IEC 63098-2

Edition 1.0 2022-12

INTERNATIONAL STANDARD

colour inside

Transmitting and receiving equipment for radiocommunication – Radio-over-fibre technologies and their performance standard –
Part 2: Radio-over-fibre-based fronthaul network for railway communication systems

IEC 63098-2:2022-12(en)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC 63098-2

Edition 1.0 2022-12

INTERNATIONAL STANDARD

colour inside

Transmitting and receiving equipment for radiocommunication – Radio-over-fibre technologies and their performance standard – Part 2: Radio-over-fibre-based fronthaul network for railway communication systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.060.20

ISBN 978-2-8322-6056-2

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

TRANSMITTING AND RECEIVING EQUIPMENT FOR RADIOCOMMUNICATION – RADIO-OVER-FIBRE TECHNOLOGIES AND THEIR PERFORMANCE STANDARD –

Part 2: Radio-over-fibre-based fronthaul network for railway communication systems

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 63098-2 has been prepared by IEC technical committee 103: Transmitting and receiving equipment for radiocommunication. It is an International Standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
103/244/FDIS	103/249/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63098 series, published under the general title *Transmitting and receiving equipment for radiocommunication – Radio-over-fibre technologies and their performance standard*, can be found on the IEC website.

Future documents in this series will carry the new general title as cited above. Titles of existing documents in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

A high-speed train communication network comprises two parts: a back-end network and wireless access system to deliver data to train cars. In this back-end network, optical fiber communication-based networks are generally utilized to reduce the complexity of the radio access units set along the railway track, which delivers the signal wirelessly to the train car, wireless signals are generated and processed at a central office, and then are transported via an optical fiber network into the radio access units. A radio-over-fiber fronthaul network is configured to transport the wireless signal, which is applicable between a node base station and radio access units set at a trackside. The radio-over-fiber-based fronthaul link connects the node base station to the trackside radio access units and carries millimeter-wave subcarrier or intermediate frequency components to transmit high-capacity signals. This document provides the required performance with reliability and quality assurance of radio-over-fiber-based fronthaul networks for railway communication networks between trains and tracksides, as well as a design guide for network configuration.

TRANSMITTING AND RECEIVING EQUIPMENT FOR RADIOCOMMUNICATION – RADIO-OVER-FIBRE TECHNOLOGIES AND THEIR PERFORMANCE STANDARD –

Part 2: Radio-over-fibre-based fronthaul network for railway communication systems

1 Scope

This part of IEC 60598 specifies a radio-over-fiber-based fronthaul network for railway communication systems between trains and tracksides and their transmitters and receivers.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60950-1, *Information technology equipment – Safety – Part 1: General requirements*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
radio over fiber
RoF
radio signal transmission method using an optical fiber whose signal is modulated by the radio signal

3.1.2
double-sideband modulation
modulation pertaining to a transmission or emission where both sidebands resulting from amplitude modulation are preserved equally

3.1.3
single-sideband modulation
modulation pertaining to a transmission or emission where only either the lower sideband or the upper sideband resulting from amplitude modulation is preserved

3.1.4
wavelength division multiplexing
WDM
multiplexing in which several independent signals are allotted separate wavelengths for transmission over a common optical transmission medium

[SOURCE: IEC 60050-704:2019, 704-08-06, modified – The Note 1 to entry has been deleted.]

3.2 Abbreviated terms

The abbreviated terms used in this document are listed in Table 1.

Table 1 – Abbreviated terms

CO	central office
DeMUX	demultiplexer
DSB	double sideband
DUT	device under test
E/O	electrical-to-optical converter
LD	laser diode
MUX	multiplexer
MZM	Mach-Zehnder interferometer-type optical modulator
O/E	optical-to-electrical converter
RF	radio frequency
RoF	radio over fiber
Rx	receiver
SSB	single sideband
TDC	train direction centre
TLD	wavelength tunable laser diode
TLI	train location information
TRx	transceiver
TS-RAU	trackside radio access unit
Tx	transmitter
WDM	wavelength division multiplexing

4 Functional specification

4.1 RoF fronthaul network

A general block diagram of the fronthaul network is shown in Figure 1. Typically, a central office (CO) is located in a train direction centre (TDC) or a train station, a radio-over-fiber transceiver (RoF TRx), which comprises an RoF transmitter (RoF Tx) and RoF receiver (RoF Rx) irradiates the RoF signal into an optical fiber. At a demultiplexer (DeMUX), the RoF signal is delivered via an optical fiber to a trackside radio access unit (TS-RAU). On the opposite side, the RoF signals from the RoF TRxs in the TS-RAU are multiplexed at a multiplexer (MUX), and then the multiplexed signal is transmitted over the fiber into the RoF TRx in the CO.

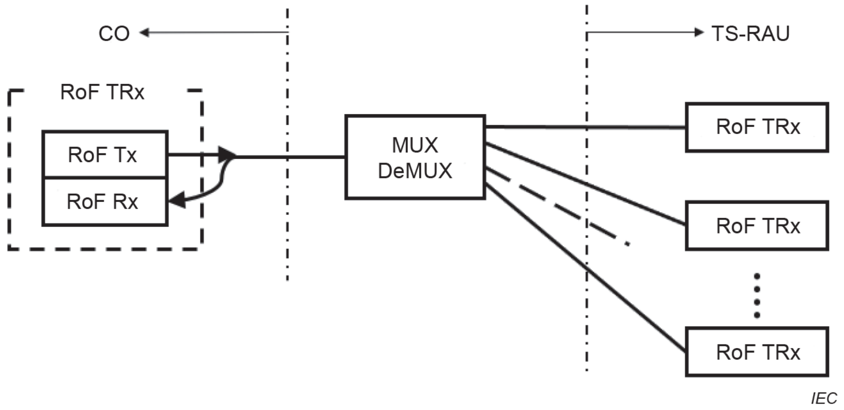

Figure 1 – Block diagram of RoF fronthaul network for a railway communication system

Functional specifications are listed in Annex A.

4.2 RoF transmitter and receiver

Functional specifications are listed in Annex B and Annex C.

4.3 Operating environment

The operating environment of the network, transmitter and receiver is specified in Table 2.

Table 2 – Operating environment

Parameter	Symbol	Value		Unit
		Minimum	Maximum	
Operating temperature (case)	T_{op}	−20	+60	°C

5 Testing

5.1 General

Initial characterizations and qualifications should be undertaken when a build standard is completed and frozen. Qualification maintenance is carried out using periodic testing programmes.

The test conditions for all tests, unless otherwise stated, are 0 °C, 25 °C, and 60 °C.

5.2 Performance testing

Performance testing is performed upon completion of the characterization testing. The performance test plan and recommended performance test failure criteria are specified in Annex A.

6 Environmental specifications

6.1 General safety

All products specified in this document shall conform to IEC 60950-1.

6.2 Laser safety

Fibre optic transmitters and transceivers using the laser diode specified in this document shall be class 1-3R laser certified under any operating condition. It includes single fault conditions, whether coupled into a fiber or out of an open bore. Fibre optic transmitters and transceivers using the laser diode specified in this document should be certified to conform to IEC 60825-1.

6.3 Temperature and environment

The measurement should be performed at 0 °C, 25 °C, and 60 °C. It is desirable to control the measurement temperature within ±5 °C to minimize the influence of the temperature drift of the measurement apparatus. The temperature of the DUT can be changed using a temperature controller to verify the temperature dependence of the measured parameters.

Annex A
(normative)

Specifications for RoF fronthaul networks in railway communication systems

A.1 Overview

The RoF fronthaul network is utilized as a radio signal delivery system between a CO and TS-RAUs, as shown in Figure A.1. A signal prepared in the processor in the CO is delivered via the network to the onboard terminal to establish a communication link between a ground CO and an onboard terminal in a train car.

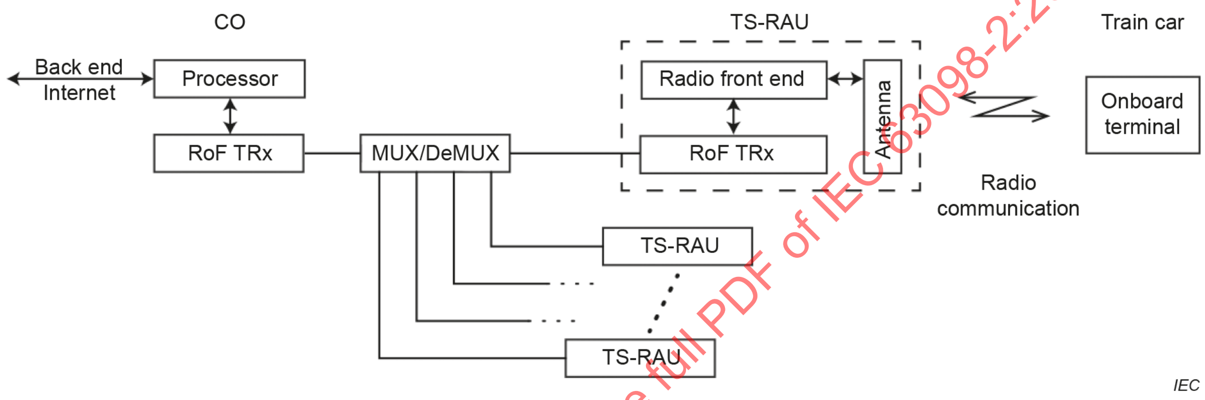

Figure A.1 – Schematic diagram of a railway communication system

In general, a communication signal from/to the back-end system and the Internet is prepared by the processor in the CO for transmission in the optical network. The RoF TRx in the CO irradiates the RoF signal into the optical fiber. The optical path to the TS-RAU is determined at the MUX/DeMUX, and the RoF signal is transmitted via the optical fiber to the TS-RAU. Subsequently, the RoF TRx in the TS-RAU receiving the RoF signal converts the optical signal into a radio signal. The radio front end, including frequency converters and amplifiers, prepares to be irradiated by the antenna. Lastly, an onboard terminal in a train car receives a radio signal transmitted through the air. Accordingly, the uplink from the train car to the CO is performed, and vice versa.

There are several configurations for the RoF network with the agile switchover of the optical path at the MUX/DeMUX: an optical switch-based system and a WDM system. The availability of these systems depends on the scalability, available numbers of optical fiber cores, stability of the laser used, etc.

A.2 Diagrams

A.2.1 Optical switch-based system

Optical switch-based systems, including core and metro networks and data centre systems, are commonly used in terrestrial optical fiber communication systems. An optical switch is inserted into the network to switch the optical path between the RoF TRx in the CO and suitable TS-RAU, as shown in Figure A.2. In this system, the m-inputs and n-outputs ($m \times n$) switch is utilized for path switching, where n denotes the number of RoF TRx in the TS-RAUs. Meanwhile, m is determined by the number of RoF TRx in the CO, as well as the number of optical ports of the RoF TRx. For instance, when the RoF TRx has two optical ports to connect to the RoF Tx and RoF Rx, the optical switch should have $2 \times n$ ports, even if one RoF TRx is set in the CO. Moreover, the optical switch is controlled by the CO and TDC, which contain train location information (TLI). The switch control signal is delivered via an optical fiber link to control the optical switch. The switch control signal is deployed between the CO and the optical switch. Accordingly, the optical path may be shared with the optical fiber core used for RoF signal delivery with the WDM.

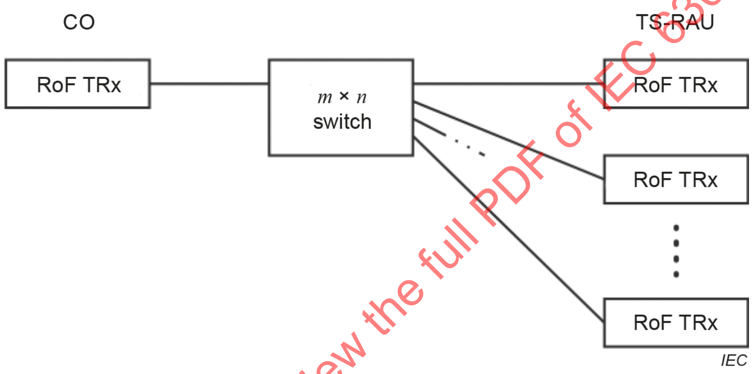

Figure A.2 – Block diagram of optical-switch-based fronthaul network

The optical switch-based system is robust to laser wavelength instability. Moreover, the same wavelength channels can be used for all TS-RAUs. On the contrary, the optical switch does not typically have a multicast feature; the signal from the RoF TRx cannot deliver two or more TS-RAUs simultaneously. Thus, a type of coordinated multipoint technique used for coordination of several TS-RAUs is difficult to configure.

Control of the switch requires another communication line between the switch fabric and the CO/TDC.

A.2.2 WDM-based system

The WDM-based system consists of a WDM MUX/DeMUX utilized as a signal MUX/DeMUX in the RoF network, as shown in Figure A.3. The WDM system is used in the same manner as an optical fiber communication system; each TS-RAU is assigned with a unique wavelength channel. The WDM MUX/DeMUX is configured with a passive optical component, such as an arrayed waveguide grating, without an active switch in the MUX/DeMUX. When it is required to change the optical path route, the wavelength of the signal in the RoF TRx of the CO is changed to a suitable wavelength channel of the TS-RAU.

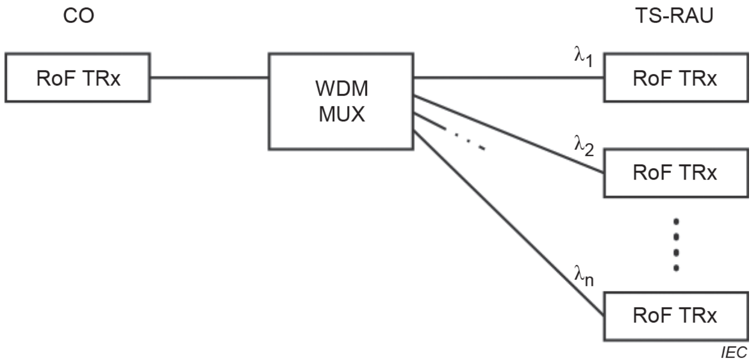

Figure A.3 – Block diagram of WDM-based fronthaul network

In the WDM system, the wavelength stability of the light wave source in the TS-RAUs is a critical factor in its implementation. Generally, since the TS-RAU is set to an outdoor condition, the ambient temperature of the wavelength tunable laser diode (TLD) in the RoF TRx will range from −20 °C to 60 °C. In this case, a thermoelectric cooler should be equipped with the TLD because the wavelength of the irradiated signal from the TLD fluctuates according to the temperature, as well as the WDM MUX/DeMUX.

The WDM system has a large scalability to a number of TS-RAUs owing to the separation of the wavelength channels. In the optical communication band, such as a C-band (1 530 nm to 1 565 nm in wavelength), up to 80 channels are possible when the separation is set at 50 GHz. In addition, the system also has scalability to a number of RoF TRx in the CO. Simultaneous signal delivery to some TS-RAUs can be performed by increasing the RoF TRx in the CO, in a similar manner to the optical fiber communication systems.

Since the WDM MUX/DeMUX consists of passive components, there is no independent control link between the WDM MUX/DeMUX and the CO/TDC, except for the temperature controller to stabilize the wavelength channels.

A.3 Functional specification

The functional specification of the RoF fronthaul network, which focuses on tracking one train car, is listed in Table A.1.

Table A.1 – Functional specification of the RoF fronthaul network

Parameter		Symbol	Value Min.	Value Typ.	Value Max.	Unit	Note
A number of TS-RAUs		*n*			50		
RoF link distance					50	km	
RoF link gain				0		dB	
Transmission performance	EVM in 3GPP rel. 12				8	%	MCS index of 11-19
	EVM in IEEE 802.15 IG HRRS				8	%	
Switch-based system	A number of input ports	*m*		2			For uplink and downlink
	Switching speed		0,1		250	ms	
	Cross talk of the output ports		25			dB	
WDM-based system	Wavelength channel separation		25	50	200	GHz	
	Wavelength switching speed		0,000 1		250	ms	
	Wavelength channel cross talk		25			dB	

A.4 Testing

A.4.1 General

Initial characterization and qualification should be undertaken when a build standard is completed and frozen. Qualification maintenance shall be carried out using periodic testing programmes. The test conditions for all tests, unless otherwise stated, are 0 °C, 25 °C, and 60 °C, as specified in IEC 62149-10:2018, Annex A.

The measurement procedure and reporting are specified in IEC 62007-2.

A.4.2 Performance testing

The performance test plan is given in Table A.2. The other performance tests are optional and are specified in IEC 62149-10:2018, Annex A.

Table A.2 – Performance test plan

No.	Test	Requirements	Max.	Min.	Unit	Details
0	Vibration	0 °C, 25 °C, 60 °C	0,7	−0,7	dB	IEC 60068-2-6 20 g 20 Hz to 2 000 Hz, 4 min per cycle, 4 cycles per axis
1	Cyclic moisture	0 °C, 25 °C, 60 °C	0,7	−0,7	dB	IEC 60068-2-38 10 cycles
2	High temperature endurance 5 000 h	70 °C	0,7	−0,7	dB	70 °C
3	Cold storage 2 000 h	−40 °C	0,7	−0,7	dB	−40 °C

Annex B
(informative)

Specifications for the DSB RoF transmitter for fronthaul systems in railway communication systems

B.1 Overview

The RoF transmitter based on double-sideband (DSB) modulation is a simple and straightforward method to apply to the RoF link. Generally, the DSB signal can be generated using a direct modulation laser diode, an external modulation laser diode integrated with a laser diode and an electro-absorption modulator, and an external modulator system using the MZM as an optical intensity modulator. However, an optical fiber has a chromatic dispersion; typically with a dispersion coefficient of 17 ps/nm/km. After photodetection at a receiver, two beat components, a pair of carrier and lower sideband components, and a pair of carrier and upper sideband components, have a relative transmission delay caused by chromatic dispersion. Ultimately, the RF signal at the receiver vanishes when the two beat components have opposite phases. The resultant RF throughput is expressed as follows:

$$\text{RF throughput} \propto \cos^2 \frac{\pi L D \lambda^2 f^2}{v}$$

where L, D, λ, f and v denote the length of the fibre, dispersion coefficient, wavelength of the signal, RF frequency, and speed of light in the fibre, respectively. Figure B.1 illustrates the RF throughput, including a fiber insertion loss of 0,2 dB/km at a different frequency using a single-mode optical fiber (a dispersion coefficient of 17 ps/nm/km). A high RF frequency has a valley structure in the transmission fibre distance. In such a case, it is necessary to implement chromatic dispersion compensation to reduce degradation. Usually, the fibre length from the CO to the furthest TS-RAU is up to 40 km. Therefore, the centre frequency of the RF signal should be less than 3 GHz under the DSB modulation.

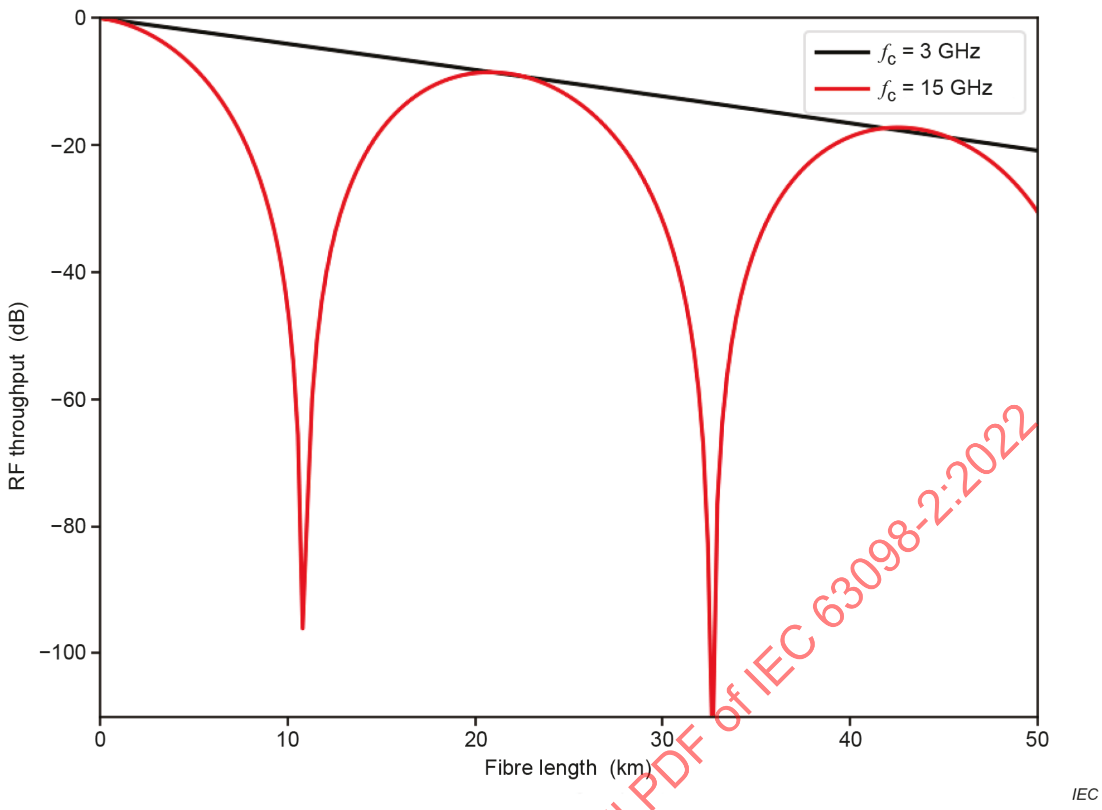

Figure B.1 – Relative RF throughput of the DSB-modulated signals over some length of the optical fibre at a centre frequency of 3 GHz and 15 GHz

B.2 Diagrams

Two types of configuration of the RoF Tx under DSB modulation are shown in Figure B.2: an external modulation system and a direct modulation system. In the external modulation system, the light wave source and modulator are located separately. For intensity modulation, the MZM is utilized for electrical-to-optical conversion. In contrast, a direct-modulation LD is the simplest way to form the RoF signal. The current driving the LD is directly modulated by the input RF signal to modulate the output light waves.

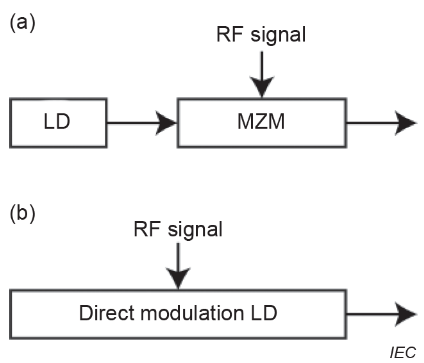

Figure B.2 – Block diagram of DSB RoF transmitter with (a) external modulation and (b) direct modulation systems

The configuration of the RoF Tx for application to the WDM-based fronthaul network is shown in Figure B.3. The structure of the system is identical to that of the RoF Tx shown in Figure B.2, except for the application of a wavelength-tunable laser diode (TLD) as a light wave source. The emitted wavelength from the TLD is adaptively changed for WDM transmission.

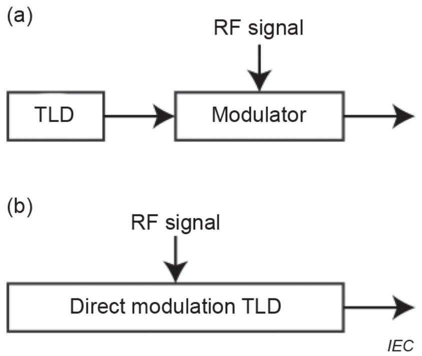

Figure B.3 – Block diagram of DSB RoF transmitter with (a) external modulation and (b) direct modulation systems for the WDM-based network

B.3 Functional specification

The functional specification of the DSB RoF Tx is specified in Table B.1.

Table B.1 – Functional specification of DSB RoF transmitter

Parameter	Symbol	Value			Unit	Note
		Min.	Typ.	Max.		
Output optical power				10	dBm	
Input signal frequency range				3	GHz	
Transmitter operating wavelength		1 270		1 610	nm	
Flatness of frequency response			±1		dB	
Input impedance			50		Ω	
Spurious free dynamic range	SFDR	110			$(dB/HZ)^{2/3}$	At 1 GHz
Input noise floor				−140	dBm Hz	At 1 GHz
Input third order intercept point		31			dBm	At 1 GHz
Switching speed of the wavelength in the TLD				250	ms	
Operating temperature (case)		−40		60	°C	

B.4 Testing

B.4.1 General

Initial characterization and qualification should be undertaken when a build standard is completed and frozen. Qualification maintenance shall be carried out using periodic testing programmes. The test conditions for all tests, unless otherwise stated, are 0 °C, 25 °C, and 60 °C, as specified in IEC 62149-10:2018, Annex A.

The measurement procedure and reporting are specified in IEC 62007-2.

B.4.2 Characterization testing

The test and test limits are specified in IEC 62149-10:2018, Annex A.

B.4.3 Performance testing

The test plan is specified in IEC 62149-10:2018, Annex A.