Simulated Characteristics of Optical Magnetic Field Probe

Tomokazu IKENAGA#1, Hiroyuki OHBA#2, Hiroyasu OTA#3 and Ken Ichi ARAI#4

#Sendai Research Center National Institute of Information and Communications Technology.
ICR bldg. 3F, 6-6-3, Minami-Yoshinari, Aoba-ku, Sendai 989-3204 Japan

1t-ikenaga@nict.go.jp
2ohbahiro@nict.go.jp
3ota@nict.go.jp
4ken-arai@riec.tohoku.ac.jp

***Abstract*—To perform magnetic near-field measurements with high accuracy in gigahertz frequency range, we are developing an optical magnetic field probe using an electrooptic crystal and a laser beam for signal transmission. Here we report the results of a FDTD (Finite Difference Time Domain) simulation of the frequency response characteristics of optical magnetic field probes up to 100 GHz and the invasiveness of the probes when measuring the electromagnetic field distribution above a microstrip line, The purpose is to verify the measurement accuracy and clarify design guidelines for optical magnetic filed probes.**

Key words: Electromagnetic field distribution, Optical magnetic filed probe, Microstrip line, FDTD.

I. Introduction

We have been developing optical magnetic field probes for high frequency magnetic field measurement [1]. The size of the optical magnetic field probes for tens of gigahertz becomes very small, and difficult to design.

Here we report the results of a FDTD simulation with the purpose of verifying the measurement accuracy and clarifying the design guideline of optical magnetic filed probes.

II. Optical Magnetic Probe System

A. Structure of Optical Magnetic Field Probe.

Figure 1 shows a schematic of the optical magnetic field probe. It consists of a copper loop element on a glass substrate and an electrooptic crystal (DAST 4-dimethylamino-N-methyl-4-stilbazolium Tosylate) inserted between electrodes at the ends of the loop. For better reflection of the laser beam, an AR-coated glass sheet and an HR-coated glass sheet are adhered to the top and bottom of the electronic crystal, respectively.

B. Structure of Magnetic Field Measurement System.

Figure 2 shows the configuration of the measurement system. A continuous wave laser beam guided through an optical fiber passes through an optical circulator and a lens and then enters the c-axis (optical axis) of DAST crystal perpendicularly. The high frequency magnetic flux through the loop aperture induces voltage between the DAST electrodes.

The reflective indices of DAST crystal vary in proportion to the applied voltage by the linear electro optic effect (the Pockels effect). The modulated laser beam is reflected back at the bottom surface of the glass attached to the DAST crystal. The beam goes through a circulator, and then through wave plates and a polarizer, finally reaching a photo receiver. The polarizer converts the phase modulation into intensity modulation. The photo receiver converts the modulated optical signal into electrical signal. A spectrum analyzer detects the desired signal.

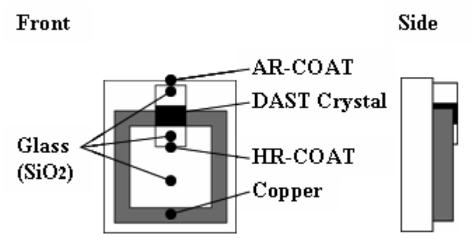

Fig. 1 Optical magnetic field probe

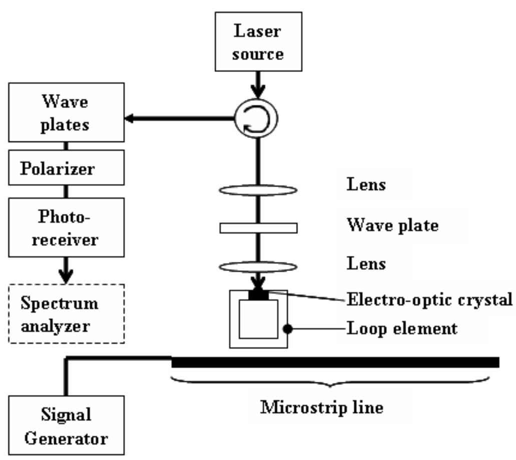

Fig. 2 Measurement system

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III. Simulation of Loop Coil Probe

A. Analysis Model for the FDTD Simulation

Figure 3 shows the model used for FDTD simulation.

We analyze the output characteristics of probes above the MSL powered by sinusoidal signal (0 dBm at 31 GHz).

The frequency response of probes above the MSL is analyzed by powering a single Gaussian pulse expressed in the following formula.

$$V(t) = \begin{cases} \exp(-\alpha(t-t_0))^2 & (0 < t < 4t_0) \\ 0 & (t = 0,\ 4t_0 \le t) \end{cases} \quad (1)$$

$$\alpha = (4/t_0)^2, \quad t_0 = 1.6 \times e^{-11}\,[\mathrm{sec}]$$

B. Magnetic Field Distribution and Invasiveness of Probe

We analyzed the invasiveness of probes, i.e., the disturbance on the magnetic field distribution above the MSL.

Figure 4 shows the calculated magnetic field distribution *Hy* on the MSL when the MSL was powered by 0 dBm at the frequency 31 GHz. Figure 5 shows the magnitude of magnetic field distribution *Hy* at height (H).

Figure 6 shows the probe models used for the FDTD simulation. Figure 6 (a) is the same configuration model with the one used in the experiment. Figure 7 shows the placement of the probe in the simulation. The probe was set parallel to the MSL and scanned across the conductor. The space between the MSL and the bottom of the loop element was maintained at 0.3 mm. The probe position was changed and the output was calculated.

In figure 8, the white square dots and solid lines show the calculated and measured output levels, respectively.

The magnetic field distribution (Fig. 5) is essentially symmetrical, but the output of the probe (Fig. 8) is slightly asymmetrical. Because there is the glass substrate on one side of the probe and the dielectric constant of the glass substrate is not negligible, the output is considered to be affected. Therefore we made the new probe model "Double-sided glass probe". We put a loop element between the glass substrate.

Figure 9 shows the output of both single and double-sided glass probes, the double-sided glass probe (Fig. 6 (b)) indicates the better symmetry.

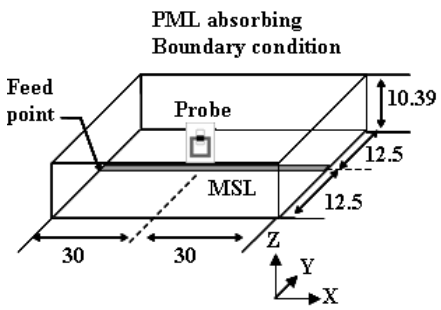

Fig. 3 Analysis model for FDTD simulation

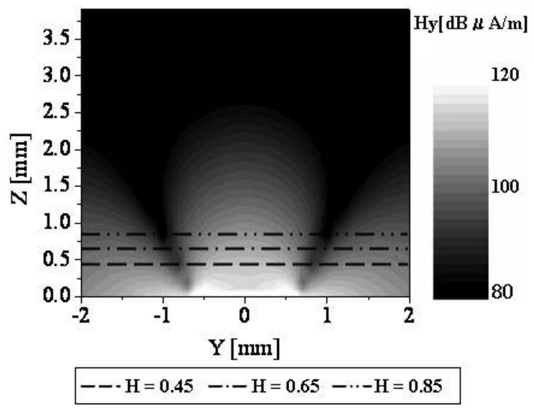

Fig. 4 Magnetic field distribution

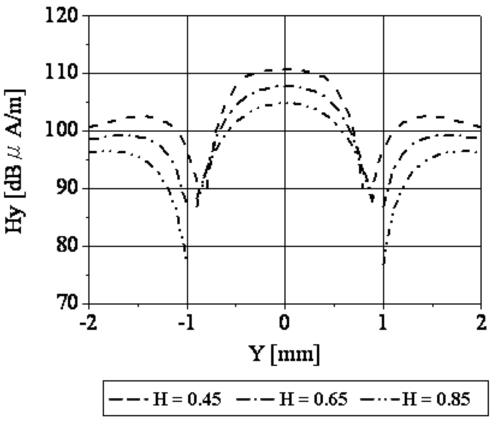

Fig. 5 Magnitude of magnetic field distribution

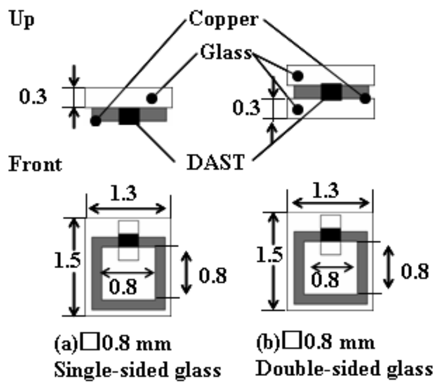

Fig. 6 Probe models for FDTD simulation

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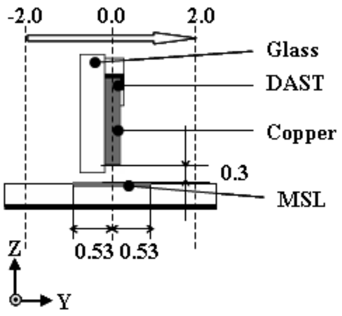

Fig. 7 Setting of probe FDTD simulation

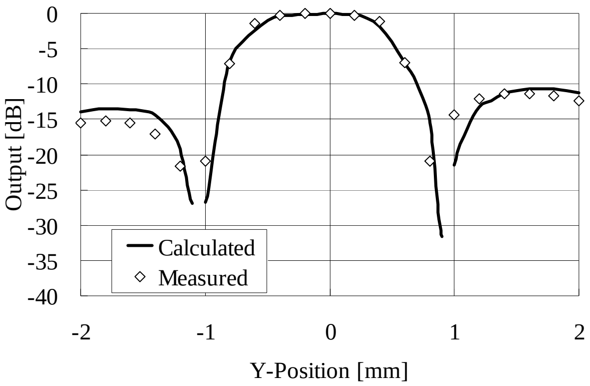

Fig. 8 Output of single-sided probe model

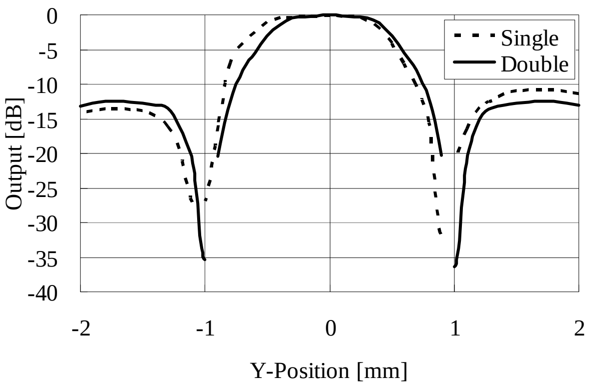

Fig. 9 Calculated output of probes

C. *Frequency Response Characteristics of Probe*

Figure 10 shows the probe models used for the FDTD simulation to evaluate the frequency response. In Figs. 10 (a)-(c), the size of probe is the same as that used in the experiment. In the simulation, the probe was set parallel to the MSL. The frequency response of the probe was calculated up to 100 GHz with a Gaussian pulse. The optical insertion loss from the laser source to the photo receiver α (= 0.3) is adjusted to the experiment data.

The signal voltage V_{out} from the optical probe system is given as,

$$V_{out} = \frac{\alpha \cdot O_{CW}}{2}\left(1 + \pi \frac{V_{DAST}}{V_{\pi}}\right) \cdot \eta_{o/e} \cdot R \qquad (2)$$

$$V_{\pi} = \frac{\lambda \cdot t}{(n_x^3 \cdot r_{11} - n_y^3 \cdot r_{21}) \cdot l}$$

where V_{π} is the half wave voltage. V_{DAST} is the voltage across the DAST crystal. r_{11} (= 53 pm/V) and r_{21} (= 25 pm/V) are the EO (electrooptic) constants of the DAST crystal. O_{CW} (=25 m W), R, $\eta_{o/e}$ (= 0.5 A/W), λ (= 1.34 μm), t (= 0.3 mm) and l (= 0.25 mm) are the power of the laser source, the output impedance of the photo receiver, the conversion efficiency, the wavelength of the laser beam, the thickness and the length of the DAST crystal, respectively.

Therefore, we calculated the output of the probe model from the following formula.

$$V_{out} = 8.1 \times 10^{-5} V_{DAST} \quad (3)$$

Figure 11 shows the FDTD calculated results for four kinds of probe models. In figures 12 to 14, experimental results for the probes with loop dimensions from 0.5 mm square to 0.3 mm square are overlaid on the calculated results. The resonant frequencies are in good agreement with the experimental results. Although the output level becomes decrease, we can expect the resonant frequency of the 0.2 mm square probe is 85 GHz.

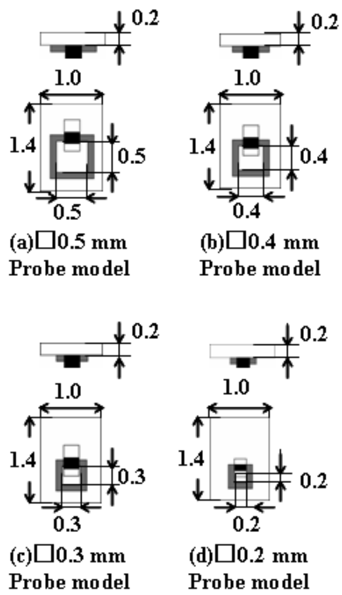

Fig. 10 Probe models for FDTD simulation

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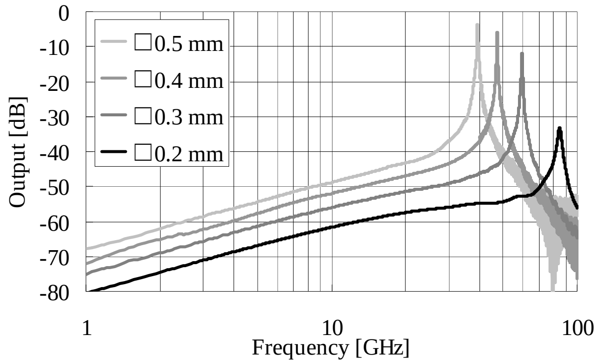

Fig. 11 Frequency characteristics of probe models

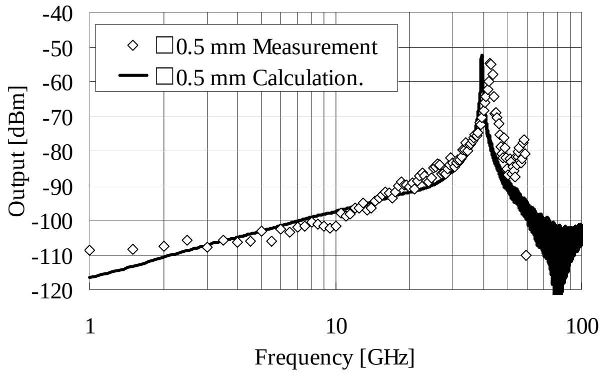

Fig. 12 Frequency characteristics of □0.5-mm probe

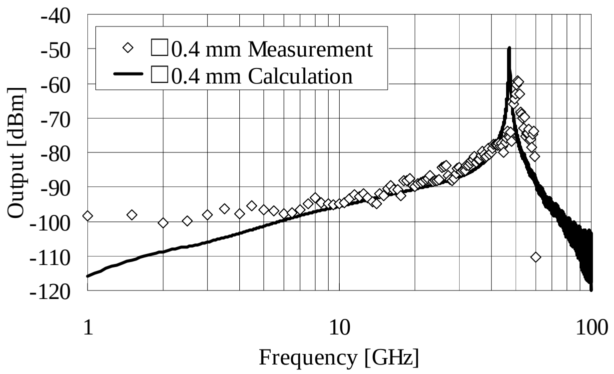

Fig. 13 Frequency characteristics of □0.4-mm probe

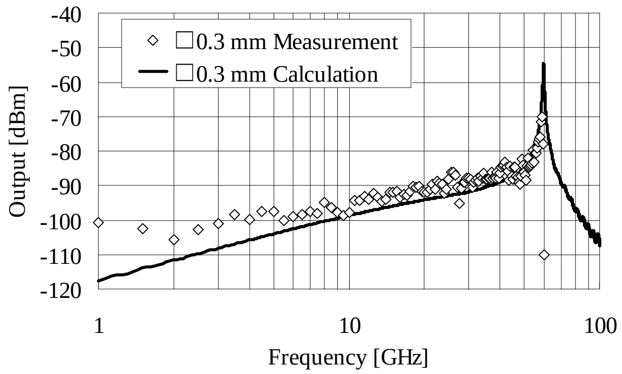

Fig. 14 Frequency characteristics of □0.3-mm probe

IV. Conclusion

We analyzed the output characteristics of optical magnetic field probes using DAST crystals in the electromagnetic field above a microstrip line by experiments and FDTD simulation. We confirmed that the use of a single glass substrate produces asymmetrical output data, whereas the use of two glass substrates produces symmetrical output data.

Moreover, we found that it was possible to analyze the frequency response of a small loop probe with high precision. These results indicate that the FDTD method works well and can be a useful tool in the design of our probe.

References

[1] E.Suzuki, S.Arakawa, H.Ota, K.I.Arai, and R.Sato, "Optical Magnetic Field Probe Working up to 15 GHz using CdTe Electrooptic Crystals," IEEE Trans. Electromagn .Compat., Vol47, No2. pp. 344-351, May 2005.

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