

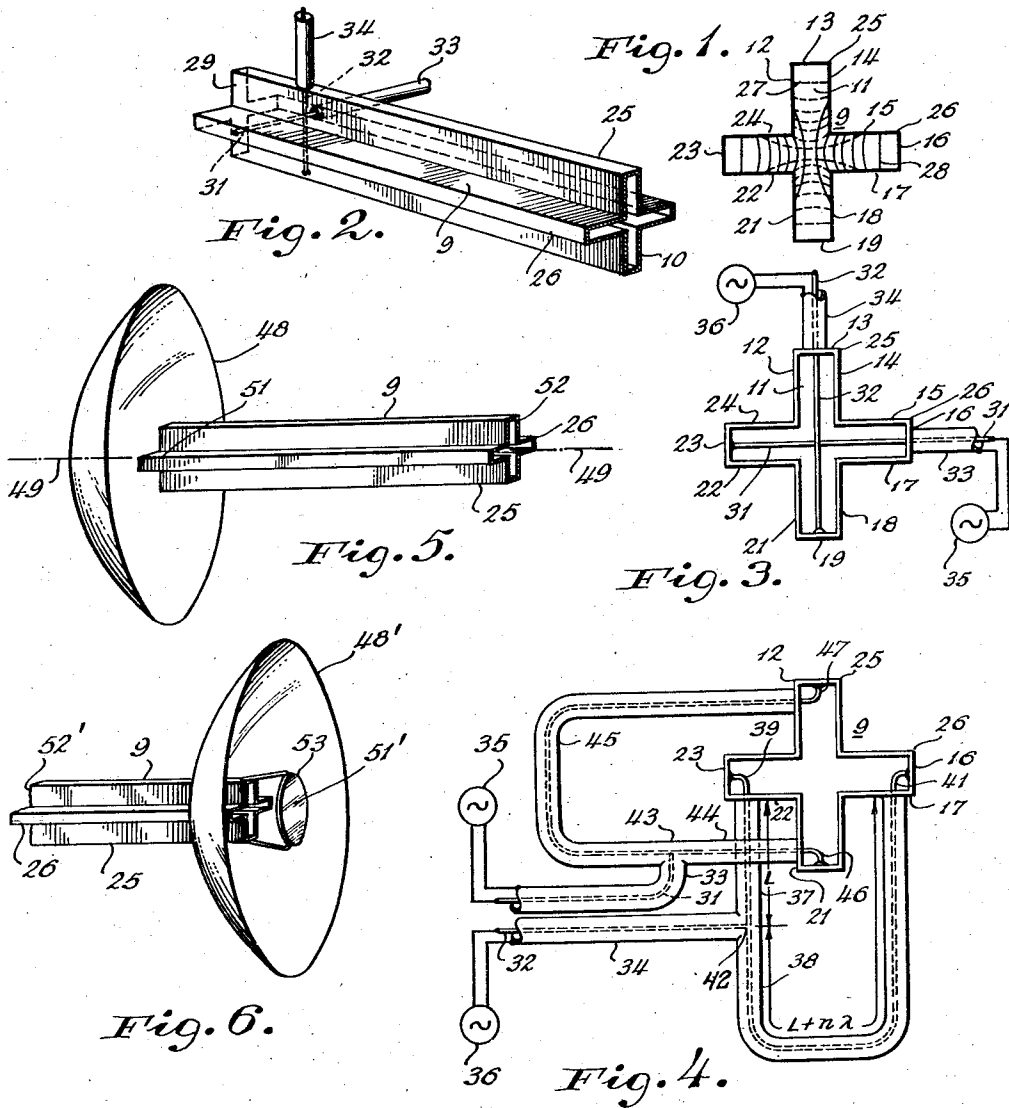
May 18, 1948.

E. T. JAYNES
ELECTROMAGNETIC WAVE GUIDE

2,441,574

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2 Sheets-Sheet 1



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Fig. 7.



Fig. 8.

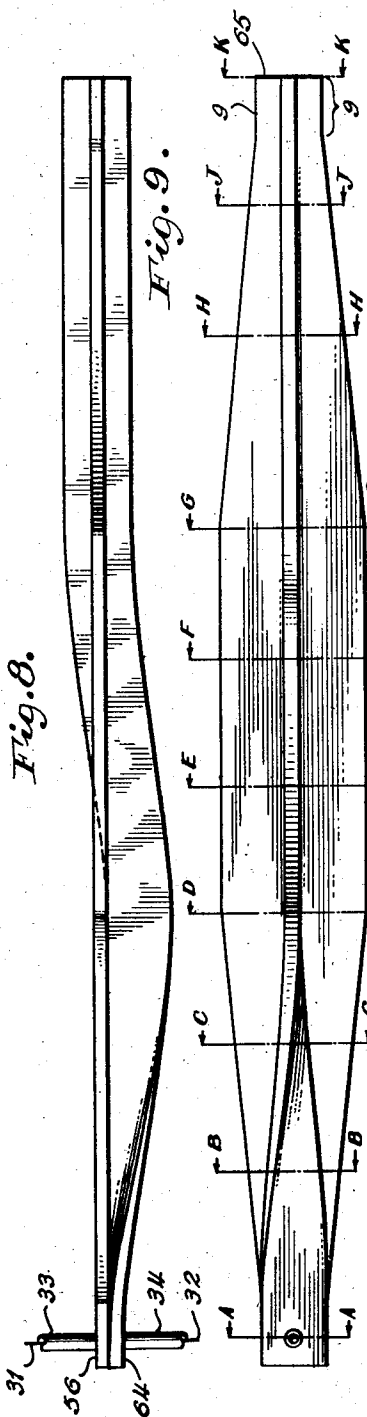


Fig. 9.

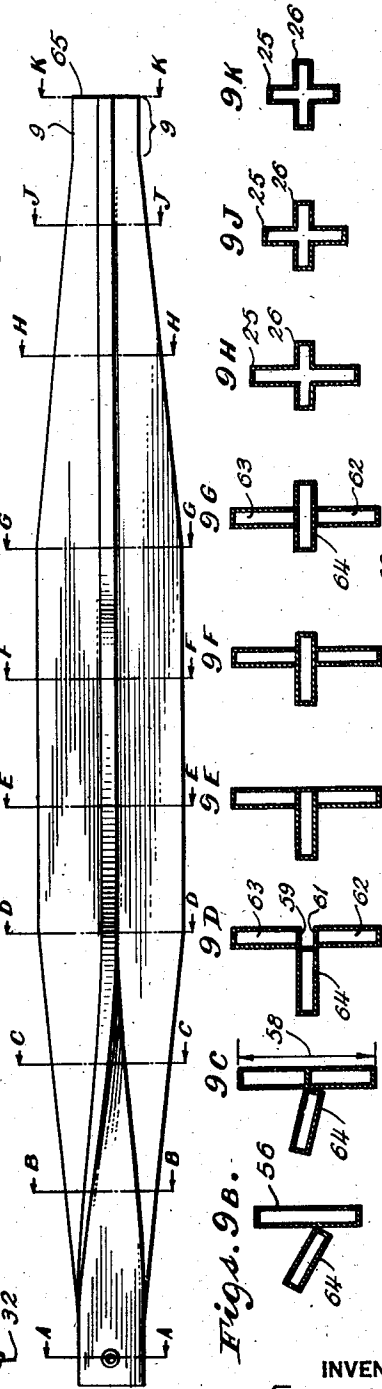


Fig. 9A.

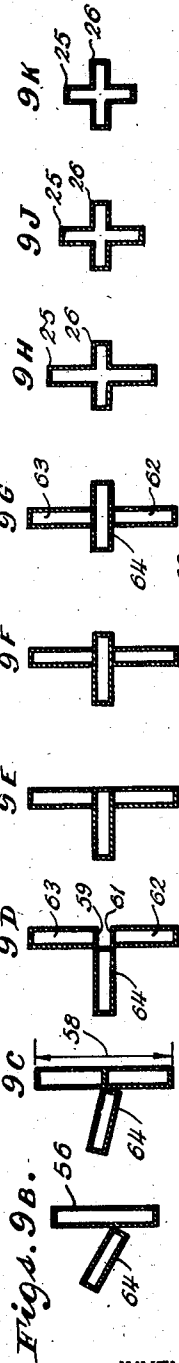


Fig. 9B.

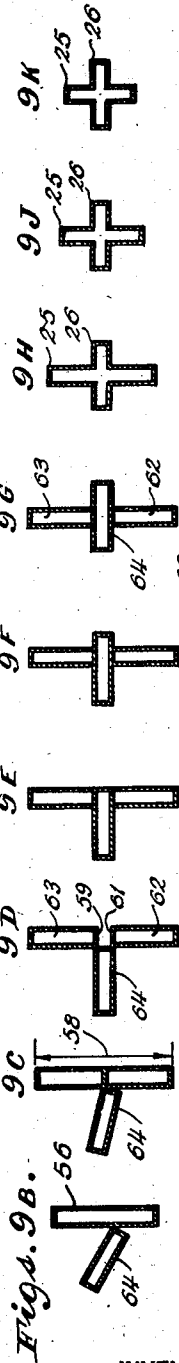
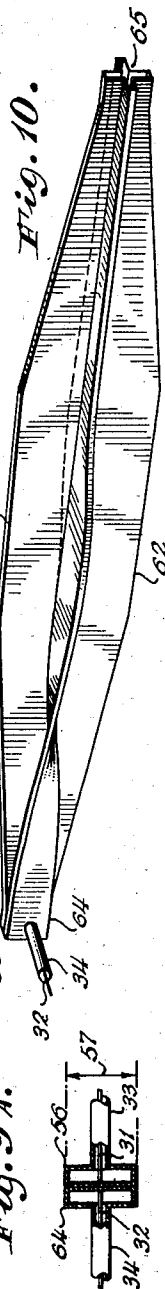


Fig. 10.



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ELECTROMAGNETIC WAVE GUIDE

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15 Claims. (Cl. 250—11)

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This invention relates to apparatus for conduction, radiation and reception of electromagnetic energy, particularly for ultra high frequencies.

The technique of guiding electromagnetic waves along a specially shaped and bounded dielectric medium is well known in the art. One type of waveguide in common use consists of an elongated conductive surface formed as a tube or a pipe with a hollow rectangular cross-section having a major dimension somewhat larger than one-half of the wavelength of the energy to be transmitted therethrough and often having a minor dimension much smaller than one-half the wavelength of the energy to be transmitted therethrough. In such a waveguide, a transverse electric wave may be transmitted with very low attenuation. The electric lines of force then extend between the two wide walls of the conductive surface.

Air at atmospheric pressure may be employed within the rectangular cross-section, electrically conductive boundary of the above waveguide as the dielectric medium for propagation of the guided electromagnetic waves. Alternatively, other dielectric material may be used, such as a gas at any desired pressure, a liquid, or a solid dielectric material. A suitable solid dielectric material, for instance, is polystyrene, a commercially available low-loss product.

It is not essential to the waveguide function that a solid dielectric material be bounded by an electrical conductor; a polystyrene rod, for instance, is itself capable of supporting and directing electromagnetic waves. Such a dielectric rod might take a form similar to that of the above discussed rectangular waveguide, with the omission of the electrically conductive skin on the boundary surfaces. The essential condition appears to be a cross-sectional area bounded by a material providing a dielectric discontinuity. The above constructions of electromagnetic wave guides are well known in the art.

In general, the type of waveguide employing a rectangular cross-section electrically conductive pipe with the air in the pipe as the dielectric medium has found wide acceptance as a convenient and efficient structure. Since compactness of the waveguide is highly desirable, such a structure is usually operated at its fundamental transverse electric mode, usually designated as the H_{01} mode. For this operating condition, the width of the dielectric passage within the pipe must be greater than one-half the

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wavelength of the electromagnetic energy to be transmitted therethrough. The other internal cross-sectional dimension of the pipe, which may in some cases be as great as the width, usually is only a fraction, such as one-third, of the width. Thus a rectangular pipe or tube for transmission of energy at 3000 megacycles may have internal cross-sectional dimensions of the order of one inch by three inches. The above major dimension is greater than one-half wavelength at the operating frequency of the waveguide, while the minor cross-sectional dimension is smaller than one-half the wavelength. Thus, only one orientation of an H_{01} wave may be transmitted through the waveguide—that having the orientation of lines of electric stress extending from one surface three inches wide to the opposite surface. For guiding horizontally electrically polarized waves along a horizontal axis, therefore the rectangular tube would be extended along the desired horizontal axis of transmission with its cross-section oriented for the three-inch dimension vertical and the one-inch dimension horizontal.

In directive antenna systems for ultra-high frequency radio systems, it is often desirable to guide vertically polarized waves and horizontally polarized waves along a common axis. A paraboloid reflector, for instance, might be used in conjunction with means for such wave guidance extending along the parabola axis to the vicinity of the focal point of the parabola. This combination might be used for guidance from a source and directive transmission of horizontally polarized waves, and directive reception and guidance to a utilization device of vertically polarized waves.

It is an object of the present invention to provide novel means for guided or directed transmission such as radiation or conduction of electromagnetic energy.

It is a further object to provide improved means for independently conducting or directing energy of a first polarization and energy of a second polarization along an axis, either in the same direction or in opposite directions.

A further object is to provide means for directing energies of different polarizations along a common axis to or from an electromagnetic energy director.

A further object is to provide methods for supplying energy to the novel waveguide mentioned above.

A further object is to direct electromagnetic energies having different polarizations along a

common axis to or from the focal point of a parabolic reflector.

A further object is to provide an electromagnetic waveguide system for transition between separate waveguide channels and the novel waveguide of the present invention.

Further objects will be apparent from a study of the following specification in conjunction with the drawings, of which,

Fig. 1 is a cross-sectional view of a dielectric waveguide formed according to the present invention, showing the lines of electric force schematically represented therein;

Fig. 2 is a perspective view and Fig. 3 an end view of a waveguide structure according to the present invention, showing one type of exciting means therefor;

Fig. 4 is an end view of an embodiment of the present invention showing a modified system of excitation for the waveguide;

Fig. 5 is a perspective view of a waveguide embodiment of the present invention in combination with a paraboloid reflector;

Fig. 6 is a perspective view of a modified combination of the cross-shaped waveguide with a parabolic reflector, wherein an auxiliary reflector is employed to permit extension of the waveguide through the paraboloid reflector;

Fig. 7 is a side view of a specially developed form of waveguide structure for transfer from separate electromagnetic waveguide channels to the cross-shaped waveguide of the present invention;

Fig. 8 is a plan view of the structure of Fig. 7;

Fig. 9 is a side elevation of the structure of Fig. 7;

Figs. 9A, 9B, 9C, 9D, 9E, 9F, 9G, 9H, 9J, 9K are sectional views, taken on lines A—A, B—B, C—C, D—D, E—E, F—F, J—J, and K—K of Fig. 9; and

Fig. 10 is a perspective view of the waveguide structure of Figs. 7 to 9, inclusive.

The waveguide 9 represented by the cross-sectional view of Fig. 1 comprises a dielectric medium 11 bounded by planar surfaces 12 to 19 and 21 to 24, inclusive. This figure may be considered to represent any of several alternative waveguide structures, such as an air dielectric waveguide arrangement in which the above planar surfaces represent electrically conductive areas, or a solid dielectric waveguide having such a material as polystyrene with or without electrically conductive boundary surfaces. This cross section may be described as of the form of a cross having two symmetrically intersecting perpendicular legs 25 and 26, the former being bounded by surfaces 12, 13, 14, 18, 19 and 21; and the latter being bounded by surfaces 15, 16, 17, 22, 23 and 24.

Transverse electric lines of force schematically indicated by dotted lines 27, may be produced in leg 25 of the cross-shaped waveguide in the manner to be described below. Similarly, transverse electric lines of force, indicated by lines 28, may be generated in waveguide leg 26. Each leg of the cross-shaped waveguide is thus substantially equivalent to a rectangular cross-sectioned waveguide of a well known type, having a major cross-sectional dimension larger than half of the wavelength of the energy to be transmitted there-through.

In the cross section illustration of Fig. 1, the sum of the widths of surfaces 17, 19 and 22 is substantially equivalent to the greater cross-sectional dimension of leg 26 as referred to above,

while the width of surface 16 would correspond to the other or minor cross-sectional dimension of a rectangular waveguide substantially equivalent to leg 26 of the cross-shaped waveguide shown in Fig. 1.

As an example of dimensions suitable for a waveguide in which copper skin surfaces 12 to 19, inclusive, and 21 to 24, inclusive, form an electrically conductive tube employing air dielectric 11, suitable widths of planar conductive strips 13, 16, 19 and 23 might be three-fourths inch, while the widths of the remaining planar surfaces, 12, 14, 15, 17, 18, 21, 22 and 24 might be two to three inches. Such dimensions would be suitable for H₀₁ mode transmission of energy at 3000 to 4000 megacycles per second, for example.

Electric lines of stress 27 could then be produced by excitation of leg 25 of waveguide 9 with electromagnetic energy having a frequency of the order of 3000 megacycles per second. Electric lines of stress 28 similarly could be produced by excitation of leg 26 of waveguide 9 with electromagnetic energy of a similar frequency not necessarily equal to the first frequency.

In Figs. 2 and 3 is seen a waveguide 9 having a cross-sectional configuration substantially equivalent to that of Fig. 1. Mutually perpendicular conductors 31 and 32 are provided for transverse electric excitation of legs 25 and 26, respectively, of the cross-shaped waveguide system. These conductors may be spaced from a conductive reflector plate 29, by dimensions corresponding to one-fourth, three-fourths, five-fourths, . . . of the respective wave lengths in the guide of energies to be transferred between the conductors and the waveguide legs. Thus, conductor 31 might be spaced from reflector plate 29 approximately one-fourth of the guide wave length of the energy to be transferred there-through, whereas conductor 32 might be spaced approximately three-fourths of the guide wave length of the energy to be transferred there-through. In Figs. 2 and 3, conductor 32 is noted to be in front of conductor 31, as seen by an observer looking into the open end 10 of the waveguide system. Surfaces 12 to 19 and 21 to 24, inclusive, as shown in Figs. 2 and 3, constitute electrically conductive walls, which may be made of copper sheet, bounding air dielectric medium 11. Coaxial lines 31, 33 and 32, 34 are clearly shown in Fig. 3 arranged for energy transfer with legs 25 and 26, respectively. The center conductor 31 of coaxial line 31, 33 is bonded as by a soldered joint, to conductive wall 23, while outer conductor 33 is bonded, again as by a soldered joint, to conductive surface 16. Center conductor 32 on line 32, 34 is similarly connected to wall 19, while the outer conductor 34 is bonded to wall 13.

With a source 35 connected to coaxial line 31, 33, the currents flowing through conductor 31 to electrically conductive surface 23, and thence through the consecutively adjacent conductive surfaces around to outer conductor 33, excite the waveguide leg 25 to produce therein the electric lines of stress indicated as dotted lines 27 in Fig. 1. Similarly, ultra high frequency generator 36, connected to coaxial line 32, 34 serves to excite leg 26 of the cross-shaped waveguide, as shown by lines 28 in Fig. 1. With the type of excitation thus provided, no coupling exists between the electromagnetic energy induced in the waveguide by source 35 and that induced in the waveguide by source 36. This fact, together with the capability of independently transmitting energy

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from source 35 and energy from source 36 along a common axis, is a feature of the present invention. Furthermore, either source 35 or source 36 may be replaced by an energy utilization device such as a radio detector, so that waveguide 9 may be used for independent transmission and reception of perpendicularly polarized electromagnetic waves.

An alternative system for feeding energy to, or extracting energy from waveguide 9 is shown in Fig. 4. In this figure, coaxial line 32, 34, connected to source 36, is coupled to leg 26 of the cross-shaped waveguide 9 through coaxial line sections 37 and 38 and the electromagnetic coupling loops 39 and 41. These loops emerge as the center conductors of coaxial sections 37 and 38, respectively, and are bonded as by soldering to walls 23 and 16, respectively, of leg 26. Coaxial line section 38 from junction 42 to conductive surface 17 is made equal to or an integral number of wavelengths longer than, the length of section 37 from junction 42 to wall 22, as indicated by the dimensions shown in Fig. 4 so that the voltages applied to the loops 39 and 41 are in phase. The resulting induced fields will be 180° out of phase due to the fact that loops 39 and 41 are turned in opposite directions. Similarly, source 35 is connected through coaxial line 31, 33 and junction 43 to coaxial line sections 44 and 45, which, in turn, are connected to electromagnetic coupling loops 46 and 47, respectively. Coaxial line section 45 extending from junction 43 to waveguide surface 12 is made equal to, or an integral number of wavelengths longer than section 44 extending from junction 43 to surface 21, whereby currents through conductor loops 46 and 47 are in phase.

The wave length used as a basis for computing the difference of lengths of coaxial line sections 44 and 45 is determined by the frequency of source 35 while the wave length used as a basis for computing the difference of lengths of coaxial lines 37 and 38 is based on the frequency of source 36. Here, also, source 35 or source 36 may be replaced by a high frequency utilization device or devices.

In Fig. 5 is shown an electrically conductive paraboloid reflector 48 having an axis 43 and a focal point 51. Fixed along axis 49 and extending substantially to focal point 51 is a cross-shaped waveguide 9 similar to that described above. The cross-shaped waveguide 9 of Fig. 5 is shown broken at 52, beyond which point may be attached a feeder system such as that of Fig. 2 or the version of Fig. 4, as described above, or that of Figs. 7 to 10 to be described.

Waveguide 9 in Fig. 6 is shown inserted from the rear of electrically conductive paraboloid reflector 48', and adapted to cooperate with auxiliary reflector 53 positioned substantially at focal point 51' of reflector 48'. Waveguide 9 is again shown broken as at point 52', beyond which feeding or utilization coupling means may be provided.

As an example of the applications to which the waveguide and reflector combinations of Figs. 5 and 6 may be adapted, a source of high frequency energy may be used to excite leg 25 of waveguide 9, thus providing horizontally polarized electromagnetic energy at focal point 51 or 51', whereby such energy is radiated by reflector 48 or 48' serving as an electromagnetic energy director. A utilization device, such as a radio receiver, may be coupled to leg 26 of waveguide 9, to receive vertically polarized electromagnetic energy re-

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flected by reflector 48 or 48' to focal point 51 or 51'. Reflector 48 or 48' and waveguide 9 may thus form part of a radio communication system, or of an object locating system, as is well known in the art.

While cross-shaped waveguide 9 is especially adapted for cooperation with a reflector of parabolic cross-section, this type of waveguide is further adapted to use in electromagnetic horn directive radiating systems.

A developed waveguide system characterized by transition from two separate rectangular waveguides to a single waveguide of cross shaped cross-section is shown in Figs. 7 to 10, inclusive. In this form of the invention, one waveguide 56 is enlarged from a major cross-sectional dimension 57 greater than one-half of the wave length of energy to be transmitted therethrough, to a cross-sectional dimension 58 appreciably greater than said wave length at section C of Fig. 9, beyond which two divergent septa 59 and 61 are introduced within guide 56 to separate waveguide 56 into two substantially parallel channels 62 and 63, extending through sections D, E, and F to section G. Waveguide 64 is twisted from vertical orientation of its major cross-sectional dimension at section A to horizontal orientation of its cross-sectional dimension at section D of Fig. 9, beyond which waveguide 64 is caused to converge to a position intermediate between channels 62 and 63 of waveguide 56. This is clearly shown by sectional view 9E, 9F, and 9G. The energy produced in waveguide 56 by current transmitted through coaxial line 31, 33, divided by septa 59 and 61 and transmitted in equal parts through channels 62 and 63 is reunited in vertical leg 25 of the cross-shaped waveguide formed at the termination at section 9G of septa 59 and 61. The energy produced in waveguide 64 by coaxial line 32, 34 is led along twisted waveguide 64 and thence along the path of convergence with channels 62 and 63. At section 9G of the waveguide structure shown in the Figs. 7 to 10, inclusive, septa 59 and 61 are terminated, leaving the interior of the waveguide structure substantially as shown in section 9H. Thereafter, the major cross-sectional dimension of the waveguide system is reduced until this dimension is substantially equal to the vertical cross-sectional dimension of waveguide 56 as indicated at 57 in sectional view 9A. Thus, the cross-sectional waveguide 9 is developed as shown in sectional view 9K, with excitation in vertical leg 25 provided by the ultra high frequency current through conductor 31, and with excitation of leg 26 produced by the ultra high frequency current through conductor 32.

It will be seen that the developed structure of Figs. 7 to 10 inclusive is suitable for use interchangeably with either the structure of Fig. 4 or that of Figs. 2 and 3. Furthermore, the waveguide structure of Figs. 7 to 10, inclusive, is suited for use with a director, such as the parabolic reflector shown in Fig. 5 or Fig. 6.

The structure of Figs. 7 to 10, inclusive, is particularly useful as an adapter for coupling to cross-shaped waveguide 9 oscillators and/or utilization devices provided with hollow-pipe waveguide fittings, to which separate waveguides 56 and 64 may be connected.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the

above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Electrical apparatus for operation at a given operating frequency comprising a dielectric waveguide bounded by twelve consecutively adjacent and intersecting substantially planar surfaces so positioned as to define a cross-shaped dielectric cross section having a medial portion dimensioned below cutoff at the operating frequency.

2. Apparatus for conducting both electromagnetic waves of a first polarization and electromagnetic waves of a second polarization comprising a dielectric waveguide of substantially rectilinear internal contour having a longitudinal extension of length greater than the wavelength of said waves and two transversely extending leg portions, means disposed parallel to one of said leg portions for exciting said waveguide for transverse electric polarization therein, and means disposed parallel to the other of said leg portions for exciting said waveguide for transverse electric polarization perpendicular to said first polarization.

3. Apparatus for conducting electromagnetic energy between an ultra high frequency device and a predetermined point spaced therefrom by a distance long relative to one wavelength of said energy and for conducting electromagnetic energy between a second ultra high frequency device and said point, comprising a waveguide extending from said point along an axis and including a tube of conductive material substantially coextensive with said guide and having an internal cross-sectional outline of substantially cross shape, means for coupling said waveguide to said first device, and means for coupling said waveguide to said second device.

4. Apparatus for conducting electromagnetic energy between a source and a first device, and between said source and a second device, comprising a waveguide extending along an axis from said source and including a dielectric medium having substantially cross-shaped internal cross section, means for coupling said waveguide to said first device for utilization of electromagnetic energy polarized substantially parallel to a plane including said axis at said source, and means for coupling said waveguide to said second device for utilization of electromagnetic energy polarized substantially perpendicularly to said plane at said source.

5. In a radio system including a source of electromagnetic energy and a utilization device for received energy, directive radiation and reception apparatus conjointly operable from a predetermined focal point comprising waveguide means extending from said focal point and including a dielectric medium having substantially cross-shaped internal cross section, means for coupling said source to said waveguide means to supply energy of a predetermined polarization at said focal point, and means for coupling said utilization device to said waveguide means for acceptance of a component of energy polarized perpendicularly to said predetermined polarization at said focal point.

6. In a radio system including a source of electromagnetic energy and a utilization device for received energy, directive radiation and reception apparatus conjointly operable from a predetermined focal point comprising waveguide means extending from said focal point and in-

cluding a dielectric medium having an internal cross section characterized by two mutually perpendicular legs, means for coupling said source to said waveguide means at one of said legs to supply energy of a predetermined polarization at said focal point, and means for coupling said utilization device to said waveguide means at the other of said legs for acceptance of a component of energy polarized perpendicularly to said predetermined polarization at said focal point.

7. In a radio system including a source of electromagnetic energy and a utilization device, apparatus comprising an electromagnetic energy director means for transmission and reception of electromagnetic wave energy along an axis, waveguide means coupled thereto for transfer of energy to and from said director including a dielectric medium having substantially cross-shaped internal cross section, means coupling said source to said waveguide means for transmission of energy of a first polarization to said director, and means coupling said waveguide means to said utilization device to render the latter responsive to energy of a second polarization received by said director.

8. Waveguide apparatus for connecting a first waveguide element, having a cross shaped continuous dielectric cross section of two perpendicular legs, to two ultimate waveguide elements having rectangular dielectric cross-sections, comprising a second waveguide element adjoining said first element and having a cross shaped cross section with two electrically conductive septa introduced therein separating said element into two separated waveguide channels and a third waveguide channel intervening between and perpendicular to said two channels; and a third waveguide element connecting said second element to said ultimate elements for high frequency energy transmission therethrough, said third element having two sections respectively connected to said two channels and a third section connected to said third waveguide channel and emergent from between said two sections at a point along said two sections, said two sections being convergent to form a single waveguide channel beyond the point of emergence of said third section and being adjoined to a first of said ultimate elements, and said third section being adjoined to the second of said ultimate elements.

9. Apparatus comprising two rectangular waveguides conjoined to terminate in a single waveguide having a cross-shaped dielectric cross-section, characterized by two divergent septa introduced into a first of said wave guides separating said first waveguide along a finite length thereof into two electromagnetic energy transmission channels, and further characterized by convergence of the second of said two waveguides to contiguity with said septa, within said finite length.

10. Apparatus comprising two rectangular waveguides conjoined to terminate in a single waveguide having a cross-shaped dielectric cross-section, characterized by two divergent septa introduced into a first of said waveguides separating said first waveguide along a finite length thereof into two electromagnetic energy transmission channels, and further characterized by convergence of the second of said two waveguides with said septa, within said finite length.

11. Apparatus comprising a waveguide element wherein three rectangular waveguides having initially distinct hollow electrical conductors

converge to form common electrically conductive boundary surfaces along the areas of contact separating the respective interior zones of said waveguides, said common conductive boundary surfaces being terminated within said conductors to render said interior zones intercommunicating.

12. Electromagnetic energy transmission apparatus comprising three rectangular waveguides having initially distinct electrically conductive surfaces converging to adjacent positions to form common electrically conductive boundary surfaces, said common conductive surfaces being terminated within said apparatus to form a single electromagnetic energy conductive structure terminating said apparatus and having a single continuous dielectric cross-section.

13. A waveguide for operation at a given operating frequency having a longitudinal axis and adapted for transmission of electromagnetic signals along said axis, comprising means defining a bounded dielectric medium having in cross-section a pair of mutually perpendicular medially intersecting legs each formed between cooperating pairs of parallel bounding surfaces, the spacing between said bounding surfaces defining crossed wave guides above cutoff and a central intersection space dimensioned below cutoff at the operating frequency.

14. Apparatus for conducting both electromagnetic waves of a first polarization and electromagnetic waves of a second polarization comprising a dielectric wave guide of substantially rectilinear internal contour and having a longitudinal extension of length greater than the wavelength of said waves and two transversely extending leg portions, means coupled to one of

said leg portions for exciting said wave guide for transverse electric polarization therein, and means coupled to the other of said leg portions for exciting said wave guide for transverse electric polarization perpendicular to said first polarization.

15. Apparatus for conducting both electromagnetic waves of a first and a second polarization comprising a dielectric waveguide of substantially rectilinear internal contour and having a longitudinal extension of length greater than the wavelength of said waves and two transversely extending leg portions, and means coupled to said leg portions for exciting said waveguide in mutually perpendicular transverse electric polarizations therein.

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REFERENCES CITED

- 20 The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
25 2,197,122	Bowen -----	Apr. 16, 1940
2,206,923	Southworth -----	July 9, 1940
2,283,935	King -----	May 26, 1942
2,395,560	Llewellyn -----	Feb. 26, 1946

FOREIGN PATENTS

Number	Country	Date
30 495,977	Great Britain -----	Nov. 23, 1938

OTHER REFERENCES

- 35 Proceedings of the I. R. E., Oct. 1936, vol. 24, No. 10, pp. 1326 and 1328.