April 5, 1960 F. CAROSELLI 2,931,992

MICROWAVE IMPEDANCE BRANCH

Filed July 2, 1956 3 Sheets-Sheet 1

FIG. 1

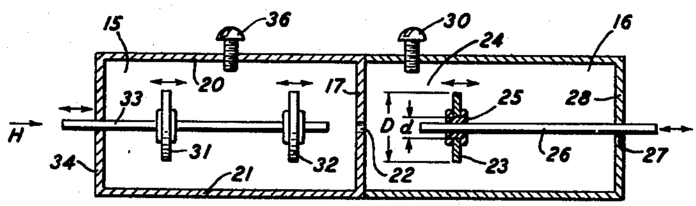


FIG. 2

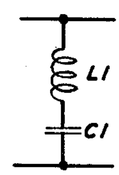


FIG. 3

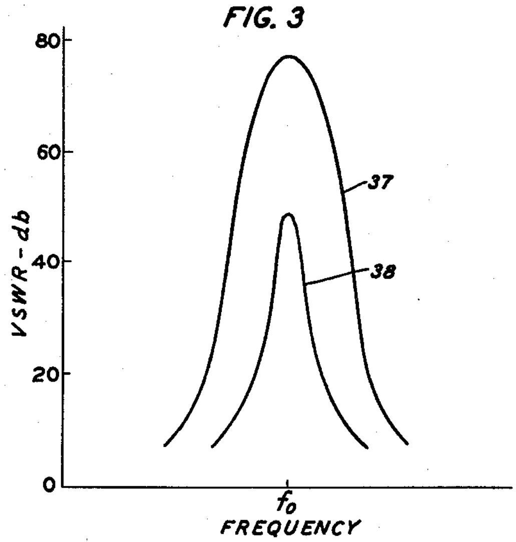
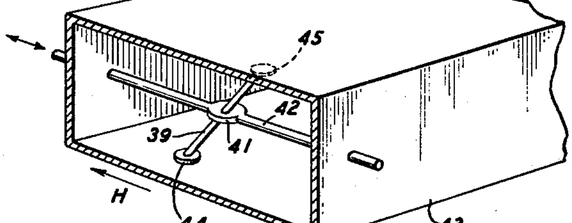


FIG. 4



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Filed July 2, 1956 3 Sheets-Sheet 2

FIG. 5

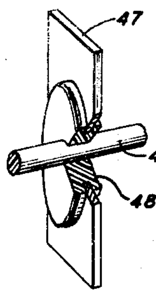

FIG. 6

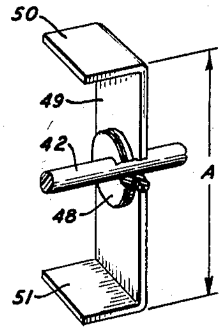

FIG. 7

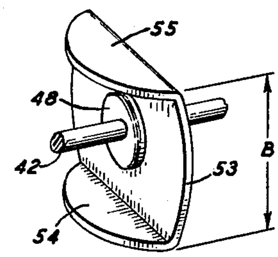

FIG. 11

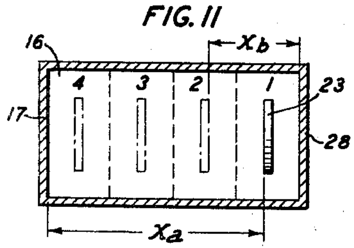

FIG. 10

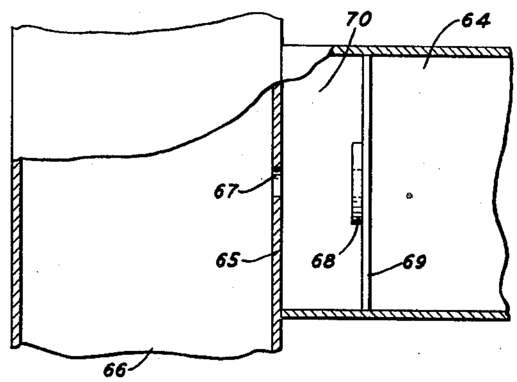

FIG. 9

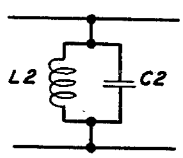

FIG. 8

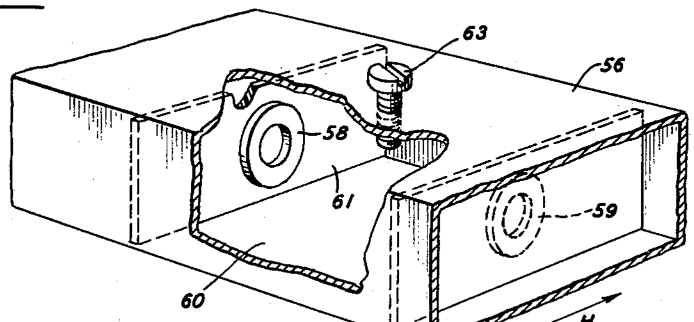

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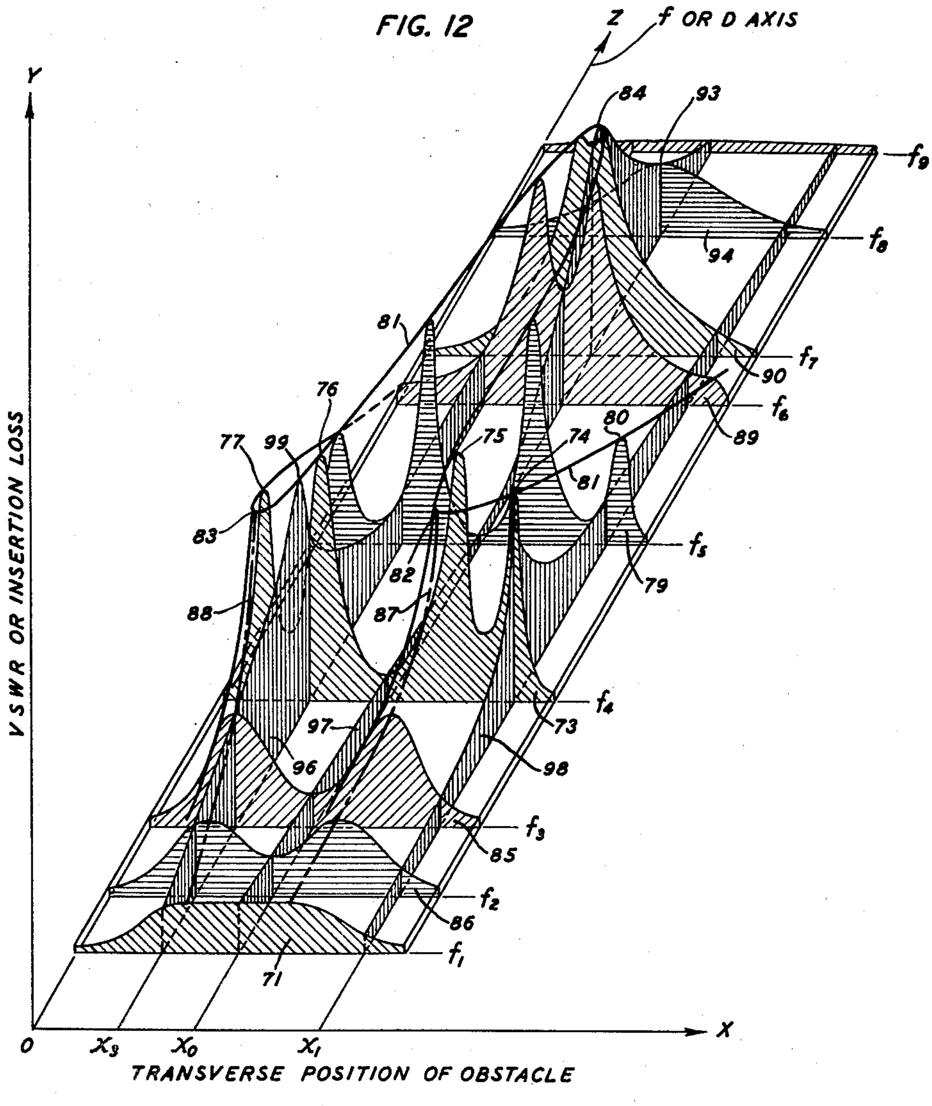
FIG. 12



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MICROWAVE IMPEDANCE BRANCH

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Application July 2, 1956, Serial No. 595,349

4 Claims. (Cl. 333—83)

This invention relates to microwave transmission structures and more particularly to a structure comprising a cavity resonator partially bounded by a conductive obstacle coupled to the magnetic field.

An object of the invention is to form a cavity resonator in a wave guide of the hollow-pipe type. A more specific object is to employ a conductive obstacle coupled to the magnetic field as a boundary of such a resonator. A further object is to utilize a resonator of this type in a branching arrangement.

It is known that a cavity resonator formed in a wave guide of the hollow-pipe type constitutes a reactive impedance branch which is very useful as a network element. In the simplest form of the present invention, a single conductive obstacle is positioned within a rectangular wave guide to form a boundary of such a resonator. The obstacle is electrically insulated from the wider walls of the guide, to provide a discontinuity in the electromagnetic field, and is shaped and positioned to couple to the magnetic field of the propagated waves. In form, it may be a disc, a ring, an ellipse, a rectangle, or a rod, or it may have some other suitable shape. The obstacle is preferably approximately centered between the wider walls of the guide, is symmetrical about an axis lying in a plane of the magnetic field vector of the propagated waves, and has a principal, frequency-determining dimension that has extent in a direction which is perpendicular to this field. The minimum value of this dimension is approximately a quarter of a wavelength, λ_g, within the guide. The maximum value may be found by trial. This principal dimension may be perpendicular to the wider walls of the wave guide, or it may make therewith any acute angle which is larger than zero. The resonator thus formed will be resonant at a frequency which depends upon the spacing of the obstacle from a side or an end wall of the guide and upon this principal dimension, but not upon other dimensions of the obstacle. However, the other dimensions determine the Q of the resonator, that is, the stiffness of the reactance characteristic. Slanting the principal dimension will also change the Q and, in some cases, will permit the use of an obstacle which is too long to fit into the guide if positioned perpendicularly. When the element is a slender rod, its effective electrical length may be increased by adding discs or other transverse projections at the ends thereof. Also, in other types of elements, such as plates, the effective length may be increased somewhat by adding a projection at each end. These projections, which are preferably parallel to the wider walls of the guide, also affect the Q of the resonator. Thus, a great variety of useful characteristics may be obtained.

As an extension of the invention, two such obstacles may be spaced from each other longitudinally within the guide to form a longitudinal cavity resonator. In a further extension of the invention, a branching wave guide and a main wave guide are connected through a common wall. The wall has a hole therein which is too small to effect useful coupling between the guides. An obstacle is positioned in the branch to form at the junction a cavity resonator which may be dimensioned or adjusted to provide the desired transmission through the hole.

The nature of the invention and its various objects, features, and advantages will appear more fully in the following detailed description of the typical embodiments illustrated in the accompanying drawing, of which:

Fig. 1 is a transverse sectional view of two rectangular wave guides arranged side by side with a common wall and coupled by a hole and a side-wall cavity resonator formed by an obstacle in accordance with the invention;

Fig. 2 shows the equivalent circuit of the side-wall resonator shown in Fig. 1;

Fig. 3 shows typical characteristics of the voltage standing wave ratio (VSWR) plotted against frequency obtainable with side-wall resonators;

Figs. 4, 5, 6, and 7 show other suitable obstacles in the form, respectively, of a rod with discs at the ends, a rectangular plate, a bent rectangle, and a bent ellipse;

Fig. 8 is a perspective view of a wave guide with two transverse rings spaced to form a longitudinal cavity resonator;

Fig. 9 is a schematic circuit representing the equivalent circuit of the longitudinal resonator of Fig. 8;

Fig. 10 is a top view, partly cut away, of a main wave guide coupled to the end of a branching guide by means of a hole and an end-wall cavity resonator in accordance with the invention;

Fig. 11 shows an obstacle in four different transverse positions, each of which will provide a side-wall cavity resonator; and

Fig. 12 is a three-dimensional representation of a surface showing how the characteristic of the VSWR versus the transverse spacing of a ring changes with frequency or with the outer diameter of the ring.

Taking up the figures in greater detail, Fig. 1 shows in transverse cross section two rectangular wave guides **15** and **16**, with unequal transverse dimensions, arranged side by side with a common narrower wall **17**. It is assumed that the guide **15** is transmitting electromagnetic waves of the dominant transverse electric mode TE_{10} with the plane of their magnetic field vector parallel to the wider walls **20** and **21**, as indicated by the arrow H. The two guides **15** and **16** are coupled through a circular hole **22** in the wall **17**. This hole, by itself, is too small to provide the desired coupling between the guides **15** and **16**. An obstacle in the form of a conductive ring **23** is positioned within the guide **16**, equidistant from the wider walls **20** and **21**, to form a side-wall cavity resonator **24** between the ring and the wall **17**. At its inner surface, the ring **23** fits into a circular groove in a dielectric bushing **25** which is slidably mounted on a circular rod **26**, which may be either dielectric or metallic. An end of the rod **26** fits slidably into a circular hole **27** at the center of the other narrower wall **28** of the guide **16**.

The major faces of the ring **23** are shown parallel to the narrower walls **17** and **28** and, therefore, perpendicular to the wider walls and the plane of the magnetic field vector H. However, other orientations may be used. For example, the ring may be rotated about any diameter D so that the major faces are no longer parallel to the narrower walls. The plane of a major face may make any angle with a narrower wall so long as a principal, frequency-determining dimension, in this case an outer diameter D, has some extent in a direction perpendicular to the magnetic field H. Both the resonant frequency and the Q of the resonator **24** change to some extent as the inclination of the ring is changed.

The ring-and-bushing assembly **23**, **25** may be slid along the rod **26** or the rod may be slid in the hole **27**, as indicated by the double-pointed arrows, to adjust the distance between the ring **25** and the wall **17** and thereby adjust the resonant frequency of the resonator **24**. The screw **30** provides fine tuning. The longitudinal axis of the screw **30** is preferably spaced approximately $\lambda_r/4$ from the ring **23**, where λ_r is the wavelength in the resonator **24** at the resonant frequency. The hole **22** and the resonator **24** largely determine the transmission characteristic of the coupling path between the guides **15** and **16**. This characteristic may be readily changed by changing the outer diameter D or the inner diameter d of the ring **23**, or by changing the inclination of the ring with respect to the narrower walls **17** and **28**.

The conductive rings **31** and **32**, similar to the ring **23**, provide additional side-wall cavity resonators in the main guide **15**. The rings **31** and **32** are slidably mounted on a circular dielectric or metallic rod **33** which fits slidably into a hole in the center of the narrower wall **34** of the guide **15** and projects perpendicularly therefrom in the direction of the hole **22**. Either or both of the rings **31** and **32** may, if desired, be located at some other longitudinal position within the guide **15**. The major faces of these rings are parallel to the narrower walls **17** and **34** and perpendicular to the plane of the magnetic field H. Their major faces may, however, be inclined with respect to the narrower walls, as explained above in connection with the ring **23**. As will be explained more fully hereinafter in connection with Figs. 11 and 12, each ring may be transversely positioned to form a cavity resonator between itself and either of the walls **17** and **34**. A screw **36** in the wall **20** provides tuning. The responses associated with these resonators are, in general, substantially independent.

Fig. 2 shows the lumped-element equivalent circuit representing the side-wall cavity resonator **24**. The circuit comprises the series combination of an inductor **L1** and a capacitor **C1** connected in shunt across the transmission line.

Fig. 3 shows typical characteristics of the VSWR, in decibels, versus frequency for the resonator **24**, with the resonant frequency indicated at f_0. If the ring **23** has an outer diameter D larger than $\lambda_g/4$, where λ_g is the wavelength at f_0 within the guide **16**, f_0 is determined by the distance between the wall **17** and the ring **23**. For a ring which is parallel to the narrower walls and has given dimeters D and d, the curve **37** will be obtained. Increasing either D or d, or inclining the ring with respect to the narrower walls, will increase the Q of the resonator **24** and the stiffness of the reactance to provide a sharper but lower characteristic, such as **38**. The thickness of the ring has negligible effect on the resonant frequency f_0 or the stiffness of the reactance.

The inner diameter d of the ring **23** may be of any value, including zero. When d is zero, the ring degenerates into a disc, which may be mounted in any suitable manner on the end of the rod **26**.

Figs. 4, 5, 6, and 7 show other forms of obstacles which may be employed to form side-wall cavity resonators in a rectangular wave guide. In Fig. 4, a conductive rod **39** has a centrally positioned dielectric collar **41** attached at an intermediate point to a circular push rod **42**, which may be dielectric or metallic. The ends of the push rod **42** fit slidably in centrally positioned holes in the narrower walls of a rectangular wave guide **43**. The rod **39** may be perpendicular to the plane of the magnetic field H. However, as shown, the rod **39** is inclined with respect to the wider walls and the magnetic field. As compared with the vertical position, the ends of the rod have been displaced both longitudinally and transversely. The inclination may be at any acute angle greater than zero. This angle must be greater than zero so that the length of the rod, which is its principal, frequency-determining dimension, will have some extent in a direction perpendicular to the field H. For a rod which has a diameter of 0.062 inch, the length has an upper limit of $0.325\lambda_g$, and for a diameter of 0.10 inch this limit is $0.375\lambda_g$, if the rod is to form a boundary of a sharply resonant cavity. By sliding the rod **42**, the rod **39** may be positioned transversely within the guide **43** to form a side-wall cavity resonator between the rod **39** and either of the narrower walls. The Q of the resonator may be changed by changing the inclination, diameter, or length of the rod **39**, or by adding the conductive discs **44** and **45** at the ends thereof. These discs are preferably parallel to the wider walls, as shown.

Figs. 5, 6, and 7 show other suitable types of obstacles which may be mounted on the push rod **42** within the guide **43**. Although the elements are shown mounted perpendicularly on the rod **42**, it will be understood that they may be inclined at any acute angle greater than zero. Fig. 5 shows a rectangular conductive plate **47** with a round central hole which fits a groove in the periphery of a circular dielectric bushing **48** mounted on the push rod **42**. Either the longer or the shorter dimension of the plate **47** may be the principal, frequency-determining dimension having extent perpendicular to H. Fig. 6 shows a longer conductive plate **49** with its ends bent at right angles to form the projections **50** and **51** which are parallel with the wider walls of the associated wave guide. The distance A between the projections **50** and **51** is the principal, frequency-determining dimension which is perpendicular to the field H. The projections effectively increase this dimension slightly and also affect the Q of the associated resonator. In Fig. 7, the obstacle is in the form of a conductive, elliptical plate **53** having its ends bent at right angles to form the projections **54** and **55**. The distance B is the principal, frequency-determining dimension perpendicular to H. The plate **53** may be circular, or of other appropriate shape, if desired. In each of the obstacles **47**, **49**, and **53**, the hole may be of any suitable diameter, including zero, depending upon the type of characteristic desired. Also, the hole may be of any other convenient shape, such as rectangular or elliptical.

Fig. 8 is a perspective view, partly cut away, of a rectangular wave guide **56** with two transverse obstacles **58** and **59** longitudinally spaced therein to form a longitudinal cavity resonator **60**. These obstacles are in the form of conductive rings, similar to the ring **23** of Fig. 1. Each ring is centrally mounted upon a face of a dielectric partition **61** which extends transversely across the guide **56**. Thus, the major faces of the rings **58** and **59** are perpendicular to the narrower sides of the guide **56** and also perpendicular to H. The resonant frequency of the resonator **60** depends upon the distance between the rings **58** and **59** and upon their outer diameter. The screw **63** projects through one of the wider walls of the guide **56** midway between the rings to provide fine tuning of the resonant frequency. The Q of the resonator **60** is determined by the inner and outer diameters of the rings. The inner diameters may be of any value, including zero. Fig. 9 gives the equivalent circuit representing the resonator **60**, comprising the parallel combination of an indicator **L2** and a capacitor **C2** shunted across the transmission line.

Fig. 10 is a top view, partly cut away, of another branching arrangement in accordance with the invention. The end of the rectangular branching guide **64** is connected to a narrower wall **65** of the rectangular main guide **66** to form a T. A small circular hole **67** in the common wall **65** connects the two guides but by itself provides insufficient coupling. A conductive ring **68** mounted on a transverse dielectric partition **69** is spaced from the wall **65** to form an end-wall cavity resonator **70** which may be designed to provide the desired transmission through the hole **67**. The assembly **68**, **69** is similar to the ring-partition assembly **58**, **61** shown in Fig. 8.

The type of transmission characteristic obtainable with a side-wall cavity resonator such as **24**, Fig. 1, will now be considered, with the aid of Figs. 11 and 12. Fig. 11 is a cross section of the guide **16** showing four different transverse positions of the ring **23** which will form a sidewall cavity resonator, providing the ring has an outer diameter D larger than $\lambda_g/4$. The three vertical broken lines divide the section into four regions numbered **1** to **4**. When the ring is in region **1** or **4**, the far side wall (**17** or **28**) is a boundary of the active cavity resonator. If the inner diameter d is no greater than $D/4$, the required spacing x_a from the far wall is given by

$$x_a=\frac{\lambda_c}{4}+\frac{\lambda_c}{2\pi}\tan^{-1}\left[\frac{\lambda_c}{\gamma_g}\tan^2\frac{\pi D}{\lambda_g}\right] \qquad (1)$$

where λ_c is the cut-off wavelength for the TE_{10} mode in the guide **16**. When the ring is in the region **2** or **3** and d is no greater than $D/4$, the near side wall (**28** or **17**) is a boundary of the active resonator and the spacing x_b is found from the expression

$$x_b=\frac{\lambda_c}{2\pi}\tan^{-1}\left[\frac{\lambda_g}{\lambda_c}\tan^2\frac{\pi D}{\lambda_g}\right] \qquad (2)$$

When D is equal to $\lambda_g/4$, the ring **23** will be located at the boundary between the regions **1** and **2** or between the regions **3** and **4** and form two cavity resonators which operate in parallel. One of these resonators is bounded by the ring and the near side wall and the other by the ring and the far side wall. In this case, Equation 2 simplifies to

$$x_b=\frac{\lambda_c}{2\pi}\tan^{-1}\frac{\lambda_g}{\lambda_c} \qquad (3)$$

The Q of the side-wall cavity resonator **24**, that is, the stiffness or shape of the reactance characteristic, depends upon the frequency and the outer diameter D of the ring **23**. The coupling diagram shown in Fig. 12 is a three-dimensional representation of a surface illustrating the interrelation between these factors. The three axes of reference OX, OY, and OZ are mutually perpendicular. The axis OX represents the transverse position of the ring **23** within the guide **16**, the axis OY represents the VSWR or the insertion loss, and the axis OZ represents the operating frequency f. The contour of the surface is outlined by the top edges of a number of plane sections. Nine of these sections, such as **71**, are parallel to the XY plane, have either diagonal or horizontal cross hatching, and are located along the OZ axis at the frequencies f_1 to f_9, respectively. Each of these sections shows the VSWR characteristic, at a fixed frequency, obtained when the ring **23** is moved across the guide.

It will be noted that the section **73**, at the frequency f_4, has four VSWR peaks, **74**, **75**, **76**, and **77**. These correspond to the four positions of the ring, in the regions **1**, **2**, **3**, and **4**, shown in Fig. 11. The section **79**, at the frequency f_5, also has four peaks. The loci of corresponding peaks, such as **74** and **80**, in successive sections outline a ridge which is indicated by the solid line **81**.

As viewed from above the figure, the line **81** is a sinusoidal-like curve having two minima, at the points **82** and **83**, and a maximum at the point **84**. The points **82** and **83** show that, as the frequency is reduced from f_4, the two separate peaks, such as **74** and **75**, in each half of the guide merge into a single peak. The sections **85** and **86** illustrate this condition. The loci of these peaks form two descending ridges, indicated by the dot-and-dash lines **87** and **88**.

On the other hand, as the frequency is increased from f_5, the two outer peaks become less pronounced and finally disappear, as shown by the sections **89** and **90**. If the frequency is further increased, the two inner peaks merge, at the point **84**, and at the frequency f_8 there remains only a single centrally positioned, broad peak **93**, as shown by the section **94**.

Fig. 12 also shows three plane sections **96**, **97**, and **98**, with vertical cross hatching, which are parallel to the YZ plane. The top contours of these planes show the VSWR response obtained with a given ring **23** of fixed position when the frequency f is changed. The section **97** is centrally positioned in the guide **16**, at x_0. The section **96** is located at x_3, in region **3** indicated in Fig. 11, and the section **98** at x_1, in region **1**. Each of these sections has a single peak. These occur at the points **99**, **84**, and **74**, respectively.

As would be expected, the two halves of each of the transverse sections **71**, **73**, **79**, **85**, **86**, **89**, **90**, and **94** are symmetrical about the central longitudinal section **97**.

Fig. 12 also illustrates, at least qualitatively, how the VSWR characteristic changes when the outer diameter D of the ring **23** is changed while the frequency is kept constant. For this purpose, the axis OZ represents an increasing D instead of f. It is seen that, in order to get four position peaks, such as **74**, **75**, **76**, and **77** on section **73**, D must be greater than the value represented by the point **82** or the point **83**, and smaller than the value represented by the section **89**. The lower limit is approximately equal to $\lambda_g/4$. However, a smaller value of D will give a type of characteristic, such as those shown by the sections **71**, **85**, and **86**, which is useful in some applications. The upper limit of D to provide four peaks is best found by trial.

It is also seen that if D is increased to a value greater than that represented by the point **84**, only a single rather rounded peak, such as **93**, is obtainable. This value of D, which may be found experimentally, is the upper limit of the principal, frequency-determining dimension, mentioned above, with extent perpendicular to the plane of the magnetic vector H.

Based on experimental data, diagrams similar to the one shown in Fig. 12 may be prepared for other types of obstacles, for example, the rod with end discs shown in Fig. 4. Such diagrams are a great aid to the designer in selecting a suitable obstacle, and in determining the required dimensions and the position within the guide, to provide a desired VSWR or insertion loss characteristic.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a wave guide of oblong cross section and a conductive ring having an outer diameter D equal at least to a quarter of a wavelength λ_g within the guide at a transmitted frequency and an inner diameter no greater than $D/4$, the ring being positioned within the guide with a face of the ring parallel to a narrower side wall of the guide and spaced therefrom to form one boundary of a cavity resonator.

2. The combination in accordance with claim 1 in which said ring is spaced from said narrower wall by a distance x_a approximately determined by the expression

$$x_a=\frac{\lambda_c}{4}+\frac{\lambda_c}{2\pi}\tan^{-1}\left[\frac{\lambda_c}{\lambda_g}\tan^2\frac{\pi D}{\lambda_g}\right]$$

where λ_c is the cut-off wavelength for the TE_{10} mode in said guide.

3. The combination in accordance with claim 1 in which said ring is spaced from said narrower wall by a distance x_b approximately determined by the expression

$$x_b=\frac{\lambda_c}{2\pi}\tan^{-1}\left[\frac{\lambda_g}{\lambda_c}\tan^2\frac{\pi D}{\lambda_g}\right]$$

where λ_c is the cut-off wavelength for the TE_{10} mode in said guide.

4. The combination in accordance with claim 1 in which D is equal to $\lambda_g/4$ and said ring is spaced from one of said narrower walls by a distance x_b approximately determined by the expression

$$x_b=\frac{\lambda_c}{2\pi}\tan^{-1}\frac{\lambda_g}{\lambda_c}$$

where λ_c is the cut-off wavelength for the TE_{10} mode in said guide.

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