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A MULTI-ELEMENT MICROSTRIP ANTENNA FOR LOCAL HYPERTHERMIA*

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ABSTRACT

A multi-element microstrip antenna applicator designed for microwave local hyperthermia is described. Design criteria for such a microstrip antenna array are presented. Various antennas were built and compared. Experimental measurements of heating patterns show the multiple microstrip spiral antenna provides controlled heating over a large area.

INTRODUCTION

Microwave direct-contact applicators commonly have been used for diathermy or local hyperthermia, as they offer efficient coupling of microwave power into the tissue with very little stray leakage. Most applicators designed for operation in the frequency range of 300-2500 MHz are useful for the treatment of surface tissue regions less than 5 cm in diameter[1]. Frequently, however, physicians find it necessary to treat much larger areas. These higher-frequency applicators are generally inadequate to treat larger areas, especially areas with appreciable curvature. The use of lower RF frequencies (10-200 MHz) may provide somewhat more uniform and deeper heating over larger areas, but the applicator becomes very large and bulky even though it may be loaded with high- dielectric material to reduce its size[2]. These applicators are also frequently unsuitable for use on curved surfaces.

Printed circuit antenna arrays have been used to produce uniform or periphery-enhanced heating patterns over large areas at 2450 MHz[3]. The present paper describes the design criteria for direct-contact independently-excited multi-element microstrip antenna applicators for microwave local hyperthermia. Experimental results obtained in tissue phantom and animals with a family of applicators designed to meet these criteria are presented. The advantages of using multiple microstrip antennas are that they are very simple, easy to fabricate, low cost, light weight, flexible, and conformable to body contours.

DESIGN CRITERIA

The basic design criteria for a versatile local hyperthermia applicator are as follows:

1. Capability to heat tissue uniformly to a depth of at least 2 cm, over an area of 200 cm^2 or greater[4].
2. Capability to conform to curved body parts such as the neck and arm.
3. Provision for surface cooling during treatment.
4. Capability of local control of the heating pattern within the treatment area.
5. Operation at an ISM frequency.

To satisfy these criteria, the use of a multi-element microstrip antenna assembled on a common flexible ground is proposed. Due to differences in geometry, blood flow, dielectric and thermal characteristics, and other parameters that vary among different areas of the body, heating in living tissue generally is not uniform, even if uniform power deposition is achieved. In order to produce uniform heating over a relatively large area, several independently controlled antenna elements must be used.

In the applicator system proposed, each antenna element is etched on a hexagonally shaped substrate of approximately 4 cm width. The hexagonal shape permits assembling several elements into a single applicator with a continuous ground plane. Water circulating in a cooling pad of controlled thickness (1 cm) is used to cool the skin and stabilize the antenna. This water pad also provides efficient coupling of microwave energy into the body and minimizes stray leakage.

An operating frequency of 915 MHz was decided upon since the penetration depth at this frequency is greater than that at 2450 MHz, and the use of this ISM frequency reduces shielding requirements. Furthermore, RF components are readily available at this frequency.

ANTENNA DESIGN

The antenna design must satisfy performance criteria that can be stated as follows: Into the water-phantom interface the antenna must exhibit

1. A symmetrical heating pattern, uniform over the area of the antenna.
2. A useful bandwidth in excess of 250 MHz.
3. A VSWR less than 1.9:1 (power reflection less than 10%).
4. A center frequency of 915 MHz.

In the course of developing the individual antenna elements, several types of microstrip antennas were considered, namely the patch antenna[5], the slot antenna, the multiple radial-arm antenna, the ring antenna[6], and the spiral antenna. Several antennas of these types operating at 915 MHz were developed and tested on tissue phantom (see Figure 1). After experimental work with various substrates these antennas were fabricated on Rogers Corporation RT/Duroid substrate, of dielectric constant 2.33 and thickness .062 inches, with 1-oz (.0014 inch) copper conductor.

Numerous microstrip antenna design papers have been published, but these antennas are generally designed to radiate into free space. However, when these flat microstrip antennas are covered with lossy, high dielectric material such as muscle and water, the operating frequency, bandwidth, and particularly the radiation pattern are severely affected.

Figure 2 shows a cross-sectional view of the microstrip antenna covered with cooling water pad and tissue. The exact design of a microstrip

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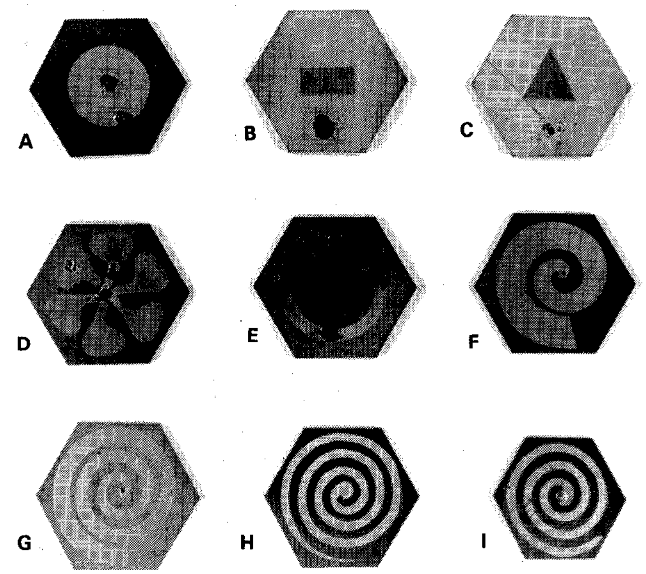

Figure 1. Prototype microstrip antennas fabricated for evaluation.

antenna covered by lossy dielectric material is extremely difficult. However, by using an effective dielectric constant, one can use the free-space design to obtain approximate dimensions for the antenna[7]. Depending on the width w (2-5 mm) of the microstrip conductor, the effective dielectric constant of the structure shown will vary between 11 and 14. Since the effective dielectric constant of the microstrip open to the air is given at lower microwave frequencies by

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}$$

the frequency reduction factor will be about 2.7[8].

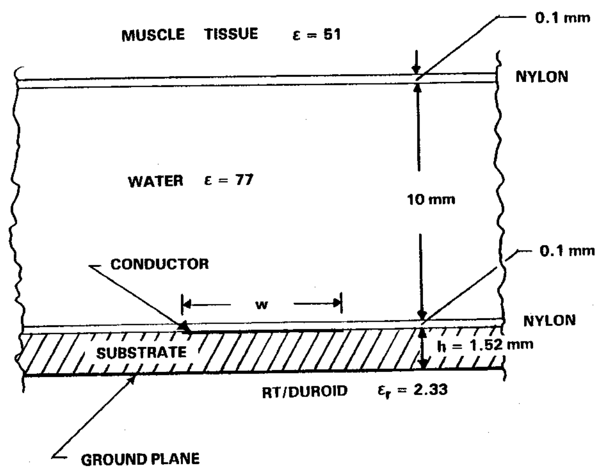

Figure 2. Cross-section of a microstrip antenna element radiating into lossy tissue through a water pad.

EXPERIMENTAL RESULTS

To evaluate these designs, the frequency response of each antenna was measured over a range of 200 - 1200 MHz with the antenna radiating through a 1 cm thick, de-ionized water bolus into a volume of muscle phantom. A Hewlett-Packard 8620A Sweep Oscillator and 8755C Swept Amplitude Analyzer were used. The measured frequency characteristic of each antenna was then compared with the criteria above.

Several patch, ring, and radial arm antennas were considered. Experiments show that these types of antennas have a relatively narrow band width and tend to have a specific direction of polarization unless the feed point and patch shape are carefully selected. As a result, they are sensitive to loading, and coupling into tissue strongly depends on the position of the antenna relative to the tissue. Also, the heating patterns tend not to be uniform. The slot antenna is simple and has much less leakage radiation. However, it also has a narrow band width, and tends to be strongly polarized in a certain direction.

Of the types of antennas considered, only the spiral design demonstrated good coupling, broad bandwidths in the desired frequency range, and a circularly symmetric radiation field. In consideration of this, various spiral designs were constructed and tested (Figure 1F-I). The best results were obtained with the spiral antenna shown in Figure 1I. This has a 3 1/2-turn, 2.5 mm wide conductor. Its VSWR is less than 1.9:1 over a 350-MHz bandwidth.

Heating patterns produced by one or more antennas were obtained using a 100 W RF signal source with a power divider network. A split-phantom technique, using a thermographic camera to record the temperature distribution with depth in the phantom was employed. A prototype applicator, composed of a four-antenna section of a closely-packed hexagonal array (see Figure 3), was assembled and evaluated. Figure 4 shows the heating profile of this four-element applicator.

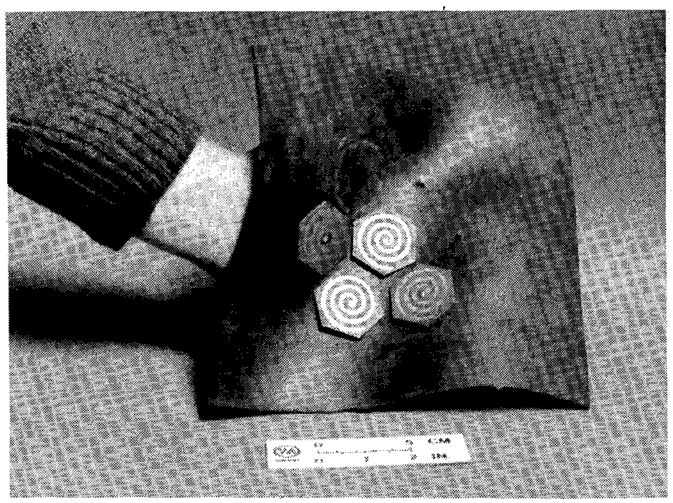

Figure 3. Prototype four-antenna applicator on a flexible supporting pad.

Figure 5 shows data taken with a single antenna and with a four-element applicator at various depths in a phantom and a live pig, using the BSD-1000 nonperturbing thermometry system (Bowman probes[9]). In all cases, the temperature is measured along the antenna system central axis with a 1 cm thick, de-ionized water bolus between the applicator and the phantom or pig. Figures 5A and 5B show the initial rate of temperature rise in a muscle phantom at a specified power, for a single antenna and an array of four antennas, respectively. Figures 5C and 5D are temperature-depth profiles produced in the thigh of a live pig under equilibrium conditions by a single antenna and

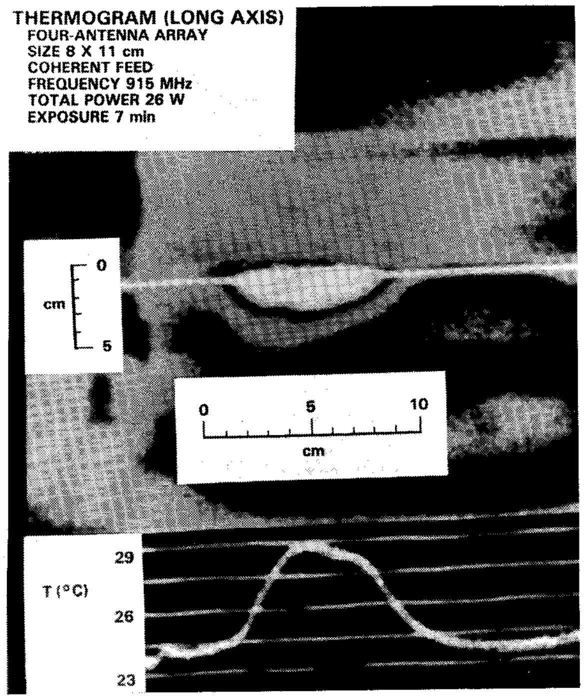

Figure 4. Thermogram of the heating pattern produced by four 3 1/2-turn spiral antennas in a closely-packed hexagonal array.

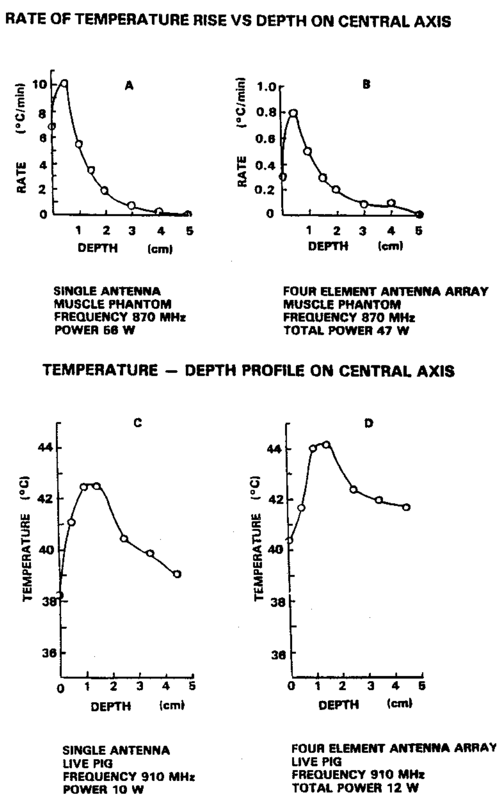

Figure 5. Temperature variation with depth along the central axis of the heating pattern. A and B show the initial rate of temperature rise in phantom material. C and D show the equilibrium temperature in live pig muscle. The surface was cooled by a water pad in all cases.

the four-antenna applicator, respectively. The fat layer in the pig is only about .5 cm thick, but certainly it is partly responsible for the apparently increased depth of significant power deposition in the pig. In this experiment we were able to alter the transverse heating pattern by varying the relative power to the individual antennas.

CONCLUSIONS

The design criteria and experimental results for a 915 MHz multi-element microstrip antenna for local hyperthermia are described. Of several antenna designs considered, the spiral antenna appears to be the most suitable for use as an applicator element since it produces the most uniform radiation pattern and also has an inherently broad bandwidth.

Experimental studies demonstrate that the multi-element microstrip antenna can provide controlled heating to a reasonable depth (2 cm) over a large area by controlling the amplitude and phase of the RF power to each individual element independently.

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