IEC/PAS 62593

Edition 1.0 2008-11

PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

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

IEC/PAS 62593:2008(E)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **V**

ICS 33.060.20

ISBN 978-2-88910-812-1

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

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Draft PAS	**Report on voting**
103/74/PAS	103/81/RVD

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INTRODUCTION

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

The RoF system is comprised mainly of two parts; one is the RF to photonic converter (E/O), and the other is photonic to RF converter (O/E). Radio waves are converted into an optical signal at E/O, and the signal is transferred into 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, electro-absorption modulators and directly modulated LDs.

This PAS has been prepared in order 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. When the optical modulation index (OMI) is calculated from the half-wavelength voltage measurement results, the intermodulation distortion of the Mach-Zehnder optical modulator can be obtained. In this PAS, the measurement method of the half-wavelength voltage for Mach-Zehnder optical modulators is described. The details of calculations of the second order intermodulation distortion (IM2) and the third order intermodulation distortion (IM3) are described in Annex B.

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

1 Scope

This PAS gives 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.

- Frequency range: 10 MHz to 30 GHz.
- Wavelength band: 0,8 µm, 1,0 µm, 1,3 µm and 1,5 µm.
- Electro-optic material based Mach-Zehnder optical modulators and their modules.

2 Normative references

The following referenced documents are indispensable for the application 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 62007-1, *Semiconductor optoelectronic devices for fibre optic system applications - Part 1: Specification template for essential ratings and characteristics*

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

3 Terms, definitions and acronyms

3.1 Terms and definitions

For the purpose of this document, the terminology concerning the physical concept, the type of devices, the general terms, those related to rating and characteristics in IEC 62007-1 and IEC 62007-2, as well as the following terms and definitions, apply.

3.1.1 Half-wavelength voltage: $V\pi$

The voltage required for a Pockels effect material based optical modulator to shift phase of the light by one-half a wavelength relative to the other. It corresponds to an ON/OFF voltage of the Mach-Zehnder optical modulator.

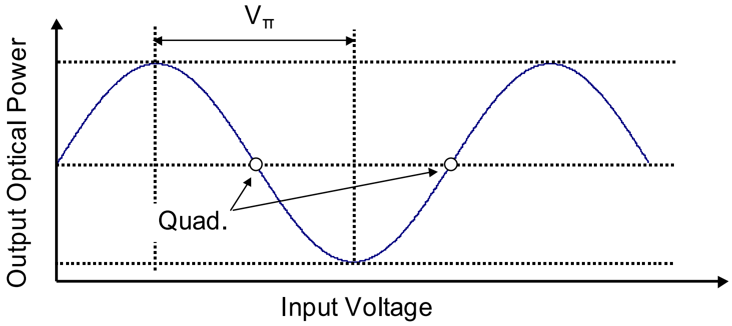

Figure 1 – A transfer curve of a Mach-Zehnder optical modulator

3.1.2 Normalized optical modulation index: NOMI

For the Mach-Zehnder optical modulator, the ratio of driving voltage and half-wavelength voltage of the modulator,

$$\text{NOMI} = (V_{\text{pp}} / V_{\pi}) \times 100\ [\%] \qquad (3.1)$$

where

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

V_{π} is the half-wavelength voltage.

NOTE NOMI does not denote actual optical modulation index defined as the ratio of the optical modulated signal power and the average optical power. The detailed explanations of OMI including measurement method are described in Annex A.

3.1.3 Extinction Ratio

The ratio of two optical power levels of the optical signal generated by the optical modulator:

$$R_{\text{ext}} = 10\log(P_1/P_2) \qquad (3.2)$$

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."

NOTE The extinction ratio is sometimes expressed as a fraction, not in dB.

3.1.4 Acronyms and symbols

The acronyms and symbols are shown in Table 3.1.

Table 1 – Acronyms and Symbols

V_{π}	A Half wavelength voltage
OMI	Optical Modulation Index
NOMI	Normalized OMI
IM2	Second-order Inter-Modulation distortion
IM3	Third-order Inter-Modulation distortion
CSO	Composite Second-Order distortion
CTB	Composite Triple-Beats distortion

4 Electro-optic material based Mach-Zehnder optical modulator

4.1 Type

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)

4.2 Structure

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

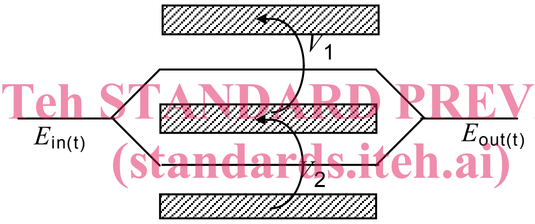

Figure 2

4.3 Requirements for Mach-Zehnder optical modulators

This method is based on the theoretical transfer curve of an 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 power of traveling lights on each arm are almost same. Requirements for the modulator of this measurement method are as follows:

4.3.1 Substrate material

The main Substrate materials of the modulator should be the 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 have pure electro optic effect, however, the semiconductor Mach-Zehnder modulators can be adjudged as electro-optic material based Mach-Zehnder modulators.

4.3.2 Optical waveguide design

The optical waveguide should 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

5.1 Sampling

A statistically significant sampling plan shall be agreed upon by user and supplier. Sampled devices shall be randomly selected and representatives 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/manufacturing lot.

6 Measurement method of half wavelength voltage

6.1 Circuit diagram

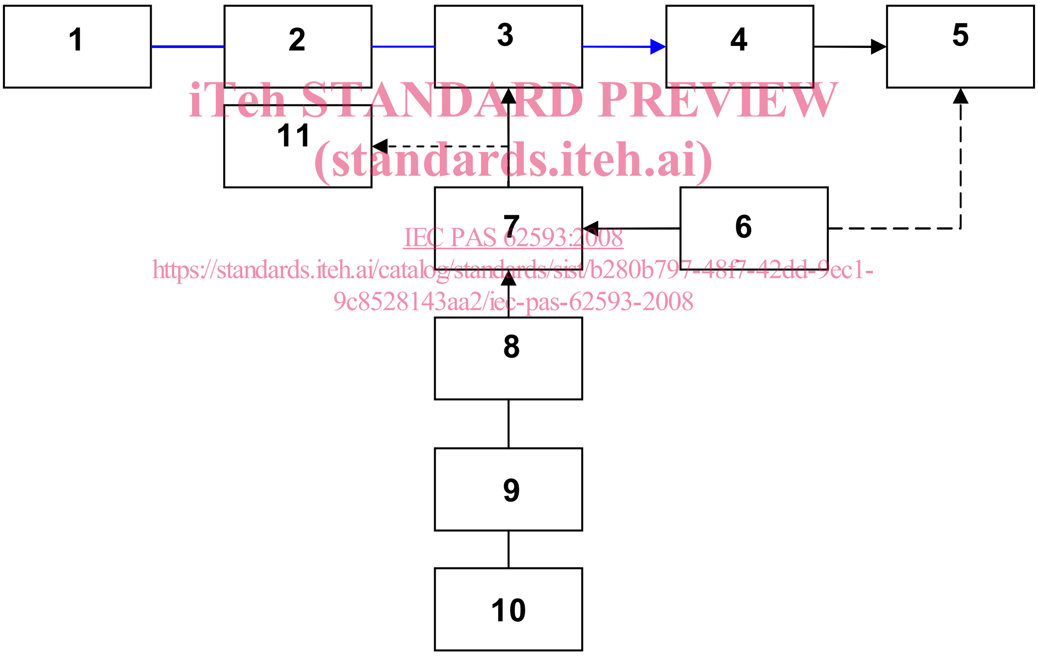

Figure 3 – Circuit diagram

6.2 Circuit description and requirement

1 = Laser diode
2 = Polarization controller
3 = Device Under Test
4 = Photo Diode
5 = Oscilloscope
6 = Monitor Signal Source (SG2)
7 = Bias Tee
8 = (Step) Attenuator (Electrical)
9 = Microwave Amplifier
10 = Microwave Signal Source (SG1)
11 = Power Meter or Spectrum Analyzer (electrical)

6.3 Measurement condition

6.3.1 Temperature and environment

The measurement should be carried out in the room from 5 °C to 35 °C. If the operation temperature ranges of the measurement apparatus are narrower than the above range, the specifications of the measurement apparatus 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 apparatus to minimum.

6.3.2 Warming up of measurement equipment

The warming-up time shall be respected, typically 60 minutes, or the time written in the specifications of the measurement equipments or systems. Moreover, the warming up time should be that of to be the longest of all the measurement equipment.

6.4 Principle of measurement method

The Method for measuring 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 function 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, 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 of $V\pi$).

6.4.1 Measurement principle

The optical output power of MZ modulators is given by,

$$I = \frac{I_0}{2}\left[1 + \cos(\Phi_1 + \Phi_2)\right] \tag{6.1}$$

$$\Phi_1 = \frac{\pi V_{pp}}{2V_\pi}\sin(2\pi f t) \tag{6.2}$$

$$\Phi_2 = \text{const.} \tag{6.3}$$

where $\phi 1$ and $\phi 2$ 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,

$$\begin{aligned} I' &= f\int_0^{1/f} \frac{I_0}{2}\left[1 + \cos(\Phi_1 + \Phi_2)\right]dt \\ &= f\int_0^{1/f} \frac{I_0}{2}\left[1 + \cos\Phi_1 \cos\Phi_2 - \sin\Phi_1 \sin\Phi_2\right]dt \end{aligned} \tag{6.4}$$

After calculation from Eq. (6.4), we get,

$$
\begin{aligned}
I' &= f\int_0^{1/f}\frac{I_0}{2}\left[1+\cos\left\{\frac{\pi V_{\mathrm{pp}}}{2V_\pi}\sin(2\pi ft)\right\}\cos\Phi_2-\sin\left\{\frac{\pi V_{\mathrm{pp}}}{2V_\pi}\sin(2\pi ft)\right\}\sin\Phi_2\right]dt\\
&= f\int_0^{1/f}\frac{I_0}{2}\left[1+\sum_{n=0}^{\infty}\varepsilon_n\cos(2n\cdot 2\pi ft)J_{2n}\left\{\frac{\pi V_{\mathrm{pp}}}{2V_\pi}\right\}\cos\Phi_2-\sum_{n=0}^{\infty}2\sin\{(2n+1)2\pi ft\}J_{2n+1}\left\{\frac{\pi V_{\mathrm{pp}}}{2V_\pi}\right\}\sin\Phi_2\right]dt \qquad (6.5)\\
&= \frac{I_0}{2}\left[1+J_0\left(\frac{\pi V_{\mathrm{pp}}}{2V_\pi}\right)\cos\Phi_2\right]
\end{aligned}
$$

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 $\pi V_{\mathrm{pp\ min}}/(2V_\pi)$ = 2,405 can be satisfied, the zero-order Bessel term in the Eq. (6.5) 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 down to zero. $V_{\mathrm{p\text{-}p\ min}}$ denotes the lowest one of them.

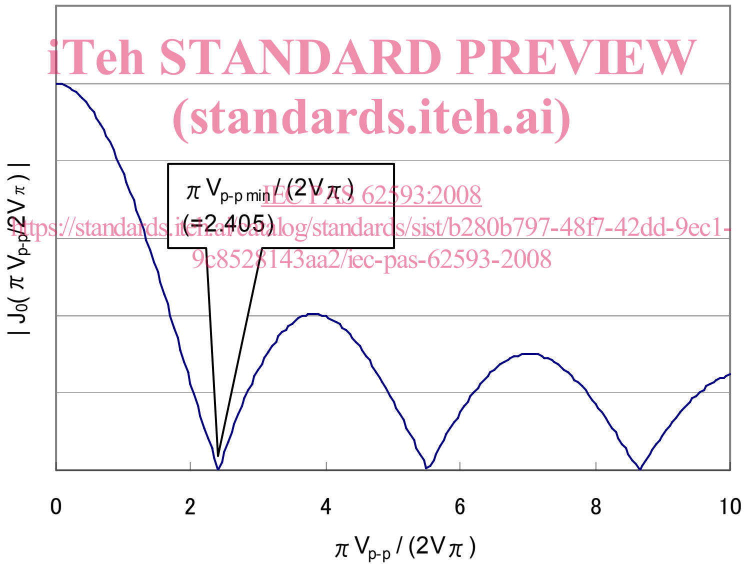

Figure 4

The schematic block diagram of the measurement setup is shown in Figure 3. In order to easily find 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 status can be observed where the monitor signal (SG2) amplitude shows the minimum value. At this status the wave form of 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 $V_{\mathrm{p\text{-}pmin}}$ using the following relation.

$$
V\pi=\frac{\pi V_{\mathrm{p-pmin}}}{2\times 2.405}=\frac{\pi\cdot 20(10^{(\mathrm{P\_S1}/10-3)})^{1/2}}{2\times 2.405} \qquad (6.6)
$$