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Calibration of electric field probes in GTEM cell using reference antenna method

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Abstract: Calibration of electric field probes in a GTEM cell is carried out using the reference antenna method. To determine the effectiveness of the calibration, we compared our results with those of calibration in an anechoic chamber from 1 to 6 GHz. Each electric field probe had three elements, one of which was used to calibrate the other two. The calibration factors in the GTEM cell agree well with those in the anechoic chamber. Therefore, the GTEM cell is as effective as the anechoic chamber for calibrating electric field probes with the same type of probe and helps save more measurement time and effort.
Keywords: electric field probe, reference antenna method, calibration factor, GTEM cell
Classification: Electromagnetic compatibility (EMC)

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1 Introduction

In general, electric field probes are calibrated in anechoic chambers. They

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cannot be calibrated for all frequencies at once, and hence, each frequency must be measured separately. Accessing the anechoic chamber and installing the probe are time consuming. Recently, a gigahertz transverse electromagnetic (GTEM) cell has been used as an alternative apparatus to an anechoic chamber for calibrating electric field probes since the GTEM cell is inexpensive and convenient to use. As the number of probes or calibrating frequencies increase, the GTEM cell can help save much time and effort compared to the anechoic chamber. However, the electric field distribution in GTEM cells is not strictly uniform, as in conventional transverse electromagnetic (TEM) waveguides. At higher frequencies, the GTEM characteristic impedance and quasi-static field may vary by up to approximately ±4 dB from the values given by asymmetric TEM cell theory [1]. Therefore, in the GTEM cell, it is difficult to utilize the standard field method based on the asymmetric TEM cell theory to calibrate electric field probes at high frequencies. Furthermore, according to IEC 61000-4-20 [2], techniques for testing and measuring the emission and immunity of electrical and electronic equipment using various types of TEM waveguides, including a GTEM cell, are needed for evaluation up to 6 GHz [2]. Therefore, it is necessary to calibrate the electric field probe for such testing up to 6 GHz. However, in the IEEE standard 1309, measurement techniques for calibration using the GTEM cell are only described for the frequency range from 9 kHz to 1 GHz [1]. Very few studies have been conducted on methods for calibrating electric field probes in the GTEM cell above 1 GHz and the relationship between the calibration factors in the anechoic chamber and GTEM cell. In this study, electric field probes are calibrated from 1 to 6 GHz in the GTEM cell using the reference antenna method. Each electric field probe has three elements; first, we used one element to calibrate the other two elements. We then investigate the uncertainties affecting the calibration factor to improve the reliability of calibration and determine the factors affecting it [3]. We also use one of the elements of the small probe, which is barely affected the electric field in the GTEM cell, to calibrate the large probe in the GTEM cell using the reference antenna method.

2 Calibration method and procedures

We calibrate the electric field probe in the GTEM cell using the reference antenna method. First, we calibrate one element of the electric field probe (E-probe$_{ref}$) as a reference antenna in an anechoic chamber using the standard field method and calculate the calibration factor. We then measure the electric field and calculate the standard field using E-probe$_{ref}$ with the calibration factor in the GTEM cell. Finally, the calibration factors of the remaining two elements are determined using this standard field. Fig. 1 shows the schematic of the measurement setup and probes; two types of electric field probes (E-probe A and E-probe B; Figs. 1 (c) and (d)) are chosen. E-probe A and E-probe B are based on the three orthogonal-dice-type design and Δ-beam–type design, respectively [4]. When calibrating an element of

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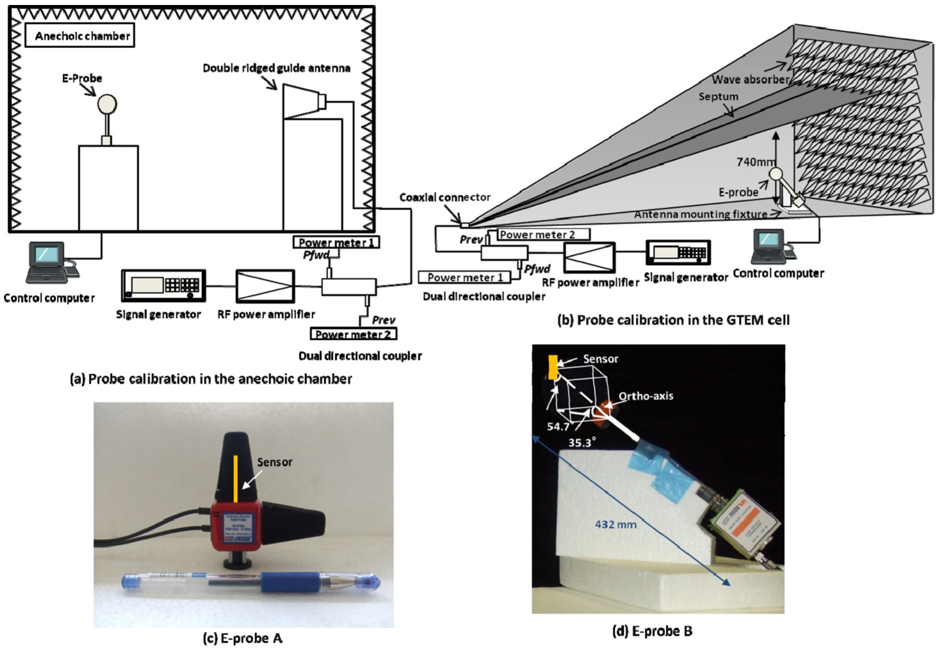

Fig. 1. Schematic of measurement setup and probes.

E-probe A, one element is aligned with the incident field and the other two elements are cross-polarized to the incident field (Fig. 1 (c)). The method for aligning E-probe B has been described [5].

2.1 Calibration procedures for anechoic chamber

Fig. 1 (a) shows the schematic of the calibration system, where E-probe$_{\mathrm{ref}}$ is calibrated in the anechoic chamber. The distance from the aperture of the double ridged guide horn (DRGH) antenna to the probe head is 3 m. The calibration factor (K_a) is determined using the standard field method, where the standard and measured electric fields are compared. 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 entering the DRGH antenna, gain of the horn antenna in the far field, and the distance between the aperture of the horn antenna and the probe head, respectively; we obtained $r = 3\,\mathrm{m}$ and calculated P_{net} from the forward and reverse powers (P_{fwd} and P_{rev}, respectively) measured using a power meter. P_{net} is defined as

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

The principles behind the measurement of electric fields using electric field probes are described in [5]. The calibration factor K_a for E-probe$_{\mathrm{ref}}$ is defined as

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

where $E_{measured}$ is the electric field strength in V/m displayed on the field monitor, which is directly connected to the electric field probe.

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2.2 Calibration procedures for GTEM cell

Fig. 1 (b) shows a schematic of the calibration system in which the GTEM cell is used to calibrate electric field probes. We control P_{net} (2.5 W) in order to compare electric fields. The electric field probes are placed 410 mm from the bottom wall; the distance between the bottom wall and septum is 740 mm (Fig. 1 (b)). The calibration factor (K_b) of the electric field probe is determined using the reference antenna method, in which the difference between the electric field measured by E-probe$_{\text{ref}}$ with calibration factor K_a and the electric field measured using the electric field probe in the GTEM cell are compared. The strength of the standard field ($E_{correct}$) measured using E-probe$_{\text{ref}}$ in the GTEM cell and corrected by the calibration factor K_a is defined as

$$E_{correct}[dBV/m] = 20\log_{10} E_{reference} - K_a \tag{4}$$

where $E_{reference}$ is the electric field strength (in V/m) displayed on the control computer for the reference antenna (E-probe$_{\text{ref}}$) in the GTEM cell. We use $E_{correct}$ as a standard field to calibrate the remaining two elements of the electric field probe. Then, the calibration factor K_b is defined as

$$K_b[dB] = 20\log_{10} E_{GTEM} - E_{correct} \tag{5}$$

where E_{GTEM} is the electric field strength (in V/m) displayed on the control computer for the remaining two elements of the electric field probe in the GTEM.

3 Probe calibration using one of three elements in a probe

We choose two types of electric field probes (E-probe A and E-probe B), each with three orthogonal elements (sensor$_{\text{ref}}$, sensor 1, and sensor 2). The probes in the GTEM cell are calibrated in the 1–6 GHz frequency range using the referece antenna method. First, as a reference, we calibrate the sensor$_{\text{ref}}$ of E-probe A or E-probe B in an anechoic chamber, using the standard field method. Then, the calibration factors K_b of the remaining two elements (sensors 1 and 2) are calculated by comparing the electric fields of these two elements and the electric field of sensor$_{\text{ref}}$, which is corrected using the K_a, of the GTEM cell. The uncertainties affecting the K_b of these probes are also investigated. Fig. 2 shows the differences between the calibration factors of GTEM and the anechoic chamber and the uncertainties affecting calibration factors. The difference D between the calibration factors of the GTEM and the anechoic chamber is defined as

$$D[dB] = K_b - K_c \tag{6}$$

where K_c is the calibration factor of the remaining two elements, which are calibrated in the anechoic chamber using the standard field method. The calibration factors of the elements of these probes agree with each other (Figs. 2 (a) and (b)). The maximum difference between the calibration factors of the GTEM cell and anechoic chamber is 0.5 dB at 5 GHz for E-probe

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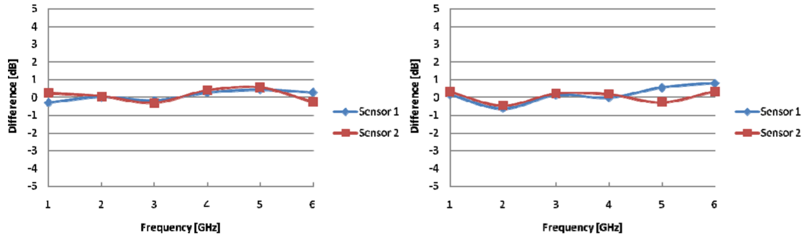

(a) E-probe A (b) E-probe B

E-probe A		Coverage factor k=2
Frequency [GHz]	Sensor 1 [dB]	Sensor 2 [dB]
1	0.51	0.51
2	0.38	0.38
3	1.04	1.04
4	0.92	0.91
5	0.86	0.86
6	1.15	1.15

(c) Expanded uncertainties for E-probe A

E-probe B		Coverage factor k=2
Frequency [GHz]	Sensor 1 [dB]	Sensor 2 [dB]
1	0.53	0.52
2	0.70	0.70
3	1.20	1.15
4	1.02	0.97
5	0.93	0.91
6	1.39	1.28

(d) Expanded uncertainties for E-probe B

Fig. 2. Results of comparison and expanded uncertainties.

A and 0.7 dB at 6 GHz for E-probe B. Therefore, the GTEM cell can be used to effectively calibrate electric field probes with probes of the same type. To enhance the reliability of the calibration and determine the factors affecting it, we also investigate the uncertainties affecting the calibration factors by carrying out field measurements and a simulation (finite integration (FI) method [6]) in the 1–6 GHz frequency range. By analyzing equations (5), uncertainties, which depend on several factors, are classified as being associated with the transmission system or the receiving system. The expanded uncertainty of the calibration factor is given in the case where the coverage factor $k = 2$. The use of a coverage factor of $k = 2$ implies that the expanded uncertainty will provide an interval with a coverage probability of approximately 95%. As a result, no significant difference was found between the probe sensors (Figs. 2 (c) and (d)). By using the reference antenna method, we find that K_a of $\text{sensor}_{\text{ref}}$ measured in the anechoic chamber is the most important factor affecting the uncertainty.

4 Probe calibration with different type of probe

E-probe A is much smaller than E-probe B and except for the elements, does not comprise metal. Therefore, the electric field barely affects this probe in the GTEM cell. We use one of the elements of E-probe A as a reference antenna to calibrate E-probe B in the GTEM cell from 1 to 6 GHz using the reference antenna method. First, we calibrate one of the three elements of E-probe A ($\text{sensor}_{\text{refA}}$) in an anechoic chamber using the standard field method. Then, the calibration factors K_b of the three elements (sensors 1, 2, and 3) for E-probe B are determined from the difference between the electric field of these three elements and the electric field of $\text{sensor}_{\text{refA}}$, which is corrected using the K_a in the GTEM cell. Fig. 3 shows the difference between the calibration factors of the GTEM cell and anechoic chamber of the three elements for E-probe B. No significant differences are observed among

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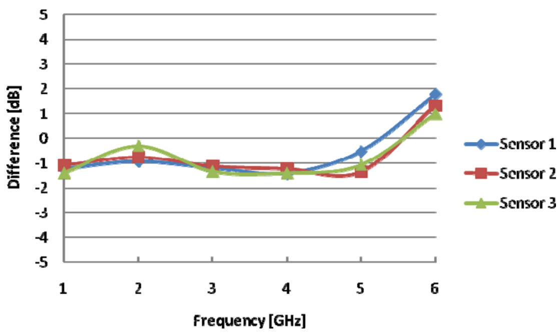

Fig. 3. Difference between calibration factors during calibration with a different type probe.

sensors. However, the difference in calibration factors is higher than 1 dB. A comparison with Fig. 2 (b) shows that the difference in calibration factors is greater when the probe types differ. The maximum difference between the calibration factors of the GTEM cell and the anechoic chamber is 1.7 dB at 6 GHz, which is caused by the nonuniform electric field distribution in the GTEM cell. The uniformity of the GTEM cell varies greatly, especially at high frequencies. When the probe sizes differ, the strengths of the electric fields in these probes differ. Therefore, the uniformity of the electric field distribution in the GTEM cell must be maintained when calibrating electric field probes with a different type of probe.

5 Conclusions

Electric field probes are calibrated in a GTEM cell in the 1–6 GHz frequency range using the reference antenna method. The electric field distribution in the GTEM cell is not strictly uniform. Therefore, the calibration results for the GTEM cell should be compared with those for the anechoic chamber to enhance the reliability of the calibration. First, we use one of the three elements of E-probe A or E-probe B to calibrate the remaining two elements. The calibration factors of the elements of these probes agree with the calibration factor in the anechoic chamber. Therefore, the GTEM cell is as effective as the anechoic chamber for calibrating electric field probes with the same type of probe and helps save more measurement time and effort. The uncertainty affecting the calibration factor of the probes is also investigated to improve the reliability of the calibration and determine the factors affecting the calibration. We found that the calibration factor measured in the anechoic chamber is the most important factor affecting the uncertainty. We also use one of the elements of E-probe A to calibrate E-probe B in the GTEM cell using the reference antenna method. The difference between the calibration factors is greater than 1 dB. This difference is caused by the nonuniform electric field distribution in the GTEM cell. Therefore, it is important to maintain the uniformity of the electric field in the GTEM cell when calibrating the electric field probes with probes of a different size.

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