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HELICAL LINE ROTARY JOINT

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Fig. 1.

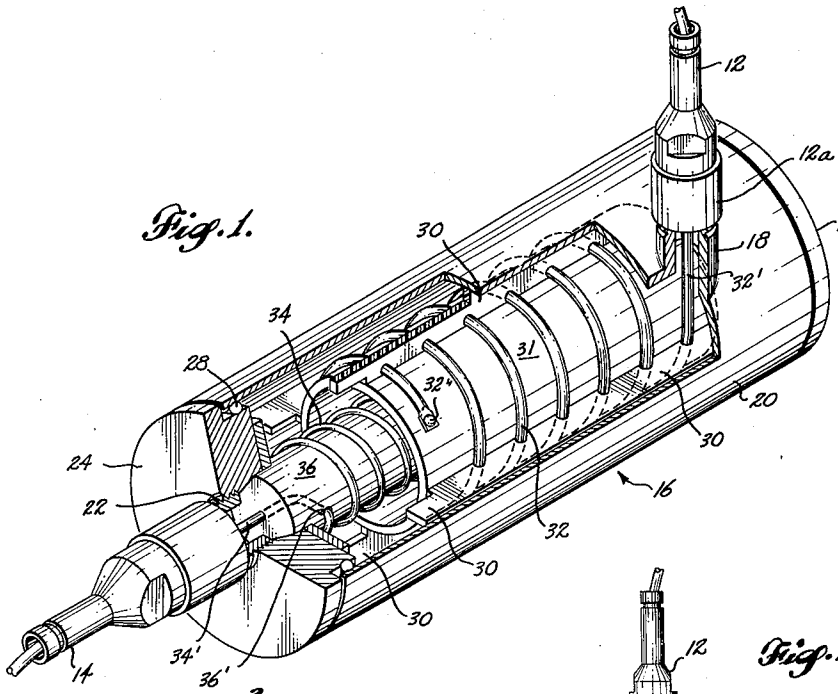


Fig. 2.

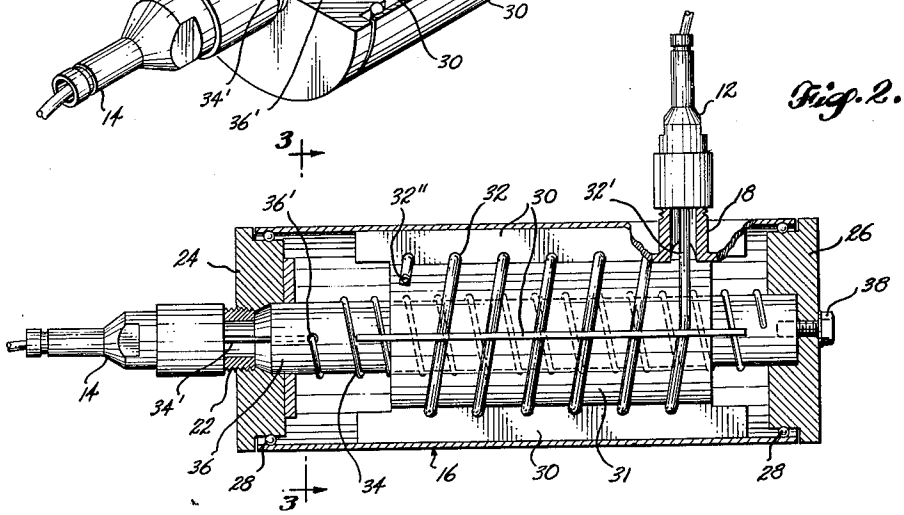
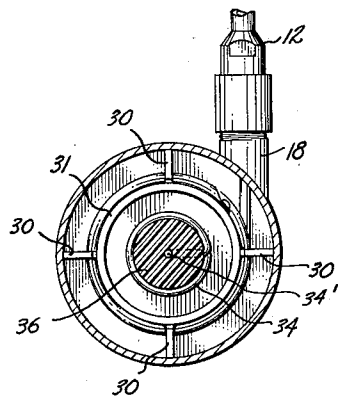


Fig. 3.



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HELICAL LINE ROTARY JOINT

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This invention relates to improvements in high frequency transmission line apparatus and more particularly concerns a rotary joint for incorporation in systems of this type. The invention is herein illustratively described by reference to the presently preferred embodiment thereof; however, it will be recognized that certain modifications and changes therein with respect to details may be made without departing from the underlying essentials thereof.

An object of this invention is to devise a high frequency (VHF, UHF or SHF) rotary joint for coaxial transmission lines or the like, which will eliminate sliding mechanical contacts, will be relatively compact and will be capable of handling high power transmissions.

A related object is to provide such a rotary joint which is highly efficient to transfer power (nearly one hundred percent efficiency) over a wide band of operating frequencies and which presents substantially constant characteristics in all of the relatively rotated positions of the joint components to which the interrupted transmission line sections are connected.

A further object is to achieve these results in a joint structure which is manufacturable at relatively low cost and without unduly critical mechanical or electrical tolerance requirements.

An illustrative application of the invention is one in which the joint is associated with the transmission line connected to an antenna mounted in an airplane cargo door, wherein a pivotal or flexible connection is necessary between the antenna bays or sections and the feed system for the antenna. Such an antenna installation in a practical case was required to transfer high power, withstand high voltage, present a low standing wave ratio and incur very low insertion loss while being durable, compact and in all other ways practicable and efficient for aircraft installation. The present invention, developed primarily for such applications, achieves these results by use of coaxially mounted helical conductors which are in concentric longitudinally overlapping relationship and, though one is larger than the other in diameter, are designed to have substantially the same phase velocity, one such helix being connected to an input feed and the other to an output feed which are to rotate relatively about the common axis of the helices. The two helical conductors are wound or pitched with opposite sense and the outer helix is surrounded by a ground plane conductor associated with the grounded shell or outer conductor of one transmission line section. The inner helical conductor requires no ground plane nor shield except in connection with the coupling which must take place between one end thereof and the associated transmission line. Under reciprocity theory either helical conductor may be the infeed or the output element of the rotary joint. Moreover, coaxial feed of either or both helices or tangential feed of either or both helices, or any combination thereof may be employed for coupling energy to and from the joint conductors. Thus, an L-type joint or an in-line type joint may be used, or still a third possibility is a joint in which conductors extend parallel to each other and perpendicular to the rotational axis of the joint.

With these and other features, objects and advantages in view the invention will now be described more fully by reference to the accompanying drawings.

FIGURE 1 is an isometric view of one embodiment of the invention, with parts broken away to show details of interior construction.

FIGURE 2 is a longitudinal sectional view of the illustrated embodiment.

FIGURE 3 is a transverse sectional view taken on line 3—3 in FIGURE 2.

In the drawings, coaxial transmission line conductor fittings **12** and **14** are depicted, either of which may represent the infeed or the outfeed of the rotary joint. These fittings may be of conventional or other suitable design the details of which represent no part of this invention and require no specific description herein. The function of the rotary joint **16** interposed between and connected to these transmission line fittings is, of course, to permit relative rotation to occur between the two fittings about an assigned axis. In this case, and purely by way of example, the central axis of the fitting **14** is selected to coincide with the relative rotation axis defined by the rotary joint **16**, whereas the fitting **12** has a central axis extending in generally tangential relationship to the cylindrical form of the fitting structure. A tangentially directed boss or flange **18** projects from the conductive tubular outside shell **20** to receive the threaded collar **12***a* of fitting **12** as a means to make contact electrically between the shell and the outer conductor of the transmission line fitting **12**. The fitting **14** has an externally threaded outside conductor plug **22** which threads into a central bore in the rotary joint end wall **24**.

Tubular sheet **16** is closed at its opposite end by the end wall **26**. The two end walls have reduced shoulders which are overlapped by the ends of the tubular shell **16** with ball bearings **28** interposed therebetween. This permits relative rotation between the shell structure and the end wall structure representing the two major structures of the rotary joint. As part of the shell structure, a set of radially disposed dielectric struts or ribs **30** are mounted on the inside wall of the shell **16** at angularly spaced locations and these serve as supports for the insulative tube **31** upon which the helical conductor **32** is mounted concentrically within the shell **16**. One end of the helical conductor **32** extends tangentially out through the collar **18** as a continuation of the central conductor **32'** of the coaxial line fitting **12**. The opposite end of the outer helical conductor **32** is terminated at **32''** and is held by a rivet or screw to the insulative supporting tube **31** upon which helix **32** is wound.

Helical conductor **32** has a certain diameter and a certain pitch and extends over a certain portion of the interior length of the rotary joint, depending upon design requirements and optional choices which will be readily understood from an understanding of present-day practices in the art and the present specifications.

Within the outer helical conductor **32** there is mounted an inner helical conductor **34** of opposite pitch and of a length which causes the two helical conductors to overlap in length by a sufficient amount to achieve the necessary coupling between them. The pitch distance of the inner helix is related to the diameter of this helix so that its phase velocity will be substantially the same as the phase velocity along the outer helix as determined by its pitch distance and diameter. When these conditions are met and there is sufficient overlapping length of the two helices in terms of the electrical wavelength therealong, virtually perfect coupling for purposes of power transfer from one helix to the other is achieved in any relatively rotated position of the two helices.

The smaller helix **34** is wound on an insulative cylindrical support **36** the ends of which are received and held in recesses in the end walls **24** and **26**. With the inner helix **34**, support **36** becomes part of the end wall struc-

ture of the rotary joint. A machine screw **38** threads into one end of the inner helix support **36** through a central opening in the end wall **26** in order to hold these parts together, whereas the opposite end of the support **36** may be suitably joined to the opposite end wall **24**. Helical conductor **34** terminates at one end adjacent the end wall **26** and terminates at its opposite end in a portion which is turned radially inwardly to pass through a transverse bore **36'** in the helix support **36**, thence turns into an axial direction to become the central conductor **34'** of fitting **14**. This axial coupling to the helix **34** for power transmission to or from this helix through the coaxial line fitting **14** is possible without the use of a ground plane or shield conductor coextensive in length with helical conductor **34**. Energy coupling relationship between the fitting **14** and helix **34** by which energy propagation along the latter takes place is effected as a result of its relationship with the surrounding outer helix and the aperture in conductive end wall **24**.

In effect, the two helical line sections form parallel transmission systems having mutual coupling along their length such that power propagating in the wave excited in one helix will induce a wave and corresponding power propagation in the other helix. The necessary conditions for maximum power transfer from one helix to the other are that the two helices have substantially the same velocity of propagation when in uncoupled or separate positions, appropriate coefficient of coupling between them, and overlap over a distance of one-quarter of a coupling wavelength which is of the order of one-tenth to one-twentieth of a free space wavelength. To a first order of approximation, the inner and outer helices **34** and **32** will have same velocities of propagation, taking into consideration their respective diameters and pitch distances, if the lineal length of the conductor of one helix when stretched out is approximately equal to that of the other helix for the same axial length of the helices. Rigorous mathematical computations show that this is not precisely true. In a typical design operating at 425 megacycles per second the insertion loss was approximately 0.1 db and the voltage standing wave ratio approximately 1.1. The inner helix mean diameter was 2.2 inches and the outer helix mean diameter 3.5 inches. The pitch of the inner helix was 0.5 inch and that of the outer helix was 0.77 inch. The diameter of the wire of the inner helix was 0.1875 inch and that of the outer helix 0.250 inch. Thirteen turns were employed in the inner helix and six turns in the outer helix. The outside diameter of the outer housing or shell was 5 inches and the total length of the joint as measured between the outside end faces thereof was 9.5 inches. The useful bandwidth was approximately 10% of the operating median frequency of 425 megacycles per second and the power transmission efficiency was approximately 96%. No signs of wearing occurred with use and the device proved capable of carrying very high voltages and high power transmissions. The device referred to weighed less than 10 pounds although it could be manufactured to weigh even less by employing specialized design techniques if necessary. Of course, at higher frequencies the dimensions will be scaled down accordingly and the weight will also be correspondingly reduced for a given type of construction.

One of the requirements properly to maintain energy propagation along the outer helix is the provision of the surrounding outer conductor **16** serving as a ground plane to which the outer conductor of the associated transmission line coupling **12** is connected. As previously mentioned, no similar ground plane is necessary in immediate proximity to the inner helix, however. The presence of the insulating struts **30** and dielectric mounting tube **31** has a small effect on the wave length or velocity of propagation along the helices, particularly the outer helix, but so does the presence of the dielectric core or tube **36** upon which the inner helix is mounted, so that in the last analysis a certain amount of empirical work was necessary to establish fully optimum design specifications for this rotary joint structure. Common techniques of design and measurement from which optimization may be established will be evident to those skilled in this art.

It should be realized that the two helical conductors **32** and **34** mounted in the disclosed relationship, excited in the disclosed manner, and having the described relationship as to propagation velocity and opposite pitch, do not resemble mere inductances as in the case of low-frequency or radio-frequency transformers. Rather these helical conductors function as transmission lines with distributed parameters in which electrical wave lengths i.e. phase velocities play the predominant roles just as they do in the case of wave guide and long transmission line theory. Moreover, it was established that such a device will have a broadband characteristic, high coupling efficiency and low insertion loss, independent of relative rotative positioning of the joint structures.

In effect, when the prescribed conditions are met, there is a normal mode of propagation along the two coaxial helices which is slower than the propagation velocity along either helix acting alone and out of the presence of the other. The resultant "slow" wave is characterized by equal voltages of unlike sign on the two helices. The normal or fast waves which propagate along the helices will produce longitudinal electric fields in the annular space between them, whereas the so-called slow wave will produce a transverse electric field in this space. The simultaneous existence of these fast and slow waves produces an interference or spatial beating effect which causes a wave-like transfer of power from one helix to the other and back, so that if both are of unlimited length there will be an alternate voltage variation between zero and a maximum at points of measurement progressing along the length of either helix. Power fed exclusively to one or the other helix will inevitably excite both the slow and fast modes equally. Thus, there are points, periodic with distance along each helix, where there is substantially no current or voltage or a maximum of current or voltage at which points a helix can be terminated or cut off, or can be connected to external circuits.

It should also be recognized that either or both the inner and outer helices may be fed along the common axis, as by having the fitting **12** coaxial with the fitting **14** but at the opposite end of the rotary joint structure, or that either or both helices may be fed in a tangential direction, as by having the fitting **14** located in a tangential position as in the case of the fitting **12**, and at the opposite end of the joint from fitting **12**. It is also possible to provide a rotary joint in which not only rotation but also limited axial relative movement between the two helices is contemplated as an additional degree of freedom of motion. In this event, it will be important that one helix overlap and extend beyond the other helix so that in all relative positions of longitudinal motion the same relative overlap will exist parallel to the common axis.

These and other aspects of the invention will be recognized by those skilled in the art on the basis of the foregoing description of the preferred form of the invention.

I claim as my invention:

1. A high-frequency helical line rotary joint comprising an inner helical conductor, a coaxial outer helical conductor surrounding said inner conductor over at least a portion of the length of one helical conductor, said helical conductors having substantially equal propagation velocity characteristics at the operating frequency and having opposite pitch, relatively, a conductive shell surrounding and spaced outwardly from the outer helical conductor, energy transmission means for the outer helical conductor comprising a coaxial fitting including a center con-

ductor extending outwardly through the shell from one end of the outer helical conductor, and an outer conductor surrounding said center conductor and mounted on said conductive shell coaxially with said center conductor, energy transmission means for the inner helical conductor comprising a center conductor extending axially from the inner helical conductor at one end of the rotary joint, and an outer conductor surrounding said latter center conductor and connected electrically to the conductive shell, and means mounting one helical conductor for rotary movement relative to the other helical conductor about the common axis thereof, including rotational bearing means interposed between the last-mentioned transmission means and the conductive shell to permit relative rotation therebetween.

2. A high-frequency helical line rotary joint comprising an inner helical conductor, a coaxial outer helical conductor surrounding said inner conductor over at least a portion of the length of one helical conductor, said helical conductors having substantially equal propagation velocity characteristics at the operating frequency and having opposite pitch, relatively, energy transmission means coupled respectively to each helical conductor, a conductive housing in which the coaxial helical conductors are received, said housing comprising a first portion upon which the inner helical conductor is physically mounted in insulated relationship, and a second portion rotationally journaled to the first portion upon which the outer helical conductor is mounted in insulative relationship and in rotational relationship to the inner helical conductor, the respective transmission means being physically mounted upon the respective housing portions and each comprising a conductor electrically connected to the associated portion.

3. A high-frequency rotary joint comprising a cylindrical tubular conductive shell having a central longitudinal axis and comprising two mutually complemental portions interconnected to be relatively rotatable about said axis, two coaxial transmission line fittings, each having an outer conductor joined to one of said portions at a location spaced longitudinally of the shell from the other outer conductor, and each having an inner conductor projecting in insulated relationship into the shell, two helical lines comprising elongated conductive helices of respectively different helix diameters, of substantially

equal propagation velocity chracteristics and of relatively opposite pitch, means supporting the helices in mutual longitudinally overlapping relationship and coaxial within the shell, the helix of smallest diameter being insulatively spaced within that of largest diameter and the latter being insulatively spaced within the shell, one end of each helical line being electrically connected to the inwardly projecting end of one line fitting, and the opposite end of each helical line forming substantially an open-circuit termination thereof, said helical lines being physically supported from the respective shell portions.

4. A high-frequency helical line rotary joint comprising two helical line conductors of respectively different diameters, of substantially equal propagation velocity characteristics and of relatively opposite pitch, means physically supporting said helical line conductors in coaxial mutually overlapping relationship, said means including elements supporting the inner and outer helical conductors with spacing therebetween across which the helical line conductors are in dielectrically coupled relationship, substantially the entire space within the inner helical line conductor being dielectric, and further comprising a conductive housing comprising an elongated shell structure surrounding the outer helical conductor in insulative relationship therewith, said shell structure comprising portions physically connected to and supporting the respective helical line conductors, said shell portions being interconnected to permit relative rotation therebetween about the common axis of the helical line conductors, and transmission line fittings including center conductors connected to the respective helical line conductors at one end of each, and outer conductors connected with the respective shell portions and surrounding the respective center conductors in insulative relationship therewith, the opposite ends of the respective helical line conductors terminating in substantially an open circuit within the housing.

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