A MICROSTRIP ANTENNA FOR MEDICAL APPLICATIONS

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ABSTRACT

A ring-type microstrip antenna as a potential microwave power radiator for biomedical applications is discussed. Heating pattern measurements show that the structure is capable of providing relatively uniform heating over a cylindrical volume.

Introduction

An increased interest in applications of electromagnetic techniques in medical diagnosis and therapy has recently been observed [1,2]. In therapy, there are indications that local and/or whole body hyperthermia provides successful modality in treatment of some malignant tumors. Microwave energy is one of the effective ways of inducing rapid hyperthermia, but diffuculties are experienced in heating deep laying tissues and heating a relatively large volume of tissue. In general, the desired characteristics of a microwave radiator include: an effective deposition of the energy in a defined tissue volume (e.g. in the muscle without overheating the skin), good impedance matching, minimum leakage of microwave energy into the outside of the treated area and lightweight, rugged and easy to handle design.

Microstrip radiators offer the advantage of being small, lightweight and capable of conforming to the shape of the body, when properly designed, with remaining characteristics comparable to those of other microwave radiators used in therapeutic heating e.g. contact applicators. A conformal applicator employing a radiator consisting of a few printed dipoles was previously used for inducing hyperthermia at 2.45 GHz [2]. A coplanar stripline coupler was used in monitoring water content in lungs [3].

A ring-type microwave radiator appears to offer a potential as a local hyperthermia applicator, and an array of such radiators can be employed for heating of a larger volume of tissue. In this contribution the design formulae and experimental results for an applicator operating at 2.45 GHz are given.

Design Principles

The geometry of a ring microstrip radiator is shown in Fig. 1. The fields inside the region between a ring conductor and a ground plane at resonance are as follows [4,5]:

$$E_z = E_o [J_n(k\rho)\, Y'_n(ka) - J'_n(ka) Y_n(k\rho)] \cos n\phi \qquad (1)$$

$$H_\rho = \frac{j\omega\varepsilon}{k^2 \rho} \frac{\partial E_z}{\partial \phi} \qquad (2)$$

$$H_\phi = -\frac{j\omega\varepsilon}{k^2} \frac{\partial E_z}{\partial \rho} \qquad (3)$$

where n is an integer, $k = 2\pi\sqrt{\varepsilon_e}/\lambda_o$ (ε_e is the effective dielectric constant of the structure and λ_o is the free space wavelength) and ε is the permittivity of the dielectric substrate. J_n and Y_n are Bessel functions of the first and second kind, respectively. The prime sign denotes derivative of Bessel functions. The surface currents on the circular ring can then be found with $K_\phi = -H_\rho$ and $K_\rho = H_\phi$. The radial component of the current must vanish at the edge of the ring, i.e.

$$K_\rho\ (\rho=b) = H_\phi\ (\rho=b) = 0 \qquad (4)$$

From (1), (3) and (4)

$$J'_n(kb)\ Y'_n(ka) - J'_n(ka)\ Y'_n(kb) = 0 \qquad (5)$$

Equation (5) allows to calculate k of consecutive modes for given dimensions and the dielectric constant of the ring resonator.

For $n \le 5$ and $(b-a)/(b+a) \le 0.35$ (Fig. 1), the approximate value of k can be found as equal to:

$$k = \frac{2n}{a+b} \qquad (6)$$

The resonant frequency can be calculated as

$$f_o = \frac{ck}{2\pi\sqrt{\varepsilon_e}} \qquad (7)$$

where c is the velocity of light.

The effective dielectric constant ε_e of a microstrip covered with two layers of lossy dielectric material, with the first layer of a finite thickness, and the second (top) layer extending to infinity has previously been derived using the variational method [6]. Figure 2 shows the relative effective dielectric constant and the characteristic impedance of a microstrip of given dimensions covered with a finite thickness layer of the dielectric material having the permittivity equal to that of fat tissue ($\varepsilon_2 = 6$), and an infinite thickness layer of the muscle tissue equivalent material ($\varepsilon_3 = 50$). In practice, the muscle tissue dielectric does not need to be of an infinite thickness, but the thickness has to be sufficient that the wave is sufficiently attenuated.

Figure 3 shows the resonant frequencies of the first three modes as a function of fat tissue thickness. The dielectric constants of fat and muscle tissues are assumed here to be constant for frequencies 1-5 GHz. This condition, in practice, is met within 20%, however, this is satisfactory since the ring resonator covered by a dielectric having a relatively large loss factor has a relatively small Q-factor.

Experimental Results

A test radiator having a = 1 cm and b = 2 cm, on a substrate with $\varepsilon_1 = 2.32$ was designed to operate at 2.45 GHz in TM_{310} mode when in contact with a dielectric having the permittivity of muscle tissue. The energy to the radiator was fed from a coaxial N-type connector through a probe protruding the substrate and in contact with the metallic ring.

Heating patterns were investigated by a thermographic method [7]. A specially prepared muscle tissue phantom (a mixture of 8.45% TX-150, 0.91% NaCℓ, 15.2% polyethylene powder and 75.44% H_2O) in a form of a right cylinder 10 cm in diameter divided into two parts along a diameter plane was irradiated by the test radiator at 2.45 GHz. The input power to the antenna was 100 W and the exposure duration 5 s. The thermographic infrared camera model AGA 750 was employed to obtain temperature images. The increase in the phantom temperature is related to the intensity of the electric field in the phantom through the following relationship:

$$\frac{\Delta T}{\Delta t} = \frac{C_v \rho_v \sigma}{2} |E|^2 \qquad (8)$$

where ΔT is the temperature rise in the time period Δt, c_v is the specific heat, ρ_v is the density, σ is the conductivity of the phantom material and E is the electric field vector. For short periods of irradiation, thermal diffusion can be neglected and the image represents the distribution of the square of the total electric field.

Heating patterns obtained at the suface of the muscle phantom in contact with the antenna, and at the surface perpendicular to the ring-antenna surface (the plane of the phantom division) are shown in Fig. 4(a) and (b), respectively. The temperature variation within 5°C in 1°C gradation is shown on a gray scale as black, white, light gray, dark gray, black for the temperatures changing from the highest to the lowest. For instance, in Fig. 4(b) the black area surrounded by the white ring indicates the surface of temperature 27°C or more, while the black area next to the dark grey area indicates the surface of temperature 23°C or less. Additionally, a bright line indicating the area having a preselected temperature (isotherm) may be imposed on the thermal image, e.g. 22°C isotherm in Fig. 4(b).

Conclusion

The design formulae and experimental results of a 2.45-GHz ring-type microstrip radiator for potential hyperthermia applications are given. The heating patterns in muscle obtained by a thermographic technique are similar to the apperture-type contact applicator. Microstrip radiators offer the advantage of being small, lightweight and capable of conforming to the shape of the body. Cooling of the skin can be easily accomplished by the air flow penetrating through performations of the radiator.

References

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Illustrations

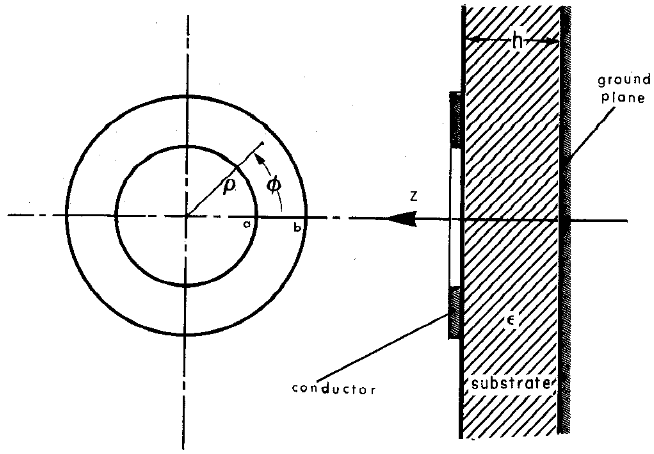

Figure 1 The geometry of a microstrip ring radiator.

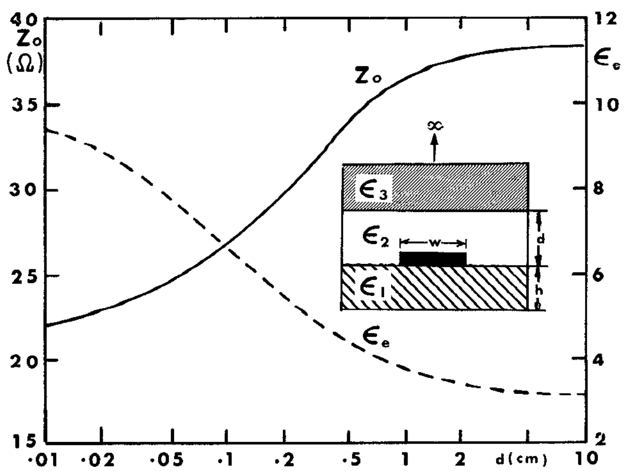

Figure 2 The effective dielectric constant and characteristic impedance of a microstrip line covered with a dielectric layer of thickness d and an infinite thickness dielectric above it; microstrip width w = 1.0 cm, substrate thickness 0.318 cm, substrate dielectric constant, $\varepsilon_1 = 2.32$, $\varepsilon_2 = 6.0$, $\varepsilon_3 = 50$.

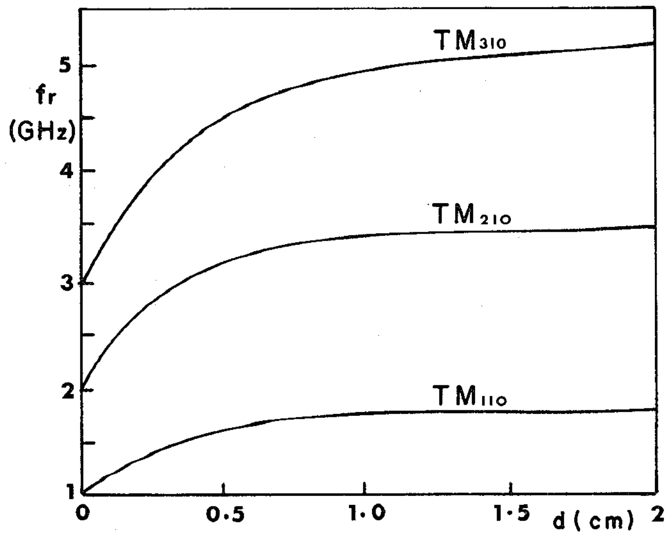

Figure 3 Resonant frequencies of the first three modes for a ring resonator covered with two layers of dielectric; the first layer thickness is d and the dielectric constant 6.0, the second layer thickness is infinite and the dielectric constant 50; the resonator parameters are a = 1 cm, b = 2 cm, h = 0.318 cm, ε_1=2.32.

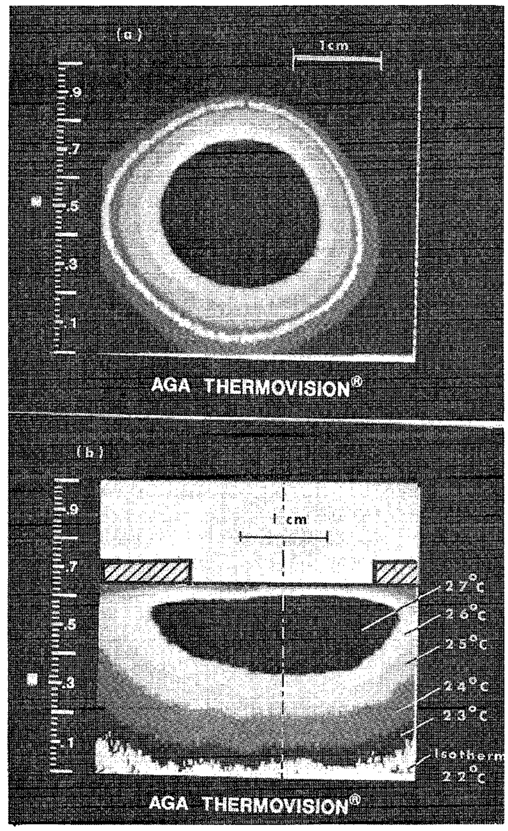

Figure 4 Heating patterns of the ring resonator at 2.45 GHz; (a) on the surface (b) in depth of the simulated muscle tissue.