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TECHNICAL REPORT

colour inside

Transmitting equipment for radiocommunication – Radio-over-fibre technologies for electromagnetic-field measurement – Part 1: Radio-over-fibre technologies for antenna measurement

IEC TR 63099-1:2017-08(en)

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TRANSMITTING EQUIPMENT FOR RADIOCOMMUNICATION – RADIO-OVER-FIBRE TECHNOLOGIES FOR ELECTROMAGNETIC-FIELD MEASUREMENT –

Part 1: Radio-over-fibre technologies for antenna measurement

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IEC TR 63099-1, which is a Technical Report, has been prepared by IEC technical committee 103: Transmitting equipment for radiocommunication.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
103/156/DTR	103/162/RVDTR

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

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

This document provides information on the current and latest applications for antenna measurement using radio-over-fibre technology. Antenna gain and antenna pattern measurement systems are covered, which are practically in use or will be used soon. It will be beneficial to system developers and system users in the fields of antenna measurement. As a Technical Report, this document contains no requirements and is informative only.

TRANSMITTING EQUIPMENT FOR RADIOCOMMUNICATION – RADIO-OVER-FIBRE TECHNOLOGIES FOR ELECTROMAGNETIC-FIELD MEASUREMENT –

Part 1: Radio-over-fibre technologies for antenna measurement

1 Scope

The purpose of this document is to provide information about the current and latest applications for antenna measurement that use radio-over-fibre technologies. Antenna gain and the antenna radiation pattern measurement system are covered, which are practically in use and will be used soon. Basic concepts, system configurations and measurement examples of the systems are included. The theoretical background of antenna measurement is beyond the scope of this document.

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.

IEEE Std. 145-2013, *IEEE Standard for Definitions of Terms for Antennas*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEEE Std. 145-2013 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
Mach-Zehnder modulator
optical modulator used for controlling the amplitude of an optical wave

3.1.2
UTC-PD
uni-travelling-carrier photo-diode
high-speed photo-diode that can generate millimeter-wave and THz wave

3.1.3
log-periodic dipole array antenna
LPDA antenna
antenna having wideband characteristics due to logarithmic periodically aligned dipole elements

3.1.4
fibre Bragg grating
FBG
optical filter that is used as inline filter to block certain wavelengths, or as wavelength-specific reflectors

3.1.5
OEWG probe
open-ended waveguide probe
low gain antenna made with rectangular waveguide transmission line for measuring electromagnetic fields with near-field antenna measurement system

3.2 Abbreviated terms

LN-MZM	lithium niobate Mach-Zehnder modulator
UTC-PD	uni-travelling-carrier photo-diode
LPDA	log-periodic dipole array
FBG	fibre Bragg grating
OEWG	open-ended waveguide

4 Practical applications

4.1 List of applications

The following list shows the application examples of antenna measurement using RoF technology:

a) antenna gain measurement system using a radio-over-fibre transceiver, described in 4.2;
b) millimetre-wave antenna pattern measurement system using a nested type LN-MZM and UTC-PD, described in 4.3;
c) very-near-field antenna pattern measurement system using an LN-MZM photonic sensor, described in 4.4.

4.2 Antenna gain measurement system using a radio-over-fibre transceiver

4.2.1 Overview

There are a few types of antenna gain measurement methods, such as the substitution method, the two-antenna method, and the three-antenna method. These methods have in common the basic configuration of one vector network analyser and two antennas with coaxial cables. By measuring the S-parameters between the two antennas, the antenna gain is calculated.

The distance between antennas and the height of 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 metres in some cases. Because coaxial cables are made from metal, they reflect and reradiate the electromagnetic waves from the antennas. Therefore, coaxial cables increase the uncertainty of the measurement system and may give inaccurate results. Antenna gain measurement system using a radio-over-fibre transceiver can solve these coaxial cable problems.

4.2.2 Features

The features of an antenna gain measurement system using a radio-over-fibre transceiver are the following:

- the optical fibre does not reflect electromagnetic waves radiated from the antennas;

- surface currents never flow on the optical fibre cable, even if the mismatch between the antenna and the cable is large;
- the system has cost advantages because the replacement cost of the optical fibre is lower than that of the coaxial cable of the same length.

4.2.3 System configuration

Figure 1 shows the system configuration of the antenna gain measurement system using radio-over-fibre transceivers. This system is composed of a transmitting antenna, a receiving antenna, two 6-dB attenuators, two pairs of radio-over-fibre transceivers, two single-mode optical fibres, and a vector network analyser.

Figure 2 shows the system configuration of the antenna gain measurement system using bi-directional type radio-over-fibre transceivers. This system is composed of a transmitting antenna, a receiving antenna, two pairs of bi-directional type radio-over-fibre transceivers, two single-mode optical fibres, and a vector network analyser.

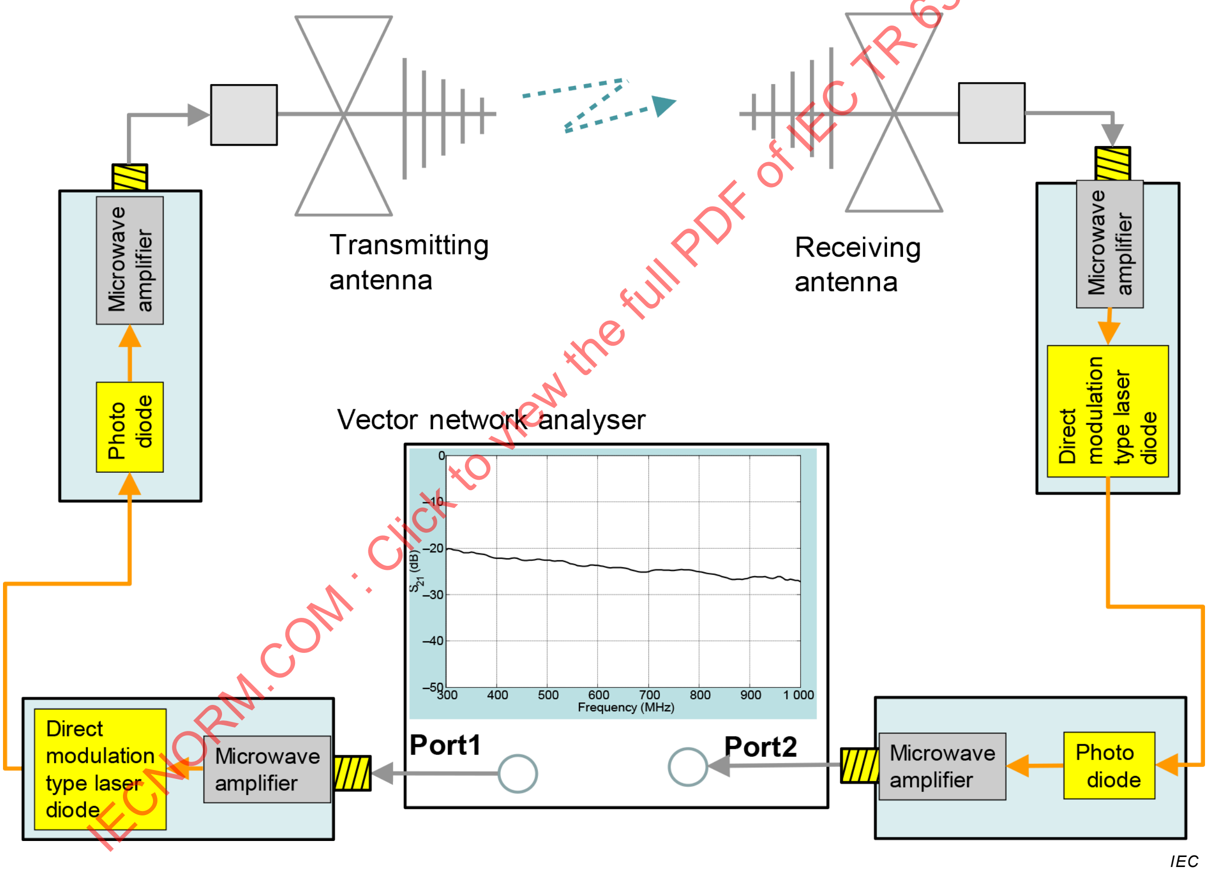

Figure 1 – System configuration of antenna gain measurement system using a radio-over-fibre transceiver

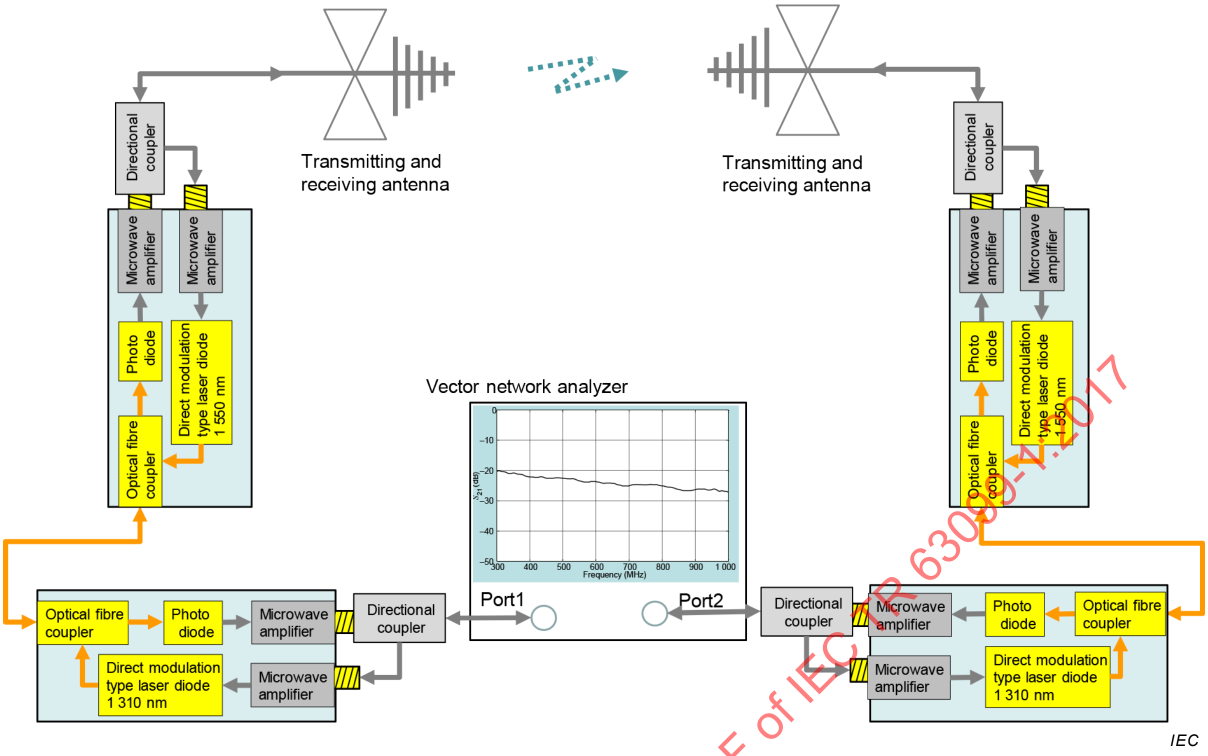

Figure 2 – System configuration of antenna gain measurement system using bi-directional type radio-over-fibre transceiver specifications

Table 1 shows the specifications of the radio-over-fibre transceiver used in the antenna gain measurement system. Figure 3 shows the appearance of a pair of radio-over-fibre transceivers.

Table 1 – Specification of a radio-over-fibre transceiver

Parameter		Minimum	Typical	Maximum	Unit	Note
Optical	Operating wavelength	1 530	1 550	1 570	nm	
	Output power	1	2	4	mW	Class 3B
	Optical return loss	40			dB	
RF Channel	Modulation bandwidth	40		6 000	MHz	
	Flatness (Tx)		12	15	dB	
	Flatness (Rx)		6	9	dB	
	RF return loss (Tx)	8	9		dB	
	RF return loss (Rx)	8	9		dB	
	1 dB compression level	−13	−10		dBm	at 1 GHz
	Output IP3	8	11		dBm	at 1 GHz
	Input damage level	20			dBm	
	RF link gain	7	10	13	dB	Optical loss 0 dB at 1 GHz
	Noise figure		17	20	dB	at 1 GHz
General	Power supply (Tx and Rx)	5 V, 300 mA max.				
	Battery drive time	Typ. 7 h (AA battery × 3)				
	Input/output optical connector	SC/PC				
	Input/output RF connector	N-P 50 ohm				
	Operating temperature	0 to 40			°C	
	Storage temperature	−20 to 60			°C	
	Fibre used	SMF/1port				
	Dimensions	93 × 51 × 45			mm	

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Figure 3 – Appearance of a pair of radio-over-fibre transceivers

4.2.4 Example of measurement results

Figure 4 shows the $S_{21}(\omega)$ measurement result of two log-periodic dipole array antennas (LPDA) of type UHALP9108A1 by Schwarzbech Mess Elektronik OHG[1] using the Figure 1 setup with a 3 m antenna distance. In order to determine the antenna gain, the frequency domain receiving signal $S_{21}(\omega,z)$ is shown in Equation (1) using the Friis transmission formula as

$$\left|S_{21}(\omega,z)\right|^2 = M_1 M_2 \left(\frac{\lambda}{4\pi z}\right)^2 G_{TX}(\omega)\cdot G_{RX}(\omega) \tag{1}$$

where $G_{TX}(\omega)$ and $G_{RX}(\omega)$ are the antenna gains of the transmitting and receiving antennas, respectively. ω is the frequency, λ is the wave length, M_i = (1-$|\Gamma_i(\omega)|^2$), (i = 1,2) is an antenna mismatch loss. The antenna gain can then be obtained by the following equation:

$$\left|S^{21}{}_{21}(\omega,z)\right|^2 = M_1 M_2 \left(\frac{\lambda}{4\pi z}\right)^2 G_1(\omega)\cdot G_2(\omega)$$

$$\left|S^{32}{}_{21}(\omega,z)\right|^2 = M_2 M_3 \left(\frac{\lambda}{4\pi z}\right)^2 G_2(\omega)\cdot G_3(\omega)$$

$$\left|S^{13}{}_{21}(\omega,z)\right|^2 = M_3 M_1 \left(\frac{\lambda}{4\pi z}\right)^2 G_3(\omega)\cdot G_1(\omega) \tag{2}$$

1 UHALP9108A1 is an example of a suitable product supplied by Schwarzbech Mess Elektronik OHG. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

$$G_i(\omega) = \frac{1}{M_i}\left(\frac{4\pi z}{\lambda}\right)\sqrt{\frac{\left|S^{ij}{}_{21}(\omega,z)\right|^2 \left|S^{ki}{}_{21}(\omega,z)\right|^2}{\left|S^{jk}{}_{21}(\omega,z)\right|^2}}$$

where G_i is the antenna gain of the antenna i and (i, j, k) is a permutation of (1, 2, 3) indicating the three antennas. Figure 5 shows the estimated antenna gain using Equation (2) and phase centre distance = z of LPDA.

Figure 6 shows the $S_{21}(\omega)$ measurement result of a two log-periodic dipole array with a bow-tie antenna of type VULB9160 by Schwarzbech Mess Elektronik OHG[2] using the Figure 2 setup with a 3 m antenna distance.

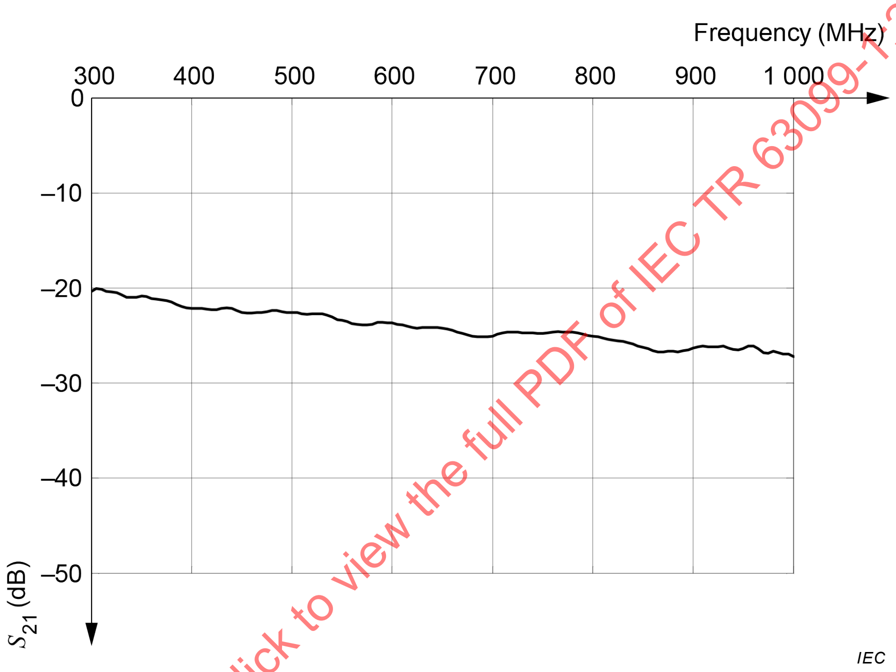


Figure 4 – $S_{21}(\omega)$ measurement result of two LPDAs

2 VULB9160 is an example of a suitable product supplied by Schwarzbech Mess Elektronik OHG. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

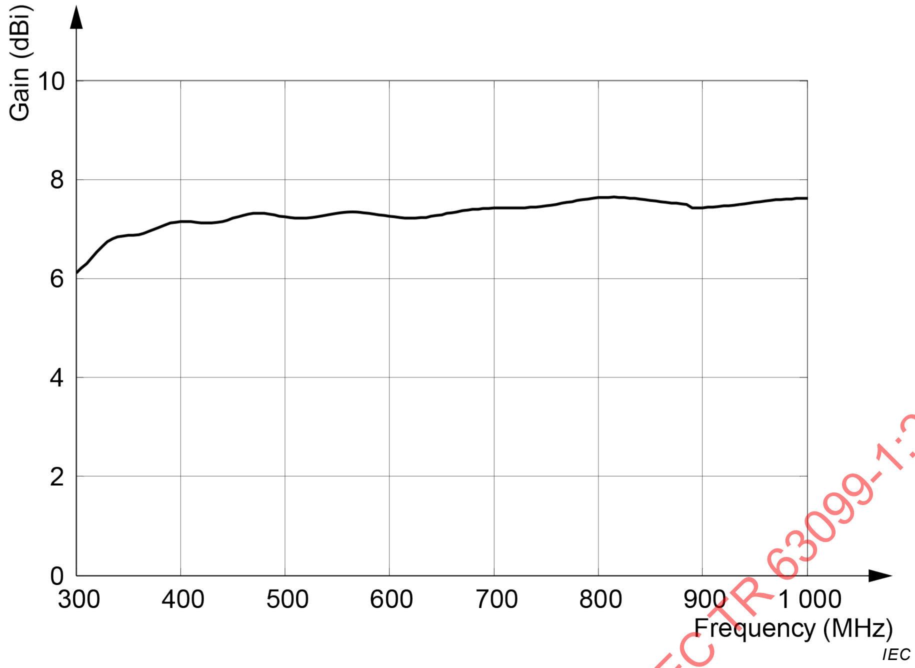
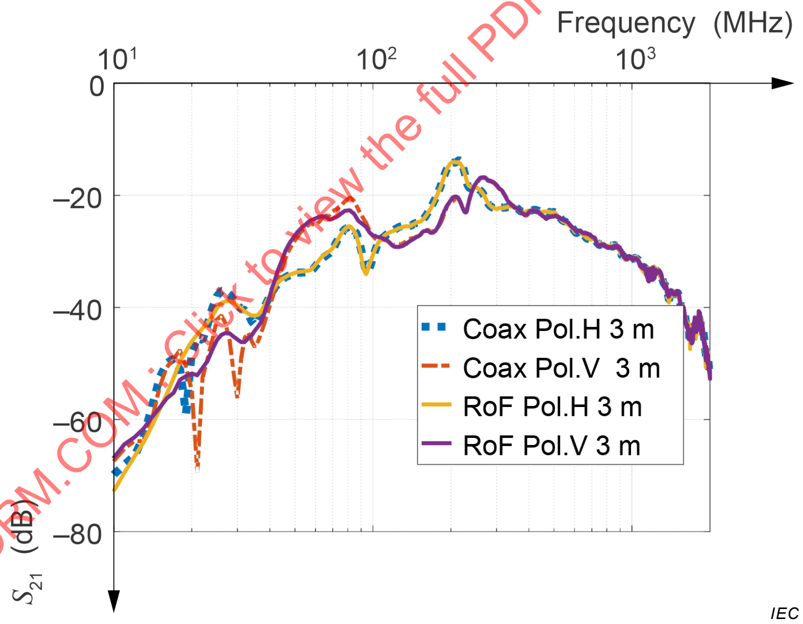


Figure 5 – Measurement gain of LPDA using a radio-over-fibre transceiver



"Coax Pol. H 3 m" and "Coax Pol. V 3 m" indicate the results using coaxial cables at horizontal polarization and vertical polarization, respectively.

"RoF Pol. H 3 m" and "RoF Pol. V 3 m" indicate the results using bi-directional type radio-over-fibre transceivers at horizontal polarization and vertical polarization, respectively.

Figure 6 – $S_{21}(\omega)$ measurement result of two VULB9160s

4.3 Millimetre-wave antenna pattern measurement system using a nested type LN-MZM and a UTC-PD

4.3.1 Overview

Millimetre-wave technology is very important for high-speed wireless communication and radar applications. In particular, 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 many waveguide components and are very expensive. In addition, it is difficult to design the movable mechanical system because the waveguide components are bulky and rigid.

The millimetre-wave antenna pattern measurement system using a nested type LN-MZM and a UTC-PD is explained in 4.3.4. Use of a nested type LN-MZM for generating the mm-wave enables mm-wave transmission through an optical fibre.

4.3.2 Features

The features of a mm-wave antenna pattern measurement system using the nested type LN-MZM and UTC-PD are the following:

- one quarter of the frequency of the mm-wave is enough for the RF signal generator because the nested LN-MZM can operate as a quadruple multiplier,
- the system can reduce the size of the equipment around the transmitting antenna and can minimize the effect of reflection from the equipment,
- the optical fibre is useful for pattern measurement using a rotational mechanism because the optical fibre is lightweight and easy to handle.

4.3.3 System configuration

Figure 7 shows the system configuration of the mm-wave antenna pattern measurement system using a nested type LN-MZM and a UTC-PD. The RF signal with the frequency up to 30 GHz modulates the optical signal at the MZ-LN modulator. By controlling the DC bias voltage of the modulator, 1st order harmonics are suppressed and the 0 and 2nd order harmonics are enhanced. After the 0-order spectrum is attenuated by an FBG, a two-tone spectrum with lines that have a frequency difference of quadruple the RF frequency can be generated. The two-tone optical signal is amplified by an optical amplifier and travels to the UTC-PD through an optical fibre. When the modulated optical signal arrives at the UTC-PD, the mm-wave signal of quadruple the RF frequency is generated by the optical heterodyne of the two-tone optical signal and is transmitted from the antenna. Figure 8 shows the appearance of the mm-wave antenna pattern measurement system using a nested type LN-MZM and a UTC-PD. Figure 9 shows the appearance of the mm-wave transmitting part of the system.

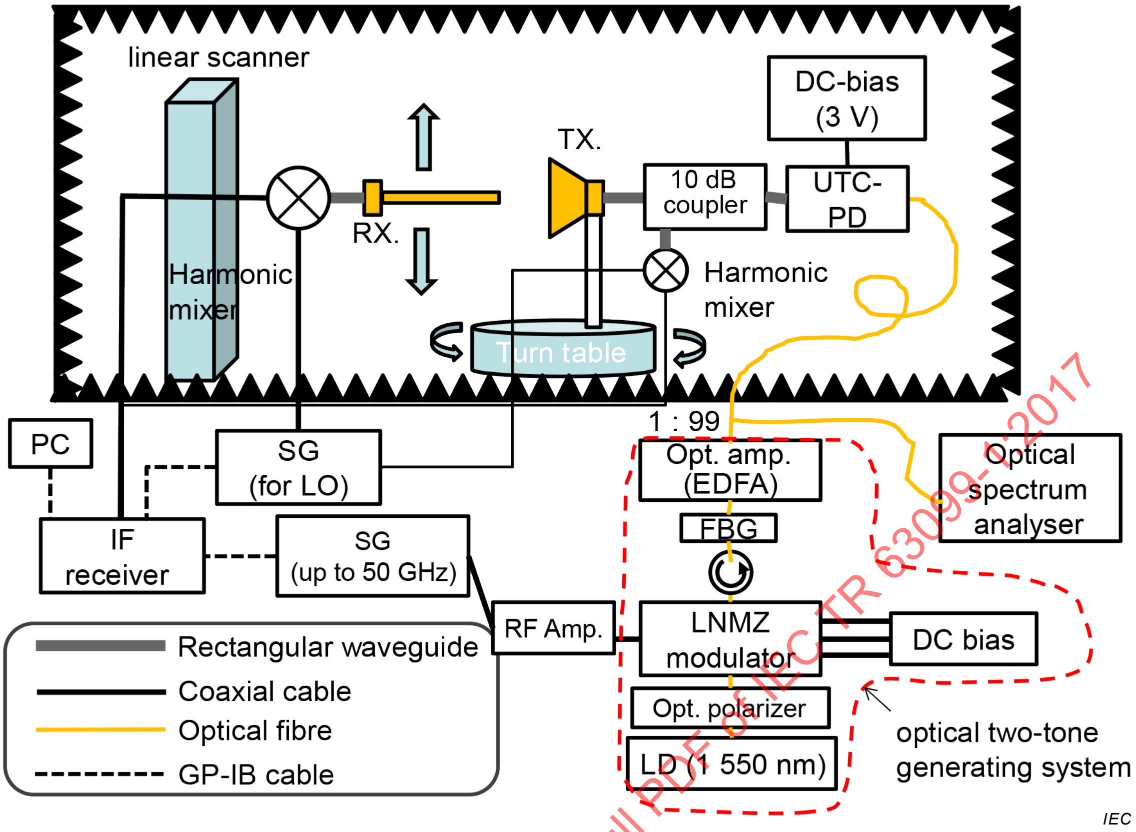


Figure 7 – System configuration for mm-wave antenna pattern measurement system using nested type LN-MZM and UTC-PD

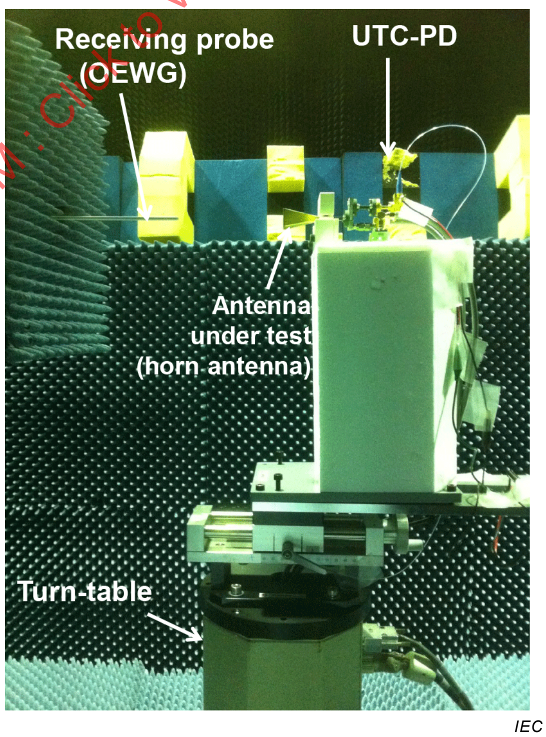


Figure 8 – Appearance of mm-wave antenna pattern measurement system using nested type LN-MZM and UTC-PD

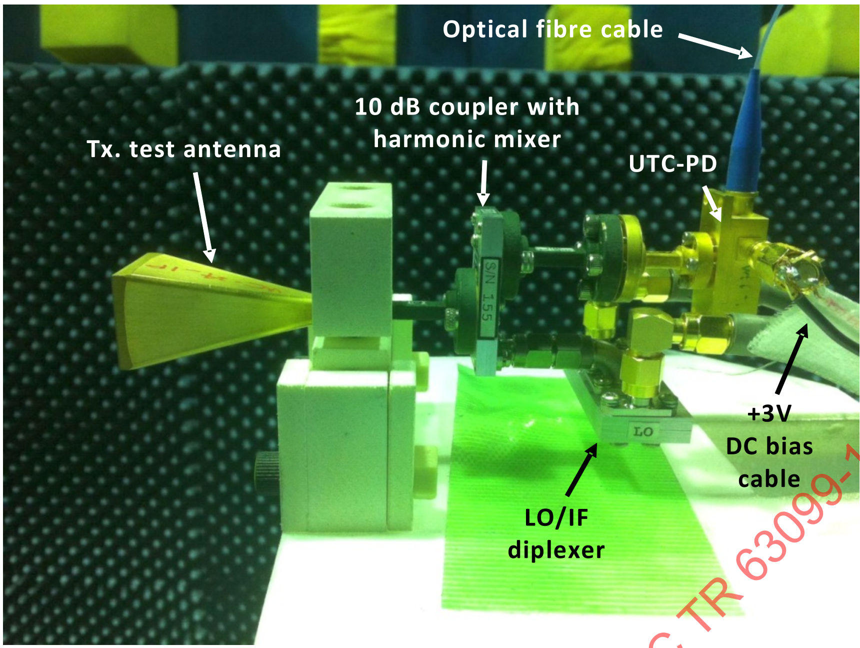


Figure 9 – Appearance of mm-wave transmitting part of mm-wave antenna pattern measurement system using nested type LN-MZM and UTC-PD

4.3.4 Specifications

Table 2 and Table 3 show the specifications of an LN-MZM and a UTC-PD, respectively.

Table 2 – Specification of an LN-MZM

Parameter	Specification
Operating wavelength	1 550 nm
Insertion loss	≤ 9,0 dB
Optical bandwidth	≥ 20 GHz
ON/OFF extinction ratio	≥ 20 dB
Driving voltage at 1 kHz	DC Port A ≤ 5,0 V, DC Port B ≤ 5,0 V, DC Port C ≤ 15,0 V
Driving voltage ($V\pi$) at 20 Gbps	RF Port A ≤ 4,0 V
Polarization extinction ratio	≥ 20 dB
Optical return loss	≥ 30 dB
Maximum input power	20 mW
Electrical connector	GPPO connector
Optical fibre (input)	0,4 mm Φ PMF LC connector
Optical fibre (output)	0,4 mm Φ SMF LC connector
Fibre lead length	≥ 0,7 m
Operating temperature	0 °C to 70 °C
Polarizer	Included

Table 3 – Specification of a UTC-PD

Parameter	Specification
Operating frequency	75 GHz to 110 GHz
Output power	−5,0 dBm (typical), −8,0 dBm (minimum)
RF output connector	Waveguide connector (WR-10)
Optical input connector	SC
Optical fibre	PMF

4.3.5 Example of measurement results

Figure 10 shows the dynamic range of the mm-wave antenna pattern measurement system using a nested LN-MZM modulator and a UTC-PD. From the figure, the dynamic range of the system is approximately 80 dB in the frequency range of 75 GHz to 110 GHz. Figure 11 shows an E-plane antenna radiation pattern of a W-band standard gain horn antenna at 120 GHz measured by the proposed system.

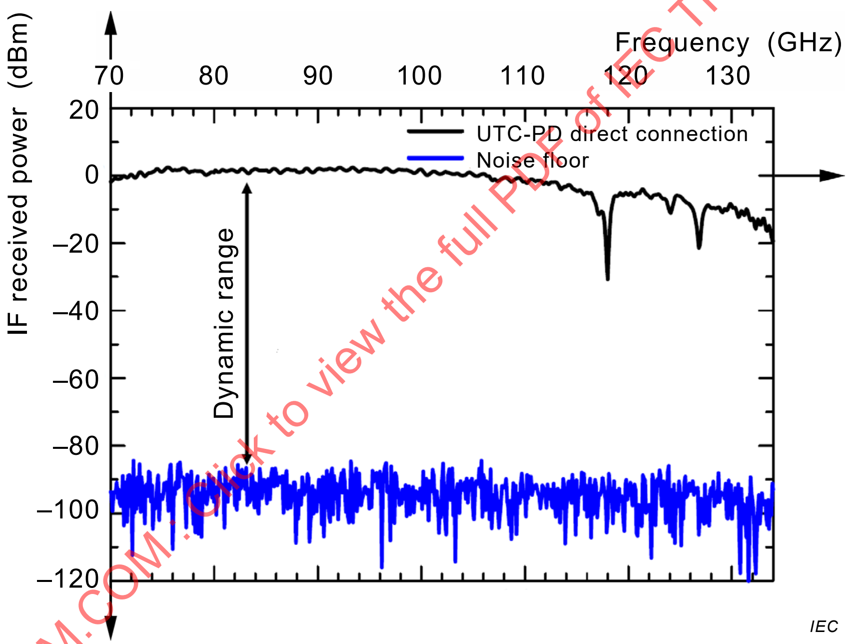


Figure 10 – Frequency characteristics and dynamic range of system using a nested LN-MZM modulator and a UTC-PD

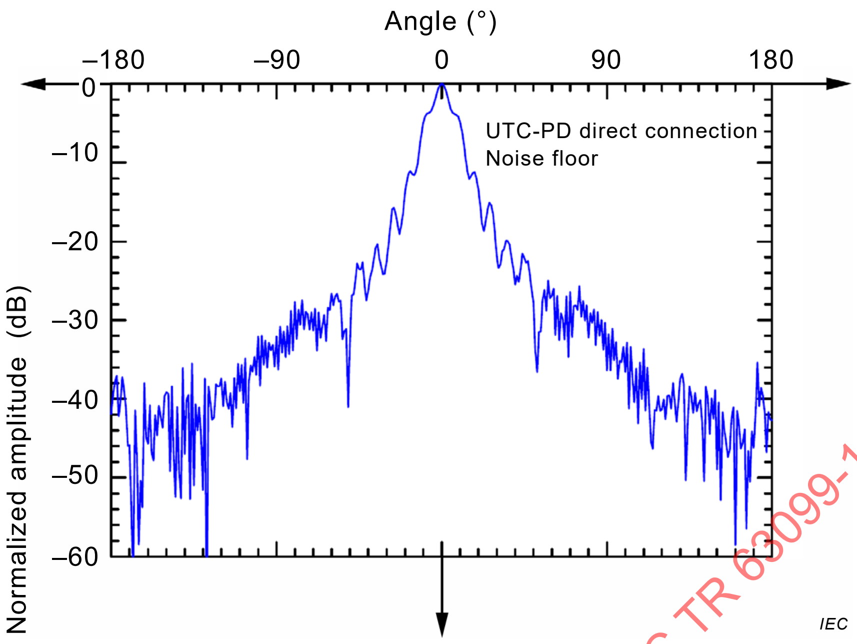


Figure 11 – Measured antenna radiation pattern in the E-plane at 120 GHz

4.4 Very-near-field antenna pattern measurement using a photonic sensor

4.4.1 Overview

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 analyser. The antenna pattern is calculated from the near-field electromagnetic-field distribution. There are different scanning geometries in near-field antenna measurement such as planar, cylindrical and spherical [4][3]. The open-ended waveguide probe (OEWG) is generally used for the probing antenna. When using the OEWG, to avoid multiple reflections between the antenna and the OEGW probe, the distance between the antenna under test and the OEWG probe should be more than ten times the wavelength. In addition, the operating bandwidth of the OEWG probe is limited by waveguide cut-off frequencies, and the OEWG probe has to be changed for wideband frequency measurement. Moreover, the size of the OEWG probe around 1 GHz is very large because the size of the OEWG probe is approximately half of the wavelength.

The very-near-field antenna pattern measurement using an LN-MZM photonic sensor is explained in 4.4. This system can solve the problems due to the OEWG probes.

4.4.2 Features

Features of a very-near-field antenna pattern measurement system using an LN-MZM photonic sensor are the following:

- no probe compensation is required below 8 GHz;
- broad band measurements from a few tens of MHz to 10 GHz are realized by the single probe;
- the photonic sensor can be treated as the more ideal infinitesimal receiving antenna if the operating frequency becomes lower;

3 Numbers in square brackets refer to the Bibliography.

- the system can be small and compact;
- the mechanical stress for the scanner is small because the photonic sensor is very lightweight.

4.4.3 System configuration

Figure 12, Figure 13 and Figure 14 show the basic configuration of the very-near-field antenna pattern measurement system. These systems are mainly composed of a transmitting antenna under test, a coaxial cable, an RF amplifier, a vector network analyser, an optical fibre, a mechanical scanner and a photonic sensor. Figure 15 shows the appearance of a planar very-near-field antenna pattern measurement system using an LN-MZM photonic sensor. Figure 16 shows the layout of the photonic sensor using an LN-MZM modulator.

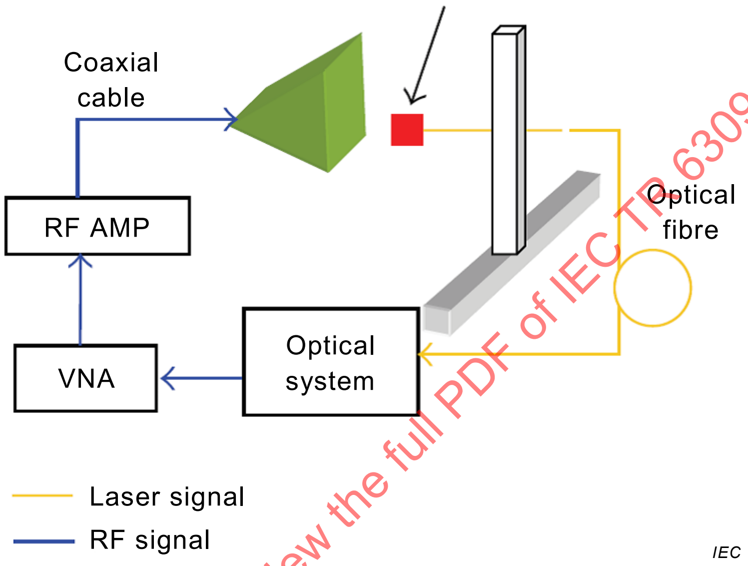


Figure 12 – System configuration of planar very-near-field antenna pattern measurement system using a photonic sensor

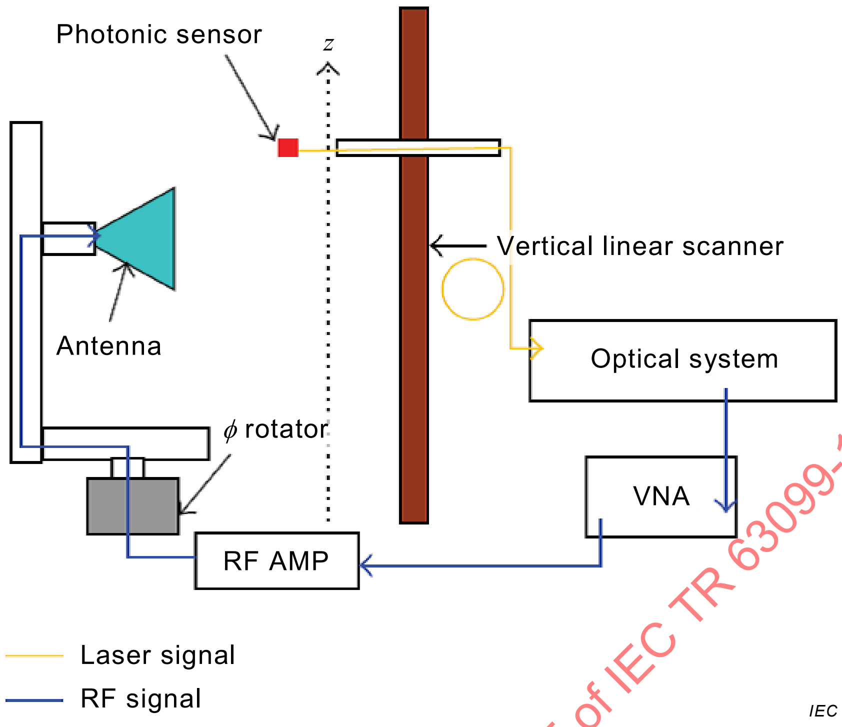


Figure 13 – System configuration of cylindrical very-near-field antenna pattern measurement system using a photonic sensor

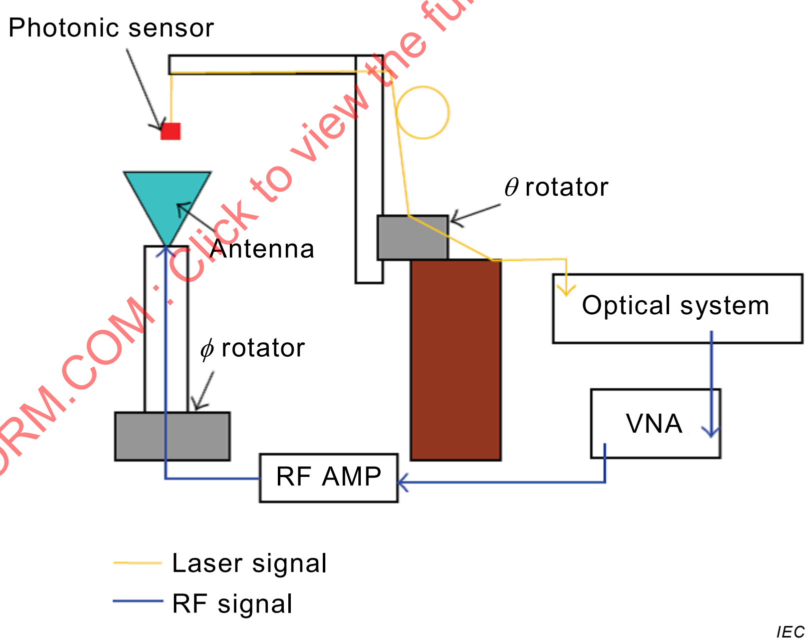


Figure 14 – System configuration of spherical very-near-field antenna pattern measurement system using a photonic sensor

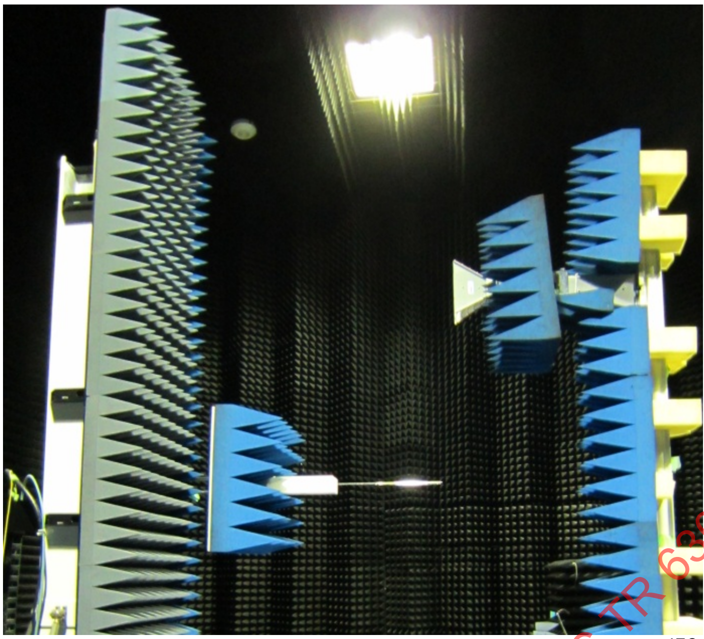


Figure 15 – Appearance of very-near-field antenna pattern measurement system using an LN-MZM photonic sensor

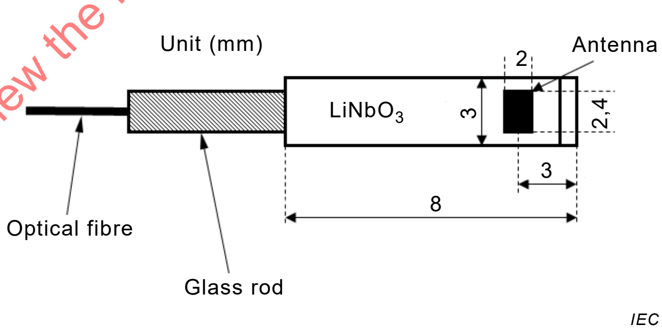


Figure 16 – Photonic sensor using an LN-MZM

4.4.4 Specifications

Table 4 shows the specifications of an LN-MZM photonic sensor for a near-field antenna measurement system.