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ELLIPTICALLY OR CIRCULARLY POLARIZED ANTENNA

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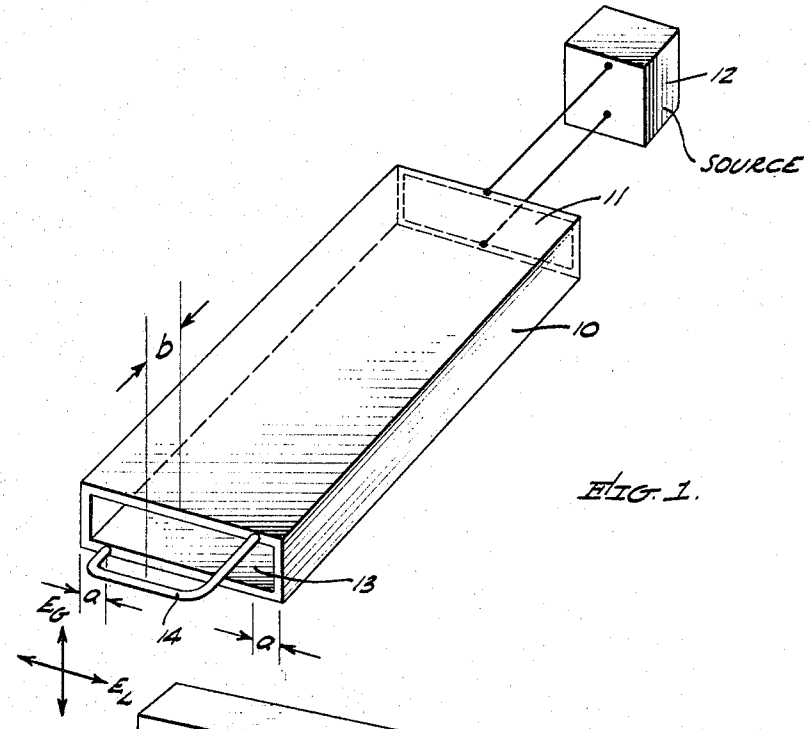


FIG. 1.

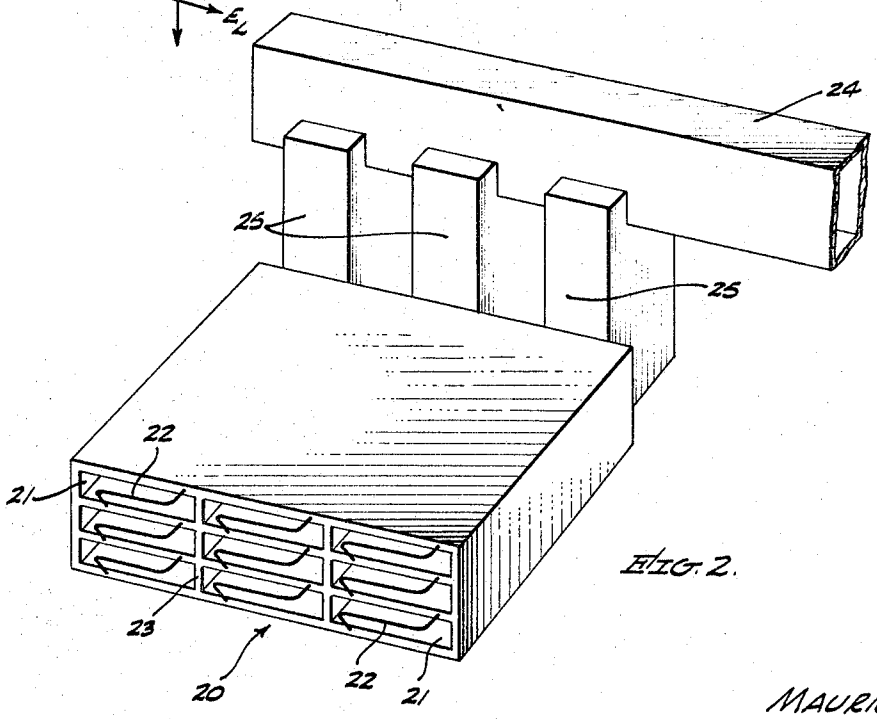


FIG. 2.

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ELLIPTICALLY OR CIRCULARLY POLARIZED ANTENNA

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This invention relates to high-frequency antennas and more specifically to antennas capable of radiating and receiving elliptically and circularly polarized wave energy.

In some applications, such as space communications systems, it is desirable to utilize antennas which radiate and receive elliptically or circularly polarized electromagnetic wave energy. The desirability of such antennas stems from the fact that with linearly polarized waves accurate coplanar polarization of the receiving and transmitting antennas is required for optimum transmission. Quite often it is difficult, if not impossible, to accurately maintain such polarization alignment. Circularly polarized antennas are therefore desirable since they obviate the necessity of polarization alignment between antennas.

It is a general object of the present invention, therefore, to provide improved antenna devices for radiating and receiving circularly and elliptically polarized electromagnetic wave energy.

In the past, circularly polarized high-frequency antennas have generally utilized a basic radiating element comprising a form of aperture in a waveguide wall. Apertures in the form of circular holes or crossed slots cut into the broad wall of a rectangular waveguide at a proper location will yield circular polarization. See, for example, the article, "Circularly Polarized Slot Radiators," by A. J. Simmons, IRE Transactions on Antennas and Propagation, vol. AP–5, No. 1, January 1957, at page 31, et seq.

In his copending application, Ser. No. 489,223, filed Sept. 22, 1965, applicant has disclosed several embodiments of a circularly or elliptically polarized antenna which overcome many of the disadvantages attendant prior art arrangements. Specifically, one of the disadvantages of prior art circularly or elliptically polarized antennas is the decreased antenna efficiency brought about by dissipative load impedances which terminate the waveguide containing the slot radiating elements. In applicant's above-mentioned copending application this disadvantage is overcome by utilizing an antenna structure capable of standing-wave operation, which has no dissipative load impedance.

The antenna of the present invention achieves increased efficiency with an alternative fundamental radiating element. In accordance with the present invention, an open-ended section of conductively bounded waveguide in combination with a conductive loop attached across the open end thereof comprises the basic radiating element. When operated in its transmitting mode the electromagnetic wave energy from the transmitter is propagated through the waveguide and is radiated at its open end. The electric vector of the wave energy radiated from the open-ended guide is polarized in a plane determined by the wave mode of the energy within the guide. The wall currents in the waveguide also excite the conductive loop which causes it to radiate. By virtue of the geometry of the loop the phase centers of the two radiated waves are different. Specifically, the phase center of the energy radiated from the open-ended waveguide is in the plane of the open end, whereas the phase center of the energy

radiated from the loop is a fraction of a wavelength away from the end of the guide. Elliptically polarized wave energy is thereby radiated from the combined radiating element. By selecting the proper length, shape and connection points of the loop, circular polarization is obtained.

In order that the present invention may be clearly understood and readily carried into effect, it will now be described with reference to the accompanying drawing in which:

FIG. 1 is a pictorial view of a basic radiating element in accordance with the present invention, and

FIG. 2 is a pictorial view of a planar array antenna in accordance with the present invention.

Referring more specifically to the drawings, in FIG. 1 there is shown a pictorial view of a conductively bounded rectangular waveguide **10**. One end **11** of waveguide section **10** is adapted for connection to a source **12** of electromagnetic wave energy. The other end **13** of waveguide section **10** is open. A loop **14** of conductive wire is mechanically and electrically connected across the open end **13** from one broad wall of guide **10** to the other. Advantageously, loop **14** is bent or twisted so that at least a substantial portion of the loop lies in a plane parallel to the broad walls of waveguide section **10**. Each end of loop **14** is soldered, brazed, welded or otherwise secured in position at the end region of the broad walls of waveguide section **10**. The distance *a* between the region of attachment of the ends of loop **14** to the nearest narrow wall of waveguide section **10** and the axial distance *b* from the loop to the open end of the guide can be selected to produce the desired radiation pattern. The perimeter of loop **14** can conform to a substantially rectangular shape, as shown, or can be oval or elliptical as desired. By the same token, the cross sectional geometry of the wire utilized to form loop **14** can be circular, as shown, or can be of any other shape, such as square or rectangular.

It is understood that the embodiment of FIG. 1 can be used as an antenna for either transmitting or receiving electromagnetic wave energy. As is generally known, the antenna can be connected to a switching device for directing outgoing wave energy from a source such as a transmitter to the antenna, or for directing incoming wave energy from the antenna to a receiver or other utilization device.

The operation of the basic radiating element of FIG. 1 will now be explained in terms of its transmitting mode. Electromagnetic wave energy, which for example can comprise a modulated carrier, is coupled from source **12** to end **11** of waveguide section **10**. This wave energy is then propagated through waveguide section **10** toward open end **13** in the dominant TE_{10} mode. Upon reaching open end **13** a portion of this wave energy is radiated into space. The phase center of the wave energy thus radiated lies in the plane containing the open end of waveguide section **10**. The electric vector of this radiated wave is oriented in a plane perpendicular to the broad walls of the guide as shown by the double headed arrow designated E_G.

The wave energy propagating within waveguide section **10** also gives rise to currents which flow in the walls of the guide. These wall currents, together with the wave energy radiated from the open end **13** of the guide, induce an alternating current in loop **14**.

By virtue of the current thereby induced, wave energy is also radiated from loop **14**. Due to the orientation of the loop, the electric vector of this radiated energy, however, is polarized in a direction parallel to the broad walls

of guide **10** as indicated by the double-headed arrow designated E_L.

By way of explanation, when there is a combination of two uniform plane waves of the same frequency but having different phases, magnitudes and orientations of the electric field vectors, the resultant combination is said to be an elliptically polarized wave. If two orthogonal waves combine so that the two electric field vectors are 90° out of phase and the magnitudes are equal, then the resultant wave is said to be circularly polarized.

It is therefore seen that the wave energy radiated from the basic radiating element of FIG. 1 is elliptically polarized. Furthermore, by proportioning loop **14** so that the phase center of the energy radiated from it is 90 electrical degrees removed from the plane of the open end of waveguide section **10**, circularly polarized radiation can be obtained. For circularly polarized radiation, however, the magnitudes of the two electric vectors must be equal. This is achieved by selecting the proper loop length and by properly positioning the ends of the loop along the longer sides of waveguide section **10** at open end **13**.

It should also be noted that the sense (that is, right-hand or left-hand rotation) of the resultant electric vector can be changed. This is accomplished by merely connecting the ends of loop **14** between the broad walls at regions near the upper-left corner and the lower-right corner rather than the upper-right corner and lower-left corner as shown.

By way of example, a basic radiating element similar to that of FIG. 1 was constructed and operated at a frequency of 9160 megacycles per second. For this device, half-height X-band waveguide having internal dimensions of 0.9 in. x 0.2 in. was employed. The wall thickness of the guide was 0.050 in. The axial distance *b* between the loop and the open end of the guide was 0.375 in. and the ends of the loop were attached a distance *a* equal to 0.20 in. from the narrow walls of the guide.

In FIG. 2 there is shown a pictorial view of a two-dimensional or planar array antenna **20** in accordance with the teachings of the present invention. The antenna array of FIG. 2 comprises a plurality of radiating elements consisting of open-ended waveguide sections **21**, across which are connected loops of conductive wire **22** in the manner of the embodiment of FIG. 1. As shown, the antenna of FIG. 2 utilizes nine basic radiating elements which are suitably disposed in a 3 x 3 matrix. The individual waveguiding channels can be constructed of nine individual open-ended waveguide sections or they can be formed by suitably partitioning a larger waveguide with conductive walls **23**. Although planar array antenna **20** has been illustrated with nine basic radiating elements arranged in a 3 x 3 matrix, it is obvious that more or less elements can be utilized. Beam shaping by varying the geometric arrangement and number of individual radiating elements is well-known to those skilled in the art. In general, an antenna array contemplated by this invention can comprise any number of individual radiating elements—the number of each depending upon the radiation pattern desired.

In any event, feed means for applying or extracting wave energy from antenna array **20** can be provided by a section of primary feed waveguide **24** to which are coupled sections of secondary feed waveguide **25**. Each of open-ended waveguide sections **21** are in turn coupled to secondary feed waveguide sections **25** by suitable coupling means well-known in the art. If desired, one or more phase shifting devices can be employed to vary the relative phase of the energy radiated from the individual elements.

In all cases it is understood that the above-described arrangements are illustrative of but a small number of many possible specific embodiments which can represent applications of the principles of the present invention. Numerous and varied other arrangements can be readily devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination,
- a section of hollow conductively bounded waveguide having at least one open end, said section being capable of supporting propagating electromagnetic wave energy having an electric vector oriented in a given plane of polarization;
- a thin elongated conductive member in the shape of a loop; and
- means for conductively connecting each end of said conductive member to opposite sides of said waveguide across said open end, at least a substantial portion of said member being disposed in a plane substantially perpendicular to said given plane.

2. In combination,
- a section of hollow conductively bounded rectangular waveguide having at least one open end;
- a thin elongated conductive member in the form of a loop; and
- means for conductively connecting each end of said conductive member to opposite broad walls of said waveguide across said open end, at least a substantial portion of said loop being disposed in a plane substantially parallel to said broad walls.

3. A high-frequency antenna comprising, in combination,
- a section of hollow conductively bounded waveguide supportive of propagating electromagnetic wave energy in the TE_{10} mode; and
- a loop of conductive wire, each end of said loop being conductively connected to one of the broad walls of said waveguide across said open end.

4. A high-frequency antenna comprising, in combination,
- a section of hollow conductively bounded waveguide capable of supporting propagating electromagnetic wave energy in the TE_{10} mode; and
- a loop of conductive wire, each end of said wire being conductively connected to one of the broad walls of said waveguide across said open end, at least a substantial portion of said loop being disposed in a plane substantially parallel to said broad walls.

5. A high-frequency antenna array comprising, in combination,
- a plurality of substantially identical sections of hollow conductively bounded waveguide, each of said waveguide sections having at least one open end;
- a plurality of thin elongated conductive members in the form of loops; and
- means for conductively connecting respective ends of each of said conductive members to opposite sides of each of said waveguide sections across said open ends.

6. A high-frequency antenna comprising, in combination,
- a plurality of substantially identical sections of hollow conductively bounded rectangular waveguide contiguously disposed in a planar array; and
- a plurality of loops of conductive wire, respective ends of each of said loops being conductively connected to respective broad walls of said of said waveguide sections across said open ends, at least a substantial portion of each of said loops being disposed in a plane substantially parallel to said broad walls.

7. In an antenna of the class comprising a plurality of sections of open-ended rectangular waveguide arranged in an array, means for obtaining elliptical polarization in such an array, said means comprising a loop of conductive wire conductively connected across each of said open ends, respective ends of each of said loops being connected to respective broad walls of each of said waveguide sections and at least a substantial portion of each

of said loops being disposed in a plane substantially parallel to said broad walls.

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