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ADJUSTABLE WAVEGUIDE ELEMENTS

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FIG. 1.

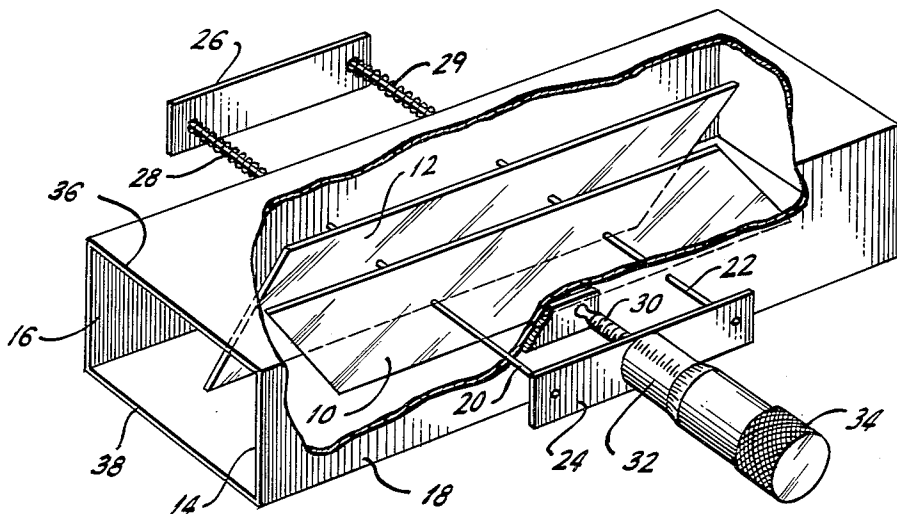
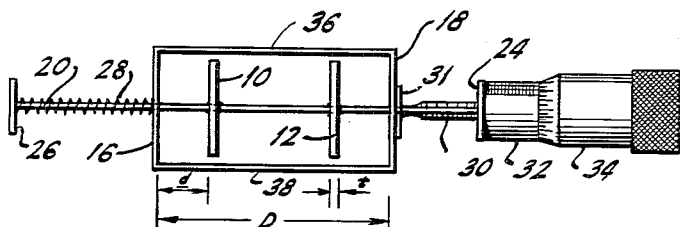


FIG. 2.

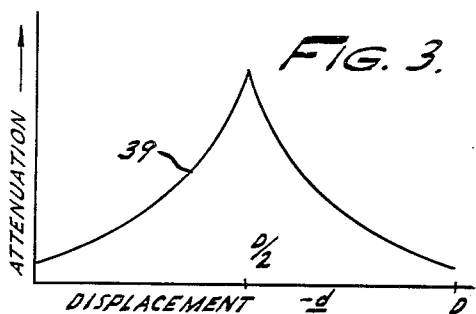
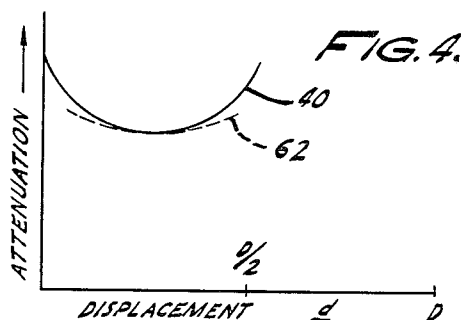
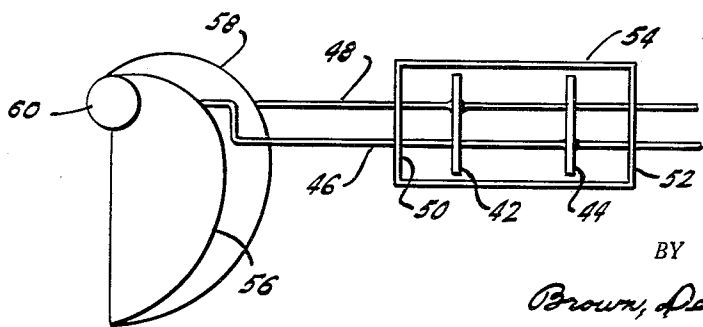


FIG. 5.

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AGENTS

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## ADJUSTABLE WAVEGUIDE ELEMENTS

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14 Claims. (Cl. 333—31)

This invention relates to electrical circuit elements and more particularly to adjustable circuit elements for use in waveguides.

Adjustable dielectric phase shifters for waveguides have been in use for several years. In one form they comprise a single slab of dielectric material disposed within the waveguide. This slab has a cross-sectional area small compared to the cross-sectional area of the waveguide, and a length equal to several wavelengths of the energy to be phase shifted. The slab is mounted parallel to the longitudinal axis of the waveguide and is movable normal to its broadest surface in the direction of the longer transverse axis of the waveguide. The slab may be supported in its position parallel to the narrow walls by two or more rods extending transversely through the narrow walls and the dielectric slab in a direction perpendicular to the electric field within the waveguide—that is, parallel to the broad walls of the waveguide. The phase shift produced by such a dielectric slab is a function of the transverse position of the slab. While the variation in phase with changes in the transverse position of the slab is not susceptible of simple mathematical expression, it has been shown experimentally and it is now generally known that the magnitude of the phase shift and the rate of change of phase shift for a unit change of position of the slab are much greater for positions of the slab near the center of the transverse cross-section of the waveguide than for positions adjacent either of the narrow walls. This is to be expected since the intensity of the electric field within a waveguide is much greater near the center of the transverse cross-section than it is near the narrow walls.

This rapid change in total phase shift for positions near the center of the cross-section is highly disadvantageous in precision phase shifters since small changes in position of the dielectric slab produce disproportionately large shifts in phase. In order to secure a more slowly varying phase shift characteristic, it is of course possible to reduce the length and/or cross-section of the dielectric slab, but only within limits of practicability. Prior art phase shifters have attempted to overcome this disadvantage by providing means for micrometrically adjusting the position of the dielectric slab. Even this expedient is not entirely satisfactory if the phase shift to be produced is of such a magnitude that the slab must be positioned near the center of the waveguide. In instances where the total phase shift introduced must be precisely known this shortcoming of prior art phase shifters cannot be completely overcome by employing two phase shifters in series, one to give a fine adjustment of the phase and one to give a coarse adjustment of the phase, since there is no way of accurately determining the exact amount of phase shift introduced by the latter phase shifter. These disadvantages are particularly noticeable in phase shifters designed to produce a large total phase shift that is adjustable over a range small compared to the maximum phase shift.

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Adjustable waveguide attenuators have been constructed along lines similar to the dielectric phase shifter described above by substituting a resistive strip for the dielectric slab. The attenuation produced by the resistive strip is again a function of the transverse position of the strip within the waveguide and is greater with the strip positioned near the center of the waveguide cross-section than it is when the strip is positioned adjacent one of the narrow walls. The rapid change in attenuation for positions of the resistive strip near the center of the cross-section has presented a problem similar in many respects to the problem discussed above in connection with the dielectric phase shifter.

At one time an attempt was made to improve the frequency response characteristic of sliding vane waveguide attenuators by providing two resistive strips that were driven simultaneously from opposite sides of the waveguide towards the center. However, it was found that an attenuator of this type was very difficult to construct. In addition it was found that this design doubled the already rapid rise of attenuation for positions of the dielectric strips near the center of the waveguide cross-section. For these and other reasons the double vane or strip attenuator fell into disuse.

Therefore, it is an object of the present invention to provide new and improved adjustable circuit elements for use in waveguides.

Another object of the present invention is to provide a new and improved dielectric phase shifter for use in waveguides.

A further object of the invention is to provide a novel waveguide attenuator that may be adjusted with great precision.

Another object is to provide a dielectric phase shifter having gradual variation in phase shift per unit of displacement of the phase shifting element.

A further object of the invention is to provide a novel attenuator having a highly desirable control characteristic.

These and other objects of the invention which will appear as the description of the invention proceeds are achieved by employing two dielectric slabs or resistive strips disposed on opposite sides of the shorter transverse axis of the waveguide and means for moving the dielectric slabs or resistive strips at the same or at selectively different rates in the direction of the longer transverse axis of the waveguide. With the slabs arranged in this manner, movement of both of them in the same direction with respect to the walls of the waveguide causes the slabs to move in opposite directions with respect to the center of the waveguide. Movement of the slabs in opposite directions with respect to the center causes the phase shift produced by one slab to increase while the phase shift produced by the other slab decreases. The increase and decrease are caused to occur at different rates so that a net change in phase shift is produced by displacement of the slabs, this shift being much smaller per unit displacement of the slabs than the change produced by conventional phase shifters due to the differential effect noted above. Movement of the resistive strips in opposite directions with respect to the center results in a similar differential change in attenuation and a correspondingly small total change in attenuation per unit shift of position of the resistive strips.

For a better understanding of the present invention together with other and further objects thereof reference should now be made to the following detailed description which is to be read in connection with the accompanying drawings, in which:

Fig. 1 is an isometric view, partially broken away, of a preferred embodiment of the invention;

Fig. 2 is an end view of the preferred embodiment shown in Fig. 1;

Fig. 3 is a graph of phase shift and attenuation versus slab displacement for a single slab phase shifter or attenuator;

Fig. 4 is a graph of phase shift and attenuation versus displacement for the double slab phase shifters or attenuator of Figs. 1 and 5; and

Fig. 5 is an end view of a second embodiment of the present invention.

Because the dielectric phase shifter and the resistive strip attenuator of the present invention are so nearly alike in construction and operation the following description will be limited to the dielectric phase shifter. At the end of the description the differences between the phase shifter and the attenuator will be discussed.

As shown in Fig. 1, the preferred embodiment of the invention comprises two slabs 10 and 12 of suitable dielectric material such as polystyrene or polyglas disposed parallel to the narrow walls 14 and 16 of the rectangular waveguide 18. The ends of dielectric slabs 10 and 12 are preferably tapered for a distance equal to approximately a half wavelength as measured in waveguide 18 in order to prevent reflection therefrom. Slabs 10 and 12 are supported by two transversely positioned rods 20 and 22 which are secured to slabs 10 and 12 and which pass through holes in walls 14 and 16 and are slidable therein. Rods 20 and 22 are so spaced that energy reflected by one of the rods is cancelled by energy reflected by the other rod. Rods 20 and 22 are rigidly joined at the ends by transverse cross members 24 and 26 which cause rods 20 and 22 to move together and thus maintain slabs 10 and 12 parallel to the narrow walls 14 and 16 of the waveguide. Motion of rods 20 and 22, and hence of slabs 10 and 12, is effected by means of a micrometer screw of conventional form comprising an internally threaded hub portion 32 which is affixed to cross member 24, and an externally threaded spindle portion 30 having a sleeve and thimble 34. The end of spindle 30 is biased against pad 31, secured to the narrow wall 14 of the waveguide, by compression springs 28 and 29. Hub 32 and sleeve 34 may be provided with the usual indicia to indicate the precise position of the slabs.

Fig. 2 is an end view of the embodiment of Fig. 1 taken from the left hand end as shown in Fig. 1. Parts in Fig. 2 corresponding to like parts in Fig. 1 have been given the same reference numerals. The thickness  $t$  of dielectric slabs 10 and 12 will depend somewhat upon the phase shift to be produced. In general, the longer and thicker the slabs are made, the greater will be the resulting phase shift. However, if the dielectric slabs are made too thick or if the width  $D$  of the waveguide is made too large, more than one mode may be propagated in the waveguide. In general, the higher the dielectric constant of the dielectric slab, the thinner the slab must be made if undesirable modes are to be eliminated. In a typical embodiment of the invention the dielectric slabs may have a length equal to 3 or 4 wavelengths as measured in the waveguide 18 and a thickness  $t$  of the order of  $\frac{1}{10}$  of a wavelength at the operating frequency. The clearance between the dielectric slabs and the broader waveguide walls 36 and 38 will depend somewhat upon the power to be transmitted through the waveguide. In high power transmission systems larger gaps may be required in order to prevent arcing between the walls 36 and 38 and the dielectric slabs 10 and 12. In low power transmission systems the clearance need only be sufficient to prevent undue friction between the dielectric slabs and the broader walls 36 and 38 of the waveguide 18. The spacing between slabs 10 and 12 is preferably equal to one-half of the width  $D$  of waveguide 18. However, the spac-

ing may be made greater or less than this amount within reasonable limits.

Fig. 3 illustrates the variation in phase shift produced by moving the single slab of a conventional prior art phase shifter completely across the broader dimension of a waveguide. The action of such a phase shifter may be visualized by assuming that slab 12 is not present in the phase shifter shown in Fig. 2 and that dielectric slab 10 is free to be moved from left to right throughout the entire width  $D$  of waveguide 18. The instantaneous displacement of slab 10 is identified by the lower case  $d$  in Fig. 2. As shown in Fig. 3, the phase shift produced by slab 10 increases slowly at first as slab 10 is moved away from narrow wall 16 and into more intense electric field near the center of the waveguide. As dielectric slab 10 nears the center of the waveguide 18 the phase shift increases more rapidly as shown by the upwardly concave shape of the curve 39 of Fig. 3. The phase shift produced by the single slab reaches a maximum with the slab 10 located on the longitudinal axis of the waveguide 18. Further movement of slab 10 toward narrow wall 14 causes a decrease in the phase shift, the decrease being rapid at first and becoming more gradual as slab 10 approaches wall 14. Curve 39 is substantially symmetrical about a line passing through the peak parallel to the phase shift axis. As pointed out above, the variation in phase shift near the central portion of waveguide 18 is so rapid that, even with a micrometer adjustment as shown in Fig. 1, an accurate reading of the phase shift introduced by a single slab phase shifter cannot always be obtained.

Fig. 4 illustrates the phase shift produced by the novel phase shifter shown in Figs. 1 and 2. It will be noted that the maximum displacement  $d$  shown in Fig. 4 is only one-half the maximum displacement shown in Fig. 3. This results from the fact that when two dielectric slabs are employed, the movement of the double slab phase shifting element through approximately one-half the width  $D$  of the waveguide 18 brings one or the other of the dielectric slabs 10 and 12 into contact with a narrow wall of the waveguide. The minimum phase shift position of the embodiment shown in Figs. 1 and 2 is at the point where dielectric slabs 10 and 12 are symmetrically positioned with respect to the center of the waveguide 18. At this position the total phase shift introduced will be substantially equal to twice the phase shift introduced by either of the two slabs taken separately. As the slabs 10 and 12 are moved from this minimum phase shift position by turning sleeve 34, one of the slabs, for example slab 10, approaches the center of the waveguide while the other slab, in this case slab 12, moves toward the nearer narrow wall 16. The incremental change in phase shift produced by slab 10 is relatively large since, as explained above, the phase shift produced by a slab increases rapidly as the slab approaches the center of the waveguide. The movement of the slab 12 toward wall 14 causes a decrease in the phase shift produced by this slab. However, the incremental decrease resulting from the movement of slab 12 is less than the incremental increase produced by slab 10 since slab 12 is moving towards a relatively flatter portion of the curve shown in Fig. 3. Therefore movement of the phase shifting elements in the manner outlined above will cause a net increase in the total phase shift produced, but this increase will be small and equal to the difference between the net increase produced by slab 10 and the decrease produced by slab 12.

The variation in phase shift with displacement for the phase shifter shown in Figs. 1 and 2 is illustrated by the solid line 40 in Fig. 4. It will be noted that this curve is relatively flat near the center but rises more sharply near the edges. It can be demonstrated, however, that, even near the ends of curve 40, the rise is less sharp than the maximum rate of rise shown in the curve of Fig. 3. To appreciate the reason for this, it is only necessary to recall that the incremental phase shift produced by the

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embodiment of Figs. 1 and 2 is always equal to the difference in phase shift produced by slabs 10 and 12 and the phase shift of one of these slabs is always decreasing as it approaches the narrow wall of the waveguide. The flattened characteristic of curve 40 of Fig. 4 permits very accurate adjustment of the phase shift since a relatively large change in position of slabs 10 and 12 is required to produce a small net change in phase shift.

Still further flattening of curve 40 may be produced at the expense of a slightly reduced range of adjustment by spacing slabs 10 and 12 by more than one-half the broader dimension D of waveguide 18. By operating the dielectric slabs in regions displaced towards the extremities of the curve shown in Fig. 3 the decrease in phase shift produced by one of the slabs will more nearly equal the increase of the phase shift produced by other of the slabs. However, as suggested above, the range of movement of the two slabs within the waveguide will be somewhat less than that shown in Figs. 1 and 2.

Another means for still further flattening the curve 40 shown in Fig. 4 is illustrated in Fig. 5. In the embodiment shown in Fig. 5 slabs 42 and 44, which may be identical to slabs 10 and 12 shown in Figs. 1 and 2, are mounted on transverse rods 46 and 48 which pass through openings in the narrow walls 50 and 52 of waveguide 54. Dielectric slab 42 is securely fastened to rod 48 but is slidable on rod 46. Similarly, rod 46 is securely fastened to dielectric slab 44 but is slidable in a hole in dielectric slab 42. Therefore slabs 42 and 44 may be moved independently of each other by appropriate movement of rods 44 and 46 respectively. Additional supporting rods, longitudinally displaced from rods 44 and 46, may be provided to give additional stability to slabs 42 and 44.

Two cams 56 and 58 mounted on a common shaft 60 engage the ends of rods 46 and 48. The end of rod 46 is so formed that rod 46 engages cam 56 along a line passing through the axis of shaft 60. A study of cams 56 and 58 will show that each of these cams is shaped to cause one of the dielectric slabs to move from a position adjacent the narrow wall of the waveguide to a position substantially coincident with the longitudinal axis of the waveguide 18. The shapes are such that, regardless of the position of shaft 60, whenever this shaft is rotated the dielectric slab nearer the center will move more slowly than the dielectric slab nearer the narrow wall of the waveguide. Preferably, the change in phase shift introduced by the dielectric slab nearer the center of the waveguide is greater than the incremental change in phase shift produced by the other dielectric slab so that a net increase in phase shift is produced by moving one of the slabs towards the center of the waveguide. The total change in phase shift with rotation of shaft 60 will vary depending upon the particular shapes chosen for cams 56 and 58. A possible curve of phase shift versus displacement of one of the dielectric slabs is shown by the broken line 62 in Fig. 4.

The mechanical arrangement shown in Fig. 5 is not necessarily the most desirable form for producing non-uniform movement of the dielectric slabs. Other forms for producing a similar motion, for example lead screws of uniform pitch driven by elliptical gears, may be preferred over the arrangement shown. Such mechanical expedients are well known in the art and are sufficiently identified by stating that the motion produced should be such that the dielectric slab nearer the center moves more slowly than the dielectric slab nearer the narrow wall of the waveguide, and that the phase shift produced by the slab nearer the center should be greater than the phase shift produced by the slab nearer the narrow wall.

It will be noted that the variation in total phase shift obtainable with the embodiment of Fig. 1 is somewhat smaller than the total variation in phase shift obtainable with a single dielectric slab phase shifter. The total range of phase shift produced with a double slab phase shifter can be controlled to a certain degree by properly selecting

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both the thickness and length of the dielectric constant of the slab. Furthermore, the limited range of phase shift produced should not be considered a disadvantage since in many instances the total phase shift to be introduced into a circuit remains relatively fixed with but a small change in total phase shift being required to balance out small irregularities produced by other circuits.

The adjustable double strip attenuator which forms a part of the present invention may have a supporting structure similar to that shown in Fig. 1 or Fig. 5. The two slabs or strips in the attenuator are formed of dielectric carrier plates coated with carbon or metalized-glass plates of suitable length and cross-section. The ends of the resistive strips preferably are tapered to prevent the reflection of energy therefrom. The curve of Fig. 3 illustrates the change in attenuation with displacement of the resistive strip in a conventional sliding vane attenuator. The differential change in attenuation is obtained in exactly the same manner as the differential change in phase shift discussed above. Therefore Fig. 4 also illustrates the change of attenuation with displacement of the two resistive strips in the attenuator embodiments of the present invention.

I am aware that other changes and modifications may be made in the embodiments disclosed herein without departing from the spirit and scope of the invention. For example, the two dielectric slabs or resistive strips may have dissimilar cross-sections, different dielectric constants or resistivity or different lengths. The number of supporting rods may be varied or the entire supporting structure may be modified and the cross-section of the waveguide may be other than rectangular. Therefore, the embodiments disclosed herein illustrate only what is at present considered to be preferred forms of the invention, the full scope of the invention being defined by the hereinafter appended claims.

What is claimed is:

1. A phase shifting device comprising a section of rectangular waveguide dimensioned to propagate the energy to be phase shifted in the dominant mode, first and second elongated dielectric slabs of substantially rectangular transverse cross-section, the cross-sectional area of each of said slabs being small compared to the cross-sectional area of the waveguide, the broader faces of each of said dielectric slabs being disposed parallel to the narrower walls of said waveguide and said two dielectric slabs occupying substantially identical longitudinal positions within said waveguide, a plurality of spaced supporting rods each disposed substantially parallel to the longer transverse axis of the waveguide, the narrower walls of said waveguide being apertured to receive said supporting rods, said dielectric slabs being joined to said supporting rods for transverse movement within said waveguide and said dielectric slabs being spaced apart by approximately one-half of the longer inside dimension of said waveguide, and means associated with said supporting rods for micrometrically varying the position of said dielectric slabs.

2. An adjustable circuit element comprising a section of dielectric filled rectangular waveguide, first and second elongated slabs of material having electrical properties substantially different from the electrical properties of the dielectric within the waveguide, said slabs being longitudinally positioned within the waveguide with the major faces thereof parallel to the electric field within the waveguide, means maintaining a fixed transverse spacing between said two slabs, said spacing being not less than half the longer transverse dimension of said waveguide, and means for varying the transverse position of said slabs within said waveguide.

3. An adjustable attenuator comprising a section of rectangular waveguide, first and second elongated slabs of resistive material, said slabs being longitudinally positioned within the waveguide with the major faces thereof parallel to the electric field within the waveguide,

means maintaining a fixed transverse spacing between said two slabs, said spacing being not less than half the longer transverse dimension of said waveguide, and means for varying the transverse position of said slabs within said waveguide.

4. An adjustable phase shifter comprising a section of rectangular waveguide, first and second elongated slabs of dielectric material, each of said slabs being longitudinally positioned within the waveguide with the major faces thereof parallel to the electric field within the waveguide, means maintaining a fixed transverse spacing between said two slabs, said spacing being not less than the half of the longitudinal transverse dimension of said waveguide, and means for varying the transverse position of said slabs within said waveguide.

5. An adjustable circuit element comprising a section of dielectric filled rectangular waveguide, first and second elongated slabs of material having electrical properties substantially different from the electrical properties of the dielectric within the waveguide, said slabs being longitudinally positioned within the waveguide with the major faces thereof parallel to the electric field within the waveguide, means for varying the transverse position of said slabs within said waveguide, said positioning means being constructed and arranged to maintain the spacing between said two slabs approximately equal to one-half the longer transverse dimension of said waveguide, the variation, if any, in said spacing over the operating range of said circuit element being a small fraction of the average spacing between said slabs.

6. The adjustable circuit element of claim 5 wherein said slabs are formed of resistive material thereby to cause said circuit element to function as an adjustable attenuator.

7. The circuit element of claim 5 wherein said slabs are formed of a dielectric material whereby said adjustable element is caused to function as a variable phase shifter.

8. An adjustable circuit element comprising a section of rectangular waveguide provided with a fluid dielectric therewithin, first and second elongated slabs of material having electrical properties substantially different from the electrical properties of the dielectric within said waveguide, said slabs being longitudinally positioned within the waveguide with the major faces thereof at all times parallel to the electric field within said waveguide, means for varying the position of said first slab in the direction of the longer transverse axis of said waveguide and within the region bounded by one narrow wall and said longitudinal axis of said waveguide, means for varying the position of said second slab in the direction of the longer transverse axis of said waveguide and within the region bounded by the other narrow wall and said longitudinal axis of said waveguide, said two last-mentioned means being so constructed and arranged that as either slab moves toward the longitudinal axis of said waveguide, the other slab moves away from said longitudinal axis, said two last-mentioned means being further constructed and arranged so that the instantaneous rate of movement of the slab nearest said longitudinal axis is not greater than the instantaneous rate of movement of the slab farthest from said longitudinal axis and the variation, if any, of the relative transverse spacing between said two slabs is much less than one-half the longer transverse dimension of said waveguide.

9. The adjustable circuit element of claim 8 wherein said last-mentioned means is so constructed and arranged that the slab nearer the longitudinal axis of said waveguide moves more slowly than the other slab.

10. An adjustable circuit element comprising a section of dielectric filled waveguide dimensioned to propagate the energy to be transmitted in the dominant mode, first and second elongated slabs of material having electrical properties substantially different from the dielectric within the waveguide, each of said slabs being disposed with the longest axis thereof at all times parallel to the longitudinal axis of the waveguide, means for supporting said slabs for movement toward and away from the longitudinal axis of said waveguide, said means for moving said slabs being so constructed and arranged that, as either slab moves toward the longitudinal axis of said waveguide, the other slab moves away from said longitudinal axis, said means for moving said slabs being further constructed and arranged so that the instantaneous rate of movement of the slab nearest said longitudinal axis is not greater than the instantaneous rate of movement of the slab farthest from said longitudinal axis and the variation, if any, of the relative transverse spacing between said two slabs is much less than one-half the longer transverse dimension of the waveguide.

11. The adjustable circuit element of claim 10 wherein said waveguide has a rectangular cross-section.

12. The adjustable circuit element of claim 10 wherein said waveguide has a rectangular cross-section and wherein said slabs are formed of a resistive material thereby to cause said circuit element to function as a variable attenuator.

13. The adjustable circuit element of claim 10 wherein said waveguide has a rectangular cross-section and wherein said slabs are formed of a dielectric material thereby to cause said circuit element to function as a variable phase shifter.

14. An adjustable circuit element comprising a section of rectangular waveguide provided with a fluid dielectric therein, first and second elongated slabs of material having electrical properties substantially different from the electrical properties of the dielectric within said waveguide, said slabs being positioned within the waveguide with the major faces thereof at all times parallel to the narrower walls of said waveguide, means for varying the position of said first slab toward and away from the longitudinal axis in a direction parallel to the longer transverse axis of said waveguide and within the region bounded by one narrow wall and the longitudinal axis of said waveguide, means for varying the position of said second slab toward and away from the longitudinal axis in a direction parallel to said longer transverse axis and within the region bounded by the other narrow wall and said longitudinal axis of said waveguide, said last-mentioned two means being so constructed and arranged that, as either slab moves toward the longitudinal axis of the waveguide, the other slab moves away from said longitudinal axis, said two last-mentioned means being further constructed and arranged so that the instantaneous rate of movement of the slab then causing the greatest change in electrical characteristic per unit change of slab position is not greater than the instantaneous rate of movement of the other slab and the variation, if any, of the relative transverse spacing between said two slabs is much less than the longer transverse dimension of said waveguide.

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