Jan. 10, 1950 W. A. TYRRELL 2,493,842

WAVE GUIDE WITH PHASE COMPENSATING PAIRED BENDS

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FIG. 1

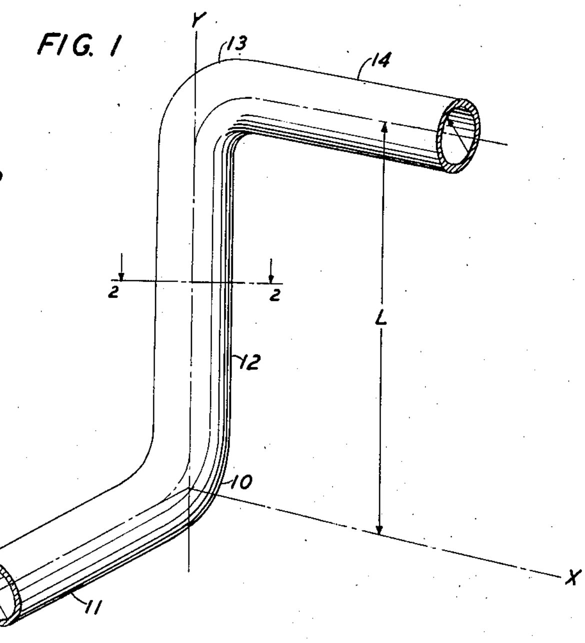


FIG. 2

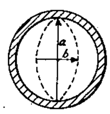


FIG. 3

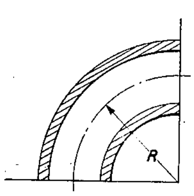
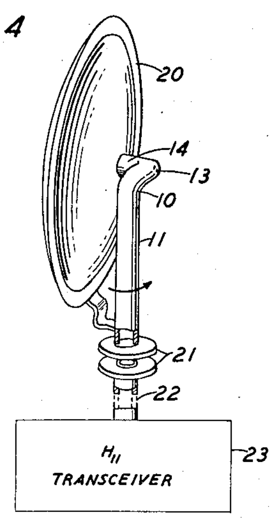


FIG. 4



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WAVE GUIDE WITH PHASE COMPENSATING PAIRED BENDS

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The present invention relates to the guided transmission of ultra-high frequency electromagnetic waves, and it has as its principal objective the elimination or substantial reduction of undesirable effects that are incident to changes in the direction of the wave guiding structure.

In accordance with a feature of the invention a desired change in the direction of the wave guide is effected, not by means of a single bend, but by a succession of differently oriented bends. In one embodiment, for example, a change of 90 degrees in the course of a hollow-pipe guide is provided by a pair of successive right angle bends disposed in mutually perpendicular planes.

The nature of the invention and its various features, objects and advantages will appear more fully from a consideration of the following detailed description of the embodiments that are illustrated in the accompanying drawing. In the latter, Figs. 1 to 3 illustrate how a 90-degree change in direction may be accomplished in accordance with the invention, and Fig. 4 shows diagrammatically a radio system embodying the invention.

In the arrangement illustrated in Fig. 1, the wave guiding structure is a hollow-pipe guide of circular cross-section. The guide comprises a tubular shell of copper or other conducting material enclosing a low loss dielectric medium, which may be air, for specific example, or any other suitable non-conducting material. It is well known that electromagnetic waves can be propagated through the interior of such a guide provided the wave frequency exceeds a critical or cut-off frequency that is dependent on the internal diameter of the pipe, the dielectric coefficient of the dielectric medium, and the type or field configuration of the waves. It may be assumed, in the interest of a complete disclosure of a specific embodiment, that the internal diameter of the pipe is 2⅞ inches, that the dielectric medium is air, and that the free-space wavelength of the guided waves is 9.80 centimeters, corresponding to a wave frequency of somewhat more than 3000 megacycles per second. Under these circumstances the guide will support waves of the dominant or H_{11} type, that is, a non-symmetric type of transverse electric wave in which the lines of electromotive force extend across the interior of the pipe approximately parallel to a diameter.

The guide is represented in Fig. 1 as having a pair of adjacent 90-degree arcuate bends. The lower bend 10 connects a guide section 11, which leads to a source of H_{11} waves, not shown, and

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a short guide section 12. The latter is connected in turn by the upper bend 13 to a guide section 14 which leads to a wave receiver, antenna or other utilization means, not shown. Referring to the indicated axes of a system of rectangular coordinates, bend 10 and the guide sections connected thereto lie in the YZ plane, while bend 13 and the guide sections connected thereto lie in a plane XY that is normal to the other. The two main guide sections 11 and 14, it will be noted, are offset from each other by the distance L.

One of the undesirable effects that is introduced by a bend in a pipe guide of circular cross-section is ellipticity of polarization of the transmitted waves. It has been found that a wave of dominant type transmitted through a bend in the guide is generally split into two mutually perpendicular components, one component lying in the plane of the bend and the other component perpendicular thereto, and that the two components travel with unequal velocities. Hence, upon emerging from the bend, one component lags the other by an appreciable part of a wavelength, or, in other words, the two are displaced in phase angle. Excepting then for the possibility that the phase displacement may be 180 degrees or a multiple thereof, the emergent waves are elliptically polarized. The usual wave receiver or other utilization means is ill adapted for elliptically polarized waves but is designed rather to utilize efficiently only plane polarized waves having a predetermined fixed orientation. A typical receiver of H_{11} waves, for example, comprises a diametral pick-up conductor so oriented in the guide that it is in registry with the electric field of the incident waves, the latter being a condition that cannot be maintained if the incident waves are elliptically polarized. In addition to, or aside from, loss of efficiency other effects produced by elliptical polarization of the transmitted waves may be regarded as deleterious in particular systems.

Fig. 2 represents diagrammatically two wave components appearing in the intermediate guide section 12 as a result of the effect of bend 10 on plane polarized waves of dominant type applied through guide section 11. The larger component a lies in the YZ plane and the smaller component b lies at right angles thereto in the XY plane. Experimental studies indicate that if the electric vector of the applied waves lies in the YZ plane, i. e., in the plane of the bend, component b is zero, and that if the electric vector is rotated 90 degrees, component a is zero, but that both components are present for all intermediate orientations of the electric vector. It should be noted in this connection that it is not always practical to prevent variations in the orientation of the guided waves and that in some instances in practice the orientation is intentionally varied, as it is in the system illustrated in Fig. 4.

The phase displacement of the two components is not represented in the drawing. In the specific embodiment described with reference to Fig. 1 in which, it may be further specified, the mean radius of curvature of the bends is 3 inches, a phase displacement of 25 degrees has been found. In another embodiment in which the radius of curvature of the bends was 4½ inches, all other conditions being the same, the measured phase displacement was 20 degrees. In both cases the plane of polarization of the incident waves was at an angle of 45 degrees to the YZ plane. Inasmuch as the difference in phase is attributable to the difference in the velocity with which the two components are propagated through the bend, it is recognized that by proper choice of operating frequency and/or dimensions, the phase displacement may be made 180 degrees or a multiple thereof. In such case, the plane of polarization of the emergent waves might be displaced but it would be invariable and elliptical polarization would be avoided. This condition would obtain, however, only for a particular operating frequency and not for any considerable range of frequencies, and it would impose a restriction on the radius of curvature or length of the bend. It is to be noted, too, that if a bend causes elliptical polarization, the effect is not cancelled, but doubled, by reflecting the emergent waves or otherwise causing them to traverse the same bend in the opposite direction.

I have discovered that the second bend **13** largely compensates for the deleterious effects introduced by the first bend **10**. More particularly, I have found that with the two bends arranged in the manner herein described, a plane polarized H_{11} wave entering through guide section **11** at any angle of polarization emerges through guide section **14** with substantially no evidence of elliptical polarization. This is taken to mean that the phase displacement introduced by the second bend is substantially equal and opposite to the phase displacement introduced by the first bend. The two bends may therefore be said to have substantially the same phase length. In explanation of these observations it may be noted that if the wave passing through guide section **11** is polarized at an angle of 45 degrees with respect to the YZ plane, it may be regarded as comprising two equal components, one in the plane of the bend and one at right angles thereto, and that the two components are subjected to substantially the same treatment in passing through the pair of bends. That is, each component passes through one bend with its electric vector in the plane of the bend and it passes through the other bend with its electric vector normal to the plane thereof. In short, the electrical length of the pair of bends appears the same to the two components and they emerge with no phase difference between them. For other angles of polarization of the applied waves the two components are not so nearly equal and the effect described therefore obtains to a lesser extent; but with the electric vector more nearly coincident with or normal to the plane of the bends, the latter have a lesser tendency to split the applied waves into phase displaced components. In view of the foregoing explanation it will be understood that the phase compensation obtaining in the Fig. 1 system is not critically dependent on the operating frequency and that the arrangement is effective to suppress elliptical polarization over a wide range of frequencies.

Partial reflection of the transmitted waves is another undesirable effect that is attributable to a single wave guide bend, for the bend tends to introduce an impedance discontinuity in the transmission path. An effect of this kind can be minimized by the introduction of a second similar impedance discontinuity so spaced from the first that the waves reflected from the one are in phase-opposing relation to the waves reflected from the other. The two bends in Fig. 1 constitute a pair of such discontinuities, and they may be advantageously spaced apart in reflection-canceling relation. In the specific embodiment described with reference to Fig. 1, a spacing L of about 7 inches was found to yield minimum reflection losses. Theoretical considerations indicate that the optimum spacing is approximately one-half of the wavelength within the guide, or a multiple thereof.

Fig. 3 is a cross-sectional view of one of the bends **10**, **13** taken in the plane of the bend. The radius R indicates the mean radius of curvature. Fig. 3 is equally illustrative of an arcuate bend in a hollow pipe guide of rectangular cross-section. The amount of reflection loss that occurs within such a bend is markedly dependent on the arcuate length of the bend or, in other words, on the mean radius of curvature R. It is found that the optimum arcuate length $\pi R/2$ for minimum internal reflection losses is critically dependent on the wave frequency and is approximately equal to a half wavelength or multiple thereof.

Fig. 4 illustrates diagrammatically a radio transmitting and/or receiving system embodying the present invention. The system comprises a horizontally aimed paraboloidal reflector **20** that is fixedly attached to the vertically disposed hollow pipe guide **11**. The guide is of circular cross-section and it is associated with means, not illustrated, for rotating it about its axis. At its upper extremity guide **11** is terminated by the double bend structure of Fig. 1, the latter being disposed with guide section **12** normal to the axis of the paraboloid and with guide section **14** aligned with the axis of the reflector **20**. The end of guide section **14** is open and it is disposed at the principal focus of the paraboloid. In transmitting, guided waves issuing from the open end of section **14** strike the reflector **20** and form an axially directed radio beam. Fig. 31 of U. S. Patent No. 2,206,923, issued July 9, 1940, to G. C. Southworth illustrates a device which can be employed for this purpose when the transceiver **23** is to be used to launch waves into the guide for transmission therethrough. In receiving, radio waves incident upon the reflector are directed to the open end and give rise to guided waves in the hollow pipe guide **11**. Fig. 12 of U. S. Patent No. 2,257,783, issued October 7, 1941, to A. E. Bowen illustrates a device which can be employed for this purpose when the transceiver **23** is to be used to receive waves incident upon the guide.

The lower end of guide **11** is connected through a wave-tight rotary joint or swivel, which may be of the known type represented schematically by a pair of spaced conductive flanges **21**, to a stationary hollow pipe guide **22** that leads to transceiver **23**. The transceiver **23** is adapted to launch waves of the H_{11} type into the lower end of guide 22 or to receive waves of that type from the guide, and in either case the orientation of the waves relative to the guide is fixed or predetermined. The Fig. 4 system is adapted primarily for radio echo ranging or object locating and for this field of use the transceiver 23 may be assumed to transmit the waves in the form of short spaced pulses and to receive selectively the pulse echoes that result from reflection of the waves at a distant object. Continuous rotation of the guide 11 and reflector 20 permits the entire horizon to be kept under observation.

It is to be noted that in the normal operation of the Fig. 4 system, as above described, the electric vector of the transmitted waves in guide 11 rotates continuously relative to the guide as the structure rotates about the vertical axis, or inasmuch as the field is non-symmetric it suffices to say that the waves so rotate. Hence, if the vertical guide 11 and guide section 14 were joined by a single 90-degree bend, the direction of the electric vector would continuously vary with respect to the plane of the bend and, intermittently, the waves would become elliptically polarized, that is, whenever the rotating structure passed through certain angular positions. The double bend provided in Fig. 4, however, substantially suppresses elliptical polarization as described with reference to Fig. 1 and by virtue of the spacing of the bends minimum reflection losses are obtained regardless of the angular position of the rotating structure. It may be noted also that the direction of polarization of the radiated waves depends on the azimuthal angle of the rotating structure, and more particularly that with continuous rotation the radiated waves vary cyclically between horizontal and vertical polarization. The direction of polarization of the received reflected waves varies in the same manner, but the orientation of the waves appearing in guide 22 is nevertheless invariable. Where two distant stations differ on azimuth by 90 degrees, it is accordingly possible to employ vertically polarized waves for communicating with the one station and, merely by rotating the antenna system, to shift to horizontal polarization for communication with the other.

A feature of the Fig. 4 system is that with ellipticity of polarization substantially eliminated in the manner described, it is possible to employ a swivel joint of the simplest time. It is not necessary, for example, to employ a joint that is adapted to convert the H_{11} wave to a symmetric type of wave for the purpose of coupling the stationary and rotating guide sections.

Although the present invention has been described with reference to specific embodiments thereof, it will be appreciated that the invention is susceptible of embodiment in other forms within the spirit and scope of the appended claims.

What is claimed is:

1. A microwave transmission system comprising a hollow-pipe guide and means for transmitting waves of non-symmetric type through said guide, said guide having two adjacent, substantially identical bends fixed in mutually perpendicular planes.

2. A microwave transmission system comprising a hollow-pipe guide of substantially circular cross-section and means for transmitting waves of dominant type through said guide, said guide having a pair of adjacent arcuate right angle bends that are of substantially equal phase length and are fixed in mutually perpendicular planes whereby said bends have similar but opposite effects with respect to the production of elliptical polarization of said waves.

3. A microwave transmission system comprising a hollow-pipe guide of substantially circular cross-section and means for transmitting waves of dominant type through said guide, said guide having a pair of similar right angle bends spaced apart an approximately integral multiple of half wavelengths in reflection cancelling relation to each other, the respective planes of said bends being mutually perpendicular.

4. In combination, a hollow-pipe guide for the transmission of ultra-high frequency electromagnetic waves, said guide being of substantially circular cross-section and having a first smoothly curving bend therein, means for applying to said bend for transmission therethrough polarized waves the field of which is subject to rotation relative to the guide, said guide having a second similar bend of substantially the same phase length adjacent the first bend, and said second bend being fixed in a plane that is substantially perpendicular to the plane of the first bend.

5. In combination, a hollow-pipe guide for the transmission of ultra-high frequency electromagnetic waves, said guide being of substantially circular cross-section and having a first substantially arcuate right angle bend therein, means for transmitting through said guide electromagnetic waves the polarization of which is subject to variation with reference to the plane of said bend, said guide having a second substantially identical bend adjacent the first bend, and the two bends being fixed in planes that are substantially perpendicular to each other.

6. In combination, a hollow-pipe guide of substantially circular cross-section for the transmission of ultra-high frequency electromagnetic waves, said guide having a bend therein such as to produce elliptical polarization of the transmitted waves, means continually changing the orientation of the transmitted waves with reference to the plane of said bend whereby the degree of ellipticity introduced by said bend continually changes, and means for substantially neutralizing the variable effect of said bend on the transmitted waves comprising a second bend in said guide adjacent said first-mentioned bend, said second bend being of substantially the same phase length as the first-mentioned bend but disposed in a different plane.

7. In combination, a hollow-pipe guide, means for rotating said guide about a longitudinal axis, means at one end of said guide for launching plane polarized waves into said guide for transmission therethrough or for receiving such waves from said guide, a pair of substantially equal arcuate bends of substantially the same phase length adjacent each other near the other end of said guide, said other end being open for the radiation or interception of radio waves and said bends being fixed in mutually perpendicular planes.

8. In combination, a vertically disposed hollow-pipe guide of substantially circular cross-section, said guide having at its upper end a pair of substantially identical right angle curving bends fixed in mutually perpendicular planes and an opening for the radiation or interception of radio waves, means for rotating said guide about a vertical axis, and means at the lower end of said guide for launching therein or receiving therefrom guided electromagnetic waves of the dominant type.

9. In combination, a section of hollow-pipe guide in the form of two successive curved bends of substantially equal phase length fixed in substantially mutually perpendicular planes, transceiver means for exciting electromagnetic waves in said guide for transmission through said bends in succession or for receiving electromagnetic waves transmitted through said bends in succession, and means for rotating said transceiver means relatively to said guide.

10. A microwave transmission system comprising a tubular uniconductor wave guiding passage for the transmission of electromagnetic waves of non-symmetric type, said passage having a pair of similar adjacent bends of substantially equal phase length fixed in respective planes that are substantially perpendicular to each other.

11. A system in accordance with claim 10 in which each of said bends is a curved right-angle bend.

12. A microwave transmission system comprising a tubular uniconductor wave-guiding passage for the transmission of electromagnetic waves of non-symmetric type, said passage having a pair of similar adjacent bends in respective planes that are substantially perpendicular to each other, said bends being spaced apart an approximately integral multiple of half wavelengths in substantially reflection-cancelling relation to each other.

13. A microwave transmission system comprising a tubular uniconductor wave guiding passage having a pair of similar adjacent bends of substantially equal phase length fixed in respective planes that are substantially perpendicular to each other, and means for exciting in one end of said pair of bends a non-symmetric plane polarized wave the orientation of which is variable relative to the plane of the bend nearest said one end.

14. A microwave transmission system comprising a tubular uniconductor wave guiding passage having a pair of adjacent bends of substantially equal phase length fixed in planes that are substantially perpendicular to each other, means including a wave transceiver for applying to or receiving from one end of said pair of bends a non-symmetric plane polarized electromagnetic wave, and means for rotating said passage about a longitudinal axis passing through said one end.

15. A microwave transmission system comprising a tubular uniconductor wave-guiding passage having a pair of adjacent, substantially identical bends of substantially equal phase length fixed in respective planes that are substantially perpendicular to each other, and transceiver means for applying to or receiving from one end of said pair of bends a non-symmetric plane polarized wave that rotates continuously with respect to the said end.

WARREN A. TYRRELL.

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