IEC TR 63099-2

Edition 1.0 2020-07

TECHNICAL REPORT

colour inside

Transmitting equipment for radiocommunication – Radio-over-fibre technologies for electromagnetic-field measurement – Part 2: Radio-over-fibre technologies for electric-field sensing

IEC TR 63099-2:2020-07 (en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC TR 63099-2

Edition 1.0 2020-07

TECHNICAL REPORT

colour inside

Transmitting equipment for radiocommunication – Radio-over-fibre technologies for electromagnetic-field measurement –
Part 2: Radio-over-fibre technologies for electric-field sensing

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.060.20; 33.180.99

ISBN 978-2-8322-8493-3

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

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

Part 2: Radio-over-fibre technologies for electric-field sensing

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63099-2, 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:

Draft TR	Report on voting
103/184/DTR	103/186A/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.

A list of all parts in the IEC 63099 series, published under the general title *Transmitting equipment for radiocommunication – Radio-over-fibre technologies for electromagnetic-field measurement*, can be found on the IEC website.

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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This document provides information on the current and latest applications for electric-field sensing using radio-over-fibre technology. Electric-field 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 electric-field 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 2: Radio-over-fibre technologies for electric-field sensing

1 Scope

The purpose of this part of IEC 63099 is to provide information about the current and latest applications for electric-field measurement that use radio-over-fibre technologies. System configurations, specifications, and measurement examples of each electric-field measurement system are included. The theoretical background of electric-field measurement and calibration method of electric-field sensors are 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
O/E converter
optical to electrical converter
converter which directly converts optical signals into electrical signal

Note 1 to entry: A photo-diode is generally used as an O/E converter device

3.1.2
isotropy
uniform sensitivity for all spherical direction

Note 1 to entry: Sometimes it is misunderstood as equivalence of each axis sensor of 3-axis.

3.1.3
TEM-Cell
transverse electromagnetic field cell waveguide which can generate a certain level of uniform electric-fields in the cell

3.2 Abbreviated terms

DUT	device under test
EO	electro-optic
LD	laser diode
LN	lithium niobate
LNA	low noise amplifier
O/E	optical to electrical
OMI	optical modulation index
PD	photodiode
PMF	polarization maintaining fibre
P1dB	1 dB power compression point
SMF	single-mode fibre
TEM	transverse electromagnetic-field
TIA	transimpedance amplifier
VCSEL	vertical cavity surface emitting laser

4 Practical examples of electric-field sensing system using RoF technologies

4.1 Overview

A lot of electric-field sensing systems using RoF technology are proposed. This document introduces the system configuration, specifications, examples of measurement results of typical electric-field sensing systems which are already commercialized.

4.2 Features of electric-field sensing system using RoF technologies

Electric-field sensing systems using RoF technologies have many features as follows:

- minimal-invasiveness to electric-field;
- electrical smallness;
- good isotropy;
- high linearity.

4.3 List of implementation examples

The following list shows the examples of implementation of electric-field measurement systems using RoF technology:

a) 3-axis electric-field sensor using LN optical modulators, described in 4.4;

b) bulk-type electric-field sensor using ZnTe optical modulators, described in 4.5;

c) electric-field probes using VCSEL, described in 4.6.

4.4 3-axis electric-field sensor using LN optical modulators

4.4.1 System configuration

Figure 1 shows the system configuration of the 3-axis electric-field sensor using an LN optical modulator. The sensor consists of a sensor head, controller, single-mode optical fibres for signal transfer, and a spectrum analyser for signal analysis. Figure 2 shows the structure of the sensor head. It uses an LN optical modulator, in which antenna elements are formed on the crystal substrate. These three LN optical modulators are arranged onto the three sides of a triangle prism, obtaining isotropy [1][1]. In other words, the three LN optical modulators are arranged so that they are at right angles to each other, and their maximum radiation angle from the optical waveguide is 54,7°, thus achieving isotropy. The controller consists of an optical source, optical circulator, optical switch, O/E converter, and control circuit. Un-modulated light emitted from the optical source passes through the optical circulator and optical switch, and is guided to the sensor head. The LN optical modulator on each axis is selected by the optical switch, and the light, which has been intensity-modulated via a spatial electric-field, returns to the optical circulator, and is guided to the O/E converter. It is possible to measure the output on each axis after O/E conversion with a spectrum analyser and measure the electric-field strength E by applying the following formula.

$$E = \sqrt{E_{\mathrm{x}}^2 + E_{\mathrm{y}}^2 + E_{\mathrm{z}}^2} \qquad (1)$$

where E_{x} is the electric-field strength on the X axis; E_{y} is the electric-field strength on the Y axis; and E_{z} is the electric-field strength on the Z axis.

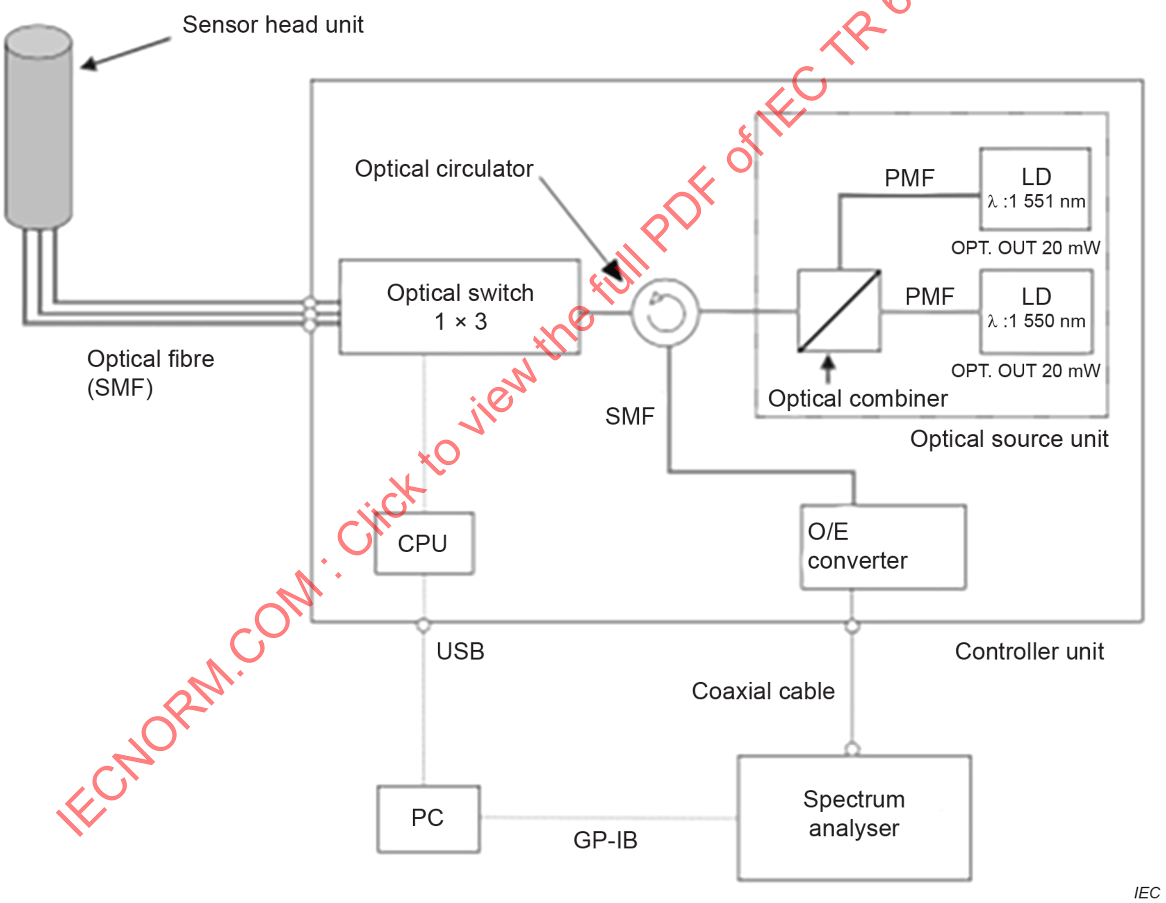

Figure 1 – System diagram of the optical E-field sensor

1 Numbers in square brackets refer to the bibliography.

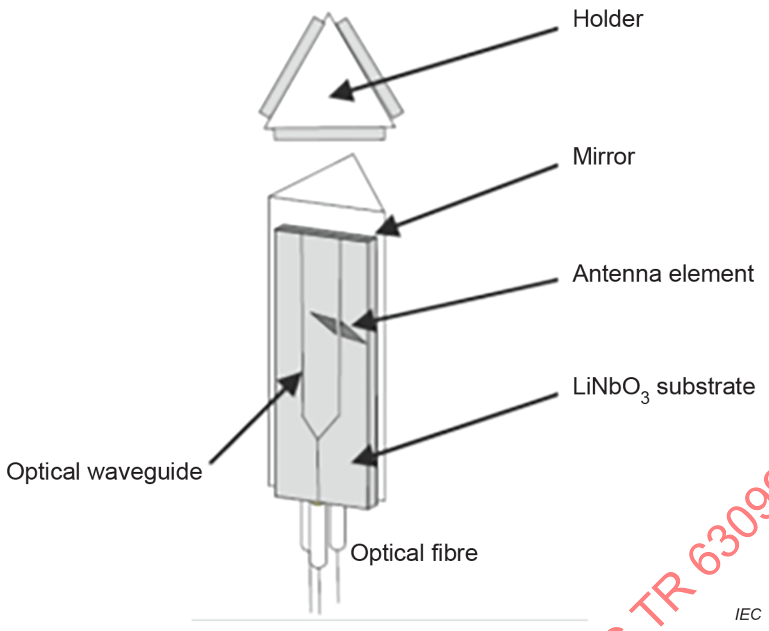

Figure 2 – Structure of the sensor head unit

4.4.2 Specifications

Table 1 shows the specifications of a 3-axis electric-field sensing system using the LN optical modulator models SH-03EX and SH-10EX of Seiko Giken Co. Ltd[2]. Figure 3 shows the appearance of the 3-axis electric-field sensing system.

Table 1 – Specification of 3-axis electric-field sensing system using LN optical modulator

<table>
<tr><th colspan="3" rowspan="2">Item</th><th colspan="4">Specification</th><th rowspan="2">Remarks</th></tr>
<tr><th>Minimum</th><th>Type</th><th>Maximum</th><th>Unit</th></tr>
<tr><td rowspan="2">Frequency range</td><td colspan="2">SH-03EX</td><td>0,1</td><td></td><td>3 000</td><td rowspan="2">MHz</td><td rowspan="2"></td></tr>
<tr><td colspan="2">SH-10EX</td><td>0,1</td><td></td><td>10 000</td></tr>
<tr><td rowspan="4">Measurement E-field strength</td><td rowspan="2">SH-03EX</td><td>< 300 MHz</td><td>0,06</td><td></td><td rowspan="2">100</td><td rowspan="4">V/m</td><td rowspan="4">S/N when minimum input: ≥ 6 dB at 301 MHz
(RBW: 10 Hz,VBW: 1 Hz)</td></tr>
<tr><td>≥ 300 MHz</td><td>0,002</td><td></td></tr>
<tr><td rowspan="2">SH-10EX</td><td>< 300 MHz</td><td>0,3</td><td></td><td rowspan="2">500</td></tr>
<tr><td>≥ 300 MHz</td><td>0,01</td><td></td></tr>
<tr><td rowspan="2">Isotropic</td><td colspan="2">SH-03EX</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">±1</td><td rowspan="2">dB</td><td rowspan="2">Impressed E-field strength:
6 V/m at 301 MHz</td></tr>
<tr><td colspan="2">SH-10EX</td></tr>
</table>

2 SH-03EX and SH-10EX of Seiko Giken Co. Ltd are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of these products.

IEC

Figure 3 – 3-axis electric-field sensing system using LN optical modulator

4.4.3 Example of measurement results

4.4.3.1 Evaluation of sensitivity and measurement dynamic range

Figure 4 shows the measurement results of the sensor's output signal relative to electric-field strength at an applied electric-field frequency of 300 MHz. The minimum detected electric-field strength is 80 dBμV/m (= 10 mV/m). Meanwhile the maximum measurement electric-field strength of the sensor is determined by linearity of the LN optical modulator and the final amplification in the O/E converter. Linearity of the LN optical modulator has been confirmed to pose no problems if the optical modulation index (OMI) is no more than 28 %. From these measurements, the optical modulation index (OMI) at an applied electric-field strength of 120 dBμV/m (= 1 V/m) was calculated as 0,001 7 % (output signal from controller of −77,8 dBm and amplifier gain at final stage of O/E converter of 36 dB) by the following Equation (2), and the applied electric-field strength at which optical modulation index is 28 % is 204,3 dBμV/m.

$$OMI = \left(\frac{V_{\mathrm{pp}}}{V_{\pi}} \right) \times 100 [\%] \qquad (2)$$

where V_{pp} is the driving voltage (peak to peak voltage) and V_{π} is the half-wavelength voltage.

The 1 dB compression (P1dB) of the final amplifier in the O/E converter is +10 dBm, and its impact can be ignored. In other words, the maximum measurement electric-field strength is dominated by the sensor head, which means that the measurement range is 80 dBμV/m to 204 dBμV/m (≅ 15 kV/m), achieving an extremely broad measurement dynamic range that greatly surpasses the target value. It should also be possible to measure even stronger fields by optimizing the antenna element length and modulation electrode length.

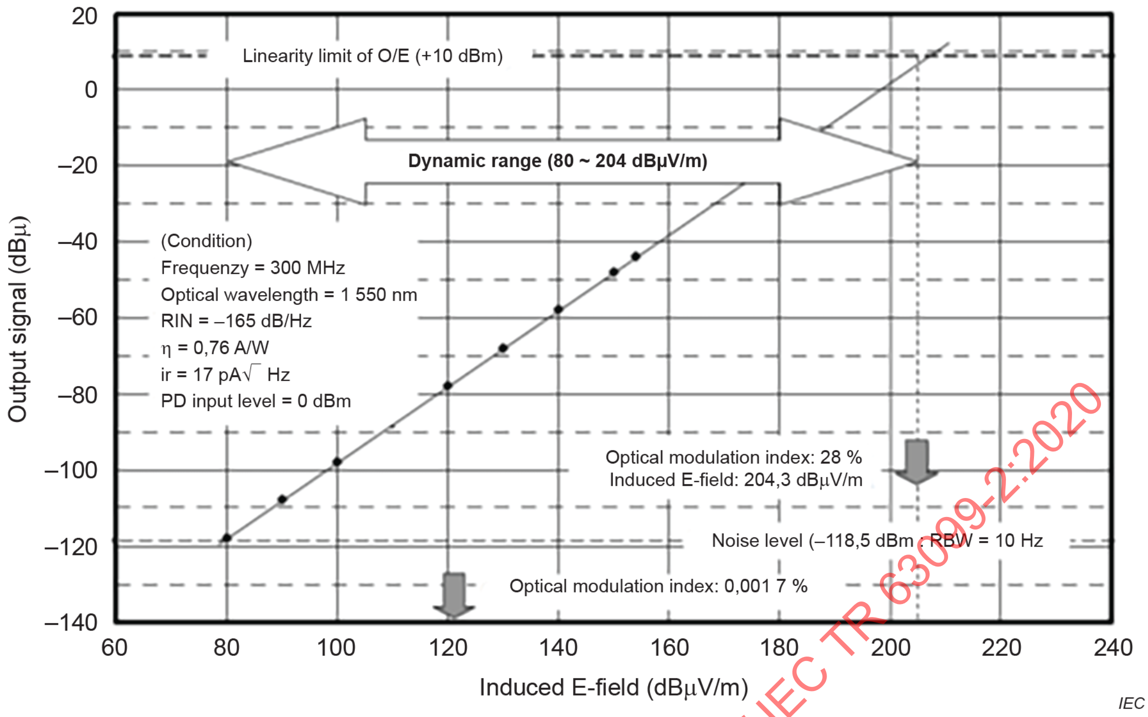

Figure 4 – Evaluation results of sensitivity and measurement dynamic range

4.4.3.2 Evaluation of sensor isotropy up to 1 GHz

The isotropy of the 3-axis electric-field sensor was evaluated using LN optical modulators in a TEM-Cell in the frequency range from 100 MHz to 1 GHz. The sensor was arranged in the TEM-Cell, and the sensor head was rotated in the direction of the applied electric-field to evaluate the isotropy as shown in Figure 5. The applied electric-field frequency was from 100 MHz to 1 GHz, and the signal input intensity to the TEM-Cell was about +30 dBm. At this time, according to the formula for calculating the electric-field strength within the TEM-Cell [3], the electric-field strength at the position where the electric-field sensor is, was estimated to be 155 dBμV/m.

Table 2 shows the evaluation results of the isotropy of the sensor in the frequency of 100 MHz, 300 MHz and 1 000 MHz. The isotropy of no more than ±0,47 dB was obtained.

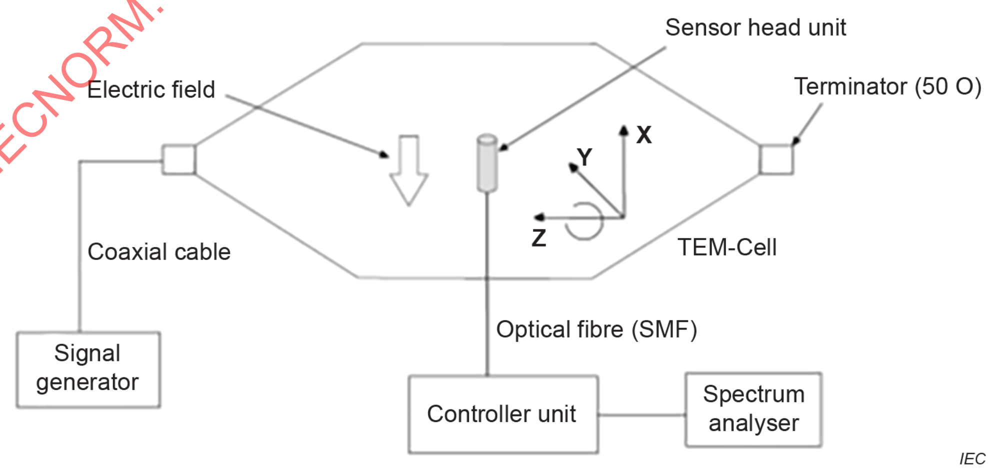

Figure 5 – Evaluation of sensor isotropy in the TEM-Cell up to 1 GHz

Table 2 – Specification of 3-axis electric-field sensing system using LN optical modulator

Frequency (MHz)	100	300	1 000
Isotropy (dB)	±0,42	±0,47	±0,3

4.4.3.3 Evaluation of sensor isotropy above 1 GHz up to 6 GHz and comparison with conventional diode-type electric-field sensor

The isotropy of the electric-field sensors was evaluated according to IEEE Std. 1309 and the isotropy in the frequency from 1 GHz to 6 GHz was compared between the conventional diode-type electric-field sensor and the electric-field sensor using an LN optical modulator [4]. Figure 6 shows the measurement setup for isotropy evaluation of each electric-field sensor. An electric-field in the range of 10 V/m to 40 V/m was applied to those sensors.

Figure 7 shows the sensitivity pattern of each sensor at 1 GHz and 6 GHz. In the frequency of 1 GHz, the 3-axis composite electric-field strength calculated by Equation (1) for both sensors has a small variation with respect to angle. On the other hand, in the frequency of 6 GHz, the 3-axis composite electric-field strength of the conventional diode-type electric-field sensor has a large variation of about 8 dB. This means that the isotropy of the conventional electric-field sensor is ±4 dB at the frequency of 6 GHz. Figure 8 shows the frequency characteristics of isotropy of those sensors. From this figure, the maximum difference of the electric-field sensor using an LN optical modulator is less than 2 dB (which means ±1 dB isotropy). Therefore, the electric-field sensor using an LN optical modulator has better isotropy than the conventional diode-type electric-field sensor up to 6 GHz.

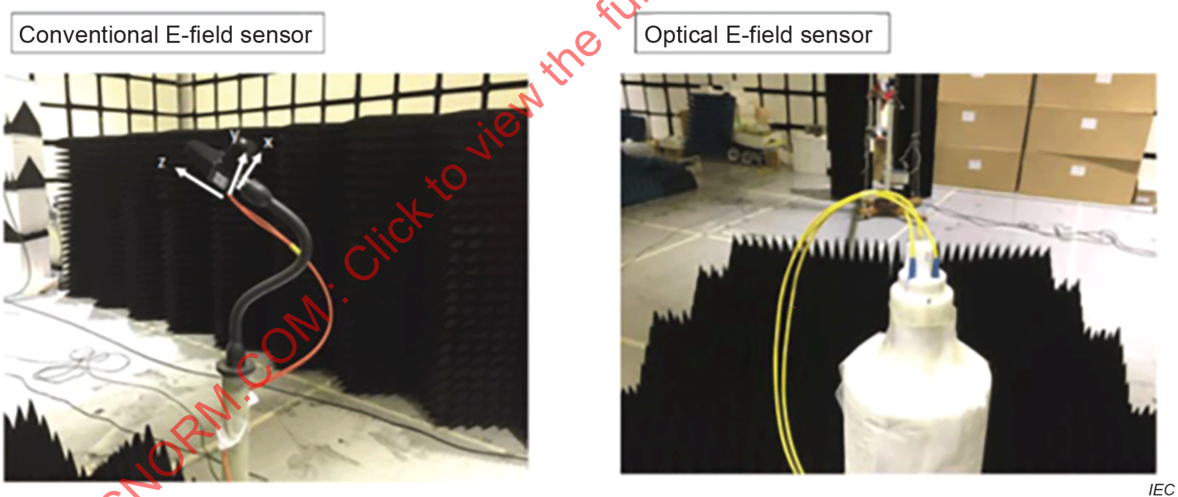

Figure 6 – Measurement setup for isotropy of the conventional diode-type electric-field sensor and electric-field sensor using LN modulator

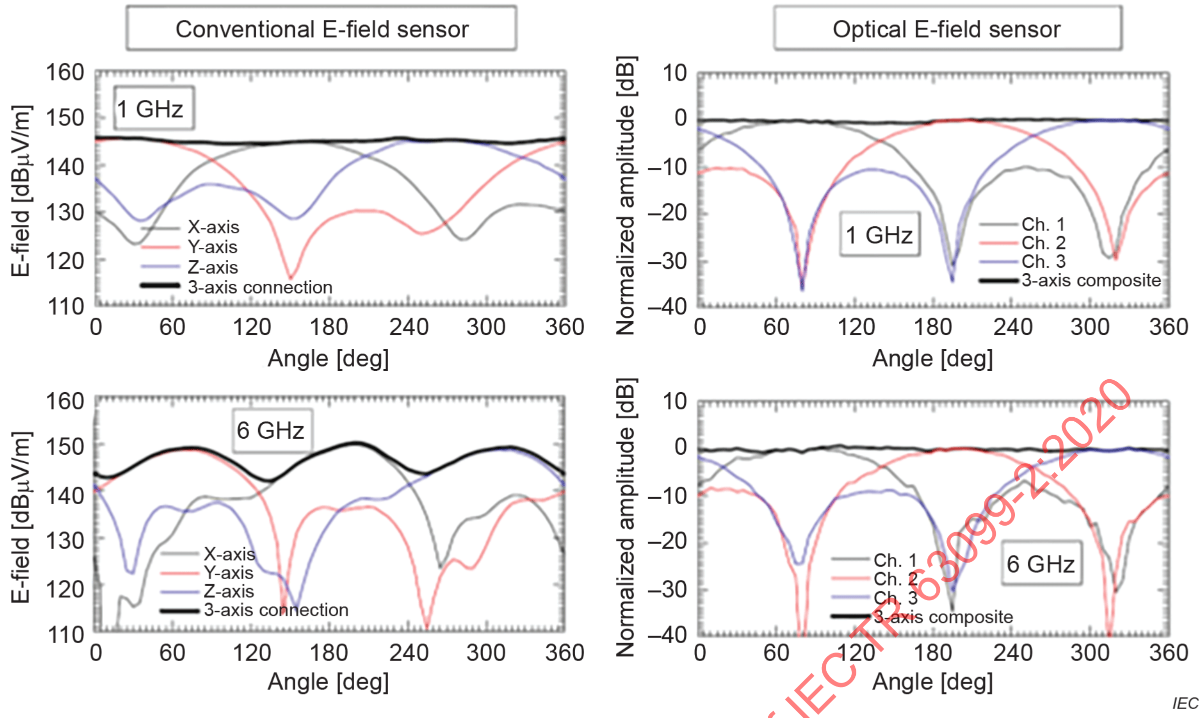

Figure 7 – Measurement results of sensitivity pattern of the conventional diode-type electric-field sensor and electric-field sensor using LN modulator according to IEEE Std. 1309

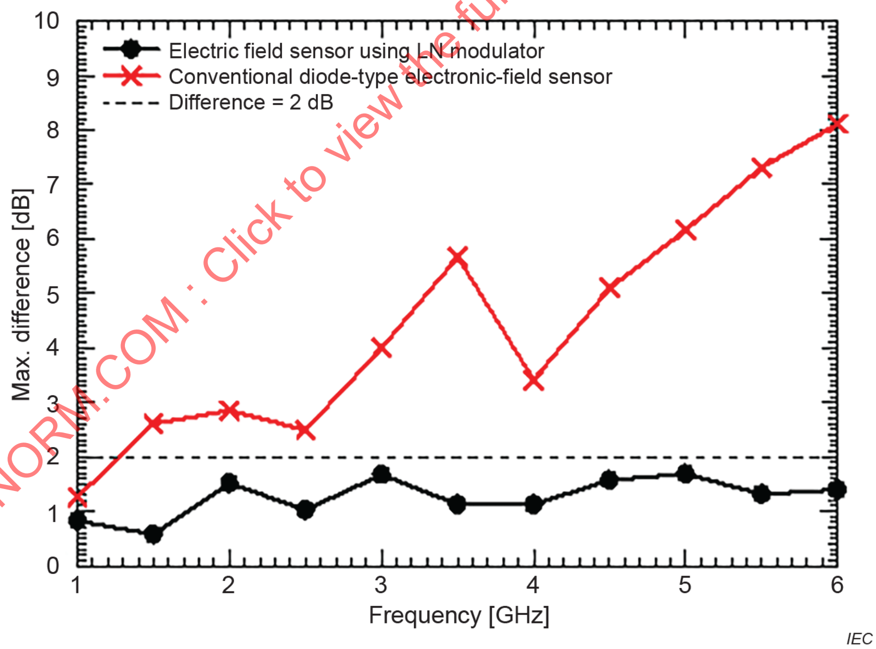

Figure 8 – Frequency characteristics of isotropy of the conventional diode-type electric-field sensor and electric-field sensor using LN optical modulator

4.5 Bulk-type electric-field sensor using ZnTe optical modulators

This electric-field sensing system has been developed based on the electro-optic effect (EO effect). The EO effect (Pockels effect) is a phenomenon of optical refractive index change caused by the electric field change around the EO crystal. Observing the refractive index change, the electric field strength change can be known indirectly. The EO crystal is a dielectric crystal and not a metallic material, and the optical signal for detection is fed through an optical fibre, so that the measuring portion is constructed with no metallic material and does not affect the electric field measured. The system configuration is illustrated in Figure 9.

The main feature of this sensing system is that the measuring performance can be very stable even if the signal frequency of the DUT is very high, since the detecting signal can be handled at relatively low frequency signals by utilizing the optical heterodyne technique, which can generate intermediate frequency signal in the EO crystal by means of optical heterodyne mixing. The probe head of approximately 6,5 mm in the tip diameter and 65 mm in the length has been developed and this shape is convenient in handheld operations. With the well-controlled focus of the detecting optical signal into the EO crystal, this probe has achieved measurement special resolution of 50 µm or less. In addition, a thinner probe tip less than 1 mm diameter, and the measuring frequency range of up to 40 GHz have been achieved. As for the frequency range, the final goal will be the THz band since EO crystal can respond in such a range.

Detailed information is described in reference [5].

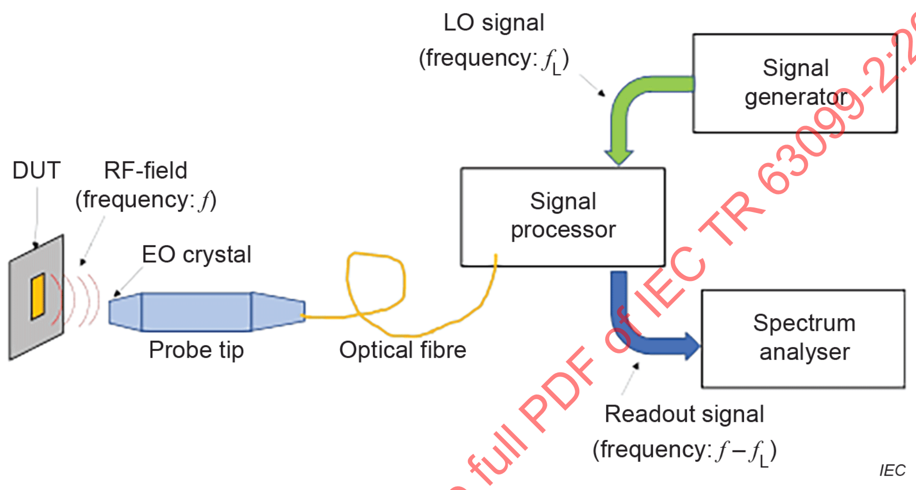

Figure 9 – Schematic representation of the bulk-type electric-field sensor using ZnTe optical modulators

4.6 Electric-field probes using VCSEL

The schematic represensation of the electric-field sensor using a vertical cavity surface emitting laser (VCSEL) consisting of a miniature sensor head that is exclusively linked via fibre optics to a remote unit is summarized in Figure 10. Every probe contains a sensor head and a sensor ID. The sensor head is located at the very tip of the probe and contains the actual electric-field sensor while the sensor ID is located in the rear of the probe body. The function of the sensor ID is to uniquely identify each probe to the remote unit and to provide a redundant optical link, which is continuously monitored for laser safety.

The remote unit acts as the optical power supply in the power-over-fibre forward link. At the sensor head the photonic energy is converted into electrical energy from which the active elements in the sensor head are supplied. The sensor head uses electrically small transducers to pick up the electric or magnetic fields. The RF signal from the transducer is amplified by a low noise amplifier (LNA) and modulates the optical output of a high speed VCSEL. The optical signal from the VCSEL is then transmitted to the remote unit over an optical fibre. At the remote unit, the optical signal is demodulated by means of a high-speed photodiode (PD), amplified by a transimpedance amplifier (TIA), and made available over a standard 50 Ω output to connect a standard measurement receiver such as an oscilloscope or spectrum analyser.

Basically, this system can be regarded as a miniature, broad-band, optically isolated antenna. The antenna factor, the frequency dependent transfer function that converts the output from the remote unit in dBm to a magnetic-field (in dBA/m) or an electric-field (in dBV/m) is made available with the calibration certificate of each probe.

Detailed information is described in reference [6].