

Oct. 29, 1963

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3,109,151

CONTINUOUSLY VARIABLE PHASE SHIFTER USING CIRCULAR POLARIZATION

Filed April 20, 1960

FIG. 1

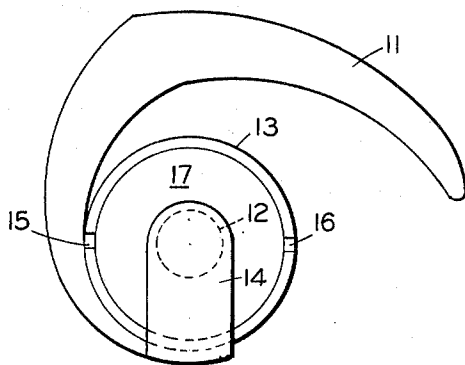
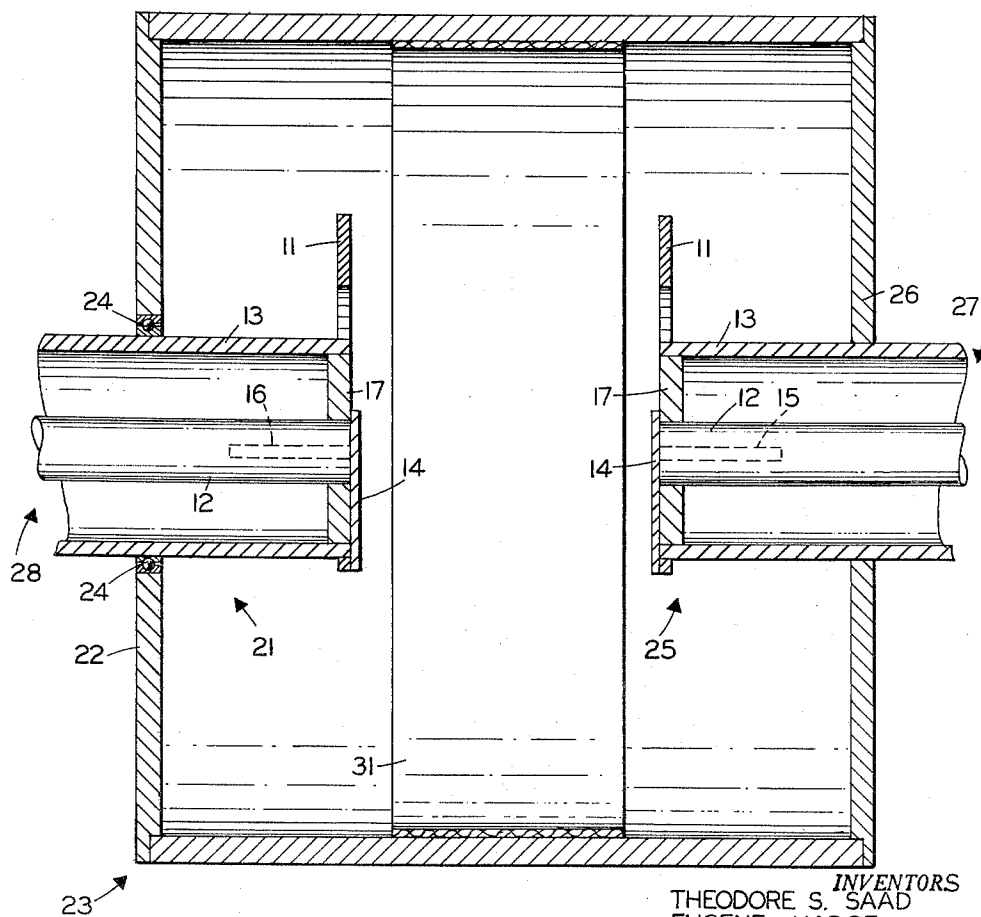


FIG. 2

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CONTINUOUSLY VARIABLE PHASE SHIFTER USING CIRCULAR POLARIZATION

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Filed Apr. 20, 1960, Ser. No. 23,466

16 Claims. (Cl. 333—31)

The present invention relates in general to high frequency wave transmission systems and more particularly concerns a novel coaxial phase shifter for continuously varying the relative phase between an input signal applied through a coaxial transmission line and an output signal withdrawn from the phase shifter through a second coaxial line.

Numerous applications exist for apparatus which imparts a prescribed degree of phase shift to a high frequency signal. For example, the directionality of an electromagnetic radiating system having two radiating elements may be controlled by varying the relative phase between energy of the same frequency applied to the different elements. Typical prior art phase shifters for use in this manner are of the oscillating or reciprocating type.

Such phase shifters have a number of disadvantages. The mechanical power required to oscillate a member in order to achieve a given range of phase shift is relatively high. It is difficult to maintain a good impedance match between the phase-shifting means and input and output wave transmission conduits over a wide range of phase variation. This is an especially difficult problem when the spectral components of the transmitted signal extend over a wide frequency range.

The problem is encountered when the transmitted energy is pulsed for a short duration, a practice not uncommon in high resolution radar systems. In order to achieve a satisfactory maximum range, the peak power of the short pulse is often of the order of megawatts. The high power which the phase shifter must handle further complicates the problem.

In order to increase the range of phase variation, efforts have been directed toward providing continuous coaxial phase shifters having a continuously adjustable phase shift over a range of 360 electrical degrees. According to one prior art approach, input and output coaxial transmission lines open into a cylindrical cavity functioning as a circular wave guide for transmitting electromagnetic energy from one transmission line to the other. Each center conductor is connected to a helical radiating element capable of radiating circularly polarized energy, the axis of the helix coinciding with that of the associated coaxial transmission line. By rotating one helix with respect to the other, the relative phase between energy in the input and output coaxial transmission lines is controllable. However, in these and other systems, the bandwidth was found to be somewhat limited.

It is an important object of the present invention to provide a continuously rotatable phase shifter for efficiently coupling energy from one coaxial transmission line to another while imparting a prescribed degree of phase shift to the transferred energy, the amplitude of the transferred energy being very nearly independent of the degree of phase shift imparted.

Another object of the invention is to achieve the preceding object over a relatively wide range of frequencies.

Still another object of the invention is to transmit relatively high levels of power in accordance with the preceding objects.

Still a further object of the invention is to minimize

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attenuation and the VSWR over the relatively wide range of frequencies.

Still a further object of the invention is to provide a mechanically simple coaxial phase shifter in accordance with the preceding objects to permit continuously varying the phase shift rapidly while requiring relatively small amounts of mechanical driving power.

According to the invention, two relatively rotatable radiating elements are located within a circular waveguide and connected to input and output coaxial transmission lines respectively. The sending element excites a circularly polarized wave in the circular waveguide section in response to high frequency energy delivered through the input coaxial transmission line. The circularly polarized wave is received by a receiving element which is substantially a duplicate of the sending element, the receiving element transforming the received energy into a linearly polarized wave for delivery to the output coaxial transmission line with phase shifted relative to that of the input signal by an increment related to the relative angular orientation between the sending and receiving elements. In a preferred embodiment of the invention, both the sending and receiving elements include like spiral conducting fins for controlling the E vector angular orientation for the TE_{11} wave propagated in the circular waveguide.

Other features, objects and advantages of the invention will become apparent from the following specification when read in connection with the accompanying drawing in which:

FIG. 1 is an end view of a preferred form of sending and receiving elements attached to an associated coaxial transmission line; and

FIG. 2 is a diametrical longitudinal sectional view through the novel phase shifter.

With reference now to the drawing and more particularly FIG. 1 thereof, there is shown an end view of the preferred spiral fin radiating element. The radiating element 11 may be termed a single fin spiral since it takes the form generally of a spiral about the axis of the associated coaxial transmission line.

The coaxial transmission line includes a center conductor 12 and an outer conductor 13. A radial shorting strap 14 is connected from the end of inner conductor 12 to the outer conductor 13. Fin 11 extends radially outward from outer conductor 13 and is connected thereto at the junction with the radial shorting strap 14. Two slots 15 and 16, respectively, are angularly displaced by approximately 90° from shorting strap 14. These slots are generally of different axial length and serve to minimize the VSWR in the associated coaxial transmission line. The slots are capacitive and their length determines the magnitude and location of capacitance.

An insulating end spacer 17 maintains the desired coaxiality between inner conductor 12 and outer conductor 13.

Referring to FIG. 2, there is shown a diametrical longitudinal sectional view through the novel phase shifter. The sending end assembly 21 is shown rotatably mounted within end plate 22 of circular waveguide 23 by ball bearings 24. Energy is delivered to the sending end from a stationary coaxial transmission line and coaxial choke joint to permit the entire sending assembly to rotate.

Since the use of coaxial choke joints to couple energy from a stationary coaxial line to a rotatable one is well-known in the radar art, details are not illustrated in the drawing so as not to obscure the inventive concepts. For similar reasons, the mechanical means for rotating the sending end assembly 21 are not shown. However, the outer conductor 13 to the left of end plate

22 may be fitted with a V-shaped circumferential track for accommodating a V-belt which passes over a drive pulley of an electric motor of suitable capacity. For stability, another set of ball bearings to the left of the illustrated section is preferably included.

The receiving end assembly 25 is rigidly supported within the end plate 26. Both the receiving assembly 25 and the sending assembly 21 are essentially identical. Elements of the two assemblies are identified by the same reference numerals used to identify corresponding elements in FIG. 1.

The receiving assembly 25 faces the sending assembly 21; hence, slot 16 is hidden from view by center conductor 12 in sending assembly 21, while slot 15 is shadowed by center conductor 12 in receiving assembly 25.

The assemblies 21 and 25 are spaced along the axis of the circular waveguide section 23. An annular section 31 of dissipative material, such as uskon cloth, is centrally located within the circular waveguide section 23 to suppress resonances which might otherwise occur due to the excitation of undesired TE_{01} and TE_{12} modes.

The relative phase between an electromagnetic wave and a predetermined plane of output coaxial transmission line 27 and a wave in a predetermined plane of input coaxial transmission line 23 is determined by the relative angular orientation about the circular waveguide axis between assemblies 21 and 25. By continuously rotating assembly 21, this relative phase may be continuously shifted through 360 electrical degrees. Moreover, there is very nearly correspondence between an angular displacement of assembly 21 and the corresponding electrical phase shift in electrical degrees.

Referring again to FIG. 1, it will be observed that the inside edge of the blade 11 is in contact with the outer conductor 13 for nearly a full quadrant extending clockwise from the shorting strap 14. The distance between this edge and outer conductor 13 then increases as a function of the angle about the coaxial line axis with respect to the radial shorting strap 14 until at an angle of approximately 270° it intersects the arc defining the outside edge of the fin blade. The maximum radial width of the fin occurs at a point approximately along the diameter passing through the radial shorting strap 14.

Having described the physical arrangement of the invention, the mode of operation will be discussed. It is believed that the coaxial transmission line, the short circuiting strap 14, the diametrically opposite slots 15 and 16, and the conducting spiral fin 11 function to establish the boundary conditions for a circularly polarized wave in the circular waveguide.

It seems as if the upper portion of the outer conductor 13 coacts with the inside edge of the spiral fin 11 to launch a TE_{11} wave oriented generally parallel to the diameter joining slots 15 and 16. The outside edge of spiral fin 11 appears to cooperate with the inside cylindrical surface of the circular waveguide 23 to establish a TE_{11} wave polarized essentially perpendicular to the diameter joining slots 15 and 16 and in time quadrature with the TE_{11} wave generally parallel to said diameter.

The reason for the two waves in space quadrature also being excited in time quadrature is possibly explained in the following manner. Since the outer conductor 13 is split at the end where the fin is attached and the center conductor 12 connected to the lower half by the conducting band 14, a potential exists at this end between the top and bottom halves of outer conductor 13. This potential also exists between the upper half of conductor 13 and the inside edge of fin 11 so that the wave established therebetween is essentially in phase with the voltage across the two halves of the end of outer conductor 13.

Band 14 is a short circuit between the inner conductor and the lower half of the outer conductor so that it effectively introduces inductance at the end of the co-

axial line and the current flowing in this short circuiting band is in time quadrature with the voltage across the split outer conductor 13. It appears as if the wave established between the outside edge of fin 11 and the inner cylindrical surface of the circular waveguide 23 is in phase with the current; hence, the two waves in space quadrature are respectively in time phase with the voltage and current at the end sections which are in time quadrature.

It is important to note that the time relationship between voltage and current is relatively insensitive to frequency so that this explanation would seem to state reasons for obtaining such a high degree of circularity over such a wide band of frequencies.

It is preferred that the distance between each end plate 22 and 26 and the plane of a respective spiral fin 11 be approximately a quarter of the circular guide wavelength for energy of the TE_{11} mode at the center frequency of the band to be transmitted, the spacing between the planes of the sending and receiving spiral fins being preferably approximately a wavelength at this frequency.

In a representative embodiment of the invention, the input and output coaxial lines 28 were $6\frac{1}{4}$ inch coaxial lines, the circular waveguide 23 was 20 inches in diameter, the separation between the spiral fins 11 was $18\frac{3}{4}$ inches, the spacing between each fin 11 and the near waveguide end wall was $8\frac{1}{4}$ inches, and the lengths of slots 15 and 16 were 5.970 and 6.000 inches, respectively. Such an embodiment of the invention operated over a band of frequencies from 400 to 440 mc. with the following characteristics:

VSWR=1.13

Insertion loss=0.8 db

Rotational amplitude variation=0.3 db

Deviation from phase linearity= ± 7.0 to -3°

These results demonstrate that the invention is characterized by a low VSWR, low insertion loss, negligible amplitude modulation due to rotation and a nearly linear relation between angular rotation and electrical phase shift. It is evident that those skilled in the art may now make numerous modifications of and departures from the specific embodiment described herein without departing from the inventive concepts. Consequently, the invention is to be construed as limited only by the spirit and scope of the appended claims.

What is claimed is:

1. High frequency apparatus comprising, a coaxial transmission line having an inner and outer conductor, a single spiral conducting fin connected to and extending radially outward from said inner and outer conductors substantially in a plane orthogonally intersecting both said inner and outer conductors, and a cylinder of conducting material with its axis coinciding with that of said line surrounding said fin and said coaxial transmission line and extending beyond to define a hollow conducting cylindrical portion immediately adjacent to the portion surrounding said fin, said single spiral fin coating with said cylinder to comprise means for transducing a TEM wave in said coaxial transmission line to a circularly polarized wave in said hollow cylindrical portion.

2. High frequency apparatus for varying the phase of an output signal with respect to that of an input signal comprising, input and output coaxial transmission lines spaced along a common axis, input and output conducting fins respectively connected to said input and output lines, each of said fins connected to and extending radially outwardly from the inner and outer conductors of its associated line substantially in a plane orthogonally intersecting both said inner and outer conductors, and a cylinder of conducting material about said fins and common axis for conveying electromagnetic energy from one of said fins to the other.

3. High frequency apparatus comprising, a coaxial transmission line, short circuiting means connecting the

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inner and outer conductors of said line together at its end, a spiral conducting fin extending radially outward from said outer conductor, and a cylinder of conducting material surrounding said spiral conducting fin with its axis coinciding with that of said coaxial transmission line with a first portion surrounding said fin and said coaxial transmission line and a second portion immediately adjacent to said fin defining a hollow cylindrical portion, said spiral fin coaxing with said cylinder to comprise means for transducing a TEM wave in said coaxial transmission line to a circularly polarized wave in said second portion.

4. High frequency apparatus comprising, a pair of axially spaced coaxial transmission lines, respective short circuiting means connecting the inner and outer conductors of each of said lines together at adjacent ends, respective spiral conducting fins extending radially outward from each outer conductor, and means for coupling high frequency energy from one of said conducting fins to the other, the relative phase between energy in the plane of said fins being related to the relative angular orientation between said fins about the axis of their respective coaxial lines.

5. Apparatus in accordance with claim 4 and further comprising, means for rotatably supporting at least one of said fins to permit adjustment of said relative angular orientation.

6. High frequency apparatus comprising, a coaxial transmission line, a radial short circuiting bar connecting the inner and outer conductors of said line together at its end, a spiral conducting fin extending radially outward from said outer conductor and connected thereto at the junction with said shorting bar, and a cylinder of conducting material surrounding both said coaxial transmission line and said fin with its axis coinciding with that of said coaxial transmission line and having a second portion extending beyond the said fin, said fin coaxing with said cylinder to comprise means for transducing a TEM wave in said coaxial transmission line to a circularly polarized wave in said second portion.

7. High frequency apparatus comprising, a pair of axially spaced coaxial transmission lines, respective radial short circuiting bars connecting the inner and outer conductors of each of said lines together at adjacent ends, respective spiral conducting fins of like shape extending radially outward from each outer conductor and connected thereto at the junction with said shorting bar, and means for guiding high frequency energy from one of said fins to the other, the relative phase between energy in the planes of said fins being related to the relative angular orientation between said fins about the axis of their respective coaxial lines.

8. Apparatus in accordance with claim 7 and further comprising, means for rotatably supporting at least one of said fins about its associated coaxial line axis to permit adjustment of said relative angular orientation.

9. High frequency apparatus comprising, a pair of axially spaced coaxial transmission lines, respective radial short circuiting bars connecting the inner and outer conductors of each of said lines together at adjacent ends, respective spiral conducting fins of like shape extending radially outward from each outer conductor and connected thereto at the junction with said short circuiting bar, a circular waveguide surrounding said fins for coupling energy from one fin to the other, and means for rotating at least one of said fins about the axis of its associated coaxial line.

10. Apparatus in accordance with claim 9 wherein said outer conductors are formed with diametrically opposed longitudinal slots extending to said ends for matching the characteristic impedance of said coaxial transmission lines to the wave impedance of said circular waveguide.

11. Apparatus in accordance with claim 10 and further

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comprising, an annular ring of lossy material within said waveguide about its axis for damping resonances at predetermined high frequencies within the band of frequencies transmitted from one of said coaxial lines to the other.

12. Wave transmission apparatus comprising, a circular waveguide dimensioned to support propagation of the TE_{11} mode, a first coaxial transmission line, coupling means for exchanging energy between said waveguide and said first transmission line, said first coupling means including field establishing means located in a predetermined cross-sectional plane of said waveguide for establishing first and second TE_{11} electric fields in said plane in time and space quadrature, said field establishing means comprising, diametrically opposed longitudinal slots in the end portion of the outer conductor of said first coaxial transmission line, a shorting strap oriented substantially perpendicular to the diameter joining said slots and connecting together the ends of the inner and outer conductors of said first coaxial transmission line, and a spiral fin substantially in said first plane connected to said outer conductor in the quadrant between said shorting strap and one of said slots, said fin curving about said outer conductor and subtending an angle thereabout of less than 360° .

13. Wave transmission apparatus in accordance with claim 12 and further comprising, a second coaxial transmission line, and second coupling means including second field establishing means located in a second predetermined cross-sectional plane of said waveguide for determining the angular orientation of electric fields in time and phase quadrature in said second plane for said TE_{11} mode, said second field establishing means comprising, diametrically opposed longitudinal slots in the end portion of the outer conductor of said second coaxial transmission line, a shorting strap oriented substantially perpendicular to the diameter joining said slots and connecting together the ends of the inner and outer conductors of said second coaxial transmission line, and a spiral fin substantially in said second plane connected to said outer conductor in the quadrant between the last-mentioned shorting strap and one of the last-mentioned slots, said fins curving about said second transmission line outer conductor.

14. Wave transmission apparatus in accordance with claim 13 and further comprising means for rotating at least one of said field establishing means about the waveguide axis to control the relative angular orientation about said axis between said electric fields in said first and second planes.

15. Wave transmission apparatus in accordance with claim 13 wherein the separation between said first and second planes is substantially equal to the guide wavelength of energy at the center frequency of the band transmitted by said apparatus.

16. Wave transmission apparatus in accordance with claim 15 and further comprising, first and second conducting end plates at opposite ends of said waveguide, each formed with a central circular opening surrounding said first and second coaxial transmission lines, respectively, the spacing between said first and second end plates and said first and second planes respectively being substantially one quarter of said guide wavelength.

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