United States Patent [19]

Mörz

[11] **3,758,882**

[45] **Sept. 11, 1973**

[54] **POLARIZATION CONVERTER FOR MICROWAVES**

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[22] Filed: **Nov. 11, 1971**

[21] Appl. No.: **197,897**

[30] **Foreign Application Priority Data**

Nov. 11, 1970 Germany .... P 20 55 443.2

[52] **U.S. Cl.** .... **333/21 A,** 333/98 R

[51] **Int. Cl.** **H01p 1/16**

[58] **Field of Search** .... 333/21, 21 A, 95, 333/98, 1, 9; 343/754, 786

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Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Marvin Nussbaum
Attorney—George H. Spencer, Harvey Kaye et al.

[57] **ABSTRACT**

A microwave polarization converter for converting a linearly polarized wave into an elliptically, and particularly a circularly, polarized wave, the converter including a waveguide which propagates only two mutually orthogonal waves and coupling means disposed in the waveguide for coupling such orthogonal waves.

18 Claims, 20 Drawing Figures

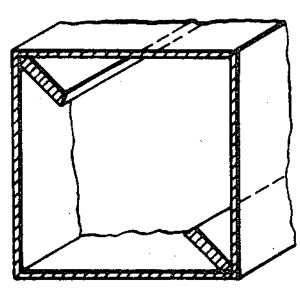


FIG.1a

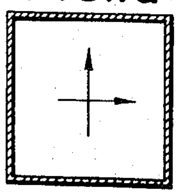


FIG.1b

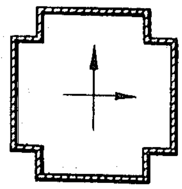


FIG.1c

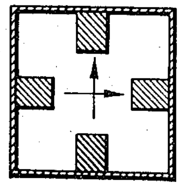


FIG.1d

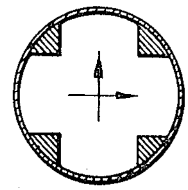


FIG.2a

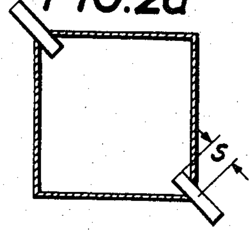


FIG.2b

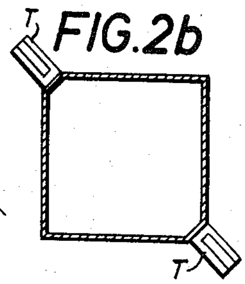


FIG.2c

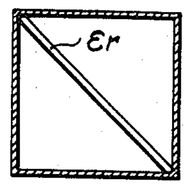


FIG.2d

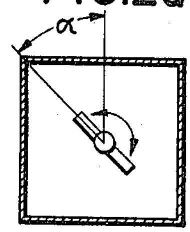


FIG.3a

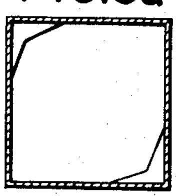


FIG.3b

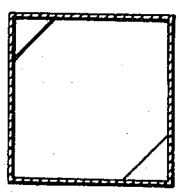


FIG.3c

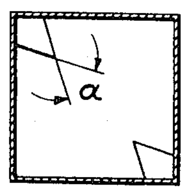


FIG.3d

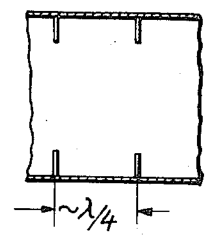


FIG.4a

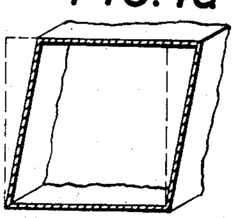


FIG.4c

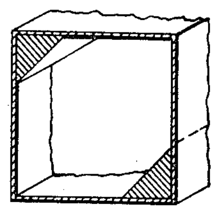


FIG.4b

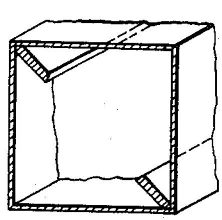


FIG.4d

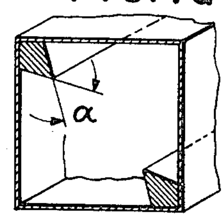


FIG. 5a

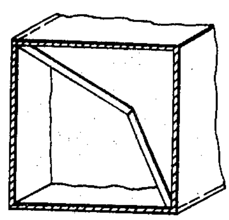


FIG. 5b

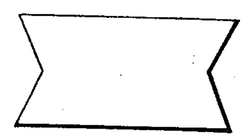


FIG. 6a

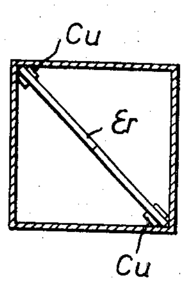
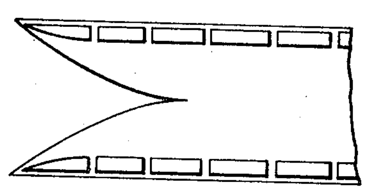


FIG. 6b



POLARIZATION CONVERTER FOR MICROWAVES

BACKGROUND OF THE INVENTION

The present invention relates to a polarization converter for microwaves, particularly for the situation where linearly polarized waves are fed into a waveguide.

Polarization converters are already used in the microwave art mainly to convert a linearly polarized wave into an elliptically or circularly polarized wave, a reconversion being similarly possible. Particular practical imporatance is attached to the production of circularly polarized waves, which are used mainly in the radar art and for the transmission of data via earth satellites.

A circularly polarized wave can be produced from two orthogonal waves having the same amplitude and a phase difference of 90°. In most of the presently employed circular polarizers with particularly rectangular cross-section two orthogonal waves having the same phase are fed into a doubly polarized waveguide. A delay structure within the waveguide then delays a part of the wave by 90° to produce the desired phase difference. These arrangements all have the drawback that they require a component which splits a linearly polarized wave into two orthogonal waves.

SUMMARY OF THE INVENTION

It is an object of the present invention to reduce the fabrication cost of polarization converting devices. This and other objects of the present invention are achieved by the provision of a polarization converter composed of a waveguide which permits the passage of only two independent orthogonal waves and which is provided with wave coupling means. Such waveguides which permit two independent orthogonal waves either have a rectangular or cruciform cross section or are provided with longitudinal bars along their inner walls.

A polarization conversion in a waveguide can be effected by means of lumped coupling elements such as coupling pins, $\lambda/4$ coaxial line resonators, coupling pins disposed on a shaft which rotates about the axis of the waveguide, or dielectric coupling pins which are perpendicular to the axis of the waveguide.

Diagonally arranged coupling apertures of different designs, depending on the particular requirement, also effect a conversion of the polarization. Use can also be made of distributed wave coupling means such as bars disposed along inner corners of the waveguide. The waveguide itself, when deformed into rhomboidal form relative to its coupling length, acts as a polarization converter. A diagonally disposed dielectric plate, particulary when it has swallow tail shaped recesses at its diagonal sides, also acts as a polarization converter.

The theory of directional couplers teaches that when two waves which have the same phase constant are coupled, a phase difference of 90° exists between the exciting and the coupling wave under certain conditions. If this coupling principle is applied to a doubly polarizable waveguide which permits only two independent orthogonal waves, it becomes a simple matter to produce a circular wave if a linearly polarized wave is fed-in and the existing coupling attenuation is 3 dB. Each coupling attenuation $\alpha \neq 3$ dB and $\neq 0$ dB then produces an elliptically polarized wave whose major-to-minor axis ratio can be calculated easily from the coupling attenuation.

A coupling attenuation of 0 dB re-establishes a linearly polarized wave which is rotated in space by 90° with respect to the fed-in wave. This arrangement corresponds to a 90°polarization shifter for doubly polarized waveguides which is constructed in the simplest manner and which would otherwise have to be substantially more complicated structurally.

The coupling of the two waves in the polarization converter may be distributed along the lengh of the polarizer or occur at concentrated, or discrete, regions thereof. Distributed coupling is intended to mean that the coupling occurs over a longer section of the waveguide, comparable to a slit coupling. An additional distinction here is that the distribution is constant over this length, in contrast with a functionally distributed but tapered coupling, which is so designed that the coupling effected is only slight at the beginning of the coupling section, increases to a maximum in the center of the coupling section, and then decreases again toward the end of the section. The latter has the advantage, compared to a constant distribution, that better directional characteristics and matching can be attained. This tapered coupling can also be used for concentrated coupling elements, a distance of $\lambda/4$ between the individual coupling elements preferably being selected. The coupling arrangement is advisably so designed that the coupled wave essentially has only one continuous component.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. *1a*, *1b*, *1c* and *1d* are cross-sectional views of several configurations of waveguides used in embodiments of the invention.

FIGS. *2a*, *2b*, *2c* and *2d* are cross-sectional views of several embodiments of waveguides with concentrated coupling elements according to the invention.

FIGS. *3a*,*3b* and *3c* are cross-sectional views of embodiments of waveguides with coupling apertures according to the invention.

FIG. *3d* is a longitudinal cross-sectional view of a waveguide with apertures provided according to the invention.

FIGS. *4a*, *4b*, *4c* and *4d* are cross-sectional perspective views of waveguides with uniformly distributed couplings according to the invention.

FIG. *5a* is a cross-sectional perspective view of a waveguide with a dielectric plate coupling according to the invention.

FIG. *5b* is an elevational view of the dielectric plate of the embodiment of FIG. *5a*.

FIGS. *6a* and *6b* are a cross sectional view of an embodiment of a polarization converter-coupling structure consisting of a dielectric plate which is partly copper-cladded.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Different cross-sectional configurations of waveguides which can be used in embodiments of the invention are shown in FIG. 1. These are waveguides in which only two independent mutually orthogonal waves can exist, this being true for the square waveguide of FIG. 1a and the cruciform waveguide of FIG. *1b*. Modified versions are the square waveguide with longitudinal bars shown in FIG. *1c*, and a circular waveguide with longitudinal bars shown in FIG. *1d*, in each case the bars establishing a cruciform waveguide cross section.

In general, the subsequently described coupling principles are suited for all such waveguides. They will be explained, however, only for the example of a square waveguide. The coupling arrangements must be adapted to the waveguide in such a manner that the propagation characteristics will be the same for the two polarization directions. This is the case when the coupling is effected at an angle of 45° to both of the polarization directions.

Embodiments of concentrated coupling elements are shown in FIG. **2.** FIG. **2***a* shows coupling pins which are arranged at diametrically opposed corners of the guide. The double-sided arrangement is particularly suited for waveguides operated with overmodes. Waveguides operated with overmodes are waveguides in which not only one wavetype or mode, exists, but which permit transmission of a plurality of modes or types. In such waveguides the coupling elements must be arranged diagonally on both sides while in waveguides which can propagate only a single mode, coupling elements are only required in one corner.

Thin coupling pins act substantially capacitively and provide a coupling attentuation which decreases with increasing frequency. Thick, short pins act mainly inductively and provide a coupling attenuation which increases with increasing frequency. The insertion depth s of the pins must be $<\lambda/4$ where λ is the wavelength, in the guide, of the wave. With a suitable selection of the pin thickness and insertion depth, a coupling attenuation frequency behavior can be attained which is approximately symmetrical about a certain frequency. If a polarization conversion is to be effected only over a very narrow frequency band, the pins may be constructed in the form of $\lambda/4$ coaxial line resonators T which are coupled in only weakly, as shown in FIG. **2***b*.

The electrical coupling pins of FIG. **2***c* show a behavior similar to metallic pins, but without the danger of resonance. The coupling pins can, of course, also be adjustable, e.g., in the form of threaded pins so that the coupling attenuation can be varied over a very wide range. This also permits the realization of very exact tuning.

A very rapid variation of the coupling attenuation can be obtained by the simultaneous movement of all coupling pins. In FIG. **2***d* the coupling pins are arranged centrally on an axially rotatable shaft within the waveguide. For $\alpha = 45°$ maximum polarization conversion results; for $\alpha = 0°$ no polarization conversion occurs. Of course the variation can also be effected in some other way, for example by means of a mechanical device which permits common variation of the insertion depth of the coupling pins.

Aperture plates as shown in FIGS. **3***a* and **3***b*, which are placed at one or two diametrically opposed corners, couple predominantly inductively, i.e., the coupling attentuation increases with increasing frequency. With the apertures of FIG. **3***c*, a substantially frequency symmetrical coupling behavior can be obtained in a certain frequency range by the appropriate selection of angle α.

The longitudinal section of a waveguide provided with apertures is shown in FIG. **3***d*. It is here to be indicated that the apertures are arranged in the polarization coverter with approximately a $\lambda/4$ spacing.

By a deformation of the waveguide a uniformly distributed coupling can be obtained. The coupling attentuation increases with increasing frequency. The most important case of this is the rhombic deformation which is shown in FIG. **4***a*.

Similarly as the described coupling pins and coupling apertures, use can be made of thin bars, as shown in FIG. **4***b*, which act capacitively. On the other hand, the triangular cross section bars shown in FIG. **4***c* are predominantly inductive. Quadrilateral arrangements as shown in FIG. **4***d*, depending on the angle α value selected, have a symmetric coupling behavior with respect to a certain frequency and are particularly broadbanded.

A dielectric plate in the diagonal plane, as shown in FIG. **5***a*, which is advisably tapered at its ends in the manner of a swallowtail, preferably acts capacitively. Its shape can be seen more clearly in FIG. **5***b*.

Parituclarly advantageous characteristics result when two coupling types with oppositely directed frequency behaviors, i.e., one inductive and one capacitative, are combined. The broadband characteristtics which are then obtained are particularly good. It is also advisable to make one of the two components turnable, e.g., a combination of capacitive coupling pins which are designed as threaded pins are provided with inductive fixed members, for example inductive apertues, an inductive bar, or a deformed waveguide.

It can thus be seen that the present invention is very versatile and that individual embodiments can be combined resulting in characteristics which can be adapted to many requirements.

The coupling structure shown in FIGS. **6***a* and **6***b* provides very good broadband coupling characteristics because of the combination of two coupling means with oppositely directed frequency behaviors. The one is caused by the dielectric plate having a decreasing coupling attenuation with increasing frequency. The other is caused by the longitudinal coatings plated on the dielectric material having increasing coupling attenuation with increasing frequency. The copper-coatings may be connected to the outer waveguide. If they are insulated to the waveguide it is advisable to make some transversal-slots in order to avoid resonances.

The polarization converter as described in this invention is capable to replace the device described in the IRE-Transactions MTT 3, December 1955, no. 6, page 18 – 22 by Mr. Simmons: Phase-shift by Periodic Loading of waveguide and its Application to Broad-Band circular Polarization. This polarizer consists of a 45°-section (diagonalizer) and a phase-shift section. The advantage of this invention is that no 45°-section is needed.

The two orthogonal modes are formed by splitting the linearily polarized vector in two componets lying diagonally. These componets can only exist in a waveguide-region with the coupling element. The coupling element (for example dielectric plate) provides a different phase shift for both components. At the end of the coupling structure each diagonal-componet splits again in two orthogonal vectors which are now again parallel to the waveguide walls. The orthogonal waves at the end of the polarization converter result in the superposition of all these vectors. The phase-shift and the amplitude ratio of these waves depends on the phase-shift of the diagonal-components caused by the coupling structure. A specific example of the polarization converter (FIG. 6*a* and 6*b*) has a 700 mm-length and a 1,1 mm dielectric plate thickness. The copper-coatings have approximately a 9 mm width. The axial ratio of the elliptical polarized wave is better than 1.12 : 1 either in the 4 GHz- and the 6 GHz-region.

It will be understood that the above description of the present invention is susceptible to various modifications, 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 polarization converter for microwaves in which a linearly polarized wave is fed into a waveguide, said polarization converter comprising a waveguide capable of propagating two independent mutually orthogonal waves and arranged to receive the linearly polarized wave, and a pair of wave coupling means disposed in said waveguide along a plane oriented at an angle of 45° to the polarization directions of both such orthogonal waves, each wave coupling means of said pair extending in the direction of wave propagation for splitting a fed-in linearly polarized wave into two mutually perpendicular components lying diagonally to such polarization directions and for imparting respectively different phase shifts to such components, whereby at the end of said coupling means there are produced two orthogonal waves having the polarization directions which said waveguide is capable of propagating and differing from one another in phase, the resultant of the waves appearing at the end of said coupling means being a wave whose polarization direction rotates about the axis of said waveguide.

2. An arrangement as defined in claim **1** wherein said waveguide has a square cross section.

3. An arrangement as defined in claim **1** wherein said waveguide has a cruciform cross section.

4. An arrangement as defined in claim **1** wherein said waveguide comprises bars extending along the inner walls of said waveguide in the longitudinal direction.

5. An arrangement as defined in claim **1** wherein said waveguide has a circular cross section and comprises longitudinal bars extending along its inner wall to give the free interior of said waveguide a cruciform cross section.

6. An arrangement as defined in claim **1** wherein each said wave coupling means of said pair comprises a plurality of concentrated coupling elements spaced apart in the direction of wave propagation.

7. An arrangement as defined in claim **6** wherein said means comprise coupling pins.

8. An arrangement as defined in claim **6** wherein said means comprise $\lambda/4$ coaxial resonators.

9. An arrangement as defined in claim **6** wherein said means comprise dielectric coupling pins which are inclined to a side of said waveguide and are perpendicular to the axis of said waveguide.

10. An arrangement as defined in claim **6** wherein said means comprise axially rotatable coupling pins which are oriented at a given angle about the longitudinal axis of the waveguide.

11. An arrangement as defined in claim **6** wherein said means comprise diagonally arranged coupling apertures.

12. An arrangement as defined in claim **1** wherein each said wave coupling means of said pair comprises a distributed coupling element extending in the direction of wave propagation.

13. An arrangement as defined in claim **12** wherein said means comrise at least one coupling bar disposed along an inner corner of said waveguide.

14. An arrangement as defined in claim **1** wherein said coupling means are constituted by said waveguide being deformed into a rhombic shape over its coupling length.

15. An arrangement as defined in claim **1** wherein said coupling means comprise a dielectric plate which is disposed in a diagonal plane of said waveguide.

16. An arrangement as defined in claim **15** wherein said plate is provided with a recess in the form of a swallowtail at least at one diagonally extending side.

17. An arrangement as defined in claim **1** wherein said wave coupling means are physically symmetrical with respect to a diagonal of the cross section of said wave guide.

18. A polarization converter for microwaves in which a linearly polarized wave is fed into a waveguide, said polarization converter comprising a waveguide which propagates only two independent mutually orthogonal waves and arranged to receive the linearly polarized wave, and wave coupling means disposed in said waveguide, said coupling means being of the distributed type and being constituted by a dielectric plate oriented at an angle of **45°** to the polarization directions of both said orthogonal waves and extending in the direction of wave propagation, and longitudinal coatings of electrically conductive material disposed on said plate along the edges thereof which extend in the direction of wave propagation, said plate having a decreasing coupling attenuation with increasing wave frequency and said coatings having increasing coupling attenuation with increasing wave frequency.

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