Oct. 20, 1953 A. P. KING 2,656,513

WAVE GUIDE TRANSDUCER

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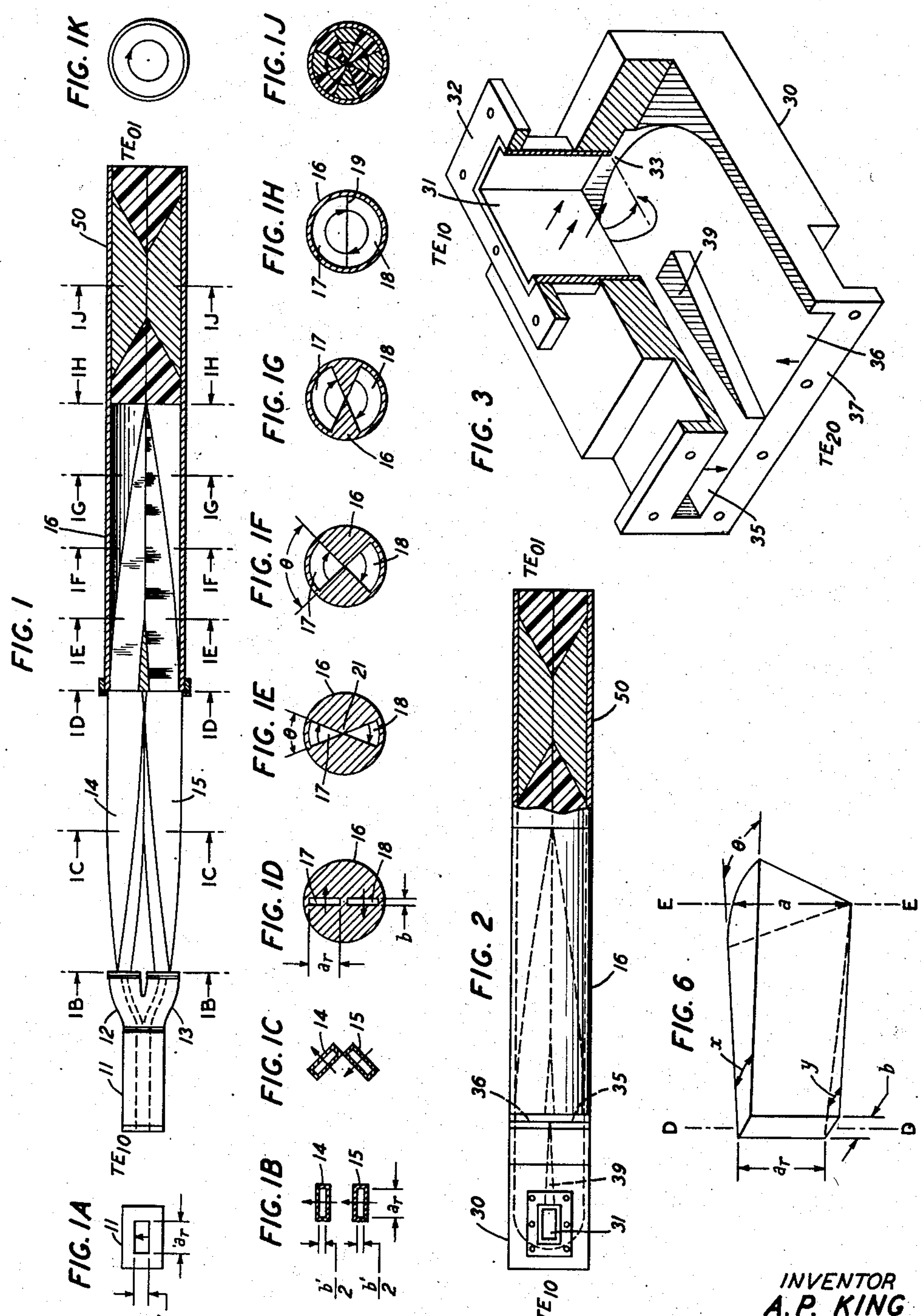

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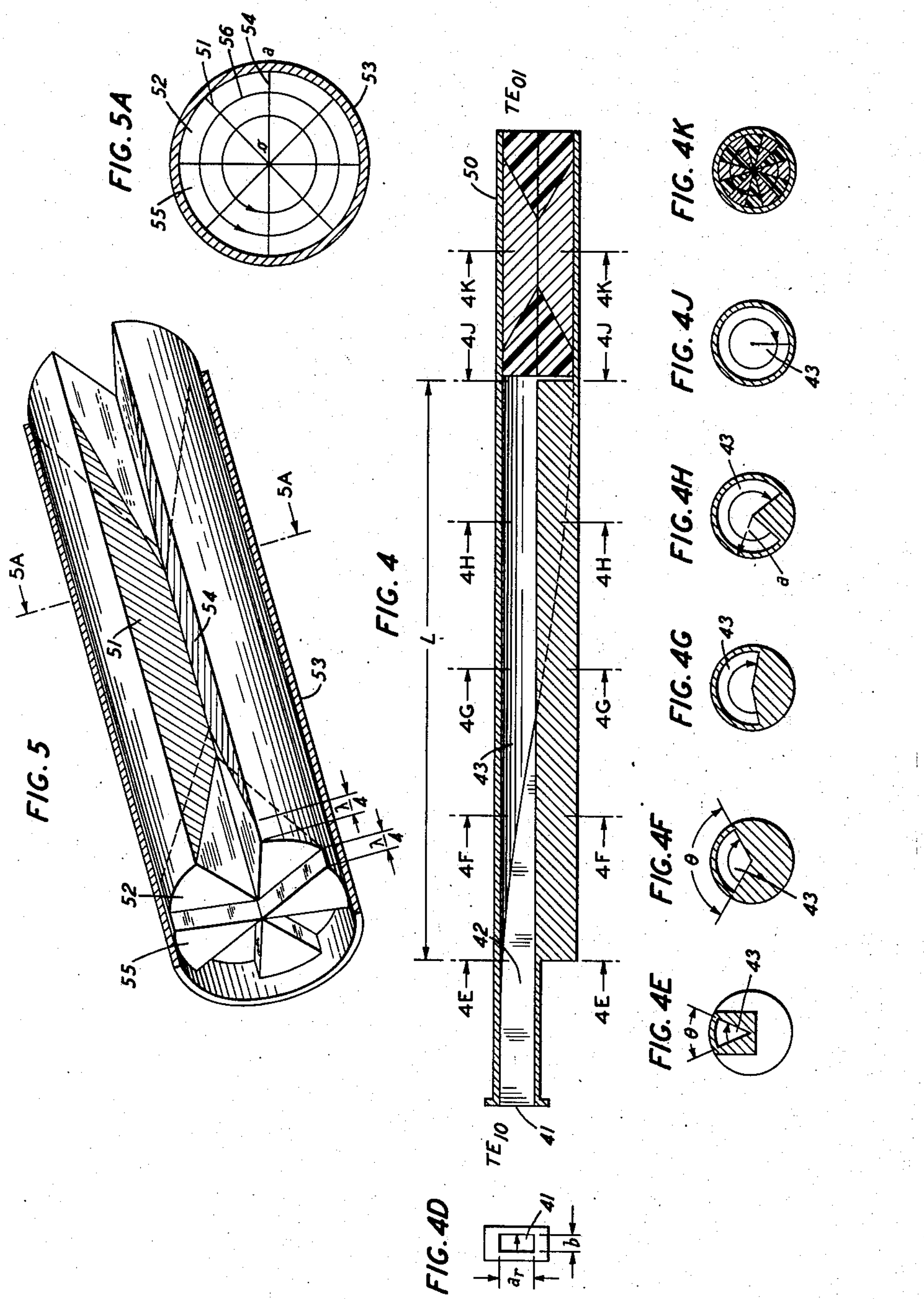

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WAVE GUIDE TRANSDUCER

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5 Claims. (Cl. 333—21)

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This invention relates to wave transmission systems for the transmission of microwaves through hollow metallic tube wave guides and more particularly to the conversion of guided waves from one mode to another.

Such guided waves, as is well known in the microwave transmission art, are capable of transmission in an infinitely large number of forms or modes, each mode being distinguished by the characteristic configuration of the component electric and magnetic fields comprising the waves.

These waves have been divided into two broad classes. In one class the electric component of the wave is transverse to the metallic pipe guide, and at no point does it have a longitudinal component. The magnetic component, on the other hand, has both transverse and longitudinal components. This class has been designated as "transverse electric" waves or TE waves. In the other class, the magnetic component is transverse to the pipe and at no point does it have a longitudinal component, but the electric component has in general both transverse and longitudinal components. This class has been designated as "transverse magnetic" waves or TM waves.

The waves in each of these classes have been further identified and distinguished from each other by their mode or the pattern of wave energy distribution as it appears in the cross-section of the wave guide. A complete discussion of wave mode may be found in any standard textbook of microwaves and microwave guides. For the purpose of the present disclosure, the usual convention is herein adopted of designating a transverse electric wave TE_{mn} where, in a rectangular wave guide, m represents the number of half period variations of the transverse component encountered in passing across the width of the wave-guide cross-section, and n represents the number of half periods of transverse components encountered in passing across the height of the wave guide; and in a circular or cylindrical wave guide, m represents the number of whole periods of the transverse component encountered in running around the circumference of the cross-section, and n represents the number of half periods encountered in passing along the radius of the wave-guide cross-section. For example, in a rectangular wave guide, TE_{10} represents a wave having a one-half electric period variation across the width of the guide, and, since the field is uniform, there is no variation across the height of the guide. This is commonly known as the dominant mode wave.

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Likewise, in a cylindrical wave guide, TE_{01} represents a wave whose electric field is wholly tangential and forms a series of circles concentric with the axis, and wherein no variations in the electric field are encountered around the circumference of the cross-section, but rather, a one-half period is encountered along the radius thereof. This latter wave mode is commonly known as a circular electric wave.

Each wave mode differs specifically from other modes in certain transmission characteristics that are important with respect to the objects of this invention. For example, the circular electric wave, when propagated through a circular metal pipe of a given diameter, suffers progressively less attenuation as the frequency is increased. Because of its low attenuation the TE_{01} wave is particularly adapted for long distance transmission systems. On the other hand, the TE_{10} wave or dominant mode wave is easily generated by presently known generators, does not easily degenerate into other modes, and in addition, is most favorable for amplification, modulation or demodulation.

It is therefore, an object of the present invention to convert wave power of a given mode to wave power of another mode.

It is a particular object of the present invention to convert dominant mode wave power to circular electric wave power and conversely circular electric wave power to dominant mode wave power by gradually varying the boundary conditions of the transmitted energy.

It is a further particular object of the present invention to convert TE_{10} mode power to TE_{20} mode power and conversely TE_{20} mode power to TE_{10} mode power.

It is a further object to permit the generation of a wave mode which is especially favorable from a generation point of view and its conversion into a mode which is especially favorable from a propagation point of view by gradually varying the boundary conditions of the generated type wave.

Still a further object of the invention is to convert wave power of a given mode to substantially pure wave power of another mode by filtering or absorbing therefrom spurious mode power having an undesirable form.

In accordance with the objects of the invention, wave power of a given mode is converted in a wave transducer section to wave power of another mode by gradually varying the boundary conditions of the transmitted energy by varying the geometry of the transducer section.

In a first embodiment of the invention, to be hereinafter described in detail, dominant wave power TE_{10} in a rectangular wave guide is converted into circular electric TE_{01} wave power by bifurcating, or dividing into two portions, the TE_{10} wave in the rectangular wave guide, launching it into two wave guides each having approximately half the height of the original, rotating the two portions counter-clockwise and clockwise, respectively, sectorially expanding each of the rotated power portions in a gradual manner to obtain a total circular configuration, and then recombining the separate portions in a circular wave guide.

A particular feature of the invention resides in an alternate bifurcating and rotating portion of the transducer, wherein the TE_{10} wave power is applied to the mid-point of a 180-degree waveguide bend by means of a T connection in the plane of the electrical field. The energy is bifurcated and brought out in two side-by-side wave-guide sections, each equal in time phase but opposite in space phase.

In a second embodiment of the invention, dominant wave power TE_{10} in a rectangular wave guide is converted directly into circular electric wave power TE_{01} in a circular wave guide by gradually varying the boundary conditions of the transducer section from rectangular cross-section to a circular sector cross-section, and then expanding the sectoral cross-section wave guide with gradually increasing sector angle until said angle reaches 360 degrees and the transition to circular electric wave is completed.

Another feature of the invention resides in the fact that the herein disclosed transducers are bilateral devices, i. e., energy may be transmitted aand converted in either direction. While, for the sake of simplicity in the following detailed description, the embodiments will be shown and described as having input and output terminals, it should be borne in mind that the converse transmission applies in each case also.

A further feature of the invention resides in the spurious mode wave absorber which substantially dissipates the power of the spurious mode waves produced in the transducer section.

The nature of the present invention, its various objects, features, and advantages will appear more fully upon consideration of the embodiments illustrated in the accompanying drawings and the following detailed description thereof.

In the drawings:

Fig. 1 represents a TE_{10} to TE_{01} wave transducer;

Figs. 1A through 1H, 1J, and 1K represent cross-sectional views of Fig. 1 as indicated;

Fig. 2 shows an alternate embodiment of the transducer of Fig. 1;

Fig. 3 shows in detail a component of the structure of Fig. 2;

Fig. 4 illustrates a single cavity TE_{10} to TE_{01} transducer;

Figs. 4D through 4H, 4J and 4K represent cross-sectional views of Fig. 4 as indicated;

Fig. 5 shows in detail the spurious mode wave absorber incorporated in Figs. 1, 2 and 4;

Fig. 5A shows a cross-section view of Fig. 5 as indicated; and

Fig. 6 shows in detail a portion of Fig. 1 or Fig. 4.

Referring now to the transducer shown in Fig. 1, a dominant TE_{10} wave to be converted into circular electric wave power is applied to one end of rectangular wave guide 11. At the other end the wave power is bifurcated into wave guides

12 and 13, and then applied to twisting members 14 and 15. Members 14 and 15 which are connected to guides 12 and 13, respectively, are progressively rotated between section B and section D in a manner to be described. The wave energy from guides 14 and 15 is applied at section D to sectorial section 16, twist member 14 delivering its energy to cavity 17, and member 15 delivering its energy to cavity 18. Cavities 17 and 18 expand the wave front with increasing sector angle between sections D and H until the combined angle of the two cavity sectors reaches 360 degrees at section H. At section H the cavities are separated only by a thin partition 19. Energy appearing at section H is applied to the spurious mode wave absorber 50, the function and construction of which will later become apparent in connection with Fig. 5.

Wave guide 11 is of the conventional and familiar rectangular hollow pipe guide construction having a height b' measured along the electric vectors and a width a_r measured across the electric field. It may be made of any electrically conducting material and, as is usual in the art, may be filled with gas or any other dielectric material, or if preferred, evacuated. Bifurcating guides 12 and 13 are connected to wave guide 11 so that microwave energy present in the input guide 11 is divided into two equal portions in guides 12 and 13, respectively. Guides 12 and 13 are each of approximately half the height and substantially equal the width of wave guide 11 so that their combined cross-sectional area is equal to the cross-sectional area of guide 11. This provides a good impedance match between guides 12 and 13 and the input guide 11.

The twist section, made up of members 14 and 15, extends from section B to section D. Members 14 and 15 are rectangularly cross-sectioned metallic wave guides having interior cross-sectional dimensions equal to guides 12 and 13, respectively. Each of these rectangular guides is provided with a linear twist or rotation about the longitudinal axis of the guide. The total of this twist is 90 degrees, distributed linearly along the length of the guide from section B to section D. Thus the cross-section of each guide at one end in section B is displaced 90 degrees from the cross-section at the other end in section D, and at a point mid-way between sections B and D, the cross-section of each of the guides will have been rotated 45 degrees as shown in Fig. 1C.

These twisted members 14 and 15 are connected at one end of each to guides 12 and 13, respectively, at section B, so that member 14 twists in a clockwise direction and member 16 in a counter-clockwise direction when viewed from section B. In order to provide proper separation between the twisted member at section D, guides 12 and 13 are provided with a gradual S curve from the input end to section B. At section B the cross-sectional openings of guides 12 and 13 appear in the same plane.

Thus the two portions of microwave energy impressed in phase upon guides 14 and 15, as indicated by the electric vectors in the same direction on Fig. 1B, will each be rotated along the length of the twist section until the two portions of energy are equal in time phase, but opposite in space phase, at section D as indicated by the electric vectors which appear in opposite directions on Fig. 1D. If, therefore, a wave guide having a height equal to that of guide 14 and a width approximately twice that of guide 14 were integrally connected to the twist members at section D, a TE_{20} wave would be launched therein. Rather, these two portions of oppositely polarized wave energy are impressed on sectoral cavity section 16, guide 14 delivering its energy to cavity 17 and guide 15 delivering its energy to cavity 18. At section D each of cavities 17 and 18 has a rectangular cross-section of the same size and shape as guides 14 and 15 to which they are connected.

Between section D and section E the transverse cross-section of each of the cavities is gradually changed from rectangular to sectorial. One characteristic which is ideally desirable for this section is that the cross-sectional change thereof be made at a constant impedance, and for this purpose, complicated mathematical expressions may be derived which would specify the exact dimensions of the cross-section at successive points between section D and section E. However, if the distance between the sections is at least several wavelengths, it is satisfactory to design the cross-sections at each end of the section to have equal impedances and to vary the dimensions of the cavity therebetween in a gradual and linear manner.

An enlarged section of either one of the cavities 17 or 18 between the rectangular cross-section at section D and the circular sector cross-section at section E is shown in Fig. 6. As indicated above, one characteristic of this section, the design for which will now be considered, is that the characteristic impedance of the rectangular section at D should equal the characteristic impedance of the circular sector section at E. The characteristic impedance of the rectangular section at D is given by the following expression:

$$Z_{D-D}=\frac{465b}{a_r\sqrt{1-\left(\frac{\lambda}{2a_r}\right)^2}} \qquad (1)$$

where a_r and b are the width and height, respectively, of the rectangular section, and λ is the wavelength. The characteristic impedance of the sectorial section at E is given by the following expression:

$$Z_{E-E}=\frac{228\theta}{\sqrt{1-\left(\frac{\lambda}{1.64a}\right)^2}} \qquad (2)$$

where θ is the angle of the sector in radians and a is the radial dimension thereof. In many cases some of the factors in the above equations may be determined by practical considerations. For example, the dimensions a_r and b may be fixed by the standard size of the rectangular wave guides of the system in which the transducer is to be used. Likewise, a may be determined by the radius of the circular wave guides of the system, but it should be noted that a and θ may be varied arbitrarily within certain limits to obtain a given value of sectorial section impedance. It is therefore possible to equate Equations 1 and 2 and to solve for the proper value of sector angle which would make the impedances at each end of the section equal. In substantially all wave-guide systems, θ will be an acute angle. With the proper value of the sector angle chosen, the dimensions of the cavity are varied gradually between the rectangular section D and the sectorial section E. The outside width dimensions of each cavity, indicated on Fig. 6 as x, is linearly increased in length and at the same time arched or curved to form the arcuate wall of the sectorial cavity. At the same time the inner dimensions, indicated on Fig. 6 as y, is decreased at a uniform rate between sections D and E, becoming zero at E, to form in effect the vertex of the sectorial cavity. The transition in cross-section shape is made gradually in order that small impedance variations which might occur between section D and section E are sufficiently distributed so that the effect of mismatch appearing at the terminals is low.

It is also possible to make the phase velocity of a wave at the rectangular section equal to that at the sectorial section, while at the same time keeping the impedances of the sections equal. The phase velocity at the rectangular section is given by the expression:

$$V_{\phi_{D-D}}=\frac{C}{\sqrt{1-\left(\frac{\lambda}{2a_r}\right)^2}} \qquad (3)$$

where C is the velocity of light in centimeters. The phase velocity at the sectorial section is given by the expression:

$$V_{\phi_{E-E}}=\frac{C}{\sqrt{1-\left(\frac{\lambda}{1.64a}\right)^2}} \qquad (4)$$

It is noted that the phase velocity is independent of θ, the sector angle, and this angle may then be used to determine the impedance of the section independently from the phase velocity. Thus, to obtain equal phase velocities in the sections, Equations 3 and 4 may be equated and the proper dimension ratio of

$$\frac{a}{a_r}$$

will be found to be equal to 1.22. With this ratio established between a and a_r, Equations 1 and 2 are employed in the manner already described to obtain the proper value of θ which will make the characteristic impedances equal. Both conditions, i. e., equal impedance and equal phase velocity, are important for maximum efficiency of the transducer section, but if, in a particular embodiment, the designer is limited by standardized wave-guide component dimensions, it is substantially more important that the impedance qualifications be met than that the phase velocity at the two sections be made equal.

With attention directed once more to Fig. 1, it is noted that the cross-sectional change described with reference to Fig. 6 takes place on both cavities 17 and 18 in substantially the same manner between sections D and E. Thus, at section E the cavities appear in the cross-sectional view of Fig. 1E as two sectorial sections each having a sector angle θ and separated from each other by the vertex partition 21.

Between sections E and H the sector of each cavity is progressively expanded in a linear manner along the length of the section. Thus, the angle θ of each cavity is increased from the acute angle at section E, in proportion to the distance from section E, until at section H, θ reaches a straight angle or an angle of 180 degrees. The progressive stages of this linear increase are shown in Figs. 1E to 1H.

The disposition of the electrical field at each of these points is indicated by the vectors on the cross-sectional view taken at the point. The phase front of the wave is expanded in each section by the sectorially expanding boundary conditions of the cavity. The components of electric field adjacent the arcuate wall of each cavity are increased in length as the sector angle is increased. At section H the transition is complete and the field distribution of a TE_{01} circular electric wave has been duplicated in the two portions of the wave power, each expanded in cavities 17 and 18, respectively. These two portions are separated now only by the radial partition 19 as seen in Fig. 1H. In the section immediately following section H, this partition no longer exists, and the two portions combine to form a circular electric wave. Since the field distribution of the sectorial waves in sections E, F and G is the same as that for the TE_{01} wave in section H, the transition to TE_{01} wave power is electrically smooth.

In spite of this fact, it is evident that the individual rays of the microwave energy will follow spiral paths in expanding the sectorial wave to the completed TE_{01} wave, and that the path length from a point in section E corresponding to a wave front point in section H is not equal for all path lengths. Such a difference in path lengths will inherently introduce other types of wave forms, for example, TE_{11} and TE_{21}, in addition to the desired TE_{01} wave. This introduction of spurious modes is minimized by making the transitions from one cross-section to the next gradually and linearly. It remains, however, to filter out the remaining spurious mode power from the microwave output of the transducer if pure TE_{01} wave power is to be obtained. For this purpose the spurious mode wave absorber 50 is connected at section H to the cavity transducer. A complete explanation of the spurious mode wave absorber will be reserved for later treatment in connection with Fig. 5.

Fig. 2 shows an alternate arrangement of the transducer of Fig. 1 wherein element 30, as shown in detail in Fig. 3, replaces the bifurcating and twisting members 11, 12, 13, 14 and 15. Element 30, therefore, must perform the function of translating the total TE_{10} wave into two portions of oppositely polarized wave power which, if combined, would form a TE_{20} wave. The remaining elements, the cavity section 16, which transforms the oppositely polarized portions into TE_{01} wave power, and the spurious mode wave absorber 50, are identical to the corresponding elements shown in Fig. 1.

The operation of transducer 30 will become apparent upon consideration of the detailed section shown in Fig. 3. In its basic configuration the tranducer comprises a 180-degree wave-guide bend with an input E-plane T connection at the center point of the bend. A section of rectangular wave guide having opposite end openings 35 and 36 is bent 180 degrees so that the ends 35 and 36 appear side by side in the same transverse plane. A rectangular input guide 31 opens into the top face of guide 35–36 at the mid-point of the 180-degree bend by means of an E-plane T connection. The cross-sectional dimensions of guide 31 are equal to those of guide 11 of Fig. 1, which it replaces, and the cross-sectional dimensions of guides 35 and 36 should be equal to those of members 14 and 15, respectively, which they replace. This means that the width, as measured across the electric field, of guides 31, 35, and 36 are equal; while the height of guides 35 and 36 is one-half that of guide 31.

As shown in Fig. 3, the transducer is integrally constructed with the basic wave-guide components described above machined or cast in a metallic block 30. The bend portion of guide 35–36 becomes a semicylindrical cavity having a semicylindrical wall 33. The straight guide sections 35 and 36 extend side by side perpendicularly from the diametral face of the cavity, and each have a height equal the height of the cavity and a width approximately equal the radius of the cavity. It has been determined that the impedance characteristic of the section may be controlled to a certain extent by the shape and size of the wall between adjacent sides of the guides 35 and 36. This partition or wall, which also serves to bifurcate the wave, is shown on Fig. 3 as a wedge-shaped partition 39 as seen in its longitudinal cross-section. It may, however, be any arbitrary shape, so chosen to provide the proper impedance characteristics.

Input guide 31, having a connection flange 32, is connected to the upper face of the cavity with its height dimension perpendicular to the diametral face of the cavity and approximately equal to the radius thereof.

The incoming TE_{10} wave to be converted into circular electric wave power is applied to rectangular guide section 31 with an electrical field direction as indicated by the arrows on Fig. 3. The wave propagates down the guide to the point of juncture with the semicircular cavity. At this point the conductor ends, and the electrical field begins to fan out or expand in an attempt to conform to the new boundary conditions of the cavity. This expansion of the electric field is indicated by the arrows on Fig. 3. In this state of field distortion, the power is bifurcated by partition 39, one-half the power going into guide 35 and the other into guide 36. The portion in each half is of opposite electrical polarity. As shown on Fig. 3, the vector indicating the electric field direction in guide 35 points downward while the vector in guide 36 points upward. These two portions of oppositely polarized TE_{10} wave power are brought out side by side, and, as was the case of the power delivered by twisting members 14 and 15, would combine in a single wave guide connected by means of flange 37 to the openings of 35 and 36 to form a TE_{20} wave. Rather guides 35 and 36 are connected to cavity section 16 so that the guides deliver their power into the cavities 17 and 18, respectively.

Thus the transducer of Fig. 3 performs the same function as the structure of Fig. 1, between section A and section B, comprising elements 11, 12, 13, 14 and 15. Transducer 30 is, however, of much more rigid construction and may be built with higher precision. It is thus possible to achieve a higher amplitude and phase equality between output wave guides 35 and 36 than between the twist members 14 and 15 and thus reduce the amount of dominant wave appearing at the terminals.

The type of wave transducers described heretofore with reference to Fig. 1 through Fig. 3 gives satisfactory performance in the centimeter wavelength band. At these wavelengths it is possible to match the two branches of the transducers producing oppositely polarized portions of wave power moderately well with respect to amplitude and phase characteristics. It is more difficult, however, to realize the higher precision required to obtain identical construction of the two branch circuits for frequencies in the millimeter range.

The single-cavity wave transducer shown in Fig. 4 avoids this difficulty of matching the two branch circuits by exciting a single cavity directly with TE_{10} wave power at input 41. The transducer consists essentially of two parts: the first part, cavity **42** extending from section D to E for converting the TE_{10} wave power to sectorial TE_{01} wave power in which the boundary conditions are varied gradually from the rectangular cross-section of D to the circular sector cross-section of E; and the second part, comprising cavity **43** extending from section E to J in which the boundary conditions of the sectoral wave cavity **43** are expanded until the sector angle θ reaches 360 degrees. At section J the circular electric wave energy is applied, as in Figs. 1 and 2, to spurious mode wave absorber **50**.

The first part comprising cavity **42**, extending from section D to section E, may be identical in its essential design characteristic to the cavity shown in Fig. 6 and hereinbefore described in detail. The input opening **41** has a transverse rectangular cross-section in section D having a height b and a width a_r and has a characteristic impedance as given by Equation 1. Between section D and section E the cross-section of cavity **42** is gradually changed in the manner described in relation to Fig. 6, until at section E, the cross-section becomes a circular sector having a radius a and a sector angle θ. The circular sector opening thus has a characteristic impedance given by Equation 2. The value of the sector angle θ is so chosen in accordance with Equations 1 and 2 to make the characteristic impedance at section E equal to that at section D. Further, it may be desirable to make the phase velocity of the wave passing section D and section E equal by choosing a sector radius equal to 1.22 times the width dimension of the rectangular cross-section at section D as shown by Equations 3 and 4. The longitudinal distance between sections D and E should be at least several wavelengths and the variation in cross-section is made linearly along this length.

Between section E and section J the sector angle θ is linearly increased from an acute angle to a plane angle. Thus, the acute angle sector at section E becomes a plane angle sector or a circular sector having a sector angle of 360 degrees at section J. At each successive cross-section between sections E and J the sector angle θ increases in relation to the distance of the section along the longitudinal axis of the transducer. Several successive cross-sections are shown in Figs. 4F, 4G and 4H. As the sector angle is increased, the boundary conditions of the cavity are changed, and the wave front of microwave energy passing through the cavity is sectorially expanded. In terms of the lines of the electric field of the wave this means that the lengths of the lines adjacent to the arcuate wall of the sectorial cavity are increased as the wave progresses down the length of the transducer more than the lengths of the lines near the vertex of the cavity. Due to the attempt of the electric field lines to conform to the boundary conditions of the cavity, the lines become concentric about the cavity vertex. This is the field distribution of the circular electric or TE_{01} wave.

The relative purity of the generated TE_{01} wave is a function of the geometry of the particular transducer design and its dimensions in terms of wavelength. In considering the latter, the diameter of the TE_{01} section determines the number of TE and TM waves which can be supported by the guide at the operating frequency. The total number of modes possible in a circular wave guide varies as the square of a/λ, where a is the radius of the wave guide and λ is the operating wavelength. For example, a wave guide with a radius of 1 inch and conducting energy with a wavelength of 6 millimeters, a value tentatively considered as a practical region of operation in a TE_{01} wave communication system, can support about 185 spurious modes.

The number of spurious modes possible is related to the TE_{01} wave transducer design problem in the following way. In transducers of the types described above, the mechanism for expanding the wave front involves different path lengths from various parts of the sectorial TE_{01} wave front to a transverse plane at the TE_{01} end of the transducer. This feature has been pointed out in connection with Fig. 1. The result is that the equiphase surface at the TE_{01} end is not a transverse plane but a curved surface. Such an equiphase may be represented as a mixture of waves, $TE_{01}+TE_{mn}+TM_{mn}$ waves. In general a given amount of wavefront distortion or curvature will generate a greater number of spurious mode waves as the guide is operated further from cut-off, with an increasing ratio of a/λ.

On the basis of the path lengths of the individual rays which follow spiral paths in expanding to the sectorial TE_{01} wavefront, the variation in length or phase may be calculated. In the case of the single-cavity wave transducer of Fig. 4, it may be shown that the variation in the path length relative to the plane of section J depends inversely upon the length L of the cavity from section E to section J, or that portion of the transducer which expands the wavefront with an increasing angle θ. If L is made several wavelengths long, or many times the radius a of the sector, the magnitude of the spurious modes generated may be maintained small compared with the magnitude of the desired TE_{01} wave. This applies equally well to the corresponding wavefront expanding portions of the transducers of Figs. 1 and 2.

It may be desirable to further decrease the spurious mode power in the TE_{01} circular wave output. For this purpose a further section, which has been referred to as the spurious mode wave absorber, is incorporated into the wave transducers. This section is indicated on Figs. 1, 2 and 4 as spurious mode absorber section **50**, which eliminates, the spurious modes by absorbing them.

Referring to Fig. 5, the spurious mode wave absorber is shown in detail. It comprises a plurality of thin strips of resistive material, as **51** and **54**, placed radially in the circular waveguide section **53**. These strips may be self-supporting or they may be supported by means of polyfoam or styrofoam spacers, as **52** and **55**, in the wave guide.

While the spurious mode wave absorber is of primary importance in absorbing spurious modes generated by a circular electric wave transducer as shown and described herein, it is by no means limited to this application. Spurious modes may arise as the result of an imperfect transmission line due to small deviations from circularity or slight impedance irregularities in the line. Further, they may be developed by terminal devices, tapers, or other components which introduce either by reflection or by transmission, modes other than the desired one. In each of these cases the spurious mode power may be suppressed by the use of the absorber employed in conjunction with the device tending to produce the undesired modes.

To insure complete elimination of the spurious modes, the reflection coefficient of the absorber should be low, otherwise the reflected component may produce undesired mode interference effects. At the same time it is required that the effect on the desired mode, in this case the TE_{01}, be a minimum, or that the attenuation of the TE_{01} wave be a small value. Further, the spurious mode wave absorber should possess the additional characteristic that no new modes are introduced or that one spurious mode will not be converted into another mode. These factors are all substantially met in the spurious mode absorber shown in Fig. 5 and now to be described in detail.

Fig. 5 illustrates a novel and advantageous construction of a spurious mode wave absorber. Casing **53** is a section of circular wave guide constructed of an electrically conductive material. Radially disposed in casing **53** and symmetrically arranged about the axis thereof are a plurality of resistive film cards or vanes **51** and **54**. These cards are very thin sheets of low dielectric material, for example, polystyrene, coated with a film of resistive material, for example, carbon black. The thickness of the cards may be of the order of 0.003 inch and they should have a resistivity in the range of 100 to 1000 ohms per square inch of surface. To improve the matching of the absorber and to reduce the reflection coefficient, the edges of each card are tapered over a distance of several wavelengths thus making the flat plane of the card a trapezoidal shape. As shown in Fig. 5, the trapezoidal-shaped cards **51** and **54** are disposed in the wave guide **53** with the longer of the trapezoidal bases adjacent to the wave guide and the shorter of the bases at the center thereof. Such disposition may be reversed, however, and the shorter base located adjacent to the guide and the longer in the center. The cards should be of such total length that either of the bases will be several wavelengths long.

To further improve impedance matching the resistive cards may be staggered in the guide, alternate cards being offset by one-quarter wavelength of the mean frequency of the wave to be conducted by the absorber. Thus as shown in Fig. 5, card **51** is located one-quarter wavelength to the left of card **54**. When employing this staggered feature it will be desirable to use an even number of cards.

The exact number of cards required depends in general on the highest order sectorial wave to be absorbed. For example, in the case of a TE_{21} wave where the electrical configuration is repeated in four quadrants of the guide cross-section, preferably eight or more cards should be used. For a TE_{41} wave in which the electric configuration is repeated eight times around the circumference, at least sixteen cards should be used. In general a much larger number than the apparent minimum should be used to assure complete cancellation of all higher order modes.

The thin resistive cards such as **51** and **54** are held in place sandwichwise between supporting spacers such as **52**, **55** and **56**. For example, resistive card **51** is held between the surfaces of spacers **52** and **56** as shown on cross-section view Fig. 5A. The spacers are made of any material of low dielectric constant. The plastic materials of polyfoam or styrofoam have proven satisfactory.

In order to improve the TE_{01} impedance match and to lower the reflection coefficient, the spacers are staggered one-quarter wavelength in the manner of the resistive cards. As shown on Fig. 5, spacer **55** is located one-quarter wavelength to the left of spacer **52** and other spacers are arranged in like manner alternatively around the guide.

The operation of the spurious mode absorber depends on the electric field distribution of the desired TE_{01} mode relative to the undesired modes. The electric field of the TE_{01} wave is circular, having only tangential electric field components which are limited to the transverse plane, as shown on Fig. 5A. This is also true of the higher order circular electric waves. If therefore a thin strip of resistive material, such as card **54** is placed radially along the line Oa, it will lie along equipotentials of the electric field and will absorb only a negligible amount of power. When such a strip is extended longitudinally along the guide, the performance remains the same for all similar electric wave components. The transverse waves, such as the TE_{10}, have transverse and/or radial components of electric field. Such fields will induce currents in the resistive strip and thereby dissipate the wave power. Also TM waves which have longitudinal electric fields will cause a current to flow longitudinally in the card and will also be dissipated thereby.

In wave guides of relatively large diameter it is possible to use resistive cards of sufficient thickness as to be self-supporting and to eliminate the supporting spacers. For this purpose the cards may be in the order of 0.025 inch thick. In many of the smaller wave guide sizes, the effect of the dielectric constant of the thick strips becomes appreciable and thus tends to introduce higher order circular electric waves. In these cases it is preferable to use the thin, supported cards.

In all cases it is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electric wave transducer for converting dominant mode wave power into two portions of oppositely polarized dominant mode wave power, said transducer comprising an enclosure of electrically conducting material forming a semi-cylindrical cavity having top and bottom walls, a diametrical plane, and an arcuate wall, a pair of contiguous rectangular wave guides opening into said cavity on said diametrical plane, and a third wave guide opening into said cavity on said top wall.

2. In a wave transducer for converting electric wave power from one mode into another mode, an elongated electrically conducting enclosure having a first end and a second end, the transverse cross-section of said first end being rectangular and having a given characteristic impedance, the transverse cross-section of said enclosure varying smoothly along the enclosure from said first end to an acute angle sector cross-section having an arcuate wall and no additional wall other than a radial one, the cross-sectional dimension a of said radial wall being substantially 1.22 times greater than the largest dimension a_r of said rectangular cross-section whereby the phase velocity for wave energy between said sections is maintained substantially constant, the acute angle at the point where said acute angle

section is first realized being substantially equal to

$$\frac{465b\sqrt{1-\left(\frac{\lambda}{1.64a}\right)^2}}{228a_r\sqrt{1-\left(\frac{\lambda}{2a_r}\right)^2}}\text{ radians,}$$

wherein b is the smallest dimension of said rectangular cross-section and λ is the wavelength of said electric wave power, whereby said acute angle section has a characteristic impedance substantially equal to said given characteristic impedance, and the successive cross-sections of said enclosure from said point to said second end varying smoothly as the length of said arcuate wall increases in relation to the distance of the successive cross-sections from said point.

3. The combination according to claim 2 wherein the sector angle of said successive cross-sections of said enclosure from said point to said second end varies gradually from said acute angle sector to a straight angle sector at said second end.

4. The combination according to claim 2 wherein the sector angle of said successive cross-sections of said enclosure from said point to said second end varies gradually from said acute angle sector to a plane angle sector at said second end.

5. A wave transducer for converting incident electric wave power from one mode into another mode comprising an enclosure of electrically conducting material forming a semicylindrical cavity having top and bottom walls, a diametrical plane, and an arcuate wall, a wave guide opening into said cavity on said top wall for receiving said incident wave, and a pair of contiguous rectangular wave guides opening into said cavity on said diametrical plane, a pair of elongated electrically conducting enclosures each having a first end

and a second end, said first end of each of said enclosures being connected respectively to one of said pair of rectangular wave guides, the transverse cross-section of each of said enclosures being rectangular at said first end and having a given characteristic impedance, said cross-section of each of said enclosures varying from said first end cross-section to an acute angle sector cross-section at a point between said first and second ends, said last-named cross-section having a characteristic impedance equal to said given characteristic impedance, the successive cross-sections of each of said enclosures from said point to said second end varying smoothly along the length of each of said enclosures with said sector angle becoming successively greater than said acute angle in relation to the distance of the successive cross-section from said point, and means for combining said two portions in a circular cross-section.

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