Oct. 10, 1961 R. L. FOGEL 3,004,228

ORTHOGONAL MODE TRANSDUCER

Filed July 1, 1958 3 Sheets-Sheet 1

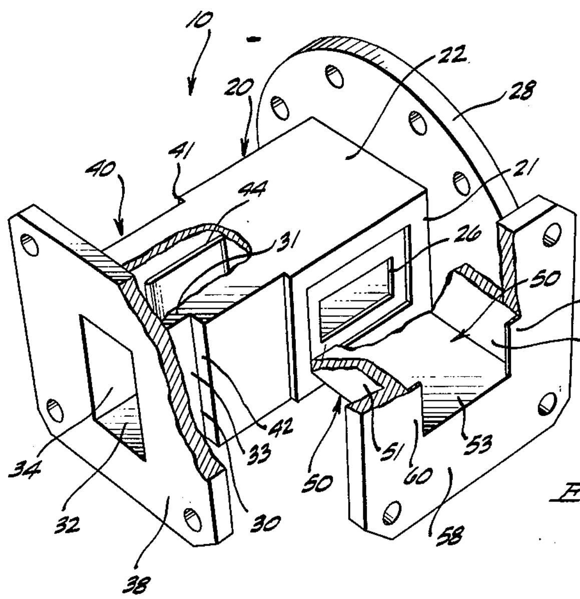

FIG. 1.

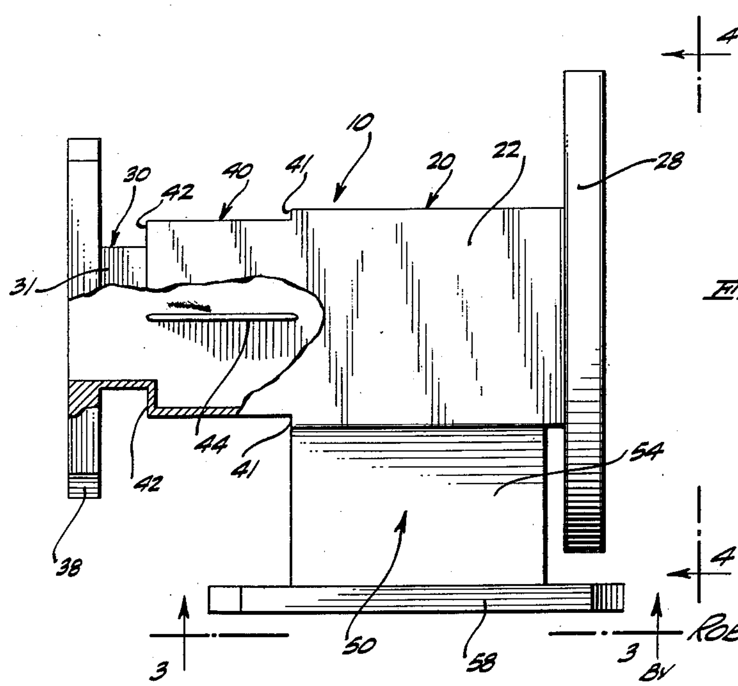

FIG. 2.

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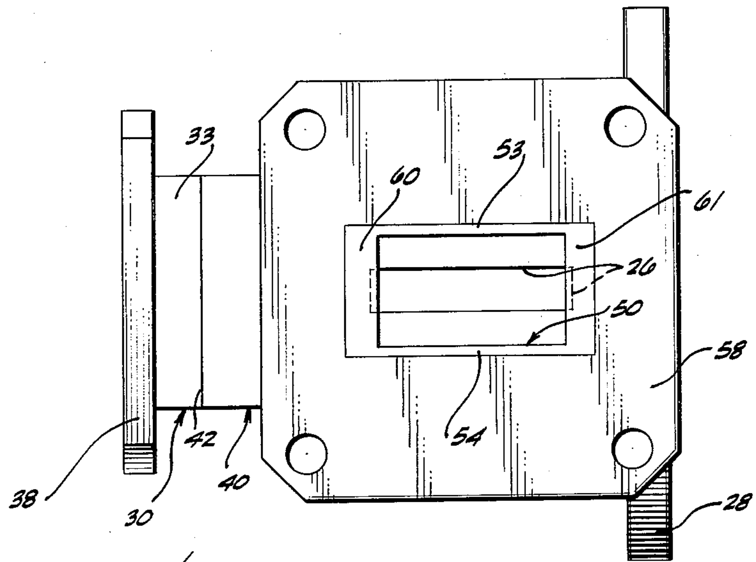

FIG. 3.

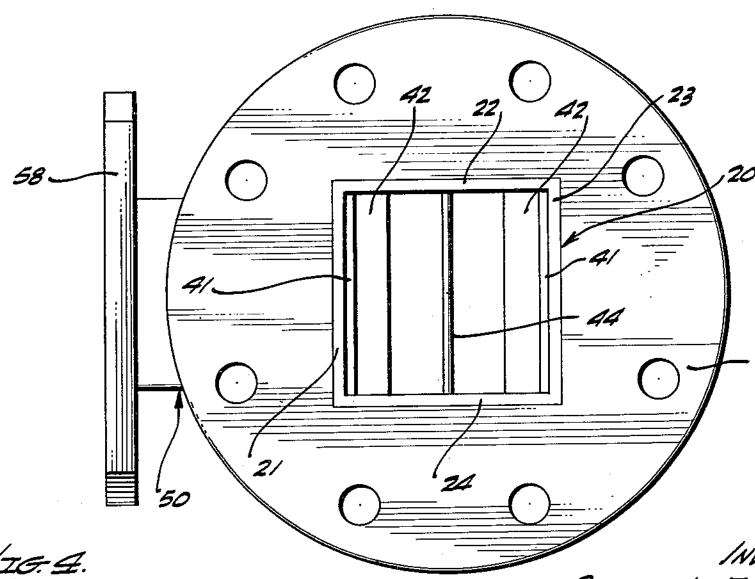

FIG. 4.

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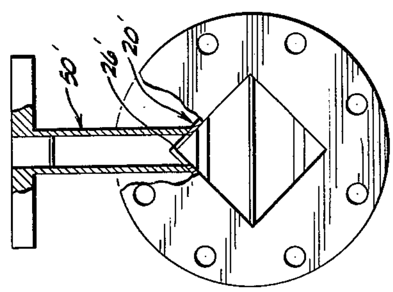

FIG. 6.

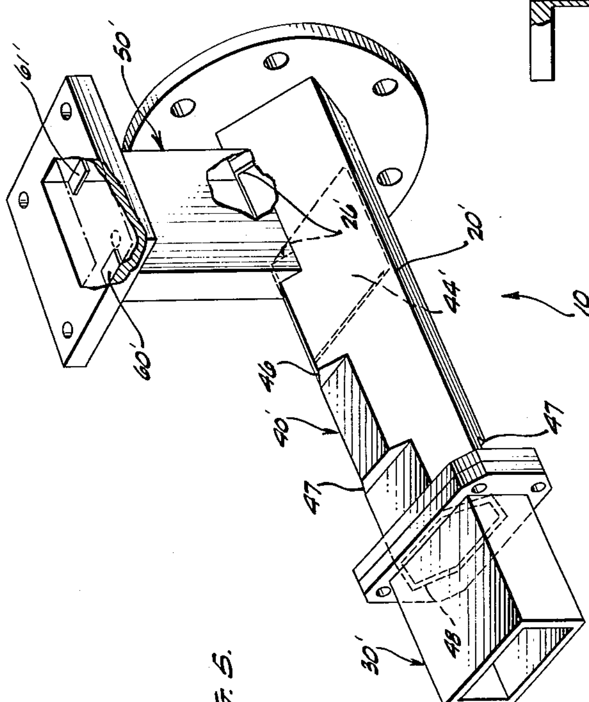

FIG. 5.

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United States Patent Office 3,004,228
Patented Oct. 10, 1961

3,004,228
ORTHOGONAL MODE TRANSDUCER

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Filed July 1, 1958, Ser. No. 745,933
3 Claims. (Cl. 333—21)

This invention relates to microwave energy coupling devices, and particularly to devices for coupling modes of energy which are orthogonal with respect to each other between individual energy transmission lines and a common transmission line.

In microwave systems it is often desirable to have an electromagnetic wave energy transmission line, such as a waveguide, which will support two energy modes which are orthogonal with respect to each other. Square waveguides, for example, may be used to conduct energy in either of two modes whose electric vectors are normal to each other. The electric vectors may be, but need not be, normal to the waveguide walls. When such orthogonal mode transmission lines are employed, it is necessary to have some means of transferring energy into and out of the common transmission line in the individual modes or in both modes simultaneously. Devices for this purpose are usually termed orthogonal mode transducers. The manner in which these devices operate is to transfer energy in a first mode between one individual arm and the common arm, and to transfer energy in a second mode, orthogonal to the first, between a second arm and the common arm. The transfer is effected in each case in both directions of propagation.

A number of devices for fulfilling this function are known and in use. One of the most effective of such devices is an orthogonal mode transducer which employs a square waveguide body for the common arm and which has a first rectangular waveguide colinear therewith as one individual arm and a second rectangular waveguide normal thereto as the other individual arm. This arrangement provides the desired transfer of energy between the arms. The devices of this configuration heretofore constructed, however, have been subject to a number of operating difficulties which in some instances are incompatible with systems applications. For one thing, reflection effects have often increased the voltage standing wave ratio (VSWR) to an excessive level. Further, there has not been pure energy coupling of each of the modes, some of the energy instead being transferred out the wrong arm. A number of transducers of this type, particularly those which employ probes for coupling energy, are frequency sensitive and accordingly suffer from high VSWR at other than a central frequency. Other such devices are known, but these principally have a circular waveguide for the common transmission line, and accordingly are not applicable in the many situations in which it is desired to employ a square waveguide for the common waveguide.

The broadest application for orthogonal mode transducers involves the transmission of dominant TE_{10} modes in a square waveguide in which electric vectors are normal to the waveguide walls. Other dominant modes may, however, be transmitted along a square waveguide. The same requirements may exist for coupling energy in such modes into and out of separate arms extending from the common square waveguide.

Accordingly, it is an object of this invention to provide an improved orthogonal mode transducer for microwave applications, which transducer effects substantially complete and individual transfer of energy of two orthogonal modes.

Another object of this invention is to provide an improved microwave device for transferring energy between

a common transmission line and one of two individual arms, dependent upon the mode of the energy provided.

A further object of this invention is to provide an improved orthogonal mode transducer for coupling energy to and from a square waveguide, which device has higher efficiency, greater broad bandedness and lower VSWR than the devices of the prior art.

A further object of this invention is to provide an improved orthogonal mode transducer for coupling energy between one square and two rectangular waveguides, which device operates with high efficiency and at the same time is simple to fabricate.

A further object of this invention is to provide an improved orthogonal mode transducer for operating at high powers and with more complete separation of the modes than has heretofore been possible.

These and other objects of this invention are achieved by an arrangement illustrative of the invention for coupling energy between a square waveguide and one rectangular arm colinear therewith or a side rectangular arm normal thereto. Energy in one dominant mode is transferred substantially without reflection or losses between the square waveguide and the colinear arm. Energy in the other dominant mode is transferred with like efficiency between the side arm and the square waveguide through a coupling aperture in a side wall of the square waveguide. Desirable operative characteristics are achieved through the combined use of a number of features. A transition section may be used between the square waveguide and the colinear arm, and a metal septum may be used within the transition section. Energy may be coupled into the side arm through a coupling aperture, and the side arm may also contain metallic irises at spaced points. By observing particular relationships between the position and configuration of the aperture, irises, septum and transition sections, the energy coupled in the various modes and directions through the transducer is maintained substantially at full strength and free from reflections, and is not directed into the wrong arm. The arrangement may be employed with orthogonal modes which are normal to the square waveguide or diagonally disposed with respect to the square waveguide.

The novel features of this invention, as well as the invention itself, both as to its organization and method of operation, may best be understood when considered in the light of the following description, when taken in connection with the accompanying drawings, in which like reference numerals refer to like parts, and in which:

FIG. 1 is a perspective view, partly broken away, of an orthogonal mode transducer for transferring the dominant TE_{10} modes in accordance with this invention;

FIG. 2 is a plan view, partly broken away, of the arrangement of FIG. 1;

FIG. 3 is a side elevation view of the arrangement of FIG. 1;

FIG. 4 is an end elevation view of the square waveguide end of the arrangement shown;

FIG. 5 is a perspective view, partly broken away, of an alternative transducer for operation with orthogonal modes in which the electric vectors lie along the diagonals of a square waveguide, and

FIG. 6 is an end view of the arrangement of FIG. 5.

An orthogonal mode transducer in accordance with the invention, referring now to FIGS. 1 through 4, utilizes a main waveguide body **10** having a square waveguide section **20** at one end and a first rectangular waveguide section **30** at the other end with a transition section **40** intermediate the square waveguide section **20** and the first rectangular waveguide **30**. The first rectangular waveguide **20** may also be called the colinear arm **30**. For purposes of convenience herein, the square waveguide **20** will be said to have opposite first and third walls

21 and 23 respectively. The first and third walls, 21 and 23 respectively, are the side walls of the square waveguide section 20, with the position shown in the figures being used to define the frame of reference. It will of course be understood that such designations are used only to simplify the description of the arrangement and that the body 10 may be used in any relative position. The square waveguide section 20 therefore also includes a second wall 22 and a fourth wall 24, which are opposite to each other and are the top and bottom walls respectively of the square waveguide section 20. As thus viewed, the first wall 21 contains a rectangular coupling aperture or slot 26 centrally disposed therein and having its direction of elongation parallel to the longitudinal axis of the square waveguide section 20.

A useful feature of this arrangement is that the top and bottom walls 22, 24 of the square waveguide section may each be coplanar and integral with the corresponding wall of the transition section 40 and the first rectangular waveguide section or colinear arm 30. In the arrangement thus constructed, the narrow walls 31, 32 of the colinear arm 30 are coplanar with the top and bottom walls 22, 24 of the square waveguide section 20. The broad walls 33, 34 of the colinear arm 30 lie in planes parallel to the planes of the side walls 21, 23 of the square waveguide 20. The walls 33, 34 are, however, coupled through successively stepped down edges 41, 42 in the transition section 40 to the more widely spaced side walls 21, 23 of the square waveguide 20. The step down edges 41, 42 in the transition section 40 form a successive pair of quarter wave transformers between the square waveguide section 20 and the colinear arm 30.

It may be seen, therefore, that the square waveguide section 20, the first rectangular waveguide section 30 and the intermediate transition section 40 lie along the same axis and that they may be formed as an integral body having planar top and bottom walls. The structure may also include terminal flanges coupled individually to the free end portions of each of the waveguide sections. Thus the square waveguide section 20 may include a square waveguide flange 28 and the colinear arm 30 may include an associated colinear arm flange 38.

Positioned within the transition section 40 is a conductive metal septum 44 or plate bisecting the transition section 40 along a plane parallel to the planes of the broad walls 33, 34 of the colinear arm 40. The metal septum 44 extends between the top and bottom walls of the transition section 40 and along the axis of the square waveguide 20 and the colinear arm 30. In axial length, the metal septum 44 may extend approximately coextensively with the length of the transition section 40. The edge of the septum 44 which is closest to the square waveguide 20 lies approximately along the plane defined by the interior surfaces of the first step down edges 41. The septum 44 may be affixed entirely within the body section 10 or may fit through a slot in the body 10 walls and be attached thereto by solder.

A second rectangular waveguide section or side arm 50 is coupled to the first side wall 21 of the square waveguide section 20 and encompasses the coupling aperture 26. The narrow walls 51, 52 of the side arm 50 are substantially normal to the axis of the square waveguide 20, and the broad walls 53, 54 are substantially parallel to the axis of the main body section 10 and to the narrow walls 31, 32 of the colinear arm 30. Thus the side arm 50 is normal to the square waveguide 20 and has its height dimension in a plane normal to the height dimension of the colinear arm 30. The second rectangular waveguide 50 may include a side arm flange 58 at the uncoupled end thereof for attachment to external devices (not shown).

A pair of elongated metallic irises 60, 61 are affixed within the side arm 30 at the side arm flange 58. Each of the metallic irises 60, 61 is adjacent a different narrow wall 51, 52 of the side arm 50, and each of the irises 60, 61 has its direction of elongation substantially parallel to the adjacent narrow wall 51 or 52. Together the irises 60, 61 form an inductive reactive element in the path of energy transmitted along the side arm 50. As may be best seen in FIG. 1, the inductive irises 60, 61 may be set into recessed portions in the associated walls of the side arm 50, so as to be flush with the surface of the side arm flange 58. The arrangement shown is merely one useful configuration. If the side arm 50 were of greater length, the irises 60, 61 could be affixed in it through slots (not shown) in each of the narrow walls 51, 52.

The arrangement of FIGS. 1 through 4 is intended to operate with the dominant TE_{10} modes of microwave energy in a square waveguide. A first of these dominant modes will, for purposes of reference, be taken to be that in which the electric vector is vertical, as viewed in the figures. Such energy therefore is to be transferred in either direction, depending upon the source, between the side arm 50 and the square waveguide 20. The second dominant mode, therefore, is that in which the electric vector is horizontal, as viewed in the figures, and which is therefore transferred in either direction between the square waveguide 20 and the colinear arm 30. In each of the rectangular waveguides 30, 50 the dominant mode is also the TE_{10} mode.

As above described, electromagnetic wave energy inputs may be provided to the square waveguide 20 in either or both modes, or individually, in the particular mode supported, to the side arm 50 or the colinear arm 30. Assuming, for purposes of description, that the square waveguide 20 is to be used as the input, outputs from the device will therefore be provided from the side arm 50 or the colinear arm 30. These outputs are desirably at full amplitude in the correct arm, with substantially no energy being coupled out the other arm. It may be seen that the electric vector of energy in the first dominant mode is normal to the broad walls 53, 54 of the side arm 50. Thus such energy should be supported by the side arm 50, but not the perpendicularly disposed colinear arm 30. Conversely, energy in the second dominant mode should be supported as the TE_{10} mode in the colinear arm 30 but not in the side arm 50. It will also be appreciated by those skilled in the art, however, that the abrupt discontinuities involved effectively prevent proper coupling of energy between the various arms and that, without more, power loss, reflections and unwanted energy propagation would occur.

The manner in which this arrangement operates to substantially minimize VSWR and to increase coupling efficiencies over a broad frequency band will now be described. The presence of the metal septum 44 in the transition section 40 provides a conductive member which acts as a short circuit for the first dominant mode but which is substantially electromagnetically transparent to the second dominant mode. The leading edge of the metal septum 44 presented to energy transmitted along the square waveguide 20 toward the colinear arm 30, however, should be placed carefully with respect to the first step down edge 41 of the transition section 40 and with respect to the coupling aperture 26 and the metallic irises 60, 61. It has been found that best results are achieved in this arrangement when the leading edge of the conductive septum 44 lies approximately in the plane of the interior surfaces of the first step down edges 41 of the transition section 40. When the metal septum 44 is thus placed the short circuit presented to energy in the first dominant mode provides maximum coupling into the side arm 50. Further, when the septum 44 is so placed a compensating inductive reactance may be introduced in the side arm 50 by the metallic irises 60, 61 in the path of the electromagnetic wave energy in the first dominant mode. Energy is coupled into the side arm 50 because currents in the first wall 21 of the square waveguide 20 are interrupted by the coupling aperture 26, which is thereby excited. Note, however, that the coupling aperture **26** has dimensions which are less than the transverse dimensions of the side arm **50**. As a consequence, the coupling aperture **26** may be considered to present both capacitive and inductive reactance to the energy coupled into the side arm **50**. The reactive components thus introduced may be chosen with respect to the other elements so that substantially complete elimination of reflections is obtained. It will be understood, therefore, that the selective use of the inductive irises **60**, **61** spaced apart from the reduced coupling aperture **26**, together with the metal septum **44** provides substantially complete coupling, without reflections, of energy in the first dominant mode between the square waveguide **20** and the side arm **50**.

Energy in the second dominant mode, whose electric vector is normal to the metal septum **44** and normal to the plane of the coupling aperture **26**, is transmitted directly through the main waveguide body **10** to the colinear arm **30** without being coupled out the side arm **50**. Currents in the first wall **21** of the square waveguide section **20** are along the length of the coupling aperture **26**. The coupling aperture **26**, however, is relatively narrow in the direction transverse to the longitudinal axis of the square waveguide **20** and is centered about that longitudinal axis. Accordingly, energy in the second dominant mode does not excite the coupling aperture **26** and accordingly does not couple through the coupling aperture **26** into the side arm **50**. The presence of the metal septum **44** in the transition section **40** does not affect the second dominant mode except to provide a small capacitive susceptance to this mode. In this connection, the transition section **40** serves, in conjunction with the coupling aperture **26**, and the metal septum **44** to maintain at a minimum the reflections in the second dominant mode due to the transistion between the square waveguide section **20** and the colinear arm **30**.

Energy provided from the side arm **50** or the colinear arm **30** as input is similarly coupled through the square waveguide **20** without substantially any coupling of energy into the opposite rectangular arm **30** or **50**. The design of an orthogonal mode transducer in this fashion makes possible the achievement of VSWR's of less than 1.10 over a $\pm 5\%$ bandwidth.

It should also be noted that the structure thus provided is extremely simple to construct and of a rugged nature. The main waveguide body **10** may be constructed as an integral piece, for example, and may thus be formed simply, without further need for precise adjustments. To this structure may be added a side arm **50** of standard characteristics. The metallic irises **60**, **61** and the metal septum **44** are extremely simple to construct and to place in the desired configuration.

Another and different arrangement in accordance with the invention is shown in FIGS. 5 and 6. In some applications a square waveguide may be used to transmit energy in modes in which the electric vectors lie along the diagonals of the square waveguide. Such modes may be induced, for example, by application of a 45° rotation to energy maintained in the TE_{10} modes. Such diagonally supported modes are independent and orthogonal with respect to each other. They may be considered to be another form of dominant mode, or at least quasi-dominant. It is often desired to couple energy from such modes into perpendicularly related rectangular waveguides, and such purposes are fulfilled by the arrangement shown in FIGS. 5 and 6, to which reference is now made. It should be noted that the arrangement of FIGS. 5 and 6 is depicted for greatest clarity, and is not drawn to scale.

In this arrangement, a metal septum **44'** is placed within a square waveguide **20'** along one of the diagonals thereof. The square waveguide **20'** includes a coupling aperture **26'** along one of its edges other than the edges contacted by the metal septum **44'**, the coupling aperture **26'** having its direction of elongation along the longitudinal axis of the square waveguide **20'**. A side arm **50'**, having its axis normal to that of the square waveguide **20'**, and to the plane of the septum **44'** is coupled to the square waveguide **20'** about the coupling aperture **26'** therein. In this instance, the coupling aperture **26'** may have the same width, or narrow dimension as the associated side arm **50'**. The length of the coupling aperture **26'**, however, may be less than the broad wall dimension of the side arm **50'** so that inductive irises are thus defined at the aperture **26'**. The septum **44'** may have its leading edge (as to energy transmitted from the free end of the square waveguide **20'**) positioned in a plane passing adjacent the trailing edge of the coupling aperture **26'**. The broad walls of the side arm **50'** are parallel to the longitudinal axis of the square waveguide **20'**.

Spaced apart from the coupling aperture or slot **26'** the narrow walls of the side arm **50'** each include a side slot in which is positioned a conductive metallic iris **60'** or **61'**. These irises **60'**, **61'** provide inductive reactances to energy in the side arm **50'**.

A transition section **40'** is defined by successive stepped sections **46**, **47**, **48** coupling from the square waveguide **20'** to a colinear arm **30'** which is diagonal with respect thereto. The colinear arm **30'** therefore has its broad walls parallel to the plane of the metal septum **44'**.

In accordance with the considerations provided with respect to FIG. 1, the relationship of the irises **60'**, **61'**, the transition section **40'**, the coupling slot **26'** and the septum **44'** may be selected with relation to each other for best energy coupling and least energy reflection.

In operation, energy in a first orthogonal mode diagonally supported within the square waveguide **20'** will be taken, for purposes of description, to be parallel to the metal septum **44'**. Energy in the second of these orthogonal modes will be taken to be normal to the metal septum **44'**. As previously described, the energy in the first diagonally supported mode in the square waveguide **20'** sees the metal septum **44'** as a short circuit. Such energy also excites the coupling slot **26'**, so that energy is coupled into the side arm **50'**, with the inductive elements at the coupling slot **26'**, and the inductive irises **60'**, **61'** positioned within the side arm **50'** minimizing the reflected energy to maintain an extremely low VSWR. As a consequence, in the first diagonally supported mode no energy is transmitted out the colinear arm **30'**, and substantially full energy is transmitted out the side arm **50'**.

Energy in the second diagonally polarized mode coupled through the square waveguide **20'** does not excite the coupling slot **26'** and is substantially unaffected by the metal septum **44'**, so that such energy is transmitted through the transition section **40'** to the colinear waveguide arm **30'**. Again, the metal septum **44'** provides only a small capacitive susceptance, and the transition section **40'** provides transfer of energy into the colinear arm **30'** without appreciable reflection effects. Like considerations prevail, and like efficiency is again obtained, for couplings of energy in the directions from the side arm **50'** or the colinear arm **30'** to the square waveguide **20'**.

An example of the orthogonal mode transducer of FIGS. 1 through 4 may employ the following dimensions:

Square waveguide 0.800" x 0.800" (cross section).
Side arm 0.400" x 0.900" (cross section).
Colinear arm 0.450" x 0.800" (cross section).
Coupling aperture 0.155" x 0.765".
Metal septum 0.600" long x 0.032" thick.
Irises 0.013" (transverse to waveguide).
Transition section 0.700" (transverse dimension).
Transition section 0.575" (between successive steps).

Thus there has been described an improved orthogonal mode transducer for microwave applications. The device is simply constructed, but provides substantially complete transfer of energy between a square waveguide and individual ones of two perpendicularly related rectangular waveguides, without the transfer of undesired energy to the other of the rectangular waveguides. The reflections in this device are kept to a minimum and the characteristics thus achieved are maintained over a broad frequency band.

I claim:

1. An orthogonal mode transducer comprising a square waveguide capable of supporting first and second modes of energy wherein the electric fields thereof are orthogonally disposed with respect to each other, a first rectangular waveguide disposed in substantial axial alignment with said square waveguide, a second rectangular waveguide coupled to said square waveguide substantially normally to the axis thereof by means of a rectangular aperture opening into said square waveguide, said aperture having the longest dimension thereof parallel to the axis of said square waveguide whereby only energy in the first of said modes will be coupled into said second rectangular waveguide, the broad walls and the narrow walls of said second rectangular waveguide being disposed substantially normal to the broad walls and the narrow walls of said first rectangular waveguide, respectively, a transition section disposed between said first rectangular waveguide and said square waveguide for coupling said square waveguide to said first rectangular waveguide, said transition section including successively stepped portions effective to vary one of the transverse dimensions of said section between those of said square waveguide and of said first rectangular waveguide whereby energy in the second of said modes will be coupled between said square waveguide and said first rectangular waveguide, means disposed within said transition section to prevent energy in said first mode from entering said first waveguide.

2. An orthogonal mode transducer comprising a square waveguide capable of supporting first and second modes of energy wherein the electric fields thereof are orthogonally disposed with respect to each other, a first rectangular waveguide disposed in substantial axial alignment with said square waveguide section, said rectangular waveguide having a pair of narrow walls disposed substantially coplanar with a first pair of side walls of said square waveguide, said rectangular waveguide having broad walls disposed substantially parallel to the other pair of side walls of said rectangular waveguide, a transition section coupling said square waveguide to said rectangular waveguide, said transition section including successively stepped portions coupling the broad walls of said first rectangular waveguide to said other pair of side walls of said square waveguide whereby energy in the first of said modes will be coupled between said square waveguide and said first rectangular waveguide, a septum disposed within said transition section to prevent energy in the second of said modes from entering said first rectangular waveguide, a second rectangular waveguide coupled to said square waveguide substantially normally to the axis thereof by means of a rectangular aperture in one of said second pair of said side walls, said aperture having the narrow dimension thereof transverse of said side wall and the long dimension thereof parallel to the axis of said square waveguide whereby only energy in said second mode will be coupled into said second rectangular waveguide, the broad walls and the narrow walls of said second rectangular waveguide being disposed substantially normal to the broad walls and the narrow walls of said first rectangular waveguide, respectively.

3. An orthogonal mode transducer comprising a square waveguide capable of supporting first and second modes of energy wherein the electric fields thereof are orthogonally disposed with respect to each other, a first rectangular waveguide disposed in substantial axial alignment with said square waveguide, said rectangular waveguide having a pair of narrow walls and a pair of broad walls that are disposed substantially parallel to the diagonals of said square waveguide section, a transition section coupling said square waveguide to said rectangular waveguide whereby energy in the first of said modes will be propagated in said first rectangular waveguide, said transition section comprising a number of successively stepped portions positioned along the longitudinal axis of said square waveguide so as to progressively change a transverse dimension between that of a diagonal and that of said narrow walls, a septum disposed in said transition section normal to said last mentioned diagonal for reflecting energy in said second mode, a coupling slot disposed in one edge of said square waveguide, a second rectangular waveguide having broad and narrow walls coupled to said square waveguide in registry with said coupling slot whereby energy in said second mode will be propagated therethrough, the axis of said second rectangular waveguide being normal to the axis of said square waveguide section with the broad walls of said rectangular waveguide being parallel to said axis of said square waveguide.

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