MICROSTRIP LOOP RADIATORS FOR LOCAL HYPERTHERMIA

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ABSTRACT

Two new microstrip radiators for inducing local hyperthermia designed to operate at 433 MHz and 915 MHz are described. Empirical design methods and experimental results obtained with phantoms are presented. The radiators have a desired uniform radiation pattern and are well matched to the muscle tissue or a water bolus.

Introduction

Various microstrip radiators and arrays of microstrip dipoles for local hyperthermia were investigated [1]- [5]. Microstrip slot radiators [4]are matched to the body tissue and have heating patterns comparable to aperture type radiators [6]. Ring-type microstrip radiators are well matched when spaced a few millimeters from the muscle tissue or muscle phantom or when the muscle tissue is covered by a thin layer of the fat tissue [7]. However, under such conditions, heating pattern for small radiators becomes nonuniform. To achieve uniform heating pattern, large diameter radiators are required so that the structure may support higher order modes. In this paper a new microstrip loop radiator for local hyperthermia is described.

Design Principles

The geometry of the new radiator is shown in Fig. 1. The radiator comprises a ring conductor on one side of a dielectric substrate having the ground plane on the other side. The structure is fed at $\phi = \pi$ and shorted to the ground plane at $\phi = 0$. The radiators are fed from a coaxial N-type connector.

Resonant frequencies of the loop antennas in air are calculated by considering a transmission line equivalent circuit and are in good agreement with the measured values. The resonance condition is given by

$$\tan(\beta\pi R) = \frac{3X_L Z_0}{2X_L^2 - Z_0^2} \quad (1)$$

where X_L is the reactance of the feed probe and the shorting pin, Z_0 is the characteristic impedance of the loop-forming line, $\beta = 2\pi\sqrt{\epsilon_e}/\lambda_0$ is the propagation constant of the line, ϵ_e is the effective dielectric constant and λ_0 is the free space wavelength.

However, when the loop radiator is covered with a semi-infinite lossy medium (viz. muscle), the transmission line model can no longer be used to calculate the resonant frequencies and therefore an empirical design method was used.

Many radiators with various strip widths and mean radii were fabricated on a 0.318 cm thick duroid substrate ($\epsilon_r = 2.32$). Resonant frequencies of these radiators placed in contact with muscle phantom or a distilled water bolus followed by a muscle phantom were measured. From these measurements an empirical relationship between the resonant frequency and the dimensions of the loop was developed. At 433 MHz the loop dimensions are W = 0.5 cm and R = 2.0 cm when placed in contact with muscle only and W = 0.5 cm and R = 1.6 cm when placed in contact with a water bolus followed by a muscle phantom. At 915 MHz the loop dimensions become W = 0.3 and R = 0.9 cm when placed in contact with muscle only.

Experimental Results

The return loss of the radiators facing phantom as a function of frequency for the 433-MHz and 915-MHz radiators is shown in Figs. 2a and 2b, respectively for various thicknesses of the water bolus.

The heating patterns of the 433-MHz and 915-MHz radiators with 2.5 cm and 0.8 cm distilled-water boluses respectively were investigated by measuring temperature rise of the phantom after irradiations by short microwave pulses. Implantable thermo-couples as well as liquid crystal film were used. The liquid crystal film gives results similar to infrared thermography. The temperature distribution in the phantom after irradiation by a 100-W, 30-S pulse was measured as a function of distance from the surface. The increase in temperature as a function of distance from the surface is plotted in Fig. 3. For comparison the theoretical results for ΔT corresponding to the plane wave irradiation are also shown. As expected the temperature decreases exponentially with the distance. It may be noted that the plane-wave penetration depth is larger than the experimental one. This was also noticed in near field measurements using a short probe method [4].

To evaluate and visualize the surface and in-depth heating patterns, liquid crystal films were used. The initial phantom temperature was kept between 24 and 25°C and the temperature range of liquid crystal film (Edmund Scientific Co. No. 72374) was 25-30°C. After irradiation, the liquid crystal film was placed in contact with the phantom and heating patterns were photographed. Different colors from red through green to blue indicate different temperatures. These heating profiles were mapped as shown in Figs. 4(a) and (b) for 433-MHz and 915-MHz radiators, respectively. It may be noted that the heating patterns in the plane of the radiator is symmetrical and fairly uniform. The

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penetration depth of the heating depends upon the frequency of operation and the size of the radiator.

Conclusion

In conclusion, microstrip loop radiators can be matched to the human muscle or to the distilled water bolus. The radiation pattern in the plane of the radiator is symmetrical and fairly uniform. The penetration depth of the heating depends on the diameter of the radiator and the frequency of operation. For example, the penetration depth of heating (37%) for the 433-MHz, 3.2-cm diameter radiator is 1.6 cm while for the 915-MHz, 1.8-cm diameter radiator is 1.1 cm. In comparison with other radiators for local hyperthermia microstrip loop radiator is small, lightweight and inexpensive.

References

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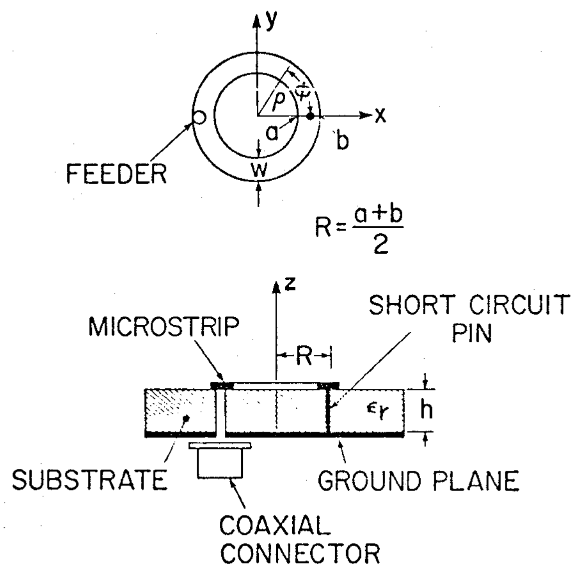

Fig. 1 The geometry of a microstrip loop radiator

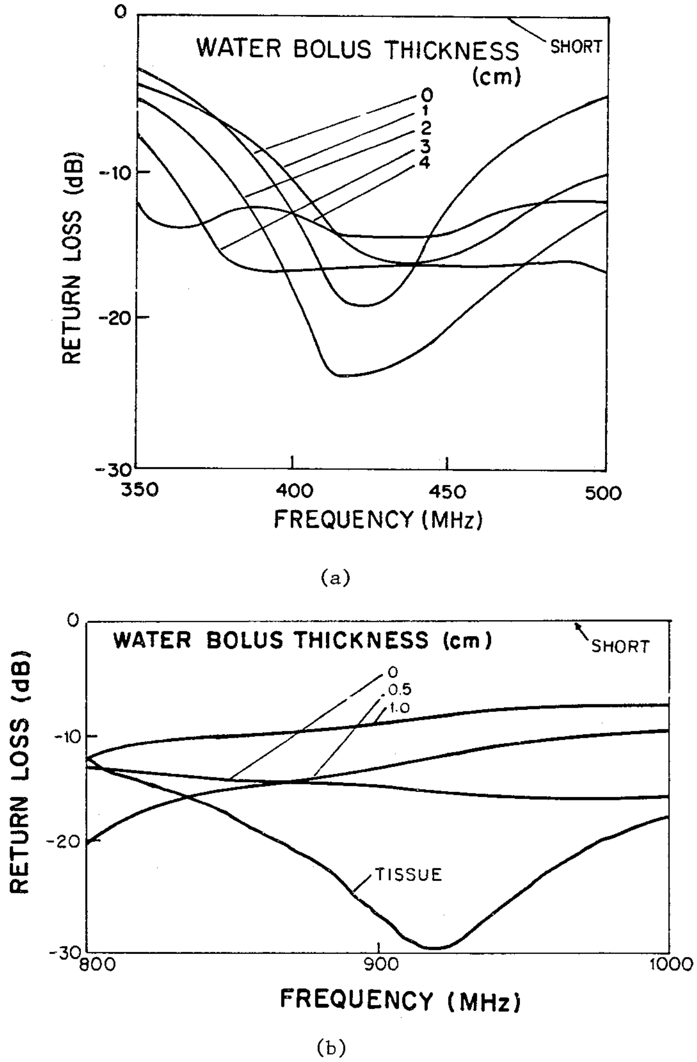

Fig. 2 Return loss of the loop radiator facing water bolus and muscle phantom (a) 433 MHz and (b) 915 MHz

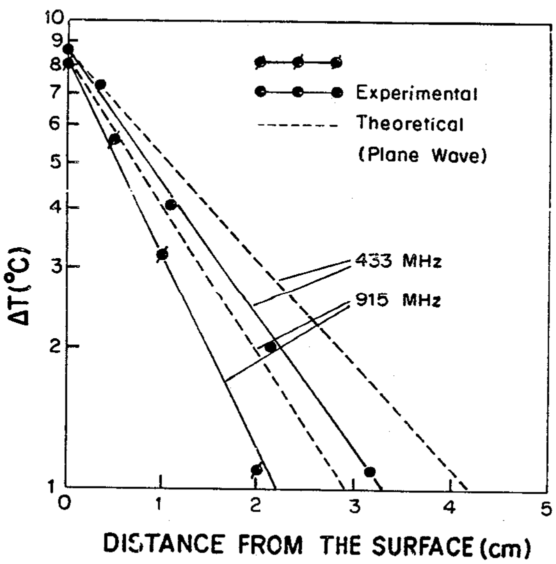

Fig. 3 Temperature rise of the muscle phantom as a function of distance from the aperture

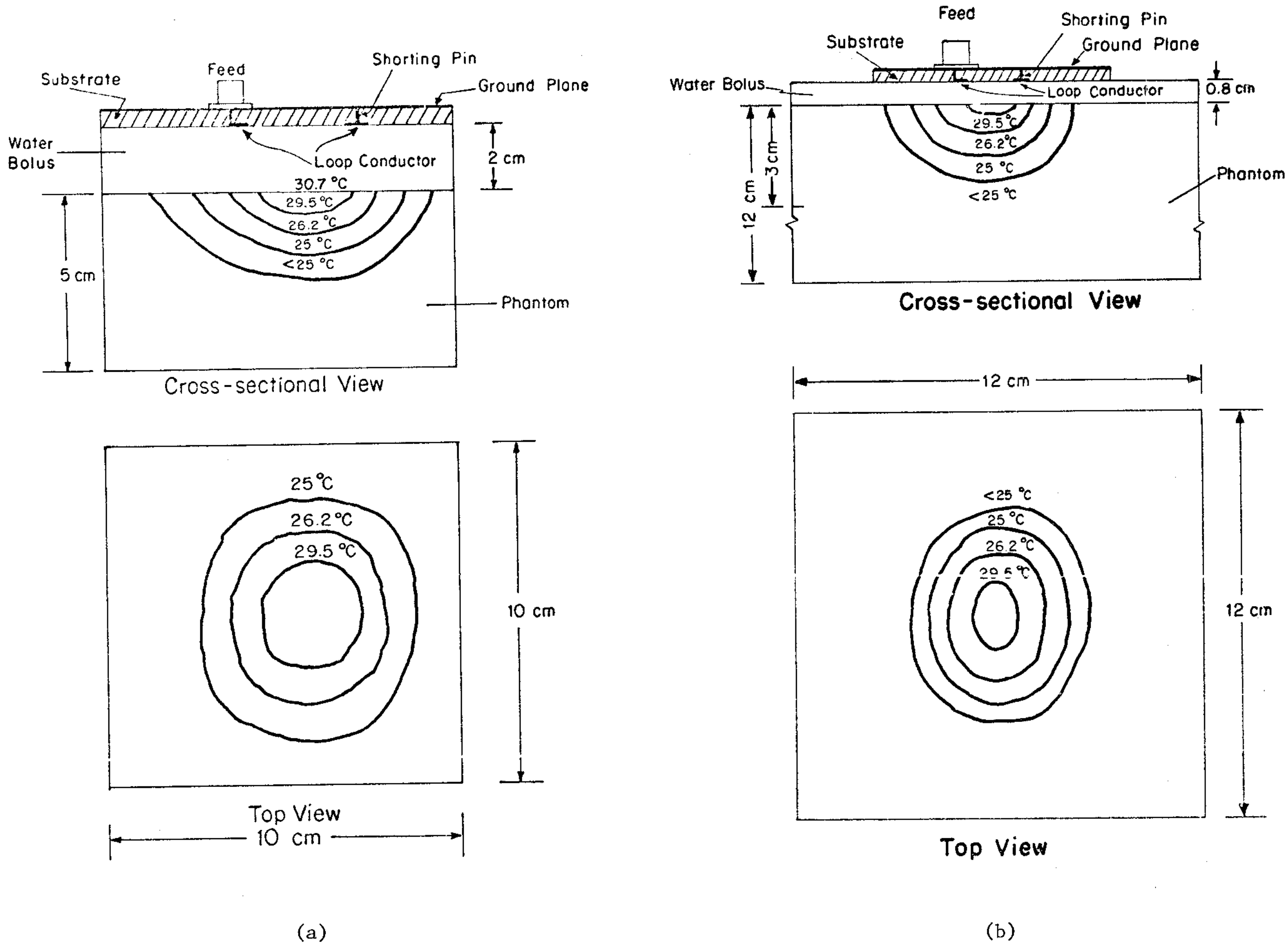

Fig. 4 Heating patterns of the loop radiators (a) 433 MHz and (b) 915 MHz