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Calibration of electric field probes with three orthogonal elements by standard field method

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Abstract: Electric field probes with three orthogonal elements were calibrated from 1–6 GHz by the standard field method in an anechoic chamber. A special jig was constructed for setting and calibrating a Δ-beam-type probe. Calibration factors of the probes were obtained for each element using this jig. To reflect the future revision of IEC 61000-4 series, uncertainty in the calibration factors was investigated to improve calibration quality and determine the factors affecting calibration. We found that fluctuation in the power transmitted from a high power amplifier and the imperfection of the anechoic chamber were the most important factors affecting uncertainty.

Keywords: electric field probe, standard field method, calibration factor, uncertainty

Classification: Electromagnetic compatibility (EMC)

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1 Introduction

Recently, a gigahertz transverse electromagnetic (GTEM) cell has been used for emission and immunity testing at high frequencies. The testing and measurement techniques for the emission and immunity testing of electrical and electronic equipment using various types of TEM waveguides, including a GTEM cell, using an electric field probe are described in IEC 61000-4-20 [1]. In general, in emission and immunity testing, only the resultant field is measured. However, according to IEC 61000-4-20, it is necessary for emission and immunity testing to measure the primary and both the secondary electric field components separately in a GTEM cell. Therefore, it is necessary to calibrate the electric field probe for each element. Methods for calibrating antennae have been published in the annex of the IEC 61000-4-3 standard [2], which include an original standard for emission and immunity testing up to 6 GHz and IEEE standard 1309 [3]. However, these standards focus on the calibration methods for antennae without discussing the method used for the arrangement of the probe or that used for evaluating uncertainty [4]. Typically, the following two types of electric field probes are used for emission and immunity testing: three orthogonal-dice-type and Δ-beam–type electric field probes. The Δ-beam–type electric field probe is more difficult to use for calibrating probes than the dice–type electric field probe. The element of the Δ-beam–type electric probe is printed on the Δ-beam based on the three orthogonal dipoles design [5], which makes it difficult to align the probe element perpendicular to the direction of the incident field. Furthermore, the IEC 61000-4 series will soon be reviewed. In this revision, standards will be included for evaluating uncertainty in emission and immunity testing, including a calibrating procedure to improve the quality of calibration factors. However, there have been very few studies that discuss the uncertainty of probes and the factors that affect their calibration. In this study, we focused on the Δ-beam-type probe and constructed special jigs to set and calibrate an electric field probe with three orthogonal elements from 1–6 GHz by the standard field method in an anechoic chamber. In order to reflect the future revision of IEC 61000-4 series, uncertainty in the calibration factor, as stated on a certificate indicating the quality of the calibration, was also investigated.

2 Calibration method and procedures

The calibration of electric field probes is carried out by the standard field method in an anechoic chamber. Fig. 1 shows the schematic diagram of the measuring setup and probes. As shown in Fig. 1 (a), a double ridged guide horn (DRGH) antenna is attached through the center of a side of the anechoic chamber and connected to an RF power amplifier and a signal generator through a directional coupler. A dual channel power meter is connected to the coupled ports of the directional coupler to measure the forward and reverse powers. The electric field probe under test is installed on an automatic positioner. The distance from the aperture of the DRGH antenna to the probe head is 3 m. As shown in Figs. 1 (a) and (b), two different types of the

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electric field probes (E-probe A and E-probe B) are chosen. These probes are based on the three orthogonal dipoles design. Each element of the probes was rotated around the ortho-axis of the Δ-beam. In order to calibrate each sensor of the probe, a special jig is constructed using polystyrene foam (see Figs. 1 (a) and (b)) to align the probe along the diagonal of a cube, as shown in Fig. 1 (b), so that one element is aligned with the incident field and the other two elements are cross-polarized to the incident field. Three orthogonal positions are given by means of three 120° rotations around the ortho-axis. The probe is rotated through a full revolution of 360° to obtain the maximum and minimum responses until all the required configurations are satisfied, i.e., each axis is aligned with the incident field vector, while the other axes are successively cross-polarized. The calibration factor (K) of the electric field probe is measured in the anechoic chamber by using the measurement system described above. The calibration factor is calibrated by the standard field method, which compares the difference between the standard electric field and the measured electric field. The strength of the standard electric field ($E_{standard}$) radiated by the DRGH antenna at the far field is defined as follows:

$$E_{standard}\,[V/m] = \frac{\sqrt{30 \times G \times P_{net}}}{r} \tag{1}$$

where P_{net}, G, and r are the net power into the DRGH antenna, the gain of the horn antenna at the far field, and the distance between the aperture of the horn antenna and the probe head, respectively. In this study, $r = 3\,\text{m}$. P_{net} is calculated from the forward power P_{fwd} and the reverse power P_{rev}, which are measured using a power meter. P_{net} is defined as follows:

$$P_{net}\,[W] = P_{fwd} - P_{rev} \tag{2}$$

The principles for measuring electric fields using electric field probes are as follows. The electric field is measured by detecting the high-frequency voltage using detector diodes at the dipole feed point to rectify the sensor voltage output; this high-frequency voltage is converted into an output signal in the sensor and sent to an optical power detector via an optical fiber; the optical signal is converted into an electric signal; the electric field strength is then displayed on the control computer in V/m for E-probe A. The calibration factor K_a for E-probe A is defined as follows:

$$K_a\,[dB] = 20\log_{10} E_{measured} - 20\log_{10} E_{standard} \tag{3}$$

where $E_{measured}$ is the electric field value displayed on the field monitor, which is directly connected to the electric field probe. However, the E-probe B cannot measure the electric field value directly. Therefore, we displace the field monitor by the spectrum analyzer measured voltage in dBm and define the calibration factor K_b of the E-probe B as follows:

$$K_b\,[dB/m] = 20\log_{10}(E_{standard} \times 10^6) - V_{measured} - 107 \tag{4}$$

where $V_{measured}$ is the voltage value displayed on the spectrum analyzer.

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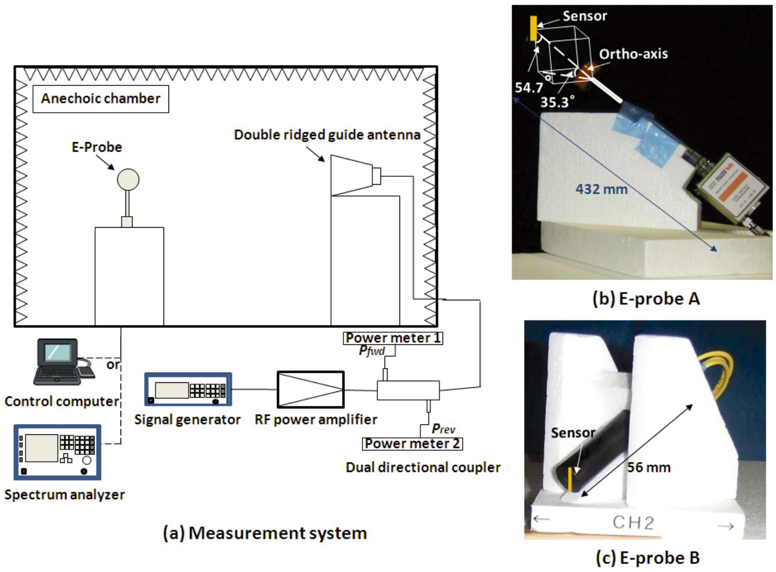

Fig. 1. Schematic diagram of measuring setup and probes.

3 Calibration results

The calibration of electric field probes with three orthogonal elements is carried out using the standard field method in an anechoic chamber. Fig. 2 shows the results of the calibration factor of two different types of probes. The three orthogonal elements of the probes were calibrated separately. A frequency range of 1–6 GHz is used. As shown in Figs. 2 (a) and (b), it is found that there are differences in the electric fields for the three sensors. It is also found that there are differences between the standard electric field values and the electric field values displayed on the control computer, as shown in Fig. 2 (a). The maximum difference between these results is 2 dB at 1 GHz. These differences may be caused by the sensor characteristic, the measurement system and the effect of the anechoic chamber. Therefore, it is important to evaluate the uncertainty in the calibration factor of the electric field probes.

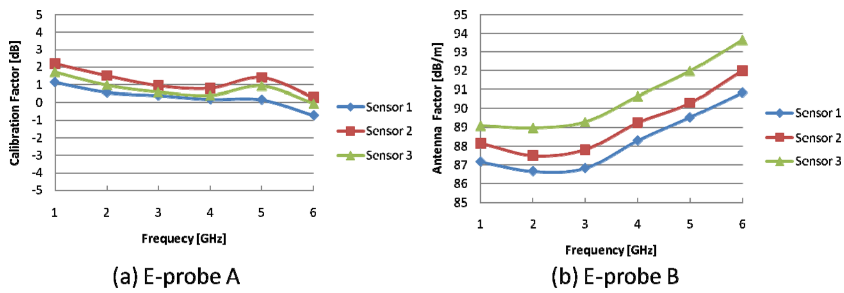

Fig. 2. Calibration factor of isotropic electric field probes.

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4 Uncertainty in calibration factor of electric field probes

To enhance the reliability of the calibration and determine the factors affecting it, it is necessary to evaluate the uncertainty in the calibration factor of the probes. In this study, uncertainty in the calibration factor is investigated by carrying out field measurements and a simulation (finite integration (FI) method [6]) in the 1–6 GHz frequency range. By analyzing equations (3) and (4), it is possible to divide the uncertainty into three main categories. Each category has several uncertainty factors. The main categories of uncertainty are provided below:

- Uncertainty associated with the transmission system;
- Uncertainty associated with the receiving system;
- Uncertainty associated with the calibration site.

Then, a standard uncertainty $u_i(x_i)$ is calculated on the basis of these uncertainty factors. The expanded uncertainty U of the calibration factor is combined from these standard uncertainties using equation (5) as follows:

$$U = kU_c(y) = k\sqrt{\sum_{i=1}^{N} u_i^2(x_i)} \tag{5}$$

where $U_c(y)$ and k are the combined standard uncertainties and coverage factor, respectively.

4.1 Uncertainty associated with the transmission system

Uncertainties associated with the transmission system include the following: (1) mismatching between the output port of the directional coupler and the input port of the DRGH antenna, (2) variation in the transmission system, (3) variation in the DRGH antenna position, (4) effect of bends in cables, etc. The mismatching is obtained from the reflection coefficients of these ports, as described above. Variation in the transmission system is caused by fluctuations in the power transmitted from a high power amplifier. Even though the power amplifier is turned on for a long time to ensure stable input power to the transmission antenna, the input power still fluctuates greatly. Therefore, it is important to maintain stability in the gain of the power amplifier. In this study, the most significant factor affecting the uncertainty associated with the transmission system is the variation in the transmission system.

4.2 Uncertainty associated with the receiving system

Uncertainties associated with the receiving system include the following: (1) variation in the readings on the receiving computer, (2) variation in the receiving system, (3) variation in the probe position, (4) effect of bends in cables, etc. Aligning each element of the probes at a right angle using the special jig is most important for measuring the calibration factor. However, this factor of uncertainty also has the most significant effect on the uncertainty associated with the receiving system.

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4.3 Uncertainty associated with the calibration site

Uncertainties associated with the calibration site include the following: (1) imperfections in the anechoic chamber, (2) measurement distance between the DRGH antenna and the probe head, etc. The imperfection of the anechoic chamber is the most important factor affecting the uncertainty value in this measurement, especially at high frequency. This uncertainty is calculated for the electric field using equation (1), which considers an ideal free space. However, the anechoic chamber is not perfect, and the electric field may be affected by the reflection of waves from the anechoic chamber.

Table I lists the results of the expanded uncertainties for each sensor of the probes. The expanded uncertainty of the calibration factor is given by equation (5) in the case where the coverage factor $k = 2$. The use of a coverage factor of $k = 2$ implies that the expanded uncertainty U will provide an interval with a coverage probability of approximately 95%. As listed in Table I, no significant difference was found between the sensors of the probes. The maximum difference is 0.04 dB at 3 GHz for the E-probe A and 0.23 dB at 2 GHz for the E-probe B. We also find the expanded uncertainty differs with the frequency. This difference in the expanded uncertainty is caused by the high power amplifier because its gain is different at different frequencies. The minimum and maximum expanded uncertainty values are 0.36 dB and 1.14 dB for the E-probe A and 0.49 dB and 1.24 dB for the E-probe B, respectively.

Table I. Expanded uncertainties for isotropic electric field probes (Coverage factor $k = 2$).

E-probe A			
Frequency [GHz]	Sensor 1 [dB]	Sensor 2 [dB]	Sensor 3 [dB]
1	0.49	0.49	0.51
2	0.36	0.39	0.37
3	1.02	1.04	1.06
4	0.89	0.92	0.91
5	0.84	0.85	0.87
6	1.14	1.12	1.12

E-probe B			
Frequency [GHz]	Sensor 1 [dB]	Sensor 2 [dB]	Sensor 3 [dB]
1	0.59	0.65	0.77
2	0.56	0.72	0.49
3	1.04	1.22	1.07
4	0.93	0.99	0.98
5	0.90	0.94	0.87
6	1.19	1.24	1.23

5 Conclusions

The calibration of Δ-beam-type probes with three orthogonal elements from 1–6 GHz is carried out by the standard field method in an anechoic chamber. In this study, a special jig is constructed to align the probe along the diagonal of a cube so that one element can be aligned with the incident field and the other two elements are cross-polarized to the incident field. The calibration factor of the Δ-beam-type probe is measured in the anechoic chamber

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using this jig. In order to reflect the future revision of IEC 61000-4 series, uncertainty in the calibration factor of the probes is investigated to enhance the reliability of the calibration and determine the factors affecting the calibration. As a result, uncertainty in the calibration factor of probes can be divided into three main categories, and each category is further divided into several uncertainty factors. By using the standard field method, we find that fluctuation in the power transmitted from the high power amplifier and the imperfection of the anechoic chamber are the most important factors affecting the uncertainty.

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