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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,574,438

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) :

NASA Patent Case No. : ERC-10011

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes ☐ No ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

Elizabeth A. Carter

Enclosure

Copy of Patent cited above

FACILITY FORM 602

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United States Patent

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[72] Inventor John W. Carson
Cambridge, Mass.

[21] Appl. No. 802,818
[22] Filed Feb. 27, 1969
[45] Patented Apr. 13, 1971
[73] Assignee the United States of America as represented by the Administrator of the National Aeronautics and Space Administration

[54] **QUASI-OPTICAL MICROWAVE COMPONENT**
21 Claims, 8 Drawing Figs.

[52] U.S. Cl. 350/1, 333/81, 350/286
[51] Int. Cl. G02b 13/14, H01p 1/22
[50] Field of Search .... 333/30 (Inquired), 31A (Inquired), 81B (Inquired); 350/1.286, 151

[56] **References Cited**

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ABSTRACT: A quasioptical microwave component having a rotatably mounted dielectric body with input and output faces is disclosed. The dielectric body is adapted for connection in an oversize waveguide system such that polarized electromagnetic energy is incident on the input face at the Brewster angle. Rotation of the dielectric body in one direction attenuates the energy transmitted from the output face and rotation in the opposite direction produces a phase shift therein.

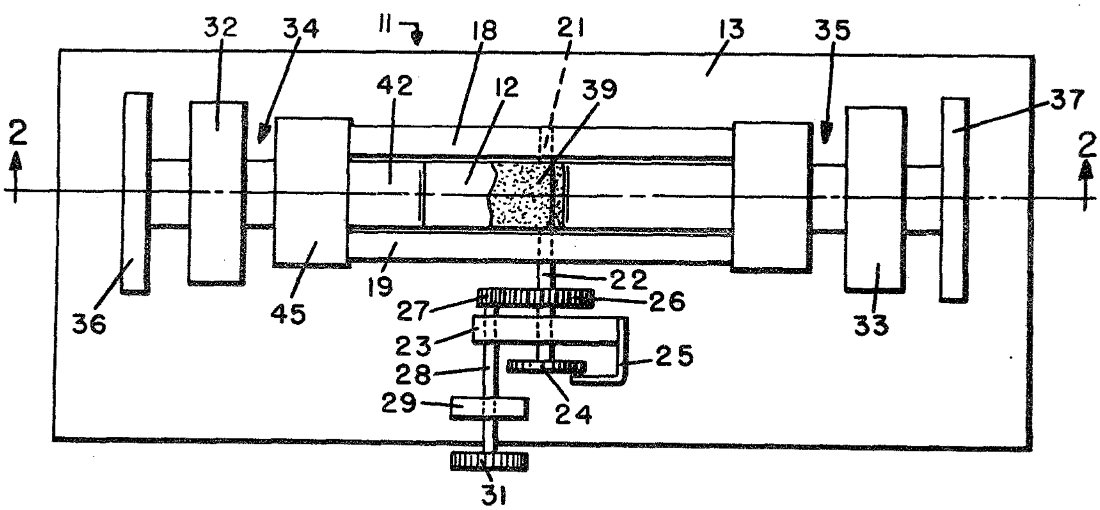

FIG. 1. N71-29065

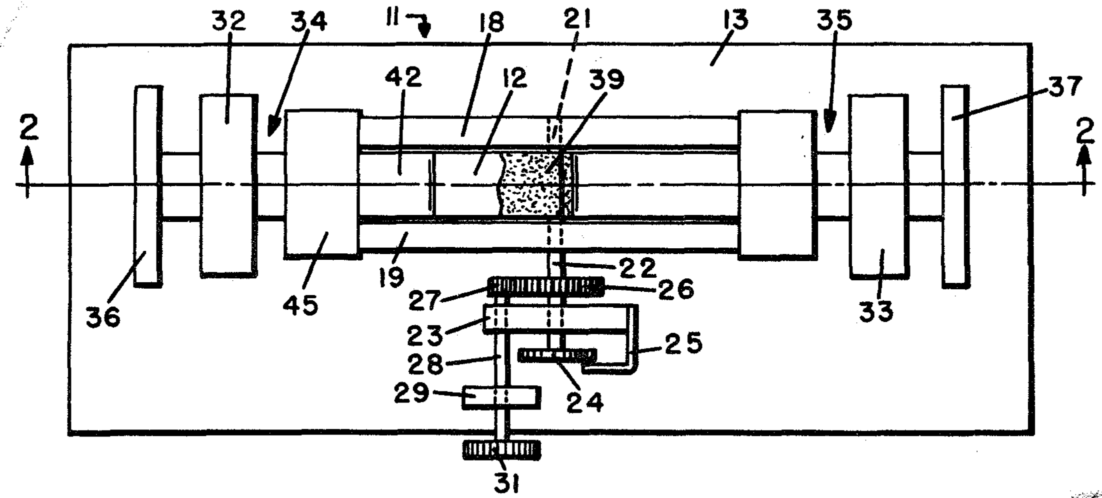

FIG. 2.

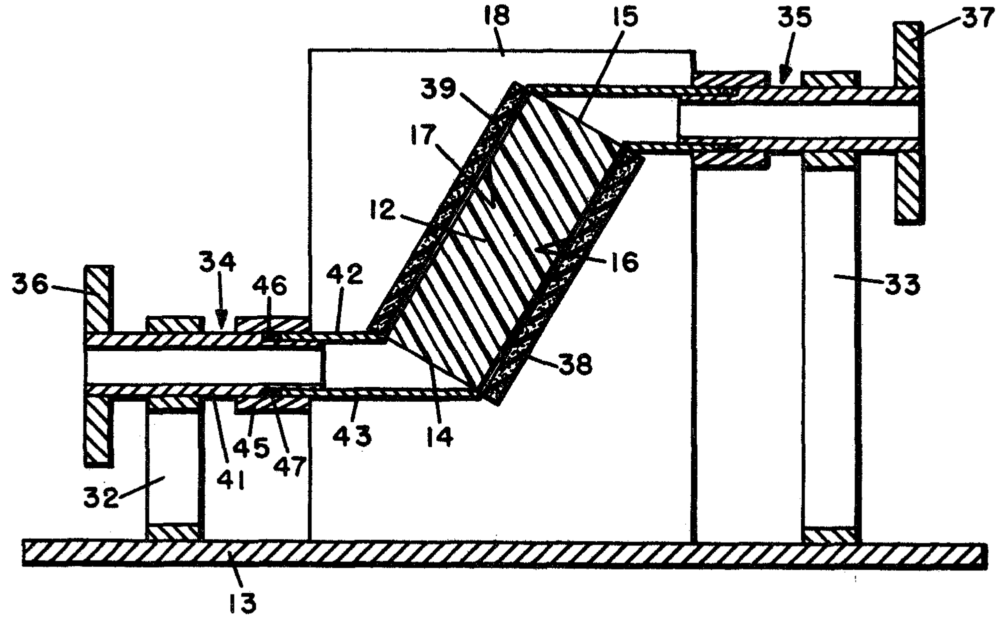

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FIG. 3.

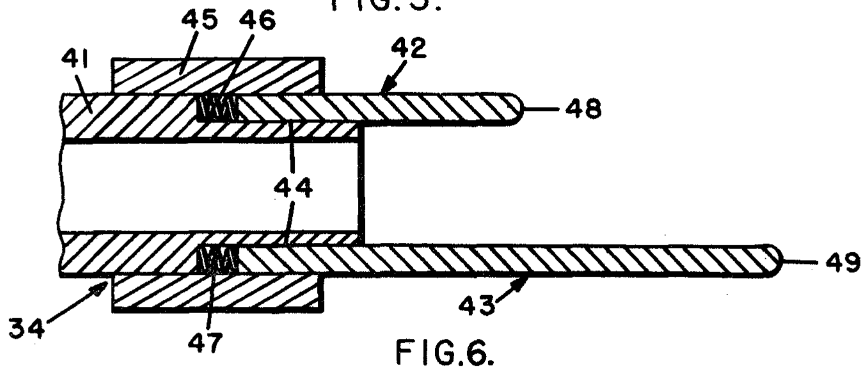


FIG. 6.

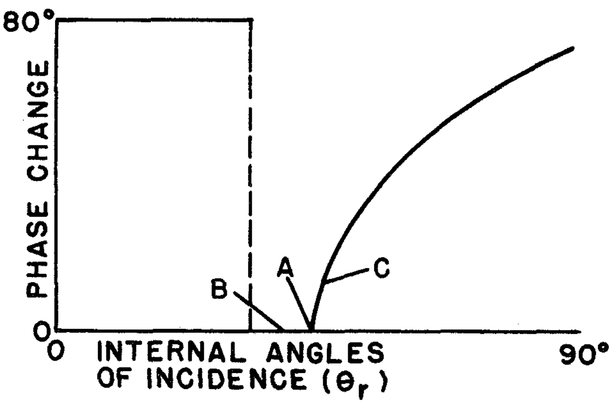


FIG. 7.

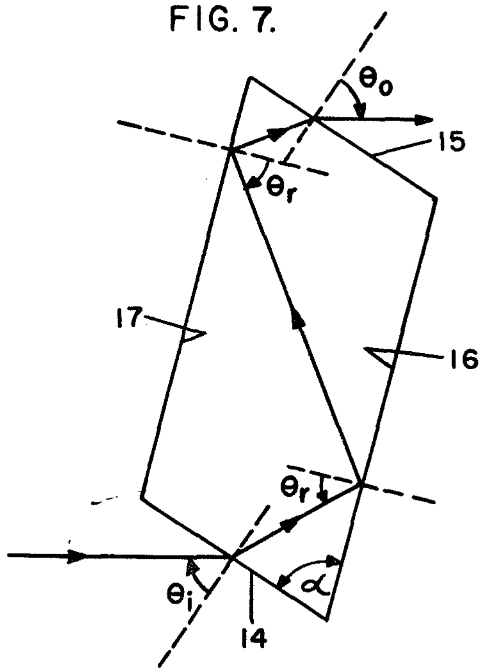


FIG. 8.

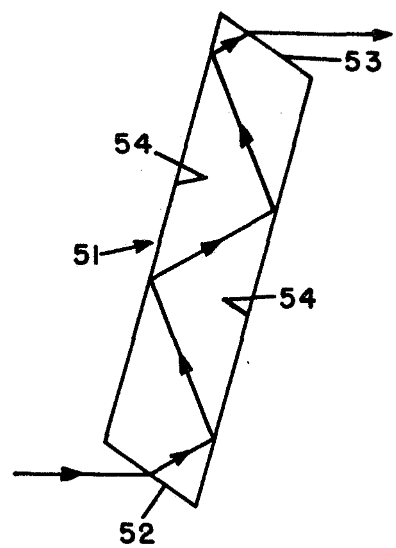


FIG. 4.

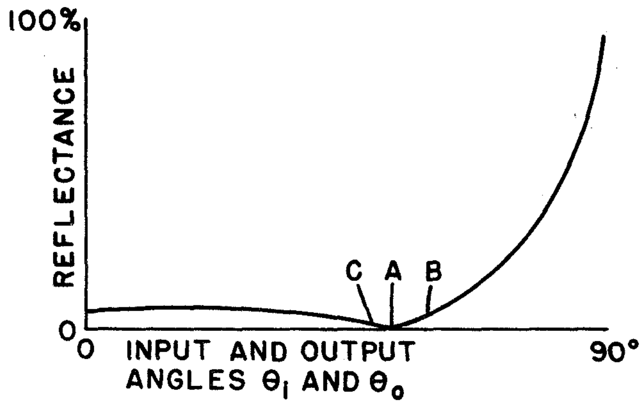
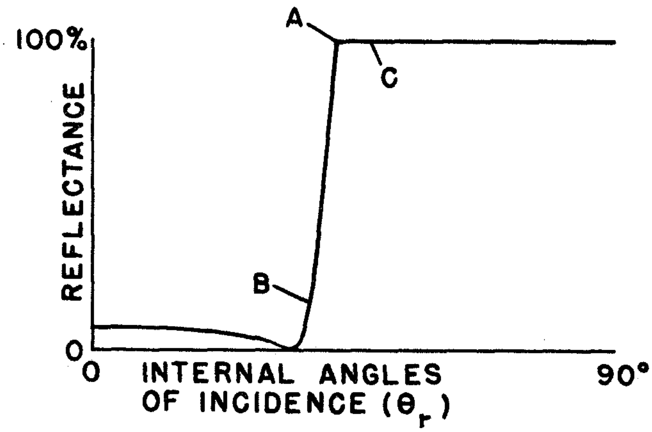

100%
REFLECTANCE
C A B
0
0
INPUT AND OUTPUT ANGLES θ_I AND θ_o
90°

FIG. 5.


A
100%
C
REFLECTANCE
B
0
0
INTERNAL ANGLES OF INCIDENCE (θ_r)
90°

QUASI-OPTICAL MICROWAVE COMPONENT

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates generally to quasioptical microwave components and, more particularly, relates to microwave components suitable for use in oversize waveguide systems.

Use of conventional, single-mode, rectangular waveguide in the millimeter and submillimeter range is accompanied by waveguide losses, which increase with frequency. One way of minimizing these losses is to use an oversize waveguide in which the propagation can approach that of a plane wave. In these cases, the microwave signals behave in a quasioptical manner, permitting the use of many standard optical components and techniques.

A known example of such a component comprises as its basic element a double prism. According to this device, the input signal is split at the adjustable air gap between the two prisms, part of the signal being reflected as one output and part transmitted as the second output. The energy division depends upon the gap distance and the wavelength. Components of this type are described in IEEE Trans. MTT 11, 338 (1963) and Microwaves, p. 20 Jan. 1964).

Although functioning to attenuate, phase shift or couple microwave energy, the above noted component exhibits a number of disadvantages. For example, because of reflection losses that occur at the input and output surfaces, a fine comb structure cut into the input and output faces normally is used to match impedance and reduce the VSWR. Such a comb structure is narrowband and becomes increasingly difficult to fabricate as the frequency is increased. Other less common impedance-matching methods also are narrowband or lossy or both. Another deficiency of the double prism component is that the parallelism of the inner prism surfaces must be accurately maintained as the gap is varied in order to have accurate and repeatable performance. This requirement presents a mechanical alignment problem. In addition, the energy division provided by the double prism unit is undesirably frequency dependent.

The object of this invention, therefore, is to provide an improved quasioptical microwave component suitable for use with oversize waveguide.

SUMMARY OF THE INVENTION

The invention is characterized by the provision of an electromagnetic component including a base mounted, solid dielectric body having an input face for receiving electromagnetic wave energy and an output face adapted to transmit at least a portion of the wave energy received by the input face. A waveguide supported by the base directs the wave energy toward the input face. Because of the quasioptical behavior of microwave signals transmitted in oversize waveguide, the solid dielectric body functions as a microwave component while eliminating problems associated with gap-separated split-prism devices.

One feature of the invention is the provision of an electromagnetic component of the above including a drive mechanism for rotating the dielectric body so as to selectively vary the angle of incidence between the input face and the polarized electromagnetic wave energy received from the waveguide. Attenuation or phase shift of the signal transmitted by the output face is attained by appropriate rotation of the dielectric body.

Another feature of this invention is the provision of an electromagnetic component of the above featured type wherein the dielectric body includes at least one inner surface adapted to reflect electromagnetic wave energy between parallel input and output faces. This arrangement facilitates use of the output signal which is unidirectional for all rotational positions of the dielectric body.

Another feature of the invention is the provision of an electromagnetic component of the above featured type wherein the drive mechanism permits formation of the Brewster angle of incidence between the input face and the polarized energy received thereby. Establishment of the Brewster angle eliminates reflective losses at both the input and output faces.

Another feature of the invention is the provision of an electromagnetic component of the above featured type wherein the dielectric body includes a pair of parallel inner surfaces making, with the input and output faces, angles equal to

$$90°+\sin^{-1}\left(\frac{1}{\sqrt{k}}\right)-\tan^{-1}(\sqrt{k})$$

where k represents the dielectric constant of the dielectric body. According to this arrangement, the Brewster angle setting provides a null position with zero attenuation or phase shift. Rotation of the dielectric body in one direction from the null position produces at the internal surfaces attenuation of the signal and rotation in the opposite direction produces phase shift thereof.

Another feature of the invention is the provision of an electromagnetic component of the above featured types wherein the dielectric body is adapted to produce a plurality of reflections at each of the internal surfaces. The plural reflections increase the maximum attenuation or phase shift attainable by rotation of the dielectric body away from the Brewster angle of incidence.

Another feature of the invention is the provision of an electromagnetic component of the above featured types including an output waveguide and wherein both the input and output waveguides include terminal portions adapted for contact with, respectively, the input and output faces of the dielectric body. The terminal portions are biased so as to remain in contact with the input and output faces during rotation of the dielectric body. In this way full energy coupling is automatically maintained during selective adjustment of the component.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and objects of the present invention will become more apparent upon a perusal of the following specification taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic plan view of a preferred embodiment of the invention;

FIG. 2 is a cross-sectional view of the embodiment shown in FIG. 1 taken along lines 2–2;

FIG. 3 is an exploded cross-sectional view of a portion of the embodiment shown in FIG. 1;

FIG. 4 is a coordinate diagram showing certain operating characteristics of the device shown in FIGS. 1—3;

FIG. 5 is another coordinate diagram illustrating other operating characteristics of the device shown in FIGS. 1—3;

FIG. 6 is another coordinate diagram illustrating still other operating characteristics of the device shown in FIGS. 1—3;

FIG. 7 is a schematic diagram illustrating operation of the dielectric body shown in FIGS. 1 and 2; and

FIG. 8 is a schematic diagram of a modified dielectric block suitable for use in the embodiment shown in FIGS. 1 and 2.

DESCRIPTION OF THE INVENTION

Referring now to FIGS. 1 and 2 there is shown the electromagnetic device 11 including the solid, unitary dielectric body 12 supported by the base 13. The body 12 is formed of a suitable dielectric material such as polystyrene, lucite, teflon, ceramic, or quartz. As shown in FIG. 2, opposite ends of the dielectric body 12 are formed by the parallel oriented input face **14** and output face **15**. The input face **14** and output face **15** are joined by parallel sidewalls of the block **12** that form, respectively, first and second internal surfaces **16** and **17**.

The dielectric block **12** is rotatably mounted between support plates **18** and **19** by the axial pin **21** and the drive shaft **22** which extends through both the end plate **19** and the support bracket **23**. Fixed to the end of the drive shaft **22** is the dial plate **24**. Preferably, the face of the dial plate **24** is marked in degrees which are indicated by the pointer **25** also attached to the support bracket **23**.

Mounted on for rotation with the shaft **22** is the spur gear **26**. Operatively engaging the spur gear **26** is the mating spur gear **27** of substantially smaller diameter. The control shaft **28** has one end keyed to the spur gear **27** and is rotatably supported between the bracket **23** and the rectangular plate **29**. Fixed to the opposite end of the control shaft **28** is the operating knob **31**.

Also supported by the base **13** on support brackets **32** and **33**, respectively, are the input waveguide **34** and the output waveguide **35**. Mounted on the input and output waveguides **34** and **35** are the flanges **36** and **37** adapted for connection to mating flanges of a suitable waveguide system. The energy absorbing pads **38** and **39** are disposed between the end walls **18** and **19** adjacent the dielectric block's side walls that form the internal surfaces **16** and **17**. The pads **38** and **39** comprise a suitable microwave energy absorbing material such as foam rubber loaded with graphite.

As shown more clearly in the enlarged sectional view of FIG. **3**, the input waveguide **34** is formed by a fixed section **41** and the reciprocable top and bottom sections **42** and **43**. Recessed portions **44** in the top and bottom walls of the fixed section **41** slideably accommodate the sections **42** and **43** which are retained vertically by the collar **45**. The compression spring members **46** and **47** bias the terminal portions **48** and **49** of, respectively, the reciprocable sections **42** and **43** in contact with the input face **14** of the dielectric block **12** during rotation thereof. Although not shown in detail, the output waveguide **35** includes similar reciprocable sections adapted to remain in contact with the output face **15**. Thus, close coupling between the input and output waveguides **34** and **35** is automatically maintained in all rotative positions of the dielectric block **12**.

The device **11** is uniquely suited for use with oversize waveguide systems. There the behavior of the TE_{10} mode approaches that of a plane wave and certain known optical principles can be applied. If a light wave is polarized in the plane of incidence at a dielectric interface, there is one angle of incidence called the Brewster angle for which the reflected signal is zero. For an air-to-dielectric surface, it is given by tangent $\theta_B = n$, where n is the refractive index (the square root of the dielectric constant). Therefore, in an oversize waveguide system, if the microwave signal (polarization in the plane of incidence) is incident on the dielectric at θ_B, there will be no reflective loss and the VSWR=1.

FIG. **4** illustrates the incident angle induced variation in reflectance for such a microwave signal entering a given air surrounded dielectric. For a dielectric having the form shown in FIG. **7** such that the output beam is parallel to the input beam, the reflectance at the output surface **15** is the same as that at the input surface **14**. Point A represents the Brewster angle of incidence at which reflectance equals zero. Thus, FIG. **4** graphically illustrates the degree to which a microwave signal is reflected by either the input face **14** or the output face **15** as determined by the relative orientations thereof with respect to the parallel longitudinal axes of the input and output waveguides **34** and **35**.

For the case of a polarized signal going from a region of higher n to a region of lower n, there is an angle of incidence (the critical angle, θ_c) beyond which reflectance is **1**. For angles less than θ_c) decreases rapidly for polarization in the plane of incidence and reflected intensity decreases to zero with only a small change in angle of incidence.

FIG. **5** illustrates this relationship for a signal directed against an internal surface of a given air-enclosed dielectric. Again, reflectance is plotted along the ordinate axis and angle of incidence is plotted along the abscissa axis. Point A on the curve represents the critical angle beyond which reflectance equals **100** percent. Thus, FIG. **5** illustrates graphically the degree to which a microwave signal transmitted by the input waveguide **34** into the dielectric block (FIG. **2**) will be reflected by the internal surfaces **16** and **17** as determined by the relative orientations thereof with respect to the internally transmitted signals.

The phase of the refracted signal is the same as that of the incident signal at a dielectric-air interface. Therefore, the input **14** and output **15** faces have no effect on the phase of the transmitted signal.

FIG. **6** represents the phase change experienced by a polarized signal reflected by an internal surface of the assumed air surrounded dielectric material. Again, point A on the curve represents the critical angle θ_c and as shown the phase change increases for incident angles greater than θ_c remains zero for incident angles a few degrees smaller than θ_c and then abruptly shifts to 180°for all other incident angles less than θ_c. Therefore, FIG. **6** graphically illustrates the phase change of a microwave signal transmitted into the dielectric block **12** and reflected by the internal surfaces **16** and **17** as determined by the relative orientations thereof with respect to the signals being reflected.

The operation of the device **11** as a variable attenuator will be described with reference to FIG. **7** which is a schematic representing of the dielectric block **12** shown in FIGS. **1** and **2**. The block **12** is shown with the input face **14** receiving polarized electromagnetic energy from the input waveguide **34** at incident angle θ_i. A portion of this energy is refracted by input surface **14** to the internal surface **16** which in turn reflects energy toward the internal surface **17** as shown. Finally, energy is reflected by the internal surface **17** to the output face **15** and refracted thereby to the output waveguide **35** at the output angle of refraction, θ_o which, because of the parallel surfaces, is equal to the input incident angle θ_i.

Assuming that the orientation of block **12** is such that the input angle of incidence θ_i and the output angle of refraction θ_o are equal to the Brewster angle θ_B for the particular dielectric material utilized, no energy reflection occurs at either the input surface **14** or the output surface **15**. This case is represented in FIG. **4** by point A which, as noted above, represents the Brewster angle of incidence. Therefore, the combined effect of the input and output faces **14** and **15** for the assumed θ_B setting is to produce no attenuation or net phase shift of a polarized microwave signal received from the input waveguide **34** and transmitted to the output waveguide **35**.

Before considering any signal modification produced by the internal surfaces **16** and **17**, one must determine the internal angles of incidence θ_r at which polarized energy is received by these surfaces. Assume first that the internal angles of incidence θ_r are equal to the critical angle θ_c represented by point A in FIG. **5** for the dielectric block orientation described above i.e. a position wherein the input and output angles θ_i, θ_o are equal to the Brewster angle θ_B. Such a relationship will exist if the angle α between the input face **14** and the internal surface **16** is equal to

$$90° + \sin^{-1}\left(\frac{1}{\sqrt{k}}\right) - \tan^{-1}(\sqrt{k})$$

where k represents the dielectric constant of the block **12**. Accordingly, all signal energy refracted by the input face **14** is reflected by both internal surfaces **16** and **17** to the output face **15**. Also, as shown in FIG. **6**, no signal phase change occurs at either of the internal surfaces **16** or **17** with the internal angles of incidence θ_r equal to the critical angle θ_c again represented by point A. Thus, for the assumed orientation A, a microwave signal received by the dielectric block 12 from input waveguide 34 is transmitted to the output waveguide 35 without either attenuation or phase shift.

Next, assume that operating handle 31 (FIG. 1) is turned so as to produce via the spur gears 26 and 27 counterclockwise rotation of the dielectric body 12. Obviously, such rotation alters the angles θ_i, θ_o and θ_r existing between the transmitted wave and the four interfaces 14—17 of the dielectric block 12. Assume further that the block 12 is rotated into a position represented by points B in the curves of FIGS. 4—6. It will be noted in FIG. 4 that for this case reflectance at the input and output faces 14 and 15 remains approximately equal to zero. Consequently, these faces continue to provide substantially 100 percent signal transmission. However, as shown in FIG. 5, a substantial decrease in reflectance occurs at internal surfaces 16 and 17 which accordingly produce considerable attenuation of the transmitted signal. It will be noted also that this attenuation varies substantially linearly as the dielectric block 12 is rotated between positions represented by points A and B on the curve of FIG. 5. Consequently, a variable attenuation of the transmitted signal is obtained by selective manipulation of the operating handle 31. Naturally, the magnitude of attenuation is determined by reference to calibrations on the dial plate 24 as indicated by the pointer 25.

FIG. 6 shows that no phase change is induced in the signals reflected by internal surfaces 16 and 17 for all input and output angles θ_i and θ_o between and including those represented by points A and B. Thus, the effect of counterclockwise rotation of the dielectric body 12 is to produce selective attenuation of the signal received from the input waveguide 34 without the introduction of any net phase shift therein.

Finally, assume that operating handle 31 is turned so as to produce clockwise rotation of the dielectric body 12 from null position A toward a position corresponding to angles of incidence represented by points C on the curves in FIGS. 4—6. As shown in FIG. 4, substantially no reflection occurs at input and output faces 14 and 15 which continue to provide virtually 100 percent transmission. Also, FIG. 5 indicates that 100 percent reflectance occurs at internal surfaces 16 and 17. Therefore, for clockwise rotation of body 12 from the null position A, the device 11 provides substantially 100 percent energy transmission between input waveguide 34 and output waveguide 35.

As shown in FIG. 6 a significant phase change of the reflected signal is introduced by internal surfaces 16 and 17 upon movement of block 12 into position C. Furthermore, the magnitude of introduced phase change varies rapidly between the null position represented by point A and the assumed new position C. Thus, a variable phase change in the transmitted signal is introduced by selective rotation of the dielectric body 12 in a clockwise direction from the null position A.

Summarizing, the present invention provides a component uniquely suited for use in oversize waveguide systems. The device functions either as a variable attenuator or as a variable phase shifter depending upon the direction in which the dielectric body 12 is rotated with respect to a null position corresponding to the Brewster angle of incidence at the input face 14. Furthermore, the performance of the unit depends only upon the above described geometrical configuration and the dielectric constant of the material used for the dielectric body 12. Because the latter is almost independent of wavelength over a wide bandwidth, the disclosed component is inherently broadband and no impedance matching networks are required. In addition, the overall performance characteristics of the device can be calculated directly from the Fresnel equations. Thus, important advantages provided by the present invention include broadband operation, directly calculable performance, no critical mechanical drive requirements, and lack of requirements for impedance matching elements.

FIG. 9 schematically illustrates a modified dielectric block 51 for use in generally the same manner as described above the dielectric block 12. Again, a suitable polarized signal directed at the input face 52 will produce from output face 53 either an attenuated or phase shifted output signal depending upon the relative orientation of the block 12. However, by increasing their lengths, plural signal reflections occur at each of the internal surfaces 54. For this reason, the above described effects of attenuation or phase shift are amplified, thereby enhancing the useful range of the device.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. For example only, with minor modifications the disclosed components can be used as directional couplers or modulators. It is to be understood, therefore, that within the scope of the appended claims the invention can be practiced otherwise than as specifically described.

I claim:

1. An electromagnetic device comprising a base means, a dielectric body supported by said base means, said dielectric body having an input face adapted to receive electromagnetic wave energy and an output surface adapted to transmit at least a portion of the electromagnetic wave energy received by said input face, and waveguide means supported by said base means for guiding plane polarized electromagnetic wave energy in the microwave region up to 300 GHz. toward said input face.

2. An electromagnetic device according to claim 1 including a selective drive means for rotating said dielectric body so as to selectively vary the angle of incidence between said input face and the polarized electromagnetic wave energy received from said waveguide means.

3. An electromagnetic device according to claim 2 wherein said drive means permits establishment of the Brewster angle of incidence between said input face and the polarized wave energy received thereby.

4. An electromagnetic device according to claim 3 wherein said dielectric body comprises at least one inner surface adapted to reflect toward said output face electromagnetic wave energy refracted by said input face.

5. An electromagnetic device according to claim 4 wherein said dielectric body comprises at least two said inner surfaces and is adapted to provide a unidirectional electromagnetic wave energy output from said output face for all rotational positions of said dielectric body.

6. An electromagnetic device according to claim 5 wherein said input and said output faces of said dielectric body are parallel.

7. An electromagnetic device according to claim 6 wherein operation of said drive means in one direction relative to said Brewster angle of incidence produces attenuation of the wave energy received by said input face and operation of said drive means in the opposite direction relative to said Brewster angle of incidence produces a phase shift of the wave energy received by said input face.

8. An electromagnetic device comprising a base means, a dielectric body supported by said base means, said dielectric body having an input face adapted to receive polarized electromagnetic wave energy and an output face adapted to transmit at least a portion of the electromagnetic wave energy received by said input face, selective drive means for rotating said dielectric body so as to selectively vary the angle of incidence between said input face and the polarized electromagnetic wave energy being received, said drive means arranged to permit establishment of the Brewster angle of incidence between said input face and the polarized wave energy received thereby, and wherein operation of said drive means in one direction relative to said Brewster angle of incidence produces attenuation of the wave energy received by said input face and operation of said drive means in the opposite direction relative to said Brewster angle of incidence produces a phase shift of the wave energy received by said input face.

9. An electromagnetic device according to claim 8 wherein said dielectric body comprises at least one inner surface adapted to reflect electromagnetic wave energy refracted by said input face.

10. An electromagnetic device according to claim **9** wherein said dielectric body comprises at least two said inner surfaces and is adapted to provide a unidirectional electromagnetic wave energy output from said output face for all rotational positions of said dielectric body.

11. An electromagnetic device according to claim **10** wherein said input and said output faces of said dielectric body are parallel.

12. An electromagnetic device comprising a dielectric body having an input face adapted to receive electromagnetic wave energy, an output face parallel to said input face and adapted to transmit at least a portion of the electromagnetic energy received thereby, a first internal surface joining said input and output faces and adapted to reflect electromagnetic wave energy refracted by said input face, a second internal surface joining said input and output faces and parallel to said first internal surface and adapted to reflect electromagnetic wave energy received therefrom, said output face being adapted to transmit reflected electromagnetic wave energy received from said second internal surface and wherein said input face and said first internal surface make an angle equal to

$$90°+\sin^{-1}\left(\frac{1}{\sqrt{k}}\right)-\tan^{-1}(\sqrt{k})$$

where k represents the dielectric constant of said dielectric body.

13. An electromagnetic device according to claim **12** including selective drive means for rotating said dielectric body so as to selectively vary the angle of incidence between said input face and electromagnetic wave energy being received thereby.

14. An electromagnetic device according to claim **12** including a base for said dielectric body, and waveguide means supported by said base and adapted to direct electromagnetic wave energy toward said input face.

15. An electromagnetic device according to claim **14** including selective drive means for rotating said dielectric body so as to selectively vary the angle of incidence between said input face and electromagnetic wave energy being received thereby.

16. An electromagnetic device according to claim **12** wherein each of said first and said second internal surfaces are adapted to at least twice reflect electromagnetic energy transmitted within said dielectric body between said input face and said output face.

17. An electromagnetic device according to claim **16** including selective drive means for rotating said dielectric body so as to selectively vary the angle of incidence between said input face and electromagnetic wave energy being received thereby.

18. An electromagnetic device according to claim **16** including a base for said dielectric body, and waveguide means supported by said base and adapted to direct electromagnetic wave energy toward said input face.

19. An electromagnetic device according to claim **18** including selective drive means for rotating said dielectric body so as to selectively vary the angle of incidence between said input face and electromagnetic wave energy being received thereby.

20. An electromagnetic device according to claim **19** wherein said waveguide means comprises terminal portions adapted for contact with said input face and including adjustment means for aligning said terminal portions with said input face at varying rotative positions of said dielectric body.

21. An electromagnetic device according to claim **20** wherein said waveguide means further comprises an output waveguide having terminal portions adapted for contact with said output face and including output adjustment means for aligning said output waveguide terminal portions with said output face at varying rotative positions of said dielectric body.