

[54] **WAVEGUIDE MODE COUPLER FOR SEPARATING WAVES OF USEFUL MODE FROM WAVES OF HIGHER MODE**

[75] Inventor: **Günter Mörz**, Ludwigsburg, Germany

[73] Assignee: **Licentia Patent-Verwaltungs-G.m.b.H.**, Frankfurt am Main, Germany

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[51] Int. Cl. **H01p 1/16, H01p 5/12**

[58] Field of Search **333/11, 21 R, 98 M, 333/98 R**

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Primary Examiner—Paul L. Gensler

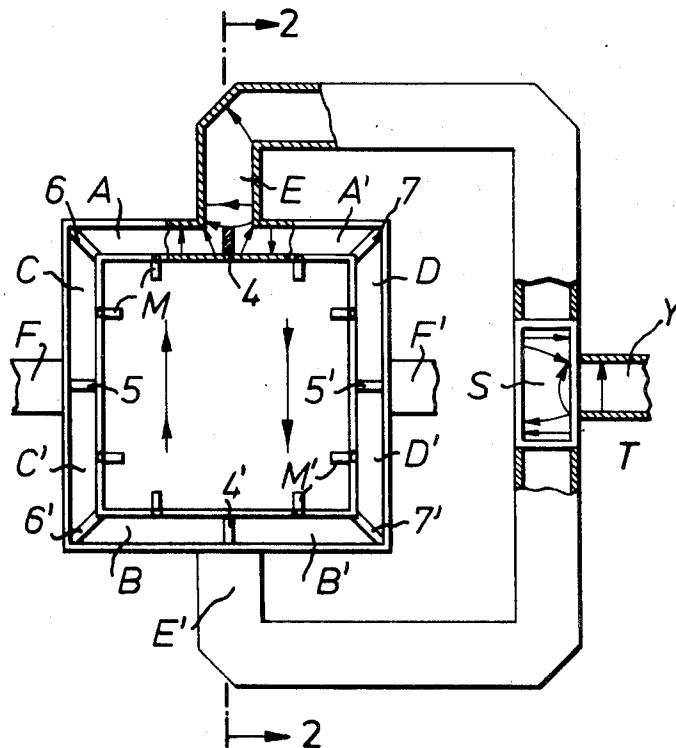
Attorney—George H. Spencer et al.

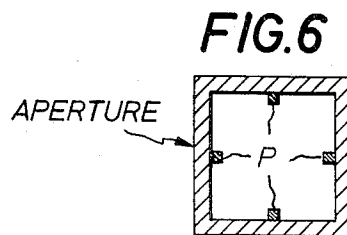
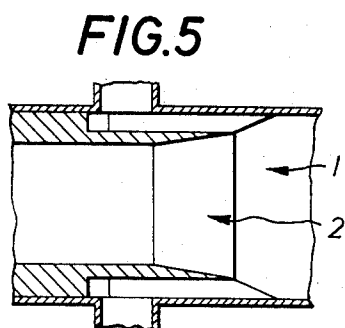
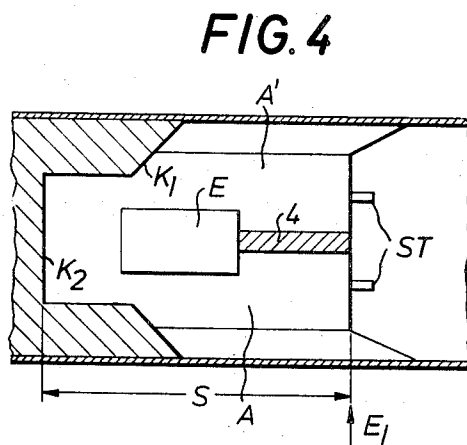
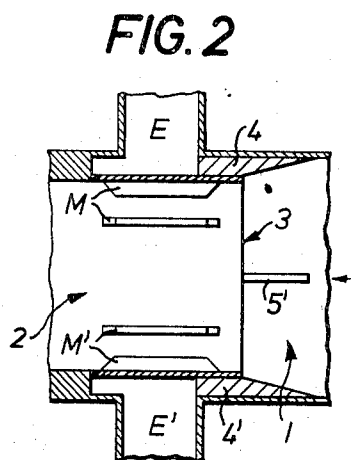
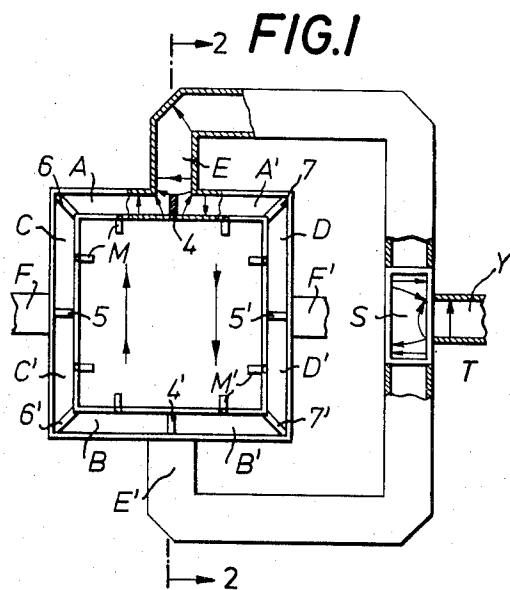
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ABSTRACT

A mode coupler useful in ranging systems for evaluating higher waveguide wave modes resulting from aperture deviations of an antenna exciter for determining angular deviation in the azimuth plane as well as in the elevation plane. Waves of the useful mode are separated from waves of a higher mode. A first waveguide section for propagating all evaluable wave modes is adapted to be coupled to an antenna. A second waveguide section for propagating exclusively the useful wave mode is connected in series with the first waveguide section. A gap is provided between the first waveguide section and the second waveguide section and is provided with a plurality of apertures for the higher wave modes in the direction of propagation of the waves. New modes corresponding to the higher wave modes are substantially excited by the useful mode containing the ranging signal.

6 Claims, 16 Drawing Figures





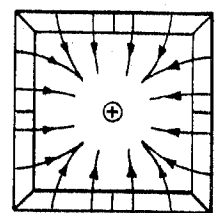
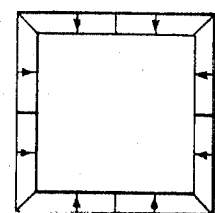


FIG. 3a
ARRIVING H_{10}
WAVE

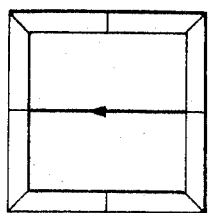
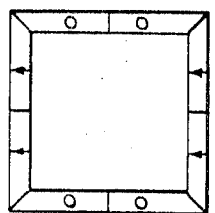


FIG. 3c
ARRIVING E_{11}
WAVE

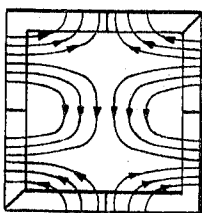
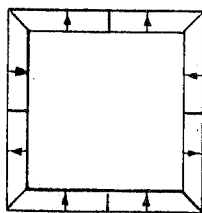


FIG. 3e
ARRIVING H_{21}
WAVE

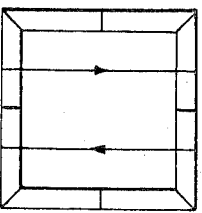
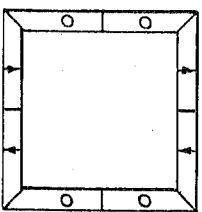


FIG. 3g
ARRIVING H_{20}
WAVE

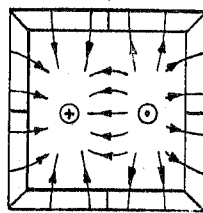
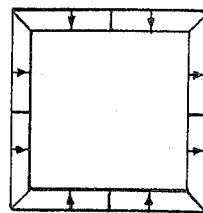


FIG. 3i
ARRIVING E_{12}
WAVE

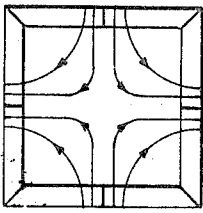
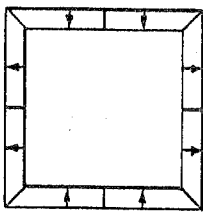


FIG. 3j
ARRIVING H_{11}
WAVE

FIG. 7

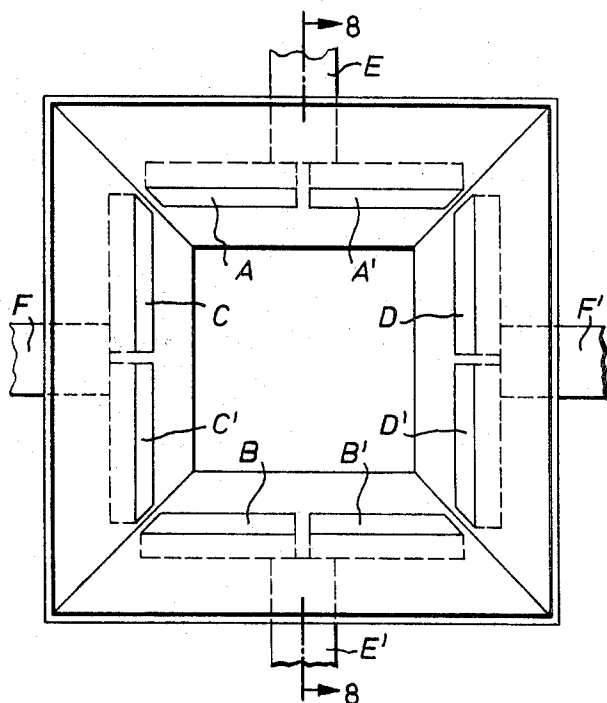


FIG. 9a

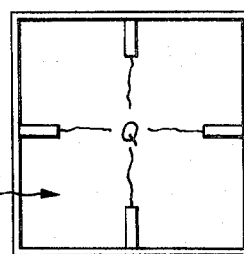


FIG. 9b

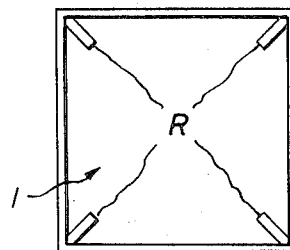


FIG. 8

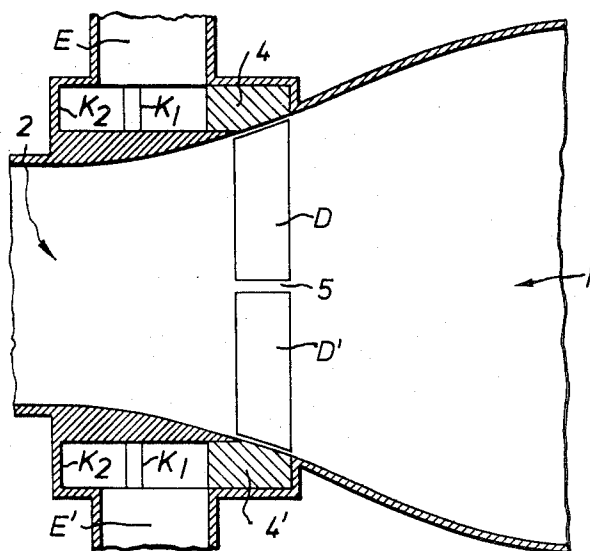
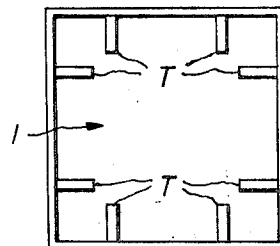


FIG. 9c



WAVEGUIDE MODE COUPLER FOR SEPARATING WAVES OF USEFUL MODE FROM WAVES OF HIGHER MODE

BACKGROUND OF THE INVENTION

This invention relates to a mode coupler for ranging systems, and particularly to a mode coupler useful in ranging systems for the evaluation of higher wave modes in a waveguide resulting from aperture deviations in the exciter of an antenna to determine the angular deviation in the azimuth plane as well as in the elevation plane wherein the waves of the useful mode are separated from the waves of a higher mode.

The requirements of ranging methods are such that it is desirable to have criteria which are as sharp and accurate as possible for determination of the ranging direction. These criteria are expressed in angular deviation in the horizontal plane, i.e. the azimuth plane, and in the vertical plane, i.e. the elevation plane. To detect the location of a transmitter, for example a satellite-carried transmitter whose operating frequency lies in the gigahertz range and which includes mirror antennae fed by waveguides, for example a parabolic antenna with an exciter horn, a Cassegrain antenna, a parabolic horn antenna, it is the established practice to evaluate higher waveguide wave modes which are produced in the receiving antenna during reception when the impinging wavefront of the useful signal does not impinge parallel to the aperture of the exciter. In particular, for use of the ranging system in satellite ground stations, it is important that the wave modes selected for evaluation simultaneously furnish criteria for the angular deviation in the azimuth plane as well as in the elevation plane.

It is known that various possible field configurations or modes can exist in a waveguide. These modes are of two fundamental types. In one type, the electric field is transverse to the axis of the waveguide and has essentially no electric field component in the direction of the waveguide axis, the associated magnetic field having a component in the direction of the axis. Modes of this type are termed H modes, or transverse electric, or TE modes. In the other type, the magnetic field is transverse to the axis of the waveguide and has essentially no magnetic field component in the direction of the waveguide axis, the associated electric field having a component in the direction of the axis. Modes of this second type are termed E modes, or transverse magnetic, or TM modes. The different modes are conveniently identified by double numerical subscripts which may be generally illustrated by letter subscripts; e.g. H_{mn} and E_{mn} .

If the characteristic of the useful mode is used, i.e. in the instant illustrative case the H_{10} mode wave or the H_{11} mode wave, this wave has a maximum of impinging energy in the aligned state. If it is inclined to the maximum at an angle, the received power decreases according to the antenna characteristic. If there exists, however, a deviation in the aperture of the exciter in the antenna at the maximum receiving level, there are produced in the antenna itself not only the useful mode of the impinging signal of the now weakened wave type, but, in addition, wave modes of a higher order whose energy is proportional, within certain limits, to the angular deviation.

A system which evaluates the E_{01} and the H_{01} mode waves is used, for example, with circular exciters. With

a quadratic exciter, the H_{20} or H_{02} mode waves are used. A mode coupler is required to evaluate the wave modes which decouples, as completely as possible, only the desired modes without significantly interfering with the useful mode (e.g. H_{10} , H_{01}) or decoupling energy components thereof. It is mandatory that no energy components whatsoever of the received useful signal be decoupled and lost in the ranging process. A further problem is the required large bandwidth of the decoupling arrangement. The H-mode corresponds to the TE-mode, and the E-mode corresponds to the TM-mode.

SUMMARY OF THE INVENTION

Since the requirements, i.e. wide bandwidth and decoupling of the ranging information free from useful energy, could not sufficiently be met by the previously used mode couplers, it is a principal object of the present invention to provide a mode coupler which meets these requirements.

The foregoing object, as well as others which are to be made clear from the following text, are accomplished by providing a mode coupler, useful in ranging systems, for evaluating higher waveguide wave modes resulting from aperture deviation of an antenna exciter for determining angular deviation in the azimuth plane as well as in the elevation plane. Waves of the useful mode are separated from waves of a higher mode. A first waveguide section for propagating all evaluable wave modes and adapted to be coupled to an antenna is provided. A second waveguide section for propagating exclusively the useful wave mode is connected in series with the first waveguide section. A gap is provided between the two waveguide sections and has a plurality of apertures of the higher wave modes in the direction of propagation of the waves. New modes corresponding to the higher wave modes are substantially excited by the useful mode containing the ranging signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially sectional view of a mode coupler according to the present invention, viewed in the direction from the associated receiving antenna.

FIG. 2 is a sectional view of the mode coupler of FIG. 1, the section being taken through a plane 2—2 of FIG. 1.

FIGS. 3a—3f show diagrammatically the various wave modes produced by the deviation of an antenna from the receiving direction and their conversion into waves of the H_{10} mode in a mode coupler according to the present invention.

FIG. 4 is a cross-sectional detail view of an arrangement for the decoupling of the higher mode waves from the mode coupler of FIGS. 1 and 2.

FIG. 5 is a simplified, cross-sectional detail view of a modified version of the coupler of FIGS. 1 and 2.

FIG. 6 is an axial cross-sectional view of a decoupling arrangement for reducing the interference with the useful signal by the decoupling of the waves of higher modes.

FIG. 7 is an axial diagrammatic view of a mode coupler according to an embodiment of the present invention with an infinite waveguide transition.

FIG. 8 is a cross-sectional view along line 8—8 of FIG. 7.

FIGS. 9a to 9c show diagrammatically compensation arrangements for suppressing E-type wave modes.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1 and 2 illustrate a mode coupler according to the present invention, FIG. 1 being a view from the antenna input and FIG. 2 being a sectional view from a side. A first waveguide section 1 (FIG. 2) with its large cross section faces the antenna (not shown) and is so dimensioned that H_{10} and H_{01} waves, which are of the useful type, and H_{20} and H_{02} waves, which provide the criterion for angular deviation which is evaluated as the follow-up criterion, can propagate. At a point 3 (FIG. 2) of the mode coupler the waveguide cross section is narrowed in such a manner that no H_{20} or H_{02} waves can propagate any longer in a second waveguide section 2 (FIG. 2), which follows section 1 and point 3 in the propagation direction of the signals arriving from the antenna. Between the two waveguide sections 1 and 2 there is a gap because of the difference in cross-sectional areas of the two waveguide sections 1 and 2. The two waveguide sections 1 and 2 are so positioned that the gap between them extends uniformly about the periphery of the second waveguide section 2. The gap is divided into eight outer waveguides A, A', B, B', C, C', D and D' by a total of four pairs of bars 4-4', 5-5', 6-6', and 7-7', all eight outer waveguides formed within the gap being able to propagate the useful H_{10} wave.

The operation is such that signals of the different wave types arriving from the antenna excite each induce useful H_{10} mode waves in the eight waveguides A, A', B, B', C, C', D and D'. The phase position of the H_{10} mode waves depends on the nature of the arriving wave mode. This dependence of the phase position on the nature of the arriving wave mode is shown diagrammatically in the individual FIGS. 3a to 3f.

These figures illustrate the path and the direction of the field lines in the eight waveguides A, A', B, B', C, C', D and D' by the gap provided between the two waveguide sections 1 and 2 for six different respective wave modes which may exist in the impinging signal. The arriving wave modes, as illustrated respectively in FIGS. 3a to 3f, are H_{10} , H_{20} , H_{11} , E_{11} , H_{21} and E_{12} . Any wave mode produced due to the deviation of the antenna from the direction of the impinging signal or by other exciter characteristics produces H_{10} mode waves of a defined polarity in these small waveguides A, A', B, B', C, C', D and D' which are formed by the gap between the two waveguide sections 1 and 2, by virtue of the differing cross sections, and a number of partitions, formed by four pairs of bars 4-4', 5-5', 6-6' and 7-7' which define apertures. Thus the different arriving wave types produce new H_{10} mode waves which correspond to the deviation of the antenna and whose energy is a measure of the deviation. Each received wave mode produces, in one pair of the outer waveguides formed in the gap (e.g. pair A, A' of FIG. 1), identically phased or oppositely phased H_{10} waves of the same amplitude. In a second pair of outer waveguides opposite this pair (e.g. pair B, B' of FIG. 1) the H_{10} amplitudes are the same. The phase difference, however, for example between A and B may be 0° (e.g. for the H_{20} mode wave) or 180° (e.g. for the H_{21} or E_{21} mode wave). The aperture-defining bars 4, 4', 5, 5' etc. associated with oppositely disposed pairs of outer waveguides A-A',

B-B' etc. have a predetermined finite length so that the oppositely phased H_{10} components combine to form an H_{20} mode wave; the identically phased H_{10} components combine to form a single H_{10} mode wave.

Four rectangular waveguides E, E', F and F' are attached to the coupler for decoupling the H_{20} component which, as shown in FIG. 1, only decouples the oppositely phased signal components of the H_{20} mode wave. These signals of the H_{20} mode are a measure of the deviation of the antenna from the direction of the arriving signals. If a signal of the H_{10} mode, for example, does not impinge perpendicularly, this deviation produces other wave modes, particularly higher modes. Their energy is thus a measure for the deviation from the direction of the impinging signal. The H_{20} mode wave is used to evaluate the deviation, the configuration of the mode coupler separating the H_{20} mode wave from the useful signal of the H_{10} mode wave. This is accomplished as a result of the staggering of the two waveguide sections 1 and 2 which have different cross-sectional areas. In the thus resulting gap, suitable arrangement of the partitions formed by the bars 4, 4', 5 and 5' which define apertures, produces a preference for the H_{20} mode wave since it exists in the corresponding waveguides, for example waveguides A-A'.

As utilized in the ranging art, as already mentioned, the H_{20} mode waves are used for determining the deviation of the antenna in a first direction, and the perpendicularly disposed H_{02} mode waves are used for determining the deviation of the antenna in a direction perpendicular to the first direction. The waveguides E-E' must be provided for the first direction (H_{20} mode) and the waveguides F-F' for the other direction (H_{02} mode) which is perpendicular to the first direction.

A single pair of outer waveguides A and A' with associated decoupling members is shown, in a top view, in FIG. 4. In order to be able to decouple the entire H_{20} energy, the wave must run against a short circuit K1 which may be realized, for example, by narrowing the broadside of the pair of waveguides A and A'. The H_{10} component is thus influenced only slightly and can be short-circuited at a point K2 at a predetermined distance S from the entry points to the waveguides A and A' so that a short circuit is transformed into plane E1, i.e.

$$l_{elec} = f(s) \approx n \cdot \lambda/2$$

wherein l_{elec} is the total electrical length from the short circuit K2 to the waveguide apertures A, A'; B, B'; C, C'; D, D'; $f(s)$ is a function of the geometrical length S (FIG. 4) of the waveguide section: $n = 1, 2, 3 \dots$; λ is the actual waveguide-wavelength. The condition defined by the foregoing formula is not critical; it is only necessary that, for all operating frequencies the expression

$$l_{elec} \neq k \cdot \lambda/4 \quad (k = 1, 3, 5, \dots)$$

prevail since otherwise resonance phenomena may become apparent which would make a broadbanded compensation of the reflection factor of the useful wave at the transition from larger waveguide section 1 to the smaller waveguide section 2 more difficult.

The arrangement of FIG. 4 corresponds to a folded magic T whose sum branch is short-circuited at the point K2 and whose difference branch is formed by the waveguide E. The partitions or bars 4, 4', 5, 5' in FIG. 1 can theoretically be left out; however, they reduce

the undesirable coupling of the H_{10} (H_{01}) mode wave from the first waveguide section 1 into the outer waveguides such as waveguides A, A'. Thus the bar 4 is present in the decoupler shown in FIG. 4.

With respect to matching, the decoupling of the oppositely phased wave components by the pairs of waveguides E, E' and F, F' does not produce difficulties. The main problem is the conversion without reflection of the H_{20} (H_{02}) mode waves of the first waveguide section 1 to oppositely phased H_{10} mode waves in the eight outer waveguides A, A'; B, B' and C, C'; D, D'. In the transition region between the two waveguide sections 1 and 2, the E field lines of the H_{20} (H_{02}) mode wave, shown in FIG. 1, experience a relatively strong field distortion so that the E field components appear in the propagation direction and their shift currents are converted by a pair of conductive pins ST to a longitudinal flux of the wave in the flat waveguides A and A'. This measure improves the H_{20} (H_{02}) mode wave matching quite considerably.

A further improvement is obtained by influencing the H_{20} mode wave blind field at the beginning of the second waveguide section 2, for example by metallic or dielectric bars M (FIGS. 1 and 2). Instead of providing the bars M, the second waveguide section 2 may be constructed to be wider at its beginning in the form of a pyramid at the point at which it meets the first waveguide section 1, as shown in FIG. 5. An additional improvement in matching may be obtained with compensation elements, for example capacitive plungers, inductive apertures, etc., in the outer waveguides A, A', B, B', C, C' D and D' and/or in the first waveguide section 1. Inductive apertures are particularly effective for the H_{20} and H_{02} mode waves in the first waveguide section 1 since the waveguide is operated relatively closely to the H_{20} mode wave limit frequency. The influence of inductive apertures on the H_{10} (H_{01}) mode wave, i.e. the useful mode, is slight and can easily be compensated by the provision of further compensating bars P, as shown in FIG. 6.

It can be seen from the above description that the waveguides E, E' serve to decouple portions of the H_{20} , H_{21} and E_{21} mode waves; the waveguides F, F' serve to decouple portions of the H_{02} , H_{12} and E_{12} mode waves. The portions of the H_{21} , E_{21} and H_{12} , E_{12} mode waves are undesirable; however, external comparator circuits or comparator networks are provided to eliminate them. FIG. 1 shows this circuit only for the waveguides E, E', for the waveguides F, F' an identical circuit is provided. The circuit shown in FIG. 1 includes the two waveguides E and E' of the same electrical length and a branch circuit T which is known as a magic T circuit. The decoupled H_{20} (H_{02}) energy portions appear in a difference branch Y and the energy of the decoupled E_{21} , H_{21} (E_{12} , H_{12}) portions appears in a sum branch S.

The mode coupler of the invention is operated as a relatively strongly excess-mode producing waveguide which leads, particularly at the point of change of cross sections between the two waveguide sections 1 and 2, to the excitation of higher wave modes. In order to meet the marginal requirements, E_{12} , H_{12} and H_{30} mode waves (as well as E_{21} , H_{21} and H_{03} mode waves) are required most of all.

The above-described mode coupler is only one of various possible embodiments according to the present invention. Another embodiment is shown in FIG. 7, in a frontal view, seen from the antenna exciter and in

FIG. 8, in a side view, in a partially sectional representation. The mode coupler shown in FIGS. 7 and 8 is constructed with an infinite waveguide transition. The change in cross section between two waveguide sections 1 and 2 is thus softened; accordingly, the intensity of the excited higher mode waves varies. It should be noted that the limit frequency of the excited E wave types in the waveguide section 1 can be increased by bar arrangements to such an extent that they can no longer propagate. Three examples are shown diagrammatically in FIGS. 9a, 9b and 9c. The bars Q of FIG. 9a influence the H_{20} mode wave only insignificantly; the bars R of FIG. 9b and the bars T of FIG. 9c reduce the H_{20} mode wave limit frequency. The embodiment according to FIGS. 9b and 9c has the additional advantage that the change in cross section between the first waveguide section 1, with bars, and the second waveguide section 2, without bars, can be reduced.

The above-described mode couplers have a relatively broad band capability of about 15 percent due to their particular configuration. Thus these mode couplers gain increased significance because the heretofore required very complicated and time-consuming frequency matching is eliminated.

In order to further improve its characteristics it is advisable to use a rather broadbanded mode coupler, but to operate it only over a narrow band, i.e. to make it tunable over a narrow band at a very defined point, namely at the point where the decoupling of the higher modes takes place.

For this purpose the space directly behind the point for decoupling of the higher modes is designed as a resonant circuit and is made tunable. The resonant frequency of this area should be limited in the transmission band to the H_{20} (H_{02}) mode wave. Since the H_{10} (H_{01}) mode wave is coexistent in this area, the resonance of which area can be set to a frequency outside of the transmission range independent of the H_{20} (H_{02}) resonance, there results a practically uninterfered with useful channel. The existence of this resonant circuit requires that this resonant area be substantially enclosed, i.e. the coupling or decoupling is low. The insertion of apertures in the direction of the mode coupler as well as toward the output (magic T) can produce this effect.

With this arrangement an almost interference-free useful channel is obtained.

This resonant circuit will have tuning members to produce tunability, which members are included in the resonant circuit in the form of calibratable tuning screws or other calibratable tuning means. The calibratability of such tuning means will then permit matching in a simple manner.

Additionally, it should be mentioned that the comparator network shown in FIG. 1 with waveguides can also be realized as a coaxial comparison circuit or a stripline arrangement.

The dimensions of an operative embodiment of the invention are:

1. width of the large waveguide 1 58.2×58.2 mm
 2. width of the smaller waveguide 2 46×46 mm
 3. dimension of the gaps A, B, C, D are 5 mm
 4. width of the bars 4, 5, 6, 7 and the wall between waveguide 1 and 2 1.1 mm
 5. the operation frequency is $5.9 \leq f \leq 6.5$ GHz.
- It will be understood that the above description of the present invention is susceptible to various modifica-

tions, changes and adaptations and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

I claim:

1. A mode coupler for use in ranging systems for evaluating waveguide wave modes resulting from aperture deviations of an antenna exciter for determining angular deviation in the azimuth plane as well as in the elevation plane wherein waves of a useful mode are separated from waves of a higher mode, comprising a first waveguide section for propagating all evaluatable wave modes and adapted to be coupled to an antenna; a second waveguide section dimensioned for propagating exclusively the useful wave mode and connected in series with said first waveguide section so as to create a gap between said first waveguide section and said second waveguide section, said gap being provided with means to define a plurality of apertures for the higher wave modes in the direction of propagation of the waves whereby new modes corresponding to the higher wave modes are substantially excited by the useful mode.

2. An arrangement as defined in claim 1 wherein said first waveguide section and said second waveguide section are each of square cross section, said second waveguide section being smaller than, and positioned within at least a portion of, said first waveguide section so as to define said gap.

3. An arrangement as defined in claim 1 wherein said first waveguide section and said second waveguide section are of square cross section and form respective parts of a single waveguide having a region of progres-

sively decreasing cross section between said first and second sections and in the direction of wave propagation, the tapering of said waveguide being so dimensioned that all evaluatable wave modes exist in said first waveguide section adapted to face the antenna and only the useful mode exists in said second waveguide section, and said means which defines said plurality of apertures includes a plurality of slits disposed between said first waveguide section and said second waveguide section, said slits being so dimensioned that only the higher mode waves are coupled out.

4. An arrangement as defined in claim 3 further comprising a three branch T circuit having two equal input branches and an output branch, and at least two oppositely disposed waveguide output means coupled respectively between said mode coupler and respective ones of said input branches of said T circuit for receiving signals from the mode coupler and supplying these signals to said T circuit, whereby a ranging signal is available at said output branch of said T circuit.

5. An arrangement as defined in claim 4 wherein each of said waveguide output means comprises a respective waveguide section each having its center axis perpendicular to the longitudinal axis of said first waveguide section and said second waveguide section.

6. An arrangement as defined in claim 5 wherein each of said waveguide output means are tunable resonant circuits whereby said waveguide output means are loosely coupled to said mode coupler and loosely decoupled to said input branches of said T circuit.

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