Sept. 5, 1944. P. S. CARTER 2,357,313

HIGH FREQUENCY RESONATOR AND CIRCUIT THEREFOR

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Fig. 1

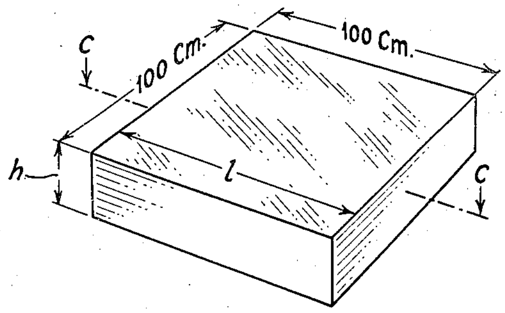

Fig. 1a

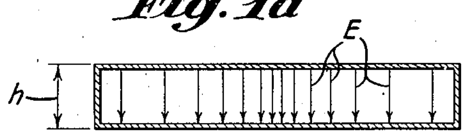

Fig. 1b

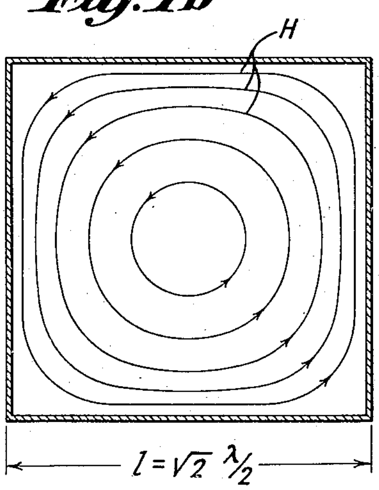

Fig. 1c

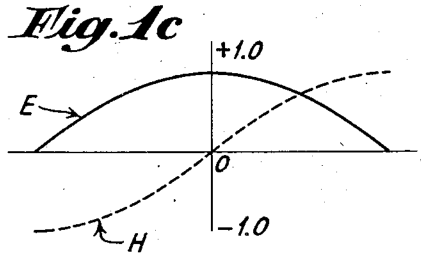

Fig. 1d

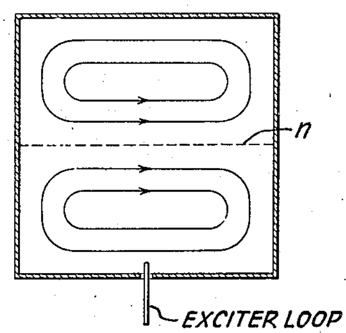

Fig. 1e

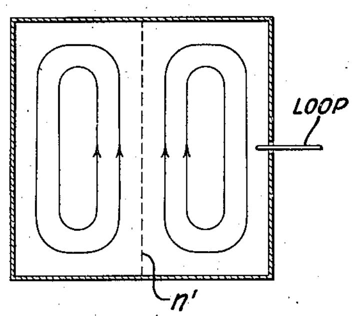

Fig. 1f

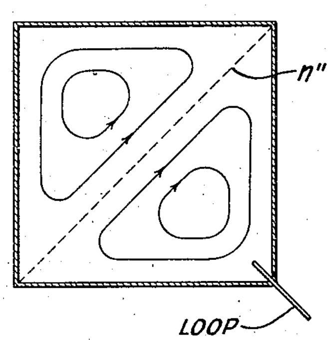

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Fig. 2

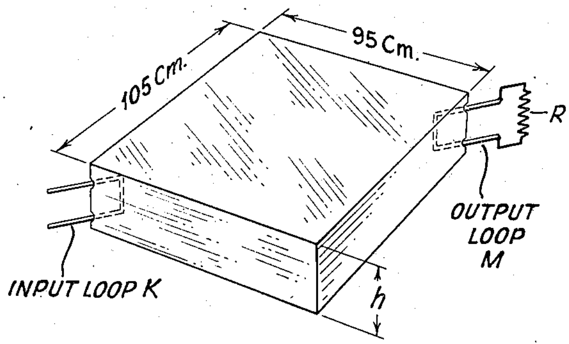

Fig. 2a

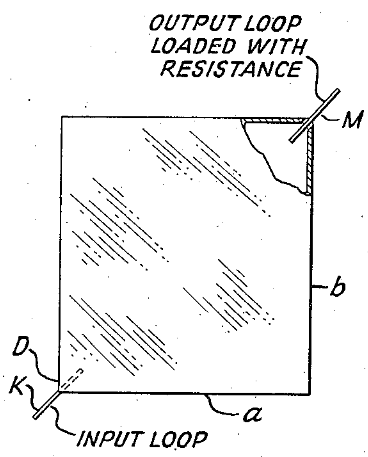

Fig. 3

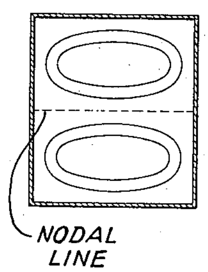

Fig. 3a

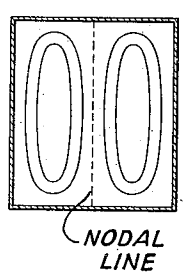

Fig. 2b

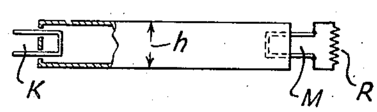

Fig. 4

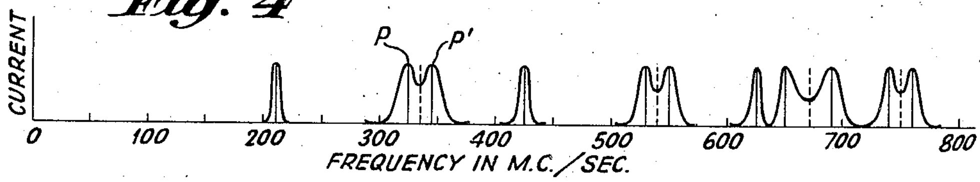

Fig. 4a

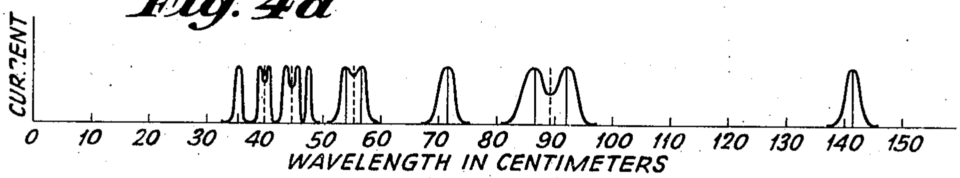

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Fig. 5

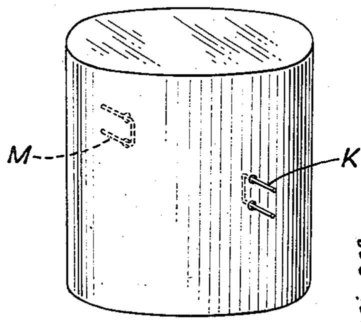


Fig. 6

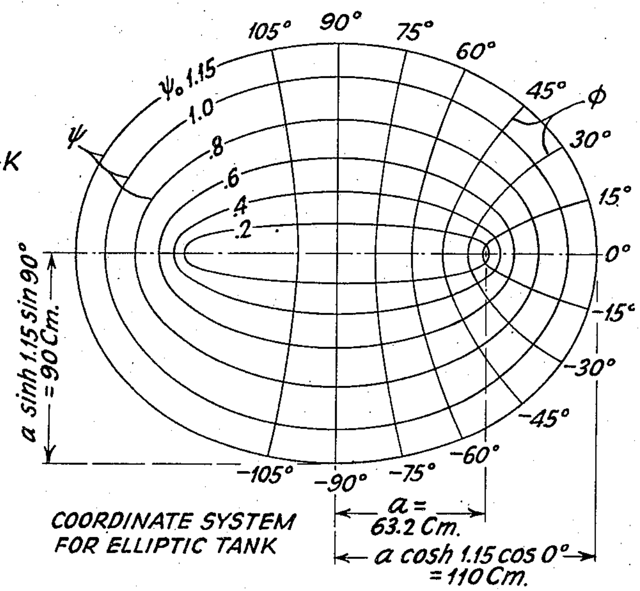


Fig. 5a

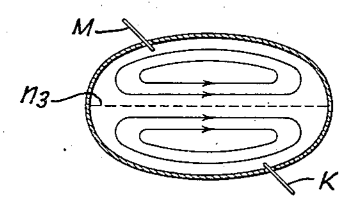


Fig. 5b

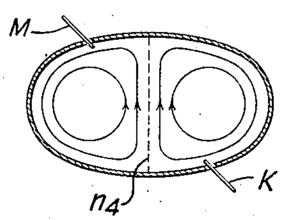
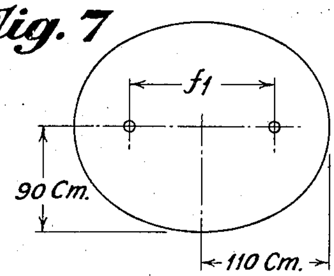


Fig. 7



ϵ = 0.575 (ECCENTRICITY)
f = 126.5 Cm.

Fig. 7a

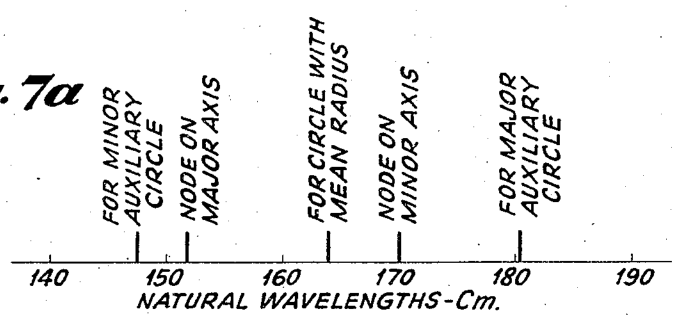


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Fig. 8

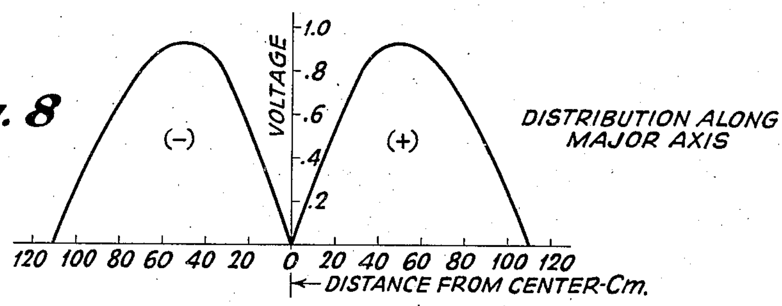

Fig. 8a

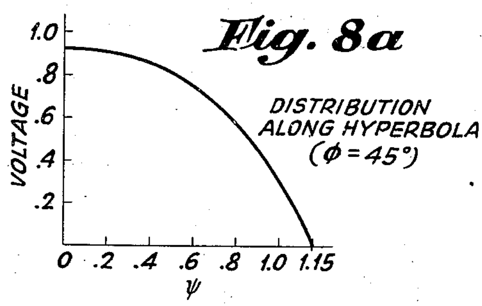

Fig. 9

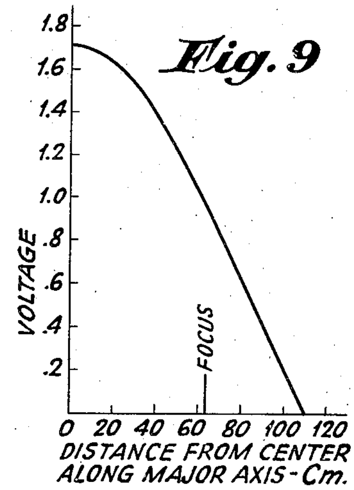

Fig. 10

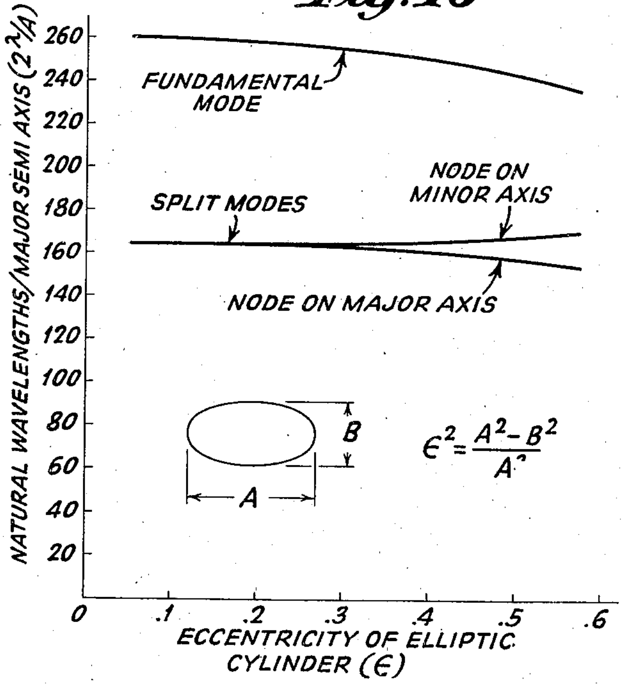

Fig. 9a

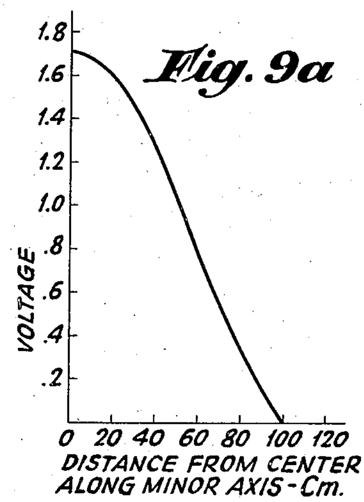

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Fig. 11

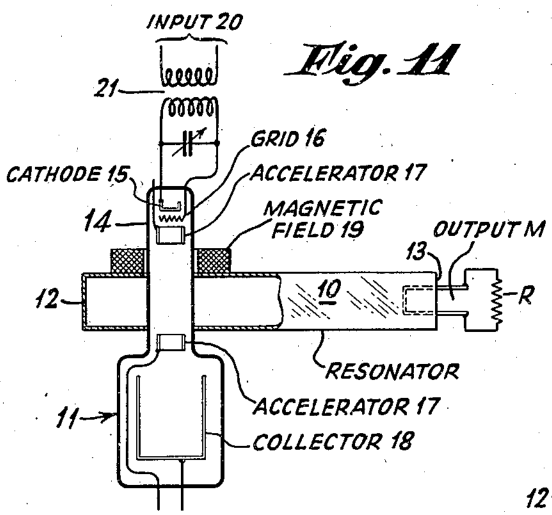


Fig. 11a

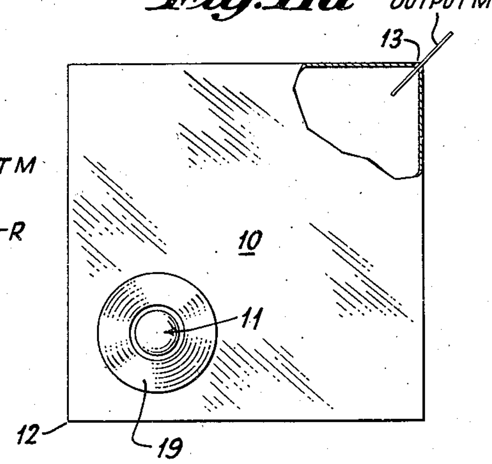


Fig. 12

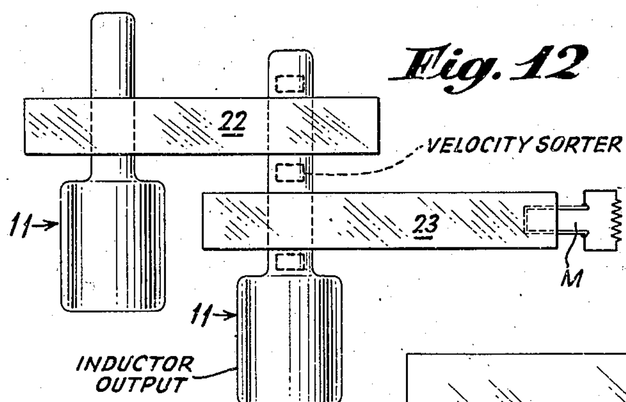
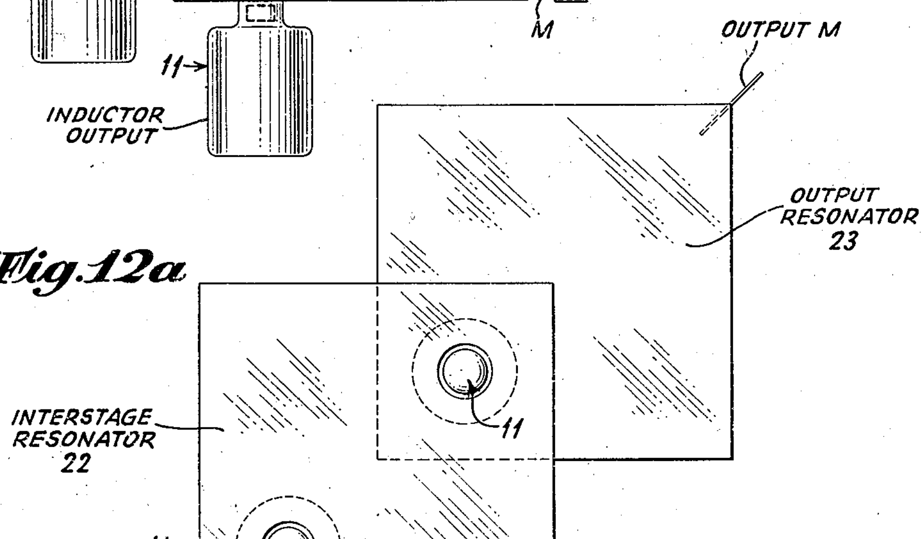


Fig. 12a



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Patented Sept. 5, 1944

2,357,313

UNITED STATES PATENT OFFICE

2,357,313

HIGH FREQUENCY RESONATOR AND CIRCUIT THEREFOR

Philip S. Carter, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application October 1, 1940, Serial No. 359,187

20 Claims. (Cl. 178—44)

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 natural frequencies of oscillation differing by a small predetermined percentage of the mid frequency. Such four-terminal circuits may take the form of two coupled tuned circuits, one being connected to the input terminals and the other 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 double peak resonance curve 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.

One of the objects of the present invention is to provide an improved coupling circuit capable of passing a desired band of frequencies with high efficiency, that is, with extremely low loss.

Another object is to provide a four-terminal coupling circuit which is compact and of extremely simple construction.

A further object is to provide a cavity resonator coupling circuit which has two natural frequencies of oscillation differing by a predetermined percentage of the mid frequency and which possesses a desired band pass characteristic.

In the drawings:

Fig. 1 represents a square cavity resonator given for the purpose of exposition;

Figs. 1*a* and 1*b* illustrate respectively the electric field and magnetic field configurations of the resonator of Fig. 1;

Fig. 1*c* graphically illustrates the magnetic field and electric field distributions of the resonator of Fig. 1 as seen through a cross-section along line *c*—*c*;

Figs. 1*d*, 1*e* and 1*f* illustrate three different magnetic field configurations which can exist in the resonator of Fig. 1, depending upon how the resonator is excited;

Fig. 2 illustrates a cavity resonator in accordance with one embodiment of the invention;

Figs. 2*a* and 2*b* illustrate, respectively, top and side views of the resonator of Fig. 2;

Figs. 3 and 3*a* illustrate the magnetic field configurations for two natural frequencies of the resonator of Fig. 2;

Figs. 4 and 4*a* graphically illustrate the resonant characteristics of the resonator of Fig. 2 plotted respectively as a function of frequency in megacycles per second and as a function of wavelengths measured in centimeters;

Fig. 5 shows an elliptic cylinder cavity resonator in accordance with another embodiment of the invention;

Figs. 5*a* and 5*b* show the magnetic field configurations for the resonator of Fig. 5 when it is oscillating at the two desired modes of oscillation;

Fig. 6 graphically illustrates a system of confocal ellipses and parabolas for an elliptic resonator having certain dimensions;

Fig. 7 shows certain dimensions of an elliptic cylinder resonator whose characteristics are illustrated in Fig. 7*a*;

Figs. 8, 8*a*, 9, 9*a* and 10 graphically illustrate various characteristics of an elliptic resonator in accordance with the invention under certain conditions;

Fig. 11 is an elevation view, in section, and Fig. 11*a* a plan view of Fig. 11, of a circuit illustrating one way in which a cavity resonator of the invention may be used in association with an electron discharge device;

Fig. 12 illustrates the use of cavity resonators of the invention employed in a multi-stage system; and

Fig. 12*a* is a plan view of the system of Fig. 12.

In order to aid in an understanding of the principles of the present invention, an exposition will now be given of certain oscillatory phenomenon leading up to the teachings of the present invention. Let us assume that we have a rectangular cavity resonator (sometimes called a tank) of square horizontal cross section whose sides are each 100 cm. in length, of the type shown in perspective in Fig. 1. In this cavity resonator the electric vector (E) is assumed to be vertical, as is shown more clearly in Fig. 1*a*, which figure illustrates the electric field configuration through a vertical section of the resonator of Fig. 1. The frequency corresponding to the fundamental mode of oscillation of the cavity resonator of Fig. 1 is approximately 212 megacycles corresponding to a wavelength of about 141.4 cm. The wavelength corresponding to the fundamental mode of oscillation is determined by the formula $\sqrt{2}$ multiplied by the length of one side of the square, in this case $\sqrt{2}\times 100$. The height h of the cavity resonator of Fig. 1 is here considered to be immaterial, provided that it is sufficient to prevent breakdown of the dielectric within the resonator due to excessive voltage. It is assumed in this particular case that the dielectric is air, although it should be understood that other gaseous dielectrics may also be employed. The magnetic field configuration for the cavity resonator of Fig. 1 for the type of oscillation under consideration is shown in Fig. 1*b*, which represents a plan view of the resonator of Fig. 1. Fig. 1*c* graphically illustrates the magnetic field and the electric field distributions of the cavity resonator as seen through a cross section through the center of the resonator along the line *c*—*c*. The electric intensity or electric vector, so to speak, is represented by the reference letter E, while the magnetic intensity or the magnetic vector is represented by the reference letter H. The current density along the top and bottom surfaces in the resonator is distributed in accordance with the H curve, while the voltage between the top and bottom of the cavity resonator is distributed in accordance with the E curve.

In addition to the fundamental mode of oscillation corresponding to a frequency of 212 megacycles, there will be found in the resonator of Fig. 1 other natural modes at all harmonics of this frequency. Moreover, there will also be found besides the harmonic mode a number of other modes whose frequencies are not in harmonic relation with the fundamental mode. For the particular cavity resonator of Fig. 1 having a square cross sectional area, there is also a mode corresponding to a wavelength of 89.5 cm., and which has a natural frequency of 335 megacycles. This wavelength is obtained from the formula

$$\frac{2}{\sqrt{5}}\times l$$

(where l is equal to one side of the square). In this case this formula

$$\frac{2}{\sqrt{5}}\times l$$

becomes

$$\frac{2}{\sqrt{5}}\times 100=89.5 \text{ cm.}$$

For this natural frequency of 335 megacycles, there are three magnetic field configurations which are shown in Figs. 1*d*, 1*e*, and 1*f*, these figures indicating plan views of the cavity resonator of Fig. 1 and illustrating three ways in which the cavity resonator can oscillate at this particular frequency (335 mc.), depending upon how the resonator is excited. The dash lines n, n' and n'' in these last three diagrams indicate the nodal lines for the electric force within the cavity resonator. It should be understood at this time that the conducting square sides of the cavity resonator or the boundary, so to speak, sustain no electric force. The configuration of Fig. 1*f* is the resultant of a super-positioning of the two field configurations of Figs. 1*d* and 1*e*. Putting it in other words, the resultant magnetic field configuration of Fig. 1*f* is the equivalent of a cavity resonator of Fig. 1 oscillating at the same time in accordance with both of the magnetic field configurations of Figs. 1*d* and 1*e*.

In accordance with one embodiment of the present invention, the cavity resonator of Fig. 1 is modified somewhat from its square cross section, and made to have unequal length sides having dimensions a and b which may, for the sake of illustration, be assumed as 95 cm. and 105 cm., respectively. A modified cavity resonator in accordance with the invention is shown in perspective in Fig. 2. Figs. 2*a* and 2*b* show top and side views, respectively, of the resonator of Fig. 2. By exciting the resonator of Fig. 2 at or near one corner D by means of a loop K, extending within the interior of the resonator over a small distance and coupled to a suitable source of oscillations, the cavity resonator of Fig. 2 is made to have two natural frequencies of 335 megacycles $\pm 3\%$, rather than the single 335 megacycle mode which was obtained with the square cavity resonator of Fig. 1. By providing the cavity resonator of Fig. 2 with a suitable utilization circuit, constituted by way of example by the output loop M located at the diagonally opposite corner to the input loop K and loaded by means of a resistance R, the cavity resonator is made to have a band pass filter characteristic equivalent to that of a pair of conventional coupled circuits with the same natural frequency. Of course, there also exists a fundamental mode of oscillation of about 212 megacycles and infinitely many higher order modes of oscillation.

Figs. 3 and 3*a* indicate the magnetic field configurations for the two natural frequencies of 335 megacycles $\pm 3\%$. The wavelengths corresponding to these two natural frequencies of oscillation, corresponding to the modes in which I am particularly interested here for the rectangular tank of Fig. 2, are determined by the following formulae:

$$\lambda_1=\frac{2ab}{\sqrt{4a^2+b^2}} \tag{1}$$

$$\lambda_2=\frac{2ab}{\sqrt{a^2+4b^2}} \tag{2}$$

in which λ_1 and λ_2 are the natural wavelengths, and a and b are the lengths of the two sides of the rectangular cavity resonator of Fig. 2. These formulae for λ_1 and λ_2 have been worked out from the solution of the partial differential equation of wave motion satisfying Maxwell's equations, and employing rectangular coordinates because of the rectangular shape of the cavity resonator.

Fig. 4 graphically illustrates the resonant characteristics of the cavity resonator of Fig. 2, plotted as a function of frequency in megacycles per second. It should be observed that at a frequency of 335 megacycles minus 3%, there is a resonance peak indicated at point P which corresponds to the magnetic field configuration of Fig. 3, while at a frequency of 335 megacycles plus 3%, there is another resonance peak P' which corresponds to the other magnetic field configuration of Fig. 3*a*. It should also be noted that at around a mid frequency of 540 and a mid frequency of about 670 and also at a mid frequency of about 750 there are other pairs of resonant peaks which combine to give a band pass characteristic. At approximately 212 and 425 and 636 megacycles there are single resonance peaks corresponding to the fundamental mode of oscillation and its second and third harmonics, with which we are not concerned here.

Fig. 4*a* is somewhat like Fig. 4, except that it graphically illustrates the resonance curves as a function of wavelength measured in centimeters. It should be noted that the mid wavelength of 89.5 centimeters corresponds to the mid frequency of 335 megacycles, shown in Fig. 4.

In proceeding to construct a tank circuit of the type shown in Fig. 2 in accordance with the present invention, the band of frequencies to be passed by the coupling circuit of the invention will, of course, be known. For most practical purposes, we may assume the band width of the cavity resonator filter or coupling circuit to be about 150% of the difference between the two natural frequencies. Hence, by substituting the two natural frequencies in the above mentioned Formulae 1 and 2 for λ_1 and λ_2, we can obtain the dimensions of the cavity resonator of the invention.

The same general principles which have been discussed above apply to elliptic cylinder resonators which constitute another embodiment of the present invention, it being understood, of course, that different formulae apply to the elliptic resonator.

Fig. 5 shows a cylindrical cavity resonator having an ellipse as a cross section, in accordance with another embodiment of the present invention.

Figs. 5*a* and 5*b* show the magnetic field configurations for the elliptic cylinder tank of Fig. 5 when oscillating at the two modes of oscillation with which the present invention is particularly concerned.

In Fig. 5*a* the major axis of the ellipse is a voltage node, as indicated by the dash lines n_3. In Fig. 5*b* the minor axis of the ellipse becomes the voltage nodal line n_4. The input and output coupling loops are located at opposite sides of the tank or cavity resonator at positions half way between the major and minor axes and are labeled K and M, respectiveley. The mean or mid frequency f_m of the double mode of oscillation is given approximately by the formulae

$$J_1\left(\frac{\pi f_m d}{c}\right)=0$$

in which J_1 is the first order Bessel function, d is the mean diameter of the ellipse in centimeters, and c the velocity of light in centimeters per second. From this relation the mean or mid frequency f_m is equal to

$$\frac{3.66.10^{10}}{d}$$

cycles per second, corresponding to a wavelength of $0.814d$ centimeters. The exact determination of the two natural frequencies of the pair of modes of oscillation is considerably involved, inasmuch as it includes the evaluation of Mathieu functions which are expressed as an infinite series of Bessel functions, but if Δ is the difference between the major diameter and the mean diameter of the ellipse, the two natural frequencies are approximately equal to

$$f_m\left(1\pm\frac{\Delta}{2d}\right)$$

The precise mathematical equations necessary to obtain the exact dimensions of the ellipse will not be given here, in view of the extremely involved and complicated nature thereof. However, these exact dimensions for the elliptic tank of the present invention can be obtained from the solution of the partial differential equation of wave motion satisfying Maxwell's equations and employing an orthogonal system of coordinates, wherein the coordinant surfaces are confocal elliptic and hyperbolic cylinders. The ordinary differential equations resulting from this method of procedure are of the so-called Mathieu type, as described in the book "Modern Analysis" by Whitaker and Watson, chapter XIX, published 1935, by Cambridge University Press, London. Graphs of the cyclic Mathieu function are shown in Jahne and Emde "Tables of Functions," published 1938, by B. G. Teubner, Leipszig and Berlin. Tables of the Mathieu function of the radial type which are necessary in determining the exact dimensions of the elliptic cylinder have been worked out by the Physics Department of the Massachusetts Institute of Technology, Cambridge, Massachusetts.

The laws governing the oscillation of an elliptic cylinder tank may be further explained by considering a resonator whose cross section is an ellipse having major and minor semi-axes of 110 and 90 centimeters, respectively. This is equivalent to an eccentricity of 0.575. In order to obtain a solution of the partial differential equation of wave motion consistent with Maxwell's laws and satisfying the boundary conditions of this problem, it is necessary to divide the space within the tank into an imaginary system of confocal, elliptic and hyperbodic cylinders. In this way we obtain an orthogonal system of coordinates and can separate the partial differential equation into two ordinary differential equations. We use the coordinates ψ, ϕ, and Z as defined by the relations

$$X=a\cosh\psi\cos\phi$$
$$Y=a\sinh\psi\sin\phi$$
$$Z=Z$$

where a is the semi-focal distance.

The system of confocal ellipses and hyperbolas for an elliptic tank having dimensions 110 cm. by 90 cm., and a semi-focal distance of 63.2 cm., is shown in Fig. 6. The differential equations resulting from this process are of the Mathieu type as described in Whitaker and Watson "Modern Analysis." The mathematical theory is quite involved and will not be discussed here. It is necessary to find the natural frequencies by successive approximations. For this particular shape of elliptic tank the two natural frequencies corresponding to nodal lines on the minor and major axes respectively are shown in Fig. 7*a*. Fig. 7*a* also shows the natural wavelength for a circular tank having a radius equal to the minor axis of the ellipse, a similar tank having a radius equal to the major axis of the ellipse, and also one having a radius equal to the mean radius of the ellipse. It is seen that the mean of the two natural wavelengths of the elliptic cylinder is substantially different than the natural wavelength for a circular tank of the same mean radius. Consequently, the rule previously stated for determining the mean wavelength is seen to be only a very rough approximation. Fig. 7 shows the dimensions referred to in Fig. 7*a*.

In Fig. 8 is shown the distribution of voltage along the major axis of the ellipse when the tank is oscillating so that the minor axis is a nodal line. Fig. 8*a* shows the voltage distribution along the hyperbola designated by $\phi=45°$, when the tank is so oscillating that the minor axis is a nodal line. This curve serves to bring out the important fact concerning the oscillation of an elliptic tank that the focal points have no particular physical significance. It will be noted that the maximum voltage is not at a position corresponding to the focus and that nothing peculiar happens to the voltage distribution curve at the point corresponding to the focus.

Figs. 9 and 9a show the voltage distributions along the major and minor axes, respectively, as a function of the distance from the center in centimeters, when an elliptic tank (110 cm. by 90 cm.) is oscillating at its fundamental mode. Although this mode is of no particular interest in connection with this invention, this voltage distribution curve is of interest in showing again that the focal positions have no particular significance with respect to the oscillation taking place.

Fig. 10 shows the way in which the natural frequencies vary with the eccentricity of an elliptic tank both for the fundamental and split modes. The natural wavelengths are given in terms of the major axis of the ellipse. The formulas for voltage distribution when the eccentricity is 0.575 are as follows:

First: For the fundamental mode

$$E=\sqrt{\frac{\pi}{2}}\{1.378\ J_0(1.538\cosh\psi)+0.392\ J_2(1.538\cosh\psi)+0.014\ J_4(1.538\cosh\psi)+\ldots\ldots\}\times\{1.378-0.392\cos 2\phi+0.014\cos 4\phi-+\ldots\ldots\} \tag{3}$$

Second: Split mode with node on minor axis

$$E=\sqrt{\frac{\pi}{2}}\{1.235\ J_1(2.34\cosh\psi)+0.248\ J_3(2.34\cosh\psi)+0.015\ J_5(2.34\cosh\psi)+\ldots\ldots\}\times\{1.235\cos\phi-0.248\cos 3\phi+0.015\cos 5\phi-+\ldots\} \tag{4}$$

Third: Split mode when node on major axis

$$E=\sqrt{\frac{\pi}{2}}(\tanh\psi)\{1.830\ J_1(2.585\cosh\psi)+0.935\ J_3(2.585\cosh\psi)+0.101\ J_5(2.585\cosh\psi)+\ldots\ldots\}\times\{1.830\sin\phi-0.312\sin 3\phi+0.0202\sin 5\phi-+\ldots\} \tag{5}$$

In these Formulas 3, 4 and 5, J_n is the nth order Bessel function of the first kind, and the first bracket therein is an infinite series in which each term is a Bessel function of $2\pi/\lambda$ times the semi-focal distance multiplied by the hyperbolic cosine of the elliptic coordinate. This is the Mathieu function determining the variation of voltage with ψ. The coefficients in the terms of this series hold only for the particular ellipse assumed and are in general functions of wavelength and focal distance. The second bracket is a Fourier series and is the Mathieu function showing the variation of voltage with the coordinate ϕ. The coefficients in this series also depend upon the wavelength and semi-focal distance and are correct only for the particular dimensions assumed here.

Fig. 11 is an elevation view, in section, and Fig. 11a a plan view of Fig. 11, of a circuit illustrating a way in which either the rectangular or elliptical cavity resonator of the invention, described above in connection with Figs. 2 and 5, may be used in connection with electron discharge devices. Although a rectangular tank or cavity resonator has been indicated in Fig. 11, the elliptical form can be used in identically the same manner.

Referring to Fig. 11, there is shown a rectangular cavity resonator **10**, constructed in accordance with the invention, which is provided with an aperture at a high voltage position of the resonator when it is oscillating at the mean frequency of the desired band, and which is penetrated by an inductive output tube **11**. The location of the aperture through which the inductive output tube **11** passes should be at approximately one-quarter of the distance along the diagonal between the two corners **12** and **13**. If the resonator **10** is made to be an elliptical cylinder, the location is approximately the same, as can be seen from the voltage distribution curves previously discussed in connection with elliptical resonators. The elevation view, in section, of such an elliptical cylinder resonator, in association with an electron discharge device circuit for exciting the same, and an output circuit therefor, is identical with that shown in Fig. 11. The output loop M is located near the corner **13** opposite to the corner **12** nearest the inductive tube **11**, in order to provide working from a lower impedance point. The inductive output tube **11** is merely shown in its essential elements as comprising an electron envelope **14** containing therein a cathode **15**, a control grid **16**, accelerator electrodes **17**, a collector electrode **18**, and a magnetic field coil **19**. Suitable input energy is supplied from an input circuit **20**, in turn coupled to a tuned circuit **21** connected between the cathode and grid. The control grid modulates the electron stream emanating from the cathode when the input circuit **20** is excited. The passage of the modulated electron stream across the aperture of the resonator or tank **10** induces a radio frequency current in the resonator **10**, and since this tank circuit is tuned, a high voltage will be produced across the gap constituted by the aperture. The phase of this voltage at or near resonance will be such as to decelerate electrons traversing the gap during the one-half period of maximum intensity of electron current in the stream. These decelerated electrons are then collected at the low voltage collector **18**. The kinetic energy lost by the electrons is transferred by the resonator or tank **10** into energy of the electromagnetic field within the spaced angle by the tank circuit. This energy is thus transferred to the useful load by means of the output coupling loop M. The electron stream is focussed into a beam by combined effects of the magnetic and electric fields. The magnetic field coil **19** is provided to aid in focussing the beam, while the accelerator electrodes accelerate and also serve to some extent to focus the electron beam. For a more complete description of inductive output electron discharge devices of this type, reference is made to an article by Dr. Haeff and Mr. Nergaard, entitled "Wide band inductive output amplifier," published in the Proceedings of the I. R. E., March, 1940, and also to copending applications Serial Nos. 326,170 and 296,045, filed respectively March 27, 1940, and September 22, 1939, by Fred H. Kroger.

Fig. 12 illustrates the use of a cavity resonator in accordance with the invention, one as an interstage coupling device and another as an output device, in connection with a pair of inductive output type electron discharge devices,

Fig. 12*a* is a plan view of Fig. 12 showing more clearly the relative positions of the cavity resonators. Here again as in Fig. 11, although a rectangular cavity resonator has been shown, the elliptical cylinder form can be used in the same manner.

Referring to Fig. 12, there is shown in side elevation, a cavity resonator 22 used as an interstage coupling circuit between a pair of inductive output electron discharge devices 11, 11. One of these inductive output electron discharge devices 11 serves as the input circuit for the output cavity resonator 23, in accordance with the invention. Inductive tubes 11, 11 are located at high voltage points in the interstage resonator 22 which for a rectangular resonator are at one-quarter and three-quarters of the distance along a diagonal. The location of the inductor tube 11 in the output resonator 23 is also at a high voltage point, and the output loop M usually at a low voltage point. Of course, if the output circuit is to work into a high impedance, then the loop M may be located also at a high voltage point.

Although Figs. 11 and 12 have been show in connection with electron discharge devices of the inductive output type, it should be distinctly understood that the resonators of the invention are not limited in their use solely to this type of electron discharge device, since they can also be used with the conventional type of vacuum tubes wherever there is need for the tuned circuits of applicant's invention.

It will thus be seen that I have been able to construct a cavity resonator which has two natural frequencies of oscillations differing by a predetermined percentage and I have achieved this by departing from the symmetry of a square cross section, in accordance with one embodiment of the invention, and by departing from the symmetry of a circle in another embodiment of the invention.

Although the principles of the invention have been explained in connection with two specific forms of cavity resonators, such as the rectangular cross section and the elliptic cross section, it should be distinctly understood that the invention is not limited to these two forms but that other forms of cavity resonators may also be used which depart from the square and cross sectional resonators.

The resonator constituting the coupling circuit of the present invention may be used wherever a filter can be used and for substantially the same purpose, such as between stages of a receiver or a transmitter.

What is claimed is:

1. A cavity resonator comprising a hollow closed electrically conducting surface in the shape of a hollow rectangular prism having unequal length sides and having closed ends and having a desired band pass characteristic, and means for exciting said resonator in its interior at such a location as to produce therein two natural frequencies of oscillation which are relatively close to each other and differ by a predetermined percentage.

2. A cavity resonator comprising a hollow closed electrically conducting surface in the shape of a hollow elliptic cylinder having closed ends and having a desired band pass characteristic, and means for exciting said resonator in its interior at such a location as to produce therein two natural frequencies of oscillation which are relatively close to each other and differ by a predetermined percentage.

3. A cavity resonator comprising a hollow closed electrically conducting surface whose principal axes at right angles to each other and perpendicular to the electric vector and passing through the center of the resonator are unequal, said resonator having a desired band pass characteristic, and means for exciting said resonator in its interior at such a location as to produce therein two natural frequencies of oscillation which are relatively close to each other and differ by a predetermined percentage.

4. A coupling circuit comprising a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, the cavity resonator being in the shape of a hollow elliptic cylinder having closed ends, an input circuit extending into the interior of said cavity resonator at a location substantially half way between the major and minor axis of said elliptic cylinder and an output circuit substantially diagonally opposite said input circuit.

5. A cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, the cavity resonator being in the shape of a hollow rectangular prism having unequal length sides and having closed ends, an input circuit extending into the interior of said resonator at one apex of the rectangular prism, and an output circuit located substantially diagonally opposite said input circuit.

6. The combination with a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, of means for exciting said resonator at a high voltage position when it is oscillating at the mean frequency of the desired band.

7. The combination with a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, of an electron discharge device for exciting said resonator, said electron discharge device being located at a high voltage position of said resonator approximately one-quarter of the distance along a diagonal.

8. The combination with a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, of means for exciting said resonator at a high voltage position when it is oscillating at the mean frequency of the desired band, and an output circuit located at a low voltage position of said resonator.

9. The combination with a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, of an electron discharge device for exciting said resonator, said electron discharge device being located at a high voltage position of said resonator approximately one-quarter of the

distance along a diagonal, and an output circuit also located along said diagonal but near the opposite end of said diagonal.

10. A band pass coupling circuit comprising a rectangular cavity resonator whose dimensions in the cross section perpendicular to the electric vector depart from the symmetry of a square by a predetermined amount, and means for exciting said resonator to produce therewithin two natural frequencies of oscillation which are relatively close to each other and differ by a predetermined percentage.

11. A band pass coupling circuit comprising a rectangular cavity resonator whose transverse dimensions perpendicular to the electric field are unequal by a predetermined amount, an input circuit comprising a loop extending into the interior of said resonator at one corner for exciting said resonator to produce therein two natural frequencies of oscillation differing by a predetermined percentage, and an output circuit comprising a loop extending into the interior of said resonator at the corner opposite said one corner.

12. A band pass coupling circuit comprising a cavity resonator whose transverse dimensions perpendicular to the electric field are unequal by a predetermined amount, and means for exciting said resonator in the interior thereof at such a location that there are produced within said resonator a plurality of natural frequencies of oscillation which are relatively close to each other and differ by a predetermined percentage.

13. A high frequency cavity resonator comprising a hollow closed electrically conducting surface having different principal dimensions, and means for exciting said resonator in its interior in such manner that there is caused to exist in said resonator a plurality of natural frequencies of oscillation which are relatively close to each other.

14. A coupling circuit comprising a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, the cavity resonator being in the shape of a hollow elliptic cylinder having closed ends, an input circuit comprising a loop extending into the interior of said cavity resonator at a location substantially half way between the major and minor axes of said elliptical cylinder and an output circuit also comprising a loop substantially diagonally opposite said input circuit.

15. A filter circuit comprising a cavity resonator in the form of an elliptic cylinder having closed ends, and an input circuit for said resonator including means for projecting a modulated electron stream through the interior of said resonator from one end to the other at a location substantially half way between major and minor axes of said resonator.

16. A filter circuit comprising a cavity resonator in the form of an elliptic cylinder having closed ends, and an input circuit for said resonator including means for projecting a modulated electron stream through the interior of said resonator from one end to the other at a location substantially half way between major and minor axes of said resonator, and an output circuit extending into the interior of said resonator at a location substantially diagonally opposite said electron stream.

17. The combination with a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, of an electron discharge device for exciting said resonator, said electron discharge device being located at a high voltage position of said resonator approximately one-quarter of the distance along a diagonal, and an output circuit in the form of an electron discharge device also located along said diagonal but three-quarters of the distance along said diagonal as measured from the same point.

18. A band pass coupling circuit comprising a rectangular cavity resonator whose dimensions in the cross section perpendicular to the electric vector depart from the symmetry of a square by a predetermined amount, and means for exciting said resonator to produce therewithin two natural frequencies of oscillation corresponding to wavelengths λ_1 and λ_2 which differ from each other by a predetermined percentage, said two wavelengths satisfying the equations

$$\lambda_1=\frac{2ab}{\sqrt{4a^2+b^2}}$$

and

$$\lambda_2=\frac{2ab}{\sqrt{a^2+4b^2}}$$

where a and b are the lengths of the two sides of the rectangular cavity resonator.

19. A band pass coupling circuit comprising an elliptical cylinder cavity resonator, and means for exciting said resonator in its interior at such a location as to produce therein two natural frequencies of oscillation approximately equal to

$$f_m\left(1\pm\frac{\Delta}{2d}\right)$$

where f_m is the mid-frequency of the band, Δ the difference between the major diameter and the mean diameter of the ellipse, and d is the mean diameter of the ellipse.

20. The combination with a cavity resonator comprising a hollow closed electrically conducting surface having a desired band pass characteristic and possessing two natural frequencies of oscillation differing by a predetermined percentage, of an electron discharge device for exciting said resonator by means of a stream of electrons passing through the interior of said resonator, said electron discharge device being located at a high voltage position of said resonator, and an output circuit in the form of a loop of conductor located in the interior of said resonator at a low voltage position.

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