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Transmitting equipment for radiocommunication — Frequency response of optical-to-electric conversion device in high-frequency radio over fibre systems — Measurement method

bsi.

National foreword

This British Standard is the UK implementation of EN 62803:2016. It is identical to IEC 62803:2016.

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Matériels émetteurs pour les radiocommunications - Réponse en fréquence des dispositifs de conversion optique-electrique dans des systèmes de transmission radio sur fibre haute fréquence - Méthode de mesure (IEC 62803:2016)

Messverfahren einer Frequenzantwort eines optisch-elektrischen Wandlers in HF-Rundfunk-über-Glasfaser-Übertragungssystemen (IEC 62803:2016)

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The text of document 103/147/FDIS, future edition 1 of IEC 62803, prepared by IEC/TC 103 "Transmitting equipment for radiocommunication" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62803:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-05-16
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

TRANSMITTING EQUIPMENT FOR RADIOCOMMUNICATION – FREQUENCY RESPONSE OF OPTICAL-TO-ELECTRIC CONVERSION DEVICE IN HIGH-FREQUENCY RADIO OVER FIBRE SYSTEMS – MEASUREMENT METHOD

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International Standard IEC 62803 has been prepared by IEC technical committee 103: Transmitting equipment for radiocommunication.

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

FDIS	Report on voting
103/147/FDIS	103/148/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.

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

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

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- withdrawn,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

INTRODUCTION

A variety of microwave-photonic devices are used in wireless communication and broadcasting systems. A photo-receiver is an interface which converts an optical signal to an electronic signal. This International Standard has been prepared to provide methods for evaluating and calibrating high speed photo-receivers to be used in Radio over Fibre systems.

The method utilizes a Mach-Zehnder modulator for generating two-tone lightwaves as stimulus signals, to provide simpler and easier methods than the conventional method utilizing a complex two-laser system phase-locked with each other.

The International Electrotechnical Commission (IEC) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning a calibration method and device for light intensity measuring instrument, as it relates to Clause 6.

Related part	Patent holder	Patent number
Clause 6	National Institute of Information and Communications Technology	JP 4753137B EP1956353A US7864330B

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TRANSMITTING EQUIPMENT FOR RADIOCOMMUNICATION – FREQUENCY RESPONSE OF OPTICAL-TO-ELECTRIC CONVERSION DEVICE IN HIGH-FREQUENCY RADIO OVER FIBRE SYSTEMS – MEASUREMENT METHOD

1 Scope

This International Standard provides a method for measuring the frequency response of optical-to-electric conversion devices in wireless communication and broadcasting systems.

The frequency range covered by this standard goes up to 100 GHz (practically limited up to 110 GHz by precise RF power measurement) and the wavelength band concerned is 0,8 μm to 2,0 μm.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

There are no normative references in this document.

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
conversion efficiency
ratio of the output current to the input optical power defined by

$$k = \frac{\Delta I_{\mathrm{out}}}{\Delta P_{\mathrm{in}}} \tag{1}$$

Note 1 to entry: See Figure 1.

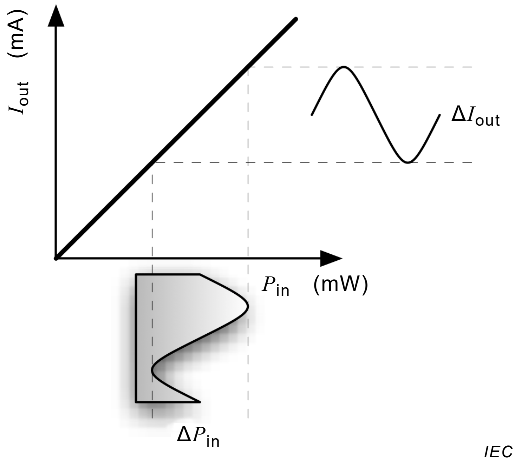


Figure 1 – Definition of "conversion efficiency "

Note 2 to entry: Conversion efficiency k, which depends on modulating signal frequency,is often expressed in dB as the ratio to the reference conversion efficiency of 1 (ampere per watt). It is well known, however, that dB has two definitions. One is the optical conversion efficiency k_o [dB_o] calculated from $10\times\log_{10}(\Delta I_{out}/\Delta P_{in})$, and the other is the electrical conversion efficiency k_e [dB_e] calculated from $20\times\log_{10}(\Delta I_{out}/\Delta P_{in})$. As for the conversion efficiency k, the numerator is the amplitude of the electrical output signal, and the denominator is the power of optical input signal. Therefore, both definitions of dB for conversion efficiency k_o *and* k_e are shown as follows:

$$k_o = k_o[\mathrm{dB_o}] = 10 * \log_{10} \frac{\Delta I_{out}}{\Delta P_{in}} \tag{2}$$

$$k_e = k_e[\mathrm{dB_e}] = 20 * \log_{10} \frac{\Delta I_{out}}{\Delta P_{in}} \tag{3}$$

3.1.2
two-tone lightwave
lightwave that contains two dominant spectral components whose power difference is relatively small and frequency separation is stable

Note 1 to entry: Undesired spectral components are suppressed significantly. The measurement methods described in this standard utilize a Mach-Zehnder modulator (MZM) for two-tone signal generation, where the MZM is biased at maximum or minimum transmission points (null or full bias) [1][1]. The suppression ratio of undesired components depends on the on-off extinction ratio and chirp parameter of the MZM. By using active trimming, high extinction-ratio and low chirp modulation can be achieved for ideal two-tone generation (see Annex A).

3.1.3
carrier-suppressed
situation when an MZM is biased at its minimum transmission point, the non-modulated carrier lightwave transmitted through and the two arms of the MZM are cancelled with each other at the output coupler

Note 1 to entry: The suppression ratio is related to how the two lightwaves in the two arms have the same power and to their anti-phase at the output coupler.

1 Numbers in square brackets refer to the Bibliography.

3.2 Abbreviations

AGC-EDFA	Automatic gain controlled-EDF amplifier
ALC	Automatic level control
DFG	Difference frequency generation
DUT	Device under test
E/O	Electrical-to-optical
EDFA	Er-doped fibre amplifier
FPGA	Field programmable gate array
LD	Laser diode.
MZM	Mach-Zehnder modulator
O/E	Optical-to-electrical
OMI	Optical modulation index
PD	Photo diode
PN	Positive-negative
RF	Radio frequency
RoF	Radio over fibre
VOA	Variable optical attenuator

4 Optical-to-electrical (O/E) conversion device

4.1 Photo diode (PD)

4.1.1 General

A PD has a positive-negative (PN) junction which can be illuminated by an optical signal. When a photon is incident to the PN junction, an electron is excited and an electron-hole pair is generated. The electron and hole drift to the opposite direction because of the built-in and reverse-biased voltage at the PN junction, and can be used as an output electric current.

4.1.2 Component parts

The O/E conversion devices consist of basic parts as follows:

– PD;
– input fibre pigtail (where appropriate);
– input receptacle (where appropriate);
– output RF port (where appropriate);
– bias electrode (where appropriate);
– transimpedance amplifier (where appropriate);
– impedance matching resistor (where appropriate).

4.1.3 Structure

The structure consists of the following (see Figure 2):

– optical input: fibre pigtail or receptacle;
– RF output: coaxial connector, microstrip line, coplanar waveguide, antenna, etc.;
– options: bias electrode, transimpedance amplifier, impedance-matching resistor.

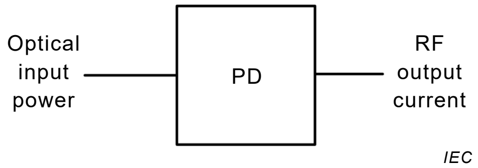


Figure 2 – Optical-to-electrical conversion by photo diode

4.1.4 Requirements for PD

4.1.4.1 General

This method is based on a heterodyne principle. Requirements for the PD of this measurement method are as follows.

4.1.4.2 Material of PD

Main materials of the PDs should be Si, GaAs, and InGaAs.

4.2 DFG device

4.2.1 General

When two coherent lightwaves are incident to a DFG device fabricated from a second order nonlinear optical material, an RF signal with the difference frequency between the incident lightwaves is generated.

4.2.2 Component parts

The component parts are as follows:

– DFG device;
– input optical lens (where appropriate);
– output RF antenna (where appropriate).

4.2.3 Structure

See Figure 3.

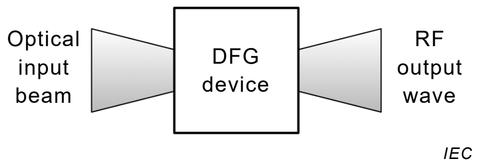


Figure 3 – DFG device

4.2.4 Requirements for DFG device

4.2.4.1 General

This method is based on the heterodyne principle. Requirements for the DFG device of this measurement method are as follows.

4.2.4.2 Material

The main substrate materials of the DFG device should be materials such as $LiNbO_3$, $LiTaO_3$, KH_2PO_4, PZT (Pb (Zr, Ti) O3), PLZT ((Pb, La) (Zr, Ti) O3), InP, GaAs, InGaAs, InAlAs, InGaAsP, Chromophore containing polymer, etc., which realize second order, nonlinear optical effect.

4.2.4.3 Device design

In general, the efficiency of the DFG is rather low. In order to enhance the conversion efficiency, the device length tends to be long, and phase matching conditions must be satisfied. Moreover, in order to avoid undesired RF wave radiation, an RF cavity or guiding structure is also required.

5 Sampling for quality control

5.1 Sampling

A statistically significant sampling plan shall be agreed upon by user and supplier. Sampled devices shall be randomly selected and representative of production population, and shall satisfy the quality assurance criteria using the proposed test methods.

5.2 Sampling frequency

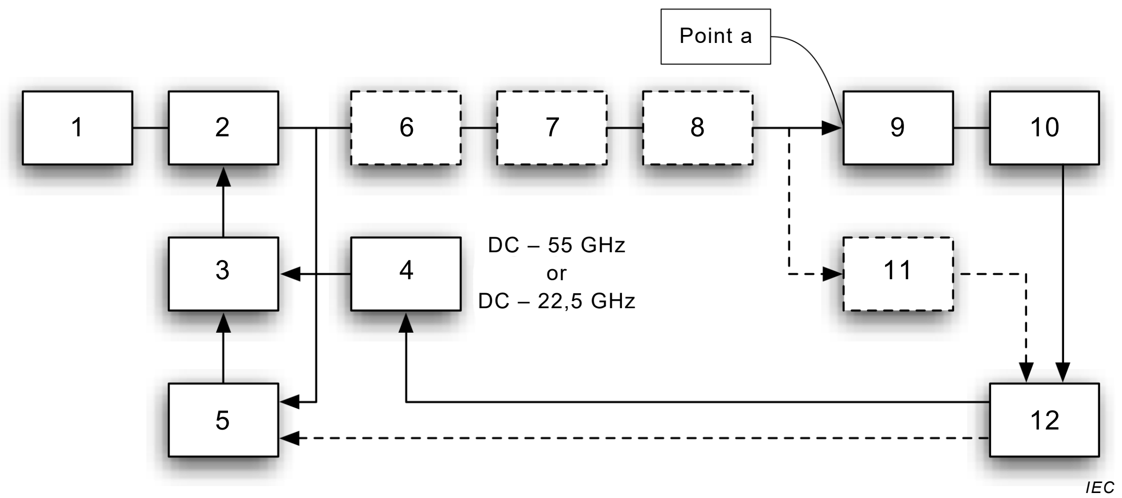
Appropriate statistical methods shall be applied to determine adequate sample size and acceptance criteria for the considered lot size. In the absence of more detailed statistical analysis, the following sampling plan can be employed.

Sampling frequency for evaluation of frequency response: two units at least per manufacturing lot.

6 Measurement method of frequency response

6.1 Circuit diagram

See Figure 4.



Key

1	Laser diode	7	Optical amplifier (optional)
2	MZM	8	Automatic level control (optional)
3	Bias tree	9	DUT
4	Microwave signal source (SC)	10	RF power meter or spectrum analyser
5	DC voltage source	11	Optical power meter (optional)
6	Optical band rejection filter (optional)	12	Personal computer

Figure 4 – Circuit diagram

6.2 Measurement condition

6.2.1 Temperature and environment

The measurement should be carried out in a room at a temperature ranging from 5 °C to 35 °C. If the operation temperature ranges of the measurement apparatuses are narrower than the above range, the specifications of the measurement apparatuses should be followed. It is desirable to control the measurement temperature within ±5 °C in order to suppress the influence of temperature drift of measurement apparatuses to a minimum. The temperature of the DUT can be changed using a temperature controller, as necessary.

6.2.2 Warming up of measurement equipment

The warming-up time shall be kept to typically 60 min, or the time written in the specifications of the measurement equipment or systems.

6.3 Principle of measurement method

The method described here is based on the heterodyne principle. A two-tone lightwave illuminates the DUT as a stimulus signal. The two-tone stimulus lightwave is generated by using an MZM at null bias or an MZM at full bias with an optical band rejection filter. The average powers of the input two-tone lightwave and that of the output monotone RF signal are measured, and the conversion efficiency at the frequency is calculated from them. By changing the frequency difference between the two tones, the frequency response of O/E conversion efficiency of the DUT is obtained.

As is well known, an MZM optical output modulated by a monotone RF signal can be expressed by

$$E_{\text{opt}} = \sum_{n=\infty}^{\infty} E_n e^{i(\omega_n t + \phi_n)},\ P_{\text{opt}} = \sum_{-\infty}^{\infty} P_n\ ,\ P_n = \left[E_n\right]^2,\ \text{and}\quad \omega_{RF} = \omega_{n+1} - \omega_n \tag{4}$$

where P_{opt} is the total average power, and ω_{RF} is the angular frequency of the modulating RF signal that corresponds to the angular frequency difference between adjacent optical tones. As an example, two-tone signal generation by an MZM with null-bias is described in 6.4. When

$$\left|E_{-1}\right| = \left|E_{+1}\right| >> \left|E_{\text{n}}\right| (n \neq -1,+1),\ \text{and}\quad P_{\text{opt}} \cong \left|E_{-1}\right|^2 + \left|E_{+1}\right|^2 = 2\left|E_{-1}\right|^2 \tag{5}$$

an ideal well-balanced optical two-tone consisting of $P_{\pm 1}$ (see 6.4) can be generated, where the following conditions should be satisfied:

a) suppression of optical carrier and higher order sidebands should be large enough;
b) frequency difference between the two desired components should be stable;
c) polarizations of the two spectral components should be well aligned;
d) power difference of the two spectral components should be small enough.

The instantaneous optical power P_{opt} illuminating the PD is calculated as

$$\begin{aligned} p_{\text{opt}} &= \left| E_{-1} e^{i(\omega_{-1} t + \phi_{-1})} + E_{+1} e^{i(\omega_{+1} t + \phi_{+1})} + \sum_{n=-\infty}^{\infty} E_{\text{n}} e^{i(\omega_n t + \phi_n)} \right|^2 (n \neq -1,+1) \\ &\cong P_{\text{opt}} + P_{\text{opt}} \times \cos(2\omega_{\text{RF}} t + \phi) \end{aligned} \tag{6}$$

where $\phi = \phi_{-1} - \phi_{+1}$, and $|E_n|(n \neq -1,+1)$ related terms are neglected from Equation (5). The PD under test outputs a DC and an RF photocurrent as a response. The RF photocurrent i_{RF} induced by the ideal well-balanced optical two-tone consisting of $P_{\pm1}$ or $P_{\pm2}$ is expressed as

$$i_{RF} = k_e \times P_{opt} \times \cos(2\omega_{RF} t + \phi) = I_{RF} \cos(2\omega_{RF} t + \phi) \tag{7}$$

where k_e is the conversion efficiency of the PD under test at $2\omega_{RF}$, and i_{RF} is the peak photocurrent. ΔP_{in} is equal to P_{opt} giving 100% OMI (optical modulation index) and ΔI_{out} is nearly equal to I_{RF}, k_e is described as

$$k_e = \frac{\Delta I_{out}}{\Delta P_{in}} \cong \frac{I_{RF}}{P_{opt}} \tag{8}$$

where I_{RF} is the amplitude of RF photocurrent induced by the ideal optical two tone.

The average RF power P_{RF} driving a load Z_L is expressed as

$$P_{RF} = \frac{I_{RF}}{\sqrt{2}} \times \frac{I_{RF}}{\sqrt{2}} Z_L = \frac{I_{RF}^2 Z_L}{2} \tag{9}$$

From Equations (7), (8) and (9), the squared k_e which corresponds to the responsivity of the PD at the measurement frequency, is calculated as

$$k_e{}^2 = \frac{I_{RF}{}^2}{P_{opt}{}^2} = \frac{2P_{RF}}{Z_L P_{opt}{}^2} \tag{10}$$

Note that the squared k_e can be calculated only from the input optical and the output RF average powers of the PD under test, if the ideal well-balanced optical two tone is launched, which are traceable to the national standards with relatively short traceability chain. In this method, the squared k_e does not depend on the frequency response of the MZM used for two-tone generation.

6.4 Measurement procedure

Two types of measurement methods are described here. In Method A, a two-tone signal is generated by an MZM with null bias, where the signal is composed of the first upper and lower modulation side bands $P_{\pm1}$. The frequency separation of the two-tone signal is equal to double the frequency of the signal fed to the MZM. In Method B, a two-tone signal is generated by an MZM with full bias, where the modulator output is composed of the carrier P_0 and the second upper and lower modulation sideband $P_{\pm2}$. By using an optical band rejection filter, the P_0 component is eliminated to generate a two-tone signal consisting of $P_{\pm2}$. The frequency separation of the two-tone signal is equal to quadruple the frequency of the signal fed to the MZM. The optical amplifier and auto level control in Figures B.1 and B.2 can enhance the frequency range of the measurement as described in Annexes B and C.

Method A

STEP 1) The measurement set-up is prepared as shown in Figures B.1 and B.2, where no optical band rejection filter is needed.

STEP 2) The output signal of SG is set as follows.

Frequency: the half of the responsivity measurement frequency.

Output power: when the unwanted third-order harmonic distortions should be suppressed lower than –30 dB from the desired components, the signal power fed to the MZM should be smaller than

$$\left\{\frac{0{,}085 \times V_{\pi}(f)}{\pi}\right\}^{2} \qquad (11)$$

where, $V_{\pi}(f)$ is the half-wavelength voltage at the modulating frequency.

STEP 3) The DC voltage applied to the MZM should be controlled to maintain the null bias.

STEP 4) The optical power meter measures the input average optical power P_{opt} to the DUT at point “A”. When P_{opt} is stabilized by ALC, it is not necessary to use the power meter.

STEP 5) The RF power meter measures the output average RF power P_{RF} from the DUT.

STEP 6) The conversion efficiency, k_{e}, at the measurement frequency is calculated by using the following formula:

$$k_{\text{e}} = \frac{\sqrt{P_{\text{RF}}}}{5P_{\text{opt}}} \qquad (12)$$

STEP 7) Repeat from STEP 2 to STEP 6 with a different frequency.

Method B

STEP 1) The measurement set-up is prepared as shown in Figures B.1 and B.2, where the centre wavelength of the optical band rejection filter should be set to be the optical output wavelength of the laser diode.

STEP 2) The output signal of SG is set as follows:
Frequency: 25 % of the conversion efficiency measurement frequency.

STEP 3) The DC voltage applied to the MZM should be controlled to maintain the full bias, where the P_0 component is eliminated by the optical band rejection filter.

STEP 4) The optical power meter measures the input average optical power P_{opt} to the DUT at point “A”. When P_{opt} is stabilized by ALC, it is not necessary to use the power meter.

STEP 5) The RF power meter measures the output average RF power PRF from the DUT.

STEP 6) The conversion efficiency, k, at the measurement frequency is calculated by using Equation (12).

STEP 7) Repeat from STEP 2 to STEP 6 with a different frequency.

Annex A
(normative)

Power balanced two-tone signal generation by using a high extinction-ratio MZM [2]

Annex A describes an example of two-tone signal generation using an MZM at null bias with high extinction ratio. The bias point can be precisely controlled, when the extinction ratio is very high. At the null bias condition, the power difference between the two desired spectral components goes to the minimum.

Assuming a push-pull type MZM driven by a monotone RF signal of ω_{RF}, its output lightwave can be expressed as

$$\begin{aligned} E &= L\frac{E_{\mathrm{input}}e^{i\omega_0 t}}{2}\left[\left(1+\frac{\eta}{2}\right)e^{i\{A_1\sin(\omega_{\mathrm{RF}}t+\phi_1)+\phi_{\mathrm{B1}}\}}+\left(1-\frac{\eta}{2}\right)e^{i\{A_2\sin(\omega_{\mathrm{RF}}t+\phi_2)+\phi_{\mathrm{B2}}\}}\right] \\ &= L\frac{E_{\mathrm{input}}e^{i(\omega_0 t+\phi_{B1})}}{2}\sum_{n=-\infty}^{\infty}e^{in(\omega_{RF}t+\phi_1)}\left[\left(1+\frac{\eta}{2}\right)J_n(A+\alpha_{\mathrm{A}})+\left(1-\frac{\eta}{2}\right)J_n(-A+\alpha_{\mathrm{A}})e^{i(n\phi+\phi_{\mathrm{B}})}\right] \end{aligned} \quad \text{(A.1)}$$

where L is the loss factor inside the MZM, and $J_n(x)$ is the Bessel function of the first kind of order n. The values of ϕ_{B1}, ϕ_{B2}, ϕ_B are the bias phases, η is the optical intensity imbalance, ϕ_1, ϕ_2, ϕ are the skews, and A_1, A_2, A, α_A are the chirp related parameters defined as

$$\begin{aligned} &\phi_{\mathrm{B}} = \phi_{\mathrm{B2}}-\phi_{\mathrm{B1}}, (P_1,P_2)=\frac{\left|L\times E_{\mathrm{input}}\right|^2}{4}\left(\left(1+\frac{\eta}{2}\right)^2,\left(1-\frac{\eta}{2}\right)^2\right), |\eta|<1 \\ &\phi=\phi_2-\phi_1, (A_1,A_2)=(A+\alpha_{\mathrm{A}}, -A+\alpha_{\mathrm{A}}), |A|>|\alpha_{\mathrm{A}}| \end{aligned} \quad \text{(A.2)}$$

Equations (A.1) and (A.2) are well known for showing good agreements with the actual performance of MZMs, because four major error parameters of MZMs are all included [3, 4]. The powers of the carrier, the upper sideband, and the lower sideband, (named “0”, “+1” and “-1”, respectively) are derived as

$$\begin{aligned} &P_0 = \left|E_0\right|^2 = \frac{\left|L\times E_{\mathrm{input}}\right|^2}{4}\left\{R^2+S^2+2RS\cos\phi_{\mathrm{B}}\right\} \\ &P_{+1} = \left|E_{+1}\right|^2 = \frac{\left|L\times E_{\mathrm{input}}\right|^2}{4}\left\{T^2+U^2-2TU\cos(\phi_{\mathrm{B}}+\phi)\right\} \\ &P_{-1} = \left|E_{-1}\right|^2 = \frac{\left|L\times E_{\mathrm{input}}\right|^2}{4}\left\{T^2+U^2-2TU\cos(\phi_{\mathrm{B}}-\phi)\right\} \\ &R=\left(1+\frac{\eta}{2}\right)J_0(A+\alpha_{\mathrm{A}}), S=\left(1-\frac{\eta}{2}\right)J_0(A-\alpha_{\mathrm{A}}) \\ &T=\left(1+\frac{\eta}{2}\right)J_1(A+\alpha_{\mathrm{A}}), U=\left(1-\frac{\eta}{2}\right)J_1(A-\alpha_{\mathrm{A}}) \end{aligned} \quad \text{(A.3)}$$

In the case of the MZM being biased at its minimum transmission point, which corresponds to the case of $\phi_B=\pi$, the powers of P_0, P_{+1}, and P_{-1} are calculated as

$$P_0 = \frac{\left|L \times E_{\text{input}}\right|^2}{4}(R - S)^2$$

$$P_{+1} = P_{-1} = \frac{\left|L \times E_{\text{input}}\right|^2}{4}\left\{T^2 + U^2 + 2TU\cos\phi\right\} \tag{A.4}$$

Equation (A.4) means that when the MZM is biased at a minimum transmission point, the carrier power P_0 becomes the minimum. Simultaneously, the upper and the lower sideband powers of P_{+1} and P_{-1} become equal. Therefore, by adjusting the bias voltages of the high-ER MZM to maintain the carrier power at minimum, the powers of the two tones automatically become equal. Note that Equation (A.4) is satisfied independently from the other parameters of η, α_A, and ϕ. Further, this technique is consistent with that of suppressing the carrier power. Monitoring the carrier power is easier than measuring each power of the two-tone signal. In the frequency response measurement, two different techniques are employed for the optical and RF method, according to the measurement frequency range. For a frequency range higher than 10 GHz, a narrow-band optical band-pass filter directly extracts the carrier lightwave and its optical power is monitored. For a frequency range lower than 10 GHz, an RF spectrum analyser monitors the RF signal from the reference PD, which has a practically flat frequency response from DC to 10 GHz.

Annex B
(informative)

Requirements for the optical amplifier with automatic level control

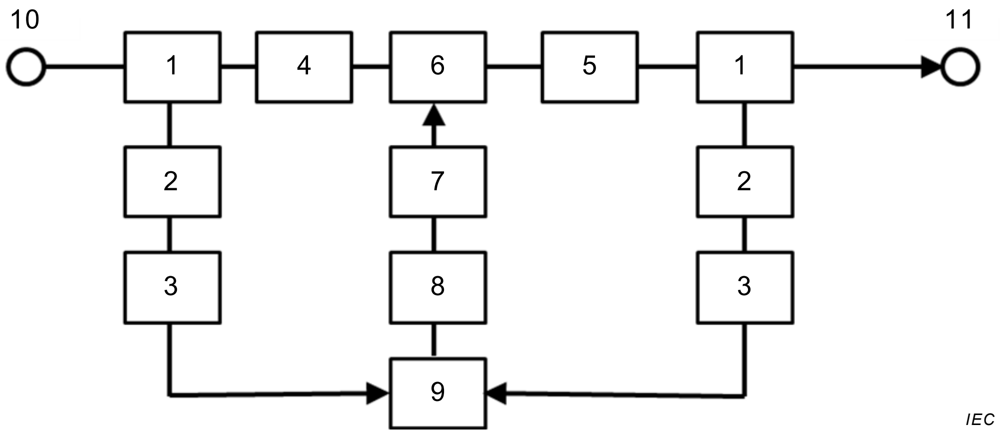
B.1 Introductory remark

Annex B describes the optical amplifier and the automatic level control system function and the general requirements needed to realize these functions.

B.2 Block diagram

B.2.1 Optical amplifier

See Figure B.1.



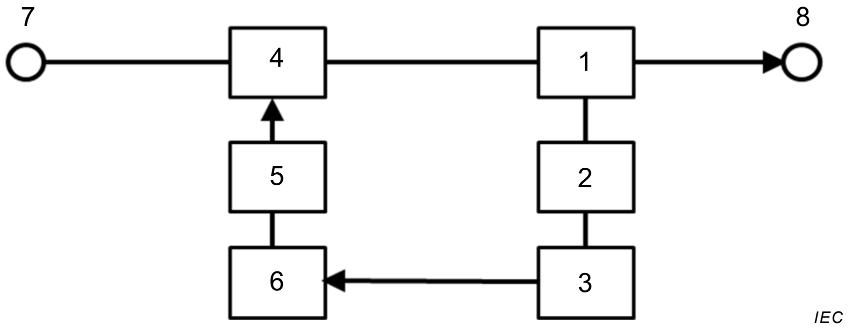
Key

1	Optical coupler	7	Pump-LD
2	Photodiode	8	Driver for the pump-LD
3	Trans-impedance amplifier	9	FPGA (field programmable gate array)
4	Optical delay line	10	Optical input
5	EDF (er-doped fibre)	11	Optical output
6	Wavelength multiplexer		

Figure B.1 – Block diagram of the optical amplifier

B.2.2 Automatic level control

See Figure B.2.



Key

1 Optical coupler
2 Photodiode
3 Trans-impedance amplifier
4 VOA (variable optical attenuator)
5 Driver for the VOA
6 FPGA (field programmable gate array)
7 Optical input
8 Optical output

Figure B.2 – Block diagram of the automatic level control

B.3 Function and capabilities

The combination of an optical amplifier and an automatic level control (ALC) system can offer enlarged frequency bandwidth as described in Figure B.3.

The output swept signals from an MZM are amplified by an AGC-EDFA (automatic gain controlled-EDF amplifier). The VOA's loss incorporated in the ALC system is set to an appropriate value in advance. The frequency bandwidth can be enlarged by adjusting the loss of the VOA. Therefore, a two-tone system with an optical amplifier and an ALC system allows wider frequency bandwidth compared to an MZM.

If the power roll-off of the MZM approaches 6 dB per octave and the pre-set loss of the VOA is set to 6 dB, the frequency bandwidth of the two-tone system can be doubled. If the power roll-off of the MZM approaches 6 dB per octave and the pre-set loss of the VOA is set to 6 dB, the frequency bandwidth of the two-tone system can be doubled.

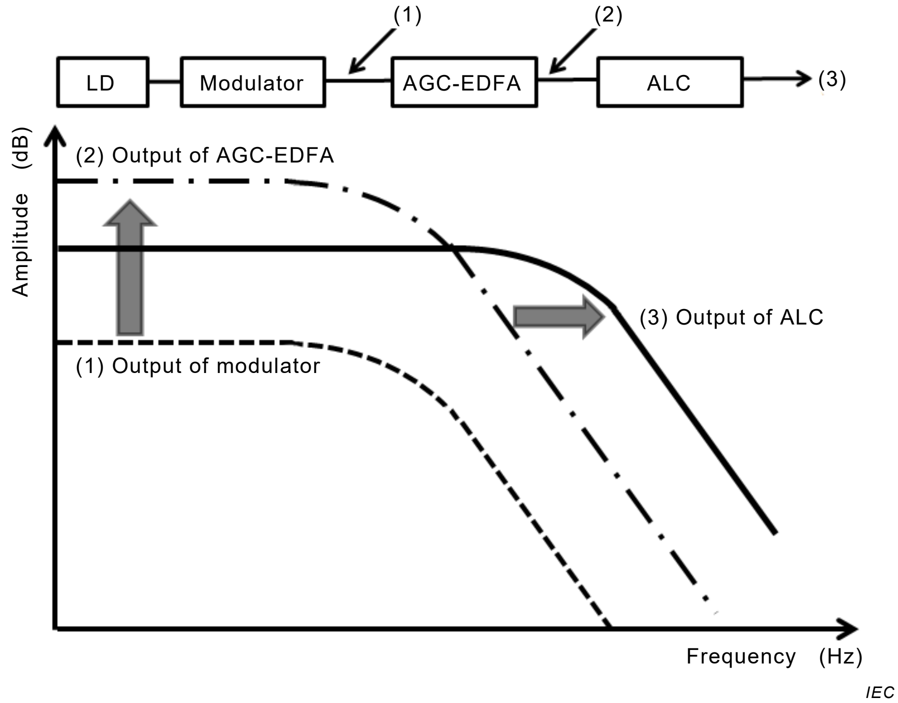


Figure B.3 – Frequency characteristics

B.4 Requirements

B.4.1 Optical amplifier

Typical requirements for the combination system of AGC-EDFA and ALC as a measurement system are a high-speed frequency-sweep with less than 1 ms and a low error measurement with less than 0,2 dB.

The following list describes the AGC-EDFA requirements:

– function: AGC (automatic gain control);
– wavelength range: 1 530 nm to 1 562 nm;
– input power range:−24 dBm to −4 dBm;
– gain: 18 dB to 23 dB;
– gain error: 0,1 dB max.;
– noise figure: 6 dB max.

The transfer function of the AGC-EDFA feedback (FB) control system is given by:

$$T_{\text{AGC-EDFA}} = \frac{G_1(s) \times G_2(s) \times G_3(s) \times G_4(s)}{1 + G_1(s) \times G_2(s) \times G_3(s) \times G_4(s) \times G_5(s)} \quad \text{(B.1)}$$

where

$G_1(s)$ is the transfer function of the input-side PD and TIA;
$G_2(s)$ is the transfer function of the driver for the pump-LD;
$G_3(s)$ is the transfer function of the pump-LD;
$G_4(s)$ is the transfer function of the EDF;
$G_5(s)$ is the transfer function of the output-side PD and TIA.

High-speed is not required for the FB control because an EDF has a sub-ms physical response-speed. However, the loop gain should be of an appropriate large value to offer a small gain error.

B.4.2 Automatic level control (ALC)

To realize a high-speed sweep-time, the VOA incorporated in the ALC system has to be a high-speed type VOA, such as E/O (electro-optic)-type or A/O (acousto-optic)-type.

The main requirements are described hereunder:

– response speed: $< 100\ \mu s$;

– insertion loss: $< 0{,}3$ dB;

– gain error: 0,1 dB max.

Here is a transfer function of the ALC FB-control system:

$$T_{\text{AGC-EDFA}} = \frac{G_1(s) \times G_2(s) \times G_3(s)}{1 + G_1(s) \times G_2(s) \times G_3(s) \times G_4(s)} \tag{B.2}$$

where

$G_1(s)$ is the transfer function of the driver for the VOA;

$G_2(s)$ is the transfer function of the VOA;

$G_3(s)$ is the transfer function of the EDF;

$G_4(s)$ is the transfer function of the output-side PD and TIA.

An optimum design for frequency characteristics of the transfer function is needed in order to have a high-speed response without instability and the loop gain should be of an appropriate large value to offer a small gain error.

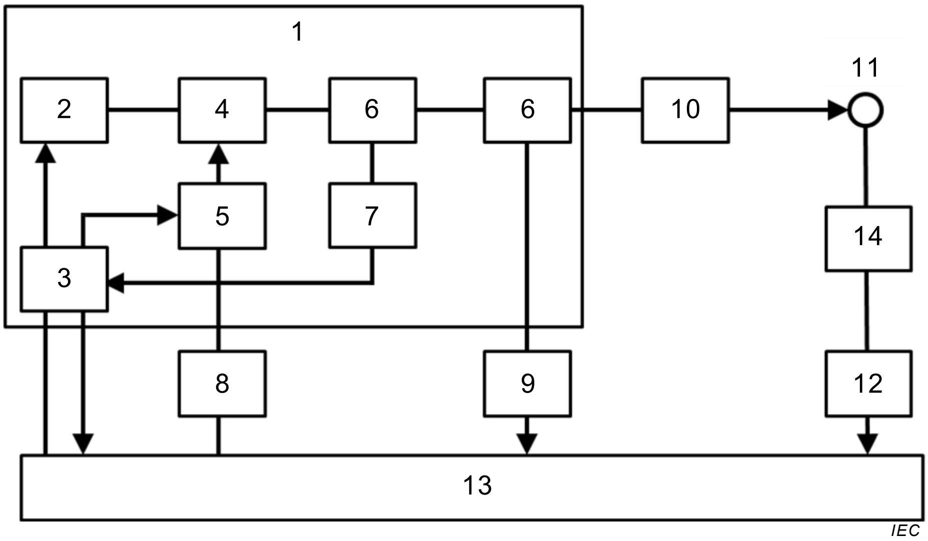
Annex C
(informative)

Frequency-response measurement system and automatic level control EDFA

C.1 Frequency response measurement system for optical-to-electric conversion devices with a two-tone generator

Figure C.1 shows the system configuration for the frequency response measurement system. The system consists of a two-tone generator, an EDFA, an RF signal generator, an optical power meter and an RF power meter. The frequency sweep measurement is executed by the RF signal generator sweeping. The efficiency of O/E conversion devices can be calculated by optical and RF power levels for each frequency.

The two-tone generator consists of a laser diode (LD), an external modulator, a monitor, a drive circuit for the external modulator and a control circuit. To suppress the spurious of the output two-tone signal, the external modulator should be controlled for maintaining an optimum bias voltage.



Key

1 Two-tone generator	6 Optical coupler	11 Optical output
2 LD (laser diode)	7 Monitor	12 RF power meter
3 Control circuit	8 RF signal generator	13 PC (personal computer)
4 External modulator	9 Optical power meter	14 DUT (device under test)
5 Drive ciruit	10 EDFA (Er-doped fibre amplifier)	

Figure C.1 – System configuration for the frequency response measurement system

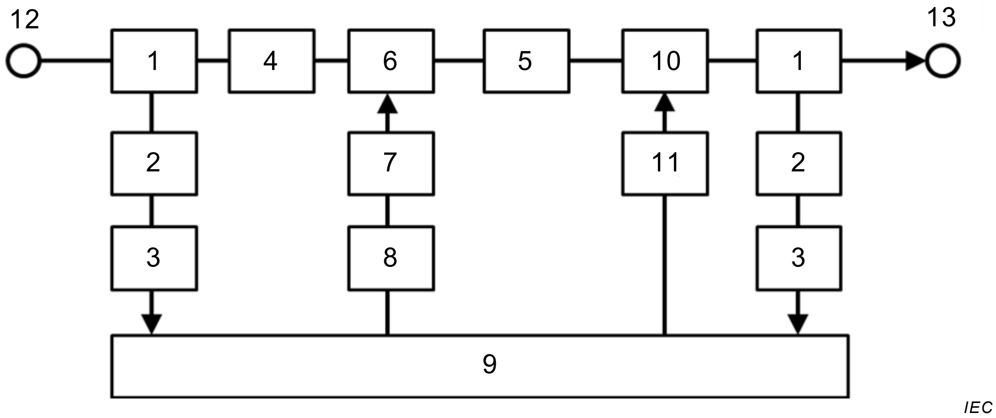
Table C.1 shows a specification example of the frequency response measurement system. Less than −30 dB spurious performance can be obtained by an optimum bias control. The RF frequency range mainly depends on the RF signal generator. A range of more than 20 GHz can be realized by using a wider range RF signal generator.

Table C.1 – Typical specifications of the frequency response measurement system

Item	Specifications	Comments
Wavelength range	1 550 nm ± 1 nm	DFB laser diode
RF frequency range	20 MHz to 20 GHz	
Output level	> –30 dBm	Two-tone signal
Spurious	> –30 dBm	Carrier suppression ratio
Relative gain accuracy	< ±0,6 dB	
Absolute gain accuracy	< ±0,8 dB	
Frequency step	> 10 MHz	RF signal generator
Frequency accuracy	< 10 MHz	RF signal generator

C.2 Automatic level control EDFA (ALC-EDFA)

Figure C.2 shows an ALC-EDFA system configuration. The ALC-EDFA consists of an EDF, a VOA, a pump-LD, two monitors, two drive circuits and a FPGA. The EDF is gain-constant controlled by the input power monitor and the pump LD. The output level-constant control is realized by the VOA, the input and output monitors.



Key

1 Optical coupler
2 Photodiode
3 Trans-impedance amplifier
4 Optical delay line
5 EDF (Er-doped fibre)
6 Wavelength multiplexer
7 Pump-LD
8 Driver for the pump-LD
9 FPGA (field programmable gate array)
10 VOA (variable optical attenuator)
11 Driver for the VOA
12 Optical input
13 Optical output

Figure C.2 – ALC-EDFA system configuration

As described in Table C.2, the wavelength range is from 1 530 nm to 1 562 nm. The power range and the level depend on the pump performance. The response speed is determined by the FPGA feedback control speed. High accurate bias control realizes power stability as low as 0,1 dB.

Table C.2 – Typical specifications of the ALC-EDFA system

Item	Specifications
Wavelength range	1 530 nm to 1 562 nm
Inupt power range	–22 dBm to –12 dBm
Response speed	< 1 ms
Output power level	> –5 dBm
Output power stability	< ±0,1 dB

Figure C.3 is an example of photodiode frequency response results with and without the use of an automatic level control EDFA [5]. The photodiode under test is a Picometrix PD model PT-15 C (bandwidth 15 GHz). The response falls by 3 dB above 12 GHz and the results correspond to the quoted bandwidth. The frequency response results show lower fluctuation, less than ±0,1 dB, when the two-tone power is controlled by the EDFA.

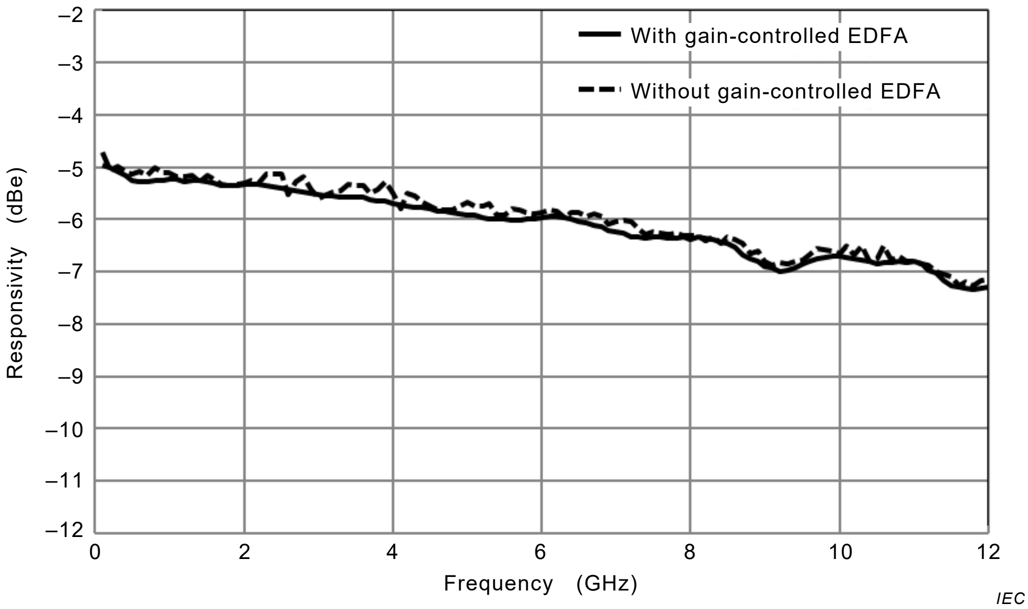


Figure C.3 – Frequency response measurement examples

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