# Experimental Study of E/O Probe for Assessment of Human Exposure to Fields of 85 kHz EV Charging System

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**Abstract** An electric/optical (E/O) probe system for measurement of in-body field strength at 85 kHz is designed and fabricated. The proposed system is composed of an optical modulator and an impedance matching circuit. The optical modulator reduces interference of conducting cables while the impedance matching circuit enhances the sensitivity of the system. It is demonstrated that the sensitivity of the probe with the impedance matching circuit is enhanced even when the probe is in lossy NaCl solution.

**Keyword** Optical modulator, in-body, low frequency

## 1. Introduction

Human exposure to the low-frequency electromagnetic (EM) field of an electric-vehicle (EV) charging system by a wireless power transfer (WPT) system should be assessed accurately in advance because the system deals with high power. Electric field strength is should be assessed according to the guidelines [1]. It is expected that the measurement of internal electric field strength suffers from low sensitivity of a probe at low frequency band and interference of a conducting cable.

An optical modulator has been introduced to reduce the interference of the conducting cable [2]. No conducting cable is necessary because a probe is connected to the optical modulator via an optical fiber. One of the disadvantages of the optical modulator is low sensitivity which comes from impedance mismatching between the probe and the optical modulator. Although various studies have been performed, they have only focused on a probe working in free space at MHz/GHz band [3][4].

In this paper, an electric/optical (E/O) probe system for measurement of in-body, low frequency field strength is designed and fabricated. The probe system is composed of an optical modulator, impedance matching circuit using toroidal coil, and dipole antenna. Field strength in air, in deionized water, and in 0.5 % NaCl solution is measured by using the fabricated probe at 85 kHz and enhanced sensitivity of the probe is demonstrated. This paper demonstrates an improvement of the fabricated E/O probe in [5].

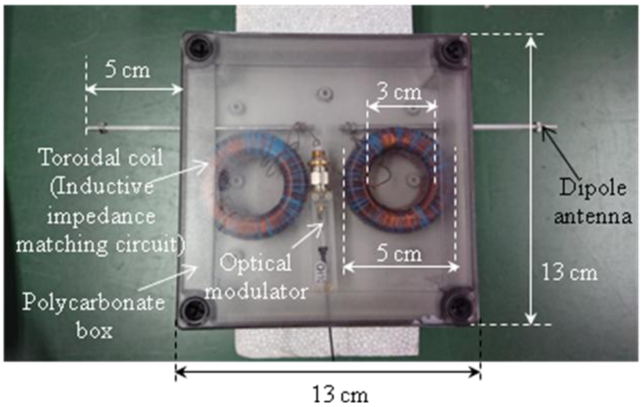



Fig.1. Photograph of fabricated probe.

## 2. Designed probe system

Here, a high sensitivity probe system is designed via conjugate impedance matching approach [4]. The fabricated probe is shown in Fig.1. The probe is composed of the optical modulator, toroidal coil, and dipole antenna. Input impedance of the optical modulator is $Z_{in}$ = 820 — $j5.8\times10^5$ Ω at 85 kHz while that of the probe inside a human body is $Z_a$ = 40 — $j3.3$ Ω at 85 kHz, respectively. Toroidal coil works as an impedance matching circuit and its inductance varies as the number of turns of coil or the permeability of ferrite core varies.

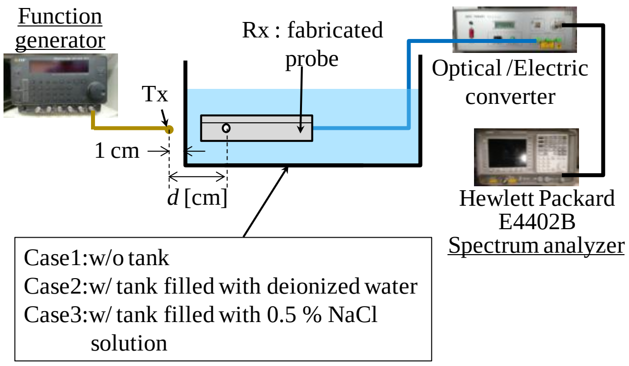
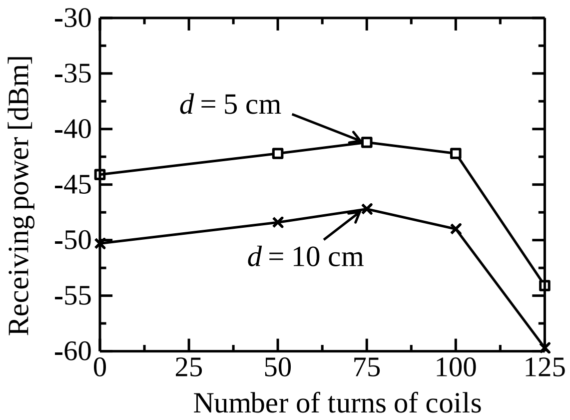


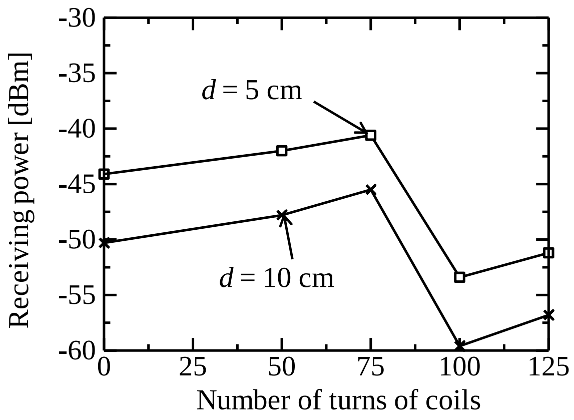

Fig.2. Experimental setup.

Table1. Measurement parameters

| | |
|---|---|
| Incident power | 22 dBm |
| Frequency | 85 kHz |
| Spacing between Tx and Rx | $d$ = 5, 10 cm |
| Number of turns of coils | $n$ = 50,75,100,125 |
| Relative permeability of ferrite cores | $\mu_r$ = 6000, 8500 |




(a) Permeability of ferrite core : 6000




(b) Permeability of ferrite core : 8500

Fig.3. Receiving power of the probe w/ or w/o coil in the tank filled with deionized water (Case2).

Table2. Receiving power of the probe ($d$ = 10 cm)

| | In air [dBm] | In deionized water [dBm] | In 0.5 % NaCl solution [dBm] |
|---|---|---|---|
| w/o coil | — 42 | — 50 | — 104 |
| w/ coil ($\mu_r$ = 6000) | — 40 | — 47 | — 100 |
| w/ coil ($\mu_r$ = 8500) | — 40 | — 46 | — 101 |

## 3. Measurement Results

Electric field strength was measured by using the fabricated probe at 85 kHz. As shown in Fig. 2, receiving power of the fabricated probe in air (Case1), in a tank filled with deionized water (Case2), and in a tank filled with 0.5% NaCl solution (Case3) was measured. A dipole antenna of 22 cm length was used as a transmission antenna. Measurement parameters are shown Table1.

Receiving power of the probe w/coil in the tank filled with deionized water (Case2) is shown in Fig.3. As shown in Fig.3, receiving power of the probe varies as the number of turns of coils or the permeability of the ferrite cores varies. A drop of the receiving power of the probe with 75 or 100 turns coils will result from the resonance of coils. Although receiving power of the probe decreases as $d$ increases, it is found that curves of receiving power are the same each other except for 5 dB shift, approximately. Table2 shows receiving power of the probe at $d$ = 10 cm. As shown in Table2, the receiving power w/o coil in 0.5 % NaCl solution is 62 dB lower than that in air. Such small receiving power comes from lossy nature of the NaCl solution ($\sigma$ = 0.6 S/m). Although the receiving power of the probe is strongly affected by medium surrounding the probe, enhanced sensitivity of the proposed system over conventional one has been demonstrated in all three cases.

## 4. Conclusion

In this paper, an E/O probe system for measurement of low frequency, in-body field strength has been designed and fabricated. The designed system is composed of an optical modulator, toroidal coil, and dipole antenna. Field strength in air, in deionized water, and in 0.5 % NaCl solution was measured by using the fabricated probe at 85 kHz. It has been demonstrated that the sensitivity of the probe is enhanced by implementing the impedance matching circuit.

## 5. ACKNOWLEDGEMENT

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## 6. COPYRIGHTS



## 7. References

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