Aug. 3, 1965 H. S. KEEN 3,199,055

MICROWAVE ROTARY JOINT

Filed Oct. 30, 1963

FIG. 1

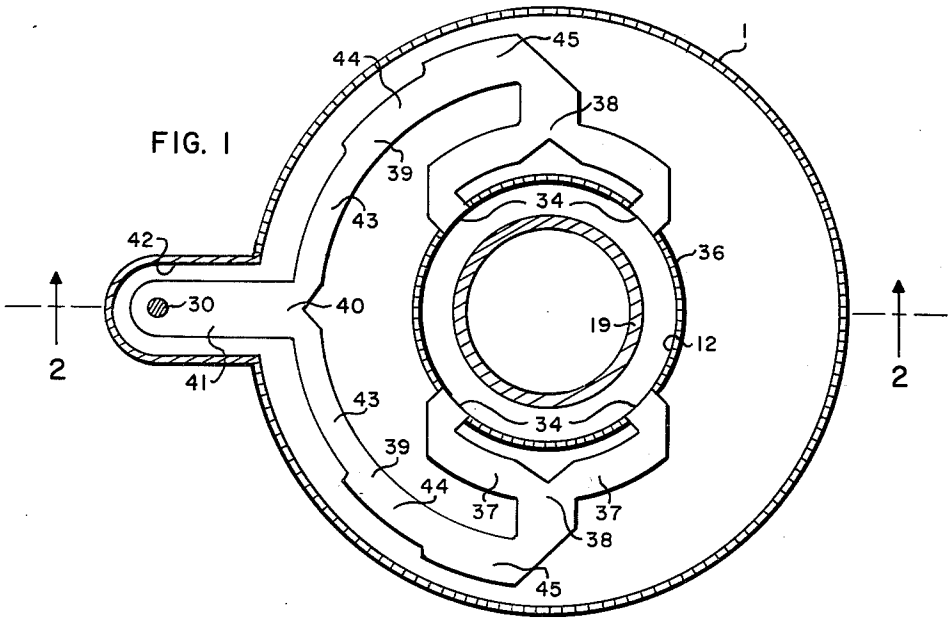
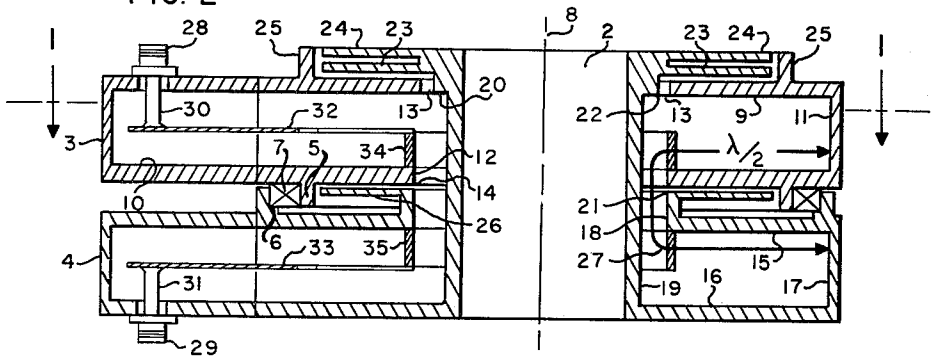


FIG. 2



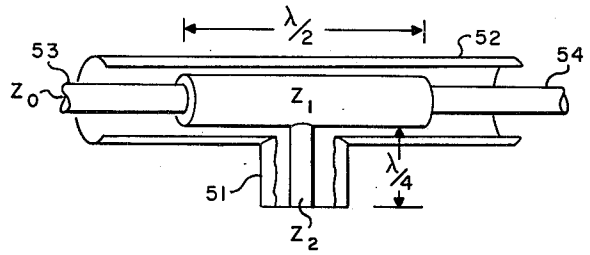


FIG. 3

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United States Patent Office 3,199,055
Patented Aug. 3, 1965

3,199,055

MICROWAVE ROTARY JOINT

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Filed Oct. 30, 1963, Ser. No. 320,151
4 Claims. (Cl. 333—98)

This invention relates to improvements in microwave rotary joints such as are used to connect radar transmitter-receiver equipment to rotary directive antennas.

The principal object of the invention is to provide a type of rotary joint that is substantially free of "wow," i.e. variation in transmission with rotation, yet simple in construction, requiring no mode suppressors or other special devices to ensure proper operation.

Another object is to provide a rotary joint that can readily be designed with a large central opening and so adapted for "around the mast" arrangement, permitting a plurality of such joints to be stacked along a common axis of rotation, with the associated external feed lines passing through the central openings.

A further object is to provide a type of rotary joint that is compact and mechanically simple, and substantially cheaper to build than prior art devices of comparable performance.

The foregoing objects are achieved in the practice of this invention by employing a pair of hollow body members arranged for relative rotation and cooperating to define a resonant cavity in the form of a half wavelength transmission line short circuited at both ends. Each body member includes a feed means that couples a respective external transmission line to the cavity symmetrically with respect to the axis of rotation, and the cavity itself serves as a common impedance element coupling the feed means to each other.

The cavity has a total length, at the design or mid-band frequency, of one half wavelength in the circumferentially uniform dominant TEM mode. This dimension is less than one half wavelength in higher order circumferentially non-uniform modes which would cause "wow," and resonance cannot occur in such modes. The feed means are designed with reference to the shunt impedances presented by the cavity to cooperate therewith in the manner of broad band quarter wavelength stub structures, whereby the rotary joint as a whole exhibits corresponding broad band characteristics. Preferably the half wavelength cavity is partly or wholly in the form of radial transmission line sections, to minimize the axial dimension of the structure. The feed means may include a distribution system comprising a network of transmission line sections including flat strip conductors disposed parallel to and midway between the radial surfaces in electrically neutral planes within the cavity.

The invention will be described with reference to the accompanying drawings, wherein:

FIG. 1 is a plan view of a presently preferred embodiment of the invention, partly broken away to show certain internal details;

FIG. 2 is a side elevation in section of the structure of FIG. 1; and

FIG. 3 is a representation of a broad band coaxial stub support, known to the art, and shown for purposes of comparison.

Referring to FIGS. 1 and 2, the external form of the assembled joint is approximately that of a rectangular torus or a short annular cylinder **1**, with a central axial opening **2**. As shown in FIG. 2, the assembly comprises two mating hollow body members **3** and **4** provided with bearing seats **5** and **6** for engagement with the inner and outer races, respectively, of a ring bearing **7**. The bearing **7** is designed to absorb both radial and thrust loads, and is preferably of the four line contact type to resist axial

deflection. The interior surface of the upper member **3** is substantially that of a reentrant figure of revolution about the axis **8**, consisting of upper and lower walls **9** and **10** in the form of annular discs, a cylindrical circumferential wall **11**, and a short cylindrical inner wall **12**. The circular boundaries of the interior surface of the member **3** are considered as defined by edges **13** and **14** respectively.

The interior surface of the lower body member **4** includes annular disc shaped walls **15** and **16**, cylindrical circumferential wall **17**, short cylindrical inner wall **18**, and also a longer cylindrical inner wall **19** and a relatively narrow annular disc shaped upper wall region **20**. The circular boundaries of the interior surface of the body member **4** are considered as defined by edges **21** and **22** respectively. The circular edges **13**, **14** and **21**, **22** also constitute the boundaries of respective open areas in the body members **3** and **4**. These open areas are each circularly symmetrical about the axis **8**, and face each other in closely conformal relationship so that the interiors of the body members jointly form a single cavity that is totally enclosed except for the narrow annular gaps between circular edges **13**, **22** and **14**, **21**.

The upper central portion of the body member **4** is provided with a pair of closely spaced annular disc shaped fins **23** and **24** extending radially outward over the upper outer surface of the member **3**, and terminating near the inner surface of a short vertical cylindrical wall **25** thereon. The radial dimensions of fins **23** and **24** are such that the structure acts as a cascade quarter wave radial choke, effectively connecting the edges **13** and **22** together for microwave energy, but permitting relative rotation without mechanical contact. The gap between edges **14** and **21** is similarly closed for microwave energy by means of a cascade quarter wave radial choke formed by an annular fin **26** on the body member **4**, extending radially outward in closely spaced parallel relationship to the adjacent outer surfaces of the members **3** and **4**.

The microwave enclosure formed by the above described structure consists of a central coaxial line section, formed by the surfaces **12** and **18** in cooperation with the adjacent portions of the surface **19**, and a pair of radial waveguide sections formed by the surfaces **9**, **10** and **15**, **16** respectively. The outer ends of the radial waveguides are short- circuited by walls **11** and **17**, and the inner ends are joined to the upper and lower ends respectively of the coaxial line section. The inner conductor **19** is hollow to provide the central opening **2** for accommodating feed lines, not shown, when a plurality of rotary joints are to be arranged coaxially one above the other. Since the conductor **19** is a single integral piece unbroken by any gaps, it may serve as a torque member in a stacked assembly, or constitute a portion of a supporting mast,

The enclosure may also be considered as a coaxial line section with its ends folded outwardly, the surfaces **9** and **16** being the folded extensions of its inner conductor, and the surfaces **10** and **15** extensions of its outer conductor. However considered, the enclosure is a resonant cavity having a principal resonance at a frequency such that the electrical length of the path between the short circuited ends **11** and **17** is one half wavelength, as indicated by arrows **27**. In this mode the electric field is circumferentially uniform, being directed radially in the central coaxial line region and vertically (parallel to the axis **8**) in the radial waveguide regions.

The dimensions of the cavity are chosen, taking into account the desired size of the central hole **2**, to make the above mentioned resonance occur within the band of microwave frequencies throughout which the joint is to operate, preferably at or near mid-band. Allowance must also be made for the fact that the electrical lengths of the radial waveguide sections differ from the mechani-

cal lengths, i.e. radial dimensions, in known manner. Incidentally, the latter consideration applies similarly to the design of the cascade quarter wave radial chokes 23, 24, etc. previously described.

Body members 3 and 4 are provided with coaxial connectors 28 and 29 for engagement with mating connectors on external lines, not shown, which may be of standard coaxial type. The insulated inner conductors 30 and 31 of the connectors 28 and 29 extend into the cavity and are connected to the radially outer terminal portions of respective distribution systems 32 and 33, for coupling each to a respective group of symmetrically disposed feed points 34 and 35 in the resonator.

The distribution systems 32 and 33 are identical arrangements of flat strip conductors, seen on edge in FIG. 2, lying in the respective neutral planes of the radial waveguide portions of the cavity, midway between the parallel wall surfaces. Referring to FIG. 1, the upper distribution system 32 appears in plan view. Feed points 34 are disposed at equal intervals around the upper edge of the outer wall 12 of the coaxial line section of the resonator, and consist essentially of short vertical conductors connecting the inner terminals of the distribution system to the bottom wall 10 of the radial waveguide section at its junction with the outer wall 12 of the coaxial line section. Although the feed points are shown in the illustrations and described in the text as contacting one particular conducting wall of the resonant cavity, one can, with equal effect causes the feed points to contact the opposite conducting wall of said cavity. Since the feed points are at cophasal equal amplitude in normal operation, as will be described, they may be merged as a single conductive ring 36 forming an extension of the surface 12 connected at its upper edge to the uniformly spaced inner terminals of the distribution system. In such case, the feed points 34 are the portions of the ring 36 where the terminals are connected, and the remainder of the ring 36 contributes to the mechanical rigidity of the structure.

The feed points 34 are connected in pairs, by way of strip conductors 37, to junctions 38. Junctions 38 are similarly symmetrically connected by way of strip conductors 39 to a junction 40. Junction 40 is connected to the end of inner conductor 30 by a strip conductor 41. The body member 3 is provided with a cavity 42 that contains a major portion of the strip conductor 41. The dimensions of cavity 42 are such that it acts as a waveguide beyond cutoff to the radial transmission line mode of the main cavity and thus does not distort the circular uniformity of the field in the main cavity.

The strip conductors may be designed to include quarter wavelength transformer sections located and dimensioned for impedance matching at the junctions 38 and 40. Shunt capacitive susceptance devices may also be included to compensate residual mismatches. These devices may be in the form of blocks of dielectric material placed between the strip conductors and ground planes at appropriate locations determined in known manner.

Since the feed points 34 are connected to the conductor 30 through electrically identical paths, and are identically coupled to the resonator, they are constrained to operate at equal amplitudes and in phase with each other. Owing to the binary nature of the distribution system, the number of feed points must be a power of two (four in the present example). The maximum number that can be used in a particular design of rotary joint is limited by mechanical considerations of space and complexity. The minimum number must be such that the spacing between adjacent feed points is less than one half wavelength, although it may exceed one quarter wavelength.

In typical designs, wherein the half wavelength cavity consists largely or entirely of radial transmission line sections, the characteristic impedance of the cavity is relatively low as compared to that of a usual coaxial transmission line. This impedance, as presented to the feed system, is further reduced by a factor of four because the vertical conductors at the feed points 34 extend across only half the cavity, from one of the radial conductors to the neutral plane midway between them.

The characteristic impedance of the cavity as presented at each feed point 34 is N times that presented to the feed system as a whole, where N is the number of feed points. This feed point impedance should be somewhere in the neighborhood of the impedance level at the coaxial connector 28, to avoid extreme transformations in the distribution system. Accordingly, it is generally desirable to use as many feed points as is convenient, considering the above-mentioned limitations.

The half wavelength cavity may be regarded as two quarter wavelength lines, each short circuited at one end, with their open ends connected in parallel. This combination is equivalent to a single quarter wavelength short circuited stub having a characteristic impedance of one half that of the actual cavity. Since the feed systems are connected to similar points on the respective halves of the half wave resonator, they can be considered as connected together at the open end of the equivalent quarter wave stub. The result is analogous to a transmission line section supported midway between its ends by a quarter wavelength stub.

Referring to FIG. 3, an equivalent circuit of the cavity and feed systems is represented as a coaxial line stub support designed for broad band operation. The short circuited quarter wavelength section 51 represents the equivalent of the half wavelength cavity. The supported section 52, extending one quarter wavelength in each direction from the connection to the stub, represents the inner quarter wavelength portions 37 of the distribution systems 32 and 33 respectively. The outside sections 53 and 54 represent the remainder of the respective distribution systems, from junctions 38 (FIG. 1) out to the terminals 28 and 29 (FIG. 2). Sections 53 and 54 are assumed to be matched at their outer ends, as junctions 38 are matched through their respective networks.

The T network formed by the resonant length line sections 51 and 52 can be designed to match the terminal lines 53 and 54 exactly at three frequencies W_0, W_1 and W_2, where W_0 is the resonant frequency and

$$W_1+W_2=2W_0$$

by choosing the characteristic impedance Z, of the line section 52 to satisfy the relationship

$$\frac{Z_1}{Z_2}=2\,\frac{1-(Z_1/Z_0)^2}{\cot^2\theta+(Z_1/Z_0)^2}$$

where θ is the electrical length of the nominally quarter wavelength line section 51 at W_1 or W_2, Z_2 is the characteristic impedance of line section 51, and Z_0 is the characteristic impedance of lines 53 and 54. An approximate match will be obtained throughout the band from W_1 to W_2.

In the design of the actual joint, the effective characteristic impedance of the resonant cavity may be computed from its dimensions as determined by electrical measurements made on a model. The value of Z_2 is taken as one-fourth the effective impedance of the cavity because the cavity is in effect center tapped by the feed points. Z_1 is

$$\frac{1}{N}$$

times the characteristic impedance of each inner quarter wavelength section 37 (FIG. 1). Z_0 is

$$\frac{1}{N}$$

times the impedance seen by each section 37 at the respective junction 38, and is determined by the design of the distribution systems. The value of θ is determined by the desired operating bandwidth W_1 to W_2. This is limited by the amount of mismatch that can be tolerated

at frequencies other than W_0, W_1 and W_2. Typically the bandwidth may be of the order of 1.3 to one.

The required numerical value of Z_1 may be obtained from the foregoing equation and the known values of Z_0, Z_2 and θ. The inner line sections **37** are then designed in known manner to have a characteristic impedance NZ_1.

In the operation of the described rotary joint, microwave power is supplied to one of the coaxial line connectors, for example connector **29**, to be delivered through the joint to the other coaxial line connector, **28** (FIG. 2). The distribution system **33** divides the input power into four equal parts and conveys each to one of the feed points **35** by way of electrically identical paths. The major portion of the distribution system **33** lies in the neutral plane of the cavity, midway between the surfaces **15** and **16** and does not couple to the cavity. Considered another way, the strip conductors couple to the surfaces **15** and **16** in equal and opposite senses, producing fields that cancel each other with regard to the cavity and therefore do not excite the cavity.

At the feed points **35**, currents flow from the neutral plane to one wall (the surface **15**) of the cavity, and are not cancelled. These currents are equal and in phase, and excite the cavity in the previously described circumferentially uniform dominant TEM mode. Since the fields in this mode are the same along any radial direction from the axis **8**, the currents induced in the vertical conductors at the feed points **35** are identical and independent of the relative angular positions of the body members **3** and **4**. These currents are combined by the distribution system **32**, and the resultant delivered to the coaxial connector **28**.

A rotary joint designed and constructed as described, for operation at L band, exhibited an insertion loss of approximately 0.2 db and "wow" of the order of 0.02 db.

I claim:

1. A microwave rotary joint, including two hollow body members each having a conductive interior surface in substantially the form of that of a figure of revolution of a re-entrant generatrix about an axis and each having an opening bounded by two respective circular edges each of which is centered on said axis and lies in a plane perpendicular to said axis, said openings being juxtaposed and conformal to each other, means electrically coupling the respective adjacent circular edges of said openings together, effectively joining said interior surfaces to provide a resonant cavity in the form of a transmission line short circuited at its ends and having an electrical length of one-half wavelength at a design center frequency, each of said members including a distribution system disposed at least in part within said resonant cavity and connecting a respective external transmission line in substantially identical relationship to a plurality of feed points in said cavity, said feed points being in circular symmetry about said axis and separated by arcuate intervals of less than one-half wavelength.

2. The invention set forth in claim **1**, wherein said distribution systems are transmission line networks including conductors in the form of flat strips disposed substantially in electrically neutral planes in said resonant cavity.

3. The invention set forth in claim **1**, wherein the terminal quarter wavelength sections of said distribution system adjacent said feed points are designed to cooperate with the impedance presented by said cavity at said feed points as broadband quarter wave stub structure.

4. The invention set forth in claim **1**, wherein said cavity comprises two radial transmission line sections and a coaxial transmission line section connected between respective ends of said radial transmission line sections, the other ends of said radial transmission line sections being short circuited.

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HERMAN KARL SAALBACH, *Primary Examiner.*