

March 23, 1948.

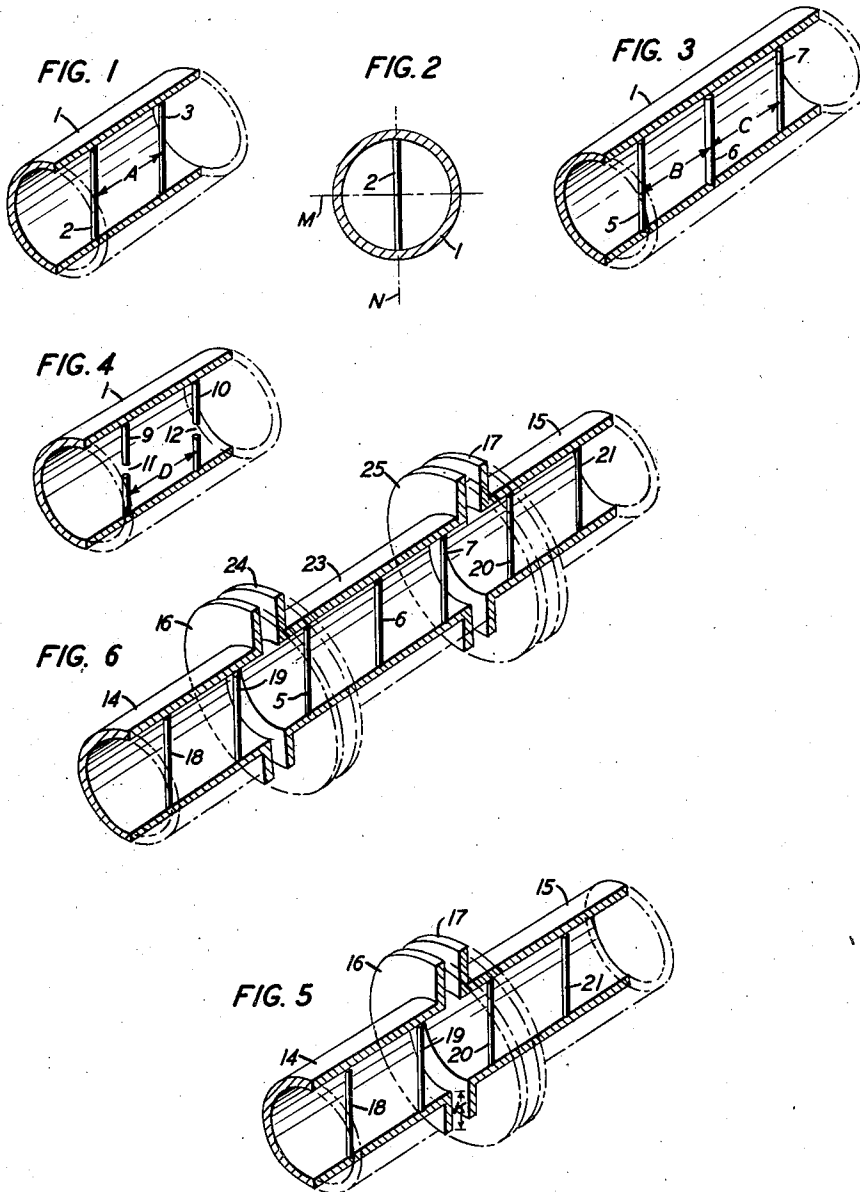
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2,438,119

WAVE TRANSMISSION

Filed Nov. 3, 1942

3 Sheets-Sheet 1



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FIG. 7

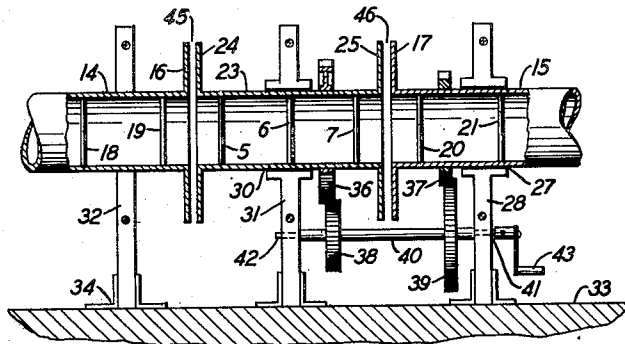


FIG. 8

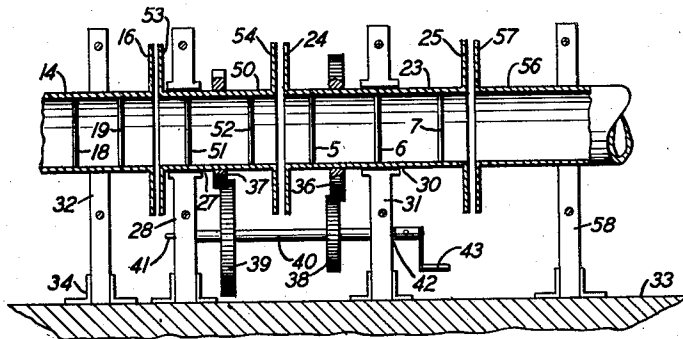
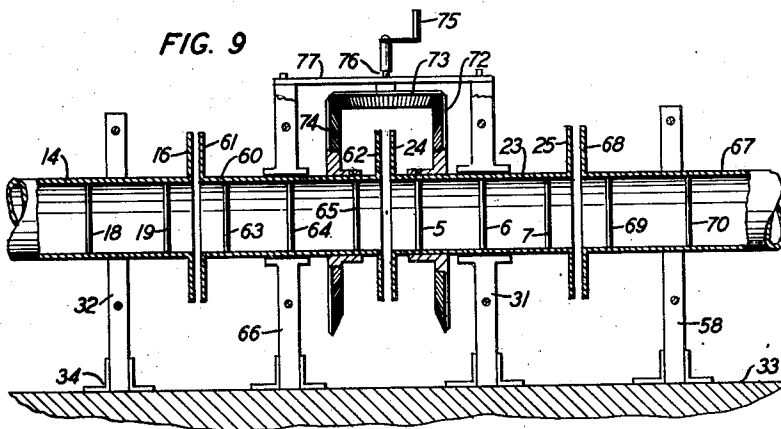


FIG. 9



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FIG. 10

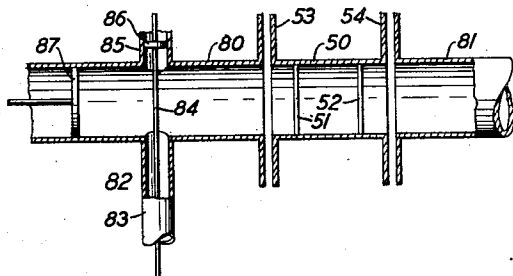


FIG. 11

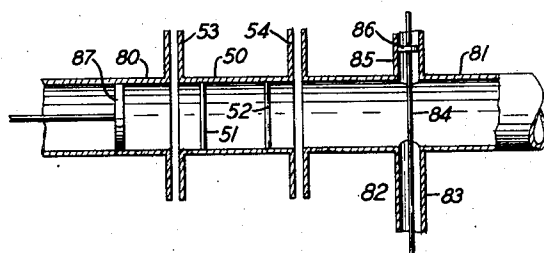


FIG. 12

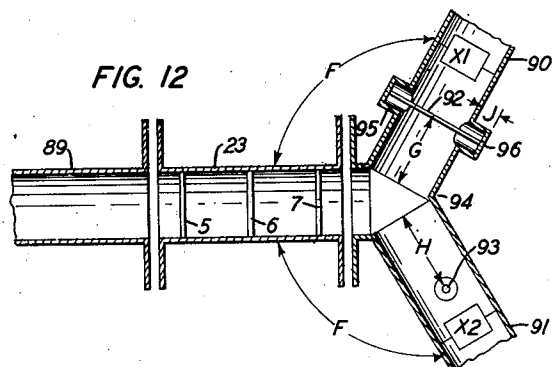
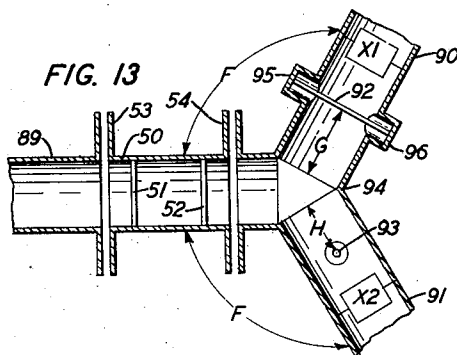


FIG. 13



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2,438,119

WAVE TRANSMISSION

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46 Claims. (Cl. 178—44)

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This invention relates to the transmission of guided electromagnetic waves and more particularly to phase changing devices for use in such transmission.

An object of the invention is to shift the phase of a guided electromagnetic wave through either a fixed or a variable angle, which may be either leading or lagging.

Another object is to permit a wave guide to be rotated at a rotary joint either without changing the phase or without changing the polarization of the wave transmitted therethrough.

A further object is to separate guided waves in accordance with their polarization.

It is known that a uniform metallic sheath with or without a dielectric filler may be used to guide suitable electromagnetic waves. In cross section the sheath may be circular, rectangular or of any other shape. For all frequencies above a minimum, known as the cut-off frequency, the guide behaves like a transmission line and has a specific propagation constant and characteristic impedance. For any particular frequency there are an infinite number of cross-sectional sizes and shapes of guide which will have the same characteristic impedance.

It is often desired to shift the phase of a polarized electromagnetic wave through a fixed or a variable angle, as it passes a particular point in a guide. In accordance with the invention there is provided an efficient phase shift section suitable for this purpose comprising a section of wave guide having therein a plurality of polar shunt reactive elements spaced apart from each other. By a proper choice of the sign and magnitude of the reactance, and the spacing interval, any desired phase shift, either leading or lagging, may be provided. For a leading phase shift the reactances should be inductive and for a lagging phase shift they should be capacitive at the frequency of interest. A suitable polar inductive element for a wave guide of circular cross section is a diametral rod. The element may be made capacitive by providing a gap at the center of the rod. Two or more reactances may be used, depending upon the over-all phase shift desired.

An application of the invention is to a rotary joint. A 90-degree phase shift section on the input side produces a circular polarization of the wave as it passes through the joint. A second 90-degree section on the output side is oriented to produce a linearly polarized wave parallel to the polarization of the terminating equipment. Rotation of the joint will, therefore, not change

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the alignment of the wave entering the receiver.

A variable phase changer may be provided by using two 90-degree phase shift sections with a rotatable 180-degree phase shift section interposed therebetween. This system may also be used as a rotary joint to transmit a linearly polarized wave from a fixed source to a rotating load without change of phase with rotation. To accomplish this, one 90-degree phase shift section is associated with the source, the other 90-degree section is associated with the load and arranged to rotate with it, and the 180-degree section is geared to the load in such a way that the 180-degree section rotates with an angular velocity which is one-half that of the load. This last described system will also operate satisfactorily if the two 90-degree sections are omitted.

Another type of variable phase changer comprises a 90-degree section associated with a fixed source, followed by a 90-degree rotatable section and a 180-degree rotatable section. Now if the rotatable 90-degree section is geared to the 180-degree section so that the latter rotates through one-half the angle of the former the system will deliver at its output a wave which may be changed in phase without a change in polarization.

An alternative system for introducing an adjustable phase shift without change in polarization comprises a 90-degree section associated with the fixed source, a second 90-degree section associated with the fixed load and two 180-degree sections interposed therebetween. The two 180-degree sections are so geared that they may be rotated in opposite directions through equal angles.

A 90-degree phase shift section may be used in a semi-reflecting system to convert a wave from linear to elliptical or circular polarization. For example, a wave guide may be fed at some point by either a coaxial line or another wave guide. A reflector is placed in the main guide at an adjustable distance from the point of feed and the phase shift section is located either between the reflector and the point of feed or on the other side of the point of feed.

A rotatable 180-degree phase shift section may be used in a wave guide to switch linearly polarized waves as desired from one to another of two branching wave guides having selective devices therein. If the 180-degree section is replaced by a 90-degree section the system will convert a wave from circular to linear polarization and

switch it to one or the other of the branches, de-

pending upon the direction of rotation of the original wave.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 is a perspective view, partly cut away, of a phase shift section using two inductive reactances to provide a leading phase shift;

Fig. 2 is an end view of the phase shift section of Fig. 1, with the principal electrical axes indicated;

Fig. 3 shows a phase shift section similar to that of Fig. 1 but using three inductive reactances;

Fig. 4 is a perspective view, partly cut away, of a phase shift section using two capacitive reactances to provide a lagging phase shift;

Fig. 5 is a perspective view, partly cut away, of a rotary joint on either side of which is a phase shift section of the type shown in Fig. 1;

Fig. 6 is a perspective view, partly cut away, of a variable phase changer using two sections of the type shown in Fig. 1 and an interposed rotatable section of the type shown in Fig. 3;

Fig. 7 is a side view, partly in section, of a system for transmitting without phase shift a linearly polarized wave from a fixed source to a rotating load;

Figs. 8 and 9 are side views, partly in section, of alternative systems for varying the phase shift without changing the polarization of a wave transmitted from a fixed source to a fixed load;

Figs. 10 and 11 are sectional views of alternative semireflecting systems using phase shift sections to convert a wave from linear to elliptical or circular polarization;

Fig. 12 is a cross-sectional view of a system using a rotatable 180-degree phase shift section to switch linearly polarized waves from one to another of two branches; and

Fig. 13 is a cross-sectional view of a system using a rotatable 90-degree phase shift section to switch circularly polarized waves from one or another of two branches.

Taking up the figures in more detail, Fig. 1 is a perspective view and Fig. 2 an end view of a phase shift section in accordance with the invention comprising a section of metallic wave guide 1 of circular cross section having therein two polar shunt reactive elements 2 and 3 spaced apart a distance A. As shown, the elements 2 and 3 are of the inductive type and are constituted by two parallel metallic diametral rods extending across the guide 1.

When a section of the type shown in Fig. 1 is properly adjusted, it has the property of retarding or advancing dominant transverse electric waves whose electric field is parallel to the elements 2 and 3, so that the phase of such waves after passing through the section will lag or lead the corresponding phase they would have had if the reactive elements 2 and 3 were not present. On the other hand, waves whose electric field is perpendicular to the reactive elements will not be affected by their presence. If symmetric or non-polar shunt reactances, such as, for example, transverse partitions with circular apertures, were used in place of the rods 2 and 3, the waves would undergo the same phase shift on passing through the section, regardless of their polarization. In contradistinction to this type, the phase shift sections referred to hereafter embody polar reactances, and the total phase shift of the trans-

mitted waves will depend upon their initial polarization. In general, there will be one angle of polarization for which transmitted waves will suffer the greatest total amount of phase shift. There will be another polarization at right angles to the first for which waves will suffer the least total amount of phase shift on passing through the section. These two polarizations determine the principal electric axes of the section, indicated by the dot and dash lines M and N in Fig. 2. Such a section corresponds closely to the doubly refractive plates used in optics.

The number of electrical degrees net phase shift which is used hereinafter to designate these sections refers specifically to the difference between the total phase shifts suffered by waves of the two principal polarizations. In the case where the shunt reactances have no effect on one polarization, the net phase shift will be the number of electrical degrees by which the reactances alter the total phase shift of waves of the quadrature polarization. Whether this net phase shift is leading or lagging depends fundamentally upon whether the reactances decrease or increase the effective length of the section. Capacitive shunt reactances increase the effective length while inductive shunt reactances decrease the effective length.

The magnitude of the desired phase shift determines the required reactances of the rods 2 and 3 which, in turn, are largely dependent upon the diameters of the rods. Once these diameters have been chosen, the spacing A between the rods 2 and 3 is determined by the wave-length to be transmitted. In practice it will usually be found that the final adjustment of the section is best made on an empirical basis. Two rods 2 and 3 of approximately the same diameter are assembled in the guide 1 and the spacing A is adjusted until resonance is obtained as indicated by maximum transmission and minimum reflection of power. The phase shift of the section is then measured. If this is too large the diameters of the rods 2 and 3 are reduced; if too small, the diameters are increased. The spacing A is again adjusted if required. These two steps are repeated, alternately, until the desired phase shift is obtained, with maximum transmission. As an example, the phase shift section of Figs. 1 and 2 may be designed and adjusted to provide a leading net phase shift of 90 degrees in which case the spacing A will be approximately equal to $\frac{3}{8}\lambda$, where λ is the wave-length within the guide at the frequency of interest.

Theoretically a pair of shunt reactive elements are capable of producing any phase shift from zero to 180 degrees, either leading or lagging. Practically, however, considerations of band width and transmission efficiency will limit the maximum useful phase shift to considerably less than 180 degrees. Where phase shifts of around 180 degrees or more are required, they may be obtained through the use of several sections of the type shown in Fig. 1, arranged in tandem, with all reactance elements parallel. If the spacing between sections is reduced to zero, it is evident that the end reactance elements of adjacent sections may be merged into common elements. Fig. 3 shows, for example, the combination of two such sections. The end diametral rods 5 and 7 will ordinarily have the same diameter, while the intermediate rod 6, which should have approximately only half the impedance of the end rods 5 and 7, will have a somewhat larger diameter. The distances B

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and C between the central rod 6 and the end rods 5 and 7, respectively, will ordinarily also be equal. This section may, for example, be designed to have a phase shift of 180 degrees, in which case each of the spacings B and C will be approximately equal to $\frac{3}{8}\lambda$.

The section shown in Fig. 3 is fundamentally a band pass filter. When adjusted as described above, the peak of transmission and the desired phase shift will occur at only one frequency. However, by readjusting the shunt reactances and their spacings, a band-pass characteristic may be obtained which will result in electrical characteristics for the phase shift section which are much less sensitive to frequency. It is, therefore, possible to attain a phase shift of any number of degrees in a section using a plurality of polar shunt reactances so adjusted as to produce a wide and substantially uniform transmission band, with low attenuation in the band.

For a lagging phase shift the reactances should be capacitive at the frequency of interest. Fig. 4 shows, for example, two capacitive elements 9 and 10 spaced apart a distance D in a circular guide 1. The elements 9 and 10 are parallel to each other and each is similar to the diametral rods 2 and 3 of Fig. 1 but has a gap at its center as shown at 11 and 12. The capacitive reactance of the elements 9 and 10 depends primarily upon the diametral lengths of the gaps 11 and 12 and secondarily upon the diameters of the rods. Ordinarily the elements 9 and 10 are designed to have approximately equal capacitive reactance at the frequency of interest.

The final adjustment is made by adjusting the length of the gaps 11 and 12 for the desired phase shift and the spacing D for maximum transmission in the manner explained above in connection with Fig. 1. For the special case where a lagging phase shift of 90 degrees is desired, the distance D will be approximately $\frac{3}{8}\lambda$. For large phase shifts several sections of the type shown in Fig. 4 may be connected in tandem in the manner shown in Fig. 3.

It should be pointed out that a lagging phase shift may be obtained by using several sections of the type shown in Fig. 1 which add up to a total of more than 180 degrees leading. Also, a leading phase shift may be obtained by connecting together a number of lagging sections such as that of Fig. 4 to produce a lagging phase shift of more than 180 degrees.

A 90-degree phase shift section, either leading or lagging, may be used to convert an electromagnetic wave either from linear to circular or from circular to linear polarization. For example, if a linearly polarized wave is launched into a 90-degree phase shift section with the electric field at 45 degrees to the principal axes M and N of the section, it may be resolved into two components of equal amplitude polarized along the principal axes. These two components will be transmitted through the section without rotation, but there will be a relative phase shift of 90 degrees of one with respect to the other. Thus the emerging components will be oriented at right angles to one another and they will also be 90 degrees out of phase in time. The sum of these vectors must then result in a circularly polarized wave. Similarly any circularly polarized wave may be resolved into two quadrature components which are linearly polarized parallel to the principal axes of a 90-degree phase shift section and are 90 degrees out of phase in time. After passing through the section the addition of

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either plus or minus 90-degree phase shift to either of the components will make them in phase or 180 degrees out of phase in time. In either case the sum of the two transmitted components will result in a linearly polarized wave at 45 degrees to the principal axes of the section.

The properties just described may be utilized in constructing a rotary joint in a wave guide, for use, for example, in a wave guide supplying energy to a rotating directive radiator. The problem is to keep the polarization of the transmitted waves from rotating with respect to the terminating equipment as the joint is rotated, assuming that on either side of the joint the equipment rotates as a unit with the wave guide. Fig. 5 shows, for example, two sections of circular wave guide 14 and 15 terminating at their opposing ends in annular flanges 16 and 17 to form a rotary joint. On either side of the joint is a 90-degree phase shift section. These are of the inductive or leading type shown in Figs. 1 and 2. The one to the left comprises two parallel diametral rods 18 and 19 spaced apart a distance approximately equal to $\frac{3}{8}\lambda$ and the one to the right comprises two other parallel diametral rods 20 and 21 with like spacing. The distance between the end rods 19 and 20 should be at least of the order of $\lambda/4$. It is to be understood that capacitive or lagging type 90-degree phase shift sections, such as shown in Fig. 4, may be substituted for those shown in Fig. 5. The two rods on the input side, for example 18 and 19, are oriented at 45 degrees to the incoming linearly polarized wave. The wave is converted by the first phase shift section into a circularly polarized wave which passes through the rotary joint. The two rods 20 and 21 on the output side are oriented so as to produce a linearly polarized output parallel to the direction of polarization of the terminating equipment, not shown. Rotation of the rotary joint will not change the alignment of the wave entering the receiving equipment. However, the device has an over-all phase shift which varies with the relative orientation of the two sections 14 and 15 and it may, therefore, be used as a variable phase changer.

The flanges 16 and 17 in Fig. 5, and similar flanges shown in subsequent figures, are used at a gap in a wave guide primarily to reduce the reflection which would otherwise occur. The radial extent K of the flange is preferably adjusted for minimum reflection of the waves transmitted through the guide. In practical cases the optimum value of K will be in the neighborhood of $\lambda/4$, or somewhat less.

A 180-degree phase shift section has the property that linearly polarized waves upon being transmitted through the section will emerge linearly polarized, but their polarization will have been rotated by an amount dependent upon the relative angle between the incident polarization and the principal axes M and N of the section. If circularly polarized waves are transmitted through the section, they will emerge circularly polarized, but the instantaneous polarization of the electric field will have been rotated with respect to the instantaneous polarization of the input by an amount depending upon the relative angle between the instantaneous input polarization and the principal axes of the section.

This latter property is made use of in the variable phase changer shown in Fig. 6 which comprises a rotatable 180-degree section inserted

between two 90-degree sections. The 180-degree section is similar to the one of Fig. 3, comprising a circular section of guide 23 with annular flanges 24, 25 at its ends and three spaced, parallel, diametral rods 5, 6 and 7. The two 90-degree sections 14 and 15 are of the type shown and described in connection with Fig. 5. It is assumed here, however, that the sections 14 and 15 do not rotate. The parallel diametral rods 18 and 19 in the section 14 are oriented at 45 degrees to the linearly polarized wave approaching from the left, and this section converts the wave to a circularly polarized one. The section 23 reverses the direction of rotation and alters the instantaneous orientation of the emerging wave in accordance with the orientation of the section. The section 15 reconverts the wave from circular to linear polarization. The parallel diametral rods 20 and 21 in the section 15 are oriented at 45 degrees to the direction of polarization of the terminating equipment, not shown, to produce a linearly polarized output parallel thereto.

As is seen above, the rotation of the central section 23 about its axis produces no change in the polarization of the output wave. It does, however, produce a time phase change in the oscillation which is substantially directly proportional to the angle through which section 23 is rotated. Furthermore, for a given direction of rotation, the sense of the time phase shift may be either positive or negative, depending upon which is used of the two possible 45-degree orientations of the electric vector of the incident wave with respect to the rods 18 and 19 in the first section 14.

As mentioned above, the rotary joint shown in Fig. 5 introduces a phase shift. Fig. 7 shows a rotary joint in which this phase shift may be eliminated. The system comprises two 90-degree sections 14 and 15 and an interposed 180-degree section 23 similar to the corresponding sections of Fig. 6. The receiver is associated with the section 15 which, in this case, is arranged to rotate in the bearing 27 formed in the support 26. The central section 23 rotates in the bearing 30 formed in the support 31 and the section 14 is fixedly supported by the member 32. The supports 26, 31 and 32 are fastened to the base 33 by means of brackets such as 34. In order to eliminate the phase shift the section 15 is geared to the section 23 so that the latter rotates through one-half of the angular displacement of the former. This is done by means of the two gears 36 and 37 fixed, respectively, to the sections 23 and 15 and the two gears 38 and 39 fixed to the shaft 40 which rotates in the bearings 41 and 42 in the supports 28 and 31. The crank 43 is provided to turn the shaft 40. A linearly polarized wave entering the system at the left will be converted to a circularly polarized wave by the section 14, in which form it will pass through both rotary joints 45 and 46, and then be reconverted to a linearly polarized wave by the section 15, without any over-all phase shift in the system.

In Fig. 7 if the two 90-degree sections 14 and 15 are omitted the system may still be used to project linearly polarized waves from a fixed source into a rotating guide while maintaining the polarization of dominant waves fixed with respect to the rotating section. This modified system will also serve to transfer circularly polarized waves across a rotary joint without change in phase with orientation of the rotating section.

Fig. 8 shows another system for introducing a controllable amount of phase shift without changing the direction of polarization. The system includes a fixed 90-degree section 14, associated with the source, a rotatable 180-degree section 23, both similar to the corresponding sections of Fig. 7, and interposed therebetween a rotatable 90-degree section 50 with diametral rods 51, 52 and end flanges 53, 54. The sections 50 and 23 are supported, respectively, by the supports 28 and 31 and are connected by the gears 37, 39, 38 and 36 and the shaft 40. The diameters of the gears are so proportioned that, when the shaft 40 is turned by means of the crank 43, the section 23 rotates through one-half the angle through which the section 50 rotates. The emerging wave is conducted to the receiver through a fixed section of guide 56 with an annular flange 57 at its end, supported by the member 58. If the input wave entering section 14 is polarized in a direction making an angle of 45 degrees with the parallel rods 18 and 19 and if all of the other rods 51, 52, 5, 6 and 7 are lined up parallel to the rods 18 and 19 the system will introduce neither phase shift nor rotation of polarization. However, if the section 50 is rotated through an angle, and the section 23 is rotated through half the angle, by means of the crank 43 and the gear train, a corresponding phase shift will be introduced as the wave passes through the system but there will be no rotation of polarization.

Fig. 9 shows an alternative system to that of Fig. 8 for introducing an adjustable amount of phase shift without rotation of polarization. The system includes a fixed 90-degree section 14 and a rotatable 180-degree section 23 similar to the corresponding sections of Fig. 8. The section 50, however, is replaced by a second rotatable 180-degree section 60 having end flanges 61, 62 and parallel diametral rods 63, 64 and 65, supported by the member 66. The system is terminated in a fixed 90-degree section 67 having an end flange 68 and diametral rods 69 and 70 which are parallel to the rods 18 and 19. The receiver is associated with the output section 67 and so oriented that its direction of polarization makes an angle of 45 degrees with the axes of the rods 69 and 70. The sections 23 and 60 are connected through the train of bevel gears 72, 73 and 74. The gears 72 and 74 are of the same diameter and are fastened, respectively, to the sections 23 and 60. The intermediate gear 73 has associated therewith a crank 75 which turns in the bearing 76 in the member 77 extending between the supports 31 and 66. Turning the crank 74 causes the sections 23 and 60 to rotate through equal angles but in opposite directions. The amount of phase shift introduced depends upon the orientation of the rods 63, 64 and 65 with respect to the rods 18 and 19, but there is no over-all rotation of the polarization of the wave as it passes through the system.

It should be pointed out that a 90-degree section such as is shown in Fig. 1 or Fig. 4 may be inserted in a wave guide carrying an elliptically polarized wave to convert it to a linearly polarized wave. In this case the diametral rods are oriented parallel to either the major or the minor axis of the ellipse.

Another use for a 90-degree section is to convert from linear to circular or elliptical polarization. Fig. 10 shows a system comprising a rotatable 90-degree section 50 interposed between two fixed sections of circular guide 80 and 81. Electromagnetic waves polarized in a fixed direction

are fed into the system from a coaxial line 82 comprising a cylindrical outer conductor 83, connected to the section 80, and a concentric inner conductor 84 which extends across the section 89 to form a diametral rod therein. Impedance transformation for the coaxial line 82 is provided, when required, by the stub line 85 within which the inner conductor 84 is terminated by the slidable reflecting piston 86. The position of the piston 86 is adjusted for a match of the resistance components of the characteristic impedances of the line 82 and the section of guide 89. Any reactive component associated with the inner conductor 84 may, in effect, be annulled by adjusting the position of the slidable reflecting piston 87 which closes the section 89 at the left. The pistons 86 and 87 are adjusted, alternately, until the maximum transmission of energy across the junction is attained. For this condition the spacing between the conductor 84 and the piston 87 will generally be approximately $\lambda/4$. By adjusting the orientation of the rotatable section 50 the system may be made to project into the fixed section 81 waves having any desired degree of elliptical polarization. As a special case, circular polarization will be produced when the plane defined by the axes of the rods 51 and 52 makes an angle of 45 degrees with the direction of the linearly polarized waves impressed upon the section 50. In order to simplify the drawings, in Fig. 10, and also in Figs. 11 and 12, the supports are not shown but these may, for example, be of the type shown in Figs. 7, 8 and 9.

Fig. 11 shows an alternative arrangement of the system of Fig. 10, in which the coaxial line 82 feeds into the section 81 instead of the section 80. In this case the impedance presented by the coaxial line 82 should be only half the characteristic impedance of the wave guide section 81. The ellipticity of polarization of the resultant wave may be controlled by movement of the piston 87 provided the 90-degree section 50 is oriented with its principal axes at 45 degrees to the inner conductor 84. In either of the systems shown in Figs. 10 and 11 a wave guide may, of course, be substituted for the coaxial line 83 to feed the system.

Fig. 12 is a cross-sectional view of a system for switching a guided linearly polarized wave from one branch to another. The system comprises a main section of wave guide 89, a 180-degree rotor section 23, two branches 90 and 91 and selective devices associated with the branches 90 and 91. All of the sections are of circular cross section, sections 23 and 89 are in axial alignment and each of the sections 90 and 91 makes an angle F with the section 23.

When the angle F is 120 degrees the selective devices may be diametral rods such as 92 and 93 spaced from the junction 94 the distances G and H , respectively, and preferably terminating in short coaxial stubs 95 and 96 of length J . The rod 92 lies in the plane of the junction, determined by the longitudinal mechanical axes of the branches 90 and 91, and the rod 93 is perpendicular to this plane. If a linearly polarized wave is sent into the section 89, rotation of the section 23 will cause the direction of polarization of the transmitted wave to rotate so that at one time it is parallel to the rod 93 and at another time it has a component which is parallel to the rod 92. By properly adjusting the length J of the stubs 95 and 96 the rods 92 and 93 may be made to reflect waves polarized parallel to themselves, while freely passing waves polarized perpendicu-

lar thereto. Furthermore, distances G and H are so chosen that the waves reflected by each of the rods 92 and 93 will be freely transmitted into the other branch. It follows, then, that for one orientation of the section 23, all of the power will be delivered to the branch 90. As this orientation is changed through 90 degrees all of the power is gradually diverted into the branch 91. There are, therefore, two switching cycles for one revolution of the rotor section 23 and the voltage of the waves entering each branch is a sinusoidal function of the orientation of the rotor 23. When the system has been properly designed the attenuation introduced as the wave is switched from one branch to the other is negligible.

The system shown in Fig. 12 may be used as a selector or a mixer for two linearly polarized waves polarized at 90 degrees with respect to one another and introduced into the section 89. For one orientation of the rotor 23, one of the waves will be entirely diverted into the branch 90 and the other, into the branch 91. Other orientations of the rotor 23 will permit part of each wave to enter each of the branches and thus the waves may be mixed in any proportions desired.

If the angle F has a value other than 120 degrees corrective shunt impedances, shown diagrammatically in Fig. 12 as X_1 and X_2 , must be provided in the branches 90 and 91 beyond the rods 92 and 93. These impedances are primarily reactances and may be either polar or non-polar. A suitable non-polar impedance is a transverse partition with a central circular aperture. A suitable polar impedance is a diametral rod either with or without a central gap therein. If rods are used, the one in the branch 90 should be perpendicular to the plane of the junction and the one in the branch 91 should lie in that plane. The magnitude and sign of the impedances X_1 and X_2 , and their distances from the junction 94, are dependent upon the choice of the angle F . Each impedance is placed at a distance beyond the rod 92 or 93 determined by trial to be the one resulting in minimum reflection at the junction. This condition is evidenced by the inability to detect a standing wave in the main branch 89 when waves are introduced from the left.

Fig. 13 is a cross-sectional view of a system for switching a circularly polarized wave into one or the other of two branches, depending upon the direction of rotation of the wave. The system is similar to that of Fig. 12 except that the 180-degree rotatable section 23 has been replaced by a rotatable 90-degree section 50. If the section 50 is so oriented that the rods 51 and 52 make an angle of 45 degrees with the plane of the junction, a circularly polarized wave entering the section 89 at the left will, as it passes the rods 51 and 52, be converted into a linearly polarized wave parallel to one of the rods 92 and 93, say 92, which will act as a reflector therefor. However, since the rod 93 is perpendicular to the plane of the junction it will permit free passage of the wave along the branch 91. On the other hand, if the wave entering the section 89 had been rotating in the other direction it is apparent that it would be blocked from the branch 91 by the rod 93 but would be freely transmitted through the branch 90, past the rod 92. By rotating the section 50 to other angles the incoming wave may be divided as desired between the two branches 90 and 91.

The system shown in Fig. 13 may be used as a selector or a mixer for two circularly polarized

waves, rotating in opposite directions, fed into the section 89. When the rods 51 and 52 are oriented at 45 degrees to the plane of the junction one of the waves will be shunted into the branch 90 and the other into the branch 91. By employing other appropriate angles any desired proportions of the two waves may be diverted into either of the branches.

What is claimed is:

1. A phase shift section for guided electromagnetic waves comprising a wave guide and three spaced polar reactive impedances connected in shunt thereto, the reactances of said impedances being chosen to provide the desired phase shift at a certain frequency, the spacing between said impedances being adjusted for maximum transmission of energy at said frequency, and the intermediate of said impedances having a reactance approximately half as large as the reactance of each of the other of said impedances.
2. A phase shift section in accordance with claim 1 in which said impedances are inductive.
3. A phase shift section in accordance with claim 1 in which the desired phase shift is 180 degrees.
4. A phase shift section in accordance with claim 1 in which the spacing between successive impedances is approximately three-eighths of a wave-length.
5. A phase shift section in accordance with claim 1 in which said impedances are transverse rods within said guide.
6. A phase shift section in accordance with claim 1 in which said guide is of circular cross section and said impedances are diametral rods.
7. In a wave guide, a rotary joint for transmitting a linearly polarized electromagnetic wave from a source to a rotating load comprising means on the input side for converting from linear to circular polarization, means on the output side for reconverting to linear polarization, and an interposed rotatable 180-degree phase shift section.
8. A rotary joint in accordance with claim 7 in which said means comprise a 90-degree phase shift section.
9. A rotary joint in accordance with claim 7 in which said means comprise a section of cylindrical wave guide and a plurality of diametral rods therein.
10. A rotary joint in accordance with claim 7 in which said means comprise a section of cylindrical wave guide and two parallel diametral rods therein, said rods being spaced apart approximately three-eighths of a wave-length at the frequency of interest.
11. In a wave guide, the combination of two 90-degree phase shift sections and a rotatable 180-degree phase shift section interposed therebetween.
12. The combination in accordance with claim 11 in which each of said phase shift sections comprises a section of cylindrical wave guide and a plurality of parallel diametral rods therein.
13. The combination in accordance with claim 11 in which said 180-degree phase shift section comprises a section of cylindrical wave guide having an annular flange at each end thereof.
14. The combination in accordance with claim 11 in which said 180-degree phase shift section comprises a section of cylindrical wave guide and three parallel diametral rods therein, said rods being spaced apart approximately three-eighths of a wave-length.
15. In a wave guide a rotary joint for transmitting without phase shift a linearly polarized

electromagnetic wave from a source to a rotating load comprising a fixed section of wave guide, a rotatable section of wave guide and a rotatable 180-degree phase shift section interposed therebetween, said phase shift section being geared to said rotatable section of guide in such a way as to rotate through one-half of the angular displacement of said rotatable section of guide.

16. A rotary joint in accordance with claim 15 which includes two 90-degree phase shift sections associated, respectively, with said fixed section and said rotatable section of guide.

17. A rotary joint in accordance with claim 15 in which said phase shift section comprises a section of cylindrical wave guide and three diametral rods therein.

18. A system for converting a guided electromagnetic wave from linear to elliptical polarization comprising a wave guide, a reflector in said guide, a rotatable 90-degree phase shift section associated with said guide and means for feeding energy into said guide, said phase shift section being located between said reflector and the point at which energy is fed into said guide and comprising a plurality of polar shunt reactive elements.

19. A system in accordance with claim 18 in which said phase shift section comprises a cylindrical section of wave guide and a plurality of diametral rods therein.

20. A system in accordance with claim 18 in which the location of said reflector in said wave guide is adjustable.

21. A system in accordance with claim 18 in which said energy feeding means comprise a coaxial line including an inner conductor which extends diametrically across said wave guide, the principal axes of said phase shift section being oriented at an angle of approximately 45 degrees to said inner conductor.

22. A system for switching a guided electromagnetic wave into one or the other of two branches comprising a main section of wave guide, two branches making equal angles therewith, selective devices in said branches responsive to different directions of polarization and a rotatable phase shift section associated with said main section, said phase shift section comprising a plurality of polar shunt reactive elements.

23. A system in accordance with claim 22 in which said phase shift section has a net phase shift of 180 degrees.

24. A system in accordance with claim 22 in which each of said equal angles is approximately 120 degrees.

25. A system in accordance with claim 22 in which said branches have longitudinal mechanical axes lying in the same plane, the selective device in one of said branches comprises a transverse rod parallel to said plane and the selective device in the other of said branches comprises a second transverse rod perpendicular to said plane.

26. A system in accordance with claim 22 in which one of said selective devices comprises a transverse rod terminating at each end in a coaxial stub.

27. A system in accordance with claim 22 in which said selective devices are polar reflectors located at distances from the junction of said branches so chosen that waves reflected by each of said devices will be freely transmitted into the other of said branches.

28. A system in accordance with claim 22 in

which the selective device in one of said branches comprises a polar reflector and a corrective shunt impedance.

29. A system in accordance with claim 22 in which the selective device in one of said branches comprises a polar reflector and a corrective shunt impedance, said reflector being located at a distance from the junction of said branches so chosen that waves reflected by said reflector will be freely transmitted into the other of said branches and said corrective impedance being located at a distance from said reflector chosen to provide minimum reflection at said junction.

30. A system for switching a linearly polarized guided electromagnetic wave from one branch to another comprising a main section of wave guide, two branches making equal angles therewith, selective devices in said branches responsive to different directions of polarization and a rotatable 180-degree phase shift section associated with said main section, said phase shift section comprising a plurality of polar shunt reactive elements.

31. A system in accordance with claim 30 in which said main section and said branches have longitudinal mechanical axes lying in the same plane and the principal electrical axes of said phase shift section are so oriented with respect to said plane that said wave is diverted into one only of said branches.

32. A system in accordance with claim 30 in which each of said equal angles is approximately 120 degrees.

33. A system in accordance with claim 30 in which said branches have longitudinal mechanical axes lying in the same plane, the selective device in one of said branches comprises a transverse rod parallel to said plane and the selective device in the other of said branches comprises a second transverse rod perpendicular to said plane.

34. A system in accordance with claim 30 in which each of said selective devices comprises a transverse rod terminating at each end in a coaxial stub.

35. A system in accordance with claim 30 in which said selective devices are polar reflectors located at distances from the junction of said branches so chosen that waves reflected by each of said devices will be freely transmitted into the other of said branches.

36. The combination in accordance with claim 11 in which each of said 90-degree phase shift sections comprises a section of cylindrical wave guide and two parallel diametral rods therein, said rods being spaced apart approximately three-eighths of a wave-length.

37. The combination in accordance with claim 11 in which each of said phase shift sections comprises a section of cylindrical wave guide and a plurality of parallel diametral rods therein, said rods being spaced apart approximately three-eighths of a wave-length.

38. The combination in accordance with claim 11 in which each of said sections comprises a plurality of spaced polar reactive impedances.

39. The combination in accordance with claim 11 in which each of said sections comprises a plurality of polar reactive impedances, said impedances being spaced apart approximately three-eighths of a wave-length.

40. The combination in accordance with claim 11 in which one of said 90-degree phase shift sections is rotatable.

41. In combination, two sections of wave guide, one of which is fixed, and an interposed phase shift section, said phase shift section comprising a plurality of spaced polar reactive impedances, having a phase shift of 180 degrees and being rotatable about its longitudinal axis.

42. The combination in accordance with claim 41 in which said impedances are diametral rods.

43. The combination in accordance with claim 41 in which said impedances are diametral rods, said rods being spaced apart approximately three-eighths of a wave-length.

44. In combination, two sections of wave guide, one of which is fixed, and an interposed phase shift section, said phase shift section comprising a plurality of spaced polar reactive impedances and being rotatable about its longitudinal axis, each end of said phase shift section and the ends of said other sections adjacent thereto having annular flanges extending outwardly for a distance approximately equal to a quarter of a wave-length.

45. In combination, two sections of wave guide, one of which is fixed, and an interposed phase shift section, said phase shift section being rotatable about its longitudinal axis and comprising three spaced polar reactive impedances, the intermediate impedance having a reactance approximately half as large as the reactance of each of the other impedances.

46. In combination, two sections of wave guide, one of which is fixed, and an interposed phase shift section, said phase shift section being rotatable about its longitudinal axis and comprising three spaced polar reactive impedances in the form of diametral rods, the intermediate rod having a reactance approximately half as large as the reactance of each of the other rods.

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