

March 29, 1949.

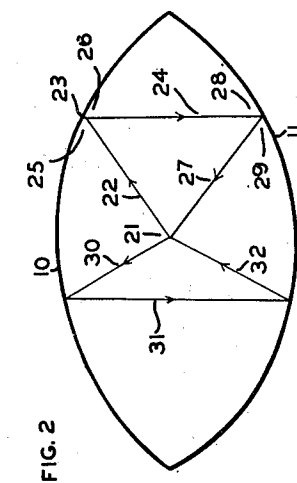
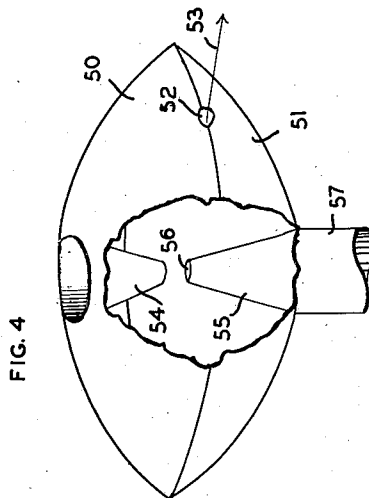
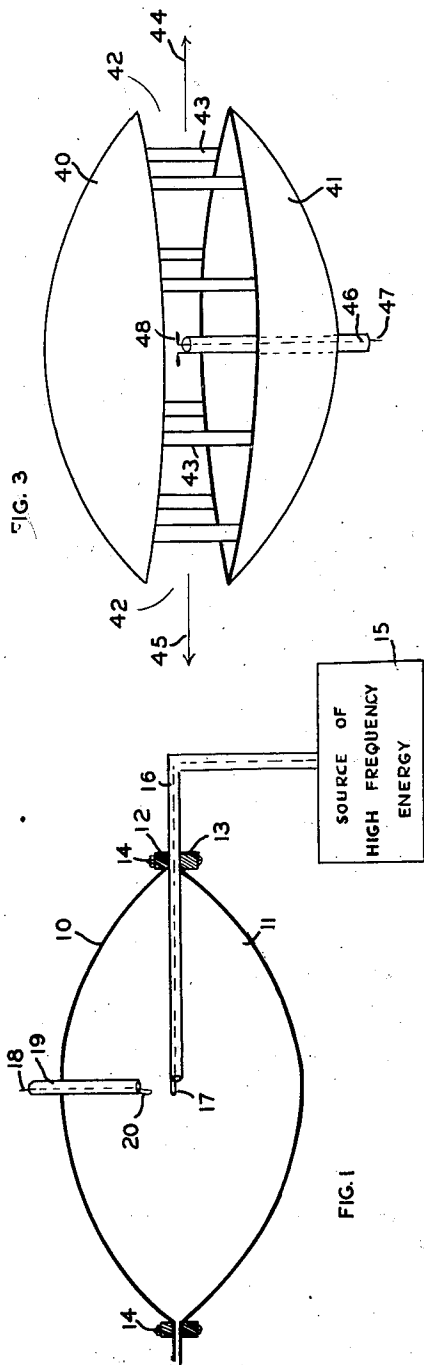
N. W. ARAM

2,465,416

RESONANT CIRCUIT AND RADIATOR

Filed Oct. 2, 1943

5 Sheets-Sheet 1



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RESONANT CIRCUIT AND RADIATOR

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5 Sheets-Sheet 2

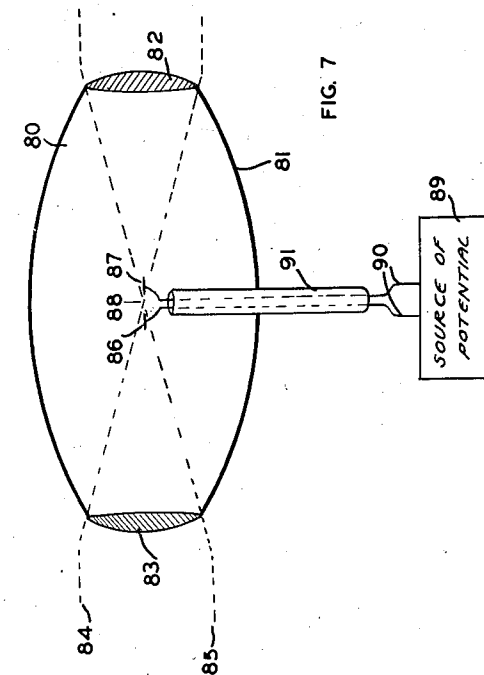


FIG. 7

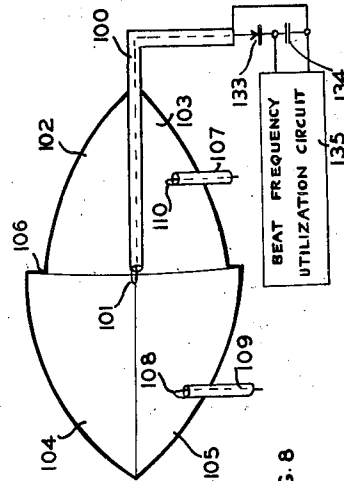


FIG. 8

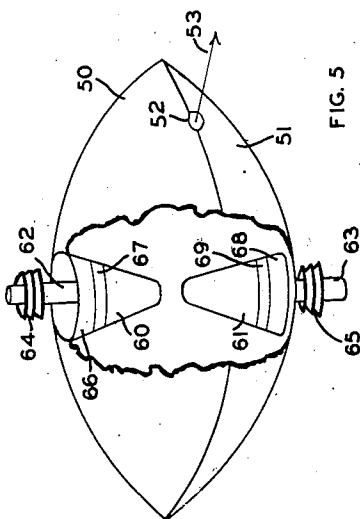


FIG. 5

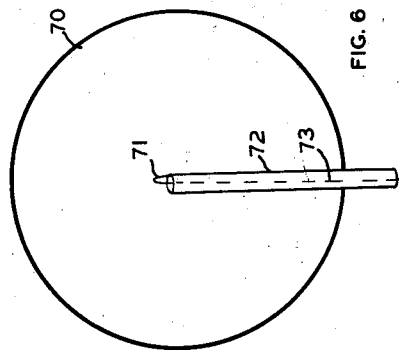


FIG. 6

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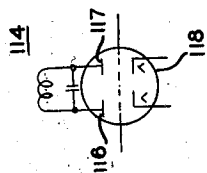
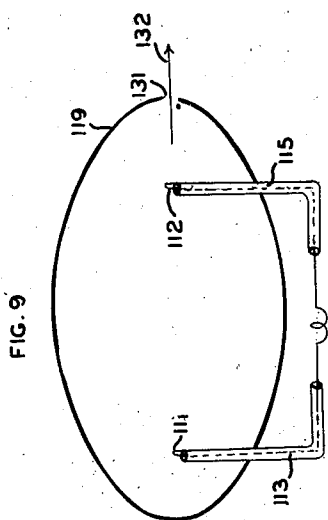
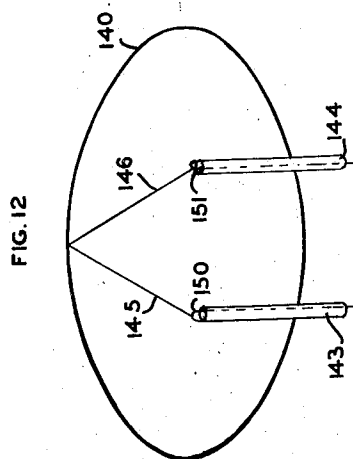
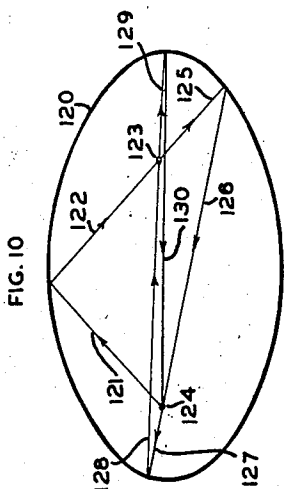
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RESONANT CIRCUIT AND RADIATOR

Filed Oct. 2, 1943

5 Sheets-Sheet 3



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RESONANT CIRCUIT AND RADIATOR

Filed Oct. 2, 1943

5 Sheets-Sheet 4

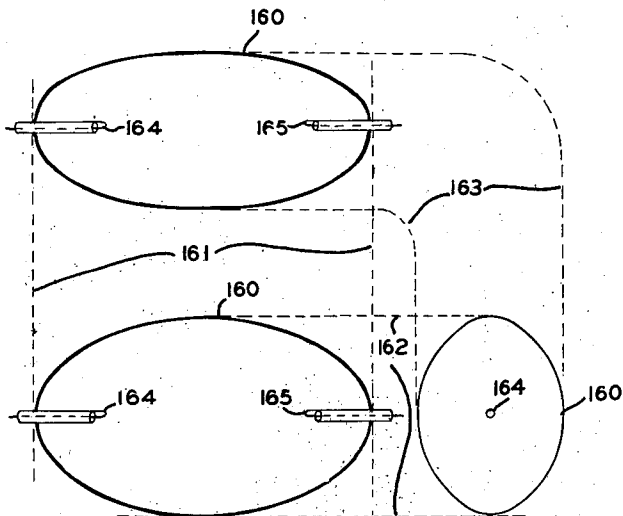


FIG. 13

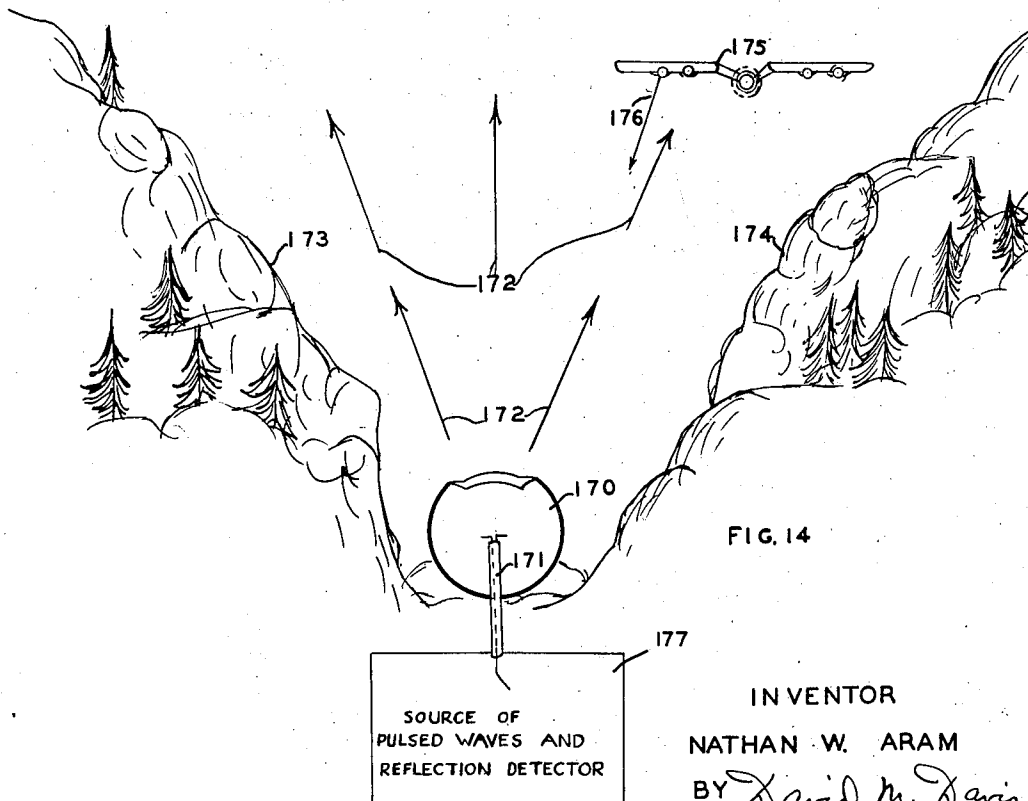


FIG. 14

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FIG. 15

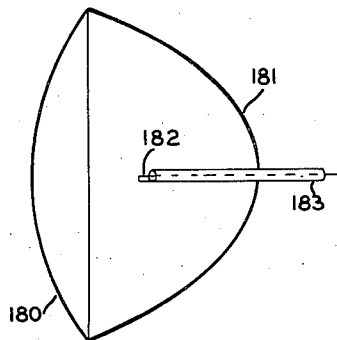
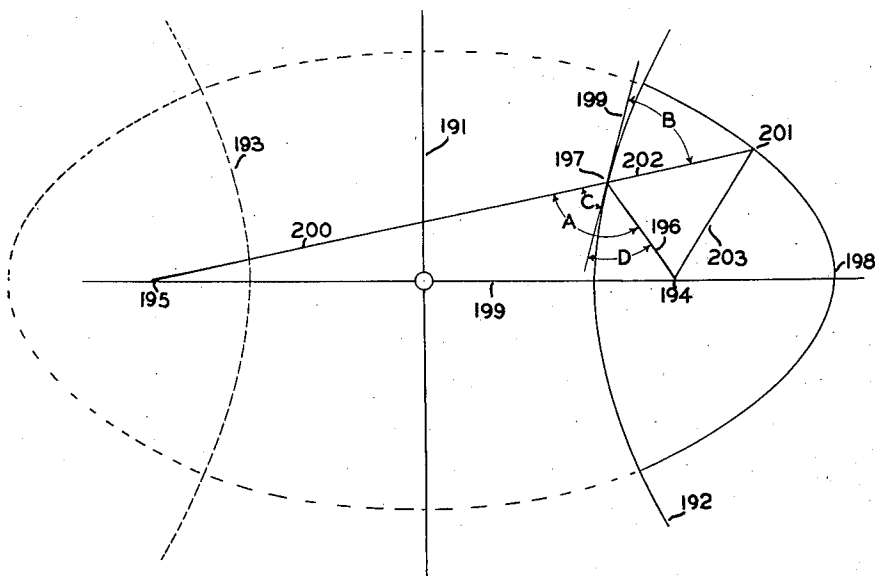


FIG. 16



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UNITED STATES PATENT OFFICE

2,465,416

RESONANT CIRCUIT AND RADIATOR

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Application October 2, 1943, Serial No. 504,717

6 Claims. (Cl. 250—33.65)

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This invention relates to electric translating systems and more particularly to such systems which include a resonant cavity.

High frequency radio signals, whose wave length is of the order of five meters or less, may be conveniently translated through resonant cavities. Any suitable cavity having conductive boundaries is space resonant. Such cavities are usually made cylindrical, toroidal or rectangular and are usually resonant in complex modes and at many frequencies.

It is an object of my invention to provide a new and improved electric translating system comprising a cavity resonant in a simple mode, that is, one in which resonance of a single type is established in a harmonic series of frequencies. In this type of cavity, the resonant frequency is a linear function of wavelength. That is, the larger the cavity, the greater is the wavelength.

It is also an object of my invention to provide a new and improved electric translating system which is space resonant in such a way that a reinforcement of energy substantially at a focal point within the space is produced.

It is a corollary object of my invention to provide such a new and improved electric translating system in which external circuits may be coupled to the system at such a focal point.

Still another object of my invention is to provide such a new and improved energy radiator which radiates energy into space in desired directions.

It is a further object of my invention to provide a new and improved resonant cavity electric translating device which may be readily designed with simple parameters so that, upon construction, it is resonant at a predetermined frequency, and its resonance is substantially of a single type in a harmonic series of frequencies.

It is an additional object of my invention to provide a new and improved space resonant translating device especially suitable for excitation by a wide variety of exciting means.

It is still another object of my invention to provide a new and improved form of space-resonant cavity having an input and an output and one capable of providing highly efficient filtering action between such input and output.

The features of my invention which I believe to be novel, are set forth with particularity in the appended claims. My invention itself, both as to its organization and manner of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

Figure 1 illustrates one embodiment of my invention;

Figure 2 illustrates schematically a principle of operation of my invention;

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Figures 3 through 9 illustrate alternative embodiments of my invention;

Figure 10 illustrates schematically a principle of operation of the embodiment of Figure 9;

Figures 11 through 15 illustrate still other embodiments of my invention; and

Figure 16 illustrates certain characteristics of an embodiment of Figure 15.

In Fig. 1 a space-resonant cavity is formed by a pair of conductive confocal paraboloidal shells 10 and 11 with their concave sides facing each other. The two shells 10 and 11 are clamped together at their edges by rings 12 and 13 held together by bolts 14. The depth of each of the paraboloidal shells 10 and 11, measured from a plane passing between the two shells perpendicular to their common axis to the deepest point of each shell, is equal to the focal distance of the paraboloid defining the shell. That is, the focus of each one of the paraboloidal shells 10 and 11 coincides with the focus of the other shell.

Energy is transferred from a suitable source 15 into the cavity bounded by the paraboloidal shells 10 and 11 through a coaxial transmission line including an inner conductor and an outer cylindrical concentric conductor 16, the terminals of the source 15 being connected to the inner and outer conductors. The coaxial line including the inner conductor and outer conductor 16 is terminated by a small loop 17 at the common focus of the two paraboloidal shells 10 and 11, said inner and outer conductors each being connected to opposite terminals of loop 17.

Energy may be abstracted from the space bounded by the shells 10 and 11 through a second coaxial transmission line including an inner conductor 18 and an outer conductor 19, terminated at any point within the shell by a small loop 20.

In Fig. 2 there is illustrated graphically the manner in which space resonance in a simple mode is produced between the two paraboloidal shells 10 and 11, these shells being identical with those illustrated in Figure 1 and being given like reference characters. The point 21, which is the confocal point at which the loop 17 of Figure 1 is placed, is the focus for each of the parabolas 10 and 11. It is a property of a parabola that a line drawn from its focus to any point along the parabola intersects the parabola at the same angle as the parabola is cut at the same point by another line parallel to the axis of the parabola.

A ray 22 of energy is illustrated in Figure 2 proceeding from the focal point 21 to impinge upon parabola 10 at a point 23. By well known laws of reflection this ray 22 is reflected at the point 23 from parabola 10 in a direction illustrated by line 24 parallel to the axis of parabola 10; the angle 25 of incidence and the angle 26 of reflection being equal.

The two axes of the two parabolas 10 and 11, as

pointed out previously in connection with the paraboloidal shells 10 and 11 of Figure 1, are common to each other so that the ray 24 is parallel not only to the axis of the parabola 10 but also to the axis of the parabola 11. Since the axes and focal points 21 of the parabolas 10 and 11 coincide, the ray 24, when it strikes parabola 11, is reflected as a ray 27 toward the focal point 21, the angle 28 of incidence and angle 29 of reflection being equal.

This process of double reflection and return to the focus takes place for any energy ray emitted from the focus 21. A ray 30 emitted from the focus 21 in a different direction from the ray 22 is reflected from parabola 10 as a ray 31 parallel to the axes of the parabolas 10 and 11 and is reflected from parabola 11 as a ray 32, which passes through the focus 21. No matter in what direction a ray is emitted from the focus 21, after being reflected from each of the parabolas 10 and 11 in succession, it returns to the focus 21.

The length of path traveled by a ray of energy emitted in any direction from the focus 21 is always the same when it first returns to the focus 21. That is, the length of path traveled by a ray of energy following lines 22, 24 and 27 in a single circuit from the focus 21 and back to the focus 21 is the same as the length of path traveled by a ray of energy in a single circuit along the lines 30, 31 and 32.

It may be proved mathematically that such paths, from focus 21 through a reflection from each of the parabolas 10 and 11 back to the focus 21, are always of the same length. If it be assumed that the parabola 10 be defined by the equation:

$$y^2 = 4ax \quad (1)$$

then the focus 21 is at a distance a from the point on parabola 10 at which it is cut by its axis. The perpendicular distance from any point x, y , on parabola 10 to a line through focus 21 perpendicular to the axis of the parabola 10 is

$$a - x \quad (2)$$

or, expressed in terms of y ,

$$a - \frac{y^2}{4a} \quad (3)$$

The distance from focus 21 to the point x, y (the coordinates of point 21 being $a, 0$) is

$$\sqrt{(a-x)^2 + y^2} \quad (4)$$

or expressed in terms of y :

$$\sqrt{\left(a - \frac{y^2}{4a}\right)^2 + y^2} \quad (5)$$

The sum of these two distances expressed by Equations 3 and 5, from the point $a, 0$ to point x, y , and from point x, y to a line through $a, 0$, perpendicular to the axis of parabola 10 is:

$$a - \frac{y^2}{4a} + \sqrt{\left(a - \frac{y^2}{4a}\right)^2 + y^2} \quad (6)$$

This expression for the total distance from focus 21 to a point x, y along parabola 10 and then along a line parallel to the axis of the parabola to a line through focus 21 perpendicular to the axis of parabola 10 may be simplified, and is then found to be:

$$2a \quad (7)$$

This mathematical analysis indicates that the distance along path 22 and half of the length of line 24 is equal to $2a$, or that the distance along paths 22, 24 and 27 is equal to $4a$. In other words, a ray of energy emitted from focus 21 in

any direction travels away from focus 21, is reflected once from each of the parabolas 10 and 11, and returns to focus 21 in phase after having traveled a distance equal to twice the distance between the parabolas 10 and 11 measured along their common axis. Therefore, all rays travel from focus 21 and are reflected once from parabola 10 and once from parabola 11, and return to focus 21 in phase.

The small loop 17 is effective in transferring energy between the end of transmission line 16 and the space surrounding loop 17 through the magnetic component of electromagnetic radiation in the vicinity of loop 17. A dipole may be substituted for loop 17 so that energy is transferred through the electric component of the radiation near the dipole.

For any particular size of parabolas 10 and 11 and with loop 17 or with the substituted dipole, resonance occurs at a harmonic series of frequencies uniquely determined by the reflection path length. When such a resonant condition exists, it is called resonance of a single type.

The loop 17 is made as small as possible with respect to the dimensions of the cavity enclosed by shells 10 and 11. This is preferable in order that energy radiated from loop 17 shall appear to come as nearly from a point source as is possible. Since the loop 17 must necessarily have finite size, energy of frequencies within a finite band of frequencies centered about a mean frequency determined by the ideal point source resonator produces resonance within the space bounded by shells 10 and 11. This finite band of frequencies has a width measured in frequency which width is a function of the size of loop 17 with respect to the size of the space bounded by shells 10 and 11. That is, as loop 17 is made smaller, the finite band of frequencies within which resonance occurs is smaller.

In order to make the relative size of loop 17 small, so as to obtain a cavity bounded by shells 10 and 11 resonant at a very narrow range of frequency, it may be desirable to make that space fundamentally resonant at a much lower frequency which frequency is a sub-harmonic of the desired frequency. It may be desirable to make line 16 an integral number of half waves in length, in order that impedance of the line 16 shall not substantially affect the resonant frequency of the space bounded by shells 10 and 11.

The phenomenon of space resonance by alternate concentration and dispersion of oscillatory energy from a focal point in a space may be utilized in several very useful ways. In Fig. 3 a pair of paraboloidal shells 40 and 41 have their concave sides facing each other and are spaced apart with their deepest points, measured along their common axis, at a distance apart equal to twice the focal distance of either one of the paraboloidal shells 40 or 41. The two shells are identical and their focal distances are correspondingly identical. These two shells 40 and 41 are identical with shells 10 and 11 of Fig. 1 except that they do not meet at their rims, so that a gap 42 is left open all of the way around the two shells 40 and 41. Proper spacing between the two shells 40 and 41 is maintained by supporting members 43, which are preferably formed of such material and so spaced that they provide minimum interference with energy radiated from within the shells 40 and 41 to external space. Radiation of such energy from within the shells 40 and 41 to external space is indicated by arrows 44 and 45.

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Oscillatory energy at a frequency such that space resonance is produced within the shells 40 and 41 is transferred from a generator, not shown, to the common focus of the shells 40 and 41 through a coaxial transmission line including an external cylindrical conductor 46, and a concentric inner conductor 47. This transmission line comprising conductors 46 and 47 is terminated at the focus of the shells 40 and 41 in a short dipole 48, of which one arm is connected to inner conductor 47 and the other arm to the outer conductor 46. The length of the arms of dipole 48 may, but need not, be an integral fractional part or multiple of the wave length of the energy radiated into shells 40 and 41.

Space resonance is produced between the shells 40 and 41 by reason of the fact that energy radiated from dipole 48 in directions intercepting either of the shells 40 and 41 is reflected once from each of the shells 40 and 41 and returned to dipole 48. Radiation from between the shells 40 and 41 passes out through the gap 42, not only by reason of radiation of energy directly from the dipole 48 but also by reason of energy reflected back to dipole 48 from shells 40 and 41, such reflected energy being thereafter radiated by the dipole 48 through gap 42.

Energy thus radiated from the gap 42 between the shells 40 and 41 is concentrated in directions from the dipole 48 through the gap 42. If the gap 42 be made quite small, this concentration of energy can be made great. With the structure shown, in which the gap 42 extends completely around the shells 40 and 41, energy is radiated substantially in a plane. If one of the shells 40 or 41 be cut off more than the other shell, so that the gap 42 faces up or down, energy is correspondingly radiated in such upward or downward direction.

Paraboloidal shells, such as shells 10 and 11 in Figure 1, or shells 40 and 41 in Figure 3, are separated by twice their focal distance measured along their common axis, since they must have a common focus, and, as explained above, this separation bears a direct relation to the resonant frequency of the space enclosed by the shells, so that the configuration of the paraboloidal shells, which is related to their focal distance, bears a definite relationship to the resonant frequency of the space enclosed thereby. It has been found in practice, however, that it is not difficult to shape such paraboloidal shells and space them apart a proper distance so as to be resonant at a desired frequency.

The necessary dimensional accuracy to which shells 10 and 11 must conform is greater as the resonant frequency approaches more closely a single desired frequency as distinct from a band of frequencies. Some mechanical distortion of one or both shells 10 and 11 may be effected to alter over a narrow range the resonant frequency of the space bounded by those shells.

The dipole 48 shown in Figure 3 should have an overall length which is a very small part of a wave length in order that it shall appear substantially as a point source of radiant energy within the space bounded by shells 40 and 41. The mechanism of such radiation is similar to that explained in connection with the loop 17 in Figure 1.

It is desirable that the surge impedance of the transmission line comprising conductors 46 and 47 be substantially matched to the impedance of dipole 48 coupled to the space bounded by shells 40 and 41.

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As with the loop 17, the smaller the dipole 48 is, the sharper is the resonance characteristic of the space bounded by shells 40 and 41 and accordingly the greater is the frequency selectivity.

In Figure 4, paraboloidal shells 50 and 51 have a common focus and a common axis, and oscillatory energy is radiated into the space bounded thereby in a somewhat different manner than is the case with the devices of Figures 1 and 3. The edges of shells 50 and 51 are joined at all points except for a small opening 52 at one point along the perimeter. Oscillatory energy represented by arrow 53 escapes in substantially a single direction through this opening 52. The device in this form therefore affords transmission of oscillatory energy in a highly concentrated beam.

Two truncated cones 54 and 55 provide excitation for the space within shells 50 and 51. Both cones are truncated near their apices, and have the truncated portions facing each other with the base portions centrally affixed respectively in shells 50 and 51. The common axis of the two cones 54 and 55 coincides with the common axis of the shells 50 and 51. The cone 54 may desirably be made hollow, but is entirely closed within the shell 50. The cone 55 is hollow and the truncated end affords an opening 56 adjacent the closed truncated end of the cone 54.

Shells 50 and 51, as well as cones 54 and 55, are made of reflecting material so that they bound the space which is enclosed by them. They may, for example, be made of conducting material, such as metal, or of material having a high dielectric constant. A wave guide or conductive pipe 57 is connected with the base portion of the cone 55, where it is joined to the shell 51, and oscillatory energy within the wave guide 57 is transferred through the cone 55 and out through opening 56 into the space enclosed by shells 50 and 51. The radiator, or cone 55, which narrows down to the small opening 56, provides that oscillatory energy from the wave guide 57 is radiated within the space enclosed by shells 50 and 51 substantially only at the common focus of the shells 50 and 51.

The size of the opening 56 is, as stated, small with respect to the size of shells 50 and 51, but it is also sufficiently large with respect to the wave length of the wave passing therethrough so that undesirably large attenuation does not occur. Similarly, the size of the wave guide or pipe 57 is sufficiently large with respect to the wave length of the wave transmitted therethrough that attenuation of the wave in passing through the pipe is not intolerably large.

When energy is transferred between pipe 57 and the space bounded by shells 50 and 51, resonance of a single type occurs, as previously explained in connection with the previous forms of the invention.

In Figure 5 certain parts of the arrangement are similar to parts of the arrangement shown in Figure 4, and have like reference numerals. A somewhat different form of excitation is provided, the structure in Figure 4 being excited through a wave guide while the structure in Figure 5 is excited from a spark or arc gap. In Figure 5 the spark or arc gap is formed by a pair of cones 60 and 61, whose apices are rounded, the cones being placed with their rounded apices adjacent so that, upon the application of suitably high potentials between the cones 60 and 61, sparks or arcs pass therebetween. Any space current flow may be induced between cones 60 and 61 so long as there are high frequency com-

ponents of that current of frequency comparable to the fundamental frequency of the resonant cavity formed by shells 50 and 51.

The cones 60 and 61 are preferably formed of a metal, such as copper, aluminum or silver, having low resistance to the flow of heat. Each cone is preferably solid and is integrally formed with a conductor of substantial cross-section. Conductor 62 is joined with cone 60 and conductor 63 is joined with cone 61. The conductors 62 and 63 each have a set of flanges or fins numbered respectively 64 and 65, for the better dissipation of heat flowing from the cone out through the conductor.

Each cone is insulated from the conductive shells 50 and 51 by an insulating support. That is, cone 60 is fastened to a hollow truncated conical section 66 by a truncated conical insulating portion 67, the conical section 66 being joined at its base to the shell 50. Similarly, the cone 61 is joined to a conical section 68 by a conical piece of insulation 69, the conical section 68 being joined to the shell 51 at its base.

Since the insulating sections 67 and 69 isolate the shells 50 and 51 from the cones 60 and 61, the shells may be grounded and suitable high potentials may be applied to conductors 62 and 63 for the formation of sparks or arcs between cones 60 and 61. When sparks or arcs containing energy of certain wavelengths are so formed, such high frequency energy is radiated from between the two cones 60 and 61 into the space bounded by the shells 50 and 51, so that energy of those certain wavelengths comparable to the physical size and configuration of the shells 50 and 51 is selectively radiated through the hole 52, as illustrated by the arrow 53.

All forms of the invention illustrated in Figures 1 through 5 have been constructed of that conic section termed a parabola, and are formed of circular paraboloidal surfaces. Other conic sections may be utilized to form surfaces of revolution bounding a space which is resonant in a manner useful in practicing my invention. In fact, other conicoids or second degree tridimensional surfaces may be used, such as confocal hollow conicoids.

In Figure 6, a hollow sphere 70, with a small loop 71 at its center fed by a coaxial transmission line including outer conductor 72 and inner conductor 73 encloses a space resonant in a single mode when excited by energy of a certain frequency transmitted through the line into that space. Energy transmitted through the line to the loop 71 and radiated within the sphere 70 is reflected from the surface of the sphere 70 directly back to the loop 71.

If it be desired that the hollow spheroid 70, loop 71, and transmission line including conductors 72 and 73 act as a two-terminal resonant net-work of very sharp resonance, the loop 71 should be as small as possible in comparison with the dimensions of the sphere 70 in order that the loop shall appear as a point source. On the other hand, if it be desired that the spheroid 70, loop 71, and the line act as a two-terminal band pass filter, the loop 71 may be made larger to obtain the desired band pass characteristics or the shell 70 be made a distorted spheroid. In fact, in all modifications of my invention, the exciting source within the resonant space may be made of such dimension with respect to the dimensions of that space so as to cause the space to act as a band pass filter of desired band pass characteristics.

If desired energy may be extracted from the space bounded by shell 70 by providing a loop extending into that space as shown for example by loop 20 in Fig. 1.

If it be desired, a dipole may be substituted for the loop 71. The dipole is connected to its line in the same manner as dipole 48 in Fig. 3 is connected to lines 46, 47.

In Fig. 7 another method of excitation is shown for a structure similar in certain respects to the structures illustrated in Figures 1 through 5. A pair of paraboloidal conducting shells 80 and 81 are arranged with their concavities facing each other and with common focal points. These two shells 80 and 81 are completely reflecting except in two opposite directions where openings are left for the egress of radiation. These openings are sealed hermetically respectively by covers 82 and 83, which are made of a material substantially transparent to the desired radiation and which may be formed in such a lens shape that radiation tends to pass from the space bounded by the shells 80 and 81 in substantially parallel lines, as indicated by the dotted lines 84 and 85.

Means is provided at the common focal point of the two shells 80 and 81 for creating corona of high intensity in the region of that common focal point. As illustrated, two conducting members 86 and 87 are placed close to the common focal point on either side of it with a gap 88 therebetween within which the corona may be formed when suitable ionizing potential is impressed between the conducting members 86 and 87. Means including a suitable source of potential 89 and conductors 90, passing respectively to the two conducting members 86 and 87 through a shield 91, are provided for the purpose of impressing suitable ionizing potential between the members 86 and 87. The shield 91 is so arranged internally as to provide a hermetic seal through which the conductors 90 pass, so that the space bounded by the shells 80 and 81 is sealed hermetically.

An atmosphere is provided in the space between the shells 80 and 81 of such nature and at such pressure that the potential supplied from source 89 between arms 86 and 87 produces corona of a desired intensity in the gap 88. The formation of corona is attended by the production of high frequency potentials of substantial intensity. Such high frequency corona potentials existing between the members 86 and 87 are accompanied by radiation of energy over a wide band of frequencies in the space bounded by shells 80 and 81, which radiation includes a particular frequency, of which the corresponding wavelength is comparable as has been heretofore explained in connection with the structures illustrated in Figs. 1 through 5 to the dimensions of the space bounded between shells 80 and 81. Energy of such frequency by direct paths and reflected paths passes out through lenses 82 and 83 as beams. By suitable choice of the character of the gaseous atmosphere filling the space between shells 80 and 81 and by suitable correlation of the pressure of that atmosphere with the potential supplied from source 89, the intensity of the potential supplied from source 89, the intensity of the radiation coming through lenses 82 and 83 may be made maximum.

The physical size of the discharge produced in the gap 88 and the overall length of the members 86 and 87 of the corona producing means influences the band width of frequencies which may be emitted. In general, the larger the sizes the greater the bandwidth of frequencies emitted and

the smaller is the selectivity produced by the composite shells 80 and 81. That is, when it is desired to make the space broadly resonant, so that the band width is relatively large, the members 86 and 87 may be made like a dipole, as illustrated, but the members 86 and 87 are made as small as possible when sharp resonance or high selectivity is desired.

In Fig. 8 a modified form of space resonant device, bounded by surfaces of revolution formed of conic sections, is shown. This device is fundamentally resonant at substantially two different frequencies. Energy is transferred into the device through a coaxial transmission line 100, terminated by a small loop 101. Space on one side of a plane passing through the center of the loop 101 is bounded by a pair of paraboloidal shells 102 and 103, the two shells having their concave sides facing each other and having a common focal point at the center of the loop 101. Space on the other side of the plane passing through loop 101 is bounded by two additional paraboloidal shells 104 and 105 having their concave sides facing each other, having a common focal point at the center of the loop 101 coinciding with the common focal point of the shells 102 and 103, and each having a major axis of different length from the major axes of shells 102 and 103. The pair of shells 104, 105 and similarly, the pair of shells 102, 103 are similar to halves of shells 50 and 51 in Figure 5. If desired, the space between the edges of shells 102 and 103 and the edges of shells 104 and 105 may be closed by a suitably shaped strip 106 lying in the previously mentioned plane passing through loop 101.

Energy transferred through the coaxial line 100 and to the loop 101 is radiated into the space bounded by the doubly resonant chamber comprising shells 102 and 103. The chamber comprising shells 102 and 103 is resonant at certain frequencies corresponding to the dimensions of that space, in a manner explained in connection with the structures of Figs. 1 through 5. Similarly, due to the shape of the chamber comprising shells 104 and 105, energy of a wavelength comparable with the shell size, such energy being transferred through line 100 and radiated from loop 101, is selectively reinforced, the wavelength and the corresponding frequency of that energy being determined by the dimensions of the space bounded by shells 104 and 105. Space resonance is therefore produced in the space bounded by shells 102, 103, 104 and 105 at substantially two discrete fundamental frequencies, and the impedance appearing between the two conductors of the coaxial line 100 is correspondingly affected at these two discrete frequencies.

Energy may be abstracted from the space bounded by shells 102 and 103 through a small loop 110 connected to a coaxial transmission line 107. Such energy abstracted through the loop 110 and line 107 is predominantly of the frequency determined by the space resonance of the space bounded by shells 102 and 103.

Similarly, energy of a frequency determined by the dimensions of a space bounded by shells 104 and 105 may be abstracted from that space by a small loop 108 and a connected coaxial transmission line 109.

When a loop and connected line such as the loops 110 and 108 and lines 107 and 109 are utilized, the structure may be used as a filter, resonant at two discrete frequencies, for separating out energy at one of those frequencies. Al-

ternatively, energy may be fed into lines 107 and 109 at respectively different frequencies and such energy transferred through the space bounded by shells 102, 103, 104, and 105 to line 100, where, for example, the energy of two different frequencies may be mixed by heterodyne action.

Such heterodyne action takes place when line 100 is connected across a crystal detector 133 in series with a condenser 134. Condenser 134 has low reactance at the frequencies of energy in lines 107 and 109 and high reactance at their beat frequency. Beat frequency voltage appearing across condenser 134 may be utilized in device 135.

In Fig. 9 there is shown another structure in which still another conic section is utilized to form a surface of revolution bounding a space which is resonant at a single predetermined frequency. In this case the conic section is an ellipse rotated about its major axis to form the desired surface of revolution. That is, the space is bounded by the shell of a prolate spheroid. The shell 119 is formed of a reflecting material in the shape of the resulting surface of revolution. Excitation of the space bounded by shell 119 may be provided through a small loop 111 at one of the foci of the ellipse determining the shape of shell 119 and through another small loop 112 at the other focus. The small loop 111 terminates a coaxial transmission line 113, of which the outer conductor is connected to the shell 119 and the inner conductor is connected to one terminal of the secondary winding of a high frequency transformer 114. The small loop 112 terminates another coaxial transmission line 115, of which the outer conductor is connected to shell 119 and the inner conductor is connected to the other terminal of the secondary winding of transformer 114. The anodes 116 and 117 of a high frequency electron discharge device 118 are connected in push-pull relation to respective terminals of the primary winding of transformer 114.

Ultra high frequency energy of a wavelength comparable to that determined by the dimensions of ellipse 119, is generated in the device 118 or amplified through it, and is then transferred through transformer 114 to the small loops 111 and 112 in push-pull, or balanced, relation, that is in opposite phase. The size of shell 119 is such that energy of the frequency of the wave from device 118, radiated from loop 111 and traveling by reflection from the shell 119 to the loop 112, reaches the loop 112 in such phase as to establish a mutual resonance between the two foci. This resonance is of a single type at a fundamental frequency or harmonic.

In Fig. 10 there is a graphical illustration of the path taken by such radiated and reflected energy. The shell 119 is represented by an ellipse 120 and a single ray of radiation 121 is represented as traveling from the focal point 124 occupied by loop 111 in Fig. 9. It is a well-known proposition (see "Coordinate Geometry" by Fine and Thompson, published by The McMillan Company in New York in 1937, on page 84) that the tangent at any point of an ellipse makes equal angles with the lines joining the points to the foci of the ellipse. According to this proposition, therefore, the ray 121, after reflection from the ellipse 120, takes the path 122 to the other focus 123 of the ellipse.

It is also a known property of an ellipse that the sum of the lengths of the paths 121 and 122 between the first focus 124 and the second focus

123 is a constant, no matter in what direction the path 121 is oriented.

It follows from the above-mentioned geometrical properties of the ellipse 120 that all energy radiated from focus 123, as along the representative path 121, must arrive at focus 123 after one reflection from the ellipse 120 in predetermined phase relation.

If the path 122 be extended through focus 123, as illustrated by path 125, so as to impinge again upon the ellipse 120, energy is reflected from the ellipse 120 along a path 126 passing through the first focus 124, the sum of the lengths of paths 125 and 126 being equal to the sum of the length of paths 121 and 122. Similarly path 126 may be extended through focus 124 as path 127, and after reflection from the ellipse 120 as path 128, energy traveling along those paths passes back through the second focus 123 again. Extension of the path 128 through focus 123, as path 129 results in still another reflection from the ellipse 120, as illustrated by path 130, which extends again back to the original focus 124.

Following the energy paths 121, 122, 125, 126, 127, 128, 129 and 130 in order, it is evident that energy radiated from either focus passes through the other focus and then alternately through the first focus and the other focus many times, and, after each reflection, approaches more and more nearly a path directly through the two foci 123 and 124. It is therefore evident that energy radiated from the foci 123 and 124 tends to become concentrated along the major axis of the ellipse. Since the prolate spheroidal shell 119 in Fig. 9 is formed by revolution of the ellipse 120 about its major axis, the same action as illustrated in Fig. 10 takes place in any plane passing through the major axis.

Because of the peculiar property of an ellipsoid, formed by revolution of an ellipse about its major axis, in reflecting radiation inside so that it ultimately is concentrated along the major axis, such an ellipsoid arranged as a space resonant cavity is useful in radiating a narrow concentrated beam of energy. The ellipsoidal shell 119 in Fig. 9 has a hole 131 at one end in line with the major axis and in line with the two small loops 111 and 112. Direct and concentrated radiation energy from the loops 111 and 112, is radiated as a narrow concentrated beam of energy through the hole 131, the beam being represented by an arrow 132.

In Fig. 11 an ellipsoidal shell 140 encloses a space into which energy is radiated from a dipole 141, energy being abstracted from the space through a dipole 142. The dipole 141 is energized through a coaxial cable 143, of which the inner conductor is connected to one arm of the dipole 141 and the outer conductor of the line 143 to the other arm. The dipole 142 is similarly connected to a coaxial cable 144 through which energy within the space bounded by the shell 140 is abstracted.

A representative path for energy traveling from the dipole 141 to the dipole 142 is illustrated as a line 145 from the dipole 141 to a representative point on the shell 140, and another line 146, representing the path taken by reflection of the ray traveling the path 145 and striking the representative point, the ray 146 passing eventually to the dipole 142. The ray 146, as it passes the dipole 142, proceeds in a path 147 to strike another point of the shell 140

and be reflected along a fourth path 148 back to the dipole 141.

In Fig. 12 a shell 140 has a small loop 150 at one focus and another small loop 151 at the other focus, those two small loops being connected respectively, as are the dipoles 141 and 142 in Fig. 11, to the coaxial transmission lines 143 and 144. In operation, the structure shown in Fig. 12 is similar to the operation described for the structure of Fig. 11. That is, energy radiated into the shell 140 from loop 150 is abstracted by loop 151.

The structures of Figs. 11 and 12 may be used as filters for selecting from a wave having harmonics, desired ones of the harmonics. In that case, the physical dimensions of the dipoles 141 and 142 and loops 150 and 151 as related to the size of shells determine the band pass characteristics of the filter. When employed as a filter, energy in a band of frequencies related to the size of the components of the resonant cavity is radiated from dipole 141 or loop 150 and then selectively transferred to the other dipole 142 or loop 151.

In Fig. 13 there is illustrated a conicoid, particularly an ellipsoid, which is not a surface of revolution and in which the three dimensions are all different. For clearness, the shell 160 is illustrated as viewed from three different directions, the relation between those directions being indicated respectively by dotted lines 161, 162, and 163. That is, the dotted lines 161 illustrate that the length of shell 160 viewed from the top and from the front elevation is the same, lines 162 illustrate that the height of the shell 160 viewed from the front elevation or from one end is the same, and lines 163 illustrate that the thickness of shell 160 viewed from the top or from the end is the same.

A small loop 164 is placed substantially at one focus of the shell 160 and a second small loop 165 is placed substantially at the other focus. It is to be understood that shell 160 does not have true foci but if the dimensions transverse to the long dimension do not differ too greatly, the foci of sections of shell 160 taken through that long dimension nearly coincide and may fall within the compass of loops 164 and 165. Such a condition is tolerable in a band pass filter. These two loops 164 and 165 are connected respectively to a source of high frequency wave and a load (not shown).

Any plane passing through the two foci, at which the loops 164 and 165 are located, cuts the shell 160 in an ellipse. Consequently radiation from one of the loops 164 or 165 in that plane is resonant at a frequency corresponding to the size of the ellipse cut by such plane. Another plane cutting the shell 160 at a different angle and passing through the loops 164 and 165 cuts the shell 160 in an ellipse of a different size in which resonance of a different frequency is produced.

As illustrated in Figure 13, a vertical plane through the loops 164 and 165 cuts the largest ellipse possible from the shell 160 and a horizontal plane through the loops 164 and 165 cuts the smallest ellipse in which resonance may be produced. These two sections correspond respectively to the lowest and the highest frequency at which resonance is produced in the space bounded by the shell 160, and resonance is produced at all intermediate frequencies by intermediate sections cut by planes passing through the loops 164 and 165. This structure is there-

fore a band-pass filter in which the cut-off frequencies correspond respectively to the highest and lowest frequencies described, corresponding respectively to the smallest and the largest ellipses in which space resonance is produced.

In general any conicoid may be excited in accordance with my invention so that in at least a single plane, space resonance is produced. That is, so that in at least that one plane energy returns from all directions in predetermined fixed phase relation.

In Fig. 14 a radiator 170, similar to the radiator illustrated in Fig. 3, except that the shells 40 and 41 are closed for a major part of their circumference, is energized through a concentric transmission line 171 from a source 177 of pulsed wave energy at a suitable frequency and radiates pulsed short bursts of high frequency electromagnetic energy represented by arrows 172 upward in a mountain pass encompassed between two mountain sides 173 and 174.

A plane, or other object, 175, passing above the mountain pass between mountains 173 and 174, intercepts the pulsed radiation 172 and reflects it back towards the radiator 170, as indicated by arrow 176. The reflection detector 177, of known form, deflects such reflected pulsed radiation and, if desired, measures the time elapsed between its transmission from radiator 170 and its later reception thereby after reflection, thereby indicating not only the presence of plane 175 but its altitude or distance from radiator 170.

In Fig. 15 there is illustrated still another resonant cavity bounded by surfaces of revolution formed by conic sections rotated about their axes. A hyperboloidal shell 180 is placed with its concave side facing an ellipsoidal shell 181, with a respective foci coincident at the position of a small loop 182 connected to a concentric transmission line 183 arranged to transmit energy into the space bounded by the shells 180 and 181. Energy radiated from the loop 182 toward the shell 180 is reflected from shell 180 as though it were radiant from the conjugate focus of the hyperbola defining shell 180. That is, the hyperbola has a focus at the loop 182, and it has also a conjugate focus behind the shell 180 from which such energy after reflection from the shell 180 appears to be radiant. That radiant reflected energy from shell 180, upon impinging upon shell 181 and reflection therefrom is directed back toward the loop 182.

Energy so reflected successively once from shell 180 and once from shell 181 and so returning to loop 182 traverses a circuit which is the same length for energy radiated from loop 182 in all directions. Hence, such energy returns to loop 182 in the same phase and resonance is established at a harmonic series of frequencies determined by the path length.

In Fig. 16 a graphic illustration is used to demonstrate why energy radiated in any direction from loop 182 is, after one reflection from each of shells 180 and 181 of Fig. 15, returned to loop 182 in predetermined phase relation. In this figure the X axis is represented by a line 199 and the Y axis by a line 191, and a hyperbola, symmetrical about both axes, is illustrated as having two arms 192 and 193. Revolution of arm 192 about axis 191 is effective to define the shell 180 of Fig. 15. The hyperbola having the two arms 192 and 193 has respective focal points 194 and 195. A line 196 drawn from the focus 194 to a representative point 197 along the arm of 192 of

the hyperbola represents a ray of energy radiant from loop 182 in Fig. 15.

An ellipse having any desired eccentricity is constructed about the two foci 194 and 195, and a portion 198 of this ellipse, forming with a part of the arm 192 of the hyperbola a closed space containing the line 196, is illustrated.

It is a known property of an hyperbola that the tangent at any point thereof bisects the angle included by the lines extending from each focus to that point (see page 108 of the previously identified text on Coordinate Geometry). The tangent 199 at point 197 on the arm 192 of the hyperbola in Fig. 16 therefore bisects the angle A between the line 196 and the line 200 joining the focus 195 with the point 197. Extension of the line 200 through point 197 to a point 201 on the ellipse 198 forms an angle B between this extension 202 and the tangent 199, such angle being equal to the angle C between line 200 and the lower part of the tangent 199, which in turn is half the angle A between the line 200 and the line 196. In consequence, the angle D between line 196 and the tangent 199 is equal to the angle B between the line 202 and the tangent 199. The line 202 therefore represents also the path of a ray which traveled toward the arm 192 along the path 196 and which was reflected from the arm 192 of the hyperbola at point 197.

It has been previously explained in connection with Fig. 16 that lines 200—202 and 203, joining the foci 195 and 194 respectively to point 201, form equal angles with the tangent to the ellipse 198 at point 201, because the points 194 and 195 at the ends of those lines are the foci of the ellipse. Consequently, the path 203 is the path of a ray reflected from a point 201 of ellipse 198 after traveling along path 202 to the ellipse. Therefore, a ray emitted from focus 194 in any direction along a representative path 196 is reflected from the arm 192 of the hyperbola along path 202 and is then reflected from the ellipse 198 along path 203 back to the focus 194. Conversely, a ray radiated from the point 194 along a representative path 203 takes the opposite circuit.

It is also demonstrated below that the total length of the path from focus 194 along the line 196 and then along lines 202 and 203 back to the focus 194 is always the same, no matter in what angular direction the rays first leave the point 194. It may be shown that the distances of any point along an arm of a hyperbola from the foci differ by a constant distance (see page 104 of the text on Coordinate Geometry cited previously). Furthermore, as explained in connection with the ellipse illustrated in Fig. 16, the sum of the distances from any point along an ellipse to its foci is a constant distance. Therefore (the numbers placed within brackets representing the length of the designated lines in Fig. 16 for convenience in forming equations) expressing well known properties of an ellipse and an hyperbola:

$$(200) \text{ minus } (196) = k_1$$

$$(200) \text{ plus } (202) \text{ plus } (203) = k_2$$

Subtracting the first of these equations from the second:

$$(196) \text{ plus } (202) \text{ plus } (203) = k_2 - k_1$$

It is therefore demonstrated that the paths 196, 202 and 203 in Fig. 16 represent the true reflection path of a ray radiated from focus 194 in any direction and the total length of the three reflection paths is always the same no matter in what direction the ray be originally radiated.

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Therefore, energy radiated from loop 122 in Fig. 15 returns in phase to the loop 122 after one complete circuit, having started from loop 122 in any direction, so that the space bounded by the shells 120 and 121 of Fig. 15 is space resonant in the same fashion as is the case with structures previously described.

It is evident from inspection of the various structures which I have illustrated that other conicoids or second degree tridimensional surfaces may be utilized as surfaces bounding spaces in which resonance of a single type is established. Such resonators are useful for many purposes besides those I have described, and they are in general useful at ultra high frequencies for the same purposes for which lumped tuned circuits are useful at lower frequencies.

While I have shown and described the particular embodiments of my invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention in its broader aspects, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

I claim:

1. A high quality singly resonant cavity comprising a pair of substantially identical circular paraboloidal reflecting shells having a common focus, the concavities of said shells being juxtaposed in continuous relation to each other, thereby defining a substantially continuous inner space, and means for radiating energy within said space at said common focus whereby radiated energy after reflection from each of said shells returns to said focus in predetermined phase relation.

2. A high quality singly resonant cavity comprising a pair of substantially identical curved conductive surfaces having a common focus, each of said surfaces being defined by revolution of a parabola about its major axis, said surfaces being substantially coaxially disposed with the concavities thereof juxtaposed in contiguous relation to each other, and means for radiating energy at said common focus whereby radiated energy after reflection from each of said surfaces returns to said focus in predetermined phase relation.

3. A high quality singly resonant cavity comprising a pair of substantially identical confocal paraboloidal reflecting shells having their concavities juxtaposed in contiguous relation to each other, an opening in said cavity communicating with outer space, and means for radiating energy in said cavity at a point such that the radiant energy after reflection from each of said shells returns to said point in predetermined phase relation and energy is radiated through said opening into said outer space.

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4. In combination, a pair of substantially identical circular paraboloidal reflecting shells having a common focus, said shells being disposed with the concave sides facing each other, and corona discharge means for radiating energy at said common focus, whereby radiant energy after reflection from each of said shells returns to said focus in predetermined phase relation.

5. In combination, a pair of substantially identical curved conductive surfaces having a common focus, each of said surfaces being defined by revolution of a parabola about its major axis, said surfaces being substantially coaxially disposed with the concavities thereof juxtaposed in contiguous relation to each other, and corona discharge means for radiating energy at said common focus, whereby radiant energy after reflection from each of said surfaces returns to said common focus in predetermined phase relation.

6. In combination, a pair of substantially identical confocal circular paraboloidal reflecting shells, the concave sides of said shells being juxtaposed in coaxial and contiguous relation to each other thereby defining a reflecting cavity, an opening in said cavity communicating with an outer space, a cover hermetically sealing said opening, and corona discharge means for radiating energy within said cavity at a point such that the radiant energy after reflection from each of said shells returns to said point in predetermined phase relation, said cover being substantially transparent to said radiant energy, whereby energy is radiated through said cover into outer space in a predetermined direction.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
775,840	Bose	Mar. 29, 1904
781,606	Hewitt	Jan. 31, 1905
1,278,026	Salto	Sept. 3, 1918
1,304,868	Franklin	May 27, 1919
1,735,377	Caughlan	Oct. 19, 1927
2,118,419	Scharlau	Sept. 15, 1932
2,044,413	Weyrich	June 16, 1936
2,106,770	Southworth et al.	Feb. 1, 1938
2,129,713	Southworth	Sept. 13, 1938
2,241,119	Dallenbach	May 6, 1941
2,245,669	Hollmann	June 17, 1941
2,250,934	Ohl	July 29, 1941
2,265,796	Boersch	Dec. 9, 1941
2,281,274	Dallenbach et al.	Apr. 28, 1942
2,281,550	Barrow	May 5, 1942
2,354,658	Barber	Aug. 1, 1944
2,445,784	Lehmann	July 27, 1948