IEC 62803

Edition 1.0 2016-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

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 62803:2016-07(en-fr)

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ICS 33.060.20 ISBN 978-2-8322-3392-4

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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

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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- withdrawn,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

$$k = \frac{\Delta I_{\text{out}}}{\Delta P_{\text{in}}} \quad (1)$$

Note 1 to entry: See Figure 1.

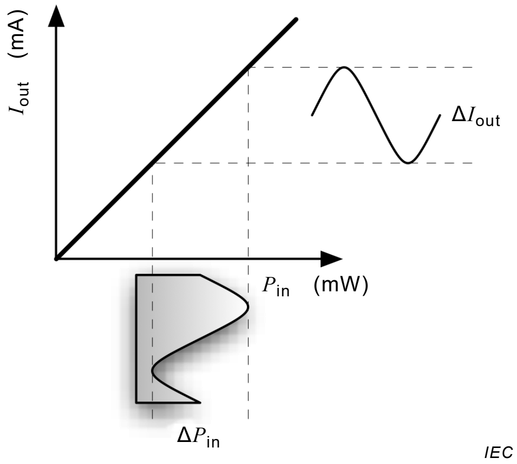


Figure 1 – Definition of "conversion efficiency "

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.

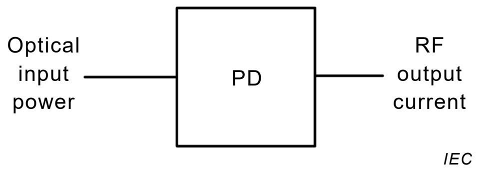


Figure 2 – Optical-to-electrical conversion by photo diode

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.

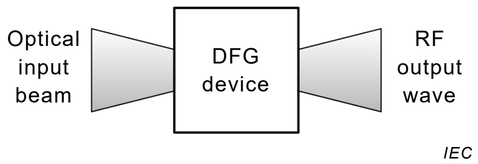


Figure 3 – DFG device

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

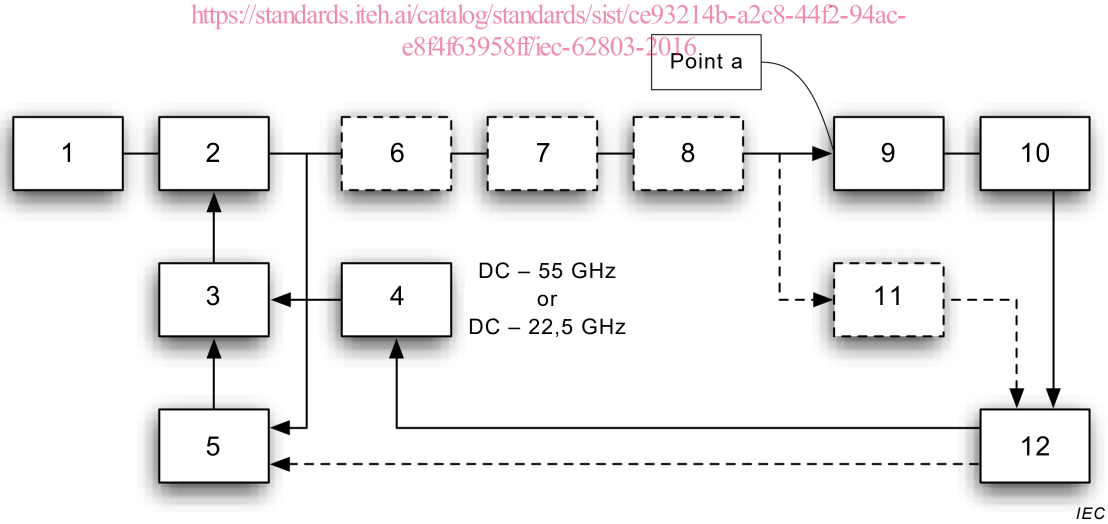
Appropriate statistical methods shall be applied to determine adequate sample size and acceptance criteria for the considered lot size. In the absence of more detailed statistical analysis, the following sampling plan can be employed.

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

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

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

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

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

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

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 $P_{\pm 1}$ or $P_{\pm 2}$ is expressed as

$$i_{\mathrm{RF}} = k_{\mathrm{e}} \times P_{\mathrm{opt}} \times \cos(2\omega_{\mathrm{RF}} t + \phi) = I_{\mathrm{RF}} \cos(2\omega_{\mathrm{RF}} t + \phi) \qquad (7)$$

where k_{e} is the conversion efficiency of the PD under test at $2\omega_{\mathrm{RF}}$, 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

$$k_e = \frac{\Delta I_{\mathrm{out}}}{\Delta P_{\mathrm{in}}} \cong \frac{I_{\mathrm{RF}}}{P_{\mathrm{opt}}} \qquad (8)$$

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

$$P_{\mathrm{RF}} = \frac{I_{\mathrm{RF}}}{\sqrt{2}} \times \frac{I_{\mathrm{RF}}}{\sqrt{2}} Z_{\mathrm{L}} = \frac{I_{\mathrm{RF}}^2 Z_{\mathrm{L}}}{2} \qquad (9)$$

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

$$k_{\mathrm{e}}^2 = \frac{I_{\mathrm{RF}}^2}{P_{\mathrm{opt}}^2} = \frac{2 P_{\mathrm{RF}}}{Z_{\mathrm{L}} P_{\mathrm{opt}}^2} \qquad (10)$$

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 $P_{\pm 1}$. 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 $P_{\pm 2}$. By using an optical band rejection filter, the P_0 component is eliminated to generate a two-tone signal consisting of $P_{\pm 2}$. 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.