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RECIPROCAL MICROWAVE PHASING UNIT FOR USE IN AN ANTENNA ARRAY

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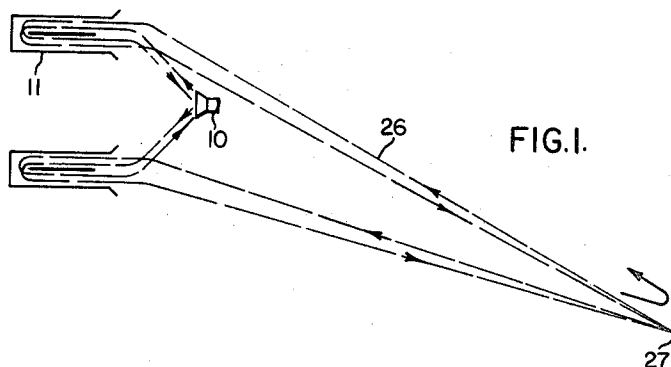


FIG. 1.

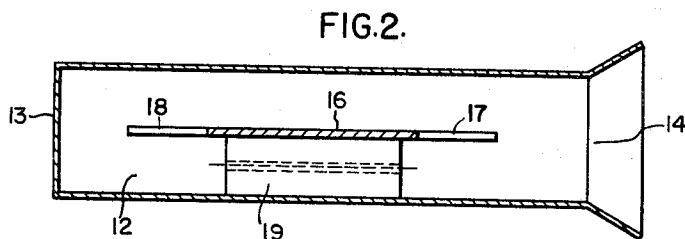


FIG. 2.

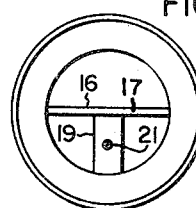


FIG. 3.

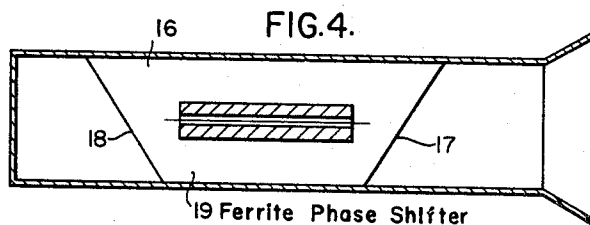


FIG. 4.

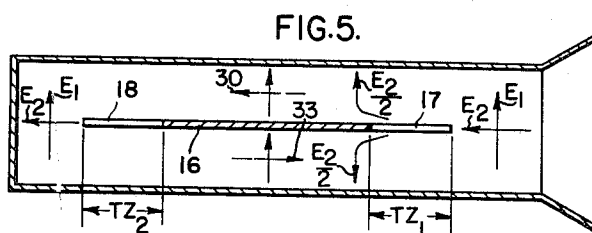


FIG. 5.

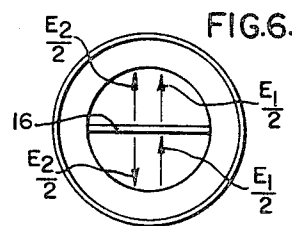


FIG. 6.

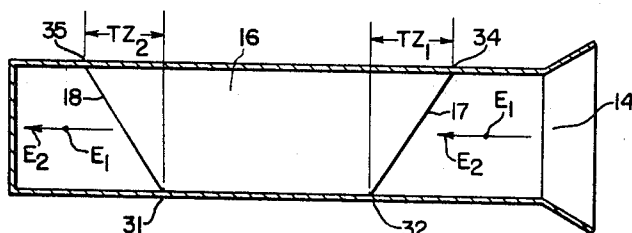


FIG. 7.

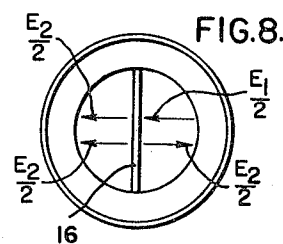


FIG. 8.

WITNESSES

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5 Claims

ABSTRACT OF THE DISCLOSURE

A microwave mode converter is combined with a non-reciprocal ferrite phase shifting element and provides a reciprocal microwave phase shifting unit. A hollow round, rectangular or square waveguide capable of propagating a circularly polarized electromagnetic wave has a horizontal central transverse septum with a front edge sloping with respect to the axis of propagation will propagate circularly polarized waves without reflection. Incoming circularly polarized waves will be converted to the linearly polarized mode with all of the energy passing to one side or the other of the septum with the electric vector perpendicular to the septum. The side of the septum on which the wave propagates is determined by the direction of the rotation of the circular polarization and by the direction of the slope of the edge of the septum. When the two halves of the wave guide, formed by the septum, are connected at one end by a zero radius 180° bend a circularly polarized wave entering the open end of the waveguide will propagate down one side of the septum and back along the other side to reappear at the open end with reverse direction of rotation and propagation. A non-reciprocal latching ferrite phase shifter arranged on one side or the other of the septum, or distributed between the two, can vary the phase of the exciting circularly polarized wave and thus make the device a reciprocal device.

This invention relates to a phasing element and more particularly to an antenna phasing element utilizing a latching phase ferrite device.

As will be apparent from the description, the device is adapted to be used where a circularly polarized signal is involved. It is particularly adapted to be used in a radar system utilizing circularly polarized transmission where the energy return is from a single-bounce reflection. In such an instance the present invention would be utilized for directing the transmitted and received signal into the single antenna system.

Ferrite phase shifters are especially desirable in high powered phased array antennas because of their high power handling qualities and the relative simplicity of the ferrite devices. Ferrite phase shifters that are reciprocal in operation require holding current to maintain a given phase shift and when used in quantity in a multi-element array lead to exorbitant power demands. In patent application Ser. No. 396,121, filed Sept. 14, 1964, by applicant for a Non-reciprocal Microwave Apparatus, now abandoned, there is described and claimed a recently developed non-reciprocal latching ferrite phase shifter which eliminates the switching and holding power problem but requires that the phase shifters be reset between transmit and receive in order to overcome the non-reciprocal operation. The present invention eliminates the resetting requirement thus further reducing antenna steering power requirements and the complexity of the control circuits. Although the present device, when utilized in the radar environment, requires that the radar signal be circularly polarized, this is not a disadvantage but is, in fact, a dis-

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tinct advantage since linearly polarized signals when operating into or through the ionosphere are degraded by Faraday rotation and accordingly an unpredictable amount of the radar echo energy would be lost to radar receiving equipment designed for linearly polarized waves.

Accordingly, the primary object of the present invention is to provide a novel and improved phasing element which is very simple, is reciprocal, has a very high power capacity and which is latching so that it does not require holding power.

Another object is to provide a novel and improved electrically adjustable antenna phasing element particularly adapted for utilization in the transmit-receive unit of a radar system and which is capable of handling large amounts of power and is very simple in construction.

The invention itself, however, both as to its novel arrangement and method of operation as well as additional objects and advantages will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIG. 1 is a diagrammatic illustration of a radar antenna system utilizing the present invention;

FIG. 2 is a sectional elevational view of one of the phasing elements of the present invention;

FIG. 3 is an end elevational view of FIG. 2;

FIG. 4 is a horizontal sectional view of the device shown in FIGS. 2 and 3;

FIGS. 5 and 6 are enlarged diagrammatic illustrations of FIGS. 2 and 3, respectively, illustrating the mode conversion operation of the present phasing element; and

FIGS. 7 and 8 are enlarged diagrammatic illustrations of FIG. 5 and of an end view of FIG. 5, respectively, illustrating the mode conversion operation of the phasing element.

As illustrated in the accompanying drawings, the present invention includes the non-reciprocal latching ferrite phase shifter of the aforementioned copending patent application in combination with a section of round or square hollow waveguide provided with a central transverse septum having a precisely sloping end that causes circular polarized waves to be collected as linear polarized waves all on one side of the septum or the other depending upon the direction of rotation of the circular polarization. As illustrated in the drawings a large number of these devices may constitute the elements of a phased array antenna where they serve both as the radiation and receiving elements of the radar system. This is illustrated in FIG. 1 wherein at 10 there is illustrated a suitable microwave horn which may be connected to any suitable source (not shown) of circularly polarized microwave energy. The open end of the horn 10 is directed toward the antenna array which is made up of a large number of the phasing elements 11 which constitute transmitting radiation and receiving elements of the radar antenna system so that the single antenna can be utilized for receiving and transmitting.

The phasing elements 11, as illustrated, may be considered as a round hollow pipe waveguide section 12 having a shorted end 13 and an open end 14. The open end may be provided with suitable space matching means. A septum 16 having precisely sloping ends 17 and 18 separates the microwave section into two equal upper and lower parts. The lower part includes a ferrite element 19. This ferrite element can be latched to give non-reciprocity in either direction and can be selectively energized to give a selected phase shift.

The sloping end septum 16 splits the round guide into two halves without causing reflections from E vectors parallel to the septum. The present invention takes advantage of this characteristic of the sloping end septum in a round or square guide capable of supporting circular

polarization to provide a mode transducer that can recognize the direction of circular polarization and thus channel both transmitted and received signals of a radar system through a non-reciprocal phase shifter in the same direction to thereby provide a reciprocal effect. The ferrite element 19, which may be in either or both halves of the waveguide, can provide the desired phase shift.

As shown in FIG. 3 the ferrite element 19 is generally rectangular in shape and extends between the septum 16 and the bottom wall of the waveguide section. It is centered on the central vertical plane of the waveguide which extends normal to the septum. If desired, the ferrite element 19 may be latched in one magnetic state in any suitable manner. As illustrated, it is provided with a central aperture 21 extending longitudinally of the element through which a suitable insulated conductor may be threaded and energized from any suitable source of pulsed or direct current for the purpose of latching the element in a fixed state.

As is clearly understood by those skilled in the art, the direction of rotation of circular polarized waves is determined jointly by the direction of propagation and by which of the linear orthogonal components is leading. Since the components are 90° apart in time phase, delaying one component by 90° puts all the components in phase and all the energy is linearly polarized. A round or square hollow pipe waveguide propagating a circularly polarized radio frequency mode can be split transversely with the centrally located septum 16 having the properly sloped leading edge 17 without introducing reflections. The circularly polarized RF mode may be considered to be composed of two orthogonal linear modes represented by the arrows E_1 and E_2 in FIGS. 4 to 7, inclusive. One of these modes E_2 , is parallel to the septum 16 and the mode E_1 is perpendicular to the septum. As indicated in FIGS. 4 and 5, when the normal mode E_1 enters the septum region of the waveguide it is propagated without change, as shown in FIG. 5, as it travels in the direction of the arrow 30, FIG. 4. On the other hand, the component E_2 parallel to the septum 16 is converted to a new configuration with two components normal to the septum and of equal amplitude on opposite sides of the septum and of opposing phase as indicated in FIG. 5. The resultant two linear waves attempting to propagate on each side of the septum are in phase coincidence on the upper side of the septum 16 as indicated in FIG. 5 and in phase opposition on the other side, thus delivering the total energy of the originally circularly polarized wave to the upper half of the wave guide section. The side of the septum upon which the total energy appears is determined by the direction of the circular polarization and the direction of the septum slope. This process is reciprocal in that a linear wave introduced onto one side of the septum will be launched from the sloping septum end and, without reflection and without coupling to the opposite side of the septum, will propagate in the round waveguide as circular polarization.

When the waveguide halves formed by the septum are coupled at the far end by a zero radius 180° bend, such as by the rear sloping edge 18 and the shorting end 13, a circularly polarized wave entering the open end 14 will propagate in the linear mode in the direction of the arrow 30 in the upper half of the waveguide over the portion of the septum 16 between the points 32 and 31, (FIG. 7) and will propagate in circular mode beyond the point 35, will be reflected from the shorted end 13 and will pass below the septum in the direction of the arrow 33 in the linear mode between the point 31 and point 32 after which it will revert to the circular mode and reappear at the open end 14 with reversed direction of rotation. Circularly polarized waves exist in the round guide between the point 34 and the open end 14 regardless of the direction of propagation, and the direction of rotation is always the same when viewed in the same direction of propagation. Circularly polarized microwaves energy propagated from

the horn 10 will enter the right-hand end 14 of the phasing unit 12 and will remain circularly polarized until it reaches the point 34 at which time transition from circular to linear polarization takes place as described above as the energy propagates in the direction of the arrow 30 in the upper half of the waveguide. As the point 31 is reached the transition back to circular polarization takes place and the energy proceeds around the edge 18 of the septum and continues to propagate in the linear mode in the direction of the arrow 33 in the lower half of the waveguide and begins the transition again back to circular polarization as it passes the point 32 and completes the transition at point 34. The wave will be launched from the open end 14 as a circularly polarized wave. When viewed looking toward the open end 14 the direction of rotation of the launched wave will be opposite to that proceeding in the direction of the arrow 30 because the direction of propagation is reversed.

In FIGURES 5 and 7 the transition zones TZ1 and TZ2 are the portions of the propagation path which are longitudinally coextensive with the front sloping edge 17 and the back sloping edge 18, respectively, of the septum 16 over which the incoming wave is undergoing a change in mode from circularly polarized to linearly polarized, and vice versa. In this connection it will be noted that in the space between the point 35 and the short circuiting end wall 13 the wall will be reflected and propagated in circular polarized mode and as it passes the point 31 the mode will change again to linear polarization and after passing through the transition zone TZ1 will be launched from the horn 14 in the circular polarized mode.

The coupling between the two sides of the septum 16 in the linear mode may be made by merely eliminating back sloping edge 18 of the septum and leaving a narrow opening between the back end of the septum and the shorted end 13 to serve as a coupling iris.

When the circular polarized radiation is propagated along the line 26 to a target 27 and it is returned by a single bounce it will enter the portion of the waveguide section above the septum 16. It is to be noted that this is the same direction in which the energy went from the horn 10 originally into the phasing element 11. The single bounce does not reverse the relative phase of the orthogonal components but since the reflected wave will be going in the opposite direction from the propagated transmitted wave the direction of rotation is reversed and accordingly the signal from the feed horn 10 and the received signal goes through the phasing elements 11 in the same direction. It follows, of course, that the received energy from the target which enters the upper portion of the waveguide section 12 will be reflected from the end wall 13 toward the open end and, of course, will be picked up by the horn 10 which in the meantime, in accordance with standard radar equipment, has been switched from the transmitter to the receiver of the radar system.

The non-reciprocal latching ferrite element 19, shown in FIG. 3 as being only in the lower half of the waveguide, may be on either or both sides of the septum 16 for the purpose of providing a selected phase change in the circularly polarized wave for providing inertialess scanning by the antenna array as is well understood in the radar art. It may be constructed in accordance with applicant's abandoned application, previously mentioned.

A number of the phasing elements 11 with open ends properly matched to space may be assembled into an array-type antenna using the front surface space feed from horns similar to horn 10 and as well understood in the radar art. Since the phasing elements 11 provide the same phase shift for the transmitted and received wave the antenna pointing integrity will be preserved.

Experimental versions of the sloping edge septum mode transducer have demonstrated circularity within 0.5 db over a frequency range of 5.4 to 5.9 GHz. in 1.5 inch inside diameter guide and isolation between sides of the septum of 15 to 20 db over the same frequency range.

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Although the invention has been illustrated in connection with an inertialess radar scanning antenna system it will be apparent that the present invention is not limited to that application. Also it will be apparent that various changes may be made without departing from the spirit of the invention.

I claim as my invention:

1. A microwave device comprising a section of hollow waveguide capable of receiving and launching circularly polarized waves, said waveguide section having one end closed by a flat conducting plate, an electrically conducting septum having a continuous uniform slope extending transversely of said guide with its edges ohmically connected to the inner surfaces of said waveguide dividing said waveguide into two halves, said septum selectively rotating one of the electric vectors of circularly polarized incoming wave energy into time and spacial coincidence with the other vector of the circularly polarized wave to thereby transmit all of the incident wave energy in the linear mode on only one side of said septum dependent upon the direction of rotation of the circular polarization, and means including said closed end and said septum for transferring the linear mode to the opposite side of said septum.

2. The combination as set forth in claim 1 in which non-reciprocal phase shifting means is positioned in at least one of said waveguide halves.

3. In combination in an antenna array, a plurality of the microwave devices as set forth in claim 1 and means

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for varying the relative phase of the circularly polarized waves launched from the open ends of said devices.

4. The combination as set forth in claim 1 in which said septum has a second sloped edge facing said shorted end.

5. The combination as set forth in claim 1 in which said septum has a second sloped edge facing the shorted end and phase shifting means in at least one of said waveguide halves to vary the phase of the existing circularly polarized wave.

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PAUL L. GENSLER, Assistant Examiner

U.S. Cl. X.R.

333—21, 31; 343—777