

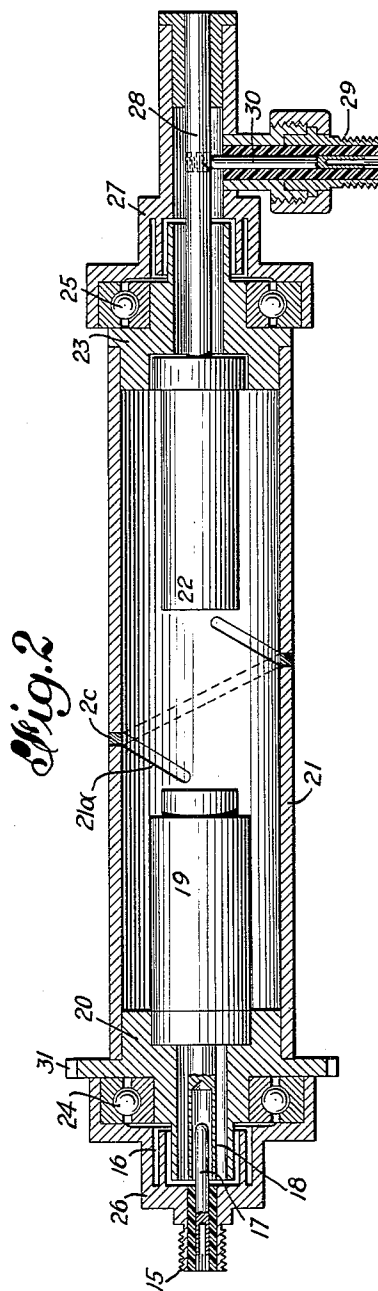
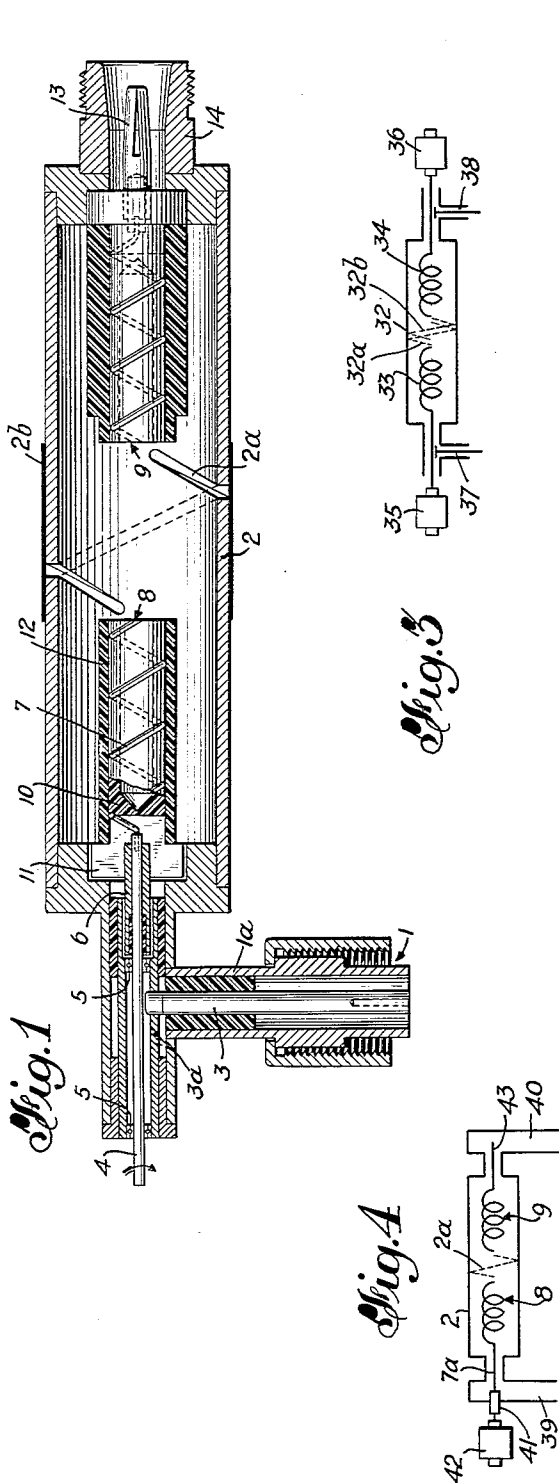
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MICROWAVE PHASE SHIFTER

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MICROWAVE PHASE SHIFTER

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This invention relates to microwave phase shifters and more specifically to high speed continuous rotary waveguide phase shifters.

Waveguide phase shifters are needed in certain microwave systems, generally for shifting the angular position of an antenna beam. Heretofore, various means and methods of shifting the phase of an output wave with respect to the input wave have been proposed. The majority of such means are primarily voltage devices with the disadvantage that the output power transmitted to the load must be kept very small so as not to disturb the phase relations in the circuit. However, one phase shifter has been proposed heretofore to transmit relatively large amounts of power to a load, but this device is not satisfactory for certain applications because of its large physical size and extreme frequency sensitivity.

One of the objects of this invention, therefore, is to provide a waveguide phase shifter of relatively small physical dimensions which is capable of relatively high power transmission.

Another object of this invention is to provide a waveguide phase shifter with relatively broad frequency response and substantially linearly phase shift.

A further object of this invention is to provide a waveguide phase shifter which is capable of transmitting relatively large amounts of power to a load with a minimum of loss.

Briefly, a phase shifter according to this invention may comprise a section of a circular waveguide with means, such as a helical antenna, for radiating a circularly polarized wave therethrough and receiving means which may also comprise a helical antenna to receive the wave at the output end of the waveguide section. One or the other or both of the antennas may be caused to rotate about a longitudinal axis, whereby the degree of phase shift may be controlled, since the phase shift of the output voltage is directly proportional to the relative angular motion of the antennas.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a longitudinal cross-sectional view of an embodiment of this invention;

Fig. 2 is a longitudinal cross-sectional view of another embodiment of this invention;

Fig. 3 is a schematic illustration of an embodiment of this invention capable of wide shifts in phase; and

Fig. 4 is a schematic illustration of a further embodiment of the invention.

Referring to Fig. 1 of the drawing, a source of microwave energy is applied to the phase shifter therein shown through a coaxial connector 1. The outer conductor 1a of the coaxial connector is joined to one end of a section of circular waveguide 2. The inner conductor 3 of the coaxial connector is coupled to a sleeve 3a which supports a rotatable shaft 4 by means of a pair of bearings 5. The sleeve 3a surrounds in spaced relation a sleeve 6 carried

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by shaft 4 whereby microwave energy is coupled through an R. F. choke, formed between the sleeves 3a and 6 and between sleeve 6 and shaft 4, and thus to the winding 7 of the input antenna 8. The input antenna is mounted on the rotating shaft 4 and is a circularly polarized, end radiating helix, adapted to launch a wave for propagation along the circular waveguide 2 in accordance with the H_{11} mode. The waveguide 2 is dimensioned below cutoff for all higher modes. Another circularly polarized helix 9 wound in the same sense as the input antenna acts as an antenna to receive the radiations emitted by said input antenna 8.

The phase of the output voltage of a circularly polarized antenna receiving a circularly polarized wave launched by a circularly polarized antenna is directly proportional to the angle of rotation of one antenna about its longitudinal axis relative to the other antenna. The output amplitude will be equal to the input amplitude and there will be no phase shift errors, if the ends are perfectly matched and the axial ratios of the helices are unitary.

The dimensions and location of each helix 8 and 9 with respect to the end of the waveguide 2 are so selected as to obtain a polarization as nearly circular as possible and a good impedance match to the coaxial line. One form of helix, which has been found satisfactory for frequencies near 9375 mc. using a 50 ohm coaxial transmission line for input and output connections, is a helix composed of a dielectric form 10, such as "Teflon," 0.3 inch in diameter, $1\frac{1}{8}$ inches long with a flange 11 which is $\frac{3}{16}$ of an inch wide by .475 inch in diameter, the flange end of the form having a hole 0.12 inch in diameter and $\frac{5}{32}$ inch deep in its center to which the shaft 4 is connected, while the other end has a hole 0.155 inch in diameter by $1\frac{1}{16}$ inch deep, the flange being bisected by a slot 0.032 inch wide and $\frac{5}{16}$ inch deep, along one of its diameters. The winding 7 is laid in semicircular channels cut in the form 0.031 inch in diameter, consist of $3\frac{1}{2}$ turns of 0.025 copper wire starting $\frac{1}{8}$ of an inch above the flange and connected to the shaft 4 on which the form 10 is mounted. The windings should be fixed firmly, but not necessarily flush with the surface. A sheath 12 made of a dielectric, such as "Teflon," and is $1\frac{1}{8}$ inches long by 0.4 inch in outside diameter and having a wall thickness of 0.1 inch, fits over the winding to prevent its displacement when the antenna is rotated at high speeds. The receiving antenna 9 is substantially identical with the input antenna 8 except that for 1 inch of dielectric form thereof out from the flange, the wall thickness is 0.2 inch. The receiving helix 9 is connected to the spring finger contact 13 of an output connector. The outer conductor 14 of said output connector is connected to the waveguide 2.

The helices of the two antennas have a spacing of one inch between their ends. Less spacing would result in direct coupling between the ends, and therefore, present large errors.

The bearing, motor drive, and helix mounting methods are important for high rotational speeds. Irregular bearing surfaces result in physical unbalance, motor overload, and sudden speed changes, all of which cause phase errors. The motor drive must be constant, because a small speed drift of the driving mechanism results in large phase shift errors at high rotational speeds. If the helix mounting is not accurate, then eccentricity errors will be introduced.

In operation, a wave is applied from the coaxial line through coupler 1 and choke 6 to the helical antenna 8. The antenna radiates the wave, circularly polarized, axially along the waveguide section 2 and is received by the helical antenna 9 for propagation over a coaxial line coupled at 13, 14. The antenna 9 is maintained fixed while the antenna 8 is rotated by shaft 4. By controlling

the rotation of the antenna 8 a phase advance or retardation is obtainable.

Where the waveguide 2 is made of a solid cylindrical wall, a substantially linearly phase shift is obtained except for two points 180° apart in the angular setting of the phase shifter. This discontinuity at these two points is relatively sharply defined and was discovered to be caused by a resonance of the circular polarization H₁₁ mode which occurs in the opposite sense to the main or desired circularly polarized H₁₁ mode for which the unit is designed. This sharp discontinuity, while not troublesome for many phase shift uses, may be substantially eliminated by suppression. While different arrangements may be provided for effecting this suppression, such as using impedance grids, the preferred means of suppression comprises the location of one or more helical slots in the wall of the cylinder forming the waveguide. The angle of the slot depends upon the R. F. frequency and the diameter of the waveguide.

From a consideration of the fields for a circularly polarized H₁₁ mode propagating in a circular waveguide, it may be shown that the resultant H field spirals down the guide in the direction of propagation. ϕ , the angle this field makes with the axis of propagation is given by

$$\phi = \arctan \frac{\lambda_c}{1.84\lambda_g}$$

where $+\phi$ is measured counterclockwise from the axis,
 λ_c = cutoff wavelength of H₁₁ mode in,
 λ_g = guide wavelength of circular waveguide.

The wall currents flow at right angles to the H field and spiral around the inner surface of the waveguide observing the same screw sense as the launching helices. Waves of the opposite sense form the angle $-\phi$ with the guide axis.

when $\lambda_c = 1.49''$
 $\lambda_g = 2.35''$
 $\phi = 19^\circ$ and the current flow angle is $\pm 90 + 19 = 109^\circ$, or -71° .

For the opposite sense, $\phi = -19^\circ$ and the current flow angle is $\pm 90 - 19 = +71^\circ$, or -109° .

In Fig. 1 one such slot is shown at 2a, the spiral of the slot having the same sense of direction as the spiral of the helix 7. By thus arranging the slot 2a to parallel the currents resulting from the magnetic field of the desired H₁₁ mode, the slot intercepts the currents resulting from the magnetic field of the undesired H₁₁ mode and radiates the energy thereof. In certain instances, it is preferable to suppress this radiation. This suppression of radiation is accomplished by either overlapping the slot 2a with a layer of lossy conductive material 2b or by filling the slot with the lossy conductive material as shown at 2c, in Fig. 2. The lossy conductive material may comprise any material having the desired lossy characteristic, one such material being a dielectric containing distributed particles of carbon. The phase shifter provided with a suppression slot as indicated in 2a lowers sharply the Q of the undesired resonance thus substantially eliminating the discontinuity observed with a solid wall cylindrical waveguide.

Another embodiment of this invention as shown in Fig. 2, has a different drive arrangement to reduce eccentricity errors and certain motor drive difficulties. The coaxial input line 15 is terminated in an open circuited quarter wave choke 16 which includes a short circular waveguide dimensioned far below cutoff for all modes higher than the H₁₁ mode. The inner conductor is terminated at 17 in telescoped relation with a sleeve conductor 18 which is connected to the helical conductor of the antenna unit 19. The antenna unit 19 is constructed similarly as shown in detail for antenna 9 in Fig. 1, the antenna being supported by the end member 20 which in turn is carried by the waveguide section 21. The antenna 19 protrudes into the waveguide section in spaced relation to a

receiving antenna 22 which protrudes through an end member 23 carried by the other end of the wave guide section 21. The two end members 20 and 23 are supported by bearings 24 and 25 in the coupling units 26 and 27. The antenna 22 is supported by a conductor 28 which is coupled to the helical conductor of antenna 22 in fixed relation coaxially of the coupling member 27. The outer conductor 29 of the output connection is coupled to the member 27 with the inner conductor 30 secured to the conductor 28. The cylindrical wall of the waveguide 21 is provided with a slot 21a similarly as in the case of waveguide 2, Fig. 1. The slot 21a is loaded with lossy conductive material 2c.

The end member 20 is provided with gear teeth 31 whereby the waveguide section 21 together with antenna 19 can be rotated. By controlling the rotation of the waveguide section and the antenna 19, the desired phase shift is obtained.

In Fig. 3 an embodiment is shown comprising a waveguide section 32 containing in the ends thereof an input antenna 33 and an output antenna 34. The two antennas are connected to motors 35 and 36, respectively, so that both antennas may be rotated simultaneously and the direction and speed of rotation controlled. The input and output connections 37 and 38 are coupled to the antennas. If the two antennas 33 and 34 are rotated in opposite directions, the phase shift can be doubled. The cylinder of waveguide 32 is shown provided with two helical slots 32a and 32b. It should be understood that more than one or two slots may be used in the wall of the waveguide employed in practicing the invention.

In Fig. 4, a phase shifter similar to the one in Fig. 1 is shown coupled at the input and output thereof by rectangular waveguides 39 and 40, respectively. The lead 7a to antenna 8 is extended into the waveguide 39 to pick up the input energy, the lead being connected to a dielectric shaft 41 driven by motor 42 whereby rotation of input antenna 8 is controlled. The output end 43 of antenna 9 is likewise disposed in waveguide 40 for launching R. F. energy in waveguide 40.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made by way of example only and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A phase shifter comprising a circular waveguide section, a helical input antenna element for radiating a circularly polarized wave at one end of said section for propagation therethrough, a helical output antenna element to receive said wave at the other end of said section, the circular waveguide section defining a path for the energy radiated from said input antenna to said output antenna, means to rotate one of said helical elements relative to the other helical element whereby the phase of the output voltage with respect to the input voltage is proportional to the relative angle of rotation of said elements, means for coupling a source of radio frequency energy to said input antenna, said helical input antenna being adapted to launch a wave circularly polarized with one sense of rotation, said waveguide section including means for suppressing propagation of waves circularly polarized in a sense of rotation opposite to said one sense of rotation including at least a slot in the wall of said section disposed substantially parallel to electric currents produced in response to the propagation of a wave circularly polarized with said given sense of rotation and having lossy conductive material disposed relative to said slot such as to absorb energy radiated by said slot, whereby relatively large amounts of power may be transmitted to a load with a minimum of loss.

2. A phase shifter comprising a circular waveguide section, a helical input antenna element for radiating a

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circularly polarized wave at one end of said section for propagation therethrough, a helical output antenna element to receive said wave at the other end of said section, the circular waveguide section defining a path for the energy radiated from said input antenna to said output antenna, means to rotate one of said helical elements relative to the other helical element whereby the phase of the output voltage with respect to the input voltage is proportional to the relative angle of rotation of said elements, means for coupling a source of radio frequency energy to said input antenna, said coupling means having a radio frequency choke disposed at least in part between the fixed and moving parts of the phase shifter, the means for rotating one of said elements including means for rotating said waveguide section, said helical input antenna being adapted to launch a wave circularly polarized with one sense of rotation, said waveguide section including means for suppressing propagation of waves circularly polarized in a sense of rotation opposite to said one sense of rotation including at least one slot in the wall of said section disposed substantially parallel to electric currents produced in response to the propagation of a wave circularly polarized with said given sense of rotation and having lossy conductive material disposed within and along said slot to absorb energy radiated by said slot, each of said antennas comprising a cylindrical member of dielectric material and a helical conductor supported thereby, said radio frequency energy source coupling means comprising a coaxial input connector for radio frequency energy, a coaxial output connector, said circularly polarized helical input antenna being coupled to the inner conductor of said input connector, said circularly polarized helical receiving antenna being coupled to the inner conductor of said output connector, means rotatably coupling said circular waveguide section to the outer conductors of said input and output connectors, said means for rotatably coupling said section including a pair of members having bearings supporting the ends of said sections, thereby permitting relatively large amounts of electromagnetic energy to be transmitted through a load with a minimum of loss.

3. A phase shifter comprising a circular waveguide section, a helical input antenna element for radiating a circularly polarized wave at one end of said section for propagation therethrough, a helical output antenna element to receive said wave at the other end of said section, the circular waveguide section defining a path for the energy radiated from said input antenna to said output antenna, means to rotate one of said helical elements relative to the other helical element whereby the phase of the output voltage with respect to the input voltage is proportional to the relative angle of rotation of said elements, means for coupling a source of radio frequency energy to said input antenna, said coupling means having a radio frequency choke disposed at least in

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part between the fixed and moving parts of the phase shifter, said helical input antenna being adapted to launch a wave circularly polarized with one sense of rotation, said waveguide section including means for suppressing propagation of waves circularly polarized in a sense of rotation opposite to said one sense of rotation including at least a slot in the wall of said section helically disposed in the same rotary sense as the helical conductors of said antennas, said slots having lossy conductive material disposed therealong to absorb energy radiated by said slots, each of said antennas comprising a cylindrical member of dielectric material and a helical conductor supported thereby, a coaxial connector having an outer conductor joined to one end of the section of circular waveguide, and having an inner conductor, a rotatable shaft, a sleeve supporting said rotatable shaft, the inner conductor of the coaxial connector being coupled to said sleeve, a second sleeve surrounded by said first sleeve, said second sleeve being carried by said shaft whereby microwave energy may be coupled through a radio frequency choke, said radio frequency choke being formed between the first sleeve and the second sleeve and between the second sleeve and the shaft, and thus to the winding of the input antenna, said input antenna being mounted on said rotating shaft, said input antenna being an end radiating helix adapted to launch a wave for propagation along the circular waveguide in accordance with the H_{11} mode, said waveguide being dimensioned below cutoff for all higher modes, each of said helix antennas being so dimensioned and so located as to obtain as near circular polarization as possible and to obtain a good impedance match to the coaxial line, an output coaxial line connector having an outer conductor and an inner conductor, said output conductor being connected to said waveguide, said output connector having a spring finger contact connected to said receiving helix antenna, the helices of the two antennas being spaced an amount to at least minimize direct coupling between the ends so as to eliminate possibility of large errors.

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