June 27, 1967 J. A. ALGEO 3,328,800

SLOT ANTENNA UTILIZING VARIABLE STANDING WAVE PATTERN FOR CONTROLLING SLOT EXCITATION

Filed March 12, 1964 5 Sheets-Sheet 1

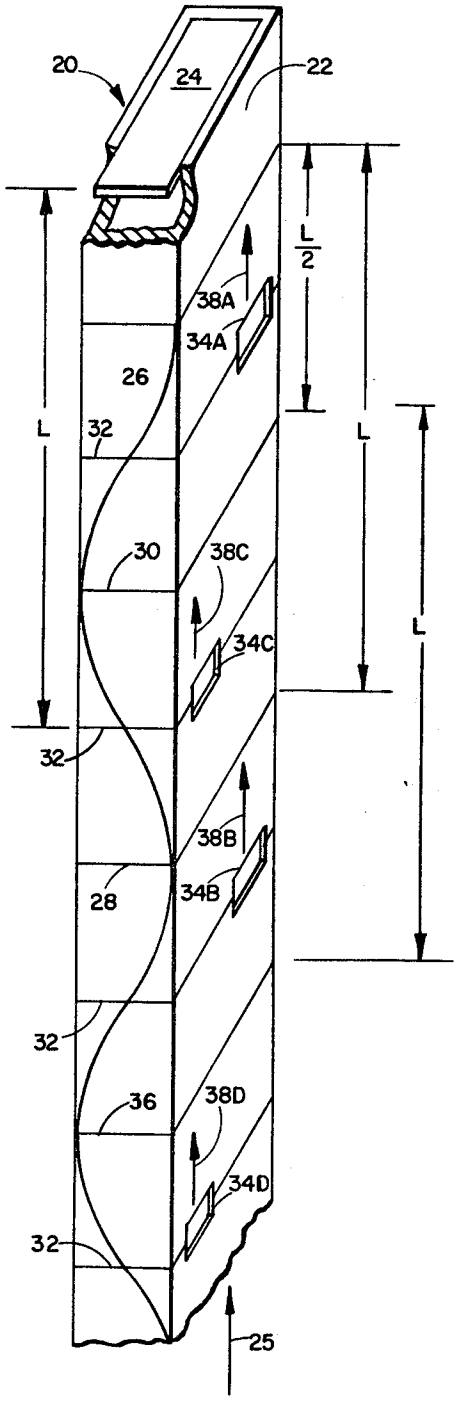


FIG. 1

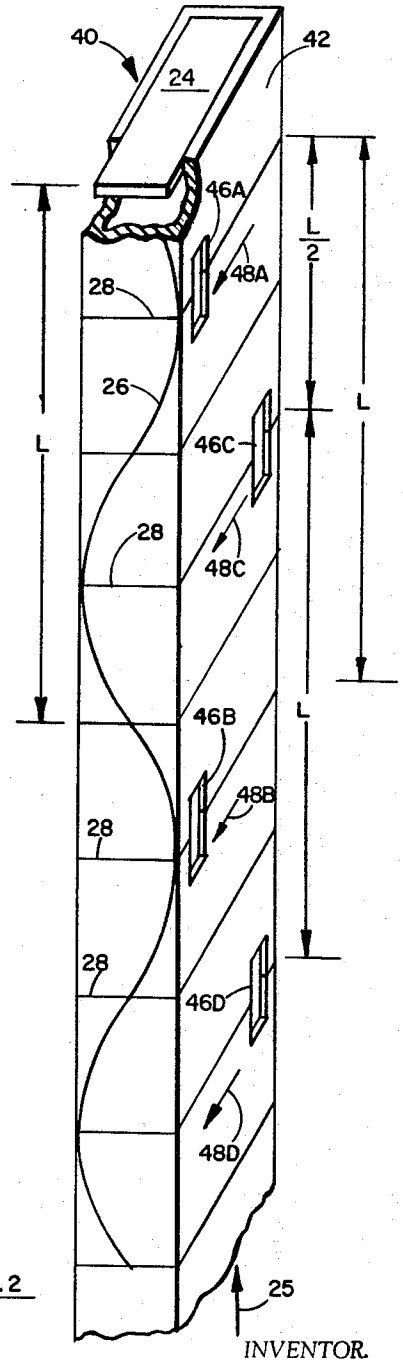


FIG. 2

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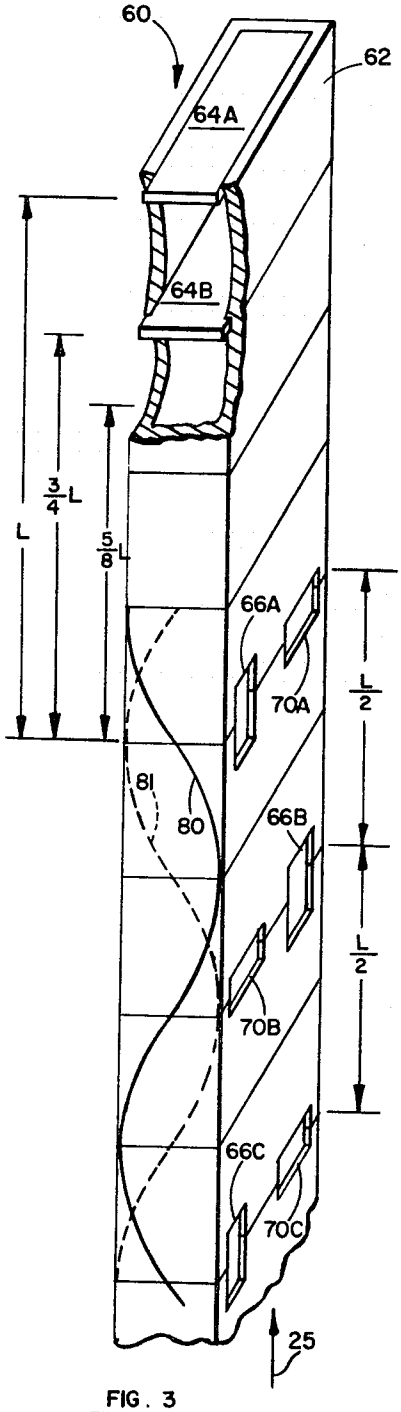


FIG. 3

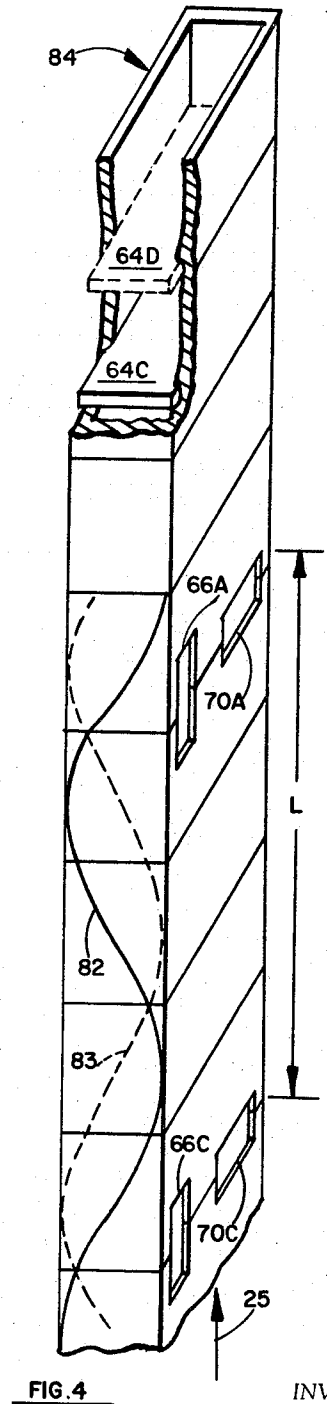


FIG. 4

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SLOT ANTENNA UTILIZING VARIABLE STANDING WAVE PATTERN FOR CONTROLLING SLOT EXCITATION

Filed March 12, 1964 5 Sheets-Sheet 3

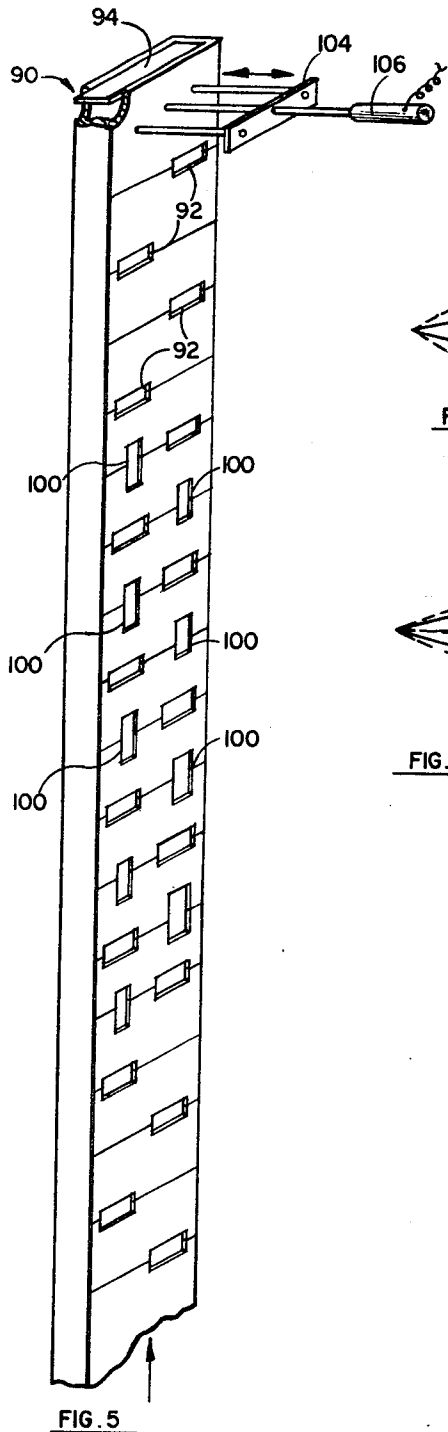


FIG. 5

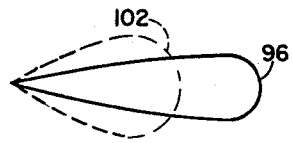


FIG. 6

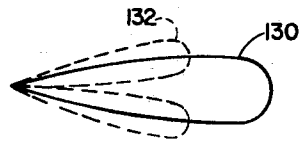


FIG. 9

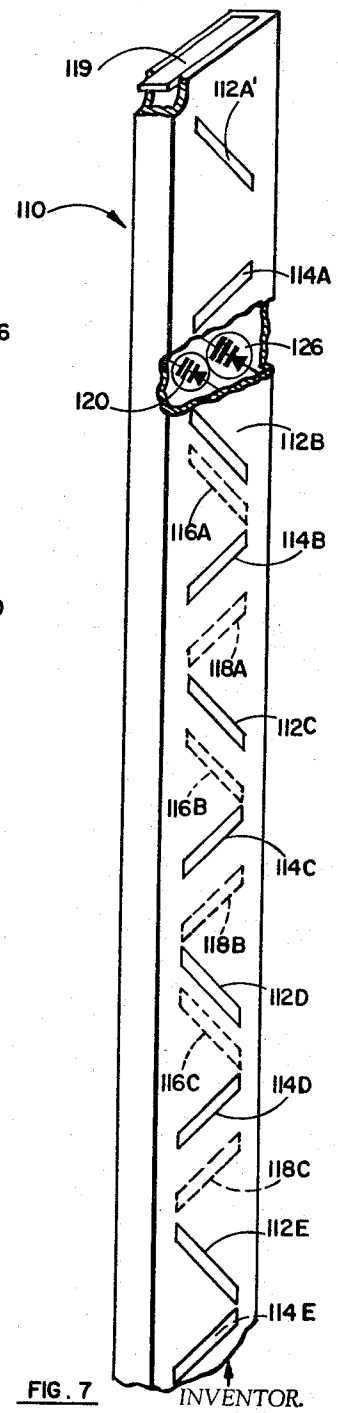


FIG. 7

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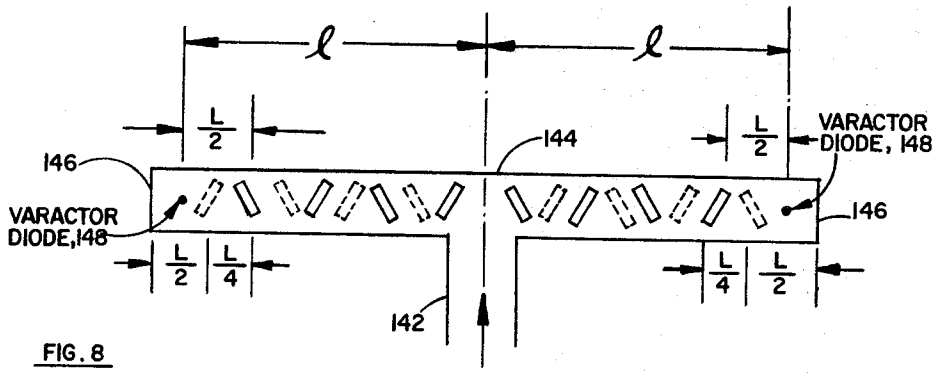


FIG. 8

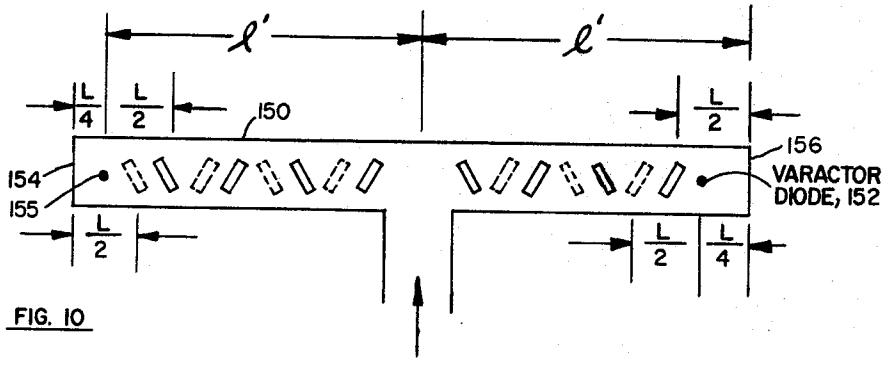


FIG. 10

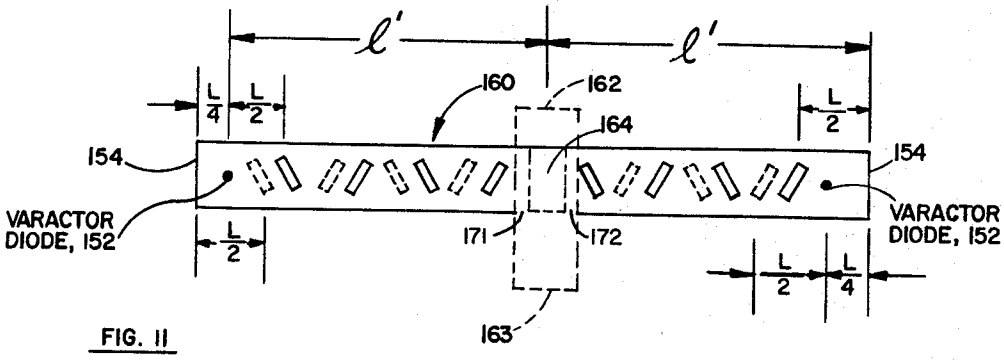


FIG. 11

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SLOT ANTENNA UTILIZING VARIABLE STANDING WAVE PATTERN FOR CONTROLLING SLOT EXCITATION

Filed March 12, 1964 5 Sheets-Sheet 5

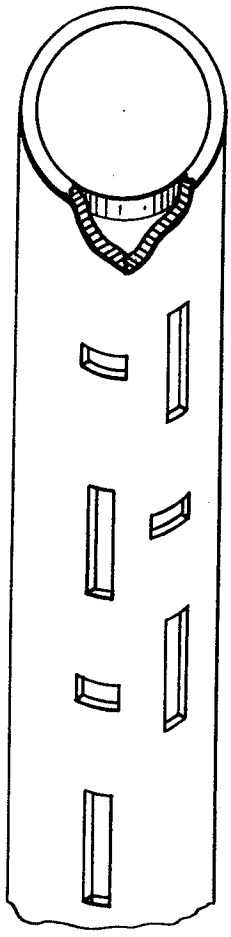


FIG. 12

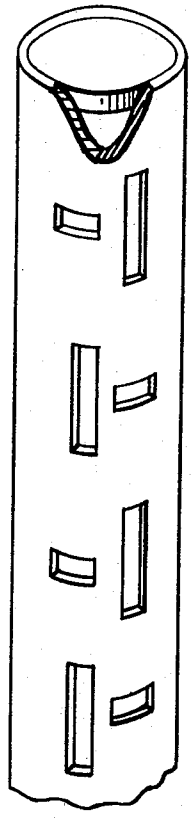


FIG. 13

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United States Patent Office 3,328,800
Patented June 27, 1967

3,328,800

SLOT ANTENNA UTILIZING VARIABLE STANDING WAVE PATTERN FOR CONTROLLING SLOT EXCITATION

Jerry A. Algeo, Buena Park, Calif., assignor to North American Aviation, Inc.

Filed Mar. 12, 1964, Ser. No. 351,320
9 Claims. (Cl. 343—768)

This invention relates to antennas; and more particularly to antennas that can produce different radiation and reception patterns, and different types of energy-polarization.

It is well known that radar operates upon the "echo" principle. In operation, a radar station causes its antenna to transmit energy outwardly to impinge upon a target; the target reflecting some of the impinging energy in the form of a return, or "echo," signal. The antenna receives the reflected echo signal; and equipment in the radar station processes the reflected energy to provide "target" information, such as the direction of, and distance to, the target.

The distance to the target is obtained by measuring the length of time that elapses between the transmission of the radar energy and the reception of the echo signal, the direction of the target being obtained—depending upon the radar system—from the echo signal or the direction in which the antenna is aimed.

As is well understood in the art, radar energy has the characteristic that it may be "polarized," the energy may be linearly-polarized either vertically, horizontally, or at any intermediate angle; or it may be polarized elliptically, of which circular polarization is a special case.

The polarization of the radar energy enters into the operation of the radar system in the following manner.

Assume that an airplane's radar operator is interested —for navigational purposes—in knowing whether the plane is flying over water, desert, or mountainous terrain. It has been found that circularly-polarized radar energy causes the magnitude of the echo signal to vary with changes in terrain; and, in this case, the radar operator would therefore prefer to use circularly-polarized radar energy. If, however, he is primarily interested in the plane's height above the ground, he would prefer to use linearly vertically-polarized radar energy, since this produces echo signals of substantially the same magnitude regardless of the type of terrain.

It has also been found that in a rain storm the echo signal depends on the size and shape of the raindrops of the storm. Therefore, if the radar operator is trying to obtain information about the location and extent of a rain storm, it is desirable to select the type of polarization that provides the strongest return echo signal from the raindrops themselves. If, on the other hand, the radar operator is interested in a target beyond the rain storm, it is desirable to select the type of polarization that pierces the rain storm, and is reflected by targets beyond the storm.

Thus, it is desirable to be able to change the polarization of the radar energy.

The type of polarization may be unimportant under other conditions, such as searching for, and tracking a target; but—under these conditions—an item of great importance is the "radiation-pattern," that is, the amount of radar energy that is radiated in various directions.

For example, in the "searching" mode of operation, when the radar operator is trying to detect a target, the radiation-pattern is preferably a wide beam, so that any target within the beamwidth will produce an echo signal. Once the presence of a target within the beamwidth has been indicated, the radar operation is changed to a so-

called "tracking" mode, wherein the radiation-pattern is changed to a narrow pencil-like beam that is used to pinpoint the direction of the target.

Other modes of radar operation require still different types of radiation-patterns.

It will be understood from the above discussion, that it is desirable to be able to change both the polarization and the radiation-pattern, depending upon particular operating conditions.

It is therefore the principal object of the present invention to provide an improved antenna having means for providing selected combinations of polarization and radiation pattern.

The attainment of this object and others will be realized from the following specification, taken in conjunction with the drawings of which:

FIGURES 1, 2, 3, and 4 illustrate antennas for producing different types of radar-energy polarization;

FIGURES 6 and 9 illustrate different beam patterns;

FIGURES 5, 7, 8, 10, and 11 illustrate antennas for producing different beam patterns; and

FIGURES 12 and 13 illustrate antennas having different cross-sectional shapes.

Broadly speaking, the present invention contemplates an antenna in which there is established a "standing-wave" pattern of radar energy. By permitting the energy to escape from the antenna only at selected points therealong, the emergent energy has a given beamwidth which is polarized in a given manner. By permitting the energy to escape from the antenna only at other selected points, the emergent energy may have a different beamwidth which is polarized in a different manner. Thus, by controlling the points from which the energy escapes, the combination of beamwidth and polarization of the energy can be selectively controlled.

Alternatively, the amounts of different types of polarization can be selectively combined, so that the emergent energy is polarized in still another manner.

The present invention contemplates control of the polarization by (1) establishing a standing-wave pattern that permits the energy to escape from given points, and thus provides emergent energy of a given polarization; and then (2) changing the standing-wave pattern to one that permits the energy to escape from different points, and thus provides emergent energy of a different polarization.

In this way the instantaneous controlled standing-wave pattern establishes the polarization of the radar energy.

The present invention also contemplates the production of particular radiation-patterns by establishing standing-wave patterns that cause the energy to escape from given sets of points, the arrangement of the escape-points establishing the radiation-pattern or beamwidth.

Moreover, the present invention also contemplates a constantly-changing standing-wave pattern, so that the energy emerges in a constantly-changing combination of polarization and radiation pattern.

FIGURE 1 shows an antenna that radiates "linearly-polarized" energy. The antenna **20** comprises a hollow tubular "waveguide" **22**, made of an electrically-conductive material such as copper or the like. Waveguides such as element **22** are ordinarily used to guide microwave energy from one point to another, hence their name waveguide. However, if the waveguide has an aperture (or slot) in the wall thereof, energy will tend to escape through the aperture. Moreover, if the waveguide has an array of slots or a set of intentionally-introduced apertures that are suitably sized, shaped, spaced, oriented, etc., the energy escaping from the various apertures will combine to form a specific radiation-pattern; and the waveguide then acts as a radiating, or transmitting antenna. This will be more fully discussed hereinafter.

In FIGURE 1, antenna 20 comprises an apertured-waveguide 22 having a "shorting" plate 24 of electrically-conductive material positioned at one end of waveguide 22. Shorting-plate 24 physically and electrically closes the end of the antenna. It therefore produces an electrical "short-circuit"; and energy cannot escape from the closed end of the antenna 20.

Shorting-plate 24 has the characteristic that when energy is applied to the open bottom-end of the antenna—as indicated by arrow 25—the shorting-plate 24 reflects the energy in such a way that a voltage "standing-wave" pattern is produced; the voltage standing-wave being represented by sinusoidal waveform 26.

It will be noted that sinusoidal waveform 26 has a positive maximum value at certain cross-sectional planes such as 28; that sinusoidal waveform 26 has negative maximum values at other cross-sectional planes such as 30; and that sinusoidal waveform 26 has an intermediate value of zero at other cross-sectional planes, such as 32.

The sinusoidal waveform 26 has a characteristic known as its "wavelength," which extends between corresponding points—for example, from a zero value through a negative maximum value and a positive maximum value back to a zero value. A wavelength of waveform 26 is represented by the distance L.

It has been found that if a transverse slot-like aperture 34A is cut through the broad wall of the waveguide 22 at a cross-sectional plane 32 where the sinusoidal waveform 26 has a value of zero, then the standing-wave will be "coupled" to the aperture; and energy will escape through the aperture. The emergent energy will be polarized in a "linear" longitudinal manner as indicated by the arrow 38A, which has a longitudinal orientation.

If another transverse slot 34B is similarly positioned at a zero-valued plane 32 that is one wavelength from the first slot 34A, it too will permit the escape of energy; the energy from transverse slot 34B also being polarized in the same linear longitudinal manner, as shown by arrow 38A.

Thus, a group of transverse slots 34A, 34B, etc. that are similarly positioned one-wavelength apart—or multiples of one-wavelength apart—will permit the escape of energy that is similarly-polarized in a linear longitudinal manner.

If another transverse slot 34C is positioned at a zero-valued plane 32 that is spaced one-half wavelength from the first slot, or is spaced one-half wavelength from a transverse slot of the first set, it too will permit the escape of energy. If the slot 34C is positioned on the other side of the longitudinal axis of the antenna's broad wall, the energy escaping from slot 34B will have the same linear longitudinal polarization, as shown by arrow 38C.

Thus a second group of transverse slots 34C, 34D, etc., spaced one wavelength apart, half-a-wavelength from the slots of the first group, and "staggered" with respect to the slots of the first group, will permit the escape of energy that is similarly-polarized in a linear longitudinal manner.

In this way, a set of "staggered" transverse slots positioned one-half wavelength apart at the zero-valued points of the standing-wave pattern 26 converts the waveguide to an antenna; and the energy emerging from the above set of slots combines to form a radiation-pattern of linear longitudinal polarization; the radiation pattern itself to be discussed later.

If the antenna is positioned vertically, as shown in FIGURE 1, the energy emerging from the set of transverse slots will be linearly polarized vertically, as shown by the vertical arrows 38; whereas, if the antenna were positioned horizontally, the emergent energy would be linearly horizontally-polarized—that is, arrows 38 would then be horizontal.

It should be noted that in order to produce the above-described longitudinal polarization of the emergent energy, the shorting-plate 24 must be spaced from the first slot 34A by a distance that is equal to one-half a wavelength; or by a distance that is equal to an integral number of half-wavelengths. This spatial relation is necessary in order to place all of the lots simultaneously at the zero-valued points of the voltage standing-wave pattern 26.

While FIGURE 1 shows shorting-plate 24 positioned at the end of the antenna, and one-half wavelength from the first slot, the shorting plate could just as well have been positioned at any of the zero-valued cross sectional planes 32 in accordance with the above explanation; although this arrangement would disable the apertures on the side of the shorting-plate away from the entry-point of the energy (arrow 25).

FIGURE 2 shows a similar antenna 40 that comprises an apertured rectangular waveguide 42 and a shorting-plate 24 that produces a standing-wave indicated by sinusoidal waveform 26. It has been found that if a longitudinal slot-like aperture 46A is cut through the broad wall of the waveguide 42 at a cross-sectional plane 28 where the sinusoidal waveform 26 has a maximum positive value, then the standing-wave will be coupled to the aperture; and energy will escape through the aperture. The emergent energy will now be polarized in a linear transverse manner as indicated by arrow 48A, which has a transverse orientation.

If another longitudinal slot 46B is similarly positioned at a maximum positive valued plane 28 that is one wavelength from the first slot 46A, it too will permit the escape of energy; the energy also being polarized in the same linear transverse manner, as shown by arrow 48B.

Thus, a group of longitudinal slots 46A, 46B, etc., that are similarly positioned one-wavelength apart—or multiples of one-wavelength apart—will permit the escape of energy that is similarly-polarized in a linear transverse manner.

If another longitudinal slot 46C is positioned at a maximum-valued positive plane 28 that is spaced one-half wavelength from a longitudinal slot of the first set, it too will permit the escape of energy. The energy in this case has the same linear transverse polarization if the slot 46C is positioned on the other side of the longitudinal axis of the antenna's broad wall.

Thus, a second group of longitudinal slots 46C, 46D spaced one wavelength apart, half a wavelength from the slots of the first group, and staggered with respect to the slots of the first group, will permit the escape of energy that is similarly-polarized in a linear transverse manner.

In this way, a set of staggered longitudinal slots positioned one-half wavelength apart at the maximum-valued points of the standing-wave pattern 26, converts the waveguide to an antenna; and the energy emerging from the set of slots combines to form a radiation-pattern of linearly transverse polarization; the radiation-pattern itself to be discussed later.

If the antenna is positioned vertically, as shown in FIGURE 2, the energy emerging from the set of longitudinal slots will be linearly polarized horizontally, as shown by the vertical arrows 48; whereas, if the antenna were positioned horizontally, the emergent energy would be linearly vertically polarized—that is, arrows 48 would then be vertical.

It should be noted that in order to produce the above-described transverse polarization of the emergent energy, the shorting-plate 24 must be spaced from the first slot 46A by a distance that is equal to an odd multiple of quarter-wavelengths. This spatial relation is necessary in order to place all of the slots simultaneously at the maximum-valued points of the voltage standing-wave pattern 26.

To recapitulate, it may be understood that by positioning a set of suitably-oriented slots at selected locations relative to a standing-wave pattern, the emergent energy may be selectively polarized in a desired manner.

The above discussion has shown that it is possible for an antenna to produce either longitudinally or transverse-

ly-polarized emergent energy. FIGURE 3 shows how a single antenna can produce either type of polarization.

In FIGURE 3, antenna **60** comprises a waveguide **62**, a shorting plate **64**, and a first set of staggered longitudinal slots **66A**, **66B**, **66C**, etc. that are spaced apart a distance of half a wavelength. As previously indicated, the set of longitudinal slots can produce emergent energy that is linearly transversely-polarized.

FIGURE 3 also shows a second set of staggered transverse slots **70A**, **70B**, **70C** etc., that are on the same cross sectional plane as the longitudinal slots **66**; and are therefore also half a wavelength apart. As previously indicated, the transverse slots can produce emergent energy that is linearly longitudinally-polarized.

It will be noted that the slots of the two sets are so positioned that the slots form "slot-pairs" **66A**, **70A**; **66B**, **70B**; **66C**, **70C**, etc. comprising one longitudinal slot **66** and one transverse slot **70** positioned at each cross-sectional plane; and that the slots-pairs are spaced apart by half a wavelength.

In FIGURE 3, when energy is introduced at the lower end of the antenna, the shorting-plate **64A** establishes a standing-wave pattern **80** having zero points or nulls positioned at the slot-pairs. Therefore, the transverse slots **70** would emit longitudinally-polarized energy, as explained in connection with FIGURE 1.

However, the longitudinal slots **66**, also positioned at the zero-valued point of the standing-wave pattern **80**, do not permit any energy to escape through them.

Thus, for the location shown for shorting-plate **64A**, the emitted energy would be longitudinally-polarized.

If the shorting plate is moved to the location **64B**, and energy is introduced at the lower end of the antenna, the dotted-line standing wave pattern **81** will be produced.

It will be seen that the maximum-valued points of the standing-wave pattern **81** are now at longitudinal slots **66**, and the escape of transversely-polarized energy resulting, as explained in connection with FIGURE 2. However, the transverse slots **70** also positioned at the maximum-valved points of standing-wave pattern **81**, and therefore they will not permit any (longitudinally polarized) energy to escape through them. Accordingly, for the **64B** location of the shorting-plate (in FIGURE 3), the emitted energy would be transversely-polarized.

Thus, by inserting or withdrawing a removable shorting-plate at location **64B** (in FIGURE 3), the emergent energy can be polarized in a transverse or in a longitudinal manner respectively.

It has been found that a maximum amount of energy escapes from the slot if the slot has a periphery that is approximately equal to the wavelength of the energy. In a typical case, the length of the slot is about one-half of the wavelength, and the width of the slot is about one-twentieth of the wavelength.

It has also been found that progressively-more energy is permitted to escape as the slot is progressively offset from the center line of the broad wall of the antenna. Thus, by suitably positioning a plurality of suitably-shaped slots, the amount of escaping radiation can be controlled.

It was previously indicated that the amount of energy escaping through a slot can be controlled by the size of the slot, and by the amount of offset from the longitudinal axis of the antenna. If the same amounts of perpendicularly-polarized energy escapes from the separate slots of a slot-pair, the emergent energy combines to produce so-called "circularly-polarized" energy.

In FIGURE 4, antenna **84** produces circularly-polarized energy by using a shorting-plate at the location indicated by reference character **64C**, and by using slot-pairs that are positioned one wavelength apart. The shorting-plate at this location, produces a standing-wave pattern indicated by the solid sinusoidal line **82**.

It will be noted that each slot of the slot-pairs is now positioned, relative to the standing-wave pattern **82**, at a point that is neither maximum-valued nor zero-valued. As a result of this particular intermediate value, equal amounts of energy escape through each slot of each slot pair; thus resulting in circularly-polarized energy.

The circularly-polarized energy has a characteristic known as "right-handedness" or "left-handedness"; which is established by the location of the slot-pair relative to the standing-wave pattern. In FIGURE 4, for example, each slot-pair is at a location that produces polarization of the same "handness."

If the slot-pairs were placed at locations half-way between those illustrated, and were offset to the other side of the longitudinal axis of the broad wall of the antenna, they would produce polarization of the opposite "handness." This same opposite handness can also be achieved by establishing a standing-wave pattern such as **83**, by the use of a shorting-plate **64D**. Thus by using insertable shorting-plates, either right-handed or left-handed circularly-polarized energy can be produced.

It has been shown that the standing-wave patterns of FIGURE 4 produce circularly-polarized energy by causing equal amounts of energy to escape from each slot of a slot-pair. If now, the standing-wave pattern were changed—as by slightly re-positioning the shorting-plate, more energy would escape from one slot than from the other. The resultant emergent energy would no longer be circularly-polarized; but would now be "elliptically" polarized.

It is therefore apparent that the antenna of FIGURE 4 may be made to establish a standing-wave pattern that produces polarization having different degrees of ellipticity; each of which may be right-handed or left-handed.

It is well known that antennas generally act in a "reciprocal" manner. For example, if an antenna *transmits* only horizontally-polarized radiation, it will *receive* only horizontally-polarized radiation. Similarly, if an antenna transmits vertically-polarized radiation, it will receive only vertically-polarized radiation. In a like manner, if an antenna transmits elliptically—or circularly—polarized radiation, it will receive only elliptically—or circularly—polarized radiation. Moreover, if the antenna transmits "right-handed"—or "left-handed"—elliptically or circularly polarized radiation (controlled by the type of slot pairs selected), it will receive only the same type of radiation. This conforms to the theory of reciprocity.

The previously-disclosed antennas act in accordance with the theory of reciprocity; and as a result they have a number of novel uses.

For example, if right-handed polarized energy is transmitted toward a rainstorm, the raindrops reflect the energy; and the echo signal comprises left-hand polarized energy. Thus, if the radar operator wants information about the rainstorm, he establishes a standing-wave pattern that causes the antenna to transmit right-handed polarized energy; and he then changes the standing-wave pattern so that the antenna will receive the left-handed polarized radiation reflected by the raindrops. The radar system then provides information about the energy-reflecting raindrops.

If, however, the radar operator wants information about targets beyond the rainstorm, he establishes a standing-wave pattern that causes the antenna to transmit right-handed polarized energy; and he maintains the same standing-wave pattern, so that the antenna receives the right-handed circularly-polarized energy that is reflected by the more-distant targets beyond the rainstorm. Thus, the radar system does not receive the echo signals from the raindrops; but does receive the echo signals from the targets.

Moreover, the radar operator can establish a standing-wave pattern whose ellipticity is optimum for reflection, or rejection, or the raindrop's echo signals.

Pulsed radar systems are also plagued by echo signals known as "second-time-around-signals." These echo signals are produced by objects that are farther away than

the maximum range of interest represented by the pulse repetition period of the radar; and such echo signals, in response to a transmitted energy pulse, arrive at the radar station during the subsequent pulsing period, whereby a false target-range indication is provided.

The present invention obviates these signals in the following manner. For an initial pulse repetition period, for example, the radar operator establishes a standing-wave pattern that causes the antenna to produce, say, horizontally-polarized energy. The desired echo signals are therefore horizontally polarized. At the beginning of the next pulse repetition period, a different standing-wave is caused to be established; and the second-time-around echo signals (due to targets beyond the range of interest) are no longer accepted by the antenna. (Target signals received from targets at ranges greater than that represented by the interval of two successive pulse repetition periods are presumed to be so attenuated in signal strength as to be negligible.)

Thus, the present invention may be employed to obviate second-time-around signals.

Since, because of the previously-discussed theory of reciprocity, the transmission radiation-pattern is similar to the reception-pattern, the term "beam-pattern" will now be used to include both the transmission and reception patterns.

As previously indicated, it is frequently desirable to control the beam-pattern in which the emergent energy is radiated and received; and FIGURE 5 shows one way of producing different beam-patterns, using the present inventive concept. In FIGURE 5, antenna **90** has a first set of slots **92**—shown to be transverse, but which may be either transverse or longitudinal—extending substantially from one end of the antenna to the other. When a suitable standing-wave pattern is established, by means such as the shorting-plate **94** as described above, the first set of slots **92** will emit energy that is polarized in a particular manner.

Due to the large longitudinal spatial distribution of the first set of slots **92** (e.g. the longitudinal distance between the upper and lower slots or extremities of the array of slots **92**), when this set of slots is emitting energy, the antenna will act as a large aperture antenna; and will produce a corresponding narrow beam of polarized energy —as indicated by the narrow beam-pattern **96** of FIGURE 6, in a plane parallel to the longitudinal axis of antenna **90** (FIGURE 5).

Antenna **90** of FIGURE 5 also contains a second set of slots **100**, which are oriented perpendicularly to the slots **92** of the first set; slots **100** being relatively few in number (e.g., the longitudinal array of slots **100** being shorter than the longitudinal array of slots **92**). In accordance with the previous explanation, when a suitable standing-wave pattern is established, this second set of slots **100** will emit energy that is polarized perpendicularly to the energy from the first set of slots.

Due to the smaller spatial distribution of the second set of slots **100** (e.g., the longitudinal distance between the upper and lower slots or extremities of the array of slots **100**), when the second set of slots is emitting energy, the antenna will act as a small aperture antenna; and will produce a corresponding wide beam, (as indicated by reference character **102** of FIGURE 6) in a plane parallel to the longitudinal axis of antenna **90** (FIGURE 5).

It may therefore be seen that, when suitably energized, the antenna **90** of FIGURE 5 can produce either a wide or a narrow beam of energy (in a plane parallel to the longitudinal axis of antenna **90**), the polarization of the particular pattern depending upon the orientation of the energized slots.

It was indicated above, that antenna **90** of FIGURE 5 needs two different types of standing-wave patterns, in order to energize the two separate sets of slots. This result may be produced by using insertable shorting-plates as described previously; but in order to switch rapidly from one radiation-pattern to the other, a different method may be used, as follows.

In FIGURE 5, the shorting plate **94** reflects the incoming energy to establish a first standing-wave pattern that energizes the first set of slots. When it is desired to adjust the standing-wave pattern so as to energize the second set of slots, a set of electrically-conductive shorting-pins **104** are inserted into the waveguide; these effectively forming a shorting-plate. Because of its location, the effective shorting-plate produced by the shorting-pins **104** now establishes a different standing-wave pattern, which energizes the second set of slots.

It may thus be seen that by inserting or withdrawing shorting-pins **104**, either of two standing-wave patterns may be produced; each standing-wave pattern being capable of exciting a different set of slots. Since the shorting-pins **104** can be rapidly inserted or withdrawn by actuation means such as a magnet **106**, the antenna **90** is able to produce a wide or a narrow beam of the desired polarization; and to quickly switch from one beam to the other. Accordingly, antenna **90** of FIGURE 5 is adapted for providing a selected combination of beamwidth and polarization.

It is evident that even the mechanical shorting-pin arrangement of FIGURE 5 has a limitation on the rapidity with which the pins can be inserted and withdrawn. This limitation is overcome in the arrangement of FIGURE 7, which also shows a different type of slot arrangement.

Here, antenna **110**, instead of having longitudinal and transverse slots, has a set shown in solid lines, of pairs of oppositely inclined slots **112A**, **114A**; **112B**, **114B**; **112C** **114C**; etc. Each slot of each pair couples to a standing wave; and each pair of inclined slots produces longitudinally-polarized emergent energy.

Antenna **110** also has a second set, shown in dotted lines, of pairs of oppositely inclined slots **116A**, **118A**; **116B**, **118B**; **116C**, **118C**; etc. Each slot of each pair couples to a standing-wave; and each pair of inclined slots produces longitudinally-polarized emergent energy.

The first set of slots **112–114** has a large spatial coverage (corresponding to the array of slots **92** in FIGURE 5); while the second set of slots **116**, **118** has a small spatial coverage (corresponding to the array of slots **100** in FIGURE 5). Thus, when the first set of slots—having the large spatial coverage—is energized by a suitable standing-wave, the antenna acts like a large antenna, and produces a narrow beam. However, when the second set of slots—having a small spatial coverage—is energized by a different standing-wave, the antenna acts like a small antenna, and produces a wide beam.

Thus, antenna **110** of FIGURE 7 is capable of producing both the narrow and broad beams **96** and **102** of FIGURE 6. It should be noted however, that in the case of antenna **110**, both beams have the same linear polarization. Accordingly, antenna **110** of FIGURE 7 is adapted for providing a selected combination of beamwidth and polarization.

FIGURE 7 also shows another way of producing different standing-waves. One standing-wave is produced by a sorting-plate **119**, as previously described. However, a plurality of electronically controlled waveguide switches, such as "varactor-diodes" **120**, takes the place of the previously-described shorting-pins. These varactor-diodes have the characteristic that they can be activated (by means of passing a direct current therethrough) to serve as an effective microwave shorting-plate; or they can be deactivated (by adjusting or reducing the current therethrough) to serve as a matched impedance—whereby the antenna acts as though the varactor-diodes were not in the antenna at all.

Thus, when the varactor-diodes are activated, they have the effect of producing a standing-wave that energizes one set of inclined slots; whereas when the varactor-diodes are matched, the physical shorting-plate **119** pro-

duces another standing-wave that energizes the other set of inclined slots.

In FIGURE 7, the varactor-diodes, instead of being located near the end of the antenna, are instead located one-half wavelength beyond the furthermost radiating aperture; this location providing improved operation of the smaller-number set of inclined slots.

It will be realized that varactor-diodes may be used in the antennas previously discussed. Referring back to FIGURE 3, for example, varactor-diodes can replace the illustrated shorting-plates; and, in fact, a plurality of suitably-located varactor-diodes may be used to produce effective shorting-plates at a plurality of locations intermediate to the illustrated shorting-plates. By suitably activating the varactor-diodes, a plurality of different standing-waves can be established; and the emergent energy can therefore be polarized in a wide variety of polarizations.

In addition, a set of varactors may be activated to act as continuously variable phase shifter; whereupon the polarization of the emergent energy will vary continuously through a given range of polarizations.

The previous discussion has shown how the disclosed antenna can provide a beam having a selected combination of beamwidth and polarization. Under some conditions, it is desirable to have two similar but not identical beams; one of the beams to be used for transmitting radar energy, while the other beam is used for receiving echo signals. FIGURE 8 schematically shows an arrangement for achieving this result.

Referring to FIGURE 8, there is illustrated an antenna **140** comprising a symmetrical T-shaped antenna structure; the energy being introduced into the stem-portion **142** of the T, and the horizontal-bar portion **144** of the T having two sets of paired inclined slots of the type previously described. One set of inclined slots is shown in solid lines, while the other set of inclined slots is shown in dotted lines.

When energy is applied through stem-portion **142** to antenna **140**, the passive or physical shorting-plates **146** at the end of the horizontal bar of the T establish a continuous standing-wave between them; the standing-wave exciting the set of inclined slots shown in dotted outline in accordance with the previously-discussed principles. Because of the large spatial extent covered by the array of dotted-line slots, the antenna acts as a large antenna that has a narrow-beam transmission pattern.

When it is desired to receive echo signals, both varactor-diodes **148** may be activated (by means well understood in the art) whereby they act as effective shorting-plates as previously described; the effective shorting-plates establishing a continuous standing-wave that activates the second set of inclined slots shown in the solid-line slots. The antenna again acts as a large antenna that has a narrow-beam reception pattern.

In order to establish slightly different transmission and reception patterns, each set of slots may have a slightly different arrangement than the other. For example, the slots of one set may be different in size, orientation, or offset, compared with the slots of the other set; so that one set of slots produces a transmission-pattern that is similar but slightly different from the reception-pattern produced by the other set of slots.

Monopulse radar systems use a concept known as "sum and difference" signals; corresponding to the even and odd distributions, respectively, of a target signal, as described, for example, in "Introduction to Monopulse," by Rhoades (published by McGraw-Hill, 1959). The application of such concept employs two reception antenna patterns which are severally combined as shown in FIGURE 9, to provide the single long, narrow "sum" beam **130**, shown in solid line and representing the sum of the two reception patterns, the two smaller lobes **132** shown by the dotted lines representing the difference between the two reception patterns.

The above-discussed theory of reciprocity also applies to an antenna that directly produces the sum and difference patterns of FIGURE 9. This means that where, by means of the invention, an antenna transmits a narrow "sum" beam, its reception-beam will also be narrow; that is, the antenna will be more sensitive to echo signals originating dead-ahead (corresponding to the boresight axis or axis of symmetry of a directional antenna), and will be less-sensitive to echo signals originating off to one side of the boresight axis.

Similarly if the antenna, by means of the invention, is caused to transmit a two-lobed "difference" beam, the reception response thereof will be sensitive to echo signals originating in such difference beam.

An antenna using the disclosed inventive concept can produce these sum and difference beam patterns; and the symbolic antenna representation of FIGURE 10 shows how this can be done. Here, antenna **150** is similar to those previously discussed, in that it has two sets of inclined slots; one set of slots being shown in solid lines, while the second set of slots is shown in dotted lines.

The antenna **150** of FIGURE 10 produces a single-lobed narrow beam as follows. Varactor-diode **152** is activated to produce an effective shorting-plate, so that the antenna is symmetrical. Energy applied to the antenna coacts with the effective shorting-plate produced by varactor-diode **152** and the physical shorting-plate **154**, to produce a continuous standing-wave between them. The standing-wave causes the solid-line slots to be energized, so that each half of the antenna produces a signal that is in-phase with the signal from the other half of the antenna. In this way the antenna produces a single-lobed pattern as described in connection with the previous illustration.

In accordance with the theory of reciprocity, incoming echo signals would enter the slots, and would establish a similar standing-wave. This standing-wave would be coupled to the stem-portion of the antenna; and would provide sum-signals to utilizing equipment.

If it were desired to transmit the two-lobed "difference" beam, varactor-diode **152** would be de-activated, or "matched" (i.e., an applied current to the diode being controlled or adjusted, as required); and diode **155** would be activated to produce an effective shorting-plate. Under these conditions, the antenna would no longer be symmetrical. The left half of antenna **150** establishes a standing-wave that would radiate energy of a given polarization from the dotted-line inclined slots in the left half of the antenna.

However, the right half of the antenna of FIGURE 10 would act in a somewhat different manner. It will be seen that the physical shorting-plate **156** is now three-quarters of a wavelength from the closest dotted-line slot. This arrangement would establish a standing-wave that would cause the dotted-line slots of the right half of the antenna to radiate energy that is 180° out-of-phase (anti-phase) compared with the energy that would be radiated by the dotted-line slots of the left half of the antenna. Hence, the mutually anti-phase energy radiated from the two halves of antenna **150** would co-act to produce the two-lobed difference pattern **132** of FIGURE 9.

In accordance with the theory of reciprocity, incoming echo signals received by the antenna of FIGURE 10 would enter the slots, and would establish two similar anti-phase standing-waves. These anti-phase standing-waves would be coupled to the stem portion of the antenna; and would provide difference-signals for use by monopulse signal utilizing equipment (not shown).

In this way the antenna of FIGURE 10 can produce either a sum or a difference pattern; and in conformance with the above-discussed theory of reciprocity, the antenna therefore also has sum-and-difference reception patterns.

Thus, energy applied to the stem-portion of the antenna of FIGURE 10 may be transmitted in a sum manner; and the echo signals may be received in a sum or a differ-

ence manner—the received echo signals appearing at the stem portion in a manner determined by the instantaneous standing-wave, as established by the states of the varactor-diodes.

In a preferred application of such arrangement, the varactor diodes would be gated in synchronism with the system trigger of a pulsed radar to provide a "sum" transmission pattern, and then alternately-gated in such combination, as to provide sampled sum and difference signals for amplification by a single channel amplifier, the output of the amplifier being switched between *two* output terminals (by electronic gating means well-known in the art) in synchronism with the gating of the varactors in order to separate the sum and difference signals into two several and distinct monopulse receiver outputs. In this way, monopulse receiver gain tracking errors are avoided due to the time-shared use of a single common amplifier for the sum and difference receiver signals. The arrangement of FIGURE 11 shows a time-duplexing arrangement for severally processing sum and difference antenna pattern signals at the antenna.

The antenna **160** of FIGURE 11 is similar to that of FIGURE 10, in that the antenna inherently has sum and difference patterns that are controlled by the state of varactor-diodes **152**, as previously explained. In FIGURE 11, however, a four-port microwave hybrid T or "magic tee" **162** is used, instead of the simple T of FIGURES 9 and 10; the magic tee having two ports or openings **171** and **172** thereof coupled to the antenna, a third port **163** symmetrically cooperates with the first two ports **171** and **172** as to represent a sum port while a fourth port **164** is symmetrically cooperated with the first two as to represent a difference port.

The construction and arrangement of magic tees is well known in the art, being described for example at page 572 in volume 12 of the Radiation Laboratory Series, "Microwave Antenna Theory and Design," by Silver (published by McGraw-Hill, 1949).

Where the varactor diodes **152** are switched to alternate states a respective one of the two slotted arrays are coupled to the waveguide section **160**, as previously explained. Hence, the beam pattern of the antenna of FIGURE 11 is alternately a sum and difference beam pattern.

Where varactors **152** are switched to a first state corresponding to a sum pattern during the application of a microwave energy pulse to sum port **163** of T **162**, then a sum pattern of energy is radiated from the antenna of FIGURE 11. If the varactors **152** are maintained in said first state during the receiving interval subsequent to the occurrence of the transmitted pulse, then the sum receiving pattern provided by each of the left and right-hand sections of the slotted waveguide element of FIGURE 11, as applied to the corresponding first and second port of magic tee **164**, will be differentially combined at the output of the difference or receiving port **164** to provide a mononpulse difference signal.

If, however, the varactors **152** in FIGURE 11 are switched to a second state corresponding to a difference antenna pattern, during the receiving interval, then the difference pattern provided by each of the left and right-hand sections of the slotted waveguide elements of FIGURE 11 (as applied to the corresponding ports of magic tee **162**) will be differentially combined at the output of receiving port **164** to provide a monopulse sum signal.

Where the state of varactors **152** is cyclically alternated during a receiving interval of an associated radar system (not shown), then the antenna of FIGURE 11 may be employed as a time-shared monopulse receiving antenna for use in cooperation with a single channel mononpulse receiver. Further, where the varactors are maintained in the first state during the pulsing interval of a radar transmitter (not shown) in response to the system trigger thereof and then cyclically alternated between the first and second states during the receiving interval of the radar system, the antenna may be employed as a duplexed, time-shared antenna in a pulsed radar system having a time-shared single channel monopulse receiver.

While the foregoing explanation has been given in terms of antennas comprising rectangular waveguides that have standing-waves produced therein, the present inventive concept is also applicable to circular, elliptical, or other cross-sectional waveguides that have standing-waves produced therein. For example, FIGURES 12 and 13 show a circular and an elliptical waveguide respectively, these waveguides having slot-pairs similar to those of a previous illustration. In the structures of FIGURES 12 and 13, the slot-pairs are spaced in accordance with the previous explanations; and suitably-positioned shorting-plates, varactor-diodes, or the like, produce desired standing-waves that cause energy to escape through the slots.

Because of the difficulty of illustrating the complex standing-waves that exist in these types of waveguides no detailed explanation will be given; but use of the above-described principles and types of slots will convert waveguides of other than rectangular cross sections into antennas capable of producing various types of polarization and beam patterns.

Accordingly, it is to be appreciated that an improved antenna has been described, comprising means for providing selected combinations of polarization and beam patterns.

Although the invention has been illustrated and described in detail, it is to be clearly understood that the same is by way of illustration and example only, and is not to be taken by way of limitation; the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. An antenna comprising
an apertured waveguide having two sets of perpendicularly-oriented apertures, the apertures of the first set coacting with the apertures of the second set to form aperture-pairs;
means for producing a standing-wave in said waveguide, and causing energy to escape from said aperture-pairs in an elliptically-polarized manner; and
voltage-sensitive means for selectively changing said standing-wave to effect a selected ellipticity of said escaping energy.

2. An antenna comprising
an apertured waveguide having a first set of inclined slots, and a second set of inclined slots;
switchable waveguide impedance means for establishing a standing-wave operative to couple to an alternate one of said first and second sets of inclined slots for causing an alternate one of said sets of inclined slots to be associated with a corresponding one of a first and second beam-pattern.

3. An antenna comprising
an apertured waveguide having a first set of inclined slots, a second set of inclined slots, and a third set of inclined slots;
first means for establishing a standing-wave capable of coupling to said first set of inclined slots, and causing said first set of inclined slots to be associated with a beam of a first beam-pattern;
second means for establishing a standing-wave capable of coupling to said second set of inclined slots, and causing said second set of inclined slots to be associated with a beam of a second beam-pattern; and
third means for establishing a standing-wave capable of coupling to said third set of inclined slots, and causing said third set of inclined slots to be associated with a beam of a third beam-pattern.

4. An antenna comprising
an apertured waveguide having a first set of inclined slots, a second set of inclined slots, and a third set of inclined slots;
first means for establishing a stand-wave capable of coupling to said first set of inclined slots, and caus-

ing said first set of inclined slots to be associated with a beam of a first beam-pattern;

second means for establishing a standing-wave capable of coupling to said second set of inclined slots, and causing said second set of inclined slots to be associated with a beam of a second beam-pattern; and

third means for establishing a stand-wave capable of coupling to said third set of inclined slots, and causing said third set of inclined slots to be associated with a beam of a third beam-pattern;

a magic-tee; and

means for coupling one port of said magic-tee with the set of slots associated with one of said beam patterns, and for coupling another port of said magic-tee with the sets of slots associated with the other two beam-patterns.

5. In a time-shared, single channel microwave monopulse receiving antenna the combination comprising

A microwave feed having a first and second slotted array,

Said first slotted array being responsive to an even distribution of received energy corresponding to a monopulse sum signal;

Said second slotted array being responsive to an odd distribution of received energy corresponding to a monopulse difference signal;

Voltage-sensitive impedance coupling means adapted to be connected to a source of a switching signal for alternately coupling said first and second arrays to said microwave feed.

6. In a duplexing microwave antenna for transmitting and receiving radar energy the combination comprising

A four-port microwave hybrid tee,

A first and second port of said tee adapted to be connected to a radar transmitter and receiver respectively;

microwave-wave feed means having

A first and second slotted array adapted for generating a monopulse sum and difference antenna pattern respectively, said microwave feed means comprising a first and second waveguide section coupled to a third and fourth port respectively of said hybrid tee;

variable microwave impedance means for alternatively coupling each of said arrays to said microwave feed, whereby said antenna is enabled to provide alternatively a monopulse sum pattern in response to transmitted energy applied to said first port of said hybrid tee and a monopulse sum pattern in response to a received energy output occurring at said second port of said hybrid tee.

7. A cross-polarized linear array microwave energy antenna including,

a rectangular waveguide including means for applying microwave energy thereto,

means for providing a standing wave pattern within said waveguide having the maximum transverse current amplitudes occurring at position of minimum longitudinal current amplitudes,

at least one series slot in said waveguide and positioned substantially ½ guide wavelength points of said standing wave pattern, developed by said means for providing,

at least one shunt slot in said waveguide and positioned substantially at ½ guide wavelength points of said standing wave pattern, developed by said means for providing, and

means for selectively shifting the standing wave pattern by an amount equal to an odd number of quarter of guide wavelengths of the energy in said waveguide.

8. A microwave antenna providing selected combinations of polarization and beamwidth of an emergent beam and having a microwave feed and comprising

At least two slotted arrays fed at one extremity thereof by said feed; and

Voltage-sensitive microwave impedance means coupling said arrays to said feed, and comprising passive microwave shorting means beyond a second extremity of said arrays and spaced apart therefrom and voltage sensitive microwave phase-shift means interposed between said second extremity of said arrays and said passive shorting means.

9. A linear array microwave energy antenna including,

a waveguide including means for applying microwave energy thereto;

means for providing a standing wave pattern within said waveguide having the maximum transverse current amplitudes occurring at positions of minimum longitudinal current amplitudes;

at least one series slot in said waveguide and positioned substantially at ½ guide wavelength points of said standing wave pattern, developed by said means for providing;

at least one shunt slot in said waveguide and positioned substantially at ½ guide wavelength points of said standing wave pattern, developed by said means for providing; and

means for selectively shifting the standing wave pattern by an amount equal to an odd number of quarter of guide wave-lengths of the energy in said waveguide.

References Cited

UNITED STATES PATENTS

2,479,209	8/1949	Chu	343—771
2,679,590	5/1954	Riblet	343—771
2,764,756	9/1956	Zaleski	343—771
2,771,605	11/1956	Kirkman	343—771
2,982,960	5/1961	Shanks	343—767
3,005,984	10/1961	Winder et al.	343—771

FOREIGN PATENTS

760,388	10/1956	Great Britain.

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