THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

IEICE Technical Report
PEM2015 FCB-4 (2015-11)

# Recent Standardization Activities for Radio over Fiber Transmitter Within IEC TC103 WG6

Satoru KUROKAWA† Michitaka AMEYA† Junichiro ICHIKAWA‡ Hiroyo OGAWA†† Atsushi KANNO††, Tetsuya KAWANISHI†† Nathan GOMES‡† Hanako NODA‡‡ and other members of IEC TC103WG6

†National institute of advanced industrial science and technology (AIST), Tsukuba, Ibaraki, 305-8563 Japan.
‡Sumitomo Osaka Cement CO., LTD. Funabashi, Chiba, 274-8601, Japan
††National Institute of Information and Communications Technology, Koganei, Tokyo, 184-8795 Japan
‡†University of Kent, Canterbury, CT2 7NT, U.K.
‡‡Anritsu CO., LTD. Atsugi, Kanagawa, 243-8555 Japan

E-mail: † {satoru-kurokawa, m.ameya}@aist.go.jp, ‡ jichikawa@soc.co.jp

**Abstract** This paper describes the outline of recent standardization activities for Radio over Fiber transmitter by IEC TC103WG6. Radio over Fiber transmitter consists of optical fibers, electrical to optical converter, and optical to electrical converter. IEC TC103WG6 is working on standardization on measurement method of these devices, and technical report for some applications using Radio over Fiber transmitter. This paper overviews those standardization activities which are being developed by TC103WG6.

**Keywords** Radio over Fiber transmitter, electrical to optical converter, optical to electrical converter, standardization, TC103, TC103WG6

## 1. Introduction

Radio over Fiber (RoF) system is widely recognized as broadband wireless signal infrastructure to shadowing areas such as the underground, the subway stations, inside the train, and inside the building. Further, RoF system can transmit and receive broadband microwave modulated light wave. For this reason, variety of RoF systems are utilized in the area of antenna property measurement and in the area of transmitting broadband microwave signal such as TV broadcasting signals, mobile phone signals, WiFi (Wireless Fidelity) signals. RoF system consists of optical fibers, electrical signal to optical signal (E/O) converter and optical signal to electrical signal (O/E) converter. At E/O converter, optical carrier is modulated by broadband wireless signals, and the modulated optical signal is transmitted through the optical fiber. Then, the broadband wireless signals are regenerated by O/E converter. E/O converter could be a dielectric material such as a LiNbO3 Mach-Zehnder optical intensity modulator (MZM), an electro-absorption modulator (EAM) and a directly modulated Laser-Diode. In the case of the MZM and the EAM, high-speed modulation up to 40 GHz can be achieved for 40Gbps digital communication systems [1]. Various types of photo diode have been used for the O/E converter. In the case of a Uni-traveling carrier photodiode (UTC-PD), 1 THz receiving bandwidth has been achieved [2][3]. IEC TC103WG6 (International Electro technical Commission, Technical Committee 103 Working Group 6) has started standardization of RoF transmitter from 2005. The national committee of TC103WG6 consists of four sub working groups (SWGs) as follows;

- SWG1: Standardization for measurement method of E/O conversion device
- SWG2: Standardization for measurement method of O/E conversion device
- SWG3: Standardization of RoF transmission system
- SWG4: Antenna measurement system

This paper presents recent standardization activities for RoF transmitters within IEC TC103WG6.

## 2. Standardization for measurement method of E/O conversion device[4][5]

SWG1 of the national committee of TC103WG6 is in charge of standardizing the measurement method for E/O conversion devices. Our standardized methods are described in Table 2. Method A, using electrical oscilloscope, is used for the frequency range less than 30 GHz. Method B, C and D, using optical spectrum analyzer, are used for the frequency range more than 10GHz. [Accuracy of half -wavelength voltage] and [Accuracy of chirp parameter] in table 1, '+++' indicates the most accurate method in method A, B, C and D. [NA] in its column indicates that the method cannot measure the chirp parameter. [Requires No. of Spectra] indicates the required number of optical frequencies for evaluating the half-wavelength voltage and the chirp parameter. [NA] indicates that the method doesn't use optical a frequency for need evaluating the half -wavelength voltage. Method A has been accepted as a new work item proposal (NP) and the project was registered as IEC 62801 Ed. 1.0 [4]. Now the revised draft is ready to be circulated as FDIS (Final Draft for International Standard). Method B, C and D are the method for measuring the half-wavelength voltage and chirp parameter of MZM more than 10GHz [5][6] that has been also approved as a NP. The project was registered as IEC 62802 Ed. 1.0 "Measurement Method of a half-Wavelength Voltage and a Chirp Parameter for Mach-Zehnder Optical Modulator in High-Frequency Radio on Fiber (RoF) Systems"[7]. Now the revised draft is ready to be circulated as FDIS.

Table 2 Comparison between Method A, B, C and D.

| Method | Bias condition | Accuracy of half-wavelength voltage | Accuracy of chirp parameter | Required No. of Spectra | Required RF power |
|---|---|---|---|---|---|
| Method A [4] < 30GHz | Fixed bias point | +++ | NA | NA | Large |
| Method B [7] > 10GHz | Fixed bias point | ++ | ++ | 1 | Middle |
| Method C [7] > 10GHz | Swept bias | +++ | +++ | 1 | Middle |
| Method D [7] > 10GHz | Minimum /Maximum transmission bias | ++ | + | 2 | Small |

## 3. Standardization for measurement method of O/E conversion device[8]

SWG2 of TC103/WG6 is in charge of standardizing the measurement method for O/E conversion devices. The proposed method is described here. Our NP of the measurement method was accepted and registered as IEC 62803 Ed. 1.0 (NP) [8]. Now the revised draft is ready to be circulated as a draft circulated for FDIS. Our method is based on the heterodyne principle. The method utilizes a MZM 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. A two-tone lightwave illuminates the DUT (Device Under Test) as a stimulus signal. The two-tone stimulus lightwave is generated by using an MZM at null bias or 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 [9-12].

## 4. Use of RoF technologies for antenna measurement

SWG4 of TC103/WG6 is in charge of standardizing some applications for antenna measurement. This document provides information on current and latest applications for antenna measurement using RoF technology. Antenna gain and antenna pattern measurement system are covered, which are practically used or will be used soon. It will be beneficial to system developers and system users in the fields of antenna measurement. The application examples of antenna measurement using RoF technology are listed below.

- Antenna gain measurement system using optical fiber link
- Millimeter-wave antenna pattern measurement system using nested type MZM and UTC-PD
- Very-near-field antenna pattern measurement system using MZM photonic sensor

### 4.1 Antenna gain measurement system using optical fiber link [14]

There are a few types of method for antenna gain measurement such as substitution method, two-antenna method, and three-antenna method. In common these methods, the basic configuration are one vector network analyzer and two antennas with coaxial cables. By measuring S-parameter between the two-antennas, the antenna gain is calculated. The distance between antennas and the height to the antennas from the ground should be enough to measure the antenna gain accurately. The length of the coaxial cables may extend to tens of meters in some cases. The coaxial cable reflects and reradiates the electromagnetic waves from the antennas because it is made from metal. Therefore, coaxial cables increase the uncertainty of the measurement system and may give inaccurate results. Antenna gain measurement system using optical fiber link can solve these coaxial cable problems. Figure 2 shows the system configuration of the antenna gain measurement system using RoF modules. This system is composed of transmitting antenna, receiving antenna, two 6dB attenuators, two pair of RoF modules, two single mode optical fibers, and a vector network analyzer.

### 4.2 Millimeter-wave antenna pattern measurement system using nested type MZM and UTC-PD[15][16]

Millimeter-wave technology is very important for high-speed wireless communication and radar applications. Especially, the antenna is a key device for mm-wave applications and the antenna pattern evaluation of mm-wave antennas is required for developing these applications. The conventional mm-wave antenna evaluation systems are composed of a lot of waveguide components and very expensive. In addition, it is difficult to design the movable mechanical system because the waveguide components are bulky and rigid. In this section, the millimeter-wave antenna pattern measurement system using nested type MZM modulator and UTC-PD are described here. Use of nested type MZM for generating the mm-wave enables mm-wave transmission on optical fiber. Figure 3 shows system configuration for mm-wave antenna pattern measurement using nested type MZM and UTC-PD. The RF signal with the frequency up to 30 GHz modulates the optical signal at the MZM. By controlling the DC bias voltage of the modulator, 1st order harmonics is depressed and the 0 and 2nd order harmonics is enhanced. After the 0-order spectrum is attenuated by FBG, two-tone spectra whose frequency difference is quadruple of RF frequency can be generated. The modulated two-tone optical signal is amplified by optical amplifier and travels to the UTC-PD through an optical fiber. When the modulated optical signal is arrived to the UTC-PD, the mm-wave signal of the quadruple of the RF frequency is generated by optical heterodyne of two-tone optical spectra and is transmitted from the antenna.

4.3 Very-near-field antenna pattern measurement using photonic sensor [17-20]

The method of near-field antenna measurement is useful for accurate antenna pattern measurement. In the near-field antenna measurement, the amplitude and the phase of the radiated electromagnetic waves from the transmitting antenna under test are measured by a probing antenna with a vector network analyzer. The antenna pattern is calculated from the near-field electromagnetic field distribution. There are some scanning geometries in near-field antenna measurement such as plane, cylindrical and spherical [4]. The open ended wave guide probe (OEWG) is generally used for the probing antenna. In the case of use of the OEWG, to avoid the multiple reflections between antenna and OEGW probe, the distance between the antenna under test and OEWG probe should be more than tens of the wavelength. In addition, the operating bandwidth of the OEWG probe is limited by waveguide cutoff frequencies, the OEWG probe has to be change for wideband frequency measurement. Moreover, the size of the OEWG probe around 1 GHz is very huge because the size of the OEWG probe is approximately the half of the wavelength. Very-near-field antenna pattern measurement using MZM photonic sensor can solve these problems due to the OEWG probes.

Figure 3 shows the basic configuration of the very-near-field antenna pattern measurement system. These systems are mainly composed of transmitting antenna under test, a coaxial cable, an RF amplifier, a vector network analyzer, an optical fiber, a mechanical scanner and a photonic sensor.

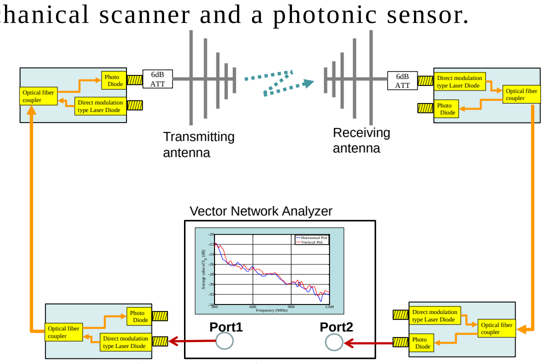

Fig. 2 System configuration of antenna gain measurement system using Rafio over fiber modules

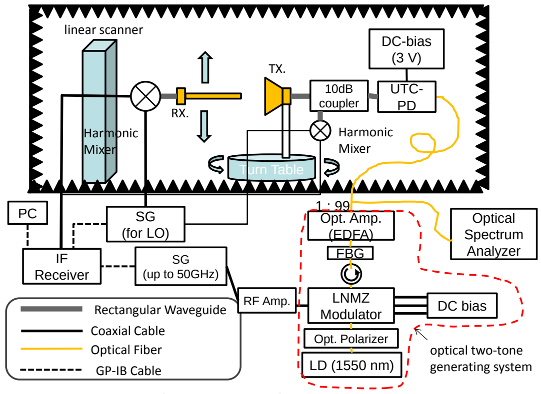

Fig. 3 System configuration for mm-wave antenna pattern measurement using nested type MZM and UTC-PD

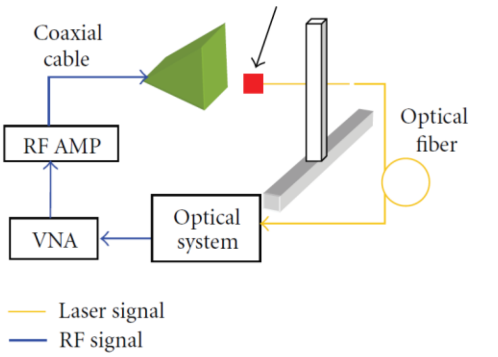

Fig. 4 System configuration of planar very-near-field antenna pattern measurement system using MZM photonic sensor

## 5. Radio Spectrum Measurement over 100 GHz using RoF Technologies [21]

The millimeter-wave band is becoming more important in next-generation wireless applications. National Committee of IEC TC103WG6 proposes to start drafting a new technical report which overviews spectrum measurement method over 100 GHz including use of radio over fiber technologies. The features of the new spectrum measurement method are high flexibility of measurement setup, low spurious and low noise performance and image free response. A combination of pre-selector and fundamental mixing is also effectively that introduced for perform these characteristics. This draft technical report shows the advantage of spectrum analyzer with RoF technologies, fundamental mixing and pre-selector

## 6. Millimeter-wave radio-over-fiber backbone for train communication network [22,23]

Millimeter-wave radio communication can provide high capacity greater than 1 Gb/s in wireless manner. Users in the high-speed train want to have multimedia streaming services including a video on demand by their smart devices. In this scenario, high-capacity wireless signal delivery as a backbone is strongly desired. National Committee of IEC TC103WG6 proposes to have discussion on preliminary work item on millimeter-wave radio-over-fiber backbone for train communication network (Fig. 5). Particularly on the high-speed train, direction center for the trains has detailed information of locations and velocities of each car. Centralized processing and control in the direction center over an optical network can realize suitable/agile signal delivery to a suitable remote site. In the remote site, as a size of signal processing functions should be smaller, a preformed radio signal is directly transmitted over the optical fiber network by a radio-over-fiber technique in millimeter-wave band. This proposal of the preliminary work item shows the technical overview, required techniques and possible implemented equipment.

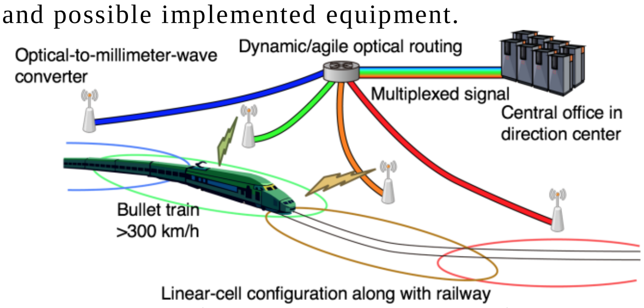


Fig. 5 Schematic of millimeter-wave radio-over-fiber backbone for high-speed trains.

### References


[1] Antao Chen & Edmond Murphy, ``Broadband optical modulators: Science, Technology, and Applications,'' CRC Press, Jan., 2012.

[2] H. Ito,T. Furuta, F. Nakajima, K. Yoshino, T. Ishibashi,``Photonic Generation of Continuous THz Wave Using Uni-Traveling-Carrier Photodiode,'' JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 23, NO. 12, Page(s): 4016-4021, DECEMBER 2005

[3] T. Ishibashi, N. Shimizu, S. Kodama, H. Ito, T. Nagatsuma, and T. Furuta, Tech.. Dig. Ultrafast Electron. And Optoelectron, pp.166-169 (1997).

[4] IEC 62801 Ed. 1.0, ``Measurement Method of a Half-Wavelength Voltage for Mach-Zehnder Optical Modulator in Wireless Communication and Broadcasting Systems,''2012-10. to be published.

[5] T. Kawanishi, K. Kogo, S. Oikawa and M. Izutsu, ``Direct measurement of chirp parameters of high-speed Mach-Zehnder-type optical modulators,'' Opt. Commun. 195, 399-404 (2001)

[6] S. Oikawa, T. Kawanishi and M. Izutsu, ``Measurement of Chirp Parameters and Halfwave Voltages of Mach-Zehnder-Type Optical Modulators by Using a Small Signal Operation," IEEE Photon. tech. lett. vol.15, no.5, may 2003.

[7] IEC 62802 Ed. 1.0,``Measurement Method of a Half -Wavelength Voltage and a Chirp Parameter for Mach-Zehnder Optical Modulator in High-Frequency Radio on Fibre (RoF) Systems,'' 2012-10. to be published.

[8] IEC 62803 Ed. 1.0,``Measurement Method of Frequency Response of O/E Conversion Devices for High-Frequency Radio on Fibre (RoF) Systems,'' 2012-10. to be published.

[9] T. Kawanishi, "Parallel Mach-Zehnder modulators for quadrature amplitude modulation", IEICE Electronics Express vol.8, no.20, pp.1678-1688, Oct., 2011.

[10] K. Inagaki, T. Kawanishi and M. Izutsu, ``Optoelectronic frequency response measurement of photodiodes by using high-extinction ratio optical modulator,'' IEICE Electronics Express, vol. 9, no.4, pp.220-226, Feb., 2012.

[11] T. Kawanishi, T. Sakamoto, A. Chiba, M. Tsuchiya and H. Toda, Ultra high extinciton-ratio and ultra low chirp optical intensity modulation for pure two-tone lightwave signal generation, CLEO2008, CFA1

[12] K. Inagaki, T. Kawanishi,`` Calibration method of optoelectronic frequency response using Mach-Zehnder modulator,'' In Proc., IEEE MWP 2010, pp. 143-146, 2010

[13] IEC 62800 Ed. 1.0, ``Radio on Fiber System conforming to different Spectral Emission Standard,'' 2012-10. to be published.

[14] S. Kurokawa, M. Hirose, M. Ameya, Y. Toba, ``Antenna Measurement by Simple Optical Link system Using Radio on Fiber Technologies,'' in Proc. EMC Tokyo 2014, May, 2014.

[15] Michitaka Ameya, Satoru Kurokawa, and Masanobu Hirose, "Millimeter-wave Antenna Pattern Measurement System Using Nested LN Modulator and UTC-PD", Proceedings of APMP2013, PB-7, April 2013.

[16] Michitaka Ameya, Masanobu Hirose, and Satoru Kurokawa, "Cylindrical near-field antenna measurement system using photonic mm-wave generation with UTC-PD", Proceedings of AMTA2013, A13-0070, pp.361-365, Oct. 2013.

[17] IEEE, “IEEE Recommended Practice for Near-field Antenna Measurements”, IEEE Std. 1720-2012, pp.1-102, Dec. 2012.

[18] A. Capozzoli, et al, “Dielectric Field Probes for Very-Near-Field and Compact-Near-Field Antenna Characterization”, IEEE Antennas and Propagation Magazine, Vol. 51, No.5, October 2009.

[19] A. Capozzoli, et al, “Photonic Probes and Advanced (Also Phase less) Near-Field Far-Field Techniques”, IEEE Antennas and Propagation Magazine, Vol. 52, No.5, October 2010.

[20] M. Hirose, S. Kurokawa, M. Ameya, K. Komiyama, “Near-Field Antenna Measurements Using Photonic Sensor of Mach-Zehnder Interferometer,'' International Journal of Antennas and Propagation, Volume 2012.

[21] M. Fuse, Y. Kimura, A. Otani, ``Over 100 GHz Millimeter-wave Spectrum Measurement System with Pre-selector,'' in Proc. IMS2014, pp.1-4, 2014

[22] A. Kanno, P. T. Dat, T. Kawanishi, S. Nobuhiko, N. Yonemoto, “90-GHz Radio-on-Radio-over-Fiber System for Linearly Located Distributed Antenna Systems,” Proc. IEEE Photon. Global, oral3-4B-3, Dec. 2012.

[23] P. T. Dat, A. Kanno, T. Kawanishi, “Energy and deployment efficiency of millimeter-wave Radio-on-Radio-over-fiber system for railways,” Proc. OFC2013, JTh2A.61, Mar. 2013.