

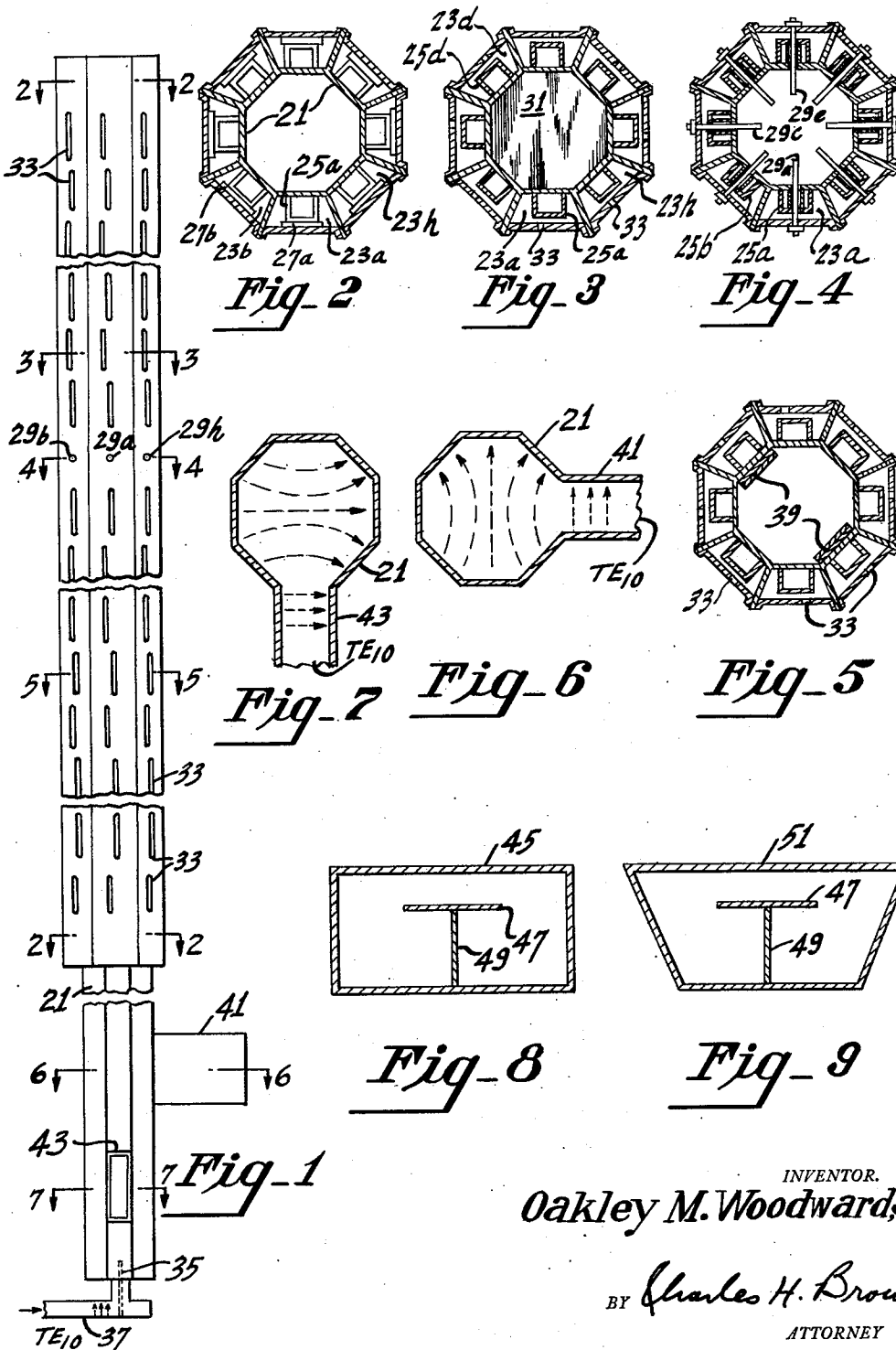
Sept. 17, 1957

O. M. WOODWARD, JR
SLOTTED WAVEGUIDE ANTENNA

2,807,018

Filed July 27, 1953

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

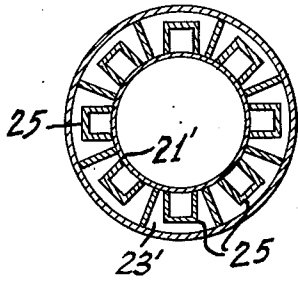


Fig-10

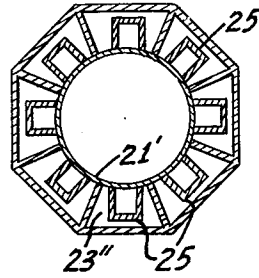


Fig-11

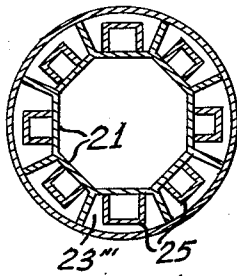


Fig-12

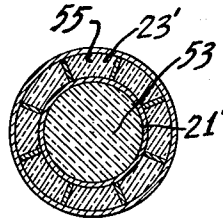
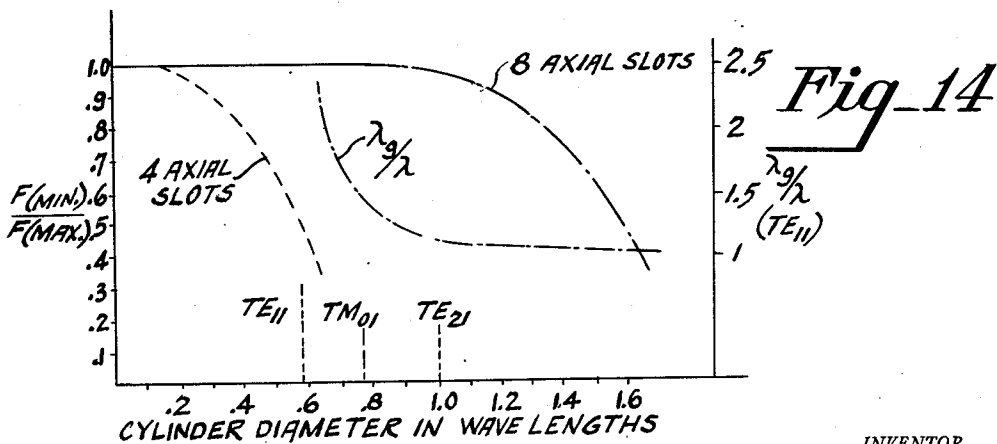


Fig-13



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2,807,018

SLOTTED WAVEGUIDE ANTENNA

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11 Claims. (Cl. 343—771)

This invention relates to antennas, and particularly pertains to an ultra-high-frequency antenna array utilizing slotted waveguides to effect the interchange of radio frequency energy with free space.

The invention is especially useful in the ultra-high-frequency services, such as U. F. F. television broadcasting. When used in television broadcasting, both the picture and accompanying sound signal may be diplexed into the same antenna by a transmission line arrangement forming part of the feed system for the antenna and without the necessity for separate frequency selective filters. Antennas for television broadcasting which utilize coaxial and other two-wise transmission lines are limited with respect to their power handling capabilities. This invention utilizes hollow pipe waveguide throughout its construction because of the attendant higher power capability.

It is an object of this invention to provide an improved antenna array for ultra-high-frequency services capable of handling very high input radio frequency power of the order of 200 kws.

Another object of this invention is to provide an omnidirectional broadcast antenna array of highly stable mechanical construction which is utilizable at full power even in heavy storm-loading areas.

It is a further object of this invention to provide an antenna array utilizing waveguide transmission line throughout in which the frequency of operation of the antenna can be changed from one frequency to another by a simple replacement of the wall of the waveguide which contains the radiating elements.

Still another object of this invention is to enable the diplexing of two radio frequency signals to a single transmission line without interaction, and feeding the diplexed signals from the single waveguide transmission line to a number of surrounding waveguide lines which have one wall slotted to act as antenna elements.

Yet another object of this invention is to provide means for broadbanding one of two radio frequency signals which are fed to a single antenna structure without interaction with the other radio frequency signal fed to the same antenna.

In accordance with the invention, these and other objects are obtained by an antenna system which includes a hollow pipe waveguide forming the central member which is utilized for bringing the radio frequency energy up to a point intermediate the ends of the array, and a number of surrounding waveguides of special configuration which have slots in one face to effect the interchange of radio frequency energy between the guides and free space. The slotted waveguides which surround the central waveguide may be basically of isosceles trapezoid cross-section. Alternatively, either the inner or the outer of the broad walls of the surrounding waveguides may be arcuate. Metal ridges are attached to the inner broad wall of the surrounding waveguides to lower the cut-off frequency. The slots which act as the antenna elements are cut in the outer walls of the specially shaped

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surrounding waveguides. The outer walls of the surrounding waveguides may be made in the form of cover plates into which the slots are cut so that the frequency of operation may be changed to any frequency of operation occurring over a broad frequency band by simply changing the outer cover plate to another containing differently dimensioned and differently positioned slots. The slots may be excited by being positioned off the center line of the walls.

Radio frequency energy is conveyed up the central waveguide member where it is transferred to the specially shaped surrounding guides in which it is propagated both upward and downward along the entire length of the aperture. Adjustable shorting bars are provided at the upper and lower ends of each of the specially shaped guides.

An important feature of the invention is the cross-sectional configuration of the antenna structure which results from a central waveguide surrounded by a plurality of waveguides. This cross-sectional configuration yields an antenna array structure which may be made from 20 to 40 wavelengths or more long yet have high bending and flexure strength and therefore capable of standing high wind velocities and severe ice loading.

A more detailed description follows in conjunction with the accompanying drawing wherein:

Figure 1 is a side elevation of an omnidirectional antenna array in accordance with the invention;

Figure 2 is a cross-section along the line 2—2 of Figure 1;

Figure 3 is a cross-section along the line 3—3 of Figure 1;

Figure 4 is a cross-section along the line 4—4 of Figure 1;

Figure 5 is a cross-section along the line 5—5 of Figure 1;

Figure 6 is a cross-section along the line 6—6 of Figure 1;

Figure 7 is a cross-section along the line 7—7 of Figure 1;

Figure 8 is a cross-section of loaded rectangular waveguide which may be utilized in the invention;

Figure 9 is a cross-section of loaded isosceles trapezoidal waveguide which may be utilized in practicing the invention;

Figures 10, 11, 12 and 13 show alternative configurations of cross-sectional arrangements of antenna arrays embodying the principles of the invention; and

Figure 14 is a graph utilized in explaining the invention.

Referring now to Figures 1 to 7, an antenna array constructed in accordance with the invention contains a central waveguide **21** of octagonal cross-sectional configuration. The central waveguide **21** must be capable of supporting two orthogonally disposed dominant polarized transverse electric loads of propagation (TE_{11}), and preferably should be able to support a mode having circular symmetry (TM_{01}). Waveguides of circular cross-section or of equilateral polygonal cross-section having an even number of sides (4, 6, 8, 10 etc.) fulfill these requirements. Also, coaxial transmission lines may be operated in the coaxial TE_{11} mode as well as the TEM mode to be used as the central waveguide **21**.

The central waveguide **21** is surrounded by a number of waveguides having a specially shaped cross-sectional configuration. Each of the surrounding waveguides is identical. The waveguides are denoted by the reference characters **23a** through **23h**. The shape and positioning of these waveguides **23a** through **23h** may be understood best by referring to Figures 2, 3, 4 and 5 as well as to Figure 1.

Figures 2, 3, 4 and 5 are cross-sectional views along the correspondingly numbered section lines of Figure 1.

The surrounding specially shaped waveguides 23a through 23h are all identical and are basically of isosceles trapezoid cross-section, loaded throughout their entire length by metal ridges 25a through 25h occupying a substantial proportion of the broad wall dimension and having a height which is a substantial proportion of the narrow wall dimension.

Because of the magnitude of the optimum diameter of the central waveguide 21, rectangular or trapezoidal guides having a two-to-one broad-to-narrow wall dimension ratio are too small, that is, below cut-off, at the frequencies at which the central guide 21 is designed to operate. The metal ridges 25a through 25h lower the cutoff frequency of the surrounding waveguides 23a through 23h so that they will efficiently transmit the frequencies which can be propagated in the central waveguide 21.

As shown in Figure 2, the surrounding waveguides 23a through 23h are terminated at the ends of the antenna array by metallic short-circuiting blocks 27a through 27h. The shortcircuiting blocks 27 may be positioned about $\lambda_g/4$ from the center of the last layer of slots at each end of the antenna array.

Referring now especially to Figures 1, 3 and 4, and assuming that the antenna is being used for transmitting purposes, the radio frequency energy is propagated up the central waveguide 21 to a layer of coupling elements 29a through 29h which are used to transfer the energy from the central guide 21 to the surrounding rectangular guides 23a through 23h. The coupling elements 29a through 29h are shown as simple voltage probes which extend through a hole in the outer broad wall of the waveguide 23, through a clearance hole in the ridge 25 and into the interior of the central guide 21. Other coupling means than the probes shown in the drawing, such as, for example, loops or slots, may of course, be used although the mechanical arrangement of the probes shown provides a simple mechanical adjustment of the degree of coupling between the individual surrounding guides 23a through 23h and the central guide 21, which may be varied easily from the exterior of the antenna structure. The layer of coupling elements or probes 29a through 29h provides the feed point for the antenna array which extends both up and down from this point.

Figure 3 shows a metallic short circuiting plate 31 located in the central guide 21 beyond the feed point (section 4-4, Fig. 1) from the associated radio frequency apparatus. This shorting plate may be used for tuning and matching by altering its position in the central waveguide 21 above the feed point, as well as for preventing energy from continuing on in the central waveguide 21.

Slots 33 cut in the broad wall of a rectangular waveguide may be fed by means of probes or loops or by carefully positioning such slots to one side or the other of the center axis of the broad wall. A waveguide of trapezoidal cross-sectional shape behaves in substantially the same way as rectangular guide, and off-center positioning of the slots to couple the wave in the trapezoidal guide between the guide and free space is shown in Figures 1, 3 and 5. When off-center positioning is used, no probes or loop couplings are required to excite the slots. The degree of slot coupling is a function of the amount of offsetting of the slot from the center line of the broad wall.

In the embodiment of the invention shown in Figures 1 through 5, the slots 33 associated with a single specially shaped waveguide, for example the one denoted by the reference character 23a, may be excited with in-phase voltages by spacing the slots 33 center-to-center a half-guide wavelength (measured along the axis of the antenna array) and offsetting the center of adjacent slots on opposite sides of the center line of the exterior broad wall. For a given slot offset distance, the effective shunting impedance of the slot across the guide at the slot center may be made a pure resistance by slightly adjusting the length of the individual slot. The width of the individual slots 33 may be used within certain limits to control the band-width characteristics. If the upper and lower halves of

the antenna are to be fed in phase, and the distances from the feed point to the coupling elements 29 are to be equal, the two slots adjacent to the feed point are offset on the same side as shown in Figure 1. The distance of the center of the first layer of slots from the feed point at the coupling elements 29 may be adjusted from approximately $\lambda_g/4$ upwards for broadbanding and matching purposes.

All of the surrounding specially shaped waveguides 23a through 23h may be excited in phase by propagating a mode having circular symmetry in the central guide 21. The lowest order mode having circular symmetry is the TM_{01} mode. This mode may be launched in the central guide 21 by means of an axial probe 35 extending into one end of the guide 21. The probe 35 may be an extension of the inner conductor of a coaxial transmission line or, as shown in Figure 1, may be a probe extending transverse (across the narrow dimension) to a rectangular waveguide 37 in which the TE_{10} mode of propagation is present.

However, for television broadcasting purposes, the use of only the TM_{01} mode in a cylindrical guide 21 requires that the picture and sound signals be diplexed into a single feed line. Systems presently in use for this diplexing operation embody frequency-selective filters. Such filters are critical in construction and adjustment in the ultra-high frequency range. A preferred method of feeding the antenna array of this invention without the use of frequency-selective filters in the diplexing operation will now be described.

Two polarized dominant waves (for example, the TE_{11} mode in circular guide) are excited in the central waveguide 21 orthogonally disposed with respect to one another and in 90° time relation. The resultant wave is a linearly polarized wave whose principal electric vector has an apparent rotation at radio carrier frequency. This is called circularly polarized (for two equal-amplitude TE_{11} waves) or rotating polarization propagation. The circularly polarized wave excites the voltage probes 29a through 29h at the feed point with equal amplitude and progressively phased voltages.

Referring now to Figures 1, 5 and 6, one method of converting a linearly polarized TE_{11} wave to a circularly polarized wave is shown. Two oppositely disposed phase-shifting fins 39 are attached to the inside of the cylindrical guide 21. The phase shifting fins 39 are at an angle of 45° with respect to the incident TE_{11} wave. For example, in Figure 6 the direction of the electric field is shown as being vertical and the phase shifting fins shown in Figure 5 are rotated through 45° . The TE_{11} wave of Figure 6 may be divided into two equal orthogonally disposed components, one component perpendicular to a plane common to the two phase shifting fins 39 and another component parallel to the same plane. The fins produce a relative phase delay between the two components due to the different loading presented to the two components of the TE_{11} wave. By properly adjusting the size and length of the phase shifting fins 39, a 90° phase difference is produced. These two components are in the proper time relation and spatial disposition to propagate as a circularly polarized wave.

The phase shifting fins 39 utilized in the present invention are different in design from those of the prior art in that they occupy a very small proportion of a diameter of the central waveguide 21. By making the phase shifting fins of the form shown in Figure 5, they may be utilized in a circular or polygonal waveguide which propagates low order circular modes (for example the TM_{01}) without acting as mode filters for such waves. The length of such fins for a given amount of phase shift must be longer than those of prior design because the amount of shift in phase per guide wavelength is much less. The ends of the fins 39 are tapered from the wall of the waveguide to their full height. This taper may be a gradual taper or, for convenience in mechanical construction, it may be of stepped configuration. If the taper of the fins is of step form, each step may conveniently be made $\lambda_g/4$ in length to provide a reflectionless transition.

An incident linearly polarized wave with its principal electric vector oriented in 90° spatial relationship to the case just described, like that, for example, shown in Figure 7 where the direction of the electric field is horizontal rather than vertical, will produce a circularly polarized wave having its rotational sense opposite to that of the TE_{11} wave of Figure 6. The two contra-rotating circularly polarized waves are completely decoupled from each other independent of the frequency at which the circular waveguide is terminated in a matched load.

Since the two TE_{11} modes are inherently decoupled, two radio frequency signals within the same frequency band may be propagated simultaneously in the guide 21 without interaction. Referring to Figures 1 and 6, a rectangular waveguide 41 having its broadwalls parallel to the longitudinal axis of the circular guide 21 may be used with a TE_{10} mode in the rectangular guide 41 to excite a directionally polarized TE_{11} wave in the circular waveguide 21.

Similarly, referring to Figures 1 and 7, a rectangular waveguide 43 with the same mode of propagation, TE_{10} , may be used to excite a TE_{11} mode in the octagonal central guide 21 at right angles to the other wave. In conjunction with the phase shifting fins 39, these two modes produce two contra-rotating circularly polarized waves in the circular waveguide 21 as explained above in connection with Figures 1, 5 and 6.

The three decoupled feed points thus provided by the axial probe 35 and the two rectangular wave guides 41, 43 allow a duplex or triplex feed of the antenna array of Figure 1. This feed system may employ all three modes for triplexing three signals into the same antenna as long as they are closely spaced in the frequency spectrum, or two signals may be duplexed and the third feed terminal terminated in an absorbing resistor for stabilization and broadbanding purposes.

With the increasingly stringent requirements of side-band transmission without phase shift arising in the radio frequency equipment, it appears more and more desirable to provide ultra-high-frequency broadcast antennas capable of accepting and radiating two or more radio frequency signals without the use of frequency selective filters.

As an example, assume that it is desired to duplex a broadband picture signal with a narrow band sound signal, the problem encountered in ultra-high-frequency television transmission. The broadband picture signal is fed to the rectangular waveguide 41 in the TE_{10} mode to create a circularly polarized TE_{11} wave in the circular waveguide 21. The accompanying sound transmission is coupled to excite the TE_{10} mode to the rectangular waveguide 37 and the axial probe 35 in the circular waveguide 21 excites the TM_{01} mode. An absorbing resistance load is used to terminate the other rectangular waveguide 43.

The radio frequency signal from the picture transmitter coupled to the rectangular waveguide 41 is converted by the polarizing fins 39 to a circularly polarized wave which couples progressively to the probes 29 to excite the surrounding waveguides in phase rotational fashion. The slots 33 in the outer walls of the surrounding waveguides 23 produce a field which is progressively phased with regard to the several slots 33. Energy from the sound transmitter which is coupled to the axial probe 35 will excite the slots 33 in an in-phase relationship.

Any picture energy which is reflected due to incorrect termination of the circular waveguide 21 because of antenna element mismatch or similar inconsistencies is converted by the polarizing fins 39 to a linearly polarized wave at right angles to the incident wave and is therefore returned to the rectangular waveguide 43 to be absorbed in the resistive load. The radio frequency transmitter for the sound signal coupled to the axial probe 35 is therefore decoupled from either direct or reflected picture energy.

A resistive load termination for the reflected energy is

very desirable because of the increased bandwidth over which the antenna system offers a constant load to the transmitter and also because of the improved isolation between the picture and sound signals.

Figure 8 shows an alternative form of loaded rectangular waveguide 45 which may be used in place of the waveguides 23a through 23h of Figures 1 through 5. Instead of utilizing the metal ridges 25 shown and described above, a plate 47 forming a cap portion of a partial septum 49 may be used to lower the cutoff frequency of the rectangular waveguide so that it will efficiently transmit frequencies which can be propagated in an octagonal guide in which one of its broad walls forms one of the sides of the octagon.

Figure 9 is an isosceles trapezoidal waveguide 51 similar to the specially shaped waveguides 23a through 23h of Figures 1 through 5 which utilizes the plate and partial septum 47, 49 arrangement like that of Figure 8. The isosceles trapezoidal waveguide 51 may be directly substituted for the specially shaped surrounding waveguides 23 in Figures 1 through 5 described above.

Figures 10, 11, 12 and 13 show alternative cross-sectional configurations of antenna arrays which may be used in practicing the invention. In Figure 10, the central waveguide 21' is circular in cross-section and the surrounding waveguides 23' are arcuate segments. These arcuate waveguides 23' are each loaded by metal ridges 25 like those described above in conjunction with Figures 1 through 5.

In Figure 11, the central waveguide 21' is shown as being of circular cross-section, surrounded by waveguides 23'' having an arcuate broad wall (the interchange for a common wall between the central circular waveguide 21'), the other broad wall and the two narrow walls being plane surfaces.

Figure 12 shows a cross-section which utilizes an octagonal central waveguide 21 surrounded by waveguides 23''' having an arcuate outer broad wall.

Figure 13 is similar to the arrangement shown in Figure 10, except that the central circular waveguide 21' is filled with a dielectric medium 53 to lower the cutoff frequency of waves which may be efficiently transmitted and thus reduce the cross-sectional size of the resulting antenna array. Some of the advantages of the arrangement shown in Figure 13 are reduced wind resistance, reduced weight of the antenna array proper, and improved pattern circularity as will be explained in further detail below.

The surrounding waveguides 23' may also be filled with a dielectric medium 55 to lower the cut-off frequency of waves propagated therethrough to dispense with the necessity for the loading ridges 25 shown in the previous figures or in conjunction with the ridged waveguides shown above to further reduce the size of the surrounding waveguides.

Referring now to Figure 14, the non-circularity ratios of the horizontal field pattern vs. antenna diameter for progressively phased antennas of four and eight slots are set forth in graphical form. It will be seen that an antenna utilizing four axial slots has minima in the horizontal field pattern which become somewhat troublesome if the diameter of the cylinder is larger than about 0.3λ .

Since the antenna diameter for an antenna array in accordance with this invention is the sum of the diameter of the central waveguide 21 or 21' plus twice the height of the specially shaped waveguides 23 (or 23', 23'' or 23'''), it is apparent that more than four slots are needed to provide a sufficiently circular pattern for reasonable range of size of the inner central waveguide 21.

Also shown on Figure 14 is a plot of the relative phase velocity, or λ_g/λ , for the TE_{11} mode plotted against the diameter of the central waveguide. The diameters at which cutoff is obtained for the first three modes, TE_{11} , TM_{01} and TE_{21} , are also indicated. A practical operating range of approximately 0.7λ to 0.95λ is chosen for the inner cylinder diameter, being limited at the lower

and by the rapidly increasing phase velocity and at the upper end by the undesired TE₂₁ mode.

However, for the eight axial slot arrangement of Figure 1, in which the rectangular guide height to width is approximately one to two, the corresponding antenna diameters are 1.07λ to 1.4λ for this range of central cylindrical waveguide size. From Figure 14, it can be seen that a non-circularity ratio minimum of about 0.7 occurs with this range of values.

By loading the central waveguide 21 or 21' with a dielectric material to increase its cutoff wavelength, as described in conjunction with Figure 13, the over-all cylinder diameter can be made smaller than the above representative values, the antenna can be made to have a pattern which will more nearly approach absolute circularity in the horizontal plane.

In practice, an important practical advantage is secured by an antenna of the design shown in Figure 1 wherein the individual waveguides 23a through 23h are made of U shaped channels. When these individual channels are assembled, the central waveguide 21 of octagonal cross-section, the metal vanes forming the narrow walls of the specially shaped waveguide and the ridges 25 form the basic portion of the antenna assembly. This portion, assuming that the specially shaped surrounding waveguides 23a through h have cover plates, may be operated over a considerable portion of the U. H. F. range without change. For a given U. H. F. television channel the slots 33 are cut in the cover plates forming the outside broad walls of the surrounding waveguides 23a through h.

The antenna array of this invention has other advantages as well, some of which are: a very strong mechanical construction is obtained due to the radial vanes which form the narrow walls of the specially shaped waveguides 23; the array is fed at or near the center, which gives an antenna having good bandwidth characteristics with no beam tilting due to change in frequency; and no protruding appendages appear on the outer surface of the antenna.

Due to the fact that waveguide transmission is used throughout the antenna, the invention is capable of handling very large amounts of radio frequency power. The cylindrical central waveguide 21 will easily and efficiently transmit 200 or more kilowatts of ultra-high-frequency energy, and it should be noted that with eight specially shaped waveguides 23a through 23h, each of the surrounding guides need be capable of handling only 1/8 of the total average input power.

In an actual embodiment built in accordance with the present invention and successfully tried out in practice, an antenna array for service on U. H. F. television channel 72 (818 to 824 megacycles) had the following dimensions: The central waveguide 21 was of octagonal configuration as shown in Figures 1 through 7 and had a radius from its center axis orthogonal to each side of the octagon of 5.72". The surrounding specially shaped waveguides 23 had an inside dimension across the outer broad wall of 6.94" and a depth from the inside of the outer broad wall to the other broad wall of 2.64". The ridges 25 were 2 1/16" wide and had a clearance from the outer broad wall of .63" with the corners near the outer broad wall having a radius of 3/32". The angle of the narrow walls to the broadwalls of the isosceles trapezoidal guides were 67 1/2° and the length of the narrow walls was 3 1/4".

The central guide 21 and the three inner walls of the surrounding waveguides 23 were fabricated of eight U shaped channels of 1/16" aluminum with the ridges 25 formed of the same material. The outer cover plates which constitute the other broad walls were fabricated of 1/2" sheet aluminum. The slots were cut into the outer broad wall and had the following pertinent dimensions: The slots were 1/2" wide and 7.18" long with a center to center spacing of 9.32" along the axis of the antenna array. All the slots were identical and were spaced alternately on one side or the other of the center line of

the specially shaped surrounding waveguides 23 by a distance of 0.455" to the center of the slot. The center line of the probes 29 to the center of the first adjacent layer of slots 33 on each side was 9.32". There were 12 layers of slots on each side of the center feed point, making a total of 24 layers of eight slots per layer. The circularly polarized fins 39 were positioned between the feed point at the probes 29 and the nearest rectangular waveguide 41 and were of stepped configuration. The total length of the fins was 63 3/8" with the first step being 1/4" in height and the second step (λ_g/4 or 5 9/32" from the end of the first step) being 3/16" in height. The fins 39 were 4 1/2" wide, and were mechanically and electrically attached to the side wall of the octagonal guide 21.

The entire antenna array was encased by a polymer welded fiberglass cover of 8 sections, averaging about 30 inches in length and having an overlap section of about one inch. This cover protects the antenna from rain, snow and ice, and further has the advantage of presenting a smooth circular cylindrical exterior to reduce local wind turbulence.

What I claim is:

1. An antenna comprising a transmission line having an enclosing side wall, a plurality of waveguides surrounding said transmission line, each of said surrounding waveguides having an outer wall oppositely disposed relative to said enclosing side wall, each of said outer walls having means adapted to interchange energy between said surrounding waveguides and free space, elements associated with each of said surrounding waveguides coupling said transmission line with each of said surrounding waveguides for transferring radio frequency energy between said transmission line and said surrounding waveguides.

2. An antenna comprising a transmission line having an enclosing side wall, a plurality of individual waveguides surrounding said transmission line, each of said surrounding waveguides having an outer wall oppositely disposed relative to said enclosing side wall, each said outer wall having a slot therein adapted to interchange energy between said surrounding waveguides and free space, coupling means between each of said surrounding waveguides and said transmission line adapted to transfer radio frequency energy between said transmission line and said surrounding waveguides.

3. An antenna comprising a hollow pipe waveguide having an enclosing side wall, a plurality of surrounding waveguides each having two broad walls and two narrow walls, one of said broad walls of each of said surrounding guides being the enclosing side wall of said hollow pipe waveguide, the other broad walls each having a slot therein adapted to interchange energy between said surrounding waveguides and free space, coupling element means extending from the interior of each of said surrounding waveguides through apertures in said enclosing side wall into the interior of said hollow pipe waveguide for transferring radio frequency energy between said hollow pipe waveguide and said surrounding waveguides.

4. An antenna comprising a hollow pipe waveguide having an enclosing side wall, a plurality of surrounding waveguides each having two broad walls and two narrow walls, one of said walls being the outer wall and oppositely disposed relative to said hollow pipe waveguide, each of said surrounding waveguides having means adapted to interchange energy between said surrounding waveguides and free space, coupling elements associated with each of said surrounding waveguides extending through apertures in said enclosing side wall into the interior of said hollow pipe waveguide for transferring radio frequency energy between said hollow pipe waveguide and said surrounding waveguides.

5. An antenna comprising a hollow pipe waveguide having an enclosing side wall and capable of supporting two directionally polarized orthogonally disposed waves, a plurality of surrounding waveguides each having two

broad walls and two narrow walls, one of said broad walls of each of said surrounding guides being the enclosing side wall of said hollow pipe waveguide, the other of said broad walls having a plurality of slots therein adapted to interchange energy between said surrounding waveguides and free space, coupling elements associated with each of said surrounding waveguides extending through apertures in said enclosing side wall into the interior of said hollow pipe waveguide for transferring radio frequency energy between said hollow pipe waveguide and said surrounding waveguides.

6. A slotted waveguide antenna adapted to interchange energy between itself and free space comprising a central hollow pipe waveguide having an enclosing side wall and capable of supporting two directionally polarized orthogonally disposed waves, a plurality of surrounding waveguides each having two broad walls and two narrow walls, one of said broad walls of each of said surrounding guides being the enclosing side wall of said hollow pipe waveguide and having a ridge extending the entire length thereof occupying the major proportion of the dimension between said broad walls, the other of said broad walls having a plurality of slots therein displaced from the center line of said broad wall and exposed to ambient free space, coupling elements extending from the interior of said surrounding waveguides through apertures in said enclosing side wall into the interior of said hollow pipe waveguide for transferring radio frequency energy between said hollow pipe waveguide and said surrounding waveguides, said surrounding waveguides extending away from said coupling elements in both directions along the length of said hollow pipe waveguide.

7. A slotted waveguide adapted to interchange energy between itself and free space comprising a central hollow pipe waveguide having an enclosing side wall and capable of supporting two directionally polarized orthogonally disposed waves, a plurality of surrounding waveguides each having two broad walls and two narrow walls, one of said broad walls of each of said surrounding guides being the enclosing side wall of said hollow pipe waveguide, the other of said broad walls having a plurality of slots therein displaced from the center line of said broad wall and exposed to ambient free space, coupling elements extending from the interior of said surrounding waveguides through apertures in said enclosing side wall into the interior of said hollow pipe waveguide for transferring radio frequency energy between said hollow pipe waveguide and said surrounding waveguides, said surrounding waveguides extending away from said coupling elements in both directions along the length of said hollow pipe waveguide, and means to couple further waveguide means to said hollow pipe waveguide at a point remote from said coupling elements with a circularly polarized wave in the portion adjacent said coupling elements.

8. A slotted waveguide antenna adapted to interchange energy between itself and free space comprising a central hollow pipe waveguide having an enclosing side wall and capable of supporting two directionally polarized orthogonally disposed waves, a plurality of surrounding waveguides each having two broad walls and two narrow walls, one of said broad walls of each of said surrounding guides being the enclosing side wall of said hollow pipe waveguide and having a ridge extending the entire length thereof occupying the major proportion of the dimension between said broad walls, the other of said broad walls having a plurality of slots therein displaced from the center line of said broad wall and exposed to ambient free space, coupling elements extending from the interior

of said surrounding waveguides through apertures in said enclosing side wall into the interior of said hollow pipe waveguide for transferring radio frequency energy between said hollow pipe waveguide and said surrounding waveguides, said surrounding waveguides extending away from said coupling elements along the length of said hollow pipe waveguide, and further waveguide means cooperating with said hollow pipe waveguide in a portion remote from said coupling elements to couple two contra-rotating circularly polarized waves between the portion adjacent said coupling elements and said further waveguide means.

9. A waveguide antenna system comprising a central waveguide having an enclosing side wall, a plurality of surrounding waveguides each having two broad walls and two narrow walls, one of said walls of each of said surrounding guides being a portion of the enclosing side wall of said central waveguide, antenna elements coupled to a wall opposite said one wall to interchange energy between said surrounding waveguides and free space, means for coupling said surrounding waveguides to said central waveguide, further transmission line means cooperating with said central waveguide to couple two contra-rotating circularly polarized waves between a portion adjacent said coupling elements in said central waveguide and said further transmission line means, and additional coupling means cooperating with said central waveguide to couple a mode having circular symmetry in said central waveguide.

10. A system for radiating the energy from two transmitters comprising, a central transmission line having an enclosing sidewall and being capable of supporting two orthogonally disposed directionally polarized waves and a wave having circular symmetry, a first input transmission line connected to said central transmission line to couple energy from a transmitter to a linearly polarized wave in said central transmission line, a second input transmission line connected to said central transmission line to couple energy from another transmitter to excite a mode therein having circular symmetry, a plurality of waveguides surrounding a portion of said central transmission line, each of said surrounding waveguides having an outer wall in spaced relation with the enclosing side wall of said central transmission line, said outer wall having slots therein adapted to couple energy from said surrounding waveguides to free space, and elements associated with each of said surrounding waveguides coupling energy from said central transmission line to said surrounding waveguides.

11. A system as defined in claim 10, and in addition, an output transmission line connected to said central transmission line in orthogonal relation with said first input line to couple a reflected linearly polarized wave therefrom, and phase shifting fins disposed within said transmission line.

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