Feb. 13, 1951 W. W. SALISBURY 2,541,836

INNER CONDUCTOR JOINT FOR COAXIAL LINES

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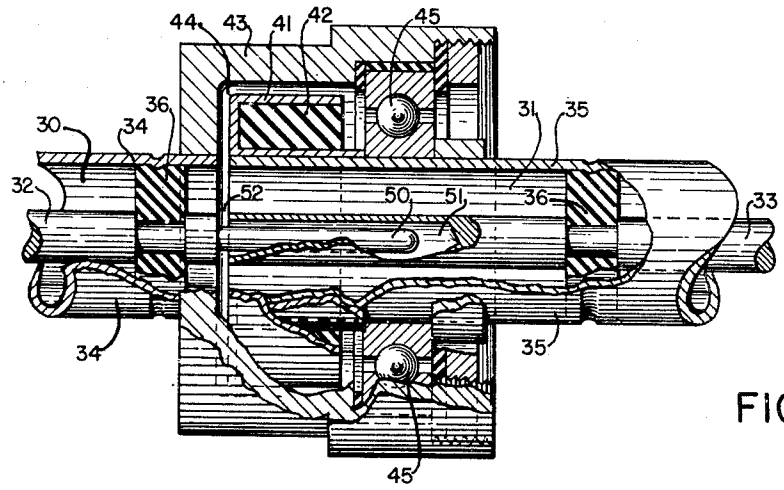


FIG. 5

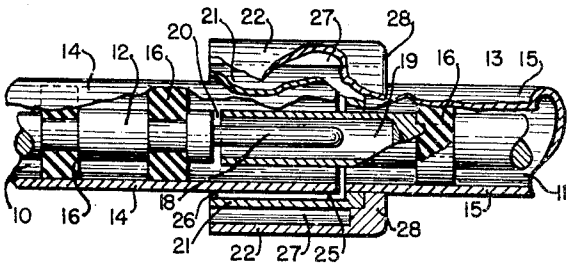


FIG. 4

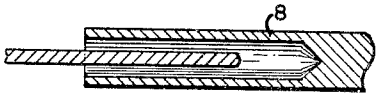


FIG. 3

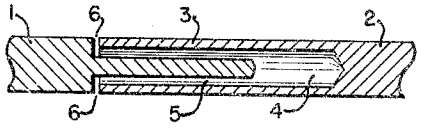


FIG. 1

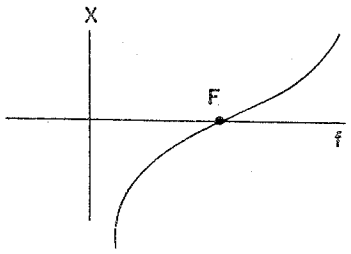


FIG. 2

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INNER CONDUCTOR JOINT FOR COAXIAL LINES

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10 Claims. (Cl. 178—44)

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This invention relates to apparatus and circuits for transferring radio frequency electrical energy and more particularly for avoiding losses in the transfer of radio frequency electrical energy from one conductor to another. The invention has particular applicability to joints in electrical transmission lines for carrying high-frequency energy, especially joints between the inner conductors of coaxial conductor transmission lines. Because of the dimensions of the structures in question, the chief utility of the invention lies in apparatus for operations at frequencies in the microwave range.

The provisions of demountable joints or of joints permitting relative movement of the elements of the joints in systems or apparatus for the transmission of microwave energy has presented a considerable problem because ordinary contact joints made without soldering generally result in considerable loss of microwave energy which it is desired to transmit across the joints. In addition, in many cases contact joints involving considerable pressure between the joint members (which pressure is necessary to keep losses at a reasonable level) are often not practical, either because relative movement of the members of the joint is desirable or else because one of the members of the joint may be mechanically connected to a delicate apparatus, the deforming of which might result in damage.

It is an object of this invention to provide a joint for high-frequency circuits or lines which possess satisfactory energy transfer characteristics without requiring soldering or the application of pressure on the members of the joints. It is a further object of the invention to provide a joint which takes advantage of the properties of resonant sections of transmission lines.

The invention is illustrated in the drawing in which:

Fig. 1 is a cross section of a joint in accordance with the present invention between two cylindrical conductors;

Fig. 2 is a theoretical diagram illustrating the properties of the structure of Fig. 1;

Fig. 3 is a cross section of a modification of the joint shown in Fig. 1;

Fig. 4 is a longitudinal cross section of a joint for coaxial conductor transmission lines in which the joint between the respective inner conductors is effected in accordance with the present invention, and

Fig. 5 is a longitudinal cross section of a rotating joint for coaxial conductor transmission lines in which the joint between the respective inner conductors embodies the present invention.

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In Fig. 1 are shown two conductors 1 and 2 between which it is desired to establish conditions permitting the interchange of radio frequency energy without substantial losses and without the provision of a soldered connection or of a connection depending for its effectiveness upon the application of mechanical pressure. In a typical case the conductors 1 and 2 will be cylindrical in shape. Supporting insulators have been omitted from Fig. 1 in order to simplyfy and generalize the representation.

The end of the conductor 1 is provided with an axial projection 3 of reduced diameter. The conductor 2, which is shown in Fig. 1 as having the same outer diameter as the conductor 1, is provided with a corresponding axial recess 4 which is substantially deeper than the length of the projection 3. In order to effect the desired joint the conductors 1 and 2 are maintained in such a position that the projection 3 is located, and preferably centered, within the recess 4 leaving an annular clearance 5 between the projection 3 and the surface of the recess 4 and so that a clearance 6 also exists at the base of the projection 3 where the outer surfaces of the conductors 1 and 2 approach each other. The clearance 6 is preferably approximately the same as the clearance 5, although small variations in this respect do not greatly affect the performance of the joint. The length of the projection 3 should be such that the electrical length of the clearances 5 and 6 together, measured from the mouth of the clearance 6 to the end of the projection 3, is approximately an electrical quarter wave length. The overlapping portions of the conductors 1 and 2 will thus provide a quarter wave section of coaxial conductor transmission line one end of which is connected across the gap between the outer surfaces of the conductors 1 and 2, which are the surfaces particularly adapted to conduct radio frequency current, and the other end of which is essentially an open circuit, being terminated by a continuation of the recess 4 beyond the end of the projection 3. This termination may impose a slight capacitance loading upon the transmission line, largely on account of the intensity of the oscillatory electric field at the end of the inner conductor, but this effect is to be taken into account in determining the electrical quarter wave length of the structure. It is also possible that the extension of the recess 4 beyond the end of the projection 3, being of a diameter much smaller than the minimum diameter necessary to permit a cylindrical pipe to pass waves of the frequency in question after the manner of a wave guide, acts as an attenuator, thus offering a high

impedance. In any event, experimental results show that a high impedance termination is provided and that the system, "looking in" at the mouth of the gap 6, has the properties of a quarter wave resonator and presents an extremely low impedance across the gap 6 for its resonant frequency. In an apparatus of the configuration of Fig. 1, the physical length of the clearance space from the mouth of the gap 6 to the end of the projection 3 is in practice about 0.23λ, where λ is the wave length in air corresponding to the frequency in question. The small variation from one-quarter of the wave length measured in open air is believed to be due partly to the presence of capacitance loading at the end of the projection 3 and partly to "end effect" or loading at the gap 6.

Although the type of joint shown in Fig. 1 is usually designed for a particular frequency, the impedance across the gap 6 does not vary rapidly with frequency in the neighborhood of the resonant frequency. To examine this phenomenon more closely, it will be convenient to neglect any losses that may occur at or near the joint and to consider the reactance at the gap 6, since the reactance will, when losses are low, be the chief determining component in the impedance at that point. Fig. 2 shows the general nature of the curve resulting when reactance is plotted against frequency, the reactance shown being the series reactance appearing between the conductors 1 and 2 at radio frequency on account of the gap 6 and the quarter wave resonator coupled thereacross. It will be noted that the reactance changes relatively slowly in the neighborhood of the resonant frequency which is shown at F. Thus small changes in the operating frequency or small changes in the amount of overlap between the conductors will not seriously interfere with the operation of the joint.

The effect of capacitance loading at the end of the projection 3 is to shift the curve of Fig. 2 upwards with respect to the frequency axis, which, for the small amounts of capacitance loading met in practice does not seriously impair the frequency characteristic of the joint. In order to reduce capacitance loading the extremity of the projection 3 is preferably rounded off.

The clearance between the projection 3 and the walls of the recess 4 is preferably made as small as mechanical consideration involved in preventing contact will permit. The characteristic impedance of the resonant coaxial line is thus lowered, decreasing the slope of the middle of the curve shown in Fig. 2. The reduction of this clearance does not increase the risk of voltage breakdown because the voltage at the open end of the line is equal to the product of the characteristic impedance and the current flowing at the gap 6, so that reduction of the characteristic impedance also reduces the voltage in the junction resonator for a given current across the junction.

In Fig. 1 the outer surfaces of the conductors 1 and 2 are shown as having substantially the same diameter, a condition which is usually met in practice, especially when the conductors 1 and 2 constitute the inner conductors of coaxial conductor transmission lines, in order to eliminate the setting up of reflections by changes in the surge impedance of the conductor or in the characteristic impedance of the transmission line of which the conductor may form a part. If it is desired to join conductors of different diameter, however, a particularly simple form of joint, shown

in Fig. 3, becomes possible. In this case the larger conductor is provided with a recess 8 substantially similar to the recess 4 of Fig. 1 and the smaller conductor is made to project into the said recess for a distance of an electrical quarter wave length, the recess 8 being deep enough to extend considerably beyond the end of the smaller conductor when it is so inserted.

Fig. 4 shows the application of a joint of the type shown in Fig. 1 in a joint for coaxial conductor transmission lines. The coaxial conductor transmission lines to be joined are shown respectively at 10 and 11, the former having an inner conductor 12 and outer conductor 14 and the latter having an inner conductor 13 and an outer conductor 15. Insulators 16 are provided for maintaining the relative position of the conductors in each of the transmission lines. The inner conductors 12 and 13 are effectively joined for radio frequencies in the range of a desired frequency of operation in the manner shown in Fig. 1 in accordance with the above described principles. More particularly, the conductor 12 is provided with a projection 18 which extends into a recess 19 which is formed in the extremity of the conductor 13 in such a manner to be somewhat deeper than the length of the projection 18. The conductors 12 and 13 are maintained in a relative position which is adapted to provide a gap 20 between their outer surfaces. The resonator or resonant section of transmission line thus formed by the projection 18 and the conducting surface of the recess 19 is made to be an electrical quarter-wave length in length and thus to provide a low impedance at the gap 20 at frequencies in the neighborhood of its resonant frequency.

The joint effected between the conductors 14 and 15 is constructed after the manner more fully described in by Patent 2,451,876, dated October 19, 1948, and entitled Radio-Frequency Joint. This joint is provided by means of two concentric conducting sleeves 21 and 22 mounted upon the conductor 15 in the manner shown in Fig. 4. The sleeve 21 is adapted to define between it and the outer surface of the conductor 14 an annular channel 25 which is of a length of an electrical quarter-wave length from the mouth of said channel where it communicates with the space between the conductors 13 and 15 and the outer mouth of said channel where it communicates with the outside of the system at 26. The sleeve 22 is arranged to define between it and the sleeve 21 an annular space 27 communicating at one end with the outside of the structure in the neighborhood of the mouth 26 of the annular space 25 and terminated at the other end by a conducting end wall 28, the space 27 having an axial length of substantially an electrical quarter-wave length. As more fully explained in my said co-pending application the resonators defining the annular spaces 25 and 27, form a system which has the advantageous properties that a very low impedance appears across the inner mouth of the annular space 25, at the frequency for which the combined length of these resonators is an electrical half-wave length thus promoting transmission of radio frequency energy from the inner surface of the conductor 14 to the inner surface of the conductor 15. In addition, energy is inhibited from leaking out of the system to the outside and it becomes relatively immaterial what type of conducting or non-conducting relation exists between the end of the sleeve 22 and the outer surface of the conductor

14, since the resulting impedance appears in the system only in series with the high impedance across the mouth of the annular cavity 27. Thus by providing a joint between the outer conductors of two coaxial conductor transmission lines in accordance with my said co-pending application and by providing a joint between the inner conductors of the said transmission lines in accordance with the present invention, a compact and reliable form of joint may be obtained between the said transmission lines. Maintenance of the desired mechanical spacing may be readily provided in a structure of the type shown in Fig. 4 by a number of means, including the provision of flanges of the outside of the conductor 14 and on the outside of the sleeve 22, respectively, which flanges may then be simply bolted together, or the use of suitable threaded coupling means for mechanically fixing the transmission lines 10 and 11 in the desired position and alignment. In the arrangement shown in Fig. 4 the transmission line 10 may be the output delivering transmission line of a mechanically sensitive apparatus, such as a vacuum tube. In such case the inner conductor 12 will usually be mechanically connected to a glass vacuum seal and must, therefore, be protected against being subjected to mechanical vibration or distortion which might result in breaking the seal. When the output transmission line 10 of such a delicate apparatus is connected to a connecting transmission line 11 by a joint of the type shown in Fig. 4, the inner conductor 12 is isolated from mechanical vibration which would otherwise be transmitted to it by the conductor 13. If desired a resilient gasket might be provided in the mechanical connecting and aligning means employed for maintaining the relative positions of the outer conductors 14 and 15.

Fig. 5 illustrates the application of the present invention to the provision of a joint for coaxial conductor transmission line which permits relative rotation of the said transmission line. The transmission lines 30 and 31 are made to approach each other in the direction of the desired axis of rotation. The transmission line 30 comprises the inner conductor 32 and the outer conductor 34 while the transmission line 31 is constituted of the inner conductor 33 and the outer conductor 35. Insulators 36 are adapted to maintain the necessary spacing between the inner and outer conductors of each transmission line. The outer conductors 34 and 35 are effectively joined for radio frequency transmission by an arrangement similar to that described in Fig. 4 with respect to the outer conductors 14 and 15 and more fully described in my said co-pending application. An annular cup-like member 41 is firmly mounted, as by soldering, upon the outer surface of the conductor 35 at its extremity and the annular space enclosed thereby is filled by a mass 42 of a solid dielectric material such as polystyrene. The axial length of the member 41 and of the dielectric mass 42 is such that an electrical resonator of an axial length of an electrical quarter wave length is constituted for the desired frequency of operation. A metal housing member 43 is mounted on the conductor 34 in such a manner as to define a small annular clearance space 44 between it and the member 41. The housing member 43 also serves to carry ball bearings 45 which serve to mount the conductors 34 and 35 with respect to each other in a manner permitting relative rotation about their common axis. The radial dimension of the sleeve

member 41 is so designed that the electrical length of the clearance space 44 from its mouth where it communicates with the inside of the transmission lines and the rear axial extremity of the cup member 41 may be substantially an electrical quarter wave length. Thus, as in the case of the outer conductor joint shown in Fig. 4, a low impedance appears across the mouth of the annular space 44 between the inner surfaces of the conductors 34 and 35. This situation is obviously not affected by relative rotation of the two transmission lines as provided by the ball bearings 45.

The joint between the conductors 32 and 33 is constructed in accordance with the present invention as explained in Fig. 4 and more fully described in connection with Fig. 1. The conductor 32 is provided with an axial projection 50 of reduced diameter. The conductor 33 has an axial recess 51 adapted to receive the projection 50 without electrical contact and to extend a substantial distance beyond the end of the projection 50. The length of the projection 50 is made to be such that a transmission line of an effective electrical length of a quarter wave length is connected to the gap 52 which separates the outer surfaces of the conductors 32 and 33. In this manner a very low impedance is made to appear across the gap 52 for the desired frequency of operation and this desirable relation is not disturbed by relative rotation of the transmission line as provided by the ball bearings 45.

What I desire to claim and obtain by Letters Patent is:

1. Means for providing transfer of radio frequency electric energy between two substantially cylindrical and relatively rotatable conductors including an axial projection on one of said conductors, an axial recess in the other of said conductors and means for maintaining a clearance between said conductors and between said projection and said recess and for positioning said projection in said recess, said projection and recess being so dimensioned and said means being so disposed that an annular clearance space is provided between said conductors having a length perpendicular to its circumferential dimension of substantially an electrical quarter wave length, said recess having a substantially greater axial dimension than said projection.

2. A rotating joint for coaxial conductor transmission lines including an axial projection on the inner conductor of one of said transmission lines, an axial recess on the inner conductor of the other of said transmission lines which is adapted to enclose said projection or a major part thereof without electrical contact and to extend axially a substantial distance beyond the end of said projection, the length of said projection being such that at a desired frequency of operation a coaxial conductor transmission line of an electrical length of substantially one-quarter wave length is constituted at the extremities of said inner conductors, means providing for relative rotation of said inner conductors, and for maintaining the said inner conductors in relative alignment and substantially in relative axial position.

3. A structure for promoting transfer of electric radio frequency energy between two conductors comprising an axial projection on one of said conductors and an axial recess coaxial with said projection on the other of said conductors adapted to provide a coaxial conductor transmission line of an electrical length of approxi-

mately a quarter wave length terminated at one end by an extension of said recess beyond the end of said projection and at the other end by a gap between the surfaces of said conductors which are adapted to conduct radio frequency current and comprising also means providing for relative rotation of said conductors about the axis of said projection and of said recess and at the same time maintaining the relative axial position of said projection and said recess.

4. Means providing for transfer of radio frequency electromagnetic energy between first and second relatively rotatable conductors comprising an axial projection on said first conductor, said second conductor having an axial recess formed therein, said projection extending into said recess in noncontacting relation to said first conductor a distance substantially equal to one quarter wave length at a desired operating frequency and means providing for relative rotation of said conductors and for maintaining said conductors in axial alignment.

5. Means providing for transfer of radio frequency electromagnetic energy between first and second relatively rotatable conductors disposed in axial alignment, said means comprising an axial projection on said first conductor, said second conductor being formed with an axial recess therein coaxial with said projection, and of an electrical length of substantially a quarter wave length terminated at one end by an extension of said recess beyond the end of said projection and at the other end by a gap between the radio frequency conducting surfaces of said conductors, and means providing for relative rotation of said conductors and for maintaining said conductors in relative alignment and in relative axial position.

6. A rotating joint for coaxial conductor transmission lines including an axial projection on the inner conductor of one of said transmission lines, the inner conductor of the other of said transmission lines being formed with an axial recess which is adapted to enclose at least a major part of said projection without electrical contact and to extend axially a substantial distance beyond the end of said projection, the length of said projection being such that at a desired frequency of operation a coaxial conductor transmission line of an electrical length of substantially one quarter wave length is constituted at the extremities of said inner conductors, means providing for relative rotation of said inner conductors and for maintaining the said inner conductors in relative alignment and substantially in relative axial position.

7. A rotating joint for coaxial conductor transmission lines including an axial projection on the inner conductor of one of said transmission lines, the inner conductor of the other of said transmission lines being formed with an axial recess therein which is adapted to enclose substantially the entire length of said projection in a noncontacting relationship, the length of said projection being such that at a desired frequency of operation a coaxial conductor transmission line of an electrical length of substantially one quarter wave length is constituted at the extremities of said inner conductor, means providing for relative rotation of said inner conductors and for maintaining the said inner conductors in relative alignment and substantially in relative axial position.

8. A rotating joint for coaxial conductor transmission lines including an axial projection on the inner conductor of one of said transmission lines, the inner conductor of the other of said transmission lines being formed with an axial recess which is adapted to enclose at least a major part of said projection without electrical contact, the length of said projection being such that at a desired frequency of operation a coaxial conductor transmission line of an electrical length of substantially one-quarter wave length is constituted at the extremities of said inner conductors, means providing for relative rotation of said inner conductors and for maintaining the said inner conductors in relative alignment and substantially in relative axial position.

9. In a coaxial conductor transmission line system including first and second coaxial lines disposed in axial alignment and rotatable with respect to each other and means associated with the outer conductor of said coaxial lines providing for relative rotation of said coaxial lines and for maintaining said coaxial lines in axial alignment, means providing for transfer of radio frequency electromagnetic energy between the inner conductors of said coaxial lines comprising an axial extension of one of said conductors, the other of said conductors being formed with a recess therein to receive said extension in noncontacting relation therewith.

10. In a coaxial conductor transmission line system including first and second coaxial lines disposed in axial alignment and rotatable with respect to each other and means associated with the outer conductor of said coaxial lines providing for relative rotation of said coaxial lines and for maintaining said coaxial lines in axial alignment, means providing for transfer of radio frequency electromagnetic energy between the inner conductors of said coaxial lines comprising, an axial projection on one of said conductors, the other of said conductors being formed with a recess therein to receive said projection in noncontacting relation therewith, said projection extending within said recess for substantially a quarter wave length at the operating frequency of said coaxial lines.

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