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MICROWAVE IMPEDANCE BRANCH

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FIG. 1

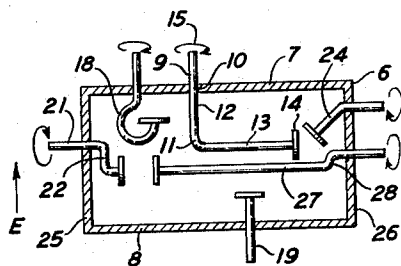


FIG. 2

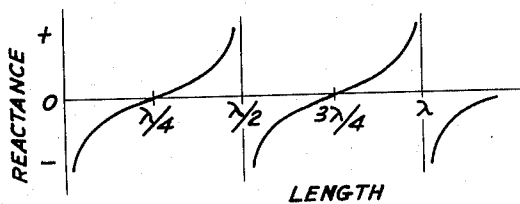


FIG. 4

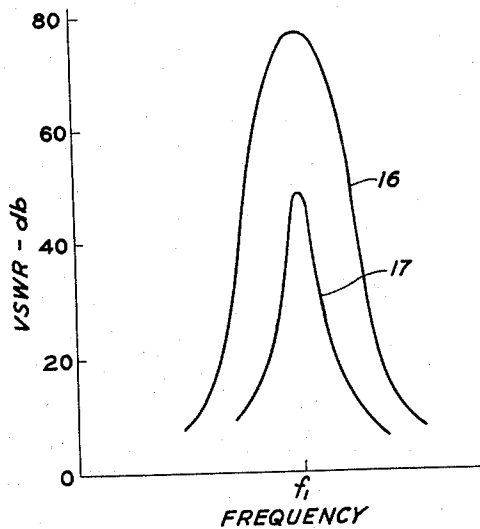
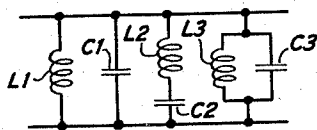


FIG. 3



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7 Claims. (Cl. 333—98)

This invention relates to microwave transmission structures and more particularly to an impedance branch comprising one or more elongated, conductive obstacles positioned within a wave guide and coupled to the electric field.

The principal object of the invention is to introduce a reactive impedance branch in a wave guide of the hollow-pipe type. A more specific object is to shape and position an elongated, conductive element or rod, connected at one end to the inner surface of such a wave guide, so that the associated reactance will be coupled to the electric field of the propagated waves in the desired degree. Further objects are to provide a convenient adjustment of this coupling or the length of the rod. Another object is to increase the variety of reactance characteristics obtainable in an impedance branch at a single longitudinal point on a wave guide. A still further object is to annul the reactance of an element used to provide coupling for an otherwise uncoupled transverse rod which is perpendicular to the electric field.

It is known that an obstacle introduced into a wave guide of the hollow-pipe type and coupled to the electric field will provide an impedance branch. The obstacle may, for example, be in the form of an elongated, conductive element or rod which is connected at one end to the inner surface of the guide. Heretofore, such a rod has been so positioned that it extends either in the direction of the electric field of the propagated waves or transversely and at right angles thereto. In the latter case, the rod can be coupled to the electric field by means of a second conductive element which is connected to the inner surface and extends in the direction of the electric field.

In its simplest form, an impedance branch in accordance with the present invention comprises a single, elongated, conductive element or rod connected at one end to the inner surface of a hollow-pipe wave guide. The rod is shaped and positioned to extend in the direction of the electric field of the waves, to provide coupling thereto, and also in a different direction. The rod may be straight or it may be bent into any suitable or convenient shape. If the wave guide is rectangular in cross section, with unequal transverse dimensions, the rod may project from either a wider or a narrower wall of the guide. When the rod is straight, it makes an acute angle with a plane perpendicular to the electric field. In any case, the rod provides its own coupling with the electric field. This coupling may be adjusted conveniently if the rod is made rotatable, and the length of the rod may be adjusted if it is made slidable in its mounting. An important advantage is that the length of the rod is not limited by a cross-sectional dimension of the guide.

The reactance of such a rod at any frequency depends upon its dimensions, shape, and position within the guide. Its length may be so chosen that, at a selected frequency, the impedance of the rod is positive, negative, zero (at resonance), or infinite (at antiresonance). The slope of the reactance-frequency characteristics (that is, the stiff-

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ness of the impedance branch) depends upon the cross-sectional dimensions of the rod, the point at which the rod is attached to the guide, and the degree of coupling.

The reactance characteristic obtainable may be further changed by adding a second rod at the same longitudinal point in the wave guide. The second rod may be either straight or bent. If the guide is rectangular in cross section and the second rod is on the same wall as the first, or on the opposite wall, and if the closest spacing between the rods is less than $\lambda/4$, where λ is the free-space wavelength at a selected operating frequency, the rods will be electrically coupled to each other and function as a single impedance branch at that frequency. However, if this spacing is greater than $\lambda/4$, the rods will function independently as two parallel impedance branches. If the two rods are on adjacent walls, they will act independently, regardless of spacing.

In a special application of the invention, a transverse rod projecting from a narrower wall of a rectangular wave guide is coupled to the electric field by a second rod connected to a wider wall, and a third rod is added on the other wider wall to annul the effect of the reactance of the second rod at a selected frequency. Therefore, at this frequency, the reactance characteristic of the first rod is substantially unaffected by the presence of the two coupling elements. If the second rod has an effective length of $\lambda/2$, the third rod may be omitted.

Another important embodiment of the invention comprises a resonant rod with a right-angle bend proportioned for maximum Q. The bent portion has an effective length of $\lambda/2$ and the remainder of the rod has an effective length equal to an odd integral number of quarter wavelengths. The rod may project from either a narrower or a wider wall of a rectangular wave guide.

In any of the elements or rods described, a disc or other symmetrical transverse projection may be added to the free end to modify further the impedance characteristic obtainable.

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 shows in cross section a rectangular wave guide with a number of obstacles in the form of elongated, conductive elements or rods projecting from the inner surfaces of the walls thereof and coupled to the electric field to constitute reactive impedance branches in accordance with the invention;

Fig. 2 is a plot of the reactance versus the effective length of the element or rod;

Fig. 3 shows equivalent circuits representing the impedance branches of Fig. 1; and

Fig. 4 shows typical characteristics of the voltage standing wave ratio (VSWR) plotted against frequency obtainable with the impedance branches of Fig. 1.

Taking up the figures in greater detail, Fig. 1 shows in cross section a conductively bounded wave guide 6 of the hollow-pipe type having a rectangular cross section with unequal transverse dimensions. It is assumed that the guide is transmitting electromagnetic waves whose electric field is linearly polarized in a direction perpendicular to the wider walls 7 and 8, as indicated by the vector E. The elongated, conductive element or rod 9, of circular cross section, constitutes a reactive impedance branch in accordance with the invention. At one end, the rod 9 fits rotatably and slidably in a circular hole 10 in the wall 7 and is thus conductively connected thereto. At the point 11, the rod is bent at substantially a right angle so that its upper portion 12 extends in the direction of the vector E, to provide coupling, and its lower part 13 extends transversely in a direction perpendicular to

E. A conductive disc 14 is attached to the free end of the rod.

The type of reactance obtainable with the rod 9 depends upon its effective length, as shown in Fig. 2. In this connection, it should be noted that bending the rod has no other effect than reducing its effective length slightly. The length may be adjusted by sliding the rod in the hole 10 so that more or less projects within the guide 6. It is seen that if the rod 9 has an effective length of less than $\lambda/4$, or falling between $\lambda/2$ and $3\lambda/4$, the reactance will be negative. If the effective length falls between $\lambda/4$ and $\lambda/2$ or between $3\lambda/4$ and λ , the reactance will be positive. If this length is equal to an odd integral number of quarter wavelengths, the rod will be resonant, and if it is equal to an integral number of half wavelengths, the rod will be antiresonant. When its reactance is positive, the equivalent lumped-element representation, at any selected frequency, is a single shunt inductor L1, as shown in Fig. 3. If its reactance is negative, the rod may be represented by the shunt capacitor C1. A resonant rod is equivalent to a shunt branch comprising an inductor L2 in series with a capacitor C2, and an antiresonant rod is represented by a shunt branch made up of an inductor L3 in parallel with a capacitor C3.

When the rod 9 is resonant, maximum Q is obtained by making the effective length of the bent portion 13 equal to a half wavelength. The length of the portion 12 is made equal to an odd integral number of quarter wavelengths, usually one or three. The latter number gives the higher Q. A resonant rod proportioned in this way may also project from one of the narrower walls 25 and 26, if desired.

The stiffness, or impedance level, of the branch depends upon several factors. For example, the stiffness may be reduced by increasing the diameter of the rod 9, by moving it farther to one side of the transverse center line of the guide, or by attaching a conductive disc, such as 14, to the free end. Also, the stiffness may be adjusted by rotating the rod 9 in the hole 10, as indicated by the curved arrow 15, thus changing the aspect of the bent portion 13 with respect to the incident electric field E. Another important advantage of bending the rod 9 is that it may be made longer than the wave guide would accommodate, if the rod were straight. It is seen from Fig. 2 that a given reactance may be obtained with rods having different lengths. The longer rod, however, will provide a stiffer circuit and one with a higher Q. A single bent rod projecting from either a wider or a narrower wall of the guide may thus be used in place of two straight rods extending, respectively, from adjacent walls.

Fig. 4 shows typical characteristics obtainable with a rod such as 9. The VSWR, in decibels, is plotted against frequency. The rod has a length chosen to make it resonant at the frequency f_1 . The curve 16 shows the type of characteristic obtainable with a centrally positioned rod 9 having an effective length of $\lambda/4$, a given diameter, an end disc 14 of a certain diameter, and a bent portion 13 which is perpendicular to the narrower walls 25 and 26 of the guide 6. The narrower, lower curve 17 may be obtained by making one or more of the following changes: (1) move the rod 9 to the left or right of the central position, (2) increase the effective length of the rod to $3\lambda/4$ or some larger odd integral multiple of $\lambda/3$, (3) decrease the diameter of the rod, (4) increase the diameter of the disc 14, or (5) rotate the bent portion 13 in azimuth. It will be understood, of course, that an infinite family of curves falling above, between, or below the curves 16 and 17 may be obtained by proper choices of the five parameters mentioned. Thus, the designer has at his disposal a great variety of desirable characteristics.

In accordance with an extension of the invention, one or more additional rods may be positioned in the same transverse plane as the rod 9 to increase further the variety of characteristics obtainable. These may project from the same wall 7 as the rod 9, from the opposite wider

wall 8, or from either or both of the narrower walls 25 and 26 of the guide 6. For example, Fig. 1 shows a second rod 18 projecting from the inner surface of the wall 7. If the rods 9 and 18 are less than $\lambda/4$ apart at their nearest approach, they will be closely coupled and operate as a single rod having a length approximately equal to the sum of their lengths. In this way, longer effective lengths may be obtained. If the rods 9 and 18 are spaced farther apart than $\lambda/4$, they will act independently to provide two parallel impedance branches. As shown, the rod 18 is in the form of a hook, but other shapes, including straight, may be employed.

Similar results may be obtained by adding a rod such as 19 on the opposite wider wall 8. The rod 19 will increase the effective length of the rod 9 if the spacing between them is less than $\lambda/4$, but will act independently if this distance is more than $\lambda/4$. The rod 19 may, for example, be designed to resonate at a second frequency, either higher or lower than f_1 .

A straight rod projecting perpendicularly from a narrower wall of the guide 6 will not be coupled to the propagated field. However, if the rod has a portion extending in the direction of the field E, this portion will provide the necessary coupling. For example, the bent rod 21 extending from a narrower wall 25 of the guide 6 has a portion 22 which is parallel to E and thus furnishes the coupling. The same result may be accomplished by the rod 24 projecting from the other narrower wall 26. The portion of this rod within the guide 6 is substantially straight, but makes an acute angle with a plane perpendicular to E, and thus has a component which is parallel to E.

The rods 18, 21, and 24 may also be made rotatable in the wall of the guide, as indicated by the curved arrows, to provide a convenient adjustment of the coupling. The coupling also depends upon the distance of the rod from the center of the associated wall, decreasing as this distance is increased. Any of the rods may be made slidable for adjusting the length within the guide. On the other hand, any or all of the rods may be fixed in position, if no adjustment is required.

An important embodiment of the invention is a rod which extends from one of the narrower walls of a rectangular guide and is coupled to the electric field in such a way as not to alter substantially its reactance at a selected frequency. For example, the rod 27, with a length chosen for resonance at a certain frequency, projects from the center of the wall 26 so that the reactance of the branch will be of maximum stiffness. Since the rod is substantially straight and perpendicular to the wall 26, it is practically uncoupled to the electric field. Coupling may be provided by the rod 9, the upper portion 12 of which is parallel to E. If the rod 27 is straight, the bent portion 13 of the rod 9 must approach the rod 27 very closely for a branch of maximum Q. In practice, it is difficult to maintain this close spacing without making physical and electrical contact between the two rods. This difficulty is avoided by off-setting the rod 27 at the point 28 and withdrawing the rod 9 by a corresponding amount. That is, the left portion of the rod 27 is below the transverse center line of the guide 6 the same distance that the portion 13 of the rod 9 is above this line. The Q of the circuit is not appreciably reduced if this symmetry with respect to the center line is maintained. The coupling element 9 will, in general, introduce an undesired reactance, which may be either positive or negative, depending upon the length of the rod. The effect of this reactance at a selected frequency may be substantially compensated or annulled by a rod such as 19 projecting from the opposite wider wall 8 and having a reactance of the same magnitude but of opposite sign. Thus, if the rod 9 has a reactance X, the rod 19 will have a reactance $-X$. Since these two reactances are effectively in parallel, they constitute a shunt antiresonant circuit of infinite or very high im-

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pedance. In this way, the two rods 9 and 19 provide coupling for the rod 27 without materially changing the reactive characteristic of the latter. The rod 21 may be added for tuning or to introduce an independent resonance or antiresonance, if desired.

The coupling element 9 alone will constitute a shunt antiresonant circuit of high impedance, and thus provide the desired coupling for the rod 27, if its effective length is made equal to $\lambda/2$ at the frequency of interest. In this case, the compensating rod 19 may be omitted.

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 rectangular wave guide having unequal transverse dimensions and two conductive rods connected at one end to the inner surface of different adjacent walls of said guide at points lying in the same transverse plane, one of said rods projecting from the center of a narrower wall and having a portion offset from a transverse center line of said guide, the other of said rods projecting from a wider wall, and the distance between said line and said offset portion being approximately equal to the distance between said line and said other rod.

2. The combination in accordance with claim 1 in which said one rod is resonant at a selected frequency and said other rod has an effective length equal to a half free-space wavelength at said frequency.

3. In combination, a wave guide of the hollow-pipe type adapted to transmit electromagnetic waves and three elongated, conductive elements connected at one end to the inner surface of said guide at different points lying in the same transverse plane, one of said elements extending transversely in a direction perpendicular to the electric field of said waves and the other two of said elements being oppositely disposed, extending in the direction of said field, and having reactances which are opposite in sign but substantially equal in magnitude at a selected frequency.

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4. In combination, a rectangular wave guide having unequal transverse dimensions and three conductive rods connected at one end to the inner surface of different walls of said guide at points lying in the same transverse plane, the first of said rods projecting from a narrower wall and the other two of said rods projecting, respectively, from the wider walls and having reactances which are opposite in sign but substantially equal in magnitude at a selected frequency.

5. The combination in accordance with claim 4 in which said first rod is connected approximately at the center of said narrower wall.

6. In combination, a rectangular wave guide having unequal transverse dimensions and three conductive rods connected at one end to the inner surface of different walls of said guide at points lying in the same transverse plane, the first of said rods projecting from approximately the center of a narrower wall, the other two of said rods projecting, respectively, from the wider walls and having reactances which are opposite in sign but substantially equal in magnitude at a selected frequency, a portion of said first rod being offset from a transverse center line of said guide, and the distance between said line and said offset portion being approximately equal to the distance between said line and one of said other rods.

7. The combination in accordance with claim 6 which includes a fourth conductive rod connected at one end to the inner surface of the other narrower wall of said guide at a point in said plane.

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