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HIGH FREQUENCY THERAPEUTIC APPARATUS

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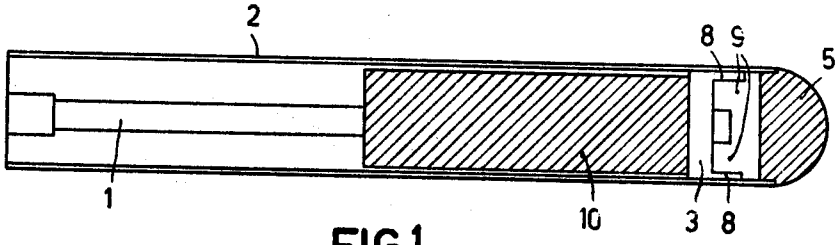

FIG.1

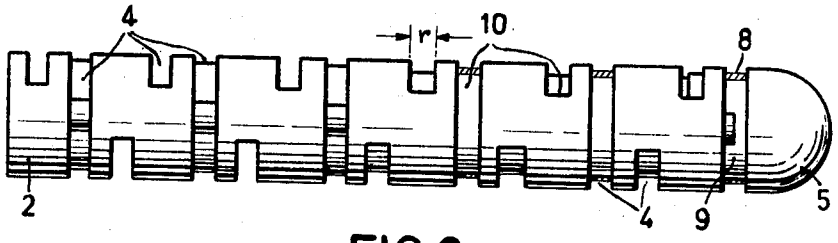

FIG.2

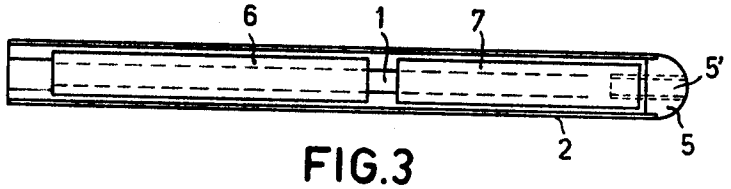

FIG.3

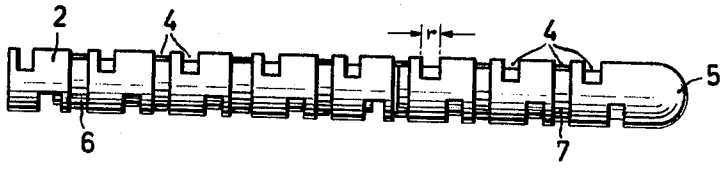

FIG.4

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HIGH FREQUENCY THERAPEUTIC APPARATUS

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13 Claims. (Cl. 128—407)

In a known therapeutic method heat is produced in the human body by irradiating it with localised high-frequency radiation of fairly long wavelength (λ). The radiators hitherto known for medical purposes are often unsuitable in the treatment of body cavities because of their excessive size. The invention relates to a rod-shaped radiator for electro-magnetic waves of decimeter wavelength for medical purposes, which is free of the said disadvantage. In accordance with the invention the radiator comprises a resonant line circuit having an internal conductor and a cylindrical outer conductor and having an electrical length substantially equal to $\lambda/4$. The outer conductor is provided with slots extending transversely to the longitudinal direction of the conductor. An electromagnetic field is produced within the outer conductor by current flow in the internal conductor and the outer conductor. As will become apparent hereafter, the various dimensions of the radiator are chosen so that the radiator operates as a quarter wavelength ($\lambda/4$) resonant line at the desired operating frequency. In a coaxial resonant line circuit the current essentially flows in the outer conductor in the longitudinal direction. Interruption of the current lines in the outer conductor by wall slots which are transverse to the lines of current flow, i.e., transverse to the longitudinal axis of the coaxial resonant line, results in the coupling of the internal electromagnetic field to the surrounding environment. The degree of coupling depends upon various factors, among which are the density of current intercepted by the slot and the component of slot length transverse to the current lines.

In a preferred embodiment of the invention, the lengths of the individual slots extend over half the circumference of the outer conductor and are offset from another about the circumference of the outer conductor by an angle of 120 degrees. A further feature is that the width of the slots is greater than the distance between adjacent slots. The combination of a quarter wavelength coaxial resonant line slotted as described above has been found to produce a radiator which can be used for therapeutic treatment of a patient by means of high frequency electromagnetic radiation. In accordance with the invention, a very compact radiator is provided which can be inserted into a body cavity and which radiates an electromagnetic field to the surrounding body tissue to heat same. The particular arrangement of the slots in combination with the resonant line produces a particularly uniform field about the radiator which is especially useful for medical treatment since the electric field vector is parallel to the longitudinal axis of the radiator.

In the frequency range from 400 to 500 megacycles per second concentrated elements such as coils and capacitors cannot be used satisfactorily as components of a radiator. Therefore use is made of coaxial resonant line circuits having distributed electrical constants, i.e. distributed inductance and capacitance. Such resonant lines are suitably shaped to produce the desired electrical and magnetic alternating fields in the body to be heated. The coupling of the resonant line circuits with the high frequency wave generator does not affect these fields, but the coupling with the body must be such that the maximum part of the supplied high-frequency energy is converted into heat in the body. Generally it is desired to utilize the energy in a given direction and to a given depth. In the radiator according to the invention the conversion of energy is at a maximum in the vicinity of the surface of the radiator and diminishes gradually owing to the normal dispersion of the wave energy in the body. The dispersion pattern is substantially uniform both radially of the radiator and beyond the end thereof. The radiator itself is not heated excessively.

FIG. 1 diagrammatically shows a longitudinal sectional view of an inductive resonant line radiator,

FIG. 2 is a side view of the device of FIG. 1.

FIG. 3 diagrammatically shows the longitudinal sectional view of a capacitative resonant line radiator and

FIG. 4 is a side view of the device of FIG. 3.

The radiator has a coaxial structure and is coupled via slots with the media to be heated. The radiator shown in FIGS. 1 and 2 comprises as inductive components the outer side of the inner conductor 1 and the inner side of the outer conductor 2, which are interconnected via a coupling bracket 3, and the inductive component of the slots 4 and the outer side of the outer conductive 2 via the slots in parallel position. The capacitive component comprises that prevailing between the inner conductor and the outer conductor and the capacity of the slots 4. It is known that the slots 4 have a desirable radiation resistance and an undesired loss resistance. The latter value may be found with the aid of known formulae for calculating the damping b_k as a function of the coupling through holes. The width r of the slots is to be considered only for half of its value. Since b_k *is* about 2.4 d/r the width r of the slots must be at a maximum and the wall thickness d is to be at a minimum. With a wall thickness of 0.5 mm. and a slot width of 4 mm., the damping b_k may amount to about

$$2.4\frac{0.5}{2}=0.6$$

It has been found that values of b_k below 1 are not detrimetal to the operation of the device or to the patient Therefore, for safe operation of the device, it is preferable to maintain the radito d/r less than 0.2. The damping is, in this case, so small that the loss current is low and the radiator is not heated excessively. This condition is to be fulfilled to prevent excessive heating of parts of the body adjacent the radiator.

Whether the radiator is to be coupled capacitively or inductively cannot be assessed with certainty. It has been found that with radiators of which the inner diameter of the outer conductor 2 is about 20 mm. inductive coupling is more effective. Owing to the large sheath surface the inductance is fairly high so that, in order to attain the resonance frequency, a relatively low capacitance is required.

With radiators having a smaller inner diameter of the outer conductor, for example, of 10 mm., a higher capacitance is required in the input coupling system owing to the lower inductances formed by the smaller sheath surface. In the embodiment shown in FIGS. 3 and 4 the space inside the radiator is filled by two brass blocks 6 and 7, which are arranged at an intermediate distance of 7 mm. in the centre and with an intermediate space of 0.5 mm. to the outer conductor. The block 6 makes direct electrical connection to the inner conductor 1 which passes through the two blocks 6 and 7. The adjustment of the inner conductor relative to the outer conductor is carried out by means of a piece of insulating material 5'. The capacitance in the system is formed by that between inner and outer spaced abutting surfaces of the blocks 6 and 7 and the tube 2 and end cap 5. The capacitance between the block 7 and the metal point 5 constitutes the coupling between the elements. By an

axial displacement of the block 7 the reflection factor of the system is varied, or in other words, the resonant frequency of the system is varied. The capacity must not be enhanced at will by strongly reducing the distance between the inner conductor surface and the outer conductor surface, since then the transitional damping may rise to such a value that the space at the closed end of the radiator is no longer excited. The radiation from the end is necessary in order to obtain uniform radiation from all parts of the radiator.

The kind of coupling used for connecting the wave generator to the radiator depends upon the diameter of the radiator, and furthermore upon the diameter of the slots, the length of the radiator and the number of slots. With a suitable choice of these values a reflection factor of 0.95 can be attained, the efficiency of the radiator being then 99.5%.

With the inductively coupled radiator shown in FIGS. 1 and 2 the coupling bracket 3 is arranged at the end of the inner conductor 1, at a short distance in front of the end of the slots 4. The contact piece 3 forms a cavity 9, and one edge resiliently engages the outer wall. The cavity 9 serves to provide a space at the end of the radiator so that radiation is derived from this portion also. Block 10 is arranged on the inner conductor 1. This block provides the capacitance relative to the outer conductor 2. The resonant coaxial line comprising the radiating device is preferably about one-fourth wavelength long ($\lambda/4$) at the nominal frequency of the energizing current supplied to the device. Therefore, the outer conductor of the radiator has a length of about $\lambda/4$, where λ is the wavelength of the energizing current supplied to the radiator at the nominal operating frequency of the device. The cooperating capacitative surfaces have a length of about $\lambda/10$ and the inner diameter of the outer conductor 2 is $\lambda/32$. The width of the slots 4 amounts to about 4.5 mm. and the distance between the slots is about 1.5 mm. With a load formed by a homogeneous specimen a standing-wave ratio of 0.95 was found at the nominal frequency.

The slots extend in their longitudinal directions in both embodiments over half the circumference of the cylindrical outer conductor and are offset relatively to each other through 120°.

What is claimed is:

1. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a tubular electrical conductor member having a longitudinal axis, and an electrical conductor member arranged within said tubular member, said inner conductor member and said tubular member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, and said tubular member further comprising a plurality of slots extending transversely to the said longitudinal axis for radiating said high frequency energy from said resonant line.

2. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member arranged within said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of slots for radiating said high frequency energy from said resonant line, said slots extending transversely to the said longitudinal axis for a distance of over half of the circumference of said cylindrical conductor.

3. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member arranged within said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of peripheral slots for radiating said high frequency energy from said resonant line, said slots extending transversely to the said longitudinal axis and having a width exceeding the distance between slots.

4. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member arranged within said cylindrical member, said inner conductor comprising a first portion having an external diameter substantially smaller than the internal diameter of said cylindrical member and comprising a second portion having an external diameter substantially equal to the internal diameter of said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of peripheral slots extending transversely to the said longitudinal axis for radiating said high frequency energy from said resonant line.

5. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a hollow cylindrical electrical conductor member having a longitudinal axis, an electrical conductor member concentrically arranged within said cylindrical member, said inner conductor comprising a first portion having a diameter substantially less than the inner diameter of said cylindrical member and comprising a contiguous second portion having a diameter substantially equal to the inner diameter of said cylindrical member, and means for electrically connecting said second portion at an end thereof to said cylindrical conductor, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of peripheral slots extending transversely to the said longitudinal axis for radiating said high frequency energy from said resonant line.

6. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a hollow cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member concentrically arranged within said hollow member, said inner conductor comprising first and second cylindrical portions spaced apart in end to end relationship and conductor means interconnecting said first and second portions and extending from one end of one of said portions, said first and second portions having a diameter substantially equal to the inner diameter of said hollow member, said inner conductor member and said hollow member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said hollow member being provided with a plurality of peripheral slots extending transversely to the said longitudinal axis for radiating said high frequency energy from said resonant line.

7. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said

radiator comprising a hollow cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member concentrically arranged within said hollow member, said inner conductor comprising first and second cylindrical portions spaced apart in end to end relationship and conductor means interconnecting said first and second portions and extending from one end of one of said portions, said inner conductor member and said hollow member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said hollow member being provided with a plurality of peripheral slots extending transversely to the said longitudinal axis for radiating said high frequency energy from said resonant line, said slots being uniformly disposed along the length of said hollow member with successive slots being offset from one another about the circumference of said hollow member.

8. Apparatus as described in claim 7 wherein said second cylindrical portion is mounted for axial movement within said hollow cylindrical member and further comprising an adjusting member of insulating material coupled to said second cylindrical portion for axially displacing said second cylindrical portion within said hollow member to vary the resonant frequency of said device.

9. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member arranged within said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of peripheral slots extending transversely to the said longitudinal axis for radiating said high frequency energy from said resonant line, said slots being disposed along the length of said cylindrical member with different ones of said slots being relatively offset from one another about the circumference of said cylindrical member.

10. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a cylindrical electrical conductor member having a longitudinal axis, and an electrical conductor member arranged within said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of slots for radiating said high frequency energy from said resonant line, said slots extending transversely to the said longitudinal axis for a distance of over half of the circumference of said cylindrical conductor and being disposed along the length of said cylindrical member with successive slots being offset from one another about the circumference of said cylindrical member.

11. Apparatus as described in claim 10 wherein successive slots are offset from one another about the circumference of said cylindrical member by an angle of approximately 120 degrees.

12. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a hollow cylindrical electrical conductor member closed at one end and having a longitudinal axis, an electrical conductor member concentrically arranged within said cylindrical member, said inner conductor comprising a first portion having a diameter substantially less than the inner diameter of said cylindrical member and comprising a contiguous second portion having a diameter substantially equal to the inner diameter of said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, and an electrically conductive partition member disposed within said hollow member in the vicinity of the closed end and resiliently contacting the inner surface of said hollow member, said partition member being electrically connected to said second portion and forming together with said inner surface of said hollow member a cavity resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of peripheral slots extending perpendicularly to the said longitudinal axis for radiating said high frequency energy from said resonant line, said slots being disposed along the length of said hollow member with successive slots being offset from one another about the circumference of said hollow cylindrical member.

13. A device for therapeutic treatment comprising a rod-shaped radiator of high frequency wave energy, said radiator comprising a hollow cylindrical electrical conductor member having a wall thickness d and a longitudinal axis, and an electrical conductor member concentrically arranged within said cylindrical member, said inner conductor member and said cylindrical member constituting an electrical line having distributed electrical constants, said line being approximately one-fourth wavelength long and resonant at the nominal frequency of said high frequency energy, said cylindrical member being provided with a plurality of peripheral slots for radiating said high frequency energy from said resonant line, said slots extending transversely to the said longitudinal axis for a distance of over half of the circumference of said cylindrical conductor and having a width r exceeding the distance between slots in the direction of the longitudinal axis, successive slots along the longitudinal direction of said cylindrical conductor member being offset from one another about the periphery of said cylindrical member, said wall thickness being less than the width of said slots.

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