Estimation of Current Distribution Using Polarization Stabilized MO Probe

S. NAKAMATSU†, S. MITANI‡, R. YAMAGUCHI†, S. UEBAYASHI†, M. KISHI‡, and M. TSUCHIYA††
†NTT DoCoMo, Inc. 3-5 Hikari-no-oka, Yokosuka, Kanagawa, 239-8536 Japan
‡The University of Tokyo. 7-3-1 Hongo, Tokyo 113-8656, Japan
††National Institute of Information and Communications Technology
4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan
E-mail: †nakamatsu@mlab.yrp.nttdocomo.co.jp

Abstract

This paper investigates a magnetic field sensor based on the rotation magnetization phenomenon of a magneto-optical (MO) crystal and the third generation probing scheme to estimate with a high level of accuracy the current distribution of mobile devices that radiate RF waves. The probing scheme, which employs an optical fiber, has a problem in that fluctuation due to optical polarization causes measurement instability. In order to achieve stable measurement, we propose employing a polarization stabilized MO probe. This probe stabilizes the optical polarization through a process in which the polarization signals, which indicate the magnetic field level, are converted into an amplifier signal immediately after the_light passes through the MO crystal. We constructed a prototype probe and its performance is compared to that of the conventional magnetic sensor, which comprises a small loop antenna. The comparison results show that the current distribution can be estimated more accurately using the MO probe than by using a small loop antenna because the MO probe can come into closer proximity to the device under test than the loop antenna and it does not disturb the electromagnetic field.

1. INTRODUCTION

In electromagnetic compatibility (EMC) assessment or the controlling of the radiation characteristics of wireless mobile devices, the current distribution on the chassis is an important parameter. The current distribution is evaluated based on the magnetic field value that is obtained from a point that is in very close proximity to the surface of the device under test (DUT). There are three requirements to estimate the current distribution with a high level of accuracy: very close proximity; a high degree of spatial resolution; and no interference to the electromagnetic field. Heretofore, mainly the small loop antenna was employed as a magnetic sensor. However, because of the loop antenna structure, it is difficult to satisfy these three requirements for estimating the current distribution. In this paper, we employ a probe that consists of a magneto-optical (MO) crystal, has no metal in its construction, and has a micro-sensitive area that is sensitive to the micrometer scale [1]. This probe is categorized as a third generation probing scheme, which employs an optical fiber and electro-optical or MO material. The third generation probing scheme has an important problem in that fluctuation in the optical polarization in the optical fiber causes measurement instability. We propose an MO probe structure to stabilize the polarization and estimate the current distribution using this probe.

2. PRINCIPLE OF MO PROBE

2.1 Probe Structure

The MO crystal generates the Faraday effect, which causes rotation of the optical polarization angle relative to the magnetic field value. By applying this effect, the MO probe measures the magnetic field value by measuring the angle of the linear polarization. Heretofore, magnetic field measurement using the MO crystal employed polarization rotation resulting from the Faraday effect, which is caused by the magnetic domain wall displacement phenomenon [2]. However, because this phenomenon is slow, the measurable frequency is limited to several megahertz at most, and it cannot measure the high-frequency magnetic fields that are generated by the recent mobile communication devices such as mobile phones. In this paper, the measurement targets are devices that use RF electromagnetic waves. Therefore, in order to measure high-frequency magnetic fields, we employ the rotation magnetization phenomenon to rotate the linear polarization angle, which can handle high-frequency magnetic fields of approximately 10 GHz [3]

The construction of the MO probe is shown in Fig. 1. Magnetic field measurements are performed using the following method. 1) Linear polarized light is incident to the MO crystal passing through a polarization-maintaining optical fiber (PMF) and a prism. 2) The angle of the linear polarization is rotated

ISBN: 89-86522-79-9 94460©KEES

relative to the magnetic field value of the MO crystal. 3) An analyzer comprising a deflecting plate converts the polarization angle into an optical power signal. 4) A photo diode (PD) converts the optical power signal into an RF signal and the resulting signal is measured using an RF spectrum analyzer.

In this measurement system, some light can pass through the analyzer when the magnetic field value is low, and more light can pass through the analyzer when the magnetic field value is large.

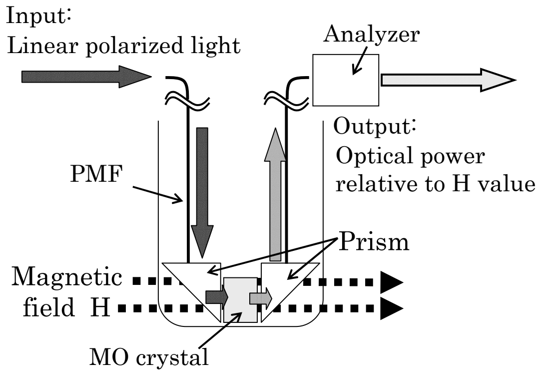

Fig. 1 Construction of MO probe

2.2 Construction of Polarization Stabilized MO Probe

In the measurement using an optical fiber, the stabilization of the polarization and the controlling techniques are important because fluctuation in the polarization in the optical fiber causes measurement instability. The polarization condition tends to fluctuate based on the fiber conditions (temperature, vibration, inflection, and so on). Even if a PMF is employed, the polarization conditions cannot be maintained except at specific polarization angles. In this paper, in order to resolve this problem, the optical fiber between the MO crystal and the analyzer is excluded by setting an analyzer at the top of the probe and next to the MO crystal. Therefore, the polarization signals are converted into an amplifier signal immediately after passing through the MO crystal. This construction achieves stable polarization conditions and enables magnetic field measurement. The construction of a prototype for the Polarization Stabilized MO Probe is shown in Fig. 2

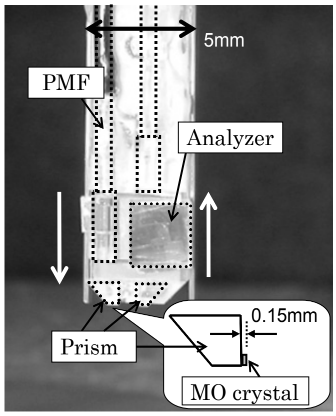

Fig. 2 The prototype of polarization stabilized MO Probe

2.3 Measurement System

A block diagram of the experimental configuration for the MO probe is shown in Fig. 3. A Laser Diode (LD) is utilized for the CW light source. The linear polarization is adjusted by a polarization controller (PC) incident to the MO probe. By using EDFA1 and EDFA2, the total optical power after passing through these two amplifiers is kept constant to improve sensitivity [4]. In order to measure the RF electromagnetic waves, a high-speed PD (20 GHz) is employed.

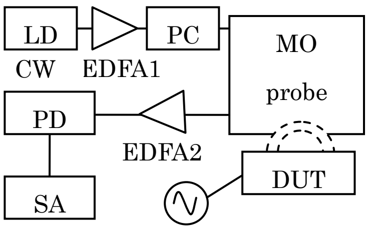

Fig. 3 Experimental configuration for MO probe

A photograph of the DUT, which is a mobile handset model, is shown in Fig. 4. A planar inverted-F antenna (PIFA) is employed in the DUT because this antenna is equipped in many communication devices and because the transmission characteristics are well known. The investigation parameters are given in Table I.

Table 1 Investigation parameter

Optical power	4.77 dBm
Light wavelength	1550 nm
DUT	Mobile handset model
Element	PIFA
RF input power	20 dBm
RF frequency	2.0 GHz
RF test signal	CW

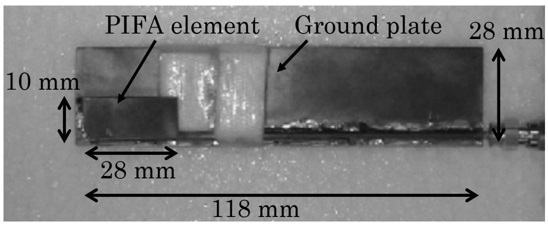

Fig. 4 Mobile handset model

3. EVALUATION OF MO PROBE

3.1 Optical Polarization Stability

In order to evaluate the construction of the polarization-stabilized MO probe, we compare the received optical power before EDFA2 in the conventional construction, which employs an optical fiber between the MO crystal and analyzer, to that of the proposed construction. In this comparison, there is no magnetic field. The results are given in Fig. 5. The optical power of the conventional construction gradually increases. The

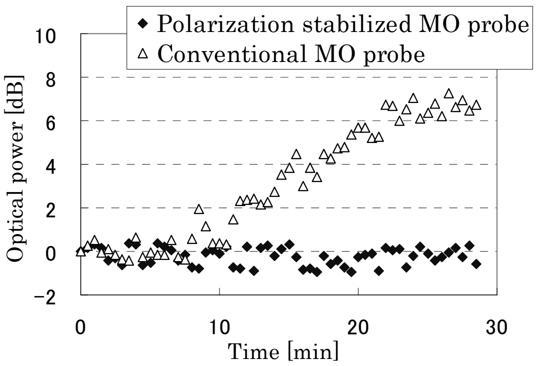

Fig. 5 Received optical power

reason for this is thought to be that the optical polarization angle is rotated gradually over time. On the other hand, the optical power of the proposed construction is stable. These results show that a stable magnetic field measurement can be achieved using the proposed construction.

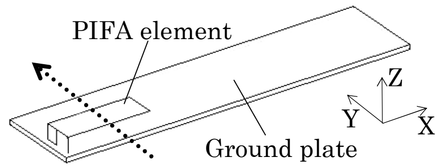

Fig. 6 Observation line on DUT

3.2 Measurement of Magnetic Field

The magnetic field value of the DUT is measured using the proposed MO probe and conventional magnetic field sensor, which employs a small loop antenna. The observation line crosses over the PIFA element, which is shown in Fig. 6. Distance "d" from the element to the observation line is 1.5 mm, which is the shortest for the small loop antenna. The measurement of the Hy value, which is the intensity of the magnetic field along the Y axis, is shown in Fig. 7. The measurement results for the proposed MO probe are similar to those for the conventional magnetic sensor.

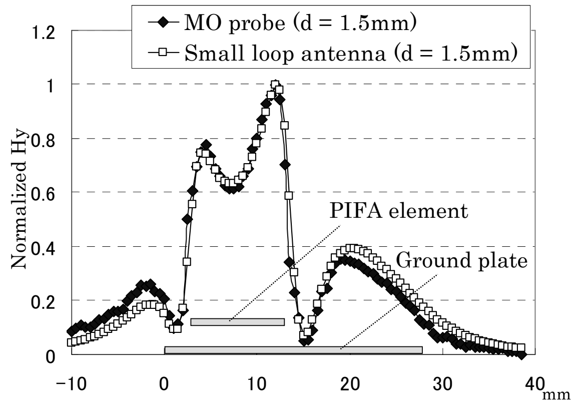

Fig. 7 Magnetic field distribution

3.3 Estimation of Current Based on Proximity to Each Magnetic Sensor

The current distribution on the DUT is estimated based on the magnetic field value from the proposed MO probe and that from the conventional small loop antenna. The magnetic field is measured at the closest point wherever possible for each magnetic sensor. The current estimation employs equivalent Formula (1). Here, because the object of the estimation is assumed to be flat, there is no current in the normal direction. Consequently, the normal vector is represented as Formula (2). From Formulae (1) and (2), the current is obtained using Formula (3).

$$I = n \times H \quad \cdot\cdot\cdot\cdot\cdot (1)$$
$$n = (0, 0, 1) \quad \cdot\cdot\cdot\cdot\cdot (2)$$
$$I = (-Hy, Hx, 0) \quad \cdot\cdot\cdot\cdot\cdot (3)$$

The results of the current estimation using each sensor and the numerical simulation value are shown in Fig. 8

Because the MO probe can measure the magnetic field at a point closer (less than 500 μm) than the conventional small loop antenna, the estimation results from the MO probe are closer to the current distribution obtained from the numerical simulation than are the results from the loop antenna.

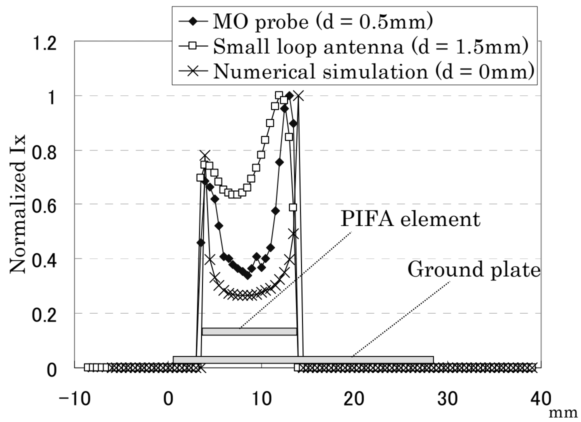

Fig. 8 Estimation of current distribution

3.4 Noninterference of Electromagnetic Field

The MO probe achieves noninterference of the electromagnetic field because it contains no metal in its construction.

In order to evaluate this effect, the electromagnetic field is calculated using the FDTD method for cases with the MO probe, with the small loop antenna, and when there is no sensor. Each sensor is set above the microstrip line (MSL). The distance between the bottom of the sensor and the MSL is 0.2 mm (the measurement point for the loop antenna (center of loop) is 1.5 mm). The simulation model and results are shown in Fig. 9. When the loop antenna is set close to the MSL, the magnetic field is dispersed along the element. On the other hand, when the MO probe is used or when there is no sensor employed, the magnetic field exhibits no disturbance.

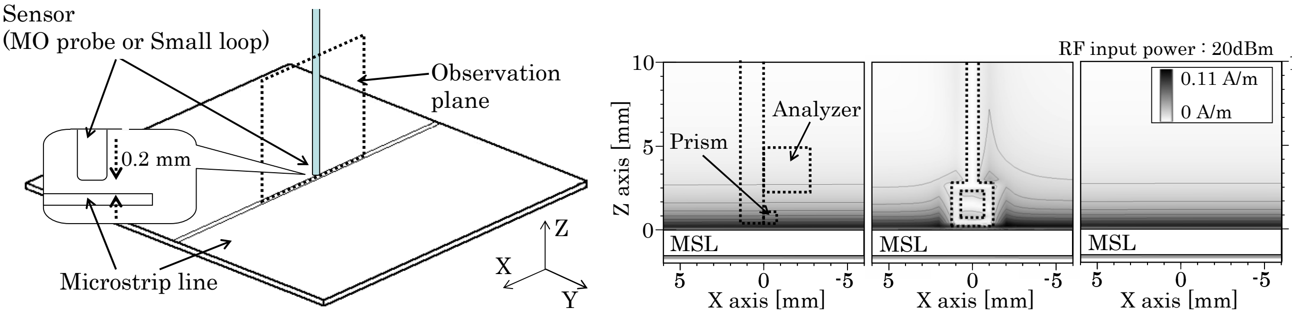

Fig. 9 Magnetic field disturbance

3.5 Estimation of Two-Dimensional Current Distribution Using MO Probe

By using the proposed MO probe, we can estimate a two-dimensional current distribution on the antenna element of the mobile handset model. The results are shown in Fig. 10. The current distribution estimated using the MO probe is in good agreement with that from the numerical simulation.

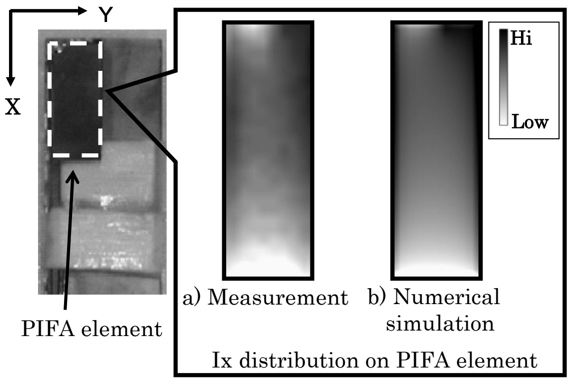

Fig. 10 Estimation of current two-dimensional distribution

4. CONCLUSION

This paper investigated measurement using an MO probe to estimate with a high level of accuracy the current distribution on a mobile device. Improvement in the measurement stability is achieved using the proposed MO probe, which does not employ an optical fiber between the MO crystal and analyzer. When comparing the MO probe and the small loop antenna, the measurement values of the magnetic field agree with each other at the same distance from the DUT. The MO probe estimation of the current approaches that from the numerical simulation because of its close proximity. Furthermore, the simulation results show that the MO probe does not cause interference to the electromagnetic field. The two-dimensional current distribution of the mobile handset estimated using the MO probe and that calculated from the FDTD simulation are in good agreement. Consequently, it is shown that the MO probe is well suited to estimating the current distribution. However, the received RF power of the MO probe measurement system is still at a low level and there is still much room for improvement. Considering this, our task is to improve the sensitivity so that we can employ this technique in the EMC assessment of mobile devices.

REFERENCE

[1]E. Yamazaki, S. Wakana, M. Kishi, M. Iwanami, S. Hoshino and M. Tsuchiya, “Three-dimensional magneto-optic near-field mapping over 10-50 μm-scale line and space circuit patterns,” Conference Proceedings - Lasers and Electro-Optics Society Annual Meeting-LEOS, vol. 1, pp. 318-319, 2001.

[2] N. Itoh, H. Minemoto, D. Ishiko, and S. Ishizuka, “Optical magnetic field sensors with high linearity using Bi-substituted rare earth iron garnets,” IEEE Transactions, vol. 31, issue 6, pp. 3191 – 3193, Nov. 1995.

[3] E. Yamazaki, S. Wakana, M. Kishi, and M. Tsuchiya, “10 GHz-class magneto-optic field sensing with bi-substituted rare-earth ion garnet rotation magnetization employed,” Japanese Journal of Applied Physics, vol. 41, no. 2 A, pp. 904-907, 2002.

[4] S. Mitani, E. Yamazaki, M. Kishi and M. Tsuchiya, “EDFA-enhanced sensitivity of RF magneto-optical probe”, Technical Digest of 2003 International Topical Meeting on Microwave Photonics(MWP2003), Budapest, Hungary, September 10-12, 200