FIG. 12

TRANVERSE POSITION OF OBSTACLE

VSWR OR INSERTION LOSS

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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, \( \lambda_p \), within the guide. The maximum value may be found by trial. This principal dimension may be perpendicular to the wider walls of the guide, or it may make an angle with the walls in 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 again be more fully illustrated 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 modes 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 required 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, 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 \( \lambda_p / 4 \) from the ring 23, where \( \lambda_p \) 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 slidable 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 therewith 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 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 \( L_1 \) and a capacitor \( C_1 \) 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 \( \lambda_p / 4 \), where \( \lambda_p \) is the wavelength at \( f_0 \) within the guide 16, \( f_0 \) is determined by the distance between the walls 17 and the ring 23. For a ring which is parallel to the narrower walls and has, given diameters \( D \) 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 sharp cut-off. The lower characteristics, 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 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\( \lambda_p \), and for a diameter of 0.10 inch this limit is 0.375\( \lambda_p \). If the rod is to form a boundary of a sharply resonant cavity. By sliding the rod 42 partially 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 and the collar 41. 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 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. 7 shows the side-effect of using a side-wall cavity resonator 24 with the resonator 47, Fig. 1, which 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 which may be circular, or of other appropriate shape, as 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 \( L_2 \) and a capacitor \( C_2 \) 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 rod 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 $\lambda_4/4$. 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 $x_0$ from the far wall is given by

$$x_0 = \frac{\lambda_4}{4} + \frac{\lambda_d}{2} + \frac{\lambda_4}{4} \tan^{-1} \left[ \frac{\pi \tan \frac{\pi D}{\lambda_4}}{\pi} \right]$$

where $\lambda_4$ is the cut-off wavelength for the TE$_{04}$ 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 $x_0$ is found from the expression

$$x_0 = \frac{\lambda_4}{2} \tan^{-1} \left[ \frac{\lambda_4}{2} \tan \frac{\pi D}{\lambda_4} \right]$$

When D is equal to $\lambda_4/4$, 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

$$x_0 = \frac{\lambda_4}{2} \tan^{-1} \left[ \frac{\lambda_4}{2} \tan \frac{\pi D}{\lambda_4} \right]$$

The O 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 $f_9$, 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 $f_9$, 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 $f_9$, 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 $f_9$, 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 $f_9$ 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 $x_0$, in region 3 indicated in Fig. 11, and the section 96 at $x_0$, 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 $\lambda_4/4$. 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 the 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 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 narrow wall by a distance $x_0$ approximately determined by the expression

$$x_0 = \frac{\lambda_4}{4} + \frac{\lambda_4}{2} \tan^{-1} \left[ \frac{\pi \tan \frac{\pi D}{\lambda_4}}{\pi} \right]$$

where $\lambda_4$ is the cut-off wavelength for the TE$_{04}$ mode in said guide.

3. The combination in accordance with claim 1 in which said ring is spaced from said narrow wall by a distance $x_0$ approximately determined by the expression

$$x_0 = \frac{\lambda_4}{2} \tan^{-1} \left[ \frac{\lambda_4}{2} \tan \frac{\pi D}{\lambda_4} \right]$$

where $\lambda_4$ is the cut-off wavelength for the TE$_{14}$ mode in said guide.

4. The combination in accordance with claim 1 in which D is equal to $\lambda_4/4$ and said ring is spaced from one of said narrower walls by a distance $x_0$ approximately determined by the expression

$$x_0 = \frac{\lambda_4}{2} \tan^{-1} \frac{\lambda_4}{\lambda_4}$$
where \( \lambda_c \) is the cut-off wavelength for the \( \text{TE}_{10} \) mode in said guide.

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