A Three-Axis Electro-Optic Probe for Specific Absorption Rate Measurement

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Abstract

This paper presents a new Specific Absorption Rate (SAR) measurement technique that employs the Electro-Optic (EO) probe. Conventionally, the electric field (E-field) probe comprising diode-loaded dipole sensors is employed for SAR measurements. We developed a prototype of a three-axis EO probe for SAR measurement. This three-axis EO probe is capable of measuring both the amplitude and phase of each E-field component, simultaneously. We demonstrated the potential of the three-axis EO probe in SAR measurements. Evaluation results show that we can apply the three-axis EO probe to practical SAR measurement.

1. Introduction

In recent years, personal mobile phones have become popular in Japan as well as worldwide. In addition, Wireless Local Area Networks (WLANs) connected to PCs or used with mobile phones have also become commonplace. It is well known that Radio Frequency (RF) waves above 100 kHz can produce heat in tissue and that a very high level RF field may cause thermally related health effects. Based on established adverse health effects, safety guidelines were determined by organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. In these guidelines, the SAR is used as the primary dosimetric parameter for RF energy absorbed by the human body. The SAR is given by

$$SAR = \frac{\sigma \, | \boldsymbol{E} |^2}{\rho} \tag{1}$$

where $\boldsymbol{E}$ is the electric field in the human body [V/m] and ρ [kg/m^3]and σ [S/m] are the density and conductivity of human tissue, respectively. The spatial average SAR over a 1 g- or 10 g-mass (1 g or 10 g averaged SAR) is adopted in order to evaluate the near-field exposure from radio devices based on the guidelines and regulations, e.g., [1]. SAR measurement procedures using an E-field probe comprising diode-loaded dipole sensors, with respect to a mobile phone for compliance testing, which is intended to be used at the side of the human head, were standardized by the International Electrotechnical Commission (IEC) [2] and other bodies. The IEC is now developing another SAR measurement procedure for various types of wireless device usage such as mounting the device on the body, taking photos or videos, and sending E-mail [3]. In this paper, a novel three-axis EO probe for SAR measurements is discussed. Recently, several studies with respect to EO probes were conducted for SAR measurement [4], [5]. This is because the EO probe can measure both the amplitude and phase information of the E-field over broadband frequency ranges. In addition, the EO probe can measure the E-field at multiple frequencies simultaneously.

2. EO Probe

Several studies with respect to the EO sensors have been conducted for various applications, e.g. measurements on antenna patterns, ICs, and other EMC problems [6]. With respect to the SAR measurement, Loader et al. conducted an investigation using an EO-probe that employs a $LiNbO_3$ substrate inserted into the gap of a small metal dipole antenna [4]. On the other hand, we investigated a different type of EO probe [5], [7].

2.1 Basic Structure

Figure 1 shows a photograph of the prototype of the three-axis EO probe, which comprises three EO crystals (1 mm^3 cube), a dielectric mirror, a collimating lens, a ferrule, and an optical fiber encased in ceramic. CdTe is selected as the EO crystal. The EO crystals are directly connected to the optical fibers and can detect each orthogonal component of

the E-field. The signs "⊗", "→", and "↑" denote the direction of the detectable E-field component of each crystal. The main noteworthy feature of this configuration is that there is no metallic element around the tip of the probe.

Figure 2 shows the experimental configuration, which comprises the three-axis EO probe, a cubic acrylic container filled with tissue-equivalent liquid (phantom), and a reference dipole antenna. The probe is inserted into the phantom, and the distance between the tip of the probe and the bottom surface of the phantom is 5 mm. A dipole antenna is located underneath the phantom and the distance between the antenna feed point and the phantom surface is 10 mm. The frequency is 1950 MHz, which is used for the middle frequency of the International Mobile Telecommunication 2000 (IMT-2000) uplink band. The dielectric properties of the phantom liquid correspond to those defined by the IEC [2], i.e., relative permittivity and conductivity are 40.0 and 1.4 S/m, respectively. The probe can be scanned using a three-axis scanning system while the dipole antenna is fixed. The origin of the coordinate is located on the phantom surface closest to the antenna feed point.

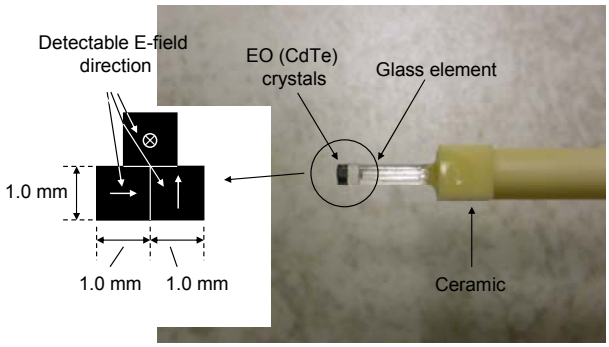

Fig. 1 Prototype of three-axis EO probe.

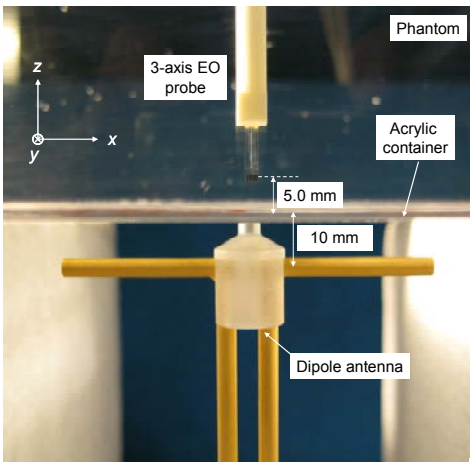

Fig. 2 Experimental configuration.

2.2 Basic Properties of Three-Axis EO Probe

The linearity, minimum sensitivity, and directivities of the three-axis EO probe are evaluated using the above experimental configuration. In order to evaluate the linearity and sensitivity of the probe, the antenna input power is varied. In this case, the tip of the probe is fixed at $(x, y, z) = (0, 0, 5\text{ mm})$. Figure 3 shows the relationship between the detectable SAR values and measurement output of the x-axis sensor. It is obvious that the measurement output of the probe is linear within ± 0.3 dB over the SAR range from 0.01 to 100 W/kg and the minimum sensitivity of the probe is 0.002 W/kg. The measured linearity and minimum sensitivity of the probe satisfies the specifications determined by the IEC [2]. The directivities of the probe are measured while rotating the dipole antenna and the probe is fixed. Figure 4 shows the directivities of the x-axis and y-axis sensors. All the data are normalized to the maximum values in each case. It is clear that the patterns of both directivities appear as eight-shape and discrimination against the cross-polarization is greater than 30 dB. We note that the directivity of the z-axis sensor has a similar result as well (not shown).

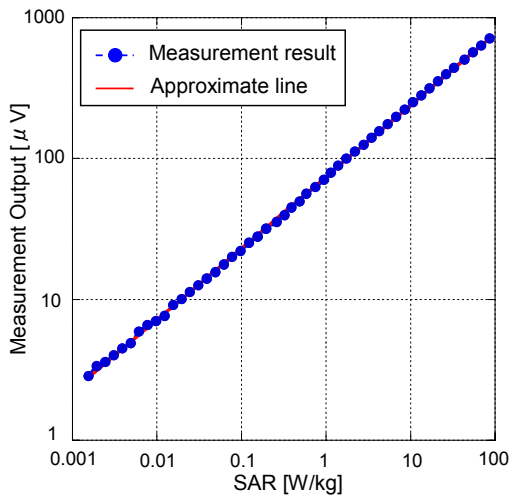

Fig. 3 Measured linearity and sensitivity of the probe.

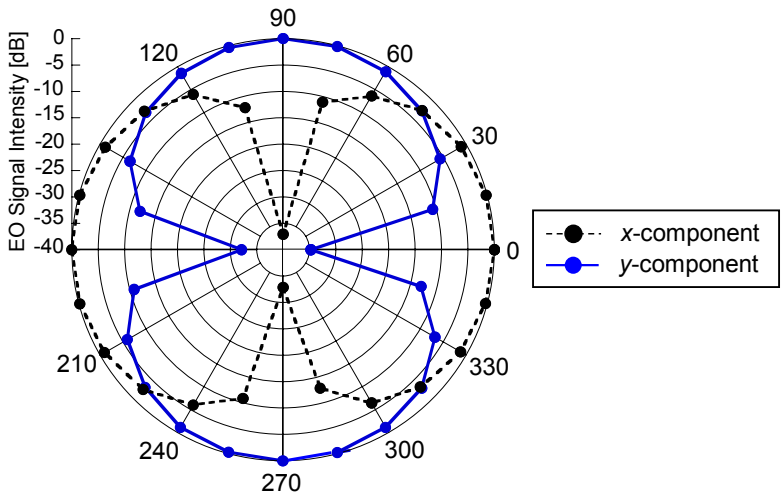

Fig. 4 Measured directivities of the probe.

2.3 Measurement Results of E-Field Distribution

E-field distributions of the dipole antenna are measured using the same experimental configuration shown in Fig. 2. As mentioned above, one of the features of the EO probe is that it is capable of measuring the phase information of the E-field. Therefore, both the amplitude and phase of the E-field are measured and compared to the calculated E-field distributions using the Finite-Difference Time-Domain (FDTD) method. Figure 5 shows the E-field distributions along the *x*-axis. Since the *x* component is the main polarization in this case, i.e., a dipole antenna, the amplitudes of the *y* and *z* components are comparatively low. Therefore, the phases of the *y* and *z* components are omitted. It is clear that the amplitude and phase of all the measured results are in good agreement with those of the calculated results. We confirmed that the EO probe can measure the amplitude and phase of the E-field at a high accuracy level. In addition, the measured electric field distributions along different axes in the phantom agree very well with the calculated results (not shown).

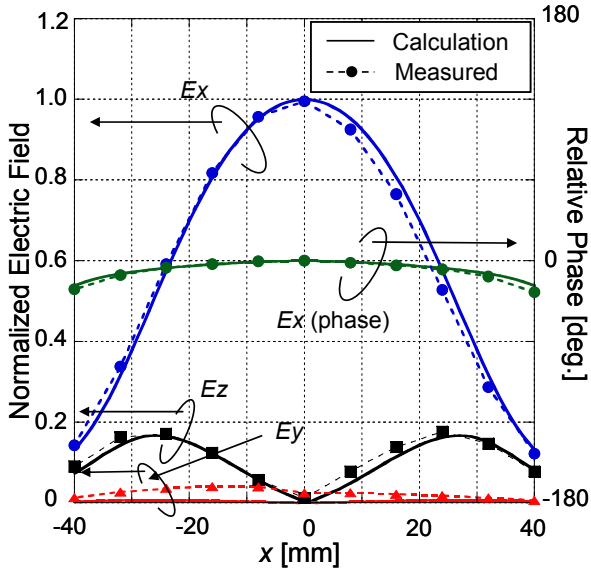

Fig. 5 Measured electric field distributions along *x*-axis.

3. Conclusion

This paper described a new SAR measurement technique employing the three-axis EO probe. As a result, we confirmed that the prototype of the three-axis EO probe is capable of measuring both the amplitude and phase of the E-field, simultaneously. The probe can detect each orthogonal component of the E-field separately. The measured E-field components are in good agreement with the calculated results. All the evaluated results exemplify the potential of applying the EO probe to a practical SAR measurement.

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5. References

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