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INTERNATIONAL STANDARD

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colour inside

Measurement methods of a half-wavelength voltage and a chirp parameter for Mach-Zehnder optical modulators in high-frequency radio on fibre (RoF) systems

Méthodes de mesure d'une tension à demi-longueur d'onde et d'un paramètre de fluctuation de la longueur d'onde pour modulateurs optiques de Mach-Zehnder dans les systèmes de radio par fibre (RoF) à haute fréquence

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MEASUREMENT METHODS OF A HALF-WAVELENGTH VOLTAGE AND A CHIRP PARAMETER FOR MACH-ZEHNDER OPTICAL MODULATORS IN HIGH-FREQUENCY RADIO ON FIBRE (ROF) SYSTEMS

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CDV	Report on voting
103/131/CDV	103/161/RVC

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INTRODUCTION

A variety of microwave/millimeter-wave-photonic devices are useful for 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 IEC 62007 series was published in 1999.

Microwave/millimeter-wave RoF systems are comprised mainly of two parts: one is 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. This signal is transferred through the optical fibre and then the radio waves are regenerated at O/E.

A variety of photonic devices that carry microwave and millimeter-wave signals as subcarrier frequencies are used for high-frequency RoF systems. In particular, the Mach-Zehnder optical modulator (MZM) plays an important role to convert electronic (high-frequency above millimeter-wave) signal to optical signal. In high-frequency RoF systems, specifications of drive voltages, chirp characteristics, inter-modulation distortion of the modulators have been the important technical parameters. This document is prepared to provide the measurement method of MZMs to the industry for evaluating electro-optic material of the modulators to be used in high-frequency RoF systems. This document defines the measurement methods of a half-wavelength voltage and a chirp parameter, which have a significant impact on the performance of RoF systems. Additionally, these methods are also used for the estimation of the intermodulation distortions and transmission performances.

The half-wavelength voltage and the chirp parameter can be measured at the same time using the methods defined in this document. 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 detailed explanations and calculation method of intermodulation distortions from the normalized optical modulation index (NOMI) are described in IEC PAS 62593:2008[1], Annex B.

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a) a method for characterization of optical modulator, and method for controlling high frequency oscillator using the same (JP 3538619B),

b) a method and apparatus for measurement of characteristic of optical modulator (JP 3866082B),

c) a method for evaluating characteristic of optical modulator having Mach-Zehnder interferometer (WO 2011-027409),

d) a method of measuring half-wave voltage of optical modulator (JP 2009-229926A).

Details pertaining to the patent holders and the locations where the patents are referred to in the document are given in Table 1.

1 Numbers in square brackets refer to the Bibliography.

Table 1 – Patents present in this document

Related clause	Patent holder	Patent number
Clause 6 Annex A (informative)	National Institute of Information and Communications Technology	JP 3538619
6.4.3	National Institute of Information and Communications Technology Sumitomo Osaka Cement Co., Ltd.	JP 3866082
A.2.1	National Institute of Information and Communications Technology Sumitomo Osaka Cement Co., Ltd.	(WO 2011-027409) EP 2477021A US 8867042 CN 102575971 JP 5622154
A.2.2	Sumitomo Osaka Cement Co., Ltd.	(JP2009-229926A) JP 4991610

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MEASUREMENT METHODS OF A HALF-WAVELENGTH VOLTAGE AND A CHIRP PARAMETER FOR MACH-ZEHNDER OPTICAL MODULATORS IN HIGH-FREQUENCY RADIO ON FIBRE (ROF) SYSTEMS

1 Scope

This document specifies measurement methods of a half-wavelength voltage and a chirp parameter applicable to MZMs in microwave and millimeter-wave RoF systems. In addition, these methods are also effective for the estimation of the intermodulation distortions and transmission performances. The methods apply for the following:

– frequency range: 5 GHz to 110 GHz;

– wavelength band: 0,8 μm to 2,0 μm;

– electro-optic material based MZMs 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.

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: Measurement methods*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62007-1:2015 and IEC 62007-2:2009 and the following apply.

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

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

SEE: Figure 1.

Note 1 to entry: It corresponds to an ON/OFF voltage of the Mach-Zehnder optical modulator.

Note 2 to entry: IEC PAS 62593 defines a measurement method for a half-wavelength voltage suitable for lower frequency applications, especially less than 5 GHz.

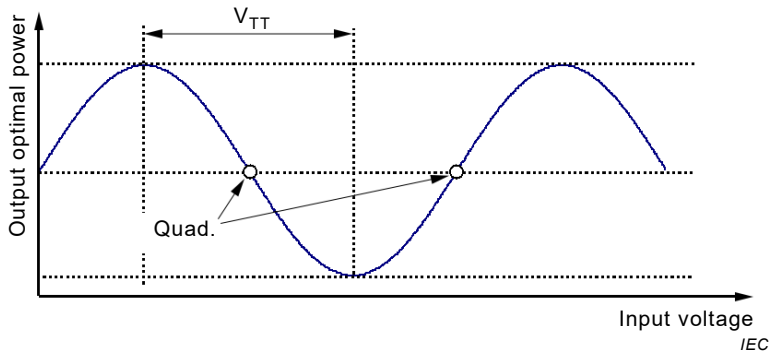

Figure 1 – Transfer curve of a Mach-Zehnder optical modulator

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

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

where

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

V_{π} is the half-wavelength voltage.

Note 1 to entry For the Mach-Zehnder optical modulator, the intermodulation distortion is dependent on NOMI. The detailed explanations of OMI including measurement method are described in IEC PAS 62593:2008, Annex A. The calculation method of intermodulation distortions from the measured NOMI is described in IEC PAS 62593:2008, Annex B.

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

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

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 1 to entry: The extinction ratio is sometimes expressed as a fraction not in dB.

3.1.4
chirp parameter
undesired optical phase change with amplitude or intensity modulation, which is defined as the ratio of amplitude modulation and the phase modulation:

$$\alpha = \frac{\frac{d\phi}{dt}}{\frac{1}{E}\frac{dE}{dt}} \quad (3)$$

where

E is the optical amplitude at the modulator output,

ϕ is the optical phase at the modulator output.

Note 1 to entry: In IEC 61280-2-9 [2], chirp measurement methods for laser transmitters were overviewed, and time-resolved chirp and alpha-parameter measurement methods for of laser transmitters for digital systems is are given in IEC 61280-2-10 [3]. The chirp parameter alpha of an MZM is explained in detail in [4].

Note 2 to entry: The alpha parameter of an MZM can also be measured together with a half-wave voltage V_{π} by the sideband monitoring methods described in [5] and [6] using an optical spectrum analyzer.

3.2 Abbreviated terms

DC	direct current
DUT	device under test
MZM	Mach-Zehnder modulator
NOMI	normalized OMI
OMI	optical modulation index
OSA	optical spectrum analyzer
RF	radio frequency

4 Electro-optic material-based Mach-Zehnder optical modulators

4.1 Mach-Zehnder optical modulators

4.1.1 Component parts

The optical modulators and their modules consist of the 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

The structure is as follows:

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

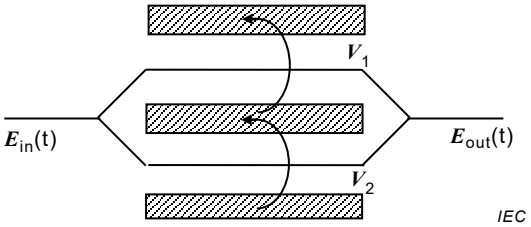

Figure 2 – Optical phase retardations

Due to the Pockels effect, optical phase retardation at each arm in the Mach-Zehnder interferometer can be controlled by the voltage applied on the electrode. The optical phase retardations at the upper arm and the lower arm are proportional to the voltages V_1 and V_2 (see Figure 2).

4.2 Requirements for MZMs

4.2.1 General

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

4.2.2 Substrate material

The main substrate materials of the modulator should be materials such as $LiNbO_3$, $LiTaO_3$, KH_2PO_4, PZT, PLZT, InP, GaAs, InGaAs, InAlAs, InGaAsP, nonlinear optical chromophore containing polymer, FTC type chromophore containing polymer, etc., which realise the 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 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 modified designs of the modulators.

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 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 per manufacturing lot.

6 Measurement method of a half wavelength voltage

6.1 Circuit diagram

See Figure 3.