June 4, 1957 A. G. FOX 2,794,959

DIRECTIONAL COUPLER FOR ALL-DIELECTRIC WAVEGUIDE

Filed March 1, 1952 3 Sheets-Sheet 1

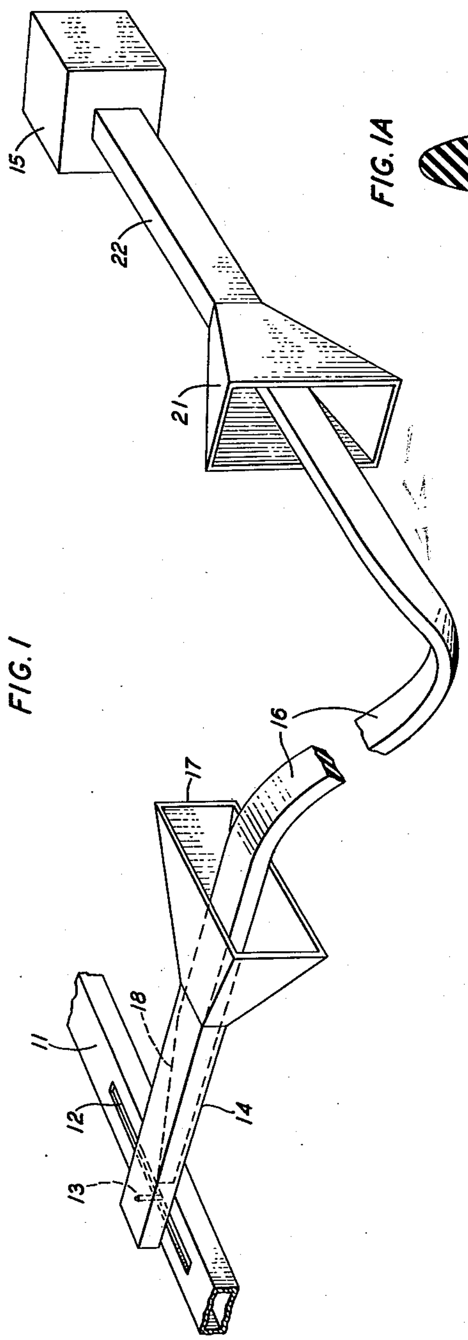



FIG. 1

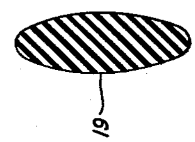



FIG. 1A

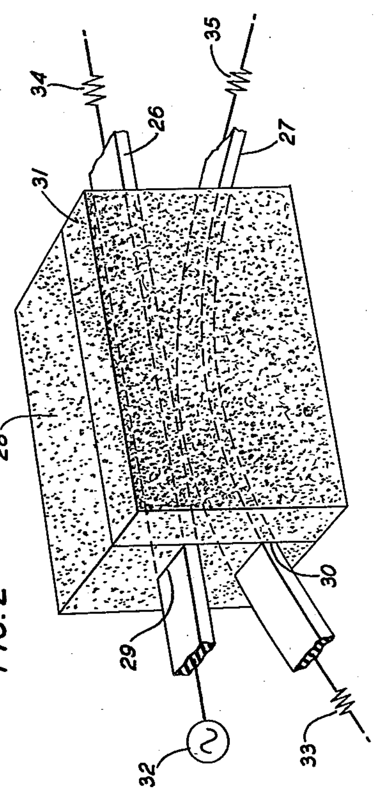



FIG. 2

INVENTOR
A. G. FOX
BY H. O. Wright
ATTORNEY

June 4, 1957 A. G. FOX 2,794,959

DIRECTIONAL COUPLER FOR ALL-DIELECTRIC WAVEGUIDE

Filed March 1, 1952 3 Sheets-Sheet 2

FIG. 3

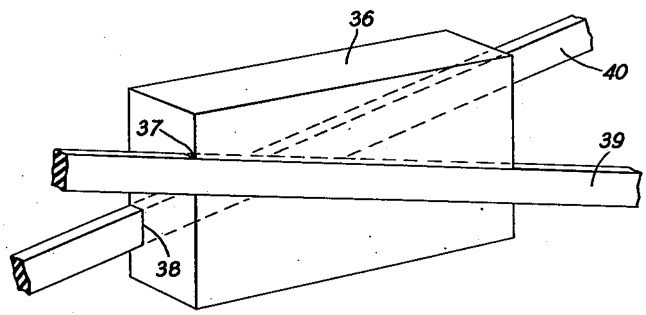



FIG. 4

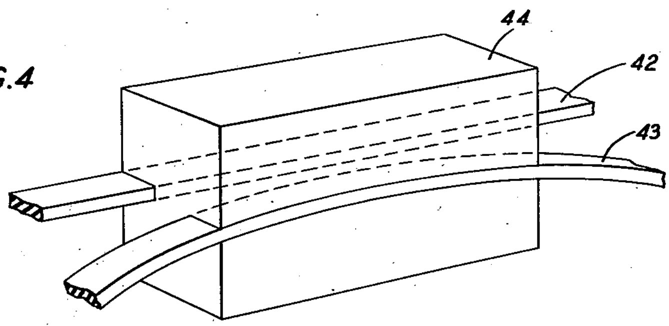
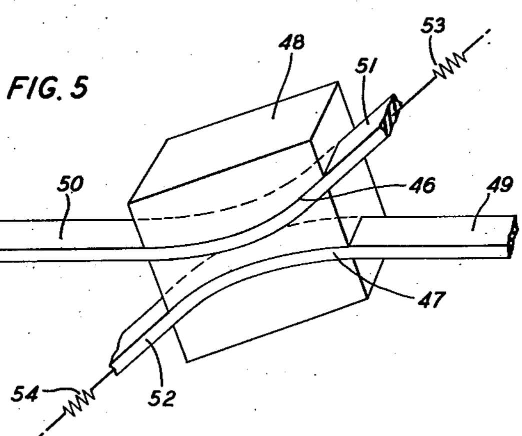



FIG. 5




INVENTOR
A. G. FOX

BY H. O. Wright
ATTORNEY

June 4, 1957 A. G. FOX 2,794,959

DIRECTIONAL COUPLER FOR ALL-DIELECTRIC WAVEGUIDE

Filed March 1, 1952 3 Sheets-Sheet 3

FIG. 6

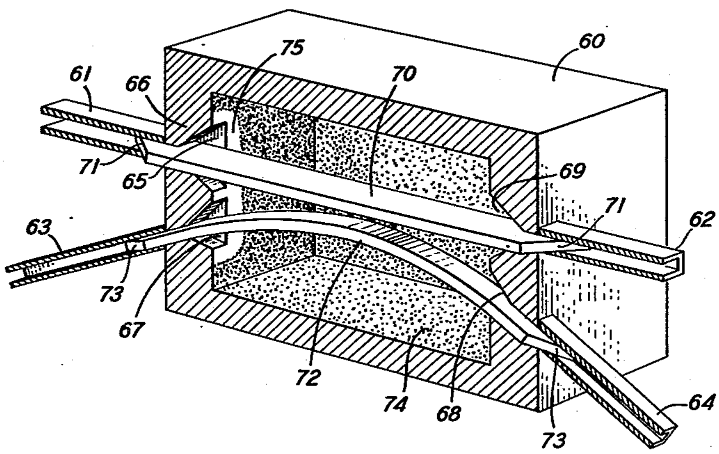
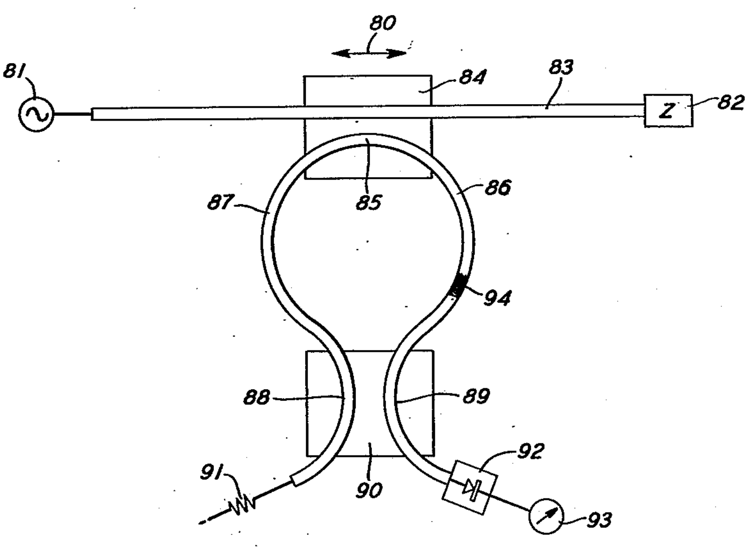



FIG. 7




INVENTOR
A. G. FOX
BY
H. O. Wright
ATTORNEY

# United States Patent Office

2,794,959
Patented June 4, 1957

1

2,794,959

## DIRECTIONAL COUPLER FOR ALL-DIELECTRIC WAVEGUIDE

Arthur G. Fox, Eatontown, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application March 1, 1952, Serial No. 274,313

12 Claims. (Cl. 333—10)

This invention relates to microwave transmission systems and, more particularly, to the transmission of wave energy having wavelengths of several millimeters along all-dielectric transmission elements.

It has been known for many years that electromagnetic wave energy may be guided along a transmission medium consisting solely of dielectric material, in other words, an all-dielectric medium as opposed to the more well known transmission media of the types either in which a longitudinal conductive shield is placed to surround the dielectric material or in which a conductive axial core is provided within the dielectric material. Some primary considerations of all-dielectric guided waves are disclosed in United States patents to G. C. Southworth, 2,129,711 and 2,460,401 granted September 13, 1948, and February 1, 1949, respectively. Investigation has indicated that the guiding effect is retained when using a very thin dielectric rod which may be only a fraction of a wavelength in diameter, a relationship which would produce a below cut-off condition in the ordinary shielded types of wave guide. In the case of the thin all-dielectric guide, however, a great portion of the guided wave energy is forced outside of the dielectric material into the space surrounding the guide and is thus not subject to its losses. For this reason the transmission attenuation of a thin all-dielectric guide is very low. Heretofore, however, transmission applications of these guides have been substantially limited to experimental installations in which the guide is rigidly held in a perfectly straight condition since bends in the all-dielectric guide or small amounts of movement thereof tend to increase the amount of power lost by degeneration from the desired mode of propagation into higher order spurious modes and likewise, and to some extent as a result of this degeneration, to increase the power lost by radiation from the guide.

It is, therefore, one object of the invention to transmit electromagnetic wave energy over flexible all-dielectric wave transmission media along a curved path.

In accordance with this object of the invention, the cross-sectional shape of the thin all-dielectric wave guide is particularly chosen, as will be shown, so that the desired mode of propagation therealong has a unique phase velocity, different from the phase velocity of other modes, to prevent mode degeneration and the resulting loss of wave power.

It is another object of the invention to directionally couple between two all-dielectric wave transmission paths.

The last-mentioned object of the invention is accomplished in the specific embodiments of the invention to be described by locating two all-dielectric transmission paths in the special manner to be disclosed to provide interaction between the fields surrounding each of the paths thereby obtaining directionally selective coupling between the paths. Particular features of this phase of the invention reside in the means for adjusting and varying the amount of coupling between the paths. A further feature resides in the means for adjusting and varying the precise point along one transmission path at which directional coupling to the other path is provided.

2

It is a further object of the invention to provide new and improved apparatus for measuring the standing-wave-ratio in all-dielectrically guided transmission systems and in other transmission systems.

This object of the invention is accomplished in the specific embodiment to be described by the novel combination of two directional couplers, at least one of which is of the type mentioned above with which the point of directional coupling of an auxiliary transmission path to the main transmission path may be varied. As this point is shifted along a longitudinal portion of the main path, the auxiliary transmission path samples the incident and reflected waves in the main transmission path. The incident and reflected waves are compared by the second directional coupler to obtain an indication of the standing-wave-ratio in the main transmission path.

These and other objects and features of the present invention, the nature of the invention and its advantages, will appear more fully upon consideration of the various specific illustrative embodiments shown in the accompanying drawings and of the following detailed description of these embodiments.

In the drawings:

Fig. 1 is a pictorial representation of a millimeter wavelength range microwave apparatus employing a flexible all-dielectric coupling element in accordance with the invention;

Fig. 1A represents an alternative cross-section, in accordance with the invention, for the all-dielectric coupling element of Fig. 1;

Fig. 2 is a perspective view of an all-dielectric directional coupler in accordance with the invention showing schematically the electrical connections thereto;

Fig. 3 shows pictorially a first alternative embodiment in accordance with the invention, of the directional coupler of Fig. 2;

Fig. 4 shows a second alternative embodiment, in accordance with the invention, of a directional coupler;

Fig. 5 illustrates pictorially a particular embodiment of directional coupler, in accordance with the invention, for electrically joining two all-dielectric wave guides;

Fig. 6 is a cut-away perspective view of an adjustable and shielded all-dielectric coupler according to a preferred embodiment of the invention; and

Fig. 7 represents in schematic diagram form a standing wave detector for all-dielectric wave-guide systems in accordance with the invention.

Fig. 1 illustrates how a flexible all-dielectric wave guide may be used to connect a fixed electromagnetic wave device to an electromagnetic wave device for which a certain degree of movement is required, such as a movable probe in a measuring system, for example, in a standing wave detector. This arrangement may be illustrated by a portion of a standing wave detector comprising a section of metallic wave guide **11** having a slot **12** through which a probe **13** projects for coupling to a second metallic wave guide **14**. As probe **13** is moved longitudinally along slot **12**, a dominant $TE_{10}$ mode wave is set up in guide **14** proportional to the amplitude of the electric field in guide **11** at the position of probe **13**. This energy is to be coupled to some electromagnetic wave device having a fixed position, illustrated on Fig. 1 by way of example, as detector **15**. At lower frequencies this connection might have been made by a conventional coaxial line or by one of the well known corrugated or vertebra types of wave-guide connections, but inasmuch as the present apparatus is contemplated as operating in the wave-length range of several millimeters, these well known connectors are not satisfactory. In accordance with the present invention, therefore, this connection is made by a flexible all-dielectric wave guide **16** comprising a flattened strip of dielectric material. In a specific embodiment, a strip of laminated polyflex has proven satisfactory. Any other material, however, having a dielectric constant substantially different from that of air or that of free space and therefore having a phase velocity for electromagnetic wave energy substantially different from the phase velocity of energy in free space may be used, for example, polyethylene and Teflon, to mention only several specific materials.

To couple the dominant mode energy in rectangular metallic guide **14** to dielectric guide **16**, the end of guide **14** is flared out into a rectangular horn **17**. Dielectric rod **16** is pushed through the horn to extend several wavelengths into guide **14**. The match between guide **14** and guide **16** is improved by providing a taper **18**, extending along several wavelengths of the portion of guide **16** within guide **14**. A similar arrangement comprising horn **21** and guide **22**, which may be identical to horn **17** and guide **14**, respectively, are provided at the other end of guide **16** to couple it to detector **15**. Thus, the dominant $TE_{10}$ mode in guide **14** is launched as a "dominant" wave upon dielectric guide **16**. This dominant wave is the lowest order hybrid electromagnetic wave whose transverse electric field pattern closely resembles that of the dominant TE wave in metallic shielded transmission lines. As in the case of metallic shielded line, there are an infinite number of the higher order waves which may be propagated along a dielectric guide **16**. However, such higher order waves are not closely bound to dielectric guides except for guides of relatively large diameter, and for such dielectric guides the attenuation of the dominant wave would approach that in the dielectric medium itself. In order to keep the attenuation low, it is preferable to use slender dielectric guides which will force a major part of the wave power into the surrounding space. For such guides the higher order waves are so loosely held that they are fairly easily stripped off by reflecting or absorbing objects along the length of the guide. Consequently, the higher order waves will not seriously interfere with the dominant mode transmission. It is interesting to contrast this with metallic shielded wave guides where in order to obtain low attenuation it is necessary to use shields of large cross-section where higher order waves do become troublesome. For the slender all-dielectric guides, conversion to higher order waves will generally represent a power loss from the dominant wave; while in the shielded guides, conversion to higher order waves means not only a loss for the desired wave but also the presence of unwanted waves which may subsequently be reconverted with deleterious effects.

Heretofore, dielectric rods of circular cross-section have been used to transmit wave power along a straight and rigid path. However, it has been found that if these rods are made flexible or bent along a curving path, an increased and substantial amount of wave power of the desired mode launched at one end of the curved all-dielectric guide with a specific plane of polarization is lost by degeneration into other modes polarized at a different angle to the original polarization which are not therefore of the polarization selected by a receiving means at the other end of the guide adapted to select the original polarization. For example, if such a circular guide is used to transmit dominant wave power from a transmitter to a receiver as in Fig. 1, an appreciable amount of the power will appear at the receiver with polarization at right angles to that which can be absorbed by the receiver. Such depolarization will cause a loss in transmission. In accordance with the present invention the transverse cross-section of all-dielectric guide **16** is provided with different orthogonal dimensions. As illustrated by way of specific example in Fig. 1, guide **16** is of rectangular cross-section having a long dimension thereof substantially three times the small dimension thereof. It has been found that the cross-sectional dimension of the guide determines the phase velocity of a wave polarized parallel to that dimension. Thus, a wave mode polarized parallel to one of the faces of the rectangular cross-sectional guide will have a phase velocity substantially different from every other mode. For example, the wave polarized parallel to the longer dimension of the cross-section is more closely confined to the guide than the wave polarized parallel to the short dimension. The former will, accordingly, have a lower phase velocity and a higher attenuation than the latter wave. Thus, when the desired dominant mode is launched in a specific polarity at one end of guide **16** polarized parallel to the short dimension thereof as illustrated in Fig. 1, it will propagate along guide **16** with the plane of polarization of the wave always following a plane of constant phase velocity. Since waves do not tend to couple or degenerate into modes having other phase velocities, the tendency to degenerate into modes of other polarities is reduced to a negligible amount. The polarity of the desired mode is maintained relative to a given face of guide **16** even when the guide is twisted and/or bent along a curving path. In an actual embodiment of the invention, which has been reduced to practice at a wavelength of 6 millimeters, a 76 centimeter length of all-dielectric wave guide having cross-sectional dimensions of 0.188 inch by 0.062 inch was bent in a 90 degree circular arc in the electric plane with no measurable loss in transmission. A 180 degree bend in the same plane increased the transmission loss not more than 0.1 decibel. With the strip straight but twisted 90 degrees about its longitudinal axis, there is no measurable increase in transmission loss. With a 90 degree circular arc in the magnetic plane and simultaneously a 90 degree twist, there is no measurable increase in the transmission loss. Several inches of transverse motion of one end, more than ample for the standing wave detector of Fig. 1, produced no noticeable effect on the detector reading.

While the all-dielectric guide **16** of Fig. 1 has been illustrated as having a rectangular cross-section, it should be kept in mind that the principal consideration of the cross-sectional shape requires that the guide have different orthogonal transverse dimensions in any given cross-section so that the phase velocity of dominant wave energy polarized parallel to one of these dimensions is substantially different from the phase velocity of dominant wave energy polarized orthogonal thereto. Thus oblong or elliptical cross-sections such as the cross-section of guide **19** represented in the alternative cross-sectional view of Fig. 1A may be used if the lengths of the major axes thereof are different. Long slender guides of these cross-sections are easier to make by presently known methods of manufacturing, such as extruding. With any of these cross-sections, there will be two principal polarizations for the dominant wave, one polarized along the maximum and the other polarized along the minimum dimension of the cross-section. Since the phase velocities of these two waves are greatly unequal, no appreciable cross-talk would be developed between them by any existing distributed coupling along the guide. Thus a rectangular, elliptical or oblong cross-sectional, all-dielectric wave guide may be used to simultaneously transmit or receive two dominant waves polarized at right angles to each other. It should be noted that when these alternative cross-sectioned shapes are employed, the horn means for launching the energy upon the guide, corresponding to horns **17** and **21** of Fig. 1, should have a cross-sectional shape consistent with the cross-sectional shape of the guide.

Fig. 2 illustrates a specific embodiment of directional coupler, in accordance with the invention, for coupling between two all-dielectric transmission paths. The coupler includes a main transmission path which can be a straight strip **26** of all-dielectric wave guide of the type hereinbefore described with reference to Fig. 1, and an auxiliary transmission path which can be a smoothly curved portion of a strip 27 of similar material which arches into proximate relation to a portion of strip or guide 26. Guide 26 and guide 27 should preferably have equal propagation velocities for electromagnetic wave energy of any frequency and this may be obtained if the guides are of materials having equal dielectric constants and having the same cross-sectional dimensions. As illustrated the corresponding narrow faces of each of strips 26 and 27 are in the same plane, while the transverse dimensions of the wider faces thereof are parallel.

While guides 26 and 27 may be held in this relative position in numerous ways, Fig. 2 illustrates one particularly novel means comprising a block 28 of any material having a low loss and a low dielectric constant substantially close to that of air and, therefore, substantially different from the dielectric constant of the material of guides 26 and 27. Block 28 has a straight slot 29 therein into which guide 26 is pressed and a curving slot 30 into which guide 27 is pressed. A suitable substance for block 28 is foamed polystyrene material. A sheet 31 of similar material may be suitably fastened across the slotted face of block 28. The forward and backward ends of both the main and auxiliary paths may be coupled by horns similar to horn 17 of Fig. 1 to related metallic wave-guide systems and the device of Fig. 2 can then serve the functions therein for which the prior art directional couplers are employed. Such connections are represented schematically on Fig. 2 by a source of signal energy 32 coupled to the backward end of guide 26, a useful load 34 coupled to the forward end thereof, and by matched loads 33 and 35 coupled to the backward and forward ends, respectively, of guide 27.

As pointed out hereinbefore, a substantial amount of wave power is carried in the space surrounding each guide particularly if the cross-sectional dimensions of guides 26 and 27 are small compared to the wavelength of energy propagated thereover. Thus, when guides 26 and 27 are brought into proximate physical relationship, the fields carried by the guides interact to produce electromagnetic coupling between the two dielectric paths. The amplitude of this coupling is inversely proportional to the distance between the guides. Therefore, the physical relationship between guides 26 and 27 produces a distributed and tapered coupling which gradually decreases from maximum coupling at the center of the coupling region to an infinitesimal coupling at points where the guides are separated by a larger amount.

In the copending application of S. E. Miller, Serial No. 216,132, filed March 17, 1951, which matured into United States Patent 2,701,340 on February 1, 1955, it is demonstrated in detail that a distributed tapered coupling between two related transmission paths provides broad band directionally selective coupling between the paths. It is also demonstrated therein that the power transmitted between the paths varies cyclically as the sine or cosine function of the product of the amplitude of coupling per unit length times the distance over which the coupling is maintained. The same principles of analysis are applicable to the present invention.

Thus, the spacing between guides 26 and 27 is chosen to determine the amplitude of coupling, which in turn determines the amount of power transferred between the guides. As auxiliary guide 27 is brought closer to guide 26 with electromagnetic wave energy applied from a source represented by 32 to the backward terminal of the main line of the coupler, i. e., the left-hand end of guide 26, the power transferred to the forward terminal of guide 26 to load 34 gradually drops to zero at which time most of the power will be found in the forward terminal of guide 27 for transmission to load 35. Substantially none of this power appears in the backward terminal of guide 27. Bringing the guides closer causes the power in the forward terminal of guide 26 to increase and the power in the forward terminal of guide 27 to



decrease again to zero. This cycle may be repeated several times before contact is made between guides 26 and 27 at their center point. By altering the spacing, therefore, between guides 26 and 27 any coupling ratio may be obtained. In a particular embodiment of the invention which has been reduced to practice at the frequency and with dielectric guides of the dimensions already detailed, a minimum spacing of one-half centimeter between the center points with guide 27 bent in a 12 inch radius was found to provide a 3 decibel coupling loss, i. e., equal division of power in the forward direction in both guides, and a directivity of well in excess of 30 decibels.

Fig. 3 illustrates an alternative directional coupler in accordance with the invention. As shown the supporting block 36 of polyfoam is provided with two straight slots 37 and 38, one in each of the opposite faces thereof. The axes of each of the slots lie, respectively, in planes which intersect each other at an acute angle along a line perpendicular to the slotted faces of block 36. Into these slots are pressed the all-dielectric wave guides 39 and 40 similar in all respects to guides 26 and 27 of Fig. 2. The maximum point of coupling between the guides is at said line of intersection and the degree of coupling is determined by the distance between guides 39 and 40 as measured along this line. By varying the angle of intersection the degree of taper of the distributed coupling and the length thereof may be adjusted.

In both Figs. 2 and 3 the dielectric guides are coupled in the electric plane, in other words, the wider faces of each of the rectangular all-dielectric guides are brought into contiguous relation in the region of coupling. Fig. 4 illustrates an embodiment of the invention in which the all-dielectric guides are coupled in the magnetic plane. Thus, in Fig. 4 a straight strip 42 and a smoothly curved strip 43 of all-dielectric wave guide are supported by block 44 with the corresponding narrow faces of each parallel and with the wider faces of guide 43 tangent, respectively, to the planes of the wider faces of guide 42. The maximum degree of coupling between the guides is thus determined by the spacing distance between adjacent narrow faces measured parallel to these planes of tangency.

An important feature of each of the directional couplers illustrated in Figs. 2, 3 and 4 resides in the fact that the precise point along one or both of the paths at which the effective electrical point of directional coupling is obtained may be varied easily and at will. This feature was never found in the prior art metallic shielded transmission lines for which the point of coupling was substantially unalterably determined by the position of the slots, apertures or openings which were cut or otherwise formed in contiguous portions of the respective shields of the coupled lines.

According to the present invention, however, either or both of the component dielectric wave guides of the directional coupler may be slideably contained in the slots of the supporting block. Thus, for example, in Fig. 2, block 28 may be moved along the path between source 32 and load 34, guide 26 sliding within slot 29 so that guide 27, carried along with block 28, may be caused to couple to guide 26 at any point between source 32 and load 34. Such adjustment may be made during operation while one or both of the guides are supporting electromagnetic wave energy. The particular application of this feature will be demonstrated hereinafter in connection with Fig. 7.

Any of the above-disclosed directional couplers when adjusted for maximum transmission of the power between the lines may serve as a means for electrically joining two dielectric guides having the same phase velocity when it is otherwise difficult to physically weld or suitably join two sections of dielectric wave guide. In Fig. 5 an embodiment of the invention particularly suitable for this purpose is shown which is similar in many respects to that of Fig. 2 except that the related all-dielectric wave guides 46 and 47 are each smoothly curved and held in position by slots in supporting block 48 so that the axis of the output end 49 of guide 47 lies along the axis of the input end 50 of guide 46. Thus, when the spacing between guides 46 and 47 is adjusted for maximum power transfer therebetween, end 50 is effectively coupled to end 49 for power transmission in either direction. Ends 51 and 52 of guides 46 and 47 are match-terminated in reflectionless impedance means 53 and 54, respectively, to avoid reflection of any small amount of power that may not be coupled.

While the directional couplers described with reference to the above figures are satisfactory for many applications, it is possible that even a small radiation of power may cause interference or cross-talk in certain systems in which these couplers are employed. In accordance with the embodiment of Fig. 6, such radiation is prevented while the simplicity of dielectric guide coupling is preserved. The directional coupler of Fig. 6 comprises a hollow metal structure 60 forming a chamber having four metal wave-guide terminals 61, 62, 63 and 64. Guides 61 and 62 open from opposite walls of the chamber and are axially aligned. Guides 63 and 64 open from opposite walls of the chamber and are each substantially directed toward a common point on the axis of guides 61 and 62. Each of the four guides terminates in a horn, the interior surface area and shape of which may be similar to that of horn 17 of Fig. 1. For example, guide 61 may terminate at the apex of a pyramidal-shaped depression 65 integrally machined in the interior wall 66 of structure 60. Similar horns or depressions 67, 68 and 69 are provided for guides 62, 63, 64, respectively, each of which is symmetrically arranged about the axis of its associated guide, and are provided for launching dielectric waves within the chamber. An all-dielectric wave guide 70 having tapers 71 at each of its ends passes through chamber 60 with one end thereof pushed within guide 61 and horn 65 and the other end within guide 62 and horn 69. A second all-dielectric guide 72, having the same cross-sectional dimensions as guide 70 and having tapers 73 at each of its ends, passes in a smoothly curved arch through chamber 60, the center portion of the arch being contiguous to the center portion of guide 70. One end of guide 72 is pushed within guide 63 and horn 67, and the other end within guide 64 and horn 68. As illustrated on Fig. 6, guides 70 and 72 are coupled in the electric plane similar to the guides of Fig. 2, but it should be noted that the guides 70 and 72 may also be coupled in the magnetic plane as illustrated in Fig. 4. The tapers 71 and 73 at the ends of the dielectric guides 70 and 72 afford a good match between the dielectric guides and the metallic guide sections 61, 62 and 63, 64, respectively. It is thus possible to move either end of dielectric guide 72 along the terminating metallic wave guides 63 or 64 without influencing the transmission of wave energy between guide 63 and guide 72 or between guide 64 and guide 72. Consequently, if the dimensions of chamber 60 are chosen so that dielectric guide 72 is approximately the correct distance from dielectric guide 70, fine adjustment in this spacing and consequent fine adjustment of the coupling factor between guides 70 and 72 can be easily made by moving either end of guide 72 along its metal launching wave guides 63 or 64. Such motion will cause guide 72 to move closer or farther away from guide 70 and thus alter the coupling factor between guides 70 and 72 so as to produce any desired power transmission from guide 72 to guide 70 in accordance with the principles already defined. In order to avoid resonance effects within chamber 60, the interior surfaces thereof are lined with an absorbing material 74 which may be, for example, a coating of carbon material, with the exception of a portion of the interior surfaces in the vicinity of dielectric guides 70 and 72 and particularly in the area surrounding the launching horns 65, 67, 68 and 69 as represented for example by area 75 surrounding horns 65 and 67. This area 75 should be large enough so that the resistive material 74 will not intercept any appreciable part of the wave energy normally propagated along guides 70 or 72.

Fig. 7 represents, in schematic diagram form, a standing wave detector for all-dielectric wave-guide systems by which the incident power delivered by dielectric guide 83 from source 81 to load 82 may be compared with power reflected back to source 81 by load 82, and to therefore determine the degree of impedance match between the impedance Z of load 82 and the characteristic impedance of guide 83. Clearly, the prior art movable probe system represented in Fig. 1 would not be satisfactory to sample the incident and reflected waves in a guide of solid dielectric construction such as guide 83. In accordance with the invention, however, a first dielectric directional coupler 84, which may be a structure of any of the types illustrated with reference to Figs. 2, 3 or 4 hereinbefore, in which guide 83 is the main transmission path slideably supported relative to the auxiliary transmission path comprising guide 85, performs the necessary sampling function. Thus, guide 85 may be moved longitudinally along guide 83, as represented by arrow 80, to vary the point of electrical coupling therebetween. The spacing between the auxiliary transmission path and the main transmission path of coupler 84 is adjusted as hereinbefore pointed out so that only a small sample of incident wave power in guide 83 is transferred to the forward arm 86 of coupler 84, and a like small sample of the reflected wave is transmitted to the backward arm 87 thereof.

Continuations of arms 86 and 87 are brought together as the coupled dielectric guide components 88 and 89, respectively, of a second all-dielectric directional coupler 90. The spacing between guides 88 and 89 is chosen, as pointed out hereinbefore, to provide a directional coupler having a 3 decibel coupling factor giving equal power division between the two forward arms thereof. The forward arm of guide 88 is terminated in a matched load 91. The forward arm of guide 89 is connected to a matched detector means 92, the output of which is registered by metering means 93.

In operation of the standing wave detector of Fig. 7, the sample of the forward wave will appear in arm 86 and pass to coupler 90 where it will divide substantially equally between load 91 and detector 92. The sample of the backward wave will appear in arm 87 and pass to coupler 90 to likewise divide substantially equally between load 91 and detector 92. The component of each wave appearing in load 91 will be dissipated. Thus, detector 92 measures a quantity proportional to the sum of the forward and reflected wave samples much as does the probe in the prior art standing wave detector arrangements. When the entire loop assembly, including guide 85 is translated back and forth along guide 83, the magnitudes of the incident and reflected waves arriving at detector 92 will not vary, but their phases will change and the result will be a series of maxima and minima readings on meter 93 corresponding to the maxima and minima amplitudes of the standing wave in guide 83. To calibrate the standing wave detector of Fig. 7, guide 83 may be terminated in a completely reflecting termination such as a metallic plate placed normal to dielectric guide 83 and observing the depths of the minima as guide 85 is moved relative to guide 83. These minima points will be zero if the magnitudes of the incident and reflected wave components at detector 92 are equal. If the minima do not reach zero either the coupling factor of coupler 90 may be adjusted or attenuation may be inserted in the proper guide 86 or 87 to make the two components at detector 92 equal. Fig. 7 illustrates how suitable attenuation may be inserted in guide 86 by a strip of resistance paint 94, for example carbon particles suspended in a suitable binder, applied to the surface of dielectric guide 86, to dissipate a portion of the wave power carried in the field surrounding the guide.

By coupling the forward and backward ends of guide 83 by horns similar to horn 17 of Fig. 1 to related metallic wave-guide systems, the apparatus of Fig. 7 may be used to measure the standing wave ratio in these systems. Its application is not, therefore, limited solely for use in all-dielectric wave-guide systems.

In all cases it is understood that the above-described arrangements are simply illustrative of a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Numerous and varied other arrangements can be readily devised in accordance with said principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A microwave directional coupler comprising a first and a second strip of flexible all-dielectric material constituting first and second electromagnetic wave transmission paths, respectively, said all-dielectric strips being unsheathed whereby a portion of the wave energy conveyed by either of said strips is propagated in a field surrounding said strip and extending away therefrom for a given distance, at least one of said strips having a smoothly curved portion of its length arching into proximate relationship to a portion of the length of the other of said strips such that said portion of one of said strips lies within said field surrounding said portion of the other of said strips to provide a region of coupling between said paths in which the coupling gradually increases from one end of said region to the center thereof, and any given transverse cross section of said curved portion of said strip having different orthogonal dimensions.

2. Microwave coupling apparatus comprising two pairs of wave-guide terminals, and a pair of elongated dielectric members each extending between a respective pair of said terminals, said dielectric members being unsheathed whereby a portion of wave energy conveyed by each of said members is propagated in a field surrounding said member with the major portion of said surrounding field extending away from said member for a given finite distance, at least one of said members being bent in the direction towards the other of said members along a path of longer length than the length of the direct path between the respective terminals of said one member, said members being spaced apart over an interval of their lengths by a distance less than the sum of said given finite distances wherein said major portions of said surrounding fields extend away from said members, and at least said bent member having different orthogonal dimensions in any given transverse cross section.

3. The combination according to claim 2, wherein at least one end of said one member slideably protrudes within its associated wave-guide terminal to vary the length of said first-named path for adjusting the spacing between the center portions of said pair of members.

4. The combination according to claim 2, including a conductive enclosure surrounding said dielectric members and forming a cavity into which said two pairs of wave-guide terminals open.

5. The combination according to claim 2, wherein both of said members have substantially identical rectangular transverse cross-sections providing each of said members with corresponding wide and narrow faces respectively, and wherein said members are at least partially embedded in a block of dielectric material having a dielectric constant substantially less than that of either of said members, with said corresponding narrow faces in the same planes and with corresponding transverse dimensions of said wider faces parallel.

6. The combination according to claim 2, said members being embedded in a block of dielectric material having a dielectric constant substantially less than that of either of said members, wherein at least one of said members is slideably embedded in said block.

7. In combination, first and second electromagnetic wave devices, a curved strip of flexible all-dielectric material connecting said devices and conforming to a curving path, said all-dielectric strip constituting an electromagnetic wave energy transmission path between said devices with a substantial portion of said wave energy that is conveyed by said strip propagating in an electromagnetic field surrounding said strip, said strip having different orthogonal transverse dimensions in any given cross-section whereby the phase velocity of wave energy polarized parallel to one of said dimensions is substantially different from the phase velocity of a wave polarized orthogonal thereto to prevent mode degeneration between said orthogonal polarizations.



8. In combination, a first strip of all-dielectric material constituting an electromagnetic wave energy transmission path wherein a portion of wave energy conveyed by said first strip is propagated in a field surrounding said strip, and extending away therefrom for a given distance, a second strip of all-dielectric material, a first portion of the length of said second strip disposed within said field surrounding a portion of said first strip and adapted for longitudinal movement along a length of said first strip, the two portions of said second strip on either side of said first portion being brought together in proximate physical relationship, at least said second strip having different orthogonal dimensions in any given transverse cross section, a reflectionless impedance terminating one end of said second strip, and a detector means terminating the other end of said second strip.

9. In combination, a source of electromagnetic radiations having a predetermined wavelength less than ten centimeters, a first elongated flexible strip of dielectric material constituting a first electromagnetic wave energy transmission path coupled to said source, said first strip having one cross-sectional dimension substantially greater than the other, said one dimension being a small fraction of said predetermined wavelength, said first dielectric strip being unsheathed whereby a portion of said wave energy conveyed by said first strip is propagated in a field surrounding said strip and extending away therefrom for a given finite distance, a second elongated flexible strip of dielectric material having one orthogonal cross sectional dimension substantially greater than the other, said second strip having a first portion in adjustable arcuate proximity to said first strip, said second strip being similarly unsheathed, the respective fields surrounding said first and second strips being in an overlapping relationship to each other in the region of said arcuate proximity, a supporting structure for retaining said two strips in their coupling proximity with each other, and a second portion of said second strip secured to microwave equipment which is movable with respect to said supporting structure.

10. In a microwave coupling device, an electromagnetic wave device, a structure defining an electromagnetic wave transmission path, an unsheathed elongated flexible strip of dielectric material having one transverse cross-sectional dimension substantially greater than the other, said dielectric strip constituting an electromagnetic wave energy transmission path with a substantial portion of said wave energy that is conveyed by said strip propagating in an electromagnetic field surrounding said strip, one portion of said strip being connected so as to couple electromagnetic wave energy from or to said electromagnetic wave device, and a second portion of said strip being curved and movable with respect to said first portion, said second portion being connected so as to couple electromagnetic wave energy from or to said structure defining an electromagnetic wave transmission path.

11. A microwave device as defined in claim 10 wherein the second portion of said strip is also movable with respect to said structure defining a transmission path.

12. A microwave device as set forth in claim 10 in which said structure defining a transmission path is a second unsheathed elongated strip of dielectric material, said second strip propagating a portion of the wave en-

ergy it supports in a field surrounding itself, the major portion of said surrounding field extending away from said second strip a given finite distance, a portion of said second strip being disposed in coupling proximity to said other strip wherein said curved portion of said other strip lies within said given finite distance from said second strip.


**References Cited** in the file of this patent

UNITED STATES PATENTS

| | | |
|---|---|---|
| 1,859,390 | Green | May 24, 1932 |
| 2,129,711 | Southworth | Sept. 13, 1938 |
| 2,197,123 | King | Apr. 16, 1940 |
| 2,511,896 | Bingley | Jan. 20, 1950 |
| 2,562,281 | Mumford | July 31, 1951 |
| 2,575,571 | Wheeler | Nov. 20, 1951 |
| 2,580,678 | Hansen | Jan. 1, 1952 |
| 2,595,078 | Iams | Apr. 29, 1952 |
| 2,613,270 | King | Oct. 7, 1952 |
| 2,617,880 | Iams | Nov. 11, 1952 |
| 2,625,605 | Chandler | Jan. 13, 1953 |
| 2,636,148 | Gorham | Apr. 21, 1953 |

OTHER REFERENCES

Publication: "A New Type of Wave Transmission," Wireless Engineer, June 1936, vol. XIII, No. 153, pages 291–93. (Copy in Patent Office Library.)