United States Patent

[11] **3,633,130**

[72] Inventor **James S. Ajioka**
Fullerton, Calif.
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[73] Assignee **Hughes Aircraft Company**
Culver City, Calif.

[54] **MULTICHANNEL ROTARY JOINT SUPPORTIVE OF ENERGY IN AT LEAST THREE MUTUALLY ORTHOGONAL CIRCULARLY SYMMETRIC WAVEGUIDE MODES SIMULTANEOUSLY**
9 Claims, 14 Drawing Figs.

[52] **U.S. Cl.** .... **333/21 A,** 333/11, 333/98 TN
[51] **Int. Cl.** **H01p 1/06,** H01p 1/16
[50] **Field of Search** .... 333/1, 21, 21 A, 98 TN, 6, 10, 11; 343/786

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Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Paul L. Gensler
Attorneys—James K. Haskell and Don O. Dennison

ABSTRACT: An improved rotary joint for the transmission of high- and low-power electromagnetic wave energy between stationary and rotatable apparatus. Three independently excited high-power channels are provided in a single circular or coaxial waveguide joint. One or more independent low-power channels can be provided in the same rotary joint by means of coaxial transmission lines located within the center of the high-power circular or coaxial waveguide.

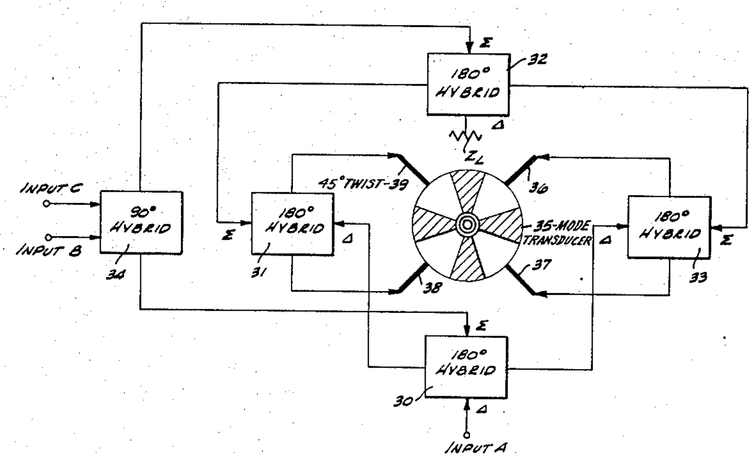
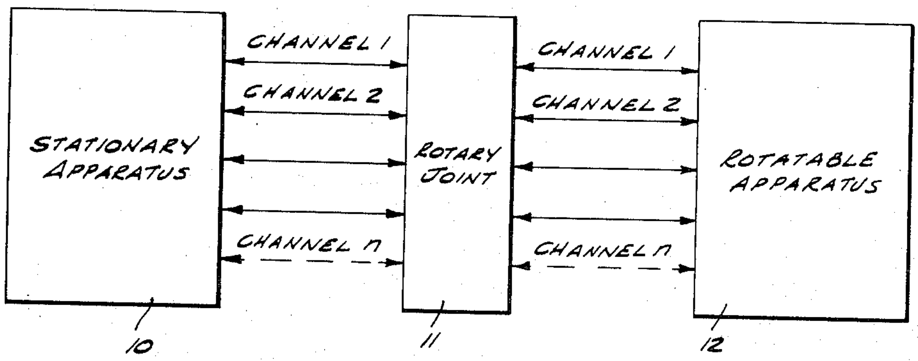
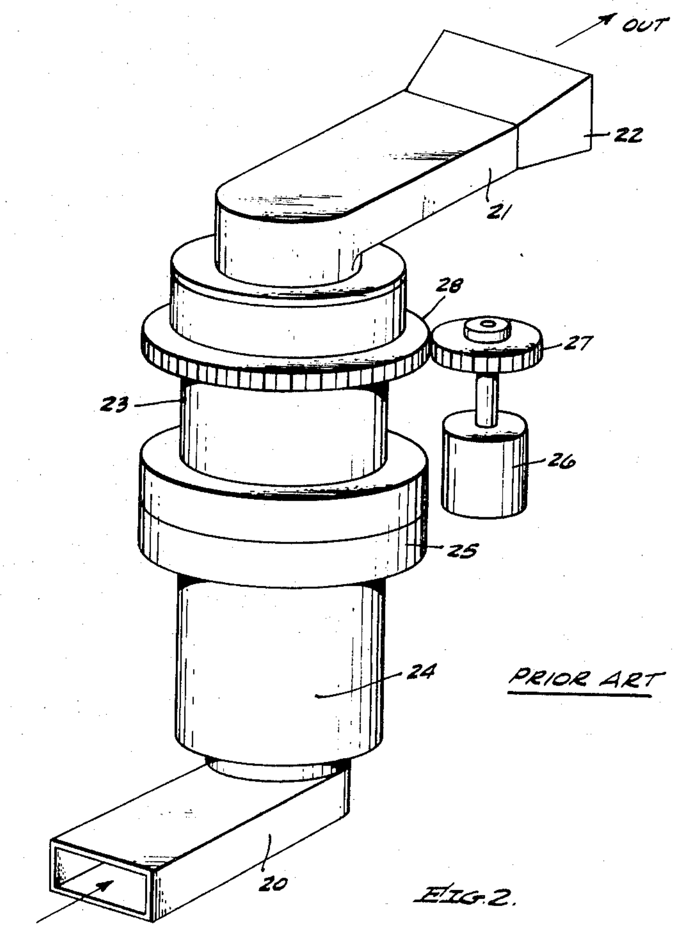


FIG. 1.





PRIOR ART

FIG. 2.

INVENTOR.
JAMES S. AJIOKA,
BY
[signature]
ATTORNEY.

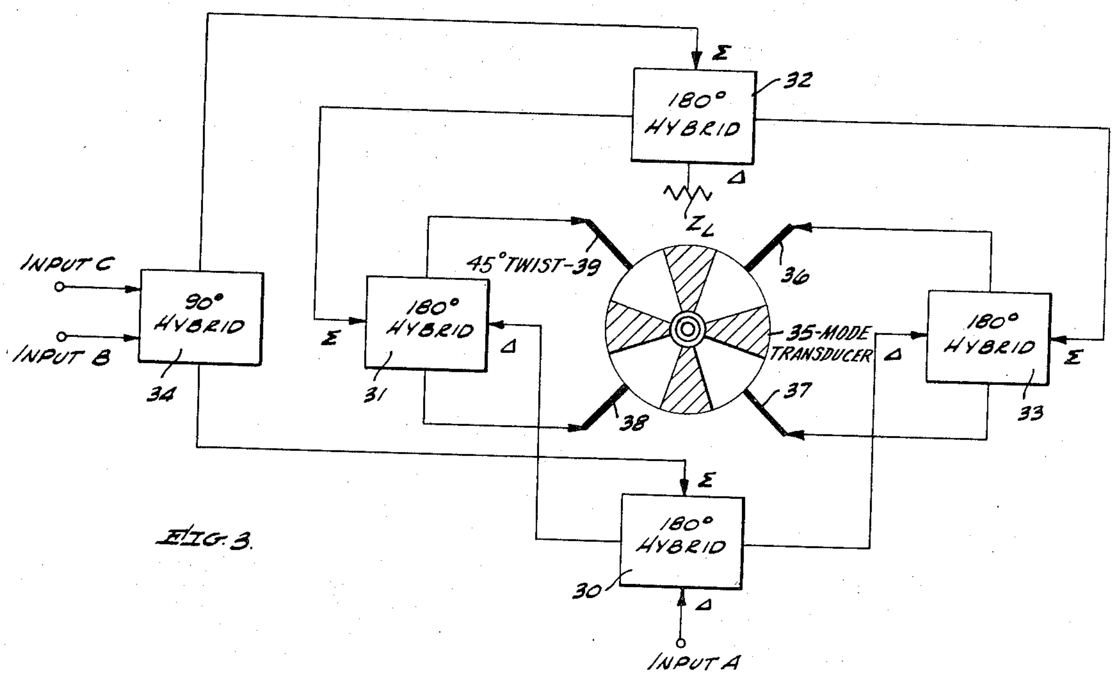

Σ
180° HYBRID
32
Δ
Z_L
45° TWIST-39
36
INPUT C
INPUT B
90° HYBRID
34
Σ
180° HYBRID
31
Δ
35-MODE TRANSDUCER
Δ
180° HYBRID
33
Σ
38
37
Σ
180° HYBRID
30
Δ
INPUT A

FIG. 3.

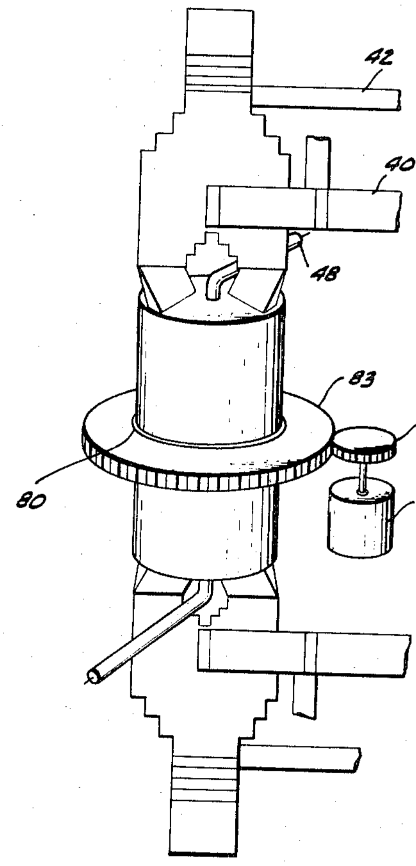

42
40
48
83
82
80
81

FIG. 8.

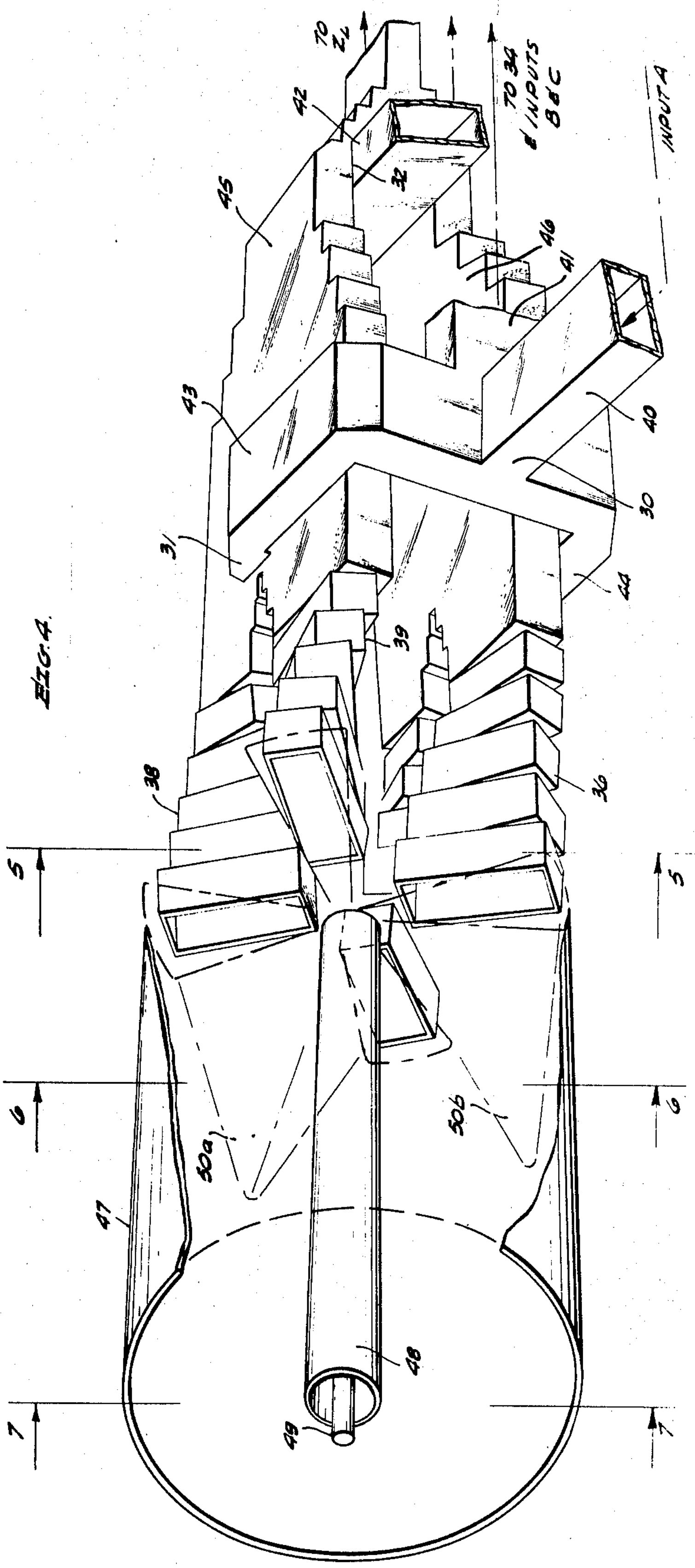

TO Zv
TO 34 INPUTS B & C
INPUT A
42
32
45
46
41
43
40
30
31
44
39
38
36
5
6
7
50a
50b
47
48
49

FIG. 4.

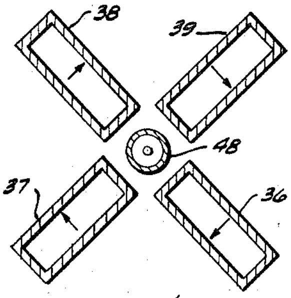


FIG. 5A.

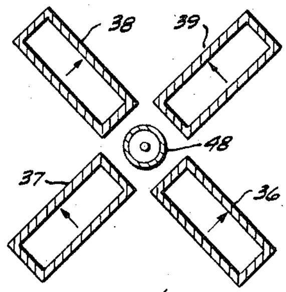


FIG. 5B.

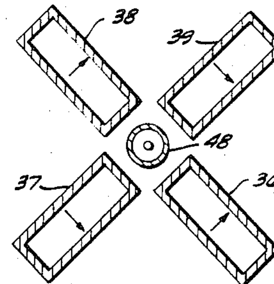


FIG. 5C.

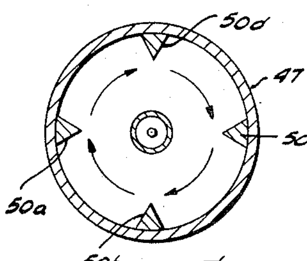


FIG. 6A.

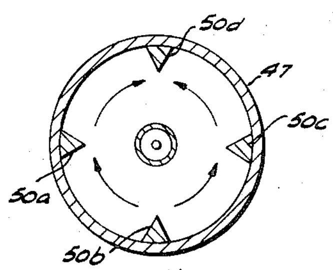


FIG. 6B.

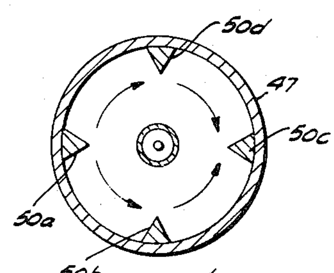


FIG. 6C.

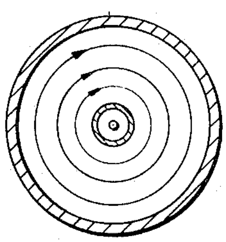


FIG. 7A.

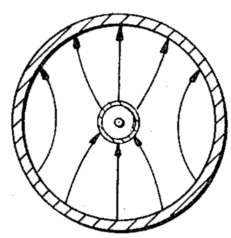


FIG. 7B.

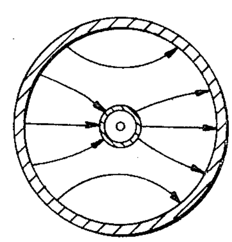


FIG. 7C.

MULTICHANNEL ROTARY JOINT SUPPORTIVE OF ENERGY IN AT LEAST THREE MUTUALLY ORTHOGONAL CIRCULARLY SYMMETRIC WAVEGUIDE MODES SIMULTANEOUSLY

FIELD OF THE INVENTION

This invention relates to rotary joints for microwave transmission structures and more specifically to broadband high-power rotary joints capable of simultaneous multichannel operation.

DESCRIPTION OF THE PRIOR ART

In many microwave installations it is desirable to couple electromagnetic wave energy from one device which is stationary to another device which is capable of rotational motion with respect to the first device. The most common example of such use is a radar installation employing a directional antenna which is rotated with respect to the stationary transmitting and receiving apparatus. In such installations a well-known device, commonly termed a rotary joint, is employed. Rotary joints have been used for many years and have reached a high degree of mechanical sophistication.

Basically, the commonly used rotary joints employ, either singly or in combination, electromagnetic wave transmission structures of either the hollow pipe or the coaxial waveguide variety. The design requirements which must be met in rotary joints are largely dictated by the apparatus and environment in which they are used. For example, for relatively low-power communication usage small rotary joints of the coaxial line type are suitable. For high-power radar installations which may have peak output powers in the multimegawatt region and average powers in the tens of kilowatt region, it is obvious that larger and more refined rotary joints are necessary. Such rotary joints must be capable of handling high powers without arcing, breakdown or *r—f* leakage and should have a low ohmic loss in order to eliminate the requirement for liquid cooling.

It is therefore an object of the present invention to provide an improved rotary joint capable of operation with very high-power apparatus.

One of the generally recognized requirements for transmission of energy through rotary joints is that of maintaining the transmission characteristics constant through all angles of mechanical rotation. Inherent in this requirement is the necessity of utilizing waveguiding structures having circular symmetry and which support wave energy propagating in a symmetrical mode. Modes such as the transverse electromagnetic TEM mode in coaxial waveguides and the circular magnetic TM_{01}°, circular electric TE_{01}° and circularly polarized TE_{11}° in circular waveguides have been utilized.

Except in the case of coaxial transmission line configurations, the input and output waveguides coupled to the rotary joints are generally of rectangular cross section and support energy in the dominant $TE_{10}^{\square}$ mode. It is therefore necessary to provide at each end of the rotary joint, mode converters capable of efficiently converting the wave energy to and from the $TE_{10}^{\square}$ mode to the symmetrical mode appropriate for the rotary joint. In the design of mode-converting apparatus for use in rotary joints two primary requirements exist. First, it is imperative that the wave energy be transformed from one mode to the other without generating spurious modes. Secondly, it is desirable that the mode-converting apparatus be made to operate over as broad a band as possible. Thirdly, the mode-converting apparatus must be low-loss and capable of handling extremely high-peak and average power.

It is therefore another object of the present invention to provide an improved broadband waveguide mode-converting apparatus.

The design of rotary joints and the mode-converting apparatus for use therewith is even more difficult when more than one channel is required. In the past, some success has been achieved with a rotary joint utilizing a plurality of concentric coaxial transmission lines supporting energy in the TEM modes. Such an arrangement, however, is limited in its power-handling capability especially for the innermost coaxial lines. By utilizing a hollow circular waveguide or a coaxial waveguide supporting energy in orthogonal nonTEM waveguide modes, a higher power-handling capability can be achieved. The problem then becomes one of efficiently transforming the energy to the selected waveguide modes with high modal purity.

It is thus another object of the present invention to provide an improved multichannel rotary joint wherein the high-power energy is simultaneously propagated therethrough in different nonTEM modes.

SUMMARY OF THE INVENTION

These and other objects of the present invention are accomplished by utilizing a rotary joint of circular waveguide or coaxial waveguide configuration having internal dimensions large enough to handle the extremely high power with low ohmic loss. The dimensions are, of course, large enough to support simultaneous propagation of wave energy in at least three circularly symmetrical modes. An improved hybrid network and mode converter design is used to provide simultaneous mode conversion from the $TE_{10}^{\square}$ mode from at least three rectangular feed waveguides to the circular electric TE_{01}° and right- and left-hand circularly polarized TE_{11}° modes. Low-power channels can be provided by separate coaxial transmission lines coaxially disposed at the center of the high-power circular or coaxial waveguide. Thus a unitary rotary joint having three independent high-power channels and one or more low-power channels is obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and objects of the present invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings wherein like reference numerals denote like elements and, in which:

FIG. 1 is a generalized block diagram included for explanatory purposes indicating a usage of a multichannel rotary joint;

FIG. 2 is a simplified pictorial representation of a prior-art-type single-channel rotary joint also included for explanatory purposes;

FIG. 3 is a block diagram of a microwave hybrid network for use in practicing the present invention;

FIG. 4 is a pictorial representation, partially broken away, of a portion of the microwave hybrid network illustrated in FIG. 3;

FIGS. 5, 6 and 7 are cross-sectional views taken at progressive sections of the embodiment of FIG. 4 and depicting the electric field configurations therein; and

FIG. 8 is a simplified pictorial view of an assembled rotary joint according to a preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring more specifically to the drawings, FIG. 1 is a block diagram generally indicating the usage of a multichannel rotary joint. In FIG. 1 stationary apparatus **10**, having a plurality of independent input-output channels designated channel 1, channel 2 ... channel *n* is coupled by means of a rotary joint **11** to a rotatable apparatus **12**. The term "stationary apparatus" is a relative term referring to the fixed condition of the apparatus with respect to an arbitrary datum plane. Thus, apparatus **10** can be mounted upon a vehicle or vessel which itself is mobile with respect to earth and still be termed stationary. The rotatable apparatus **12** is meant to include apparatus which is capable of partial or complete rotary motion with respect to the stationary apparatus **10**.

As mentioned hereinabove, one common system in which the present invention may be used is a high-power radar system. In such use, stationary apparatus **10** would comprise a radar transmitter, receiver and other associated equipment.

Rotatable apparatus 12 would, of course, represent a directional antenna structure. In some instances a single channel coupling wave energy between the stationary and rotatable apparatus is all that is required. In may other applications it is desirable to have a plurality of channels although some of these may require only a relatively low-power handling capability.

FIG. 2 is a simplified pictorial representation of a typical rotary joint of prior art design included here for the sake of explanation. In the structure of FIG. 2 a first section of rectangular waveguide **20** is adapted for coupling to stationary apparatus not shown. A second section of rectangular waveguide **21** is adapted for electromagnetic coupling to the rotatable apparatus. A flared section or horn **22** can be provided to feed to and from a reflector or subreflector structure, also not shown.

Between the first and second waveguide sections **20** and **21** are coupled first and second sections **23** and **24** of a circular waveguide which are joined by a composite choke-bearing structure **25**. A drive motor **26** mechanically coupled by appropriate gears **27** and **28** provide the means for rotating the rotatable portion of the rotary joint.

In general, waveguide sections **20** and **21** support wave energy propagating in the dominant $TE_{10}^{\square}$ mode. Due to the requirement of rotational symmetry within the rotary joint, the circular waveguide sections **23** and **24** support wave energy in one of the circularly symmetric modes mentioned hereinabove. It is apparent, therefore, that at the transitions between waveguide sections **20** and **24** and **21** and **23**, suitable mode transducers are required.

The operation of rotary joints such as that of FIG. 2 is well known in the art and need not be described in detail. Briefly, microwave energy such as that from a radar transmitter is coupled into waveguide section **20** in the $TE_{10}^{\square}$ mode. At the junction of waveguide sections **20** and **24**, the energy undergoes a mode transformation from the $TE_{10}^{\square}$ mode to one of the circularly symmetric modes for propagation in circular waveguide sections **24** and **23**. The composite choke-bearing section **25** allows relative rotation of sections **23** and **24** while preventing *r—f* leakage from the joint.

The wave energy propagates through the joint where it undergoes a mode transformation at the junction of wave guide sections **21** and **23**. After the second mode transformation the wave energy propagates through waveguide section **21**, and out of flared section **22**. A particular design of the mode transformers used between the rectangular and circular wave guide sections are dictated primarily by which circularly symmetric mode is used. Many suitable mode transition sections are described by G. L. Ragan, *Microwave Transmission Circuits*, Vol. 9, Rad. Lab. Series, McGraw-Hill Book Co., New York, 1948 at Chap. 7.

For the simultaneous transmission of more than one independent high-power broadband channel of microwave energy, more complicated mode exciting structures are required. In FIG. 3 there is shown in block diagram a preferred embodiment of a three-channel microwave hybrid network according to the present invention. The network of FIG. 3 utilizes four 180° hybrid junctions **30, 31, 32** and **33**, one 90° hybrid junction **34** and a pyramidal mode transducer structure **35**. The 180° hybrid junctions **30** and **33** can take many forms such as the well-known magic tee, for example. Hybrid junctions **34**, sometimes known as a 3*dB* directional coupler can also assume many forms, as is well known in the art.

Hybrid junctions **30** through **33** illustrated in FIG. 3 comprise two pairs of conjugate ports. Their operation is such that when properly terminated, power applied to a first port of a first conjugate pair will divide equally between the ports of the second conjugate pair with no direct transmission to the second port of the first pair. Power applied to either of the ports of the second conjugate pair divides between the ports of the first pair in a like manner. The 90° or 180° designation of the hybrid junction denotes the relative phase of the output wave energy with input energy applied to the appropriate input port.

Such hybrid junctions are further characterized by designating the ports of the first conjugate pair as either the sum (Σ) port or the difference (Δ) port. This designation relates to the output characteristic when fed at the second pair of ports by wave energy which is either in phase or out of phase, respectively. In phase energy will appear at the sum port and out of phase energy at the difference port.

Returning to the description of the network of FIG. 3, a first input A is coupled to the so-called difference port of hybrid junction **30**. The first and second ports of the second conjugate pair of hybrid junction **30** are coupled to the difference ports of hybrid junctions **31** and **33**, respectively. Inputs B and C are coupled to respective conjugate input ports of 90° hybrid junction **34** with one output port of the second conjugate pair being coupled to the sum port of hybrid junction **30** and the other output port being coupled to the sum port of hybrid junction **32**. The conjugate output ports of hybrid junction **32** are, in turn, coupled to respective sum ports of hybrid junctions **31** and **33**. The difference port of hybrid junction **32** is terminated in a substantially reflectionless load impedance Z_L. Each of the conjugate output ports of hybrid junctions **31** and **33** are coupled through 45° twist sections **36, 37, 38** and **39** to pyramidal mode transducer structure **35**, as will be discussed in greater detail hereinbelow.

In FIG. 4 there is shown a pictorial representation, partially broken away, of the network of FIG. 3 implemented with hollow conductively bounded and coaxial waveguide elements. Where appropriate, like reference numerals have been carried over from FIG. 3 to designate like structural elements. For the sake of clarity, the 90° hybrid junction **34** and load impedance Z_L have been omitted from FIG. 4, as have the various flanges, chokes and other mechanical coupling means which are utilized.

Input A is coupled to the difference port of 180° hybrid junction **30** by means of a rectangular waveguide section **40**. Inputs B and C are coupled to the conjugate input ports of 90° hybrid junction **34**, not shown, the conjugate output ports of which are coupled to waveguide sections **41** and **42** which, in turn, correspond to the sum ports of 180° hybrid junctions **30** and **32**, respectively. The difference port of hybrid junction **32** is coupled to reflectionless load impedance Z_L, not shown.

The conjugate output ports of hybrid junction **30** are coupled to the difference ports of 180° hybrid junctions **31** and **33** by means of rectangular waveguide sections **43** and **44**, respectively. The conjugate output ports of hybrid junctions **31** and **33** are, in turn, coupled to the pyramidal mode transducer structure **35** by means of 45° step-twist sections **36, 37, 38** and **39**. The conjugate output ports of hybrid junction **32** are coupled to the sum ports of hybrid junctions **31** and **33** by means of stepped waveguide sections **45** and **46**, respectively. Stepped waveguide sections **45** and **46**, although identified as discrete elements, can be considered as integral portions of the H-plane folded magic tees, which comprise hybrid junctions **31** and **33**. Although the 45° twist sections are illustrated as step-twist sections it is obvious that smooth twist sections can be employed if desired.

The pyramidal mode transducer section **35** is shown partially broken away in FIG. 4. This transducer structure comprises a section of coaxial waveguide having an outer conductor **47** and hollow inner conductor **48**. Four separate pyramid-shaped conductive elements, two of which **50*a*** and **50*b*** are shown, provide a smooth taper between twist sections **36** through **39** and the interior of the coaxial waveguide section. Coaxially disposed within the interior of inner conductor **48** is another inner conductor **49**. Inner conductors **49** and **48** serve as a separate low-power channel which is supportive of energy in the TEM mode. In practice, additional coaxial low power channels can be provided, each located coaxially within another as is known in the art. On the other hand, if desired, all of the coaxial center conductors can be omitted, in which case only outer conductor **47** need be present. In this configuration the resulting cylindrical structure would be more accurately termed a circular waveguide rather than a coaxial waveguide.

Wave propagating toward the pyramidal mode transducer 35 through each of the 45° twist sections 36 through 39 is gradually transformed from the rectangular $TE_{10}^{\square}$ modes and combined in the circularly symmetrical modes for transmission through the coaxial waveguide section. This mode transformation takes place simultaneously for all three high-power modes. The operation of the embodiment of FIG. 4 and the mode transformation can be more readily understood with the aid of FIGS. 5, 6 and 7 which are cross-sectional views of the structure of FIG. 4 taken at successive transverse cross sections.

In operation, high-power wave energy is applied to inputs A, B and C either singly or simultaneously. Inputs B and C are combined in the 90° hybrid junction 34, not shown, for application to waveguide sections 41 and 42. Treating the inputs individually, operation for each high-power channel can be understood. Simultaneous operation with more than one channel is independent of the existence of wave energy in any other channel and there is, therefore, no mutual interaction.

If input A is considered first, high-power wave energy is coupled to waveguide section 40 in the $TE_{10}^{\square}$ mode. This wave energy is split at hybrid junction 30 and coupled to hybrid junctions 31 and 33 by means of waveguide sections 43 and 44, respectively. The wave energy is further divided by the latter hybrid junctions and coupled to 45° twist sections 36 through 39 in equal amounts.

The mode transformation is shown sequentially in FIGS. 5A, 6A and 7A. The electric vectors of the resultant wave energy in 45° twist sections 36 through 39 are indicated in the cross-sectional view of FIG. 5A. As seen, the electric vectors are directed downward in twist sections 39 and 36 and upward in twist sections 37 and 38. In the cross-sectional view of FIG. 6A the twist sections have merged into the pyramidal mode transducer section 35 and the electric vectors begin to assume a continuous clockwise configuration with four separate electric vectors extending between the conductive pyramids 50*a*, 50*b*, 50*c* and 50*d* of the transducer. In FIG. 7A the electric vectors are merged to form one circular electric field pattern characteristic of the well-known circular electric TE_{01}° mode. Since, with this mode, the electric field component in the center of the coaxial waveguide is substantially zero the presence of a relatively small inner conductor 48 has substantially no perturbing effect.

The sequence of cross-sectional views depicted in FIGS. 5B, 6B and 7B indicate the mode transformation for input energy applied to input B. As mentioned hereinabove, energy applied to input B is divided in the 90° hybrid junction, as shown in FIG. 3, and applied to waveguide sections 41 and 42 as shown in FIG. 4. The energy thus applied is again divided at 180° hybrid junctions 30 and 32, respectively, and combined again at 180° hybrid junctions 31 and 33 to produce the electric field pattern depicted in FIG. 5B in the 45° twist sections. The mode transformation shown in FIGS. 6B and 7B results in a circularly polarized TE_{11}° mode. By the same procedure, wave energy applied to wave input C is transformed into a counterrotating circularly polarized TE_{11}° mode as shown in the transformation sequence indicated in FIGS. 5C, 6C and 7C. The 90° hybrid junction and waveguides coupled thereto are proportioned so that Input B results in left-hand circular polarization and Input C results in right-hand circular polarization, or vice versa. In the case of the TE_{11}° modes, the electric fields are substantially normal to center conductor 48 and therefore are substantially unperturbed thereby.

When energized simultaneously, therefore, Inputs A, B and C result in three separate circularly symmetrical modes propagating in the coaxial waveguide section. As mentioned, these modes are in the circular electric TE_{01}° mode and the right- and left-hand counterrotating circularly polarized TE_{11}° modes. Due to their mutual orthogonality, these three high-power modes are independent. As stated hereinabove, the wave energy in the three channels can be of different frequencies within the operating limitations imposed by the bandwidths of the constituent elements of the microwave hybrid network. In addition, the inner conductors 48 and 49 support wave energy in a coaxial TEM mode and may be adapted for any frequency including DC.

Although the microwave hybrid network of FIGS. 3 and 4 has been described in terms of its transmitting mode, transmission in the reverse direction is readily apparent. For example, wave energy in the circular electric TE_{01}° mode coupled into the coaxial waveguide section is converted at mode transducer 35 in equal amounts to the $TE_{10}^{\square}$ modes in 45° twist sections 36 through 39. The energy is thereafter additively combined in hybrid junctions 31, 33 and 30 to result in output energy in the $TE_{10}^{\square}$ mode from waveguide section 40. By the same token, wave energy in counterrotating circularly polarized TE_{11}° modes coupled into the coaxial waveguide section yields independent outputs from the 90° hybrid network 34.

In order to realize a complete multichannel rotary joint therefor, it is necessary only to couple two of the microwave hybrid networks of FIGS. 3 and 4 by means of a rotary interface as shown in the simplified pictorial view of FIG. 8. The rotary joint of FIG. 8 therefore comprises two identical microwave hybrid networks separated by a composite choke-bearing structure 80 and driven by a suitable motor 81 by means of gears 82 and 83. In the embodiment of FIG. 8 the 45° step-twist sections have been replaced by 45° smooth-twist sections. In addition, the centrally located low-power coaxial line is represented by an extended inner conductor 48. The rotary interface for the low-power channel can be situated, if desired, either above or below the rotary interface of the high-power coaxial waveguide. Also, if desired, additional low-power channels can be provided.

In all cases it is understood that the above-described embodiments are merely illustrative of but a small number of the many possible specific embodiments which can represent applications of the principles of the present invention. Numerous and varied other arrangements can be readily devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A multichannel rotary joint comprising, in combination:

first and second circularly symmetric waveguide sections, said waveguide sections being coupled for relative rotary motion about a common axis, said waveguide sections being capable of supporting propagating eletromagnetic wave energy in at least three mutually orthogonal circularly symmetric waveguide modes simultaneously;

a first hybrid network having at least three independent input ports, said first hybrid network including means for coupling each of said respective input ports to a separate orthogonal mode of said first circularly symmetrical waveguide section; and

a second hybrid network having at least three independent output ports, said second hybrid network including means for coupling each of said separate orthogonal modes in said second circularly symmetrical waveguide section to respective ones of said output ports.

2. The rotary joint according to claim 1 wherein one of said mutually orthogonal modes is the circular electric TE_{01}° mode.

3. The rotary joint according to claim 1 wherein said mutually orthogonal modes correspond to the TE_{01}° mode and two counterrotating circularly polarized TE_{11}° modes.

4. The rotary joint according to claim 1 wherein said first and second circularly symmetric waveguide sections are of the coaxial waveguide type.

5. The rotary joint according to claim 1 wherein said first and second circularly symmetric waveguide sections are coupled by means of a composite choke-bearing structure.

6. A multichannel rotary joint comprising, in combination:

first and second coaxial waveguide sections, each of said waveguide sections having an outer conductor and a hollow coaxially disposed center conductor and at least one inner conductor coaxially disposed within said center conductor, said coaxial waveguide sections being coupled for relative rotary motion about a common axis, the portion of each coaxial waveguide section defined by said outer and center conductors being capable of supporting propagating electromagnetic wave energy in at least three mutually orthogonal circularly symmetric waveguide modes simultaneously, and the portion of each coaxial waveguide section defined by said center conductor and said inner conductor being capable of supporting propagating electromagnetic wave energy in the TEM mode;

a first hybrid network having at least three independent input ports, said first hybrid network including means for coupling each of said respective input ports to a separate orthogonal mode of said first coaxial waveguide section;

a second hybrid network having at least three independent output ports, said second hybrid network including means for coupling each of said separate orthogonal modes in said second coaxial waveguide section to respective ones of said output ports;

separate input means independent of said first hybrid network coupled to the portion of said first coaxial waveguide section defined by said center and inner conductors; and

separate output means independent of said second hybrid network being coupled to the portion of said second coaxial waveguide section defined by said center and inner conductors.

7. The rotary joint according to claim **6** wherein one of said mutually orthogonal modes is the circular electric TE°_{01} mode.

8. The rotary joint according to claim **6** wherein said mutually orthogonal modes correspond to the TE°_{01} mode and two counterrotating circularly polarized TE°_{11} modes.

9. The rotary joint according to claim **6** wherein said first and second coaxial waveguide sections are coupled by means of a composite choke-bearing structure.

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