POS2-15

Near-Field Gain Measurement of Waterproofed Shielded Loop Antenna in Tissue-Equivalent Liquid

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1. Introduction

Recently, it has been expected that the wireless energy transmission system which uses the phenomenon of magnetic-field resonance will be launched and the methodology of estimating SAR (Specific Absorption Rate) for this system can be required. In this system, the distance that the energy can transfer between the transmitted and received equipments will be tens of centimeters. To estimate SAR for the mobile communication devices, a standard SAR measurement system is generally used to measure the electric-field intensity in the tissue-equivalent liquid surrounded by the shell shaped like a half of head with an electric-field probe [1],[2] . Conversely, the magnetic-field is so dominant that the SAR measurement with the electric-field probe cannot be made accurate at the frequencies which might be allocated for the wireless energy transmission. Therefore, the SAR measurement with the magnetic-field probe should be developed. Also, the magnetic-field probe should be calibrated by relating its voltage to the magnetic-field intensity produced by a shielded loop antenna, which is a candidate of reference antennas at those frequencies.

According to our previous studies, the calibration of the electric-field probe is based on the extended Friis transmission formula and two-antenna method [3]-[5]. In the case that the distance between two antennas is not so long that the far-field condition cannot be satisfied, the near-field gain should be introduced to find the behavior of the electric-field intensity near the reference antennas. For the application of the wireless energy transmission, the distance between the reference antennas would be so short that the above technique of calibrating the probe could be used. In this paper, a waterproofed shielded loop antenna is designed to use the reference antennas in the liquid at 30MHz, and the near-field gain of this antenna is measured by our gain measurement system in the liquid.

2. Measurement Method of Gain in Liquid

As shown in Fig.1, two loop antennas are faced with a shared central axis in the liquid. Then, transmitting and receiving antennas are connected to the ports of the vector network analyzer. If the distance between the two antennas, r, is long enough, the transmitted power $|S_{21}|^2$ can be given as

$$|S_{21}|^2 = (1-|S_{11}|^2)(1-|S_{22}|^2)\frac{G_1 G_2 \exp(-2\alpha r)}{4\beta^2 r^2}. \tag{1}$$

Eq.(1) can be derived by use of the Friis transmission formula which is valid in the far-field zone of the two antennas. $S_{ij}\,(i,j=1,2)$ is S-parameters between two antennas and G_1 and G_2 are the gains of transmitting and receiving antennas. Also, α and β are the attenuation and phase constants in the liquid. The condition of $G_1 = G_2 = G$ can be found by applying the two-antenna method to Eq.(1), then Eq.(1) can be solved for G as

$$G_n(r) = \frac{|S_{21}|\exp(\alpha r)\cdot 2\beta r}{\sqrt{(1-|S_{11}|^2)(1-|S_{22}|^2)}}, \tag{2}$$

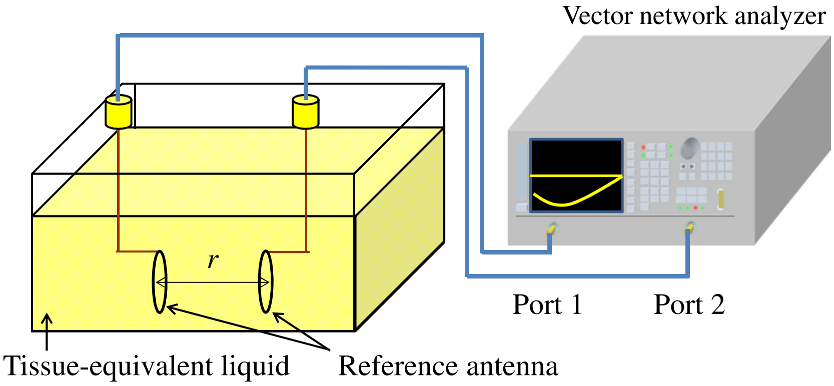

Figure 1: Measurement system of the gain of reference antenna in the liquid

where $G_n(r)$ is defined as the near-field gain, which converges the far-field gain, G, for long distance under the far-field condition. S_{21} should be measured in the far-field zone to replace $G_n(r)$ as constant G. However, it is difficult to measure S_{21} in the far-field zone because of the large loss in the liquid and the long distance between the two antennas. Therefore, S_{21} must be measured in the near-field zone so that the near-field gain, $G_n(r)$, should be treated as a function of r.

An extension of Eq.(2) for the near-field zone in the liquid can be given as

$$|S_{21}|^2 = (1 - |S_{11}|^2)(1 - |S_{22}|^2)\frac{G^2 \exp(-2\alpha r)}{4\beta^2 r^2} \cdot \exp\left\{2\left(\frac{a_1}{r} + \frac{a_2}{r^2} + \cdots\right)\right\}, \tag{3}$$

where $a_i\,(i = 1, 2, \cdots)$ are complex constants which are dependent upon antenna's configuration and surrounding medium. By applying the two-antenna method to Eq.(3), the near-field gain, $G_n(r)$, can be given as

$$G_n(r) = G \cdot \exp\left\{-\left(\frac{a_1}{r} + \frac{a_2}{r^2} + \cdots\right)\right\}. \tag{4}$$

The dB representation of Eq.(4) can be given as

$$G_{n,\mathrm{dB}}(r) = G_{\mathrm{dB}} + \sum_{i=1}^{n} \frac{A_i}{r^i}, \tag{5}$$

where $A_i\,(i = 1, 2, \cdots, n)$ are real constants. For example, when $n = 2$, Eq.(5) consists of G_{dB}, the term which is inversely proportional to the distance, r, and the term which is inversely proportional to the square of the distance, r^2. As described above, the dB representation of the gain, G_{dB}, can be determined by the following procedure.

1. To calculate the near-field gain, $G_n(r)$, by using measured S-parameters.
2. To fit the above calculated near-field gain to its theoretical curve Eq.(5) and determine the dB representation of the gain, G_{dB}.

3. A Shielded Loop Antenna in Liquid

In this paper, a shielded loop antenna operated in the liquid is selected as the reference antenna to detect the magnetic-field intensity. The configuration of this antenna is shown in Fig.2. It consists of semi-rigid coaxial cable shaped as a circle and a voltage is fed in the gap. The resonant frequency of this antenna depends on the effective wavelength in the liquid. When a measuring frequency is set to 30MHz, the loop length, l, should be equal to 310mm. Also, the antenna should be waterproof by covering it with thin rubber tube or adhesive material to avoid the physical contact between the liquid and the metallic material of the reference antenna.

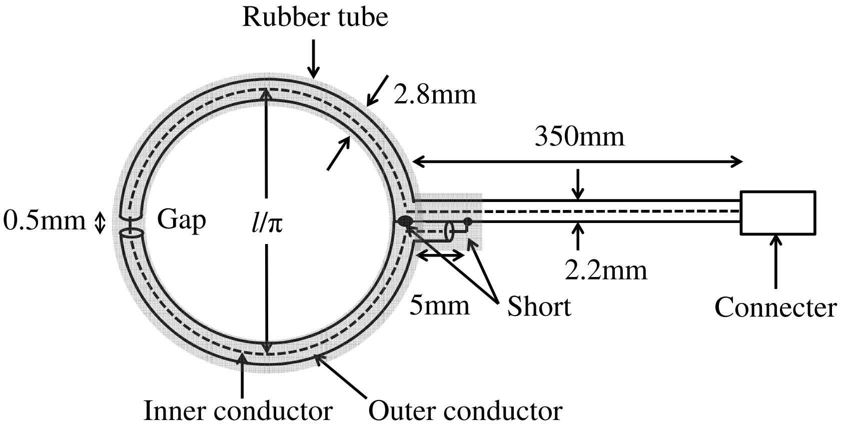

Figure 2: The shielded loop antenna

4. Measured Near-Field Gain

4.1 Complex Permittivity of the Liquid

The tissue-equivalent liquid used in this paper is HT0030 (30MHz), which is available from NTT Advanced Technology Co., Ltd. According to the IEC document [2], the complex permittivity of the liquid should be adjusted as $55.00 - j449.64$ at 30MHz. In practice, it was measured as $55.26 - j386.78$ at 30MHz by the contact probe method (Agilent 85070E). The temperature in the liquid was 23.0°C. The attenuation and phase contents are calculated as $\alpha = 70.61$dB/m, $\beta = 9.38$rad/m. Also, the temperature in the liquid at the gain measurement was controlled to be equal to the temperature when measuring the complex permittivity of the liquid.

4.2 Measurement Equipments

The vector network analyzer (Agilent N5230A , *VNA*) is used for measuring S-parameters between the reference antennas, with IF bandwidth of 50Hz and input power of −5dBm. The liquid is filled to the rectangular container of 600mm × 350mm × 350mm. The distance between the two antennas, r, is controlled by the sliding stage and moved from 0mm to 200mm at intervals of 1mm to measure S_{21} between the two antennas. S_{11} and S_{22} are measured at r =200mm.

4.3 Measurement Results

Fig.3 shows the curve of $|S_{21}|$ measured by *VNA* as a function of r. As the noise floor of $|S_{21}|$ is about −80dB in our measurement setup, no fluctuation in $|S_{21}|$ can be observed. Also, $|S_{11}|$ and $|S_{22}|$ measured were −0.66dB and −0.65dB.

Fig.4 shows the curve of estimated near-field gain, $G_n(r)$, of reference antenna as a function of r. No fluctuation in $G_n(r)$ can be observed. Despite the fact that $G_{n,\mathrm{dB}}(r)$ has a few negative slope in the range from 50mm to 200mm, because $G_{n,\mathrm{dB}}(r)$ converges as r is larger. We can find that our gain measurement method could be used to estimate the near-field gain of the magnetic-field type reference antenna. Next, the far-field gain of the antenna, G_{dB}, can be estimated by fitting $G_{n,\mathrm{dB}}(r)$ to the theoretical curve. The fitting range was selected as 5mm-170mm, with the number of the terms in Eq.(5) of $n = 5$. As shown in Fig.4, the theoretical curve is fitted to $G_{n,\mathrm{dB}}(r)$ well in the above fitting range. The gain, G_{dB}, is estimated −3.22dBi.

5. Conclusion

In this paper, the shielded loop antenna operated in the liquid as the magnetic-field type reference antenna is designed to estimate SAR of the equipments for the wireless energy transfer system. It is found that our gain measurement method developed for the electric-field type reference antenna can apply to the shielded loop antenna which is one of the magnetic-field type reference antennas: we confirm that

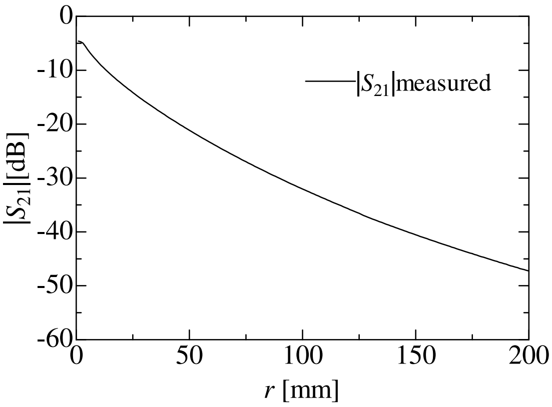

Figure 3: Measured $|S_{21}|$

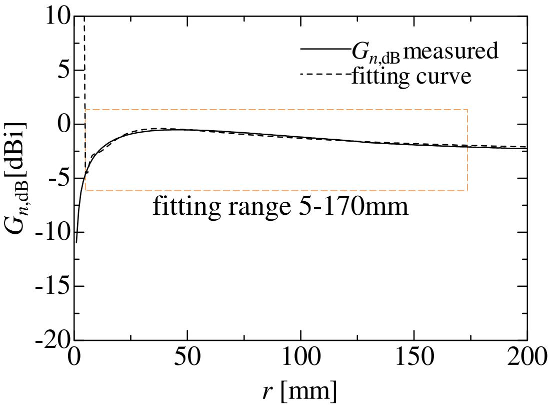

Figure 4: Estimated near-field gain

the theoretical curve of the near-field gain can be derived from the extended Friis transmission formula and the far-field gain can be estimated by curve fitting technique.

In the future, we are going to optimize the design parameters of the waterproofed shielded loop antenna and the fitting range to obtain the near-field gain. To decrease the reflection of the shielded loop antenna, some matching circuits should be introduced. In addition, we are going to analyze the magnetic-field components produced by the shielded loop antenna by use of methods of moment.

Acknowledgments

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