names given as choices shall denote elements of that record type. If the choice **others** is given as a choice of a record aggregate, it shall represent at least one element. An element association with more than one choice, or with the choice **others**, is only allowed if the elements specified are all of the same type. The expression of an element association shall have the type of the associated record elements.

A record aggregate is evaluated as follows. The expressions given in the element associations are evaluated in an order (or lack thereof) not defined by the language. The expression of a named association is evaluated once for each associated element. A check is made that the value of each element of the aggregate belongs to the subtype of this element. It is an error if this check fails.

7.3.2.2 Array aggregates

For an aggregate of a one-dimensional array type, each choice shall specify values of the index type, and the expression of each element association shall be of the element type. An aggregate of an *n*-dimensional array type, where *n* is greater than 1, is written as a one-dimensional aggregate in which the index subtype of the aggregate is given by the first index position of the array type, and the expression specified for each element association is an (*n*–1)-dimensional array or array aggregate, which is called a *subaggregate*. A string or bit string literal is allowed as a subaggregate in the place of any aggregate of a one-dimensional array of a character type.

Apart from a final element association with the single choice **others**, the rest (if any) of the element associations of an array aggregate shall be either all positional or all named. A named association of an array aggregate is allowed to have a choice that is not locally static, or likewise a choice that is a null range, only if the aggregate includes a single element association and this element association has a single choice. An **others** choice is locally static if the applicable index constraint is locally static.

The subtype of an array aggregate that has an **others** choice shall be determinable from the context. That is, an array aggregate with an **others** choice shall appear only in one of the following contexts:

a) As an actual associated with a formal parameter or formal generic declared to be of a constrained array subtype (or subelement thereof)

b) As the default expression defining the default initial value of a port declared to be of a constrained array subtype

c) As the result expression of a function, where the corresponding function result type is a constrained array subtype

d) As a value expression in an assignment statement, where the target is a declared object, and the subtype of the target is a constrained array subtype (or subelement of such a declared object)

e) As the expression defining the initial value of a constant or variable object, where that object is declared to be of a constrained array subtype

f) As the expression defining the default values of signals in a signal declaration, where the corresponding subtype is a constrained array subtype

g) As the expression defining the value of an attribute in an attribute specification, where that attribute is declared to be of a constrained array subtype

h) As the operand of a qualified expression whose type mark denotes a constrained array subtype

i) As a subaggregate nested within an aggregate, where that aggregate itself appears in one of these contexts

The bounds of an array that does not have an **others** choice are determined as follows. If the aggregate appears in one of the contexts in the preceding list, then the direction of the index subtype of the aggregate is that of the corresponding constrained array subtype; otherwise, the direction of the index subtype of the aggregate is that of the index subtype of the base type of the aggregate. For an aggregate that has named associations, the leftmost and rightmost bounds are determined by the direction of the index subtype of the aggregate and the smallest and largest choices given. For a positional aggregate, the leftmost bound is determined by the applicable index constraint if the aggregate appears in one of the contexts in the preceding list; otherwise, the leftmost bound is given by S'LEFT where S is the index subtype of the base type of the array. In either case, the rightmost bound is determined by the direction of the index subtype and the number of elements.

The evaluation of an array aggregate that is not a subaggregate proceeds in two steps. First, the choices of this aggregate and of its subaggregates, if any, are evaluated in some order (or lack thereof) that is not defined by the language. Second, the expressions of the element associations of the array aggregate are evaluated in some order that is not defined by the language; the expression of a named association is evaluated once for each associated element. The evaluation of a subaggregate consists of this second step (the first step is omitted since the choices have already been evaluated).

For the evaluation of an aggregate that is not a null array, a check is made that the index values defined by choices belong to the corresponding index subtypes, and also that the value of each element of the aggregate belongs to the subtype of this element. For a multidimensional aggregate of dimension *n*, a check is made that all (*n*–1)-dimensional subaggregates have the same bounds. It is an error if any one of these checks fails.

7.3.3 Function calls

A function call invokes the execution of a function body. The call specifies the name of the function to be invoked and specifies the actual parameters, if any, to be associated with the formal parameters of the function. Execution of the function body results in a value of the type declared to be the result type in the declaration of the invoked function.

function_call ::=
  *function*_name [(actual_parameter_part)]

actual_parameter_part ::= *parameter*_association_list

For each formal parameter of a function, a function call shall specify exactly one corresponding actual parameter. This actual parameter is specified either explicitly, by an association element (other than the actual part **open**) in the association list, or in the absence of such an association element, by a default expression (see 4.3.2).

Evaluation of a function call includes evaluation of the actual parameter expressions specified in the call and evaluation of the default expressions associated with formal parameters of the function that do not have actual parameters associated with them. In both cases, the resulting value shall belong to the subtype of the associated formal parameter. (If the formal parameter is of an unconstrained array type, then the formal parameter takes on the subtype of the actual parameter.) The function body is executed using the actual parameter values and default expression values as the values of the corresponding formal parameters.

NOTE—If a name (including one used as a prefix) has an interpretation both as a function call and an indexed name, then the innermost complete context is used to disambiguate the name. If, after applying this rule, there is not exactly one interpretation of the name, then the name is ambiguous. See 10.5.

7.3.4 Qualified expressions

A qualified expression is a basic operation (see the introduction to Clause 3) that is used to explicitly state the type, and possibly the subtype, of an operand that is an expression or an aggregate.

```
qualified_expression ::=
      type_mark ' ( expression )
    | type_mark ' aggregate
```

The operand shall have the same type as the base type of the type mark. The value of a qualified expression is the value of the operand. The evaluation of a qualified expression evaluates the operand and checks that its value belongs to the subtype denoted by the type mark.

NOTE—Whenever the type of an enumeration literal or aggregate is not known from the context, a qualified expression can be used to state the type explicitly.

7.3.5 Type conversions

A type conversion provides for explicit conversion between closely related types.

```
type_conversion ::=  type_mark ( expression )
```

The target type of a type conversion is the base type of the type mark. The type of the operand of a type conversion shall be determinable independent of the context (in particular, independent of the target type). Furthermore, the operand of a type conversion is not allowed to be the literal **null**, an allocator, an aggregate, or a string literal. An expression enclosed by parentheses is allowed as the operand of a type conversion only if the expression alone is allowed.

If the type mark denotes a subtype, conversion consists of conversion to the target type followed by a check that the result of the conversion belongs to the subtype.

Explicit type conversions are allowed between *closely related types*. In particular, a type is closely related to itself. Other types are closely related only under the following conditions:

a) *Abstract numeric types*—Any abstract numeric type is closely related to any other abstract numeric type. In an explicit type conversion where the type mark denotes an abstract numeric type, the operand can be of any integer or floating-point type. The value of the operand is converted to the target type, which shall also be an integer or floating-point type. The conversion of a floating-point value to an integer type rounds to the nearest integer; if the value is halfway between two integers, rounding may be up or down.

b) *Array types*—Two array types are closely related if, and only if, all of the following apply:
   - The types have the same dimensionality
   - For each index position, the index types are either the same or are closely related
   - The element types are the same

   In an explicit type conversion where the type mark denotes an array type, the following rules apply: If the type mark denotes an unconstrained array type and if the operand is not a null array, then, for each index position, the bounds of the result are obtained by converting the bounds of the operand to the corresponding index type of the target type. If the type mark denotes a constrained array subtype, then the bounds of the result are those imposed by the type mark. In either case, the value of each element of the result is that of the matching element of the operand (see 7.2.2).

No other types are closely related.

In the case of conversions between numeric types, it is an error if the result of the conversion fails to satisfy a constraint imposed by the type mark.

In the case of conversions between array types, a check is made that any constraint on the element subtype is the same for the operand array type as for the target array type. If the type mark denotes an unconstrained array type, then, for each index position, a check is made that the bounds of the result belong to the corresponding index subtype of the target type. If the type mark denotes a constrained array subtype, a check is made that for each element of the operand there is a matching element of the target subtype, and vice versa. It is an error if any of these checks fail.

In certain cases, an implicit type conversion will be performed. An implicit conversion of an operand of type *universal_integer* to another integer type, or of an operand of type *universal_real* to another floating-point type, can only be applied if the operand is either a numeric literal or an attribute, or if the operand is an expression consisting of the division of a value of a physical type by a value of the same type; such an operand is called a *convertible* universal operand. An implicit conversion of a convertible universal operand is applied if and only if the innermost complete context determines a unique (numeric) target type for the implicit conversion, and there is no legal interpretation of this context without this conversion.

NOTE—Two array types may be closely related even if corresponding index positions have different directions.

7.3.6 Allocators

The evaluation of an allocator creates an object and yields an access value that designates the object.

allocator ::=
  new subtype_indication
 | **new** qualified_expression

The type of the object created by an allocator is the base type of the type mark given in either the subtype indication or the qualified expression. For an allocator with a subtype indication, the initial value of the created object is the same as the default initial value for an explicitly declared variable of the designated subtype. For an allocator with a qualified expression, this expression defines the initial value of the created object.

The type of the access value returned by an allocator shall be determinable solely from the context, but using the fact that the value returned is of an access type having the named designated type.

The only allowed form of constraint in the subtype indication of an allocator is an index constraint. If an allocator includes a subtype indication and if the type of the object created is an array type, then the subtype indication shall either denote a constrained subtype or include an explicit index constraint. A subtype indication that is part of an allocator shall not include a resolution function.

If the type of the created object is an array type, then the created object is always constrained. If the allocator includes a subtype indication, the created object is constrained by the subtype. If the allocator includes a qualified expression, the created object is constrained by the bounds of the initial value defined by that expression. For other types, the subtype of the created object is the subtype defined by the subtype of the access type definition.

For the evaluation of an allocator, the elaboration of the subtype indication or the evaluation of the qualified expression is first performed. The new object is then created, and the object is then assigned its initial value. Finally, an access value that designates the created object is returned.

In the absence of explicit deallocation, an implementation shall guarantee that any object created by the evaluation of an allocator remains allocated for as long as this object or one of its subelements is accessible directly or indirectly; that is, as long as it can be denoted by some name.

NOTE 1—Procedure deallocate is implicitly declared for each access type. This procedure provides a mechanism for explicitly deallocating the storage occupied by an object created by an allocator.

NOTE 2—An implementation may (but need not) deallocate the storage occupied by an object created by an allocator, once this object has become inaccessible.

Examples:

```
new NODE                         -- Takes on default initial value.
new NODE'(15 ns, null)           -- Initial value is specified.
new NODE'(Delay => 5  ns,
         \Next\=> Stack)         -- Initial value is specified.
new BIT_VECTOR'("00110110")      -- Constrained by initial value.
new STRING (1 to 10)             -- Constrained by index constraint.
new STRING                       -- Illegal: must be constrained.
```

7.4 Static expressions

Certain expressions are said to be *static*. Similarly, certain discrete ranges are said to be static, and the type marks of certain subtypes are said to denote static subtypes.

There are two categories of static expression. Certain forms of expression can be evaluated during the analysis of the design unit in which they appear; such an expression is said to be *locally static*. Certain forms of expression can be evaluated as soon as the design hierarchy in which they appear is elaborated; such an expression is said to be *globally static*.

7.4.1 Locally static primaries

An expression is said to be locally static if and only if every operator in the expression denotes an implicitly defined operator whose operands and result are scalar and if every primary in the expression is a *locally static primary*, where a locally static primary is defined to be one of the following:

a) A literal of any type other than type TIME
b) A constant (other than a deferred constant) explicitly declared by a constant declaration and initialized with a locally static expression
c) An alias whose aliased name (given in the corresponding alias declaration) is a locally static primary
d) A function call whose function name denotes an implicitly defined operator and whose actual parameters are each locally static expressions
e) A predefined attribute that is a value, other than the predefined attributes 'INSTANCE_NAME and 'PATH_NAME, and whose prefix is either a locally static subtype or is an object name that is of a locally static subtype or of a locally static subnature
f) A predefined attribute that is a function, other than the predefined attributes 'EVENT, 'ACTIVE, 'LAST_EVENT, 'LAST_ACTIVE, 'LAST_VALUE, 'DRIVING, and 'DRIVING_VALUE, whose prefix is either a locally static subtype or is an object that is of a locally static subtype or of a locally static subnature, and whose actual parameter (if any) is a locally static expression
g) A user-defined attribute whose value is defined by a locally static expression
h) A qualified expression whose operand is a locally static expression
i) A type conversion whose expression is a locally static expression
j) A locally static expression enclosed in parentheses

A locally static range is either a range of the second form (see 3.1) whose bounds are locally static expressions, or a range of the first form whose prefix denotes either a locally static subtype or an object that is of a locally static subtype. A locally static range constraint is a range constraint whose range is locally static. A locally static scalar subtype is either a scalar base type or a scalar subtype formed by imposing on a locally static subtype a locally static range constraint. A locally static discrete range is either a locally static subtype or a locally static range.

A locally static index constraint is an index constraint for which each index subtype of the corresponding array type is locally static and in which each discrete range is locally static. A locally static array subtype is a constrained array subtype formed by imposing on an unconstrained array type a locally static index constraint. A locally static record subtype is a record type whose fields are all of locally static subtypes. A locally static access subtype is a subtype denoting an access type. A locally static file subtype is a subtype denoting a file type.

A locally static subtype is either a locally static scalar subtype, a locally static array subtype, a locally static record subtype, a locally static access subtype, or a locally static file subtype.

A locally static scalar subnature is a scalar subnature. A locally static array subnature is a constrained array subnature formed by imposing on an unconstrained array nature a locally static index constraint. A locally static record subnature is a record nature whose elements are all of locally static subnatures. A locally static subnature is either a locally static scalar subnature, a locally static array subnature, or a locally static record subnature.

7.4.2 Globally static primaries

An expression is said to be globally static if and only if every operator in the expression denotes a pure function and every primary in the expression is a *globally static primary*, where a globally static primary is a primary that, if it denotes an object or a function, does not denote a dynamically elaborated named entity (see 12.5) and is one of the following:

a) A literal of type TIME

b) A locally static primary

c) A generic constant

d) A generate parameter

e) A constant (including a deferred constant)

f) An alias whose aliased name (given in the corresponding alias declaration) is a globally static primary

g) An array aggregate, if and only if

  1) All expressions in its element associations are globally static expressions, and

  2) All ranges in its element associations are globally static ranges

h) A record aggregate, if and only if all expressions in its element associations are globally static expressions

i) A function call whose function name denotes a pure function and whose actual parameters are each globally static expressions

j) A predefined attribute that is a value and whose prefix is either a globally static subtype, or an object that is of a globally static subtype or subnature, or a function call that is of a globally static subtype

k) A predefined attribute that is a function, other than the predefined attributes 'EVENT, 'ACTIVE, 'LAST_EVENT, 'LAST_ACTIVE, 'LAST_VALUE, 'DRIVING, and 'DRIVING_VALUE, whose prefix is either a globally static subtype, or an object that is of a globally static subtype or subnature, or a function call that is of a globally static subtype, and whose actual parameter (if any) is a globally static expression

l) A user-defined attribute whose value is defined by a globally static expression

m) A qualified expression whose operand is a globally static expression

n) A type conversion whose expression is a globally static expression

o) An allocator of the first form (see 7.3.6) whose subtype indication denotes a globally static subtype

p) An allocator of the second form whose qualified expression is a globally static expression

q) A globally static expression enclosed in parentheses

r) A subelement or a slice of a globally static primary, provided that any index expressions are globally static expressions and any discrete ranges used in slice names are globally static discrete ranges

A globally static range is either a range of the second form (see 3.1) whose bounds are globally static expressions, or a range of the first form whose prefix denotes either a globally static subtype or an object that is of a globally static subtype. A globally static range constraint is a range constraint whose range is globally static. A globally static scalar subtype is either a scalar base type or a scalar subtype formed by imposing on a globally static subtype a globally static range constraint. A globally static discrete range is either a globally static subtype or a globally static range.

A globally static index constraint is an index constraint for which each index subtype of the corresponding array type is globally static and in which each discrete range is globally static. A globally static array subtype is a constrained array subtype formed by imposing on an unconstrained array type a globally static index constraint. A globally static record subtype is a record type whose fields are all of globally static subtypes. A globally static access subtype is a subtype denoting an access type. A globally static file subtype is a subtype denoting a file type.

A globally static subtype is either a globally static scalar subtype, a globally static array subtype, a globally static record subtype, a globally static access subtype, or a globally static file subtype.

A globally static scalar subnature is a scalar subnature. A globally static array subnature is a constrained array subnature formed by imposing on an unconstrained array nature a globally static index constraint. A globally static record subnature is a record nature whose elements are all of globally static subnatures. A globally static subnature is either a globally static scalar subnature, a globally static array subnature, or a globally static record subnature.

NOTE 1—An expression that is required to be a static expression shall either be a locally static expression or a globally static expression. Similarly, a range, a range constraint, a scalar subtype, a discrete range, an index constraint, or an array subtype that is required to be static shall either be locally static or globally static.

NOTE 2—The rules for locally and globally static expressions imply that a declared constant or a generic may be initialized with an expression that is neither globally nor locally static; for example, with a call to an impure function. The resulting constant value may be globally or locally static, even though its subtype or its initial value expression is neither. Only interface constant, variable, and signal declarations require that their initial value expressions be static expressions.

7.5 Universal expressions

A *universal_expression* is either an expression that delivers a result of type *universal_integer* or one that delivers a result of type *universal_real*.

The same operations are predefined for the type *universal_integer* as for any integer type. The same operations are predefined for the type *universal_real* as for any floating-point type. In addition, these operations include the following multiplication and division operators:

Operator	Operation	Left operand type	Right operand type	Result type
*	Multiplication	*Universal real*	*Universal integer*	*Universal real*
		Universal integer	*Universal real*	*Universal real*
/	Division	*Universal real*	*Universal integer*	*Universal real*

The accuracy of the evaluation of a universal expression of type *universal_real* is at least as good as the accuracy of evaluation of expressions of the most precise predefined floating-point type supported by the implementation, apart from *universal_real* itself.

For the evaluation of an operation of a universal expression, the following rules apply. If the result is of type *universal_integer*, then the values of the operands and the result shall lie within the range of the integer type with the widest range provided by the implementation, excluding type *universal_integer* itself. If the result is of type *universal_real*, then the values of the operands and the result shall lie within the range of the floating-point type with the widest range provided by the implementation, excluding type *universal_real* itself.

NOTE—The predefined operators for the universal types are declared in package STANDARD as shown in 14.2.

7.6 Linear forms

A name appears in an expression if it is textually contained in the expression and:

— If a primary is a simple name of an object, the name appears in the expression.

— If a selected name whose prefix denotes a value bearing object is a primary, the longest static prefix of the name is said to appear in the expression.

— If an expanded name whose prefix denotes a value bearing object is a primary, the longest static prefix of the name is said to appear in the expression.

— If an indexed name whose prefix denotes a value bearing object is a primary, the longest static prefix of the name is said to appear in the expression. In this case, all names that appear in all expressions of the indexed name as defined by this rule are also said to appear in the expression containing the indexed name.

— If a slice name whose prefix denotes a value bearing object is a primary, the longest static prefix of the name is said to appear in the expression. In this case, all names that appear in all expressions in the slice name as defined by this rule are also said to appear in the expression containing the slice name.

— If an attribute name is a primary and the designator denotes a value, the longest static prefix of the attribute name is said to appear in the expression.

— If an aggregate is a primary in the expression, then all names that appear in each expression occurring after the choices and the => as defined by this rule are said to appear in the expression.

— If a function call is a primary in an expression, then all names that appear in each actual designator in every parameter association, as defined by this rule, are said to appear in the expression containing the function call. This does not apply to an actual designator of **open**. In addition, for any formal of the corresponding function declaration for which a parameter association does not exist in the function call, all names in the static expression of the interface declaration of that parameter are said to appear in the expression containing the function call.

- If a qualified expression is a primary in the expression, then all names that appear in each expression or aggregate qualified by the type mark, as defined by this rule, are said to appear in the expression containing the qualified expression.
- If a type conversion is a primary in the expression, then every name that appears in the expression type converted by the type mark, as defined by this rule, is said to appear in the expression containing the type conversion.
- If a parenthesized expression is a primary in the expression, then all names that appear in the expression enclosed within the parentheses are said to appear in the expression containing the parenthesized expression.

The equivalent function Ef of an expression E with respect to the name N of a value bearing object that appears in E is defined as follows:

```
function Ef (N: <typeofN>) return <typeofE> is
begin
   return E;
end Ef;
```

where Ef is a name unique to the expression and the name, <typeofN> is the type of the value denoted by the name N, and <typeofE> is the type of expression E. Given an expression E of a nature type, an increment function Incf is defined with respect to the name N of a value bearing object in E as follows:

```
function Incf (N, V: <typeofN>) return <typeofE> is
   definition of Ef;
begin
   return Ef(N) - Ef(V);
end Incf;
```

where V is any value and other names are as given previously. The partial derivative function, Pdf, of an expression E with respect to the name N of a value bearing object in expression E, evaluated at V, is defined as follows:

```
function Pdf (N,V: <typeofN>) return <typeofE> is
    definition of Incf;
begin
    implement Pdf;
end Pdf;
```

where “implement Pdf” is any reasonable numerical algorithm that returns the limit of the following expression:

```
Incf(N, V) / (N - V)
```

as the value of N approaches the value V, Incf is formed from the expression as described previously, and other names are as given previously.

The *linearized form* of any expression with respect to the quantity names N_0, ..., N_m in that expression evaluated at values V_0, ..., V_m is the following expression:

$$Pdf_0(N_0,V_0)*N_0 + Pdf_1(N_1,V_1)*N_1 + ... + Pdf_m(N_m,V_m)*N_m$$

where the Pdf’s for each name in the expression is constructed as shown.

In all the expressions previously given, if the type of the expression is a composite type, the definitions of +, –, /, and * shall apply to the matching scalar subelements of each operand. In all cases, the definitions of +, /, –, and * used are those implicitly defined for the floating-point type of the scalar subelement.

NOTE 1—An expression E is said to be linear with respect to the name N of a value bearing object in E if the value of Pdf(N,V) is the same for any value of N in its subtype. An expression is linear in a set of names if it is linear with respect to each name in the set.

NOTE 2—An expression is independent of a name if the value of the expression does not change regardless of the value of the name.

NOTE 3—The linearized form of an expression E is linear with respect to each quantity whose name appears in E.

8. Sequential statements

The various forms of sequential statements are described in this clause. Sequential statements are used to define algorithms for the execution of a subprogram or process; they execute in the order in which they appear.

```
sequence_of_statements ::=
   { sequential_statement }

sequential_statement ::=
     wait_statement
   | assertion_statement
   | report_statement
   | signal_assignment_statement
   | variable_assignment_statement
   | procedure_call_statement
   | if_statement
   | case_statement
   | loop_statement
   | next_statement
   | exit_statement
   | return_statement
   | null_statement
   | break_statement
```

All sequential statements may be labeled. Such labels are implicitly declared at the beginning of the declarative part of the innermost enclosing process statement, simultaneous procedural statement, or subprogram body.

8.1 Wait statement

The wait statement causes the suspension of a process statement or a procedure.

wait_statement ::=
  [label :] **wait** [sensitivity_clause] [condition_clause] [timeout_clause] ;

sensitivity_clause ::= **on** sensitivity_list

sensitivity_list ::= *signal*_name { , *signal*_name }

condition_clause ::= **until** condition

condition ::= *boolean*_expression

timeout_clause ::= **for** *time_or_real*_expression

The sensitivity clause defines the *sensitivity set* of the wait statement, which is the set of signals to which the wait statement is sensitive. Each signal name in the sensitivity list identifies a given signal as a member of the sensitivity set. Each signal name in the sensitivity list shall be a static signal name, and each name shall denote a signal for which reading is permitted. If no sensitivity clause appears, the sensitivity set is constructed according to the following (recursive) rule:

The sensitivity set is initially empty. For each primary in the condition of the condition clause, if the primary is:

— A simple name that denotes a signal, add the longest static prefix of the name to the sensitivity set.
— A selected name whose prefix denotes a signal, add the longest static prefix of the name to the sensitivity set.
— An indexed name whose prefix denotes a signal, add the longest static prefix of the name to the sensitivity set and apply this rule to all expressions in the indexed name.
— A slice name whose prefix denotes a signal, add the longest static prefix of the name to the sensitivity set and apply this rule to any expressions appearing in the discrete range of the slice name.
— An attribute name, if the designator denotes a signal attribute, add the longest static prefix of the name of the implicit signal denoted by the attribute name to the sensitivity set; otherwise, apply this rule to the prefix of the attribute name.
— An aggregate, apply this rule to every expression appearing after the choices and the =>, if any, in every element association.
— A function call, apply this rule to every actual designator in every parameter association.
— An actual designator of **open** in a parameter association, do not add to the sensitivity set.
— A qualified expression, apply this rule to the expression or aggregate qualified by the type mark, as appropriate.
— A type conversion, apply this rule to the expression type converted by the type mark.
— A parenthesized expression, apply this rule to the expression enclosed within the parentheses.
— Otherwise, do not add to the sensitivity set.

This rule is also used to construct the sensitivity sets of the wait statements in the equivalent process statements for concurrent procedure call statements (9.3), concurrent assertion statements (9.4), concurrent signal assignment statements (9.5), and concurrent break statements (9.8).

If a signal name that denotes a signal of a composite type appears in a sensitivity list, the effect is as if the name of each scalar subelement of that signal appears in the list.

The condition clause specifies a condition that shall be met for the process to continue execution. If no condition clause appears, the condition clause **until** TRUE is assumed.

The timeout clause specifies the maximum amount of time the process will remain suspended at this wait statement. If no timeout clause appears, the timeout clause **for** (STD.STANDARD.TIME'HIGH – STD.STANDARD.NOW) is assumed. It is an error if the time or real expression in the timeout clause evaluates to a negative value.

The execution of a wait statement causes the time or real expression to be evaluated to determine the *timeout interval*; the type of the expression shall be determinable independent of the context. It also causes the execution of the corresponding process statement to be suspended, where the corresponding process statement is the one that either contains the wait statement or is the parent (see 2.2) of the procedure that contains the wait statement. The suspended process will resume, at the latest, at the greater of: 1) the current time, and 2) the universal time corresponding to: a) if the type of the expression in the timeout clause is TIME, the sum of the current discrete time and the value of the timeout interval, or b) if the type of the expression in the timeout clause is REAL, the sum of the current time and the value of the timeout interval.

The suspended process can also resume as a result of an event occurring on any signal in the sensitivity set of the wait statement. If such an event occurs, the condition in the condition clause is evaluated. If the value of the condition is TRUE, the process will resume. If the value of the condition is FALSE, the process will resuspend. Such resuspension does not involve the recalculation of the timeout interval.

It is an error if a wait statement appears in a function subprogram or in a procedure that has a parent that is a function subprogram. Furthermore, it is an error if a wait statement appears in an explicit process statement that includes a sensitivity list or in a procedure that has a parent that is such a process statement. Finally, it is an error if a wait statement appears within any subprogram whose body is declared within a protected type body, or within any subprogram that has an ancestor whose body is declared within a protected type body.

Example:

```
type Arr is array (1 to 5) of BOOLEAN;
function F (P: BOOLEAN) return BOOLEAN;
signal S: Arr;
signal l, r: INTEGER range 1 to 5;

--  The following two wait statements have the same meaning:

wait until F(S(3)) and (S(l) or S(r));
wait on S(3), S, l, r until F(S(3)) and (S(l) or S(r));
```

NOTE 1—The wait statement **wait until** Clk = '1'; has semantics identical to

```
loop
   wait on Clk;
   exit when Clk = '1';
end loop;
```

because of the rules for the construction of the default sensitivity clause. These same rules imply that wait until True; has semantics identical to wait;.

NOTE 2—The conditions that cause a wait statement to resume execution of its enclosing process may no longer hold at the time the process resumes execution if the enclosing process is a postponed process.

NOTE 3—The rule for the construction of the default sensitivity set implies that if a function call appears in a condition clause and the called function is an impure function, then any signals that are accessed by the function but that are not passed through the association list of the call are not added to the default sensitivity set for the condition by virtue of the appearance of the function call in the condition.

8.2 Assertion statement

An assertion statement checks that a specified condition is true and reports an error if it is not.

assertion_statement ::= [label :] assertion ;

assertion ::=
  assert condition
    [**report** expression]
    [**severity** expression]

If the **report** clause is present, it shall include an expression of predefined type STRING that specifies a message to be reported. If the **severity** clause is present, it shall specify an expression of predefined type SEVERITY_LEVEL that specifies the severity level of the assertion.

The **report** clause specifies a message string to be included in error messages generated by the assertion. In the absence of a **report** clause for a given assertion, the string “Assertion violation.” is the default value for the message string. The **severity** clause specifies a severity level associated with the assertion. In the absence of a **severity** clause for a given assertion, the default value of the severity level is ERROR.

Evaluation of an assertion statement consists of evaluation of the Boolean expression specifying the condition. If the expression results in the value FALSE, then an *assertion violation* is said to occur. When an assertion violation occurs, the **report** and **severity** clause expressions of the corresponding assertion, if present, are evaluated. The specified message string and severity level (or the corresponding default values, if not specified) are then used to construct an error message.

The error message consists of at least the following:

a) An indication that this message is from an assertion
b) The value of the severity level
c) The value of the message string
d) The name of the design unit (see 11.1) containing the assertion

8.3 Report statement

A report statement displays a message.

```
report_statement ::=
    [ label : ]
        report expression
            [ severity expression ] ;
```

The **report** statement expression shall be of the predefined type STRING. The string value of this expression is included in the message generated by the report statement. If the **severity** clause is present, it shall specify an expression of predefined type SEVERITY_LEVEL. The severity clause specifies a severity level associated with the report. In the absence of a **severity** clause for a given report, the default value of the severity level is NOTE.

The evaluation of a report statement consists of the evaluation of the report expression and severity clause expression, if present. The specified message string and severity level (or corresponding default, if the severity level is not specified) are then used to construct a report message.

The report message consists of at least the following:

a) An indication that this message is from a report statement
b) The value of the severity level
c) The value of the message string
d) The name of the design unit containing the report statement

Example:

```
report "Entering process P";
   -- A report statement with default severity NOTE.

report "Setup or Hold violation; outputs driven to 'X'"
   severity WARNING;
   -- Another report statement; severity is specified.
```

8.4 Signal assignment statement

A signal assignment statement modifies the projected output waveforms contained in the drivers of one or more signals (see 12.6.1).

```
signal_assignment_statement ::=
    [ label : ] target <= [ delay_mechanism ] waveform ;

delay_mechanism ::=
      **transport**
    | [ **reject** *time*_expression ] **inertial**

target ::=
      name
    | aggregate

waveform ::=
      waveform_element { , waveform_element }
    | **unaffected**
```

If the target of the signal assignment statement is a name, then the name shall denote a signal, and the base type of the value component of each transaction produced by a waveform element on the right-hand side shall be the same as the base type of the signal denoted by that name. This form of signal assignment assigns right-hand side values to the drivers associated with a single (scalar or composite) signal.

If the target of the signal assignment statement is in the form of an aggregate, then the type of the aggregate shall be determinable from the context, excluding the aggregate itself but including the fact that the type of the aggregate shall be a composite type. The base type of the value component of each transaction produced by a waveform element on the right-hand side shall be the same as the base type of the aggregate. Furthermore, the expression in each element association of the aggregate shall be a locally static name that denotes a signal. This form of signal assignment assigns slices or subelements of the right-hand side values to the drivers associated with the signal named as the corresponding slice or subelement of the aggregate.

If the target of a signal assignment statement is in the form of an aggregate, and if the expression in an element association of that aggregate is a signal name that denotes a given signal, then the given signal and each subelement thereof (if any) are said to be *identified* by that element association as targets of the assignment statement. It is an error if a given signal or any subelement thereof is identified as a target by more than one element association in such an aggregate. Furthermore, it is an error if an element association in such an aggregate contains an **others** choice or a choice that is a discrete range.

The right-hand side of a signal assignment may optionally specify a delay mechanism. A delay mechanism consisting of the reserved word **transport** specifies that the delay associated with the first waveform element is to be construed as *transport* delay. Transport delay is characteristic of hardware devices (such as transmission lines) that exhibit nearly infinite frequency response: any pulse is transmitted, no matter how short its duration. If no delay mechanism is present, or if a delay mechanism including the reserved word **inertial** is present, the delay is construed to be *inertial* delay. Inertial delay is characteristic of switching circuits: a pulse whose duration is shorter than the switching time of the circuit will not be transmitted, or in the case that a pulse rejection limit is specified, a pulse whose duration is shorter than that limit will not be transmitted.

Every inertially delayed signal assignment has a *pulse rejection limit*. If the delay mechanism specifies inertial delay, and if the reserved word **reject** followed by a time expression is present, then the time expression specifies the pulse rejection limit. In all other cases, the pulse rejection limit is specified by the time expression associated with the first waveform element.

It is an error if the pulse rejection limit for any inertially delayed signal assignment statement is either negative or greater than the time expression associated with the first waveform element.

It is an error if the reserved word **unaffected** appears as a waveform in a (sequential) signal assignment statement.

NOTE 1—The reserved word **unaffected** shall only appear as a waveform in concurrent signal assignment statements (see 9.5.1).

NOTE 2—For a signal assignment whose target is a name, the type of the target shall not be a protected type; moreover, it is an error if the type of any subelement of the target is a protected type.

NOTE 3—For a signal assignment whose target is in the form of an aggregate, it is an error if any element of the target is of a protected type; moreover, it is an error if the type of any element of the target has a subelement that is a protected type.

NOTE 4—If a right-hand side value expression is either a numeric literal or an attribute that yields a result of type *universal_integer* or *universal_real*, then an implicit type conversion is performed.

Examples:

```
-- Assignments using inertial delay:

-- The following three assignments are equivalent to each other:

Output_pin <= Input_pin after 10 ns;
Output_pin <= inertial Input_pin after 10 ns;
Output_pin <= reject 10 ns inertial Input_pin after 10 ns;

-- Assignments with a pulse rejection limit less than the time
expression:

Output_pin <= reject 5 ns inertial Input_pin after 10 ns;
Output_pin <= reject 5 ns inertial Input_pin after 10 ns,
                                   not Input_pin after 20 ns;

-- Assignments using transport delay:

Output_pin <= transport Input_pin after 10 ns;
Output_pin <= transport Input_pin after 10 ns,
                        not Input_pin after 20 ns;

-- Their equivalent assignments:

Output_pin <= reject 0 ns inertial Input_pin after 10 ns;
Output_pin <= reject 0 ns inertial Input_pin after 10 ns,
                                   not Input_pin after 20 ns;
```

8.4.1 Updating a projected output waveform

The effect of execution of a signal assignment statement is defined in terms of its effect upon the projected output waveforms (see 12.6.1) representing the current and future values of drivers of signals.

waveform_element ::=
    *value*_expression [**after** *time*_expression]
  | **null** [**after** *time*_expression]

The future behavior of the driver(s) for a given target is defined by transactions produced by the evaluation of waveform elements in the waveform of a signal assignment statement. The first form of waveform element is used to specify that the driver is to assign a particular value to the target at the specified time. The second form of waveform element is used to specify that the driver of the signal is to be turned off, so that it (at least temporarily) stops contributing to the value of the target. This form of waveform element is called a *null waveform element*. It is an error if the target of a signal assignment statement containing a null waveform element is not a guarded signal or an aggregate of guarded signals.

The base type of the time expression in each waveform element shall be the predefined physical type TIME as defined in package STANDARD. If the **after** clause of a waveform element is not present, then an implicit "**after** 0 ns" is assumed. It is an error if the time expression in a waveform element evaluates to a negative value.

Evaluation of a waveform element produces a single transaction. The time component of the transaction is the greater of: 1) the current time, and 2) the universal time corresponding to the sum of the current discrete time and the value of the time expression in the waveform element. For the first form of waveform element, the value component of the transaction is determined by the value expression in the waveform element. For the second form of waveform element, the value component is not defined by the language, but it is defined to be of the type of the target. A transaction produced by the evaluation of the second form of waveform element is called a *null transaction*.

For the execution of a signal assignment statement whose target is of a scalar type, the waveform on its right-hand side is first evaluated. Evaluation of a waveform consists of the evaluation of each waveform element in the waveform. Thus, the evaluation of a waveform results in a sequence of transactions, where each transaction corresponds to one waveform element in the waveform. These transactions are called *new transactions*. It is an error if the sequence of new transactions is not in ascending order with respect to time.

The sequence of transactions is then used to update the projected output waveform representing the current and future values of the driver associated with the signal assignment statement. Updating a projected output waveform consists of the deletion of zero or more previously computed transactions (called *old transactions*) from the projected output waveform and the addition of the new transactions, as follows:

a) All old transactions that are projected to occur at or after the time at which the earliest new transaction is projected to occur are deleted from the projected output waveform.
b) The new transactions are then appended to the projected output waveform in the order of their projected occurrence.

If the initial delay is inertial delay according to the definitions of 8.4, the projected output waveform is further modified as follows:

1) All of the new transactions are marked.
2) An old transaction is marked if the time at which it is projected to occur is less than the time at which the first new transaction is projected to occur minus the pulse rejection limit.
3) For each remaining unmarked, old transaction, the old transaction is marked if it immediately precedes a marked transaction and its value component is the same as that of the marked transaction.
4) The transaction that determines the current value of the driver is marked.
5) All unmarked transactions (all of which are old transactions) are deleted from the projected output waveform.

For the purposes of marking transactions, any two successive null transactions in a projected output waveform are considered to have the same value component.

The execution of a signal assignment statement whose target is of a composite type proceeds in a similar fashion, except that the evaluation of the waveform results in one sequence of transactions for each scalar subelement of the type of the target. Each such sequence consists of transactions whose value portions are determined by the values of the same scalar subelement of the value expressions in the waveform, and whose time portion is determined by the time expression corresponding to that value expression. Each such sequence is then used to update the projected output waveform of the driver of the matching subelement of the target. This applies both to a target that is the name of a signal of a composite type and to a target that is in the form of an aggregate.

If a given procedure is declared by a declarative item that is not contained within a process statement, and if a signal assignment statement appears in that procedure, then the target of the assignment statement shall be a formal parameter of the given procedure or of a parent of that procedure, or an aggregate of such formal parameters. Similarly, if a given procedure is declared by a declarative item that is not contained within a process statement, and if a signal is associated with an **inout** or **out** mode signal parameter in a subprogram call within that procedure, then the signal so associated shall be a formal parameter of the given procedure or of a parent of that procedure.

NOTE 1—These rules guarantee that the driver affected by a signal assignment statement is always statically determinable if the signal assignment appears within a given process (including the case in which it appears within a procedure that is declared within the given process). In this case, the affected driver is the one defined by the process; otherwise, the signal assignment shall appear within a procedure, and the affected driver is the one passed to the procedure along with a signal parameter of that procedure.

NOTE 2—Overloading the operator "=" has no effect on the updating of a projected output waveform.

NOTE 3—Consider a signal assignment statement of the form

T <= **reject** t_r **inertial** e_1 **after** t_1 { , e_i **after** t_i }

The following relations hold:

0 ns £ $t_r < t_1$

and

0 ns £ $t_i < t_{i+1}$

Note that, if t_r = 0 ns, then the waveform editing is identical to that for transport-delayed assignment; and if $t_r = t_1$, the waveform is identical to that for the statement

T <= e_1 after t_1 { , e_i after t_i }

NOTE 4—Consider the following signal assignment in some process:

```
S <= reject 15 ns inertial 12 after 20 ns, 18 after 41 ns;
```

where S is a signal of some integer type.

Assume that at the time this signal assignment is executed, the driver of S in the process has the following contents (the first entry is the current driving value):

1	2	2	12	5	8
NOW	+3 ns	+12 ns	+13 ns	+20 ns	+42 ns

(The times given are relative to the current time.) The updating of the projected output waveform proceeds as follows:

a) The driver is truncated at 20 ns. The driver now contains the following pending transactions:

1	2	2	12
NOW	+3 ns	+12 ns	+13 ns

b) The new waveforms are added to the driver. The driver now contains the following pending transactions:

1	2	2	12	12	18
NOW	+3 ns	+12 ns	+13 ns	+20 ns	+41 ns

c) All new transactions are marked, as well as those old transactions that occur at less than the time of the first new waveform (20 ns) less the rejection limit (15 ns). The driver now contains the following pending transactions (marked transactions are in bold type):

1	**2**	2	12	**12**	**18**
NOW	**+3 ns**	+12 ns	+13 ns	**+20 ns**	**+41 ns**

d) Each remaining unmarked transaction is marked if it immediately precedes a marked transaction and has the same value as the marked transaction. The driver now contains the following pending transactions:

1	**2**	2	**12**	**12**	**18**
NOW	**+3 ns**	+12 ns	**+13 ns**	**+20 ns**	**+41 ns**

e) The transaction that determines the current value of the driver is marked, and all unmarked transactions are then deleted. The final driver contents are then as follows, after clearing the markings:

1	2	12	12	18
NOW	+3 ns	+13 ns	+20 ns	+41 ns

NOTE 5—No subtype check is performed on the value component of a new transaction when it is added to a driver. Instead, a subtype check that the value component of a transaction belongs to the subtype of the signal driven by the driver is made when the driver takes on that value (see 12.6.1).

8.5 Variable assignment statement

A variable assignment statement replaces the current value of a variable with a new value specified by an expression. The named variable and the right-hand side expression shall be of the same type.

```
variable_assignment_statement ::=
    [ label : ] target := expression ;
```

If the target of the variable assignment statement is a name, then the name shall denote a variable, and the base type of the expression on the right-hand side shall be the same as the base type of the variable denoted by that name. This form of variable assignment assigns the right-hand side value to a single (scalar or composite) variable.

If the target of the variable assignment statement is in the form of an aggregate, then the type of the aggregate shall be determinable from the context, excluding the aggregate itself but including the fact that the type of the aggregate shall be a composite type. The base type of the expression on the right-hand side shall be the same as the base type of the aggregate. Furthermore, the expression in each element association of the aggregate shall be a locally static name that denotes a variable. This form of variable assignment assigns each subelement or slice of the right-hand side value to the variable named as the corresponding subelement or slice of the aggregate.

If the target of a variable assignment statement is in the form of an aggregate, and if the locally static name in an element association of that aggregate denotes a given variable or denotes another variable of which the given variable is a subelement or slice, then the element association is said to *identify* the given variable as a target of the assignment statement. It is an error if a given variable is identified as a target by more than one element association in such an aggregate.

For the execution of a variable assignment whose target is a variable name, the variable name and the expression are first evaluated. A check is then made that the value of the expression belongs to the subtype of the variable, except in the case of a variable that is an array (in which case the assignment involves a subtype conversion). Finally, the value of the expression becomes the new value of the variable. A design is erroneous if it depends on the order of evaluation of the target and source expressions of an assignment statement.

The execution of a variable assignment whose target is in the form of an aggregate proceeds in a similar fashion, except that each of the names in the aggregate is evaluated, and a subtype check is performed for each subelement or slice of the right-hand side value that corresponds to one of the names in the aggregate. The value of the subelement or slice of the right-hand side value then becomes the new value of the variable denoted by the corresponding name.

An error occurs if the aforementioned subtype checks fail.

The determination of the type of the target of a variable assignment statement may require determination of the type of the expression if the target is a name that can be interpreted as the name of a variable designated by the access value returned by a function call, and similarly, as an element or slice of such a variable.

NOTE 1—If the right-hand side is either a numeric literal or an attribute that yields a result of type universal integer or universal real, then an implicit type conversion is performed.

NOTE 2—For a variable assignment whose target is a name, the type of the target shall not be a protected type; moreover, it is an error if the type of any subelement of the target is a protected type.

NOTE 3—For a variable assignment whose target is in the form of an aggregate, it is an error if any element of the target is of a protected type; moreover, it is an error if the type of any element of the target has a subelement that is a protected type.

8.5.1 Array variable assignments

If the target of an assignment statement is a name denoting an array variable (including a slice), the value assigned to the target is implicitly converted to the subtype of the array variable; the result of this subtype conversion becomes the new value of the array variable.

This means that the new value of each element of the array variable is specified by the matching element (see 7.2.2) in the corresponding array value obtained by evaluation of the expression. The subtype conversion checks that for each element of the array variable there is a matching element in the array value, and vice versa. An error occurs if this check fails.

NOTE—The implicit subtype conversion described for assignment to an array variable is performed only for the value of the right-hand side expression as a whole; it is not performed for subelements or slices that are array values.

8.6 Procedure call statement

A procedure call invokes the execution of a procedure body.

procedure_call_statement ::= [label :] procedure_call ;

procedure_call ::= *procedure*_name [(actual_parameter_part)]

The procedure name specifies the procedure body to be invoked. The actual parameter part, if present, specifies the association of actual parameters with formal parameters of the procedure.

For each formal parameter of a procedure, a procedure call shall specify exactly one corresponding actual parameter. This actual parameter is specified either explicitly, by an association element (other than the actual **open**) in the association list or, in the absence of such an association element, by a default expression (see 4.3.2).

Execution of a procedure call includes evaluation of the actual parameter expressions specified in the call and evaluation of the default expressions associated with formal parameters of the procedure that do not have actual parameters associated with them. In both cases, the resulting value shall belong to the subtype of the associated formal parameter. (If the formal parameter is of an unconstrained array type, then the formal parameter takes on the subtype of the actual parameter.) The procedure body is executed using the actual parameter values and default expression values as the values of the corresponding formal parameters.

8.7 If statement

An if statement selects for execution one or none of the enclosed sequences of statements, depending on the value of one or more corresponding conditions.

```
if_statement ::=
    [ if_label : ]
        if condition then
            sequence_of_statements
        { elsif condition then
            sequence_of_statements }
        [ else
            sequence_of_statements ]
        end if [ if_label ] ;
```

If a label appears at the end of an if statement, it shall repeat the if label.

For the execution of an if statement, the condition specified after **if**, and any conditions specified after **elsif**, are evaluated in succession (treating a final **else** as **elsif** TRUE **then**) until one evaluates to TRUE or all conditions are evaluated and yield FALSE. If one condition evaluates to TRUE, then the corresponding sequence of statements is executed; otherwise, none of the sequences of statements is executed.

8.8 Case statement

A case statement selects for execution one of a number of alternative sequences of statements; the chosen alternative is defined by the value of an expression.

```
case_statement ::=
    [ case_label : ]
        case expression is
            case_statement_alternative
            { case_statement_alternative }
        end case [ case_label ] ;

case_statement_alternative ::=
    when choices =>
        sequence_of_statements
```

The expression shall be of a discrete type or of a one-dimensional array type whose element base type is a character type. This type shall be determinable independently of the context in which the expression occurs, but using the fact that the expression shall be of a discrete type or a one-dimensional character array type. Each choice in a case statement alternative shall be of the same type as the expression; the list of choices specifies for which values of the expression the alternative is chosen.

If the expression is the name of an object whose subtype is locally static, whether a scalar type or an array type, then each value of the subtype shall be represented once and only once in the set of choices of the case statement, and no other value is allowed; this rule is likewise applied if the expression is a qualified expression or type conversion whose type mark denotes a locally static subtype, or if the expression is a call to a function whose return type mark denotes a locally static subtype.

If the expression is of a one-dimensional character array type, then the expression shall be one of the following:

— The name of an object whose subtype is locally static
— An indexed name whose prefix is one of the members of this list and whose indexing expressions are locally static expressions
— A slice name whose prefix is one of the members of this list and whose discrete range is a locally static discrete range
— A function call whose return type mark denotes a locally static subtype
— A qualified expression or type conversion whose type mark denotes a locally static subtype

In such a case, each choice appearing in any of the case statement alternatives shall be a locally static expression whose value is of the same length as that of the case expression. It is an error if the element subtype of the one-dimensional character array type is not a locally static subtype.

For other forms of expression, each value of the (base) type of the expression shall be represented once and only once in the set of choices, and no other value is allowed.

The simple expression and discrete ranges given as choices in a case statement shall be locally static. A choice defined by a discrete range stands for all values in the corresponding range. The choice **others** is only allowed for the last alternative and as its only choice; it stands for all values (possibly none) not given in the choices of previous alternatives. An element simple name (see 7.3.2) is not allowed as a choice of a case statement alternative.

If a label appears at the end of a case statement, it shall repeat the case label.

The execution of a case statement consists of the evaluation of the expression followed by the execution of the chosen sequence of statements. A sequence of statements in a given case statement alternative is the chosen sequence of statements if and only if the expression “E = V” evaluates to True, where “E” is the expression, “V” is the value of one of the choices of the given case statement alternative (if a choice is a discrete range, then this latter condition is fulfilled when V is an element of the discrete range), and the operator “=” in the expression is the predefined “=” operator on the base type of E.

NOTE 1—The execution of a case statement chooses one and only one alternative, since the choices are exhaustive and mutually exclusive. A qualified expression whose type mark denotes a locally static subtype can often be used as the expression of a case statement to limit the number of choices that need be explicitly specified.

NOTE 2—An **others** choice is required in a case statement if the type of the expression is the type *universal_integer* (for example, if the expression is an integer literal), since this is the only way to cover all values of the type *universal_integer*.

NOTE 3—Overloading the operator “=” has no effect on the semantics of case statement execution.

8.9 Loop statement

A loop statement includes a sequence of statements that is to be executed repeatedly, zero or more times.

loop_statement ::=
  [*loop*_label :]
    [iteration_scheme] **loop**
      sequence_of_statements
    end loop [*loop*_label] ;

iteration_scheme ::=
   while condition
  | **for** *loop*_parameter_specification

parameter_specification ::=
  identifier **in** discrete_range

If a label appears at the end of a loop statement, it shall repeat the label at the beginning of the loop statement.

Execution of a loop statement is complete when the loop is left as a consequence of the completion of the iteration scheme (see the following), if any, or the execution of a next statement, an exit statement, or a return statement.

A loop statement without an iteration scheme specifies repeated execution of the sequence of statements.

For a loop statement with a **while** iteration scheme, the condition is evaluated before each execution of the sequence of statements; if the value of the condition is TRUE, the sequence of statements is executed; if FALSE, the iteration scheme is said to be *complete* and the execution of the loop statement is complete.

For a loop statement with a **for** iteration scheme, the *loop parameter* specification is the declaration of the loop parameter with the given identifier. The loop parameter is an object whose type is the base type of the discrete range. Within the sequence of statements, the loop parameter is a constant. Hence, a loop parameter is not allowed as the target of an assignment statement. Similarly, the loop parameter shall not be given as an actual corresponding to a formal of mode **out** or **inout** in an association list.

For the execution of a loop with a **for** iteration scheme, the discrete range is first evaluated. If the discrete range is a null range, the iteration scheme is said to be *complete* and the execution of the loop statement is therefore complete; otherwise, the sequence of statements is executed once for each value of the discrete range (subject to the loop not being left as a consequence of the execution of a next statement, an exit statement, or a return statement), after which the iteration scheme is said to be *complete*. Prior to each such iteration, the corresponding value of the discrete range is assigned to the loop parameter. These values are assigned in left-to-right order.

NOTE—A loop may be left as the result of the execution of a next statement if the loop is nested inside of an outer loop and the next statement has a loop label that denotes the outer loop.

8.10 Next statement

A next statement is used to complete the execution of one of the iterations of an enclosing loop statement (called *loop* in the following text). The completion is conditional if the statement includes a condition.

next_statement ::=
  [label :] **next** [*loop*_label] [**when** condition] ;

A next statement with a loop label is only allowed within the labeled loop and applies to that loop; a next statement without a loop label is only allowed within a loop and applies only to the innermost enclosing loop (whether labeled or not).

For the execution of a next statement, the condition, if present, is first evaluated. The current iteration of the loop is terminated if the value of the condition is TRUE or if there is no condition.

8.11 Exit statement

An exit statement is used to complete the execution of an enclosing loop statement (called *loop* in the following text). The completion is conditional if the statement includes a condition.

exit_statement ::=
  [label :] **exit** [*loop*_label] [**when** condition] ;

An exit statement with a loop label is only allowed within the labeled loop and applies to that loop; an exit statement without a loop label is only allowed within a loop and applies only to the innermost enclosing loop (whether labeled or not).

For the execution of an exit statement, the condition, if present, is first evaluated. Exit from the loop then takes place if the value of the condition is TRUE or if there is no condition.

8.12 Return statement

A return statement is used to complete the execution of the innermost enclosing function or procedure body.

return_statement ::=
  [label :] **return** [expression] ;

A return statement is only allowed within the body of a function or procedure, and it applies to the innermost enclosing function or procedure.

A return statement appearing in a procedure body shall not have an expression. A return statement appearing in a function body shall have an expression.

The value of the expression defines the result returned by the function. The type of this expression shall be the base type of the type mark given after the reserved word **return** in the specification of the function. It is an error if execution of a function completes by any means other than the execution of a return statement.

For the execution of a return statement, the expression (if any) is first evaluated and a check is made that the value belongs to the result subtype. The execution of the return statement is thereby completed if the check succeeds; so also is the execution of the enclosing subprogram. An error occurs at the place of the return statement if the check fails.

NOTE 1—If the expression is either a numeric literal, or an attribute that yields a result of type *universal_integer* or *universal_real*, then an implicit conversion of the result is performed.

NOTE 2—If the return type mark of a function denotes a constrained array subtype, then no implicit subtype conversions are performed on the values of the expressions of the return statements within the subprogram body of that function. Thus, for each index position of each value, the bounds of the discrete range shall be the same as the discrete range of the return subtype, and the directions shall be the same.

8.13 Null statement

A null statement performs no action.

null_statement ::=
    [label :] **null** ;

The execution of the null statement has no effect other than to pass on to the next statement.

NOTE—The null statement can be used to specify explicitly that no action is to be performed when certain conditions are true, although it is never mandatory for this (or any other) purpose. This is particularly useful in conjunction with the case statement, in which all possible values of the case expression shall be covered by choices: for certain choices, it may be that no action is required.

8.14 Break statement

The execution of a break statement notifies the analog solver that it shall determine the discontinuity augmentation set for the next analog solution point. It may also specify reset values for quantities. The effect is conditional if the statement includes a condition.

break_statement ::=
    [label :] **break** [break_list] [**when** condition] ;

break_list ::= break_element { , break_element }

break_element ::= [break_selector_clause] *quantity*_name => expression

break_selector_clause ::= **for** *quantity*_name **use**

In each break element the quantity denoted by the quantity name is the *break quantity* of the break element. If the break selector clause is present, then the quantity name in the break selector clause is the *selector quantity* of the break element; otherwise the selector quantity is the same as the break quantity. The break quantity, the selector quantity, and the expression shall have the same type, and the selector quantity shall be either the prefix Q of a quantity of the form Q'DOT that appears in the text of the model or a quantity of the form Q'INTEG.

For the execution of a break statement the condition, if present, is first evaluated. A break is indicated if the value of the condition is TRUE or if there is no condition. If a break is indicated, the break flag is set and then each break element is evaluated in the order in which the elements appear.

For the evaluation of a break element, the selector quantity, the break quantity, and the expression are first evaluated. A model is erroneous if it depends on the order of this evaluation. Then the triple consisting of the selector quantity, the break quantity, and the value of the expression is added to the break set for the current simulation cycle (see 12.6.4 and 12.6.6.1).

It is an error if a break statement appears in a function subprogram or in a procedure that has a parent that is a function subprogram. It is also an error if a break statement appears within any subprogram whose body is declared within a protected type body, or within any subprogram that has a parent whose body is declared within a protected type body.

NOTE—It is a consequence of these definitions that in the absence of a selector clause in a break element the corresponding break quantity shall be either the prefix Q of a quantity of the form Q'DOT that appears in the text of the model or a quantity of the form Q'INTEG.

9. Concurrent statements

The various forms of concurrent statements are described in this clause. Concurrent statements are used to define interconnected blocks and processes that jointly with simultaneous statements describe the overall behavior or structure of a design. Concurrent statements execute asynchronously with respect to each other.

```
concurrent_statement ::=
      block_statement
    | process_statement
    | concurrent_procedure_call_statement
    | concurrent_assertion_statement
    | concurrent_signal_assignment_statement
    | component_instantiation_statement
    | generate_statement
    | concurrent_break_statement
```

The primary concurrent statements are the block statement, which groups together other architecture statements, and the process statement, which represents a single independent sequential process. Additional concurrent statements provide convenient syntax for representing simple, commonly occurring forms of processes, as well as for representing structural decomposition and regular descriptions.

Within a given simulation cycle, an implementation may execute concurrent statements in parallel or in some order. The language does not define the order, if any, in which such statements will be executed. A description that depends upon a particular order of execution of concurrent statements is erroneous.

All concurrent statements may be labeled. Such labels are implicitly declared at the beginning of the declarative part of the innermost enclosing entity declaration, architecture body, block statement, or generate statement.

9.1 Block statement

A block statement defines an internal block representing a portion of a design. Blocks may be hierarchically nested to support design decomposition.

```
block_statement ::=
    block_label :
        block [ ( guard_expression ) ] [ is ]
            block_header
            block_declarative_part
        begin
            block_statement_part
        end block [ block_label ] ;

block_header ::=
    [ generic_clause
    [ generic_map_aspect ; ] ]
    [ port_clause
    [ port_map_aspect ; ] ]

block_declarative_part ::=
    { block_declarative_item }
```

```
block_statement_part ::=
    { architecture_statement }
```

If a guard expression appears after the reserved word **block**, then a signal with the simple name GUARD of predefined type BOOLEAN is implicitly declared at the beginning of the declarative part of the block, and the guard expression defines the value of that signal at any given time (see 12.6.4). The type of the guard expression shall be type BOOLEAN. Signal GUARD may be used to control the operation of certain statements within the block (see 9.5).

The implicit signal GUARD shall not have a source.

If a block header appears in a block statement, it explicitly identifies certain values, quantities, terminals, or signals that are to be imported from the enclosing environment into the block and associated with formal generics or ports. The generic and port clauses define the formal generics and formal ports of the block (see 1.1.1.1 and 1.1.1.2); the generic map and port map aspects define the association of actuals with those formals (see 5.2.1.2). Such actuals are evaluated in the context of the enclosing declarative region.

If a label appears at the end of a block statement, it shall repeat the block label.

NOTE 1—The value of signal GUARD is always defined within the scope of a given block, and it does not implicitly extend to design entities bound to components instantiated within the given block. However, the signal GUARD may be explicitly passed as an actual signal in a component instantiation in order to extend its value to lower-level components.

NOTE 2—An actual appearing in a port association list of a given block can never denote a formal port of the same block.

9.2 Process statement

A process statement defines an independent sequential process representing the behavior of some portion of the design.

```
process_statement ::=
    [ process_label : ]
        [ postponed ] process [ ( sensitivity_list ) ] [ is ]
            process_declarative_part
        begin
            process_statement_part
        end [ postponed ] process [ process_label ] ;

process_declarative_part ::=
    { process_declarative_item }

process_declarative_item ::=
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | variable_declaration
    | file_declaration
    | alias_declaration
    | attribute_declaration
    | attribute_specification
    | use_clause
    | group_template_declaration
    | group_declaration

process_statement_part ::=
    { sequential_statement }
```

If the reserved word **postponed** precedes the initial reserved word **process**, the process statement defines a *postponed process*; otherwise, the process statement defines a *nonpostponed process*.

If a sensitivity list appears following the reserved word **process**, then the process statement is assumed to contain an implicit wait statement as the last statement of the process statement part; this implicit wait statement is of the form

wait on sensitivity_list ;

where the sensitivity list of the wait statement is that following the reserved word **process**. Such a process statement shall not contain an explicit wait statement. Similarly, if such a process statement is a parent of a procedure, then it is an error if that procedure contains a wait statement.

It is an error if any name that does not denote a static signal name (see 6.1) for which reading is permitted appears in the sensitivity list of a process statement.

If the reserved word **postponed** appears at the end of a process statement, the process shall be a postponed process. If a label appears at the end of a process statement, the label shall repeat the process label.

It is an error if a variable declaration in a process declarative part declares a shared variable.

The execution of a process statement consists of the repetitive execution of its sequence of statements. After the last statement in the sequence of statements of a process statement is executed, execution will immediately continue with the first statement in the sequence of statements.

A process statement is said to be a *passive process* if neither the process itself, nor any procedure of which the process is a parent, contains a signal assignment statement. It is an error if a process or a concurrent statement, other than a passive process or a concurrent statement equivalent to such a process, appears in the entity statement part of an entity declaration.

NOTE 1—The rules in 9.2 imply that a process that has an explicit sensitivity list always has exactly one (implicit) wait statement in it, and that wait statement appears at the end of the sequence of statements in the process statement part. Thus, a process with a sensitivity list always waits at the end of its statement part; any event on a signal named in the sensitivity list will cause such a process to execute from the beginning of its statement part down to the end, where it will wait again. Such a process executes once through at the beginning of simulation, suspending for the first time when it executes the implicit wait statement.

NOTE 2—The time at which a process executes after being resumed by a wait statement (see 8.1) differs depending on whether the process is postponed or nonpostponed. When a nonpostponed process is resumed, it executes in the current simulation cycle (see 2.6.4). When a postponed process is resumed, it does not execute until a simulation cycle occurs in which the next simulation cycle is not a delta cycle. In this way, a postponed process accesses the values of signals that are the “final” values at the current simulated time.

NOTE 3—The conditions that cause a process to resume execution may no longer hold at the time the process resumes execution if the process is a postponed process.

9.3 Concurrent procedure call statements

A concurrent procedure call statement represents a process containing the corresponding sequential procedure call statement.

concurrent_procedure_call_statement ::=
  [label :] [**postponed**] procedure_call ;

For any concurrent procedure call statement, there is an equivalent process statement. The equivalent process statement is a postponed process if and only if the concurrent procedure call statement includes the reserved word **postponed**. The equivalent process statement has a label if and only if the concurrent procedure call statement has a label; if the equivalent process statement has a label, it is the same as that of the concurrent procedure call statement. The equivalent process statement also has no sensitivity list, an empty declarative part, and a statement part that consists of a procedure call statement followed by a wait statement.

The procedure call statement consists of the same procedure name and actual parameter part that appear in the concurrent procedure call statement.

If there exists a name that denotes a signal in the actual part of any association element in the concurrent procedure call statement, and that actual is associated with a formal parameter of mode **in** or **inout**, then the equivalent process statement includes a final wait statement with a sensitivity clause that is constructed by taking the union of the sets constructed by applying the rule of 8.1 to each actual part associated with a formal parameter.

Execution of a concurrent procedure call statement is equivalent to execution of the equivalent process statement.

Example:

```
CheckTiming (tPLH, tPHL, Clk, D, Q);  --  A concurrent procedure call
                                      --  statement.

process                               --  The equivalent process.
begin
   CheckTiming (tPLH, tPHL, Clk, D, Q);
   wait on Clk, D, Q;
end process;
```

NOTE 1—Concurrent procedure call statements make it possible to declare procedures representing commonly used processes and to create such processes easily by merely calling the procedure as a concurrent statement. The wait statement at the end of the statement part of the equivalent process statement allows a procedure to be called without having it loop interminably, even if the procedure is not necessarily intended for use as a process (i.e., it contains no wait statement). Such a procedure may persist over time (and thus the values of its variables retain state over time) if its outermost statement is a loop statement and the loop contains a wait statement. Similarly, such a procedure may be guaranteed to execute only once, at the beginning of simulation, if its last statement is a wait statement that has no sensitivity clause, condition clause, or timeout clause.

NOTE 2—The value of an implicitly declared signal GUARD has no effect on evaluation of a concurrent procedure call unless it is explicitly referenced in one of the actual parts of the actual parameter part of the concurrent procedure call statement.

9.4 Concurrent assertion statements

A concurrent assertion statement represents a passive process statement containing the specified assertion statement.

concurrent_assertion_statement ::=
  [label :] [**postponed**] assertion ;

For any concurrent assertion statement, there is an equivalent process statement. The equivalent process statement is a postponed process if and only if the concurrent assertion statement includes the reserved word **postponed**. The equivalent process statement has a label if and only if the concurrent assertion statement has a label; if the equivalent process statement has a label, it is the same as that of the concurrent assertion statement. The equivalent process statement also has no sensitivity list, an empty declarative part, and a statement part that consists of an assertion statement followed by a wait statement.

The assertion statement consists of the same condition, **report** clause, and **severity** clause that appear in the concurrent assertion statement.

If there exists a name that denotes a signal in the Boolean expression that defines the condition of the assertion, then the equivalent process statement includes a final wait statement with a sensitivity clause that is constructed by applying the rule of 8.1 to that expression; otherwise, the equivalent process statement contains a final wait statement that has no explicit sensitivity clause, condition clause, or timeout clause.

Execution of a concurrent assertion statement is equivalent to execution of the equivalent process statement.

NOTE 1—Since a concurrent assertion statement represents a passive process statement, such a process has no outputs. Therefore, the execution of a concurrent assertion statement will never cause an event to occur. However, if the assertion is false, then the specified error message will be sent to the simulation report.

NOTE 2—The value of an implicitly declared signal GUARD has no effect on evaluation of the assertion unless it is explicitly referenced in one of the expressions of that assertion.

NOTE 3—A concurrent assertion statement whose condition is defined by a static expression is equivalent to a process statement that ends in a wait statement that has no sensitivity clause; such a process will execute once through at the beginning of simulation and then wait indefinitely.

9.5 Concurrent signal assignment statements

A concurrent signal assignment statement represents an equivalent process statement that assigns values to signals.

concurrent_signal_assignment_statement ::=
    [label :] [**postponed**] conditional_signal_assignment
  | [label :] [**postponed**] selected_signal_assignment

options ::= [**guarded**] [delay_mechanism]

There are two forms of the concurrent signal assignment statement. For each form, the characteristics that distinguish it are discussed in the following paragraphs.

Each form may include one or both of the two options **guarded** and a delay mechanism (see 8.4 for the delay mechanism, 9.5.1 for the conditional signal assignment statement, and 9.5.2 for the selected signal assignment statement). The option **guarded** specifies that the signal assignment statement is executed when a signal GUARD changes from FALSE to TRUE, or when that signal has been TRUE and an event occurs on one of the signal assignment statement’s inputs. (The signal GUARD shall be either one of the implicitly declared GUARD signals associated with block statements that have guard expressions, or it shall be an explicitly declared signal of type Boolean that is visible at the point of the concurrent signal assignment statement.) The delay mechanism option specifies the pulse rejection characteristics of the signal assignment statement.

If the target of a concurrent signal assignment is a name that denotes a guarded signal (see 4.3.1.2), or if it is in the form of an aggregate and the expression in each element association of the aggregate is a static signal name denoting a guarded signal, then the target is said to be a *guarded target*. If the target of a concurrent signal assignment is a name that denotes a signal that is not a guarded signal, or if it is in the form of an aggregate and the expression in each element association of the aggregate is a static signal name denoting a signal that is not a guarded signal, then the target is said to be an *unguarded target*. It is an error if the target of a concurrent signal assignment is neither a guarded target nor an unguarded target.

For any concurrent signal assignment statement, there is an equivalent process statement with the same meaning. The process statement equivalent to a concurrent signal assignment statement whose target is a signal name is constructed as follows:

a) If a label appears on the concurrent signal assignment statement, then the same label appears on the process statement.

b) The equivalent process statement is a postponed process if and only if the concurrent signal assignment statement includes the reserved word **postponed**.

c) If the delay mechanism option appears in the concurrent signal assignment, then the same delay mechanism appears in every signal assignment statement in the process statement; otherwise, it appears in no signal assignment statement in the process statement.

d) The statement part of the equivalent process statement consists of a statement transform [described in item e)].

e) If the option **guarded** appears in the concurrent signal assignment statement, then the concurrent signal assignment is called a *guarded assignment*. If the concurrent signal assignment statement is a guarded assignment, and if the target of the concurrent signal assignment is a guarded target, then the statement transform is as follows:

```
if GUARD then
   signal_transform
else
   disconnection_statements
end if;
```

Otherwise, if the concurrent signal assignment statement is a guarded assignment, but if the target of the concurrent signal assignment is *not* a guarded target, then the statement transform is as follows:

```
if GUARD then
   signal_transform
end if;
```

Finally, if the concurrent signal assignment statement is *not* a guarded assignment, and if the target of the concurrent signal assignment is *not* a guarded target, then the statement transform is as follows:

```
signal_transform
```

It is an error if a concurrent signal assignment is not a guarded assignment and the target of the concurrent signal assignment is a guarded target.

A *signal transform* is either a sequential signal assignment statement, an if statement, a case statement, or a null statement. If the signal transform is an if statement or a case statement, then it contains either sequential signal assignment statements or null statements, one for each of the alternative waveforms. The signal transform determines which of the alternative waveforms is to be assigned to the output signals.

f) If the concurrent signal assignment statement is a guarded assignment, or if any expression (other than a time expression) within the concurrent signal assignment statement references a signal, then the process statement contains a final wait statement with an explicit sensitivity clause. The sensitivity clause is constructed by taking the union of the sets constructed by applying the rule of 8.1 to each of the aforementioned expressions. Furthermore, if the concurrent signal assignment statement is a guarded assignment, then the sensitivity clause also contains the simple name GUARD. (The signals identified by these names are called the *inputs* of the signal assignment statement.) Otherwise, the process statement contains a final wait statement that has no explicit sensitivity clause, condition clause, or timeout clause.

Under certain conditions [see item e) in the preceding list] the equivalent process statement may contain a sequence of disconnection statements. A *disconnection statement* is a sequential signal assignment statement that assigns a null transaction to its target. If a sequence of disconnection statements is present in the equivalent process statement, the sequence consists of one sequential signal assignment for each scalar subelement of the target of the concurrent signal assignment statement. For each such sequential signal assignment, the target of the assignment is the corresponding scalar subelement of the target of the concurrent signal assignment, and the waveform of the assignment is a null waveform element whose time expression is given by the applicable disconnection specification (see 5.3).

If the target of a concurrent signal assignment statement is in the form of an aggregate, then the same transformation applies. Such a target shall contain only locally static signal names; moreover, it is an error if any signal is identified by more than one signal name.

It is an error if a null waveform element appears in a waveform of a concurrent signal assignment statement.

Execution of a concurrent signal assignment statement is equivalent to execution of the equivalent process statement.

NOTE 1—A concurrent signal assignment statement whose waveforms and target contain only static expressions is equivalent to a process statement whose final wait statement has no explicit sensitivity clause, so it will execute once through at the beginning of simulation and then suspend permanently.

NOTE 2—A concurrent signal assignment statement whose waveforms are all the reserved word **unaffected** has no drivers for the target, since every waveform in the concurrent signal assignment statement is transformed to the statement

```
null;
```

in the equivalent process statement (see 9.5.1).

9.5.1 Conditional signal assignments

The conditional signal assignment represents a process statement in which the signal transform is an if statement.

conditional_signal_assignment ::=
    target <= options conditional_waveforms;

conditional_waveforms ::=
    { waveform **when** condition **else** }
    waveform [**when** condition]

The options for a conditional signal assignment statement are discussed in 9.5.

For a given conditional signal assignment, there is an equivalent process statement corresponding to it as defined for any concurrent signal assignment statement. If the conditional signal assignment is of the form

```
target <= options
          waveform1   when condition1   else
          waveform2   when condition2   else
             .
             .
             .
          waveformN-1 when conditionN-1 else
          waveformN   when conditionN;
```

then the signal transform in the corresponding process statement is of the form

```
if condition1 then
   wave_transform1
elsif condition2 then
   wave_transform2
      .
      .
      .
elsif conditionN-1 then
   wave_transformN-1
elsif conditionN then
   wave_transformN
end if;
```

If the conditional waveform is only a single waveform, the signal transform in the corresponding process statement is of the form

wave_transform

For any waveform, there is a corresponding wave transform. If the waveform is of the form

waveform_element1, waveform_element2, ..., waveform_elementN

then the wave transform in the corresponding process statement is of the form

target <= [delay_mechanism] waveform_element1, waveform_element2, ..., waveform_elementN;

If the waveform is of the form

unaffected

then the wave transform in the corresponding process statement is of the form

null;

In this example, the final **null** causes the driver to be unchanged, rather than disconnected. (This is the null statement—not a null waveform element).

The characteristics of the waveforms and conditions in the conditional assignment statement shall be such that the if statement in the equivalent process statement is a legal statement.

Example:

```
S <= unaffected when Input_pin = S'DrivingValue else
     Input_pin after Buffer_Delay;
```

NOTE—The wave transform of a waveform of the form unaffected is the null statement, not the null transaction.

9.5.2 Selected signal assignments

The selected signal assignment represents a process statement in which the signal transform is a case statement.

selected_signal_assignment ::=
    with expression **select**
        target <= options selected_waveforms ;

selected_waveforms ::=
    { waveform **when** choices , }
    waveform **when** choices

The options for a selected signal assignment statement are discussed in 9.5.

For a given selected signal assignment, there is an equivalent process statement corresponding to it as defined for any concurrent signal assignment statement. If the selected signal assignment is of the form

```
with expression select
   target <= options waveform1   when choice_list1,
                     waveform2   when choice_list2,
                        .
                        .
                        .
                     waveformN-1 when choice_listN-1,
                     waveformN   when choice_listN;
```

then the signal transform in the corresponding process statement is of the form

```
case expression is
   when choice_list1 =>
      wave_transform1
   when choice_list2 =>
      wave_transform2
         .
         .
         .
   when choice_listN-1 =>
      wave_transformN-1
   when choice_listN =>
      wave_transformN
end case;
```

Wave transforms are defined in 9.5.1.

The characteristics of the select expression, the waveforms, and the choices in the selected assignment statement shall be such that the case statement in the equivalent process statement is a legal statement.

9.6 Component instantiation statements

A component instantiation statement defines a subcomponent of the design entity in which it appears, associates signals, quantities, terminals, or values with the ports of that subcomponent, and associates values with generics of that subcomponent. This subcomponent is one instance of a class of components defined by a corresponding component declaration, design entity, or configuration declaration.

component_instantiation_statement ::=
    *instantiation*_label :
        instantiated_unit

```
        [ generic_map_aspect ]
        [ port_map_aspect ] ;

instantiated_unit ::=
    [ component ] component_name
  | entity entity_name [ ( architecture_identifier ) ]
  | configuration configuration_name
```

The component name, if present, shall be the name of a component declared in a component declaration. The entity name, if present, shall be the name of a previously analyzed entity declaration; if an architecture identifier appears in the instantiated unit, then that identifier shall be the same as the simple name of an architecture body associated with the entity declaration denoted by the corresponding entity name. The architecture identifier defines a simple name that is used during the elaboration of a design hierarchy to select the appropriate architecture body. The configuration name, if present, shall be the name of a previously analyzed configuration declaration. The generic map aspect, if present, optionally associates a single actual with each local generic (or member thereof) in the corresponding component declaration or entity declaration. Each local generic (or member thereof) shall be associated at most once. Similarly, the port map aspect, if present, optionally associates a single actual with each local port (or member thereof) in the corresponding component declaration or entity declaration. Each local port (or member thereof) shall be associated at most once. The generic map and port map aspects are described in 5.2.1.2.

If an instantiated unit containing the reserved word **entity** does not contain an explicitly specified architecture identifier, then the architecture identifier is implicitly specified according to the rules given in 5.2.2. The architecture identifier defines a simple name that is used during the elaboration of a design hierarchy to select the appropriate architecture body.

A component instantiation statement and a corresponding configuration specification, if any, taken together, imply that the block hierarchy within the design entity containing the component instantiation is to be extended with a unique copy of the block defined by another design entity. The generic map and port map aspects in the component instantiation statement and in the binding indication of the configuration specification identify the connections that are to be made in order to accomplish the extension.

NOTE 1—A configuration specification can be used to bind a particular instance of a component to a design entity and to associate the local generics and local ports of the component with the formal generics and formal ports of that design entity. A configuration specification can apply to a component instantiation statement only if the name in the instantiated unit of the component instantiation statement denotes a component declaration. See 5.2.

NOTE 2—The component instantiation statement may be used to imply a structural organization for a hardware design. By using component declarations, signals, quantities, terminals, and component instantiation statements, a given (internal or external) block may be described in terms of subcomponents that are interconnected by signals, quantities, and terminals.

NOTE 3—Component instantiation provides a way of structuring the logical decomposition of a design. The precise structural or behavioral characteristics of a given subcomponent may be described later, provided that the instantiated unit is a component declaration. Component instantiation also provides a mechanism for reusing existing designs in a design library. A configuration specification can bind a given component instance to an existing design entity, even if the generics and ports of the entity declaration do not precisely match those of the component (provided that the instantiated unit is a component declaration); if the generics or ports of the entity declaration do not match those of the component, the configuration specification shall contain a generic map or port map, as appropriate, to map the generics and ports of the entity declaration to those of the component.

9.6.1 Instantiation of a component

A component instantiation statement whose instantiated unit contains a name denoting a component is equivalent to a pair of nested block statements that couple the block hierarchy in the containing design unit to a unique copy of the block hierarchy contained in another design unit (i.e., the subcomponent). The outer block represents the component declaration; the inner block represents the design entity to which the component is bound. Each is defined by a block statement.

The header of the block statement corresponding to the component declaration consists of the generic and port clauses (if present) that appear in the component declaration, followed by the generic map and port map aspects (if present) that appear in the corresponding component instantiation statement. The meaning of any identifier appearing in the header of this block statement is that associated with the corresponding occurrence of the identifier in the generic clause, port clause, generic map aspect, or port map aspect. The statement part of the block statement corresponding to the component declaration consists of a nested block statement corresponding to the design entity.

The header of the block statement corresponding to the design entity consists of the generic and port clauses (if present) that appear in the entity declaration that defines the interface to the design entity, followed by the generic map and port map aspects (if present) that appear in the binding indication that binds the component instance to that design entity. The declarative part of the block statement corresponding to the design entity consists of the declarative items from the entity declarative part, followed by the declarative items from the declarative part of the corresponding architecture body. The statement part of the block statement corresponding to the design entity consists of the concurrent statements from the entity statement part, followed by the architecture statements from the statement part of the corresponding architecture body. The meaning of any identifier appearing anywhere in this block statement is that associated with the corresponding occurrence of the identifier in the entity declaration or architecture body.

For example, consider the following component declaration, instantiation, and corresponding configuration specification:

```
component
   COMP port (A,B: inout BIT);
end component;

for C: COMP use
   entity X(Y)
      port map (P1 => A, P2 => B);
   .
   .
   .
C: COMP port map (A => S1, B => S2);
```

Given the following entity declaration and architecture declaration:

```
entity X is
   port (P1, P2: inout BIT);
   constant Delay: Time := 1 ms;
begin
   CheckTiming (P1, P2, 2*Delay);
end X ;

architecture Y of X is
   signal P3: Bit;
begin
   P3 <= P1 after Delay;
   P2 <= P3 after Delay;
   B: block
      .
      .
      .
   begin
      .
      .
      .
   end block;
end Y;
```

then the following block statements implement the coupling between the block hierarchy in which component instantiation statement C appears and the block hierarchy contained in design entity X(Y):

```
C: block                                --  Component block.
   port (A,B: inout BIT);               --  Local ports.
   port map (A => S1, B => S2);         --  Actual/local binding.
begin
   X: block                             --  Design entity block.
      port (P1, P2 : inout BIT);        --  Formal ports.
      port map (P1 => A, P2 => B);      --  Local/formal binding.
      constant Delay: Time := 1 ms;     --  Entity declarative item.
      signal P3: BIT;                 --  Architecture declarative item.
   begin
      CheckTiming (P1, P2, 2*Delay);           --  Entity statement.
      P3 <= P1 after Delay;           --  Architecture statements.
      P2 <= P3 after Delay;
      B: block                        --  Internal block hierarchy.
         .
         .
         .
      begin
         .
         .
         .
      end block;
   end block X ;
end block C;
```

The block hierarchy extensions implied by component instantiation statements that are bound to design entities are accomplished during the elaboration of a design hierarchy (see Clause 12).

9.6.2 Instantiation of a design entity

A component instantiation statement whose instantiated unit denotes either a design entity or a configuration declaration is equivalent to a pair of nested block statements that couple the block hierarchy in the containing design unit to a unique copy of the block hierarchy contained in another design unit (i.e., the subcomponent). The outer block represents the component instantiation statement; the inner block represents the design entity to which the instance is bound. Each is defined by a block statement.

The header of the block statement corresponding to the component instantiation statement is empty, as is the declarative part of this block statement. The statement part of the block statement corresponding to the component declaration consists of a nested block statement corresponding to the design entity.

The header of the block statement corresponding to the design entity consists of the generic and port clauses (if present) that appear in the entity declaration that defines the interface to the design entity, followed by the generic map and port map aspects (if present) that appear in the component instantiation statement that binds the component instance to a copy of that design entity. The declarative part of the block statement corresponding to the design entity consists of the declarative items from the entity declarative part, followed by the declarative items from the declarative part of the corresponding architecture body. The statement part of the block statement corresponding to the design entity consists of the concurrent statements from the entity statement part, followed by the architecture statements from the statement part of the corresponding architecture body. The meaning of any identifier appearing anywhere in this block statement is that associated with the corresponding occurrence of the identifier in the entity declaration or architecture body.

For example, consider the following design entity:

```
entity X is
   port (P1, P2: inout BIT);
   constant Delay: DELAY_LENGTH := 1 ms;
   use WORK.TimingChecks.all;
begin
   CheckTiming (P1, P2, 2*Delay);
end entity X;

architecture Y of X is
   signal P3: BIT;
begin
   P3 <= P1 after Delay;
   P2 <= P3 after Delay;
   B: block
      .
      .
      .
   begin
      .
      .
      .
   end block B;
end architecture Y;
```

This design entity is instantiated by the following component instantiation statement:

```
C: entity Work.X (Y) port map (P1 => S1, P2 => S2);
```

The following block statements implement the coupling between the block hierarchy in which component instantiation statement C appears and the block hierarchy contained in design entity X(Y):

```
C: block                              --   Instance block.
begin
   X: block                           --   Design entity block.
      port (P1, P2: inout BIT);       --   Entity declaration ports.
      port map (P1 => S1, P2 => S2);  --   Instantiation statement
                                      --   port map.
      constant Delay: DELAY_LENGTH    --   Entity declarative items.
                           := 1 ms;
      use WORK.TimingChecks.all;
      signal P3: BIT;                 --   Architecture declarative item.
   begin
      CheckTiming (P1, P2, 2*Delay);  --   Entity statement.
      P3 <= P1 after Delay;        --   Architecture statements.
      P2 <= P3 after Delay;
      B: block
         .
```

```
          .
          .
      begin
          .
          .
          .
      end block B;
   end block X;
end block C;
```

Moreover, consider the following design entity, which is followed by an associated configuration declaration and component instantiation:

```
entity X is
   port (P1, P2: inout BIT);
   constant Delay: DELAY_LENGTH := 1 ms;
   use WORK.TimingChecks.all;
begin
   CheckTiming (P1, P2, 2*Delay);
end entity X;

architecture Y of X is
   signal P3: BIT;
begin
   P3 <= P1 after Delay;
   P2 <= P3 after Delay;
   B: block
      .
      .
      .
   begin
      .
      .
      .
   end block B;
end architecture Y;
```

The configuration declaration is

```
configuration Alpha of X is
   for Y
      .
      .
      .
   end for;
end configuration Alpha;
```

The component instantiation is

```
C: configuration Work.Alpha port map (P1 => S1, P2 => S2);
```

The following block statements implement the coupling between the block hierarchy in which component instantiation statement C appears and the block hierarchy contained in design entity X(Y):

```
C: block                               --  Instance block.
begin
   X: block                            --  Design entity block.
      port (P1, P2: inout BIT);        --  Entity declaration ports.
      port map (P1 => S1, P2 => S2); --  Instantiation statement
                                       -- port map.
      constant Delay: DELAY_LENGTH     --  Entity declarative items.
                      := 1 ms;
      use WORK.TimingChecks.all;
      signal P3: BIT;                  --  Architecture declarative item.
   begin
      CheckTiming (P1, P2, 2*Delay); --  Entity statement.
      P3 <= P1 after Delay;         --  Architecture statements.
      P2 <= P3 after Delay;
      B: block
         .
         .
         .
      begin
         .
         .
         .
      end block B;
   end block X;
end block C;
```

The block hierarchy extensions implied by component instantiation statements that are bound to design entities occur during the elaboration of a design hierarchy (see Clause 12).

9.7 Generate statements

A generate statement provides a mechanism for iterative or conditional elaboration of a portion of a description.

generate_statement ::=
    *generate*_label :
        generation_scheme **generate**
            [{ block_declarative_item }
        begin]
            { architecture_statement }
        end generate [*generate*_label] ;

generation_scheme ::=
      for *generate*_parameter_specification
    | **if** condition

label ::= identifier

If a label appears at the end of a generate statement, it shall repeat the generate label.

For a generate statement with a **for** generation scheme, the generate parameter specification is the declaration of the *generate parameter* with the given identifier. The generate parameter is a constant object whose type is the base type of the discrete range of the generate parameter specification.

The discrete range in a generation scheme of the first form shall be a static discrete range; similarly, the condition in a generation scheme of the second form shall be a static expression.

The elaboration of a generate statement is described in 12.4.2.

Example:

```
Gen: block
begin
   L1: CELL port map (Top, Bottom, A(0), B(0));
   L2: for I in 1 to 3 generate
      L3: for J in 1 to 3 generate
         L4: if I+J>4 generate
            L5: CELL port map (A(I-1),B(J-1),A(I),B(J));
         end generate;
      end generate;
   end generate;

   L6: for I in 1 to 3 generate
      L7: for J in 1 to 3 generate
         L8: if I+J<4 generate
            L9: CELL port map (A(I+1),B(J+1),A(I),B(J));
         end generate;
      end generate;
   end generate;
end block Gen;
```

9.8 Concurrent break statement

The concurrent break statement represents a process containing a break statement.

concurrent_break_statement ::=
    [label :] **break** [break_list] [sensitivity_clause] [**when** condition] ;

For any concurrent break statement there is an equivalent process statement. The equivalent process statement has a label if and only if the concurrent break statement has a label; if the equivalent process statement has a label it is the same as that of the concurrent break statement. The equivalent process statement does not include the reserved word **postponed**, has no sensitivity list, an empty declarative part, and a statement part that consists of a break statement followed by a wait statement.

If the concurrent break statement includes a condition, then the break statement of the equivalent process statement contains a when clause with the same condition as the concurrent break statement; otherwise the break statement does not contain a when clause. If the concurrent break statement includes a break list, then the break statement contains the same break list; otherwise the break statement does not contain a break list.

If the concurrent break statement has a sensitivity clause, then the wait statement of the equivalent process statement contains the same sensitivity clause; otherwise, if a name that denotes a signal appears in the Boolean expression that defines the condition of the break, then the wait statement includes a sensitivity clause that is constructed by applying the rule of 8.1 to that expression; otherwise the wait statement contains no sensitivity clause. The wait statement does not contain a condition clause or a timeout clause.

10. Scope and visibility

The rules defining the scope of declarations and the rules defining which identifiers are visible at various points in the text of the description are presented in this clause. The formulation of these rules uses the notion of a declarative region.

10.1 Declarative region

With two exceptions, a declarative region is a portion of the text of the description. A single declarative region is formed by the text of each of the following:

a) An entity declaration, together with a corresponding architecture body
b) A configuration declaration
c) A subprogram declaration, together with the corresponding subprogram body
d) A package declaration together with the corresponding body (if any)
e) A record type declaration
f) A record nature declaration
g) A component declaration
h) A block statement
i) A process statement
j) A simultaneous procedural statement
k) A loop statement
l) A block configuration
m) A component configuration
n) A generate statement
o) A protected type declaration, together with the corresponding body

In each of these cases, the declarative region is said to be *associated* with the corresponding declaration or statement. A declaration is said to occur *immediately within* a declarative region if this region is the innermost region that encloses the declaration, not counting the declarative region (if any) associated with the declaration itself.

Certain declarative regions include disjoint parts. Each declarative region is nevertheless considered as a (logically) continuous portion of the description text. Hence, if any rule defines a portion of text as the text that *extends* from some specific point of a declarative region to the end of this region, then this portion is the corresponding subset of the declarative region (thus, it does not include intermediate declarative items between the interface declaration and a corresponding body declaration).

In addition to the preceding declarative regions, there is a *root declarative region*, not associated with a portion of the text of the description, but encompassing any given primary unit. At the beginning of the analysis of a given primary unit, there are no declarations whose scopes (see 10.2) are within the root declarative region. Moreover, the root declarative region associated with any given secondary unit is the root declarative region of the corresponding primary unit.

There is also a *library declarative region* associated with each design library (see 11.2). Each library declarative region has within its scope declarations corresponding to each primary unit contained within the associated design library.

NOTE—An architecture body, though a declaration, does not occur immediately within any declarative region.

10.2 Scope of declarations

For each form of declaration, the language rules define a certain portion of the description text called the *scope of the declaration*. The scope of a declaration is also called the scope of any named entity declared by the declaration. Furthermore, if the declaration associates some notation (either an identifier, a character literal, or an operator symbol) with the named entity, this portion of the text is also called the scope of this notation. Within the scope of a named entity, and only there, there are places where it is legal to use the associated notation in order to refer to the named entity. These places are defined by the rules of visibility and overloading.

The scope of a declaration, except for an architecture body, extends from the beginning of the declaration to the end of the immediately closing declarative region; the scope of an architecture body extends from the beginning to the end of the architecture body. In either case, this part of the scope of a declaration is called the *immediate scope*. Furthermore, for any of the declarations in the following list, the scope of the declaration extends beyond the immediate scope:

a) A declaration that occurs immediately within a package declaration
b) An element declaration in a record type declaration
c) A nature element declaration in a record nature declaration
d) A formal parameter declaration in a subprogram declaration
e) A local generic declaration in a component declaration
f) A local port declaration in a component declaration
g) A formal generic declaration in an entity declaration
h) A formal port declaration in an entity declaration
i) A declaration that occurs immediately within a protected type declaration
j) An architecture body

In the absence of a separate subprogram declaration, the subprogram specification given in the subprogram body acts as the declaration, and rule c) applies also in such a case. In each of these cases except j), the given declaration occurs immediately within some enclosing declaration, and the scope of the given declaration extends to the end of the scope of the enclosing declaration.

In addition to the preceding rules, the scope of any declaration that includes the end of the declarative part of a given block (whether it be an external block defined by a design entity or an internal block defined by a block statement) extends into a configuration declaration that configures the given block.

If a component configuration appears as a configuration item immediately within a block configuration that configures a given block, and if the scope of a given declaration includes the end of the declarative part of that block, then the scope of the given declaration extends from the beginning to the end of the declarative region associated with the given component configuration. A similar rule applies to a block configuration that appears as a configuration item immediately within another block configuration, provided that the contained block configuration configures an internal block. Furthermore, the scope of a use clause is similarly extended. Finally, the scope of a library unit contained within a design library is extended along with the scope of the logical library name corresponding to that design library.

NOTE 1—These scope rules apply to all forms of declaration. In particular, they apply also to implicit declarations and to named primary units.

NOTE 2—The scope of an entity declaration includes an associated architecture body, if any. Thus, the entity name may be used within the architecture body as the prefix of an expanded name denoting a declaration that occurs immediately within the entity declaration or the architecture body. The scope of an architecture body does not include the corresponding entity declaration. Thus, the entity cannot use an expanded name to refer to the architecture body nor to any declaration within the architecture body.

10.3 Visibility

The meaning of the occurrence of an identifier at a given place in the text is defined by the visibility rules and also, in the case of overloaded declarations, by the overloading rules. The identifiers considered in this subclause include any identifier other than a reserved word or an attribute designator that denotes a predefined attribute. The places considered in this subclause are those where a lexical element (such as an identifier) occurs. The overloaded declarations considered in this subclause are those for subprograms and enumeration literals.

For each identifier and at each place in the text, the visibility rules determine a set of declarations (with this identifier) that define the possible meanings of an occurrence of the identifier. A declaration is said to be *visible* at a given place in the text when, according to the visibility rules, the declaration defines a possible meaning of this occurrence. The following two cases arise in determining the meaning of such a declaration:

— The visibility rules determine *at most one* possible meaning. In such a case, the visibility rules are sufficient to determine the declaration defining the meaning of the occurrence of the identifier, or in the absence of such a declaration, to determine that the occurrence is not legal at the given point.

— The visibility rules determine *more than one* possible meaning. In such a case, the occurrence of the identifier is legal at this point if and only if *exactly one* visible declaration is acceptable for the overloading rules in the given context.

A declaration is visible only within a certain part of its scope; this part starts at the end of the declaration except in the declaration of a design unit or a protected type declaration, in which case it starts immediately after the reserved word **is** occurring after the identifier of the design unit or protected type declaration. This rule applies to both explicit and implicit declarations.

Visibility is either by selection or direct. A declaration is visible *by selection* at places that are defined as follows:

a) For a primary unit contained in a library: at the place of the suffix in a selected name whose prefix denotes the library.

b) For an entity name in a configuration declaration whose entity name is a simple name: at the place of the simple name, and the context is that of the library WORK.

c) For an architecture body associated with a given entity declaration: at the place of the block specification in a block configuration for an external block whose interface is defined by that entity declaration.

d) For an architecture body associated with a given entity declaration: at the place of an architecture identifier (between the parentheses) in the first form of an entity aspect in a binding indication.

e) For an architecture body associated with a given entity declaration: at the place of an architecture identifier (between the parentheses) in the second form of an instantiated unit in a component instantiation statement.

f) For a declaration given in a package declaration: at the place of the suffix in a selected name whose prefix denotes the package.

g) For an element declaration of a given record type or nature declaration: at the place of the suffix in a selected name whose prefix is appropriate for the type or nature; also at the place of a choice (before the compound delimiter =>) in a named element association of an aggregate of the type or nature.

h) For a user-defined attribute: at the place of the attribute designator (after the delimiter ') in an attribute name whose prefix denotes a named entity with which that attribute has been associated.

i) For a formal parameter declaration of a given subprogram declaration: at the place of the formal designator in a formal part (before the compound delimiter =>) of a named parameter association element of a corresponding subprogram call.

j) For a local generic declaration of a given component declaration: at the place of the formal designator in a formal part (before the compound delimiter =>) of a named generic association element of a corresponding component instantiation statement; similarly, at the place of the actual designator in an actual part (after the compound delimiter =>, if any) of a generic association element of a corresponding binding indication.

k) For a local port declaration of a given component declaration: at the place of the formal designator in a formal part (before the compound delimiter =>) of a named port association element of a corresponding component instantiation statement; similarly, at the place of the actual designator in an actual part (after the compound delimiter =>, if any) of a port association element of a corresponding binding indication.

l) For a formal generic declaration of a given entity declaration: at the place of the formal designator in a formal part (before the compound delimiter =>) of a named generic association element of a corresponding binding indication; similarly, at the place of the formal designator in a formal part (before the compound delimiter =>) of a generic association element of a corresponding component instantiation statement when the instantiated unit is a design entity or a configuration declaration.

m) For a formal port declaration of a given entity declaration: at the place of the formal designator in a formal part (before the compound delimiter =>) of a named port association element of a corresponding binding specification; similarly, at the place of the formal designator in a formal part (before the compound delimiter =>) of a port association element of a corresponding component instantiation statement when the instantiated unit is a design entity or a configuration declaration.

n) For a formal generic declaration or a formal port declaration of a given block statement: at the place of the formal designator in a formal part (before the compound delimiter =>) of a named association element of a corresponding generic or port map aspect.

o) For a subprogram declared immediately within a given protected type declaration: at the place of the suffix in a selected name whose prefix denotes an object of the protected type.

Finally, within the declarative region associated with a construct other than a record type or nature declaration or a protected type, any declaration that occurs immediately within the region and that also occurs textually within the construct is visible by selection at the place of the suffix of an expanded name whose prefix denotes the construct. Similarly, within an architecture body, any declaration that occurs immediately within the architecture body or the corresponding entity declaration is visible by selection at the place of the suffix of an expanded name whose prefix denotes the entity declaration.

Where it is not visible by selection, a visible declaration is said to be *directly visible*. A declaration is said to be directly visible within a certain part of its immediate scope; this part extends to the end of the immediate scope of the declaration but excludes places where the declaration is hidden as explained in the following paragraphs. In addition, a declaration occurring immediately within the visible part of a package can be made directly visible by means of a use clause according to the rules described in 10.4.

A declaration is said to be *hidden* within (part of) an inner declarative region if the inner region contains a homograph of this declaration; the outer declaration is then hidden within the immediate scope of the inner homograph. Each of two declarations is said to be a *homograph* of the other if both declarations have the same identifier, operator symbol, or character literal, and if overloading is allowed for at most one of the two. If overloading is allowed for both declarations, then each of the two is a homograph of the other if they have the same identifier, operator symbol, or character literal, as well as the same parameter and result type profile (see 3.1.1).

Within the specification of a subprogram, every declaration with the same designator as the subprogram is hidden. Where hidden in this manner, a declaration is visible neither by selection nor directly.

Two declarations that occur immediately within the same declarative region shall not be homographs, unless exactly one of them is the implicit declaration of a predefined operation. In such cases, a predefined operation is always hidden by the other homograph. Where hidden in this manner, an implicit declaration is hidden within the entire scope of the other declaration (regardless of which declaration occurs first); the implicit declaration is visible neither by selection nor directly.

Whenever a declaration with a certain identifier is visible from a given point, the identifier and the named entity (if any) are also said to be visible from that point. Direct visibility and visibility by selection are likewise defined for character literals and operator symbols. An operator is directly visible if and only if the corresponding operator declaration is directly visible.

In addition to the aforementioned rules, any declaration that is visible by selection at the end of the declarative part of a given (external or internal) block is visible by selection in a configuration declaration that configures the given block.

In addition, any declaration that is directly visible at the end of the declarative part of a given block is directly visible in a block configuration that configures the given block. This rule holds unless a use clause that makes a homograph of the declaration potentially visible (see 10.4) appears in the corresponding configuration declaration, and if the scope of that use clause encompasses all or part of those configuration items. If such a use clause appears, then the declaration will be directly visible within the corresponding configuration items, except at those places that fall within the scope of the additional use clause. At such places, neither name will be directly visible.

If a component configuration appears as a configuration item immediately within a block configuration that configures a given block, and if a given declaration is visible by selection at the end of the declarative part of that block, then the given declaration is visible by selection from the beginning to the end of the declarative region associated with the given component configuration. A similar rule applies to a block configuration that appears as a configuration item immediately within another block configuration, provided that the contained block configuration configures an internal block.

If a component configuration appears as a configuration item immediately within a block configuration that configures a given block, and if a given declaration is directly visible at the end of the declarative part of that block, then the given declaration is visible by selection from the beginning to the end of the declarative region associated with the given component configuration. A similar rule applies to a block configuration that appears as a configuration item immediately within another block configuration, provided that the contained block configuration configures an internal block. Furthermore, the visibility of declarations made directly visible by a use clause within a block is similarly extended. Finally, the visibility of a logical library name corresponding to a design library directly visible at the end of a block is similarly extended. The rules of this paragraph hold unless a use clause that makes a homograph of the declaration potentially visible appears in the corresponding block configuration, and if the scope of that use clause encompasses all or part of those configuration items. If such a use clause appears, then the declaration will be directly visible within the corresponding configuration items, except at those places that fall within the scope of the additional use clause. At such places, neither name will be directly visible.

NOTE 1—The same identifier, character literal, or operator symbol may occur in different declarations and may thus be associated with different named entities, even if the scopes of these declarations overlap. Overlap of the scopes of declarations with the same identifier, character literal, or operator symbol can result from overloading of subprograms and of enumeration literals. Such overlaps can also occur for named entities declared in the visible parts of packages and for formal generics and ports, record elements, and formal parameters, where there is overlap of the scopes of the enclosing package declarations, entity declarations, record type declarations, or subprogram declarations. Finally, overlapping scopes can result from nesting.

NOTE 2—The rules defining immediate scope, hiding, and visibility imply that a reference to an identifier, character literal, or operator symbol within its own declaration is illegal (except for design units). The identifier, character literal, or operator symbol hides outer homographs within its immediate scope—that is, from the start of the declaration. On the other hand, the identifier, character literal, or operator symbol is visible only after the end of the declaration (again, except for design units). For this reason, all but the last of the following declarations are illegal:

```
constant K: INTEGER := K*K;            --  Illegal
constant T: T;                         --  Illegal
```

```
procedure P (X: P);                      --  Illegal
function Q (X: REAL := Q) return Q;      --  Illegal
procedure R (R: REAL);                   --  Legal (although perhaps confusing)
```

Example:

```
L1: block
   signal A,B: Bit;
begin
   L2: block
      signal B: Bit;                     --  An inner homograph of B.
   begin
      A <= B after 5 ns;                 --  Means L1.A <= L2.B
      B <= L1.B after 10 ns;             --  Means L2.B <= L1.B
   end block ;
   B <= A after 15 ns;                   --  Means L1.B <= L1.A
end block;
```

10.4 Use clauses

A use clause achieves direct visibility of declarations that are visible by selection.

use_clause ::=
  use selected_name { , selected_name } ;

Each selected name in a use clause identifies one or more declarations that will potentially become directly visible. If the suffix of the selected name is a simple name, character literal, or operator symbol, then the selected name identifies only the declaration(s) of that simple name, character literal, or operator symbol contained within the package or library denoted by the prefix of the selected name. If the suffix is the reserved word **all**, then the selected name identifies all declarations that are contained within the package or library denoted by the prefix of the selected name.

For each use clause, there is a certain region of text called the *scope* of the use clause. This region starts immediately after the use clause. If a use clause is a declarative item of some declarative region, the scope of the clause extends to the end of the given declarative region. If a use clause occurs within the context clause of a design unit, the scope of the use clause extends to the end of the root declarative region associated with the given design unit. The scope of a use clause may additionally extend into a configuration declaration (see 10.2).

In order to determine which declarations are made directly visible at a given place by use clauses, consider the set of declarations identified by all use clauses whose scopes enclose this place. Any declaration in this set is a potentially visible declaration. A potentially visible declaration is actually made directly visible except in the following two cases:

a) A potentially visible declaration is not made directly visible if the place considered is within the immediate scope of a homograph of the declaration.

b) Potentially visible declarations that have the same designator are not made directly visible unless each of them is either an enumeration literal specification or the declaration of a subprogram (either by a subprogram declaration or by an implicit declaration).

NOTE 1—These rules guarantee that a declaration that is made directly visible by a use clause cannot hide an otherwise directly visible declaration.

NOTE 2—If a named entity X declared in package P is made potentially visible within a package Q (e.g., by the inclusion of the clause "**use** P.X;" in the context clause of package Q), and the context clause for design unit R includes the clause "**use** Q.**all**;", this does not imply that X will be potentially visible in R. Only those named entities that are actually declared in package Q will be potentially visible in design unit R (in the absence of any other use clauses).

10.5 The context of overload resolution

Overloading is defined for names, subprograms, and enumeration literals.

For overloaded entities, overload resolution determines the actual meaning that an occurrence of an identifier or a character literal has whenever the visibility rules have determined that more than one meaning is acceptable at the place of this occurrence; overload resolution likewise determines the actual meaning of an occurrence of an operator or basic operation (see the introduction to Clause 3).

At such a place, all visible declarations are considered. The occurrence is only legal if there is exactly one interpretation of each constituent of the innermost *complete context*; a complete context is either a declaration, a specification, or a statement.

When considering possible interpretations of a complete context, the only rules considered are the syntax rules, the scope and visibility rules, and the rules of the form as follows:

a) Any rule that requires a name or expression to have a certain type or to have the same type as another name or expression.

b) Any rule that requires the type of a name or expression to be a type of a certain class; similarly, any rule that requires a certain type to be a discrete, integer, floating-point, physical, universal, or character type.

c) Any rule that requires a prefix to be appropriate for a certain type.

d) The rules that require the type of an aggregate or string literal to be determinable solely from the enclosing complete context. Similarly, the rules that require the type of the prefix of an attribute, the type of the expression of a case statement, or the type of the operand of a type conversion to be determinable independently of the context.

e) The rules given for the resolution of overloaded subprogram calls; for the implicit conversions of universal expressions; for the interpretation of discrete ranges with bounds having a universal type; and for the interpretation of an expanded name whose prefix denotes a subprogram.

f) The rules given for the requirements on the return type, the number of formal parameters, and the types of the formal parameters of the subprogram denoted by the resolution function name (see 2.4).

NOTE 1—If there is only one possible interpretation of an occurrence of an identifier, character literal, operator symbol, or string, that occurrence denotes the corresponding named entity. However, this condition does not mean that the occurrence is necessarily legal since other requirements exist that are not considered for overload resolution: for example, the fact that the expression is static, the parameter modes, conformance rules, the use of named association in an indexed name, the use of **open** in an indexed name, the use of a slice as an actual to a function call, and so forth.

NOTE 2—A loop parameter specification is a declaration, and hence a complete context.

NOTE 3—Rules that require certain constructs to have the same parameter and result type profile fall under the preceding category a). The same holds for rules that require conformance of two constructs, since conformance requires that corresponding names be given the same meaning by the visibility and overloading rules.

11. Design units and their analysis

The overall organization of descriptions, as well as their analysis and subsequent definition in a design library, are discussed in this clause.

11.1 Design units

Certain constructs are independently analyzed and inserted into a design library; these constructs are called *design units*. One or more design units in sequence comprise a *design file*.

```
design_file ::=  design_unit { design_unit }

design_unit ::=  context_clause library_unit

library_unit ::=
        primary_unit
      | secondary_unit

primary_unit ::=
        entity_declaration
      | configuration_declaration
      | package_declaration

secondary_unit ::=
        architecture_body
      | package_body
```

Design units in a design file are analyzed in the textual order of their appearance in the design file. Analysis of a design unit defines the corresponding library unit in a design library. A *library unit* is either a primary unit or a secondary unit. A secondary unit is a separately analyzed body of a primary unit resulting from a previous analysis.

The name of a primary unit is given by the first identifier after the initial reserved word of that unit. Of the secondary units, only architecture bodies are named; the name of an architecture body is given by the identifier following the reserved word **architecture**. Each primary unit in a given library shall have a simple name that is unique within the given library, and each architecture body associated with a given entity declaration shall have a simple name that is unique within the set of names of the architecture bodies associated with that entity declaration.

Entity declarations, architecture bodies, and configuration declarations are discussed in Clause 1. Package declarations and package bodies are discussed in Clause 2.

11.2 Design libraries

A *design library* is an implementation-dependent storage facility for previously analyzed design units. A given implementation is required to support any number of design libraries.

```
library_clause  ::=  library logical_name_list ;

logical_name_list  ::=  logical_name { , logical_name }

logical_name  ::=  identifier
```

A library clause defines logical names for design libraries in the host environment. A library clause appears as part of a context clause at the beginning of a design unit. There is a certain region of text called the *scope* of a library clause; this region, contained within the root declarative region (see 10.1), starts immediately after the library clause, and it extends to the end of the root declarative region associated with the design unit in which the library clause appears. Within this scope each logical name defined by the library clause is directly visible, except where hidden in an inner declarative region by a homograph of the logical name according to the rules of 10.3.

If two or more logical names having the same identifier (see 13.3) appear in library clauses in the same context clause, the second and subsequent occurrences of the logical name have no effect. The same is true of logical names appearing both in the context clause of a primary unit and in the context clause of a corresponding secondary unit.

Each logical name defined by the library clause denotes a design library in the host environment.

For a given library logical name, the actual name of the corresponding design library in the host environment may or may not be the same. A given implementation shall provide some mechanism to associate a library logical name with a host-dependent library. Such a mechanism is not defined by the language.

There are two classes of design libraries: *working libraries* and *resource libraries.* A working library is the library into which the library unit resulting from the analysis of a design unit is placed. A resource library is a library containing library units that are referenced within the design unit being analyzed. Only one library is the working library during the analysis of any given design unit; in contrast, any number of libraries (including the working library itself) may be resource libraries during such an analysis.

Every design unit except package STANDARD is assumed to contain the following implicit context items as part of its context clause:

```
library STD, WORK; use STD.STANDARD.all;
```

Library logical name STD denotes the design library in which package STANDARD and package TEXTIO reside; these are the only standard packages defined by the language (see Clause 14). (The use clause makes all declarations within package STANDARD directly visible within the corresponding design unit; see 10.4.) Library logical name WORK denotes the current working library during a given analysis.

The library denoted by the library logical name STD contains no library units other than package STANDARD and package TEXTIO.

A secondary unit corresponding to a given primary unit shall be placed into the design library in which the primary unit resides.

NOTE—The design of the language assumes that the contents of resource libraries named in all library clauses in the context clause of a design unit will remain unchanged during the analysis of that unit (with the possible exception of the updating of the library unit corresponding to the analyzed design unit within the working library, if that library is also a resource library).

11.3 Context clauses

A context clause defines the initial name environment in which a design unit is analyzed.

context_clause ::= { context_item }

context_item ::=

```
    library_clause
  | use_clause
```

A library clause defines library logical names that may be referenced in the design unit; library clauses are described in 11.2. A use clause makes certain declarations directly visible within the design unit; use clauses are described in 10.4.

NOTE—The rules given for use clauses are such that the same effect is obtained whether the name of a library unit is mentioned once or more than once by the applicable use clauses, or even within a given use clause.

11.4 Order of analysis

The rules defining the order in which design units can be analyzed are direct consequences of the visibility rules. In particular:

a) A primary unit whose name is referenced within a given design unit shall be analyzed prior to the analysis of the given design unit.

b) A primary unit shall be analyzed prior to the analysis of any corresponding secondary unit.

In each case, the second unit *depends* on the first unit.

The order in which design units are analyzed shall be consistent with the partial ordering defined by the preceding rules.

If any error is detected while attempting to analyze a design unit, then the attempted analysis is rejected and has no effect whatsoever on the current working library.

A given library unit is potentially affected by a change in any library unit whose name is referenced within the given library unit. A secondary unit is potentially affected by a change in its corresponding primary unit. If a library unit is changed (e.g., by reanalysis of the corresponding design unit), then all library units that are potentially affected by such a change become obsolete and shall be reanalyzed before they can be used again.

12. Elaboration and execution

The process by which a declaration achieves its effect is called the *elaboration* of the declaration. After its elaboration, a declaration is said to be elaborated. Prior to the completion of its elaboration (including before the elaboration), the declaration is not yet elaborated.

Elaboration is also defined for design hierarchies, declarative parts, statement parts (containing architecture statements), simultaneous statements, and concurrent statements. Elaboration of such constructs is necessary in order ultimately to elaborate declarative items that are declared within those constructs.

In order to execute a model, the design hierarchy defining the model shall first be elaborated. Initialization of nets and quantities (see 12.6.2) in the model then occurs. Finally, simulation of the model proceeds. Simulation consists of the repetitive execution of the *simulation cycle*, during which processes are executed, the analog solver invoked, and nets and quantities updated.

12.1 Elaboration of a design hierarchy

The elaboration of a design hierarchy creates a collection of processes interconnected by nets and certain *characteristic expressions* that are an implicit consequence of the declaration and association of quantities and terminals; these characteristic expressions are said to be in the *structural set* of characteristic expressions. The behavior of the design can be simulated by executing the collection of processes and nets and determining the values of the quantities using the structural set of characteristic expressions, an explicit set of characteristic expressions (see Clause 15), and an augmentation set (see 12.6.5).

A design hierarchy is defined either by a design entity or by a configuration.

Elaboration of a design hierarchy defined by a design entity consists of the elaboration of the block statement equivalent to the external block defined by the design entity. The architecture of this design entity is assumed to contain an implicit configuration specification (see 5.2) for each component instance that is unbound in this architecture; each configuration specification has an entity aspect denoting an anonymous configuration declaration identifying the visible entity declaration (see 5.2) and supplying an implicit block configuration (see 1.3.1) that binds and configures a design entity identified according to the rules of 5.2.2. The equivalent block statement is defined in 9.6.2. Elaboration of a block statement is defined in 12.4.1.

Elaboration of a configuration consists of the elaboration of the block statement equivalent to the external block defined by the design entity configured by the configuration. The configuration contains an implicit component configuration (see 1.3.2) for each unbound component instance contained within the external block and an implicit block configuration (see 1.3.1) for each internal block contained within the external block.

An implementation may allow, but is not required to allow, a design entity at the root of a design hierarchy to have generics and ports. If an implementation allows these *top-level* interface objects, it may restrict their allowed types and modes in an implementation-defined manner. Similarly, the means by which top-level interface objects are associated with the external environment of the hierarchy are also defined by an implementation supporting top-level interface objects.

Elaboration of a block statement involves first elaborating each not-yet-elaborated package containing declarations referenced by the block. Similarly, elaboration of a given package involves first elaborating each not-yet-elaborated package containing declarations referenced by the given package. Elaboration of a package consists additionally of the following:

a) Elaboration of the declarative part of the package declaration, eventually followed by

b) Elaboration of the declarative part of the corresponding package body, if the package has a corresponding package body.

Step b), the elaboration of a package body, may be deferred until the declarative parts of other packages have been elaborated, if necessary, because of the dependencies created between packages by their interpackage references.

Elaboration of a declarative part is defined in 12.3.

Examples:

```
--  In the following example, because of the dependencies between
--  the packages, the elaboration of either package body shall
--  follow the elaboration of both package declarations.

package P1 is
   constant C1: INTEGER := 42;
   constant C2: INTEGER;
end package P1;

package P2 is
   constant C1: INTEGER := 17;
   constant C2: INTEGER;
end package P2;

package body P1 is
   constant C2: INTEGER := Work.P2.C1;
end package body P1;

package body P2 is
   constant C2: INTEGER := Work.P1.C1;
end package body P2;

--  If a design hierarchy is described by the following design entity:

entity E is end;

architecture A of E is
   component comp
      port (...);
   end component;
begin
   C: comp port map (...);
   B: block
      ...
   begin
      ...
   end block B;
end architecture A;

--  then its architecture contains the following implicit configuration
--  specification at the end of its declarative part:

for C: comp use configuration anonymous;
```

```
--  and the following configuration declaration is assumed to exist
--  when E(A) is-elaborated:

configuration anonymous of L.E is      --  L is the library in which
                                       --  E(A) is found.
   for A                               --  The most recently analyzed
                                       --  architecture of L.E.
   end for;
end configuration anonymous;
```

12.2 Elaboration of a block header

Elaboration of a block header consists of the elaboration of the generic clause, the generic map aspect, the port clause, and the port map aspect, in that order.

12.2.1 Generic clause

Elaboration of a generic clause consists of the elaboration of each of the equivalent single generic declarations contained in the clause, in the order given. The elaboration of a generic declaration consists of elaborating the subtype indication and then creating a generic constant of that subtype.

The value of a generic constant is not defined until a subsequent generic map aspect is evaluated or, in the absence of a generic map aspect, until the default expression associated with the generic constant is evaluated to determine the value of the constant.

12.2.2 Generic map aspect

Elaboration of a generic map aspect consists of elaborating the generic association list. The generic association list contains an implicit association element for each generic constant that is not explicitly associated with an actual or that is associated with the reserved word **open**; the actual part of such an implicit association element is the default expression appearing in the declaration of that generic constant.

Elaboration of a generic association list consists of the elaboration of each generic association element in the association list. Elaboration of a generic association element consists of the elaboration of the formal part and the evaluation of the actual part. The generic constant or subelement or slice thereof designated by the formal part is then initialized with the value resulting from the evaluation of the corresponding actual part. It is an error if the value of the actual does not belong to the subtype denoted by the subtype indication of the formal. If the subtype denoted by the subtype indication of the declaration of the formal is a constrained array subtype, then an implicit subtype conversion is performed prior to this check. It is also an error if the type of the formal is an array type and the value of each element of the actual does not belong to the element subtype of the formal.

12.2.3 Port clause

Elaboration of a port clause consists of the elaboration of each of the equivalent single port declarations contained in the clause, in the order given. The elaboration of a port declaration consists of elaborating the subtype or subnature indication and then creating a port of that subtype or subnature.

12.2.4 Port map aspect

Elaboration of a port map aspect consists of elaborating the port association list.

Elaboration of a port association list consists of the elaboration of each port association element in the association list whose actual is not the reserved word **open**. Elaboration of a port association element consists of the elaboration of the formal part; the port or subelement or slice thereof designated by the formal part is then associated with the signal, expression, terminal, or quantity designated by the actual part. This association involves a check that the restrictions on port associations (see 1.1.1.2) are met. It is an error if this check fails.

If a given port is a quantity port or a terminal port, the association of the formal and the actual consists of the creation of characteristic expressions. If the port is a quantity port, the difference between each scalar subelement of the formal and the corresponding scalar subelement of the actual is a characteristic expression of the structural set. Its tolerance group is the tolerance group of the corresponding scalar subelement of the formal. Similarly, if the port is a terminal port, the difference between each scalar subelement of the reference quantity of the formal and the corresponding scalar subelement of the reference quantity of the actual is a characteristic expression of the structural set. Its tolerance group is the tolerance group of the corresponding scalar subelement of the reference quantity of the formal. Additionally, if the port is a terminal port, the contribution expression (see 12.3.1.4) of each scalar subelement of the actual is replaced by a simple expression that consists of a + operator whose left operand is the contribution expression of the scalar subelement of the actual and whose right operand is the contribution expression of the matching scalar subelement of the formal.

If a given port is a port of mode **in** whose declaration includes a default expression, and if no association element associates a signal, quantity, or expression with that port, then the default expression is evaluated and the effective and driving value of the port (if the port is a signal port) is set to the value of the default expression. Similarly, if a given port of mode **in** is associated with an expression, that expression is evaluated and the effective and driving value of the port (if the port is a signal port) is set to the value of the expression. In the event that the value of a port is derived from an expression in either fashion, references to the predefined attributes of the port whose kind is signal return values indicating that the port has the given driving value with no activity at any time (see 12.6.3). For a quantity port, the appropriate attributes each reflect a constant value.

If an actual signal or quantity is associated with a port of any mode, and if the type of the formal is a scalar type, then it is an error if (after applying any conversion function or type conversion expression present in the actual part) the bounds and direction of the subtype denoted by the subtype indication of the formal are not identical to the bounds and direction of the subtype denoted by the subtype indication of the actual. If an actual expression is associated with a formal port (of mode **in**), and if the type of the formal is a scalar type, then it is an error if the value of the expression does not belong to the subtype denoted by the subtype indication of the declaration of the formal.

If an actual signal, quantity, terminal, or expression is associated with a formal port, and if the formal is of a constrained array subtype or subnature, then it is an error if the actual does not contain a matching element for each element of the formal. In the case of an actual signal or quantity, this check is made after applying any conversion function or type conversion that is present in the actual part. If an actual signal, terminal, quantity, or expression is associated with a formal port, and if the subtype or subnature denoted by the subtype or subnature indication of the declaration of the formal is an unconstrained array type or nature, then the subtype or subnature of the formal is taken from the actual associated with that formal. It is also an error if the mode of the formal is **in** or **inout** and the value of each element of the actual array (after applying any conversion function or type conversion present in the actual part) does not belong to the element subtype of the formal. If the formal port is of mode **out**, **inout**, or **buffer**, it is also an error if the value of each element of the formal (after applying any conversion function or type conversion present in the formal part) does not belong to the element subtype of the actual.

If an actual signal, quantity, terminal, or expression is associated with a formal port, and if the formal is of a record subtype or subnature, then it is an error if the rules of the preceding three paragraphs do not apply to each element of the record subtype or subnature. In the case of an actual signal or quantity, these checks are made after applying any conversion function or type conversion that is present in the actual part.

12.3 Elaboration of a declarative part

The elaboration of a declarative part consists of the elaboration of the declarative items, if any, in the order in which they are given in the declarative part. This rule holds for all declarative parts, with the following three exceptions:

a) The entity declarative part of a design entity whose corresponding architecture is decorated with the 'FOREIGN attribute defined in package STANDARD (see 5.1 and 14.2).
b) The architecture declarative part of a design entity whose architecture is decorated with the 'FOREIGN attribute defined in package STANDARD.
c) A subprogram declarative part whose subprogram is decorated with the 'FOREIGN attribute defined in package STANDARD.

For these cases, the declarative items are not elaborated; instead, the design entity or subprogram is subject to implementation-dependent elaboration.

In certain cases, the elaboration of a declarative item involves the evaluation of expressions that appear within the declarative item. The value of any object denoted by a primary in such an expression shall be defined at the time the primary is read (see 4.3.2). In addition, if a primary in such an expression is a function call, then the value of any object denoted by or appearing as a part of an actual designator in the function call shall be defined at the time the expression is evaluated. Additionally, it is an error if a primary that denotes a shared variable, or a method of the protected type of a shared variable, is evaluated during the elaboration of a declarative item. During static elaboration, the function STD.STANDARD.NOW[**return** DELAY_LENGTH] (see 14.2) returns the value 0 ns. Similarly, during static elaboration, the function STD.STANDARD.NOW[**return** REAL] (see 14.2) returns the value 0.0.

NOTE—It is a consequence of this rule that the name of a signal or quantity declared within a block cannot be referenced in expressions appearing in declarative items other than source quantity declarations and step limit specifications within that block, an inner block, simultaneous procedural statement, or process statement; nor can it be passed as a parameter to a function called during the elaboration of the block. These restrictions exist because the value of a signal is not defined until after the design hierarchy is elaborated. However, a signal parameter name may be used within expressions in declarative items within a subprogram declarative part, provided that the subprogram is only called after simulation begins, because the value of every signal will be defined by that time.

12.3.1 Elaboration of a declaration

Elaboration of a declaration has the effect of creating the declared item.

For each declaration, the language rules (in particular scope and visibility rules) are such that it is either impossible or illegal to use a given item before the elaboration of its corresponding declaration. For example, it is not possible to use the name of a type for an object declaration before the corresponding type declaration is elaborated. Similarly, it is illegal to call a subprogram before its corresponding body is elaborated.

12.3.1.1 Subprogram declarations and bodies

Elaboration of a subprogram declaration involves the elaboration of the parameter interface list of the subprogram declaration; this in turn involves the elaboration of the subtype indication of each interface element to determine the subtype of each formal parameter of the subprogram.

Elaboration of a subprogram body has no effect other than to establish that the body can, from then on, be used for the execution of calls of the subprogram.

12.3.1.2 Type declarations

Elaboration of a type declaration generally consists of the elaboration of the definition of the type and the creation of that type. For a constrained array type declaration, however, elaboration consists of the elaboration of the equivalent anonymous unconstrained array type followed by the elaboration of the named subtype of that unconstrained type.

Elaboration of an enumeration type definition has no effect other than the creation of the corresponding type.

Elaboration of an integer, floating-point, or physical type definition consists of the elaboration of the corresponding range constraint. For a physical type definition, each unit declaration in the definition is also elaborated. Elaboration of a physical unit declaration has no effect other than to create the unit defined by the unit declaration.

Elaboration of an unconstrained array type definition consists of the elaboration of the element subtype indication of the array type.

Elaboration of a record type definition consists of the elaboration of the equivalent single element declarations in the given order. Elaboration of an element declaration consists of elaboration of the element subtype indication.

Elaboration of an access type definition consists of the elaboration of the corresponding subtype indication.

Elaboration of a protected type definition consists of the elaboration, in the order given, of each of the declarations occurring immediately within the protected type definition.

Elaboration of a protected type body has no effect other than to establish that the body, from then on, can be used during the elaboration of objects of the given protected type.

12.3.1.3 Subtype declarations

Elaboration of a subtype declaration consists of the elaboration of the subtype indication. The elaboration of a subtype indication creates a subtype. If the subtype does not include a constraint, then the subtype is the same as that denoted by the type mark. The elaboration of a subtype indication that includes a constraint proceeds as follows:

a) The constraint is first elaborated.

b) A check is then made that the constraint is compatible with the type or subtype denoted by the type mark (see 3.1 and 3.2.1.1).

Elaboration of a range constraint consists of the evaluation of the range. The evaluation of a range defines the bounds and direction of the range. Elaboration of an index constraint consists of the elaboration of each of the discrete ranges in the index constraint in some order that is not defined by the language.

If the subtype indication includes a tolerance aspect, then the tolerance group is the value of the string expression of the tolerance aspect.

12.3.1.4 Object declarations

Elaboration of an object declaration that declares an object other than a file object or an object of a protected type proceeds as follows:

a) The subtype indication or subnature indication is first elaborated; this establishes the subtype or subnature of the object.

b) If the object declaration includes an explicit initialization expression, then the initial value of the object is obtained by evaluating the expression. It is an error if the value of the expression does not belong to the subtype of the object; if the object is an array object, then an implicit subtype conversion is first performed on the value unless the object is a constant whose subtype indication denotes an unconstrained array type. Otherwise, any implicit initial value for the object is determined, if applicable.

c) The object is created.

d) Any initial value is assigned to the object.

The initialization of such an object (either the declared object or one of its subelements) involves a check that the initial value belongs to the subtype of the object. For an array object declared by an object declaration, an implicit subtype conversion is first applied as for an assignment statement, unless the object is a constant whose subtype is an unconstrained array type.

The elaboration of a terminal declaration also includes the creation of a *contribution expression* corresponding to each scalar subelement of the terminal. The contribution expression is initialized to the literal 0.0; it may be modified by other steps of the elaboration process. Similarly, the elaboration of an across quantity declaration includes the creation, for each scalar subelement q of the across quantity, of the expression (q minus the reference quantity of the plus terminal of q plus the reference quantity of the minus terminal of q). This expression is a characteristic expression of the structural set. Its tolerance group is the tolerance group of q. Finally, if the object is a through quantity, then for each scalar subelement q of the through quantity, the contribution expression of the plus terminal of q is replaced by a simple expression that consists of a + operator whose left operand is the contribution expression of the plus terminal of q and whose right operand is a primary that denotes q. Similarly, the contribution expression of the minus terminal of q is replaced by a simple expression that consists of a – operator whose left operand is the contribution expression of the plus terminal of q and whose right operand is a primary that denotes q.

The elaboration of a file object declaration consists of the elaboration of the subtype indication followed by the creation of the object. If the file object declaration contains file open information, then the implicit call to FILE_OPEN is then executed (see 4.3.1.4).

The elaboration of an object of a protected type consists of the elaboration of the subtype indication, followed by creation of the object. Creation of the object consists of elaborating, in the order given, each of the declarative items in the protected type body.

NOTE 1—These rules apply to all object declarations other than port and generic declarations, which are elaborated as outlined in 12.2.1 through 12.2.4.

NOTE 2—The expression initializing a constant object need not be a static expression.

NOTE 3—Each object whose type is a protected type creates an instance of the shared objects.

12.3.1.5 Alias declarations

Elaboration of an alias declaration consists of the elaboration of the subtype indication to establish the subtype or subnature associated with the alias, followed by the creation of the alias as an alternative name for the named entity. The creation of an alias for an array object involves a check that the subtype associated with the alias includes a matching element for each element of the named object. It is an error if this check fails.

12.3.1.6 Attribute declarations

Elaboration of an attribute declaration has no effect other than to create a template for defining attributes of items.

12.3.1.7 Component declarations

Elaboration of a component declaration has no effect other than to create a template for instantiating component instances.

12.3.1.8 Nature and subnature declarations

Elaboration of a nature declaration consists of associating the type declarations in the nature declaration with the nature and setting the values of the predeclared attributes of the nature accordingly. The elaboration of a nature declaration that declares a scalar nature also creates the reference terminal of the simple nature of that scalar nature. Elaboration of a subnature declaration proceeds analogously to the elaboration of a subtype declaration; the subnature indication is elaborated, the constraint is elaborated, and then checked.

12.3.2 Elaboration of a specification

Elaboration of a specification has the effect of associating additional information with a previously declared item.

12.3.2.1 Attribute specifications

Elaboration of an attribute specification proceeds as follows:

a) The entity specification is elaborated in order to determine which items are affected by the attribute specification.

b) The expression is evaluated to determine the value of the attribute. It is an error if the value of the expression does not belong to the subtype of the attribute; if the attribute is of an array type, then an implicit subtype conversion is first performed on the value, unless the subtype indication of the attribute denotes an unconstrained array type.

c) A new instance of the designated attribute is created and associated with each of the affected items.

d) Each new attribute instance is assigned the value of the expression.

The assignment of a value to an instance of a given attribute involves a check that the value belongs to the subtype of the designated attribute. For an attribute of a constrained array type, an implicit subtype conversion is first applied as for an assignment statement. No such conversion is necessary for an attribute of an unconstrained array type; the constraints on the value determine the constraints on the attribute.

NOTE—The expression in an attribute specification need not be a static expression.

12.3.2.2 Configuration specifications

Elaboration of a configuration specification proceeds as follows:

a) The component specification is elaborated in order to determine which component instances are affected by the configuration specification.

b) The binding indication is elaborated to identify the design entity to which the affected component instances will be bound.

c) The binding information is associated with each affected component instance label for later use in instantiating those component instances.

As part of this elaboration process, a check is made that both the entity declaration and the corresponding architecture body implied by the binding indication exist within the specified library. It is an error if this check fails.

12.3.2.3 Disconnection specifications

Elaboration of a disconnection specification proceeds as follows:

a) The guarded signal specification is elaborated in order to identify the signals affected by the disconnection specification.

b) The time expression is evaluated to determine the disconnection time for drivers of the affected signals.

c) The disconnection time is associated with each affected signal for later use in constructing disconnection statements in the equivalent processes for guarded assignments to the affected signals.

12.3.2.4 Step limit specifications

Elaboration of a step limit specification proceeds as follows:

a) The quantity specification is elaborated in order to identify the quantities affected by the step limit specification.

b) The real expression is associated with each affected quantity for later use by the analog solver.

12.4 Elaboration of a statement part

Architecture statements appearing in the statement part of a block shall be elaborated before execution begins. Elaboration of the statement part of a block consists of the elaboration of each architecture statement in the order given. This rule holds for all block statement parts except for those blocks equivalent to a design entity whose corresponding architecture is decorated with the 'FOREIGN attribute defined in package STANDARD (see 14.2).

For this case, the statements are not elaborated; instead, the design entity is subject to implementation-dependent elaboration.

12.4.1 Block statements

Elaboration of a block statement consists of the elaboration of the block header, if present, followed by the elaboration of the block declarative part, followed by the elaboration of the block statement part, followed by the creation of certain characteristic expressions of the structural set.

Elaboration of a block statement may occur under the control of a configuration declaration. In particular, a block configuration, whether implicit or explicit, within a configuration declaration may supply a sequence of additional implicit configuration specifications to be applied during the elaboration of the corresponding block statement. If a block statement is being elaborated under the control of a configuration declaration, then the sequence of implicit configuration specifications supplied by the block configuration is elaborated as part of the block declarative part, following all other declarative items in that part.

The sequence of implicit configuration specifications supplied by a block configuration, whether implicit or explicit, consists of each of the configuration specifications implied by component configurations (see 1.3.2) occurring immediately within the block configuration, in the order in which the component configurations themselves appear.

A scalar terminal is a *root terminal* if it is not a reference terminal or a connected terminal. The contribution expression of each scalar subelement of any root terminal of the block is a characteristic expression of the structural set. Its tolerance group is the tolerance group implied by the through type of the nature of the terminal. In addition, the difference between each scalar subelement of each quantity T'CONTRIBUTION and the contribution expression of the corresponding scalar subelement of terminal T is a characteristic expression of the structural set. Its tolerance group is the tolerance group of the scalar subelement of T'CONTRIBUTION.

12.4.2 Generate statements

Elaboration of a generate statement consists of the replacement of the generate statement with zero or more copies of a block statement whose declarative part consists of the declarative items contained within the generate statement and whose statement part consists of the concurrent statements contained within the generate statement. These block statements are said to be *represented* by the generate statement. Each block statement is then elaborated.

For a generate statement with a for generation scheme, elaboration consists of the elaboration of the discrete range, followed by the generation of one block statement for each value in the range. The block statements all have the following form:

a) The label of the block statement is the same as the label of the generate statement.
b) The block declarative part has, as its first item, a single constant declaration that declares a constant with the same simple name as that of the applicable generate parameter; the value of the constant is the value of the generate parameter for the generation of this particular block statement. The type of this declaration is determined by the base type of the discrete range of the generate parameter. The remainder of the block declarative part consists of a copy of the declarative items contained within the generate statement.
c) The block statement part consists of a copy of the concurrent statements contained within the generate statement.

For a generate statement with an if generation scheme, elaboration consists of the evaluation of the Boolean expression, followed by the generation of exactly one block statement if the expression evaluates to TRUE, and no block statement otherwise. If generated, the block statement has the following form:

— The block label is the same as the label of the generate statement.
— The block declarative part consists of a copy of the declarative items contained within the generate statement.
— The block statement part consists of a copy of the concurrent statements contained within the generate statement.

Examples:

```
--  The following generate statement:

LABL: for I in 1 to 2 generate
   signal s1: INTEGER;
begin
   s1 <= p1;
   Inst1: and_gate port map (s1, p2(I), p3);
end generate LABL;

--  is equivalent to the following two block statements:

LABL: block
   constant I: INTEGER := 1;
   signal s1: INTEGER;
begin
   s1 <= p1;
   Inst1: and_gate port map (s1, p2(I), p3);
```

```
end block LABL;

LABL: block
   constant I: INTEGER := 2;
   signal s1: INTEGER;
begin
   s1 <= p1;
   Inst1: and_gate port map (s1, p2(I), p3);
end block LABL;

--  The following generate statement:

LABL: if (g1 = g2) generate
   signal s1: INTEGER;
begin
   s1 <= p1;
   Inst1: and_gate port map (s1, p4, p3);
end generate LABL;

--  is equivalent to the following statement if g1 = g2;
--  otherwise, it is equivalent to no statement at all:

LABL: block
   signal s1: INTEGER;
begin
   s1 <= p1;
   Inst1: and_gate port map (s1, p4, p3);
end block LABL;
```

NOTE—The repetition of the block labels in the case of a for generation scheme does not produce multiple declarations of the label on the generate statement. The multiple block statements represented by the generate statement constitute multiple references to the same implicitly declared label.

12.4.3 Component instantiation statements

Elaboration of a component instantiation statement that instantiates a component declaration has no effect unless the component instance is either fully bound to a design entity defined by an entity declaration and architecture body or bound to a configuration of such a design entity. If a component instance is so bound, then elaboration of the corresponding component instantiation statement consists of the elaboration of the implied block statement representing the component instance and (within that block) the implied block statement representing the design entity to which the component instance is bound. The implied block statements are defined in 9.6.1.

Elaboration of a component instantiation statement whose instantiated unit denotes either a design entity or a configuration declaration consists of the elaboration of the implied block statement representing the component instantiation statement and (within that block) the implied block statement representing the design entity to which the component instance is bound. The implied block statements are defined in 9.6.2.

12.4.4 Other concurrent statements

All other concurrent statements are either process statements or are statements for which there is an equivalent process statement.

Elaboration of a process statement proceeds as follows:

a) The process declarative part is elaborated.

b) The drivers required by the process statement are created.

c) The initial transaction defined by the default value associated with each scalar signal driven by the process statement is inserted into the corresponding driver.

Elaboration of all concurrent signal assignment statements and concurrent assertion statements consists of the construction of the equivalent process statement followed by the elaboration of the equivalent process statement.

12.4.5 Simultaneous statements

The elaboration of a simple simultaneous statement consists of the evaluation of the string expression that determines the tolerance group of its characteristic expressions. The elaboration of a simultaneous procedural statement consists of creating the type declaration, the subprogram body and the simple simultaneous statement implied by the simultaneous procedural statement, and elaborating each in turn. The elaboration of any other simultaneous statement has no effect.

12.5 Dynamic elaboration

The execution of certain constructs that involve sequential statements rather than concurrent statements also involves elaboration. Such elaboration occurs during the execution of the model.

There are three particular instances in which elaboration occurs dynamically during simulation. These are as follows:

a) Execution of a loop statement with a for iteration scheme involves the elaboration of the loop parameter specification prior to the execution of the statements enclosed by the loop (see 8.9). This elaboration creates the loop parameter and evaluates the discrete range.

b) Execution of a subprogram call involves the elaboration of the parameter interface list of the corresponding subprogram declaration; this involves the elaboration of each interface declaration to create the corresponding formal parameters. Actual parameters are then associated with formal parameters. Next, if the subprogram is a method of a protected type (see 3.5.1) or an implicitly declared file operation (see 3.4.1), the elaboration *blocks* (suspends execution while retaining all state), if necessary, until exclusive access to the object denoted by the prefix of the method or to the file object denoted by the file parameter of the file operation is secured. Finally, if the designator of the subprogram is not decorated with the 'FOREIGN attribute defined in package STANDARD, the declarative part of the corresponding subprogram body is elaborated and the sequence of statements in the subprogram body is executed. If the designator of the subprogram is decorated with the 'FOREIGN attribute defined in package STANDARD, then the subprogram body is subject to implementation-dependent elaboration and execution.

c) Evaluation of an allocator that contains a subtype indication involves the elaboration of the subtype indication prior to the allocation of the created object.

NOTE 1—It is a consequence of these rules that declarative items appearing within the declarative part of a subprogram body are elaborated each time the corresponding subprogram is called; thus, successive elaborations of a given declarative item appearing in such a place may create items with different characteristics. For example, successive elaborations of the same subtype declaration appearing in a subprogram body may create subtypes with different constraints.

NOTE 2—If two or more processes access the same set of shared variables, livelock or deadlock may occur. That is, it may not be possible to ever grant exclusive access to the shared variable as outlined in the preceding item b). Implementations are allowed to, but not required to, detect and, if possible, resolve such conditions.

12.6 Execution of a model

The elaboration of a design hierarchy produces a *model* that can be executed in order to simulate the design represented by the model. Simulation involves the execution of user-defined processes that interact with each other and with the environment, and the invocation of the analog solver to determine the values of quantities within the model.

The *kernel process* is a conceptual representation of the agent that coordinates the activity of user-defined processes during a simulation. This agent causes the propagation of signal values to occur and causes the values of implicit signals [such as S'Stable] to be updated. Furthermore, this process is responsible for detecting events that occur and for causing the appropriate processes to execute in response to those events.

For any given signal that is explicitly declared within a model, the kernel process contains a variable representing the current value of that signal. Any evaluation of a name denoting a given signal retrieves the current value of the corresponding variable in the kernel process. Similarly, for any given quantity that is explicitly or implicitly declared within a model, the kernel process contains a similar variable, and any evaluation of a name denoting the quantity returns the current value of the corresponding variable. During simulation, the kernel process updates these variables from time to time, based upon the current values of sources of the corresponding signal and the results of the analog solver.

In addition, the kernel process contains a variable representing the current value of any implicitly declared GUARD signal resulting from the appearance of a guard expression on a given block statement. Furthermore, the kernel process contains both a driver for, and a variable representing the current value of, any signal S'Stable(T), for any prefix S and any time T, that is referenced within the model; likewise, for any signal S'Quiet(T) or S'Transaction, and likewise, for each textual occurrence of any name of the form Q'ABOVE(E). Finally, the kernel process contains a driver for the DOMAIN signal of type DOMAIN_TYPE.

The *analog solver* is a conceptual representation of the agent that updates the values of the quantities of a model. The analog solver also updates the driver of each implicit signal Q'ABOVE(E) of the model. The analog solver is said to determine an *analog solution point* when it determines these values.

NOTE—Since the kernel process contains a driver for the DOMAIN signal, and since the type of the DOMAIN signal is an unresolved type, the model shall not contain a source for the DOMAIN signal.

12.6.1 Drivers

Every signal assignment statement in a process statement defines a set of *drivers* for certain scalar signals. There is a single driver for a given scalar signal S in a process statement, provided that there is at least one signal assignment statement in that process statement and that the longest static prefix of the target signal of that signal assignment statement denotes S or denotes a composite signal of which S is a subelement. Each such signal assignment statement is said to be *associated* with that driver. Execution of a signal assignment statement affects only the associated driver(s).

A driver for a scalar signal is represented by a *projected output waveform*. A projected output waveform consists of a sequence of one or more *transactions*, where each transaction is a pair consisting of a value component and a time component. For a given transaction, the value component represents a value that the driver of the signal is to assume at some point in time, and the time component specifies which point in time. These transactions are ordered with respect to their time components.

A driver always contains at least one transaction. The initial contents of a driver associated with a given signal are defined by the default value associated with the signal (see 4.3.1.2).

For any driver, there is exactly one transaction whose time component is not greater than the current simulation time. The *current value* of the driver is the value component of this transaction. If, as the result of the advance of time, the current time becomes equal to the time component of the next transaction, then the first transaction is deleted from the projected output waveform and the next becomes the current value of the driver.

12.6.2 Propagation of signal values

As simulation time advances, the transactions in the projected output waveform of a given driver (see 12.6.1) will each, in succession, become the value of the driver. When a driver acquires a new value in this way, regardless of whether the new value is different from the previous value, that driver is said to be *active* during that simulation cycle. For the purposes of defining driver activity, a driver acquiring a value from a null transaction is assumed to have acquired a new value. A signal is said to be *active* during a given simulation cycle if

— One of its sources is active.

— One of its subelements is active.

— The signal is named in the formal part of an association element in a port association list and the corresponding actual is active.

— The signal is a subelement of a resolved signal and the resolved signal is active.

If a signal of a given composite type has a source that is of a different type (and therefore a conversion function or type conversion appears in the corresponding association element), then each scalar subelement of that signal is considered to be active if the source itself is active. Similarly, if a port of a given composite type is associated with a signal that is of a different type (and therefore a conversion function or type conversion appears in the corresponding association element), then each scalar subelement of that port is considered to be active if the actual signal itself is active.

In addition to the preceding information, an implicit signal is said to be active during a given simulation cycle if the kernel process updates that implicit signal within the given cycle.

If a signal is not active during a given simulation cycle, then the signal is said to be *quiet* during that simulation cycle.

The kernel process determines two values for certain signals during any given simulation cycle. The *driving value* of a given signal is the value that signal provides as a source of other signals. The *effective value* of a given signal is the value obtainable by evaluating a reference to the signal within an expression. The driving value and the effective value of a signal are not always the same, especially when resolution functions and conversion functions or type conversions are involved in the propagation of signal values.

A *basic signal* is a signal that has all of the following properties:

— It is either a scalar signal or a resolved signal (see 4.3.1.2)

— It is not a subelement of a resolved signal

— Is not an implicit signal of the form S'Stable(T), S'Quiet(T), S'Transaction, or Q'ABOVE(E) (see 14.1)

— It is not an implicit signal GUARD (see 9.1)

Basic signals are those that determine the driving values for all other signals.

The driving value of any basic signal S is determined as follows:

— If S has no source, then the driving value of S is given by the default value associated with S (see 4.3.1.2).

— If S has one source that is a driver and S is not a resolved signal (see 4.3.1.2), then the driving value of S is the current value of that driver.

— If S has one source that is a port and S is not a resolved signal, then the driving value of S is the driving value of the formal part of the association element that associates S with that port (see 4.3.2.2). The driving value of a formal part is obtained by evaluating the formal part as follows: If no conversion function or type conversion is present in the formal part, then the driving value of the formal part is the driving value of the signal denoted by the formal designator. Otherwise, the driving value of the formal part is the value obtained by applying either the conversion function or type conversion (whichever is contained in the formal part) to the driving value of the signal denoted by the formal designator.

— If S is a resolved signal and has one or more sources, then the driving values of the sources of S are examined. It is an error if any of these driving values is a composite where one or more subelement values are determined by the null transaction (see 8.4.1) and one or more subelement values are not determined by the null transaction. If S is of signal kind **register** and all the sources of S have values determined by the null transaction, then the driving value of S is unchanged from its previous value. Otherwise, the driving value of S is obtained by executing the resolution function associated with S, where that function is called with an input parameter consisting of the concatenation of the driving values of the sources of S, with the exception of the value of any source of S whose current value is determined by the null transaction.

The driving value of any signal S that is not a basic signal is determined as follows:

— If S is a subelement of a resolved signal R, the driving value of S is the corresponding subelement value of the driving value of R.

— Otherwise (S is a non-resolved, composite signal), the driving value of S is equal to the aggregate of the driving values of each of the basic signals that are the subelements of S.

For a scalar signal S, the *effective value* of S is determined in the following manner:

— If S is a signal declared by a signal declaration, a port of mode **buffer**, or an unconnected port of mode **inout**, then the effective value of S is the same as the driving value of S.

— If S is a connected port of mode **in** or **inout**, then the effective value of S is the same as the effective value of the actual part of the association element that associates an actual with S (see 4.3.2.2). The effective value of an actual part is obtained by evaluating the actual part, using the effective value of the signal denoted by the actual designator in place of the actual designator.

— If S is an unconnected port of mode **in**, the effective value of S is given by the default value associated with S (see 4.3.1.2).

For a composite signal R, the effective value of R is the aggregate of the effective values of each of the subelements of R.

For a scalar signal S, both the driving and effective values shall belong to the subtype of the signal. For a composite signal R, an implicit subtype conversion is performed to the subtype of R; for each element of R, there shall be a matching element in both the driving and the effective value, and vice versa.

In order to update a signal during a given simulation cycle, the kernel process first determines the driving and effective values of that signal. The kernel process then updates the variable containing the current value of the signal with the newly determined effective value, as follows:

a) If S is a signal of some type that is not an array type, the effective value of S is used to update the current value of S. A check is made that the effective value of S belongs to the subtype of S. An error occurs if this subtype check fails. Finally, the effective value of S is assigned to the variable representing the current value of the signal.

b) If S is an array signal (including a slice of an array), the effective value of S is implicitly converted to the subtype of S. The subtype conversion checks that for each element of S there is a matching element in the effective value and vice versa. An error occurs if this check fails. The result of this subtype conversion is then assigned to the variable representing the current value of S.

Updating a signal S of type T is said to *change* the current value of S if and only if the expression “S = S'Delayed” evaluates to False, where the “=” operator in the expression is the predefined “=” on type T. If updating a signal causes the current value of that signal to change, then an *event* is said to have occurred on the signal. This definition applies to any updating of a signal, whether such updating occurs according to the preceding rules or according to the rules for updating implicit signals given in 12.6.3. The occurrence of an event will cause the resumption and subsequent execution of certain processes during the simulation cycle in which the event occurs, if and only if those processes are currently sensitive to the signal on which the event has occurred.

For any signal other than one declared with the signal kind **register**, the driving and effective values of the signal are determined and the current value of that signal is updated as previously described, in every simulation cycle. A signal declared with the signal kind **register** is updated in the same fashion during every simulation cycle except those in which all of its sources have current values that are determined by null transactions.

A *net* is a collection of drivers, signals (including ports and implicit signals), conversion functions, and resolution functions that, taken together, determine the effective and driving values of every signal on the net.

Implicit signals GUARD, S'Stable(T), S'Quiet(T), and S'Transaction, for any prefix S and any time T, and Q'ABOVE(E) for any prefix Q and expression E, are not updated according to the preceding rules; such signals are updated according to the rules described in 12.6.3.

NOTE 1—In a given simulation cycle, situations can occur where a subelement of a composite signal is quiet, and the signal itself is active.

NOTE 2—The rules concerning association of actuals with formals (see 4.3.2.2) imply that, if a composite signal is associated with a composite port of mode **out**, **inout**, or **buffer**, and if no conversion function or type conversion appears in either the actual or formal part of the association element, then each scalar subelement of the formal is a source of the matching subelement of the actual. In such a case, a given subelement of the actual will be active if and only if the matching subelement of the formal is active.

NOTE 3—The algorithm for computing the driving value of a scalar signal S is recursive. For example, if S is a local signal appearing as an actual in a port association list whose formal is of mode **out** or **inout**, the driving value of S can only be obtained after the driving value of the corresponding formal part is computed. This computation may involve multiple executions of the preceding algorithm.

NOTE 4—Similarly, the algorithm for computing the effective value of a signal S is recursive. For example, if a formal port S of mode **in** corresponds to an actual A, the effective value of A shall be computed before the effective value of S can be computed. The actual A may itself appear as a formal port in a port association list.

NOTE 5—No effective value is specified for **out** and **linkage** ports, since these ports cannot be read.

NOTE 6—Overloading the operator “=” has no effect on the propagation of signal values.

NOTE 7—A signal of kind **register** may be active even if its associated resolution function does not execute in the current simulation cycle if the values of all of its drivers are determined by the null transaction and at least one of its drivers is also active.

NOTE 8—The definition of the driving value of a basic signal exhausts all cases, with the exception of a non-resolved signal with more than one source. This condition is defined as an error in 4.3.1.2.

12.6.3 Updating implicit signals

The kernel process updates the value of each implicit signal GUARD associated with a block statement that has a guard expression. Similarly, the kernel process updates the values of each implicit signal S'Stable(T), S'Quiet(T), or S'Transaction for any prefix S and any time T; this also involves updating the drivers of S'Stable(T) and S'Quiet(T). In addition, the kernel process updates the values of each signal Q'ABOVE(E).

If the driver of any implicit signal Q'ABOVE(E) is active, then the kernel updates Q'ABOVE(E) by assigning the current value of the driver to the variable representing the current value of Q'ABOVE(E).

For any implicit signal GUARD, the current value of the signal is modified if and only if the corresponding guard expression contains a reference to a signal S and if S is active during the current simulation cycle. In such a case, the implicit signal GUARD is updated by evaluating the corresponding guard expression and assigning the result of that evaluation to the variable representing the current value of the signal.

For any implicit signal S'Stable(T), the current value of the signal (and likewise the current state of the corresponding driver) is modified if and only if one of the following statements is true:

— An event has occurred on S in this simulation cycle.
— The driver of S'Stable(T) is active.

If an event has occurred on signal S, then S'Stable(T) is updated by assigning the value FALSE to the variable representing the current value of S'Stable(T), and the driver of S'Stable(T) is assigned the waveform TRUE **after** T. Otherwise, if the driver of S'Stable(T) is active, then S'Stable(T) is updated by assigning the current value of the driver to the variable representing the current value of S'Stable(T). Otherwise, neither the variable nor the driver is modified.

Similarly, for any implicit signal S'Quiet(T), the current value of the signal (and likewise the current state of the corresponding driver) is modified if and only if one of the following statements is true:

— S is active.
— The driver of S'Quiet(T) is active.

If signal S is active, then S'Quiet(T) is updated by assigning the value FALSE to the variable representing the current value of S'Quiet(T), and the driver of S'Quiet(T) is assigned the waveform TRUE **after** T. Otherwise, if the driver of S'Quiet(T) is active, then S'Quiet(T) is updated by assigning the current value of the driver to the variable representing the current value of S'Quiet(T). Otherwise, neither the variable nor the driver is modified.

Finally, for any implicit signal S'Transaction, the current value of the signal is modified if and only if S is active. If signal S is active, then S'Transaction is updated by assigning the value of the expression (**not** S'Transaction) to the variable representing the current value of S'Transaction. At most one such assignment will occur during any given simulation cycle.

For any implicit signal S'Delayed(T), the signal is not updated by the kernel process. Instead, it is updated by constructing an equivalent process (see 14.1) and executing that process.

The current value of a given implicit signal denoted by R is said to *depend* upon the current value of another signal S if one of the following statements is true:

— R denotes an implicit GUARD signal and S is any other implicit signal named within the guard expression that defines the current value of R.
— R denotes an implicit signal S'Stable(T).
— R denotes an implicit signal S'Quiet(T).
— R denotes an implicit signal S'Transaction.
— R denotes an implicit signal S'Delayed(T).

These rules define a partial ordering on all signals within a model. The updating of implicit signals by the kernel process is guaranteed to proceed in such a manner that, if a given implicit signal R depends upon the current value of another signal S, then the current value of S will be updated during a particular simulation cycle prior to the updating of the current value of R.

NOTE—These rules imply that, if the driver of S'Stable(T) is active, then the new current value of that driver is the value TRUE. Furthermore, these rules imply that, if an event occurs on S during a given simulation cycle, and if the driver of S'Stable(T) becomes active during the same cycle, the variable representing the current value of S'Stable(T) will be assigned the value FALSE, and the current value of the driver of S'Stable(T) during the given cycle will never be assigned to that signal.

12.6.4 Simulation cycle

The execution of a model consists of an initialization phase followed by the repetitive execution of process statements in the description of that model. Each such repetition is said to be a *simulation cycle*. In each cycle, the values of all signals and quantities in the description are computed. If as a result of this computation an event occurs on a given signal, process statements that are sensitive to that signal will resume and will be executed as part of the simulation cycle.

At the beginning of initialization, the current time, T_c, is assumed to be 0.0, the simulation frequency is assumed to be 0.0, the break set is assumed to be empty, and the break flag is assumed to be cleared.

The initialization phase consists of the following steps:

— The driving value and the effective value of each explicitly declared signal are computed, and the current value of the signal is set to the effective value. This value is assumed to have been the value of the signal for an infinite length of time prior to the start of simulation.

— The value of each implicit signal of the form S'STABLE(T) or S'QUIET(T) is set to TRUE. The value of each implicit signal of the form S'DELAYED(T) is set to the initial value of its prefix, S. The value of each implicit signal of the form Q'ABOVE(E) is set to the value of the Boolean expression Q > E. The value of each implicit quantity of the form T'REFERENCE, T'CONTRIBUTION, Q'DOT, Q'INTEG, Q'ZOH(T, Initial_delay), Q'LTF(Num, Den), Q'ZTF(Num, Den, T, Initial_delay) is set to 0.0. The value of each implicit quantity of the form Q'DELAYED(T) or Q'SLEW(max_rising_slope, max_falling_slope) is set to the initial value of its prefix, Q. The value of each implicit quantity of the form S'RAMP(TRISE, TFALL) or S'SLEW(RISING_SLOPE, FALLING_SLOPE) is set to the initial value of its prefix, S.

— The value of each implicit GUARD signal is set to the result of evaluating the corresponding guard expression.

— Each nonpostponed process in the model is executed until it suspends.

— Each postponed process in the model is executed until it suspends.

— The quiescent state augmentation set is determined.

— The break set is applied to the quiescent state augmentation set.

— The time of the next simulation cycle (which in this case is the first simulation cycle), T_n, is set to 0.0.

A simulation cycle consists of the following steps:

a) The analog solver is executed.

b) The current time, T_c, is set equal to T_n. Simulation is complete when T_n is equal to the universal time corresponding to TIME'HIGH and there are no active drivers or process resumptions at T_n.

c) Each active explicit signal in the model is updated. (Events may occur on signals as a result.)

d) Each implicit signal in the model is updated. (Events may occur on signals as a result.)

e) For each process, P, if P is currently sensitive to a signal, S, and if an event has occurred on S in this simulation cycle, then P resumes.

f) Each nonpostponed process that has resumed in the current simulation cycle is executed until it suspends.

g) If the break flag is set, the time of the next simulation cycle, T_n, is set to T_c. Otherwise, T_n is determined by setting it to the earliest of

1) The value of type *universal_time* corresponding to TIME'HIGH,

2) The next time at which a driver becomes active, or

3) The next time at which a process resumes.

If $T_n = T_c$, then the next simulation cycle (if any) will be a *delta cycle*.

h) If the value of the DOMAIN signal is TIME_DOMAIN, or if $T_n = 0.0$, the remainder of this step is skipped. Otherwise, the driver of the DOMAIN signal is assigned one of the following waveforms:

1) FREQUENCY_DOMAIN **after** 0 ns if the simulation cycle is executed as described in 12.8

2) TIME_DOMAIN **after** 0 ns otherwise

Then, T_n is reset to 0.0. The next simulation cycle will be a delta cycle.

i) If the next simulation cycle will be a delta cycle, the remainder of this step is skipped. Otherwise, each postponed process that has resumed but has not been executed since its last resumption is executed until it suspends. Then T_n is recalculated according to the rules of step g). It is an error if the execution of any postponed process causes a delta cycle to occur immediately after the current simulation cycle.

The model is said to be at a *quiescent point* when the value returned by the function DOMAIN'EVENT is TRUE after step d).

NOTE 1—The initial value of any implicit signal of the form S'TRANSACTION is not defined.

NOTE 2—Updating of explicit signals is described in 12.6.2; updating of implicit signals is described in 12.6.3.

NOTE 3—When a process resumes, it is added to one of two sets of processes to be executed (the set of postponed processes and the set of nonpostponed processes). However, no process actually begins to execute until all signals have been updated and all executable processes for this simulation cycle have been identified. Nonpostponed processes are always executed during step f) of every simulation cycle, while postponed processes are executed during step i) of every simulation cycle that does not immediately precede a delta cycle.

NOTE 4—The second and third steps of the initialization phase and steps c) and d) of the simulation cycle may occur in interleaved fashion. This interleaving may occur because the implicit signal GUARD may be used as the prefix of another implicit signal; moreover, implicit signals may be associated as actuals with explicit signals, making the value of an explicit signal a function of an implicit signal.

NOTE 5—There are two quiescent points that differ in the value of the DOMAIN signal.

12.6.5 Augmentation sets

An *augmentation set* is a set of characteristic expressions, each corresponding to a scalar subelement of a source quantity or a scalar subelement of an implicit quantity of the form Q'DOT, Q'INTEG, and Q'DELAYED(T). The corresponding scalar subelement is said to be the *tag* of the characteristic expression. The tolerance group of the characteristic expression is the tolerance group of the tag.

There are five different augmentation sets. The *current augmentation set,* together with the structural set and an explicit set, is used by the analog solver to determine the values of the quantities. The determination of an augmentation set consists of the creation of the corresponding characteristic expressions and the determination of their tag and their tolerance group, and it makes the augmentation set the current augmentation set.

12.6.5.1 Quiescent state augmentation set

The quiescent state augmentation set is the collection of characteristic expressions that, when combined with the structural set and an explicit set, allows the analog solver to determine the quiescent or “DC” values of the quantities of the model.

Each scalar subelement of each source quantity is a characteristic expression of the quiescent state augmentation set.

Each scalar subelement of each quantity of the form Q'DOT is a characteristic expression of the quiescent state augmentation set.

Each scalar subelement of the prefix Q of each quantity of the form Q'INTEG is a characteristic expression of the quiescent state augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DELAYED(T) and the corresponding scalar subelement of its prefix Q is a characteristic expression of the quiescent state augmentation set.

12.6.5.2 Time domain augmentation set

The time domain augmentation set is the collection of characteristic expressions that, when combined with the structural set and an explicit set, allows the analog solver to determine the values of the quantities of the model over time.

Each scalar subelement of each source quantity is a characteristic expression of the time domain augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DOT and the derivative with respect to time of the corresponding scalar subelement of its prefix Q is a characteristic expression of the time domain augmentation set.

The difference between each scalar subelement of each quantity of the form Q'INTEG and the integral over time from 0.0 to T_c, the current time, of the corresponding scalar subelement of its prefix Q is a characteristic expression of the time domain augmentation set.

For quantities of the form Q'DELAYED(T) the following rules apply:

— If T = 0.0, the difference between each scalar subelement of Q'DELAYED(T) and the corresponding scalar subelement of its prefix Q is a characteristic expression of the time domain augmentation set.

— If T > 0.0 and T_c <= T, the difference between each scalar subelement of Q'DELAYED(T) and the value of the corresponding scalar subelement of its prefix Q at the quiescent point is a characteristic expression of the time domain augmentation set.

— If T > 0.0 and T_c > T, the difference between each scalar subelement of Q'DELAYED(T) and the value of the corresponding scalar subelement of its prefix Q at time T_c – T is a characteristic expression of the time domain augmentation set.

The derivative with respect to time and the integral over time have their conventional mathematical meaning.

12.6.5.3 Discontinuity augmentation set

The discontinuity augmentation set is the collection of characteristic expressions that, when combined with the structural set and an explicit set, defines initial conditions following a discontinuity that express the conservation of charge and flux in electrical systems (or their equivalents in other natures).

Each scalar subelement of each source quantity is a characteristic expression of the discontinuity augmentation set.

The difference between each scalar subelement of the prefix Q of each quantity of the form Q'DOT and the numeric value of that scalar subelement of Q when the discontinuity augmentation set is determined is a characteristic expression of the discontinuity augmentation set.

The difference between each scalar subelement of each quantity of the form Q'INTEG and the numeric value of that scalar subelement when the discontinuity augmentation set is determined is a characteristic expression of the discontinuity augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DELAYED(T) and the numeric value of that scalar subelement when the discontinuity augmentation set is determined is a characteristic expression of the discontinuity augmentation set.

12.6.5.4 Frequency domain augmentation set

The frequency domain augmentation set is the collection of characteristic expressions that, when combined with the structural set and the linearized form of an explicit set, allows the values of the quantities of the model at a specified frequency to be calculated.

The difference between each scalar subelement of each spectral source quantity and the value of the expression

(magnitude * (IEEE.MATH_REAL.COS(phase) +
IEEE.MATH_COMPLEX.CBASE_J * IEEE.MATH_REAL.SIN(phase))),

where magnitude and phase denote the corresponding scalar subelements of the magnitude simple expression and phase simple expression from the declaration of the spectral source quantity, is a characteristic expression of the frequency domain augmentation set.

Each scalar subelement of each noise source quantity is a characteristic expression of the frequency domain augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DOT and the corresponding scalar subelement of its prefix Q multiplied by the value of the expression

(IEEE.MATH_COMPLEX.MATH_CBASE_J * IEEE.MATH_REAL.MATH_2_PI * FREQUENCY)

is a characteristic expression of the frequency domain augmentation set.

The difference between each scalar subelement of each quantity of the form Q'INTEG and the corresponding scalar subelement of its prefix Q divided by the value of the expression

(IEEE.MATH_COMPLEX.MATH_CBASE_J * IEEE.MATH_REAL.MATH_2_PI * FREQUENCY)

is a characteristic expression of the frequency domain augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DELAYED(T) and the corresponding scalar subelement of its prefix Q multiplied by the value of the expression

(IEEE.MATH_REAL.COS(IEEE.MATH_REAL.MATH_2_PI * T * FREQUENCY) –
IEEE.MATH_COMPLEX.MATH_CBASE_J *
IEEE.MATH_REAL.SIN(IEEE.MATH_REAL.MATH_2_PI * T * FREQUENCY))

is a characteristic expression of the frequency domain augmentation set.

NOTE—The preceding definitions prefixed by the IEEE.MATH_REAL and IEEE.MATH_COMPLEX package names are defined in IEEE Std 1076.2-1996.

12.6.5.5 Noise augmentation set

The noise augmentation set is the collection of characteristic expressions that, when combined with the structural set and the linearized form of an explicit set, allows the noise values of the quantities of the model at a specified frequency to be calculated (see 12.8).

Each scalar subelement of each source quantity is a characteristic expression of the noise augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DOT and the corresponding scalar subelement of its prefix Q multiplied by the value of the expression

(IEEE.MATH_COMPLEX.MATH_CBASE_J * IEEE.MATH_REAL.MATH_2_PI * FREQUENCY)

is a characteristic expression of the noise augmentation set.

The difference between each scalar subelement of each quantity of the form Q'INTEG and the corresponding scalar subelement of its prefix Q divided by the value of the expression

(IEEE.MATH_COMPLEX.MATH_CBASE_J * IEEE.MATH_REAL.MATH_2_PI * FREQUENCY)

is a characteristic expression of the noise augmentation set.

The difference between each scalar subelement of each quantity of the form Q'DELAYED(T) and the corresponding scalar subelement of its prefix Q multiplied by the value of the expression

(IEEE.MATH_REAL.COS(IEEE.MATH_REAL.MATH_2_PI * T * FREQUENCY) –
IEEE.MATH_COMPLEX.MATH_CBASE_J *
IEEE.MATH_REAL.SIN(IEEE.MATH_REAL.MATH_2_PI * T * FREQUENCY))

is a characteristic expression of the noise augmentation set.

NOTE—The preceding definitions prefixed by the IEEE.MATH_REAL and IEEE.MATH_COMPLEX package names are defined in IEEE Std 1076.2-1996.

12.6.6 Analog solver

The analog solver is said to determine an *explicit set* of characteristic expressions when it evaluates the simultaneous statements appearing in the statement part of each block in the model.

The *characteristic number* of an external block is the number of scalar free quantities, scalar through quantities, and scalar interface quantities of mode **out** declared in the block, its entity, or its internal blocks, minus the number of scalar quantities associated with formal quantities of mode **out** in the external block.

It is an error if the number of characteristic expressions obtained by the evaluation of the simultaneous statements appearing in all statement parts of an external block and its internal blocks is not equal to the characteristic number of the external block or its internal blocks.

The analog solver has successfully determined an analog solution point when it has determined an explicit set of characteristic expressions and a value for each quantity such that another determination of an explicit set will yield the same explicit set and the evaluation of each characteristic expression of the model will yield a value sufficiently close to zero. Upon such a determination, the analog solver updates the kernel variable corresponding to each quantity with the determined value. A model is erroneous if, for any analog solution point, no such values for the quantities exist or if the values are not unique.

During the determination of an analog solution point, the analog solver may evaluate any characteristic expression a number of times, where each evaluation may provide different values for the quantities that appear in the characteristic expression (see 7.6 for a definition of what it means for a quantity name to appear in an expression). Any expression that evaluates to the same value each time it is evaluated during the determination of the same analog solution point with identical values for all of the quantities that appear in the expression, regardless of the number of times it is evaluated or the order in which the characteristic expressions in general are evaluated, is called *cycle pure*. A model is erroneous if any characteristic expression is not cycle pure. An implicit signal Q'ABOVE(E) is said to be *contradictory* when Q – E is sufficiently greater than 0.0 and Q'ABOVE(E)=FALSE, or when Q – E is sufficiently less than 0.0 and Q'ABOVE(E)=TRUE.

When the analog solver resumes at time T_c, if the break flag is set, the following steps occur:

a) The current augmentation set (which may have been modified by the application of a break set) is saved.

b) If the value of the predefined DOMAIN signal is TIME_DOMAIN, the discontinuity augmentation set is determined.

c) The break set is applied to the current augmentation set.

d) The analog solver determines an analog solution point.

e) The analog solver evaluates the expression in each step limit specification in the model. It is an error if any such expression has a non-positive value.

f) The augmentation set saved in step a) is restored and becomes the current augmentation set.

g) The break flag is cleared.

Otherwise, when the analog solver resumes at time T_c it simultaneously resets T_n to a new value T_n' and determines a sequence of times T_i in the interval $[T_c, T_n']$. T_n' is the lesser of T_n and the least value in the interval $[T_c, T_n]$ at which any signal Q'ABOVE(E) becomes contradictory. The times T_i shall include T_n'. At each time T_i the following steps occur:

1) The current time T_c is set equal to T_i.

2) If the value of the predefined DOMAIN signal is TIME_DOMAIN, the time domain augmentation set is determined.

3) The analog solver determines an analog solution point.

4) The analog solver evaluates the expression in each step limit specification in the model. It is an error if any such expression has a non-positive value.

Next, the analog solver assigns the waveform "**not** Q'ABOVE(E) **after** 0 sec" to the driver of each contradictory signal Q'ABOVE(E). Finally, the analog solver suspends.

NOTE 1—Each evaluation of the simultaneous statements appearing in all statement parts of a model may yield a different explicit set of characteristic expressions.

NOTE 2—The times T_i are not specified by the language. They are determined by the analog solver, typically based on the solution accuracy requested by the user. However, step limit specifications place an upper limit on the distance between two times T_i and T_{i+1}.

NOTE 3—The criteria determining sufficiency (as used in the phrases “sufficiently close to,” “sufficiently greater than,” and so on) are intended to be implementation-dependent and may vary from time to time and quantity to quantity to effect trade-offs between simulation time and accuracy of the result.

NOTE 4—Mode **out** on an interface quantity of a block indicates that this block provides one characteristic expression corresponding to the quantity set of which this interface quantity is a member.

NOTE 5—If none of the formals in a quantity set has mode **out**, then a characteristic expression shall be provided in the declarative region where the free quantity or unassociated interface quantity has been declared.

12.6.6.1 Application of the break set

The *break set* is a set of triples, each consisting of a selector quantity, a break quantity, and a value. It is formed by the execution of sequential break statements in each simulation cycle. The application of the break set modifies the current augmentation set.

For each triple in the break set, the difference between each scalar subelement of the break quantity and the corresponding scalar subelement of the value is a characteristic expression that replaces one of the following characteristic expressions in the current augmentation set:

— If the selector quantity is of the form Q'INTEG, the characteristic expression whose tag is the corresponding scalar subelement of Q'INTEG is replaced.

— If the selector quantity is of the form Q, the characteristic expression whose tag is the corresponding scalar subelement of Q'DOT is replaced.

Each characteristic expression formed from an element of the break set retains the tag and the tolerance group of the characteristic expression it replaces. It is an error if any scalar subelement of any quantity is selected more than once by any selector quantity in a break set.

After application, the break set is empty.

12.7 Time and the analog solver

The anonymous predefined floating-point type that is called *universal_time* in this standard is the representation for simulation time used by the analog solver.

The following four anonymous functions involving *universal_time* are called by their corresponding names in this standard:

```
function universal_to_physical_time (U: universal_time) return TIME;
function universal_to_real_time (U: universal_time) return REAL;
function physical_to_universal_time (N: TIME) return universal_time;
function real_to_universal_time (R: REAL) return universal_time;
```

The bounds and precision of *universal_time* shall be chosen and the implementations of the four functions on *universal_time* shall be defined so as to have the following characteristics. For U_0, U_1, U_2 of type *universal_time*, N, N_0 of type STD.STANDARD.TIME, and R, R_0 of type STD.STANDARD.REAL, all non-negative:

— universal_to_physical_time(physical_to_universal_time(N)) = N.

— universal_to_real_time(real_to_universal_time(R)) = R.

— physical_to_universal_time(0 sec) = real_to_universal_time(0.0).

— physical_to_universal_time(1 sec) = real_to_universal_time(1.0).

— If N_0 is that value of type TIME equal to one resolution limit unit then

$$0.0 <= \text{universal\_to\_physical\_time}(U_1+U_2) - \text{universal\_to\_physical\_time}(U_1) - \text{universal\_to\_physical\_time}(U_2) <= N_0.$$

— If U_0 is the smallest positive value of type *universal_time* such that

$$R_0 = \text{universal\_to\_real\_time}(U_0+U_1+U_2) - \text{universal\_to\_real\_time}(U_1+U_2) > 0.0,$$

then

$$0.0 <= \text{universal\_to\_real\_time}(U_1+U_2) - \text{universal\_to\_real\_time}(U_1) - \text{universal\_to\_real\_time}(U_2) <= R_0.$$

The kernel process variables T_c and T_n are objects of the type *universal_time*. The functions denoted STD.STANDARD.NOW is equivalent to universal_to_physical_time(T_c) (where it returns a value of type DELAY_LENGTH) and universal_to_real_time(T_c) (where it returns a value of type REAL).

A value U of type *universal_time* is said to correspond to or be the universal time *corresponding to* a value N of type TIME if physical_to_universal_time(N) = U. The value of STD.STANDARD.NOW that returns a value of type DELAY_LENGTH is said to be the *current discrete time*.

12.8 Frequency and noise calculation

The *small-signal model* is a set of characteristic expressions obtained by linearizing certain characteristic expressions of the model about a quiescent point.

Frequency domain and noise calculation consists of the determination of the small-signal model followed by the calculation of the frequency domain value or the noise value for each quantity at a particular frequency. This calculation involves complex values rather than real values.

The determination of the small-signal model involves the following steps:

a) The model is executed until it is at a quiescent point and the value of the DOMAIN signal is FREQUENCY_DOMAIN. The simulation cycle ends.
b) The analog solver determines an explicit set of characteristic expressions.
c) Each characteristic expression in the explicit set and in the structural set is replaced by its linearized form (see 7.6) with respect to all quantities whose names appear in the characteristic expression, evaluated at the values obtained in step a).

To calculate the frequency domain value for each quantity at a frequency F, the simulation frequency is first set to F. Then, the frequency domain augmentation set is determined. Finally, the value of each quantity is determined such that the evaluation of each characteristic expression yields a value sufficiently close to 0.0.

The calculation of the noise values for each quantity at frequency F involves the following steps:

1) The simulation frequency is set to F.
2) The noise augmentation set is determined.
3) For each noise source quantity in the model, the power simple expression is evaluated.
4) For each scalar quantity in the model, one variable of the base type of the corresponding quantity is created in the noise kernel and initialized to 0.0.
5) For each scalar subelement Q of each noise source quantity in the model:
   a) The characteristic expression whose tag is Q is replaced by the expression "Q – IEEE.MATH_REAL.SQRT(power)", where power is the value of the corresponding scalar subelement of the power simple expression of the noise source quantity evaluated in step 3).

   b) The value of each quantity is determined such that the evaluation of each characteristic expression yields a value sufficiently close to 0.0.
   c) The original characteristic expression replaced in step 5a) is restored.
   d) For each scalar quantity in the model the square of the magnitude of its value is added to its corresponding variable.

6) The value of each scalar quantity is set to the square root of its corresponding variable.

The predefined function FREQUENCY returns the value of the simulation frequency. It is an error if a function call whose function name denotes the predefined function FREQUENCY appears in an expression that is not part of a source aspect.

13. Lexical elements

The text of a description consists of one or more design files. The text of a design file is a sequence of lexical elements, each composed of characters; the rules of composition are given in this clause.

13.1 Character set

The only characters allowed in the text of a VHDL description (except within comments—see 13.8) are the graphic characters and format effectors. Each graphic character corresponds to a unique code of the ISO eight-bit coded character set (ISO/IEC 8859-1:1998 [B7]) and is represented (visually) by a graphical symbol.

basic_graphic_character ::=
    upper_case_letter | digit | special_character | space_character

graphic_character ::=
    basic_graphic_character | lower_case_letter | other_special_character

basic_character ::=
    basic_graphic_character | format_effector

The basic character set is sufficient for writing any description. The characters included in each of the categories of basic graphic characters are defined as follows:

a) Uppercase letters
   A B C D E F G H I J K L M N O P Q R S T U V W X Y Z À Á Â Ã Ä Å Æ Ç È É Ê Ë Ì Í Î Ï Ð Ñ Ò Ó Ô Õ Ö Ø Ù Ú Û Ü Ý Þ
b) Digits
   0 1 2 3 4 5 6 7 8 9
c) Special characters
   " # & ' () * + , - . / : ; < = > [ ] _ |
d) The space characters
   SPACE[5] NBSP[6]

Format effectors are the ISO (and ASCII) characters called *horizontal tabulation, vertical tabulation, carriage return, line feed,* and *form feed.*

The characters included in each of the remaining categories of graphic characters are defined as follows:

e) Lowercase letters
   a b c d e f g h i j k l m n o p q r s t u v w x y z ß à á â ã ä å æ ç è é ê ë ì í î ï ð ñ ò ó ô õ ö ø ù ú û ü ý þ ÿ
f) Other special characters
   ! $ % @ ? \ ^ ` { } ~ ¡ ¢ £ ¤ ¥ ¦ § ¨ © ª « ¬ ® ¯ ° ± ² ³ ´ µ ¶ · ¸ ¹ º » ¼ ½ ¾ ¿ × ÷ - (soft hyphen)

Allowable replacements for the special characters vertical line (|), number sign (#), and quotation mark (") are defined in 13.10.

[5]The visual representation of the space is the absence of a graphic symbol. It may be interpreted as a graphic character, a control character, or both.

[6]The visual representation of the nonbreaking space is the absence of a graphic symbol. It is used when a line break is to be prevented in the text as presented.

NOTE 1—The font design of graphical symbols (for example, whether they are in italic or bold typeface) is not part of ISO/IEC 8859-1:1998 [B7].

NOTE 2—The meanings of the acronyms used in this clause are as follows: ASCII stands for American Standard Code for Information Interchange, ISO stands for International Organization for Standardization.

NOTE 3—There are no uppercase equivalents for the characters ß and ÿ.

NOTE 4—The following names are used when referring to special characters:

Character	**Name**		
"	Quotation mark	£	Pound sign
#	Number sign	¤	Currency sign
&	Ampersand	¥	Yen sign
'	Apostrophe, tick	¦	Broken bar
(	Left parenthesis	§	Paragraph sign, clause sign
)	Right parenthesis	¨	Diaeresis
*	Asterisk, multiply	©	Copyright sign
+	Plus sign	ª	Feminine ordinal indicator
,	Comma	«	Left angle quotation mark
-	Hyphen, minus sign	¬	Not sign
.	Dot, point, period, full stop	-	Soft hyphen*
/	Slash, divide, solidus	®	Registered trademark sign
:	Colon	¯	Macron
;	Semicolon	°	Ring above, degree sign
<	Less-than sign	±	Plus-minus sign
=	Equals sign	²	Superscript two
>	Greater-than sign	³	Superscript three
_	Underline, low line	´	Acute accent
|	Vertical line, vertical bar	µ	Micro sign
!	Exclamation mark	¶	Pilcrow sign
$	Dollar sign	·	Middle dot
%	Percent sign	¸	Cedilla
?	Question mark	¹	Superscript one
@	Commercial at	º	Masculine ordinal indicator

*The soft hyphen is a graphic character that is represented by a graphic symbol identical with, or similar to, that representing a hyphen, for use when a line break has been established within a word.

Character	Name		
[	Left square bracket	»	Right angle quotation mark
\	Backslash, reverse solidus	¼	Vulgar fraction one quarter
]	Right square bracket	½	Vulgar fraction one half
^	Circumflex accent	¾	Vulgar fraction three quarters
`	Grave accent	¿	Inverted question mark
{	Left curly bracket	×	Multiplication sign
}	Right curly bracket	÷	Division sign
~	Tilde		
¡	Inverted exclamation mark		
¢	Cent sign		

13.2 Lexical elements, separators, and delimiters

The text of each design unit is a sequence of separate lexical elements. Each lexical element is either a delimiter, an identifier (which may be a reserved word), an abstract literal, a character literal, a string literal, a bit string literal, or a comment.

In some cases an explicit separator is required to separate adjacent lexical elements (namely when, without separation, interpretation as a single lexical element is possible). A separator is either a space character (SPACE or NBSP), a format effector, or the end of a line. A space character (SPACE or NBSP) is a separator except within an extended identifier, a comment, a string literal, or a space character literal.

The end of a line is always a separator. The language does not define what causes the end of a line. However if, for a given implementation, the end of a line is signified by one or more characters, then these characters shall be format effectors other than horizontal tabulation. In any case, a sequence of one or more format effectors other than horizontal tabulation shall cause at least one end-of-line.

One or more separators are allowed between any two adjacent lexical elements, before the first of each design unit or after the last lexical element of a design file. At least one separator is required between an identifier or an abstract literal and an adjacent identifier or abstract literal.

A delimiter is either one of the following special characters (in the basic character set):

& ' ( ) * + , - . / : ; < = > | [ ]

or one of the following compound delimiters, each composed of two adjacent special characters:

=> ** := /= >= <= <> ==

Each of the special characters listed for single character delimiters is a single delimiter except if this character is used as a character of a compound delimiter or as a character of an extended identifier, comment, string literal, character literal, or abstract literal.

The remaining forms of lexical elements are described in subclauses of this clause.

NOTE 1—Each lexical element shall fit on one line, since the end of a line is a separator. The quotation mark, number sign, and underline characters, likewise two adjacent hyphens, are not delimiters, but may form part of other lexical elements.

NOTE 2—The following names are used when referring to compound delimiters:

Delimiter	**Name**
=>	Arrow
**	Double star, exponentiate
:=	Variable assignment
/=	Inequality (pronounced "not equal")
>=	Greater than or equal
<=	Less than or equal; signal assignment
<>	Box
==	Double equal

13.3 Identifiers

Identifiers are used as names and also as reserved words.

identifier ::= basic_identifier | extended_identifier

13.3.1 Basic identifiers

A basic identifier consists only of letters, digits, and underlines.

basic_identifier ::=
    letter { [underline] letter_or_digit }

letter_or_digit ::= letter | digit

letter ::= upper_case_letter | lower_case_letter

All characters of a basic identifier are significant, including any underline character inserted between a letter or digit and an adjacent letter or digit. Basic identifiers differing only in the use of corresponding uppercase and lowercase letters are considered the same.

Examples:

```
COUNT     X      c_out         FFT                  Decoder
VHSIC     X1     PageCount     STORE_NEXT_ITEM
```

NOTE—No space (SPACE or NBSP) is allowed within a basic identifier, since a space is a separator.

13.3.2 Extended identifiers

Extended identifiers may contain any graphic character.

extended_identifier ::=
    \ graphic_character { graphic_character } \

If a backslash is to be used as one of the graphic characters of an extended literal, it shall be doubled. All characters of an extended identifier are significant (a doubled backslash counting as one character). Extended identifiers differing only in the use of corresponding uppercase and lowercase letters are distinct. Moreover, every extended identifier is distinct from any basic identifier.

Examples:

```
\BUS\     \bus\                    --  Two different identifiers,
                                   --  neither of which is
                                   --  the reserved word bus.
\a\\b\                             --  An identifier containing
                                   --  three characters.
VHDL      \VHDL\      \vhdl\       --  Three distinct identifiers.
```

13.4 Abstract literals

There are two classes of abstract literals: real literals and integer literals. A real literal is an abstract literal that includes a point; an integer literal is an abstract literal without a point. Real literals are the literals of the type *universal_real*. Integer literals are the literals of the type *universal_integer*.

abstract_literal ::= decimal_literal | based_literal

13.4.1 Decimal literals

A decimal literal is an abstract literal expressed in the conventional decimal notation (that is, the base is implicitly ten).

decimal_literal ::= integer [. integer] [exponent]

integer ::= digit { [underline] digit }

exponent ::= E [+] integer | E – integer

An underline character inserted between adjacent digits of a decimal literal does not affect the value of this abstract literal. The letter E of the exponent, if any, can be written either in lowercase or in uppercase, with the same meaning.

An exponent indicates the power of 10 by which the value of the decimal literal without the exponent is to be multiplied to obtain the value of the decimal literal with the exponent. An exponent for an integer literal shall not have a minus sign.

Examples:

```
12          0          1E6          123_456       --  Integer literals.
12.0        0.0        0.456        3.14159_26    --  Real literals.
1.34E-12    1.0E+6     6.023E+24                  --  Real literals
                                                  --  with exponents.
```

NOTE—Leading zeros are allowed. No space (SPACE or NBSP) is allowed in an abstract literal, not even between constituents of the exponent, since a space is a separator. A zero exponent is allowed for an integer literal.

13.4.2 Based literals

A based literal is an abstract literal expressed in a form that specifies the base explicitly. The base shall be at least two and at most sixteen.

based_literal ::=
  base # based_integer [. based_integer] # [exponent]

base ::= integer

based_integer ::=
  extended_digit { [underline] extended_digit }

extended_digit ::= digit | letter

An underline character inserted between adjacent digits of a based literal does not affect the value of this abstract literal. The base and the exponent, if any, are in decimal notation. The only letters allowed as extended digits are the letters A through F for the digits 10 through 15. A letter in a based literal (either an extended digit or the letter E of an exponent) can be written either in lowercase or in uppercase, with the same meaning.

The conventional meaning of based notation is assumed; in particular the value of each extended digit of a based literal shall be less than the base. An exponent indicates the power of the base by which the value of the based literal without the exponent is to be multiplied to obtain the value of the based literal with the exponent. An exponent for a based integer literal shall not have a minus sign.

Examples:

```
--  Integer literals of value 255:
    2#1111_1111#                16#FF#                016#0FF#

--  Integer literals of value 224:
    16#E#E1                     2#1110_0000#

--  Real literals of value 4095.0:
    16#F.FF#E+2                 2#1.1111_1111_111#E11
```

13.5 Character literals

A character literal is formed by enclosing one of the 191 graphic characters (including the space and nonbreaking space characters) between two apostrophe characters. A character literal has a value that belongs to a character type.

character_literal ::= ' graphic_character '

Examples:

```
'A'   '*'  '''   ' '
```

13.6 String literals

A string literal is formed by a sequence of graphic characters (possibly none) enclosed between two quotation marks used as string brackets.

string_literal ::= " { graphic_character } "

A string literal has a value that is a sequence of character values corresponding to the graphic characters of the string literal apart from the quotation mark itself. If a quotation mark value is to be represented in the sequence of character values, then a pair of adjacent quotation marks shall be written at the corresponding place within the string literal. (This means that a string literal that includes two adjacent quotation marks is never interpreted as two adjacent string literals.)

The length of a string literal is the number of character values in the sequence represented. (Each doubled quotation mark is counted as a single character.)

Examples:

```
"Setup time is too short"        --  An error message.
""                               --  An empty string literal.
" "    "A"    """"               --  Three string literals of length 1.

"Characters such as $, %, and } are allowed in string literals."
```

NOTE—A string literal shall fit on one line, since it is a lexical element (see 13.2). Longer sequences of graphic character values can be obtained by concatenation of string literals. The concatenation operation may also be used to obtain string literals containing nongraphic character values. The predefined type CHARACTER in package STANDARD specifies the enumeration literals denoting both graphic and nongraphic characters. Examples of such uses of concatenation are as follows:

```
"FIRST PART OF A SEQUENCE OF CHARACTERS " &
"THAT CONTINUES ON THE NEXT LINE"

"Sequence that includes the" & ACK & "control character"
```

13.7 Bit string literals

A bit string literal is formed by a sequence of extended digits (possibly none) enclosed between two quotations used as bit string brackets, preceded by a base specifier.

bit_string_literal ::= base_specifier " [bit_value] "

bit_value ::= extended_digit { [underline] extended_digit }

base_specifier ::= B | O | X

An underline character inserted between adjacent digits of a bit string literal does not affect the value of this literal. The only letters allowed as extended digits are the letters A through F for the digits 10 through 15. A letter in a bit string literal (either an extended digit or the base specifier) can be written either in lowercase or in uppercase, with the same meaning.

If the base specifier is 'B', the extended digits in the bit value are restricted to 0 and 1. If the base specifier is 'O', the extended digits in the bit value are restricted to legal digits in the octal number system, i.e., the digits 0 through 7. If the base specifier is 'X', the extended digits are all digits together with the letters A through F.

A bit string literal has a value that is a string literal consisting of the character literals '0' and '1'. If the base specifier is 'B', the value of the bit string literal is the sequence given explicitly by the bit value itself after any underlines have been removed.

If the base specifier is 'O' (respectively 'X'), the value of the bit string literal is the sequence obtained by replacing each extended digit in the bit_value by a sequence consisting of the three (respectively four) values representing that extended digit taken from the character literals '0' and '1'; as in the case of the base specifier 'B', underlines are first removed. Each extended digit is replaced as follows:

Extended digit	Replacement when the base specifier is 'O'	Replacement when the base specifier is 'X'
0	000	0000
1	001	0001
2	010	0010
3	011	0011
4	100	0100
5	101	0101
6	110	0110
7	111	0111
8	(illegal)	1000
9	(illegal)	1001
A	(illegal)	1010
B	(illegal)	1011
C	(illegal)	1100
D	(illegal)	1101
E	(illegal)	1110
F	(illegal)	1111

The *length* of a bit string literal is the length of its string literal value.

Example:

```
B"1111_1111_1111"    --  Equivalent to the string literal "111111111111".
X"FFF"                --  Equivalent to B"1111_1111_1111".
O"777"                --  Equivalent to B"111_111_111".
X"777"                --  Equivalent to B"0111_0111_0111".

constant c1: STRING := B"1111_1111_1111";

constant c2: BIT_VECTOR := X"FFF";

type MVL is ('X', '0', '1', 'Z');
type MVL_VECTOR is array (NATURAL range <>) of MVL;
constant c3: MVL_VECTOR := O"777";

assert c1'LENGTH = 12 and c2'LENGTH = 12 and c3 = "111111111";
```

13.8 Comments

A comment starts with two adjacent hyphens and extends up to the end of the line. A comment can appear on any line of a VHDL description and may contain any character except the format effectors vertical tab, carriage return, line feed, and form feed. The presence or absence of comments has no influence on whether a description is legal or illegal. Furthermore, comments do not influence the execution of a simulation module; their sole purpose is to enlighten the human reader.

Examples:

```
--  The last sentence above echoes the Algol 68 report.

end;  --  Processing of LINE is complete.

--  A long comment may be split onto
--  two or more consecutive lines.

-----------  The first two hyphens start the comment.
```

NOTE 1—Horizontal tabulation can be used in comments, after the double hyphen, and is equivalent to one or more spaces (SPACE characters) (see 13.2).

NOTE 2—Comments may contain characters that, according to 13.1, are non-printing characters. Implementations may interpret the characters of a comment as members of ISO/IEC 8859-1:1998 [B7], or of any other character set; for example, an implementation may interpret multiple consecutive characters within a comment as single characters of a multi-byte character set.

13.9 Reserved words

The following identifiers are called *reserved words* and are reserved for significance in the language. For readability of this standard, the reserved words appear in lowercase boldface.

abs	**file**	**nand**	**select**
access	**for**	**nature**	**severity**
across	**function**	**new**	**signal**
after		**next**	**shared**
alias	**generate**	**noise**	**sla**
all	**generic**	**nor**	**sll**
and	**group**	**not**	**spectrum**
architecture	**guarded**	**null**	**sra**
array			**srl**
assert	**if**	**of**	**subnature**
attribute	**impure**	**on**	**subtype**
	in	**open**	
begin	**inertial**	**or**	**terminal**
block	**inout**	**others**	**then**
body	**is**	**out**	**through**
break			**to**
buffer	**label**	**package**	**tolerance**
bus	**library**	**port**	**transport**
	limit	**postponed**	**type**
case	**linkage**	**procedural**	
component	**literal**	**procedure**	**unaffected**
configuration	**loop**	**process**	**units**
constant		**protected**	**until**
	map	**pure**	**use**
disconnect	**mod**		
downto		**quantity**	**variable**
else		**range**	**wait**
elsif		**record**	**when**
end		**reference**	**while**
entity		**register**	**with**
exit		**reject**	
		rem	**xnor**
		report	**xor**
		return	
		rol	
		ror	

A reserved word shall not be used as an explicitly declared identifier.

NOTE 1—Reserved words differing only in the use of corresponding uppercase and lowercase letters are considered as the same (see 13.3.1). The reserved words **across**, **range**, **reference**, **through**, and **tolerance** are also used as the names of predefined attributes.

NOTE 2—An extended identifier whose sequence of characters inside the leading and trailing backslashes is identical to a reserved word is not a reserved word. For example, \next\ is a legal (extended) identifier and is not the reserved word **next**.

13.10 Allowable replacements of characters

The following replacements are allowed for the vertical line, number sign, and quotation mark basic characters:

— A vertical line (|) can be replaced by an exclamation mark (!) where used as a delimiter.

— The number sign (#) of a based literal can be replaced by colons (:), provided that the replacement is done for both occurrences.

— The quotation marks (") used as string brackets at both ends of a string literal can be replaced by percent signs (%), provided that the enclosed sequence of characters contains no quotation marks, and provided that both string brackets are replaced. Any percent sign within the sequence of characters shall then be doubled, and each such doubled percent sign is interpreted as a single percent sign value. The same replacement is allowed for a bit string literal, provided that both bit string brackets are replaced.

These replacements do not change the meaning of the description.

NOTE 1—It is recommended that use of the replacements for the vertical line, number sign, and quotation marks be restricted to cases where the corresponding graphical symbols are not available. Note that the vertical line appears as a broken line on some equipment; replacement is not recommended in this case.

NOTE 2—The rules given for identifiers and abstract literals are such that lowercase and uppercase letters can be used indifferently; these lexical elements can thus be written using only characters of the basic character set.

NOTE 3—The use of these characters as replacement characters may be removed from a future version of the language. See Annex E.

14. Predefined language environment

This clause describes the predefined attributes of VHDL and the packages that all VHDL implementations shall provide.

14.1 Predefined attributes

Predefined attributes denote values, functions, types, and ranges associated with various kinds of named entities. These attributes are described as follows. For each attribute, the following information is provided:

- The kind of attribute: value, type, range, function, signal, or quantity
- The prefixes for which the attribute is defined
- A description of the parameters or arguments, if they exist
- The result of evaluating the attribute, and the result type (if applicable)
- If applicable, an equivalent block that defines the result of evaluating the attribute more precisely
- Any further restrictions or comments that apply

14.1.1 Predefined attributes of types and objects

T'BASE	Kind:	Type.
	Prefix:	Any type or subtype T.
	Result:	The base type of T.
	Restrictions:	This attribute is allowed only as the prefix of the name of another attribute; for example, T'BASE'LEFT.
T'LEFT	Kind:	Value.
	Prefix:	Any scalar type or subtype T.
	Result Type:	Same type as T.
	Result:	The left bound of T.
T'RIGHT	Kind:	Value.
	Prefix:	Any scalar type or subtype T.
	Result Type:	Same type as T.
	Result:	The right bound of T.
T'HIGH	Kind:	Value.
	Prefix:	Any scalar type or subtype T.
	Result Type:	Same type as T.
	Result:	The upper bound of T.
T'LOW	Kind:	Value.
	Prefix:	Any scalar type or subtype T.
	Result Type:	Same type as T.
	Result:	The lower bound of T.

T'ASCENDING	Kind:	Value.
	Prefix:	Any scalar type or subtype T.
	Result Type:	Type Boolean
	Result:	It is TRUE if T is defined with an ascending range; FALSE otherwise.
T'IMAGE(X)	Kind:	Function.
	Prefix:	Any scalar type or subtype T.
	Parameter:	An expression whose type is the base type of T.
	Result Type:	Type String.
	Result:	The string representation of the parameter value, without leading or trailing whitespace. If T is an enumeration type or subtype and the parameter value is either an extended identifier or a character literal, the result is expressed with both a leading and trailing reverse solidus (backslash) (in the case of an extended identifier) or apostrophe (in the case of a character literal); in the case of an extended identifier that has a backslash, the backslash is doubled in the string representation. If T is an enumeration type or subtype and the parameter value is a basic identifier, then the result is expressed in lowercase characters. If T is a numeric type or subtype, the result is expressed as the decimal representation of the parameter value without underlines or leading or trailing zeros (except as necessary to form the image of a legal literal with the proper value); moreover, an exponent may (but is not required to) be present and the language does not define under what conditions it is or is not present. If the exponent is present, the "e" is expressed as a lowercase character. If T is a physical type or subtype, the result is expressed in terms of the primary unit of T unless the base type of T is TIME, in which case the result is expressed in terms of the resolution limit (see 3.1.3.1); in either case, if the unit is a basic identifier, the image of the unit is expressed in lowercase characters. If T is a floating-point type or subtype, the number of digits to the right of the decimal point corresponds to the standard form generated when the DIGITS parameter to TextIO. Write for type REAL is set to 0 (see 14.3). The result never contains the replacement characters described in 13.10.
	Restrictions:	It is an error if the parameter value does not belong to the subtype implied by the prefix.
T'VALUE(X)	Kind:	Function.
	Prefix:	Any scalar type or subtype T.
	Parameter:	An expression of type String.
	Result Type:	The base type of T.
	Result:	The value of T whose string representation (as defined in Clause 13) is given by the parameter. Leading and trailing whitespace is allowed and ignored. If T is a numeric type or subtype, the parameter shall be expressed either as a decimal literal or as a based literal. If T is a physical type or subtype, the parameter shall be expressed using a string representation of any of the unit names of T, with or without a leading abstract literal. The parameter shall have whitespace between any abstract literal and the unit name. The replacement characters of 13.10 are allowed in the parameter.
	Restrictions:	It is an error if the parameter is not a valid string representation of a literal of type T or if the result does not belong to the subtype implied by T.

T'POS(X)	Kind:	Function.
	Prefix:	Any discrete or physical type or subtype T.
	Parameter:	An expression whose type is the base type of T.
	Result Type:	*universal_integer*.
	Result:	The position number of the value of the parameter.
T'VAL(X)	Kind:	Function.
	Prefix:	Any discrete or physical type or subtype T.
	Parameter:	An expression of any integer type.
	Result Type:	The base type of T.
	Result:	The value whose position number is the *universal_integer* value corresponding to X.
	Restrictions:	It is an error if the result does not belong to the range T'LOW **to** T'HIGH.
T'SUCC(X)	Kind:	Function.
	Prefix:	Any discrete or physical type or subtype T.
	Parameter:	An expression whose type is the base type of T.
	Result Type:	The base type of T.
	Result:	The value whose position number is one greater than that of the parameter.
	Restrictions:	An error occurs if X equals T'HIGH or if X does not belong to the range T'LOW **to** T'HIGH.
T'PRED(X)	Kind:	Function.
	Prefix:	Any discrete or physical type or subtype T.
	Parameter:	An expression whose type is the base type of T.
	Result Type:	The base type of T.
	Result:	The value whose position number is one less than that of the parameter.
	Restrictions:	An error occurs if X equals T'LOW or if X does not belong to the range T'LOW **to** T'HIGH.
T'LEFTOF(X)	Kind:	Function.
	Prefix:	Any discrete or physical type or subtype T.
	Parameter:	An expression whose type is the base type of T.
	Result Type:	The base type of T.
	Result:	The value that is to the left of the parameter in the range of T.
	Restrictions:	An error occurs if X equals T'LEFT or if X does not belong to the range T'LOW **to** T'HIGH.

T'RIGHTOF(X)	Kind:	Function.
	Prefix:	Any discrete or physical type or subtype T.
	Parameter:	An expression whose type is the base type of T.
	Result Type:	The base type of T.
	Result:	The value that is to the right of the parameter in the range of T.
	Restrictions:	An error occurs if X equals T'RIGHT or if X does not belong to the range T'LOW **to** T'HIGH.

NOTE 1—The relationship between the values of the LEFT, RIGHT, LOW, and HIGH attributes is expressed as follows:

		Ascending range	**Descending range**
T'LEFT	=	T'LOW	T'HIGH
T'RIGHT	=	T'HIGH	T'LOW

NOTE 2—For all values V of any scalar type T except a real type, the following relation holds:

V = T'Value(T'Image(V))

14.1.2 Predefined attributes of arrays

A'LEFT [(N)]	Kind:	Function.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	Type of the left bound of the Nth index range of A.
	Result:	Left bound of the Nth index range of A. (If A is an alias for an array object, then the result is the left bound of the Nth index range from the declaration of A, not that of the object.)
A'RIGHT [(N)]	Kind:	Function.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	Type of the Nth index range of A.
	Result:	Right bound of the Nth index range of A. (If A is an alias for an array object, then the result is the right bound of the Nth index range from the declaration of A, not that of the object.)

A'HIGH [(N)]	Kind:	Function.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	Type of the Nth index range of A.
	Result:	Upper bound of the Nth index range of A. (If A is an alias for an array object, then the result is the upper bound of the Nth index range from the declaration of A, not that of the object.)
A'LOW [(N)]	Kind:	Function.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	Type of the Nth index range of A.
	Result:	Lower bound of the Nth index range of A. (If A is an alias for an array object, then the result is the lower bound of the Nth index range from the declaration of A, not that of the object.)
A'RANGE [(N)]	Kind:	Range.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	The type of the Nth index range of A.
	Result:	The range A'LEFT(N) **to** A'RIGHT(N) if the Nth index range of A is ascending, or the range A'LEFT(N) **downto** A'RIGHT(N) if the Nth index range of A is descending. (If A is an alias for an array object, then the result is determined by the Nth index range from the declaration of A, not that of the object.)
A'REVERSE_RANGE [(N)]	Kind:	Range.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	The type of the Nth index range of A.
	Result:	The range A'RIGHT(N) **downto** A'LEFT(N) if the Nth index range of A is ascending, or the range A'RIGHT(N) **to** A'LEFT(N) if the Nth index range of A is descending. (If A is an alias for an array object, then the result is determined by the Nth index range from the declaration of A, not that of the object.)

A'LENGTH [(N)]	Kind:	Value.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal_integer*, the value of which shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	*universal_integer*.
	Result:	Number of values in the Nth index range; i.e., if the Nth index range of A is a null range, then the result is 0. Otherwise, the result is the value of T'POS(A'HIGH(N)) – T'POS(A'LOW(N)) + 1, where T is the subtype of the Nth index of A.
A'ASCENDING [(N)]	Kind:	Value.
	Prefix:	Any prefix A that is appropriate for an array object, or an alias thereof, or that denotes a constrained array subtype or subnature.
	Parameter:	A locally static expression of type *universal integer*, the value of which shall be greater than zero and shall not exceed the dimensionality of A. If omitted, it defaults to 1.
	Result Type:	Type Boolean.
	Result:	TRUE if the Nth index range of A is defined with an ascending range; FALSE otherwise.

14.1.3 Predefined attributes of signals

S'DELAYED [(T)]	Kind:	Signal.
	Prefix:	Any signal denoted by the static signal name S.
	Parameter:	A static expression of type TIME that evaluates to a non-negative value. If omitted, it defaults to 0 ns.
	Result Type:	The base type of S.
	Result:	A signal equivalent to signal S delayed T units of time.

Let R be of the same subtype as S, let T >= 0 ns, and let P be a process statement of the form

```
P: process (S)
   begin
      R <= transport S after T;
end process;
```

Assuming that the initial value of R is the same as the initial value of S, then the attribute 'DELAYED is defined such that S'DELAYED(T) = R for any T.

S'STABLE [(T)]	Kind:	Signal.
	Prefix:	Any signal denoted by the static signal name S.
	Parameter:	A static expression of type TIME that evaluates to a non-negative value. If omitted, it defaults to 0 ns.
	Result Type:	Type Boolean.
	Result:	A signal that has the value TRUE when the universal time of the last event on S is less than the universal time corresponding to NOW – T, and the value FALSE otherwise (see 12.6.2).

S'QUIET [(T)]	Kind:	Signal.
	Prefix:	Any signal denoted by the static signal name S.
	Parameter:	A static expression of type TIME that evaluates to a non-negative value. If omitted, it defaults to 0 ns.
	Result Type:	Type Boolean.
	Result:	A signal that has the value TRUE when the universal time of the last transaction on S is less than the universal time corresponding to NOW – T, and the value FALSE otherwise (see 12.6.2).
S'TRANSACTION	Kind:	Signal.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type Bit.
	Result:	A signal whose value toggles to the inverse of its previous value in each simulation cycle in which signal S becomes active.
	Restrictions:	A description is erroneous if it depends on the initial value of S'Transaction.
S'EVENT	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type Boolean.
	Result:	A value that indicates whether an event has just occurred on signal S. Specifically:

For a scalar signal S, S'EVENT returns the value TRUE if an event has occurred on S during the current simulation cycle; otherwise, it returns the value FALSE.

For a composite signal S, S'EVENT returns TRUE if an event has occurred on any scalar subelement of S during the current simulation cycle; otherwise, it returns FALSE.

S'ACTIVE	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type Boolean.
	Result:	A value that indicates whether signal S is active. Specifically:

For a scalar signal S, S'ACTIVE returns the value TRUE if signal S is active during the current simulation cycle and S has been updated; otherwise, it returns the value FALSE.

For a composite signal S, S'ACTIVE returns TRUE if any scalar subelement of S is active during the current simulation cycle and has been updated; otherwise, it returns FALSE.

S'LAST_EVENT	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type Time.
	Result:	The amount of time that has elapsed since the last event occurred on signal S. Specifically:

For a signal S, S'LAST_EVENT returns the smallest value T of type TIME such that S'EVENT = True during any simulation cycle at time NOW – T, if such a value exists; otherwise, it returns TIME'HIGH.

S'LAST_EVENT	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type REAL.
	Result:	The amount of time that has elapsed since the last event occurred on signal S. Specifically:
	For a signal S, S'LAST_EVENT returns the smallest value T of type REAL such that S'EVENT = TRUE during any simulation cycle at time NOW – T, if such a value exists; otherwise, it returns universal_to_real_time(U) where U is the universal time corresponding to TIME'HIGH.	
S'LAST_ACTIVE	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type Time.
	Result:	The amount of time that has elapsed since the last time at which signal S was active. Specifically:
	For a signal S, S'LAST_ACTIVE returns the smallest value T of type TIME such that S'ACTIVE = True during any simulation cycle at time NOW – T, if such value exists; otherwise, it returns TIME'HIGH.	
S'LAST_VALUE	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	The base type of S.
	Result:	The previous value of S, immediately before the last change of S.
S'DRIVING	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	Type Boolean.
	Result:	If the prefix denotes a scalar signal, the result is False if the current value of the driver for S in the current process is determined by the null transaction; True otherwise. If the prefix denotes a composite signal, the result is True if and only if R'DRIVING is True for every scalar subelement R of S; False otherwise. If the prefix denotes a null slice of a signal, the result is True.
	Restrictions:	This attribute is available only from within a process, a concurrent statement with an equivalent process, or a subprogram. If the prefix denotes a port, it is an error if the port does not have a mode of **inout**, **out**, or **buffer**. It is also an error if the attribute name appears in a subprogram body that is not a declarative item contained within a process statement and the prefix is not a formal parameter of the given subprogram or of a parent of that subprogram. Finally, it is an error if the prefix denotes a subprogram formal parameter whose mode is not **inout** or **out**.

S'DRIVING_VALUE	Kind:	Function.
	Prefix:	Any signal denoted by the static signal name S.
	Result Type:	The base type of S.
	Result:	If S is a scalar signal S, the result is the current value of the driver for S in the current process. If S is a composite signal, the result is the aggregate of the values of R'DRIVING_VALUE for each element R of S. If S is a null slice, the result is a null slice.
	Restrictions:	This attribute is available only from within a process, a concurrent statement with an equivalent process, or a subprogram. If the prefix denotes a port, it is an error if the port does not have a mode of **inout**, **out**, or **buffer**. It is also an error if the attribute name appears in a subprogram body that is not a declarative item contained within a process statement and the prefix is not a formal parameter of the given subprogram or of a parent of that subprogram. Finally, it is an error if the prefix denotes a subprogram formal parameter whose mode is not **inout** or **out**, or if S'DRIVING is False at the time of the evaluation of S'DRIVING_VALUE.

NOTE 1—Since the attributes S'EVENT, S'ACTIVE, S'LAST_EVENT, S'LAST_ACTIVE, and S'LAST_VALUE are functions, not signals, they cannot cause the execution of a process, even though the value returned by such a function may change dynamically. It is thus recommended that the equivalent signal-valued attributes S'STABLE and S'QUIET, or expressions involving those attributes, be used in concurrent contexts such as guard expressions or concurrent signal assignments. Similarly, function STANDARD.NOW should not be used in concurrent contexts.

NOTE 2—S'DELAYED(0 ns) is not equal to S during any simulation cycle where S'EVENT is true.

NOTE 3—S'STABLE(0 ns) = (S'DELAYED(0 ns) = S), and S'STABLE(0 ns) is FALSE only during a simulation cycle in which S has had a transaction.

NOTE 4—For a given simulation cycle, S'QUIET(0 ns) is TRUE if and only if S is quiet for that simulation cycle.

NOTE 5—If S'STABLE(T) is FALSE, then, by definition, for some t where 0 ns < t < T, S'DELAYED(t) /= S.

NOTE 6—If Ts is the smallest value such that S'STABLE (T_s) is FALSE, then for all t where 0 ns < t < T_s, S'DELAYED(t) = S.

NOTE 7—S'EVENT should not be used within a postponed process (or a concurrent statement that has an equivalent postponed process) to determine if the prefix signal S caused the process to resume. However, S'LAST_EVENT = 0 ns can be used for this purpose.

14.1.4 Predefined attributes of named entities

E'SIMPLE_NAME	Kind:	Value.
	Prefix:	Any named entity as defined in 5.1.
	Result Type:	Type String.
	Result:	The simple name, character literal, or operator symbol of the named entity, without leading or trailing whitespace or quotation marks but with apostrophes (in the case of a character literal) and both a leading and trailing reverse solidus (backslash) (in the case of an extended identifier). In the case of a simple name or operator symbol, the characters are converted to their lowercase equivalents. In the case of an extended identifier, the case of the identifier is preserved, and any reverse solidus characters appearing as part of the identifier are represented with two consecutive reverse solidus characters.

E'INSTANCE_NAME	Kind:	Value.
	Prefix:	Any named entity other than the local ports and generics of a component declaration.
	Result Type:	Type String.
	Result:	A string describing the hierarchical path starting at the root of the design hierarchy and descending to the named entity, including the names of instantiated design entities. Specifically:

The result string has the following syntax:

```
instance_name ::= package_based_path | full_instance_based_path

package_based_path ::=
    leader *library*_logical_name leader
        [ *package*_simple_name leader ]
        { *subprogram*_simple_name signature leader }
        [ local_item_name ]

full_instance_based_path ::= leader full_path_to_instance [ local_item_name ]

full_path_to_instance ::= { full_path_instance_element leader }

local_item_name ::=
    simple_name
    character_literal
    operator_symbol

full_path_instance_element ::=
    [ *component_instantiation*_label @ ]
        *entity*_simple_name ( *architecture*_simple_name )
    | *block*_label
    | generate_label
    | process_label
    | *procedural*_label
    | *loop*_label
    | *subprogram*_simple_name signature

generate_label ::= *generate*_label [ ( literal ) ]

process_label ::= [ *process*_label ]

leader ::= :
```

Package-based paths identify items declared within packages. Full-instance-based paths identify items within an elaborated design hierarchy.

A library logical name denotes a library (see 11.2). Since it is possible for multiple logical names to denote the same library, the library logical name may not be unique.

The local item name in E'INSTANCE_NAME equals E'SIMPLE_NAME, unless E denotes a library, package, subprogram, or label. In this latter case, the package-based path or full-instance-based path, as appropriate, will not contain a local item name.

There is one full path instance element for each component instantiation, block statement, generate statement, process statement, simultaneous procedural statement, or subprogram body in the design hierarchy between the root design entity and the named entity denoted by the prefix.

In a full path instance element, the architecture simple name shall denote an architecture associated with the entity declaration designated by the entity simple name; furthermore, the component instantiation label (and the commercial at following it) are required unless the entity simple name and the architecture simple name together denote the root design entity.

The literal in a generate label is required if the label denotes a generate statement with a for generation scheme; the literal shall denote one of the values of the generate parameter.

A process statement with no label is denoted by an empty process label.

All characters in basic identifiers appearing in the result are converted to their lowercase equivalents. Both a leading and trailing reverse solidus surround an extended identifier appearing in the result; any reverse solidus characters appearing as part of the identifier are represented with two consecutive reverse solidus characters.

E'PATH_NAME	Kind:	Value.
	Prefix:	Any named entity other than the local ports and generics of a component declaration.
	Result Type:	Type String.
	Result:	A string describing the hierarchical path starting at the root of the design hierarchy and descending to the named entity, excluding the name of instantiated design entities. Specifically:

The result string has the following syntax:

path_name ::= package_based_path | instance_based_path

instance_based_path ::=
  leader path_to_instance [local_item_name]

path_to_instance ::= { path_instance_element leader }

path_instance_element ::=
  *component_instantiation*_label
  | *entity*_simple_name
  | *block*_label
  | generate_label
  | process_label
  | *procedural*_label
  | *subprogram*_simple_name signature

Package-based paths identify items declared within packages. Instance-based paths identify items within an elaborated design hierarchy.

The local item name in E'PATH_NAME equals E'SIMPLE_NAME, unless E denotes a library, package, subprogram, or label. In this latter case, the package-based path or instance-based path, as appropriate, will not contain a local item name.

There is one path instance element for each component instantiation, block statement, generate statement, process statement, simultaneous procedural statement, or subprogram body in the design hierarchy between the root design entity and the named entity denoted by the prefix.

Examples:

```
library Lib;    -- All design units are in this library:
package P is    --  P'PATH_NAME = ":lib:p:"
                --  P'INSTANCE_NAME = ":lib:p:"
   procedure Proc (F: inout INTEGER);
      -- Proc'PATH_NAME = ":lib:p:proc [integer]:"
      -- Proc'INSTANCE_NAME = ":lib:p:proc [integer]:"
   constant C: INTEGER := 42;    --  C'PATH_NAME = ":lib:p:c"
end package P;                   --  C'INSTANCE_NAME = ":lib:p:c"

package body P is
   procedure Proc (F: inout INTEGER) is
      variable x: INTEGER;    --  x'PATH_NAME = ":lib:p:proc [integer]:x"
   begin                      --  x'INSTANCE_NAME = ":lib:p:proc [integer]:x"
      .
      .
      .
   end;
end;
```

```
library Lib;
use Lib.P.all;             --  Assume that E is in Lib and
entity E is                --  E is the top-level design entity:
                           --  E'PATH_NAME = ":e:"
                           --  E'INSTANCE_NAME = ":e(a):"
   generic (G: INTEGER);   --  G'PATH_NAME = ":e:g"
                           --  G'INSTANCE_NAME = ":e(a):g"
   port (P: in INTEGER);   --  P'PATH_NAME = ":e:p"
end entity E;              --  P'INSTANCE_NAME = ":e(a):p"

architecture A of E is
   signal S: BIT_VECTOR (1 to G);   --  S'PATH_NAME = ":e:s"
                                    --  S'INSTANCE_NAME = ":e(a):s"
   procedure Proc1 (signal sp1: NATURAL; C: out INTEGER) is
      --  Proc1'PATH_NAME = ":e:proc1[natural,integer]:"
      --  Proc1'INSTANCE_NAME = ":e(a):proc1[natural,integer]:"
      --  C'PATH_NAME = ":e:proc1[natural,integer]:c"
      --  C'INSTANCE_NAME = ":e(a):proc1[natural,integer]:c"
      variable max: DELAY_LENGTH;
         --  max'PATH_NAME = ":e:proc1[natural,integer]:max"
         --  max'INSTANCE_NAME = ":e(a):proc1[natural,integer]:max"
   begin
      max := sp1 * ns;
      wait on sp1 for max;
      c := sp1;
   end procedure Proc1;

begin
   p1: process
      variable T: INTEGER := 12;   --  T'PATH_NAME =  :e:p1:t"
   begin                           --  T'INSTANCE_NAME = ":e(a):p1:t"
      .
      .
      .
   end process p1;

   process
      variable T: INTEGER := 12;   --  T'PATH_NAME = ":e::t"
   begin                           --  T'INSTANCE_NAME = ":e(a)::t"
      .
      .
      .
   end process ;
end architecture;

entity Bottom is
   generic (GBottom: INTEGER);
   port (PBottom: INTEGER);
end entity Bottom;

architecture BottomArch of Bottom is
   signal SBottom: INTEGER;
begin
   ProcessBottom: process
      variable V: INTEGER;
   begin
      if GBottom = 4 then
         assert V'Simple_Name = "v"
```

```
                and V'Path_Name = ":top:b1:b2:g1(4):b3:l1:processbottom:v"
                and V'Instance_Name =
      ":top(top):b1:b2:g1(4):b3:l1@bottom(bottomarch):processbottom:v";
         assert GBottom'Simple_Name = "gbottom"
                and GBottom'Path_Name = ":top:b1:b2:g1(4):b3:l1:gbottom"
                and GBottom'Instance_Name =
                ":top(top):b1:b2:g1(4):b3:l1@bottom(bottomarch):gbottom";

      elsif GBottom = -1 then
         assert V'Simple_Name = "v"
                and V'Path_Name = ":top:l2:processbottom:v"
                and V'Instance_Name =
                ":top(top):l2@bottom(bottomarch):processbottom:v";
         assert GBottom'Simple_Name = "gbottom"
                and GBottom'Path_Name = "top:l2:gbottom"
                and GBottom'Instance_Name =
                ":top(top):l2@bottom(bottomarch):gbottom";
      end if;
      wait;
   end process ProcessBottom;
end architecture BottomArch;

entity Top is end Top;

architecture Top of Top is
   component BComp is
      generic (GComp: INTEGER)
      port (PComp: INTEGER);

   end component BComp;
   signal S: INTEGER;
begin
   B1: block
      signal S: INTEGER;
   begin
      B2: block
         signal S: INTEGER;
      begin
         G1: for I in 1 to 10 generate
            B3: block
               signal S: INTEGER;
               for L1: BComp use entity Work.Bottom(BottomArch)
                  generic map (GBottom => GComp)
                  port map (PBottom => PComp);
            begin
               L1: BComp generic map (I) port map (S);
               P1: process
                  variable V: INTEGER;
               begin
                  if I = 7 then
                     assert V'Simple_Name = "v"
                            and V'Path_Name = ":top:b1:b2:g1(7):b3:p1:v"
                            and V'Instance_Name =
                                ":top(top):b1:b2:g1(7):b3:p1:v";
                     assert P1'Simple_Name = "p1"
                            and P1'Path_Name = ":top:b1:b2:g1(7):b3:p1:"
                            and P1'Instance_Name =
                                ":top(top):b1:b2:g1(7):b3:p1:";
                     assert S'Simple_Name = "s"
```

```
                                and S'Path_Name = ":top:b1:b2:g1(7):b3:s"
                                and S'Instance_Name =
                                    ":top(top):b1:b2:g1(7):b3:s";
                         assert B1.S'Simple_Name = "s"
                                and B1.S'Path_Name = ":top:b1:s"
                                and B1.S'Instance_Name = ":top(top):b1:s";
                      end if;
                      wait;
                   end process P1;
                end block B3;
             end generate;
          end block B2;
       end block B1;
       L2: BComp generic map (-1) port map (S);
    end architecture Top;

    configuration TopConf of Top is
       for Top
          for L2: BComp use
             entity Work.Bottom(BottomArch)
                generic map (GBottom => GComp)
                port map (PBottom => PComp);
          end for;
       end for;
    end configuration TopConf;
```

NOTE 1—The values of E'PATH_NAME and E'INSTANCE_NAME are not unique. Specifically, named entities in two different, unlabeled processes may have the same path names or instance names. Overloaded subprograms, and named entities within them, may also have the same path names or instance names.

NOTE 2—If the prefix to the attributes 'SIMPLE_NAME, 'PATH_NAME, or 'INSTANCE_NAME denotes an alias, the result is respectively the simple name, path name, or instance name of the alias. See 6.6.

14.1.5 Predefined analog and mixed-signal attributes

N'ACROSS	Kind:	Type.
	Prefix:	Any nature or subnature N.
	Result:	The across type of the nature denoted by N.
N'THROUGH	Kind:	Type.
	Prefix:	Any nature or subnature N.
	Result:	The through type of the nature denoted by N.
T'REFERENCE	Kind:	Quantity.
	Prefix:	Any terminal denoted by the static terminal name T.
	Result Type:	The across type of the nature of terminal T.
	Result:	The across quantity whose plus terminal is T and whose minus terminal is the reference terminal of the nature of T.
T'CONTRIBUTION	Kind:	Quantity.
	Prefix:	Any terminal denoted by the static terminal name T.
	Result Type:	The through type of the nature of terminal T.
	Result:	The contribution quantity of terminal T.

T'TOLERANCE	Kind:	Value.
	Prefix:	Any floating-point type or subtype T.
	Result Type:	Type STRING.
	Result:	The tolerance group of T.
Q'TOLERANCE	Kind:	Value.
	Prefix:	Any scalar quantity denoted by the static name Q.
	Result Type:	Type STRING.
	Result:	The tolerance group of Q.
Q'DOT	Kind:	Quantity.
	Prefix:	Any quantity denoted by the static name Q.
	Result Type:	The subtype of Q.
	Result:	The derivative with respect to time of Q at the time the attribute is evaluated.
	Restrictions:	It is an error if the prefix is an attribute name of the form Q'INTEG, for any quantity Q.
Q'INTEG	Kind:	Quantity.
	Prefix:	Any quantity denoted by the static name Q.
	Result Type:	The subtype of Q.
	Result:	The time integral of Q from time 0 to the time the attribute is evaluated.
	Restrictions:	It is an error if the prefix is an attribute name of the form Q'DOT, for any quantity Q.
Q'DELAYED[(T)]	Kind:	Quantity.
	Prefix:	Any quantity denoted by the static name Q.
	Parameter:	A static expression of type REAL that evaluates to a non-negative number. If omitted, defaults to 0.0.
	Result Type:	The subtype of Q.
	Result:	A quantity equal to Q delayed by T.
Q'ABOVE(E)	Kind:	Signal.
	Prefix:	Any scalar quantity denoted by the static name Q.
	Parameter:	An expression of the same type as Q. Any quantity appearing in the expression shall be denoted by a static name.
	Result Type:	Type BOOLEAN.
	Result:	TRUE if Q – E is sufficiently larger than 0.0, FALSE if Q – E is sufficiently smaller than 0.0, Q'ABOVE(E)'DELAYED otherwise.

NOTE—Although the name of any quantity appearing in the expression E in Q'ABOVE(E) shall be a static name, the expression is not required to be static. This is different from any other attribute names whose parameters, if present, shall be static expressions.

Q'ZOH (T [, INITIAL_DELAY])	Kind:	Quantity.
	Prefix:	Any quantity denoted by the static name Q.
	Parameters:	T: A static expression of type REAL that evaluates to a positive value. This is the sampling period. INITIAL_DELAY: A static expression of type REAL that evaluates to a non-negative value. The first sampling will occur after INITIAL_DELAY seconds. If omitted, it defaults to 0.0.
	Result Type:	The subtype of Q.
	Result:	A quantity where the value of each scalar subelement is set to the value of the corresponding scalar subelement of Q at the sampling times INITIAL_DELAY + k*T (where k is any non-negative integer) and held constant till the next sampling time.

Suppose that QZOH is an alias for any scalar subelement of the attribute name, that QTYPE designates its type, that QELEM is an alias for the corresponding scalar subelement of Q, and that T and INITIAL_DELAY designate the actual or defaulted values of the parameters with the same names. Then the behavior of each scalar subelement of Q'ZOH is formally described by the value of QZOH produced by the following equivalent block:

```
use ieee.math_real.all;
block
   generic (t: REAL; initial_delay: REAL);
   generic map (t => real(T),
                initial_delay => real(INITIAL_DELAY));
   port (quantity q: in REAL; quantity zoh: out REAL);
   port map (q => real(QELEM), QTYPE(zoh) => QZOH);
   constant pi_t: REAL := math_pi * t;   signal s: REAL := 0.0;
begin
   process
   begin
      wait on DOMAIN;
      if initial_delay > 0.0 then
         wait for initial_delay;
      end if;
      loop
         s <= q; wait for t;
      end loop;
   end process;
   break on s when s /= q;
   if DOMAIN = FREQUENCY_DOMAIN use
      if FREQUENCY = 0.0 use
         zoh == q;
      else
         zoh == q'Delayed(0.5 * t)*sin(FREQUENCY*pi_t)
                                 /(FREQUENCY*pi_t);
      end use;
   elsif DOMAIN'DELAYED = QUIESCENT_DOMAIN use
      if initial_delay = 0.0 use
         zoh == q;
      else
         zoh == 0.0;
      end use;
   else
      zoh == s;
   end use;
end block;
```

NOTE—This is not a legal VHDL 1076.1 description although it uses VHDL 1076.1 syntax. The predefined FREQUENCY function cannot be called in a simultaneous statement.

Q'LTF(NUM, DEN)	Kind:	Quantity.
	Prefix:	Any scalar quantity denoted by the static name Q.
	Parameters:	NUM: A static expression of type REAL_VECTOR that contains the numerator coefficients.
		DEN: A static expression of type REAL_VECTOR that contains the denominator coefficients.
	Result Type:	The subtype of Q.
	Result:	The Laplace transfer function of Q with NUM as the numerator and DEN as the denominator polynomials.
	Restrictions:	The first scalar subelement of DEN shall not be 0.0.

Suppose that QLTF is an alias for the attribute name, that QTYPE designates its type, that QELEM is an alias for Q, and that NUM and DEN designate the actual values of the parameters with the same names. Then the behavior of Q'LTF is formally described by the value of QLTF produced by the following equivalent block:

```
use ieee.math_real.all;
block
   generic (num, den: REAL_VECTOR);
   generic map (num => NUM, den => DEN);
   port (quantity q: in REAL; quantity ltf: out REAL);
   port map (q => real(QELEM), QTYPE(ltf) => QLTF);
   constant nnum: INTEGER := num'LENGTH - 1;
   constant nden: INTEGER := den'LENGTH - 1;
   alias snum: REAL_VECTOR(0 to nnum) is num;
   alias sden: REAL_VECTOR(0 to nden) is den;
   quantity qin: REAL_VECTOR(0 to nnum);
   quantity qout: REAL_VECTOR(0 to nden);
   function "*"(v1, v2: REAL_VECTOR) return REAL is
      variable result: REAL := 0.0;
   begin
      for i in v1'RANGE loop
         result := result + v1(i) * v2(i);
      end loop;
      return result;
   end function "*";
begin
   q == qin(0);
   qin(1 to nnum) == qin(0 to nnum-1)'DOT;
   ltf == qout(0);
   qout(1 to nden) == qout(0 to nden-1)'DOT;
   qout(0) == (qin * snum -
               qout(1 to nden) * sden(1 to nden))
              /sden(0);
end block;
```

Q'ZTF (NUM, DEN, T [, INITIAL_DELAY])	Kind:	Quantity.
	Prefix:	Any scalar quantity denoted by the static name Q.
	Parameters:	NUM: A static expression of type REAL_VECTOR with the numerator coefficients. DEN: A static expression of type REAL_VECTOR with the denominator coefficients. T: A static expression of type REAL that evaluates to a positive value, which is the sampling period. INITIAL_DELAY: A static expression of type REAL that evaluates to a non-negative value, which is the time of the first sampling. If omitted, it defaults to 0.0.
	Result Type:	The subtype of Q.
	Result:	The Z-domain transfer function of Q with NUM as the numerator and DEN as the denominator polynomials, T as the sampling frequency, and INITIAL_DELAY as the time of the first sampling.
	Restrictions:	The first scalar subelement of DEN shall not be 0.0.

Suppose that QZTF is an alias for the attribute name, that QTYPE designates its type, that QELEM is an alias for Q, and that NUM, DEN, T, and INITIAL_DELAY designate the actual or defaulted values of the parameters with the same names. Then the behavior of Q'ZTF is formally described by the value of QZTF produced by the following equivalent block:

```
use ieee.math_real.all;
block
   generic (num, den: REAL_VECTOR;
            t, initial_delay: REAL);
   generic map (num => NUM, den => DEN, t = >T,
                initial_delay => INITIAL_DELAY);
   port (quantity q: in REAL; quantity ztf: out REAL);
   port map (q => real(QELEM), QTYPE(ztf) => QZTF);
   constant nnum: INTEGER := num'LENGTH - 1;
   constant nden: INTEGER := den'LENGTH - 1;
   alias snum: REAL_VECTOR(0 to nnum) is num;
   alias sden: REAL_VECTOR(0 to nden) is den;
   quantity qin: REAL_VECTOR(0 to nnum);
   quantity qout: REAL_VECTOR(0 to nden);
   function "*"(v1, v2: REAL_VECTOR) return REAL is
      variable result: REAL := 0.0;
   begin
      for i in v1'RANGE loop
         result := result + v1(i) * v2(i);
      end loop;
      return result;
   end function "*";
begin
   qin(0) == q'ZOH(t, initial_delay);
   qin(1 to nnum) == qin(0 to nnum-1)'DELAYED(t);
   ztf == qout(0);
   qout(1 to nden) == qout(0 to nden-1)'DELAYED(t);
   qout(0) == (qin * snum -
               qout(1 to nden) * sden(1 to nden))
              /sden(0);
end block;
```

S'RAMP [(TRISE [, TFALL])]	Kind:	Quantity.
	Prefix:	Any signal denoted by the static name S whose scalar subelements are of a floating-point type.
	Parameters:	TRISE: A static expression of a floating-point type that evaluates to a non-negative value. If omitted, it defaults to 0.0.
		TFALL: A static expression of a floating-point type that evaluates to a non-negative value. If omitted, it defaults to the value of TRISE.
	Result Type:	The subtype of S.
	Result:	A quantity where each scalar subelement follows the corresponding scalar subelement of S. If the value of any parameter is greater than 0.0, the corresponding value change is linear from the current value of the scalar subelement of S to its new value, whenever that subelement has an event.

Suppose that SRAMP is an alias for any scalar subelement of the attribute name, that STYPE designates its type, that SELEM is an alias for the corresponding scalar subelement of S, and that TRISE and TFALL designate the actual or defaulted values of the parameters with the same names. Then the behavior of each scalar subelement of S'RAMP is formally described by the value of SRAMP produced by the following equivalent block:

```
block
   generic (trise, tfall: REAL);
   generic map (trise => REAL(TRISE), tfall => REAL(TFALL));
   port (signal s: in REAL; quantity sramp: out REAL);
   port map (s => REAL(SELEM),
             STYPE(sramp) => SRAMP);
   signal slope, tt: REAL := 0.0;
begin
   assert trise >= 0.0 and tfall >= 0.0;
   sramp == s'DELAYED + slope * (tt - s'DELAYED'LAST_EVENT);
   break on s'DELAYED, slope; -- Start or end of ramp
   process
   begin
      wait on DOMAIN;
      loop
         wait on s;
         while s'EVENT loop
            if s > sramp and trise > 0.0 then
               tt <= trise;
               slope <= (s-sramp)/trise;
               wait on s for trise;
            elsif s < sramp and tfall > 0.0 then
               tt <= tfall;
               slope <= (s-sramp)/tfall;
               wait on s for tfall;
            else
               wait on s for 0.0;
            end if;
         end loop;
         slope <= 0.0;
      end loop;
   end process;
end block;
```

S'SLEW [(RISING_SLOPE [, FALLING_SLOPE])]	Kind:	Quantity.
	Prefix:	Any signal denoted by the static name S whose scalar subelements are of a floating-point type.
	Parameters:	RISING_SLOPE: A static expression of type REAL that evaluates to a positive value. If omitted, it defaults to REAL'HIGH, which is interpreted as an infinite slope. FALLING_SLOPE: A static expression of type REAL that evaluates to a negative value. If omitted, it defaults to the negative of RISING_SLOPE. The value REAL'LOW is interpreted as a negative infinite slope.
	Result Type:	The subtype of S.
	Result:	A quantity where each scalar subelement follows the corresponding scalar subelement of S. If the value of RISING_SLOPE is less than REAL'HIGH, or if the value of FALLING_SLOPE is greater than REAL'LOW, the corresponding value change is linear from the current value of the scalar subelement of S to its new value, whenever that subelement has an event.

Suppose that SSLEW is an alias for any scalar subelement of the attribute name, that STYPE designates its type, that SELEM is an alias for the corresponding scalar subelement of S, and that RISING_SLOPE and FALLING_SLOPE designate the actual or defaulted values of the parameters with the same names. Then the behavior of each scalar subelement of S'SLEW is formally described by the value of SSLEW produced by the following equivalent block:

```
block
   generic (rising_slope, falling_slope: REAL);
   generic map (rising_slope => RISING_SLOPE,
                falling_slope => FALLING_SLOPE);
   port (signal s: in REAL; quantity sslew: out REAL);
   port map (s => REAL(SELEM),
             STYPE(sslew) => SSLEW);
   signal slope, tt: REAL := 0.0;
begin
   assert rising_slope > 0.0 and falling_slope < 0.0;
   sslew == s'DELAYED - slope * (tt - s'DELAYED'LAST_EVENT);
   break on s'DELAYED, slope; -- Start or end of ramp
   process
      variable ttv: REAL;
   begin
      wait on DOMAIN;
      loop
         wait on s;
         while s'EVENT loop
            if s > sslew and rising_slope /= REAL'HIGH then
               ttv := (s-sslew)/rising_slope;
               slope <= rising_slope;
            elsif s < sslew and falling_slope /= REAL'LOW then
               ttv := (s-sslew)/falling_slope;
               slope <= falling_slope;
            else
               ttv := 0.0;
            end if;
            tt <= ttv;
            wait on s for ttv;
         end loop;
         slope <= 0.0;
      end loop;
   end process;
end block;
```

Q'SLEW [(MAX_RISING_SLOPE [, MAX_FALLING_SLOPE])]	Kind:	Quantity.
	Prefix:	Any quantity denoted by the static name Q.
	Parameters:	MAX_RISING_SLOPE: A static expression of type REAL that evaluates to a positive value. If omitted, it defaults to REAL'HIGH, which is interpreted as an infinite slope.
		MAX_FALLING_SLOPE: A static expression of type REAL that evaluates to a negative value. If omitted, it defaults to the negative of MAX_RISING_SLOPE. The value REAL'LOW is interpreted as a negative infinite slope.
	Result Type:	The subtype of Q.
	Result:	A quantity where each scalar subelement follows the corresponding scalar subelement of Q, but its derivative w.r.t. time is limited by the specified slopes.

Suppose that QSLEW is an alias for any scalar subelement of the attribute name, that QTYPE designates its type, that QELEM is an alias for the corresponding scalar subelement of Q, and that MAX_RISING_SLOPE and MAX_FALLING_SLOPE designate the actual or defaulted values of the parameters with the same names. Then the behavior of each scalar subelement of Q'SLEW is formally described by the value of QSLEW produced by the following equivalent block:

```
block
   generic (max_rising_slope, max_falling_slope: REAL);
   generic map ( max_rising_slope => MAX_RISING_SLOPE,
                 max_falling_slope => MAX_FALLING_SLOPE);
   port (quantity q: in REAL; quantity qslew: out REAL);
   port map (q => REAL(QELEM),
             QTYPE(qslew) => QSLEW);
   type slewstate is (falling, none, rising);
   signal slewing: slewstate := none;
begin
   assert max_rising_slope > 0.0 and
          max_falling_slope < 0.0;
   case slewing use
      when rising => qslew'DOT == max_rising_slope;
      when none => qslew == q;
      when falling => qslew'DOT == max_falling_slope;
   end case;
   break on slewing when slewing'DELAYED /= none;
   process
   begin
      if q'DOT > max_rising_slope then
         slewing <= rising;
         wait on q'ABOVE(qslew);
      elsif q'DOT < max_falling_slope then
         slewing <= falling;
         wait on q'ABOVE(qslew);
      else
         slewing <= none;
         wait on q'DOT'ABOVE(max_rising_slope),
                 q'DOT'ABOVE(max_falling_slope);
      end if;
   end process;
end block;
```

14.2 Package STANDARD

Package STANDARD predefines a number of types, subtypes, and functions. An implicit context clause naming this package is assumed to exist at the beginning of each design unit. Package STANDARD cannot be modified by the user.

The operators that are predefined for the types declared for package STANDARD are given in comments since they are implicitly declared. Italics are used for pseudo-names of anonymous types (such as *universal_integer*), formal parameters, and undefined information (such as *implementation_defined*).

```
package STANDARD is

   --  Predefined enumeration types:
   type BOOLEAN is (FALSE, TRUE);

   --  The predefined operators for this type are as follows:

   --  function "and"  (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "or"   (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "nand" (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "nor"  (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "xor"  (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "xnor" (anonymous, anonymous: BOOLEAN) return BOOLEAN;

   --  function "not"  (anonymous: BOOLEAN) return BOOLEAN;

   --  function "="    (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "/="   (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "<"    (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function "<="   (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function ">"    (anonymous, anonymous: BOOLEAN) return BOOLEAN;
   --  function ">="   (anonymous, anonymous: BOOLEAN) return BOOLEAN;

   type BIT is ('0', '1');

   --  The predefined operators for this type are as follows:

   --  function "and"  (anonymous, anonymous: BIT) return BIT;
   --  function "or"   (anonymous, anonymous: BIT) return BIT;
   --  function "nand" (anonymous, anonymous: BIT) return BIT;
   --  function "nor"  (anonymous, anonymous: BIT) return BIT;
   --  function "xor"  (anonymous, anonymous: BIT) return BIT;
   --  function "xnor" (anonymous, anonymous: BIT) return BIT;

   --  function "not"  (anonymous: BIT) return BIT;

   --  function "="    (anonymous, anonymous: BIT) return BOOLEAN;
   --  function "/="   (anonymous, anonymous: BIT) return BOOLEAN;
   --  function "<"    (anonymous, anonymous: BIT) return BOOLEAN;
   --  function "<="   (anonymous, anonymous: BIT) return BOOLEAN;
   --  function ">"    (anonymous, anonymous: BIT) return BOOLEAN;
   --  function ">="   (anonymous, anonymous: BIT) return BOOLEAN;

   type CHARACTER is (
      NUL,     SOH,     STX,     ETX,     EOT,     ENQ,     ACK,     BEL,
      BS,      HT,      LF,      VT,      FF,      CR,      SO,      SI,
      DLE,     DC1,     DC2,     DC3,     DC4,     NAK,     SYN,     ETB,
      CAN,     EM,      SUB,     ESC,     FSP,     GSP,     RSP,     USP,

      ' ',     '!',     '"',     '#',     '$',     '%',     '&',     ''',
      '(',     ')',     '*',     '+',     ',',     '-',     '.',     '/',
      '0',     '1',     '2',     '3',     '4',     '5',     '6',     '7',
      '8',     '9',     ':',     ';',     '<',     '=',     '>',     '?',

      '@',     'A',     'B',     'C',     'D',     'E',     'F',     'G',
      'H',     'I',     'J',     'K',     'L',     'M',     'N',     'O',
      'P',     'Q',     'R',     'S',     'T',     'U',     'V',     'W',
      'X',     'Y',     'Z',     '[',     '\',     ']',     '^',     '_',

      '`',     'a',     'b',     'c',     'd',     'e',     'f',     'g',
      'h',     'i',     'j',     'k',     'l',     'm',     'n',     'o',
      'p',     'q',     'r',     's',     't',     'u',     'v',     'w',
      'x',     'y',     'z',     '{',     '|',     '}',     '~',     DEL,

      C128,    C129,    C130,    C131,    C132,    C133,    C134,    C135,
      C136,    C137,    C138,    C139,    C140,    C141,    C142,    C143,
      C144,    C145,    C146,    C147,    C148,    C149,    C150,    C151,
      C152,    C153,    C154,    C155,    C156,    C157,    C158,    C159,

      ' ',[8]   '¡',     '¢',     '£',     '¤',     '¥',     '¦',     '§',
      '¨',     '©',     'ª',     '«',     '¬',     '-',[9]  '®',     '¯',
      '°',     '±',     '²',     '³',     '´',     'µ',     '¶',     '·',
      '¸',     '¹',     'º',     '»',     '¼',     '½',     '¾',     '¿',

      'À',     'Á',     'Â',     'Ã',     'Ä',     'Å',     'Æ',     'Ç',
      'È',     'É',     'Ê',     'Ë',     'Ì',     'Í',     'Î',     'Ï',
      'Ð',     'Ñ',     'Ò',     'Ó',     'Ô',     'Õ',     'Ö',     '×',
      'Ø',     'Ù',     'Ú',     'Û',     'Ü',     'Ý',     'Þ',     'ß',

      'à',     'á',     'â',     'ã',     'ä',     'å',     'æ',     'ç',
      'è',     'é',     'ê',     'ë',     'ì',     'í',     'î',     'ï',
      'ð',     'ñ',     'ò',     'ó',     'ô',     'õ',     'ö',     '÷',
      'ø',      ù',     'ú',     'û',     'ü',     'ý',     'þ',     'ÿ');
```

[8]The nonbreaking space character.

[9]The soft hyphen character.

```
--  The predefined operators for this type are as follows:

--  function "="  (anonymous, anonymous: CHARACTER)
--                                      return BOOLEAN;
--  function "/=" (anonymous, anonymous: CHARACTER)
--                                      return BOOLEAN;
--  function "<"  (anonymous, anonymous: CHARACTER)
--                                      return BOOLEAN;
--  function "<=" (anonymous, anonymous: CHARACTER)
--                                      return BOOLEAN;
--  function ">"  (anonymous, anonymous: CHARACTER)
--                                      return BOOLEAN;
--  function ">=" (anonymous, anonymous: CHARACTER)
--                                      return BOOLEAN;

type SEVERITY_LEVEL is (NOTE, WARNING, ERROR, FAILURE);

--  The predefined operators for this type are as follows:

--  function "="  (anonymous, anonymous: SEVERITY_LEVEL)
--                                      return BOOLEAN;
--  function "/=" (anonymous, anonymous: SEVERITY_LEVEL)
--                                      return BOOLEAN;
--  function "<"  (anonymous, anonymous: SEVERITY_LEVEL)
--                                      return BOOLEAN;
--  function "<=" (anonymous, anonymous: SEVERITY_LEVEL)
--                                      return BOOLEAN;
--  function ">"  (anonymous, anonymous: SEVERITY_LEVEL)
--                                      return BOOLEAN;
--  function ">=" (anonymous, anonymous: SEVERITY_LEVEL)
--                                      return BOOLEAN;

--  type universal_integer  is range implementation_defined;

--  The predefined operators for this type are as follows:

--  function "="   (anonymous, anonymous: universal_integer)
--                                      return BOOLEAN;
--  function "/="  (anonymous, anonymous: universal_integer)
--                                      return BOOLEAN;
--  function "<"   (anonymous, anonymous: universal_integer)
--                                      return BOOLEAN;
--  function "<="  (anonymous, anonymous: universal_integer)
--                                      return BOOLEAN;
--  function ">"   (anonymous, anonymous: universal_integer)
--                                      return BOOLEAN;
--  function ">="  (anonymous, anonymous: universal_integer)
--                                      return BOOLEAN;
--  function "+"   (anonymous: universal_integer)
--                                      return universal_integer;
--  function "-"   (anonymous: universal_integer)
--                                      return universal_integer;
--  function "abs" (anonymous: universal_integer)
--                                      return universal_integer;
--   function "+"   (anonymous, anonymous: universal_integer)
--                                        return universal_integer;
--   function "-"   (anonymous, anonymous: universal_integer)
--                                        return universal_integer;
--   function "*"   (anonymous, anonymous: universal_integer)
--                                        return universal_integer;
--   function "/"   (anonymous, anonymous: universal_integer)
--                                        return universal_integer;
--   function "mod" (anonymous, anonymous: universal_integer)
--                                        return universal_integer;
--   function "rem" (anonymous, anonymous: universal_integer)
--                                        return universal_integer;

--   type universal_real  is range implementation_defined;

--   The predefined operators for this type are as follows:

--   function "="   (anonymous, anonymous: universal_real)
--                                         return BOOLEAN;
--   function "/="  (anonymous, anonymous: universal_real)
--                                         return BOOLEAN;
--   function "<"   (anonymous, anonymous: universal_real)
--                                         return BOOLEAN;
--   function "<="  (anonymous, anonymous: universal_real)
--                                         return BOOLEAN;
--   function ">"   (anonymous, anonymous: universal_real)
--                                         return BOOLEAN;
--   function ">="  (anonymous, anonymous: universal_real)
--                                         return BOOLEAN;

--   function "+"   (anonymous: universal_real)
--                                         return universal_real;
--   function "-"   (anonymous: universal_real)
--                                         return universal_real;
--   function "abs" (anonymous: universal_real)
--                                         return universal_real;

--   function "+"   (anonymous, anonymous: universal_real)
--                                         return universal_real;
--   function "-"   (anonymous, anonymous: universal_real)
--                                         return universal_real;
--   function "*"   (anonymous, anonymous: universal_real)
--                                         return universal_real;
--   function "/"   (anonymous, anonymous: universal_real)
--                                         return universal_real;

--   function "*"   (anonymous: universal_real;
--                   anonymous: universal_integer)
--                                         return universal_real;
--   function "*"   (anonymous: universal_integer;
--                   anonymous: universal_real)
--                                         return universal_real;
--   function "/"   (anonymous: universal_real;
--                     anonymous: universal_integer)
--                                            return universal_real;

--  Predefined numeric types:
type INTEGER is range implementation_defined;

--  The predefined operators for this type are as follows:

--  function "**"  (anonymous: universal_integer;
--                  anonymous: INTEGER) return universal_integer;
--  function "**"  (anonymous: universal_real;
--                  anonymous: INTEGER) return universal_real;

--  function "="   (anonymous, anonymous: INTEGER) return BOOLEAN;
--  function "/="  (anonymous, anonymous: INTEGER) return BOOLEAN;
--  function "<"   (anonymous, anonymous: INTEGER) return BOOLEAN;
--  function "<="  (anonymous, anonymous: INTEGER) return BOOLEAN;
--  function ">"   (anonymous, anonymous: INTEGER) return BOOLEAN;
--  function ">="  (anonymous, anonymous: INTEGER) return BOOLEAN;
--  function "+"   (anonymous: INTEGER) return INTEGER;
--  function "-"   (anonymous: INTEGER) return INTEGER;
--  function "abs" (anonymous: INTEGER) return INTEGER;

--  function "+"   (anonymous, anonymous: INTEGER) return INTEGER;
--  function "-"   (anonymous, anonymous: INTEGER) return INTEGER;
--  function "*"   (anonymous, anonymous: INTEGER) return INTEGER;
--  function "/"   (anonymous, anonymous: INTEGER) return INTEGER;
--  function "mod" (anonymous, anonymous: INTEGER) return INTEGER;
--  function "rem" (anonymous, anonymous: INTEGER) return INTEGER;

--  function "**"  (anonymous: INTEGER; anonymous: INTEGER)
--                                            return INTEGER;

type REAL is range implementation_defined;

--  The predefined operators for this type are as follows:

--  function "="   (anonymous, anonymous: REAL) return BOOLEAN;
--  function "/="  (anonymous, anonymous: REAL) return BOOLEAN;
--  function "<"   (anonymous, anonymous: REAL) return BOOLEAN;
--  function "<="  (anonymous, anonymous: REAL) return BOOLEAN;
--  function ">"   (anonymous, anonymous: REAL) return BOOLEAN;
--  function ">="  (anonymous, anonymous: REAL) return BOOLEAN;

--  function "+"   (anonymous: REAL) return REAL;
--  function "-"   (anonymous: REAL) return REAL;
--  function "abs" (anonymous: REAL) return REAL;

--  function "+"   (anonymous, anonymous: REAL) return REAL;
--  function "-"   (anonymous, anonymous: REAL) return REAL;
--  function "*"   (anonymous, anonymous: REAL) return REAL;
--  function "/"   (anonymous, anonymous: REAL) return REAL;

--  function "**"  (anonymous: REAL; anonymous: INTEGER) return REAL;
--  Predefined type TIME:

type TIME is range implementation_defined
   units
      fs;                         --  femtosecond
      ps   =  1000 fs;            --  picosecond
      ns   =  1000 ps;            --  nanosecond
      us   =  1000 ns;            --  microsecond
      ms   =  1000 us;            --  millisecond
      sec  =  1000 ms;            --  second
      min  =  60 sec;             --  minute
      hr   =  60 min;             --  hour
   end units;

--  The predefined operators for this type are as follows:

--  function "="   (anonymous, anonymous: TIME) return BOOLEAN;
--  function "/="  (anonymous, anonymous: TIME) return BOOLEAN;
--  function "<"   (anonymous, anonymous: TIME) return BOOLEAN;
--  function "<="  (anonymous, anonymous: TIME) return BOOLEAN;
--  function ">"   (anonymous, anonymous: TIME) return BOOLEAN;
--  function ">="  (anonymous, anonymous: TIME) return BOOLEAN;
--  function "+"   (anonymous: TIME) return TIME;
--  function "-    (anonymous: TIME) return TIME;
--  function "abs" (anonymous: TIME) return TIME;

--  function "+"   (anonymous, anonymous: TIME) return TIME;
--  function "-"   (anonymous, anonymous: TIME) return TIME;

--  function "*"   (anonymous: TIME;    anonymous: INTEGER)
--                                        return TIME;
--  function "*"   (anonymous: TIME;    anonymous: REAL)
--                                        return TIME;
--  function "*"   (anonymous: INTEGER; anonymous: TIME)
--                                        return TIME;
--  function "*"   (anonymous: REAL;    anonymous: TIME)
--                                        return TIME;
--  function "/"   (anonymous: TIME;    anonymous: INTEGER)
--                                        return TIME;
--  function "/"   (anonymous: TIME;    anonymous: REAL)
--                                        return TIME;

--  function "/"   (anonymous, anonymous: TIME)
--                                        return universal_integer;

type DOMAIN_TYPE is
       (QUIESCENT_DOMAIN, TIME_DOMAIN, FREQUENCY_DOMAIN);

--  The predefined operators for this type are as follows:

--  function "="  (anonymous, anonymous: DOMAIN_TYPE) return BOOLEAN;
--  function "/=" (anonymous, anonymous: DOMAIN_TYPE) return BOOLEAN;
--  function "<"  (anonymous, anonymous: DOMAIN_TYPE) return BOOLEAN;
--  function "<=" (anonymous, anonymous: DOMAIN_TYPE) return BOOLEAN;
--  function ">"  (anonymous, anonymous: DOMAIN_TYPE) return BOOLEAN;
--  function ">=" (anonymous, anonymous: DOMAIN_TYPE) return BOOLEAN;

signal DOMAIN: DOMAIN_TYPE := QUIESCENT_DOMAIN;

subtype DELAY_LENGTH is TIME range 0 fs to TIME'HIGH;

--  A function that returns  universal_to_physical_time (Tc ),
-- (see 12.6.4 and 12.7):

impure function NOW return DELAY_LENGTH;

--  A function that returns universal_to_real_time(Tc) (see 12.6.4
--  and 12.7; it is an error if this value is not in the range
--  of REAL):

impure function NOW return REAL;

--  A function that returns the current simulation frequency
--  (see 12.8):

function FREQUENCY return REAL;

--  Predefined numeric subtypes:

subtype NATURAL is INTEGER range 0 to INTEGER'HIGH;
subtype POSITIVE is INTEGER range 1 to INTEGER'HIGH;

--  Predefined array types:

type REAL_VECTOR is array (NATURAL range <>) of REAL;

type STRING is array (POSITIVE range <>) of CHARACTER;

--  The predefined operators for these types are as follows:

--  function "="  (anonymous, anonymous: STRING) return BOOLEAN;
--  function "/=" (anonymous, anonymous: STRING) return BOOLEAN;
--  function "<"  (anonymous, anonymous: STRING) return BOOLEAN;
--  function "<=" (anonymous, anonymous: STRING) return BOOLEAN;
--  function ">"  (anonymous, anonymous: STRING) return BOOLEAN;
--  function ">=" (anonymous, anonymous: STRING) return BOOLEAN;

--  function "&"  (anonymous: STRING;    anonymous: STRING)
--                                       return STRING;
--  function "&"  (anonymous: STRING;    anonymous: CHARACTER)
--                                       return STRING;
--  function "&"  (anonymous: CHARACTER; anonymous: STRING)
--                                       return STRING;
--  function "&"  (anonymous: CHARACTER; anonymous: CHARACTER)
--                                       return STRING;

type BIT_VECTOR is array (NATURAL range <>) of BIT;
```

```
--  The predefined operators for this type are as follows:

--  function "and"  (anonymous, anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "or"   (anonymous, anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "nand" (anonymous, anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "nor"  (anonymous, anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "xor"  (anonymous, anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "xnor" (anonymous, anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;

--  function "not"  (anonymous: BIT_VECTOR) return BIT_VECTOR;

--  function "sll"  (anonymous: BIT_VECTOR; anonymous: INTEGER)
--                                        return BIT_VECTOR;
--  function "srl"  (anonymous: BIT_VECTOR; anonymous: INTEGER)
--                                        return BIT_VECTOR;
--  function "sla"  (anonymous: BIT_VECTOR; anonymous: INTEGER)
--                                        return BIT_VECTOR;
--  function "sra"  (anonymous: BIT_VECTOR; anonymous: INTEGER)
--                                        return BIT_VECTOR;
--  function "rol"  (anonymous: BIT_VECTOR; anonymous: INTEGER)
--                                        return BIT_VECTOR;
--  function "ror"  (anonymous: BIT_VECTOR; anonymous: INTEGER)
--                                        return BIT_VECTOR;

--  function "="    (anonymous, anonymous: BIT_VECTOR)
--                                        return BOOLEAN;
--  function "/="   (anonymous, anonymous: BIT_VECTOR)
--                                        return BOOLEAN;
--  function "<"    (anonymous, anonymous: BIT_VECTOR)
--                                        return BOOLEAN;
--  function "<="   (anonymous, anonymous: BIT_VECTOR)
--                                        return BOOLEAN;
--  function ">"    (anonymous, anonymous: BIT_VECTOR)
--                                        return BOOLEAN;
--  function ">="   (anonymous, anonymous: BIT_VECTOR)
--                                        return BOOLEAN;

--  function "&"    (anonymous: BIT_VECTOR; anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "&"    (anonymous: BIT_VECTOR; anonymous: BIT)
--                                        return BIT_VECTOR;
--  function "&"    (anonymous: BIT; anonymous: BIT_VECTOR)
--                                        return BIT_VECTOR;
--  function "&"    (anonymous: BIT; anonymous: BIT)
--                                        return BIT_VECTOR;

--  The predefined types for opening files:
    type FILE_OPEN_KIND is (
       READ_MODE,                -- Resulting access mode is read-only.
       WRITE_MODE,               -- Resulting access mode is write-only.
       APPEND_MODE);             -- Resulting access mode is write-only;
                                 -- information is appended to the end
                                 -- of the existing file.

    -- The predefined operators for this type are as follows:

    -- function "="  (anonymous, anonymous: FILE_OPEN_KIND)
    --                                     return BOOLEAN;
    -- function "/=" (anonymous, anonymous: FILE_OPEN_KIND)
    --                                     return BOOLEAN;
    -- function "<"  (anonymous, anonymous: FILE_OPEN_KIND)
    --                                     return BOOLEAN;
    -- function "<=" (anonymous, anonymous: FILE_OPEN_KIND)
    --                                     return BOOLEAN;
    -- function ">"  (anonymous, anonymous: FILE_OPEN_KIND)
    --                                     return BOOLEAN;
    -- function ">=" (anonymous, anonymous: FILE_OPEN_KIND)
    --                                     return BOOLEAN;

    type FILE_OPEN_STATUS is (
       OPEN_OK,                  -- File open was successful.
       STATUS_ERROR,             -- File object was already open.
       NAME_ERROR,               -- External file not found
                                 -- or inaccessible.
       MODE_ERROR);              -- Could not open file with requested
                                 -- access mode.

    -- The predefined operators for this type are as follows:

    -- function "="  (anonymous, anonymous: FILE_OPEN_STATUS)
    --                                     return BOOLEAN;
    -- function "/=" (anonymous, anonymous: FILE_OPEN_STATUS)
    --                                     return BOOLEAN;
    -- function "<"  (anonymous, anonymous: FILE_OPEN_STATUS)
    --                                     return BOOLEAN;
    -- function "<=" (anonymous, anonymous: FILE_OPEN_STATUS)
    --                                     return BOOLEAN;
    -- function ">"  (anonymous, anonymous: FILE_OPEN_STATUS)
    --                                     return BOOLEAN;
    -- function ">=" (anonymous, anonymous: FILE_OPEN_STATUS)
    --                                     return BOOLEAN;

    -- The 'FOREIGN attribute:

    attribute FOREIGN: STRING;

 end STANDARD;
```

The 'FOREIGN attribute shall be associated only with architectures (see 1.2) or with subprograms. In the latter case, the attribute specification shall appear in the declarative part in which the subprogram is declared (see 2.1).

NOTE 1—The ASCII mnemonics for file separator (FS), group separator (GS), record separator (RS), and unit separator (US) are represented by FSP, GSP, RSP, and USP, respectively, in type CHARACTER in order to avoid conflict with the units of type TIME.

NOTE 2—The declarative parts and statement parts of design entities whose corresponding architectures are decorated with the 'FOREIGN attribute and subprograms that are likewise decorated are subject to special elaboration rules. See 12.3 and 12.4.

14.3 Package TEXTIO

Package TEXTIO contains declarations of types and subprograms that support formatted I/O operations on text files.

```
package TEXTIO is

   --  Type definitions for text I/O:


   type LINE is access STRING;  --  A LINE is a pointer
                                --  to a STRING value.

   --  The predefined operators for this type are as follows:

   --  function"="  (anonymous, anonymous: LINE) return BOOLEAN;
   --  function"/=" (anonymous, anonymous: LINE) return BOOLEAN;

   type TEXT is file of STRING;  --  A file of variable-length
                                 --  ASCII records.

   --  The predefined operators for this type are as follows:

   --  procedure FILE_OPEN  (file F: TEXT; External_Name; in STRING;
   --                        Open_Kind: in FILE_OPEN_KIND := READ_MODE);
   --  procedure FILE_OPEN  (Status: out FILE_OPEN_STATUS; file F: TEXT;
   --                        External_Name: in STRING;
   --                        Open_Kind: in FILE_OPEN_KIND := READ_MODE);
   --  procedure FILE_CLOSE (file F: TEXT);
   --  procedure READ       (file F: TEXT; VALUE: out STRING);
   --  procedure WRITE      (file F: TEXT; VALUE: in STRING);
   --  function  ENDFILE    (file F: TEXT) return BOOLEAN;

   type SIDE is (RIGHT, LEFT);  --  For justifying output data
                                --  within fields.

   --  The predefined operators for this type are as follows:

   --  function "="  (anonymous, anonymous: SIDE) return BOOLEAN;
   --  function "/=" (anonymous, anonymous: SIDE) return BOOLEAN;
   --  function "<"  (anonymous, anonymous: SIDE  return BOOLEAN;
   --  function "<=" (anonymous, anonymous: SIDE) return BOOLEAN;
   --  function ">"  (anonymous, anonymous: SIDE) return BOOLEAN;
   --  function ">=" (anonymous, anonymous: SIDE) return BOOLEAN;

   subtype WIDTH is NATURAL;  --  For specifying widths of output fields.

   --  Standard text files:

   file INPUT:  TEXT open READ_MODE  is "STD_INPUT";

   file OUTPUT: TEXT open WRITE_MODE is "STD_OUTPUT";

   --  Input routines for standard types:

   procedure READLINE (file F: TEXT; L: inout LINE);

   procedure READ (L: inout LINE; VALUE: out BIT;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out BIT);

   procedure READ (L: inout LINE; VALUE: out BIT_VECTOR;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out BIT_VECTOR);

   procedure READ (L: inout LINE; VALUE: out BOOLEAN;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out BOOLEAN);

   procedure READ (L: inout LINE; VALUE: out CHARACTER;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out CHARACTER);

   procedure READ (L: inout LINE; VALUE: out INTEGER;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out INTEGER);

   procedure READ (L: inout LINE; VALUE: out REAL;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out REAL);

   procedure READ (L: inout LINE; VALUE: out STRING;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out STRING);

   procedure READ (L: inout LINE; VALUE: out TIME;
                                  GOOD:  out BOOLEAN);
   procedure READ (L: inout LINE; VALUE: out TIME);

   --  Output routines for standard types:

   procedure WRITELINE (file F: TEXT; L: inout LINE);

   procedure WRITE (L: inout LINE; VALUE: in BIT;
                    JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0);

   procedure WRITE (L: inout LINE; VALUE: in BIT_VECTOR;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0);

    procedure WRITE (L: inout LINE; VALUE: in BOOLEAN;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0);

    procedure WRITE (L: inout LINE; VALUE: in CHARACTER;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0);

    procedure WRITE (L: inout LINE; VALUE: in INTEGER;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0);

    procedure WRITE (L: inout LINE; VALUE: in REAL;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0;
                      DIGITS: in NATURAL:= 0);

    procedure WRITE (L: inout LINE; VALUE: in STRING;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0);

    procedure WRITE (L: inout LINE; VALUE: in TIME;
                      JUSTIFIED: in SIDE:= RIGHT; FIELD: in WIDTH := 0;
                      UNIT: in TIME:= ns);

end TEXTIO;
```

Procedures READLINE and WRITELINE declared in package TEXTIO read and write entire lines of a file of type TEXT. Procedure READLINE causes the next line to be read from the file and returns as the value of parameter L an access value that designates an object representing that line. If parameter L contains a non-null access value at the start of the call, the object designated by that value is deallocated before the new object is created. The representation of the line does not contain the representation of the end of the line. It is an error if the file specified in a call to READLINE is not open or, if open, the file has an access mode other than read-only (see 3.4.1). Procedure WRITELINE causes the current line designated by parameter L to be written to the file and returns with the value of parameter L designating a null string. If parameter L contains a null access value at the start of the call, then a null string is written to the file. It is an error if the file specified in a call to WRITELINE is not open or, if open, the file has an access mode other than write-only.

The language does not define the representation of the end of a line. An implementation shall allow all possible values of types CHARACTER and STRING to be written to a file. However, as an implementation is permitted to use certain values of types CHARACTER and STRING as line delimiters, it might not be possible to read these values from a TEXT file.

Each READ procedure declared in package TEXTIO extracts data from the beginning of the string value designated by parameter L and modifies the value so that it designates the remaining portion of the line on exit.

The READ procedures defined for a given type other than CHARACTER and STRING begin by skipping leading *whitespace characters*. A whitespace character is defined as a space, a nonbreaking space, or a horizontal tabulation character (SP, NBSP, or HT). For all READ procedures, characters are then removed from L and composed into a string representation of the value of the specified type. Character removal and string composition stops when a character is encountered that cannot be part of the value according to the lexical rules of 13.2; this character is not removed from L and is not added to the string representation of the value. The READ procedures for types INTEGER and REAL also accept a leading sign; additionally, there can be no space between the sign and the remainder of the literal. The READ procedures for types STRING and BIT_VECTOR also terminate acceptance when VALUE'LENGTH characters have been accepted. Again using the rules of 13.2, the accepted characters are then interpreted as a string representation of the specified type. The READ does not succeed if the sequence of characters removed from L is not a valid string representation of a value of the specified type or, in the case of types STRING and BIT_VECTOR, if the sequence does not contain VALUE'LENGTH characters.

The definitions of the string representation of the value for each data type are as follows:

— The representation of a BIT value is formed by a single character, either 1 or 0. No leading or trailing quotation characters are present.
— The representation of a BIT_VECTOR value is formed by a sequence of characters, either 1 or 0. No leading or trailing quotation characters are present.
— The representation of a BOOLEAN value is formed by an identifier, either FALSE or TRUE.
— The representation of a CHARACTER value is formed by a single character.
— The representation of both INTEGER and REAL values is that of a decimal literal (see 13.4.1), with the addition of an optional leading sign. The sign is never written if the value is non-negative, but it is accepted during a read even if the value is non-negative. No spaces can occur between the sign and the remainder of the value. The decimal point is absent in the case of an INTEGER literal and present in the case of a REAL literal. An exponent may optionally be present; moreover, the language does not define under what conditions it is or is not present. However, if the exponent is present, the “e” is written as a lowercase character. Leading and trailing zeroes are written as necessary to meet the requirements of the FIELD and DIGITS parameters, and they are accepted during a read.
— The representation of a STRING value is formed by a sequence of characters, one for each element of the string. No leading or trailing quotation characters are present.
— The representation of a TIME value is formed by an optional decimal literal composed following the rules for INTEGER and REAL literals previously described, one or more blanks, and an identifier that is a unit of type TIME, as defined in package STANDARD (see 14.2). When read, the identifier can be expressed with characters of either case; when written, the identifier is expressed in lowercase characters.

Each WRITE procedure similarly appends data to the end of the string value designated by parameter L; in this case, however, L continues to designate the entire line after the value is appended. The format of the appended data is defined by the string representations previously defined for the READ procedures.

The READ and WRITE procedures for the types BIT_VECTOR and STRING respectively read and write the element values in left-to-right order.

For each predefined data type there are two READ procedures declared in package TEXTIO. The first has three parameters: L, the line to read from; VALUE, the value read from the line; and GOOD, a Boolean flag that indicates whether the read operation succeeded or not. For example, the operation READ (L, IntVal, OK) would return with OK set to FALSE, L unchanged, and IntVal undefined if IntVal is a variable of type INTEGER and L designates the line "ABC". The success indication returned via parameter GOOD allows a process to recover gracefully from unexpected discrepancies in input format. The second form of read operation has only the parameters L and VALUE. If the requested type cannot be read into VALUE from line L, then an error occurs. Thus, the operation READ (L, IntVal) would cause an error to occur if IntVal is of type INTEGER and L designates the line "ABC".

For each predefined data type there is one WRITE procedure declared in package TEXTIO. Each of these has at least two parameters: L, the line to which to write; and VALUE, the value to be written. The additional parameters JUSTIFIED, FIELD, DIGITS, and UNIT control the formatting of output data. Each write operation appends data to a line formatted within a *field* that is at least as long as required to represent the data value. Parameter FIELD specifies the desired field width. Since the actual field width will always be at least large enough to hold the string representation of the data value, the default value 0 for the FIELD parameter has the effect of causing the data value to be written out in a field of exactly the right width (i.e., no leading or trailing spaces). Parameter JUSTIFIED specifies whether values are to be right- or left-justified within the field; the default is right-justified. If the FIELD parameter describes a field width larger than the number of characters necessary for a given value, blanks are used to fill the remaining characters in the field.

Parameter DIGITS specifies how many digits to the right of the decimal point are to be output when writing a real number; the default value 0 indicates that the number should be output in standard form, consisting of a normalized mantissa plus exponent (e.g., 1.079236E-23). If DIGITS is nonzero, then the real number is output as an integer part followed by '.' followed by the fractional part, using the specified number of digits (e.g., 3.14159).

Parameter UNIT specifies how values of type TIME are to be formatted. The value of this parameter shall be equal to one of the units declared as part of the declaration of type TIME; the result is that the TIME value is formatted as an integer or real literal representing the number of multiples of this unit, followed by the name of the unit itself. The name of the unit is formatted using only lowercase characters. Thus the procedure call WRITE(Line, 5 ns, UNIT=>us) would result in the string value "0.005 us" being appended to the string value designated by Line, whereas WRITE(Line, 5 ns) would result in the string value "5 ns" being appended (since the default UNIT value is ns).

Function ENDFILE is defined for files of type TEXT by the implicit declaration of that function as part of the declaration of the file type.

NOTE 1—For a variable L of type Line, attribute L'Length gives the current length of the line, whether that line is being read or written. For a line L that is being written, the value of L'Length gives the number of characters that have already been written to the line; this is equivalent to the column number of the last character of the line. For a line L that is being read, the value of L'Length gives the number of characters on that line remaining to be read. In particular, the expression L'Length = 0 is true precisely when the end of the current line has been reached.

NOTE 2—The execution of a read or write operation may modify or even deallocate the string object designated by input parameter L of type Line for that operation; thus, a dangling reference may result if the value of a variable L of type Line is assigned to another access variable and then a read or write operation is performed on L.

15. Simultaneous statements

NOTE—The material in this clause is related to material in Clause 8 and Clause 9; it is included here to avoid perturbing the numbering scheme of the VHDL 1076 language reference manual.

Simultaneous statements express explicit differential and algebraic equations that together with implicit equations constrain the values of the quantities of a model.

```
simultaneous_statement_part ::=
    { simultaneous_statement }
```

```
simultaneous_statement ::=
      simple_simultaneous_statement
    | simultaneous_if_statement
    | simultaneous_case_statement
    | simultaneous_procedural_statement
    | simultaneous_null_statement
```

The evaluation of a simultaneous statement part consists of the evaluation of its simultaneous statements. Any characteristic expression created during the evaluation of a simultaneous statement part is said to be in an *explicit set*.

15.1 Simple simultaneous statement

The evaluation of a simple simultaneous statement creates one or more characteristic expressions of an explicit set.

```
simple_simultaneous_statement ::=
    [ label : ] simple_expression == simple_expression [ tolerance_aspect ] ;
```

The base type of each simple expression shall be the same nature type. If the type of the simple expressions is a scalar type then the statement has a single characteristic expression, which is the difference between the value of the right-hand simple expression and the value of the left-hand simple expression. If the type of the simple expressions is composite, then there shall be a matching scalar subelement of the right-hand value for each scalar subelement of the left-hand value, and the characteristic expressions are the differences of the matching scalar subelements of the simple expression values.

Some simple simultaneous statements have an associated *tolerance quantity* that is determined as follows. If the simple expression on the left-hand side of the compound delimiter == is a name (including a slice name) that denotes a quantity, then this quantity is the tolerance quantity of the simple simultaneous statement. Otherwise, if the simple expression on the right-hand side of the compound delimiter == is a name (including a slice name) that denotes a quantity, then this quantity is the tolerance quantity of the simple simultaneous statement. Otherwise, the simple simultaneous statement has no associated tolerance quantity. It is an error if a simple simultaneous statement that does not include a tolerance aspect has no associated tolerance quantity.

If the simple simultaneous statement does not include a tolerance aspect, then the tolerance group of each scalar subelement of the characteristic expression created by the statement is the tolerance group of the corresponding scalar subelement of the tolerance quantity associated with the statement. If the simple simultaneous statement does include a tolerance aspect, then the tolerance group of each scalar subelement of the characteristic expression created by the statement is the value of the string expression of the tolerance aspect.

Example:

```
-- A diode described by simple simultaneous statements

entity Diode is
   generic (Is0: REAL := 1.0e-14; Tau, Rd: REAL := 0.0);
   port (terminal Anode, Cathode: Electrical);
end entity Diode;

architecture Simultaneous of Diode is
   quantity Vd across Id, Ic through Anode to Cathode;
   quantity Charge: REAL;
   constant Vt: Voltage := 0.0258;
begin
   Id == Is0*(exp((Vd-Rd*Id)/Vt) - 1.0);
   Charge == Tau*Id tolerance "charge";  -- tolerance group
                                       -- defined by explicit tolerance
aspect
   Ic == Charge'Dot;
end architecture Simultaneous;
```

15.2 Simultaneous if statement

A simultaneous if statement selects for evaluation one of the enclosed simultaneous statement parts depending on the value of one or more conditions.

```
simultaneous_if_statement ::=
   [ if_label : ]
      if condition use
         simultaneous_statement_part
      { elsif condition use
         simultaneous_statement_part }
      [ else
         simultaneous_statement_part ]
      end use [ if_label ] ;
```

For the evaluation of a simultaneous if statement, the condition specified after **if** and any conditions specified after **elsif** are evaluated in succession (treating a final **else** as **elsif** TRUE **use**) until one evaluates to TRUE or all conditions are evaluated and yield FALSE. If one condition evaluates to TRUE, then the corresponding simultaneous statement part is evaluated; otherwise, none of the simultaneous statement parts is evaluated.

15.3 Simultaneous case statement

A simultaneous case statement selects for evaluation one of a number of alternative simultaneous statement parts; the chosen alternative is defined by the value of an expression.

```
simultaneous_case_statement ::=
   [ case_label : ]
      case expression use
         simultaneous_alternative
         { simultaneous_alternative }
      end case [ case_label ] ;
```

```
simultaneous_alternative ::=
    when choices =>
        simultaneous_statement_part
```

The expression of the simultaneous case statement, the expressions of the choices of the simultaneous alternatives and the case label shall follow the rules of 8.8 for the corresponding parts of the sequential case statement.

The evaluation of a simultaneous case statement consists of the evaluation of the expression followed by the evaluation of the chosen simultaneous statement part.

15.4 Simultaneous procedural statement

The simultaneous procedural statement provides a sequential notation for expressing differential and algebraic equations.

```
simultaneous_procedural_statement ::=
    [ procedural_label : ]
        procedural [ is ]
            procedural_declarative_part
        begin
            procedural_statement_part
        end procedural [ procedural_label ] ;

procedural_declarative_part ::=
    { procedural_declarative_item }

procedural_declarative_item ::=
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | variable_declaration
    | alias_declaration
    | attribute_declaration
    | attribute_specification
    | use_clause
    | group_template_declaration
    | group_declaration

procedural_statement_part ::=
    { sequential_statement }
```

The simultaneous procedural statement is defined by a series of transformations. For the longest static prefix of each quantity name that occurs in the procedural statement part, the following transformations are defined:

— The *interface name* of the quantity is a unique identifier that does not hide any named entity visible within the simultaneous procedural statement. The quantity is called the *replaced quantity*.

— The *variable name* of the quantity is another unique identifier that does not hide any named entity visible within the simultaneous procedural statement. Similarly, the quantity is called the *replaced quantity*.

- For either an interface name or a variable name, the *replacement declaration* is the name, followed by a colon, followed by the subtype indication of the replaced quantity.
- For a given variable name, the *replacement variable declaration* of the name consists of the reserved word **variable**, followed by the replacement declaration, followed by the compound delimiter :=, followed by the interface name whose replaced quantity is the same as the variable name, followed by a semicolon.

For the simultaneous procedural statement itself, the following lists of quantifiers are defined:

- The *assigned quantity list* is formed from the longest static prefix of each quantity name that is either the target of any variable assignment statement or an actual in any procedure call whose corresponding formal has mode **out** or **inout** in the procedural statement part of the simultaneous procedural statement, in any order. A simultaneous procedural statement with a null assigned quantity list is equivalent to a simultaneous null statement.
- The *referenced quantity list* consists of quantity names of the following forms: the longest static prefix of each quantity name appearing in any statement in the procedural statement part of the simultaneous procedural statement; and the longest static prefix of any quantity name appearing in any default expression in the procedural declarative part of the simultaneous procedural statement. These quantity names occur in any order.

The following textual constructs are defined using the previous definitions given.

- The *assigned quantity declaration* consists of the replacement declaration for the variable name of each quantity in the assigned quantity list, in that order, separated by semicolons.
- The *interface quantity declaration* consists of the replacement declaration for the interface name of each quantity in the assigned quantity list, in that order, separated by semicolons.
- The *altered procedural declarative part* consists of the procedural declarative part of the simultaneous procedural statement where the longest static prefix of each of the quantity names is replaced by its interface name.
- The *replaced variable declaration list* consists of the replacement variable declaration for the variable name of each quantity in the referenced quantity list.
- The *altered procedural statement part* consists of the procedural statement part of the simultaneous procedural statement where the longest static prefix of each of the quantity names is replaced by its variable name.
- The *textual replaced quantity list* consists of each of the variable names for each quantity in the assigned quantity list, separated by commas, in the order in which they occur.
- The *textual assigned quantity list* consists of the variable name for each quantity in the assigned quantity list, separated by commas, in the order in which they occur.
- The *textual referenced quantity list* consists of the names of all the quantities in the referenced quantity list, separated by commas, in the order in which they occur.
- *Quantity record name* and *new name* are names that, like the replacement names, are unique and are not visible from anywhere in the simultaneous procedural statement.

The simultaneous procedural statement has an equivalent simple simultaneous statement and creates an accompanying implied subprogram body. The subprogram body (along with an accompanying record type definition) is created from the simultaneous procedural statement as follows:

```
type quantity_record_name is record assigned_quantity_declaration; end
record;

function new_name (interface_quantity_declaration)
                    return (quantity_record_name) is
   altered_procedural_declarative_part
```

```
    replaced_variable_declaration_list;
begin
    altered_procedural_statement_part
    return (textual_replaced_quantity_list);
end function;
```

The implied simple simultaneous statement is:

```
procedural_label:
    (textual_assigned_quantity_list)
       == new_name(textual_referenced_quantity_list);
```

where *procedural_label* is the label of the simultaneous procedural statement, and it and the following colon are omitted if there is no label attached to the simultaneous procedural statement.

It is an error if a return statement occurs in the procedural statement part that does not, when executed, have the same effect as the statement at the end of the statement part of the implied subprogram declared as shown. It is also an error if a wait statement, a break statement, or a signal assignment statement occurs in the procedural statement part.

Example:

```
-- A procedural description of the diode model

architecture Proc of Diode is
   quantity Vd across Id, Ic through Anode to Cathode;
   quantity Charge: REAL;
   constant Vt: Voltage := 0.0258;
begin
   p1: procedural begin
      Id := Is0*(exp((Vd-Rd*Id)/Vt) - 1.0);
      Charge := Tau*Id;
      Ic := Charge'Dot;
   end procedural;
end architecture Proc;

-- Its equivalent statements are

type \p1_type\ is
   record
      \Id\: Electrical'Through;
      \Charge\: REAL;
      \Ic\: Electrical'Through;
   end record;

function \p1_function\(Vd: Electrical'Across,
                       Id: Electrical'Through,
                       Ic: Electrical'Through,
                       Charge: REAL,
                       \Charge'Dot\: REAL) return \p1_type\ is
   variable \Vd\: Electrical'Across := Vd;
   variable \Id\: Electrical'Through := Id;
   variable \Ic\: Electrical'Through := Ic;
   variable \Charge\: REAL := Charge;
   variable \\\Charge'Dot\\\: REAL := \Charge'Dot\;
begin
   \Id\ := Is0*(exp((\Vd\-Rd*\Id\)/Vt) - 1.0);
   \Charge\ := Tau*\Id\;
   \Ic\ := \\\Charge'Dot\\\;
   return (\Id\, \Charge\, \Ic\);
end function;
```

```
p1: (Id, Charge, Ic) == \p1_function\(Vd, Id, Ic, Charge, Charge'Dot);
```

NOTE—It is a consequence of the preceding definitions that subtype constraints are not checked on the quantities within the subprogram declaration defined as shown until the return statement is executed.

15.5 Simultaneous null statement

The evaluation of a simultaneous null statement has no effect. Simultaneous null statements are always considered cycle pure.

simultaneous_null_statement ::=
    [label :] **null** ;

Annex A

(informative)

Syntax summary

This annex provides a summary of the syntax for VHDL. Productions are ordered alphabetically by left-hand nonterminal name. The number listed to the right indicates the clause or subclause where the production is given.

abstract_literal ::= decimal_literal | based_literal [§ **13.4**]

access_type_definition ::= **access** subtype_indication [§ **3.3**]

across_aspect ::= [§ **4.3.1.6**]
identifier_list [tolerance_aspect] [:= expression] **across**

actual_designator ::= [§ **4.3.2.2**]
expression
| *signal*_name
| *variable*_name
| *file*_name
| *terminal*_name
| *quantity*_name
| **open**

actual_parameter_part ::= *parameter*_association_list [§ **7.3.3**]

actual_part ::= [§ **4.3.2.2**]
actual_designator
| *function*_name (actual_designator)
| type_mark (actual_designator)

adding_operator ::= + | – | & [§ **7.2**]

aggregate ::= [§ **7.3.2**]
(element_association { , element_association })

alias_declaration ::= [§ **4.3.3**]
alias alias_designator [: alias_indication] **is** name [signature] ;

alias_designator ::= identifier | character_literal | operator_symbol [§ **4.3.3**]

alias_indication ::= subtype_indication | subnature_indication [§ **4.3.3**]

allocator ::= [§ **7.3.6**]
new subtype_indication
| **new** qualified_expression

architecture_body ::= [§ **1.2**]
architecture identifier **of** *entity*_name **is**
architecture_declarative_part

```
    begin
        architecture_statement_part
    end [ architecture ] [ architecture_simple_name ] ;

architecture_declarative_part ::=                                        [§ 1.2.1]
    { block_declarative_item }

architecture_statement ::= simultaneous_statement | concurrent_statement [§ 1.2.2]

architecture_statement_part ::=                                          [§ 1.2.2]
    { architecture_statement }

array_nature_definition ::=                                              [§ 3.6.2.1]
    unconstrained_nature_definition | constrained_nature_definition

array_type_definition ::=                                                [§ 3.2.1]
    unconstrained_array_definition | constrained_array_definition

assertion ::=                                                            [§ 8.2]
    assert condition
        [ report expression ]
        [ severity expression ]

assertion_statement ::= [ label : ] assertion ;                          [§ 8.2]

association_element ::=                                                  [§ 4.3.2.2]
    [ formal_part => ] actual_part

association_list ::=                                                     [§ 4.3.2.2]
    association_element { , association_element }

attribute_declaration ::=                                                [§ 4.4]
    attribute identifier : type_mark ;

attribute_designator ::= attribute_simple_name                           [§ 6.6]

attribute_name ::=                                                       [§ 6.6]
    prefix [ signature ] ' attribute_designator [ ( expression { , expression } ) ]

attribute_specification ::=                                              [§ 5.1]
    attribute attribute_designator of entity_specification is expression ;

base ::= integer                                                         [§ 13.4.2]

base_specifier ::= B | O | X                                             [§ 13.7]

based_integer ::=                                                        [§ 13.4.2]
    extended_digit { [ underline ] extended_digit }

based_literal ::=                                                        [§ 13.4.2]
    base # based_integer [ . based_integer ] # [ exponent ]

basic_character ::=                                                      [§ 13.1]
    basic_graphic_character | format_effector
```

basic_graphic_character ::= [§ **13.1**]
    upper_case_letter | digit | special_character| space_character

basic_identifier ::= letter { [underline] letter_or_digit } [§ **13.3.1**]

binding_indication ::= [§ **5.2.1**]
    [**use** entity_aspect]
    [generic_map_aspect]
    [port_map_aspect]

bit_string_literal ::= base_specifier " [bit_value] " [§ **13.7**]

bit_value ::= extended_digit { [underline] extended_digit } [§ **13.7**]

block_configuration ::= [§ **1.3.1**]
    for block_specification
        { use_clause }
        { configuration_item }
    end for ;

block_declarative_item ::= [§ **1.2.1**]
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | signal_declaration
    | *shared*_variable_declaration
    | file_declaration
    | alias_declaration
    | component_declaration
    | attribute_declaration
    | attribute_specification
    | configuration_specification
    | disconnection_specification
    | step_limit_specification
    | use_clause
    | group_template_declaration
    | group_declaration
    | nature_declaration
    | subnature_declaration
    | quantity_declaration
    | terminal_declaration

block_declarative_part ::= [§ **9.1**]
    { block_declarative_item }

block_header ::= [§ **9.1**]
    [generic_clause
    [generic_map_aspect ;]]
    [port_clause
    [port_map_aspect ;]]

block_specification ::= [§ **1.3.1**]
  *architecture*_name
  | *block_statement*_label
  | *generate_statement*_label [(index_specification)]

block_statement ::= [§ **9.1**]
  *block*_label :
    block [(*guard*_expression)] [**is**]
      block_header
      block_declarative_part
    begin
      block_statement_part
    end block [*block*_label] ;

block_statement_part ::= [§ **9.1**]
  { architecture_statement }

branch_quantity_declaration ::= [§ **4.3.1.6**]
  quantity [across_aspect] [through_aspect] terminal_aspect ;

break_element ::= [break_selector_clause] *quantity*_name => expression [§ **8.14**]

break_list ::= break_element { , break_element } [§ **8.14**]

break_selector_clause ::= **for** *quantity*_name **use** [§ **8.14**]

break_statement ::= [§ **8.14**]
  [label :] **break** [break_list] [**when** condition] ;

case_statement ::= [§ **8.8**]
  [*case*_label :]
    case expression **is**
      case_statement_alternative
      { case_statement_alternative }
    end case [*case*_label] ;

case_statement_alternative ::= [§ **8.8**]
  when choices =>
    sequence_of_statements

character_literal ::= ' graphic_character ' [§ **13.5**]

choice ::= [§ **7.3.2**]
  simple_expression
  | discrete_range
  | *element*_simple_name
  | **others**

choices ::= choice { | choice } [§ **7.3.2**]

component_configuration ::= [§ **1.3.2**]
  for component_specification
    [binding_indication ;]
    [block_configuration]

end for ;

component_declaration ::= [§ **4.5**]
  component identifier [**is**]
    [*local*_generic_clause]
    [*local*_port_clause]
  end component [*component*_simple_name] ;

component_instantiation_statement ::= [§ **9.6**]
  *instantiation*_label :
    instantiated_unit
      [generic_map_aspect]
      [port_map_aspect] ;

component_specification ::= [§ **5.2**]
  instantiation_list : *component*_name

composite_nature_definition ::= [§ **3.6.2**]
  array_nature_definition | record_nature_definition

composite_type_definition ::= [§ **3.2**]
  array_type_definition
  | record_type_definition

concurrent_assertion_statement ::= [§ **9.4**]
  [label :] [**postponed**] assertion ;

concurrent_break_statement ::= [§ **9.8**]
  [label :] **break** [break_list] [sensitivity_clause] [**when** condition] ;

concurrent_procedure_call_statement ::= [§ **9.3**]
  [label :] [**postponed**] procedure_call ;

concurrent_signal_assignment_statement ::= [§ **9.5**]
  [label :] [**postponed**] conditional_signal_assignment
  | [label :] [**postponed**] selected_signal_assignment

concurrent_statement ::= [§ **9**]
  block_statement
  | process_statement
  | concurrent_procedure_call_statement
  | concurrent_assertion_statement
  | concurrent_signal_assignment_statement
  | component_instantiation_statement
  | generate_statement
  | concurrent_break_statement

condition ::= *boolean*_expression [§ **8.1**]

condition_clause ::= **until** condition [§ **8.1**]

conditional_signal_assignment ::= [§ **9.5.1**]
  target <= options conditional_waveforms ;

conditional_waveforms ::= [§ **9.5.1**]
{ waveform **when** condition **else** }
waveform [**when** condition]

configuration_declaration ::= [§ **1.3**]
configuration identifier **of** *entity*_name **is**
configuration_declarative_part
block_configuration
end [**configuration**] [*configuration*_simple_name] ;

configuration_declarative_item ::= [§ **1.3**]
use_clause
| attribute_specification
| group_declaration

configuration_declarative_part ::= [§ **1.3**]
{ configuration_declarative_item }

configuration_item ::= [§ **1.3.1**]
block_configuration
| component_configuration

configuration_specification ::= [§ **5.2**]
for component_specification binding_indication ;

constant_declaration ::= [§ **4.3.1.1**]
constant identifier_list : subtype_indication [:= expression] ;

constrained_array_definition ::= [§ **3.2.1**]
array index_constraint **of** *element*_subtype_indication

constrained_nature_definition ::= [§ **3.6.2.1**]
array index_constraint **of** subnature_indication

constraint ::= [§ **4.2**]
range_constraint
| index_constraint

context_clause ::= { context_item } [§ **11.3**]

context_item ::= [§ **11.3**]
library_clause
| use_clause

decimal_literal ::= integer [. integer] [exponent] [§ **13.4.1**]

declaration ::= [§ **4**]
type_declaration
| subtype_declaration
| object_declaration
| interface_declaration
| alias_declaration
| attribute_declaration
| component_declaration

| group_template_declaration
| group_declaration
| entity_declaration
| configuration_declaration
| subprogram_declaration
| package_declaration
| primary_unit
| architecture_body
| nature_declaration
| subnature_declaration

delay_mechanism ::= [§ **8.4**]
transport
| [**reject** *time*_expression] **inertial**

design_file ::= design_unit { design_unit } [§ **11.1**]

design_unit ::= context_clause library_unit [§ **11.1**]

designator ::= identifier | operator_symbol [§ **2.1**]

direction ::= **to** | **downto** [§ **3.1**]

disconnection_specification ::= [§ **5.3**]
disconnect guarded_signal_specification **after** *time*_expression ;

discrete_range ::= *discrete*_subtype_indication | range [§ **3.2.1**]

element_association ::= [§ **7.3.2**]
[choices =>] expression

element_declaration ::= [§ **3.2.2**]
identifier_list : element_subtype_definition ;

element_subnature_definition ::= [§ **3.6.2.2**]
subnature_indication

element_subtype_definition ::= subtype_indication [§ **3.2.2**]

entity_aspect ::= [§ **5.2.1.1**]
entity *entity*_name [(*architecture*_identifier)]
| **configuration** *configuration*_name
| **open**

entity_class ::= [§ **5.1**]
entity
| **architecture**
| **configuration**
| **procedure**
| **function**
| **package**
| **type**
| **subtype**
| **constant**

```
    | **signal**
    | **variable**
    | **component**
    | **label**
    | **literal**
    | **units**
    | **group**
    | **file**
    | **nature**
    | **subnature**
    | **quantity**
    | **terminal**
```

entity_class_entry ::= entity_class [<>] [§ **4.6**]

entity_class_entry_list ::= [§ **4.6**]
    entity_class_entry { , entity_class_entry }

entity_declaration ::= [§ **1.1**]
    entity identifier **is**
        entity_header
        entity_declarative_part
    [**begin**
        entity_statement_part]
    end [**entity**] [*entity*_simple_name] ;

entity_declarative_item ::= [§ **1.1.2**]
    subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | signal_declaration
    | *shared*_variable_declaration
    | file_declaration
    | alias_declaration
    | attribute_declaration
    | attribute_specification
    | disconnection_specification
    | step_limit_specification
    | use_clause
    | group_template_declaration
    | group_declaration
    | nature_declaration
    | subnature_declaration
    | quantity_declaration
    | terminal_declaration

entity_declarative_part ::= [§ **1.1.2**]
    { entity_declarative_item }

entity_designator ::= entity_tag [signature] [§ **5.1**]

entity_header ::= [§ **1.1.1**]

[*formal*_generic_clause]
[*formal*_port_clause]

entity_name_list ::= [§ **5.1**]
entity_designator { , entity_designator }
| **others**
| **all**

entity_specification ::= [§ **5.1**]
entity_name_list : entity_class

entity_statement ::= [§ **1.1.3**]
concurrent_assertion_statement
| *passive*_concurrent_procedure_call
| *passive*_process_statement

entity_statement_part ::= [§ **1.1.3**]
{ entity_statement }

entity_tag ::= simple_name | character_literal | operator_symbol [§ **5.1**]

enumeration_literal ::= identifier | character_literal [§ **3.1.1**]

enumeration_type_definition ::= [§ **3.1.1**]
(enumeration_literal { , enumeration_literal })

exit_statement ::= [§ **8.11**]
[label :] **exit** [*loop*_label] [**when** condition] ;

exponent ::= E [+] integer | E – integer [§ **13.4.1**]

expression ::= [§ **7.1**]
relation { **and** relation }
| relation { **or** relation }
| relation { **xor** relation }
| relation [**nand** relation]
| relation [**nor** relation]
| relation { **xnor** relation }

extended_digit ::= digit | letter [§ **13.4.2**]

extended_identifier ::= \ graphic_character { graphic_character } \ [§ **13.3.2**]

factor ::= [§ **7.1**]
primary [** primary]
| **abs** primary
| **not** primary

file_declaration ::= [§ **4.3.1.4**]
file identifier_list : subtype_indication [file_open_information] ;

file_logical_name ::= *string*_expression [§ **4.3.1.4**]

file_open_information ::= [§ **4.3.1.4**]

[**open** *file_open_kind*_expression] **is** file_logical_name

file_type_definition ::= [§ **3.4**]
file of type_mark

floating_type_definition ::= range_constraint [§ **3.1.4**]

formal_designator ::= [§ **4.3.2.2**]
*generic*_name
| *port*_name
| *parameter*_name

formal_parameter_list ::= *parameter*_interface_list [§ **2.1.1**]

formal_part ::= [§ **4.3.2.2**]
formal_designator
| *function*_name (formal_designator)
| type_mark (formal_designator)

free_quantity_declaration ::= [§ **4.3.1.6**]
quantity identifier_list : subtype_indication [:= expression] ;

full_type_declaration ::= [§ **4.1**]
type identifier **is** type_definition ;

function_call ::= [§ **7.3.3**]
*function*_name [(actual_parameter_part)]

generate_statement ::= [§ **9.7**]

```
generate_label :
    generation_scheme generate
        [ { block_declarative_item }
    begin ]
        { architecture_statement }
    end generate [ generate_label ] ;
```

generation_scheme ::= [§ **9.7**]
for *generate*_parameter_specification
| **if** condition

generic_clause ::= [§ **1.1.1**]
generic (generic_list) ;

generic_list ::= *generic*_interface_list [§ **1.1.1.1**]

generic_map_aspect ::= [§ **5.2.1.2**]
generic map (*generic*_association_list)

graphic_character ::= [§ **13.1**]
basic_graphic_character | lower_case_letter | other_special_character

group_constituent ::= name | character_literal [§ **4.7**]

group_constituent_list ::= group_constituent { , group_constituent } [§ **4.7**]

group_declaration ::= [§ **4.7**]
  group identifier : *group_template*_name (group_constituent_list) ;

group_template_declaration ::= [§ **4.6**]
  group identifier **is** (entity_class_entry_list) ;

guarded_signal_specification ::= [§ **5.3**]
  *guarded*_signal_list : type_mark

identifier ::= basic_identifier | extended_identifier [§ **13.3**]

identifier_list ::= identifier { , identifier } [§ **3.2.2**]

if_statement ::= [§ **8.7**]
  [*if*_label :]
    if condition **then**
      sequence_of_statements
    { **elsif** condition **then**
      sequence_of_statements }
    [**else**
      sequence_of_statements]
    end if [*if*_label] ;

incomplete_type_declaration ::= **type** identifier ; [§ **3.3.1**]

index_constraint ::= (discrete_range { , discrete_range }) [§ **3.2.1**]

index_specification ::= [§ **1.3.1**]
   discrete_range
  | *static*_expression

index_subtype_definition ::= type_mark **range** <> [§ **3.2.1**]

indexed_name ::= prefix (expression { , expression }) [§ **6.4**]

instantiated_unit ::= [§ **9.6**]
   [**component**] *component*_name
  | **entity** *entity*_name [(*architecture*_identifier)]
  | **configuration** *configuration*_name

instantiation_list ::= [§ **5.2**]
   *instantiation*_label { , *instantiation*_label }
  | **others**
  | **all**

integer ::= digit { [underline] digit } [§ **13.4.1**]

integer_type_definition ::= range_constraint [§ **3.1.2**]

interface_constant_declaration ::= [§ **4.3.2**]
  [**constant**] identifier_list : [**in**] subtype_indication [:= *static*_expression]

interface_declaration ::= [§ **4.3.2**]

```
      interface_constant_declaration
    | interface_signal_declaration
    | interface_variable_declaration
    | interface_file_declaration
    | interface_terminal_declaration
    | interface_quantity_declaration

interface_element ::= interface_declaration                         [§ 4.3.2.1]

interface_file_declaration ::=                                      [§ 4.3.2]
    file identifier_list : subtype_indication

interface_list ::=                                                  [§ 4.3.2.1]
    interface_element { ; interface_element }

interface_quantity_declaration ::=                                  [§ 4.3.2]
    quantity identifier_list : [ in | out ] subtype_indication [ := static_expression ]

interface_signal_declaration ::=                                    [§ 4.3.2]
    [ signal ] identifier_list : [ mode ] subtype_indication [ bus ] [ := static_expression ]

interface_terminal_declaration ::=                                  [§ 4.3.2]
    terminal identifier_list : subnature_indication

interface_variable_declaration ::=                                  [§ 4.3.2]
    [ variable ] identifier_list : [ mode ] subtype_indication [ := static_expression ]

iteration_scheme ::=                                                [§ 8.9]
      while condition
    | for loop_parameter_specification

label ::= identifier                                                [§ 9.7]

letter ::= upper_case_letter | lower_case_letter                    [§ 13.3.1]

letter_or_digit ::= letter | digit                                  [§ 13.3.1]

library_clause ::= library logical_name_list                        [§ 11.2]

library_unit ::=                                                    [§ 11.1]
      primary_unit
    | secondary_unit

literal ::=                                                         [§ 7.3.1]
      numeric_literal
    | enumeration_literal
    | string_literal
    | bit_string_literal
    | null

logical_name ::= identifier                                         [§ 11.2]

logical_name_list ::= logical_name { , logical_name }               [§ 11.2]
```

logical_operator ::= **and** | **or** | **nand** | **nor** | **xor** | **xnor** [§ **7.2**]

loop_statement ::= [§ **8.9**]
    [*loop*_label :]
        [iteration_scheme] **loop**
            sequence_of_statements
        end loop [*loop*_label] ;

miscellaneous_operator ::= ** | **abs** | **not** [§ **7.2**]

mode ::= **in** | **out** | **inout** | **buffer** | **linkage** [§ **4.3.2**]

multiplying_operator ::= * | / | **mod** | **rem** [§ **7.2**]

name ::= [§ **6.1**]
    simple_name
    | operator_symbol
    | selected_name
    | indexed_name
    | slice_name
    | attribute_name

nature_declaration ::= [§ **4.8**]
    nature identifier **is** nature_definition ;

nature_definition ::= [§ **4.8**]
    scalar_nature_definition | composite_nature_definition

nature_element_declaration ::= [§ **3.6.2.2**]
    identifier_list : element_subnature_definition ;

nature_mark ::= [§ **4.8**]
    *nature*_name | *subnature*_name

next_statement ::= [§ **8.10**]
    [label :] **next** [*loop*_label] [**when** condition] ;

null_statement ::= [label :] **null** ; [§ **8.13**]

numeric_literal ::= [§ **7.3.1**]
    abstract_literal
    | physical_literal

object_declaration ::= [§ **4.3.1**]
    constant_declaration
    | signal_declaration
    | variable_declaration
    | file_declaration
    | terminal_declaration
    | quantity_declaration

operator_symbol ::= string_literal [§ **2.1**]

options ::= [**guarded**] [delay_mechanism] [§ **9.5**]

package_body ::= [§ **2.6**]
    package body *package*_simple_name **is**
        package_body_declarative_part
    end [**package body**] [*package*_simple_name] ;

package_body_declarative_item ::= [§ **2.6**]
      subprogram_declaration
    | subprogram_body
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | *shared*_variable_declaration
    | file_declaration
    | alias_declaration
    | use_clause
    | group_template_declaration
    | group_declaration

package_body_declarative_part ::= [§ **2.6**]
    { package_body_declarative_item }

package_declaration ::= [§ **2.5**]
    package identifier **is**
        package_declarative_part
    end [**package**] [*package*_simple_name] ;

package_declarative_item ::= [§ **2.5**]
      subprogram_declaration
    | type_declaration
    | subtype_declaration
    | constant_declaration
    | signal_declaration
    | *shared*_variable_declaration
    | file_declaration
    | alias_declaration
    | component_declaration
    | attribute_declaration
    | attribute_specification
    | disconnection_specification
    | use_clause
    | group_template_declaration
    | group_declaration
    | nature_declaration
    | subnature_declaration
    | terminal_declaration

package_declarative_part ::= [§ **2.5**]
    { package_declarative_item }

parameter_specification ::= [§ **8.9**]
    identifier **in** discrete_range

physical_literal ::= [abstract_literal] *unit*_name [§ **3.1.3**]