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United States Patent

Rosen

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[45] **June 6, 1972**

[54] **DUAL MODE ROTARY MICROWAVE COUPLER**

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[73] Assignee: **Hughes Aircraft Company,** Culver City, Calif.

[22] Filed: **July 2, 1970**
[21] Appl. No.: **51,869**

[52] **U.S. Cl.** ....333/21 A, 333/9, 333/11, 333/98 TN, 343/756
[51] **Int. Cl.** H01p 1/16, H01p 5/12
[58] **Field of Search** ....333/21, 21 A, 11, 6, 1, 98, 333/9, 98 TN; 343/756, 786

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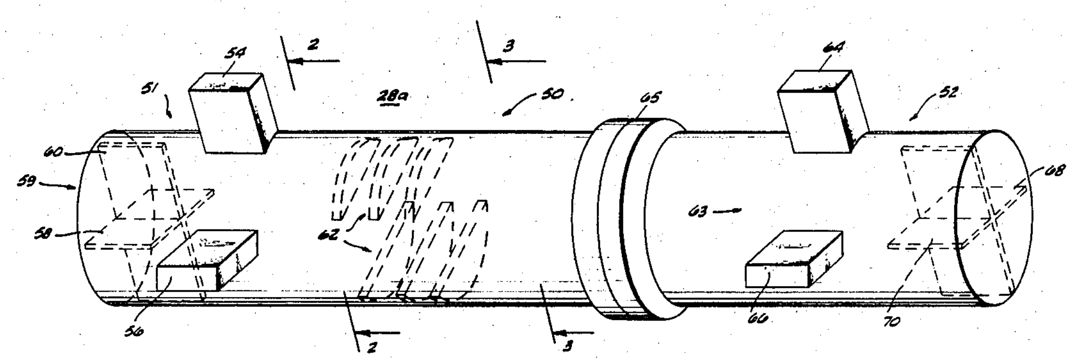
[57] **ABSTRACT**

Microwave coupling devices having input and output rotatably mounted circular waveguide sections with a phase shifter and an orthogonal mode transducer coupled to the input circular waveguide section for converting a pair of linearly polarized input signals to counterrotating circularly polarized signals. A second orthogonal mode transducer, associated with the output circular waveguide section, provides output signals of the proper phase for dual mode transmission by a multiple feed horn antenna system.

10 Claims, 13 Drawing Figures



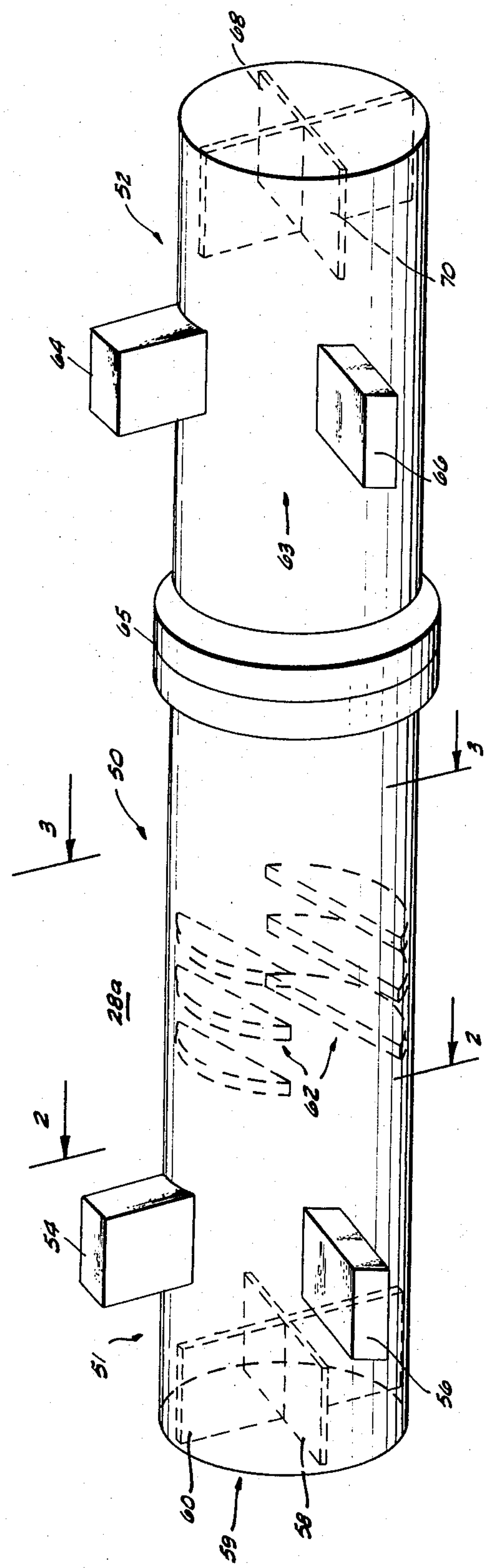


FIG. 1.

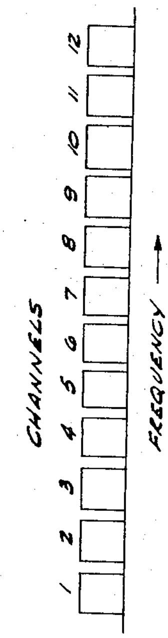


FIG. 8.

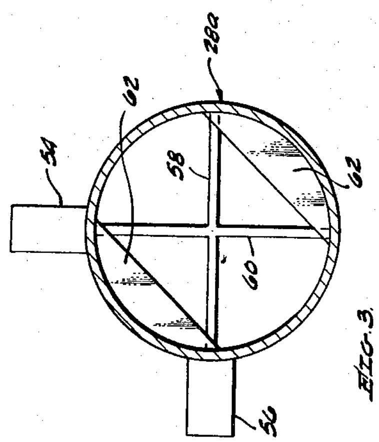


FIG. 3.

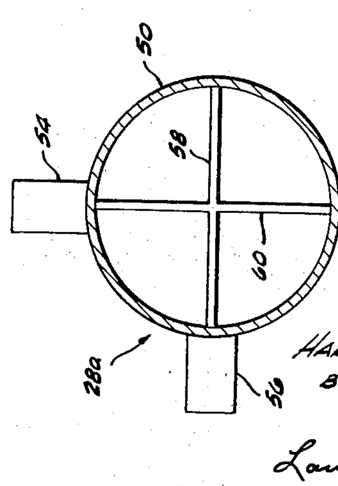


FIG. 2.

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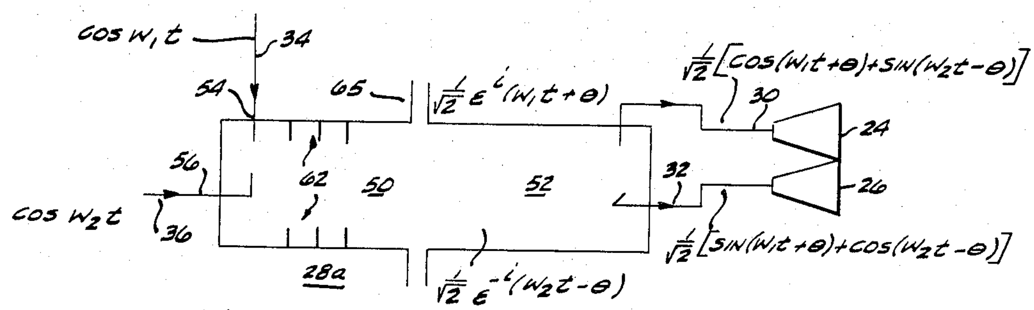


FIG. 4.

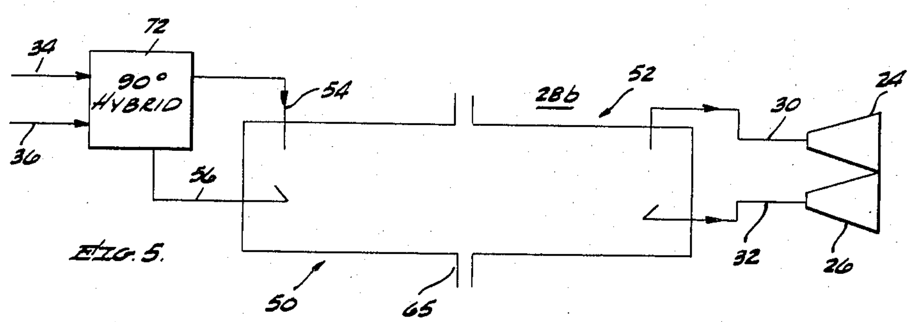


FIG. 5.

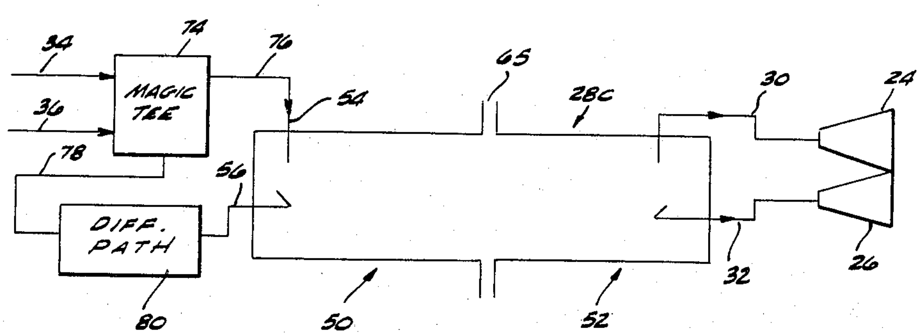


FIG. 6.

FIG. 9d.

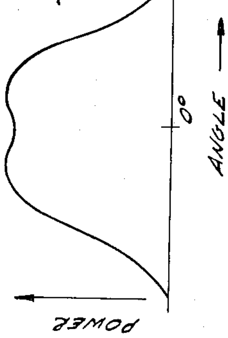


FIG. 9a.

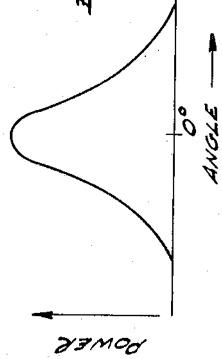


FIG. 9b.

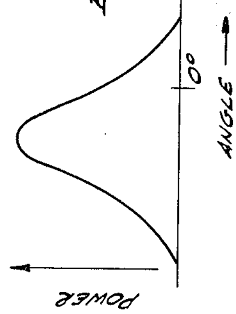
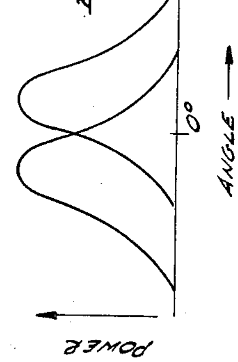


FIG. 9c.



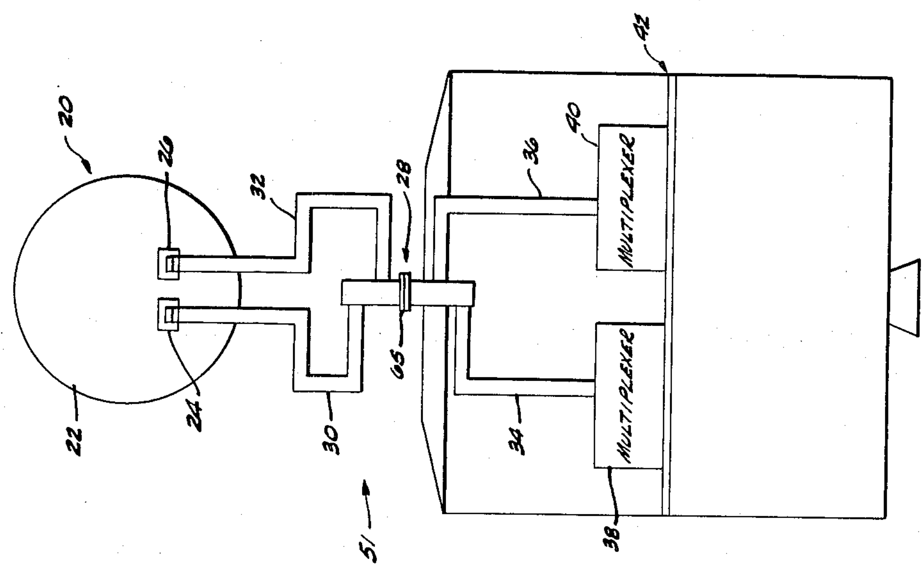
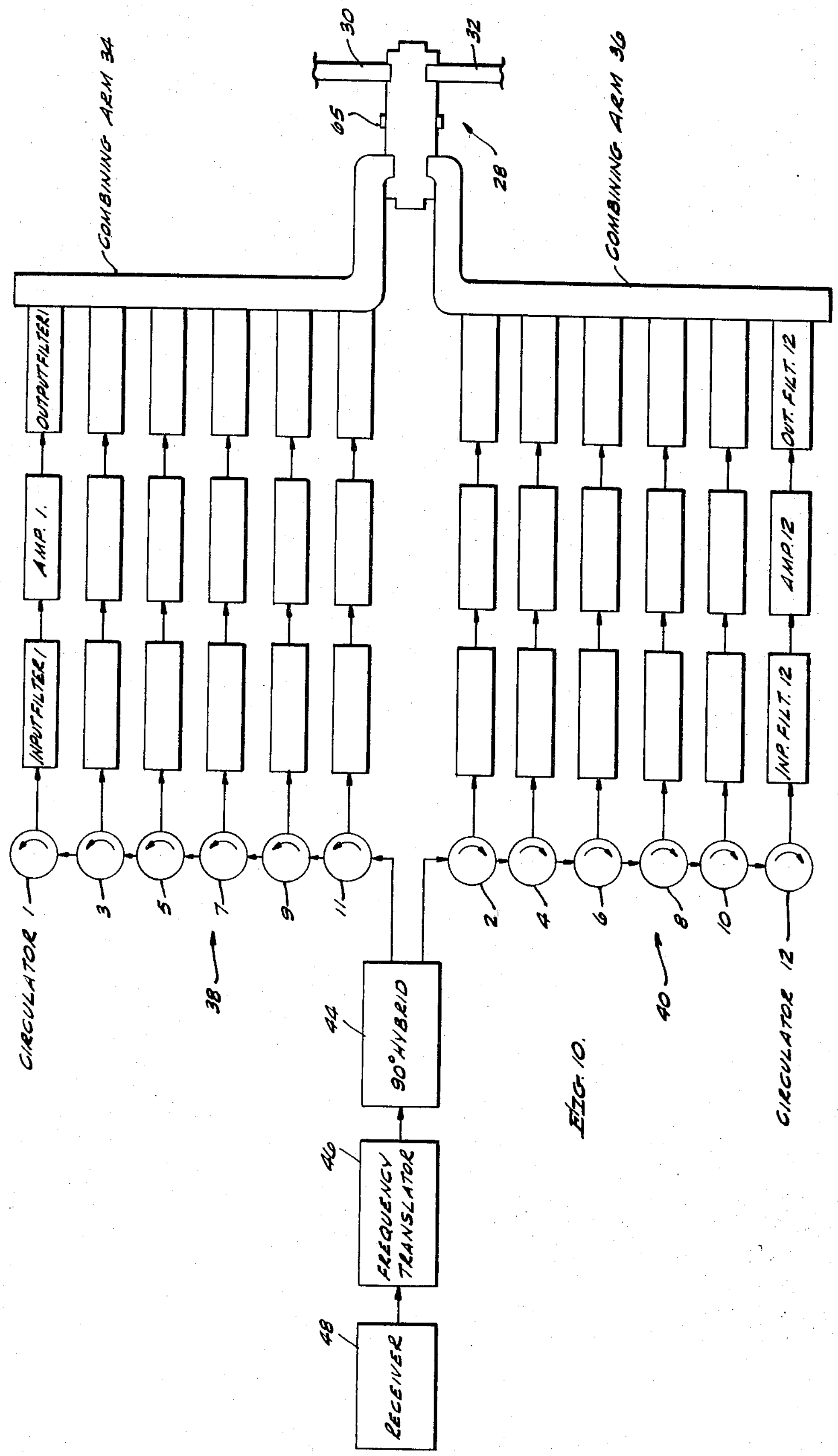


FIG. 7.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32
65
28
COMBINING ARM 34
COMBINING ARM 36
OUTPUT FILTER 1
AMP. 1.
INPUT FILTER 1
OUT. FILT. 12
AMP. 12
INP. FILT. 12
CIRCULATOR 1
3
5
7
9
11
38
2
4
6
8
10
CIRCULATOR 12
40
44
90° HYBRID
46
FREQUENCY TRANSLATOR
48
RECEIVER

FIG. 10.

DUAL MODE ROTARY MICROWAVE COUPLER

BACKGROUND OF THE INVENTION

This invention relates to dual mode microwave couplers and particularly to improved coupling devices of reduced complexity for applying output signals from a pair of rotating transmitter output terminals to an antenna feed network with isolation between signal channels and with the signals applied to the antenna input terminals being properly phased for transmission of a desired shaped beam pattern.

In certain applications such as communication satellites, it is necessary to apply energy from a pair of rotating transmitters or transmitter output multiplexers to input terminals of an antenna system. Economies and improved performance may be realized in the transmitter multiplexer units if sufficient isolation between signal channels is provided; and reduction in size and weight of the antenna feed-coupler network may be obtained if the antenna input terminals are excited by signals of the proper phase for transmission of a desired shaped beam pattern.

SUMMARY OF THE INVENTION

Therefore it is an object of the subject invention to provide an improved dual mode microwave coupler.

Another object is to provide an improved rotary coupler device of reduced complexity for coupling a pair of transmitter channels to a pair of input terminals of an antenna system such that isolation is provided between channels.

A further object is to provide a rotary joint of increased efficiency and reduced size, weight and complexity for directly feeding a pair of input terminals of a shaped beam antenna system.

The microwave coupling devices in accordance with the principles of the subject invention include input and output rotatably mounted circular waveguide sections. An orthogonal mode transducer and a phase shifter are coupled to the input circular waveguide section whereby linearly polarized input signals from a pair of transmitter multiplexer channels are converted to counterrotating circularly polarized signals. The output circular waveguide section includes a mode transducer for converting the counterrotating circularly polarized signals to a pair of linearly polarized signals suitable for directly feeding the input terminals of a "shaped beam" antenna system.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of this invention, as well as the invention itself, will best be understood from the accompanying description taken in connection with the accompanying drawings, in which like characters refer to like parts, and in which:

FIG. **1** is a side elevational view, partially in phantom, of one embodiment of the dual mode rotary coupling device in accordance with the invention;

FIG. **2** is a sectional view taken along the line **2—2** of FIG. **1**;

FIG. **3** is a sectional view taken along the line **3—3** of FIG. **1**;

FIG. **4** is a schematic diagram of the coupling device of FIG. **1**;

FIG. **5** is a schematic and block diagram of a second embodiment of the dual mode rotary microwave coupling device in accordance with the principles of the invention;

FIG. **6** is a schematic and block diagram of a third embodiment of the rotary joint coupling device in accordance with the invention;

FIG. **7** is a front view of a portion of a communication satellite system incorporating the coupling device of the invention for explaining the operation thereof;

FIG. **8** is a plot of communication channels versus frequency for explaining the operation of the subject invention;

FIGS. **9*a***, **9*b***, **9*c*** and **9*d*** are diagrams of transmitted antenna power patterns for explaining the advantages of the couplers of the subject invention; and

FIG. **10** is a schematic and block diagram of a dual channel transmitter multiplexer system which could be utilized to drive the coupler devices in accordance with the subject invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The coupler devices of the subject invention are indicated generally by the reference numeral **28** with one embodiment **28*a*** being shown in FIGS. **1** through **4**, and second and third embodiments **28*b*** and **28*c*** shown in FIGS. **5** and **6** respectively. Coupler **28** includes an input circular waveguide section **50** and an output circular waveguide section **52** coupled by a rotatable joint **65**.

FIG. **7** shows a portion of a communication satellite **51** which could incorporate the coupler **28** and the subject invention may be better understood by first briefly considering the system thereshown. The satellite **51** has an antenna **20** with a parabolic reflector **22** illuminated by a pair of contiguous feed horns **24** and **26**. As described in an application entitled "Shaped Beam Antenna," filed July, 1970, by Harold A. Rosen and James S. Ajioka and assigned to the assignee hereof, and as will be summarized hereinafter, a beam shaped in one axis to provide a large coverage area with signals of approximately uniform power levels is desirable for many communication satellite applications. Such a beam pattern may be formed by exciting the two feed horns with signals having a quadrature phase relationship.

The signals which excite horns **24** and **26** are applied from the rotary joint coupler **28** through waveguides **30** and **32**. The input ports of the rotary joint **28** are excited by signals applied from combining arms (waveguides) **34** and **36** which are driven by transmitter multiplexer units **38** and **40** respectively. The transmitter multiplexer units are mounted on a support structure **42** together with other units such as receivers, signal processor units, power supplies, control units and positioning engines which are not relevant to the subject invention and are not shown.

FIG. **10** shows the transmitter multiplexer units **38** and **40** in greater detail. Each unit comprises six transmission channels having a bandwidth of 40 megahertz, for example, and including a circulator, an input filter, a power amplifier and an output filter. Each of the transmission channel paths are identified by a reference numeral corresponding to the channel number, with the odd numbered channels associated with combining arm **34** and the even numbered channels with combining arm **36**.

The transmission multiplexer units are driven by ninety degree hybrid **44** energized by a frequency translation unit **46** in response to a receiver unit **48**. The frequency translation unit **46** operates to translate the received signal to the desired portion of the frequency spectrum for transmission.

One of the more important advantages of the subject invention is that due to the frequency separation between even and odd channels (see FIG. **8**) the multiplexer units **38** and **40** may be simplified if proper isolation of the output signals from these units is maintained in rotary joint coupler unit **28**. With the isolation provided by the coupler devices in accordance with the subject invention, the "out of band" attenuation requirements on the output filters of the multiplexers are reduced and economies may therefore be realized. For example the output filters, which could be the interdigital type, and the combining arms may be constructed of aluminum instead of INVAR in systems incorporating coupler **28**.

The dual mode feature of the combination of antenna **20** and coupler **28** provides the desired broad uniform gain pattern with a reduction in size, weight, and complexity of the antenna feed-coupler network. As used herein, the dual mode feature refers to the provision of two independent antenna terminals each providing the same gain pattern and polarization sense but having differing senses of phase progression across the pattern. The importance of the two independent terminals in transmission is alleviating the above-described multiplexing problem encountered when multiple transmitters separated in frequency share the same antenna. It is noted that when only two transmitters are involved the provisions of two terminals eliminates the requirement of a transmitter output multiplexer entirely. When a large number of transmitters is required, the provision of two terminals permits connecting to each a set of transmitters having twice the adjacent channel frequencies separation thereby simplifying the design of the multiplexer.

The shaped beam feature provides a far field pattern which has a greater gain-bandwidth product than can be achieved with comparable conventional aperture excitation techniques. Since in satellite communication applications the beam must cover a large prescribed area on earth to fulfill its objectives, the minimum gain achieved over the coverage area should be maximized rather than the beam center gain. As will be explained in detail subsequently, coupler **28** excites the input feed network of antenna **20** with a pair of signals comprising approximately equal components of the signals from the multiplexer units **38** and **40** and the signals applied to the two feed horns are approximately in phase quadrature. The advantages of this type of excitation of horns **24** and **26** may be explained by reference to FIG. **9** which traces the development of the desired shaped beam transmission pattern. FIG. **9***a* shows the far field pattern for a parabolic reflector having a single "on center" feed. FIG. **9***b* shows a similar transmission pattern for a parabolic reflector having an "off center" feed and FIG. **9***c* depicts the pattern resulting from a reflector illuminated by a pair of feeds disposed on opposite sides of the center of the reflector. FIG. **9***d* shows the resultant improvement (more constant gain across a broader pattern) resulting from two "off center" feeds excited by a pair of signals in phase quadrature. This arrangement provides identical patterns for the output signals from each of the transmission multiplexer units.

Also it should be noted that in spinning satellite applications for the antenna **20** to maintain a fixed orientation the antenna section of the satellite must rotate with respect to the spinning platform **42**, and hence the upper section of coupler **28** (FIGS. **7** and **8**) must be rotatable with respect to the lower section.

The dual mode microwave rotary coupling device of FIGS. **1** through **4** exhibits the above-described advantages of minimum size, weight and complexity and fulfills the above-described requirements of providing electrical isolation between the multiplexer output channels and properly phased signals to antenna **20**. Referring now primarily to these last-mentioned figures, the rotary coupler unit **28***a* includes an input circular waveguide section **50** having rectangular input waveguide ports **54** and **56** spaced 90 degrees apart above the circumference of the circular waveguide section **50**. Input ports **54** and **56** are adapted to be coupled to the output terminals of combining arms **34** and **36** (FIG. **7**), and in association with septums **58** and **60** form an orthogonal mode transducer **51**, i.e. the linearly polarized signals applied from combining arms **34** and **36** launch linearly polarized signals within the circular waveguide section **50** which are spatially oriented 90 degrees relative to one another. Septums **58** and **60** are spaced the proper distance from the input ports **54** and **56** to cause the wave energy reflected from end section **51** back to the input ports to be in phase with the energy injected into the input ports. A plurality of irises **62** (one may be sufficient in some applications) vary the propagation velocity of the waves of one polarization relative to the other and hence perform the function of a polarization sensitive differential phase shifter. The design of the septums and irises for optimum performance is well documented in the literature such as the text, Principles and Applications of Waveguide Transmission, by George C. Southworth, published by D. Van Nostrand Company Inc., Princeton, New Jersey, 1956.

A rotatable joint **65** which may be of the noncontacting choke joint type, allows rotation between the input section **50** and the output section **52** of the coupler **28***a*. Output section **52** includes an orthogonal mode transducer **63** which comprises output ports **64** and **66** and septums **68** and **70**, which elements operate in the same manner as described for orthogonal mode transducer **51** discussed above. Output ports **64** and **66** are adapted to be coupled to waveguides **30** and **32** (FIG. **7**) which feed antenna **20**.

In actuality the signals generated by each of the multiplexer units **38** and **40** contains a great many different frequency components grouped in channels separated by frequency zones equal to the bandwidth of a single channel (due to the even and odd multiplexing arrangement). However, for the purpose of clarity of explanation of the operation of the coupler **28***a* it will be assumed that each of the two output signals of the multiplexer units comprise a single frequency and that vectors depicting the transverse electric wave of the signals at any one point may be represented by the notation $\cos \omega_1 t$ and $\cos \omega_2 t$. FIG. **4** analytically traces the signals as they progress through the coupler **28***a*. The signals applied from the transmitter multiplexer units **38** and **40** (FIG. **7**) are applied to input ports **54** and **56** of circular waveguide section **50** and are spatially oriented 90 degrees by means of the positioning of the input ports. The phase shifter which comprises the irises **62** develops counterrotating circularly polarized waves which may be TE_{11} circularly polarized waves, designated by the notation

$$\frac{1}{\sqrt{2}}\epsilon^{i\omega_1 t} \text{ and } \frac{1}{\sqrt{2}}\epsilon^{-i\omega_2 t}.$$

In the output section **52** of the coupler the signals maintain their circularly polarized form except for the addition of a phase angle θ due to the rotation of the output section of the coupler relative to the input section. This rotation effect is accounted for by the designation of the signals as

$$\frac{1}{\sqrt{2}}\epsilon^{i(\omega_1 t+\theta)} \text{ and } \frac{1}{\sqrt{2}}\epsilon^{-i(\omega_2 t-\theta)}.$$

The orthogonal mode transducer **63** formed in the output circular section **52** by output ports **64** and **66** apply linearly polarized waves of orthogonal phase characteristics to each of the output ports as represented by the term $\cos(\omega_1 t+\theta)+\sin(\omega_2 t-\theta)$ and $\sin(\omega_1 t+\theta)+\cos(\omega_2 t-\theta)$ which signals are applied to the feed horns **24** and **26** through coupling waveguide sections **30** and **32** respectively (FIG. **7**).

A second preferred embodiment of the subject invention is shown in FIG. **5** and is indicated generally by reference numeral **28***b*. Coupler **28***b* is similar to the one (**28***a*) shown in FIG. **1** except that the input signals from the transmission multiplexer units **38** and **40** are applied to input ports of a ninety degree hybrid junction **72** and the phase shift network **62** is eliminated. The output ports of the hybrid junction are coupled to the input ports of circular waveguide section **50**. Again assuming that the signals applied from the transmission multiplexer units **38** and **40** are in the form $\cos \omega_1 t$ and $\cos \omega_2 t$, the outputs signals from the hybrid junction **72** applied to input ports **54** and **56** are

$$\frac{1}{\sqrt{2}}\cos \omega_1 t+\sin \omega_2 t)$$

and

$$\frac{1}{\sqrt{2}}(\sin \omega_1 t+\cos \omega_2 t).$$

$\omega_2 t$). Because the signals applied to the input ports of the circular waveguide section **50** are in phase quadrature and are transformed into a space quadrature arrangement by orthogonal mode transducer **51**, counterrotating circularly polarized waves are launched in the input section. The output section **52** of the coupler **28***b* is identical to that of coupler **28***a* discussed previously.

Referring now primarily to FIG. **6** which shows a third preferred embodiment of the subject invention, the output signals from the multiplexer units **38** and **40** are applied to input ports of a magic tee device **74**. Magic tee **74** divides the input signals equally between a pair of output ports **76** and **78** and a differential phase shift is obtained by using a longer transmission path for one of the output signals. In FIG. **6** this increase in output paths is shown in block diagram form by a block **80**, designated "diff. path." It is understood that the path length difference between the signals applied from the different ports of magic tee **74** may be obtained at any point in the signal path to circular waveguide section **50**. For example a portion of the differential path length may be included in the coupling between the magic tee **74** and the input ports of the circular waveguide section **50**, and an additional portion obtained by staggering the input ports along the length of the circular waveguide section. Once again it will be noted that the signals applied to the input ports of circular waveguide section **50** are in phase quadrature (due to the differential path length) and are in a space quadrature relationship due to the effect of the orthogonal mode transducer input section **51**. The output section **52** of the coupler unit **28c** is identical to that described previously relative to coupler **28a**.

The configuration of FIGS. **5** and **6** afford the designer a means of reducing the overall length of the circular waveguide sections in those applications where space along the central axis of the coupler is critical. The simplicity of the design of the couplers in accordance with the principles of the subject invention eliminates tolerance buildups encountered in more complex arrangement thereby relaxing tolerances on components of the remaining units and reducing beam pattern perturbations associated with imperfections in the coupling-antenna feed network.

Thus, there has been described an improved and reliable microwave coupling device for applying a pair of output signals from a transmitter multiplexer system through a rotatable joint to a pair of input terminals of an antenna system such that the signals are isolated during transmission through the coupler thereby simplifying the design of the multiplexer system. The signals are converted in form at the output section of the coupler such that they are properly phased for efficient transmission of a relatively wide beam pattern.

Although one specific satellite application has been disclosed herein to illustrate the advantages and features of the subject invention it will be understood that the couplers in accordance with the subject invention are applicable to a wide range of applications. For example, instead of coupling the output ports of the circular waveguide section **52** directly to feed horns **24** and **26** they may be coupled to any one of a number of well known antenna input terminal networks. For instance the antenna terminal network could process the signals applied thereto for application to a four-feed horn arrangement; for example, having a pair of centrally disposed offset feed horns radiating a "sum" signal and outer feed horns in conjunction with the inner pair radiating a "difference" signal. Additionally, although the ports for coupling microwave energy to and from the various units have been shown herein as the waveguide type such as ports **54** and **56**, it will be understood that other well known techniques such as probes or slotted wall coupling means may be used in place thereof. Also, the disclosure deals mainly with a transmission application but it will be appreciated that the invention may be readily used with a receiving system or with a combination of the transmit and receive functions. For example, with feed horns that allow two orthogonal linear modes, the received signals (of one polarization) could be coupled through the rotary joint **28** by means of a coaxial cable, having rotary couplings, routed through the center of the sections **50** and **52**.

What is claimed is:

1. A microwave coupling device comprising:

first and second rotatably mounted circular waveguide sections;

first means responsive to first and second linearly polarized input signals for launching counterrotating circularly polarized signals in said first waveguide section, said first means including a pair of input ports formed in said first circular waveguide section with approximately a ninety degree interval about the circumference of the section therebetween, a pair of septums in said first circular waveguide section approximately orthogonally disposed to each other, and a differential phase shifter comprising at least one iris disposed within said first circular waveguide section; and

second means including first and second output ports formed in said second circular waveguide section, for providing first and second linearly polarized output signals at said first and second output ports respectively, such that each said output signal has first and second linearly polarized signal components with the first signal component of each said output signal being derived from said first input signal and being substantially in phase quadrature with the other said first signal component, and the second signal component of each output signal being derived from said second input signal and being substantially in phase quadrature with the other said second signal component.

2. The device of claim **1** wherein the vectors representative of the transverse electric field of said linearly polarized input signals are designated cos $\omega_1 t$ and cos $\omega_2 t$, wherein ω_1 and ω_2 are the radian frequencies of said first and second input signal respectively; said first means includes means for converting said input signals into signals of the form

$$\frac{1}{\sqrt{2}}\epsilon^{i\omega_1 t} \text{ and } \frac{1}{\sqrt{2}}\epsilon^{-i\omega_2 t};$$

and said second means includes means for providing said first linearly polarized output signal in the form $\cos \omega_1 t + \sin \omega_2 t$ and said second linearly polarized output signal in the form $\sin \omega_1 t + \cos \omega_2 t$.

3. The device of claim **1** wherein the output ports of said second means are separated by approximately a 90 degree interval about the circumference of said second circular waveguide section.

4. A microwave coupling device comprising:

first and second rotatably mounted circular waveguide sections;

first means responsive to first and second linearly polarized input signals for launching counterrotating circularly polarized signals in said first waveguide section, said first means including an orthogonal mode transducer having a pair of input ports formed in said first circular waveguide section; and a ninety degree hybrid junction having a pair of input ports adapted to be energized by said linearly polarized input signals, and having a pair of output ports coupled to said pair of input ports of said orthogonal mode transducer; and

second means including first and second output ports formed in said second circular waveguide sections, for providing first and second linearly polarized output signals at said first and second output ports respectively, such that each said output signal has first and second linearly polarized signal components with the first signal component of each said output signal being derived from said first input signal and being substantially in phase quadrature with the other said first signal component, and the second signal component of each output signal being derived from said second input signal and being substantially in phase quadrature with the other said second signal component.

5. The device of claim **4** wherein the input ports of the orthogonal mode transducer are separated by approximately a ninety degree interval about the circumference of said first circular waveguide section.

6. The device of claim **5** further including a different pair of approximately orthogonally disposed septum plates in each said first and second circular waveguide sections.

7. The device of claim **4** wherein the output ports of said second means are separated by approximately a ninety degree interval about the circumference of said circular waveguide section.

8. A microwave coupling device comprising:

first and second rotatably mounted circular waveguide sections;

first means responsive to first and second linearly polarized input signals for launching counterrotating circularly polarized signals in said first waveguide section, said first means including an orthogonal mode transducer having substantially orthogonally disposed input ports formed in said first circular waveguide section; a magic tee junction having a pair of input ports and a pair of output ports; and means for coupling the output ports of said magic tee to the input ports of the orthogonal mode transducer of said first means so that the phase delay in one coupling path is approximately ninety degrees greater than in the other coupling path; and

second means including first and second output ports formed in said second circular waveguide section, for providing first and second linearly polarized output signals at said first and second output ports respectively, such that each said output signal has first and second linearly polarized signal components with the first signal component of each said output signal being derived from said first input signal and being substantially in phase quadrature with the other said first signal component, and the second signal component of each output signal being derived from said second input signal and being substantially in phase quadrature with the other said second signal component.

9. The device of claim **8** wherein the output ports of said second means are separated by approximately a 90 degree interval about the circumference of said second circular waveguide section.

10. The device of claim **9** further including a different pair of approximately orthogonally disposed septum plates in each said first and second circular waveguide sections.

* * * * *