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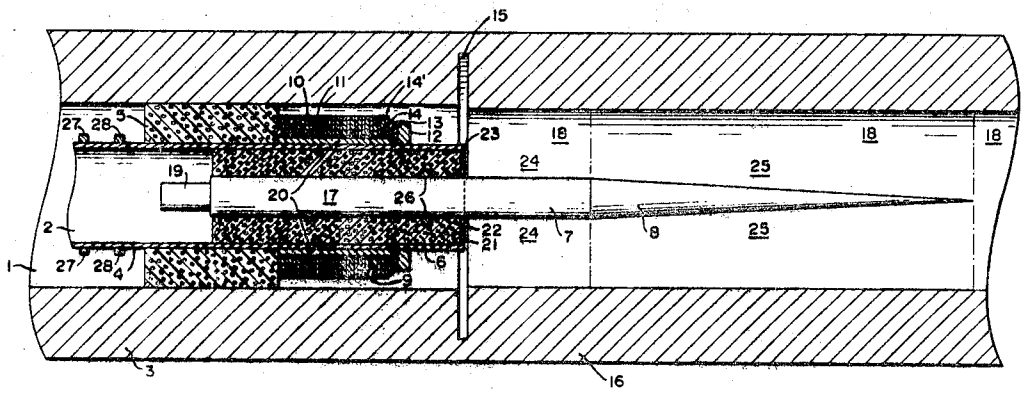
[54] **DUAL-POLARIZED DUAL-FREQUENCY COUPLER**
10 Claims, 1 Drawing Fig.

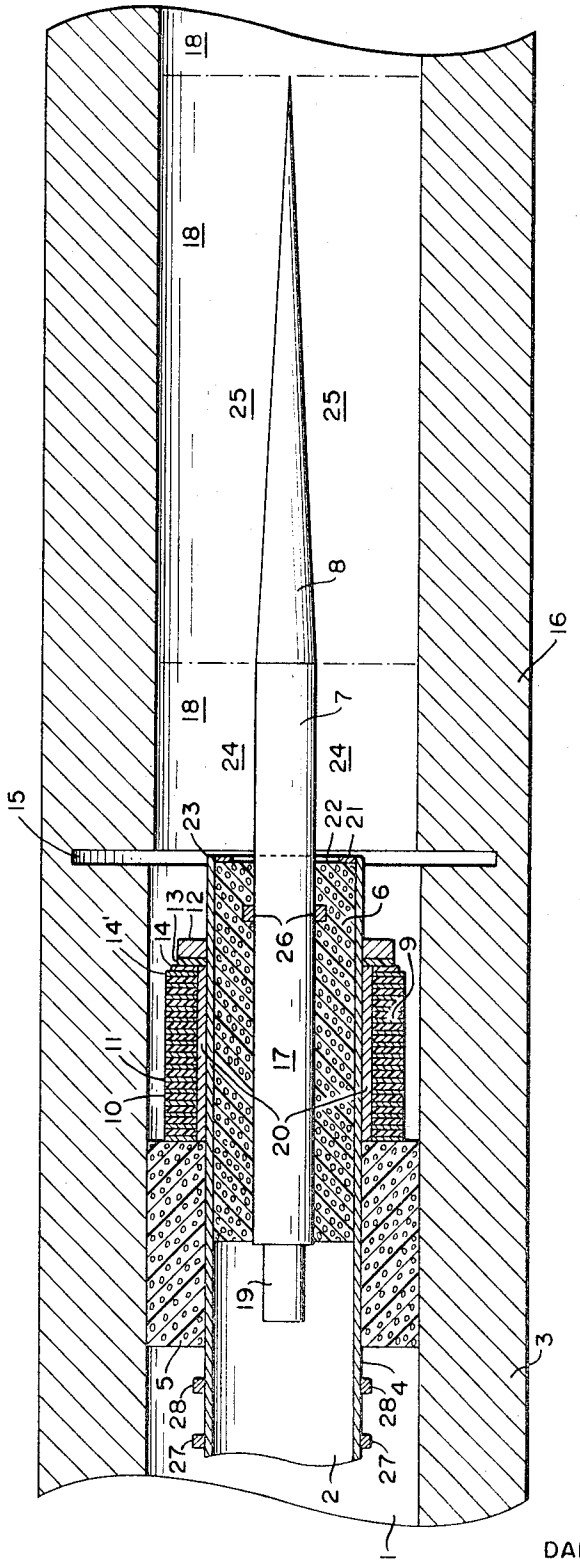
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ABSTRACT: A waveguide transition coupler having a coaxial waveguide and a first circular waveguide formed inside the center conductor of the coaxial waveguide for coupling with a second circular waveguide. Two frequencies of two orthogonally polarized waves in the TE 11 mode are propagated together through the second circular waveguide while each frequency is propagated separately by the first circular and coaxial waveguides. Isolation of the two frequencies is secured in the coaxial and first circular waveguide by dimensioning the first circular waveguide so that it is beyond cutoff for the lower frequency, and by placing a distributed choke-transformer in the coaxial waveguide to attenuate the higher frequency electromagnetic waves. Unwanted mode conversion is inhibited in the energy transfer by a tapered pin inserted through both circular waveguides and impedance-matching elements are provided.





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DUAL-POLARIZED DUAL-FREQUENCY COUPLER

BACKGROUND OF THE INVENTION

TE 11 mode dual-frequency dual-polarization waveguide couplers that I am familiar with from the prior art have cost and performance disadvantages which this coupler overcomes. The known prior art couplers are fabricated as square or rectangular multiple slot couplers with each band and polarization tandemly mounted. This makes the entire assembly in excess of 15 feet in length as compared to about 2 feet of length for the coupler of this invention operating over the same frequencies. With prior art square designs the squareness and straightness of the waveguide is harder to maintain than the circularities and concentricities of the present invention's circular design. A further defect of the prior art multiple slot tandem couplers is their tendency to resonate at certain frequencies. These resonances cause phase-delay distortion which is bothersome in modern FM systems. In the present design the improved waveguide isolation and lack of multiple slots reduces the possibilities of resonant frequencies.

It is thus an object of this invention to provide a TE 11 mode waveguide coupler having a high degree of isolation between the waveguides carrying separate frequencies.

It is a further object of this invention to reduce the number of input or output waveguides for each polarization and frequency being carried in a coupler and thus to reduce resonance and phase-delay distortion in the microwave coupler for TE 11 modes.

SUMMARY OF THE INVENTION

In the preferred embodiment of this invention a first circular waveguide is formed within the inner conductor of a coaxial waveguide. Beyond a termination of the inner conductor a second circular waveguide extends within an extension of the outer conductor of the coaxial waveguide. The coaxial and first circular waveguides each propagate a different frequency of TE 11 mode microwave energy with two orthogonally polarized waves propagated at each frequency. Both frequencies are propagated together in the second circular waveguide.

In the preferred embodiment coupling of the energy in the second circular waveguide with the energy in the coaxial and first circular waveguides is facilitated by a conductive pin axially supported within the end region of the first circular waveguide and extending into the second circular waveguide. The presence of the pin extension beyond the first circular waveguide lessens the abruptness of the impedance change for the waves carried by the coaxial waveguide and converts the TE 11 circular mode waves in the first circular waveguide to the TE 11 coaxial mode. The portion of the pin extending into the second circular waveguide is dimensioned to suppress propagation of the TM 11 modes of both frequencies. The pin ends in a taper in the second circular waveguide which insures that as the TE 11 coaxial mode waves at both frequencies change to the TE 11 circular mode the generation of TM 11 modes will be minimized.

Maximum isolation is achieved between the coaxial and first circular waveguides with a distributed choke-transformer in the waveguide carrying the lower frequency to attenuate higher frequency energy from the other of these two waveguides, and by dimensioning the termination of the other of these two waveguides so that it is beyond the cutoff for and thus attenuates the lower frequency. In the preferred embodiment the higher frequency waves are carried by the first circular waveguide while the lower frequency waves are carried in the coaxial waveguide.

Further features of the preferred embodiment include a reactive groove formed in the outer conductors of the coaxial and second circular waveguides where they join. This reactive groove which is effectively a short-circuited radial transmission line improves the impedance matching for the lower frequency waves between the coaxial waveguide and second

circular waveguide. A conductive ring in the first circular waveguide contacting its outer conducting surface at its termination increases the cutoff isolation of the first circular waveguide to the lower frequency waves. Finally, various impedance matching rings are placed in the first circular and coaxial waveguides by empirical design techniques to eliminate wave reflections in the coupler.

The present invention will be more fully understood by considering the following detailed description of the preferred embodiment accompanied by the drawing which is a longitudinal sectional view of the coupler at any plane passing through and including its axis, the structure being radially symmetrical.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the preferred embodiment of the present invention a first circular waveguide **2** is formed coaxially within an inner conductor **4** of a coaxial waveguide **1**. The coaxial waveguide **1** is formed between an inner conductive wall of an outer conductor **3** and an outer conductive wall of the inner conductor **4**. A low loss dielectric spacer **5** centers the inner conductor **4** within the outer conductor **3**. The first circular waveguide **2** is coaxial with the coaxial waveguide **1** and is bounded by an inner wall of the inner conductor **4**.

The inner conductor **4** terminates at a point of transition **23** for the coaxial and first circular waveguides **1** and **2**. Beyond this point of transition **23** of the coaxial and first circular waveguides a second circular waveguide **18** extends coaxially, defined by the inner conductive wall of an outer conductor **16** which is formed by an extension of the outer conductor **3** of the coaxial waveguide.

Four channels of TE **11** mode microwave energy are carried by the preferred embodiment of this invention. Two channels are carried by the coaxial waveguide **1** as two orthogonally polarized waves in a first frequency band. Two other channels are carried by the first circular waveguide **2** as two orthogonally polarized waves in a second frequency band which in the preferred embodiment is roughly twice the first frequency. In the second circular waveguide **18** both polarizations and both frequencies providing the four channels are carried together in superimposed relationship.

A conductive pin **17** extends within the first and second circular waveguides and has at opposite ends of a cylindrical center portion a stepped-down cylindrical projection **19** and a tapered section **8**. Pin **17** is coaxially centered within the first circular waveguide by a low loss dielectric **6** filling the space between the pin **17** and the interior wall of inner conductor **4** giving a coaxial transition to the first circular waveguide **2**. The radius of the pin **17**, the inside radius of the inner conductor **4** and the dielectric constant of the dielectric **6** cooperate to make the cutoff frequency of the first circular waveguide in the region surrounding the pin **17** above the frequency of the wave carried in the coaxial waveguide **1**. The length of the cylindrical center portion of pin **17** within the first circular waveguide **2** and its surrounding dielectric **6** is not critical so long as the length is great enough to substantially inhibit transmission of all waves at the frequency carried by the coaxial waveguide **1**.

The isolation of the first circular waveguide **2** from the frequencies carried by the coaxial waveguide **1** is further increased by the presence of a conductive ring **21** contacting the inner wall of the inner conductor **4** at its termination **23**. The effective spacing **22** between the pin **17** and the inner conductor **4** is decreased by the ring **21** to further increase the cutoff effect and consequently further inhibit the transmission into the first circular waveguide **2** of frequencies carried by the coaxial waveguide **1**. The axial length of the ring **21** is not critical and in the preferred embodiment it is substantially less than a wavelength at either frequency.

An impedance-matching conductive ring **26** is disposed around the pin **17** and spaced back into the first circular

waveguide 2 from the termination 23 approximately a quarter wavelength of the higher frequency wave carried by the first circular waveguide 2. This impedance matching ring 26 compensates for the effects of the ring 21 on the higher frequency wave carried by the first circular waveguide and its dimension and location for this purpose are empirically determined.

The projection 19 is coaxially disposed on the end of pin 17 facing into the first circular waveguide 2 away from its termination at 23. The projection 19 matches the impedance of the first circular waveguide 2 to its coaxial termination containing the pin 17 and dielectric 6.

A portion 7 formed as a continuation of the pin 17 extends beyond the termination at point 23 of the first circular waveguide 2 into a region 24 of the second circular waveguide 18. The portion 7 joins the taper 8 which converges in a region 25 of the second circular waveguide 18 to zero radius. In the first region 24, the radius of the pin extension 7, the inner radius of the outer conductor 16 of the second circular waveguide 18, and the gas dielectric cooperate to give a cutoff frequency above TM 11 modes for either frequency. The length of the pin extension, portion 7, and the first region 24 is preferably approximately one wavelength of the higher frequency wave. The taper 8 may converge linearly, but is preferably slightly concave to produce a narrower taper beyond the point in the region 25 where the radius of the taper 8 has diminished enough to allow the TM 11 modes to exist. The narrower the taper 8 the less will be the mode conversion to TM 11 modes in the second region 25. It has been found that for a taper approximately three to six wavelengths of the upper frequency in length mode conversion is substantially inhibited.

Surrounding the inner conductor 4 a distance back from its termination is a filter indicated at 9 which surrounds and contacts the inner conductor 4 but does not contact the outer conductor 3. The filter 9 is composed of a stack of alternate metallic and dielectric annuli around the inner conductor 4 and a metallic sleeve 20 fitting between the stack and inner conductor 4. Proceeding back from the termination 23 of the inner conductor 4, a first metallic annulus 12 is somewhat thicker than the other annuli and is directly in contact with the inner conductor 4. Behind the first annulus 12 is a thinner dielectric annulus 13 directly contacting the inner conductor 4.

Beyond this point the metallic sleeve 20 surrounds and contacts the inner conductor 4 for the entire length of the rest of the stack. Beginning from dielectric annulus 13 two metallic annuli 14 and 14' surround the sleeve 20. The metallic annuli 14 and 14' increase the outside diameter of the stack in two steps. The outside diameter of the metallic annulus 14' is maintained by all subsequent annuli 10 and 11 in the rest of the stack of filter 9. Beyond metallic annulus 14' dielectric annuli 10 and metallic annuli 11 alternate making up the remainder of the stack. The annuli 12, 13, 14, and 14' differ from the annuli 10 and 11 only for impedance-matching considerations.

The end of the stack butts against the dielectric spacer 5 centrally supporting the inner conductor 4 in the coaxial waveguide 1. In the preferred embodiment the first metallic annulus 12 is placed approximately one-half wavelength of the higher frequency back from the termination 23 of the inner conductor 4.

The dimensions and number of the annuli in the stack of filter 9 may be adjusted. These dimensions are arrived at by accounting for impedance-matching considerations for the lower frequency and attenuation considerations for the upper frequency. The greater the length of the filter 9, the greater will be the isolation for the higher frequency. It is thus desirable to use a matching technique for the lower frequency which will allow a maximum length to the filter 9. It has been found that approximately 35 db. of attenuation in the upper frequency is achieved fore every wavelength of the upper frequency that the stack extends. For the intended uses of this preferred embodiment an attenuation of 30 or 35 db. has been found sufficient. The length of the stack of filter 9 is accordingly adjusted.

The characteristic impedance of the filter 9 can be adjusted in several ways and still maintain its attenuation for the higher frequency. With the proper selection of dielectric material as well dimensional sizes, i.e., diameters and thicknesses, the characteristic impedance can be made to match the impedance of the region to the left of dielectric 5 to the impedance of the region to the right of annulus 12. This is not necessarily desirable, however, since the impedance mismatch at the lower frequency between the coaxial waveguide 1 at its termination at 23 and the first region 24 of the second circular waveguide 18 is quite large and require correspondingly large reactive impedances elsewhere to counteract it. In the design established the filter impedance at the lower frequency is lower than both the characteristic impedance of the region of the coaxial waveguide 1 to the left of the dielectric support 5 and the characteristic impedance of the region to the right of the first metallic annulus 12 up to the termination of the inner conductor 4. It appears as a lumped reactance to the lower frequency.

In general the thickness of the annuli in the stack of filter 9 will be much smaller than a wavelength. The stack of alternating metallic and dielectric annuli appear as a series of radial short circuited transmission lines. The outer diameters of the metallic and dielectric annuli are chosen so that each radial section has an input impedance of infinity at the center of the upper frequency. The higher the dielectric constant of the dielectric annuli 10 the smaller can be the outside diameter of both metallic and dielectric annuli 10 and 11.

At the point where the outer conductors 3 and 16 of the coaxial waveguide 1 and second circular waveguide 18 join, and in the same transverse plane as is the termination point 23, a reactive groove 15 is cut into these outer conductors 3 and 16. The reactive groove is circular and approximately one-quarter wavelength deep at the upper frequency band. It is effectively a short circuited radial transmission line whose impedance transforms to infinity at the upper frequency and has little effect on that upper frequency. At the lower frequency, it is, however, an apparent series inductance which in part compensates for a capacitive series reactance due to the dielectric support 6 and in part compensates for impedance mismatches between the coaxial waveguide 1 and the second circular waveguide 18. The groove is thin with respect to a wavelength at either frequency.

A set of metallic matching rings 27 and 28 may be placed around and in contact with the inner conductor 4 of the coaxial waveguide 1. The size and placement of these rings 27 and 28 are empirically determined so that they function to minimize reflections of the low frequency waves carried by the coaxial waveguide 1.

In operation this waveguide coupler is designed to couple four channels of electromagnetic microwave energy between a common circular waveguide and two orthogonally polarized ports of one frequency and two orthogonally polarized ports of a second frequency band. This coupling is accomplished with a maximum degree of isolation between all the ports, produced by orthogonality, cutoff phenomena and filtration. This coupling is also reciprocal allowing energy to be coupled between the common circular waveguide and the ports in either direction. For simplicity the following description of the operation of the coupler will be in terms of coupling from the ports into the common circular waveguide. It should at this point be emphasized that the coupler operates equally well in reverse to couple energy from the common circular waveguide to the port of the proper frequency and polarization. Furthermore the microwave energy in each polarization in each frequency is independent of the energy in the other three waves so that coupling can occur in both directions simultaneously between the common waveguide and different ports.

When operating to propagate two frequencies into a common circular waveguide the lower frequency band of two

orthogonal waves is introduced into the coaxial waveguide **1**, while the higher frequency band of two orthogonal waves is introduced into first circular waveguide **2**. The mode in both input waveguides is the TE **11** mode coaxially and circularly oriented in the coaxial and first circular waveguides respectively. These modes are introduced from the ports by standard waveguide couplers.

The energy in the first circular waveguide is transferred into the coaxial termination of the first circular waveguide formed by the pin **17** and its dielectric support **6**. In this transfer the mode changes from TE **11** circular to TE **11** coaxial. The energy in this coaxial termination is coupled into the first region **24** of the second circular waveguide **18** along the pin extension **7**.

Likewise the electromagnetic wave energy in the coaxial waveguide **1** passes through the dielectric support **5** which centers the inner conductor **4** within the outer conductor **3** of the coaxial waveguide **1**. This lower frequency wave passes through the filter **9** which acts as a filter transformer or distributed choke-transformer to the higher frequency wave but as a lumped reactance to the lower frequency. The lower frequency wave finally makes the step transition from the inner conductor **4** to the pin extension **7** in the first region **24**. There, it joins the higher frequency energy wave from the first circular waveguide and together they are launched into the second circular waveguide along the pin **17**. They make the transition from the TE **11** coaxial mode in the first region **24** along the taper **8** in the second region **25** to the circular portion of the second circular waveguide **18** to become TE **11** circular mode waves. The first region **24** beyond cutoff for the TM **11** modes for both frequencies, and the taper **8** on the pin extension **7** inhibits the generation of TM **11** modes as the waves at both frequencies from the coaxial first region **24** are transformed into the circular TE **11** modes in the circular region of the second circular waveguide **18**.

The lower frequency microwave energy in the first region **24** is kept out of the first circular waveguide **2** by having its coaxial termination with the pin **17**, ring **21** and dielectric support **6** beyond cutoff for all lower frequency modes. The higher frequency wave in the first region **24** is inhibited from entering the coaxial waveguide **1** by the filter **9** placed around the inner conductor **4** approximately a quarter wavelength of the lower frequency or one-half a wavelength of the higher frequency back from the termination **23** of the inner conductor **4** in the coaxial waveguide **1**.

To compensate for the effect of the filter **9** upon the lower frequency wave transmitted by the coaxial waveguide **1**, impedance-matching devices are used in the coaxial waveguide **1**. These include rings **27** and **28** placed around the inner conductor **4**, the reactive groove **15** and the shape and position of the dielectric annuli **10**, **11**, **12**, **13** and **14** as well as the thickness of the sleeve **20** between the stack of annuli and the inner conductor **4**.

It is apparent that the coupler of this invention can be designed with the higher frequency carried by the coaxial waveguide **1** and the lower frequency carried by the first circular waveguide **2** in which case the filter **9** is placed around the pin **17** while the coaxial waveguide **1** is maintained beyond cutoff for the lower frequency wave in the first circular waveguide **2**.

Because all elements of the coupler are circular, the polarization of the electromagnetic microwave energy may be of an arbitrary linear or circular polarization though the specific use for the coupler is with dual orthogonally polarized waves.

It is also intended to cover all other modifications and alternatives to the above-described preferred embodiment which do not depart from the scope and spirit of this invention.

What I claim is:

1. A four-channel TE **11** mode microwave system having a coupling between one waveguide where the four channels are propagated as two frequencies of orthogonally polarized waves and two other waveguides where the four channels are propagated as two orthogonally polarized waves of a different single frequency in each waveguide comprising:

a. a coaxial waveguide carrying electromagnetic waves of a first frequency;

b. a first circular waveguide carrying electromagnetic waves of a second frequency, said first circular waveguide being contained within the inner conductor of said coaxial waveguide and coaxial therewith with a termination to said inner conductor and said first circular waveguide;

c. a second circular waveguide capable of carrying TE **11** mode waves from said first circular and said coaxial waveguides and enclosing the region beyond the termination of said first circular waveguide and the inner conductor of said coaxial waveguide, the outer conductor of said second circular waveguide formed by an extension of the outer conductor of said coaxial waveguide;

d. means for attenuating waves at said first frequency in said first circular waveguide; and

e. means for attenuating waves at said second frequency in said coaxial waveguide.

2. A waveguide coupler for coupling electromagnetic energy of arbitrary polarization at two frequencies in the TE **11** mode between a common waveguide carrying both frequencies and two waveguides carrying each frequency separately comprising:

a. a coaxial single frequency waveguide carrying electromagnetic waves of a first frequency;

b. first circular single frequency waveguide carrying electromagnetic waves of a second frequency said first circular waveguide being contained within the inner conductor of said coaxial waveguide with a termination to said inner conductor which terminates said first circular and coaxial waveguides;

c. cutoff means within the single frequency waveguide carrying the higher of said first and second frequencies, said cutoff means supporting TE **11** mode propagations of said higher frequency in that single frequency waveguide but being beyond cutoff for the TE **11** mode of the lower frequency;

d. a filter in the single frequency waveguide carrying the lower of said first and second frequencies, said filter attenuating the transmission in that single frequency waveguide of the electromagnetic waves at said higher frequency; and

e. a second circular waveguide capable of carrying TE **11** mode waves from said first circular and said coaxial waveguides and enclosing the region beyond the termination of said first circular waveguide and the inner conductor of said coaxial waveguide, the outer conductor of said second circular waveguide formed by an extension of the outer conductor of said coaxial waveguide.

3. An apparatus for coupling electromagnetic waveguided energy of arbitrary polarization in the TE **11** mode for two waveguides carrying different frequencies into one waveguide and from one waveguide carrying both frequencies into said two waveguides carrying different frequencies comprising:

a. a coaxial waveguide carrying electromagnetic wave of a desired frequency;

b. a first circular waveguide carrying electromagnetic wave of a desired frequency which is higher than those in said coaxial waveguide, said first circular waveguide being contained within the inner conductor of said coaxial waveguide, with a termination to said inner conductor which terminates said first circular and coaxial waveguides;

c. cutoff means within said first circular waveguide extending for a distance up to said termination, said cutoff means supporting TE **11** mode transmissions of said higher frequency energy but being beyond cutoff for the TE **11** mode of the lower frequency energy;

d. a filter in said coaxial waveguide placed around said inner conductor, said filter attenuating in said coaxial waveguide the electromagnetic waves carried by said first circular waveguide; and

e. a second circular waveguide capable of carrying TE 11 mode waves from said first circular and said coaxial waveguides and enclosing the region beyond the termination of said first circular waveguide and the inner conductor of said coaxial waveguide, the outer conductor of said second circular waveguide formed by an extension of the outer conductor of said coaxial waveguide.

4. The apparatus of claim 3 further comprising launching means for lowering mode conversion in the transfer of energy in said second circular waveguide with said first circular and coaxial waveguides.

5. The apparatus of claim 4 wherein:

a. said cutoff means includes a pin axially supported within said first circular waveguide, the ratio of the radii of said pin and said first circular waveguide's outer conductor defining a cutoff frequency above the frequency carried by said coaxial waveguide;

b. said launching means includes an extension of said pin beyond the termination of said inner conductor, said extension having a radius which in cooperation with the radius of said second circular waveguide's outer conductor defines a TM 11 mode cutoff frequency above both frequencies carried by said apparatus, said extension ending in a taper which at a point has a radius which permits TM 11 modes of at least one frequency carried by said apparatus but which taper substantially inhibits their generation; and

c. the polarization of said waveguided energy at each frequency is dual orthogonal polarization.

6. The apparatus of claim 3 wherein said filter further comprises a filter transformer having a stack of alternating metallic and dielectric annuli which are thin with respect to either wavelength carried and which said inner conductor passing through them.

7. The apparatus of claim 6 wherein said filter transformer commences approximately one-half wavelength of the higher frequency back from the terminations of said inner conductor, and extends back approximately one wavelength of the higher frequency for every 35 db. attenuation of the high frequency desired, and has a metallic sleeve disposed between said inner conductor and said stack, said stack appearing as a series of short circuited radial transmission lines with an impedance of infinity to the higher frequency at their outside diameter.

8. The apparatus of claim 6 further comprising:

a. a reactive groove cut into the outer conductor of said coaxial and second circular waveguides, said groove cut in approximately an odd multiple of a quarter wavelength of the higher frequency, and said groove providing impedance-matching reactance at the lower frequency;

b. impedance-matching means disposed on the end of said pin within said first circular waveguide to match the impedance of said first circular waveguide to the impedance of its termination containing said pin; and

c. a conducting ring disposed between said pin and the inner conducting surface of said inner conductor at its termination said ring contacting said inner conductor but not contacting said pin.

9. The apparatus of claim 8 further comprising: 1

a. a first set of at least one impedance-matching ring for said coaxial waveguide; and

b. a second set of at least one impedance-matching ring for said first circular waveguide, said first and second sets of impedance matching rings arranged within their respective waveguides to reduce reflections in waves carried by said coaxial and first circular waveguides.

10. A waveguide coupler for coupling two frequencies of electromagnetic waveguided energy of dual orthogonal polarization in the TE 11 mode from two separate frequency waveguides into one combined frequency waveguide and from one combined frequency waveguide into two separate frequency waveguides comprising:

a. a coaxial waveguide carrying electromagnetic waves of a first frequency; and

b. a first circular waveguide carrying electromagnetic waves of a second and higher frequency, said first circular waveguide being contained within the inner conductor of said coaxial waveguide, with a termination to said inner conductor, said first circular waveguide and said coaxial waveguide;

c. a pin axially supported within said first circular waveguide and having an extension to said pin extending beyond the termination of said inner conductor the portion of said pin and its support within said first circular waveguide forming a coaxial termination thereto with a cutoff frequency between the higher and lower frequencies, the end of said pin within said first circular waveguide having means matching the impedance of said coaxial termination of said first circular waveguide to the remainder of said first circular waveguide;

d. a filter transformer comprising a stack of alternating metal and dielectric annuli in said coaxial waveguide surrounding said inner conductor a distance from its termination said annuli being thin with respect to a wavelength at either frequency and providing an attenuation varying with stack length to the higher frequency waves in said coaxial waveguide, but appearing as lumped reactances to the lower frequency waves in said coaxial waveguide;

e. a second circular waveguide capable of carrying the TE 11 mode waves from said first circular and coaxial waveguides and enclosing the region beyond the termination of said first circular waveguide and said inner conductor, the outer conductor of said second circular waveguide formed by an extension of the outer conductor of said coaxial waveguide, the extension of said pin beyond the termination of said inner conductor extending into said second circular waveguide and ending in a taper, the region of said second circular waveguide surrounding the extension of said pin being cutoff for the TM 11 mode of both frequencies carried, but the region surrounding the tapered ending being able at some point in the taper to support TM 11 modes of at least one frequency carried but having the taper substantially inhibiting their generation; and

f. a reactive groove cut into the outer conductors of said coaxial and second circular waveguides, said groove cut in approximately an odd multiple of a quarter wavelength of the higher frequency wave, said groove providing impedance-matching reactance at the lower frequency.