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A61N 5/02

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GB 0830116

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A5R

(54) Electromagnetic irradiation apparatus for destruction of tumours

(57) For heating internal body organs or the interior of limbs by e-m radiation to kill malignant tissue, three 120°-spaced radiators 2 are located in a tank 1 so distanced from one another as to produce a voltage standing wave pattern having a maximum within the trunk or limb 3 at the operating frequency. The radiator impedances and operating frequencies are adjusted so that the non-absorbed radiation received by each radiator from the other two is correct in phase and amplitude to substantially cancel the power otherwise reflected back from the third radiator to the RF source, thereby producing effective matching and preventing damage to the RF sources due to a high voltage. Either two or four (at the points of an equilateral tetrahedron) radiators may be used in similar arrangements.

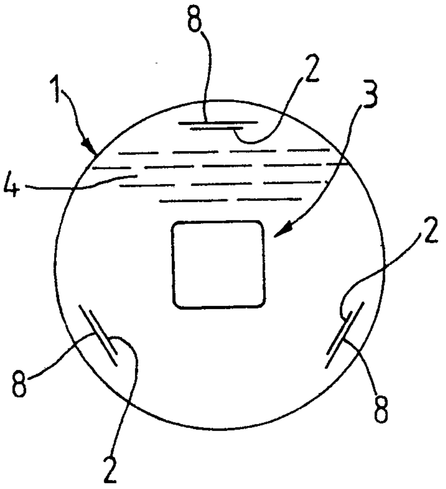

Fig.8.

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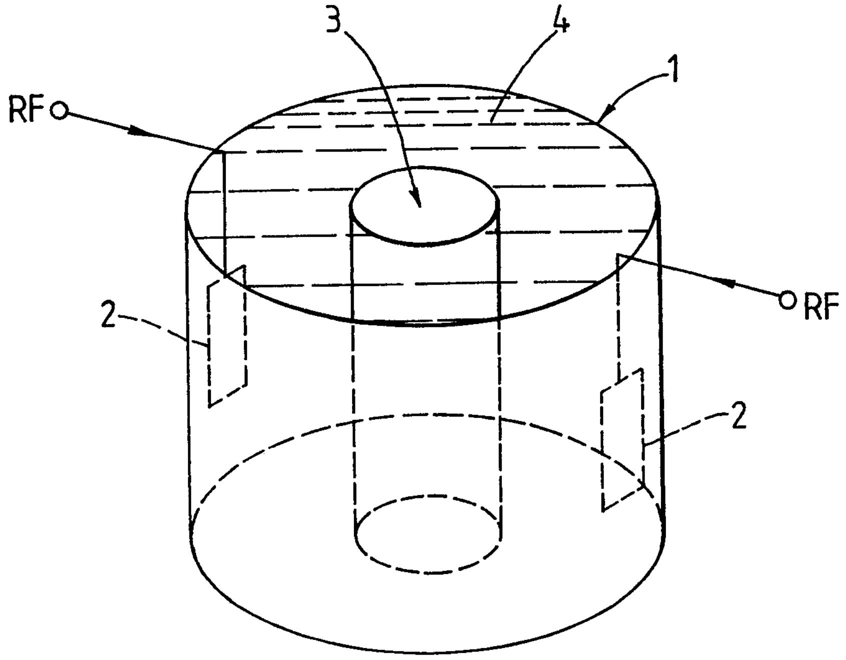

Fig.1.

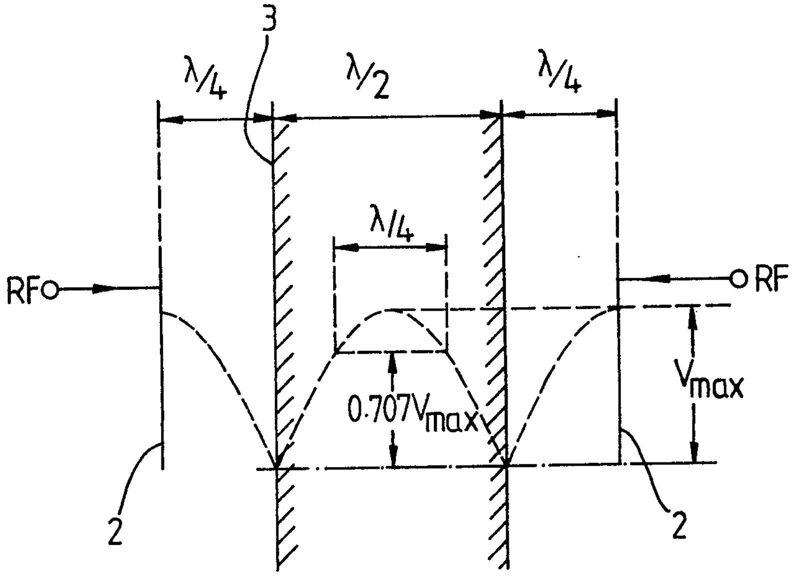

Fig.2.

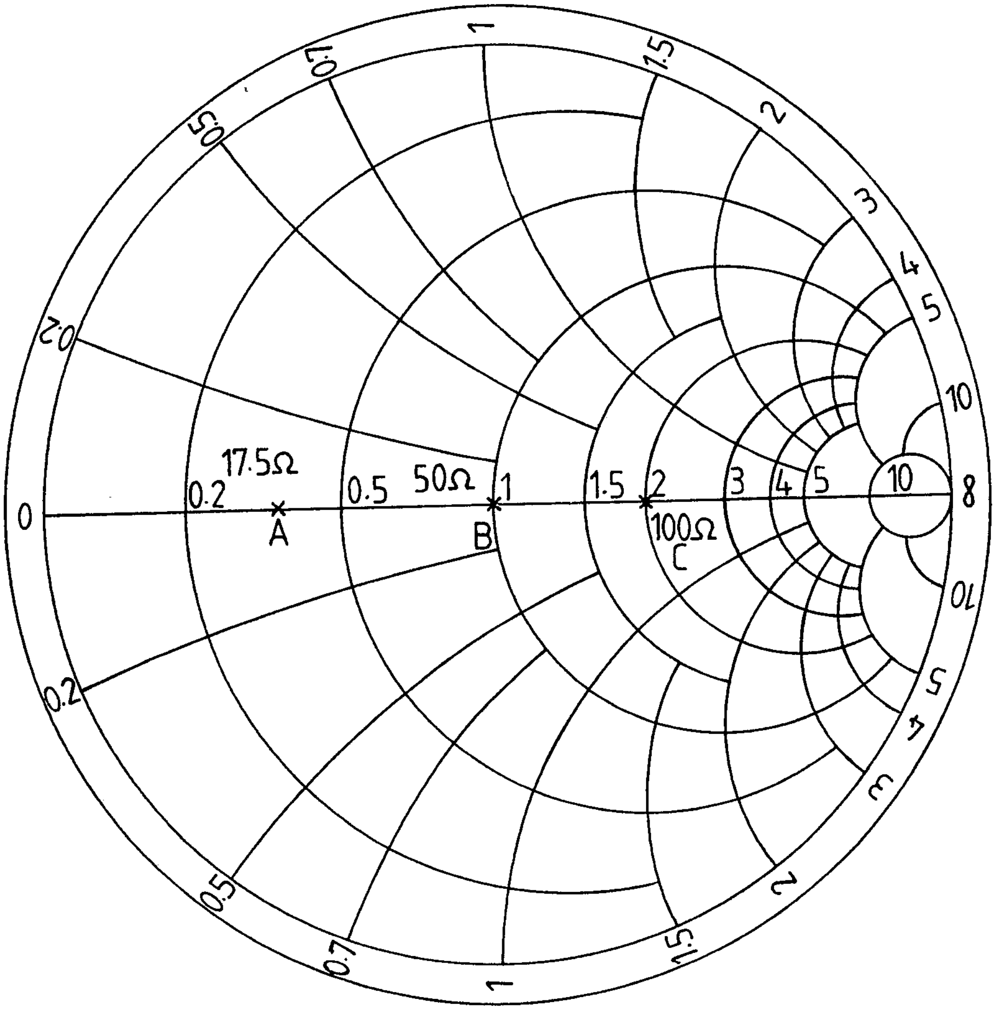

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Fig.3.

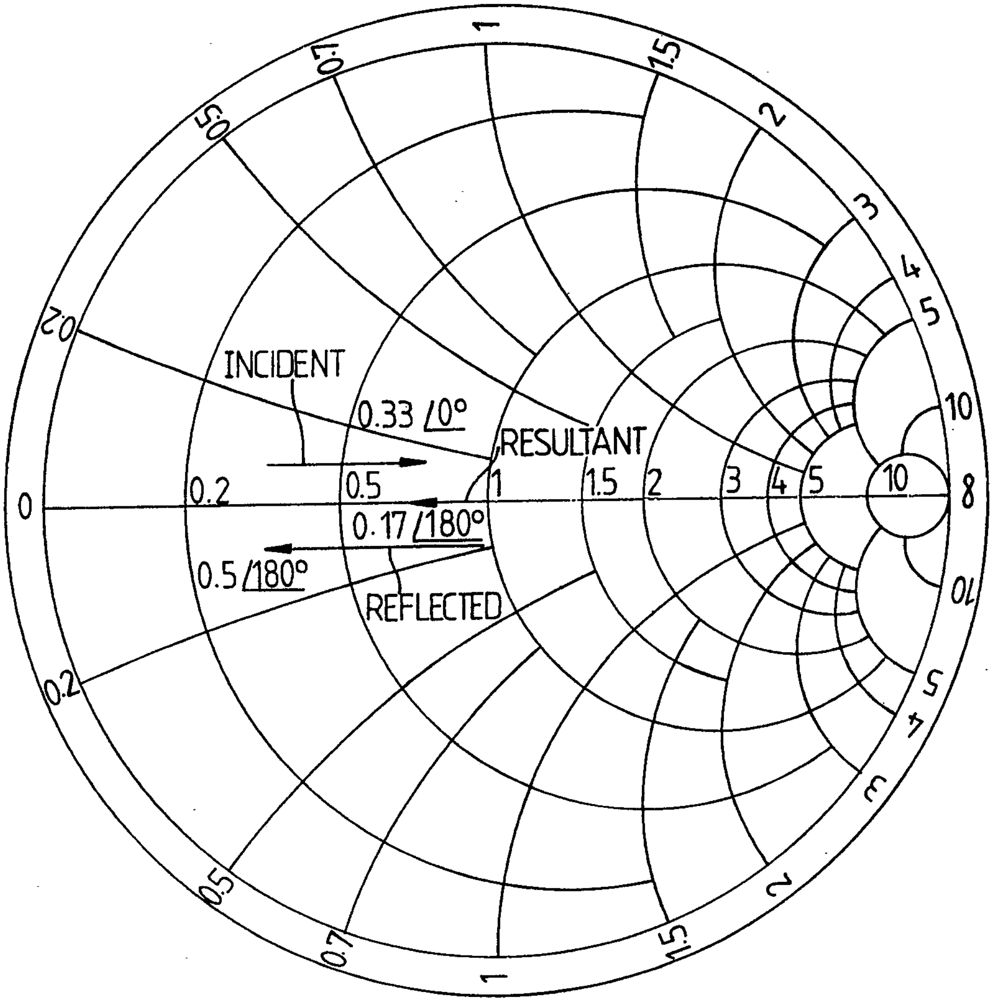
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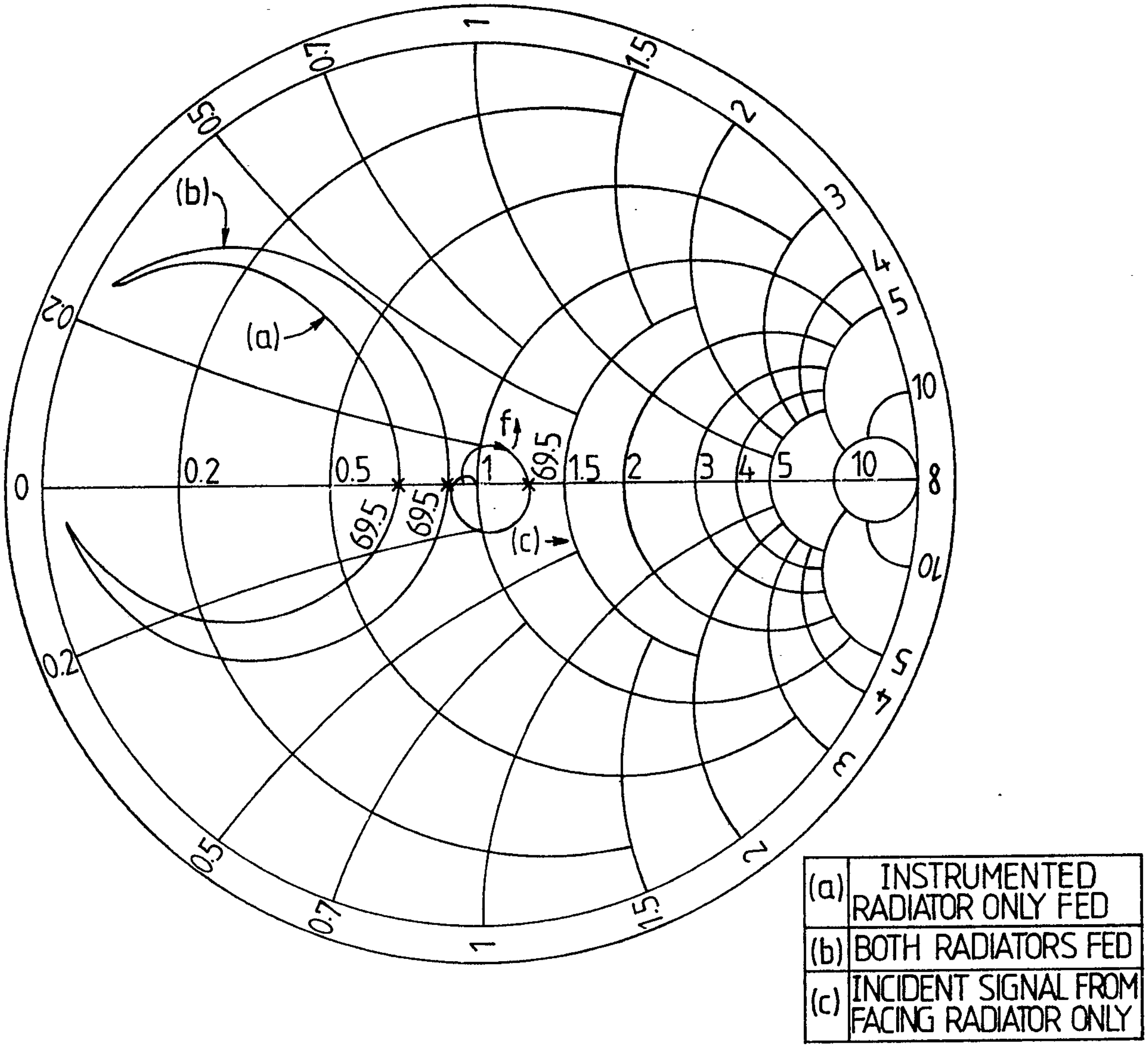
Fig.4.


(b)
(a)
(c)
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69.5
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(a) INSTRUMENTED RADIATOR ONLY FED
(b) BOTH RADIATORS FED
(c) INCIDENT SIGNAL FROM FACING RADIATOR ONLY

Fig.5.

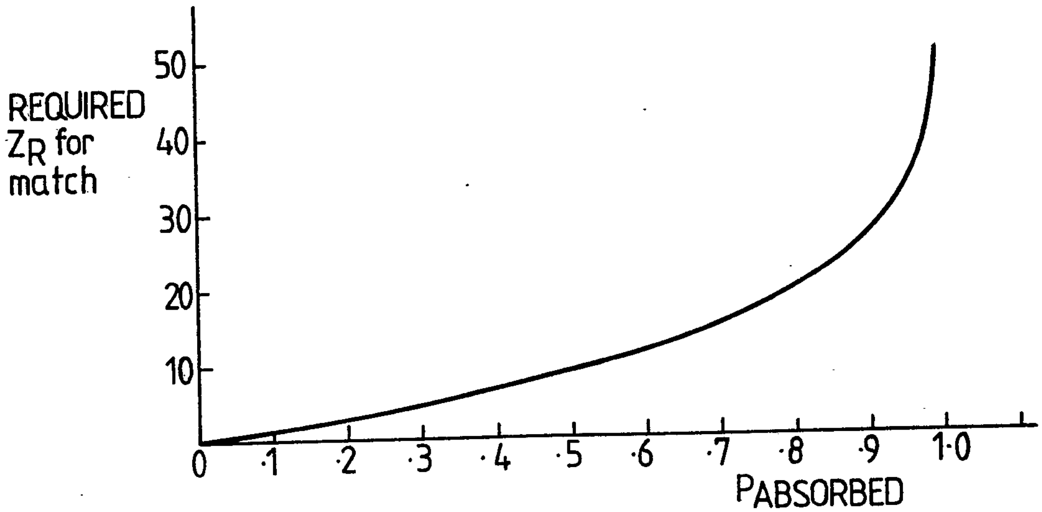
REQUIRED
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Fig.6.

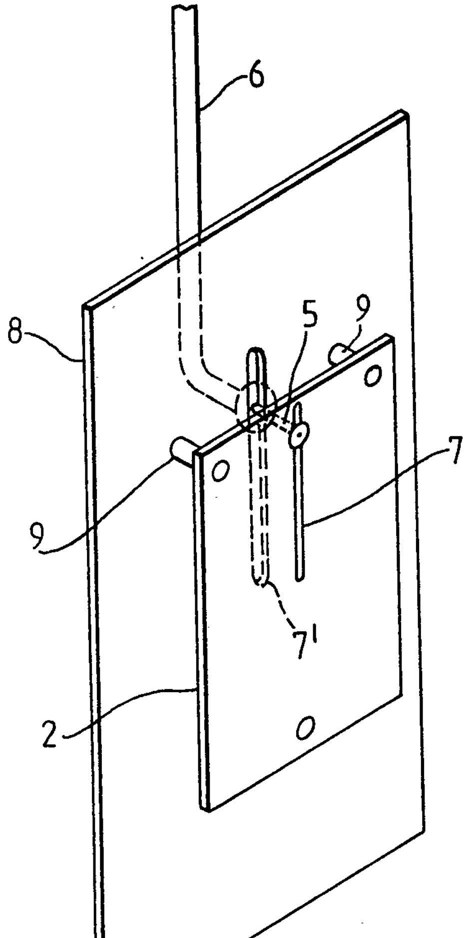
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Fig.7.

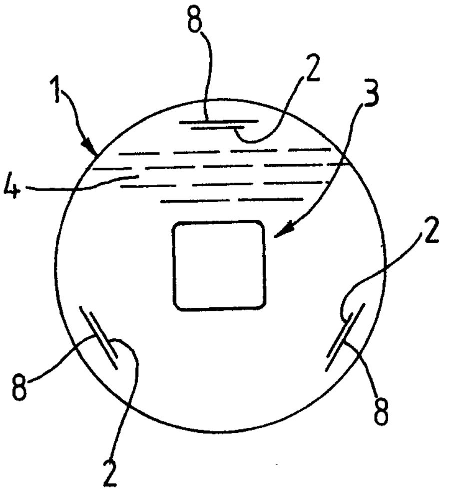


Fig.8.

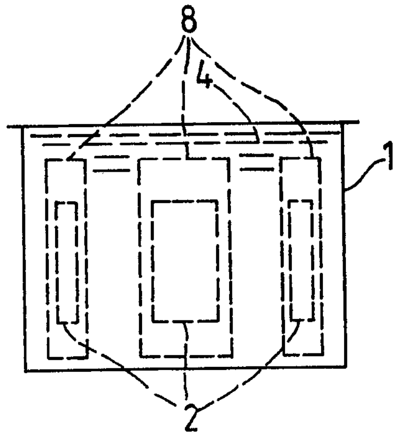


Fig.9.

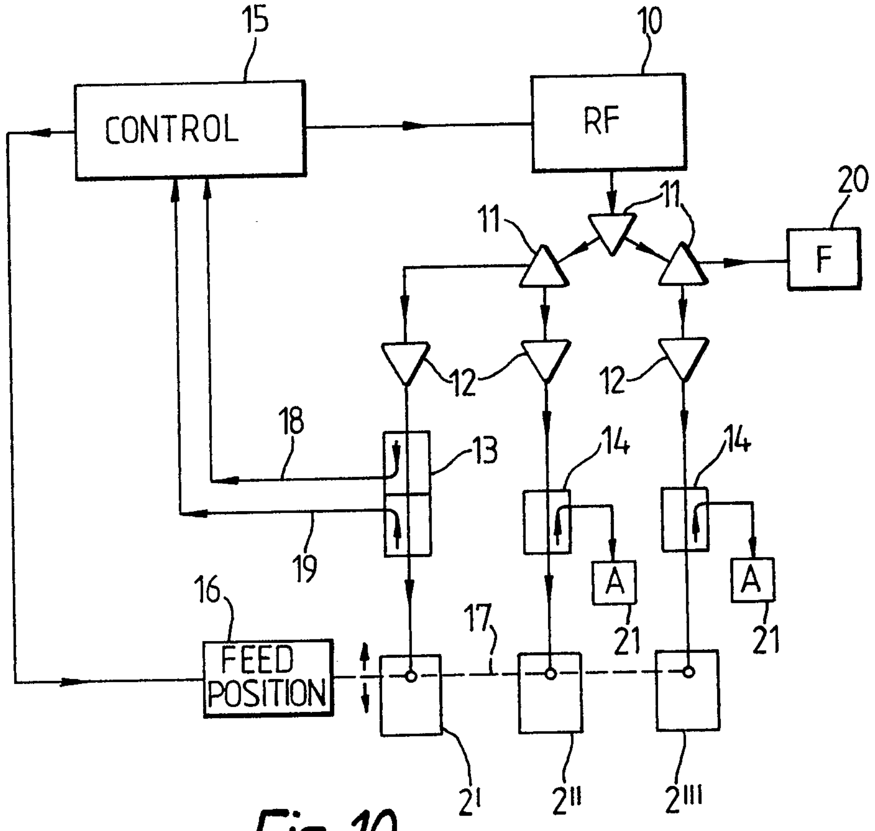
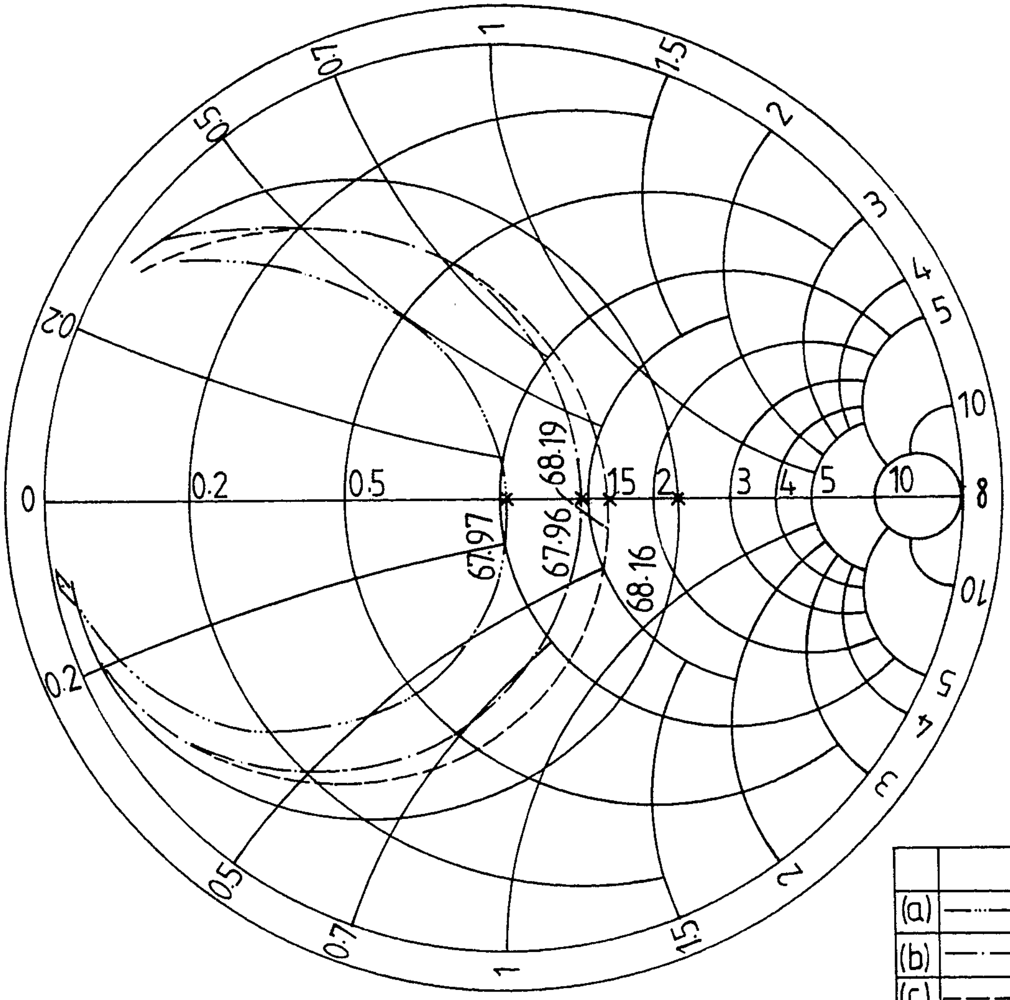
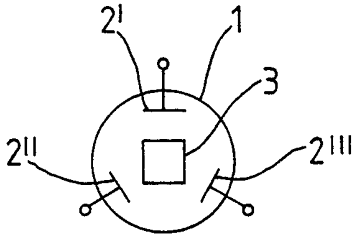


Fig.10.





		2ᴵ	2ᴵᴵ	2ᴵᴵᴵ
(a)	—··—··—	Fed	Term	Term
(b)	—·—·—	Fed	Term	Fed
(c)	— — —	Fed	Fed	Term
(d)	———	Fed	Fed	Fed

Fig. 11.

SPECIFICATION

Improvements in or Relating to Electromagnetic Irradiation Methods and Apparatus

This invention relates to electromagnetic irradiation methods and apparatus and has a principal application in the hyperthermia treatment of tumours which are deep-seated in the human body.

In our copending UK Patent Applications Nos 8314655, 8303179 and 8309776 there are described forms of electromagnetic applicators for the treatment of near-surface tumours by hyperthermia. Such applicators are unlikely to be effective at depths greater than about 6 cm, and there is a need for a non-invasive method of heating deep-seated sites.

One known approach to meeting this need uses a whole-body irradiation apparatus in which irradiation is directed into the body (trunk or limb) from an array of surrounding radiators, in order to produce concentrated heating at the deep-seated site. The body is located in a tank of dielectric liquid, suitably de-ionised water, within which is an annular array of radiators. By suitably phasing the RF power fed to the several radiators, in the manner of an antenna array, it is said to be possible to "steer" the zone of concentrated heating to a desired site within the body. The water is provided to improve the power transfer to the body by impedance matching, and can also be circulated to cool the body surface.

From the described results for one such commercially available apparatus however, it appears that the above technique tends to produce more heating at the body surface than is produced in the central deep-seated region. This disadvantage will be inherent in any attempt to produce a small "hot spot" (ie localised heating) by using differential phasing to cause constructive interference; this side-effect is due to unwanted interference peaks, and can produce a severe penalty in the form of the unproductive heat load on the body. Inspection of the available data on this commercially-available apparatus suggests that, if the heating pattern has radial symmetry, this extra heat load around the body's circumference is about six times that of the useful part.

The use of a phased array seems unnecessarily complicated unless some form of steerable hot-spot is envisaged. Such an arrangement can only be useful if the wavelengths used are commensurate with the tumour dimensions and, as indicated above, this results in the problem of the production of other hot-spots within the body. Another problem with this approach is that at the frequencies (wavelengths) required (upwards of 100 MHz), it is difficult to propagate energy into the body due to high losses. There is also a fundamental problem, when using multiple radiating sources which face each other, of a deleterious effect (having some analogy with "load-pulling") on the power sources due to the power returned to them. This effect, which will be discussed later cannot readily or economically be avoided when using a phased array.

It is an object of the present invention to provide an irradiation method and apparatus which allows the alleviation of some of these problems.

According to the present invention a radio-frequency electromagnetic irradiation method comprises;

locating the object to be irradiated at the intersection of the radiation patterns of at least two spaced-apart radiators so aligned that the radiators receive radiation from each other;

the frequency of the power supplied to each radiator, in relation to the radiation path-length between the or each pair of radiators, being such as to produce a voltage standing-wave pattern between the radiators which, at least approximately, has a maximum within said object.

Preferably the voltage standing-wave pattern also has maxima at least approximately at the radiators, but this is not essential.

Where the voltage standing-wave pattern has maximal at least approximately at the radiators, preferably the method also comprises adjusting the impedance of each radiator, in relation to the characteristic impedance of the transmission line supplying power thereto, so that the total power received by each radiator from the other radiator or radiators, said power being at least approximately in voltage antiphase with the power which would otherwise be reflected back from each radiator along said transmission line, at least approximately cancels out said otherwise reflected-back power.

Preferably the method comprises varying the frequency of the power supply to all the radiators to bring the power received by, and the power which would otherwise be reflected back from, each radiator, substantially into antiphase with one another.

Preferably the method comprises locating the radiators and the object in a vessel containing an impedance-matching dielectric liquid. However, the method may also use applicators applied directly to the object, eg trunk or limb, such as those described in a paper by R. H. Johnson and J. R. James, "Design of hyperthermia applicators for optimum power transfer", 3rd IEE Int Conf on Antennas and Propagation 12—15 April, 1983, although in this case, using the preferred standing-wave pattern above, there will not be voltage minima at the surface of the object as hereinafter described.

Preferably the radiation path-length is such that the voltage standing-wave pattern consists of maxima at least approximately at the radiators and within said object and minima at least approximately at the object surface. The radiation path-length is preferably approximately one wavelength, but may be an integral number of wavelengths when using the aforesaid radiator impedance-adjusting technique.

For some purposes the method may use two radiators spaced opposite one another, preferably diametrically opposite. For irradiating the interior of an object, and in particular of a human body or limb, the apparatus may more suitably use three radiators spaced 120° apart on the circumference of a circle whose radius, in relation to the wavelength and the cross-section of the object, is preferably such that the said minima lie close to the surface of the object. For other purposes the method may use four radiators located on the faces of a notional regular tetrahedron. Only the two latter configurations give the necessary equal path-lengths between pairs of radiators when more than two radiators are used.

Also according to the present invention, a radio-frequency electromagnetic irradiation apparatus comprises;

at least two radiators spaced apart with their radiation patterns aligned to intercept, in use, in an object to be irradiated and to receive radiation from each other;

source means for supplying radio-frequency power to all said radiators via means including a transmission line connected to each radiator;

the radiator path-length between the or each pair of radiators being such, in relation to the frequency of said source means, as to allow the production of a voltage standing-wave pattern between the radiators which, at least approximately, has maxima at the radiators and within said object respectively;

the impedance of each radiator in relation to the characteristic impedance of the transmission line connected thereto being adjustable so that the total power received by each radiator from the other radiator or radiators, said power being at least approximately in voltage antiphase with the power which would otherwise be reflected back from each radiator along the transmission line connected thereto towards the source means, at least approximately cancels-out said otherwise reflected-back power.

Preferably the frequency of said source means is variable to allow the power received by, and the power which would otherwise be reflected back from, each radiator, substantially into antiphase with one another.

Preferably the radiators are located in a vessel for containing an impedance-matching dielectric liquid and within which the object to be irradiated can be located.

Preferably the radiation path-length is such that the voltage standing-wave pattern can consist of maxima at least approximately at the radiators and within said object. The radiation path-length is preferably approximately one wavelength, but may be an integral number of wavelengths.

For some purposes the apparatus may use two radiators spaced opposite one another, preferably diametrically opposite. For irradiating the interior of an object, and in particular of a human body or limb, the apparatus may more suitably use three radiators spaced 120° apart on the circumference of a circle. For other purposes four radiators located on the faces of a notional regular tetrahedron may be used. Only the two latter configurations give the necessary equal radiation path-lengths between pairs of radiators when more than two radiators are used. Preferably the radius of the circle, in relation to the wavelength and the cross-section of the object, allows said single minima to be close to the surface of the object.

To enable the nature of the present invention to be more readily understood, attention is directed, by way of example, to the accompanying drawings wherein;

Fig. 1 is a perspective diagram of a simplified form of the invention, not to scale.

Fig. 2 shows a voltage standing-wave pattern obtainable with the apparatus of Fig. 1.

Fig. 3 is a Smith Chart plot for different radiator impedances at resonance.

Fig. 4 is a Smith Chart plot showing the result of adding incident and reflected signals at a radiator.

Fig. 5 shows experimental Smith Chart plots for two radiators facing one another.

Fig. 6 is a graph of the variation of radiator impedance as a function of absorbed power for two facing radiators.

Fig. 7 is a perspective view of a single radiator showing an impedance-varying arrangement.

Figs. 8 and 9 are respectively plan and elevation view of a three-radiator arrangement, not to scale.

Fig. 10 is an instrumentation and control circuit diagram.

Fig. 11 is a Smith Chart plot obtained with the arrangement of Figs 8 and 9.

Fig. 1 shows a vessel 1, suitably made of an insulating plastic such as polyethylene, in which two RF radiators 2 are located diametrically opposite one another. The object, here a human body or limb, whose interior is to be heated, is indicated by the cylinder 3. The vessel is filled with de-ionised water 4. The immersion of the radiators and the object 3 in the water 4 enables cooling to be applied to the outside surface of the body 3 by circulating the water, thereby reducing the heat load on the body's natural temperature-control system. The high dielectric constant of water (ε_r approximately 80) enables a reduction in the size of resonant radiators at a given frequency compared with equivalent air-spaced items, and also reduces the reflection of power from the body surface since the dielectric discontinuity threat is relatively small. The power loss in the water is low provided it is sufficiently pure.

Fig. 2 shows how, by suitably relating the frequency (ie wavelength) to the spacing of the radiators and the cross-section of the body, it is possible to produce a voltage standing-wave pattern having maxima at least approximately at the radiators and at the body interior and minima at least approximately at the body surface. (Fig. 2 assumes an ideal lossless body for clarity). If a "hot-spot" is defined as the volume circumscribed by the half-power level, it can be seen to be $\lambda/4$ across or half the body diameter, the radiation path-length between the radiators being a full wavelength.

The hot-spot can be steered inside the body by moving the body within the fixed standing-wave pattern, assuming that such body causes only small disturbance to the pattern. Such steering will be at the expense of some heating at the body surface, since the surface will move away from the standing-wave minima. With the pattern shown, the efficiency will be high, since power is essentially dissipated in the body alone.

The vessel 1 need not be of insulating material and, if conducting, can also constitute the "ground plane" for the radiators described later with reference to Fig 7. Use of a conducting vessel may affect the voltage standing-wave pattern produced to some extent.

A problem which is fundamental to the use of multiple radiating sources which at least partially face each other, is the apparent mismatch of each radiator to its power source due to power incident on that radiator for other radiator(s). This incident power looks, from the source end of the feeder line to each radiator, like a reflected signal and hence appears as if there were a mismatch condition. To illustrate this, consider two radiators diametrically facing each other in an ideal situation, ie each perfectly matched to its source when in isolation and no extraneous losses, with an absorbing body between them. If the body absorbs 75% of the power radiated by each radiator, then each radiator will have 25% of the forward power incident upon it. The sources will both see this incident power as a reflected signal giving a mismatch with a VSWR=3.0 (ie voltage reflection coefficient $|\Gamma|=0.5$), there being no actual reflection due to the assumed perfect matching. (The phase relationship of the forward and incident signals is a function of the path-length between radiators). Such a situation is unlikely to be tolerated by a large (250 W or more) power source because the large VSWR produced would damage a conventional power amplifier. Large power amplifiers capable of withstanding high VSWR's are very expensive. At microwave frequencies this problem is often solved by using ferrite circulators, but at radio frequencies in the region of 100 MHz special bridge networks are needed to separate the forward and reflected signals. Such networks have an insertion loss of at least 3 dB (theoretical) which, together with the "dumping" of the reflected power, not only makes the system expensive to produce but increase the power required from each source by a factor of 3 or more.

To further illustrate the problem, the return loss of a radiator will now be demonstrated, as by using a network analyser reflectometer, plotted on a Smith Chart. Such a plot is a voltage vector plot of the reflected/incident signal quotient in a transmission line of given characteristic impedance. Fig 3 shows the cases of (A) 17.5Ω, (B) 50Ω and (C) 100Ω load (radiator) impedances for a 50Ω line, all being purely resistive for simplicity. These are equivalent to voltage reflection coefficients (Γ) of 0.5 $\angle 180°$, 0 $\angle 0°$ and 0.33 $\angle 0°$ respectively.

Fig. 4 shows the result which would be observed if the actual reflected signal for a radiator impedance of 17.5Ω ($\Gamma=0.5\ \angle 180°$ in isolation) is added to an incident signal, from an identical facing radiator, corresponding to a reflected signal for $\Gamma=0.33\ \angle 0°$, again for a 50Ω line. The resultant is observed as for a load giving $\Gamma=0.17\ \angle 180°$, and represents the case where 11% of the power from the facing radiator is incident on the radiator to which the measurement relate.

Fig. 5 shows experimental plots (variation of vector with frequency f) obtained using two radiators arranged as in Fig 1 with a 30 l phantom of 10% saline solution in a polyethylene vessel between them corresponding to the object 3. (The experimental apparatus used is described later with reference to Fig. 11.) The saline-containing vessel was about 250 mm square in cross-section, dimensions similar to a human body. The distance between the radiators was adjusted so that the signal received from the facing radiator, via the phantom, by the instrumented radiator had a phase of 0° relative to its forward (radiated) signal at the radiators' resonant frequency of 69.5 MHz, or in 180° antiphase with the reflected signal at the instrumented radiator in isolation. It will be seen at resonance (ie on the horizontal, resistive, axis), the signal (c) vector (the incident signal from the facing radiator only) is equal to amplitude to the difference between the signal (a) vector (instrumented radiator only fed) and the signal (b) vector (both radiators fed).

Reverting to Fig. 4, it will be seen that if the radiator impedance were 25Ω ($|\Gamma|=0.33$), the reflected signal vector and the incident signal vector would cancel out, giving a perfect match. Accordingly, in the present invention the solution to the problem is to adjust the radiator impedance(s) to suit the incident power. This solution eliminates both the aforesaid bridge network and the need to "dump" unwanted reflected power.

For the case of two identical radiators in the ideal situation of Fig. 1, it is possible to relate the required radiator impedance to the power absorbed by the body. To equalise the incident power with the reflected power in isolation, in the present case where the radiators are an integral number of wavelengths apart, the radiator impedances Z_L must always be less than the characteristic impedance Z_0 of the power source/transmission line system, ie Z_L must always lie on the left-hand side of unity on the Smith Chart. (It will be seen that this situation exists in Fig. 5, where curve (b) is approaching the matched condition).

In the above case the required radiator

impedance can be determined from the relationship

$$\frac{Z_L}{Z_o} = \frac{1+\Gamma}{1-\Gamma},$$

which gives

$$Z_L = Z_o\frac{1-\Gamma}{1+\Gamma}$$

where $0<Z_L<Z_o$ and hence Γ is negative, as in this case.

In terms of power absorbed by the body, P_A, it can be shown that this gives:

$$Z_L = Z_o\frac{1-\sqrt{1-P_A}}{1+\sqrt{1-P_A}}$$

A plot of the radiator impedance Z_R required for equalisation or matching as a function of P_A is shown in Fig. 6. Control of radiator impedance can be achieved as shown in Fig 7 by making the contact between the central conductor 5 of the eg 50Ω coaxial feed line 6 movable in a slot 7 along the major axis of the radiator 2. Fig 7 also shows a copper sheet "ground-plane" 8 (omitted for clarity from Fig 1) mounted behind the radiator 2 on insulating spacers 9 and including a corresponding slot 7′ to which is slidably connected the outer conductor of line 6. The thus-aligned slot 7 does not interrupt any currents in the radiator, whose impedance therefore does not become reactive. In one embodiment this arrangement has proved capable of varying the radiator impedance from 60Ω $\angle 0°$ down to 22.5Ω $\angle 180°$ when the feed-point distance from the top of the slot was changed from 0 to 60 mm, the radiator being 225 mm long by 160 mm wide and the ground-plane 450 mm long by 230 mm wide spaced 11 mm therefrom. The resonant frequency of the radiator, ie when the reflected signal lies on the resistive (horizontal) axis of the Smith Chart, of approx 68 MHz changed by <1%. These quantities are typical of those required for apparatus for heating the trunk. Other known methods of varying radiator impedance can be used, eg varying the width.

It will be seen that some form of phase control of the signal from the facing radiator, relative to that of the reflected signal at the receiving radiator, is necessary in order to obtain matching. In principle this could be obtained either by using phase-shifters in the feed connections to each radiator, or by adjusting the path-length (ie the distance) between the radiators, at some fixed frequency. Both these methods have practical disadvantages, and the preferred method is to adjust the frequency, and hence the wavelength, with the radiators a fixed distance apart; changing the wavelength then effectively changes the relative phases as required, provided one stays within the useful operating range of the radiators.

The use of more than one radiator not only allows the production of a valuable heating profile of the kind shown in Fig 2, but has an important effect on the power required from the sources (or split single source) during the individual radiators. In a standing wave produced by the interference pattern between two (or more) coherent waves, the E-field in the pattern is the vector sum of the component waves. Hence if, as is generally assumed, the heating effect is due to the E-field, the power is proportional E^2. If the component waves have equal amplitudes, then vector addition gives an amplitude of nE from n sources, and hence n sources produce n^2 times the heating effect of a single source; or, to produce a given power P in the body, each source need produce only $P/\sqrt{n}$ output.

In the description so far, only two radiators have been used, directly facing one another. The use of more than two radiators produces the benefit of a two-dimensional pattern of power distribution. Because of the need for equal path-lengths between the radiators, the matching method described above allows the use of only three radiators arranged symmetrically ie at 120° intervals, around the body to be irradiated, in order to produce the correct phasing of the waves. (A four-radiator arrangement with the radiators located on the respective faces of a notional regular tetrahedron is possible for other irradiation purposes, but considered impractical for the human trunk or limbs). Such an arrangement is shown diagrammatically in Figs 8 and 9, in plan and elevation respectively. In one embodiment the vessel 1 was 800 mm in diameter and 500 mm deep, the radiator and ground-plane dimensions being as given in relation to Fig. 7 and the radiators 2 located 330 mm from the vessel axis. These dimensions are suitable for heating the human trunk.

Fig. 10 shows an instrumentation and control circuit for the arrangement of Figs. 8 and 9. A variable-frequency RF source 10 is connected via three splitters 11 to three identical power amplifiers 12 each of which is connected to a radiator 7. The feeder lengths between the source 10 and each radiator 7, via the splitters 11, are all made equal in order to maintain a constant phase at all the radiators. Between one amplifier 12 and its associated radiator 7 is connected a dual-direction coupler 13. A single-direction coupler 14 is connected between each remaining amplifier and its radiator. Samples of the forward and return signals from coupler 13 are fed via leads 18 and 19 respectively to a control unit 15 which includes a scaler analyser (not shown). The latter is known instrument comprising an amplitude analyser which substracts the logarithms of the two signals to give the power ratio forward signal/return signal. This ratio is applied to adjust the impedance of all three radiators 7 (by the same amount) by means of a feed-position unit 16; the latter includes an electro-mechanical drive (indicated at 17) for moving the feeder contacts along the slots in the radiators shown in Fig. 7.

The balancing or matching procedure is suitably an iterative one in which, starting from an initial condition, the feed-point on the three radiators, and the operating frequency, are adjusted alternately in the direction which increases the return loss, ie reduces the signal to unit 15 via lead 19 and thus maximises the forward/return signal ratio as measured by unit 15. These operations can be done either manually, or automatically by incorporating a suitably programmed computer in unit 15. The small frequency changes involved do not significantly affect the desired standing-wave pattern. The iterative procedure can be performed at a reduced power level to avoid the risk of damage to the amplifiers due to an excessively high initial imbalance, and so that a specified treatment-programme is performed as scheduled. The circuit also includes a frequency meter 20, and alarm units 21 which operate if the return signal from either coupler 14 exceeds a predetermined danger level.

Fig. 11 shows experimental results obtained with the aforementioned phantom using a radiator configuration and feed arrangement basically similar to those of Figs. 8, 9 and 10, but without items 12, 14, 15, 16 and 21 and in which the frequency and feed-point positions were adjusted manually. Additionally, for experimental purposes only, the simple scalar analyser of unit 15 was replaced by a network analyser which enabled the return-signal vector values relating to radiator 2′ to be plotted on a Smith Chart as the frequency was varied about the resonant frequency of about 68 MHz. (The Fig 5 results were obtained similarly, part from using only two radiators.) In curves (a), (b) and (c), the feeders connected to the unfed radiators 2″ and 2‴ were terminated with their characteristics impedance (50Ω). It will be seen that curves (b) and (c) are approximately coincident and that their vector sum along the resistive (horizontal) axis approximately equals curve (d). Curve (a) represents the matched condition of radiator 2′ in isolation; a balanced or matched condition would evidently exist when the intersection of curve (a) with the axis, ie for radiator 2′ *unmatched* in isolation, was sufficiently far to the left of unity to cause resultant curve (d) to pass through unity. This condition is achieved by the adjustment of operating frequency and radiator impedance as described earlier. As already indicated, measurement of vector values is not necessary in routine operation, for which an ordinary amplitude analyser is sufficient.

Because limbs have a smaller cross-section than the trunk, embodiments for irradiating the former may be smaller than for the latter and use a higher frequency, in order that the voltage minima remain near the limb surface. Alternatively the same apparatus dimensions can be used at a higher, harmonically-related frequency, the path-length thereby becoming a correspondingly larger integral number of shorter wavelengths. As another alternative, a higher frequency may be used such that the path-length is an odd number of half-wavelengths (producing off-axis voltage maxima), in which case a similar radiator impedance-adjustment technique to that hereinbefore described can be used, except that in this case, because of the phase reversal, Z_L for matching is now $>Z_o$, ie on the right-hand side of unity on the Smith Chart.

A form of the invention may also be usable in which, unlike the form hereinbefore described with reference to the drawings, the standing-wave pattern has voltage minima, instead of voltage maxima, at the radiators, ie the radiators are current-driven instead of voltage-driven. However, the particular matching technique hereinbefore described necessarily uses voltage-driven radiators.

CLAIMS

1. A radio-frequency electromagnetic irradiation method comprising:

locating the object to be irradiated at the intersection of the radiation patterns of at least two spaced-apart radiators so aligned that the radiators receive radiation from each other;

the frequency of the power supplied to each radiator, in relation to the radiation path-length between the or each pair of radiators, being such as to produce a voltage standing-wave pattern between the radiators which, at least approximately, has a maximum within said object.

2. A method as claimed in claim 1 wherein the voltage standing-wave pattern also has maxima at least approximately at the radiators.

3. A method as claimed in claim 2 comprising adjusting the impedance of each radiator, in relation to the characteristic impedance of the transmission line supplying power thereto, so that the total power received by each radiator from the other radiator or radiators, said power being at least approximately in voltage antiphase with the power which would otherwise be reflected back from each radiator along said transmission line, at least approximately cancels out said otherwise reflected-back power.

4. A method as claimed in claim 3 comprising varying the frequency of the power supply to all the radiators to bring the power received by, and the power which would otherwise be reflected back from, each radiator, substantially into antiphase with one another.

5. A method as claimed in any preceding claim comprising locating the radiators and the object in a vessel containing an impedance-matching dielectric liquid.

6. A method as claimed in any preceding claim wherein the radiation path-length is such that the voltage standing-wave pattern consists of maxima at least approximately at the object surface.

7. A method as claimed in claim 6 wherein the

radiation path-length is approximately one wavelength.

8. A method as claimed in any preceding claim suitable for irradiating the interior of an object, eg of a human body or limb, comprising using three radiators spaced substantially 120° apart on the circumference of a circle.

9. A method as claimed in claim 8 as dependent on claim 6 or claim 7 wherein the radius of the circle, in relation to the wavelength and cross-section of the object, is such that said minima lie close to the surface of the object.

10. A radio-frequency electromagnetic irradiation apparatus comprising:

at least two radiators spaced apart with their radiation patterns aligned to intercept, in use, in an object to be irradiated and to receive radiation from each other;

source means for supplying radio-frequency power to all said radiators via means including a transmission line connected to each radiator;

the radiation path-length between the or each pair of radiators being such, in relation to the frequency of said source means, as to allow the production of a voltage standing-wave pattern between the radiators which, at least approximately, has maxima at the radiators and within said object respectively;

the impedance of each radiator in relation to the characteristic impedance of the transmission line connected thereto being adjustable so that the total power received by each radiator from the other radiator or radiators, said power being at least approximately in voltage antiphase with the power which would otherwise be reflected back from each radiator along the transmission line connected thereto towards the source means, at least approximately cancels-out said otherwise reflected-back power.

11. Apparatus as claimed in claim 10 wherein the frequency of said source means is variable to allow the power received by, and the power which would otherwise be reflected back from, each radiator, to be brought substantially into antiphase with one another.

12. Apparatus as claimed in claim 10 or claim 11 wherein the radiators are located in a vessel for containing an impedance-matching dielectric liquid and within which the object to be irradiated can be located.

13. Apparatus as claimed in any of claims 10—12 wherein the radiation path-length is such that the voltage standing-wave pattern can consist of maxima at least approximately at the radiators and within said object and minima at least approximately at the object surface.

14. Apparatus as claimed in claim 13 wherein the radiation path-length is approximately one wavelength.

15. Apparatus as claimed in any of claims 10—14 suitable for irradiating the interior of an object, eg a human body or limb, comprising three radiators spaced substantially 120° apart on the circumference of a circle.

16. Apparatus as claimed in claim 15 as dependent on claim 13 or 14 wherein the radius of the circle, in relation to the wavelength and the cross-section of the object, allows said single minima to be close to the surface of the object.

17. A method or apparatus for radio-frequency electromagnetic irradiation of an object substantially as hereinbefore described with reference to the accompanying drawings.

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