A NEW TYPE OF LIGHTWEIGHT LOW FREQUENCY ELECTROMAGNETIC HYPERTHERMIA APPLICATOR

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SUMMARY

A new applicator is described consisting of a resonant circuit formed from a current carrying sheet in the absence of a ground plane and which can be easily matched to a coaxial feeder. Designs for operation at frequencies in a range 10 to 1000 MHz are possible and aperture dimensions can be chosen almost independently of frequency.

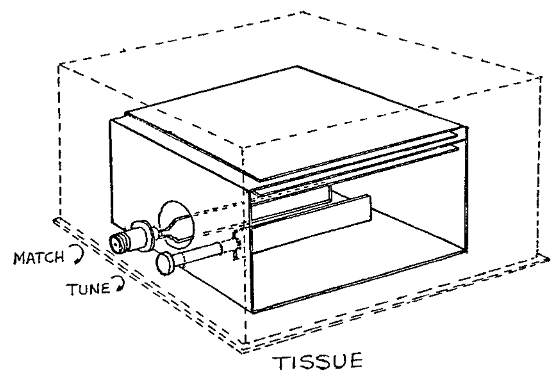
INTRODUCTION

The treatment of tumours by hyperthermia depends on achieving effective penetration of electromagnetic energy into high water content tissue such as muscle. Such penetration, (e^{-2} electric field), for a plane wave, is approximately 3 cm at 900 MHz and 15 cm at 27 MHz. For deep seated tumours, it is desirable to employ frequencies of the order of 27 to 100 MHz and to make the aperture size of the applicator sufficiently large to obtain the benefit of the increased penetration possible, Turner & Kumar(1), Johnson et al(2). Dielectric loaded and ridged waveguide type applicators are massive and relatively difficult to use at these frequencies, and simple capacitative systems or inductive applicators tend to produce non-uniform heating patterns or hot spots, Hand & Johnson(3). An alternative approach described by Anderson et al for uses an inductive applicator consisting of current carrying conductors above a ground plane, tuned by capacitors for resonance at 150MHz. This has been shown to overcome the excessive heating associated with capacitor or coiled systems. This paper describes a new type of applicator which does not suffer from any of the above limitations, Johnson(4).

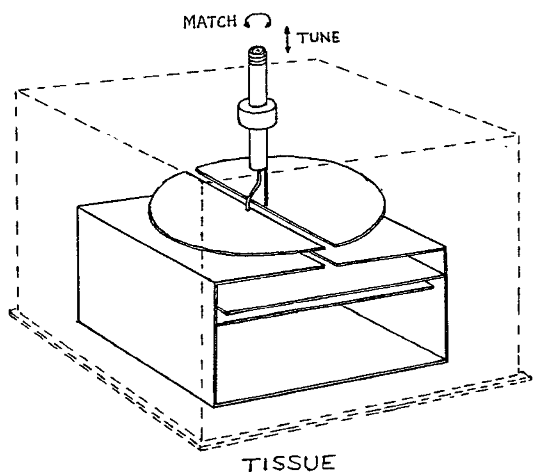
NEW DESIGN

The new applicator consists of a flat high conductivity plate folded back to form a U. Capacitor plates between the arms of the U form a resonant circuit as shown diagrammatically in Figure 1. This resonant circuit is enclosed in a screening box with an aperture covered by a suitable low loss dielectric. Figure 1a shows how the circuit can be excited by an inductive coupling loop, rotation of which matches the coaxial input. Rotation of a high conductivity plate adjacent to the coupling loop provides about 10% frequency adjustment. This arrangement is suitable for frequencies of about 100 MHz and below, whereas at higher frequencies the construction shown in Figure 1b is suitable.

Figure 1 Applicator construction



(a) Below about 100MHz



(b) Above about 100MHz

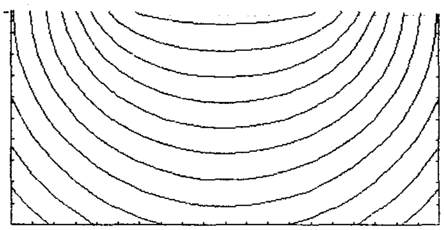
Here rotation of a split conducting disc connected to the coaxial input varies the input coupling to either side of the resonant circuit without appreciably affecting the resonant frequency. The latter is varied by moving the split disc either nearer to or further from the two half plates which form part of the resonant circuit capacitance.

EXPERIMENTAL MODELS

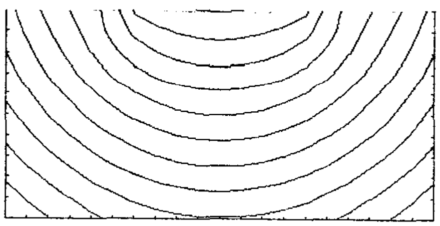
Table 1 lists examples of the new design and demonstrates that operating frequency and aperture dimensions can be chosen almost independently. This relationship is only constrained by the physical need to limit the length of the resonant plate to less than about one fifth of the free space wavelength and the practical difficulty of obtaining high values of capacitance without introducing unacceptable loss.

All the applicators listed in Table 1 use air as the dielectric, but solid (such as PTFE), or liquid (such as paraffin or carbon tetrachloride) dielectrics are possible. For continuous operation at the highest power levels some cooling method may be necessary.

Figure 2 Computed heating profiles of 200 MHz applicator (3dB contours).



(a) Central section parallel to current direction.



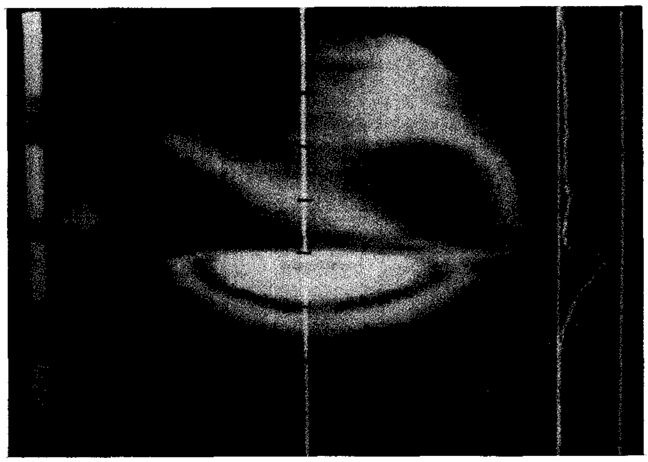
(b) Central section normal to current direction.

MODELLING OF APPLICATOR PERFORMANCE

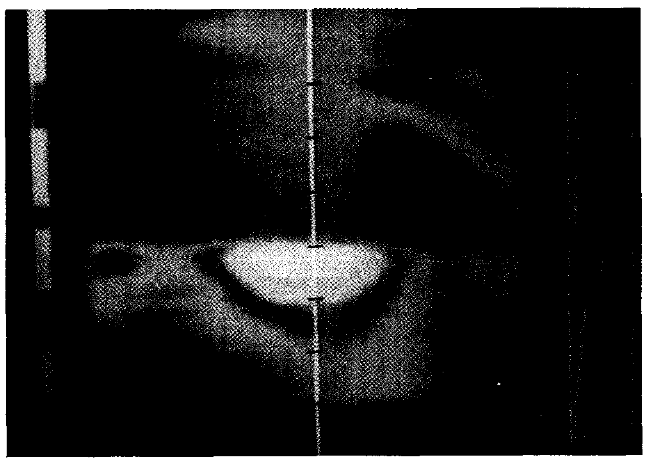
The high Q-factor resonant circuit is contained in a screening box and electromagnetic energy is radiated primarily from the current in the high conductivity plate forming the base of the U. This current is assumed to be uniformly distributed normal to the current direction, (across the width of the plate), but to have a sinusoidal component in the current direction.

The electric field, E, in an elemental volume of lossy medium can be calculated by integrating the contribution from a matrix of current elements representing the current distribution in the radiating plate using Maxwell's equations.

Figure 3 Measured heating profiles of 200MHz applicator.



(a) Central section parallel to current direction.



(b) Central section normal to current direction.

Figure 4 Impedance characteristics of 200MHz applicator.

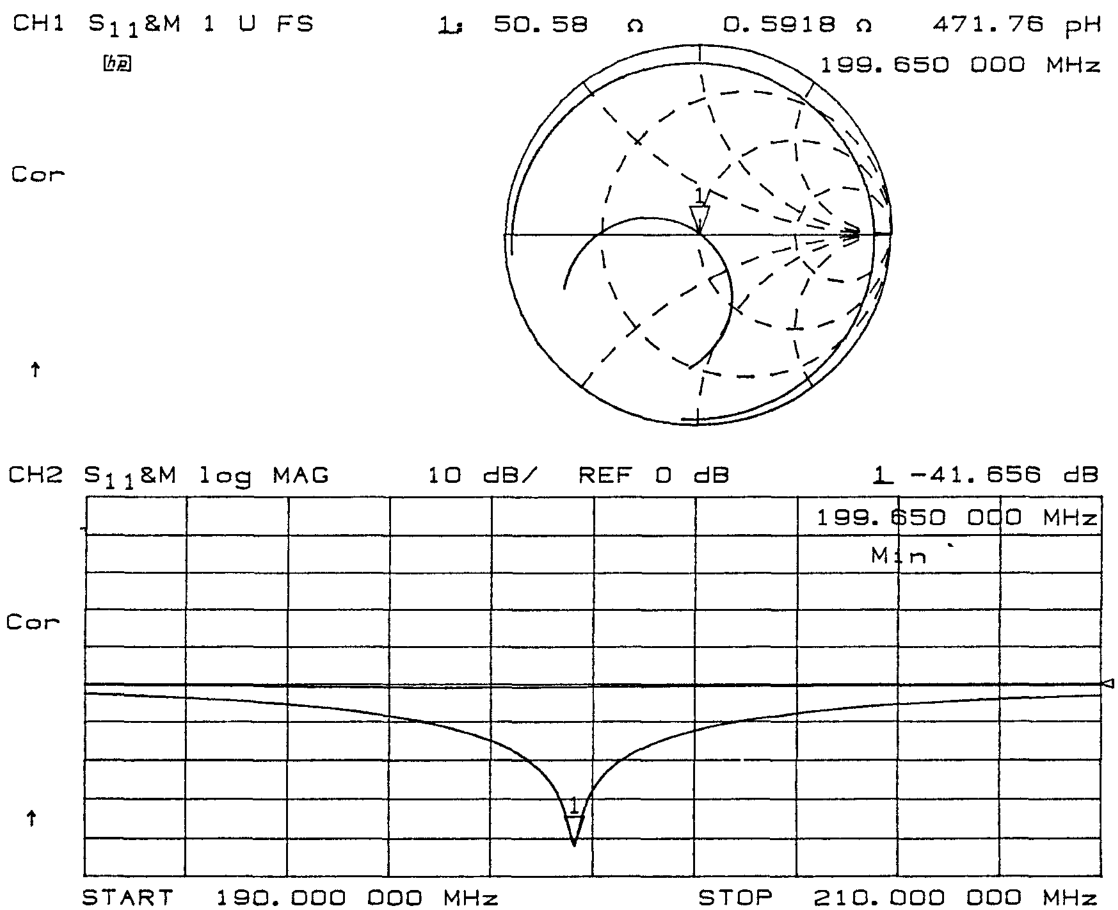


Table 1 Examples of the new lightweight applicators

Frequency, MHz	27	100	200	400	200/400/900	900
Radiator, LxW, cm	16 x 16	10 x 8.7	10 x 8.7	8 x 8	4 x 2.5	2.7 x 1.7
Aperture, LxW, cm	20 x 22	12.5 x 15.7	12.5 x 8.7	10 x 11.5	6 x 5	4 x 4
Height, cm	10	9	10	5.5	4	4
Weight, kg	4	0.7	0.9	0.4	0.2	0.1
Penetration(e^{-2}),cm	6.7	4.1	3.5	2.9	1.6/1.7/1.7	1.6
Test Power, W	1000	-	1000	200	50	50

Heating of the elemental volumes is given by $E^2\sigma$, where σ is the conductivity of the medium.

Figure 2 a,b, shows the calculated heating patterns in muscle phantom for the 200 MHz applicator and Table 1 lists the calculated field penetration for muscle phantom (e^{-2} electric field).

MEASURED PERFORMANCE

All the applicators could be matched to 50 ohm coaxial input and tuned to the design frequency when applied to muscle phantom.

Figure 4 shows the impedance characteristics of the 200 MHz applicator which are typical of this type of applicator. When unloaded the applicator presents a high impedance and the power radiated is greatly reduced. Penetration depths have been measured by means of thermocouples or thermographic camera(6). Results have been in good agreement with theory within the limits of measurement acuracy and phantom characteristics, but more especially the measured heating profiles follow closely the predicted patterns. This can be seen from Figure 3 a,b, which shows the surface heating and depth profiles parallel to and normal to the direction of current flow obtained by the split phantom technique.

The measurements reported above refer to muscle phantom and show that the applicator produces heating profiles similar to those obtained with comparable conventional applicators. An evaluation of the new applicator is being made on both patients and animals.

CONCLUSIONS

The new lightweight applicator offers much greater frequency/size design flexibility than previously available for particular treatment sites.

It can be designed for a large range of sizes independently of frequency.

The applicator is insensitive to the permittivity of the material between it and muscle tissue to be heated, for example, fat or bolus.

Polarisation is linear with electric field parallel to the aperture and consequently parallel to fat muscle interface.

It does not produce hot spots and can be operated at high power.

The applicator is inexpensive and can be used individually or in multiple arrays.

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