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Capacitive-loaded interstitial antenna for perfect matching

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

A coaxial-cable capacitive-loaded interstitial antenna (CCIA) is proposed for 2.45 GHz. The capacitive load 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. Owing to this excellent result, the CCIA can also be applied for treatment of deep-seated tumours or cancer.

Introduction: Since a stable temperature gradient may be expected, microwave coaxial-cable interstitial antennas (CCIAs) are especially suitable for hyperthermia of deep-seated tumours (e.g. certain brain tumours), and plastic catheters are used embedded in the target area to prevent direct electrical contact with tissue. Owing to the fact that they are less expense, easy to operate and have a short recovery time, their use has recently been on a dramatic increase and many studies of these antennas have been published [1–4]. However, since the conventional ones were designed with optimisation [3] or a not exact design method [4], the antenna matching is poor, which results in poor energy concentration. In this Letter, a CCIA is proposed, so that high energy concentration and almost perfect matching can be produced with as little damage as possible to the healthy surrounding tissue. To prove the excellent performance, a CCIA is compared with a conventional antenna [3], and the compared results show much better performances for specific absorption rate (SAR) distribution and smaller size. While all the other conventional antennas have a sinusoidal current distribution with a 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. Owing to these distinctive characteristics, good matches together with a smaller size may be achieved for the CCIA. To verify the excellent performances, the antenna has been designed, fabricated and measured for a 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 tumour or cancer.

Analyses: Fig. 1 shows a CCIA and its capacitive load. It basically consists of coaxial cable, and its inner conductor is extended to approximately $\lambda_{eff}/4$ (Region 1) and tipped with the capacitive load shown in Fig. 1*b*. It is insulated by a dielectric layer (inner and outer radii, c and d, respectively, and a dielectric constant ε_3), forming Region 3, and Region 2 is filled with air, all of which are immersed in an infinite ambient medium (Region 4) as shown in Fig. 1*a*. The capacitive load in Fig. 1*b* is composed of a certain length of the coaxial cable and its inner conductor at the end ($z = l'$) is connected with the outer conductor which is open-circuited at $z = l$. Therefore, when the power is fed to the CCIA, the current will flow along its inner conductor and opposite charges are induced at the same time on the outer conductor. Owing to the surface being wider than the cross section of the inner conductor at $z = l'$, the current on the inner conductor at $z = l'$ spreads faster on the top plate. Fig. 1*b* shows the case that positive current is excited and the approximate electric-field is produced as indicated with arrows. The opposite charges on the outer conductor help the current on the top plate at $z = l'$ flow faster towards the end at $z = l$ in $-z$ direction. Thus, the electric field can be concentrated around the capacitive load but not too strongly at the end, which is very important to protect healthy surrounding tissue.

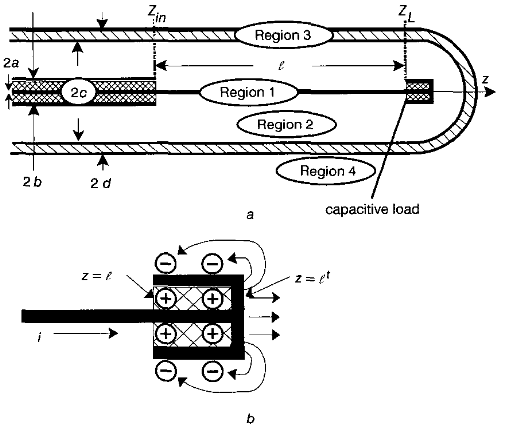

Fig. 1 *CCIA and its capacitive load*
a CCIA *b* Capacitive load

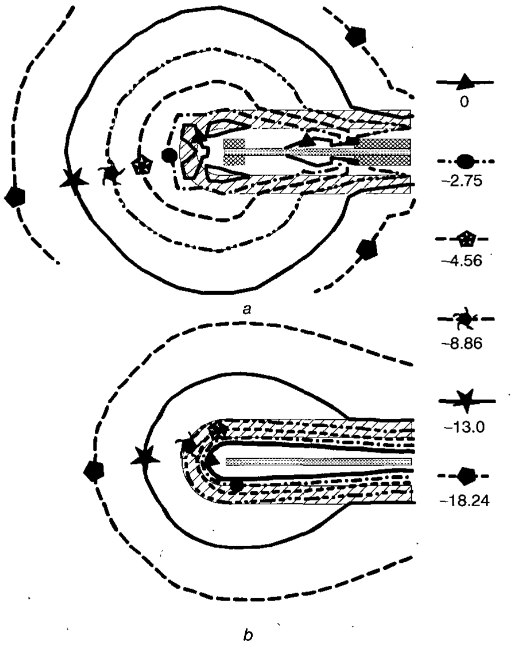

Fig. 2 *Simulated electric energy density*
a CCIA *b* Conventional interstitial antenna

Since SAR is proportional to electric energy density, it has been simulated and the CCIA is compared with a conventional antenna [3]. For the 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 utilised. 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 Region 4 filled in air but the comparison will have the same effect in the case of a lossy medium because of the same behaviour of electric energy density. The simulated results are plotted in Fig. 2 with the CCIA in Fig. 2*a* and the conventional antenna in Fig. 2*b*. The numbers are normalised to the maximum value. 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 generalised propagation constants that reflect the losses due to radiation from the antennas to the ambient medium. Since the dielectrics actually used in Region 2 and 3 are highly non-conducting and that of the ambient medium in Region 4 conducting, ε_2 and ε_3 are assumed to be real and $\tilde{\varepsilon}_4$ complex. The input impedance of CCIA, $Z_{\rm in}$ in Fig. 1*a*, may be calculated based on the transmission line model [1] and derived as

$$Z_{\rm in} = Z_c(a)\frac{Z_L + jZ_c(a)\tan[k_c(a)\ell]}{Z_c(a) + jZ_L\tan[k_c(a)\ell]} \qquad (1)$$

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

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

$$k_{2e}(a) = \omega\sqrt{\mu_0\varepsilon_0\varepsilon_2}\left[\frac{\ln(d/a)}{\ln(c/a) + n_{24}^2\ln(d/c)}\right]^{1/2}$$

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

$$k_4 = \omega\sqrt{\mu_0\varepsilon_0\tilde{\varepsilon}_4} \quad \tilde{\varepsilon}_4 = \varepsilon_4 + \frac{j\sigma_4}{\omega}$$

$n_{23}^2=\varepsilon_2/\varepsilon_3$, $n_{24}^2=\varepsilon_2/\tilde{\varepsilon}_4$, and $F=\tilde{H}_0^{(1)}\ (k_4d)/(k_4dH_1^1(k_4d))$ with H: Hankel function.

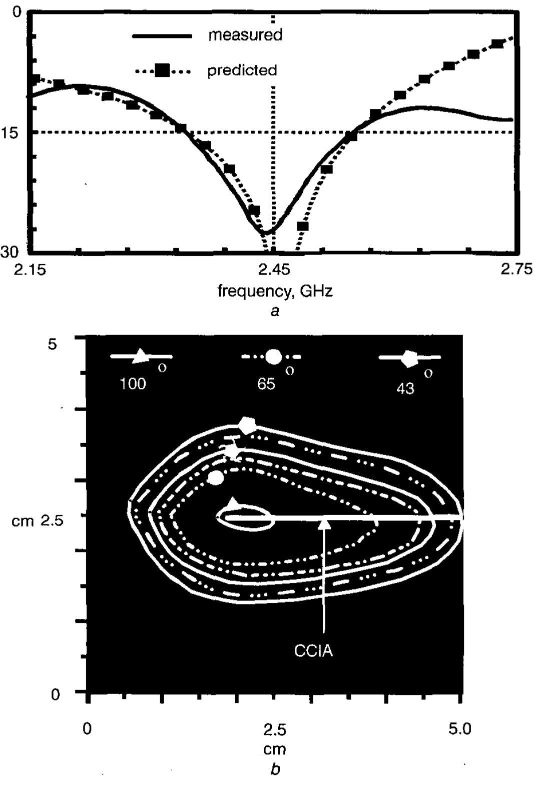

Fig. 3 *Measured results of CCIA*
a Measured and predicted return losses *b* Measured SAR distribution

Based on (1), the calculated Z_L is $275-j\ 130\,\Omega$ with length 2 mm and the optimal value of ℓ 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 $\tilde{\varepsilon}_4=52.7+j13.3$ (muscle). The designed CCIA has been tested, immersed in a 10 cm × 10 cm × 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 × 5 cm × 5 cm muscle phantom is used and it is shown 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). Before the temperature measurements, an RF power of 20 W was supplied for 3 min.

Conclusions: A CCIA has been proposed that basically consists of coaxial cable and a capacitive load. The capacitive load is required for matching and a desirable SAR distribution. For the design of the CCIA, it is modelled 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, a better SAR distribution can be expected.

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Dielectric rod antenna based on image NRD guide coupled to rectangular waveguide

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A dielectric rod antenna based on an image NRD guide fed by a slot in the broad wall of a rectangular waveguide is proposed. This configuration is developed for the use in the design of an array of this antenna. The antenna characteristics are investigated using the finite difference time domain (FDTD) technique. Measured results at 30 GHz band are presented to validate the numerical analysis.

Introduction: There has been increasing interest in millimetre-wave band in recent years. High-performance and low-cost antennas are strongly required to develop millimetre-wave applications such as high-speed wireless LANs and automobile collision avoidance radar. Dielectric rod antennas [1, 2] are good candidates for these systems. A dielectric rod antenna fed by an image NRD guide [3] was recently proposed [4]. In this investigation, the image NRD guide, which is a class of dielectric waveguide derived from a conventional NRD guide