Oct. 17, 1967 J. C. ROLFS 3,348,227

CROSS-POLARIZED MICROWAVE ANTENNA

Filed Aug. 3, 1964 3 Sheets-Sheet 1

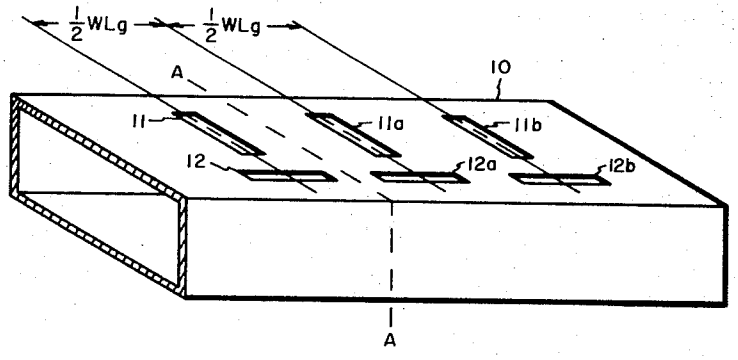


FIG. 1

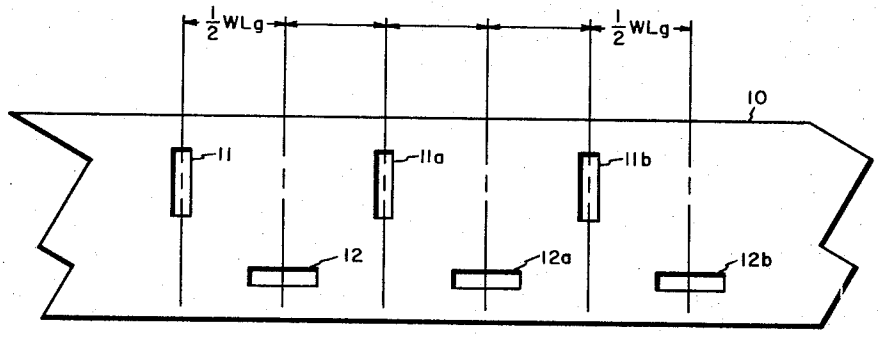


FIG. 2

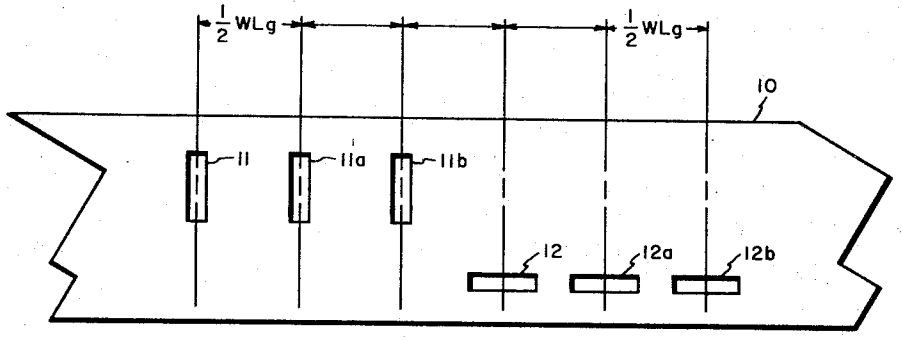


FIG. 3

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CROSS-POLARIZED MICROWAVE ANTENNA

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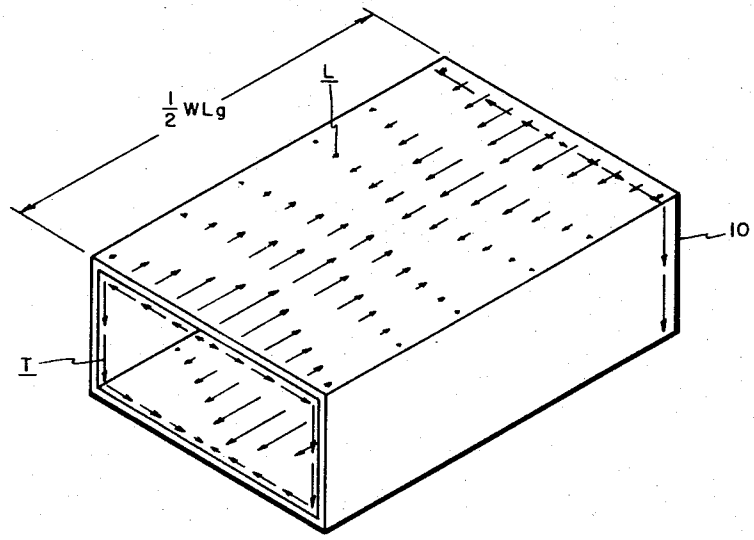


FIG. 4

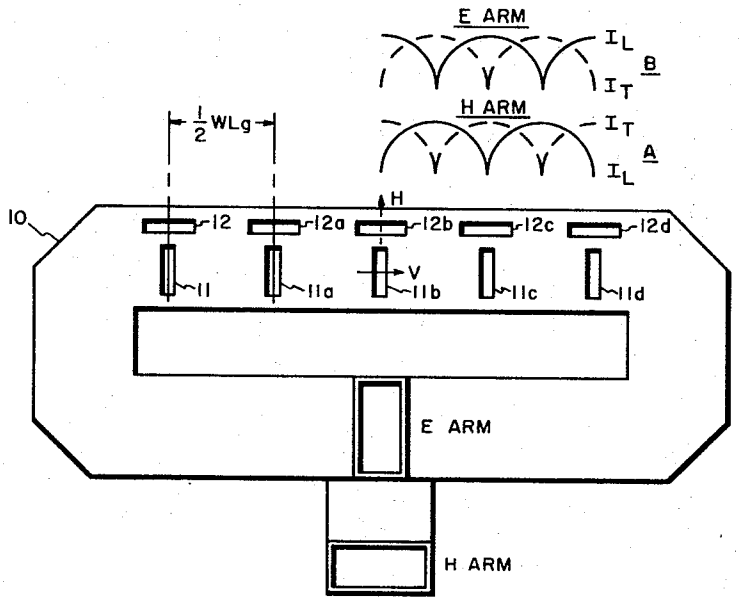


FIG. 7

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CROSS-POLARIZED MICROWAVE ANTENNA

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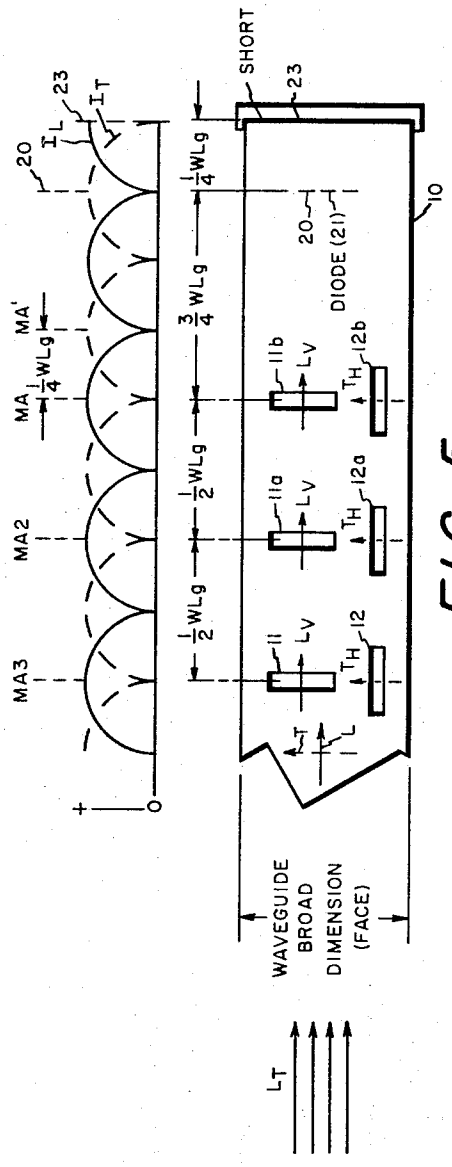


FIG. 5

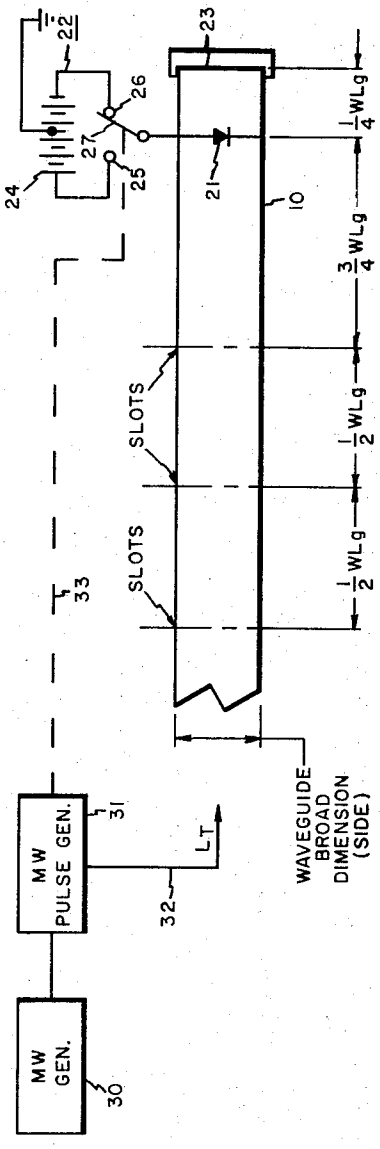


FIG. 6

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3,348,227

CROSS-POLARIZED MICROWAVE ANTENNA

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Filed Aug. 3, 1964, Ser. No. 387,045
2 Claims. (Cl. 343—768)

The present invention relates to an improvement in antennas for transmitting and receiving microwave energy. More particularly my invention relates to an improved antenna for use in a radar system in which waveguide, in rectangular form, is arranged so as to selectively couple microwave energy in the interior of the waveguide to free space so as to selectively provide transmission of microwave energy in a predetermined polarized plane and provide reception of cross-polarized microwave energy.

It is well known that when microwave energy in the dominant TE_{10} mode is applied to a rectangular waveguide, two electrical components are developed in the interior of the waveguide. These two components are sometimes referred to as the transverse current and the longitudinal current. These currents are characterized by such terms because of the normal direction of flow of such currents within the internal structure of the waveguide. It is also known that a standing wave pattern of the internal currents may be developed or established within the interior of the waveguide and that the values of the respective currents of such pattern are substantially offset 90° with respect to each other. That is, when one current is at maximum value or amplitude the other current may be at substantially zero or minimum value or amplitude at a predetermined point or points on the interior of the waveguide.

Radiation of microwave energy from a waveguide section may be accomplished through a slot cut in the wall of the waveguide. Radiation of microwave energy is dependent upon the value (normally amplitude) of the energy and the physical position of the slot relative to the direction of energy flow within the waveguide. Ideally, maximum coupling of one of the currents of the internal microwave energy to free space is provided when the long dimension of the slot is at right angles to the direction of energy flow of that current and the slot is substantially physically centrally located at a point of maximum amplitude of that current. If the long dimension of the slot is parallel to the direction of that current flow or if the slot is substantially physically centrally located at a point of substantially zero amplitude of that current, little or no radiation of energy will occur.

Since the direction of current flows are substantially at right angles with respect to each other a slot which may couple one current to free space will not couple the other current to free space. A series slot, for example, positioned with its long dimension transverse to the long dimension of the waveguide section, will couple longitudinal current to free space and will provide a vertically polarized beam of radiated energy. A shunt slot, for example, positioned with its long dimension parallel to the long dimension of the waveguide section, will couple transverse current to free space and will provide a horizontally polarized beam of radiated energy.

Since the amount of radiated energy is related to the amplitude of the current coupled to free space, and the amplitude values of the currents are displaced 90° with respect to each other in the standing wave pattern then, ideally a series slot or element would be positioned at a point of maximum amplitude of the longitudinal current and a shunt slot or element would be positioned at a point of maximum amplitude of the transverse current for ideal radiation of the respective currents. The distance along the waveguide between the point of maximum amplitude of one current and the closest point of maximum amplitude of the other current is ¼ of a guide wavelength of the standing wave pattern within the waveguide with adjacent points of maximum amplitude of the same current ½ of a guide wavelength of the standing wave pattern apart.

The present invention is concerned with the complex use of at least two types of slots, normally singularly employed in the broad dimension or face of a waveguide section and the selective control of the standing wave pattern of the energy within the waveguide so as to transmit one or the other of the two currents within the waveguide in either a vertically polarized beam or a horizontally polarized beam through one or the other of the same kind of slots in a cross-polarized linear array antenna and to receive both vertically polarized energy and horizontally polarized energy through the same cross-polarized linear array antenna.

It has been found that when a particular polarized beam is transmitted by a radar antenna, part of the reflected microwave energy of the transmitted beam may be reversed in polarization by the reflecting surface. Thus, for example, a vertically polarized transmitted beam of microwave energy may be reflected substantially in its vertically polarized form and part of the same transmitted beam may be reversed in polarization and be reflected as a horizontally polarized beam. This latter effect is normally a result of what is referred to as back-scattering, which may occur from reflection of microwave energy from terrain and/or water surfaces, for example.

To be able to receive the reversed polarized reflected energy or back-scattering via the same antenna assembly has great advantage. This eliminates the need of a second antenna. Another advantage of the present invention is that selective beam transmission, either in a vertically polarized beam or in a horizontally polarized beam, may be accomplished through use of the same antenna assembly.

Thus transmission of a selected form of beam energy becomes a matter of remote selection, through use of the same antenna with the additional advantage of receiving cross-polarized beam energy, both vertically polarized beam energy and horizontally polarized beam energy through use of the same antenna and the same remote selection.

The present invention provides for the positioning of a series slot and a shunt slot at the same or corresponding ½ guide wavelength point of the same current of a normal standing wave pattern of a waveguide section and remotely controlling the position of the standing wave pattern so as to selectively reverse the amplitude values of the respective currents at the ½ guide wavelength points within the waveguide section.

Thus when both series and shunt slots are positioned at the same or similar half wave points, only one of the currents of the energy, for example the longitudinal current of the standing wave pattern will couple to free space. This will provide transmission of radiant microwave energy in a particular polarized beam, for example, a vertically polarized beam.

When the amplitude values of the standing wave patterns are substantially reversed so that the amplitude of, for example the longitudinal current (heretofore assumed at maximum) becomes minimum and the transverse current (heretofore assumed at minimum) becomes maximum, the transverse current will couple to free space and the longitudinal current will be substantially uncoupled.

In, for example, a radar system, an antenna may be employed so as to selectively transmit either a vertically polarized or a horizontally polarized beam of microwave energy as desired. In such radar system the standing wave pattern may be so oriented during one period so as to couple the shunt slot or slots to the internal currents so

as to provide transmission and reception of horizontally polarized microwave energy. During another period, the standing wave patterns may be shifted so as to couple the series slot or slots, thereby providing for transmission and reception of vertically polarized microwave energy. Thus, in a pulsed radar system, for example, the "one" period may be in on-pulse time and the "other" may be the inter-pulse time so that horizontally polarized energy may be both transmitted and received during the time of the pulse and vertically polarized energy may be received during the inter-pulse period.

Obviously the example above described may be reversed so that vertically polarized energy may be both transmitted and received during the time of the pulse and horizontally polarized energy may be received during the inter-pulse period.

In accordance with one embodiment of the invention, the waveguide is shorted in tuned arrangement, as by closing or blocking, either physically or electrically, one end of the waveguide section so as to develop a standing wave pattern with one of the internal currents at maximum amplitude at the location or locations of the slot or slots and the other of the two currents at minimum or zero amplitude at such locations. Such arrangement provides for selectively shifting or orienting the standing wave pattern so as to substantially reverse the current amplitude values at the slot location or locations.

In accordance with another embodiment of the invention, a standing wave pattern of the internal currents in a waveguide is established by applying microwave energy to a waveguide section through the input arm or arms of a hybrid junction with selective positioning or orientation of the standing wave pattern controlled by selectively applying microwave energy to the waveguide via one or the other of the two input arms of the hybrid junction.

It is therefore an object of the invention to provide a waveguide antenna for microwave energy which may selectively couple one or the other of the two electrical components of microwave energy to free space through the use of pairs of oppositely arranged slots in a rectangular waveguide section and selective control of the precise position of the standing wave pattern within the waveguide section.

Another object of the invention is to provide a waveguide antenna for microwave energy in which oppositely polarized microwave energy beams may be received through the use of a cross-polarized linear array antenna arrangement, and selective positioning of the standing wave pattern within the waveguide.

It is a further object of the invention to provide a small, lightweight radar antenna having cross-polarized radiating elements for selectively transmitting a predetermined form polarized beam of microwave energy and for receiving cross-polarized beams of microwave energies through selective control of the position of the standing wave patterns within the waveguide.

Another object is to provide a cross-polarized array waveguide antenna in which the standing wave pattern developed within the waveguide section is selectively oriented so as to couple one or the other of the two internal currents to one or the other of matched radiating elements in the cross-polarized array.

Another object is to provide a cross-polarized linear array waveguide antenna for remotely selectively coupling one or the other of the internal currents to matched radiating elements of the cross-polarized array through selectively positioning the short across the waveguide section.

A further object is to provide a cross-polarized linear array waveguide antenna for remotely selectively coupling one or the other of the internal currents to matched radiating elements of the cross-polarized array through selectively applying microwave energy to the waveguide through one or the other of the two input arms of a hybrid junction.

For a more complete description of my invention, reference may be had to the following detailed description of the invention with reference to the accompanying drawings, in which:

FIG. 1 illustrates a section of rectangular waveguide in which has been cut three pairs of radiating elements;

FIG. 2 illustrates another arrangement of the slot pairs;

FIG. 3 illustrates a further arrangement of the slot pairs;

FIG. 4 is an end view of a waveguide section with arrows representing the directional current flows;

FIG. 5 is a plan view of the broad dimension of a waveguide antenna section with a graph representation of the energy waves;

FIG. 6 is a plan view of the narrow dimension of a waveguide antenna section, with a microwave generator and microwave pulse generator, represented in block form, and

FIG. 7 illustrates a waveguide loop or resonant antenna to which microwave energy is applied through input arms of a hybrid junction.

FIG. 1 illustrates a section of rectangular waveguide **10** in which a plurality of pairs of rectangular slots are cut in the broad dimension of the waveguide and positioned substantially centrally at ½ guide wavelength positions. The slots **11**, **11***a* and **11***b* are physically positioned so as to have their long dimension transverse to the long dimension of the waveguide. Slots so positioned are generally referred to as transverse or series slots. The slots **12**, **12***a* and **12***b* are physically positioned so as to have their long dimension parallel to the long dimension of the waveguide. Slots so positioned are generally referred to as longitudinal or shunt slots.

Although three slots of each type are illustrated with the slots in a configuration so as to appear as pairs of slots, other arrangements of the slots may be made, as represented in FIGS. 2 and 3. It should also be noted that the number of slots employed is not to be implied as limited to three of each type. More or fewer slots may be used, if desired.

FIGS. 2 and 3 illustrate alternate arrangements or placement of the slots on the broad dimension of the waveguide. FIG. 2 shows that the slots of different type may be alternated at ½ guide wavelength (½ WLg) positions while FIG. 3 shows slots of the same type in separate groups at ½ guide wavelength positions. It will be noted that corresponding components throughout the several figures have been given corresponding reference characters. It should be noted that FIGS. 1, 2 and 3 assume that the waveguide is matched or tuned so that a standing wave pattern may be generated therein.

FIG. 4 represents an end view of the waveguide section **10**, along line A—A of FIG. 1 showing, in perspective, a section ½ guide wavelength in length. The plurality of arrows indicating a pattern of current flow, each collectively represent a different direction of a current flow, the arrows, L, representing the longitudinal current flow and the arrows, T, representing the transverse current flow. Thus it may be visualized that the direction of flow of the longitudinal current is generally in a loop extending along the length of the waveguide while the direction of flow of the transverse current is generally in a loop transverse to the length of the waveguide. The slots have been eliminated from FIG. 4 for convenience of illustration.

Referring to FIGS. 5 and 6, a waveguide antenna section in broad dimension, or top plan view, FIG. 5, and in narrow dimension, or side plan view, FIG. 6, are shown illustrating one form of the present invention. Representations of the wave value patterns are illustrated above the broad dimension view of FIG. 5 with the longitudinal current, I_L, shown in solid line form and the transverse current, I_T, shown in broken line form.

The directions of current flow of the currents within the waveguide are indicated by the solid arrow L and the broken line arrow T on the face of the waveguide, **10**, in FIG. 5.

The microwave currents at the short circuit, **23**, are reflected to form a standing wave pattern within the waveguide. With the short positioned at **23**, for example, the longitudinal current I_L is at maximum value at the points MA, MA2 and MA3. The point MA being one guide wavelength (¼ WLg+¾ WLg) from the short circuit position **23** and points MA2 and MA3 being ½ guide wavelength points (½ WLg), each more distant from the short circuit position at the terminal in the waveguide respectively. It will be noticed that when the longitudinal current value is at maximum, the transverse current value is at minimum, which may be substantially zero.

Broken line **20** represents the position at which a microwave switching diode **21** may be located. The location is illustrated at a point ¼ of a guide wavelength (¼ WLg) from the short **23**.

By shifting the position of the short circuit ¼ of a guide wavelength, from position **23**, for example, to position **20**, the standing wave pattern of the currents is also shifted ¼ of a guide wavelength. Thus, for example, the current values at point MA' are effectively shifted to the point MA. If the standing wave pattern is so shifted ¼ of a guide wavelength then the current I_T will be at maximum value at points MA, MA2 and MA3 and the current I_L will be at substantially zero at such points.

It should be noted that the short circuit at position **23** may be an electrical barrier or short, similar to that proposed at position **20**, in lieu of the physical short illustrated.

The microwave switching diode **21** may be a crystal diode which generally consists of a semiconducting material such as silicon or germanium, for example, with contact to one side of the semiconducting material made with the aid of fusible conducting material and contact to the other side of the semiconducting material made by a fine wire conductor, commonly referred to as a "whisker." The current-voltage characteristics of such crystal diode are such that the diode conducts in both directions but the resistance in the "reverse" or "back" direction is much greater than in the "forward" direction.

By properly energizing the switching diode **21**, an electrical or electronic barrier or short circuit may be provided and the short circuit position may be essentially shifted from position **23** to position **20**, or vice versa.

FIGS. 5 and 6 assume that the short position on the waveguide **10** is at position **23**, so that current I_L is at maximum value at points MA, MA2 and MA3 and the current I_T is at substantially zero value at such points. Thus, for example, if microwave energy is applied to the waveguide, as represented by the arrows LT, then the longitudinal current I_L will be coupled to free space via the series slots **11**, **11***a* and **11***b* as represented by the solid arrows L_V across the series slots. The transverse current will not couple through the slots **11**, **11***a* and **11***b* because of the position of the slots, relative to the direction of the flow of the current I_T. Further, the current I_L will not couple through the shunt slots **12**, **12***a* and **12***b* because of the position of the slots, relative to the direction of the flow of the current I_L. Also since the value of the current I_T is substantially at zero at the slot positions there is substantially no coupling of the I_T current via slots **12**, **12***a* and **12***b*.

In other words, with the short at position **23**, the waveguide section **10** is tuned to transmit and receive (solid line arrows L_V) the longitudinal current components of the microwave energy, I_L, via the series slots **11**, **11***a* and **11***b* in vertically polarized beam form.

If, on the other hand, the short position is shifted from position **23** to position **20**, which is ¼ guide wavelength from position **23** (¼ WLg) then the standing wave pattern is shifted so that the value of the respective currents at the slot locations are reversed. The current I_T is then at maximum and the current I_L is then at minimum at such slots. The condition provides a tuned arrangement to transmit and receive (broken line arrow T_H) the transverse current I_T via the shunt slots **12**, **12***a* and **12***b* in horizontally polarized beam form. The slots **12**, **12***a* and **12***b* may then couple the transverse current to free space since the position of the slots **12**, **12***a* and **12***b* relative to the direction of flow of the current I_T are such that the current I_T will be so coupled to free space. Conversely, the current I_L will not couple via slots **12**, **12***a* and **12***b* because of the position of these slots relative to the current flow of I_L and since the current I_L is substantially zero at the slot positions no radiation via slots **11**, **11***a* and **11***b* will occur.

It will be noted that the several slots are substantially centrally located at the ½ guide wavelength points. Obviously the ½ guide wavelength points depend upon characteristics of the waveguide and the frequency of the microwave energy applied to the waveguide.

Keeping the short shifting features in mind, it will be seen that either a vertically polarized or a horizontally polarized radiant energy beam may be transmitted, according to the position of the short.

Also, either vertically polarized energy or horizontally polarized energy may be received, according to the position of the short.

If, for example, such antenna were employed in a pulse microwave system and, during the pulse of microwave energy the switch **27** were positioned so as to provide a negative potential, as from terminal **26** to the switching diode **21**, the short position, in an untuned diode mount, would be at position **23** and the slots **11**, **11***a* and **11***b* would couple the current I_L to free space so as to provide vertically polarized radiated energy. (For a tuned diode mount, the condition of bias would be reversed.) During the pulse period vertically polarized energy may also be received by such series slots **11**, **11***a* and **11***b* (represented by the solid line arrow L_V). If during the off-pulse or inter-pulse period the switch **27** were positioned to terminal **25** so that network **22** may provide a positive potential to the switching diode **21** so as to develop an electrical barrier, or shift the short to position **20**, then the shunt slots **12**, **12***a* and **12***b* will be matched or tuned to the short and horizontally polarized energy may be received, (represented by the broken line arrow T_H).

To represent such pulse radar system, block **30**, representing a microwave generator and block **31**, representing a microwave pulse generator is presented with the line **32** representing a means of channelling microwave energy LT to the waveguide section **10**. Broken line **33** represents that the switch **27** may be connected to the microwave pulse generator so as to be selectively operated by such pulse generator, from one terminal **26** to the other terminal **25**, in accordance with the condition of the microwave pulse generator, or in the alternative the microwave pulse generator may itself supply the power required to selectively provide a barrier so as to position the short circuit at **20** or "open-circuit" the diode so as to effectively shift the short to position **23**.

Thus this combination provides transmission and reception of one type of polarized energy during the on-pulse period and reception of cross-polarized energy during the off-pulse period.

Obviously the conditions may be reversed so that transmission and reception of horizontally polarized energy during the on-pulse period may be made via the shunt slots **12**, **12***a* and **12***b* by positioning the short at position **20** during the on-pulse period, and reception of vertically polarized energy may be made during the off-period, by shifting the position of the short to position **23** during such off-pulse period.

The embodiment illustrated in the combined FIGS. 5 and 6 is the preferred embodiment for use in a pulsed radar system.

The switch **27** may be an electronic switch or any type of rapid reversing switch while the network **22**, including the battery **24**, may be other electrical components which may provide the function of such battery.

In such case, the switch **27**, in its electronic form, may be controlled by the microwave pulse generator as indicated by the connecting broken line **33**.

In either the mechanical form or the electronic form the operation of the switch **27** may be synchronized with and/or by the pulse generator so that the short position is changed in synchronism with the pulse rate of the radar system.

Obviously if the pulse rate of the pulsed microwave energy were relatively slow and a mechanical device were provided so as to react rapidly, the electronic short position shifter may be substituted with a plunger. Such plunger may be reciprocated from position **20** to position **23** and vice versa. Such plunger may then be operated in synchronism with the pulse generator.

FIG. 6 illustrates a loop or resonant waveguide antenna arrangement having pairs of series and shunt slots substantially centrally located on corresponding ½ guide wavelength points. The arrangement provides a hybrid junction or "magic T" waveguide section including an E arm and an H arm which type of junction separates the currents of the microwave energy.

Above the slot pairs **12***b*/**11***b*, **12***c*/**11***c* and **12***d*/**11***d* are two pairs of waveforms of the transverse, I_T, and longitudinal I_L currents, showing the standing waveforms provided by applying microwave energy to the waveguide loop by the E arm and by the H arm of the hybrid junction.

As described above, relative to FIGS. 5 and 6, the position of the standing wave pattern may be oriented or shifted by selectively shifting the short position.

This required shift in standing wave pattern may be produced by either shifting the position of the short circuit at the terminal position in the waveguide, by an odd number of quarter guide wavelengths, as above described or by selectively feeding the E arm or the H arm of a hybrid junction connected to the input and output of an array, such as the loop array shown in FIG. 7.

By selectively applying microwave energy to the E arm or the H arm, selective positioning of the standing wave pattern may be provided as shown in the standing waveforms. For example, when energy is applied to the waveguide loop through the H arm, the transverse current I_T will be maximum at the ½ guide wavelength points as shown in waveform A, with the longitudinal current I_L at minimum or zero value at such points. Thus, the transverse current will couple to the shunt slots **12**–**12***d* and transmission and reception of horizontally polarized beam energy, as indicated by arrow H across the slot **12***b*.

When energy is applied to the waveguide loop through the E arm, the longitudinal current I_L will be maximum at the ½ guide wavelength points and the transverse current will be substantially minimum or zero, such as shown in waveform B. Thus the longitudinal current will couple to the series slots **11**–**11***d* and provide for transmission and reception of vertically polarized beam energy, as indicated by arrow across slot **11***b*.

The arrangement shown in FIG. 7 illustrates the preferred embodiment of the invention for use in a continuous wave (CW) radar system although the arrangement in FIG. 7 could be used in a pulsed system.

A microwave generator may be provided in which selective feeding of the microwave energy may be remotely controlled so that microwave energy may be applied to the E arm or the H arm of the hybrid junction or "magic T," as desired.

A CW radar system which may employ the loop or resonant antenna arrangement of FIG. 7. may be similar in some respects to the radar system shown in FIG. 6 except that the microwave pulse generator **31** of FIG. 6 would be replaced with a selective feeding means so that the microwave energy generated in block **30**, for example, may be selectively applied to the E arm or the H arm of the hybrid junction of "magic T," as desired. The latter arrangement would, of course, eliminate the short circuit and switch control operation.

While a preferred arrangement for a pulsed radar system and a CW radar system have each been shown and described and several alternate arrangements of the present invention have been shown and described and other arrangements suggested, obviously other arrangements may be made as will be familiar to those skilled in the art, without departing from the spirit of the invention as defined in the appended claims.

What is claimed is:

1. A cross-polarized linear array microwave antenna for radiating microwave energy in one polarized plane for receiving microwave energy in two different polarized planes including,

a rectangular waveguide having an input end and an output end for transmission of microwave energy,

a hybrid junction coupled to said input end and said output end,

means for providing microwave energy to said waveguide to establish standing wave patterns therein comprising first and second waveguide wall currents, said currents having values which are substantially 90° offset with respect to each other at a common point in said waveguide,

a first plurality of elements in the wall of said waveguide for effectively radiating and receiving microwave energy in a first polarized plane when said first current is substantially maximum at said common point,

a second plurality of elements in the wall of said waveguide for effectively radiating and receiving microwave energy in a second polarized plane when said second current is substantially maximum at said common point,

said means to establish said standing wave patterns comprising,

a first arm associated with said hybrid junctions and operative to provide a first standing wave pattern whereby said first current is substantially maximum at said common point and said second current is substantially minimum at said common point and said first current is coupled to said first plurality of elements,

a second arm associated with said hybrid junction and operative to provide for providing a second standing wave pattern whereby said second current is substantially maximum at said common point and said first current is substantially minimum at said common point and said second current is coupled to said second plurality of elements, and

means for selectively applying microwave energy to said first arm for providing said first standing wave pattern and for alternately applying microwave energy to said second arm for providing said second standing wave pattern.

2. A cross-polarized linear array microwave antenna for radiating and receiving microwave energy in one polarized plane during one period of time and for radiating and receiving microwave energy in another polarized plane during another period of time including,

a rectangular waveguide having an input end for receiving microwave energy,

means for providing microwave energy to said waveguide to establish standing wave patterns therein comprising a transverse current and a longitudinal current having values which are substantially offset 90° with respect to each other at a common point in said waveguide,

a first plurality of elements in the wall of said waveguide for effectively radiating microwave energy in a first polarized beam and for effectively receiving microwave energy in said first polarized beam when one current of the two currents of the microwave energy is substantially maximum at a said common point,

a second plurality of elements in the wall of said waveguide for effectively radiating microwave energy in a second polarized beam and for effectively receiving microwave energy in said second polarized beam when the said other current of the two currents is substantially maximum at said common point,

said means to establish being so positioned so as to normally provide a standing wave whereby said one current is substantially maximum at said common point and said other current is substantially minimum at said common point,

means for selectively effectively shifting the standing wave pattern for reversing the values of the two currents at said common point during one period of time so that microwave energy may be radiated and

received in said first polarized beam during said one period and

means for effectively reshifting the standing wave pattern during another period for re-reversing the values of the two currents at said common point during such other period so that microwave energy may be transmitted and received in said second polarized beam of two different polarized beams during said other period of time,

said means to establish including a hybrid waveguide junction,

said means for effectively shifting comprising a first arm associated with said hybrid waveguide punction,

said means for effectively reshifting comprising a second arm associated with said hybrid waveguide junction, and

means for alternately applying microwave energy to said first and second arms.

No references cited.

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