Measurement of Electric Near Field Distribution by Optical Electric Field probe

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Abstract Recently through technique development of communication and information devices, the frequency used has come to extend into the gigahertz range. Especially, smaller probes of broadband with high-resolution are requested in the EMC field to measure and analyze devices. An optical electric field probe may present an accurate method for near-field measurement in the gigahertz range. In the present work, various characteristics of the optical electric field probe are evaluated and near-field electric field distributions on a micro-strip line (MSL) are measured using both the probe and a conventional coaxial monopole antenna. Compared with results for an optical probe, the monopole antenna is used with identical measuring conditions. Simulation results agree well with measured results.

1. Introduction
It has been noted that optical probes have the unique property of not influencing the surrounding electric field distribution because they use optical cable in place of traditional coaxial cable. Optical electric field probes have some other characteristics: smaller volume, they keep a broad band, and they influence electric fields less – the influence can be called negligible. From those above characteristics, a 3D-optical electric field probe can be constructed in the probe. [1][2].

The present study addresses accurate measurement of near-field electric distribution. We used an optical electric field probe, and a micro-strip line (MSL) as a field source. Our work includes evaluation of frequency and output characteristics of evaluation and near-field electric distribution of MSL. It presents a comparison to a monopole antenna and theoretical calculation. This paper reports both measured and simulated results.

2. Optical electric field probe principle
The construction principle of optical electric field probe is shown in Fig. 1. Light wave-guides are set up an optical electric crystal LiNbO₃ board by the diffusion method. Module electrodes are established on both sides of light wave-guides. The small dipole antennas are connected with module electrodes. Laser light (λ = 1310 nm) is used as an illumination. When induction voltage is added on module electrodes, the resultant optical wave interacts with an electric field and the polarization state of an incidence is changed with light as shown in Fig. 1, along with the probe construction refractive index and the change in proportion to induction voltage. The module principle is shown in Fig. 2. When modulated voltage is Vi, the strength of incidence light is Pm; light output is given as

\[ P_{\text{out}} = \alpha \left( \frac{P_m}{2} \right) \left[ 1 + \sin \left( \frac{\pi V}{V_{1/2}} \right) + \Phi \right] \]  \hspace{1cm} (1)

where \( V_{1/2} \) is a voltage of half wave length, \( \alpha \) is insertion loss, and \( \Phi \) indicates the different phase of the light wave-guide.

The measurement system is shown in Fig. 3. The system comprises an optical electric field probe, a laser lightsource, a light detector, an optical circulator, and a spectrum analyzer; the laser wavelength is 1310 nm and its power is 20 mW.
The near-field electric measurement experiment is carried out with 1-mm MSL; 50 Ohm termination is used with input power of +20 dBm.

3 Measured results and discussion

3.1 Linear properties of input and output
Properties of input and output are observed using MSL at frequency 1 GHz. The result is shown in Fig. 4. These results express excellent linear properties of input and output for a 1 GHz frequency field.

3.2 Frequency characteristic
Frequency characteristics depend on dimensions of the antenna element which is connected to module electrodes. The antenna element dimension is 2.46 mm and probe dimensions are 6 mm × 20 mm. The frequency characteristic is shown in Fig. 5. The broader frequency band can be confirmed in Fig. 5 from 10 MHz to 5 GHz with measured MSL. Resonance was not observed in the full frequency field. The frequency appears to decrease at over 5 GHz frequency because propagation loss increased when the frequency band increased to 1 GHz. Above 5 GHz frequency, the characteristic is measured by another method.

3.3 Near-field electric distribution
A 4-axis drive device, which can scan along the X, Y, Z, and angle directions in 0.1 mm steps, was used along the X-Y and Y-Z planes to measure the dimension distribution of the electric field. Electric field measurement was carried out by the program in both vertical and horizontal states, as shown in Fig. 7.
The placement of probe antenna elements is shown in Fig. 6. The distance from the center of the antenna element to the MSL is 5 mm with element vertical placement and 7 mm in the horizontal position. These vertical and horizontal results are shown in Fig. 7. To obtain the space distribution, the probe is mounted on a scan apparatus which scans the distribution of electric field along the X-Y and Y-Z plane. Those measured results are shown in Figs. 8 and 9, respectively.

4 Comparison with a monopole antenna

The optical electric field probe presents the advantage that it does not influence the electric field distribution of surroundings because it uses an optical cable instead of a traditional coaxial cable. The present study measures the distribution of electric field using the probe and the monopole antenna, respectively. Then it compares these results as shown in Fig. 12 with our selected length of the antenna element and measuring distance. Especially, a ferrite core is used in monopole antenna to reduce noise issuing from the
cable. The 20-mm-long core has 5-mm inner diameter and 10-mm outside diameter. It is difficult to accurately measure the electric field distribution using a monopole antenna because of existence of a metallic coaxial cable, which disturbs the electric field distribution.

![Optical Electric Field Probe](image1)

**Fig. 12** Horizontal $E_y$ results are compared with the monopole antenna in the $Y$ direction

![Horizontal Field](image2)

**Fig. 13** Theoretical calculation and measured results

**5 Comparison with theoretical calculation**

The present work simulates an ideal electric field distribution of MSL by Finite Difference Time Domain Method (FDTD); it compares the distribution with results measured using an optical electric field probe; these results are shown in Fig. 13. Simulation is carried out in the space field of $17 \text{ mm} \times 30 \text{ mm} \times 7 \text{ mm}$ per $0.1 \text{ mm}$ step. Regarding the simulation, the boundary condition is Perfectly Matched Layer (PML), frequency is $1 \text{ GHz}$, and input is $+10 \text{ dBm}$. The MSL parameters are identical to the real MSL: width is $1 \text{ mm}$, thickness is $0.6 \text{ mm}$, and the dielectric constant is $4.8$. Results of the FDTD calculation agree well with the measured results. The measurement distance and computation were $2.5 \text{ mm}$, which is the shortest distance of the probe antenna element center to MSL.

The optical electric field probe resolution depends on the distance of measurement and the size of the antenna element.

**6 Conclusions**

This paper described characteristics and construction of an optical electric field probe; it presents a comparison of a traditional monopole antenna and theoretical calculation. The monopole antenna influences spatial distribution of the electric field because a metallic coaxial cable is connected. For this reason, accuracy of the horizontal $E_y$ field measurement becomes more difficult than that of the vertical one. The optical probe accurately measures any electric field component, either horizontal or vertical. We have measured the electric field distribution of MSL on $X-Y$ and $Y-Z$ plane, and have showed images of these results. The theoretical calculation of FDTD shows the correctly measured results. We selected identical conditions and parameters correctly when we analyzed the monopole antenna and performed theoretical calculation, but error was minimal. The reason was that the probe contains a smaller dipole antenna (Au).

**7 Acknowledgements**

We thank Mr. H. Torihata of the Department Optical devices of NEC/TOKIN Corp. for valuable support and assistance.

**References**


