Feb. 2, 1960 H. G. LOWHURST 2,923,897

DUO-MODE WAVE ENERGY FEED

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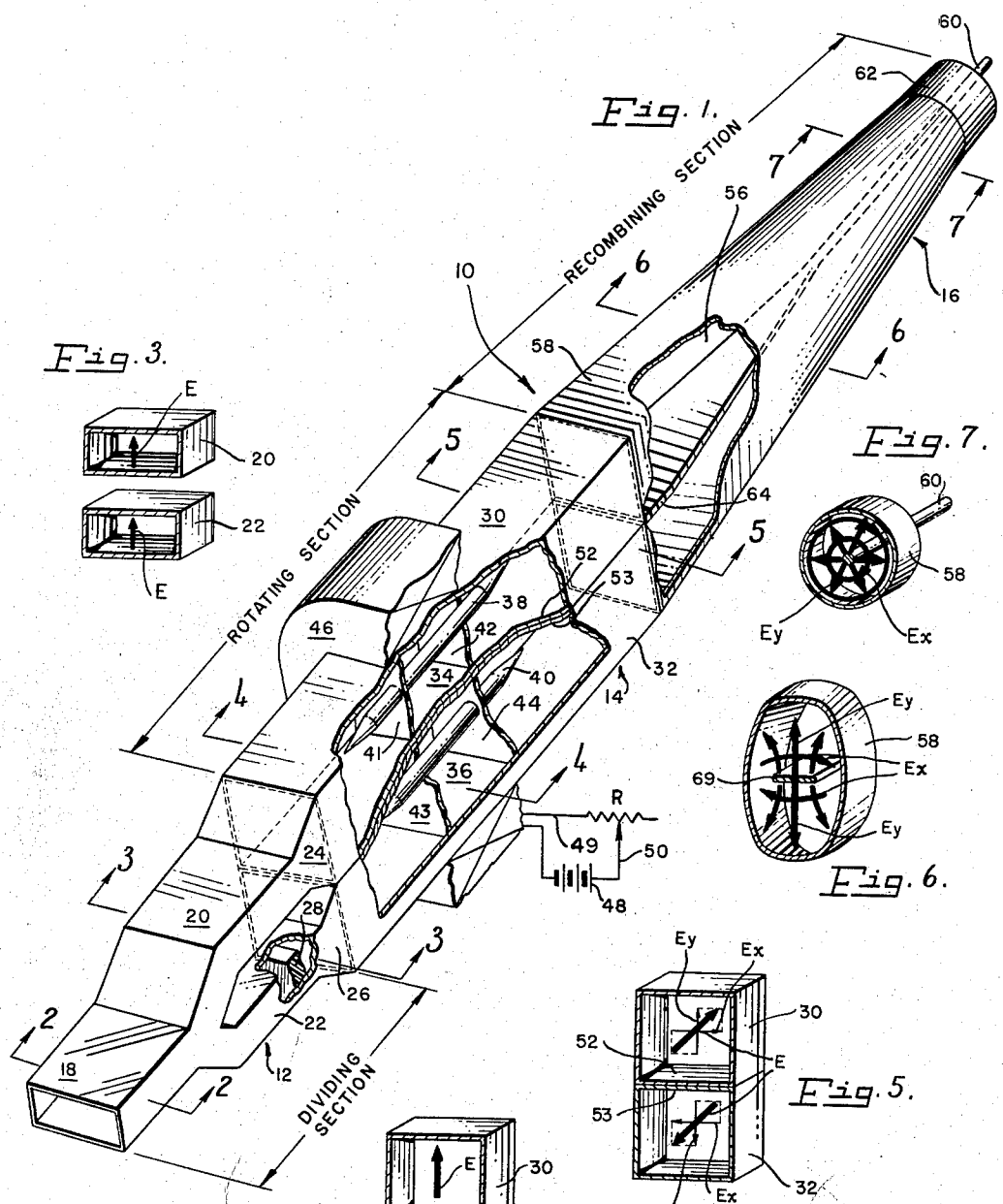


Fig. 1.

Fig. 3.

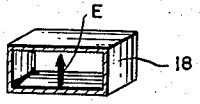


Fig. 2.

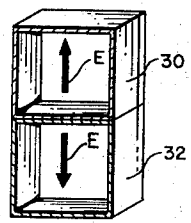


Fig. 4.

Fig. 5.

Fig. 7.

Fig. 6.

INVENTOR,
HARVEY G. LOWHURST

BY

ATTORNEY

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DUO-MODE WAVE ENERGY FEED

Harvey G. Lowhurst, Los Angeles, Calif., assignor to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

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This invention relates to duo-mode wave energy feeds and more particularly to a wave energy transducer which provides wave energy in a combination of the principal TEM-mode and the higher TE_{10}-mode of a coaxial waveguide.

In certain applications, wave energy antenna systems may be called upon to radiate a cross-polarized beam of wave energy. The antenna of such a system is adapted to receive and to radiate wave energy polarized in two mutually perpendicular planes. The feed means used in conjunction with such an antenna must likewise be adapted to excite and be excited by wave energy polarized in two mutually perpendicular planes. An adequate feed means is one adapted to excite wave energy in two modes having their respective electric field vectors at right angles to one another.

An example of an antenna adapted to radiate and receive orthogonally polarized wave energy is an omnidirectional surface wave beacon antenna having a dielectric clad metallic surface, the dielectric being utilized as a trapping agent. If the dielectric is of the multiple slab type, it may be adapted to propagate the orthogonal surface wave components with the same velocity. To utilize the properties of this antenna, a coaxial waveguide feed is used to supply the composite dielectric trapping agent with elliptically polarized wave energy of high power. One way to obtain the desired cross components of wave energy is to excite wave energy in the coaxial feed waveguide in two modes, namely the TEM-mode and the TE_{10}-mode.

It is therefore an object of this invention to provide a wave energy feed which is adapted to excite wave energy in a combination of the TEM-mode and the TE_{10}-mode of a coaxial waveguide at its output end.

It is a further object of this invention to provide a device which, upon being excited with wave energy in the dominant TE_{10}-mode of a rectangular waveguide, directly transforms a predetermined and adjustable portion of the energy of the excited mode into the TE_{10}-mode of a coaxial waveguide and directly transforms the remaining energy portion of the excited mode into the TEM-mode of a coaxial waveguide.

It is another object of this invention to provide a new and novel duo-mode wave energy feed capable of providing wave energy in an easily adjustable proportion of the TEM and TE_{10}-modes of the coaxial waveguide without the employment of interposed excitation elements which feed is simple in operation and capable of handling large amounts of power.

In accordance wtih this invention, wave energy propagated along a rectangular waveguide in the dominant TE_{10}-mode is divided into two equal portions in such a manner that the electric field vectors of the two divided portions are colinear. The electric field vector of each of the two portions of wave energy is then rotated so that the direction of linear polarization of the two portions suffers an angular displacement through an angle of θ degrees and $\theta+180$ degrees, respectively. This rotation leaves the electric field vectors of the two divided portions parallel and opposite to one another. Thereafter, the two portions of wave energy are recombined such that the components of the angularly displaced electric field vectors along the original direction of linear polarization will combine to provide the TEM-mode of a coaxial waveguide, and the components of the angularly displaced electric field along a direction perpendicular to the original direction of linear polarization will combine to provide the higher TE_{10}-mode of a coaxial waveguide. The ratio of the energies divided between the two modes is proportional to the angle θ so that control of the rotation of the electric field vector controls the relaitve amounts of the energy in the resulting modes.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawing in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only, and is not intended as a definition of the limits of the invention.

Fig. 1 is a fragmentary perspective view of an embodiment of the duo-mode wave energy feed of this invention; and

Figs. 2 to 7 are cross-sectional perspective views of different portions of the duo-mode feed of Fig. 1 showing the progressive reorientation of the electric field vector or vectors E.

Referring now to the drawing and particularly to Fig. 1 there is shown a duo-mode wave energy feed **10** in accordance with this invention. For the purpose of the specification and to facilitate the description of the wave energy feed of the invention, the device **10** is considered as being made up of a dividing section **12**, a rotating section **14** and a recombining section **16**. Such division is arbitrary and does not designate physical entities which are coupled to one another.

The dividing section **12** is essentially a Y-type power divider comprising a standard rectangular waveguide **18** which separates to provide a pair of identical branch waveguides **20** and **22**. The branch waveguides **20** and **22** may also be standard rectangular waveguides as shown. The end of the branch waveguides **20** and **22** are equipped respectively with tapered or flared end portions **24** and **26** to effect a smooth transition to a pair of square waveguides. One of the branch waveguides is further provided with a 180 degrees phase-shift means such as a dielectric plate **28** here shown inserted into waveguide **22** which is adapted to change the electric path length by one-half of the working wavelength from that of the physical path length. It will be obvious to those skilled in the art that the dielectric plate **28** is just one of many means of affecting the desired path length and that choke sections, twisted waveguides, folded waveguides and certain dielectric plugs subjected to magnetic or electric fields may be substituted therefor.

The ultimate purpose of the dividing section **12** is to receive wave energy in the dominant TE_{10}-mode of a rectangular waveguide and to provide to the rotating section **14** as a source the received wave energy divided into two substantially equal portions having a relative phase shift of 180 degrees therebetween. Therefore a Y-type power divider whose branch arms are each twisted through an angle of 90 degrees or a Magic Tee whose symmetry arms are each twisted through an angle of 90 degrees, may be substituted for the dividing section **12** hereabove described.

The rotating section **14** of the wave energy feed **10**

comprises a pair of identical square waveguides **30** and **32**, each one of which is coupled to a different one of the tapered end portions **24** and **26** of the dividing section **12** and capable of supporting cross-polarized wave energy. Each of the waveguides **30** and **32** is provided with wave energy rotating means **34** and **36** adapted to rotate the plane of polarization of the wave energy passing therethrough. Wave energy rotating means are well known in the art and are illustrated by way of example to comprise a pair of elongated ferromagnetic ceramic pencils **38** and **40** axially positioned within the respective waveguides **30** and **32**. These ferromagnetic ceramic pencils may be supported by polystyrene supports **41**, **42**, **43** and **44** respectively.

Surrounding the pair of square waveguides **30** and **32** is an electromagnet **46** connected to a battery **48**. The current through the electromagnet **46** may be adjusted by means of a resistance "R" put in series with lead **49** and a sliding contact **50**. The magnitude of the current passing through the electromagnet **46** determines the magnitude of the axial magnetic field produced. As is well known in the art, ferromagnetic ceramic elements subjected to a steady axial magnetic field exhibit the Faraday effect which produces antireciprocal rotation of the plane of polarization. The extent of rotation suffered by the wave energy passing through the pencils **34** and **36** is directly proportional to the magnitude of the magnetic field and the physical characteristics of the pencils **38** and **40**. It therefore follows that motion of the sliding contact **50** changes the current flow through the electromagnet **46** which in turn results in a change of the angular displacement of the plane of polarization. Many other materials exhibit charactertistics similar to these of ferromagnetic ceramic substances and may be substituted therefor.

The recombining section **16** of the wave energy feed **10** is essentially a waveguide transition from an oversized rectangular waveguide partitioned by the pair of thin conducting walls **52** and **53** of the square waveguides **30** and **32** to a coaxial waveguide **56** having an outer conductor **58** and an inner conductor **60**. The outer conductor **58** progressively changes in cross-section from that of the over-sized rectangular waveguide to that of a uniform cylindrical outer conductor **62** of the coaxial waveguide **56**. The thin conducting walls **52** and **53** which extend into the recombining section **16** merge to form the inner conductor **60** and are disconnected from the outer conductor **58** at the point **64**. Thereafter the merged walls gradually taper in width towards the center line of the coaxial waveguide **56** until their cross-section becomes circular.

Figs. 2–7 are cross-sectional perspective views taken along the various lines **2—2** to **7—7** taken along the wave energy feed of Fig. 1 and have been included to aid in the explanation of operation of this invention.

Wave energy in the TE_{10}-mode enters the dividing section **12** of the wave energy feed **10** through the rectangular waveguide **18**. Fig. 2 shows the vertical orientation of the electric field vector E. The Y-type power divider which feeds the pair of branch waveguides **20** and **22** splits up the wave energy from the waveguide **18** into two substantially equal portions. Fig. 3 shows the wave energy split into two equal portions whose respective electric field vectors E are colinear. As wave energy traverses the branch waveguide **22** it encounters the 180 degrees phase shift means **28** which changes the physical path length by one-half of the working wavelength. Fig. 4 shows relative phase relations between the electric field vectors of the two energy portions after one portion has suffered traversal through the 180 degrees phase shift means.

As wave energy is propagated through the rotating section **14** of the wave energy feed **10**, the direction of linear polarization or, which is the same, the electric field vector E of the wave energy passing through each of the rotators **34** and **36** is rotated through the same angle. As mentioned above, the angular displacement of the linear polarization is determined by the strength of the current passing through the electromagnet **46**. Fig. 5 shows the position of the rotated electric field vectors. Fig. 5 also shows the components of the electric vectors E along lines parallel to the walls of the square waveguides. These components are designated respectively as E_x and E_y. As can readily be seen from the drawing, related E_y components are colinear and 180 degrees out of phase with one another and related E_x components are parallel and also 180 degrees out of phase with one another.

Upon traversing the recombining section **16**, the wave energies of the two portions are recombined so that the E_y components provide the TEM-mode of a coaxial waveguide whereas the E_x components provide the TE_{10}-mode of a coaxial waveguide. Fig. 6 shows one single sequence in the progressive reorientation of the electric field vector components E_x and E_y resulting in the gradual formation of the desired output modes. Fig. 7 illustrates the TEM-mode and the TE_{10}-mode of a coaxial waveguide which is the output of the wave energy feed **10**.

As is readily seen from the foregoing description of the operation of the wave energy feed of the invention, the electric field generated by the electromagnet **46** will determine the energy ratio of the two output modes. At all times the sum of the energies of the two modes is equal to the input energy. If the magnetic field is zero and no rotation of the plane of polarization of the wave energy traveling through the rotators **34** and **36** takes place, the E_x component of wave energy is zero and consequently all wave energy will appear at the output in the TEM-mode. Similarly if the current in the electromagnet is adjusted to produce a magnetic field of such a strength that the linear polarization of the wave energy passing through the rotators **34** and **36** suffer a 90 degrees rotation, the E_y component of the wave energy is zero and consequently the only output mode at the end of the coaxial waveguide **56** is the TE_{10}-mode. By adjustment of the magnetic field, the desired energy ratio of the TEM-mode and the TE_{10}-mode may be obtained.

For best operation of the wave energy feed **10** it has been found desirable to use identical rotators **34** and **36** so that upon recombination, the amount of distortion of the two portions of wave energy will be equal. The device **10** will also work if the respective rotators **34** and **36** produce unequal rotation but higher modes will be generated thereby. The 180 degrees phase-shift means which has been shown to be located in the branch waveguide **22** may be placed in the square waveguide **32** as appears obvious from the function to be performed.

Elliptically and circularly polarized wave energy is obtainable in an antenna coupled to the feed of this invention by using a length of coaxial line which provides a 90 degrees relative phase shift between the two modes. As is well known, wave energy in the TEM-mode will be propagated through a coaxial waveguide at a different velocity than the TE_{10}-mode. Accordingly, it is only necessary to find a length of coaxial waveguide at which the desired phase shift exists.

What is claimed is:

1. A duo-mode wave energy feed adapted to effect a unity transition between the dominant TE_{10}-mode of a rectangular waveguide and a predetermined energy ratio of the principal TEM-mode and higher TE_{10}-mode of a coaxial waveguide, said feed comprising in combination: waveguide dividing means for equally dividing wave energy in the dominant TE_{10}-mode of a rectangular waveguide into two portions having co-linearly disposed electric field vectors, said dividing means including phase shifting means to provide a 180 degrees phase differential between said two portions; rotating means coupled to said dividing means for separately rotating the plane

of polarization of each of said two portions of wave energy through a predetermined angular displacement; and combining means coupled to said rotating means for combining said two rotated portions of wave energy to provide said principal TEM-mode and said higher TE_{10}-mode of a coaxial waveguide.

2. A duo-mode wave energy feed adapted to effect a unity transition between the dominant TE_{10}-mode of a rectangular waveguide and a predetermined energy ratio of the principal TEM-mode and higher TE_{10}-mode of a coaxial waveguide, the energy ratio being adjustable, said feed comprising in combination: dividing means for equally dividing wave energy in the dominant TE_{10}-mode of a rectangular waveguide into two portions; rotating means coupled to said dividing means for separately rotating the plane of polarization of each of said two portions of wave energy through a predetermined angular displacement of the same screw sense, said rotating means including two separate ferrite pencils within two separate waveguides subjected to a substantially identical adjustable magnetic field for changing the magnitude of said predetermined angular displacement; phase-shift means coupled to said feed and adapted to provide a relative phase shift of 180 degrees between said two portions of wave energy; and combining means coupled to said rotating means for combining said two rotated and phase shifted portions of wave energy to provide said principal TEM-mode and said higher TE_{10}-mode of a coaxial waveguide.

3. A duo-mode wave energy feed adapted to effect a unity transition between the dominant TE_{10}-mode of a rectangular waveguide and a predetermined energy ratio of the principal TEM-mode and higher TE_{10}-mode of a coaxial waveguide, the ratio of said combination being changeable, said feed comprising in combination: dividing means for equally dividing wave energy in the dominant TE_{10}-mode of a rectangular waveguide into two portions having co-linearly disposed electric field vectors, said dividing means including phase shifting means to provide a 180 degrees phase differential between said two portions; rotating means coupled to said dividing means and including a pair of waveguides defining wave energy propagation paths, each waveguide having an elongated ferromagnetic ceramic body axially located therein, said rotating means also including electromagnetic field means adapted to provide a magnetic field passing axially through each of said bodies, and adjustment means included in said field means to vary the magnitude of said magnetic field, said rotating means imparting an angular displacement to the plane of polarization of each of said two portions of wave energy; and combining means coupled to said rotating means for combining said two portions of wave energy to provide said principal TEM-mode and said higher TE_{10}-mode of a coaxial waveguide.

4. A duo-mode wave energy feed comprising: a rectangular input Y-type power divider having two output waveguides capable of supporting energy in various positions of rotation, means included within said output waveguides to provide 180 degrees relative phase shift between respective wave energy propagated therethrough, two elongated ferromagnetic ceramic elements, each of said output waveguides being provided with one of said ceramic elements; electromagnetic field means adapted to provide a magnetic field passing axially through each of said ceramic elements, and adjustment means included within said field means to vary the strength of said magnetic field, said output waveguides being disposed in parallel relationship having corresponding walls disposed adjacent in parallel relationship, the walls separating said output waveguides merging with one another to form a merged wall, said merged wall being detached from the remaining waveguide walls and being progressively tapered in width to form the center conductor of a coaxial waveguide, the remaining walls of said output waveguides being combined to form a rectangular waveguide whose cross-section progressively changes along its length into a cylindrical waveguide to form the outer conductor of said coaxial waveguide.

5. A duo-mode wave energy feed adapted to effect a unity transition between the dominant TE_{10}-mode of the rectangular waveguide and a continuously adjustable energy ratio of the principal TEM-mode and higher TE_{10}-mode of a coaxial waveguide comprising: dividing means responsive to wave energy in the dominant TE_{10}-mode of a rectangular waveguide and adapted to equally divide said dominant TE_{10}-mode into two portions, said dividing means including phase shift means adapted to impart a 180 degrees phase differential between said portions; rotating means responsive to said two portions of wave energy and adapted to separately rotate each of said two portions of wave energy through a substantially identical predetermined angular displacement; and combining means, said combining means including an outer member having a substantially rectangular input section and a substantially circular output section and whose cross-sectional shape changes progressively from rectangular to circular cross-section, said combining means further including a conductive wall across said input section dividing said input section into two substantially equal square waveguide portions, each of said two square waveguide portions being coupled to said rotating means for receiving a different one of said rotated portions of wave energy, said conductive wall being separated from said outer member and progressively tapering in width towards its center-line to provide the center of a coaxial waveguide forming said output section of said combining means.

6. A duo-mode wave energy feed adapted to effect a unity transition between the dominant TE_{10}-mode of a rectangular waveguide and an energy ratio of the principal TEM-mode and higher TE_{10}-mode of a coaxial waveguide, the energy ratio being adjustable, said feed comprising in combination: a rectangular waveguide Y-type power divider having two output ports, two square waveguide sections, each being coupled to a different output port of said divider, phase shift means included within said square waveguide sections and adapted to provide 180 degrees relative phase shift between wave energy propagated by said two square waveguide sections; two elongated ferromagnetic ceramic elements, said square waveguide sections each being provided with one of said ceramic elements, electromagnetic field means coupled to said square waveguide sections and adapted to provide a magnetic field passing axially through each of said ceramic elements, adjustment means included in said field means to vary the strength of said magnetic field; and a rectangular-to-coaxial waveguide transition, said transition including an outer member having a substantially rectangular input section and a substantially circular output section and whose cross-sectional shape changes progressively from rectangular to circular cross-section, said transition also including a conductive wall across its input section dividing said input section into two equal square waveguide portions, said two square waveguide sections being coupled to said two square waveguide portions, said conductive wall being separated from the outer member and progressively tapering in width towards its center line to provide the center conductor of a coaxial waveguide forming the output section of said transition.

7. A duo-mode wave energy feed adapted to effect a unity transition between the dominant TE_{10}-mode of a rectangular waveguide and a predetermined energy ratio of the principal TEM-mode and higher TE_{10}-mode of a coaxial waveguide, the ratio of said combination being changeable, said feed comprising in combination: dividing means for equally dividing wave energy in the dominant TE_{10}-mode of a rectangular waveguide into two portions, said dividing means including phase shifting means to provide a 180 degree phase differential between

said two portions; rotating means coupled to said dividing means and including a pair of waveguides defining wave energy propagation paths, each waveguide having an elongated ferromagnetic ceramic body axially located therein, said rotating means also including electromagnetic field means adapted to provide a magnetic field passing axially through each of said bodies and adjustment means included in said field means to vary the magnitude of said magnetic field, said rotating means imparting an angular displacement to the plane of polarization of each of said portions of wave energy; and combining means coupled to said rotating means for combining said two portions of wave energy to provide said principal TEM-mode and said higher TE_{10}-mode of a coaxial waveguide, said combining means including two output waveguides disposed in parallel relationship having contiguous walls, said contiguous walls merging with one another to form a merged wall, said merged wall being detached from the remaining waveguide walls and being progressively tapered in width to form the center conductor of a coaxial waveguide, the remaining walls of said output waveguides being combined to form a rectangular waveguide whose cross-section progressively changes along its length into a cylindrical waveguide to form the outer conductor of said coaxial waveguide.

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