

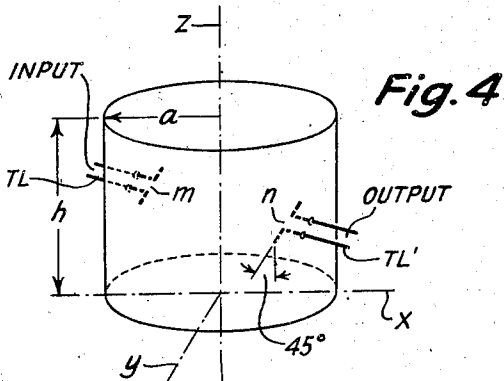
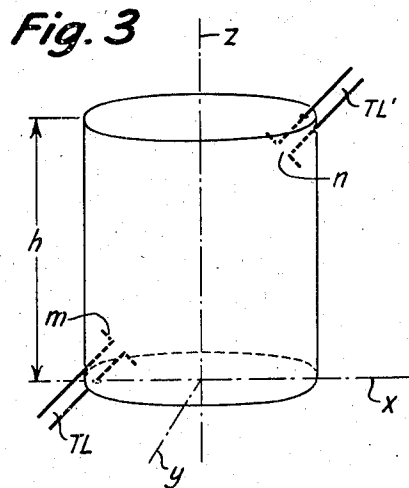
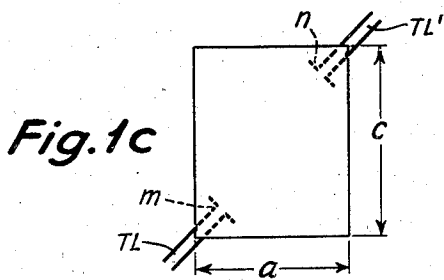
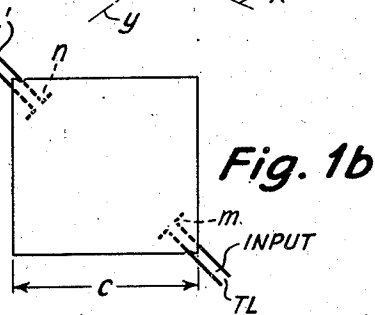
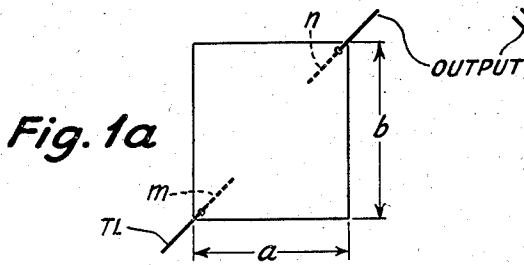
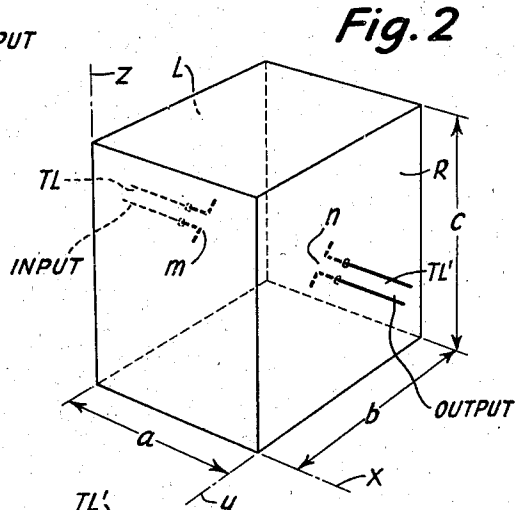
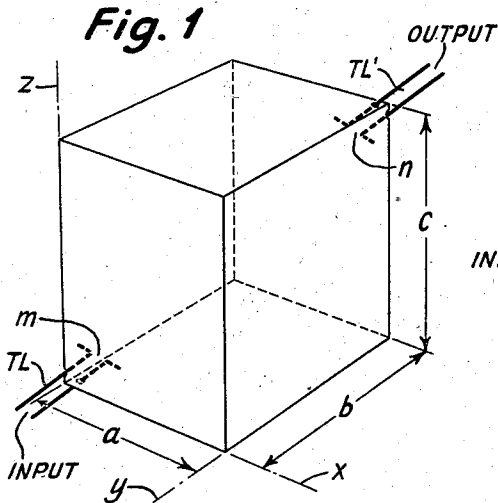
June 29, 1948.

P. S. CARTER
CAVITY RESONATOR CIRCUIT

2,444,152

Filed July 15, 1944

5 Sheets-Sheet 1



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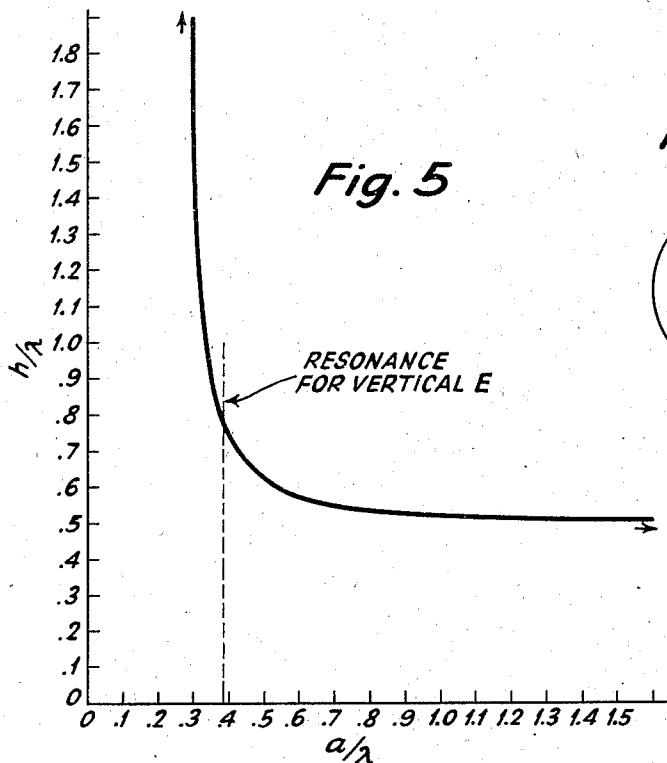


Fig. 5a

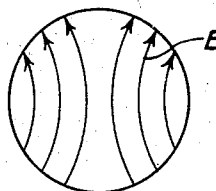


Fig. 6a

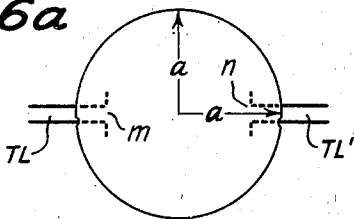


Fig. 6b

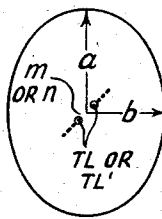
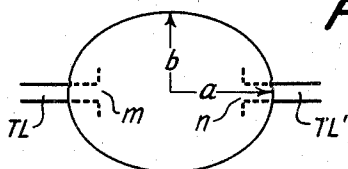


Fig. 6c



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Fig. 7a

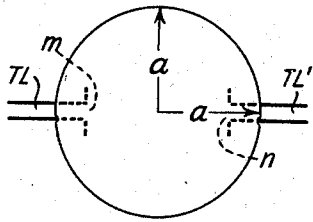


Fig. 7c

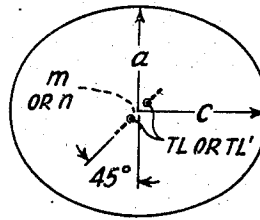


Fig. 7b

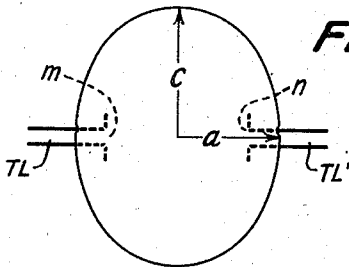


Fig. 8a

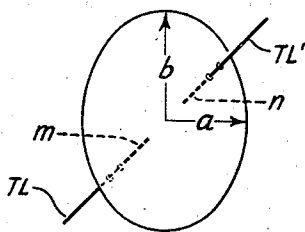


Fig. 8c

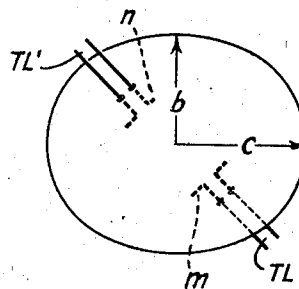
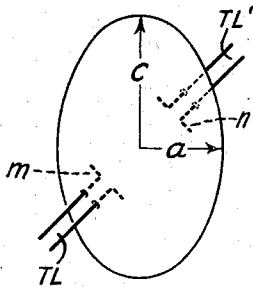


Fig. 8b



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Fig. 9a.

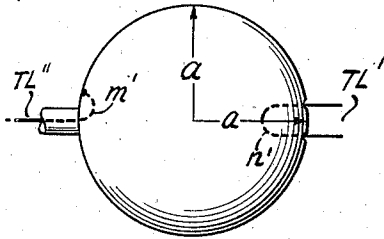


Fig. 9b.

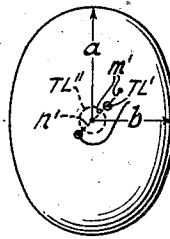


Fig. 9c.

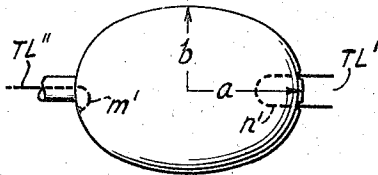


Fig. 10a.

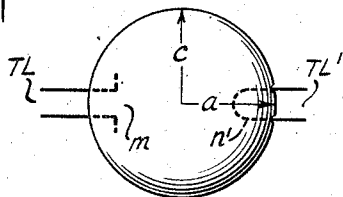


Fig. 10c.

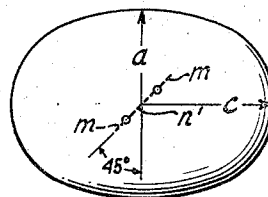
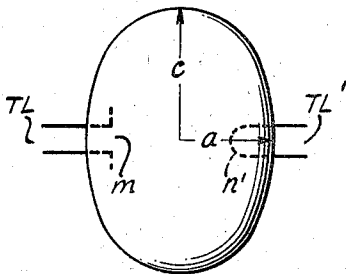


Fig. 10b.



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Fig. 11a.

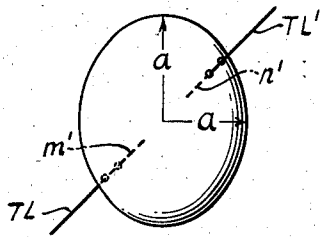


Fig. 11c.

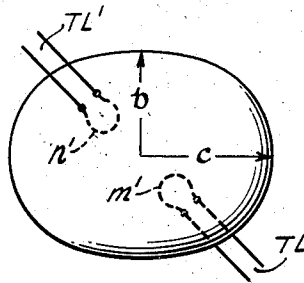
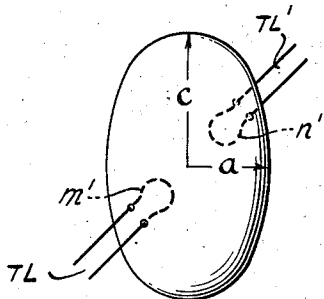


Fig. 11b.



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UNITED STATES PATENT OFFICE

2,444,152

CAVITY RESONATOR CIRCUIT

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Application July 15, 1944, Serial No. 545,098

9 Claims. (Cl. 178-44)

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This application is a continuation in part of my copending application Serial No. 373,072, filed January 4, 1941, now United States Patent 2,357,314, granted September 5, 1944.

This invention relates to coupling circuits for passing a band of frequencies, and particularly to such circuits employing cavity resonators. The term "cavity resonator" is intended to include any high frequency electrical resonator comprising a closed electrically conducting surface enclosing a hollow space, and wherein the enclosure contains a periodically repeating electromagnetic field. The term "coupling circuit" used herein is intended to include any circuit which selectively passes a band of frequencies, such as, for example, an electrical wave filter, or a selective circuit, which might be used between stages of a receiver or transmitter.

In the communication field, it is often desirable to employ a four-terminal band pass coupling circuit which has two or more natural frequencies of oscillation differing by a small predetermined percentage of the mid frequency. Such four-terminal circuits may take the form of two or more coupled tuned circuits, one being connected to the input terminals and another to the output terminals, or may take the form of any suitable impedance network. It is known that such circuits may be made to obtain a band pass characteristic when loaded with a resistance. This resistance, which may constitute the useful load per se, serves to smooth out the multi-peak resonance of the four-terminal coupling circuit. It has been found, however, that when using ultra high frequencies it is impractical to construct such circuits of coils and condensers.

In my copending application Serial No. 359,187, filed October 1, 1940, now United States Patent 2,357,313, granted September 5, 1944, there are described several types of band pass cavity resonators wherein use is made only of modes of oscillation in which the electric field is entirely in one direction. When the electric field is entirely in one direction, let us say vertical (by way of example) then the natural frequencies of oscillation will be determined entirely by the dimensions of the base, and there will exist only one fundamental natural frequency. In order to obtain two natural frequencies lying close together, in accordance with the teachings of my U. S. Patent 2,357,313 supra, use is made of higher modes of oscillation than fundamental.

However, the present invention employs cavity resonators which are excited in a predetermined manner to cause the existence in the resonator si-

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multaneously of two or three types of waves. These types of waves which are produced and employed, in accordance with the teachings of the invention, in order to provide a band pass characteristic, are only the fundamental modes of oscillation, thus differing from the modes of oscillation employed in my U. S. Patent 2,357,313, which are of a higher order than the fundamental. One advantage of the present invention over that disclosed in my U. S. Patent 2,357,313 is that the use of the fundamental modes of oscillation to provide a band pass characteristic enables me to use cavity resonators of reduced size in at least two dimensions.

One of the objects of the present invention is to provide a cavity resonator coupling circuit so excited that there is caused to exist two or three fundamental frequencies of oscillation differing by a predetermined percentage of the mid frequency and which possesses a desired band pass characteristic. Where the cavity resonator of the invention has three fundamental frequencies of oscillation, it is contemplated that one of the fundamental frequencies of oscillation correspond to the mid frequency of the band pass.

The following is a description of the invention accompanied by drawings wherein:

Figs. 1, 2, 3 and 4 represent different cavity resonators constructed in accordance with the principles of the present invention;

Figs. 1a, 1b and 1c are respectively plan, side and end elevations of Fig. 1;

Fig. 5 is a curve given to aid in an understanding of the principles involved in connection with the resonator of Fig. 4;

Fig. 5a illustrates the electric field configuration for a mode of oscillation present in the structure of Fig. 4;

Figs. 6a, 6b and 6c illustrate plan, side and end elevations, respectively, of an oblate spheroid cavity resonator embodiment of the present invention utilizing dipoles for feeding and extracting energy;

Figs. 7a, 7b and 7c illustrate plan, side and end elevations, respectively, of a prolate spheroid cavity resonator embodiment of the present invention utilizing dipoles for feeding and extracting energy;

Figs. 8a, 8b and 8c illustrate plan, side and end elevations, respectively, of a hollow ellipsoid cavity resonator embodiment of the present invention utilizing dipoles for feeding and extracting energy;

Figs. 9a, 9b and 9c illustrate plan, side and end views of an oblate spheroid resonator utilizing

a combination of a loop and a dipole for feeding and extracting energy;

Figs. 10a, 10b and 10c illustrate plan, side and end views of a prolate spheroid resonator utilizing a combination of a loop and a dipole for feeding and extracting energy; and

Figs. 11a, 11b and 11c illustrate plan, side and end views of a hollow ellipsoid resonator utilizing loops for both feeding and extracting energy.

Fig. 1 illustrates a cavity resonator in accordance with the invention which, from a theoretical standpoint, is the simplest embodiment showing how to make use of three types of waves and their fundamental modes of oscillation. This figure represents a rectangular prism whose sides are indicated by the dimensions a , b , c of different predetermined lengths, lying along the directions x , y , z , respectively. At one corner of the prism there is shown an input transmission line TL terminating in a dipole m in the interior of the prism. The axis of this dipole m is arranged to make equal angles of 54.7° with the three directions x , y , z in order to obtain equal excitation of all three types of waves. Transmission line TL, of course, is coupled to a suitable source of high frequency oscillations (not shown). At the diagonally opposite corner of the prism, Fig. 1 and in its interior is a second dipole n coupled to a transmission line TL' forming the output circuit. The axis of dipole n is parallel to the axis of dipole m and hence also makes equal angles of 54.7° with the directions x , y and z . The cavity resonator of Fig. 1 is thus excited to have three natural fundamental frequencies of oscillation. All three modes of oscillation tend to be excited in equal amplitudes from the feeding dipole m , which makes equal angles with the directions of the three coordinate axes. By properly loading the output dipole n , the band pass characteristic is obtained. For such a resonator let λ_x , λ_y and λ_z indicate the natural wavelengths corresponding to the three fundamental modes of oscillation, the sub letters indicating the direction of the electric field in the standing wave. When the electric field is entirely vertical and in the z direction, the natural wavelength is determined entirely by the dimensions a , b of the base, and is given by the relation

$$\lambda_z = \frac{2ab}{\sqrt{a^2 + b^2}}$$

When the electric field is entirely horizontal and in the y direction, the natural frequency is determined entirely by the dimensions a and c , and is given by the relation

$$\lambda_y = \frac{2ac}{\sqrt{a^2 + c^2}}$$

When the electric field is horizontal and in the x direction, the natural frequency is determined by the dimensions c and b and given by the relation

$$\lambda_x = \frac{2bc}{\sqrt{b^2 + c^2}}$$

From the relations given above in connection with λ_x , λ_y , λ_z , we thus are able to obtain any three natural frequencies desired by suitably choosing the lengths of the sides.

If the dimensions a , b and c of Fig. 1 were all made to be equal, the resulting structure would be a cube, and the three natural modes of oscillation would coincide in frequency. The electromagnetic field within the resonator of the cube when fed in the manner shown in Fig. 1 would then be the equivalent of a superpositioning of the three types of waves above mentioned and the electric field of the resultant oscillation would be

in the direction of the diagonal from one corner to the opposite corner of the cube; that is, the diagonal which is parallel to the axis of the dipoles m and n .

Although the dipoles m and n have been shown in Fig. 1 as being so arranged that they make equal angles of 54.7° with the three dimensions x , y and z , it should be understood that the axis of these dipoles may make different angles with respect to the directions x , y and z , with a resulting difference in the degree of excitation of the three modes of oscillation. It might be desirable, under some conditions, to tend to under-excite the mid frequency of the three fundamental frequencies, which mid frequency might correspond to the wave having its electric field in the z direction. This can be done by decreasing the angle of the dipole axis with respect to the z direction.

Where it is desired to obtain a band pass characteristic produced by the use of a circuit having two natural fundamental frequencies rather than three, a structure such as shown in Fig. 2 can be employed. Fig. 2 shows a rectangular prism having an input transmission line TL entering the middle of the left hand side L and terminating in a dipole m . The axis of the dipole m is parallel to the x - y plane and is arranged to make equal angles of 45° with the directions z and y . The output dipole n is parallel to dipole m and is located in the interior of the resonator in a similar manner at the right hand side R of the resonator. The output transmission line TL' enters the right hand side R at its middle. The input dipole m which is excited by high frequency oscillations from a source (not shown) coupled to the transmission line TL, tends to excite oscillations of equal amplitude in the resonator wherein the electric field is either vertical in direction z or horizontal in the direction y . The feeding arrangement, however, cannot excite oscillations having an electric field in the direction x because the axis of the dipole m is perpendicular or at right angles to the direction x . In the circuit of Fig. 2, use is made of the fundamental modes of oscillation which correspond to the oscillations excited in the resonator by the feeding dipole m . By choosing the proper dimensions, these two fundamental modes of oscillations will have frequencies which differ from each other by a predetermined amount. Generally, it is preferred that these two frequencies be separated by an amount approximately two-thirds the width of the frequency band. In a manner discussed in more detail in my copending application supra, when the electric field is vertical in the z direction, in Fig. 2, the natural wavelength is given by

$$\lambda_z = \frac{2ab}{\sqrt{a^2 + b^2}}$$

When the electric field is horizontal in the direction of y , the natural wavelength is given by

$$\lambda_y = \frac{2ac}{\sqrt{a^2 + c^2}}$$

So long as the above two mathematical relations are satisfied, it does not matter whether the sides a and b are equal or unequal.

Fig. 3 shows another embodiment of the invention in the form of a hollow tank whose shape is an elliptic cylinder. This resonator is excited by a transmission line TL and dipole m in a manner corresponding to that of Fig. 1 for the hollow prism, and the output is obtained by dipole n and transmission line TL' also in a manner similar to that of Fig. 1. Dipoles m and n are

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parallel to each other and make equal angles with the directions x , y and z . The resonator of Fig. 3 has three natural fundamental frequencies whose oscillations can be said, in a way, to correspond to the oscillations present in the resonator of Fig. 1, except for the more complex electric field distribution. The fundamental modes of oscillations of the resonator of Fig. 3 are determined by the dimensions of the major and minor axes of the ellipse and also by the height. When the electric field is vertical in the direction z , the natural fundamental wavelength is determined by the dimensions of the major and minor axes of the ellipse. When the electric field is horizontal, and principally in either the directions of the y or the x axis, the fundamental modes of oscillation are determined by all three dimensions through a very complex relationship. It is not believed to be necessary to enter into a detailed discussion of this relationship here. In this last case, the dimensions can be determined experimentally, that is, by trial and error, or by employing tables of Mathieu functions. Such tables of the Mathieu function of the radial type which may be used in determining the exact dimensions of the elliptic cylinder have been worked out by the Physics Department of the Massachusetts Institute of Technology, Cambridge, Mass.

Fig. 4 shows another embodiment of the present invention giving two natural fundamental frequencies of oscillations and which consist essentially of a hollow circular cylinder tank in which the axis of the exciting dipole m is tilted at an angle of 45° to the horizontal. When the electric field is entirely vertical, the fundamental wavelength of such a tank is obtained from the expression

$$J_0\left(\frac{2\pi a}{\lambda}\right) = 0$$

where J_0 is the zero order of the Bessel function and a is the radius of the tank. This relation results in a diameter of approximately 0.766 wavelength. When the electric field is horizontal, the natural fundamental frequency is determined by both the radius a and the height h of the cylindrical tank, and there are a series of values of a and h which result in the same natural fundamental frequency of oscillation. The ratios of a and b to the natural frequency are shown in the curve of Fig. 5 by means of which it is possible to so choose the height and diameter as to obtain any two fundamental frequencies for the two types of waves in the cylinder. As an example, let us assume that it is desired to have the two natural fundamental frequencies of the cylinder correspond to the wavelengths of 100 and 110 centimeters. If we choose the 100 centimeter wave to be the one whose electric field is entirely vertical, we then find for the radius of the cylinder a value of approximately 38.3 centimeters, as obtained from the foregoing expression

$$J_0\left(\frac{2\pi a}{\lambda}\right) = 0$$

The ratio of this radius to the second wavelength of 110 centimeters then becomes

$$\frac{38.3}{110} = 0.35 \text{ (approximately)}$$

From the curve of Fig. 5, we then find that the value of the ratio of the height h to the second natural wavelength must be approximately 0.9. The height in centimeters then becomes 0.9×110 , or 99 centimeters. If the ratio of height to radius is made approximately equal to 2.02,

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the two natural fundamental frequencies of oscillation coincide, a condition which roughly corresponds to that wherein the rectangular prism of Fig. 2 is made to be a perfect cube.

The term "fundamental" used in connection with Fig. 4 and Fig. 5 in regard to the condition when the electric field is horizontal, designates that mode of oscillation corresponding to the lowest frequency or longest wavelength regardless of the mathematical viewpoint. For purposes of exposition, Fig. 5a shows the electric field configuration for the mode just referred to. The radial and angular components E_r and E_ϕ are given, respectively, by the formulas

$$E_r = \frac{J_1(1.84 r/a)}{1.84 r/a} \sin \pi \frac{z}{h} \cos \phi$$

where J_1 is the first order Bessel function, r equals the radial distance, z equals the vertical distance, and ϕ the horizontal angle;

$$E_\phi = J_1'(1.84 r/a) \sin \pi \frac{z}{h} \sin \phi$$

where J_1' is the derivative of the first order Bessel function with respect to its argument.

There is also a zero order mode, where the electric force is entirely along concentric circles, but while of lower order mathematically, the natural wavelength is shorter for a given radius and height of tank than for the mode under consideration. For the purpose of the present invention, I am interested here in the longest natural wavelengths or lowest natural frequencies of oscillation.

Figs. 6a, 6b and 6c indicate respectively plan, side elevation and end views of another embodiment of the invention comprising an oblate spheroid. Such structure approximates generally the form of a compressed sphere. Figs. 7a, 7b and 7c are plan, side and end elevations, respectively, of a further embodiment in the form of a prolate spheroid, corresponding generally, so to speak, to a football or a stretched sphere. In the embodiments of the oblate and prolate spheroids, the input and output circuits constituting the dipoles m and n , respectively, are shown arranged at an angle of 45° to the major and minor axes of the elliptic cross-section. The embodiments of Figs. 6 and 7 constitute resonators which have only two fundamental frequencies. The best dimensions of the oblate and prolate spheroid can be determined experimentally.

A further embodiment of the invention is shown in Figs. 8a, 8b and 8c which respectively show plan, side elevation and end elevation views of a hollow ellipsoid having three elliptic cross-sections. Generally speaking, such a resonator structure resembles a compressed football. Because there are three principal axes in the structure of Figs. 8a, 8b and 8c which have different dimensions, there is a band pass characteristic composed of three fundamental modes of oscillation, if properly excited in accordance with the principles of the present invention. It is proposed to excite the hollow ellipsoid by arranging the input dipole m and the output dipole n in such manner that they are parallel and make equal angles of 54.7° to the directions of the three principal axes of the three elliptic cross-sections. The phenomenon is quite similar to that for the rectangular prism arranged for Fig. 1.

Although the input and output circuits of all the embodiments have been shown as employing dipoles, it should be understood that the invention is not limited to such specific arrange-

ments but that other forms of input and output circuits can be employed. For example, if desired, ordinary U-shaped loops can be employed for the input and output circuits. Due consideration must be given to the types of waves which can be excited by a particular loop. For the purpose of the present invention, let us define the direction of the axis of a loop, or U-shaped circuit, as a line perpendicular to the plane in which the U-shaped circuit lies. With this definition, a U-shaped loop can only excite electromagnetic waves having a component of magnetic field corresponding to the direction of the axis. Taking Fig. 1 as an illustration, if loops were substituted for the dipoles m and n such that the end conductors or short circuiting members coincide with the positions of the dipoles as shown in this figure, and the legs of the loops coincide with the wires of the transmission lines which connect with the dipoles, then the input loop would tend to excite in the resonator all three types of waves at the three fundamental modes of oscillation, provided, of course, that the direction of the loop axis makes equal angles with the three directions x, y, z of the prism. In Fig. 2, however, if loops are substituted for the dipoles in the same manner as described above in connection with Fig. 1, it is possible to excite three types of waves corresponding to the three fundamental modes of oscillation, because of the fact that in this case the only restriction on the wave is that its magnetic field must lie in a plane parallel to the $y-z$ plane. It should be noted that the substitution of the loops for the dipoles of Fig. 2 provides three fundamental modes of oscillation, whereas with the use of dipoles only two fundamental modes of oscillation are obtained. This statement holds true provided the dimensions a and b of Fig. 2 are different from each other. However, if dimensions a and b are equal to each other, then the substitution of loops for dipoles in Fig. 2 could only produce two natural fundamental frequencies of oscillation.

If loops are substituted for dipoles in the hollow elliptic cylinder resonator of Fig. 3, there will be obtained three natural fundamental frequencies. If loops are substituted for the dipoles of the hollow circular cylindrical tank of Fig. 4, there will result only two natural fundamental frequencies of oscillation, due to the fact that there are only two natural fundamental frequencies of oscillation in a resonator of such a configuration. Since there are only two natural fundamental frequencies of oscillation in the oblate and prolate spheroids of Figs. 6a-6c and 7a-7c, the substitution of loops for dipoles in these two figures will, of course, result in only two fundamental modes of oscillation. As for the hollow ellipsoid of Fig. 8, the same considerations mentioned above in connection with Fig. 1 apply to the hollow ellipsoid when loops are substituted for the dipole.

If desired, the input and output circuits can consist of concentric lines with the inner conductor entering the interior of the resonator in the manner of a probe for exciting and for driving energy from the resonator.

Figs. 9a, 9b and 9c show the oblate spheroid provided with loops for the input and output circuits. The input loop is a half loop and labeled m' and constitutes an extension of a coaxial line feeder TL' . The output loop is labeled n' and is a full loop. The plane of both loops is inclined at an angle of approximately 45° to the two principal axes of the elliptical cross-section.

In the prolate spheroid of Figs. 10a, 10b and 10c, the input circuit is shown using a dipole m while the output circuit uses a loop n' . Both the axis of the dipole and the plane of the loop are inclined at an angle of about 45° to the two principal axes of the elliptical cross-section.

The ellipsoid of Figs. 11a, 11b and 11c employs loops m' and n' for the input and output circuits. Here the plane of the loop should make approximately equal angles with two of the three principal axes of the ellipsoid for a filter circuit using double resonance phenomenon. If it should be desired to use the three resonances, the plane of these loops should be inclined so as to make equal angles with all three of the principal axes of the ellipsoid.

The circuits of Figs. 6 to 11, inclusive, are primarily useful as band pass circuits in accordance with the principles of the present invention.

The resonators of the present invention find particular application in the ultra short wave field and may be used wherever a filter can be used and for substantially the same purpose, such as between stages of a receiver and a transmitter. When used as a band pass coupling circuit, it is preferred that the fundamental frequencies of oscillation caused to exist by exciting the resonator in the manner described above be reasonably close to one another in order to obtain a smooth band pass characteristic. The resonator of the present invention may also be used as an input circuit of a frequency mixer or detector, wherein a pair of relatively close frequencies can be mixed in the resonator and the beat frequency delivered from an electronic tube. This last application is primarily for use in a superheterodyne receiver, wherein it is desired to obtain an intermediate frequency from a detector.

What is claimed is:

1. A high frequency cavity resonator comprising a hollow closed electrically conducting ellipsoid having different principal dimensions, and means for exciting said resonator including an exciting element in the interior of said resonator and positioned in a plane which forms an appreciable angle with the major and minor axes of an elliptic cross-section of said ellipsoid so as to produce oscillations of at least two fundamental modes simultaneously.

2. A high frequency cavity resonator comprising a hollow closed electrically conducting oblate spheroid having only two different principal dimensions, and means for exciting said resonator including an exciting element in the interior of said resonator and positioned in a plane which forms an appreciable angle with the major and minor axes of an elliptic cross-section of said spheroid so as to produce oscillations in said resonator of at least two fundamental modes simultaneously.

3. A high frequency cavity resonator comprising a hollow closed electrically conducting prolate spheroid having only two different principal dimensions, and means for exciting said resonator including an exciting element in the interior of said resonator and positioned in a plane which forms an appreciable angle with the major and minor axes of an elliptic cross-section of said spheroid so as to produce oscillations in said resonator of at least two fundamental modes simultaneously.

4. A high frequency cavity resonator comprising a hollow closed electrically conducting spheroid having only two different principal dimensions, and means for exciting said resonator in-

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cluding an exciting element in the interior of said resonator and positioned in a plane which forms an appreciable angle with the major and minor axes of an elliptic cross-section of said spheroid so as to produce oscillations in said resonator of at least two fundamental modes simultaneously.

5. A high frequency cavity resonator comprising a hollow closed electrically conducting body having a pair of principal axes of different lengths, said body being an ellipse in at least one cross-section, and means for exciting said resonator including an element in the interior of said resonator and positioned in a plane which forms an appreciable angle with the major and minor axes of said ellipse in such manner as to produce oscillations of at least two fundamental modes simultaneously.

6. A high frequency cavity resonator comprising a hollow closed electrically conducting ellipsoid having different principal dimensions, one cross-section of said ellipsoid being a circle, and means for exciting said resonator including an element in the interior of said resonator and positioned in a plane which forms an appreciable angle with the major and minor axes of an elliptic cross-section of said ellipsoid so as to produce oscillations of at least two fundamental modes simultaneously.

7. A high frequency cavity resonator comprising a hollow closed electrically conducting spheroid, and means for exciting said resonator including an exciting element in the interior of said resonator and positioned in a plane which forms an angle of approximately 45° to the major and minor axes of the elliptic cross-section of said spheroid, so as to produce oscillations in said resonator of at least two fundamental modes simultaneously.

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8. A high frequency cavity resonator comprising a hollow closed electrically conducting spheroid, and a probe located in the interior of said resonator for exciting said resonator, said probe being in a plane which forms an angle of approximately 45° to the two principal axes of the elliptic cross-section of said resonator, so as to produce oscillations in said resonator of at least two fundamental modes simultaneously.

9. A high frequency cavity resonator comprising a hollow closed electrically conducting body having a pair of principal axes of different lengths, said body being an ellipse in at least one cross-section, and means for exciting said resonator including an exciting element in the interior of said resonator, said exciting element being positioned in a plane which forms at an appreciable angle to the major and minor axes of said ellipse in such manner as to produce oscillations of at least two fundamental modes simultaneously.

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