June 28, 1949. L. B. HIMMEL 2,474,420

HIGH-FREQUENCY DIELECTRIC HEATING APPARATUS

Filed July 16, 1945

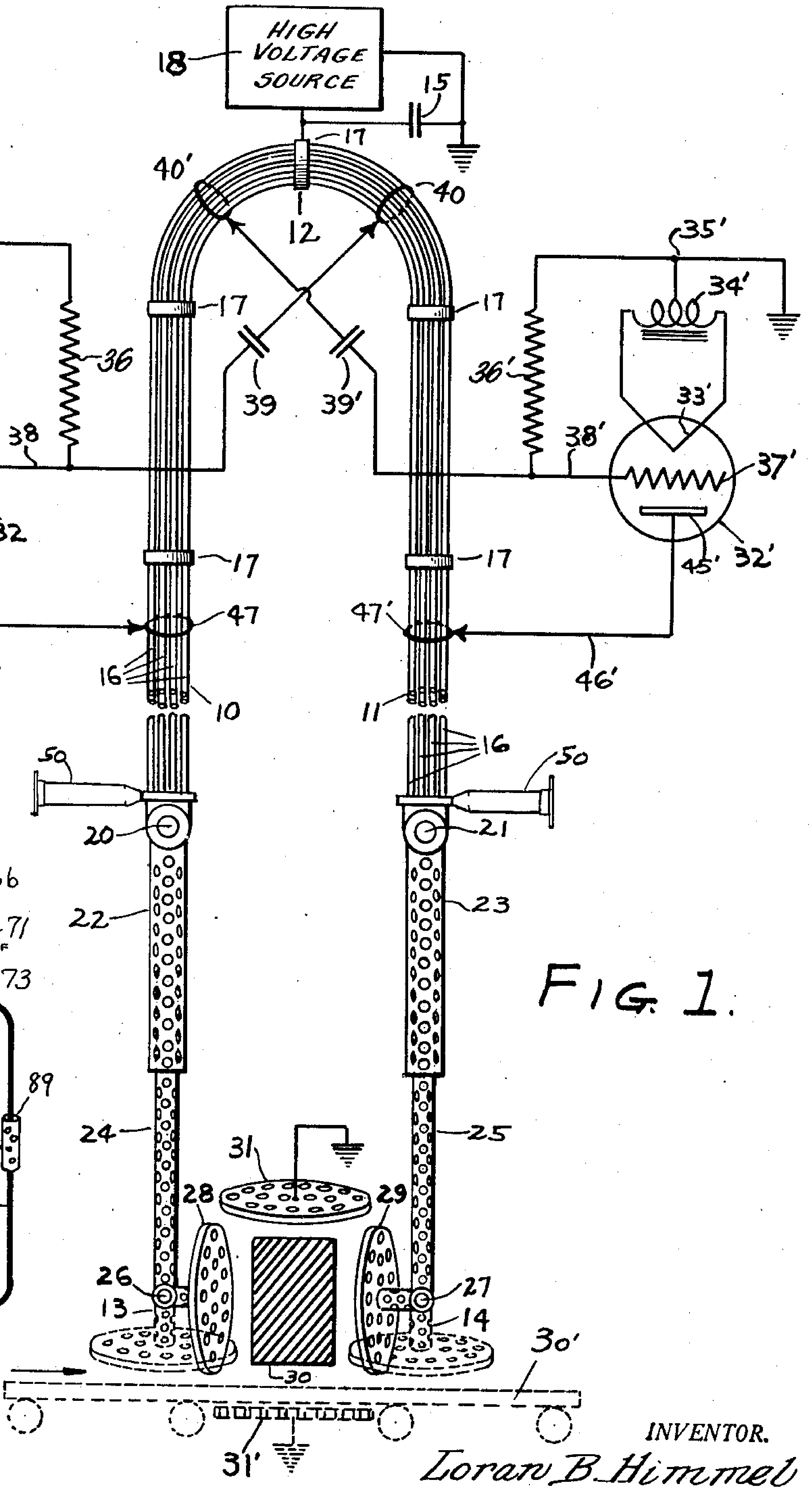

FIG. 1.

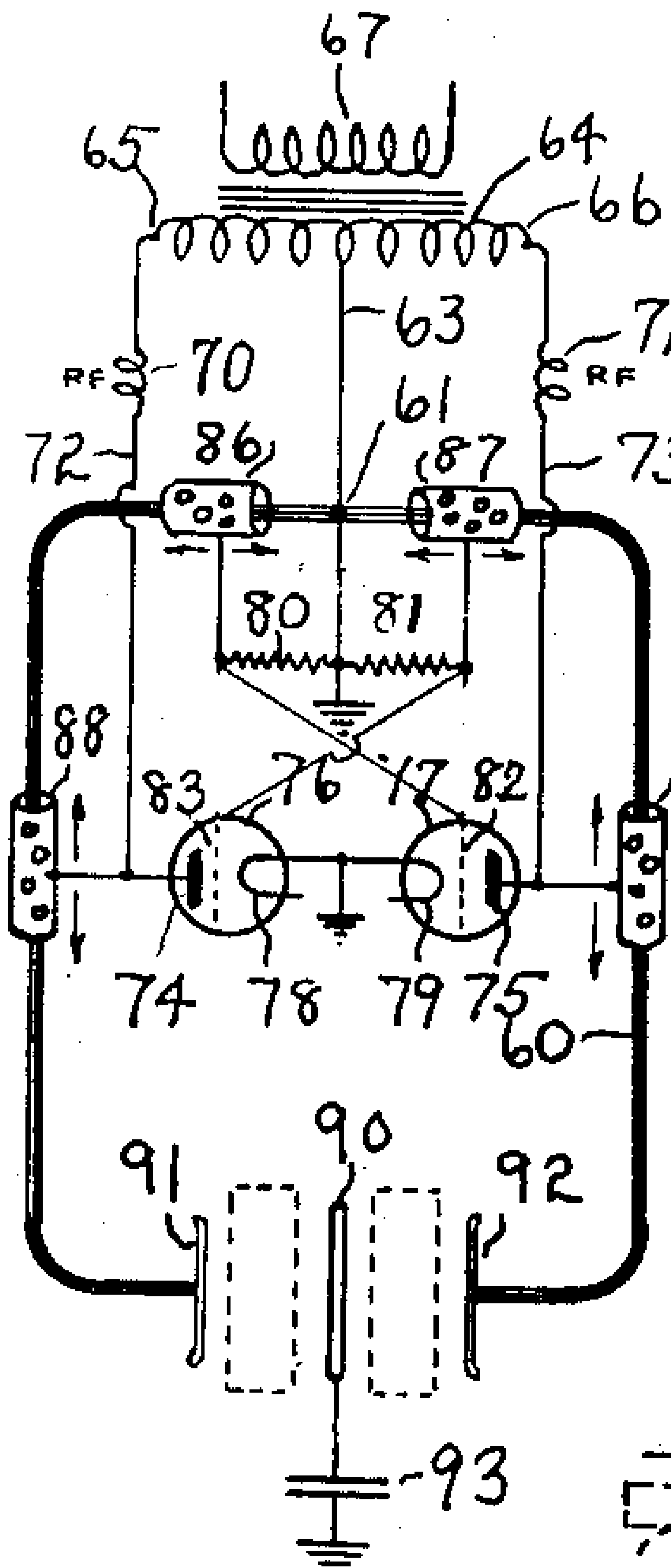

FIG. 2

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atty.

Patented June 28, 1949

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UNITED STATES PATENT OFFICE

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HIGH-FREQUENCY DIELECTRIC HEATING APPARATUS

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Application July 16, 1945, Serial No. 605,394

11 Claims. (Cl. 219—47)

This invention relates to an electrical apparatus and particularly to a dielectric furnace system. This application is a continuation in part of my prior application, Ser. No. 411,711, filed September 20, 1941, now abandoned. In a dielectric furnace, high frequency electrostatic fields are impressed upon suitable material which constitutes the furnace load. By virtue of losses present in this furnace load, heat may be generated.

I have discovered that a quarter wave open wire transmission line having one end metallically short circuited and the other end loaded with a dielectric furnace has remarkable properties. A simple way in which oscillations may be generated in such a line is to connect thereto one or more vacuum tubes having three or more electrodes so that the transmission line forms a tank circuit. The line may have forming part thereof or attached thereto at the ends suitable electrodes between which processing may occur.

A system of this character has remarkable properties and characteristics which have never been hitherto obtained in any system. These characteristics and properties briefly are as follows: The radio frequency potential impressed across the work electrodes is always the maximum potential generated. It is possible to maintain potentials at the electrodes far greater than has hitherto been possible. The frequency at which the system operates is optimum and tends to adapt itself to changes in the load. The transformer property of a quarter wave line provides good impedance matching. Efficiency is far greater than has hitherto been available. The system does not radiate power.

With reference to the maximum potential at the electrodes, a tank circuit consisting of a quarter wave transmission line has lumped capacitance concentrated at the furnace electrodes. There is no lumped inductance and no other capacitances through which tank currents may flow to dissipate power. The distributed inductance and capacitance of the transmission line are inherent in any system having a transmission line. These are not merely tolerated as is true in the prior art but deliberately used. This use imparts a remarkable operative stability to the system under various load conditions. The combination of quarter wave transmission line and load provides a system which determines its own resonant frequency. Thus, the system tends to operate at the most efficient frequency in view of all processing factors.

During processing, it is well known that the

physical properties of a load may change substantially and suddenly. In a system embodying my invention, the changes in load constitute the sole variable for changing frequency during a working cycle. The system follows the load changes and maintains maximum electrostatic potential differences across the load at one frequency resonant for the system. A highly desirable property of a quarter wave transmission line system with suitable load is that the physical simplicity provides only one natural resonant frequency. In systems having coil inductances or coupled circuits, it is well known that there may be several resonant frequencies, thus making it possible for parasitic oscillations in other modes to exist. This robs the load and tends to shorten the life of various elements.

A further highly desirable property of a system embodying this invention resides in the fact that the open construction of the tank permits the use of any desired construction of conductor. With a conventional coil type inductance, it is necessary to use conductors which can be coiled. On the other hand, a construction embodying this invention may utilize a conductor in any desired form designed so that it conducts with minimum loss. No considerations or susceptibility to coil formation need exist. It is, therefore, especially suitable for high power ratings.

A further highly desirable property of a quarter wave transmission line resides in its ability to function as a transformer. High and low impedances may be matched by choosing proper portions of the line to which connections may be made. Impedance variations are also matched. Thus, the load may go through wide impedance variations and result in relatively small impedance variations where the tubes are coupled. This is a highly important consideration. At high frequencies, matching is of vital importance for effective transmission of power and avoidance of unnecessary losses. Vacuum tubes have certain impedance requirements and characteristics while loads upon which the system will work may have their own impedance characteristics, which characteristics do not even remain at a constant value during a processing cycle.

Another important characteristic inherent in a system embodying this invention resides in the geometry of the construction. Thus, as long as separation between the opposite portions of the line is not excessive from the point of view of radiation, the line may be shaped or its length adjusted in any manner desired to accommodate work.

A system embodying the invention herein has substantially all components and leads at such radio frequency potentials that ground is a point of substantial symmetry at all times in the radio frequency field. The result is that there is little or no radio frequency unbalance and radiation is prevented to a degree far beyond what has hitherto been considered possible.

In practice, the quarter wave circuit and load has operated at frequencies ranging above a megacycle per second and may go up to one hundred megacycles and more. As a rule, tube losses and physical dimensions of parts determine top frequency limits. Frequency-determining load capacitances may be substantially less than the tube capacitances in this system. Thus, greater leeway in tube choice is possible while maintaining desirable tank conditions.

It is preferred to maintain a space between work and electrodes, said space having a high degree of insulation. Such space may be either air or material having low dielectric loss. Thus, the furnace capacitance consists essentially of a component which is substantially constant and the work which may vary. As a result of this, the variation in load capacitance is reduced. A system embodying the invention permits wide ranges of load conditions with resultant smaller changes at the tube terminals.

Under certain conditions, a grounded electrode may be disposed at the furnace in proximity to the work. Such an arrangement has been known to permit a noticeable increase of power absorbed by the load.

The entire tank may thus have the general shape of a U (a V shape is considered as falling within this definition), depending upon the disposition of the conductors forming the short circuit at one end of the transmission line. The arms of the tank need not necessarily be parallel or straight and, in general, the ends of the arms are adapted to be bent or shaped to accommodate work. The ends of the arms may also be adjusted for length over a substantial range. While this may have a tendency to disturb the symmetry of the system, such lack of symmetry is not serious enough to alter the highly desirable normal operating characteristics of the system.

In other systems, the oscillating system is a complete entity distinct from the cables leading to the work. In such prior art systems, the cables unavoidably constitute a transmission line having substantial electrical length and require the matching of oscillator to line and line to load. It is for this purpose that prior art systems tune the oscillator so that effective transmission through the leads to the load may be provided. This requires auxiliary circuit components wherein power may be wasted. Furthermore, during processing of many materials, load changes occur too fast for tuning adjustments. In distinction to this, however, the transmission line in this invention itself functions as the seat of continuous oscillations. Thus, any shaping or variation of length of the lines adjacent to or around the load has no deleterious effect electrically. The system instantaneously adapts itself to load requirements as an inherent property.

Referring to the drawing, Figure 1 shows a system embodying one form of the invention. Figure 2 shows a modification.

Open wire line consisting of conductors **10** and **11** meet at **12** for convenience referred to as a

junction though the conductors may be continuous, and have free ends **13** and **14**. Junction **12** is preferably at or near the geometrical center of the continuous metallic conductor extending between free ends **13** and **14**. This open wire line and shorted end constitutes a tank and may be of the usual construction for handling radio frequency currents. Thus, the conductor may be fabricated of one or more hollow tubes, pipes, stranded cable or the like.

However, for substantial power particularly involving heavy currents, it is preferred to form the tank at least in the neighborhood of the region around junction **12** as a plurality of separate metallic conducting elements **16**. These elements are preferably spaced from each other, but disposed symmetrically to form a generally tubular cage construction. At frequent intervals, rings **17** may be disposed either outside or inside of the cage structure to maintain the separate elements rigidly in position.

Rings **17** may be of insulating or conducting material. Insulating material may tend to reduce losses due to differences in potential circumferentially around the cage structure. However, in practice, conducting rings are satisfactory and easier to make and install. Each element **16** may be solid wire, stranded wire, rod or tubing depending upon how finely divided the cage construction is made. To provide good surface conductivity, it is essential that copper or silver along the outer surface of the various conductors be used. It is understood that the drawing is merely illustrative of a cage structure for number and spacing of elements **16** and, in practice, an extensive conducting surface is desired.

It is well known that in a transmission line a quarter wave length long with one end short circuted and the other end open circuited (as far as a metallic connection is concerned) a voltage minimum and current maximum will occur at or near junction **12**. As far as radio frequency is concerned, node **12** may be fixed and prevented from wandering along the conductor length if desired by grounding this point through condenser **15**. As will be explained later, some physical adjustments of the conductors may throw node **12** off from the geometrical center of the tank. Furthermore, in some instances, some lack of symmetry in loading or attenuation may tend to move the point of electrical symmetry away from node **12**. However, this has no substantial undesirable effects and, in any event, may be corrected quite simply by adjusting the line. With load, node **12** is spread out to a region of several inches along the tank.

At any suitable points preferably spaced a substantial distance from node **12**, the distance being in terms of electrical wave length, conductors **10** and **11** may have joints **20** and **21**. These joints may be either of the universal type permitting movement in any direction or simply pivot joints permitting bending or adjustment of one portion of the conductor with respect to another portion. For ease in manufacture, joints **20** and **21** may have metallic pipe sections adjacent the pivots. Such sections may be soldered or sweated over the tubular cage construction of the conductor proper.

Beyond joints **20** and **21** may be conducting portions **22** and **23**. These conducting portions need not have as great a carrying surface as is present near node **12**, since currents decrease in intensity away from the nodal point. Conductors **22** and **23** may telescope with conductors **24** and **25**, these conductors preferably being slidable within conductors **22** and **23** to adjust the over-all conductor length. Conductors **24** and **25** may have pivot joints **26** and **27** near free ends **13** and **14** of the quarter wave line. Conducting portions **22** and **23** may be advantageously formed of perforated metal pipe or tubing. Similarly, conductors **24** and **25** may be formed of perforated metal tubing so that the telescopic action may be smooth.

Free ends **13** and **14** carry electrodes **28** and **29** having any desired area and configuration. These electrodes are preferably formed of wire, gauze or perforated metal, it being understood that the metal has good electrical conductivity. Thus, copper, brass, or silver plate may be relied upon. By virtue of the various joints and telescoping conductors, the physical length of the quarter wave line may be varied and the shape of the line may be changed as desired. Work **30** disposed between electrodes **28** and **29** may be treated and will be considered as the load. Grounded electrode **31** may be used if desired and disposed as desired.

The spacing between line conductors **10** and **11** should be small in terms of wave length to prevent radiation of power. However, under some conditions, it may be desirable to spread the line apart for mechanical reasons.

The actual physical length of line between free ends **13** and **14** is a matter of design and is determined by various factors. Thus, an important factor is the frequency range over which the system is to operate. Another factor is the amount of power to be handled. A physically shorter length of conductor is required for moving the frequency range higher. However, in order to handle desired currents, the transverse dimension of conductors **10** and **11** may have to be quite substantial. Inasmuch as it is highly desirable to avoid sharp bends or curves in the conductors, it is evident that the transverse dimensions of the conductors will be a factor in the tank dimensions. In addition, excessively close spacing between the opposing parts of the line particularly near the high potential ends **13** and **14** may induce breakdown through air or other insulating medium.

In order to excite the transmission line, one or two, or even more, vacuum tubes may be provided. Thus, vacuum tubes **32** and **32′** may be provided. The system will operate with only one tube and, if two tubes are used, it is desirable, though not necessary, that the two tubes have similar characteristics. In this way, electrical and physical symmetry will result. However, dissimilar tubes may be paired and the connections altered accordingly.

As shown here, tubes **32** and **32′** have cathodes **33** and **33′** of any suitable type. These cathodes are energized by transformer windings **34** and **34′** respectively whose centers **35** and **35′** may be grounded. The vacuum tubes have control grids **37** and **37′** connected by conductors **38** and **38′** to blocking condensers **39** and **39′** and thence to points **40** and **40′** on the tank. Grids **37** and **37′** are connected to their corresponding cathodes through resistors **36** and **36′** respectively.

Tubes **32** and **32′** have anodes **45** and **45′** connected through leads **46** and **46′** to connectors **47** and **47′** movable over lines **10** and **11**. It is preferred to have both grid and anode connections to the line adjustable to permit proper choice of connecting points. A suitable source **18** of high potential, either direct or alternating, is connected between node **12** on the tank and ground. It is understood that the tank frequency

is largely determined by the tank circuit proper. The vacuum tubes merely act to feed pulses of power into the tank.

It will be observed that grid and anode connections of a tube are on opposite sides of voltage node **12**. Thus, proper phase relationship between grid and plate will result. The exact point of connection along the line is generally not critical and, at no or light loads, may be varied within wide limits. As a rule, physical movement of the grid connection results in a greater electrical change than the same physical movement of the anode connection. This, of course, is due to the rising potential away from node **12**.

As the loading on the tank due to furnace operation increases, this voltage rise tends to flatten out. Under some circumstances, the adjustment for the grid and anode connections to the tank circuit must be made during such loaded conditions. With no load, the Q of the tank is so high that an adjustment of grid and anode connections satisfactory for load will generally be tolerable to maintain oscillations at no or light loads. Obviously, as the loading falls off, the power input to the tank falls off. This is an important consideration in intermittent loading. Thus, the system embodying this invention inherently has a high Q with the decrease in Q being due solely to the load.

As is well known, at node **12**, current and voltage are ordinarily in phase. The two get out of phase as points **13** and **14** are approached. Thus, adjustment of the grid and anode connections along the line not only affect the potentials on these tube electrodes but also have a tendency to affect the reactance faced by the tubes. The amount of reactance along the line varies in a manner generally well known in the art. Thus, a reactance match between tank and tubes is also inherent in the anode and grid adjustments. The further the distance electrically from node **12**, the greater the effective reactance presented by the line. This, of course, is well known in transmission line tuning.

In the system shown in Figure 1, the relative positions of grid and anode take-off points on the tank will be determined in some measure by the capacitance of each grid blocking condenser. Thus, if grid blocking condensers **39** and **39′** have a sufficiently low capacitance, then the reactance presented at the frequency range of operation of the system will be such that the potential on the control grids may be too low for the take-off positions shown in Figure 1. In such case, it will be necessary to move the grid take-off point on the tank further away from the node. Thus, with two tubes, as shown in Figure 1, it is possible that the grid take-off point for one tube may be made to coincide with the anode take-off point for the other tube. Under such conditions, the two brushes may be merged into one physical structure. Hence, it follows that, while the grid take-off point of one tube is oppositely phased from the anode take-off point for the same tube, it is not necessary that the grid take-off point be at a lower radio frequency potential than the anode take-off point for the same tube. The actual radio frequency potentials present in the grid and anode of a tube are important. The operating characteristics are also important.

It is possible to dispose a plurality of tubes in parallel for each tube shown. Thus, a number of tubes may be connected at the same points in the tank or may be connected at different points along the tank. If such tubes are staggered or laddered along the tank, it will in general be desirable that the tubes have different characteristics, since their connection points are at different distances from the voltage node. This, of course, is different than a simple paralleling of tubes to increase the power handling capacity.

The quarter wave line thus functions as a transformer upon which may be hung vacuum tubes and loads in the most effective manner possible. Between electrodes **28** and **29**, suitable load **30** either stationary or movable may be disposed. Air gaps or low loss spacing between electrodes and load are desirable to stabilize the normal mode of oscillation. A grounded electrode **31** may be disposed between or adjacent the furnace electrodes under some conditions.

It is not essential that the work be disposed geometrically between the electrodes. Thus, in certain installations, the electric field between opposing electrodes may curve so that the work is outside of the geometrical region between electrodes. By this is meant that straight lines joining the opposed electrodes will not necessarily intersect or enclose the work. It is clear, therefore, that work may be either between or adjacent the work electrodes.

A true load acts so that the lines of force are drawn toward it. This may eliminate the necessity for a grounded electrode apart from potential considerations.

In certain installations, particularly where the surface presented by the load is extensive, such as might be the case in large sheet material, it becomes impractical from both a physical and electrical consideration to have electrodes on opposite sides of work material. To dispose electrodes on opposite sides of parts of wide webs or sheets would require such long physical tanks as to reduce frequency characteristics to an undesirable value. In particular, the large physical length of such a tank may make it impossible to operate it at a desired high frequency.

To overcome such undesirable factors, it is possible to dispose the electrodes as shown in the dotted line position, so that they are more or less in the same plane and face a load as shown. The load may be a sheet or travel on a suitable conveyor or be stationary. The electrodes need not be parallel or symmetrically disposed. Beyond the load may be disposed grounded electrode **31'**, this serving to distort the electrostatic field toward the load. The grounded electrode may be omitted if desired, or there may be several grounded electrodes.

The actual physical length of the line will naturally not correspond exactly to the theoretical length of a quarter wave line operating at the frequency at which the system actually operates. In fact, as load conditions change, the resultant variation in frequency may go through a substantial range, thus changing the electrical length without any physical variation in the length of line.

Under normal conditions of operation, there is a voltage node in the furnace system between the free ends of the line. This merely means that, at some region in the furnace, there is a point corresponding in general to node **12**.

The conductors may be adjusted by movement around joints **20** and **21** as well as adjustment of the telescoping sections. Similarly, the furnace electrodes may be adjusted on the pivot joints. In making all these adjustments, it is not necessary that precise equality of physical length on the two sides of the node be maintained. For a permanent installation, it is preferred to have as much physical symmetry as possible. However, I have successfully adjusted the arms to various positions without impairing the satisfactory operation of the system.

Thus, the entire system under operating conditions has a high degree of symmetry to ground. This tends to eliminate radiation.

Another desirable feature of the invention resides in the fact that the furnace electrodes are both at a high positive potential to ground if the high voltage source supplies direct current. It is, of course, possible to reverse the entire system so that the furnace electrodes are at a negative potential and the cathode connections to the tubes are interchanged with anode connections to the tubes. During the operation of the system, radio frequency voltage oscillations at the furnace electrodes will tend to reduce the potential of said electrodes below the normal static value. However, the amplitude of such oscillations may be controlled so that the average potential at both furnace electrodes may be well above ground during normal operation. If such average potential is at a sufficiently high value such as of the order of five thousand volts or higher, then precipitating action on fine solids between the electrodes may result, assuming that the load is of a liquid or gas nature. Even with solids, some migration of particles may occur.

It is understood that no attempt is made to show proper proportions of physical dimensions in the drawing. This is particularly true of electrodes, their relative positions, the relative areas of the electrodes and load, the spacing between electrodes and load and between the grounded electrode if one is used, and the remaining portions of the furnace. All these are matters which must be varied for individual requirements.

The tank may be supported on suitable posts **50** of low loss material such as quartz. The vacuum tubes and leads at high radio frequency potential such as anode and grid leads may be suitably supported by low loss material. The entire system may be considered as having an axis extending from voltage node **12** between conductors **10** and **11** and through the furnace between the furnace electrodes. Such an axis should lie in an equi-potential surface extending throughout the entire system. Theoretically, in the absence of any ground surface, such an equi-potential surface would consist of a flat plane bisecting the entire system and perpendicular to the drawing, assuming, of course, that all the parts are symmetrically disposed. The axis would be a line in this plane exceeding from node **12** to the furnace and symmetrically disposed with respect to the various portions of the system. In actual practice, the furnace system must be supported with reference to ground. The tank itself under normal conditions may be supported so that the transmission line is disposed in a horizontal plane or a vertical plane or in any intermediate position. By disposing the various portions of the system so that corresponding portions of the system on opposite sides of the axis are symmetrically disposed with respect to ground, radiation may be eliminated or reduced to such a low value as to be negligible.

It is possible to support the entire system so that electrical symmetry to ground is obtained without necessarily relying upon physical symmetry. Thus, if the tank for some reason must be supported in a vertical plane with one conductor above the other so that the conductors are at different distances from the floor, then some supporting material suitably grounded may be disposed so that ground for the system becomes not only the floor but also a more or less vertical member. Thus, the capacitance of the various portions of the system may be balanced.

Referring now to Figure 2, tank **60** may have the same general structural features as tank **10** in Figure 1. Tank **60** has grounded nodal region **61**. To node **61**, there is also connected center-tap **63** of transformer secondary **64** having terminals **65** and **66**. Transformer secondary **64** has primary **67** fed by suitable alternating current. Secondary **64** is adapted to provide suitably high potentials at terminals **65** and **66**.

Terminals **65** and **66** are connected by leads to radio frequency chokes **70** and **71**, and these chokes are connected by leads **72** and **73** to anodes **74** and **75** of vacuum tubes **76** and **77** respectively. Tubes **76** and **77** have cathodes **78** and **79** grounded, it being understood that these cathodes are suitably energized by heaters or heating current.

Grid resistors **80** and **81** are connected between ground and control grids **82** and **83** of the respective tubes. Grids **82** and **83** are also connected to take-off points on tank **60**. The grid connections may be direct metallic connections to the tank or may be through blocking condensers **86** and **87** as shown. These blocking condensers may be formed by metal sleeves disposed in spaced relation around or insulated from the tank cable, it being understood that suitable insulating supports may be provided to maintain the relationship. Thus, physical sliding contacts between the tank and the take-off leads may be eliminated if desired. It is understood that the length of the sleeves along the cable may be adjusted to desired values and that the spacing between the opposed condenser surfaces may also be adjusted to desired values. The sleeves may be either solid or perforated, and the physical dimensions of the sleeves will determine the effective capacitance.

Similarly, anodes **74** and **75** are connected through blocking condensers **88** and **89** respectively to suitable points on the tank. These blocking condensers may also be formed in a manner similar to condensers **86** and **87**.

In both Figures 1 and 2, it is understood that the various leads from the tubes to the tank and various circuit components such as grid resistors may be enclosed in grounded shields. Similarly, the vacuum tubes may be enclosed in shields if found desirable.

In operation, it is clear that the vacuum tubes will rectify the alternating current from the transformer.

The furnace may also be modified by disposing neutral grounded electrode **90** between furnace electrodes **91** and **92** and carried by the tank. Thus, in the absence of such a grounded electrode, there will be a voltage node somewhere in the furnace under normal operating conditions. Without the grounded electrode, the voltage node may move in space depending upon the nature of the work, its physical changes, and other factors. However, by disposing a grounded electrode between the furnace electrodes, the voltage node will be stabilized and fixed. The potential distribution through the node between the furnace electrodes may be controlled by the shape, size and location of the neutral electrode. It is understood that the neutral electrode may be of perforated material similar to the furnace electrodes shown in Figure 1. It is obvious that the grounded electrode shown in Figure 1 may be disposed between the furnace electrodes in a manner similar to that just described for Figure 2.

Blocking condenser **93** may be disposed between ground and neutral electrode **90**. Thus, electrode **90** will be grounded for radio frequencies. Condenser **93** will tend to suppress damaging arcs. In case the tank is at high potential to ground because of direct connection to a high voltage source, as in Figure 1, an arc between electrode **90** and ground might damage the apparatus in the absence of condenser **93**. This condenser, like other grounded condensers, should provide a low reactance path for radio frequency.

What is claimed is:

1. A dielectric heating system comprising a generally U-shaped conducting structure with work electrodes at the free ends of said structure, said electrodes forming a condenser whose dielectric includes a load, said load and conducting structure operating as a quarter-wave transmission line type tank circuit having a nodal point about mid-way along the structure, at least one vacuum tube having at least a cathode, control grid and anode, a resistor between the grid and cathode, a connection for radio frequencies between the anode and said tank, a connection for radio frequencies between the grid and said tank, said grid and anode connections having negligible length along said tank and being oppositely phased, a radio frequency connection between the cathode and nodal point and a source of high potential between said cathode and anode, said tank being otherwise free of discrete high frequency inductors or capacitors to minimize the formation of parasitic circuits and, within the power limits of the system, the condenser containing the load being the dominant influence in the amount of power dissipated in the dielectric.

2. A dielectric heating system comprising a generally U-shaped conducting structure having work electrodes at the free ends of said structure, said electrodes forming a condenser whose dielectric includes a load, said load and conducting structure operating as a quarter-wave transmission line type tank circuit having a nodal point about mid-way along the structure, two vacuum tubes each having at least a cathode, control grid and anode, resistors between the grid and cathode of each tube, connections for radio frequencies between the control grid and tank and between the anode and tank respectively for each tube, grid and anode connections for a tube being oppositely phased and the two tubes being oppositely phased, said connections on said tank having negligible length along said tank, radio frequency connections between said cathodes and nodal point and a source of high potential between said cathodes and anodes, said tank being otherwise free of discrete high frequency inductors or capacitors to minimize the formation of parasitic circuits and, within the power limits of the system, the condenser containing the load being the dominant influence in the amount of power dissipated in the dielectric.

3. The system of claim 1 wherein the radio frequency connections for at least one of the electrodes of each tube includes a blocking condenser, said blocking condenser consisting of a sleeve surrounding a length of said conducting structure.

4. The system of claim 1 wherein a grounded

electrode is provided adjacent the work electrodes.

5. The system of claim 1 wherein said work electrodes are disposed to face the same side of a work region and wherein a grounded electrode is disposed to face an opposing side of the work region.

6. The system of claim 1 wherein means are provided for adjusting the length and shape of said conducting structure so that said work electrodes may be disposed in any desired position with respect to the load.

7. A dielectric heating system comprising a generally U-shaped conducting structure having work electrodes at the free ends of said structure, said electrodes forming a condenser whose dielectric includes a load, said load and conducting structure operating as a quarter-wave transmission line type tank circuit having a nodal point about mid-way along the structure, an even number of vacuum tubes, each tube having at least a cathode, control grid and anode, a resistor between the grid and cathode of each tube, connections for radio frequencies between a control grid and tank and between an anode and tank respectively for each tube, each tube having its grid and anode connections to the tank oppositely phased and one-half of the tubes having their corresponding electrodes oppositely phased with respect to the corresponding electrodes of the remaining tubes, said connections on said tank having negligible length along said tank, radio frequency connections between said nodal point and said cathodes and a source of high potential between said cathodes and anodes, said tank being otherwise free of discrete high frequency inductors or capacitors to minimize the formation of parasitic circuits and, within the power limits of the system, the condenser containing the load being the dominant influence in the amount of power dissipated in the dielectric.

8. A dielectric heating system comprising a generally U-shaped conducting structure having work electrodes at the free ends of said structure, said electrodes forming a condenser whose dielectric includes a load, said load and conducting structure operating as a quarter-wave transmission type tank circuit having a nodal point about mid-way along the structure, at least one vacuum tube having at least a cathode, control grid and anode, a connection for radio frequencies for grounding said nodal point and said cathode, a resistor between grid and cathode of a tube, connections for radio frequencies between the tank and control grid for a tube, a connection for radio frequencies between the tank and anode for a tube, said grid and anode connections for a tube being oppositely phased, said connections on said tank having negligible length along said tank, means for connecting a source of high potential to the anode and cathode of a tube, said tank being otherwise free of discrete high frequency inductors or capacitors to minimize the formation of parasitic circuits and, within the power limits of the system, the condenser containing the load being the dominant influence in the amount of power dissipated in the dielectric.

9. The system of claim 8 wherein the connection from an anode to the tank includes a blocking condenser, said blocking condenser consisting of a sleeve surrounding a length of conducting structure.

10. The structure of claim 8 wherein the connections from the grid and anode include blocking condensers, each blocking condenser consisting of a sleeve surrounding a length of conducting structure.

11. A dielectric heating system comprising a generally U-shaped conducting structure, said structure having a portion formed of spaced metallic tubular elements to form a generally cylindrical cage, said cage portion having extensions forming the free ends of the structure, each extension comprising a tubular conducting structure, electrodes secured to the free ends of said extensions, said electrodes forming a condenser whose dielectric includes a load, said load and conducting structure operating as a quarter-wave transmission line type circuit having a nodal point about mid-way along the conducting structure, at least two vacuum tubes each having a cathode, control grid and anode, a radio frequency connection between the nodal point and the cathodes and ground, a radio frequency connection between each grid and tank circuit, a radio frequency connection between each anode and tank circuit, the cooperating grid and anode connections for any one tube being oppositely phased, said tubes being divided into two groups oppositely phased with respect to each other, a resistor between the grid and cathode of each tube, said anode and grid connections having negligible length along said tank, a source of high potential connected between the cathode and anode of said tubes, said tank circuit being otherwise free of discrete high frequency inductors or capacitors to minimize the formation of parasitic circuits and, within the power limits of the system, the condenser containing the load being the dominant influence in the amount of power dissipated in said condenser dielectric.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,900,573	McArthur	Mar. 7, 1933
1,972,050	Davis	Aug. 28, 1934
2,112,418	Hart et al.	Mar. 29, 1938
2,149,387	Brown	Mar. 7, 1939
2,179,261	Keller	Nov. 7, 1939
2,229,205	Braaten	Jan. 21, 1941
2,276,994	Milinowsi	Mar. 17, 1942
2,298,038	Crandell	Oct. 6, 1942
2,304,958	Rouy	Dec. 15, 1942
2,382,435	Mann et al.	Aug. 14, 1945
2,397,615	Mittelmann	Apr. 2, 1946

OTHER REFERENCES

A. I. E. E. Transactions, vol. 53, pages 1046–1053, published 1934.

Hoyler: An electronic sewing machine, Electronics, August 1943, pages 90–93, 160, 162, 164, 166 and 168, particularly page 92.

Certificate of Correction

Patent No. 2,474,420. June 28, 1949.

LORAN B. HIMMEL

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 10, lines 69 and 75, column 11, lines 3 and 8, for the claim reference numeral "1" read *2*;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 29th day of November, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.