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Optical *E*-field probe characterization in a TEM cell

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Abstract A well-defined *E*-field is necessary for the characterization of the *E*-field probes. A transverse electromagnetic (TEM) cell is a well-known instrument to generate the standard *E*-field. However, the field distribution inside the cell is degraded by the higher-order modes and the upper usable frequency is limited based on the cross-sectional dimensions of the cell. A straightforward approach to extend the frequency range is to use a smaller cell and the optical *E*-field probe is a suitable choice for the installation into the space inside such a cell. Characterization of the optical *E*-field transfer probe is discussed in the present paper. The calibration factor is defined for the system characterization and sources that affect the results are carefully investigated.

Keyword Standard *E*-field, TEM Cell, Optical *E*-field probe, Calibration Factor

1. Introduction

The *E*-field measurement is often carried out to claim that a device under test (DUT) satisfies the regulation requirements. Since the *E*-field strength emitted from the DUT is ordinary very weak, an antenna is employed for the measurements due to the sensitivity. In contrast to this, the immunity test applying a high *E*-field level onto the DUT requires the field measurement with the high spatial resolution. Consequently, the sensitivity is less important compared with the emission measurement. An optical E-field probe is one choice for this purpose. However, the optical *E*-field probing system response is usually unknown and it should be characterized for the precision field level measurement.

The standard *E*-field is necessary for the probe calibration. Several methods to generate the well-defined E-field have been proposed. Each method has an applicable frequency range and some other limitations to generate the standard field and it is difficult to cover the whole frequency range by one method. A TEM cell is used as a standard field generator [1]. However, one major drawback is the higher frequency limitation since the TEM cell is one of the deformed coaxial transmission line and the cross-sectional dimensions determine the higher-order mode cutoff frequency [2]. Although the smaller cell can generate the standard field at higher frequencies, an ordinary *E*-field probe is too large to be installed in a test volume of such a small cell. In this study a TEM cell designed to work up to 1 GHz is used to generate the standard *E*-field and the optical *E*-field probe is installed in the midpoint of the cell.

2. Measurement Setup and *E*-field Distribution

2.1 Measurement Setup

Fig. 1 shows the measurement setup. The system consists of the RF components for the standard E-field generation, the optical probing components and RF readout instrument. The RF signal flows into the TEM cell through a scalar reflectometer. The reflectometer consists of a dual-directional coupler and a pair of power sensors. The net power *P* flowing into the cell is measured by the reflectometer. Although the end port of the cell is ordinary terminated by a matched load, another power sensor is connected to confirm the validity of the measured net power by the reflectometer.

Since the target application of the *E*-field probe is the precision measurement, the *E*-field probe has one axial element for the high polarization selectivity. The probe head is made of lithium niobate ($LiNbO_3$:LN) crystal substrate and a dipole element is attached to the electrodes to improve the sensitivity. Since the spatial resolution and sensitivity of the probe is in the trade-off relationship, the total element length is 10 mm. The optical waveguides on LN crystal substrate are reflected by a mirror and the optical signal is modulated proportional to the applied *E*-field strength by the Pockels' effect. The optical source is 1.55 μm band super luminescent diode (SLD) having a very wide spectrum (Δλ: 60 nm). Although the SLD source increase the noise, the stability of the optical probing system is considerably improved. The RF signal output from the diode detector is measured by a spectrum analyzer. Both the RF signal generator and the spectrum analyzer refer the 10 MHz reference signal of the calibrated frequency counter.

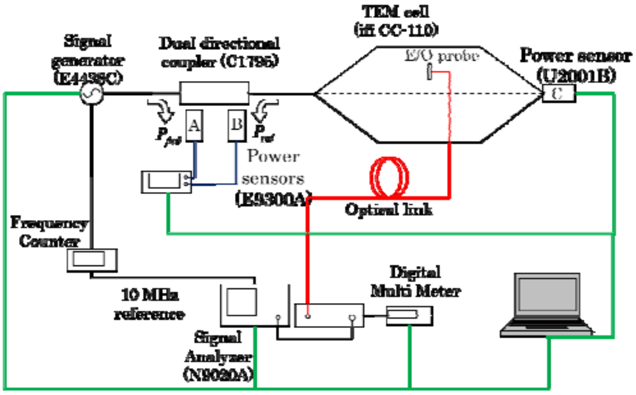


Fig. 1 Sketch of the measurement setup.

2.2 *E*-field Distribution of TEM Cell

The test volume of the TEM cell is located between the septum and the ceiling (or the floor). Taking into account the field uniformity the probe should be smaller than $d/5$ for the probe calibration. The E-field distribution in the x-y plane calculated by the finite element method at 0.5 GHz is shown in Fig. 2 (b). The field distribution at another frequency below the higher-order mode cutoff frequency is almost identical. The E-field strength at the measurement location is given by:

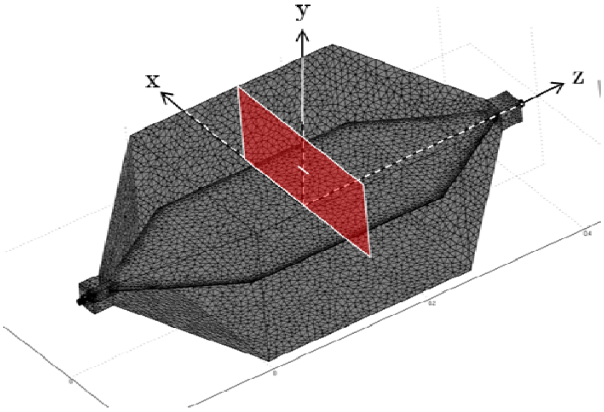
$$E = \sqrt{PZ_0}\Big/d \qquad (1)$$

where Z_0 is the characteristic impedance of the cell and calculated by using the dimensions shown in Fig. 2 (b) as

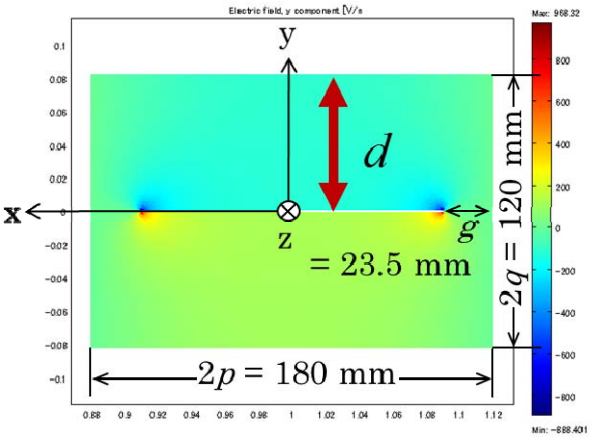
$$Z_0 \approx \frac{377}{4\left[\frac{p}{q} - \frac{2}{\pi}\ln\left(\sinh\frac{\pi g}{2q}\right)\right] - \frac{\Delta c}{\varepsilon_0}}. \qquad (2)$$

The cross-sectional dimensions of the cell employed in this study are 180 mm ($2p$) and 120 mm ($2q$). The gap width (g) between the side wall and the septum is 23.5 mm and thickness of the septum is 1 mm.

The probe is inserted vertically through a small hole on the ceiling of the cell. The feed point of the dipole element is located at the center point between the septum and ceiling. No dielectric material is necessary for this method to support the probe and this results in the accurate measurement of the E-field. Since the diameter of the hole on the ceiling is 4 mm and this is only 1.3 % of the wavelength at 1 GHz, the effects of the hole is neglected here.



(a) Meshed model of the TEM cell for the FEM analysis.



(b) Cross-sectional dimensions and E-field distribution at 0.5 GHz

Fig. 2 Calculated E-field distribution in a TEM cell.

3. Calibration Factors

The system response of the E-field probe against· the applied field is related to the spectrum power measured by the spectrum analyzer. When the E-field strength is estimated by (1) and the output power measured by the spectrum analyzer is P_r, E should be proportional to $P^{1/2}$. Accordingly, the calibration factor C_r is given by:

$$C_r = E\Big/\sqrt{P_r} \qquad (3)$$

Note that C_r includes all the E/O components. This means that when a cable is replaced with another, recalibration or collection is necessary to keep the accuracy of the measurement.

Fig. 3 shows the frequency characteristics of the calibration factor of an optical E-field probe. To confirm the net power estimation by the reflectometer two directional couplers are used in the measurement. Each plot shows the average of the five repeated measurements and the error bars show the standard deviation. These plots are almost identical and the calibration of the reflectometer surely corrects the coupler characteristics. The standard deviation of the measurement is 1 % of C_r approximately and the repeatability is good enough to carry out the precision measurement. The rapid change of C_r around 1 GHz is considered to be caused by the higher-order mode perturbation. Below 900 MHz the *E*-field generated inside the cell can be considered to be the basic TEM mode. Since the output power from the signal generator is not controlled, the *E*-field strength at the measurement point varies from 10 V/m to 20 V/m approximately with respect to the measurement frequency. The *E*-field probing system linearity is small enough to be neglected. By multiplying C_r to the square root of the measured RF output power from probe system shows the absolute value of the *E*-field strength at the probe location.

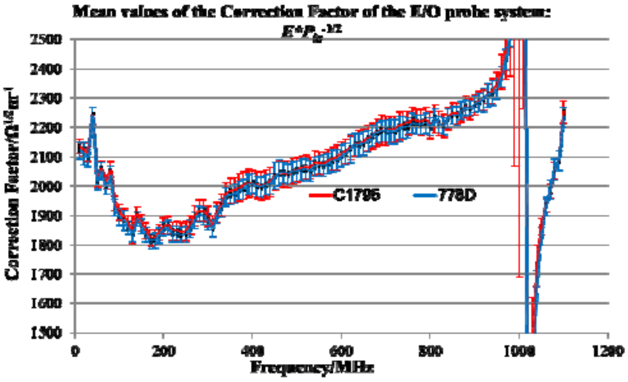


Fig. 3 Calibration factors with respect to the frequency.

4. Conclusions

Taking the size advantage of the optical *E*-field probe, a small TEM cell designed to operate up to 1 GHz without the higher-order mode perturbation is employed for the standard *E*-field generation. The correction factor of the optical field probe system is calibrated against the known *E*-field level generated in the cell. By applying the calibration factor the precision *E*-field strength measurement can be achieved.

References

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