Constant Near-Field Gain for Folded Loop Antennas in Normal Saline At 6.78MHz

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***Abstract*—It is required that specific absorption rate of mobile devices operated in HF band should be evaluated by using a calibrated probe. In this paper, we propose an extension of reference antenna method, which is one of methods for calibrating the probe. As a reference antenna, we examine a circular folded loop antenna immersed in normal saline solution. If its perimeter is well selected, constant near-field gain can be realized in its near-field region. And, to reduce its size, the number of folding should be larger. Also, we show the validity of estimated formula for electric field intensity radiated by the reference antenna with its near-field gain.**

Keywords—near-field gain; folded loop antenna; normal saline; specific absorption rate; HF band

I. Introduction

In recent years, mobile devices operated in HF band, for example, for near-field wireless power transfer system have been developed. Therefore, it is our research imperative to establish a technique of evaluating specific absorption rate (SAR) of the above devices.

The authors have examined an extension of reference antenna method [1], which is one of methods for calibrating the probe, into HF band, for example, at 30 MHz, where the size of the reference antennas is suitable to submerge them in the liquid surrounded by a container [2]. As a result, it is found that a circular loop antennas (CLAs) can be used for the reference antennas when they are faced along their central axis in the liquid [2]. In an IEC standard document for evaluating SAR of devices [3], dielectric property for the liquid is described until 30 MHz. However, there is no authorized references to give dielectric property of the phantom liquid lower than that frequency, such as at 6.78 MHz. One way to set the dielectric property is to use that of 2/3 muscle tissue, therefore we have determined corresponding density of saline solution, which is 0.04 mol/l in 6 MHz band [4]. As another alternative, normal saline is used as the liquid for evaluating SAR. Although well-suited liquid to evaluate SAR at this frequency may be proposed, the normal saline is selected as the liquid in this paper.

A big problem to realize SAR evaluation based on the reference antenna method is the size of the reference antenna or CLA. Since the antenna is operated in the liquid, the wavelength in the liquid is much smaller than free space. However, the size or the diameter of CLA can be determined by a criteria that the near-field gain is flat as respect to the distance from the antenna because the field distribution can be easily evaluated by using near-field gain if the wave impedance is constant [2].

In this paper, to reduce the size of the antenna, the authors propose the use of circular folded loop antennas (CFLA). To validate the use of CFLA, some CFLAs are numerically analyzed by method of moments (MoM), which can treat a wire structure with dielectric coat in the homogeneous lossy medium or the liquid. Also, distance property of the near-field gain and estimated electric field intensity are examined as well as an optimal perimeter of CLFAs can be selected.

II. Near-Field Gain and Electric Field Intensity

A. Near-Field Gain

In the near-field region of the antenna, the near-field gain can be defined and determined by measuring S parameters between two identical antennas according to two antenna method. In the liquid with attenuation and phase constants of α and β, the near-field gain can be given by [2]

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

as a function of the distance between the two antennas, r, where $S_{ij}(r)$s are S parameters between the two antennas, which can be measured by a vector network analyzer.

B. Electric Field Intensity

In the IEC standard document [1], the electric field intensity radiated by the reference antenna is described as a function of the distance, r, but could be determined if the far-field gain were evaluated. In practice, S parameters between the two antennas located in the far-field region cannot be measured in the liquid container. To overcome this difficulty, the authors proposed an expression for the electric field intensity using the near-field gain, which is given as [2]

$$|\boldsymbol{E}(r)| = \left[\omega\mu_0 \frac{P_{\rm in}(1-|\Gamma_t(r)|^2)G_n(r)}{4\pi\beta}\right]^{1/2} \frac{e^{-\alpha r}}{r}, \qquad (2)$$

where $P_{\rm in}$ denotes input power and $\Gamma_t(r)$ denotes refection coefficient at the distance, r, of transmitting reference antenna.

III. Simulated Results

A. Geometry of CLA and CFLAs

As candidates for the reference antenna, we examine a circular loop antenna (CLA), doubly and quadruply circular folded loop antennas (CFLA-3, and CFLA-5) as shown in Fig. 1. All these antennas are fed by delta gap model on the positive x axis and consist of insulated wire conductor, where the wire conductor is assumed to have a radius of 1.1 mm and conductivity of 5.8 S/m and the tubed insulator is assumed to have a thickness of 0.4 mm and dielectric constant of $3.2 - j0.0$. For CFLA-3 and CFLA-5, loop clearance and gap angle at folding part are set to be 20 mm ($= t$) and 10 degrees ($= 2\Delta\phi_{\text{gap}}$), respectively. Also, the ambient medium is assumed to be normal saline with molar concentration of 0.153 mol/l or with dielectric constant of 76.59, conductivity of 1.5 S/m, and wavelength of 982.1 mm at 6.78 MHz [5].

The above antennas are numerically analyzed by using MoM developed by Richmond [6]. In modeling, a circular wire with a diameter of $2a$ is approximated by a regular hexadecagon (regular convex 16-gon) and so on. By facing the two identical antennas as shown in Fig. 2, corresponding near-field gain can be evaluated by calculating S parameters between the two antennas. To calculate electric field intensity radiated by the antenna using MoM, only one antenna is assumed to exist in the liquid. However, it is noted that the near-field gain to estimate the electric field intensity according to (2) can be obtained by using the two identical antennas. Also, the distance between the two antennas is defined as the shortest distance along their central axis in this paper.

B. Distance Property of Near-Field Gain

As mentioned before, if the near-field gain is coincident with the far-field gain, the electric field intensity in the near-field region can be easily estimated by extending the field expression in the far-field region. Also, for CLA, CFLA-3, and CFLA-5, we can find that the distance property of the near-field gain largely depends on their perimeter and the near-field gain is constant if the perimeter is well selected. In this paper, this perimeter is found by inspecting zero slope of the near-field gain in the range of 1000 mm to 3000 mm.

In the case of CLA, constant gain can be realized if the perimeter C is selected to be 1580 mm, as shown in Fig. 3(a). For $C = 1580$ mm or $2a = 506$ mm, the near-field gain converges with the far-field gain, but it does not converge up to 300 mm, where S parameters can be measured in the liquid container, for example, with a size of 600 mm $\times$ 300 mm $\times$350 mm. This means that the size of selected CLA is too large to implement CLA in the liquid container. In the case of CFLA-3, constant gain can be obtained if the perimeter C is selected to be 2620 mm as shown in Fig. 3(b). For $C = 2620$ mm or $2a = 272$ mm, the diameter of optimized CFLA-3 is smaller than CLA, but its size is not small enough to implement it in the container. In the case of CFLA-5, constant gain can be obtained if the perimeter C is selected to be 3070 mm as shown in Fig. 3(c). For $C = 3070$ mm or $2a = 195$ mm, the diameter of optimized CFLA-5 is smaller than CLA and CFLA-3, and it is barely able to implement optimized CFLA-5 in the container. By analogy with the above, it seems that the diameter of optimized CFLA can be reduced if the number of its folding increases.

C. Distance Property of Electric Field Intensity

For SAR probe calibration, the probe can detect the electric field intensity, $|\boldsymbol{E}|$, at its tip in the liquid so that the distance property of the electric field intensity radiated by the reference antenna should be examined. For some selected reference antennas, $|\boldsymbol{E}|$ is calculated as a function of the distance by using MoM and is estimated by using (2) with corresponding near-field gain, which is also a function of the distance. The formula for estimating $|\boldsymbol{E}|$ is valid if the two curves coincide each other. Fig. 4 shows the distance property of calculated and estimated $|\boldsymbol{E}|$for three optimized loop antennas discussed before. Fig. 4(a) shows the distance property of $|\boldsymbol{E}|$ for CLA with $C =$1580mm. For $r >$1180 mm, the difference between two curves is below 1 dB. This means that $|\boldsymbol{E}|$ cannot be accurately estimated in the container if CLA is used as a reference antenna. Fig. 4(b) shows the distance property of $|\boldsymbol{E}|$ for CFLA-3 with $C =$2620 mm. For $r >$110 mm, the difference between two curves is below 1 dB. It is noted that the distance that calculated and estimated $|\boldsymbol{E}|$ coincide each other is short. Fig. 4(c) shows the distance property of $|\boldsymbol{E}|$ for CFLA-5 with $C = 3070$ mm. For $r >$230 mm, the difference between two curves is below 1 dB. If CFLA-5 is used as the reference antenna, calculated and estimated $|\boldsymbol{E}|$ coincide each other as well as the near-field gain is constant in the container.

IV. CONCLUSIONS

To realize SAR probe calibration at 6.78 MHz, the reference antenna method can be extended by using circular folded loop antenna in the normal saline solution. The perimeter of the antenna can be adjusted to obtain constant near-field gain in its near-field region. To reduce the size of the reference antenna, the folded loop antenna with insulation should be used and the number of its folding should be larger. Also, electric field intensity in the near-field region can be estimated by using the field expression with the corresponding near-field gain if the near-field gain is well estimated.

ACKNOWLEDGMENT

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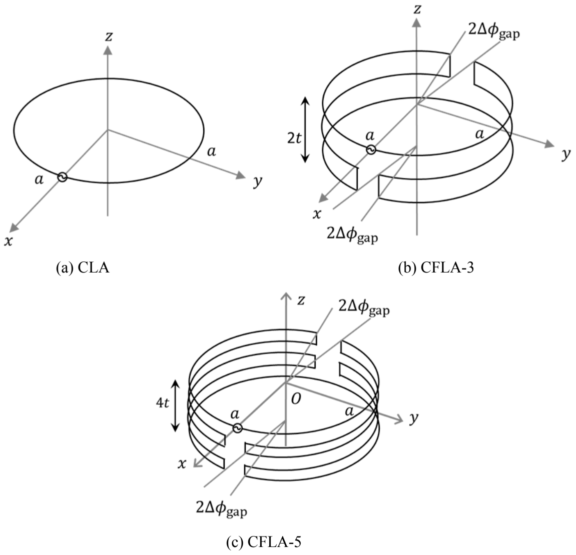


Fig. 1. Geometry of CLA and CFLAs

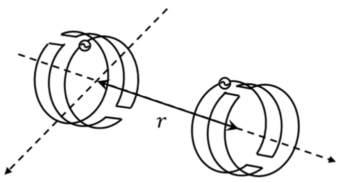
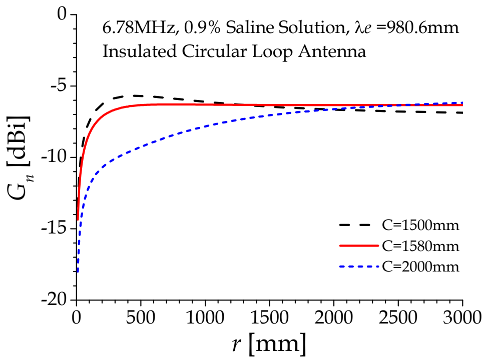
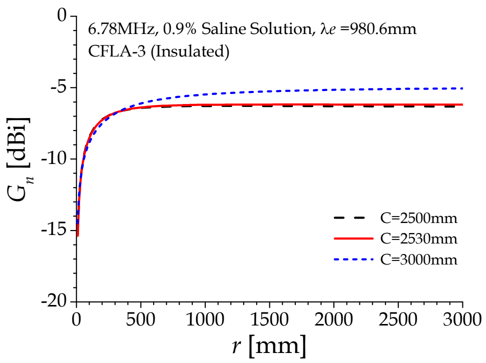


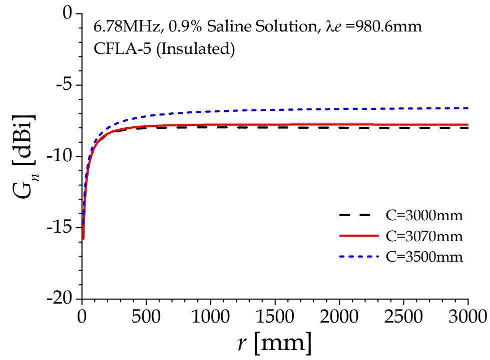
Fig. 2. Indentical two refence loop antennas faced in the normal saline to evaluate their near-field gain



(a) CFA

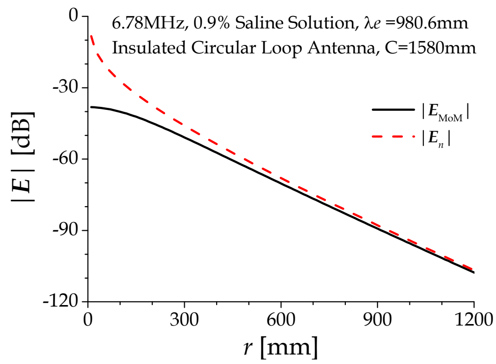


(b) CFLA-3

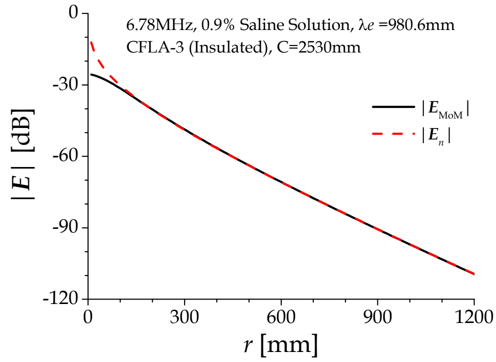


(c) CFLA-5

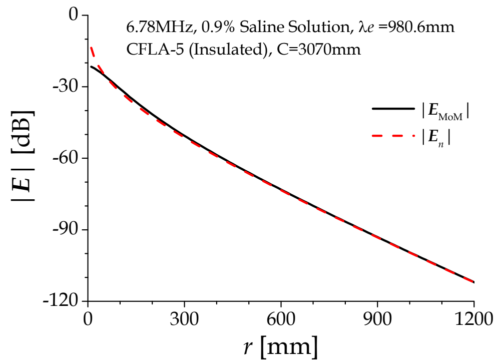
Fig. 3. Distance property of near-field gain for CLA and CFLAs



(a) CLA



(b) CFLA-3



(c) CFLA-5

Fig. 4. Distance property of electric field intensity for CLA and CFLAs