Oct. 19, 1948. W. W. SALISBURY 2,451,876

RADIO-FREQUENCY JOINT

Filed June 5, 1943 5 Sheets-Sheet 1

FIG. 1

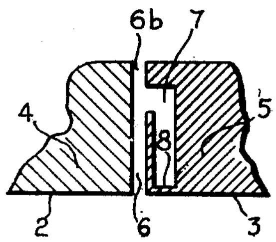
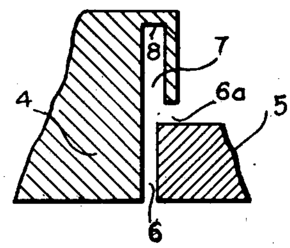



FIG 2



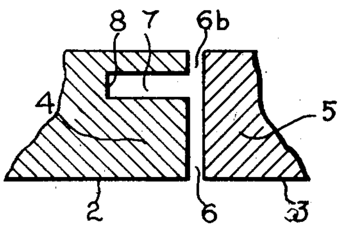




FIG. 3

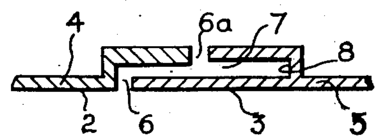



FIG. 4

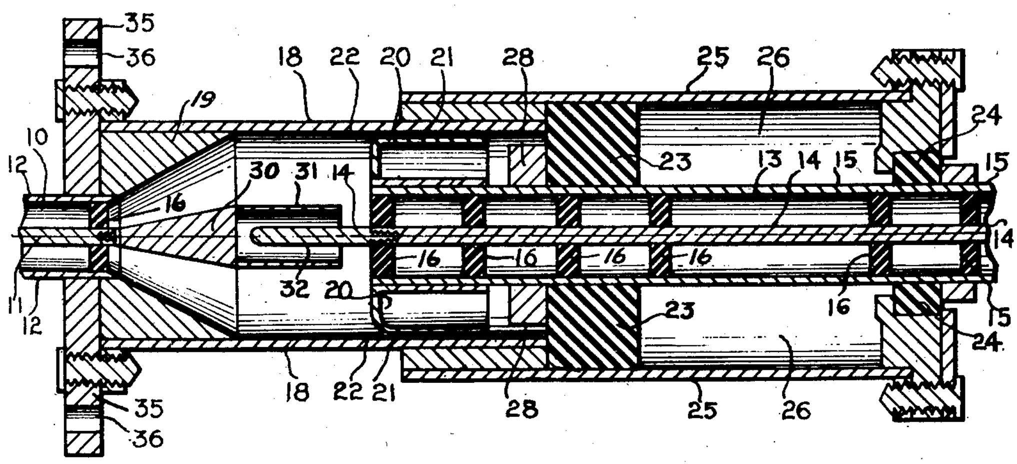



FIG. 5

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2,451,876

RADIO-FREQUENCY JOINT

Filed June 5, 1943

5 Sheets-Sheet 2

FIG 6

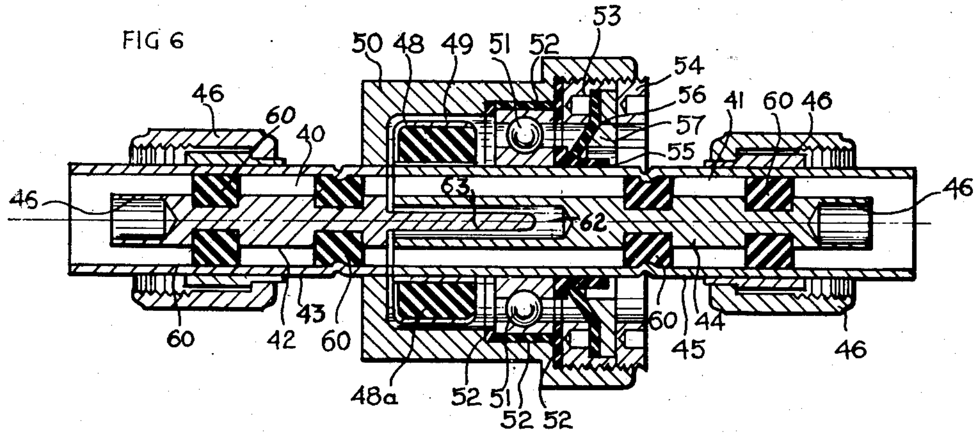
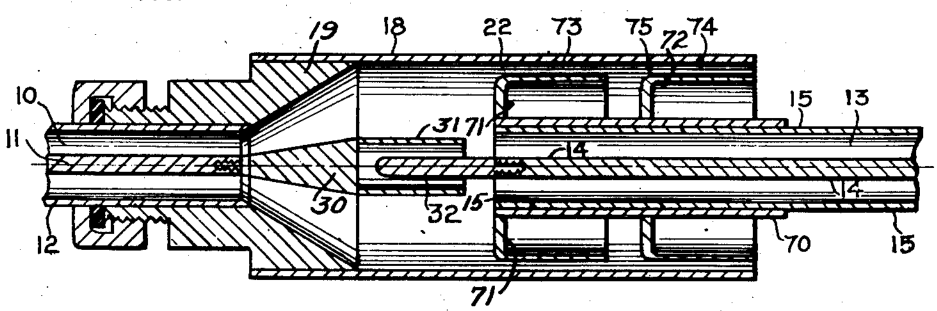


FIG. 7



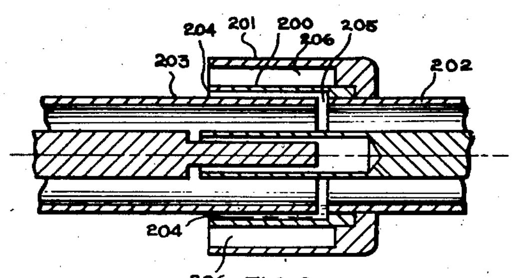


FIG. 8

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RADIO-FREQUENCY JOINT

Filed June 5, 1943 5 Sheets-Sheet 3

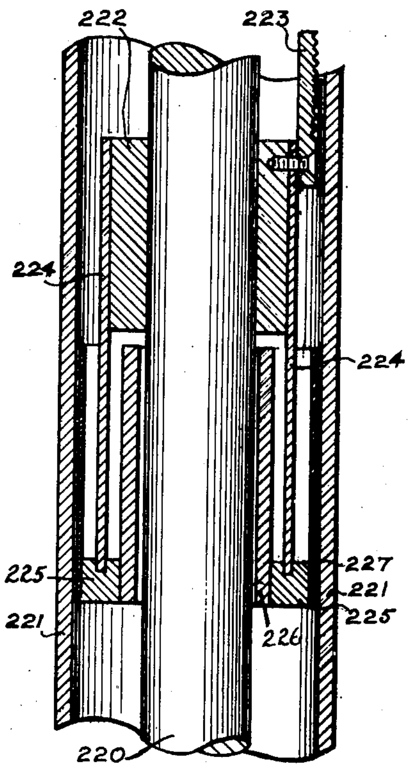


FIG.10

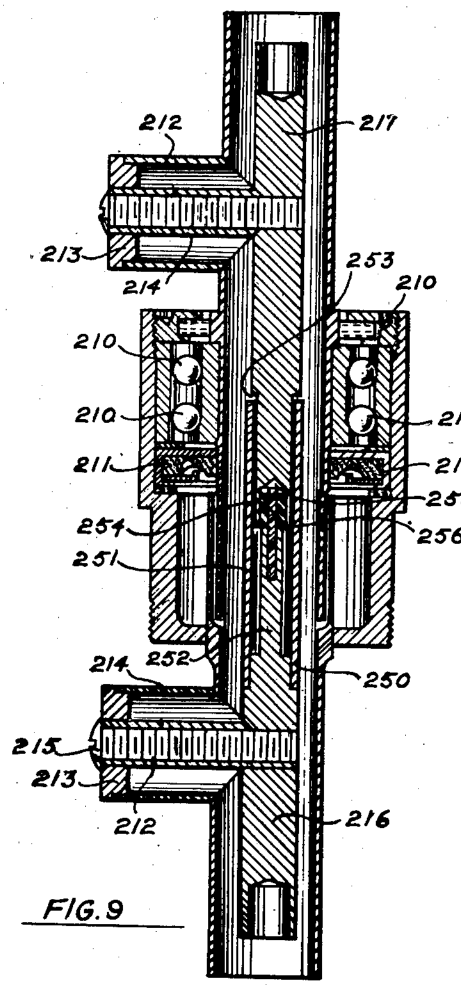


FIG.9

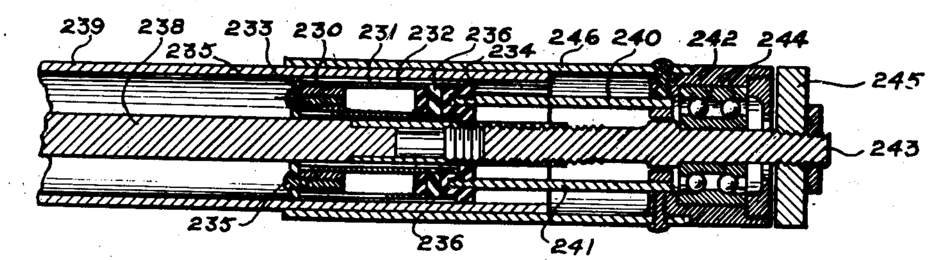


FIG.11

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FIG 12

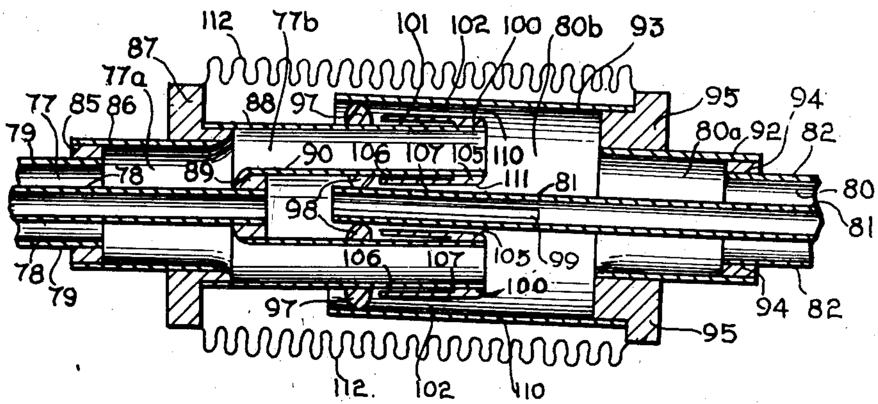



FIG.13

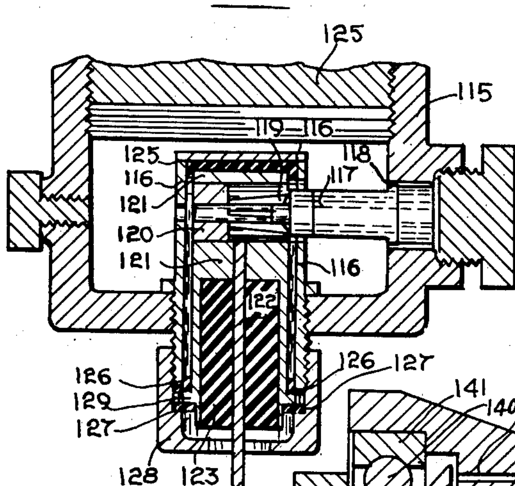
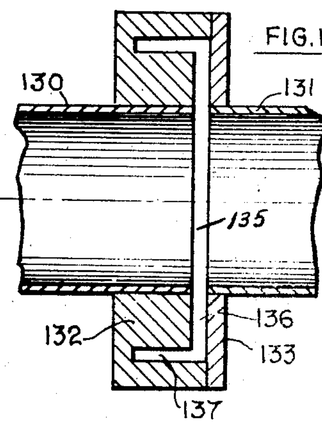



FIG.14



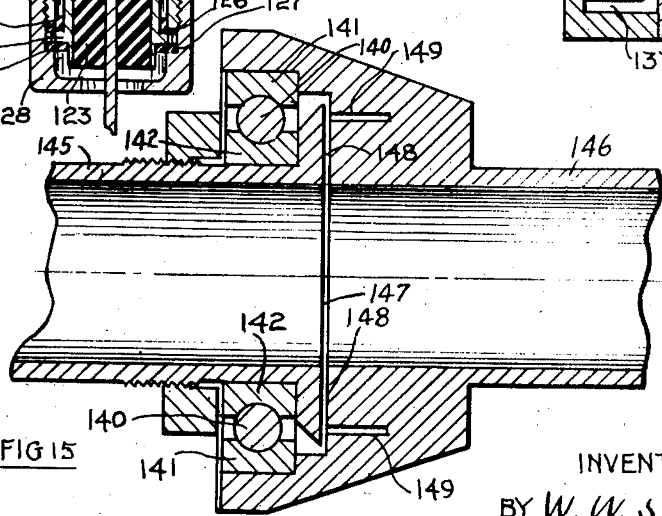




FIG 15

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FIG 16

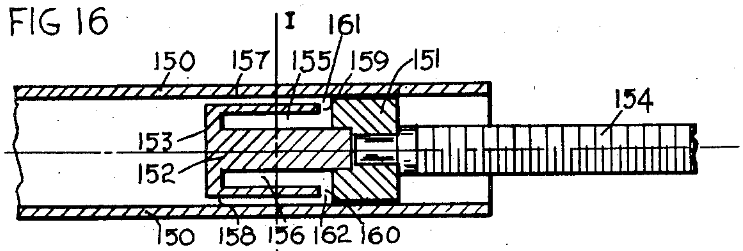



FIG 16A

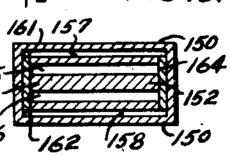



FIG 17

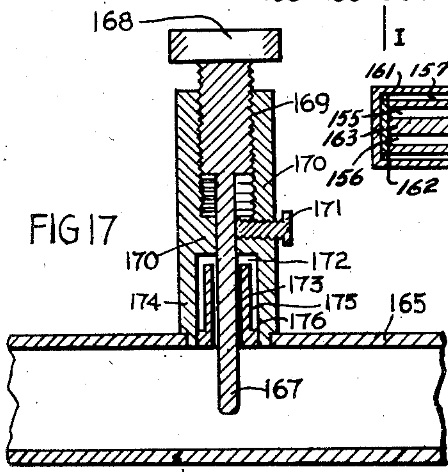



FIG. 18

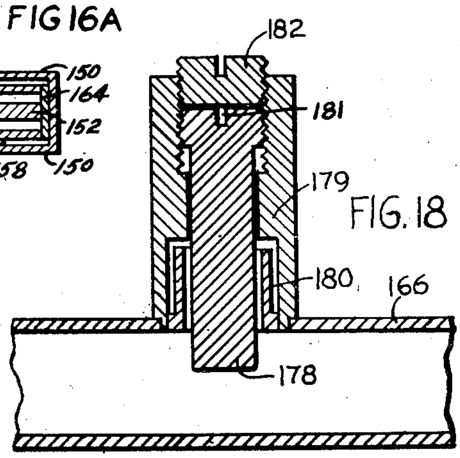



FIG 19

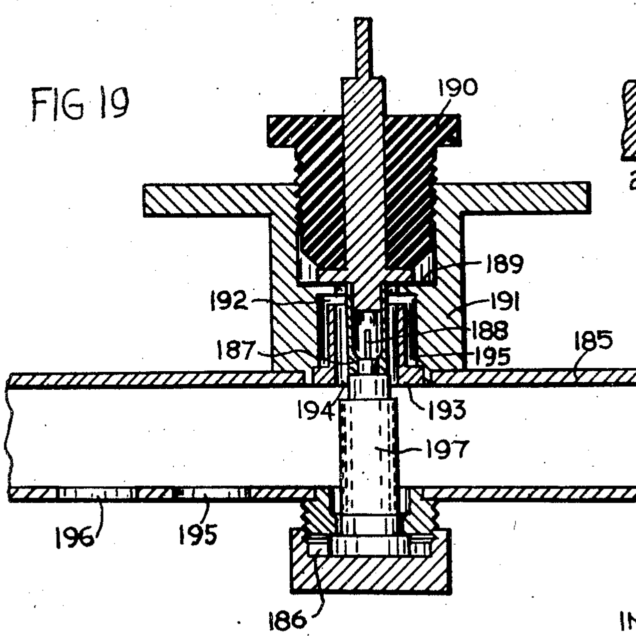
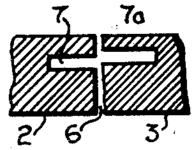



FIG 20

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Patented Oct. 19, 1948

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# UNITED STATES PATENT OFFICE

2,451,876

## RADIO-FREQUENCY JOINT

Winfield W. Salisbury, Arlington, Mass., assignor, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Application June 5, 1943, Serial No. 489,844

25 Claims. (Cl. 178—44)

1

This invention relates to systems for the transmission and reception of high-frequency radio waves. It is especially concerned with the minimizing of the discontinuities caused by joints in structures intended and adapted for conveying or utilizing radio waves in such systems.

Electrical contact zones between current-carrying or wave-guiding surfaces are generally a source of losses or reflections, or both, in high-frequency radio systems, especially systems operating at frequencies in the microwave range. Such losses have the usual consequences of reduced power output in the case of transmission and reduced sensitivity in the case of reception. Undesired reflections seriously interfere with energy transfer in electrical apparatus. In addition to the difficulties arising from the losses and reflections occurring even when the conducting members in question are held in relatively good physical contact, additional difficulties arise because of the variability of the effectiveness of the contact when subjected to vibrations, atmospheric action, sliding movements or adjustments, and so on.

It is an object of this invention to provide a structure which is adapted to avoid contact losses and to establish a high quality radio frequency conducting relationship between two physically distinct conducting elements which are intended to carry current or guide waves to and/or from each other. It is a further object of this invention to provide means for reducing the losses in the transmission of high frequency electromagnetic energy between components of high-frequency radio systems. Still a further object of this invention is to provide means for reducing the losses in adjustable or movable parts of high-frequency radio systems by avoiding contact losses and thereby to make possible greater use of such components. The manner in which the invention is carried out is best explained with reference to the drawings, in which:

Figs. 1, 2, 3 and 4 are diagrams illustrating the principles of the invention;

Fig. 5 is a longitudinal cross-section of a rotating joint embodying the present invention;

Fig. 6 is a longitudinal cross-section of another fom of rotating joint embodying the present invention;

Fig. 7 is a longitudinal cross-section of a modification of the apparatus shown in Fig. 5;

Fig. 8 is a longitudinal cross-section of a form of joint in accordance with the present invention;

Fig. 9 is a longitudinal cross-section of another form of rotating joint in accordance with the present invention;

2

Fig. 10 is a longitudinal cross-section of one form of an adjustable terminating closure for coaxial conductor transmission lines;

Fig. 11 is a longitudinal cross-section of another form of adjustable terminating closure for coaxial conductor transmission lines;

Fig. 12 is a longitudinal cross-section of an articulated joint embodying the present invention;

Fig. 13 is a cross-section of a high-frequency heterodyne mixer apparatus in which is embodied means in accordance with the present invention for establishing an apparent radio frequency conducting relationship between two elements thereof without actual electrical contact;

Fig. 14 is a longitudinal cross-section of a joint according to the present invention between two sections of wave guide pipe;

Fig. 15 is a longitudinal cross-section of a rotating joint for wave guide pipe in accordance with the present invention;

Fig. 16 is a longitudinal cross-section of an adjustable closure for a wave guide pipe constructed according to this invention;

Fig. 16A is a transverse sectional view along the line I—I of Fig. 16;

Fig. 17 is a cross-section of a structure for providing an adjustable loading capacitance in a wave guide pipe;

Fig. 18 is a cross-section of a variant form of the type of apparatus shown in Fig. 17;

Fig. 19 is a cross-section of a structure for mounting a crystal detector across a wave guide pipe, and

Fig. 20 is a diagram illustrating the principles of a modified form of structure according to the present invention.

Figs. 1, 2, 3 and 4 show, for purposes of illustration of the principles of this invention, pairs of metallic structures between the lower surfaces of which it is desired to establish an electrically conducting relationship for high-frequency electromagnetic oscillations, which is to say that it is desired to establish conditions for energy transfer between the members of each pair at high frequencies with as low losses as possible. The lower surfaces of the metallic structures shown in these figures may be considered as current-carrying surfaces or they may be regarded as wave guiding surfaces which guide electromagnetic waves in their immediate neighborhood. On Fig. 1, the current-carrying and wave guiding surfaces are shown at 2 and 3, being located respectively on the lower sides of the structures 4 and 5. The structures 4 and 5 are separated by a gap 6 which likewise separates the surfaces 2 and 3, causing a discontinuity in the electrical circuit which it is desired to establish. In accordance with this invention the gap 6 is made to form a channel or slot extending away from the mouth of the gap where it intersects the conducting surfaces 2 and 3 for a distance of at least one-quarter wave length (the wave length corresponding to the frequency at which it is desired to operate the apparatus in question). At a distance of approximately a quarter-wave length from the surfaces 2 and 3 the channel-like gap 6 joins with a branch channel 7. The branch channel 7 is a "dead end" channel having a conducting termination, shown at 8 which is located at a distance of approximately a quarter-wave length from the junction of the branch channel 7 and the gap 6.

The wave length dimensions here refer to what is known as the "electrical wave length" and refer to the length in which an electrical wave travelling through the structure goes through a certain change in phase (90° change in phase for a quarter-wave length). In structures of the type here described such electrical quarter-wave lengths are approximately equal to one-quarter of the wave length of the electromagnetic wave of the frequency in question when travelling through the open air or along a two-conductor air-insulated transmission line, which wave length may simply be called the "wave length in air." The difference between the electrical length in question and the corresponding fraction of the wave length in air for certain typical structures will be given below for purposes of illustration. These differences are believed to be due to "end effects" occurring at the open ends of such structures, and the like. The dimensions in question can be established experimentally because of the resonant phenomena which occur when the proper lengths are used and upon which the proper functioning of the apparatus in accordance with the present invention depends.

When the gap 6 is excited at its junction with the surfaces 2 and 3 by electrical oscillations of the frequency in question, an electromagnetic wave will travel down the gap 6 away from the surfaces 2 and 3 and into the branch channel 7. Because it is at a distance of an electrical quarter-wave length from the junction of the channels 6 and 7, the terminating conducting closure 8 causes the entire energy of the wave travelling down the gap 6 to be reflected back towards the surfaces 2 and 3 (except for a very small amount of energy absorbed in the flow of current in the walls of the channels 6 and 7, a quantity so small that it may be neglected). Thus, because of the location of the branch channel 7 and its conducting termination 8, no energy proceeds along the gap 6 beyond the branch channel 7 and consequently the shape and length of the gap 6 beyond the branch channel 7 and the existence or non-existence of electrical contacts thereacross or the quality of such contacts are entirely immaterial. In practice, minor improvements in the performance of particular forms of apparatus may sometimes be achieved by establishing a short circuit or maintaining an open circuit beyond the branch channel 7, and illustrations in which these measures are taken will be given in the description of various embodiments of the invention. In general, however, the invention is applicable both to joints the members of which are in electrical contact and joints the members of which are insulated from each other, the main principle of the invention applying alike to both types, as above described. As a further explanation of the principles which are believed to control the present invention, it may be pointed out that when the gap 6 is excited as aforesaid, the low impedance (short circuit) termination of the branch channel 7 appears at the mouth of the said channel 7 as a high impedance and, by virtue of the quarter-wave distance between the junction of the branch channel 7 and the gap 6 and the junction of the gap 6 with the surfaces 2 and 3, the termination surfaces 8 causes a low impedance to appear across the mouth of the gap 6 where it intersects the surfaces 2 and 3. In consequence, high frequency alternating currents of the frequency in question flow on the surfaces 2 and 3 and the usual conductor-guided electromagnetic waves travel as if a high quality electrical contact existed between these surfaces across the gap 6.

By way of explanation of the phenomenon that very little, or no energy at all, leaks out of the gap 6b of Figs. 1 and 3 or out of the gap 6a of Figs. 2 and 4, it may be pointed out that since the discontinuity offered by the gap 6a or 6b respectively is located at an electrical quarter-wave length from the conducting termination 8 of the channel 7, it is located at a point of minimum current and since there is little or no tendency for current to flow across the gaps 6a or 6b respectively, no potential appears thereacross. In the neighborhood of the gap 6b there is a potential maximum for the oscillatory system leading into the branch channel 7 but both sides of the gap 6b, or of the gap 6a, are of the same walls of the said oscillatory system so that, again, no potential appears across the gap 6b or across the corresponding gap 6a in the case of Figs. 2 and 4. It may be said that whatever impedance the gap 6b, or the gap 6a, may offer, such impedance appears in series with the high impedance of the branch channel, and therefore does not affect the input impedance of the gap 6.

The constitution of the gap 6 and the branch channel 7 in electrical quarter-wave length dimensions as heretofore explained amounts to the construction of an electrical resonator. The dimensions given in terms of electrical wave length are equivalent for the condition of a desired type of resonance at the frequency in question. The resonator thus constituted has a dimension of an electrical half-wave length between the point of excitation, which is the mouth of the gap 6 and a conducting termination wall 8 so that a very low impedance, practically a short circuit, appears at the place of excitation. The resonator cavity constituted by the channels 6 and 7 may be adapted to entertain oscillations in the "transverse electromagnetic" mode, as when bounded by parallel planes or coaxial cylinders, or it may be adapted to entertain oscillations in other modes, such as the $TE_{0,1}$, as in the case described below in connection with Fig. 16.

Resonators suitable under some circumstances for the practice of the present invention could be constructed with a dimension between the place of excitation and the terminating conducting wall equal to two or more integral electrical half-wave lengths, and the discontinuity represented by the gap 6b in Figs. 1 and 3 and by the gap 6a in Figs. 2 and 4 could then be located at any of a number of positions which is an odd number of quarter-wave lengths from the conducting terminating wall. In general, such structures are not preferred because of their larger physical dimensions and because of the greater amount of frequency sensitivity which they exhibit.

The particular geometrical configuration of the gap 6, the branch channel 7 and the surfaces 2 and 3 are by no means limited to the arrangement shown for purposes of illustration in Fig. 1. The gap 6 itself may be bent and the branch channel 7 may form with part of the gap 6 a straight channel, as shown in Fig. 2, for instance. Or again, as shown in Fig. 3, the branch channel 7 may extend away from the gap 6 without being bent over as shown in Fig. 1. Again, as shown in Fig. 4, the gap 6 may form a channel which is bent on itself between its mouth and its junction with the branch channel 7, which in Fig. 4 as in Fig. 2 forms a continuation of the gap 6. In Figs. 2 and 4 the gap 6 leads to the outside through the opening 6a which corresponds to the opening 6b on Figs. 1 and 3. The size of this opening is not important and it may, if desired, be sealed by material of any conductivity.

Arrangements such as those shown diagrammatically in the above-described figures are particularly well-adapted for application to rotating joints in which the desired relative movements of the members of the joints makes ordinary electrical contact arrangements highly unsatisfactory. Fig. 5 shows one form of rotating joint embodying arrangements according to the present invention. The rotating joint in Fig. 5 is designed to establish a connection adapted for the transfer of high-frequency radio energy between two coaxial conductor transmission lines which it is desired to rotate with respect to each other. One of these transmission lines is shown at 10 with an inner conductor 11 and an outer conductor 12. The other of these transmission lines appears at 13, having an inner conductor 14 and an outer conductor 15. Insulating beads 16 serve to support the inner conductors of the respective transmission lines from the corresponding outer conductors in suitable electrical isolation.

The outer conductor 12 of the transmission line 10 is broadened out into the wide tube 18 by means of the conical conducting structure 19. The outer conductor 15 of the transmission line 13 carries a cup-shaped member 20 firmly fastened in good electrical contact on its extremity The axial dimension of the cup-shaped member 20 is substantially equal to an electrical quarter-wave length; i. e., approximately equal to one-quarter of the open air wave length for the frequency in question. The inside of the cup-shaped member 20, since the member 20 is in annular shape, thus defines a resonant chamber corresponding to the branch channel 7 of Figs. 1, 2, 3 and 4. The inside of the cup member 20 communicates around the back of the said member with an annular gap 21 between the outside of the cup member 20 and the tubular conductor 18. The annular gap 21 thus corresponds to the gap 6 of Figs. 1, 2, 3 and 4. By virtue of the above-defined axial length of the cup member 20, the cup member 20 and the conductor 18 are caused to act at the frequency in question as if a high quality electrical contact existed between them across the annular mouth 22 of the gap 21. The conductors 12 and 15 are thus effectively brought into energy-transferring relation for the high frequency in question and it is evident that this relation will not be disturbed by relative rotation of the transmission line about their common axis.

The effectiveness of the radio frequency connection just constituted between the conductors 12 and 15 is at a maximum at the frequency for which the electrical quarter-wave length dimension above mentioned exactly obtains. It is possible to establish a reasonably good radio frequency connection between the conductors for a range for frequencies in the neighborhood of the said frequency by properly dimensioning the transverse width of the resonating channels. Thus in the apparatus of Fig. 5 the annular channel 21 is narrow whereas the annular cavity enclosed by the cup member 20 is relatively large. Thus the coaxial conductor transmission line constituted by the outer part of the sleeve 20 and the conductor 18 will have a low characteristic impedance, whereas the coaxial conductor transmission line formed by the inner surfaces of cup member 20 will have a substantially higher characteristic impedance. It is well known that the input impedance of a transmission line which is terminated by an impedance other than its characteristic impedance, when losses are neglected, will be proportional to the characteristic impedance of the transmission line as well as to a trigonometric tangent function determined by the frequency. Thus, because of its relatively high characteristic impedance, the short-circuited transmission line constituted by the inner surfaces of the cup member 20 will have a relatively high impedance even when the frequency is such that the length of this transmission line is somewhat different from an electrical quarter-wave length. In order to cause the transmission line constituted by the outer surface of the cup member 20 and the inner surface of the conductor 18 to appear to be substantially open circuited, the impedance at the rear edge of the cup member 20 need only be large relative to the characteristic impedance of the latter transmission line, which, as before pointed out, is relatively low. So long as this is the case, an impedance will be presented at the mouth 22 of the annular space 21 which is small even relative to the already small characteristic impedance of the transmission line constituted by the outer surface of the sleeve 20 and the inner surface of the conductor 18. In the device shown in Fig. 5, consequently, good energy transferring relationship is established between the conductors 12 and 15 for a substantial range of frequencies in the neighborhood of the desired mid-range frequency.

Referring to Figs. 1, 2, 3, and 4, the foregoing explanation of the operation of the apparatus shown in Fig. 5 shows that for operation of apparatus in accordance with the present invention over a range of frequencies it is desirable that the gap 6 should have a relatively low characteristic impedance with regard to the propagation of electromagnetic waves towards the branch channel 7 and that the branch channel 7 should have a relatively high characteristic impedance with regard to the propagation of electromagnetic waves between its junction with the gap 6 and the terminating closure 8.

In the apparatus of Fig. 5, in order to maintain the alignment of the axes of the transmission lines 10 and 13 in the immediate neighborhood of the rotating joint, bearings in the form of annular porous oil-bearing masses 23 and 24 are provided between the outer surface of the conductor 15 and the inner surface of an extension 25 of the conductor 18. If desired, pressure-sealing means may be provided in the space 26 between the bearings 23 and 24, an arrangement which is desirable when the coaxial conductor transmission lines are filled with compressed air to increase the breakdown voltage. An annular metallic block mounted on the outside of the conductor 15 at a short distance in back of the cup-shaped member 20 is shown at 28. The use of this type of block is preferred as it is believed that it aids the effectiveness of the cup-shaped member 20 and reduces somewhat the energy loss at the joint. The block 28 is not, however, necessary for the operation of the device and results satisfactory for many purposes may be obtained without the use of such a structure if for some reason that structure should be inconvenient. The amount of improvement to be obtained by the use of a structure such as the block 28 depends to some extent upon the nature of the structure in back of the cup-shaped member 20 or its equivalent.

The inner conductors 11 and 14 are brought into effective energy transferring relationship by a structure operating on a principle different from that described above. The conductor 11 is broadened out by means of a conical section 30 and extended in the form of a tube 31. The conductor 14 projects within the tube 31 as shown at 32. The length of the conductor 14 which projects as at 32 into the tubular conductor 31 is substantially a quarter-wave length. Since a quarter-wave length transmission line is thus formed with the farther and open-circuited, the nearer end, at the mouth of the annular space between the conductor 14 and the tube 31, offers a very low impedance. The series reactance interposed between the conductors 11 and 14 by the structure 31, 32 not only passes through zero at the frequency for which the quarter-wave dimension holds, but it also changes relatively slowly with frequency (or, conversely, with slight changes in length of the overlap between the conductors 14 and 31) under these conditions.

The flare of the conical structures 30 and 19 and the relative radii of the tubular structures 31 and 18 are so constructed as to create a minimum of discontinuity with respect to the transmission line 10. In other words, the configuration of the structure is designed to maintain a characteristic impedance equal to the characteristic impedance of the transmission line 10 in accordance with the well-known dependence of the characteristic impedance of a coaxial conductor transmission line upon the ratio of the inner diameter of the outer conductor to the outer diameter of the inner conductor.

A flange 35 is provided suitably fastened to the structure 18, 19 and to the conductor 12 for the purpose of mounting the apparatus upon a suitable support. Bolt holes for such mounting are shown at 36.

Fig. 6 shows an improved form of rotating joint operating essentially in the manner of the apparatus shown in Fig. 5 but better adapted for compact construction. The two transmission lines which it is desired to connect by a joint permitting relative rotation are shown at 40 and 41, the transmission line 40 having an inner conductor 42 and an outer conductor 43 and the transmission line 41 having an inner conductor 44 and an outer conductor 45. The transmission lines 40 and 41 are shown provided with couplings 46 adapted for coupling of said transmission lines to further sections of transmission line or to other radio apparatus. The cup-shaped member 48 mounted upon the outside of the conductor 45 corresponds to the cup-shaped member 20 shown in Fig. 5. The annular interior of the member 48, is, however, filled with a solid dielectric, preferably polystyrene as shown at 48*a*. The presence of the said dielectric acts to shorten the physical length of an electrical quarter-wave length in a similar structure having air dielectric. Thus it is possible to construct a structure of the configuration of Fig. 6 in which the inside of the cup member 48 will define an electrical quarter-wave length and the channel 49 around the outside of the cup member 48 will also define an electrical quarter-wave length between the back of the cup member 48 and the nearest approach of the conductors 43 and 45. The length of the latter path is longer than the axial dimension of the cup member 48, but since the dielectric is air, the above-described relation may be established. The radial dimension of the cup member 48 may be designed to provide the above-mentioned relation between the electrical wave length in the dielectric-filled interior of the cup member and in the air-filled channel 49 around the outside of the cup member 48. As shown on Fig. 6 the housing structure 50 which is securely fastened upon the conductor 43 cooperates with the cup member 48 to define an annular gap 49.

Behind the cup member 48 ball bearings 51 are mounted between the conductor 45 and the housing 50 to facilitate relative rotation of the members of the joint. A resilient gasket 52 is preferably provided between the ball bearings and their associated races and the housing 50. Back of the ball bearings is provided a pressure seal for maintaining the pressure within the coaxial conductor line system irrespective of the atmospheric pressure. The pressure seal mechanism includes the threaded rings 53 and 54, the sleeve 55, the gasket 56 and the bevel ring 57. The gasket 56 is preferably made of a compressible or resilient material such as chloroprene or a similar material, such as butadiene derivatives and materials known to the trade as "neoprene" and "Duprene."

The inner conductors 42 and 44, which are supported relative to the corresponding outer conductors by means of the insulators 60, are brought into effective energy-transferring relationship in a manner similar to that shown in Fig. 5 in connection with the conductors 11 and 14. Because of the greater thickness of the inner conductor in the transmission line shown in Fig. 6, it is unnecessary to spread either of the inner conductors in the apparatus of Fig. 6, the conductor 44 being simply axially bored at its end to define a cavity 62 into which an extension 63 of the conductor 42 projects without establishing contact therewith. The length of the extension 63 within the cavity 62 is an electrical quarter-wave length so that energy-transferring relationship between the conductors 42 and 44 is established as described in connection with Fig. 5. More accurately speaking, the length of the channel between the conductor 42 and its extension 63 on one hand and on the other hand the conductor 44 is an electrical quarter-wave length. The said channel includes not only a portion extending in a generally axial direction but also a small radial portion between the extremity of the conductor 44 and the conductor 42, which radial portion should be taken into account. It has been found that the desired electrical quarter-wave length relationship is obtained in the inner conductor joint of a structure such as that shown in Fig. 6 when the total length of the narrow channel in question is equal to about 0.23 times the wave length in air.

The following dimensions relating to the apparatus of Fig. 6 given in terms of the "wave length in air" as above defined will serve to illustrate the details of construction and design by giving one particular configuration which has been found suitable in practice. The dimensions given are generally applicable to wave lengths in the microwave range, at least, but it is to be understood that they may be interdependent, so that if the diameter of the conductors 42, 43, 44 and 45 are varied in terms of wave length, corresponding changes in the joint structure should preferably be made for best results, although the frequency sensitivity of the joint is low enough so that the dimensions in question are not extremely critical.

*Table I*

| Description of dimension | Length (wave length in air=1) |
|---|---|
| Outer diameter of conductors 42 and 44 | 0.064 |
| Inner diameter of conductors 43 and 45 | 0.144 |
| Gap between conductors 43 and 45 | 0.008 |
| Axial length of polystyrene block 48a | 0.119 |
| Dimension *a* (see Fig. 6) of block 48a | 0.048 |
| Outer diameter of cup member 48 | 0.294 |
| Length of projection 63 | 0.224 |
| Diameter of projection 63 | 0.032 |
| Depth of recess 62 | About 0.26 |
| Diameter of recess 62 | 0.048 |

The following table gives illustrative dimensions for the arrangement shown in Fig. 5:

*Table II*

| | | |
|---|---|---|
| Axial length of cup member 20 | inside | 0.21 |
| | outside | 0.23 |
| Outer diameter of conductors 11 and 14 | | 0.032 |
| Inner diameter of conductors 12 and 15 | | 0.144 |
| Inner diameter of tube 18 | | 0.416 |
| Outer diameter of 31 | | 0.112 |
| Inner diameter of 31 | | 0.096 |
| Overlap between 14 and 31 | | 0.18 |

Fig. 7 shows a form of rotating joint for coaxial conductor transmission lines essentially similar to that shown in Fig. 5 except that the cup member 20 is replaced by a double cup member comprising a sleeve 70 bearing two cup-like flanges 71 and 72. The sleeve 70, like the inner sleeve of the cup member 20 and 48 in Figs. 5 and 6 respectively, is provided for ease of assembly and could of course be dispensed with, in which case the cup-like flanges would be fastened, preferably soldered, directly to the outer conductor 15. Although in most cases a second cup section such as is provided by the member 72 is unnecessary it may be of advantage to employ such a member where a very great reduction of the energy loss to the system at the rotating joint is desired. Multiple resonant choke sections arrangement such as in Fig. 7 may also have advantages for operation over a range of frequencies if the two resonator sections are tuned to neighboring but slightly different frequencies.

Theoretically, in order that both cup members 71 and 72 may respectively act to produce an apparent short circuit for radio frequencies at the mouth 22 of the channel system 73, 74, the front of the member 72 should be spaced from the



back of the member 71 by a quarter-wave length. Rotating joints with such spacing between the members 71 and 72 have been found to operate satisfactorily but experimental results have shown that closer spacing between the two cup-like elements will give equally good results and in some cases slightly better results and are moreover more convenient in many cases because of their greater compactness. In the type of construction shown in Fig. 7, where the spacing between the cup elements 71 and 72 is less than a quarter-wave length the cup member 72 may be regarded as producing an apparent radio frequency short circuit at the mouth 75 of the channel 74, thus tending to eliminate any residual radio frequency voltage that may appear across the annular gap 75 in spite of the action of the cup member 71. Thus, in the arrangement of Fig. 7, the element 72 apparently does not itself contribute appreciably to creating an apparent short circuit at the mouth 22 of the channel 73 but does assist to reduce the amount of energy which is able to "leak" out of the system at the rotating joint. For most purposes the effectiveness of a single cup member is so high that a single section arrangement such as that shown in Fig. 6 is preferable.

Fig. 8 shows a form of joint for coaxial conductor transmission lines which is particularly compact and is adapted for both fixed and rotating joints. The inner conductor joint is similar in physical configuration to that shown in Fig. 6 between the conductors 42 and 44. The outer conductor joint is effected by means of two forwardly projecting sleeves 200 and 201 mounted upon one of the outer conductors which is shown at 202. The sleeve 200 is adapted to project over the other outer conductor 203 in such a manner as to leave a small clearance 204 communicating with the gap 205 between the extremities of the conductors 202 and 203. The outer sleeve 201 is so shaped as to provide an annular space 206 between it and the sleeve 200 having an axial depth of an electrical quarter-wave length and a transverse width or clearance preferably several times as great as the clearance between the sleeve 200 and the conductor 203. Any impedance which may appear at the extremity of the sleeve 201 and the conductor 203 will appear across the clearance 204 only in series with the high impedance at the mouth of the annular space 206 at frequencies in the range of desired operation, so that a low impedance will be presented across the gap 205 and energy transferring relationship will thus be established between the conductors 202 and 203. Means for supporting the various conducting structures with respect to each other have been omitted in Fig. 8, as in Fig. 7, to promote simplicity of illustration. It is to be understood that various well-known types of mechanical joint may be provided to maintain the desired physical relationship between the conductors 202 and 203. Since the type of transmission line joint shown in Fig. 8 does not require any actual physical contact between the corresponding conductors of the two coaxial conductor transmission lines being joined, and since a shock-absorbing or elastic physical mounting may be employed to keep the two coaxial conductor lines in general alignment and proximity, this type of joint is useful for isolating part of the electrical system from mechanical shock which would otherwise be transmitted from other parts of the system. The one of the coaxial conductor transmission lines shown in Fig. 8 might be rigidly connected to a delicate apparatus, such as a transmitting tube, and the joint may then be used to transfer electric energy to or from such apparatus while isolating the apparatus in question from mechanical shock. The said delicate apparatus together with the portion of transmission line connecting it to the joint could be sheltered in a shock-absorbing mounting. Small relative motion between the members of the joint shown in Fig. 8 may be permitted without serious interference to the electrical properties of the joint.

Fig. 9 shows a joint similar to the joint of Fig. 8 provided with ball bearings for service as a rotating joint and incorporating an inner conductor joint constructed in accordance with the present invention instead of the type of inner conductor joint above described (which I have claimed in a copending application). The apparatus shown in Fig. 9 is provided with a pressure sealing arrangement 211 of the type known to the trade as "Garlock number 95." Seal 211 is an annular washer made of a fibrous, leather-like material tightly pressed into the annular opening defined by the outer conductor of the coaxial line and the inner surface of the bearing housing, and held in place by an annular retaining washer as shown. The provision of the said pressure sealing means permits the maintenance of an air pressure inside the coaxial conductor transmission line system which is higher than that on the outside of said transmission line which serves the purpose of inhibiting the occurrence of corona discharges and at the same time tends to prevent penetration of water or dust from the outside into the system.

In the apparatus shown in Fig. 9 the inner conductors of the coaxial conductor line which are joined by the rotating joints are supported by stub-line supports 212. These stub-line supports are essentially branch transmission lines of a length of approximately a quarter-wave length terminated at their extremities by a short-circuiting plug 213. The stub-supports in this case are of a demountable type. The inner conductors of the stubs each comprise a sleeve 214 and a machine screw 215. The sleeve 214 is preferably soldered to the plug 213, since good electrical connection is desired at the short-circuited end of the stub line, where currents may be relatively heavy. The machine screw 215 fits inside the sleeve 214 and is threated into one of the transmission line inner conductors 216 and 217. Tightening the machine screw 215 brings the inner conductor in question into good mechanical and electrical contact with the sleeve 214. A soldered joint is not necessary at this point since little current flows in and out of the stub because of its quarter-wave length dimension.

The inner conductor joint in the apparatus of Fig. 9, connecting the conductors 216 and 217 is constituted in a different manner from that of the inner conductor joint previously shown for coaxial conductor lines. Instead of employing a simple open-ended quarter-wave line connection, a system of annular cavities designed in accordance with the present invention is provided. The conductor 217 projects for an electrical quarterwave length into a tubular extension 250 of the conductor 215, with a relatively narrow clearance, thus constituting a coaxial conductor transmission line of a length of an electrical quarterwave length. The narrow clearance between the conductor 217 and the extension 250 of the conductor 216 is continued into a wider



annular cavity 251 between the extension 250 and an inner central projection 252 of the conductor 216. The cavity 251 has an axial length of an electrical quarter-wave length, so that it cooperates with the previously mentioned narrow annular clearance to establish a low radio frequency impedance between the conductor 217 and the extremity of the tubular extension 250 across the gap 253, and this for a range of frequency in accordance with the principles above described. In order that the narrow annular clearance between the tubular member 250 and the conductor 217 may be maintained, the central projection 252 is adapted to grip a projecting pivot pin 254 preferably made of hardened and ground steel, which projects into a recess 255 of relatively large diameter within the end of the conductor 217. In this recess is provided a suitable bearing 256 in which the pin 254 is adapted to turn and which centers the pin with respect to the conductor 217. I prefer to make the bearing 256 of a graphite-bearing cadmium alloy. In accordance with the principles of the present invention, the electrical properties of the bearing material are unimportant because such material appears across the narrow clearance only in series with the open end of a quarter-wave resonator.

Figs. 10 and 11 illustrate the application of the present invention to the construction of movable terminating closures or "plungers" for coaxial conductor transmission lines. Such structures have great utility for tuning coaxial conductor line systems, especially in such devices as "double stub tuners" and wave meters. Adjustable closures of the simple electrical contact type introduce excessive losses while those of the "quarter-wave cup" type may introduce reflections at points other than the desired termination, because of their configuration. Adjustable closures constructed in accordance with the present invention provide the effect of a straight terminating wall across the coaxial conductor line in question, without the introduction of contact losses.

Referring to Fig. 10, 220 is the inner conductor and 221 is the outer conductor of a coaxial conductor line which it is desired to tune or terminate by an adjustable short-circuiting closure. For this purpose a slider 222 is mounted upon the conductor 220 in a manner adapted to permit axial displacement along the conductor 220. The slider is adapted to be actuated by means of a rack 223, which, may be driven by a suitable adjusting mechanism. The slider 222 carries a forwardly projecting conducting sleeve 224 which is located approximately midway between the conductors 220 and 221. The sleeve 224 carries at its forward extremities an annular conducting structure 225 upon which are mounted two conducting sleeves 226 and 227, the former being positioned close to, but spaced from, the conductor 220 and the latter being positioned close to, but spaced from, the conductor 221. The sleeves 226 and 227 are each of a length of substantially a quarter-wave length preferably of a frequency in the middle of the range of frequencies at which operation of the device is intended. The axial dimension of the annular structure 225 is so determined that the path around the rear ends of the sleeves 226 and 227 and down between the said sleeve and the supporting sleeve 224 to the rear face of the annular structure 225 will likewise be an electrical quarter-wave length long. The spaces between the sleeves 226 and 224 and between the sleeves 227 and 224 are relatively wider than the spaces between the sleeve 226 and the conductor 220 and between the sleeve 227 and the conductor 221, in order that the device will provide the desired short-circuiting closure effect at a range of frequencies, instead of substantially at one frequency only.

In accordance with the principles of the present invention an apparent radio frequency short circuit will be established between the conductor 220 and the lower or forward end of the sleeve 226, and likewise between the conductor 221 and the lower or forward end of the sleeve 227, with respect to energy fed to the line 220, 221 from below. Thus a radio frequency short circuit will be established between the conductors 220 and 221 in the plane of the front face of the annular structure 225. The location of this short circuit may be varied by moving the entire terminating closure structure by actuating the rack 223 and displacing the slider 222. The small clearances between the quarter-wave sleeves and the conductors of the transmission line do not in practice give rise to undesired sparking or corona, even at their rear extremities. Structures of this type may thus advantageously be employed even in systems operating at high power. Joints and closures of the types herein described are operative at relatively high power partly because of the fact that the voltage across the narrow clearances is not as high as that across the transmission line with which the apparatus is associated, on account of the dependence of the voltage amplitude in a resonant transmission line upon the characteristic impedance of the line. Since the characteristic impedance of the lines having narrow annular clearance is low and these lines "current fed," the voltage developed in them will be relatively low even for such currents as the main transmission line may carry when operating at full power rating.

In order to facilitate the construction of the terminating closure for coaxial conductor transmission line in the form shown in Fig. 10, it is convenient first to solder the sleeves 226, 224, and 227, preferably by hard soldering and in the order given, to the annular structure 225 and then to hold the sleeve 227 in a chuck for boring the inner hole of the sleeve 226 to the desired diameter and for reaming the central hole of the slider 222 to its proper dimension, these holes being kept in line. In this manner concentricity of the outer surface of the sleeve 227, the inner surface of the sleeve 226 and the inner surface of the slider 222 may be practically assured.

Fig. 11 illustrates another type of terminating closure in accordance with the present invention. This type of closure employs insulation across the coaxial conductor transmission line and is, therefore, not preferred for high power operation. Because of its compact and simple structure, however, it is particularly suitable for use in a wave meter. The annular structure 230 corresponds to the annular structure 225 of Fig. 10. The sleeves 231 and 232 correspond respectively to the sleeves 226 and 227. Instead of a central supporting sleeve, mechanical support for the structure is provided by insulating structures 233 and 234. The structure 233 is fixed with respect to the structure 230 by means of machine screws 235. The structure 234 is secured to the sleeves 231 and 232 by means of pins of insulating material 236 passing through suitable perforations in the sleeves 231 and 232 and corresponding holes drilled in the insulating structure 234. The insulating supports 233 and 234 are designed to slide with respect to the transmission line conductors 238 and 239. Because of the presence of the insulation 234, 236 between the sleeves 231 and 232, an electrical quarter-wave length in the space between the said sleeves will be physically shorter than if the said space were filled only with air and in consequence the actual dimension of the annual structure 230 is somewhat greater than that of the annular structure 225 for a given frequency of operation. The sliding closure is mechanically actuated by means of rods 240 and 241 threaded into the insulating structure 234 and fastened at their other end in a crosshead 242. The crosshead 242 is adapted to be advanced or retracted in response to turning of a shaft 243 mounted in ball bearings 244 in the crosshead 242 and threaded at its extremity into the end of the inner conductor 238 of the transmission line to be terminated. A knob 245 mounted on the shaft 243 may be provided for facilitating manipulation of the shaft and for furnishing a micrometer reading. Additional indication of the position of the terminating closure may be furnished by a sleeve 246 mounted on the crosshead 242 and slipping over the outer conductor 239. The indication may be furnished by a scale marked on that part of the outer conductor 239 which is covered and uncovered by the movement of the crosshead 242.

In the apparatus of Fig. 11, the branch channels (i. e. corresponding to the channel 7 of Fig. 1) of the two annular resonating structures designed to achieve the establishment of radio-frequency short circuit are combined into a single quarter-wave resonator which communicates both with the annular space between the sleeve 231 and the conductor 238 and with the annular space between the sleeve 232 and the conductor 239, in each case so communicating at a point approximately an electrical quarter-wave length from the desired electrical closure. This illustrates another of the many variations in physical structure which may be made in the design of apparatus for operation in accordance with the principles of the present invention.

Fig. 12 shows an articulated joint for coaxial conductor lines in which advantage is taken of the present invention. This joint is designed to provide freedom for "wobbling" movements which may include small amounts of relative angular movements of the axes of the coaxial conductor lines as well as small amounts of relative translatory movements back and forth.

In the apparatus of Fig. 12 it is desired to effect a joint between the transmission line 77 which comprises the inner conductor 78 and the outer conductor 79, and the transmission line 80 which comprises the inner conductor 81 and the outer conductor 82. In this case the inner conductors as well as the outer conductors of the transmission line 77 and 80 are provided in hollow form, the purpose being to provide lightness of construction. The transmission line 77 is expanded into the transmission lines 77a and 77b in two steps. In the first of these steps the conductor 79 connects through the ring 85 with the tubular conductor 86 which together with the inner conductor 78 form the transmission line 77a. In the second step the conductor 86 connects through the annular structure 87 to the conductor 88 and the inner conductor 78 connects through the annular structure 89 with the tubular conductor 90, the conductors 90 and 88 forming the transmission line 77b. The lengths of the transmission lines 77a and 77b and the radii of their respective conductors are so provided as to reduce the total resultant reflection effect of the various changes in transmission line dimensions between the end of the transmission line 77 and the articulated joint at the opposite end of the transmission line 77b in accordance with well-known principles. The transmission line 77a accordingly has a length of approximately a quarter-wave length and the transmission line 77b has a length of approximately a half-wave length.

The transmission line 80 is built out into the transmission lines 80a and 80b in succession by connecting the conductor 82 to the tubular conductor 92, of larger diameter, and in turn connecting the conductor 92 to the tubular conductor 93 which has a still larger diameter. The aforesaid connections are made by means of the annular conducting and supporting structures 94 and 95 respectively. As in the case of the transmission lines 77a and 77b, the transmission line 80a is so dimensioned as to reduce the total resultant reflection occurring between the transmission line 80b and the transmission line 80 in accordance with well-known principles. Thus the transmission line 80a is a quarter-wave length long.

An annular boss 97 is provided on the outside of the conductor 88 for engagement with the conductor 93 in order to maintain the desired physical relationship of these conductors. The boss 97 may conveniently be made of brass and soldered to the conductor 88. An inwardly directed annular boss 98 is similarly provided on the inside of the conductor 90 for engagement with the conductor 81. The conductor 81 is slotted, as shown at 99, in order to permit compression, which angular movement at the joint tends to produce, without deforming the conductor 90 or its associated parts. Preferably two or more slots such as the slot 99 are provided. The conductor 93 may also be slotted in the neighborhood of the boss 97 although this precaution is usually unnecessary because angular movement at the joint decreases the contact between the conductor 93 and the boss 97 instead of increasing it as in the case of the conductor 81 and the boss 98. It is not necessary to maintain any particular quality of contact between the boss 97 and the conductor 93, in accordance with the principles controlling the present invention, so that slotting of the conductor 93 for spring contact becomes an unnecessary measure. An annular sleeve-type member 100 corresponding in function to the cup-like member 20, 48 and 71 of Figs. 5, 6 and 7, is mounted upon the outside of the conductor 88 at the extremity of the latter. In order that the apparatus of Fig. 12 may be sufficiently compact the sleeve member 100 is only slightly greater in its radial dimension than the conductor 88, so that the annular space 101 between the back part of the sleeve member 100 and the conductor 88, which corresponds to the branch channel 7 of Fig. 1, is quite narrow. Because of the extreme narrowness of this space, and the increased "end effect" resulting at the cavity mouth, the depth of such space necessary to produce resonance at the desired frequency (i. e. an electrical quarter-wave length) is considerably shorter than one-quarter of the wave length of the corresponding electromagnetic waves in air. Thus for an apparatus of the configuration of Fig. 8 for operation in the range between 5 and 20 centimeters (i. e. for operation in the neighborhood of some particular frequency at that range) a depth of approximately 0.15 times the wave length in air is suitable. The electrical quarter-wave length at the same frequency in the annular channel 102 between the sleeve member 100 and the conductor 93 is somewhat longer, being approximately 0.22 of the wave length in air. The sleeve member 100 consequently has an ample surface of contact with the outer surface of the conductor 88 for the establishment of a good mechanical and electrical joint.

In a similar manner, an annular sleeve member 105 is mounted near the extremity of the conductor 90 on the inner side of the latter conductor facing the conductor 81. The sleeve member 105 is so shaped as to provide an annular space or cavity 106 having essentially the same properties as the cavity 101 and to establish an annular channel 107 between the conductor 81 and the sleeve member 105. In accordance with the previously explained principles of the present invention, the sleeve structure 100 cooperates with the neighboring walls of the conductors 88 and 93 to create an apparent radio frequency short circuit at the annular mouth 110 of the channel 102 while the sleeve member 105 cooperates with the neighboring walls of the conductors 90 and 81 to establish an apparent radio frequency short circuit across the annular mouth 111 of the channel 107. Thus at the frequency of operation of the apparatus the conductor 78 is brought into energy-transferring relation with the conductor 81 through the conductor 90, and the conductor 79 is brought into energy transferring relation with the conductor 82 through the conductors 86, 88, 93 and 92.

In order that the joint shown in Fig. 12 may be employed for connecting transmission lines in a system in which the air pressure inside the transmission lines is maintained above the pressure of the atmosphere outside them, a Sylphon bellows 112 is provided around the joint. One end of the Sylphon bellows 112 is soldered onto the annular structure 87 while the other end is soldered onto the annular structure 95.

Fig. 13 shows an arrangement for establishing an apparent radio frequency short circuit in accordance with the principles of the present invention for the purpose of filtering the radio frequency current from the intermediate frequency output of a heterodyne mixer or first detector apparatus. The heterodyne mixer apparatus shown in Fig. 13 comprises a coaxial type resonator having an outer housing 115 and an inner cylindrical column 116 and comprises also a rectifier element 117 which may be and preferably is a cartridge containing a silicon crystal and associated "cat's whisker" wire. Such crystal and wire when adjusted are held in place by wax and are enclosed in a cartridge having suitable electrical contact surfaces at the end and an outer body portion composed of insulation as shown generally at 117. The rectifier element 117 is mounted between a suitable recess 118 in the outer housing 115 and a clip 119 electrically connected to an inner conducting structure 120, 121, 122 which is located inside of and insulated from the cylindrical structure 116. The housing 115 constitutes a resonator and is provided with an adjustable plug 125 for purposes of tuning and is adapted to be excited by signal voltage and local oscillator voltage through suitable coupling arrangements not shown in Fig. 13. It is desired that the voltage appearing across the crystal may be impressed upon an intermediate frequency amplifier which may be connected to the wire

122, but it is also desired that the voltage of signal and local oscillator frequencies appearing across the crystal shall not appear across the intermediate frequency amplifier but that the radio and local oscillator frequency currents may complete their circuit in the resonator 115, 116. For this reason it is desirable to establish an apparent radio short circuit between the upper part of the conducting element 121 and the cylindrical structure 116. For this purpose the lower part of the conducting structure 121 is provided with a cavity surrounding the wire 122, which cavity is preferably filled with a mass 123 of solid dielectric, such as polystyrene. The axial dimensions of the mass of dielectric 123 and of the cavity which it fills is substantially an electrical quarter-wave length. Thus at a distance of an electrical quarter-wave length up from the bottom of the metallic structure 121 an apparent radio frequency short circuit will appear between the structure 121 and the structures 116. This apparent short circuit is preferably made to occur in the neighborhood of the clip 119, 120 which is carried in a hole drilled in the structure 121. At the intermediate frequency produced by the interaction of the signal and local oscillator frequencies there is of course no such apparent short circuit so that the intermediate frequency voltage can be utilized to excite an intermediate frequency amplifier. The apparent radio frequency short circuit is of great importance for the successful operation of the device, for the local oscillator would otherwise pass radio frequency oscillations to the intermediate frequency amplifier which would result in considerably increased noise in the amplifier.

In order to provide the desired insulation between the structure 121 and the structure 116, insulation is provided as shown at 125, 126 and 127. A metal cap 128 threaded onto the lower part of the structure 116 cooperates with the insulating washers 126 and 127 and with a ridge 129 suitably located on the outside of the structure 121 in order to maintain the parts in the desired alignment and position.

Fig. 14 illustrates the application of the principles of the present invention for the formation of a joint between two sections of wave guide pipe. The ends of two sections of cylindrical wave guide pipe having metal walls are shown in axial cross section at 130 and 131. The pipe 130 is provided with a terminal flange structure 132 and the pipe 131 is provided with a simple perpendicular terminal flange 133. When the flange structure 132 and the flange 133 are fastened together, as by clamping arrangement not shown in the figure, in such a manner as to bring the guide pipe 130 and 131 into axial alignment, an annular gap 135 is left between the extremities of the pipes 130 and 131. The flange structure 132 is so built that the gap 135 is extended into an annular recess 136 which at a distance of an electrical quarter-wave length from the mouth of the gap 135 leads into an annular groove 137 having a depth of an electrical quarter-wave length. Except for the development in annular shape, the structure of Fig. 14 is exactly analagous to that shown in Fig. 3. The groove 137, for instance, corresponds to the branch channel 7 of Fig. 3. Instead of the definite gap shown in Fig. 3 at 6b there is in the arrangement of Fig. 14 only the contact boundary between the flange structure 132 and the flange 133, but since the existence of electrical contact at this location is essentially immaterial, this difference is not of



great importance. If desired, a thin layer of insulating material might be interposed as a gasket between the otherwise contacting faces of the flange structure 132 and the flange 133, but in general electrical contact at this point is preferred in order to keep the entire wave guide at the same direct-current potential.

Fig. 15 shows a rotating joint for cylindrical wave guide pipes. Except for the provision of the ball bearings 140 mounted in the races 141 and 142, the structure shown in Fig. 15 is analogous to that in Fig. 14. The wave guide pipes between which the rotating joint is provided are shown at 145 and 146 and a small gap between them appears at 147 which extends into the radial channel 148, which corresponds to the channel 136 of Fig. 14. Instead of being directly closed off as in Fig. 14, the channel 148 continues beyond the branch channel 149, which corresponds to the groove 137, in order that the only contact between the relatively rotating structure may be at the ball bearings, thus reducing friction. In accordance with the principles of the present invention, the branch channel or groove 149 has a depth equal to an electrical quarter-wave length and the distance from the intersection of the branch channel 149 with the radial channel 148 to the mouth 147 of the radial channel 148 where it opens into the cylindrical wave guide system is also an electrical quarter-wave length. Although in Figs. 14 and 15 the wave length of the oscillations in the cylindrical wave guide system may be considerably longer than the wave length of oscillations of the same frequency in unconfined air on account of the difference in the form of the wave, the electrical quarter-wave lengths in the structure 136, 137 and the structures 148, 149 closely approximate one-quarter of the wave length of oscillations of the said frequency in open air, which may be explained by the fact that in these annular structures the waves are of the "transverse electromagnetic" variety.

Grooved flange structures such as those shown in Figs. 14 and 15 might also be used in cooperation with a movable metallic closure, such as a disk rotated on an axis outside the wave guide and having perforations adapted to open the wave guide when they are in registry with the wave guide cross section, thereby constituting a switch or wave guide valve. A single rotating disk may be arranged to switch several wave guides alternately.

Fig. 16 shows the application of the present invention for the construction of an improved form of terminating closure for a rectangular wave guide pipe. The rectangular wave guide 150 is shown in longitudinal cross section. The plane of the view is perpendicular to the broader side of the wave guide pipe. The wave guide pipe 150 is designed to transmit electromagnetic waves in its interior which are of the $H_{0,1}$ mode, known also as the $TE_{0,1}$ mode, so that the electric vector of such oscillations in the pipe will be directed perpendicularly to the broader sides of the pipe which appear in Fig. 16 at the top and bottom. The electric vector will consequently lie in the plane of the figure, oriented in a vertical direction. The provision of an adjustable conducting closure in a wave guide pipe such as the pipe 150 has heretofore presented a considerable problem because extremely good electrical contact was necessary to prevent excessive losses at the contact zone and extremely good electrical contact was difficult to obtain in an adjustable device. In the arrangement shown in Fig. 16 the necessity of extremely good electrical contact between the terminating closure and the walls of the wave guide pipe is avoided. The terminating closure shown in Fig. 16 includes a sliding guide portion 151 which may conveniently be a block of metal, and a suitably shaped plunger or piston 152 mounted on the block 151 in such a manner as to clear the upper and lower surfaces of the wave guide pipe 150 without electrical contact therewith and having a flat front surface 153 which acts as a conducting terminating surface closing off the pipe wave guide 150. A threaded handle 154 is fastened on the back of the block 151 and is adapted to be operated by a suitable threaded adjusting mechanism for adjusting the location of the closure apparatus and particularly of the terminating surface 153.

Because the electric vector is vertically oriented in the plane of the paper with respect to Fig. 16, there is no problem of contact losses at the lateral edges, not shown, of the terminating surface 153 and these may thus rest in contact with the narrow walls of the wave guide 150 (the vertical walls with respect to Fig. 16). At the top and bottom edges of the surface 153, however, the application of the present invention is desirable in order to provide the desired radio frequency conducting relation between the surface 153 and the upper and lower walls of the wave guide 150. The piston 152 is accordingly provided with two cavities 155 and 156 which communicate at their rear ends with the clearance spaces 157 and 158 respectively through slots 159 and 160. The slots 159 and 160 open respectively into the clearance spaces 157 and 158 at a distance of an electrical quarter-wave length from the front surface 153 of the piston 152. Likewise the electrical length of the cavities 155 and 156, including the contribution of slots 159 and 160 respectively, is also a quarter-wave length. The desired radio-frequency short circuit is therefore established in accordance with the principles already outlined of the present invention, the clearance spaces 157 and 158 corresponding to the gap 6 of Fig. 1 and the cavities 155 and 156 corresponding with the branch channel 7 of Fig. 1.

The electrical quarter-wave lengths here in question differ in their relation to the corresponding "wave length in air" from the example heretofore given, on account of the different configuration of the resonators which in this case are rectangular in shape instead of annular, so that the waves in the cavities are probably of the longer-wave-length $H_{0,1}$ mode instead of "transverse electromagnetic." For rectangular wave guides for operation at frequencies for which the wave length in the guide is about one and one-half times the wave length in free space, a terminating closure such as that shown in Fig. 16 is preferably provided with a plunger so shaped that the channels 157 and 158 have a length from the surface 153 to the nearer edge of the slots 159 and 160 of approximately one-third the "wave length in air" previously defined. The longitudinal dimension of the cavities 155 and 156 from their forward end to the nearer edge of the slots 159 and 160 is preferably approximately 0.28 times the said wave length in air. As previously explained, both these dimensions are electrical quarter-wave lengths, it being understood that the electrical quarter-wave length relating to the cavities 155 and 156 is so defined as to include the contribution of the slots 159 or 160 respectively.

In the apparatus of Fig. 16 it is undesirable to leave the lateral terminations of the cavities 155 and 156 closed off merely by the vertical walls of the wave guide 150. Since some of the circulating current of the resonant cavities might in such case be allowed to flow across the zone of doubtful contact between the plunger 152 and the lateral wall of the wave guide 150, the cavities 155 and 156 are instead closed off by a structure electrically integral with the plunger 152. This may be provided by soldering two lateral sheet metal walls (the edges of one of which appear in Fig. 16 at 161 and 162 respectively) on the lateral faces of the plunger or piston 152. These sheet metal side pieces of the piston 152 may slide in flush contact with the vertical walls of the wave guide 150, or may be slightly spaced therefrom. These sheet metal side pieces are indicated in Fig. 16A by numerals 163 and 164.

Figs. 17 and 18 show the application of the present invention in the construction of devices for applying an adjustable loading capacitance in a wave guide pipe. Wave guide pipes are shown at 165 in Fig. 17 and 166 in Fig. 18. These wave guide pipes are of the rectangular type (but round pipe could, of course, also be used) and are shown in a longitudinal cross section corresponding to that of the wave guide pipe 150 shown in Fig. 16, so that the electric vector of the oscillations intended to be transmitted by the pipes 165 and 166 lies in the plane of the figure in a vertical orientation. In many wave guide pipe systems it is desirable to introduce an adjustably projecting metallic member which projects through either the upper or lower wall of the wave guide and thus acts as a loading capacitance. In order to reduce undesired losses arising from the charging current of the loading capacitance it is advantageous to apply the principles of the instant invention for establishing an apparent radio-frequency short circuit where the loading capacitance element passes through the plane of the inner conducting surface of the wave guide wall. In Fig. 17 the capacitance loading element is a rod 167 which is adapted to be advanced or retracted with respect to the wave guide wall by manipulation of a knurled knob 168 cooperating with screw threads 169. The element 167 is mounted in the supporting structure 170 which is itself mounted on the wall of the wave guide 165. A set screw 171 is provided for maintaining an adjustment of the apparatus which it is desired to fix. A cylindrical cavity 172 is provided in the lower end of the housing 170 surrounding the rod element 167. At the mouth of this cavity is mounted (preferably by soldering) a sleeve member 173 which extends upwards into the cylindrical cavity 172 dividing it into two annular spaces which are respectively the annular channel 174, between the rod element 167 and the sleeve member 173, and the annular chamber 175 which is closed at the bottom, as at 176, by the part of the sleeve member 173 which is fastened to the housing 170 near where the latter is mounted upon the wave guide wall. The annular spaces 174 and 175 communicate at their upper extremities over the upper edge of the sleeve member 173 which does not extend so far upward as to come in contact with the top of the cavity 172. In accordance with the principles of this invention the electrical length of the annular gap 174 is made substantially equal to an electrical quarter-wave length and the electrical length of the annular cavity 175, including that part of the cavity 172 which connects the cavity 175 with the annular gap 174, is also made substantially equal to an electrical quarter-wave length. In apparatus of the configuration of Figs. 17 and 18 such electrical quarter-wave lengths closely approximates one-quarter of the "wave length in air." On account of the configuration of the structures 173, 174, 175 and its associated element, therefore, an apparent short circuit appears at the desired radio frequency between the rod element 167 and the bottom surface of the sleeve element 173 which is electrically integral with the upper wall of the wave guide 165. Thus a good radio-frequency connection is established between the part of the rod 167 projecting into the wave guide and the wave guide wall irrespective of the nature of the electrical contact that may exist at the screw threads 169.

Fig. 18 shows a structure similar in principle to that shown in Fig. 17. The rod 178 provides an adjustable loading capacitance in the same manner as does the rod 167 of Fig. 17. The housing 179 is essentially similar to the housing 170 and the sleeve structure 180 corresponds to the sleeve 173. The cavities and clearance surrounding the sleeve member 180 are organized in the same manner as the corresponding cavities and clearances shown in Fig. 17 around the sleeve member 173 with the result that at the desired frequency of operation an apparent short circuit appears between the rod member 178 and the bottom surface of the sleeve member 180 which is electrically integral with the upper wall of the wave guide 166. Instead of the knurled knob 168 and the set screw 171 of Fig. 17 different means are provided in Fig. 18 for making the adjustment of the loading capacitance. The upper part of the rod 178 does not extend above the screw-threaded portion of the housing 179 but is provided with a slotted upper surface for engagement with a screw driver, the slot being shown at 181. The upper part of the rod 178 is threaded into the housing 179 in the same manner as the rod 167 is threaded into the housing 170. A threaded plug 182 is provided which may be screwed down on top of the rod member 178 for fixing and sealing the adjustment of the latter.

A variable inductance may be provided in a similar fashion by orienting the rods 167 or 178 perpendicularly to the electric vector. The rod would then, in the case of rectangular wave guides, usually be introduced through one of the narrower walls.

Fig. 19 illustrates the application of the invention to apparatus for employing a crystal rectifier in a heterodyne mixer circuit in conjunction with a wave guide pipe system. A rectangular pipe wave guide similar to the wave guide 150 of Fig. 16 and the wave guides 165 and 166 of Figs. 17 and 18 is shown at 185, again in a longitudinal cross section parallel to the direction of the electric vector. A recess 186 is provided in the lower wave guide wall for mounting a crystal rectifier cartridge 197 similar to the rectifier element 117 of Fig. 13 across the wave guide 185. The recess 186 is thus similar to the crystal mounting recess 118 of Fig. 13. The upper end of the crystal rectifier cartridge is inserted in the clip 187. As in the case of the clip 119 of Fig. 13, the clip 187 is slotted as shown at 188 in order to provide a spring grip. In order that the radio frequency circuit may properly be completed it is desired to establish a radio frequency short circuit or the equivalent thereof between the upper end of the crystal cartridge 197 and the nearby portions of the upper wall of the wave guide 185. On the other hand it is desired that the clip 187 should be isolated from the wave guide 185 and its associated structure for all frequencies in the range of the intermediate frequency which the crystal rectifier element 197 is adapted to generate when oscillations of signal and local oscillator frequency are introduced into the wave guide 185.

The clip 188 is insulated from the wave guide 185 and its associated structure by a washer 189 and a plug 190 and is mounted and supported on a metallic housing structure 191 which is preferably soldered onto the wave guide 185 as shown in Fig. 19. The lower part of the housing 191 is provided with a cylindrical cavity 192 in which is located a sleeve member 193 arranged in the same manner as the sleeve member 173 of Fig. 17 and the sleeve member 180 of Fig. 18. Thus an annular clearance space 194 is provided around the clip 187 into which, at a distance of an electrical quarter-wave length from the inner surface of the wave guide wall 185 is connected a branch cavity 195 having a total length of another electrical quarter-wave length. This structure as previously explained causes an apparent radio-frequency short circuit to appear at the lower extremity of the annular clearance space 194 for the desired frequency of operation.

In order that the apparatus of Fig. 19 may best function as a heterodyne mixer, it is desirable to associate tuning structures with the wave guide 185 in the neighborhood of the crystal position in order to provide conditions for maximum energy transfer between the oscillations in the wave guide 185 and the crystal circuit. For this purpose it is desirable to terminate the wave guide 185 at side of the crystal position, which may be to the right in Fig. 19 by an adjustable closure such as that shown in Fig. 16 and further to provide loading capacitances by means of arrangements such as that shown in Fig. 17, mounted on the wave guide 185 on the other side of the crystal position from the terminating closure. Holes 195 and 196 are shown in Fig. 19 in the lower wall of the wave guide 185 for mounting adjustable loading capacitance structures such as that shown in Fig. 17, it being understood that the respective housings of such structures should preferably be soldered to the wave guide 185 in order to provide good electrical contact. Thus it may be seen that in a complete heterodyne mixer operating with a rectangular wave guide input, this present invention may advantageously be used in four different parts of a single mixer apparatus.

The foregoing examples of the application of the present invention to different types of apparatus for microwave radio systems are only illustrative of the many ways in which advantage may be taken of the principles of the present invention for avoiding losses occurring at poor electrical contacts and for establishing higher efficiency energy transfer relationship between parts or components of high-frequency radio apparatus. Further variations in form are possible. For example, referring to Figs. 1 and 3, more than one branch channel 7 may be provided opening into the gap 6, each of said branch channels connecting with the gap 6 at a distance of an electrical quarter-wave length from the gap 6 which communicates with the surfaces 2 and 3. Such an arrangement would ordinarily have no special advantage since the single branch channel 7 shown in Fig. 1 and Fig. 3 is usually sufficient to produce the desired result. In one form, shown diagrammatically in Fig. 20, the double branch arrangement may have some advantages. In Fig. 20 the surfaces 2 and 3 are again shown between which it is desired to establish a radio-frequency conducting relation. The surfaces 2 and 3 are, as in Figs. 1–4, separated by a gap 6. Two branch channels 7 and 7a open into the gap 6. In this case the location and depth of the branch channel 7 is calculated to provide an apparent radio-frequency short circuit across the mouth of the gap 6 between the surfaces 2 and 3 at a certain radio frequency and the location and depth of the branch channel 7a are calculated to provide such an apparent radio-frequency short circuit at a frequency slightly different from the first-mentioned frequency. The frequencies for which the branch channels 7 and 7a are respectively designed are sufficiently close together (i. e. commensurate in magnitude) so that for frequencies between these two frequencies only a small impedance is presented at the mouth of the gap 6. In this manner a relatively good radio-frequency conducting condition is established between the surfaces 2 and 3 for a range of frequencies, thus making the structure somewhat better adapted to "broadband" operation than the corresponding structure of Fig. 3.

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

1. A joint providing for transfer of radio-frequency energy between two electrically conducting surfaces which includes an electrical resonator one electrical dimension of which is substantially a half-wave length for said radio-frequency, said resonator having a mouth constituted by a gap between said surfaces and located at one end of said half-wave length dimension, said resonator having also a terminating conducting wall at the other end of said dimension and being so constructed that an interruption is present in the wall of said resonator, other than said mouth, as a result of the assembly of said joint, located at a place approximately an electrical quarter-wave length from said terminating wall.

2. Means for establishing low impedance radio-frequency connection between two conducting surfaces, said means comprising an electrical resonator having a cavity, the walls of the cavity of said resonator being defined by conducting surfaces integral with the aforesaid conducting surfaces between which connection is desired, said cavity having an end wall located at approximately an electrical half-wave length in said cavity from the location at which it is desired to establish the aforesaid connection, said resonator being constituted so that said first-named surfaces are in close proximity but not in contact at said last-mentioned location, and being further constituted with an interruption in the walls of said cavity between the cavity walls integral with one of said surfaces and the cavity walls integral with the other of said surfaces, which interruption is located approximately midway in said cavity between said end wall and the location at which it is desired to establish the aforesaid connection.

3. Means for establishing low impedance radio-frequency connection between two conducting surfaces, said means comprising a conducting structure defining a cavity adapted to resonate at a frequency at which such low impedance connection is desired, the walls of said cavity being defined by conducting surfaces electrically integral with the aforesaid conducting surfaces between which connection is desired, said cavity having an end wall located at approximately an integral number of electrical half-wave lengths from the location at which it is desired to establish the aforesaid connection and having a narrow mouth at said location separating said first-named two surfaces, said cavity being further provided with at least one discontinuity between the cavity wall integral with one of said surfaces and the cavity wall integral with the other of said surfaces, located at a distance in said cavity from said end wall of approximately an odd number of electrical quarter-wave lengths.

4. Means for establishing low impedance radio-frequency connection across a gap between two conducting surfaces, said means comprising an electrical resonator having conducting surfaces integral with the said first mentioned conducting surfaces and defining a cavity having a mouth at said gap and having an end wall located approximately at an electrical half-wave length in said cavity from said gap, said resonator being further provided with a discontinuity between the cavity walls integral with one of said surfaces and the cavity walls integral with the other of said surfaces, situated substantially entirely at locations approximately an electrical quarter-wave length from said end wall.

5. In apparatus for operation at radio frequency, a joint between two relatively movable conducting surfaces separated by a narrow gap, comprising relatively movable conducting structures associated with said surfaces extending said gap for a distance of at least an electrical quarter-wave length from said surfaces, at least one of said structures providing a branch channel disposed perpendicularly to and communicating with said gap at a location substantially an electrical quarter-wave length distant from said surfaces, said branch channel having a length of substantially an electrical quarter-wave length and having at its extremity a conducting terminating closure.

6. In an apparatus for operation at radio frequency, a joint between relatively movable conducting surfaces including means for maintaining a gap between said surfaces, relatively movable structures associated with said surfaces extending said gap uniformly for a distance of at least an electrical quarter-wave length from said surfaces, at least one of said structures providing a branch channel disposed perpendicularly to and communicating with said gap at a location substantially an electrical quarter-wave length distant from said surfaces, said branch channel having a length of substantially an electrical quarter-wave length and having at its extremity a conducting terminating closure.

7. In an apparatus for operation at radio frequency, a joint between two relatively movable conducting surfaces including means for maintaining a gap between said surfaces, relatively movable structures associated with said surfaces extending said gap for a distance of at least $^{23}/_{100}$ of the wave length in open air corresponding to a desired frequency of operation, at least one of said structures providing a branch channel disposed at an angle to and communicating with said gap at a location distant from said surfaces by about one-quarter of said wave length, said branch channel having a length of about one-quarter of said wave length and having at its extremity a conducting terminating closure.

8. A resonator for establishing a readily demountable low impedance radio-frequency connection between two conducting elements com-

prising a cavity resonator the walls of which are defined by structures fixed on said conducting elements, said cavity resonator having a conducting end wall substantially without loss-producing discontinuities located approximately at an electrical half-wage length in said resonator from the location at which it is desired to establish the aforesaid connection having also a mouth at said location separating said conducting elements, and having discontinuity between that part of the walls of said cavity resonator defined by one of said conducting elements and that part of the walls of said cavity resonator defined by the other of said conducting elements located approximately an electrical quarter-wave length in said resonator from said end wall.

9. A joint for relatively rotatable coaxially adjacent wave guide conductors for facilitating transfer of radio-frequency energy across said joint, including means for maintaining a gap between the said conductors at said joint, relatively rotatable structures on the extremities of said conductors in the neighborhood of said gap substantially integral electrically with said conductors and so shaped as to extend said gap for a distance of at least an electrical quarter-wave length from the mouth of said gap, said mouth being defined as the opening of said gap at the current-carrying surfaces of said conductors, said conductors having a configuration providing also for a branch channel having a depth of substantially an electrical quarter-wave length disposed perpendicularly to and communicating with said gap at a distance from said mouth of substantially an electrical quarter-wave length.

10. A joint for tubular conductors for facilitating transfer of radio-frequency energy across said joint, including means for maintaining a gap between the said conductors at said joint, a cylindrical sleeve mounted on one of said conductors and spaced from said conductor except near the extremity of the latter where it is joined thereto by a conducting structure, said sleeve enclosing between itself and said conductor a mass of solid dielectric and thereby defining an electrical resonator having an axial dimension of an electrical quarter-wave length with respect to a desired radio frequency of operation, and a conducting surface associated with the other of said conductors adapted to extend the said gap between said conductors at said joint without substantial changes in clearance for a distance of at least an electrical quarter-wave length to form an annular clearance space between said surface and said sleeve, said sleeve and said conducting surface being so dimensioned that said resonator communicates with said annular clearance space at a distance from said gap at said joint of substantially an electrical quarter-wave length.

11. A joint for cylindrical conductors in accordance with claim 9 which includes means providing rotation of at least one of said conductors about the axis thereof.

12. A joint for tubular conductors in accordance with claim 10 which includes means providing for relative axial rotation of the members of said joint.

13. A joint for coaxial conductor transmission lines for operation at radio frequency including an outer conductor joint and an inner conductor joint, and including means for maintaining a gap between the respective outer conductors of the said transmission line and for maintaining a gap between the respective inner conductors of said transmission line, said outer conductor joint including a sleeve located outwardly of one of said outer conductors and spaced from said conductor except at and near the extremity of the latter where it is joined thereto by a conducting structure, said sleeve being of such dimensions as to enclose between itself and said conductor a cavity having an axial dimension of an electrical quarter-wave length with respect to a desired radio frequency of operation, and a conducting surface associated with the other of said outer conductors disposed so as to define between itself and said sleeve an annular clearance space having a length of at least an electrical quarter-wave length and communicating with said cavity at a distance of substantially an electrical quarter-wave length from the extremity of said clearance space nearest the effective location of said outer conductor joint; said inner conductor joint comprising a central recess in one of said inner conductors and a projection of the other of said inner conductors extending within said recess to such a distance that the annular clearance space between said inner conductor has a length of substantially an electrical quarter-wave length with respect to said frequency, said recess being deeper by a substantial amount than the length of said projection extending therein.

14. A joint for coaxial conductor transmission lines in accordance with claim 13 which includes means providing for relative axial rotation of the respective coaxial conductor transmission lines constituting the elements of said joint.

15. Means for promoting transfer of radio-frequency energy between two electrically conducting surfaces for a range of radio frequencies, said means including structures associated with said surfaces, maintaining a narrow gap between said surfaces, defining an electrical wave guide of relatively low characteristic impedance communicating with said gap and defining also a branch wave guide of relatively high characteristic impedance, with a short-circuit termination and of a depth of an odd number of electrical quarter-wave lengths, said branch wave guide communicating with said first-mentioned wave guide at a location an odd number of electrical quarter-wave lengths from said gap.

16. Means for promoting transfer of radio-frequency energy between two electrically conducting surfaces for a range of radio frequencies, said means including structures associated with said surfaces, maintaining a narrow gap between said surfaces, defining an electrical wave guide of relatively low characteristic impedance communicating with said gap and defining also an additional wave guide of relatively high characteristic impedance, with a short-circuit termination and of a depth of an electrical quarter-wave length, said additional wave guide communicating with said first-mentioned wave guide at a location an electrical quarter-wave length from said gap, said first-mentioned wave guide having no substantial interruptions in its walls between said gap and said additional wave guide.

17. Means for promoting transfer of radio-frequency energy between two electrically conducting surfaces for a range of radio frequencies, said means including structures associated with said surfaces, maintaining a narrow gap between said surfaces and defining an electrical wave guide of relatively low characteristic impedance adapted to entertain transverse electromagnetic waves and communicating with said gap, said structures defining also an additional wave guide

of a characteristic impedance substantially higher than that of said first-mentioned wave guide and likewise adapted to entertain transverse electromagnetic waves, said additional wave guide having a short-circuit termination, having a length of an electrical quarter-wave length and communicating with said first-mentioned wave guide at a location an electrical quarter-wave length from said gap.

18. A joint according to claim 6 in which the branch channel is such as to exhibit a characteristic impedance to the propagation of oscillations therein substantially higher than the corresponding characteristic impedance of said gap.

19. A joint according to claim 7 in which the branch channel is substantially wider than the gap with which it communicates and is thereby adapted to provide a discontinuity in one wall of the gap which is substantially of the open-circuit type for a relatively wide range of frequencies.

20. A rotating joint for tubular conductors for facilitating transfer of radio-frequency energy across said joint, including means for maintaining a gap between the said conductors at said joint, structures on the extremities of said conductors in the neighborhood of said gap substantially integral electrically with said conductors and so shaped as to extend said gap for a distance effectively of an electrical quarter-wave length from the mouth of said gap, said mouth being defined as the opening of said gap at the current-carrying surfaces of said conductors, said conductors having a configuration providing also for a branch channel having a depth of substantially an electrical quarter-wave length and communicating with said gap at a distance from said mouth effectively of an electrical quarter-wave length.

21. A rotating joint for tubular conductors for facilitating transfer of radio-frequency energy across said joint, including means defining a gap between the said conductors at said joint, structures on the extremities of said conductors in the neighborhood of said gap substantially integral electrically with said conductors and so shaped as to extend said gap for a distance effectively of an electrical quarter-wave length from the mouth of said gap, said mouth being defined as the opening of said gap at the current-carrying surfaces of said conductors, said conductors having a configuration providing also for a branch in one of said structures, said branch having a depth of substantially an electrical quarter-wave length and communicating with said gap at a distance from said mouth effectively of an electrical quarter-wave length.

22. A rotating electrical joint for coaxial transmission lines including an outer conductor joint and an inner conductor joint, means for maintaining an axial gap between the outer conductors of said lines at said joint, said outer conductor joint including a cylindrical sleeve secured to the outer surface of one of said outer conductors and enclosing between itself and said one conductor a mass of solid dielectric, said sleeve and said mass of dielectric being of a dimension less than a quarter-wave length of the desired frequency of operation but defining a resonator having an axial length of an electrical quarter-wave length of said frequency, and a conducting surface associated with the other outer conductor disposed so as to define between itself and said sleeve an annular clearance space of at least an electrical quarter wave length, said clearance space communicating between said gap and said resonator; said inner conductor joint comprising a central opening in one of said inner conductors and a projection of the other of said inner conductors extending in spaced non-contacting relationship within said opening.

23. A rotating electrical joint for coaxial transmission lines including an outer conductor joint an an inner conductor joint, means for maintaining an axial gap between the outer conductors of said lines at said joint, said outer conductor joint including a cylindrical sleeve secured to the outer surface of one of said outer conductors and defining an annular cavity between itself and the outer surface of said one conductor, said cavity being closed at the end adjacent said gap and extending axially therefrom a distance of approximately a quarter wave length of the desired frequency of operation, and a conducting surface associated with the other outer conductor disposed so as to define between itself and said sleeve an annular clearance space of at least an electrical quarter-wave length, said clearance space communicating with said cavity and said gap; said inner conductor joint comprising a central opening in one of said inner conductors and a projection of the other of said inner conductors extending in spaced, non-contacting relationship within said opening.

24. A rotating electrical joint for coaxial transmission lines including an outer conductor joint and an inner conductor joint, means for maintaining an axial gap between the outer conductors of said lines at said joint, said outer conductor joint comprising, a first cylindrical sleeve secured to the outer surface of one of said outer conductors extending across said gap and enclosing an annular clearance space between itself and the outer surface of the other of said outer conductors, a second cylindrical sleeve secured to the outer surface of said one conductor and enclosing an annular cavity between itself and the outer surface of said first sleeve, said cavity being closed at the end adjacent said gap, said cavity and said annular clearance each being of approximately an electrical quarter-wave length; said inner conductor joint comprising a central opening in one of said inner conductors and a projection of the other of said inner conductors extending in spaced, non-contacting relationship within said opening.

25. A rotating joint for tubular conductors for facilitating transfer of radio frequency energy across said joint, including means for maintaining a gap between said conductors at said joint, structures secured to the extremities of said conductors adjacent said gap substantially integral electrically with said conductors and so shaped as to extend said gap for a distance effectively an electrical quarter-wave length from the mouth of said gap, said mouth being defined as the opening of said gap at the current carrying surface of said conductors, one of said structures having a groove cut therein providing a branch channel having a depth of substantially an electrical quarter-wave length and communicating with said gap at a distance from said mouth effectively of an electrical quarter-wave length, said structures further being in mechanical, but poor electrical contact on a surface further removed from said mouth than the location of said branch channel.

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