

May 6, 1941.

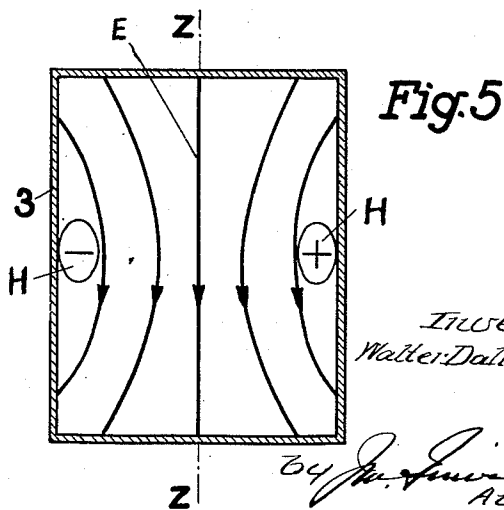
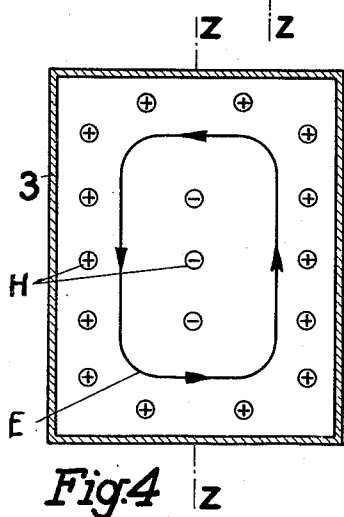
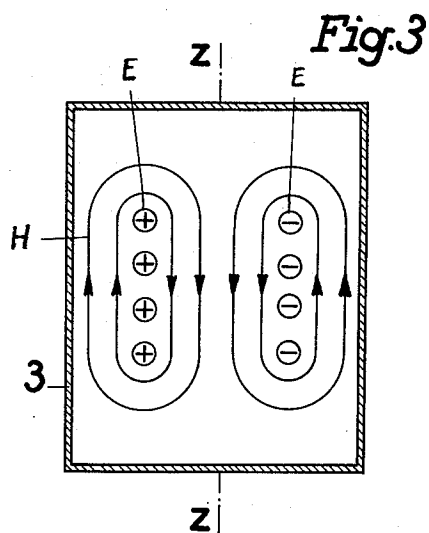
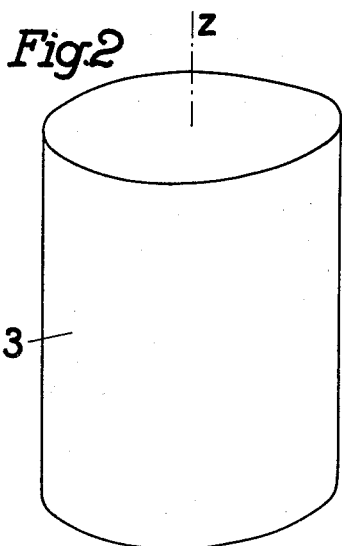
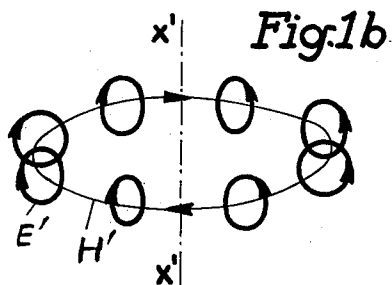
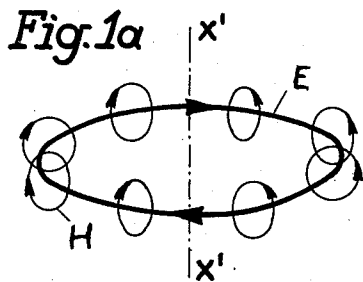
W. DALLENBACH

2,241,119

ULTRA-SHORT-WAVE APPARATUS

Filed Sept. 18, 1937

3 Sheets-Sheet 1



Inventor
Walter Dalenbach

By *J. J. J. J.*
Att'y

May 6, 1941.

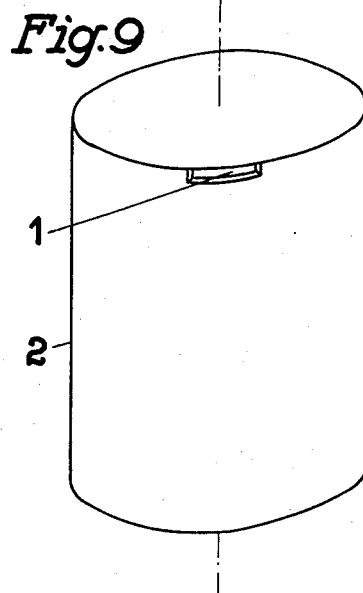
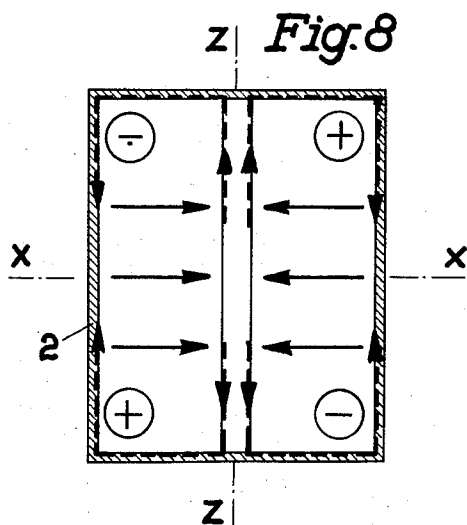
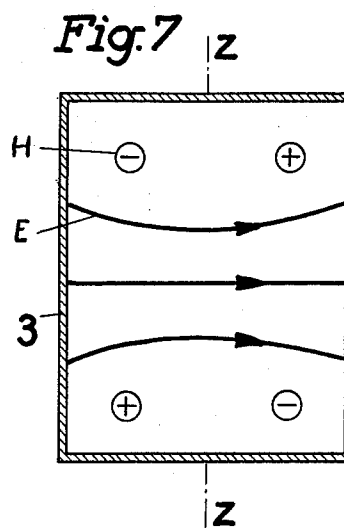
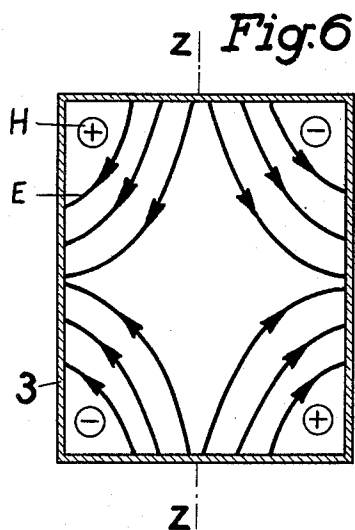
W. DALLENBACH

2,241,119

ULTRA-SHORT-WAVE APPARATUS

Filed Sept. 18, 1937

3 Sheets-Sheet 2



Inventor
Walter Dalenbach

By *J. M. Lawrence*
Atty

May 6, 1941.

W. DALLENBACH

2,241,119

ULTRA-SHORT-WAVE APPARATUS

Filed Sept. 18, 1937

3 Sheets-Sheet 3

Fig. 10

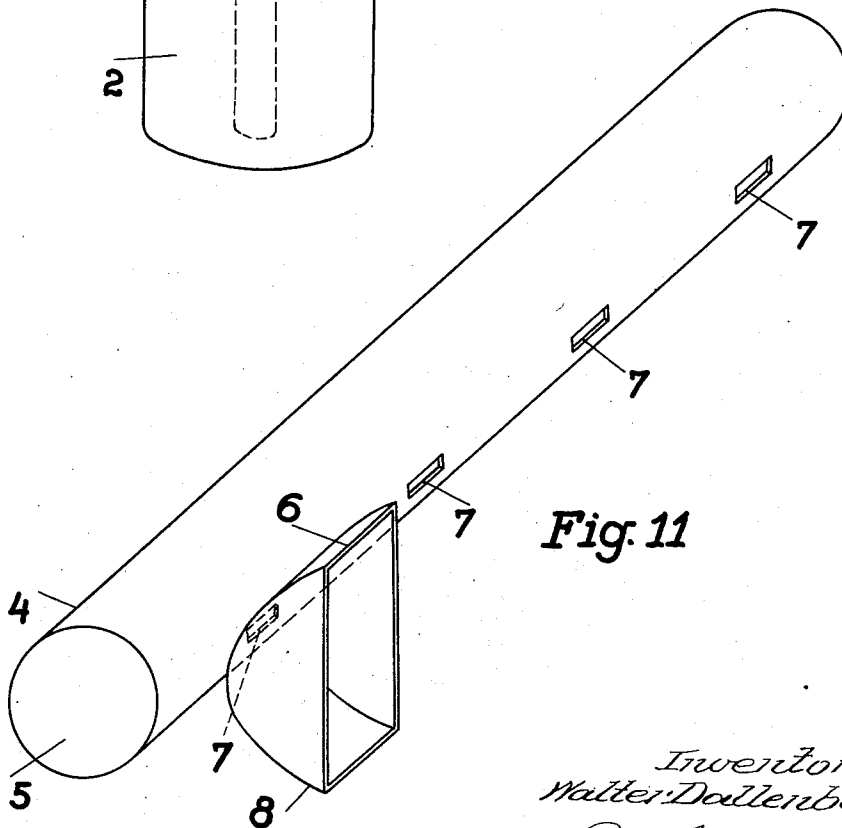
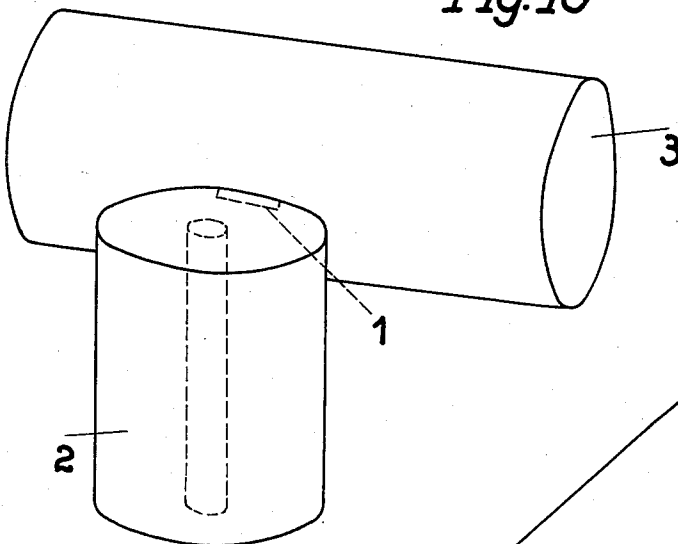


Fig. 11

Inventor
Walter Dallenbach
by *J. Swire*
Atty.

UNITED STATES PATENT OFFICE

2,241,119

ULTRA-SHORT-WAVE APPARATUS

Walter Dallenbach, Berlin-Charlottenburg, Germany, assignor to Julius Pintsch Kommanditgesellschaft, Berlin, Germany

Application September 18, 1937, Serial No. 164,589
In Germany September 15, 1936

9 Claims. (Cl. 178—44)

The invention relates to apparatus for the production, amplification, or reception of ultra-short-waves, in particular decimetre or centimetre waves, and concerns the connection of a tubular dielectric guide without an internal conductor with a radiating or receiving device or with another dielectric guide.

A tubular dielectric guide without an internal conductor will hereinafter be called shortly a "conducting tube." It is preferred to use a connecting tube with a circular cross-section, but a conducting tube may have an elliptical or rectangular or similar cross-section and instead of being of uniform cross-section it may be formed with bulges. It is essential that the conducting tube be a hollow body by which there is bounded a dielectric space which in consequence of the reflection at the surfaces bounding it possesses natural oscillations that are dependent on its cross-section—in the case of a tube of circular cross-section, on its diameter. The conducting tube, which is advantageously tuned by the choice of its cross-section to one of its natural oscillations, may be excited to travelling waves. However, recourse may be had to the length of the conducting tube for the purpose of enabling the natural oscillations to be determined or fixed and accordingly the conducting tube to be excited to stationary waves or to travelling and stationary waves.

For example there may serve as a conducting tube a hollow cylinder which consists of metal and which is open at its two ends and the axial length of which is equivalent to half a wave length. A specially preferred constructional form of the conducting tube consists contrariwise in that the spatial potential-node places are determined also in the longitudinal direction of the conducting tube by the reflecting surfaces or walls. For this purpose a hollow body serving as a conducting tube is, apart from the slit-like opening hereinafter described, closed on all sides or a metal cylinder serving as a conducting tube is closed at one or each end by a metal plate. In this case the axial length between two end plates is equivalent to half a wave length or a multiple thereof. This construction of the conducting tube excited to stationary waves presents in particular the advantage that any undesired radiation can be avoided and thus radiation damping be reduced to a minimum, whilst the conducting tube can be excited to the different possible forms of oscillation, particularly into such a form of oscillation that the dielectric field lines are chiefly or exclusively endless

eddy lines (i. e. endless field lines that do not arise at and impinge against metal surfaces or surface charges).

The dielectric of the conducting tube consists preferably of air or a high vacuum. It may, however, in particular cases consist of a gaseous, liquid, or solid dielectric that is sufficiently free as regards ultra-short-wave losses. The dielectric constant of the dielectric, the conductivity of the reflecting walls bounding the dielectric, and the cross-section or diameter and the length of the tube are determinative as regards the natural oscillation of the conducting tube. For the sake of simplicity, in the following explanations it will be assumed that the dielectric consists of air and that the conductivity of the surfaces bounding the dielectric may be regarded practically as infinite. The natural oscillations of the conducting tube can be calculated from the integration of the Maxwell equation, regard being had to the limiting conditions. One is led to the solution of the Bessel differential equation. Zero roots of the Bessel functions are determinative as regards the natural wave of the conducting tube. If one considers as a conducting tube a metal tube with circular cross-section the diameter of which is δ and the length of which is $2l$, the following relation exists between the diameter, the length, and the natural wave-length of the conducting tube.

$$\frac{4\pi^2}{\lambda^2} = \left(\frac{k_m}{\delta}\right)^2 + \frac{n^2\pi^2}{(2l)^2}$$

where n is a whole number (0, 1, 2 . . .) and k_m is the value of the zero root of the corresponding Bessel function.

For the case in which n has the value zero it appears from the equation given that the natural wave-length is independent of the length of the cylinder. This case occurs, for example, when the conducting tube is closed at both ends by metal plates and the length of the cylinder or the distance apart of the two end plates is small in comparison with the diameter of the cylinder. If n has a value differing from zero, the length of the cylinder is co-determining in regard to the natural wave-length λ .

Now according to the invention the conducting tube is coupled to a second dielectric guide by means of a slit-like opening provided in its wall in such a manner that a portion of the surface current of the second dielectric guide flows over an edge of the slit-like opening as a surface current into the conducting tube, or, vice versa,

a portion of the surface current of the conducting tube flows over an edge of the slit-like opening as a surface current into the second dielectric guide and upon the external conductor thereof; for this purpose the longitudinal direction of the slit-like opening is parallel to the axis of the conducting tube. In this way there may be produced a specially favorable coupling of the conducting tube to the second dielectric guide or of the second dielectric guide to the conducting tube. The forms of oscillation or the courses of the surface currents in the two parts coupled together may be quite different from one another—for example the conducting tube may be excited to such a form of oscillation that the electrical field lines are endless eddy lines whilst the field lines extend radially in a dielectric guide with an internal conductor. Likewise, in the manner stated, for example a coupling may be effected between two conducting tubes that are excited to like forms of oscillation or to different forms of oscillation, of which for example one oscillates in a natural oscillation in the case of which the electrical field lines are exclusively endless eddy lines, but the other oscillates in a form of oscillation in the case of which the electrical field lines arise at one part of the wall of the conducting tube and impinge at another part of the wall of the conducting tube.

The second dielectric guide to be coupled with the conducting tube is likewise provided with a slit-like opening that serves for coupling it with the conducting tube. The conducting tube, the dielectric guide coupled thereto, and the slit-like openings are arranged in such a manner that the slit-like opening of the conducting tube and the slit-like opening of the other dielectric guide coincide. In particular, for the purpose of producing an optimum coupling, according to the invention the arrangement of the positions of the conducting tube, of the dielectric guide coupled thereto, and of the slit-like openings is such that the direction of the greatest extension (longitudinal direction) of each of the slit-like openings is perpendicular to the direction of the corresponding surface currents of the conducting tube and of the dielectric guide coupled thereto. One or each of the slit-like openings may be adjustable as regards its length or width or both. In many cases it is sufficient if only one of the two slit-like openings is adjustable. In other cases it may be advantageous to provide either the conducting tube or the dielectric guide coupled thereto or both with a plurality of cooperating slit-like openings of which at least one is adjustable. A slit-like opening may be provided with a covering plate by means of which any desired portion of the area of the slit-like opening may be covered so that the desired coupling is effected over the edge of the remaining opening. In this way the coupling of zero value (with complete metallic closure of the opening) may be increased to the maximum value, which occurs when, as already mentioned, each of the slit-like openings of the conducting tube and of the dielectric guide to be coupled thereto, or an equivalent slit-like opening common to the conducting tube and to the dielectric guide to be coupled thereto, has its longitudinal direction perpendicular to the directions of the surface currents of the conducting tube and of the coupled dielectric guide. The width of the slit-like opening is small in relation to its length and the length is preferably a multiple of its width.

The conducting tube and the dielectric guide to be coupled thereto are preferably so chosen and arranged in relation to each other in such a position and provided with slit-like openings in such a manner that the conducting tube or the conducting tube and the dielectric guide to be coupled thereto is or are excited to a prescribed form of oscillation, in particular the conducting tube is excited to a natural oscillation in the case of which the electrical lines of force are chiefly or exclusively endless eddy lines. In this condition of oscillation the conducting tube is a dielectric guide of specially small damping. The arrangements may be such that either the conducting tube and a concentric dielectric guide have both the same form of oscillation, or that they have different forms of oscillation respectively.

Preferably the conducting tube is coupled at a current loop of the dielectric guide with which the conducting tube is coupled. The arrangement of the position of the slit-like openings is to be selected accordingly. Furthermore it is preferred to effect the coupling between the conducting tube and another dielectric guide at a current-loop place of the conducting tube and accordingly to make the arrangement such that the slit-like opening of the conducting tube is at a current-loop place of the conducting tube. Finally, a particularly preferred constructional form consists in that the coupling place is located both at a current loop place of the dielectric guide and also at a current-loop place of the conducting tube and that the slit-like openings are arranged accordingly.

In the case in which the coupling is effected at a potential loop place of the conducting tube, and for example in the case of a cylindrical conducting tube at one or each end of which a metallic closing plate is provided, it is advantageous, particularly in the case of the excitation of the conducting tube into a form of oscillation in the case of which the electrical field lines are chiefly or exclusively endless eddy lines, to provide the slit-like opening in the wall of the tube not at a place at which there is a closing plate. It is, further, advantageous to place the slit-like opening at a current-loop place at which there is no closing plate and maybe to choose the length of the tube so that there is a current-loop place at which there is no closing plate.

The invention is applicable especially advantageously when it is a question of coupling a concentric dielectric guide with a tubular dielectric guide without an internal conductor. A particular application of the invention consists therefore in coupling in the manner stated a conducting tube with the resonator of an electron tube which consists of a concentric dielectric guide and contains partly or wholly an electron stream serving for its excitation. It is specially favourable to use the invention to this effect for the purpose of producing a desired coupling between a conducting tube and the resonator of an electron tube in the case of which the resonator consists of a concentric dielectric guide which as regards high frequencies is closed outwardly practically in all directions and is excited by an electron stream existing in its internal space (compare patent application Serial No. 8938 filed March 1, 1935 which issued as U. S. Patent No. 2,128,233 August 30, 1938).

The invention may also advantageously be used for the purpose of coupling, with the aid of a conducting tube, electron tubes of the kind stated

with one or more radiators, particularly where radiating surfaces serve as radiators (compare in particular patent application Serial No. 129,218 filed March 5, 1937). The arrangement may according to the invention be such that the conducting tube is coupled in the manner stated on the one hand with the resonator of the electron tube and on the other hand with the radiating surface or surfaces. In this case the radiating surface, which may itself be regarded as a conducting tube, can be coupled and used in such a manner that it is excited to a form of oscillation in the case of which the electrical field lines are endless eddy lines.

Apparatus according to the invention may be regarded as a transformer of forms of oscillation, inasmuch as for example the form of oscillation of a concentric dielectric guide is converted into a form of oscillation in the case of which the electrical field lines are chiefly or exclusively endless eddy lines.

The conducting tube itself may be formed as a radiating surface, being coupled in the manner stated with the dielectric guide of the resonator of the electron tube and so dimensioned that the open end (or maybe both open ends) acts (or act) as a radiator (or radiators). The radiator proper is then formed so to speak by the external cross-sectional area of the conducting tube. The opening or the diameter of the tube at the open end is to be selected accordingly. The diameter is advantageously an equivalent of half a wave length or of a multiple thereof. Particularly favorable results are obtained when the diameter of the opening is the equivalent of a whole wave length. From the opening serving as a radiator the conducting tube may extend as a cylindrical tube to the place of coupling with the dielectric guide of the resonator of the electron tube, or the diameter of the conducting tube may decrease gradually from the opening towards the coupling place according to a prescribed law (for example after the manner of the exponential horn).

The invention, the various features of which are defined in the appended claims, is illustrated by the accompanying drawings, of which Figures 1a and 1b are diagrams representing the course of electric and magnetic field lines in conducting tubes; Figure 2 is a perspective view of a cylinder in which the lines of force arrangements shown in Figures 1a and 1b are assumed to be inserted for the purpose of explanation; Figures 3, 4, 5, 6, and 7 are longitudinal sections of cylinders such as that shown in Figure 2 showing diagrammatically various types of waves that may occur therein; Figure 8 is a longitudinal section of a concentric dielectric guide showing diagrammatically the course of surface currents therein; Figure 9 is a perspective view of the dielectric guide shown in Figure 8 with its slit-like opening; Figure 10 shows a conducting tube coupled, according to the invention, with a concentric dielectric guide and Figure 11 shows a conducting tube coupled, according to the invention, with a radiator.

For the sake of the better understanding of the invention there will now be described some types of stationary waves that may occur in cylindrical dielectric guides. It is simplest to start from the line of force arrangements which are shown in Figures 1a and 1b and which as it were exist as if free in space. The thick lines indicate electrical field lines and the less thick lines indicate magnetic field lines. In the case of Figure 1a, a circularly annular bundle E of electrical lines

of force, which is regarded as rotationally symmetrical to the axis $x'-x'$, is surrounded by a torus-like bundle H of magnetic lines of force in a manner like that of the copper of a shell-type transformer. Conversely in Figure 1b an annular bundle H' of magnetic lines of force is surrounded by a toroidal bundle E' of electrical lines of force. The two cases are of course physically not substantially different from each other. If there is chosen as a conducting tube a straight cylinder 3 closed at both ends and having the axis $z-z$ (Figure 2), the arrangement shown in Figure 1a can be placed in two different ways in this cylinder—namely, first, so that the axis $x'-x'$ coincides with the axis $z-z$, and secondly so that $z-z$ is perpendicular to $x'-x'$. In the first case there is obtained a stationary wave of the type shown in Figure 3. The annular bundle of electrical field lines E is arranged rotationally symmetrically to the axis $z-z$ and is enveloped and screened on all sides against contact with the metal wall of the cylinder by the bundle of magnetic lines of force H that extends toroidally. As regards the limiting conditions to be fulfilled at the surface of conductors, annular surface currents that are rotationally symmetrical to the axis $z-z$ extend on the internal surface of the cylinder. There are no free charges on the internal surface of the metal cylinder because no electrical lines of force end thereat, but these exist as endless eddy lines. When the axis $z-z$ of the cylinder 3 (Figure 2) is perpendicular to the axis $z-z$ of Figure 1a, there occurs the type of waves shown in Figure 4. This type of waves has in common with that according to Figure 3 that on the internal surface of the cylinder there flow only surface currents but there exist no free charges. In the case of Figure 4, however, these surface currents flow substantially in planes parallel to the axis $z-z$.

The arrangement shown in Figure 1b can be placed in the cylinder of Figure 2 in a manner analogous to that of Figure 1a. For example there is shown in Figure 5 one of the cases in which the axis $x'-x'$ of Figure 1b coincides with the axis $z-z$. The electrical field lines E, since they are no longer protected by the magnetic lines of force, are not in this case endless but end at the surface of the cylinder so that the displacement currents determined by the field lines are closed by galvanic currents.

In Figure 6 there is represented another case of the same combination as that shown in Figure 5. If the arrangement shown in Figure 1b is regarded as being placed within the cylinder of Figure 2 as represented in Figure 5, but the end surfaces of the cylinder of Figure 5 are omitted, there is obtained a distribution in the case of which the electrical lines of force extend from the upper edge of the cylinder through the middle to the lower edge of the cylinder, they being concentrated in the plane of symmetry perpendicular to the axis by the bundle of magnetic lines of force. It is, of course, possible without difficulty, in the place of this plane of symmetry, to insert a metal sheet into the cylinder open at both ends, because the electrical lines of force are perpendicular to this sheet. By this step the lines-of-force picture of the open cylinder is not disturbed. If this cylinder open at the ends and divided in its plane of symmetry perpendicularly to the axis by a metal sheet is cut through in the middle in the place of this sheet and the two halves are arranged with their open ends together, there is obtained with reversal of the sign

of the field lines in one half the type of waves shown in Figure 6.

The surface currents flowing on the internal surface of the cylinder lie in meridional planes, and, together with the displacement currents determined by the electrical lines of force, surround the bundle of magnetic lines of force. A quite analogous current distribution exists in Figure 5, only the currents issuing from the equatorial plane pass in meridional planes to the two ends of the cylinder.

If the lines-of-force arrangement of Figure 1b is arranged in the cylinder of Figure 2 in such a manner that the axis $x'-x'$ is perpendicular to the axis $z'-z'$, there is obtained the type of waves shown in Figure 7. In this case the surface currents flow substantially in meridional planes in relation to the axis $x'-x'$.

There can of course be conceived the most manifold and spatial upper harmonics pertaining to the wave types shown in Figures 3-7, and, in fact both longitudinally and radially of the cylinder.

If, for example, in the cases represented in Figures 3-7 there is made a picture of the course of the surface currents on the internal surface of the hollow cylinder, it can be immediately stated in what way, with the smallest possible disturbance of the lines-of-force picture, the coupling of the chamber or hollow body in question to a second chamber or hollow body of the same or another kind can be effected. It is sufficient to provide in the wall of the chamber a narrow slot the longitudinal extension of which is perpendicular to the surface currents flowing on the internal surface of the hollow body. The second chamber or hollow body that is to be coupled thereto may be for example a concentric dielectric guide closed at both ends such as shown in Figure 8. If this hollow body of Figure 8, which is also represented in Figure 9 in perspective, is provided with a slot 1 that is peripheral (i. e., perpendicular to the axis of the body 2) and is arranged in proximity to its end and consequently in proximity to a current loop, the surface currents extending as indicated by broken lines provided with arrows (Figure 8) are compelled to traverse this slot in the direction of its width. If, now, the cylinder 2 of Figure 9 communicates through the slot 1 as shown in Figure 10 with a conducting tube 3 in which the wave type of Figure 3 is to be produced, the conducting tube 3 and the concentric dielectric guide 2 must obviously be arranged with their axes crossing perpendicularly, the longitudinal direction of the slot in the conducting tube 3 being parallel to the axis of the conducting tube. In the case of this arrangement the surface currents flowing in the concentric dielectric guide 2 perpendicularly over the slot 1 enter the conducting tube 3 and there take a course such as is necessary for the excitation of the type of waves according to Figure 3. In this case the surfaces of the two chambers have been changed as little as possible.

Figure 10 shows how a concentric dielectric guide can be coupled to a conducting tube so as to produce in the latter the wave type of Figure 3. The wave types of Figures 4, 5, 6, and 7 can be excited on the same principle.

Of course, in addition to the arrangement of the slot, it is necessary to the actual excitation or non-excitation of the wave type in question, that there be also the correct tuning of the conducting tube—i. e., the tuning to the frequency of the natural oscillation occurring in the concentric

dielectric guide. The concentric dielectric guide 2 (Figure 10) may for example be the transition piece leading from the chamber resonator of an electron tube or be a supplementary conducting piece by means of which to the chamber resonator there is coupled a further dielectric guide (for example 3) of small impedance, the one part 2 or the other part 3 or both for example serving for affecting the wave-length of the electron tube.

In a manner quite analogous to that in which the coupling of a conducting tube with a concentric dielectric guide has hereinbefore been described the conducting tube can be coupled with a radiator, in particular a radiator formed in surface fashion. Figure 11 shows a constructional example. The conducting tube 4 is fed at the end 5 by an ultra-short-wave generator having a chamber resonator coupled as by a concentric dielectric guide such as 2 (Figure 10) as hereinbefore described to the conducting tube 4. In the conducting tube 4 there is thus produced a wave of the type of Figure 3. This may be either a stationary or a travelling wave. Along this conducting tube 4 there are arranged at a suitable distance apart axially placed slit-like openings or slots 7 through which the interior of the conducting tube communicates with surface-like radiators 6, which are advantageously parabolic in section. In Figure 11 there is shown only one such radiator, whilst there are indicated for three other radiators the slots through which the coupling of the radiators can take place. As the conducting tube 4 oscillates with the wave type of Figure 3 the surface currents on the internal side of the conducting tube 4 flow peripherally and consequently transversely to each slot 7. These surface currents will consequently on issuing from the slot produce in the interior of each radiator 6 surface currents flowing substantially perpendicularly to the corresponding slot, which will then result in radiation into space.

When there is produced in the interior of the tube 4, a stationary wave, it is advantageous to make the openings 7 all of about the same size. If it is regarded as important, as it may be for the purpose of making the damping small, to produce in the interior of the conducting tube 4 no stationary wave, but a travelling wave, it may be advantageous to make the openings increase with increasing distance from the source of energy in order that at each one of the surface-like radiators arranged side by side there may be radiated outwards as nearly as possible the same energy.

What I claim is:

1. The combination of a conducting tube for a natural frequency of oscillation and provided with a slot in its side wall, with a second dielectric guide radiator coupled to said tube through said slot, said slot being located at an antinode of the conducting tube.

2. The combination of a conducting tube for a natural frequency of oscillation and provided with a slot in its side wall, with a second dielectric guide radiator coupled to said tube through said slot, the conducting tube consisting of an open ended hollow cylinder having an axial length equivalent to one-half the wave length to be produced, said slot being located at an antinode of the conducting tube.

3. The combination of a conducting tube for a natural frequency of oscillation and provided with a slot in its side wall, with a second dielectric guide radiator coupled to said tube through said slot, the conducting tube consisting of an

open ended hollow cylinder having an axial length of l , l being a whole number constituting a multiple of one-half the wave length to be produced, said slot being located at an antinode of the conducting tube.

4. The combination with a resonator tube constituting a dielectric guide having a rectangular slot therein extending longitudinally of said tube and of less dimensions circumferentially of the tube than its longitudinal extent, of a radiator tube having a cross section of greater extent longitudinally at right angles to said slot than its extent at right angles to its longitudinal extent, the axis of the radiator tube being at right angles to the axis of the resonator tube and offset laterally therefrom.

5. The combination with a resonator tube constituting a dielectric guide having a rectangular slot therein extending longitudinally of said tube and of less dimensions circumferentially of the tube than its longitudinal extent, of a conducting tube having a longitudinal extent greater than its cross-sectional dimension, the axis of the conducting tube being at right angles to the axis of the resonator tube and offset laterally therefrom, said slot communicating with the conducting tube through one side wall adjacent one end thereof.

6. The combination of a resonator tube, consisting of an open ended hollow cylinder, the axial length of which is equivalent to l , l being a whole number which is equivalent to a multiple of one-half the wave length to be produced, said cylinder being provided with a slot in its side wall; with a guide coupled to said tube through said slot, said slot being located at the antinode of the resonator tube.

7. The combination of a resonator tube, consisting of an open ended hollow cylinder, the axial length of which is equivalent to one-half the wave length to be produced, said cylinder being provided with a slot in its side wall; with a guide coupled to said tube through said slot, said slot being located at the antinode of the resonator tube.

8. The combination with a resonator tube constituting a dielectric guide having a rectangular slot therein extending longitudinally of said tube and of less dimensions circumferentially of the tube than its longitudinal extent, of a radiator tube having a cross section of greater extent longitudinally at right angles to said slot than its extent at right angles to its longitudinal extent, the axis of the radiator tube being at right angles to the axis of the resonator tube and offset laterally therefrom, said slot being located at the antinode of the conducting tube.

9. The combination with a resonator tube constituting a dielectric guide having a rectangular slot therein extending longitudinally of said tube and of less dimensions circumferentially of the tube than its longitudinal extent, of a radiator tube having a cross section of greater extent longitudinally at right angles to said slot than its extent at right angles to its longitudinal extent, the axis of the radiator tube being at right angles to the axis of the resonator tube and offset laterally therefrom, said slot communicating with the radiator tube through one side wall adjacent one end thereof, said slot being located at the antinode of the conducting tube.

WALTER DALLENBACH.