June 30, 1970 J. A. ALGEO 3,518,576

CROSSED GUIDE DIRECTIONAL COUPLER

Filed June 27, 1967 4 Sheets-Sheet 1

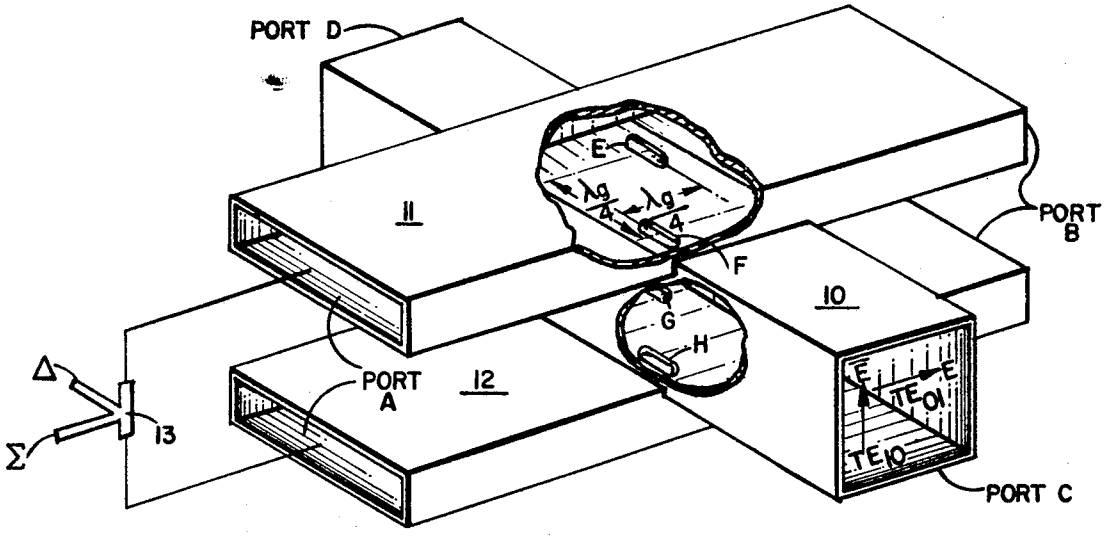


FIG. 1

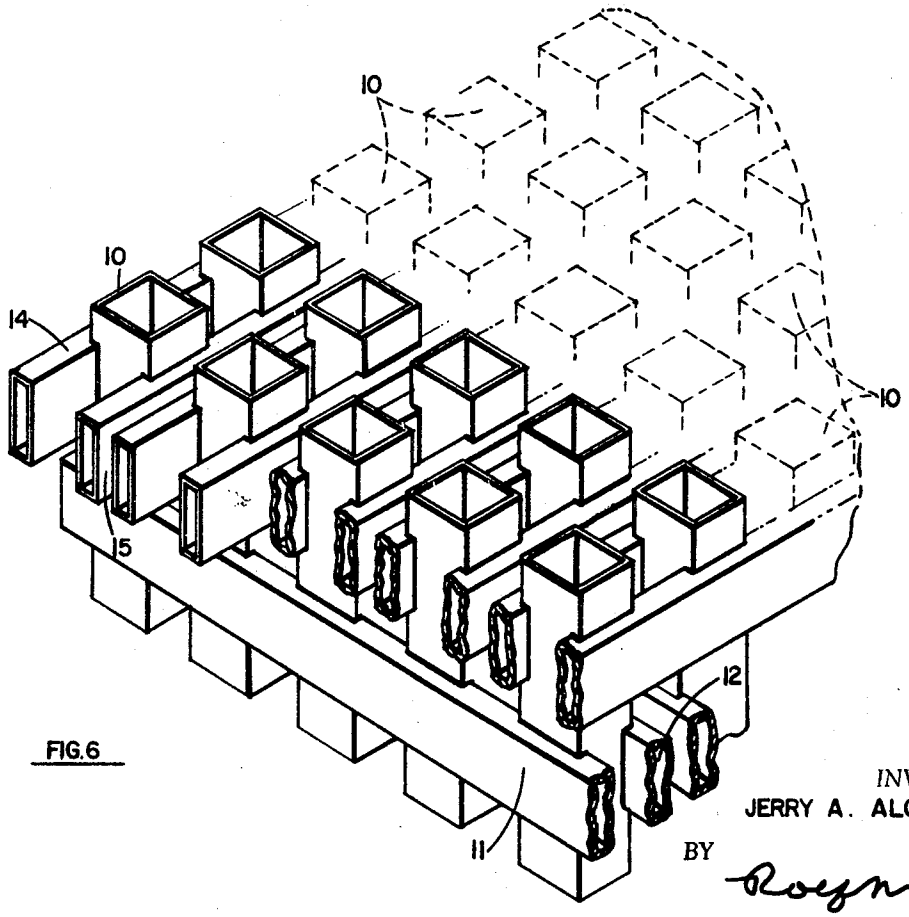


FIG. 6

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CROSSED GUIDE DIRECTIONAL COUPLER

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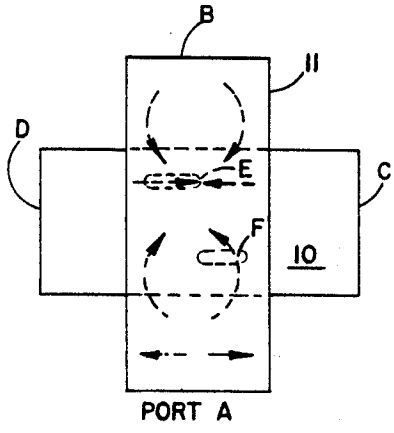


FIG. 2A

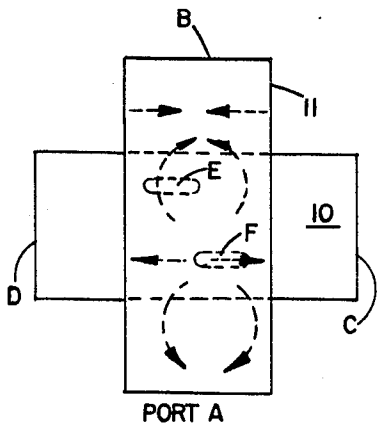


FIG. 2B

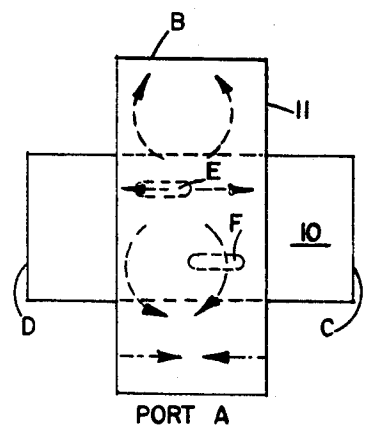


FIG. 2C

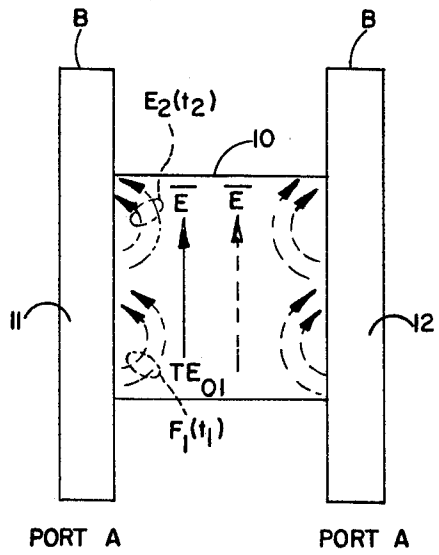


FIG. 3A

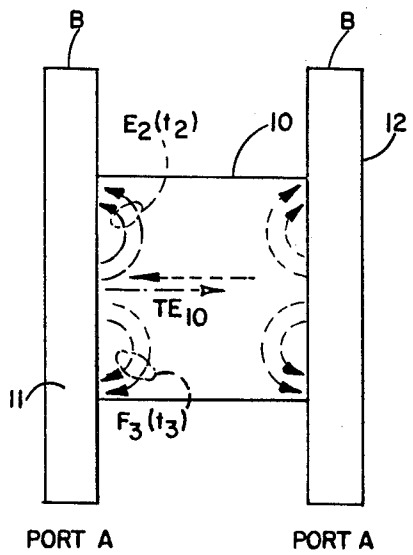


FIG. 3B

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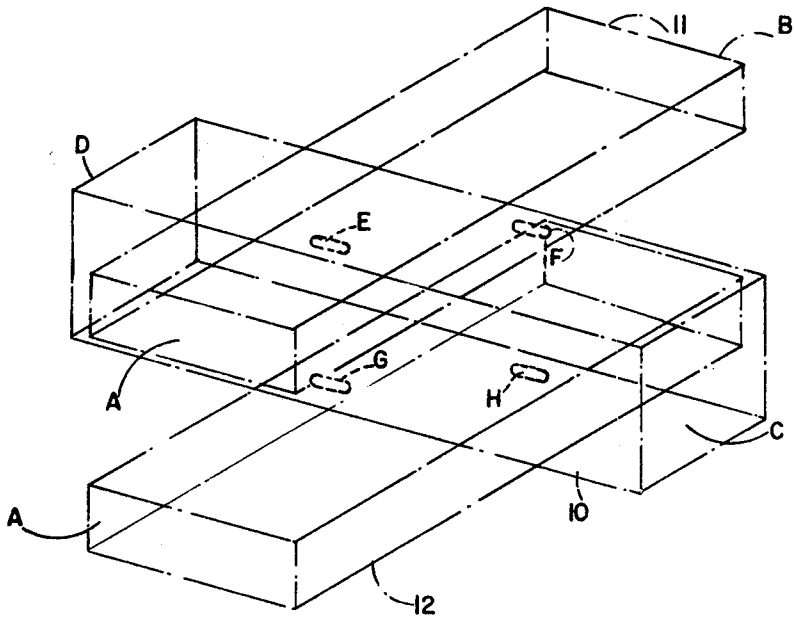


FIG. 4

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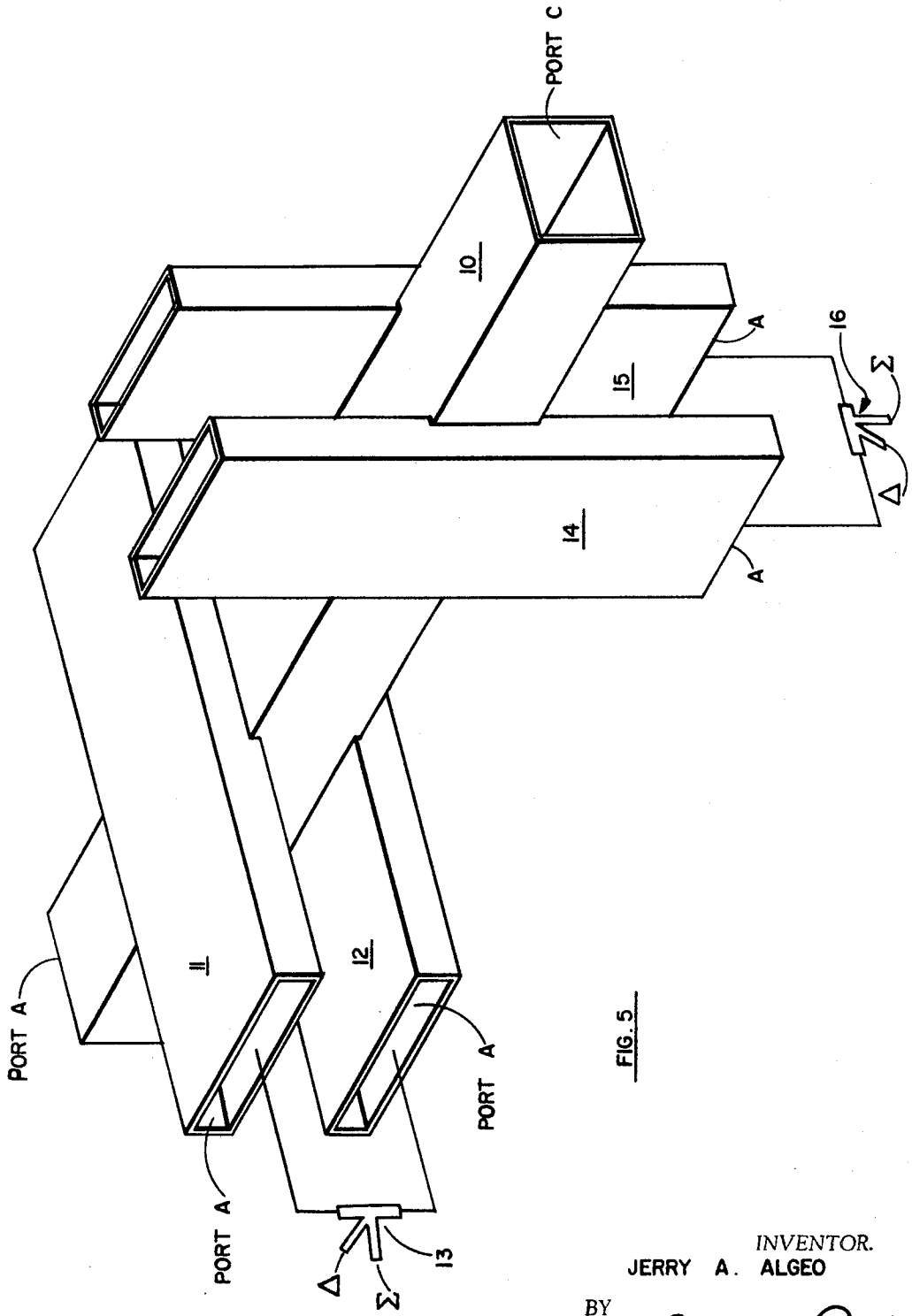


FIG. 5

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United States Patent Office 3,518,576 Patented June 30, 1970

3,518,576

CROSSED GUIDE DIRECTIONAL COUPLER

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Filed June 27, 1967, Ser. No. 649,166
Int. Cl. H01p 5/14
U.S. Cl. 333—10 6 Claims

ABSTRACT OF THE DISCLOSURE

A directional coupler feed for cooperation with a square waveguide, which directionally couples a preselected one of the TE_{01} and TE_{10} modes (while suppressing higher modes) from a crossed feed to the square cross-section waveguide. The crossed feed comprises two commonly-excited, mutually-parallel rectangular waveguides, a broadwall of each of which is crossed with and coupled to an opposite wall of the square waveguide in a mutually phased-spaced relation, whereby the components of one of the induced TE_{01} and TE_{10} modes are in substantially anti-phase relation (as to be mutually suppressed) and the components of the other of the two modes are substantially in-phase.

CROSS-REFERENCES TO RELATED APPLICATIONS

(1) U.S. application Ser. No. 472,236, now Pat. No. 3,434,139, filed July 15, 1965 by J. A. Algeo for Frequency Controlled Scanning Monopulse Antenna.

(2) U.S. application Ser. No. 621,007 filed Mar. 6, 1967 by J. A. Algeo et al., for Frequency-Sensitive Cross-Scanning Antenna.

BACKGROUND OF THE INVENTION

The utilization of a doubly-dispersive frequency scanned planar array of discrete radiating elements to provide a dual-plane scanning beam is known in the art, being described for example in my above-noted copending application Ser. No. 472,236. The inclusion in such array of dual-mode capability, whereby two separately-controlled mutually-coupled cross-scanning beams are simultaneously provided by a cross fed matrix array, is described in copending application Ser. No. 621,007 filed Mar. 6, 1967 by J. A. Algeo et al., assignors to North American Aviation, Inc., assignee of the subject invention. Such cross-fed arrays employ crossed-guide directional couplers. However, since crossed-guide directional couplers are typically not symmetrical junctions, their coupling holes tend to generate higher order modes. In the prior art, these higher order modes have been suppressed by designing all waveguide areas of the coupler to be of rectangular cross section and to propagate only a desired mode.

A cross-fed dual-beam, dual-polarized array requires a directional coupler which produces a desired one of two mutually cross-polarizations, by employing either of the TE_{01} and TE_{10} modes.

A square waveguide will support the propagation of at least the TE_{01} and TE_{10} modes. Also, these modes are generated by the coupling holes of most crossed-guide directional couplers. Therefore, a directional coupler is required in cooperation with a radiating square cross-section waveguide.

The prior art in crossed-waveguide couplers is illustrated by the following U.S. Pats: 2,636,082—T. S. Saad, 2,667,620—H. J. Riblet, 2,866,595—G. R. P. Marie.

The patent to Marie shows rectangular waveguide feeds in parallel with a main waveguide having a square cross section and arranged to cooperate as narrow bandpass

filters. In other words, Marie does not teach a crossed guide coupler for a square waveguide for utilization as a polarized broadband device in a frequency-scanned antenna array.

The patent to Riblet shows a pair of mutually-parallel rectangular guides cross-coupled to a second pair of parallel rectangular guides for coupling a single dominant mode in a preselected guide of the second pair of waveguides. In other words, Riblet does not teach the cooperation of a crossed-feed in cooperation with a radiating square waveguide for preselectively coupling two propagated modes, both the TE_{01} and TE_{10} modes. Similarly, the patent to Saad shows a pair of rectangular guides cross-coupled to a third or main rectangular guide for coupling both of two oppositely-travelling waves of a like mode in the main waveguide. Therefore, non-directional coupling is employed for the purpose of continually monitoring the standing wave ratio in the main waveguide. In other words, Saad does not teach a crossed-guide directional coupler for a square waveguide.

In summary, the prior art does not teach a crossed guide directional coupler in cooperation with a square cross-section waveguide, for utilization as a polarized broadband element in a frequency-scanned antenna array.

SUMMARY OF THE INVENTION

By means of the concept of the invention, a crossed guide directional coupler cooperates with a square cross-section main waveguide for directionally-coupling and propagating in the main guide in two mutually crossed polarizations in a preselected ratio.

In a preferred embodiment of the inventive concept, there is provided two commonly excited mutually parallel rectangular waveguides, a broadwall of each of which is crossed with and coupled to an opposite wall of the square waveguide. The respective couplings of the coupled rectangular waveguides are established in a preselective phase-spaced relation, whereby the components of one of the TE_{01} and TE_{10} modes, induced in the square waveguide by both of the crossed rectangular guides, are in substantially anti-phase relation and the components of the other of the two modes are substantially in-phase. In other words, one of the two modes thus propagated in the square cross-section waveguide may be suppressed.

By means of the above-described crossed-guide directional coupler, a polarized broadband element is provided for utilization in a frequency-scanned antenna array. Also, a second pair of commonly-excited mutually-parallel rectangular waveguides may be similarly crossed with and directionally coupled to a second pair of opposite walls of the square cross-section waveguide for generating a second polarized electromagnetic wave, cross-polarized with respect to the first-generated (non-suppressed) mode. Such an arrangement may thus be utilized as a dual-polarization broadband element in a dual-beam cross-fed frequency-scanned array. Accordingly, it is an object of the subject invention to provide an improved directional coupler.

It is another object of the invention to provide a crossed-guide directional coupler.

It is still another object to provide a crossed-guide directional coupler in cooperation with a square cross-section main guide for generating a preselected polarization at a preselected port of said main guide.

A further object of the invention is to provide a directional coupler responsive to a preselected linear polarization.

A still further object is to provide a crossed-guide directional coupler for use in a dual-mode electronically-scanned antenna array.

These and other objects of the invention will become

apparent from the following description, taken together with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view, partially torn away, of a directionally-coupled crossed guide having a square cross-section, and illustrating an aspect of the inventive concept;

FIGS. 2A, 2B and 2C are schematic plan views of top crossed guide **11** and main guide **10** of FIG. 1, at successive points in time, showing the progression of an electromagnetic wave applied at port A of guide **11**;

FIGS. 3A and 3B are schematic side views of the arrangement of FIG. 1 as viewed from port C;

FIG. 4 is a schematic isometric view of the crossed guides of FIG. 1 and illustrating an alternative coupling slot arrangement;

FIG. 5 is an isometric view of a main guide employing mutually-crossed, directionally-coupled feed means; and

FIG. 6 is an isometric arrangement of a cross-fed electronically scanned antenna array, employing the structural feature of FIG. 5.

In the figures, like reference characters refer to like parts.

Referring now to FIG. 1, there is illustrated an isometric view, partially torn away, of a directionally-coupled crossed guide having a square cross section illustrating one aspect of the inventive concept. There is provided microwave means for directionally coupling at least one of the TE_{01} and TE_{10} modes from a crossed feed to a main guide **10** capable of supporting both such modes. In other words, the cross-section of main guide **10** is substantially square. The crossed feed comprises two mutually parallel rectangular waveguides **11** and **12** adapted to be commonly excited, a broadwall of each of rectangular waveguides **11** and **12** being crossed with and directionally coupled to a respective one of two opposing walls of main guide **10**. Such directional coupling may be effected in each waveguide by two slots mutually spaced one-quarter waveguide wavelength ($\lambda g/4$) apart in each of two mutually orthogonal directions, each slot extending traversely of the longitudinal axis of the rectangular waveguide, as shown in FIG. 1, although other types of directional couplers may be used, such as a crossed slot coupler, for propagating both a TE_{01} and TE_{10} mode in the main guide **10**. The design of such coupling slots is understood in the art, being further described for example, in my copending application Ser. No. 472,236 filed July 15, 1965.

The couplings of parallel guides are arranged in a mutually phase-spaced relation for providing an elliptical polarization at a preselected part of the main guide and having a preselected degree of ellipticity.

Parallel feed guides **11** and **12** are adapted to be commonly excited in either of a mutually in-phase or anti-phase excitation relationship, by excitation coupling means **13** such as a magic-tee, a simple E-plane folded T, or an E-plane bifurcated waveguide.

In a selected combination of (1) space-phase relation between the couplings of coupled guides **11** and **12** and (2) relative time phase excitation relation between the commonly excited guides **11** and **12**, a selected one of the TE_{01} and TE_{10} modes may be propagated at a selected one of the ports C and D of main guide **10**. (Alternatively, it is to be understood from the theory of reciprocity that the injection of a preselected one of the TE_{01} and TE_{10} modes at a preselected one of ports C and D of main guide **10** will result in an output at a preselected one of the pairs of ports A and B of crossed guides **11** and **12**.) For example, with the quarter-guide-wavelength spaced coupling slots of each of guides **11** and **12** in a mutually opposed or in-line relation (as shown in FIG. 1), and co-phasal excitation of ports A of guides **11** and **12** with equal amounts of energy (by application of an excitation input at the sum (Σ) port of input coupling means **13**), a TE_{01} mode may be generated at port D. Such exemplary mode

of operation may be more clearly appreciated from a consideration of FIGS. 2A, 2B, 2C, 3A and 3B.

Referring to FIGS. 2A, 2B and 2C, there is illustrated a schematic plan view of top crossed guide **11** and main guide **10** of FIG. 1 at successive points in time, and showing field current plots of the progression of an incident electromagnetic field (applied at port A) toward port B of guide **11**. At a first point in time t_1 (FIG. 2A), slot E has no transverse current and therefore does not couple guide **11** to main guide **10**, while slot F is energized and does couple guide **11** to guide **10**, which coupled energy travels to both of ports C and D of main guide **10**. At a second point in time t_2 (FIG. 2B) corresponding to the time interval (t_2-t_1) required for the wave to travel the distance $\lambda g/4$ in guide **11**, slot E becomes energized and slot F is inactive. Hence, in FIG. 2B slot E intercouples guides **10** and **11**. During the interval (t_2-t_1), the energy coupled by slot F (at time t_1) moves the distance $\lambda g/4$ (within guide **10**) to the left toward slot E. As a result, the two separately coupled energy components coincide in space-phase and time-phase to form a resultant TE_{01} mode in main guide **10** and which travels toward port D. (Note that in a standard coupler, the main guide is rectangular as to cut-off the TE_{01} mode; this prohibits propagation of the TE_{01} mode in the standard coupler and no energy exists at port D. In other words, in a standard directional coupler, port D is the isolated arm and port A the incident arm.)

Such propagation of the TE_{01} mode at port D of guide **10**, due to the coupling of energy introduced at port A of guide **11**, is also shown in the composite diagram of FIG. 3A. Such diagram illustrates the arrangement of FIGS. 2A and 2B as seen by looking toward port D from port C, the lower left field $F_1(t_1)$ occurring due to the coupling of slot F at time t_1 and the upper left field $E_2(t_2)$ occurring due to the coupling of slot E at time t_2, the coplanar combination of the two fields in the plane of FIG. 3A resulting in the illustrated solid line vector or TE_{01} mode travelling into the plane of FIG. 3A toward port D.

The corresponding mode coupled from guide **11** to port C of main guide **10** may be understood from a similar examination of FIGS. 2B, 2C and 3B. As the incident wave in FIG. 2B (which excites slot E at time t_2) progresses in guide **11** toward port B, slot F is subsequently excited (by a current transverse thereto) at a third point in time t_3 (FIG. 2C), corresponding to the time interval $(t_3-t_2)=(t_2-t_1)$, and slot E is no longer energized. Now the field coupled by slot A (at t_2) travels toward both of ports C and D (in main guide **10**) and at time t_3 has moved to the right a distance $\lambda g/4$ in main guide **10** (toward port C), coinciding in space-phase and time-phase with the F_3 energy component coupled by slot F at time t_3. The opposed transverse sense of the arrowheads at slot E in FIG. 2B and at slot F in FIG. 2C indicate that the TE_{01} modes from port A of guide **11** will cancel at port C, as is more clearly seen in FIG. 3B.

Referring to FIG. 3B, there is illustrated the arrangement of FIGS. 2B and 2C, as seen looking toward port D from port C, the upper left field $E_2(t_2)$ occurring due to the coupling of slot E at time t_2 and the lower field $F_3(t_3)$ occurring due to the coupling of slot F at time t_3, the coplanar combination of the two fields in the plane of FIG. 3B resulting in the illustrated solid line vector or TE_{10} mode, travelling out of the plane of FIG. 3B toward port C.

If, of course, the excitation of guide **11** were applied at port B, then the TE_{01} mode would occur at port D and the TE_{10} mode would occur at port C. Thus, the illustrated arrangement of main guide **10** and crossed guide **11** results in directionally coupling one of the TE_{01} and TE_{10} modes between one port of main guide **10** and a preselected port of crossed guide **11**, while directionally coupling the other mode between such preselected

port of crossed guide **11** and a second port of main guide **10**. In other words, mutually exclusive modes are coupled between a preselected port of guide **11** and an alternative port of main guide **10**.

By suitably arranging the coupling slots of second-crossed guide **12** (of FIG. 1) to main guide **10**, a fully-directional coupler may be provided whereby only a preselected one of the two modes is coupled and whereby only a preselected port of main guide **10** cooperates with a preselected excitation mode of a crossed guide feed in response to common excitation of feed guides **11** and **12**.

For example, if the coupling of bottom feed guide **12** to main guide **10** in FIG. 1 is achieved by coupling slots G and H, vertically aligned with slots E and F, respectively, then a corresponding TE_{01} component will be propagated toward port D (as shown by the dotted vector resulting from the dotted field lines in FIG. 3A), and a corresponding TE_{10} component will be propagated toward port C (as shown by the dotted vector resulting from the dotted field lines in FIG. 3B). It is to be observed (in FIG. 3A) that the TE_{01} mode components propagated toward port D by guides **11** and **12** are of like sense or phase as to support each other, while in FIG. 3B it is seen that the TE_{10} mode components propagated toward port C by guides **11** and **12** are of opposing sense or anti-phase, as to suppress each other. In other words, by means of the illustrated crossed-feed arrangement of FIG. 1, only a preselected one of the TE_{01} and TE_{10} modes is directionally coupled between a preselected pair of input and output ports. The combination of directionally coupled ports and an associated mode may be varied by varying the coupler slot arrangement as shown in FIG. 4. In other words, a slot pair (E, F or G, H) for a given one of guides **11** and **12** is placed at opposite extremities of a selected one of the crossed diagonals of the rectangular shape

$$\left(\frac{\lambda g}{4} \times \frac{\lambda g}{4}\right)$$

However, other coupling slot arrangements may be employed.

An alternative way of varying the coupled main guide port and the polarization or coupled mode resulting from excitation of a given feed port of each of feedlines **11** and **12**, is to excite such feed ports in anti-phase relation by applying such excitation to the difference (Δ) port of excitation coupling means **13** (in FIG. 1) rather than the sum (Σ) port. By means of such anti-phase excitation, the TE_{01} component vectors in FIG. 3A are of opposite sense as to be mutually suppressing, and the TE_{10} component vectors of FIG. 3B are of like sense or phase as to support each other. In this way, port A of feeds **11** and **12** are coupled to port C of guide **10** in the TE_{10} mode. By the proper combination of coupling slot arrangements and time-phase excitation of the crossed feeds, a preselected one of the TE_{01} and TE_{10} modes may be directionally coupled between a preselected combination of feedline ports and main guide port.

Because a preselected one of the TE_{01} and TE_{10} modes may be directionally coupled from a preselected port of main guide **10** to the crossed feed formed by mutually parallel rectangular guides **11** and **12**, a second one of such modes may be similarly coupled from such main guide port to a second crossed feed, to provide a dual mode of operation as shown in FIG. 5.

Referring to FIG. 5, there is illustrated a main guide **10**, crossed feed elements **11** and **12**, and coupling means **13** arranged to cooperate substantially the same as like referenced elements of FIG. 1 for coupling a preselected mode between port C and the crossed-feed coupling means **13**. There is also provided a second crossed feed comprising a second pair of mutually parallel rectangular waveguides **14** and **15**, adapted to be commonly excited, and crossed relative to both main guide **10** and crossed feed combinations **11** and **12**, a broadwall of each of guides **14** and **15** being directionally coupled to a respective one of a second pair of opposing walls of main guide **10** in a mutually spaced relation for suppressing one of the TE_{01} and TE_{10} modes induced in the main guide by second guide pair **14** and **15**. Excitation coupling means **16** cooperate with guides **14** and **15** in like manner as coupling means **13** cooperates with guides **11** and **12**. Because of the orthogonal relation between first feed guide pair **11** and **12** and second feed guide pair **14** and **15**, the employment of a like coupler slot arrangement with guides **14** and **15** as with guides **11** and **12** will result in a single mode directional-coupling response between feed guide pair **14** and **15** and port C of main guide **10**, the polarization of such response being mutually crossed at port C relative to the single mode coupling response between first feed guide pair **11** and **12** and main guide **10**.

Thus, the arrangement of FIG. 5 provides a dual mode of operation, in which a preselected port of main guide **10** is directionally coupled to each of first crossed feed means **11** and **12** and second crossed feed means **14** and **15** by a mutually exclusive one of two polarizations. Such functional feature may be used in providing a frequency-scanned antenna array, having a dual mode of operation, as shown in FIG. 6.

Referring to FIG. 6, there is provided a frequency-sensitive, cross-scanning antenna comprising a coplanar matrix of radiating waveguide elements **10**, arranged in rows and columns and comprising like waveguides of substantially square cross-section. There is also provided a like number of first feedlines as rows each first feedline connected to feed a mutually exclusive one of the rows of radiating elements each first feedline comprising a first pair of mutually parallel rectangular waveguides **11** and **12**, adapted to be commonly excited, a broadwall of each of which is crossed with and directionally coupled to a respective one of a like first pair of opposite walls of each radiating element **10** of the rows of radiating elements in a mutually phase-spaced relation for suppressing one of the TE_{01} and TE_{10} modes induced in the radiating elements **10** by the first pairs of rectangular guides **11** and **12**.

There is further provided (in FIG. 6) a like number of second feedlines as columns of radiating elements, each second feedline connecting to feed a mutually exclusive one of the columns of radiating elements, each second feedline comprising a second pair of mutually parallel rectangular waveguides **14** and **15** adapted to be commonly excited, a broadwall of each of which is crossed with and directionally coupled to a like respective one of a second pair of opposite walls of each radiating element **10** of the columns of elements in a mutually phase-spaced relation for suppressing one of the TE_{01} and TE_{10} modes induced in radiating elements **10** by the second pairs of rectangular guides **14** and **15**. In such arrangement, the mutually phase-spaced relation of the coupled second pairs of rectangular waveguides **14** and **15** is preselected to induce in, or couple with, the radiating apertures of guides **10** a linearly polarized wave which is cross-polarized relative to that induced by the first pairs of rectangular waveguides **11** and **12**. Thus, in normal operation of the crossed feed array of FIG. 6, each of the two directionally coupled crossed feed assemblies responds to a mutually exclusive polarization, whereby two separately controlled, mutually-angled, cross-scanning beams may be simultaneously provided by the two feed assemblies, as explained more fully in copending application Ser. No. 621,007 filed Mar. 6, 1967 by Algeo et al., assignors to North American Aviation, Inc., assignee of the subject invention. Although such application of the invention to an electronically scanned antenna has been described in terms of a frequency-scanned array, it is clear that the concept is equally useful in phased-arrays.

Accordingly, it is to be appreciated that an improved crossed guide directional coupler has been described for providing coupling between a selected combination of ports of a crossed feed and a main guide, and for providing such coupling in a preselected mode. Because of such selective coupling feature, such structure may be used to simultaneously directionally couple a respective one of two mutually orthogonal polarizations between a main waveguide port and a respective one of mutually exclusive crossed feed means cooperating with such guide.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. Microwave means for directionally coupling a preselected one of the TE_{01} and TE_{10} modes from a crossed feed to a waveguide having a square cross-section, the crossed feed comprising two mutually parallel rectangular waveguides, a broadwall of each of which is crossed with and coupled to an opposite wall of the square waveguide in a mutually phase-spaced relation, whereby the components of the TE_{01} mode are in substantially anti-phase time relation and the components of the TE_{10} mode are substantially in-phase; and excitation coupling means for providing a preselected one of a mutually in-phase and anti-phase excitation relationship between said rectangular waveguides, whereby a selected one of said modes is preselectively directionally coupled between said crossed feed and said waveguide having a square cross section.

2. Microwave means for directionally coupling a preselected one of the TE_{01} and TE_{10} modes from a source of microwave energy to a waveguide having a square cross-section and comprising a crossed feed of two mutually parallel rectangular waveguides adapted to be commonly excited, a broadwall of each of said rectangular waveguides being crossed with and directionally coupled to an opposite wall of the square waveguide in a mutually phase spaced relation, and excitation coupling means for providing a selected one of a mutually-in-phase and mutually anti-phase excitation relationship between said rectangular waveguides, whereby the components of one of the TE_{01} and TE_{10} modes in said square waveguides are in substantially anti-phase time relation and the components of the other of the two modes are substantially in phase.

3. A crossed feed comprising two commonly-excitable mutually-parallel rectangular waveguides coupled to a square cross-section waveguide to effect a selected one of

a TE_{01} and TE_{10} mode and excitation coupling means for providing a preselected one of a mutually-in-phase and mutually anti-phase excitation relationship between said rectangular waveguides, whereby said TE_{01} mode is preselectively directionally coupled between said square cross-section guide and said rectangular waveguides.

4. A crossed feed comprising

a pair of mutually parallel rectangular waveguides adapted to be commonly excited;

a main waveguide, capable of supporting both a TE_{01} mode and a TE_{10} mode, a broadwall of each of said rectangular waveguides being crossed with and directionally coupled to a respective one of two opposing walls of said main waveguide in a mutually phase-spaced relation for suppressing one of said modes without suppressing the other; and

excitation coupling means for providing a preselected one of a mutually in-phase and mutually anti-phase excitation relationship between said rectangular waveguides.

5. A crossed feed comprising

a first pair of mutually parallel rectangular waveguides adapted to be commonly excited;

a main waveguide, capable of supporting both a TE_{01} mode and a TE_{10} mode, a broadwall of each of said rectangular waveguides being crossed with and directionally coupled to a respective one of two opposing walls of said main waveguide in a mutually phase-spaced relation for suppressing one of said modes without suppressing the other; and

a second pair of mutually parallel rectangular waveguides adapted to be commonly excited, a broadwall of each of said second pair of rectangular waveguides being crossed with and directionally coupled to a respective one of a second pair of opposing walls of said main waveguide in a mutually phase-spaced relation for suppressing one of the TE_{01} and TE_{10} modes induced in said square cross section waveguide by said second pair.

6. The device of claim 5 in which said phase-spaced relation of said second pair of rectangular waveguides is preselected to induce in said square cross section waveguide a linearly polarized electromagnetic wave, which is cross-polarized relative to that induced by said first pair of rectangular waveguides.

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