

Feb. 20, 1940.

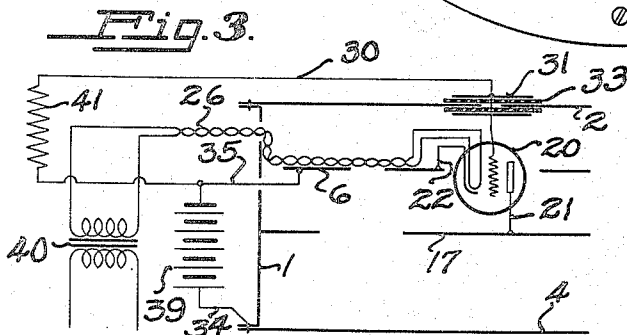
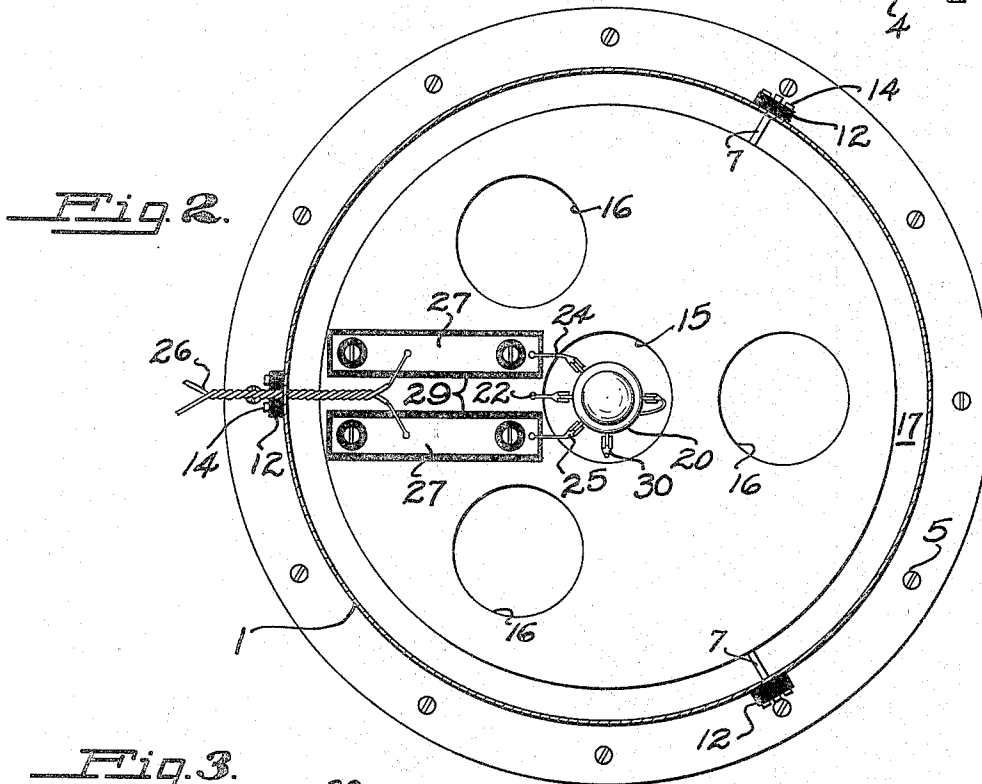
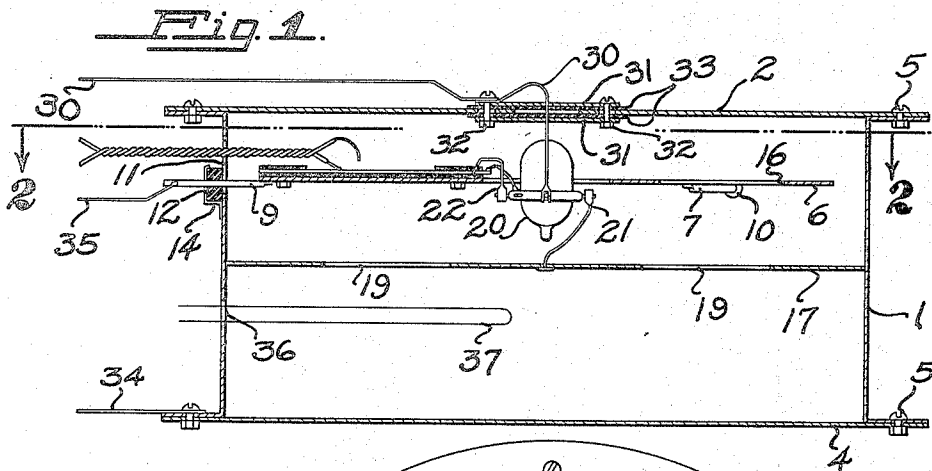
W. W. HANSEN

2,190,712

HIGH EFFICIENCY RESONANT CIRCUIT

Filed July 27, 1936

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

Fig. 4.

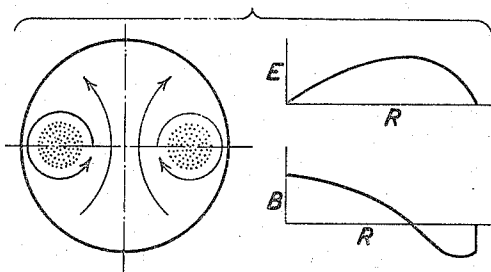


Fig. 5.

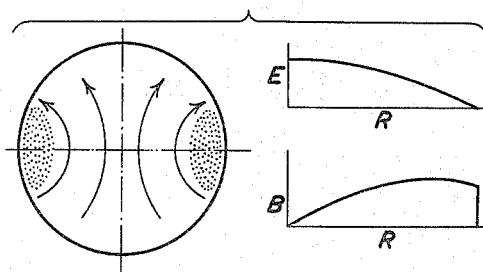


Fig. 6.

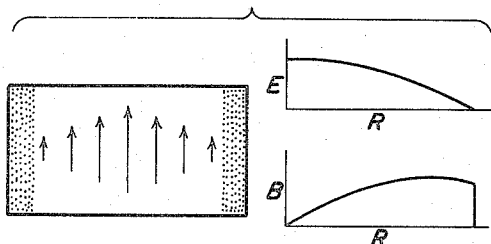


Fig. 7.

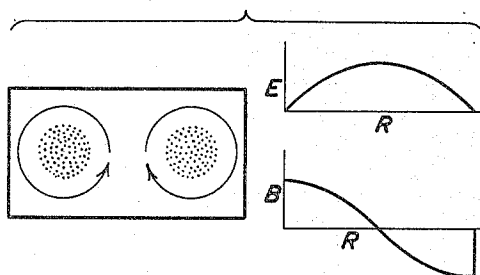
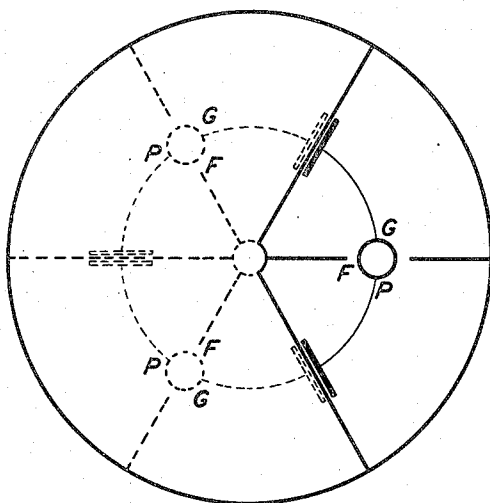


Fig. 8.



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3 Sheets-Sheet 3

Fig. 10.

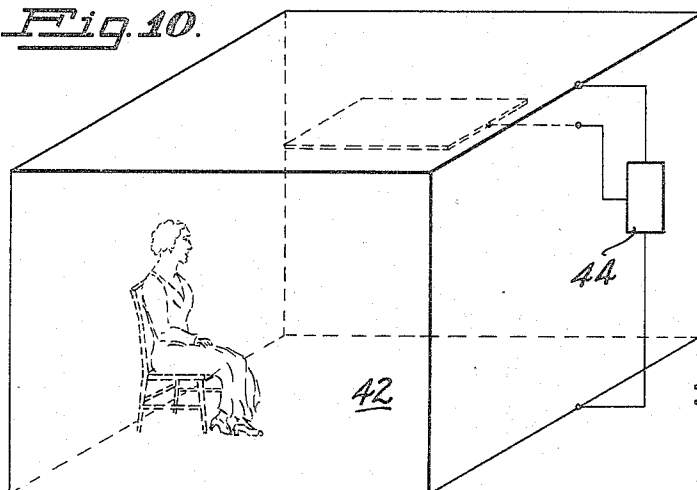


Fig. 9.

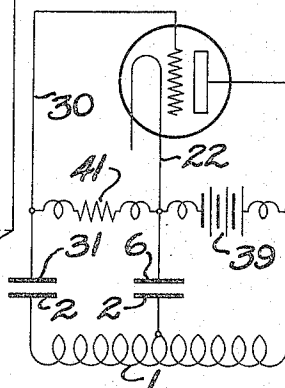


Fig. 11.

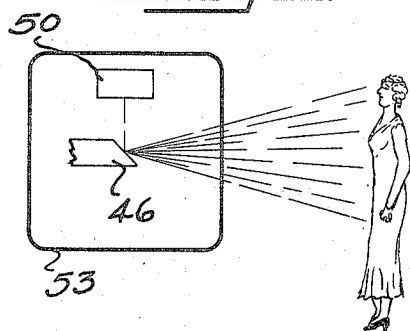
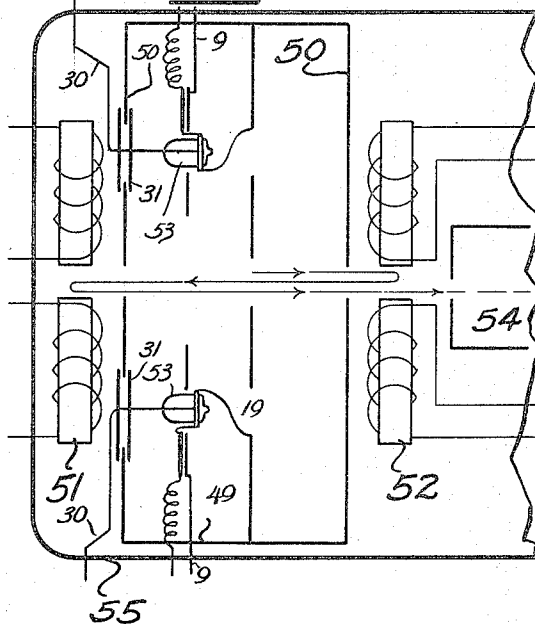


Fig. 12.



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UNITED STATES PATENT OFFICE

2,190,712

HIGH EFFICIENCY RESONANT CIRCUIT

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Application July 27, 1936, Serial No. 92,787

9 Claims. (Cl. 250—36)

My invention relates to resonant circuits, and particularly to high-efficiency oscillating circuits for ultra high-frequency.

Among the objects of my invention are: To
 5 provide a new type of resonant circuit; to provide a high-efficiency oscillator and amplifier operating at ultra high-frequency; to provide an ultra high-frequency resonant circuit embodiment wherein the current distribution is substantially
 10 symmetrical in the conducting members; to provide such a circuit embodiment wherein a relatively large amount of conducting material is introduced into the current path; to provide a type of resonant circuit wherein the physical dimensions of the resonator shall be of the same
 15 order as the wave length of the oscillations produced by the circuit, and to provide such a circuit embodiment in a form preventing undesired radiation therefrom; to provide a resonant circuit embodiment wherein the amount of conducting material in the resonator in the region of maximum current, may be varied within wide limits without changing the frequency of oscillation; to provide means and a method for converting direct current, or low-frequency alternating current, into high-frequency oscillating currents with high efficiency; to provide a more satisfactory method for the parallel operation of vacuum tubes at ultra high-frequencies; to
 20 provide means for connecting vacuum tubes in parallel for operation at ultra high-frequency such that the frequency of oscillation is not affected by the length of the connecting leads; to provide means for parallel operation of vacuum tubes at ultra high-frequencies wherein undesired reactions between connecting leads may be eliminated; to provide means for producing high oscillating potentials within a closed shell; to provide means for producing ultra high-frequency oscillations within a closed conductor constituting both the capacity and inductance of a resonant circuit without radiation therefrom; to provide such a non-radiating, oscillating, resonant circuit in a form permitting the
 45 withdrawal of power therefrom or the production of high potential; to provide means for accelerating electrons to high velocities; to provide means for producing strong, high-frequency electric fields within a non-radiating closure and
 50 to provide means for the production of high temperatures in living organisms.

My invention possesses numerous other objects and features of advantage, some of which, together with the foregoing, will be set forth in
 55 the following description of specific apparatus

embodying and utilizing my novel method. It is therefore to be understood that my method is applicable to other apparatus, and that I do not limit myself, in any way, to the apparatus of the present application, as I may adopt various other
 5 apparatus embodiments, utilizing the method, within the scope of the appended claims.

Briefly as to apparatus, my invention comprises a closed conducting shell constituting the inductance and capacitance of a resonant circuit, with one or more generators mounted preferably within the shell connected to energize the circuit.

In the drawings:

Figure 1 is a partially sectional view of a preferred embodiment of my invention.

Figure 2 is a sectional view taken along line 2—2 of Figure 1.

Figure 3 is a schematic diagram of my invention connected for operation.

Figure 4 shows schematically and graphically the distribution of potential and magnetic lines of force in a spherical embodiment of my invention, oscillating in a preferred manner.

Figure 5 shows relations similar to those of Figure 4 for an alternative mode of oscillation.

Figure 6 shows relations similar to those of Figures 4 and 5 for a cylindrical embodiment of my invention.

Figure 7 shows relations similar to those of Figure 6 for an alternative mode of oscillation.

Figure 8 is a schematic diagram illustrating an alternative arrangement of the oscillating resonant circuit of Figures 1 to 3.

Figure 9 is a schematic circuit diagram of my resonant oscillator.

Figure 10 illustrates a preferred embodiment of my invention for therapeutic use.

Figure 11 illustrates schematically the use of my invention for the production of X-rays.

Figure 12 illustrates schematically the use of my resonant oscillator to produce electrons of extremely high velocity.

The production of electromagnetic oscillations of the order of one meter or less in wave length is difficult owing to the increased capacitive and inductive interaction between various circuit leads and elements, the increased effective resistance of the conductors, and a tendency to parasitic radiation from leads and inductances as the wave length is reduced to the same order of magnitude as that of various circuit elements.

Proper shielding and arrangement of parts can overcome in part the inter-lead reactions, but if it is desired to operate several tubes in parallel

to secure greater output, these effects are compensated by the additional physical handicaps in spacing and arranging the parts, and offer a serious obstacle to satisfactory operation.

5 The increase in the effective resistance is due to the unsymmetrical distribution of current in the conductors and inductances. The higher the frequency, the greater the tendency of the current to travel on the surface of the conductors, and to crowd to the outer side of inductance windings; consequently the amount of conducting material actually serving is reduced and the effective resistance increased. There is a limit to the gain that may be made by using conductors of larger size, set by the physical limitations of the circuit and the frequencies which are to be produced.

These obstacles and the tendency toward parasitic radiations may be overcome, however, by utilizing the type of resonant circuit hereinafter described, wherein more stable operation is secured by eliminating the interlead reactions, and high efficiency is obtained by eliminating parasitic radiation and securing an even distribution of current through a large conducting path.

The operation of my invention may be better understood by reference to the drawings.

In Figure 1, I have shown a sectional view of a preferred embodiment of my invention, wherein a cylindrical shell 1, of copper or other material of high conductivity, is closed by end plates 2 and 4, of similar material, fixed to the cylindrical shell 1 by bolts 5 or equivalent means. Within the shell 1, a cathode plate 6, of diameter substantially less than that of said shell, is supported parallel to the end plates 2 and 4 by symmetrically placed supporting studs 7 and 9. Ports 10 and 11 through the shell 1 permit studs 7 and 9 to pass therethrough without making contact with the shell, and engage insulating blocks 12, fixed to shell 1 by brackets 14, which serve to support the cathode plate 6 in fixed position relative to the shell 1. Cathode plate 6 is centrally perforated by passage 15, and further passages 16 are symmetrically disposed thereabout.

An anode plate 17 is fixed between and parallel to the ends 2 and 4, soldered or otherwise suitably connected and attached to shell 1. Apertures 19 are symmetrically disposed there-through: in Figures 1 and 2, these apertures are shown in registry with apertures 16 through the cathode plate 6. This arrangement is optional, as is the position of the apertures 16 in the cathode ground plate 6.

In the embodiment of my invention shown in Figures 1 and 2, I have made use of one vacuum tube 20 as the oscillation generator; the tube shown is a triode with heater cathode, known to the trade as the "acorn" type, which is peculiarly adapted by reason of its low internal capacity, low transit time, and short, well spaced leads to operation on wavelengths down to 0.5 meter. Connection is made to the leads by a special clip type of terminal. Lead and clip 21 connect the anode to anode plate 17. The cathode plate 6 is connected to the cathode terminal by lead 22. Leads 24 and 25 supply current to the heater. The necessary current is carried into the shell by a twisted pair of wires 26, which connect to a pair of flat copper strips 27 separated from the cathode plate 6 by mica spacers 29; one of the strips 27 is connected to lead 24 and the other to lead 25. The strips 27 form a radio-frequency by-pass to the cathode ground plate 6. End plate 2 is perforated to permit entrance of grid lead 30, which is

centrally positioned by a pair of copper plates 31 fixedly held by bolts 32 relative to end 2, but insulated therefrom by mica sheets 33. The copper plates 31 form a capacitive connection between the grid circuit and the end plate 2 of the shell, although conductive connection is prevented by the mica sheets 33. Lead 34 connects shell 1 to an external anode potential source, and lead 35, connected to supporting stud 9, supplies the negative return from that source to the cathode.

An aperture 36 may be formed through shell 1, and a loop 37 inserted through it, for reasons later to be explained. It will be apparent to those skilled in the art that the "acorn" tube could be replaced by any other suitable type of generator capable of producing oscillations of the frequency of the resonant system. The means and method of transferring energy from the generator to the interior of the resonant chamber is, of course, a part of my invention.

While I have shown the oscillation generator inside the shell, it is also possible to mount it outside, and operate the circuit in similar fashion. In Figure 10, to be described later, this has been done, and in various other embodiments such external mounting may be advantageous in providing better cooling facilities, greater ease of mounting, or different arrangements of the plates within the shell. The form of the anode and cathode plates may be modified greatly; in some cases a wire loop is sufficient, and many other modifications in form may be made within the scope of the claims.

Figure 3 shows schematically the connections for operation. A battery 39 or other constant potential source of direct current is so connected to leads 34 and 35 as to place a positive potential on the anode of tube 20. An alternating current transformer 40, connected to the twisted pair of leads 26, supplies the heater current. Grid bias is obtained from the drop across a resistor 41 connected between cathode plate 6 and grid lead 30. Or, tubes may be operated in parallel, and supported within apertures 16.

A schematic circuit diagram for the embodiment of Figures 1 to 3 is shown in Figure 9. The closed inductive loop formed by shell 1 and end plates 2 and 4 is coupled to the grid by the capacitance between plates 31 and end plate 2. The direct current return connection to the cathode is provided through a closed inductive loop composed of lead 30, resistor 41 supplying the grid bias, and the cathode plate 6. A "C" battery might be substituted for the resistor 41, and be deemed equivalent thereto. The radio frequency current between the cathode and grid through the inductance loop including plate 6 and shell 1 is accomplished by the capacitive connection between end plate 2 and cathode plate 6. The circuit between cathode and grid either by way of resistor 41 or by way of shell 1 encloses exactly the same lines of force.

Similarly in the anode circuit: the direct conductive path between anode and cathode links the same lines of force as does the capacitatively coupled path.

By virtue of the blocking-condenser action of these capacitances, a path is provided for leading anode and grid potentials to the tube without passing through the main inductance, and without setting up circulating currents in the loop formed by the parallel paths, since the same number of lines of force are enclosed by both.

With the embodiment shown in Figures 1 to 3, 75

as with any closed shell, oscillations may be set up in the circuit at a number of resonant frequency points but there will be no radiation from the closed shell, in spite of the fact that the physical dimensions may be of the order of the wavelengths produced by the frequency of oscillation. That this is possible may be seen from certain considerations.

Assume that the closed conducting surface within which an oscillating field exists, has a thickness large compared with the skin effect depth.

There will then be always in the conductor a depth at which the field E is vanishingly small. Therefore the Poynting vector also vanishes, and integrating the Poynting vector over the closed surface it is found that no energy diverges from the region bounded by the conductor.

The frequency of oscillation within such closed surfaces may be calculated analytically for a few shapes of closures.

It is well known that electro-magnetic fields vary in accord with Maxwell's equations, which in free space simplify to

$$\begin{aligned} \Delta \cdot E &= 0 & \Delta \cdot B &= 0 \\ \Delta \times E &= -\frac{1}{c} \ddot{B} & \Delta \times B &= \frac{1}{c} \dot{E} \end{aligned} \quad (1)$$

where E is the strength of the electric field, B is the strength of the magnetic field, and c is a constant.

These may be changed by standard transformations to the form

$$\Delta^2 E - \frac{1}{c^2} \ddot{E} = 0 \quad (2)$$

and an equivalent equation for B .

Assuming that the equations are to be applied to a wave of a single radian frequency ω , the wave number

$$k = \frac{\omega}{c}$$

may be introduced into Equation 2, which becomes

$$\Delta^2 E + k^2 E = 0 \quad (3)$$

The above equations apply strictly to the conditions in free space. If a conductor is present, Equations 1-3 must be supplemented by adding terms involving charges and currents. In the present case, these terms may be taken into account by requiring that E satisfy certain boundary conditions as well as Equation 3. Assuming a thin closed surface of infinite conductivity Equation 3 must hold inside and outside of the surface, and the tangential component of E must be zero on that surface.

When Equation 3 is applied to wave motion in free space, any value of k is possible, but when boundary conditions are imposed, only certain discrete values of k will be compatible with those conditions. For example, for any value of l and m , a solution of Maxwell's equations is:

$$E_z = \cos l x \cos m y \sin \omega t$$

$$l^2 + m^2 = k^2 \quad (4)$$

with

$$\omega = 2\pi \tau$$

If a cubical shell of zero resistance and side α is considered, for solutions good inside the shell, the boundary conditions require that, assuming one corner of the cube at the origin,

$$E_z = 0 \text{ at } x=0, \alpha \text{ and } y=0, \alpha \quad (5)$$

To satisfy this limitation, certain values of l and m must be used such that

$$l = \frac{n\pi}{\alpha} \text{ and } m = \frac{n'\pi}{\alpha} \quad (6)$$

where $n, n' = 1, 2, 3, \dots$ and accordingly k is fixed, with the frequency

$$k = \frac{\pi}{\alpha} \sqrt{n^2 + (n')^2} \quad (7)$$

This assumes that the shell is a perfect conductor with a finite resistance, the allowed frequencies will be shifted slightly, and the oscillations damped exponentially.

Any closed box will have a set of frequencies at which it may oscillate; for certain simple shapes, analyses similar in general form to that given above for the cube, may be made. For spheres, the analysis may be carried out by the use of functions developed by Mie and Debye; for cylinders, by combinations of functions developed by the inventor and James G. Beckers; comparable analyses may also be carried out with shapes determined by holding constant various coordinates in any of the separable systems of Stäckel.

The separable systems of Stäckel are orthogonal systems of confocal quadric surfaces. These systems are well known in the field of mathematical literature, examples of which are:

- (1) Comptes Rendus, vol. 116 (1893) page 485.
- (2) Mathematische Annalen, vol. 54 (1901) page 86.
- (3) Mathematische Annalen, vol. 98 (1928) page 749.
- (4) Annals of Mathematics, vol. 35 (1934) page 284.
- (5) Courant-Hilbert, "Methoden der Mathematischen Physik" I, pages 275-279.
- (6) Darboux, "Lecons sur les Systems Orthogonaux et les Coordonnes Curvilignes" especially Livre II, Chap. III, IV, and V.

These mathematical systems, although well known as means for the delineation of a wide range of geometrical forms, have not heretofore been used in the computation of resonant circuits. Inasmuch as a complete mathematical discussion of the orthogonal systems can be found in the mathematical literature it is sufficient for present purposes to indicate some simple examples applicable to the computation and design of practical embodiments of this invention.

One convenient system is that described by a pair of hyperbolae of revolution intersecting and confocal with an ellipsoid of revolution. This system develops enclosures that resemble a barrel with the ends dented in. The dented ends are hyperbolae confocal with the ellipsoid of which the side of the barrel is a sector. This system may be varied between two easily described limits. One limit is that in which the two foci become coincident and thus become the center of a hollow sphere with reentrant sections of conical shape meeting in the two conical apexes at the center of the sphere. In other words the barrel side has become a sector of a sphere and the dented ends have been formed into cones whose apexes meet at the center of the spherical barrel. The other limit is that in which the foci have been separated by an infinite distance, in which case the sides of the ellipsoid are straight and the intersecting section of the hyperboloids are flat. This pro-

duces a right circular cylinder as shown in Fig. 1 in which the cylindrical shell 1 is a section of an ellipsoid and the flat ends 2 and 4 are sections of hyperboloids.

5 Similarly the cube is a limiting case of intersecting confocal superposed hyperboloids and ellipsoids. The sphere is a special case of one system.

10 All the forms of my invention derivable in coordinates of the Stäckel systems are subject to exact mathematical computation, although some of them present considerable practical difficulties in the complete exact solutions. However, it is entirely feasible to compute a configuration approximating any practical form ordinarily desired. For example, exact computations can be made of the properties of the limiting case of the barrel-shaped form in which the side is spherical and the ends are reentrant cones. Then exact computations can be made of the same form in which the foci have been separated so the reentrant hyperbolic barrel ends reach well into the barrel but do not touch, for example, one-fourth the way from each end. 25 The two computations then will give results between which a practical intermediate form can be estimated.

Obviously the mathematically derived forms will but rarely be the precise form desired for manufacture. The sharp edges of intersection of the mathematical surfaces will be rounded for spinning in sheet metal, although for forms closed by rolling as may be done with metal can machines the edges may have square corners.

35 The references to the Stäckel systems are made primarily for convenience in computation. The practical configuration of the invention may be of any form whatever. For example, the limiting Stäckel form of the right circular cylinder may be deformed by making the ends reentrant and of any convenient shape, keeping the sides straight for convenience in manufacture. By computing a series of dimensioned Stäckel configurations, it will be immediately apparent that 45 the electrical properties will vary in accordance with the dimensions. The following properties are the ones usually considered in resonant circuits: i. e., natural frequency, shunt impedance, ratio of reactance to resistance, etc. Accordingly, it is obvious that any range of adjustment of any of the properties, can be had by changing the shape of the chamber.

In the case of a sphere, the most simple fields and the lowest frequency radiations may be 55 shown to occur with wavelengths of $1.40r$ and $2.30r$, where r is the radius of the sphere. These values may be derived from the vector wave equations in spherical coordinates, all possible non-infinite solutions of which are given by:

$$60 \quad A_{2,1,m} = k\Delta \times (r\xi_{1,m}) \quad (8)$$

and

$$A_{3,1,m} = k\Delta \times A_{2,1,m} \quad (9)$$

where

$$65 \quad \xi = \frac{1}{\sqrt{kr}} J_{1+\frac{1}{2}}(kr) P_1^m(\cos \theta) e^{im\phi}$$

and

$$k = \frac{\omega}{c}$$

70 Letting Equations 8 or 9 represent the field E, the problem is resolved into finding k and hence ω values which will make the tangential component vanish at the conducting surface. This involves finding the roots of a certain combination of Bessel's functions. There are an in-

finite number of such roots, but the simplest one corresponds to only one nodal surface for E, at the conducting boundary, and it is this mode of oscillation that would normally be used.

For the function A_2 of Equation 8, the wavelength is given by the relation $\lambda = 1.40r$, and oscillations are produced within the sphere in the mode of Figure 4, wherein the arrows represent the direction and relative magnitude of the magnetic field B, and the dots represent the electrostatic field E, lines of which run parallel to the equator. The graphs of Figure 4 show the variations of E and B plotted along the equatorial plane against the radius R, with the origin at the center of the sphere. 15

The function A_3 of Equation 9 involves the value $\lambda = 2.30r$, and the oscillations occur with a voltage and field distribution such as that shown in Figure 5, where the arrows represent the direction of the electrostatic field and the dots represent the points of greatest intensity of magnetic field, which runs parallel to the equator. The accompanying graphs show E and B again plotted equatorially against the radius R, with origin at the center of the sphere. 25

With a circularly cylindrical shell the two simplest modes of oscillation occur as shown in Figure 6, with a wavelength $\lambda = 2.62r$ and Figure 7 with

$$30 \quad \lambda = \frac{1}{\sqrt{\frac{1}{4H^2} + \frac{1.49}{r^2}}}$$

where r =radius and H =height of the shell.

In Figure 6, the field relations are shown for the method of oscillation used in the embodiment of Figures 1 and 2. The arrows represent the direction and strength of the electric field, and the dots represent the points of greatest intensity of the magnetic field, which runs around the interior periphery of the shell normal to the electric field. The graphs show E and B values against the radius R on the horizontal midplane of the shell. 40

In Figure 7 the arrows represent the direction of the magnetic field, and the dots represent the electric field, which runs around the shell horizontally. The curves are plotted on the horizontal midplane of the cylindrical shell. The arrangement of the shell and tube for oscillation in the manner of Figure 7 is shown schematically in Figure 8. In this case, the dividing partitions are inserted parallel to the axis of the cylindrical container rather than normal thereto. The dotted lines indicate the method of inserting additional tubes for parallel operation to increase the power input. The connecting leads must be kept at right angles to the electric field, but may be otherwise arranged at will. 45

The mode of oscillation may be changed by varying the position and arrangement of the leads and tubes, and since there are an infinite number of discrete resonance frequencies possible in a closed container, the tubes and connecting leads may be so inserted as to excite any desired mode of oscillation. 50

There is in general a discontinuity of the magnetic field at the inner surface of the conductor, which implies a current sheet there. The power lost in maintaining this current sheet is proportional to the square of the field strength, the square root of the resistivity (inversely to the square root of the conductivity), and the $3/2$ power of the wavelength. The latter factor is due to the fact that if the size of the shell is 75

doubled to double λ , the area is multiplied four times and the skin depth increased by

$$\sqrt{2}$$

so raising the losses by

$$\frac{2}{\sqrt{2}}, \text{ or } 2^{3/2}$$

The losses are given to order of magnitude in

$$\text{ergs./sec. by } P = \frac{E^2 \lambda^{3/2} c^{3/2}}{16\pi^2 \sigma^{1/2}} \quad (10)$$

where E =field strength in electrostatic volts,

λ =wave length in cm.

c =vel. of light= 3×10^{10} cm./sec.

σ =conductivity= 5.14×10^{17}

for the copper shell used.

A more useful figure for some purposes is 2π times the ratio of the energy stored in the electromagnetic field to the energy lost per half cycle ϕ . This number is independent of the field strength and is the quantity which plays the same role for the present type of oscillating circuit that

$$Q = \frac{L\omega}{r}$$

plays in ordinary circuits. In fact one easily finds that

$$Q = \frac{L\omega}{r} = 2\pi \frac{\text{energy in inductance at peak of cycle}}{\text{energy lost per cycle}} \quad (11)$$

For any reasonable shape of "resonant circuit" of the type herein described the equivalent Q is about 10^5 for a wavelength of 100 cm.

It should be noted, that since the current distribution is uniform in the conductor, and the size of the path is much greater than that available by other means, the I^2R losses are slight compared to those in conventional circuits.

The theoretical discussion given above, properly interpreted, constitutes a mathematical description of my invention as an energy field, together with its associated currents and material boundary. A comparison of the mathematical statement given above, with corresponding statements applicable to the prior art, will clearly distinguish my invention from other resonant devices and shielding arrangements that might be confused with it because of apparent external resemblances.

Having thus shown that it is possible to produce oscillations at various desired resonant frequencies and high efficiencies, various embodiments will now be described for the useful application of the ultra high-frequency currents produced.

If it is desired to utilize the resonant circuit as a power source for radio transmission, an aperture, as 36 in Figure 1, may be made in the shell 1, and a loop 37 inserted to link the fields, thereby producing a current in the loop which may be fed directly to an antenna system. The size, shape, and position of the loop may be varied in accord with the mode of oscillation used.

In Figure 10, I have indicated schematically an embodiment useful in producing "artificial fever", or temperatures higher than normal, in the bodies of human patients, or in any living organism. A chamber 42 is formed of conducting material, large enough to permit the patient to sit or lie at ease, in proper position to intercept the field, thereby causing currents

to circulate within the body and raise the temperature thereof. The oscillator 44 is shown mounted externally of the resonant circuit, which, due to the very great number of possible resonance points, may by proper arrangements be operated at any one of many desired frequencies. Any shape of closed chamber of course might be used, and the variations in such are matters of detail within the scope of the claims.

The fields produced are not only useful in providing circulating currents, but by proper construction, they may be used to accelerate electrons for various purposes, as shown in Figure 12.

In Figure 12, I have shown schematically a cylindrical shell 49 within an airtight envelope 55 having suitably apertured cathode and anode plates 6' and 17' therein, and centrally apertured end plates 50, set between two pairs of electromagnets 51 and 52 arranged to concentrate a magnetic field close to the central axis of and at either end of said cylinder and normal thereto. Free electrons directed by suitable emitting means, not shown, into the central portion of shell 49, are accelerated by the electric component of an intense oscillating electromagnetic field built up by the oscillators 53. The electric component of this field is most intense at the center of member 49 and extends from end to end of this member, within the same. If sufficient accelerating potential is available, a single passage across the shell may suffice to give the desired electron velocity. If a greater velocity is desired, or the accelerating potential is low, the electron may be caused to reverse its direction of travel each half cycle, and travel back and forth until the desired velocity is obtained, as indicated schematically by the arrows. If the electrons enter the chamber with an initial velocity of several hundred thousand volts, the velocity is so large a percentage of the speed of light that further energy additions do not increase the speed markedly, and the electrons may be passed back and forth, gaining energy each half cycle, without getting out of phase with the oscillating field. These reversals of direction are accomplished by passing the electrons into the field of magnets 51 and 52 in a direction normal thereto, whereupon they are diverted from their paths in a direction perpendicular to both path and field, and caused to return in the opposite direction. The dimensions of the resonant circuit shell 49 and the distances between the reversing magnets 51 and 52 are determined by the frequency of oscillation of the system and the velocity of the electrons. The distance between magnets 51 and 52 should be substantially that traversed in one-half period of oscillation of the system by an electron of velocity corresponding to the voltage by which it has been accelerated.

By properly arranging the fields the electrons may be permitted to leave the accelerating chamber after developing a certain desired velocity, and shot into a chamber 54 for any desired use.

In Figure 11 I have indicated that an oscillator 50 arranged to develop high velocity electrons may be so placed within an envelope 53, as to direct a stream of said electrons upon a suitable anode 46 to develop X-rays of great penetrating power, for producing X-ray for cancer treatment, or for other desired purposes.

A number of modifications of the embodiments described, all within the scope of the appended claims, will occur to those skilled in the art.

It is apparent that the envelope 55 shown in Figure 12 may be evacuated to any desired degree, and the envelopes of tubes 53 may be removed. This may be extended to the design of Figures 1 and 2, and to other embodiments, particularly those utilizing large amounts of power, and the tube elements may be freely modified and simplified without regard to conventional limitations resulting from the necessity of maintaining a vacuum and providing supporting and connecting leads within a closely associated envelope. It is also apparent that I may utilize the oscillating fields within a closed conducting shell to heat inorganic matter, both conducting and non-conducting, as well as organic, the device then constituting an ultra-high-frequency induction furnace. It is also apparent that suitable modifications of my oscillating circuit will permit it to be used as an amplifier.

For a complete understanding of this invention it should be emphasized that it is concerned primarily with the delineation of a confined oscillating electromagnetic field and the transfer of energy into or out of said field. The geometrical form of the apparatus and of the electromagnetic field bounded and delineated thereby is of secondary importance, particularly in view of the variety of mechanical shapes of shielded electromagnetic circuits known in the prior art. What is important is the mode of oscillation of the confined electromagnetic field and the corresponding arrangements for sustaining and using said field.

In particular, three arrangements are used for transferring energy into or out of the confined oscillating field. These are the inductive coupling loop 37, and the capacitive coupling plate 6 shown in Fig. 1, and the beam of electrons projected through the field shown in Fig. 12. The inductive coupling loop 37 is placed in the field so as to interlink a quantity of lines of magnetic flux. The capacitive coupling plate 6 is placed in the field where it will intercept the desired electric flux, and the beam of electrons of Fig. 12 is projected through the field in a direction and location such that the electric field will either accelerate or decelerate the electrons. Obviously, all of these three arrangements for energy coupling to the electromagnetic field may be used equally well for delivering energy to the field or for taking energy from the field inasmuch as the direction of energy flow relative to the circuit is dependent merely upon the phase relationship of the several voltages, currents, and fields concerned in the energy transfer.

The inductive loop is effective only to the extent to which it interlinks magnetic flux of the resonant field. In this connection it will be noted that conductors are not ordinarily carried entirely through the resonant field for coupling. The reason for this is evident from Figs. 6 and 7 for example. In Fig. 6 a conductor carried through the center of the resonant circular cylinder from top to bottom would, in principle, with its external connections interlink all the magnetic flux of the enclosed field and the coupling would apparently be a maximum. If the conductor carried through did not lie on the center line, but were formed into a loop reaching into the magnetic flux toward either edge of the container the result would be a decrease in the coupling because some of the magnetic flux would not be interlinked with the coupling circuit or would be included twice inside the coupling circuit with the consequent cancellation of an

amount of flux equivalent to the flux which is included twice. Thus, for small coefficients of coupling with a conductor carried through the center structure, the conductor must be formed into a large loop with consequent disadvantages of distributed capacitance and high resistance. Accordingly inductive coupling is made as shown by loop 37 in Fig. 1. In this arrangement the smaller the loop in general the lesser the coupling.

Further, regarding the conductor carried through the center of an enclosed field of the form shown in Fig. 7, it will be seen that such an arrangement will have zero coupling inasmuch as the magnetic flux is confined to regions which are not magnetically interlinked with the conductor. Coupling in a field of this form is, however, made conveniently by means of a coupling loop as indicated by 37 in Fig. 1, but rotated 90 degrees from the position shown in Fig. 1. In general, for any mode of oscillation of the confined field a coupling loop 37 inserted through the wall of the enclosing surface 1 as shown in Fig. 1 either in the orientation shown or in quadrature therewith will accomplish effective coupling.

Similarly in the use of capacitive coupling elements, such elements for maximum effect are comparatively thin plates placed so their flat surfaces are perpendicular to the electric field lines. In Fig. 6 the proper location for a capacitive coupling element is parallel to the flat surfaces of the enclosing member 1. Such a capacitive element may have an area approximating that of the top or bottom of member 1. In Fig. 7 a large capacitive element might be inoperative because it would short circuit the electric flux in certain regions. A proper capacitive element would be one comparatively small in comparison with the structure as a whole placed in a region in which the electric flux is in one direction only. Proper locations would be anywhere perpendicular to the circular solid lines representing electric flux in Fig. 7.

In coupling an electron beam into the enclosed electromagnetic field as shown in Fig. 12, a condition that should be fulfilled for best results is that the electrons should pass through the field in one-half period of oscillation or less. Effective results are obtained with a time of transit of the order of a tenth of a period or less. Obviously, the transfer of energy between the electrons and the field will take place in any geometrical form of field although for some arrangements it is desirable to have the field comparatively intense and uniform in the region through which the electrons are projected. These conditions are easily attained using the geometrical delineations of electromagnetic field described above in reference to the Stackel systems of surfaces. Other desirable forms, however, are obviously derivable from the form shown in Fig. 12.

I claim:

1. A vacuum tube oscillator comprising a cylindrical chamber of conductive material having substantially parallel ends, an incomplete diaphragm mounted substantially parallel to said ends and dividing said chamber into communicating compartments, a vacuum tube having cathode, anode and control electrodes mounted within said chamber, said cathode being connected to said diaphragm and said anode and control electrode being connected for high fre-

quency currents respectively to the opposite ends of adjacent compartments.

2. A high frequency oscillator comprising a conducting container having closed, flat ends, a capacity member mounted within said container and capacity coupled to the ends thereof, a thermionic tube contained within said container and having elements including a cathode, anode and control grid, means for supplying exciting potentials to said tube elements, and means including capacity elements for electrically connecting said cathode and control grid to said capacity member and an end of said container, respectively, and means connecting said anode to the other end of said container.

3. A high efficiency resonant circuit comprising a conducting container having two compartments resonant at substantially the same frequency, a conducting and apertured wall separating said compartments, thermionic tube means wholly within one of said compartments and connected for setting up standing electromagnetic waves therein, said waves penetrating the apertures in said separating wall for setting up a standing wave field of the same frequency in said other compartment, and loop means in said other compartment and coupled to the field therein for removing energy therefrom.

4. A non-radiating oscillatory system comprising an axially symmetrical substantially closed conductive chamber having no conductor within the distance of one half of the radius of the chamber from the axis thereof extending in the direction of the latter, means for converting electrical energy of relatively low frequency and zero frequency into high frequency oscillating energy of a frequency for which standing waves can exist within said conductive chamber, said means including means for propagating said high frequency oscillating energy in a direction perpendicular to the axis of said chamber, whereby the electric vector of said standing waves extends in the direction of said axis, and means for coupling said converting means to said system of standing waves.

5. A non-radiating oscillatory system comprising an axially symmetrical, substantially closed conductive member providing an interior chamber and having no conductor within the distance of one half of the radius of the chamber from the axis thereof extending in the direction of the latter, means for converting electrical energy of relatively low frequency and zero frequency into oscillating energy of a frequency for which standing waves can exist within said conductive chamber, said means including means for propagating said high frequency oscillating energy in a direction perpendicular to the axis of said chamber whereby the electric vector of said standing waves extends in the direction of said axis, said member carrying on its inner surface currents oscillating substantially in

planes having said axis lying therein and at a frequency determined substantially by dimensions perpendicular to the said axis and substantially independent of proportional changes of all dimensions parallel to the said axis, and means for coupling said converting means to said system of standing waves.

6. A resonant circuit comprising a hollow, substantially closed conducting member, a cathode partition within said member dividing the same into two communicating chamber portions, thermionic tube means including a cathode, an anode and a grid, said thermionic tube means being carried by said cathode partition and having its cathode directly connected thereto and arranged for setting up a standing electromagnetic field therein, said thermionic tube means having its cathode-plate circuit linking a part of the field in one of said chamber portions and its cathode-grid circuit linking a part of the field in the other chamber portion, the electric component of said field having its lines of maximum intensity at least as long as those thereof that are of lesser intensity.

7. A resonator comprising a hollow body having flat, substantially parallel ends unbroken on the inside, thermionic tube means within said body for generating and launching electromagnetic waves so that substantially all the energy thereof travels parallel to the directions of said ends of the body, the dimensions of the body and the frequency of said waves being such that standing electromagnetic waves are set up in the body.

8. A space resonant device comprising a substantially closed hollow conducting body having flat, substantially parallel ends unbroken on the inside, thermionic tube means contained within said body for emitting electromagnetic waves so that substantially all the energy thereof travels parallel to the directions of said ends of the body, said waves being of such frequency and said body being of such dimensions that standing electromagnetic waves are set up within said body, the electric vector of said waves extending from end to end within said body and being of greatest intensity at the center thereof.

9. A resonant circuit comprising a hollow cylindrical substantially closed conducting member having flat, substantially parallel ends unbroken on the inside, thermionic tube means within said member for establishing an electromagnetic field of high intensity within said hollow member, said means including a coupling element located at a point at least one half the radius of said cylindrical member from the center of said member and within said field where the electric component thereof is relatively weak, said electric component extending from end to end of the body and being strongest at the center thereof.

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