Jan. 27, 1959 J. J. USTICA 2,871,331

COOLED RADIO FREQUENCY COUPLING UNIT

Filed Sept. 10, 1957

FIG. 1.

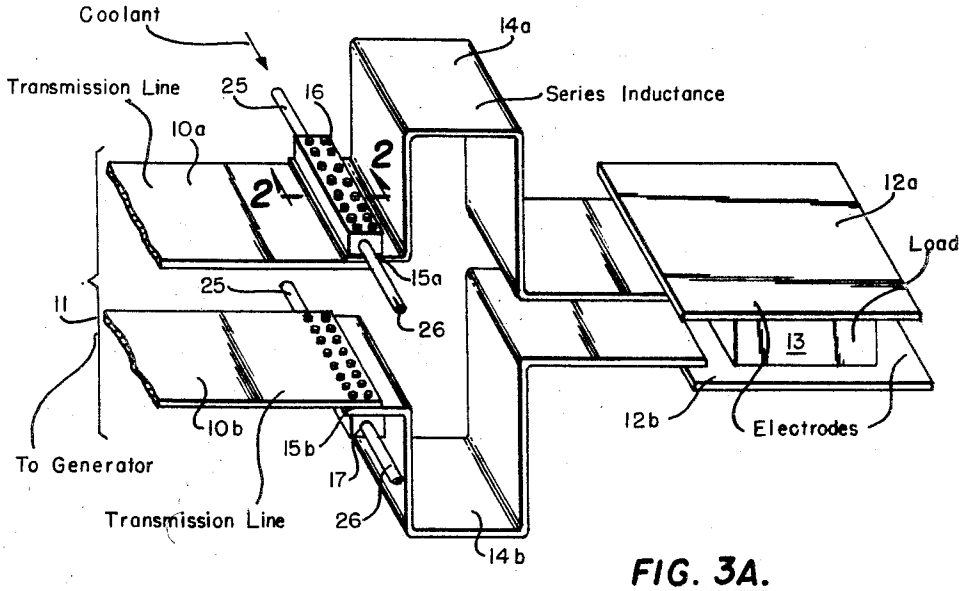


FIG. 3A.

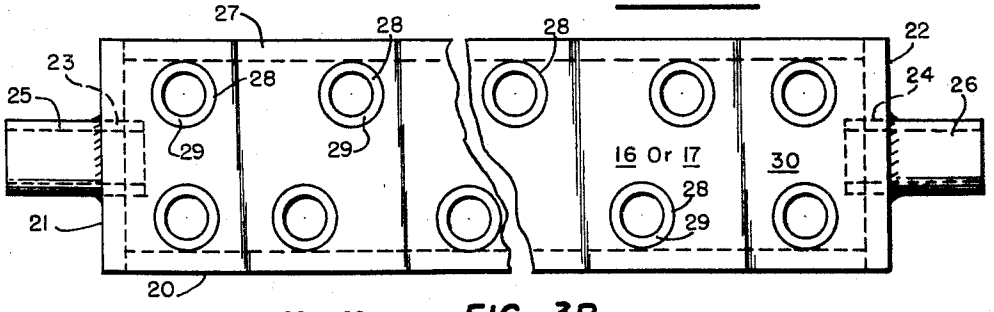


FIG. 3B.

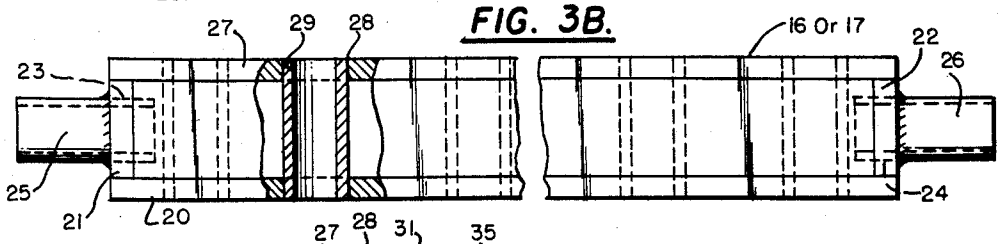
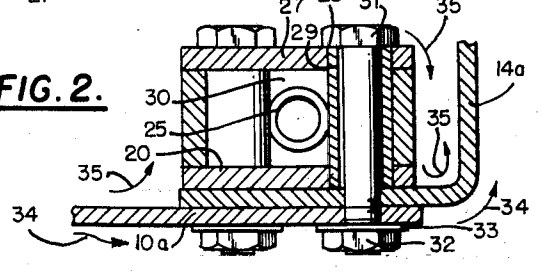


FIG. 2.



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COOLED RADIO FREQUENCY COUPLING UNIT

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The present invention relates to coupling systems for use in high-frequency high-energy level applications; and is more particularly concerned with a joint structure adapted for use in such applications and exhibiting better electrical and mechanical characteristics than has been possible heretofore. In this respect, the present invention is particularly concerned with a novel coolant jacket and with joint structures employing such a coolant jacket in high-frequency high-energy level systems.

Various high-frequency high-energy level electrical applications are known at the present time. One typical such system comprises, for example, dielectric heater arrangements wherein high-frequency energy generated by an appropriate oscillator circuit is ultimately impressed upon a dielectric load through the agency of electrodes or applicators disposed adjacent said load. Such a dielectric heater system as well as other high-frequency high-energy level systems known to those skilled in the art, are often characterized by the provision of a plural section transmission network coupling a source of energy to an ultimate utilization circuit; and these plural sections may include, for example, multi-section transmission lines, various coupling reactances, etc.

It has been the practice in the past to join the several sections of a plural section transmission network to one another by means of a brazed joint; and such joints in general do not impair the electrical or mechanical characteristics of the overall network. However, in many instances, it is highly desirable to provide separable joints, either between separate portions of a transmission line, or between portions of the said transmission line and portions of a coupling reactor, for example, to permit replacement or substitution of one coupling component for another. Such separable joints necessarily require that some form of mechanical connection be provided; and in practice, it has been found that these mechanical connections are usually somewhat less than perfect electrically, and actually comprise relatively high resistance portions of the overall network, wherefore the said mechanical joints tend to burn up and become defective within a relatively short time.

By way of example, a typical dielectric heating arrangement may comprise a source of energy which is ultimately coupled to a utilization circuit, e. g. a pair of spaced electrodes, via a transmission line and series inductance connected to one another between said source and electrodes. The transmission line itself may have an impedance of only five to ten ohms, and may be required to carry approximately 1,000 amperes at a frequency, for example, of 27 megacycles. A typical installation, operating substantially at the foregoing figures and utilizing known mechanical joint connections between the said transmission line and series inductance will be found to operate at a joint temperature of approximately 300° F. This heating or temperature rise at the mechanical joint connection, is believed to result from the fact that mechanical connectors of types suggested heretofore, regardless of how perfect, provide relatively poor electrical

connections for the flow of high density electrical currents, particularly in high-frequency systems where such currents tend to flow in the skins of the jointed conductors.

The aforementioned temperature rise is, of course, accompaned by an appreciable power loss at the mechanical joint, and indeed is also accompanied by oxidation, scale and deterioration at the connection, resulting in frequent failure through burn-out at the said connection. In order to obviate these appreciable disadvantages of known mechanically jointed electrical connections, the present invention therefore contemplates the provision of a novel joint structure providing an improved mechanical and electrical connection between separable conductors thereby to reduce joint resistance and attendant heat dissipation; and the said joint structure further includes improved cooling means which serves to dissipate heat at said mechanical joint to positively prevent burn-out from occuring.

It should be noted that, in providing joint structures capable of operating in the improved manner described above, certain problems are encountered. In particular, a good electrical connection between two conductors of the types here involved requires that an appreciable compressive force be applied between said conductors. Moreover, if the cooling structure is to be disposed in good heat transfer relation to the joint, this necessarily requires that a fairly high compressive force also be imposed between the mechanical joint being cooled and the cooling structure itself. Prior mechanical joint coupling and cooling structures have not been capable of carrying the compressive forces necessary to provide an adequate electrical and heat transfer joint between adjacent conductors in such high-frequency high-energy applications. The structure of the present invention, however, does permit such high compressive forces to be imposed, so as to effect a good electrical connection between adjacent conductors, as well as between the said conductors and the cooling structure itself.

In addition, and as will become apparent from the subsequent description, the reduced joint resistance effected by the aforementioned high compression forces between the jointed conductors, is further reduced by the fact that the coolant structure itself is so constructed and arranged that it presents a conductive skin surface which comprises a portion of the current path between adjacent conductors joined to one another. This additional skin surface thus aids in maintaining a relatively low resistance joint, and accordingly assists in preventing undue temperature rise at said joint.

It is accordingly an object of the present invention to provide an improved joint structure for mechanically joining plural conductors to one another.

Another object of the present invention resides in the provision of an improved cooled mechanical joint capable of use in high-frequency high-energy level systems.

Still another object of the present invention resides in the provision of a novel coolant jacket for use in cooling joints, the said jacket being so constructed that it is capable of carrying extremely high compressive forces.

A still further object of the present invention resides in the provision of an improved high-frequency high-energy transmission network employing plural conductors mechanically joined to one another in such manner that they may be readily separated for replacement or other purposes.

A further object of the present invention resides in the provision of a mechanical joint structure in combination with improved cooling means for preventing burn-up of said joint.

A still further object of the present invention resides in the provision of an electrical joint structure so arranged with respect to a separable cooling device that the said

cooling device itself acts as a portion of the current path at said joint, thereby to reduce the resistance of said joint.

Still another object of the present invention resides in the provision of a cooled mechanical joint so constructed and arranged with respect to clamping means that said clamping means may be caused to impose appreciable compressive forces between electrical connectors comprising said joint as well as between said connectors and a separable cooling structure.

A still further object of the present invention resides in the provision of an improved mechanical joint which may be readily separated for replacement purposes, and which is so constructed that deterioration of the joint, due to temperature rise, is eliminated.

Another object of the present invention resides in the provision of a transmission network having a plurality of separable parts joined to one another in an improved manner, thereby to permit ready separation of said parts.

In providing for the foregoing objects and advantages, the present invention contemplates the provision of a transmission network comprising a pair of conductors, e. g. a transmission line and a coupling reactance, which are mechanically connected to one another, for example by bolt means. The joint is further associated with a unitary cooling jacket separable from the joint and so arranged with respect to the aforementioned bolt means that said bolt means pass not only through the mechanical joint itself but also pass through the coolant jacket. The coolant jacket in turn includes structural means on the interior thereof which serve to resist collapse of the jacket due to compressive forces applied thereto; and as a result of this arrangement, the aforementioned bolt means can be drawn up tight to impose extreme compressive forces between the adjacent conductors as well as between the conductors and the coolant jacket, whereby a good electrical connection is assured between said conductors, and a good heat transfer connection is also assured between said conductors and the coolant jacket without the attendant possibility of collapse of the coolant jacket due to these high compressive forces.

The coolant jacket itself is preferably constructed of a conductive material, and when disposed adjacent the aforementioned mechanical joint in the manner described, the skin of the coolant jacket becomes a portion of the current-carrying path between the mechanically connected conductors, whereby current flowing from one to the other of said conductors also flows at least in part through the skin of the coolant jacket thereby to reduce appreciably the resistance and heating effect at the mechanical joint.

The foregoing objects, advantages, construction and operation of the present invention will become more readily apparent from the following description and accompanying drawings, in which:

Figure 1 is a diagrammatic perspective view of a cooled joint structure incorporated into a dielectric heater system, in accordance with the present invention.

Figure 2 is a cross-sectional view taken on line 2—2 of Figure 1, illustrating the improved joint and cooling structure of the present invention.

Figure 3A is a top view of an improved unitary coolant jacket constructed in accordance with the present invention; and

Figure 3B is a side view of the structure shown in Figure 3A.

Referring now to Figure 1, it will be seen that in accordance with the present invention, a high-frequency high-energy transmission system, typified in the arrangement of Figure 1 as a dielectric heater system, may comprise a pair of transmission lines or tabs **10***a*—**10***b* coupled at **11** to an appropriate generator of high-frequency oscillations. The energy thus fed via transmission lines **10***a*—**10***b* is ultimately impressed upon a pair of electrodes **12***a*—**12***b* having a dielectric load **13** therebetween whereby said load may be heated and/or dried in accordance with known principles.

In general, the transmission lines **10***a*—**10***b* are coupled to the said electrodes **12***a*—**12***b* via a pair of series inductances **14***a*—**14***b* comprising, in the examples of Figure 1, a pair of relatively massive U-shaped conductors. Inductors **14***a*—**14***b* are connected to transmission lines **10***a*—**10***b* at a pair of joints **15***a*—**15***b*, each of which joints comprises a portion of one of the transmission lines **10***a*—**10***b* disposed in overlapping superposed relation to a complementary adjacent portion of one of the series inductances **14***a*—**14***b*. It will be appreciated that when such an overlapping arrangement is provided, a mechanical joint could be effected by merely bolting the two overlapping portions to one another. But, as mentioned previously, this construction has been found to result in a relatively high resistance joint at the high current densities normally involved, whereby excessive heating of the joint occurs and the joints tend to burn up within a relatively short time.

In order to make such a mechanical joint practical, therefore, it is necessary that the joint somehow be cooled; and in accomplishing this particular purpose the present invention further contemplates that a pair of elongated coolant jackets **16** and **17** be disposed along each of the joints **15***a*—**15***b* thereby to remove excessive heat generated at said joints. Certain characteristics of such a cooled joint must be noted.

First, the joint must be such that an extremely good mechanical and electrical connection is provided between transmission lines **10***a*—**10***b* and the corresponding inductance portions which are joined to the termini of those lines. This necessarily requires that a high compressive force somehow be applied between the conductor portions comprising the joint; for in the absence of such a high compression joint, extreme heat dissipation will occur at the joint with the attendant disadvantages already described. It is also necessary, moreover, that the coolant jacket be disposed in close proximity to the joint itself in order to permit good heat transfer to the coolant in the jacket; and this necessarily requires that a special coupling arrangement be provided to permit extremely close proximity between the jackets **16** and **17** and their associated joints, as well as between the conductors of the joint itself.

The present invention, recognizing these requirements of cooled radio frequency joints is, therefore, particularly concerned with a novel structure which permits a cooled high compression joint to be effected between adjacent conductors as well as between said conductors and the cooling jacket. The characteristics of the jacket and joint will be best appreciated by examination of Figures 2 and 3.

Thus, referring to Figures 2 and 3, it will be seen that jackets **16** and **17** each preferably comprises an elongated substantially hollow rectangular jacket or container. The top, sides and bottom walls of the container comprise a conductive material, preferably copper, and these several container or jacket walls may be formed of a number of individual rectangular sections, silver-soldered to one another; or in the alternative may be formed of a sheet of copper wrapped into a closed rectangular configuration, with the ends of said configuration thereafter being closed by further end pieces.

It will be appreciated that while a rectangular configuration comprises a preferred embodiment for the coolant jacket of the present invention, other configurations are possible, including jackets having curved surfaces; but each such alternative configuration preferably includes a substantially planar wall **20** adapted to be disposed in close planar contiguity with the superposed conductors, such as **10***a*—**14***a*, in a direction substantially parallel to the joint, e. g. **15***a*, between said conductors. The said planar wall **20** is, of course, chosen for those cases in which the joint **15***a* is also of planar configuration; and

again it will be appreciated by those skilled in the art that in the event the uppermost one of said superposed conductors is other than planar, it is preferred that the coolant jacket to be associated with said conductors exhibit a wall configuration complementary to said uppermost conductor, whereby the coolant jacket may be disposed in close proximity to at least one of said conductors adjacent the joint between the superposed conductors.

In the fabrication of the jackets **16** and **17**, the end walls **21** and **22** are, subsequent to initial jacket manufacture, drilled, as at **23** and **24**; and a pair of conductive pipes **25** and **26** are thereafter inserted into said drilled end walls and silver-soldered in place. The said pipes **25** and **26** are, of course, provided to permit coolant to be circulated through the jackets **16** and **17**, and in ordinary circumstances would be connected to an appropriate pump, e. g. a water pump, for passing an appropriate coolant such as water through said jackets **16** and **17**.

As mentioned previously, the prime considerations in fabricating a jacket capable of cooling joints of the types here involved, is that the jacket should permit, or at least should not interfere with, the application of high compressive forces to the joint itself; and, moreover, the jacket should be so constructed and arranged that it can be disposed in very close proximity to the joint to permit a good heat transfer from the joint to the coolant in the jacket. In order to effect a low resistance, high compression joint, as well as a good heat transfer disposition between jacket and joint, it is therefore necessary somehow to impose highly compressive forces upon the joint as well as upon the jacket and preferably upon both the joint and jacket simultaneously; but jackets of types suggested heretofore have not been capable of resisting compressive forces of the magnitudes required without the attendant possibility of jacket collapse or leakage.

In order to permit the high compression joint provided by the present invention, the lower and upper walls **20** and **27** of each jacket **16** and **17** are, subsequent to initial jacket fabrication, drilled at a plurality of locations **28**. As will be noted from an examination of Figures 2 and 3B, the drill holes **28** in the said upper and lower walls **27** and **20** are in alignment with one another; and the several drill holes in each wall are preferably spaced in staggered relation to one another (see Figure 3A). A number of tubular brass plugs or sleeves **29** are then inserted into the several aligned holes **28** between the lower and upper walls **20—27** of each jacket; and the upper and lower ends of each sleeve or plug **29** are thereafter silver-soldered to the edges of their corresponding adjacent holes **28**. As a result of this configuration, a unitary, water-tight chamber **30** is provided between pipes **25** and **26** for the circulation of coolant; and this chamber includes a number of tubular brass plugs passing therethrough, with the upper and lower end of each such plug **29** being open to the exterior of the jacket **16** or **17**.

As is most clearly illustrated in Figure 2, this configuration permits a number of bolts **31** to pass through each of the jackets **16** and **17** and thence through the superposed conductors **10***a*—**14***a*, whereafter said bolts may be held in place by appropriate nuts and washers **32—33**. Inasmuch as the several bolts **31** pass not only through the superposed conductors **10***a*—**14***a* but pass as well through the jackets **16—17**, these bolts may be drawn extremely tight. Extremely high compressive forces are exerted between the superposed conductors **10***a*—**14***a* (thereby to effect a high compression joint at **15***a*), and also to effect high compression forces between the lower wall **20** of the coolant jacket **16** and the upper conductor **14***a* of the superposed conductors, whereby the coolant packets are disposed in good heat transfer relation to the joint **15***a*—**15***b*. The high compression forces existing between the lower wall **20** of the coolant jacket and the upper conductor **14***a* of the joint **15***a* in fact provides a good electrical connection between the coolant jacket walls and the conductor joint, whereby the coolant jacket walls can enter into the electrical circuit in the manner to be described.

It should be noted that in providing this extremely high compression joint, the high compression forces applied to the joint do not tend to collapse the jackets **16—17** nor do they tend to effect leakage in said jackets, inasmuch as the compression forces exerted upon the jacket are absorbed by the several brass sleeves **29** which pass through and are sealed to the jackets **16—17**.

As mentioned previously, the construction contemplated by the present invention is such that the conductive skin presented by the jackets **16** and **17** enters directly into the electrical path between the superposed conductors **10***a*—**14***a*, and skin currents passing from conductor **10***a* to conductor **14***a* along paths such as **34** may also pass at least in part along paths such as **35** over the skin of the copper water jackets **16—17**. This increase in skin surface adjacent the joints **15***a*—**15***b* therefore lowers the resistance of each of these joints whereby joint heating is reduced; and the lowered resistance of each joint is accompanied by the disposition of a circulating coolant in close proximity and good heat transfer relation to the superposed conductors.

Summarizing the structure of the present invention, therefore, it will be noted that each of the joints is cooled by a unitary jacket so constructed that fastening means such as bolt elements can pass directly through the jacket and through the joint so as to allow extremely high compression junctures to be effected not only between the superposed conductors but between the uppermost one of said conductors and the jacket itself. This high compression reduces the resistance at the joints such as **15***a* and this reduction in resistance is augmented by the additional skin surface presented by the jacket. The high compression forces do not tend to collapse the jacket inasmuch as each jacket includes internal supporting means such as the several brass sleeves which support the bolt forces; and these sleeves are so arranged with respect to the remainder of the jacket that a unitary non-leaking chamber is still provided for the circulation of coolant.

One of the prime purposes in providing a mechanical joint structure is of course to permit the joint to be broken at will in order that replacement or substitution of parts can occur. The structure of the present invention is in complete accord with this purpose; and it will be appreciated that once the several bolts **31** are removed, the unitary jackets **16** and **17** can be lifted from place and the joints **15***a*—**15***b* can then be separated to permit removal of one or both of conductors **10***a*—**14***a* or **10***b*—**14***b*. As a result, the overall structure provides an excellent electrical and mechanical joint which can be readily broken; and which in its assembled configuration is cooled and, in fact, exhibits lower resistance than joints suggested heretofore.

While I have thus described a preferred embodiment of the present invention, many variations will be suggested to those skilled in the art, and certain of these variations have already been discussed. Other variations will be apparent, however, and it must therefore be stressed that the foregoing description is meant to be illustrative only and should not be considered limitative of my invention. All such variations and modifications as are in accord with the principles described are meant to fall within the scope of the appended claims.

Having thus described my invention, I claim:

1. In combination, an electrical conductor, a hollow coolant jacket removably overlying said conductor fastening means passing through said jacket for tightly clamping said jacket to said conductor, and structural means on the interior of said jacket adjacent said fastening means for resisting compressive forces exerted on said hollow jacket by said fastening means.

2. In combination, a plurality of separable planar

conductors disposed in superposed relation to one another, a hollow coolant jacket removably overlying said conductors, an elongated sleeve on the interior of said jacket extending transverse to the planes of said conductors, the opposing ends of said sleeve being open to the exterior of said jacket, and fastening means passing through said sleeve and conductors for tightly clamping said conductors to one another and for mounting said jacket in good heat transfer relation to said superposed conductors.

3. In combination, a substantially planar conductor, an elongated hollow coolant jacket extending substantially parallel to the plane of said conductor, said jacket having a plurality of tubular sleeves on the interior thereof spaced from one another and respectively extending transverse to the plane of said conductor, the opposing ends of each of said tubular sleeves being open to the exterior of said jacket, means for circulating coolant through said jacket and around said sleeves, and bolt means passing through said sleeves for fastening said jacket to said conductor.

4. In combination, a pair of separable conductors disposed in superposed relation to one another, a hollow coolant jacket removably overlying said conductors, clamp means for applying a highly compressive force between said jacket and conductors for tightly clamping said conductors to one another and to said jacket, and structural means on the interior of said jacket for resisting collapse of said jacket due to said compressive force.

5. The combination of claim 4 wherein said clamp means comprises bolt means passing through said jacket and thence through said superposed conductors, said structural means being disposed adjacent a portion of said bolt means on the interior of said jacket in spaced relation to the walls of said jacket.

6. The combination of claim 4 wherein one of said pair of conductors comprises a transmission line, the other of said pair of conductors comprising a portion of an inductor.

7. In combination, a pair of conductors disposed adjacent one another, an elongated hollow coolant jacket overlying said conductors, said jacket having a pair of elongated substantially parallel boundary walls, a plurality of tubular sleeves extending through said jacket in a direction transverse to said conductors, the ends of said sleeves being sealed to said pair of boundary walls respectively whereby coolant in said jacket is prevented from entering said sleeves, the opposing ends of said sleeves being open to the exterior of said jacket adjacent said boundary walls respectively, and a plurality of bolts passing through said jacket via said sleeves for tightly clamping said jacket in good heat transfer relation to said pair of conductors.

8. The combination of claim 7 wherein said jacket comprises a conductive material whereby current may pass from one to the other of said pair of conductors via the conductive material of said jacket.

9. In combination, a coolant jacket comprising a unitary fluid container having a pair of spaced boundary walls, a plurality of spaced hollow sleeves extending between said spaced walls on the interior of said jacket for resisting compressive forces between said walls, the ends of said sleeves being respectively sealed to said boundary walls and the interior of said sleeves being open to the exterior of said jacket adjacent both ends of each sleeve, a structure to be cooled disposed adjacent one of said boundary walls, and fastening means extending from said structure through said sleeves to the other of said boundary walls for compressively clamping said jacket to said structure.

10. The combination of claim 9 wherein said structure to be cooled comprises the joint between a pair of elongated conductors disposed in superposed separable relation to one another adjacent said one boundary wall.

11. In combination, an elongated high-energy transmission line, a massive inductor, means disposing a portion of said line adjacent a portion of said inductor, bolt means passing through said portions of said line and inductor for tightly clamping one to the other to effect a relatively low resistance mechanical joint therebetween, and means for cooling said joint comprising a unitary coolant jacket separably disposed adjacent said joint in good heat transfer relation thereto, said bolt means including a portion fastening to said jacket whereby said bolt means clamps said jacket to said line and inductor portions while simultaneously clamping said portions to one another.

12. The combination of claim 11 wherein said bolt means passes through a portion of said jacket, and structural means on the interior of said jacket adjacent said bolt means for resisting compressive forces exerted on said jacket by said bolt means.

13. In a dielectric heater, a pair of spaced electrodes, a source of high frequency energization, means for coupling said source to said electrodes comprising a transmission line and a coupling reactance connected in series with one another between said source and electrodes, a portion of said line being separably disposed adjacent a portion of said reactance, means for fastening said portions to one another to effect a separable mechanical joint therebetween, and means for cooling said joint comprising a separable coolant jacket disposed in close proximity to said joint.

14. The combination of claim 13 wherein said fastening means includes portions for clamping said jacket to said joint.

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