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TECHNICAL REPORT

colour inside

Transmitting equipment for radiocommunication – Radio-over-fibre technologies and their performance standard – Part 1: System applications of radio over fibre technology

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

Part 1: System applications of radio over fibre technology

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IEC TR 63098-1, which is a Technical Report, has been prepared by IEC technical committee 103: Transmitting equipment for radiocommunication.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
103/153/DTR	103/168/RVDTR

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

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63098 series, published under the general title *Transmitting equipment for radiocommunication*, can be found on the IEC website.

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

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

Using radio-over-fibre technology, RF modulated optical carriers and signals can be transmitted in optical fibre with very low loss. Fundamentally, radio-over-fibre (RoF) is an analogue transmission system that allows radio frequency signals to be transmitted and processed without being digitized. Remote antenna systems including distributed antenna system (DAS) which use RoF technology in terrestrial broadcasting and mobile communications have also become established infrastructures.

In terrestrial broadcasting, the conventional microwave links for studio-transmitter links (STLs), transmitter-studio links (TSLs), transmitter-transmitter links (TTLs) and field pickup units (FPUs) have been replaced by RoF systems, particularly in Japan.

RoF technology is a promising technology for broadband access networks combined with the mobility and the flexibility of wireless access. An advantage of RoF technology is multiplexing of RF signals. Multiple RF signals can be converged on the physical layer and they are transmitted to the remote site transparently. RoF technology can also be used for multiplexed transmission that supports CATV (cable television) trunk line systems, cellular phone systems, etc. for blind spots, such as inside buildings, underground areas and subways. RoF systems are also used in digital signage systems and rapid and agile deployment of broadcasting and communication services.

This document provides information on the current and latest applications of radio-over-fibre technology, which are already implemented or will be in the near future. This document will also be beneficial to system developers and system users in the fields of mobile communications and optical fibre technologies.

An example of the technical specification of a radio over fibre (RoF) link in accordance with the spectral emission standard for digital terrestrial television broadcasting in Japan is given in Annex A.

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

Part 1: System applications of radio over fibre technology

1 Scope

The purpose of this document is to provide information on the current and latest applications of radio-over-fibre technology. Wireless communication, broadcasting, and airport multilateration systems, which are already implemented or will be in the near future, are introduced. This document includes the basic concept, a brief outline and related standards of the applications of RoF technology.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

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

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

3.2 Abbreviated terms

AGC	automatic gain control
CATV	cable television
DAS	distributed antenna system
FPU	field pickup unit, equivalent to microwave link
STL	studio-transmitter link
TSL	transmitter-studio link
TTL	transmitter-transmitter link
TIA	transimpedance amplifier
LNA	low noise amplifier

NF	noise figure
MZ	Mach-Zehnder
BTS	base transceiver station
E/O	electric to optical
O/E	optical to electric
W-CDMA	wideband code division multiple access
LTE	long term evolution
C-RAN	centralized-radio access network
MOF	multi drop optical feeder
DSP	digital signal processing
SCM	sub-carrier multiplexing
RoF	radio over fibre
DRoF	digital radio over fibre
TX	transmitter
RX	receiver
DTTB	digital terrestrial television broadcasting

4 Advantages and disadvantages of RoF

Advantages of RoF are:

- low attenuation,
- low complexity,
- lower cost.

RoF is an analogue transmission system that allows radio frequency signals to be transmitted and processed without being digitized. RF modulated optical carriers and signals can be transmitted in optical fibre with very low propagation loss. By modulating and demodulating the optical signals at the sending and receiving ends of the optical fibre, the optical fibre operates as a low-loss, high-frequency analogue RF transmission medium. RoF technology is more efficient, less complex, and less costly than conventional electronic systems, especially at high microwave and millimetre wave frequencies.

Disadvantages of RoF are:

- dynamic range,
- intermodulation distortion,

- chromatic dispersion.

Basically, the RoF technology is an analogue transmission system and analogue modulation is required. Therefore, the transmission issues that are serious in analogue communication systems are present in RoF systems as well.

The dynamic range of a system is one of the practical issues of the system tolerance when the received power varies. Generally, the dynamic range of RoF systems is limited by optical device parameters such as relative intensity noise and shot noise.

The RoF link system inherently suffers from intermodulation distortions arising from the nonlinearity of both microwave (driver amplifier, transimpedance amplifier [TIA], low-noise amplifier [LNA]) and optical (E/O converter: optical modulator, O/E converter: photodetector) components. A large modulation index introduces more intermodulation. The system should be designed by considering the device features. In particular, adjusting of modulation index, optical power and gain are critical parameters for the optimization of the optical link design. A Mach-Zehnder (MZ) modulator is suitable for broadband signal transmission; however, the transfer curve of an MZ modulator is inherently nonlinear.

Noise figure (NF), optical signal gain and second intermodulation distortions are strongly dependent on the bias condition of the MZ modulator and have trade-off relationships. Stable bias control of an optical modulator is also a technical issue when a Mach-Zehnder intensity modulator is used. Fine-tuned integration of individual devices and circuits is required for an optimal overall performance.

5 Practical applications

5.1 List of applications

Table 1 shows application examples using RoF technology. RoF systems have been utilized in many fields such as broadcasting systems, mobile communication systems and railway systems. In recent years, RoF technology has been applied for the development of an aircraft multilateration systems and train communication systems.

Table 1 – Application examples

Mobile communication system	Broadcasting system	Airport system	Train communication system
• Mobile communication underground service system • In-building mobile enhancement system • Remote radio head See 5.2	• Digital terrestrial • Television broadcasting • Repeating system • Microwave link (ENG) See 5.3	• Multilateration system See 5.4 • Foreign object and debris detection radar system	• Millimetre-wave fronthaul and backhaul
Key ENG: electronic news gathering			

5.2 Mobile communication system

5.2.1 General

RoF systems have been used in mobile communications for an economical and speedy area expansion and area construction in a covered space such as an underground shopping mall and tunnels.

5.2.2 Features

Features of RoF systems for mobile communications are based on the characteristics of optical fibre, such as extremely wide transmission bandwidth and flexibility, very small diameter and light weight. RoF is a flexible RF signal transmission system, so it can transmit any kind of RF modulation format used by mobile telephony systems, such as W-CDMA (wideband code division multiple access), LTE (long term evolution) and all RF signal frequency bands.

5.2.3 System configuration

RoF systems are configured using small BTS (base transceiver station) including RF modulators and demodulators, EO (electric to optical signal transformer) units, optical fibre, OE (optical to electric signal transformer) units and antennas.

This document suggests that the following systems should be further discussed to apply RoF technologies to future mobile access networks including C-RAN (centralized-radio access network):

a) wireless relay for in-building, underground, metro systems;

b) moving cell to support Gbps data transmission and high-speed mobility;

c) fronthaul/backhaul.

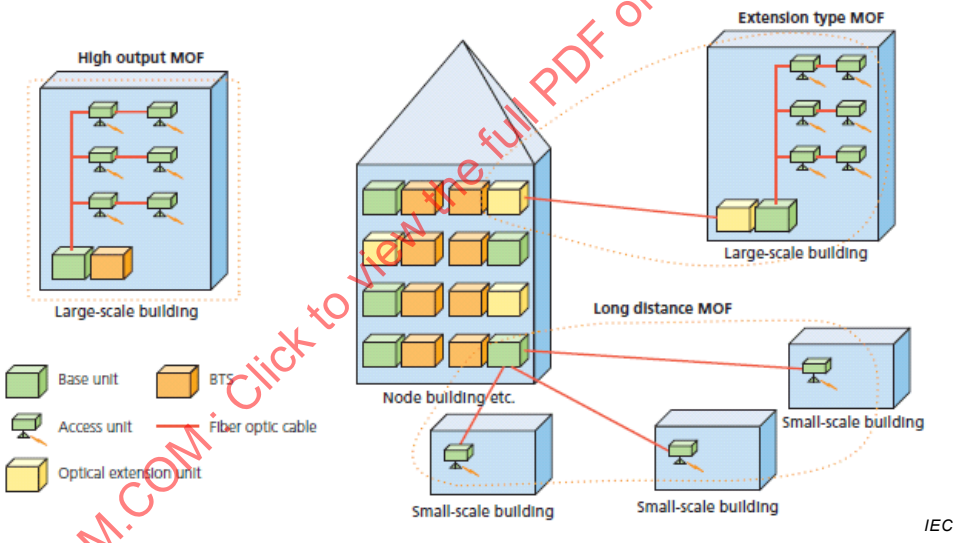


Figure 1 – Usage Image of each Multi Drop Optical Feeder (MoF) [1][1]

5.2.4 Specifications

Table 2 shows the example of specifications of the RoF system for in-building mobile systems. Down link (base station to mobile terminal) signal quality is specified by the regulation.

1 Numbers in square brackets refer to the Bibliography.

Table 2 – Specification of RoF links

	Down link	Up link
Frequency band	2 130 MHz to 2 150 MHz (3G)	1 940 to 1 960 MHz (3G)
Number of RF carriers	3G: 4	
RoF link gain	3G: 25 dB	0 dB
CNR	3G: ≧ 45 dB/4 MHz	3G: ≧ 40 dB/4 MHz
IM3	≦−45 dBc	≦−56 dBc
Optical transmission Distance	20 km maximum (See the extension type MOF and the large distance MOF in Figure 1) 2 km maximum (See the high output MOF in Figure 1)	
Optical fibre	1 310 nm zero dispersion SM fibre	
Key SM: single mode		

5.3 Relay station for digital terrestrial TV

5.3.1 General

RoF systems using the MZ modulator have been developed and put to practical use in broadcasting relay applications. This system can be constructed using a unique optical modulator of Mach-Zehnder waveguide type with no power supply, in which the intensity of the light signal to be transmitted from the receiving to transmitting point facilities varies in response to weak RF signal amplitude.

This system does not require electrical power at the receiving point and has the advantages of multi-carrier waves long distance transmission through an optical fibre.

Therefore, transmitting and receiving points can be easily separated and the system has been adopted as one of the separation reception methods in the distribution network of digital terrestrial TV broadcasting in Japan [2].

5.3.2 Features

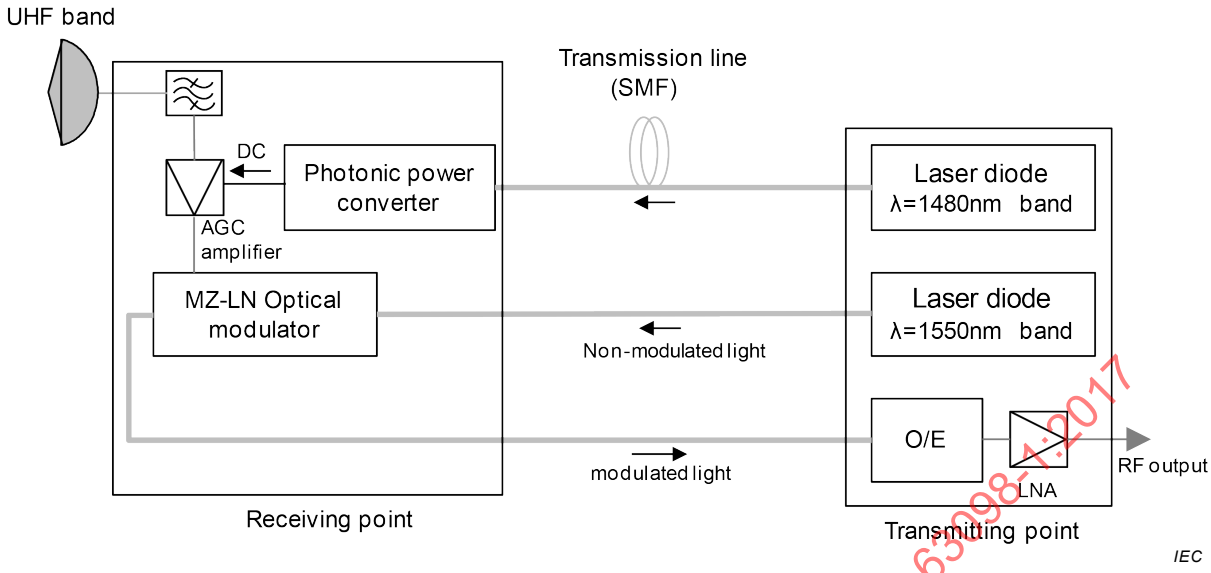
Features of this system are as follows:

1) An electric power supply is unnecessary at the receiving point.
2) The light, modulated directly with an RF signal, is transmitted through an optical fibre with low loss (0,3 dB/km).
3) Multiplexing technology for radio signals is available.
4) The receiving point and the transmitting point are electrically isolated to realize high immunity to lightning damage.

5.3.3 System configuration

Figure 2 shows the basic configuration of the system. This system is composed of a receiving antenna, a receiving unit, a transmitting unit and 3 single-mode optical fibres.

The system operates an AGC amplifier by optical powering. In this way, this system has achieved high efficiency and a wide dynamic range without an electrical power supply at the receiving point.



Key

SMF: single mode fibre

Figure 2 – System configuration [2]

5.3.4 Specifications

Table 3 shows the specifications of the RoF system for digital terrestrial television relay stations [3].

Table 3 – Specifications of an RoF system

Item		Specification
Frequency		470 – 770 MHz
Input Power	Rating	−47 dBm ± 20 dBm/ch
	Maximum	-13 dBm
	Impedance	50 Ω
Output power	Rating	−40 dBm ± 20 dBm/ch
	Variable range	±5 dBm
	Impedance	50 Ω
Frequency response		2 dBm_{p-p} max
Transmission distance		3 km max
Noise figure		5.0 dBm max
Fiber used		Single mode
Operating temperature range		−20 - 60°C
Power stability		DC +48 V, 70 W max

5.4 Airport multilateration system

5.4.1 General

Multilateration (MLAT), which is an aircraft surveillance system for airport surface taxiing, has been installed at major airports for their expansion of air traffic capacity. MLAT receivers detect RF signals transmitted by aircraft, and the aircraft positions are calculated using a hyperbolic positioning method. However, multipath interference signal reflecting on structures

such as terminal buildings and passenger boarding bridges sometimes degrades MLAT performance.

Here an RoF system is used for an advanced MLAT system which has better interference immunity in the multipath environment. The advanced MLAT system developed is called "Optically Connected Passive Surveillance System (OCTPASS)" [4]. This system uses RoF for RF signal convergence from all receiver stations, and has a superior ability for the positioning of aircraft with small remote radio heads.

5.4.2 Features

Features of this system are as follows:

1) better immunity to multipath interference due to the microwave reflections on structures at airport apron or spot area;
2) simple configuration and compact size: cost of installation and maintenance is kept low;
3) low power consumption receiver stations with optical power feeding: need for installation of electrical power supply is eliminated.

5.4.3 System configuration

Figure 3 shows the configuration of the advanced MLAT system. This system is mainly constructed with a number of receiver units (including receiver stations, RoF connection and detector unit), a digital signal processing (DSP) unit and a target processing unit which undertakes positioning calculations. Because all received signals are directly converged to the DSP unit by using RoF connections, un-decodable interference signals can be used for positioning calculations. The calculated position error is less than 7,5 m at runway and taxiway. This system optionally contains a transmitter unit also including an RoF connection which emits interrogation signals and test signals for field monitoring.

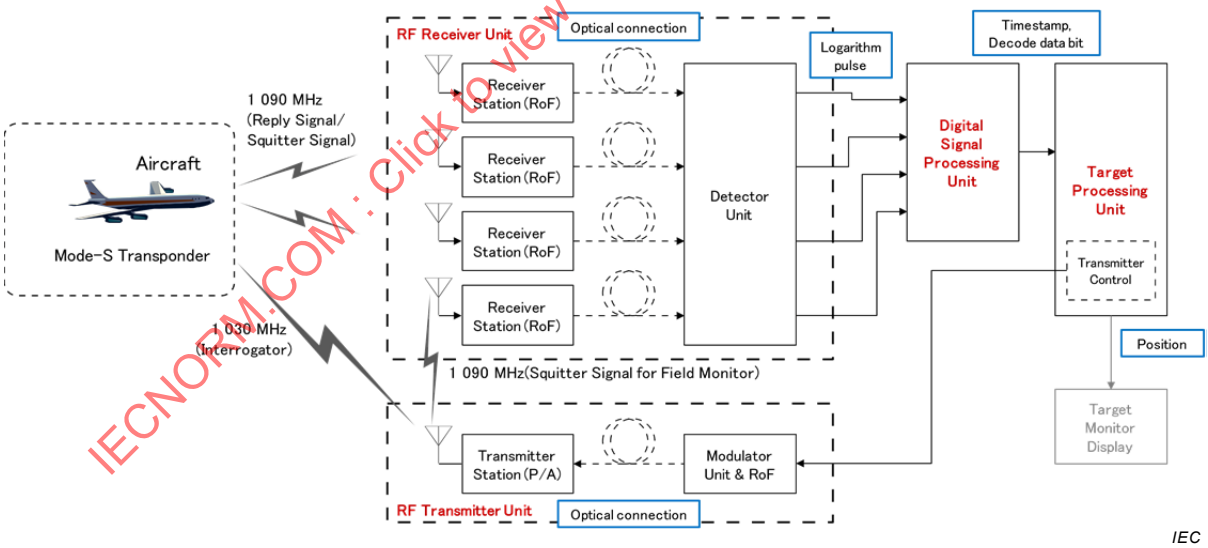


Figure 3 – System configuration of the advanced MLAT "OCTPASS"

5.4.4 Specifications

Table 4 shows specifications of an RoF system for multilateration [5].

Table 4 – Specifications of an RoF system for multilateration

	Receiver unit	Transmitter unit (optional)
Carrier frequency and bandwidth(BW)	1 090 MHz (BW = 14,5 MHz)	1 030 MHz (BW = 20 MHz)[a] 1 090 MHz (BW = 14.5 MHz)[b]
Power	−20 dBm to −80 dBm input	150 W P/A output
Signal duration	64 µs (short reply) 120 µs (long reply)	19,75 µs[a] 120 µs[b]
Data block modulation	Pulse position modulation	Differential PSK[a] Pulse position modulation[b]
Pulse rise time	0,05 µs (min.) 0,1 µs (max.)	0,05 µs (min.) 0,1 µs (max.)
Processing capacity	500 signals per second	600 interrogations per second
[a] for interrogation [b] for field monitor		

6 Examples of standardization activities

- IEC 62803
- ITU-T SG15 Q2

  Supplement 55 to ITU-T G-series Recommendations provides general information on radio over fiber (RoF) technologies and their applications in optical access networks (https://www.itu.int/itu-t/workprog/wp_item.aspx?isn=9799).

- The Asia-Pacific Telecommunity (APT)

  ASTAP Expert Group on Seamless Access communication Systems (SACS) published an APT report on characteristics and requirements of optical and electric components for millimeter-wave Radio over Fibre systems (ASTAP/REPT3 http://www.aptsec.org/sites/default/files/Upload-files/ASTAP/Rept-3-R1-Millimeter-wave%20Radio%20on%20Fiber%20Systems.pdf),

  APT Report on Wired and Wireless Seamless Connections using Millimeter-Wave Radio over Fiber Technology for Resilient Access Networks (APT/ASTAP/REPT-11),

  APT Report on Integration of Radio-over-Fiber with WDM PON for Seamless Access Communication System (APT/ASTAP/REPT-19),

  APT Report on Radio-over-Fiber Relay Link for Indoor Communication System (APT/ASTAP/REPT-20).

  APT Report on Fixed Wireless System in APT Region (APT/AWG/REP-65).

- Common Public Radio Interface (CPRI: http://www.cpri.info/), Open Base Station Architecture Initiative (OBSAI: http://www.obsai.com/) and open applicable standard interface.

Annex A
(informative)

Radio-over-fibre system in accordance with spectral emission standards

A.1 General

Annex A specifies the radio over fibre system's parameters in accordance with different spectral emission standards of digital terrestrial television broadcasting (DTTB) defined by ITU-R Recommendations.

A.2 Reference model

The reference model (see Figure A.1) comprises EO and OE modules that are connected to a transceiver or antenna, an optical network, and EO and OE modules that are connected to a transceiver or antenna at another location. The configuration may also include a receiving antenna in place of a transceiver, such as in the case of a broadcast signal repeater.

Considerations for the target system are listed below.

- RoF systems including SCM systems that perform analogue optical modulation of single-channel or multiple-channel signals.
- DRoF transmission systems, in which a high-frequency modulated signal is converted to a digital signal (analogue to digital conversion) for transmission and the digital output of the OE is then converted to analogue (digital to analogue conversion) are outside the application of this document.
- Link configuration: the optical networks part can have any configuration.

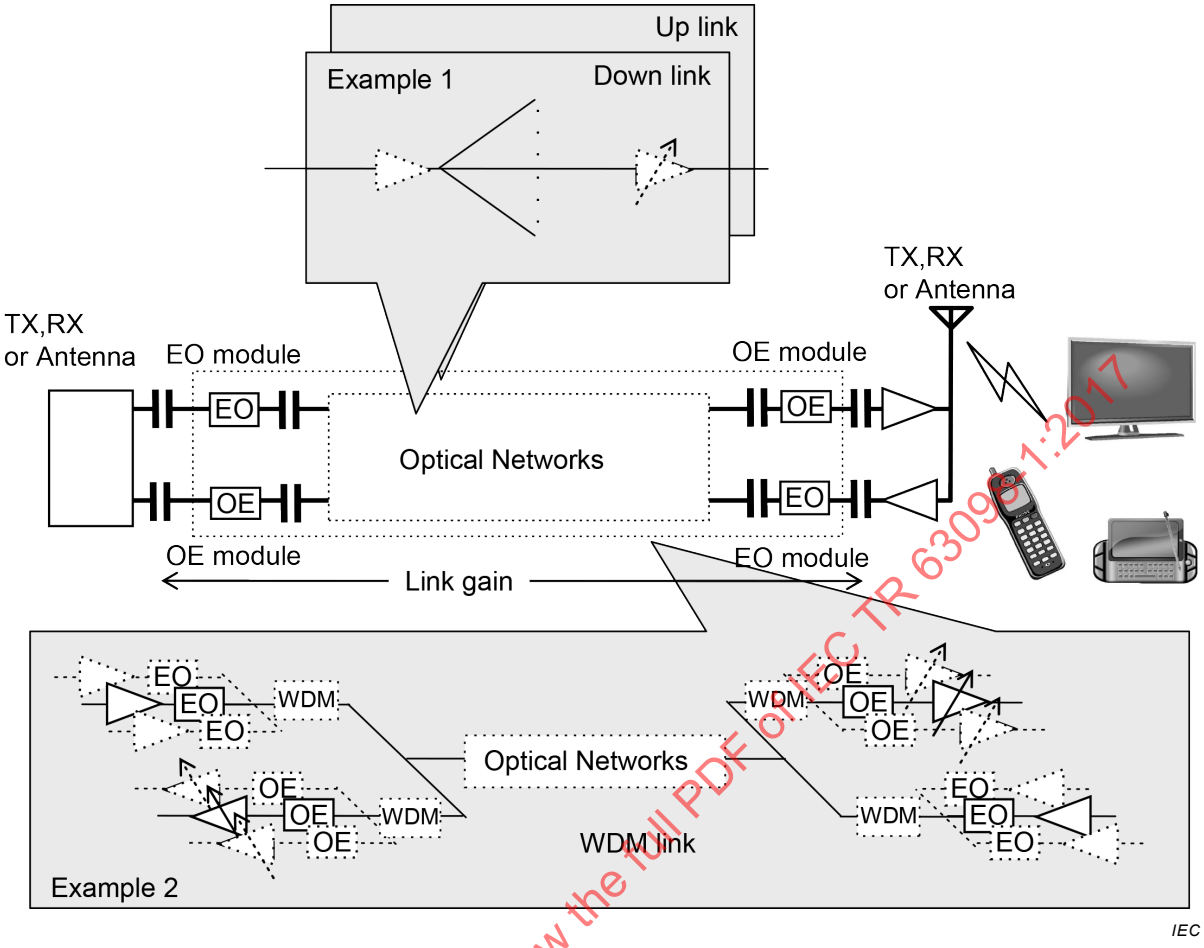


Figure A.1 – RoF system reference model

A.3 Equipment

A.3.1 General

The spectrum mask and the unwanted emission are specified as the signal quality factors to be satisfied as hardware specifications. For the down link, the spectrum mask specified in 5.1 should be satisfied for each channel of a signal that is emitted into free-space. Concerning out-of-band emission and spurious emission, the regulations specified in 5.2 should be satisfied.

A.3.2 Down link transmission signal

A.3.2.1 Spectrum mask

For the down link transmission signal, the break point specifications are listed in Table A.1 and the spectrum mask is shown in Figure A.2. In the DTTB system A, B, and C are defined in ITU-R Recommendation BT.1306-5 and P_{sig} is the average signal power per channel.

The equipment should satisfy the specifications at the terminal for connections to the antenna. For the purpose of dealing with the DTTB systems and mobile communication together, the offset frequencies from the centre frequency are represented by coefficients. The frequencies in parentheses in Figure A.2 are frequencies applied to 6-MHz bandwidth DTTB systems A and C as one example.

For multiple adjacent channel signals, the spectral mask is applied at the break point on the low frequency side of the lowest carrier wave and at the break point on the high frequency side of the highest carrier wave.

Table A.1 – Transmission spectrum break points

Coefficients of offset frequencies from centre frequency		**Power spectral density** [dB]	
DTTB system A, C	DTTB system B	$P_{sig} \leq 14$ dBm	14 dBm $< P_{sig} \leq$ 20,4 dBm
±0,93	±0,952	0	
±0,953	±0,975	−20	
±1	±1	−27	
±1,453	±1,453	−30	$-16 - P_{sig}$

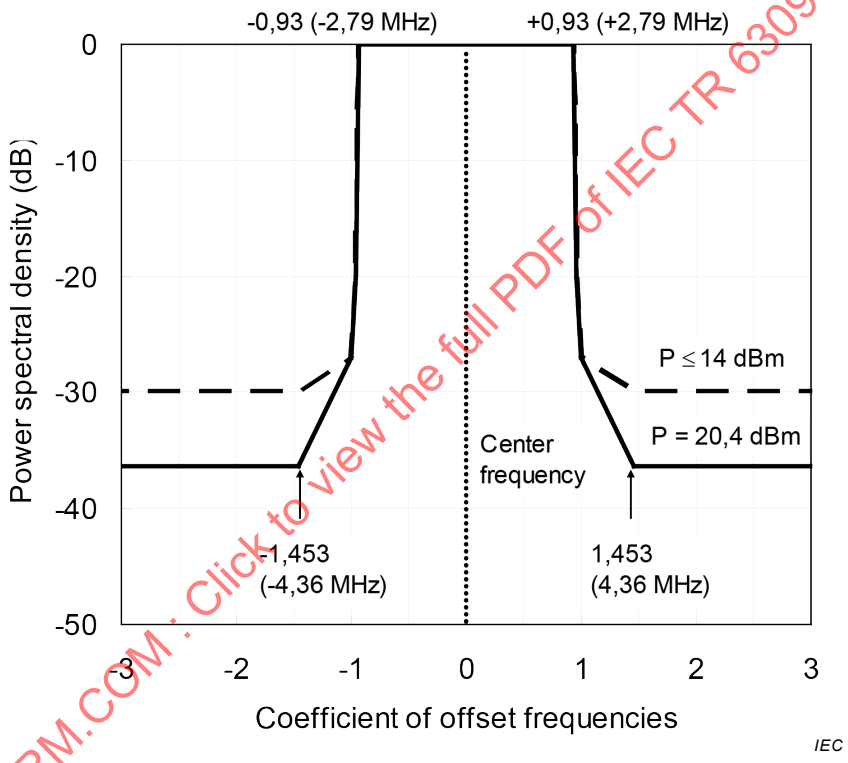


Figure A.2 – Spectrum mask

A.3.2.2 Unwanted emission of the down link transmission signal

To prevent interference with other radio devices, filters that suppress unwanted emission in the relevant frequency bands are recommended.

Equipment that radiates DTTB signals satisfy the specifications listed in Table A.2.

Table A.2 – Unwanted emission specifications for DTTB

Item	Specification
Spurious emission in the out-of-band domain	100 µW or less
Unwanted emission in the spurious domain	25 µW or less
NOTE 1 Spurious emission is an emission at a frequency or frequencies which are outside the necessary bandwidth and the level of which can be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products, frequency conversion products, and single sideband phase noise, but exclude out-of-band emissions. NOTE 2 Out-of-band emission is an emission in a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emission. The boundary between the out-of-band and spurious domain occurs at a separation of ±250 % of the necessary bandwidth.	

A.3.3 Physical specifications

A.3.3.1 Cabinet of equipment

There are no particular specifications for the case dimensions, weight, installation method, or material properties, etc.

A.3.3.2 Electrical interface

For high-frequency input and output signals, coaxial connectors that have characteristic impedance of 50 Ω or 75 Ω are recommended. For example, an N type (IEC 60169-14), SMA type (IEC 60169-15) or F type (IEC 60169-24) can be selected according to the wireless device to be connected and the installation conditions.

A.3.3.3 Optical interface

There are no particular specifications for the optical connector form, ferrule terminal surface polish, reflection attenuation, and minimum connector connection interval, etc.

A.3.4 Example of EO and OE performance

A performance example of EO and OE for use in an RoF system is presented in Table A.3.