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Measurement method of half-wavelength voltage for Mach-Zehnder optical modulator in wireless communication and broadcasting systems

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Méthode de mesure de la tension à une demi-longueur d'onde relative aux modulateurs optiques Mach-Zehnder dans les systèmes de communication et transmission radiofréquence

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INTERNATIONAL
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ICS 33.060.20; 33.180.99

ISBN 978-2-8322-8761-3

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CONTENTS

iTeh STANDARD PREVIEW
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IEC 62801:2020
https://standards.iteh.ai/catalog/standards/sist/9f05a9a8-f003-472f-94ab-d67da96c2af8/iec-62801-2020

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MEASUREMENT METHOD OF HALF-WAVELENGTH VOLTAGE FOR MACH-ZEHNDER OPTICAL MODULATOR IN WIRELESS COMMUNICATION AND BROADCASTING SYSTEMS

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CDV	Report on voting
103/120/CDV	103/133/RVC

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

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INTRODUCTION

A variety of microwave-photonic devices may be used in wireless communication and broadcasting systems. An optical modulator is an interface which converts an electronic signal to an optical signal. In the field of optical fibre communication systems, the first editions of the IEC 62007 series "Semiconductor optoelectronic devices for fibre optic system applications" were published in 1997. In the field of wireless systems, specifications of intermodulation and composite distortion of modulators have been the important issue and have been typically negotiated between users and suppliers. During the International Meeting on Microwave Photonics, a proposal was announced to address standardizations for key devices for radio-over-fibre (RoF) systems.

An RoF system is comprised mainly of two parts; one is the RF to photonic converter (E/O), and the other is the photonic to RF converter (O/E). Radio waves are converted into an optical signal at E/O, and the signal is transferred through the optical fibre, and then the radio waves are regenerated at O/E. The nonlinear distortion characteristics of both E/O and O/E are important for the performance of the system. Semiconductor photodiodes are commonly used for O/E. Several types of optical modulator are used for E/O, such as Mach-Zehnder modulators (MZM), electro-absorption modulators and directly modulated laser diodes (LDs).

This document has been prepared to provide industry standard measurement methods for evaluating electro-optic material based Mach-Zehnder optical modulators, to be used in wireless communication and broadcasting systems. The nonlinear distortion characteristics are also important for the performance of the systems. The intermodulation distortion of the MZM is calculated from the driving voltage and the half-wavelength voltage. The details of calculations of the second-order intermodulation distortion (IM2) and the third-order intermodulation distortion (IM3) are described in Annex B. General characteristics of Mach-Zehnder optical modulators in wireless communication and broadcasting systems are described in Annex C. Notes on measurement of the half-wavelength voltage are described in Annex D.

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MEASUREMENT METHOD OF HALF-WAVELENGTH VOLTAGE FOR MACH-ZEHNDER OPTICAL MODULATOR IN WIRELESS COMMUNICATION AND BROADCASTING SYSTEMS

1 Scope

This document specifies a measurement method of half-wavelength voltage applicable to Mach-Zehnder optical modulators in wireless communication and broadcasting systems. In addition, this method is also effective for the estimation of the intermodulation distortion of Mach-Zehnder optical modulators. The method applies for the following:

– frequency range: 10 MHz to 30 GHz;

– wavelength band: 0,8 µm to 2,0 µm;

– electro-optic material based Mach-Zehnder optical modulators and their modules.

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.

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IEC 62007-1, *Semiconductor optoelectronic devices for fibre optic system applications – Part 1: Essential ratings and characteristics*

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IEC 62007-2, *Semiconductor optoelectronic devices for fibre optic system applications – Part 2: Measurement methods*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62007-1 and IEC 62007-2 and the following apply.

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

3.1.1
half-wavelength voltage
V_{π}
voltage required for a Pockels effect material based Mach-Zehnder optical modulator to induce a phase shift of one-half a wavelength between the lightwaves of two arms of the Mach-Zehnder interferometer

Note 1 to entry: It corresponds to an ON/OFF voltage of the Mach-Zehnder optical modulator as shown in Figure 1

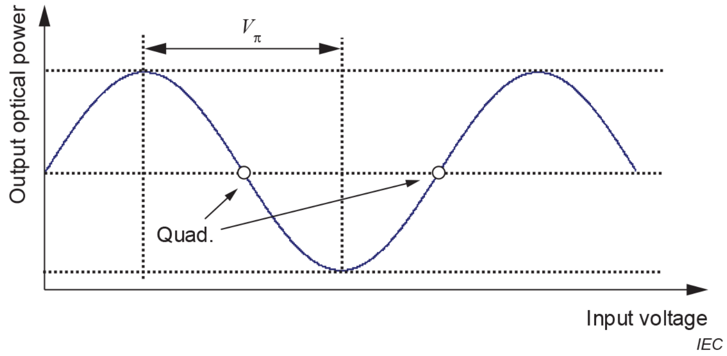

Figure 1 – Transfer curve of a Mach-Zehnder optical modulator

3.1.2
normalized optical modulation index
NOMI
for the Mach-Zehnder optical modulator, ratio of driving voltage and half-wavelength voltage of the modulator, defined as

$$\text{NOMI} = (V_{pp} / V_\pi) \times 100\ [\%] \tag{1}$$

where

V_{pp} is the driving voltage (peak to peak voltage);

V_π is the half-wavelength voltage

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Note 1 to entry: NOMI does not denote actual optical modulation index (OMI), defined as the ratio of the optical modulated signal power and the average optical power. Detailed explanations of OMI including measurement methods are described in Annex A.

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Note 2 to entry: This note applies to the French language only.

3.1.3
extinction ratio
R_{ext}
ratio of two optical power levels of the optical signal generated by the optical modulator, defined as

$$R_{ext} = 10\log(P_1/P_2) \tag{2}$$

where

P_1 is the optical power level generated when the output power is "on";

P_2 is the power level generated when the output power is "off"

3.2 Symbols and abbreviated terms

The symbols and abbreviated terms used in this document are shown in Table 1.

Table 1 – Symbols and abbreviated terms

R_{ext}	extinction ratio
V_π	half-wavelength voltage
CSO	composite second-order distortion
CTB	composite triple-beats distortion
DUT	device under test
ESA	electrical spectrum analyser
IMD	intermodulation distortion
IM2	second-order intermodulation distortion
IM3	third-order intermodulation distortion
LD	laser diode
MZM	Mach-Zehnder modulator
NOMI	normalized OMI
OMI	optical modulation index
PD	photodiode
RoF	radio-over-fibre

4 Electro-optic material based Mach-Zehnder optical modulator

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4.1 Mach-Zehnder optical modulator

4.1.1 Component parts

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The optical modulators and their modules consist of basic parts as follows:

– Mach-Zehnder interferometer type optical modulator;
– input and output fibre pigtails (where appropriate);
– bias control port (where appropriate);
– photodiode for bias monitoring (where appropriate);
– laser diode for light source (where appropriate);
– thermal sensor (where appropriate);
– Peltier element (where appropriate).

4.1.2 Structure

A basic structure of the Mach-Zehnder interferometer type optical modulators is shown in Figure 2. The modulators are grouped by electrode types and options.

– Electrode: lumped type, traveling-wave type, etc.
– Options: optical isolator, photodiode, half-mirror, laser diode, etc.

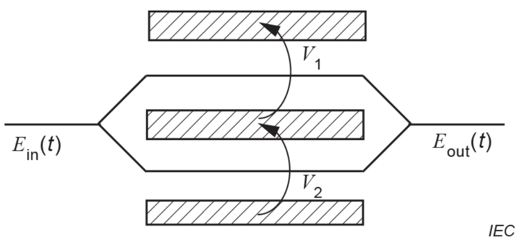

Figure 2 – Structure of Mach-Zehnder interferometer type optical modulator

4.2 Requirements for Mach-Zehnder optical modulator

4.2.1 General

This method is based on the theoretical transfer curve of the electro-optic material based Mach-Zehnder interferometer, where the phase shift of traveling light on each arm of the interferometer should be proportional to the applied voltage, and the power of traveling lightwaves in each arm are almost the same. Requirements for this measurement method and applicable for the modulator are given in 4.2.2 and 4.2.3.

4.2.2 Substrate material

The main substrate materials of the modulator shall be materials such as $LiNbO_3$, $LiTaO_3$, KH_2PO_4, PZT, PLZT, InP, GaAs, InGaAs, InAlAs, InGaAsP, CLD type chromophore containing polymer, FTC type chromophore containing polymer, etc., which realize an electro-optic effect (Pockels effect). If strictly considered, semiconductor materials do not possess a pure electro optic effect, however, the semiconductor Mach-Zehnder modulators can be adjudged as electro-optic material based Mach-Zehnder modulators.

4.2.3 Optical waveguide design

The optical waveguide shall be designed as a single Mach-Zehnder interferometer type comprised of two Y-junctions or symmetric directional couplers and parallel waveguides. Reflection type Mach-Zehnder optical modulators are included.

5 Sampling for quality control

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5.1 Sampling

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A statistically significant sampling plan shall be agreed upon by the 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

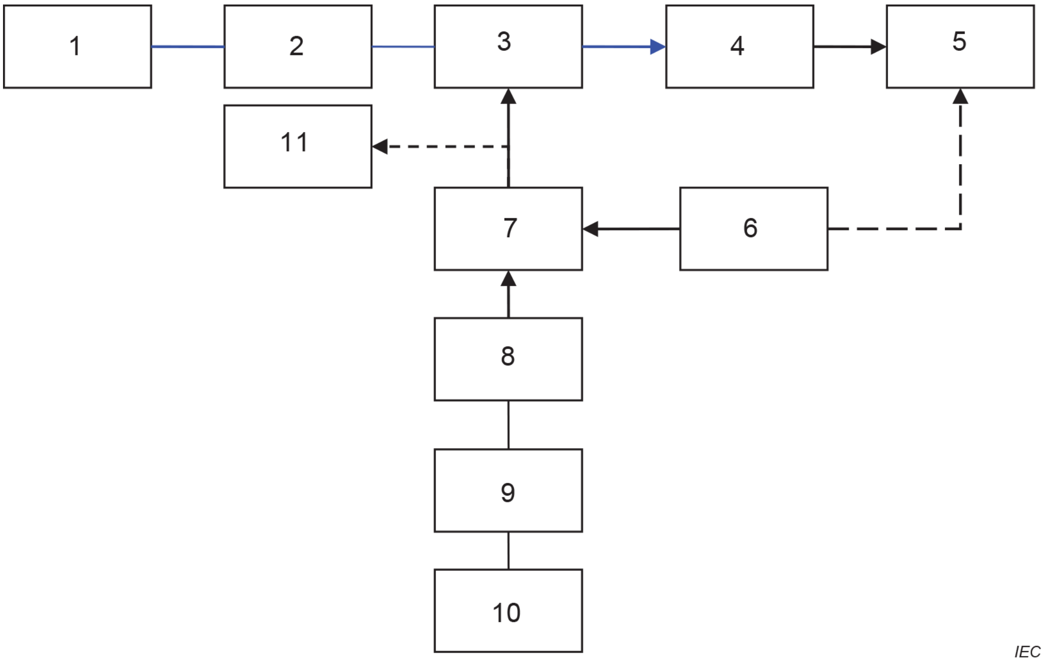
Appropriate statistical methods shall be applied to determine adequate sample size and acceptance criteria for the considered lot size. In the absence of more detailed statistical analysis, the following sampling plan can be employed.

Half wavelength voltage: two units at least per manufacturing lot.

6 Measurement method of half wavelength voltage

6.1 Circuit diagram

See Figure 3 for the circuit description and requirements.



Key

1 Laser diode
2 Polarization controller
3 Device under test
4 Photodiode
5 Oscilloscope
6 Monitor signal Source (SG2)
7 Bias tee
8 (Step) attenuator
9 Microwave amplifier
10 Microwave signal source (SG1)
11 Power meter or spectrum analyser (during measurement)

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Figure 3 – Schematic block diagram of the measurement setup

6.2 Measurement conditions

6.2.1 Temperature and environment

The measurement should be carried out in a room with 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 the temperature drift of measurement apparatuses to a minimum. The temperature of the DUT can be changed using a temperature controller, as necessary, to verify the temperature dependence of the measured parameters, for example.

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. Moreover, the warming up time should be taken to be the longest among all of the measurement equipment.

6.3 Principle of measurement method

6.3.1 General

The method for measuring the half-wavelength voltage (AC half-wavelength voltage) of a Mach-Zehnder type optical modulator is described here. In this method, the half-wavelength voltages of Mach-Zehnder type optical modulators can be measured accurately without depending on the bias voltage of an optical modulator. When the input RF signal to the modulator is set to such a specific level that the zero-order Bessel functions can be zero, the average optical output power of the modulator becomes constant regardless of the bias voltage. By measuring the input RF power or voltage at this condition, the half-wavelength voltage, V_π, is determined. This measurement can be achieved through a wide frequency range, though it needs a high-voltage signal source (of about 1,5 times V_π).

6.3.2 Measurement principle

The optical output power of MZ modulators is given by

$$I = \frac{I_0}{2}\left[1+\cos(\Phi_1+\Phi_2)\right] \tag{3}$$

$$\Phi_1 = \frac{\pi V_{pp}}{2V_\pi}\sin(2\pi ft) \tag{4}$$

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$$\Phi_2 = \text{const.} \tag{5}$$

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where Φ_1 and Φ_2 are the phase change caused by the high-frequency RF signal and that due to the bias voltage, respectively. V_π is the half-wavelength voltage at the RF signal frequency f, V_{pp} is the peak to peak voltage amplitude of the high-frequency wave, and I_0 is the maximum optical output power. The time average power of I, I' is calculated by

$$I' = f\int_0^{1/f}\frac{I_0}{2}\left[1+\cos(\Phi_1+\Phi_2)\right]dt$$

$$= f\int_0^{1/f}\frac{I_0}{2}\left[1+\cos\Phi_1\cos\Phi_2-\sin\Phi_1\sin\Phi_2\right]dt \tag{6}$$

After some calculation from Equation (6), we obtain:

$$\begin{aligned}
I' &= f\int_0^{1/f}\frac{I_0}{2}\left[1+\cos\left\{\frac{\pi V_{pp}}{2V_\pi}\sin(2\pi ft)\right\}\cos\Phi_2-\sin\left\{\frac{\pi V_{pp}}{2V_\pi}\sin(2\pi ft)\right\}\sin\Phi_2\right]dt \\
&= f\int_0^{1/f}\frac{I_0}{2}\left[1+\sum_{n=0}^{\infty}\varepsilon_n\cos(2n\cdot 2\pi ft)J_{2n}\left\{\frac{\pi V_{pp}}{2V_\pi}\right\}\cos\Phi_2-\sum_{n=0}^{\infty}2\sin\{(2n+1)2\pi ft\}J_{2n+1}\left\{\frac{\pi V_{pp}}{2V_\pi}\right\}\sin\Phi_2\right]dt \\
&= \frac{I_0}{2}\left[1+J_0\left(\frac{\pi V_{pp}}{2V_\pi}\right)\cos\Phi_2\right]
\end{aligned} \tag{7}$$

where

$$\varepsilon_n = \begin{cases}1\cdots n=0\\ 2\cdots n\neq 0\end{cases}$$

When the input RF signal is tuned so that the relation $\pi V_{pp\ min}/(2\ V_{\pi}) = 2{,}405$ can be satisfied, the zero-order Bessel term in Equation (7) becomes zero, and the time average of the optical output power becomes constant. As shown in Figure 4, there are many voltage amplitudes at which the AC component of I' goes to zero. $V_{pp\ min}$ denotes the lowest one of them.

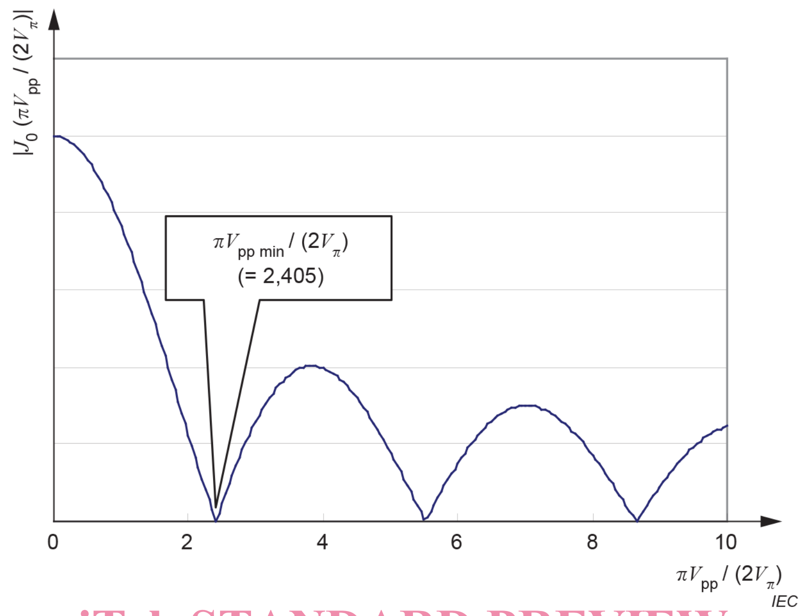

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Figure 4 – Zero-order Bessel function

The schematic block diagram of the measurement setup is shown in Figure 3. In order to find easily the state where the optical output is constant, a low frequency signal for monitor (SG2) is superimposed on the RF signal. By adjusting the RF voltage amplitude of the high-frequency signal (SG1), the condition can be observed where the monitor signal (SG2) amplitude shows the minimum value. At this condition, the wave form of the monitor signal is observed as a flat line on the screen of the oscilloscope. V_{π} at the frequency of SG1 can be calculated from the measured result of $V_{pp\ min}$ using the following relation.

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$$V_{\pi} = \frac{\pi V_{pp\ min}}{2 \times 2{,}405} = \frac{\pi \cdot 20(10^{(P\_S1/10-3)})^{1/2}}{2 \times 2{,}405} \tag{8}$$

According to this method, the half-wavelength voltage V_{π} of a Mach-Zehnder type optical modulator can be measured easily by measuring the minimum value $V_{pp\ min}$ of the voltage amplitude of the high-frequency AC signal when the intensity change of an output lightwave related to the monitoring low-frequency AC signal is almost zero, as shown in Figure 5. In addition, if the frequency for testing is a high frequency, because there is no need to observe the high-frequency waveform directly, accurate measurement is possible, and at the same time, because this is not a measurement method which depends on a bias point, there is no need to adjust the bias point, and there is no effect from bias point variation of the optical modulator.

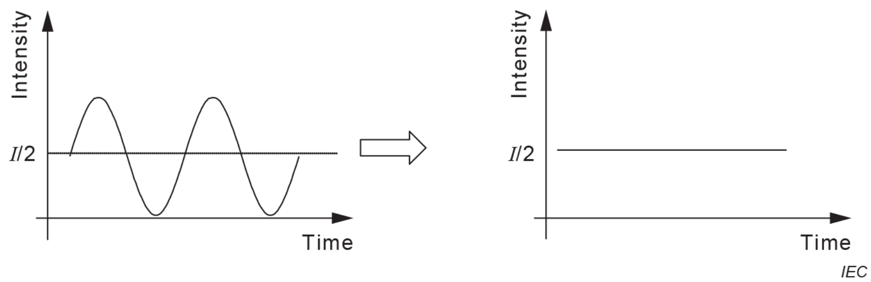

Figure 5 – Waveform change on the oscilloscope screen