CAPACITIVE-LOADED INTERSTITIAL ANTENNA

Hee-Ran Ahn, Noh-Hoon Myung and Bumman Kim*

Dept. of Electrical Engineering, KAIST, Korea
*Dept. of Electronic and Electrical Engineering, POSTECH, Korea
e-mail: hrahm@cais.kaist.ac.kr

A coaxial-cable capacitive-loaded interstitial antenna (CCIA) is proposed for 2.45 GHz. The capacitive load is tipped at the end of the antenna and contributes to almost perfect matching and desirable heating area. The measured return loss of the CCIA is -28.377 dB, which may be considered as the best among those reported. Due to the excellent result, the CCIA can also be applied for treatment of deep-seated tumor or cancer.

I. INTRODUCTION

Since stable temperature gradient may be expected, the microwave coaxial-cable interstitial antennas are especially suitable for hyperthermia of deep-seated tumors (e.g. certain brain tumors), and plastic catheters are used embedded in target area for preventing direct electrical contact with tissue. Due to less expense, easy operation and short recover time, their use has recently been on a dramatic increase and many studies on it have been published [1]-[4]. However, since the conventional ones were designed with optimization [3] or not exact design method [4], antenna matching is poor, which results in poor energy concentration. In this paper, a CCIA is proposed, so that high energy concentration and almost perfect matching can be produced for as little damage as possible to the healthy surrounding tissue. To prove the excellent performance, a CCIA is compared with a conventional one [3], and the compared results show much better performances for SAR (specific absorption rate) distribution and smaller size. While all the other conventional ones have sinusoidal current distribution with null at the end points [1]-[4], the CCIA has no current null at the end point and its input impedance may arbitrarily be changed. Due to these distinctive characteristics, good matches together with smaller size may be achieved for the CCIA. To verify the excellent performances, it has been designed, fabricated and measured for muscle phantom. The measured return loss is -28.377 dB at 2.45 GHz and the measured region greater than 43°C is a ruby ball (major axis 4.5 cm and minor axis 2.45 cm). The value of -28.377 dB can be considered as the best among those reported and the measured SAR distribution confirms that the CCIA can be applied for the removal of a deep-seated tumor or cancer.
compared with the conventional one. For the density, it has been simulated and the CCA is
proportional to electric energy since $\frac{1}{2} \mu_{\text{F}}$ is proportional to electric energy.

Theoretically, when the power is fed to the CCA, the opposite charges are induced at the same time on
the inner conductor and the CCA. Therefore, the power flow is more uniform when the CCA is used.

**Figure 1.** A conventional coaxial cable, (a) A coaxial cable, (b) A coaxial load.

**Figure 2.** Simulating electric source discharge, (a) $\mathbf{E} = \mathbf{z}$, (b) $\mathbf{E} = \mathbf{z}$.

**Figure 3.** Capacitive load.

- $j = z$
- $\mathbf{E}$
- $\mathbf{R}$

**Figure 4.** An infinite medium (Region 4) shown in an infinite medium (Region 4). Region 2 is filled with air, all of which are immersed in a dielectric constant of 3, forming Region 3, and a dielectric constant of 2, forming Region 2.

- $\mathbf{E}$
- $\mathbf{R}$
- $\mathbf{I}$

The current in the inner conductor is divided into two parts: (1) A coaxial cable and (2) An infinite medium consists of coaxial cable and air. If

$\mathbf{I}$ shows a CCA and the capacitive load.
simulations, a semi rigid coaxial cable with inner and outer radii 0.29 mm and 1.4 mm, respectively, and $\varepsilon_d = 2.1$ is utilized. A crystal glass tube $\varepsilon_3 = 5.1$ with inner and outer radii, 2.3 mm and 4.2 mm is used as a microwave catheter. The two antennas are designed for good matching and the length of the capacitive load shown in Fig. 1(b) is 2 mm. The two are immersed in air, the air is also filled in Region 2, and the excited powers are the same in both cases. The simulations have been carried out with the Region 4 filled in air but the comparison will be the same effect in the case of lossy medium because of the same behavior of electric energy density. The simulated results are plotted in Fig. 2 where the CCIA in Fig. 2(a) and the conventional one in Fig. 2(b). The numbers are normalized values to the maximum one. The simulated results indicate the electric energy density around the CCIA is more concentrated. When these interstitial antennas in Fig. 1 are placed in dissipative media, they may be treated as sections of lossy transmission lines with generalized propagation constants that reflect the losses due to radiation from the antennas to the ambient medium. Since the dielectrics actually used in the Region 2 and 3 are highly non-conducting and that of the ambient medium in the Region 4 conducting, $\varepsilon_2$ and $\varepsilon_3$ are assumed to be real and $\varepsilon_4$ complex. The input impedance of CCIA, $Z_{in}$ in Fig. 1(a), may be calculated based on the transmission line model [1] and derived as

$$Z_{in} = Z_c(a) \frac{Z_L + jZ_L \tan[k_c(a)\ell]}{Z_c(a) + jZ_L \tan[k_c(a)\ell]}$$

(1)

where $Z_L$ is an input impedance of the capacitive load at $z = \ell$ in Fig. 1(a),

$$k_c(a) = k_{2e}(a) \left[ \frac{\ln(d/a) + F}{\ln(c/a) + n_{24}^2 F} \right]^{1/2},$$

$$k_{2e}(a) = \omega \sqrt{\mu_0 \varepsilon_2} \left[ \frac{\ln(d/a)}{\ln(c/a) + n_{24}^2 \ln(d/c)} \right]^{1/2},$$

$$Z_c(a) = \left( \omega \mu_0 k_c(a) / 2\pi k_{2e}^2 \right) \left[ \ln(d/a) + n_{23}^2 \ln(d/c) + n_{24}^2 F \right],$$

$$k_4 = \omega \sqrt{\mu_0 \varepsilon_4} \bar{\varepsilon}_4 = \varepsilon_4 + j \sigma_4 / \omega,$$

$n_{23}^2 = \varepsilon_2 / \varepsilon_3$, $n_{24}^2 = \varepsilon_2 / \bar{\varepsilon}_4$, and $F = H_0^{(1)}(k_4d) / (k_4dH_1^{(1)}(k_4d))$ with $H$ : Hankel function.

Based on (1), the calculated $Z_L$ is 275- j130 $\Omega$ with the length 2 mm and the optimal values of $\ell$ is 18.64 mm in the case of $2a = 0.29$ mm, $2b = 1.19$ mm, $2c = 2.3$ mm, $2d = 4.2$ mm, $\varepsilon_d = 2.1$, $\varepsilon_2 = 1$, $\varepsilon_3 = 5.1$ and $\bar{\varepsilon}_4 = 52.7+j13.3$ (Muscle). The designed CCIA has been tested, immersed in a 10 cm x 10 cm x 10 cm muscle phantom. Measured and simulated return losses are compared in Fig. 3(a). The simulations have been carried out by a program working on mathematical software and the measured return loss is -28.377 dB at 2.45 GHz. The value of -28.377 dB can be considered as the best among those reported [2]-[3]. Fig. 3(b) shows the measured SAR distribution pictured by IRCON (Inspect IR 500 PS) digital camera, serial number SS-7. For the measurement, a 5 cm x 5 cm x 5 cm muscle phantom is used and it is displayed in Fig. 3(b) that the measured region greater than 43°C is a ruby ball (major axis 4.5 cm and minor axis 2.45 cm).
Fig. 3. Measured results of CCIA.  
(a) Measured and predicted return losses.  
(b) Measured SAR distributions

III. CONCLUSIONS

A CCIA is proposed. It basically consists of coaxial cable and a capacitive load. The capacitive load is needed for matching and desirable SAR distribution. For the design of the CCIA, it is modeled as lossy transmission line sections, which reflects losses due to radiation from the antennas to the ambient medium. If a different type of capacitive load is placed in the middle of the CCIA, better SAR distribution can be expected.

REFERENCES


