March 30, 1948. P. D. ZOTTU 2,438,595

HIGH-FREQUENCY GENERATOR

Filed May 3, 1944 9 Sheets-Sheet 1

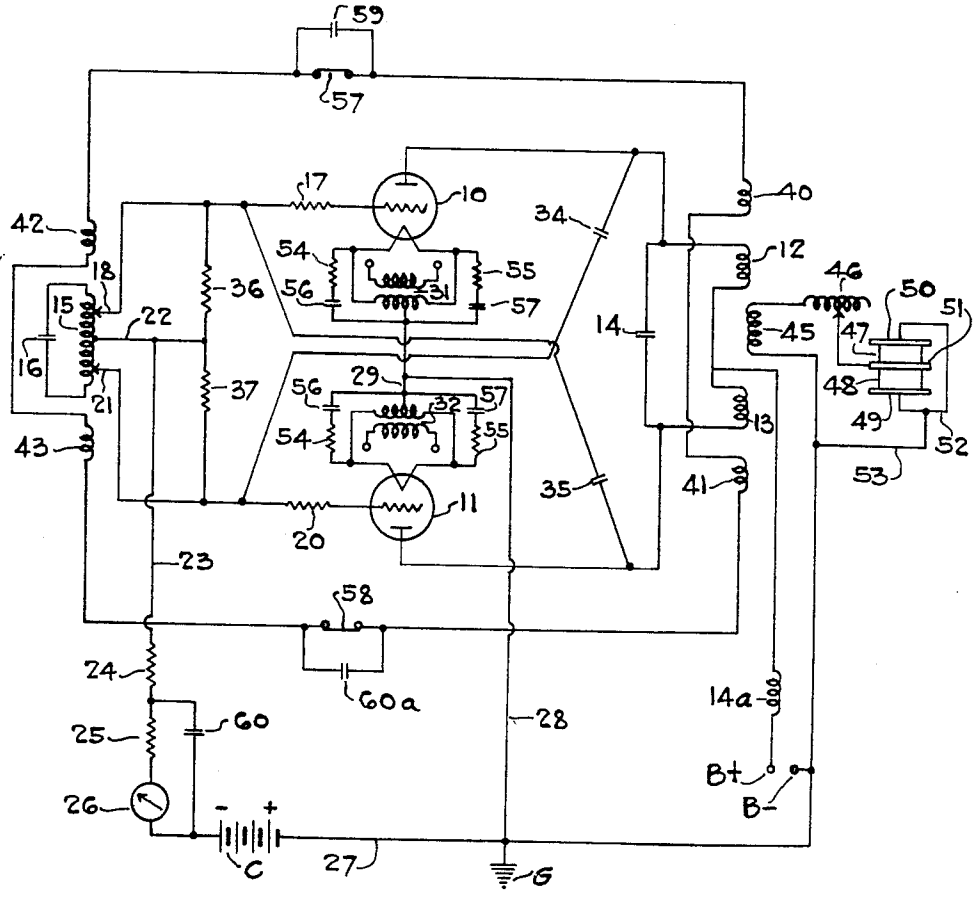


FIG. 1

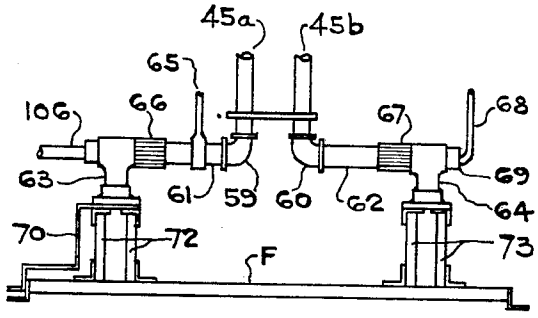


FIG. 4

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HIGH-FREQUENCY GENERATOR

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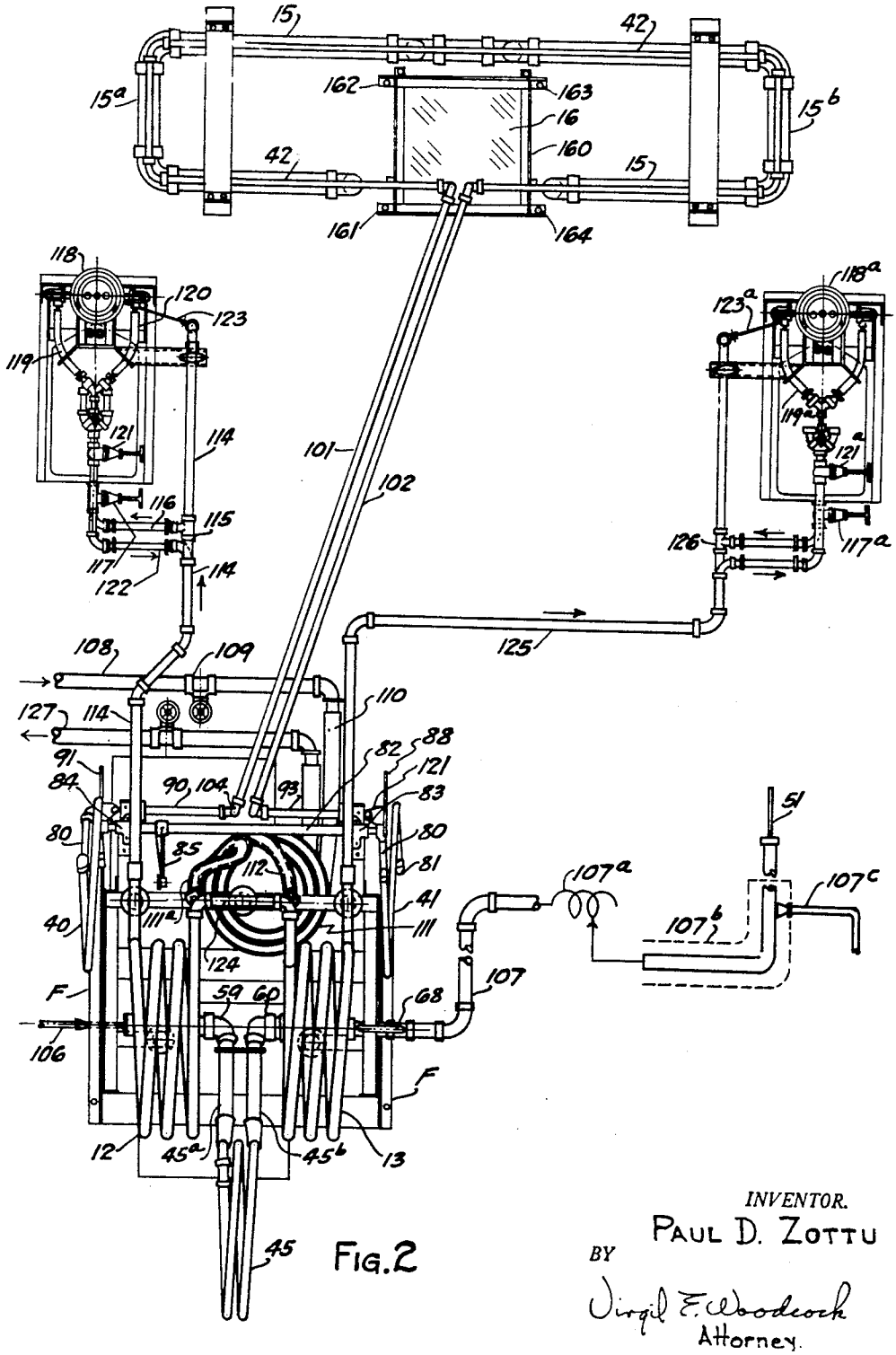


FIG. 2

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HIGH-FREQUENCY GENERATOR

Filed May 3, 1944 9 Sheets-Sheet 3

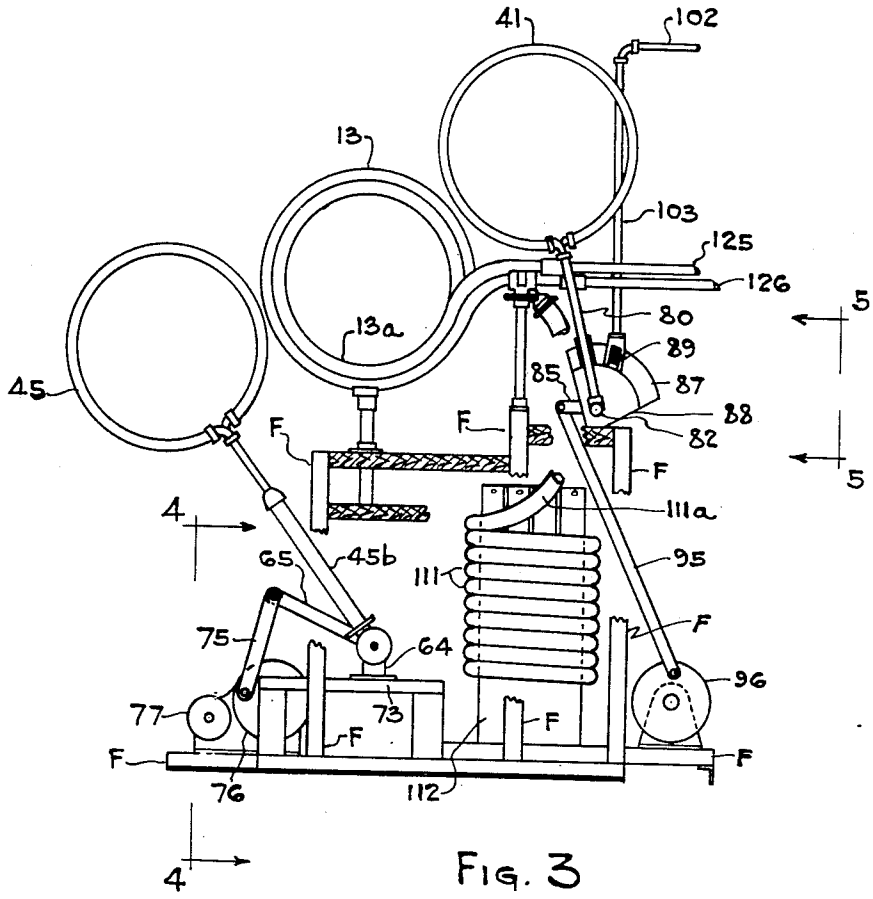


FIG. 3

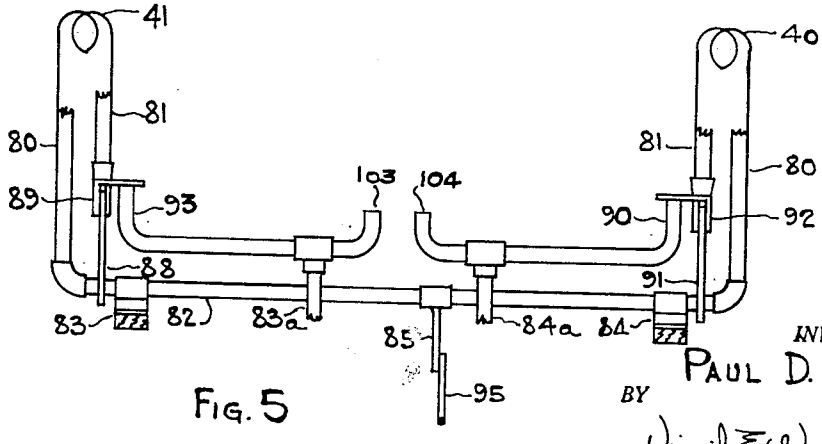


FIG. 5

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HIGH-FREQUENCY GENERATOR

Filed May 3, 1944 9 Sheets-Sheet 4

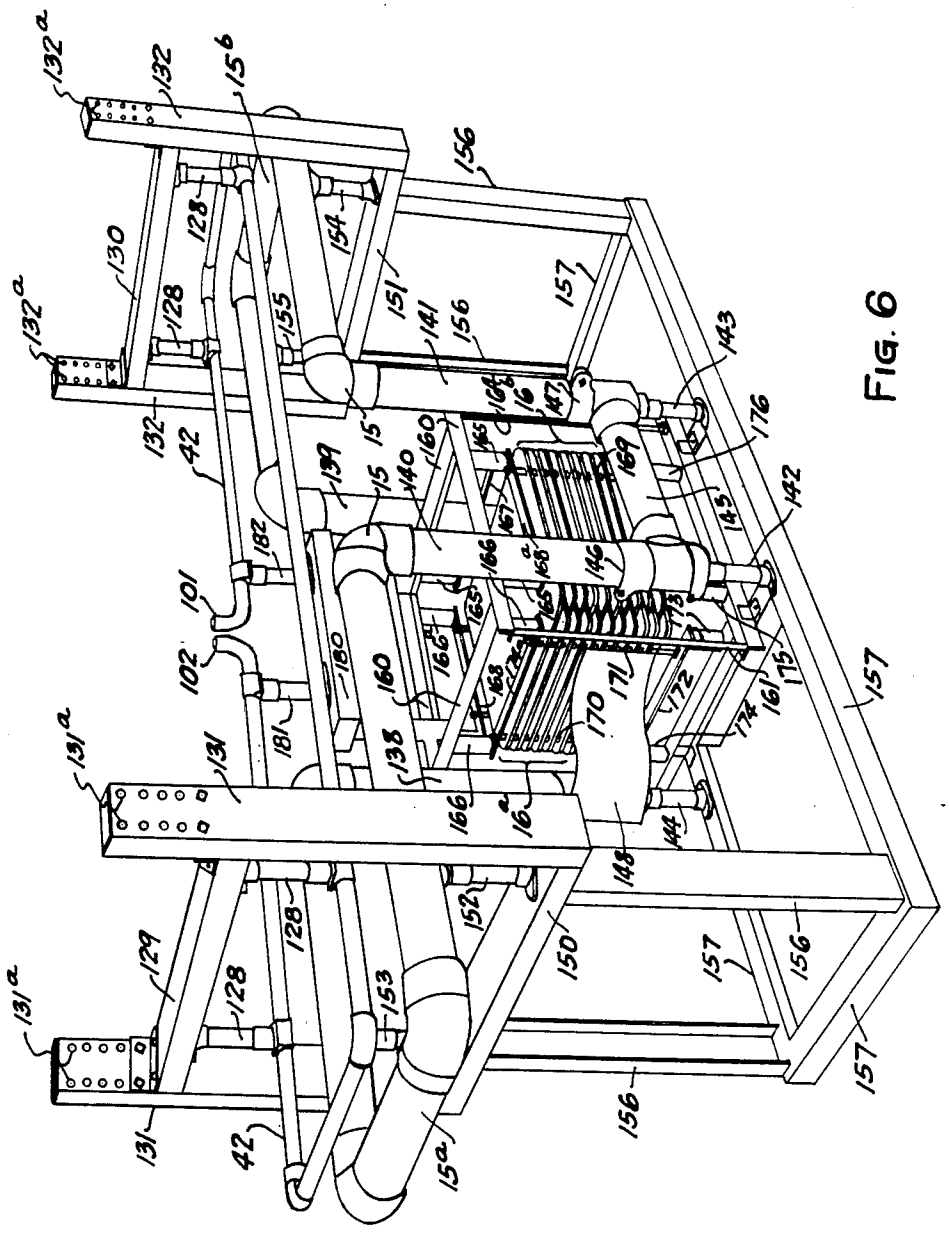


FIG. 6

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HIGH-FREQUENCY GENERATOR

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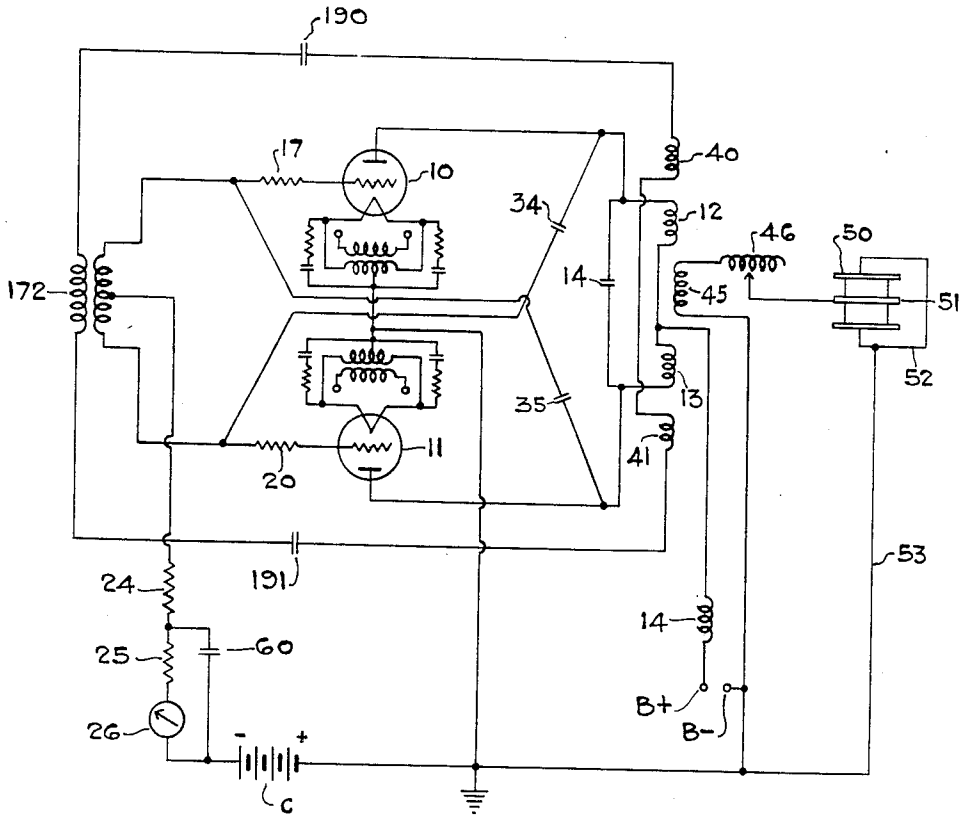


FIG. 7

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HIGH-FREQUENCY GENERATOR

Filed May 3, 1944 9 Sheets-Sheet 6

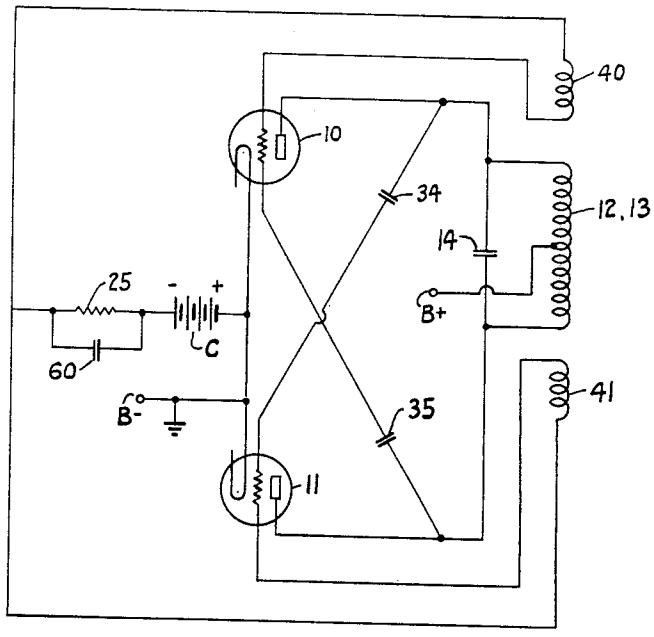


FIG. 8

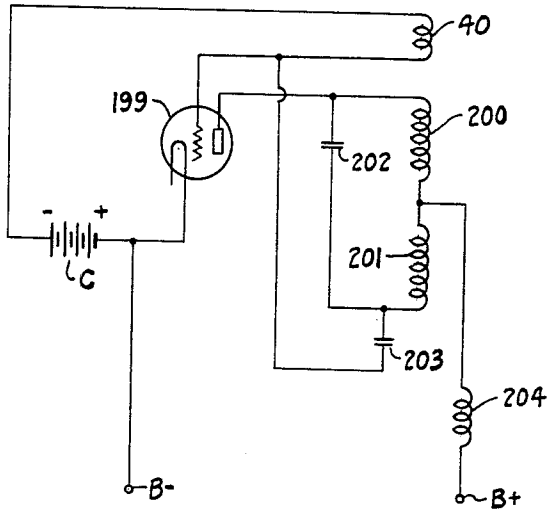


FIG. 9

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HIGH-FREQUENCY GENERATOR

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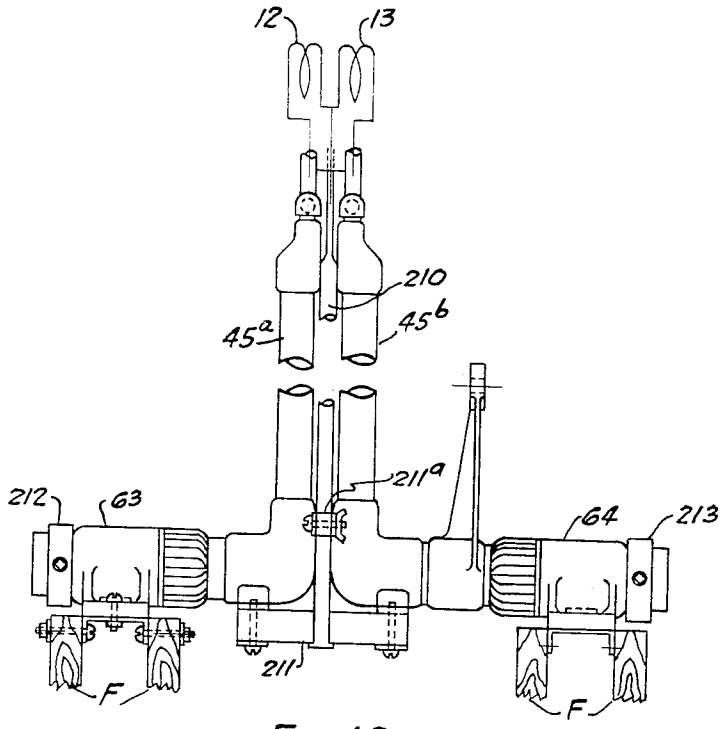


FIG. 10

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HIGH-FREQUENCY GENERATOR

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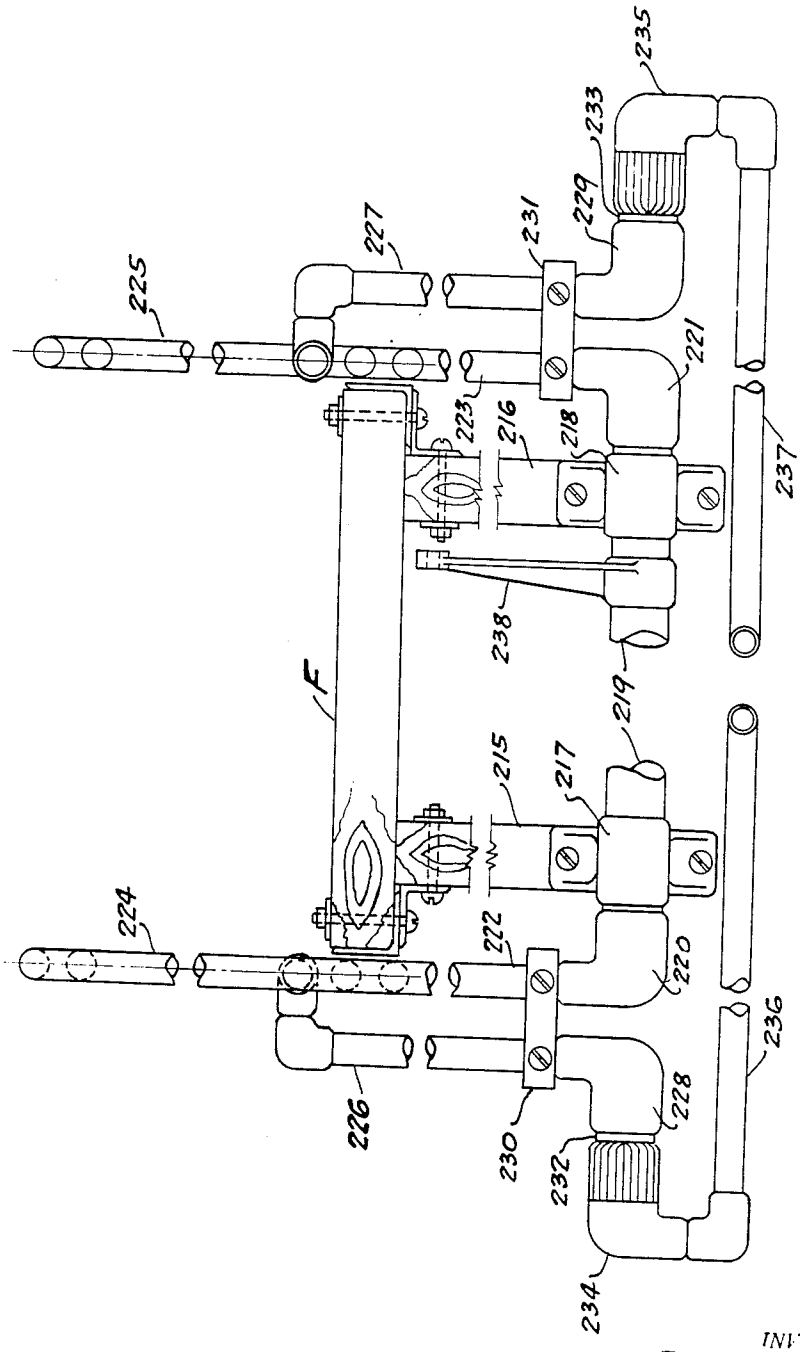


FIG. 11

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HIGH-FREQUENCY GENERATOR

Filed May 3, 1944 9 Sheets-Sheet 9

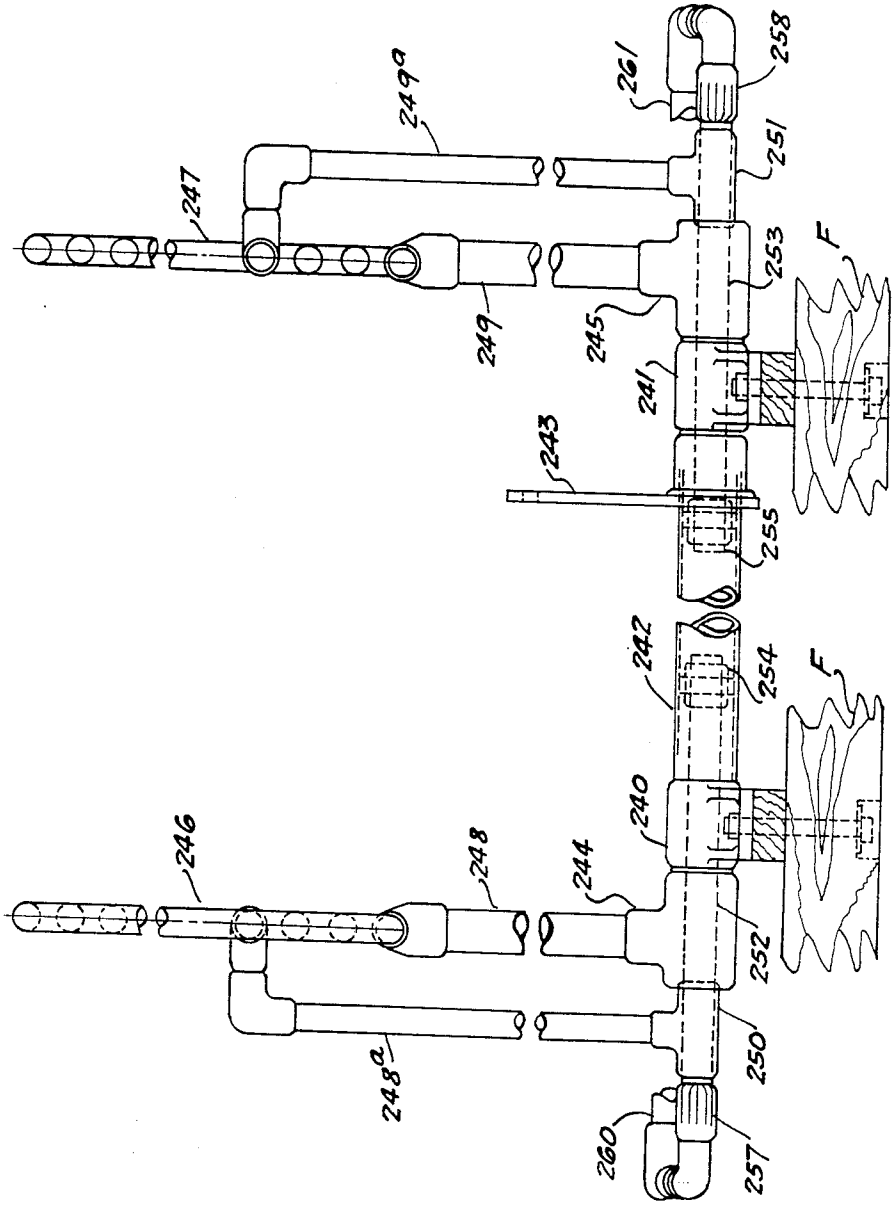


FIG. 12

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Patented Mar. 30, 1948

2,438,595

UNITED STATES PATENT OFFICE

2,438,595

HIGH-FREQUENCY GENERATOR

Paul D. Zottu, Indian Hills, Ky., assignor to The Girdler Corporation, Louisville, Ky., a corporation of Delaware

Application May 3, 1944, Serial No. 533,997

12 Claims. (Cl. 250—36)

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This invention relates to high frequency generators, more particularly to systems and apparatus of the type adapted for the generation of high frequency with large power output capabilities, and has for an object the provision of such a system which combines mechanical ruggedness with electrical simplicity and relatively high efficiency.

For many years it has been recognized by those skilled in the art that dielectrics, materials both liquid and solid of a character generally considered as insulators, may be heated if subjected to an electric field of substantial potential and of relatively high frequency. From the time of Tesla's first observation of the internal heating of the body and of dielectrics, by electrical current of high frequency, apparatus of different kinds have been employed to produce the heating effect. High frequency energy comprising damped oscillations from spark gaps, as well as continuous wave oscillations from apparatus of the type used for radio broadcasting, have been utilized. The internal or diathermic heating has been applied to materials of widely differing character; it has been applied to solutions, to all parts of the human body, to various animals, to grains, cereals, and other organic and inorganic non-conducting substances of widely differing character such as plastics, glass, plywood, and also to conducting and semi-conducting substances.

Though the application of high frequency heating to dielectric materials has been extensive, much is yet to be desired in the way of systems and apparatus of relatively low initial, maintenance, and operating costs for producing the required high frequency energy. Resort has been had to coupled stages consisting of a master oscillator, a buffer amplifier and a final power amplifier stage. Such multistage systems are costly both in first cost and in maintenance and are relatively complicated in operation.

It is an object of the present invention to provide a single stage high frequency generating system which has all of the advantages of the multistage system and few of the disadvantages, and which is particularly suited for high power, or relatively high power, industrial installations for high frequency electric heating.

It is a further object of the invention to provide an efficient system having a power output adequate to meet the heating requirements of such industrial installations, and which at the same time is simple and economical to operate and requires minimum upkeep costs.

Another object of the invention is to provide

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a single stage oscillator which is not only efficient but which may be readily adjusted to meet the requirements of a wide variety of industrial operating conditions.

In carrying out the invention in one form thereof, there is provided a high frequency generator having the desirable characteristics of an amplifier and a power output which is satisfactorily high as compared with the input. The invention includes a method of introducing into the output circuit loads of widely varying electrical constants, which constants may vary continuously during the application of high frequency energy. This is accomplished by the provision of a circuit and circuit elements which provide a continuously variable transformation ratio so that, regardless of the nature of the load in the high frequency secondary circuit, the primary circuit can be made to appear resistive and essentially of constant magnitude. Moreover, the adjustments may be carried out with large amounts of energy present in the secondary circuit. Thus the generator may be operated efficiently at high power levels, even though the electrical characteristics of the material being heated vary to a substantial degree during the heating operations.

Further, in accordance with the invention there is provided a single stage oscillator of the push-pull type, which is neutralized, preferably by means of criss-cross balancing condensers between the anodes and grids of the tubes. Tank circuits may be provided in both the input and output circuits. These tank circuits are inductively coupled together by means of pivotally mounted coils through which the degree of feed back coupling may be changed through relatively wide limits. The grids of the tubes may be provided with a negative bias adequate to insure the desired operating characteristics. Additionally, provision is made to prevent the appearance of bothersome parasitics in the various meshes of the circuit. Provision is also made for the circulation of a cooling fluid through the inductor in the output tank circuit, as well as through the inductor forming the secondary or output coil, the tuning coil and through the inner conductor of a coaxial transmission line, through which the high frequency energy is supplied to the load circuit.

Numerous additional advantages and features of the invention are set forth in the detailed description based upon the accompanying drawings, in which:

Fig. 1 is a schematic wiring diagram of the

principal circuits of an oscillator embodying the invention;

Fig. 2 is a plan view of the principal component parts of a typical apparatus comprising mechanical features of the oscillator of Fig. 1;

Fig. 3 is an end view illustrating the sub-assembly comprising the output coupling coil, the output tank inductor and the feedback coil;

Fig. 4 is a fractional end view of the pivotal support for the output coil;

Fig. 5 is a fractional end view of the pivotal support for the feedback coil;

Fig. 6 is a view in perspective of the input tank circuit together with the exciting coil therefor;

Fig. 7 is a wiring diagram of a modified oscillator or high frequency generator;

Figs. 8 and 9 are wiring diagrams of modified forms of oscillators or high frequency generators; and

Figs. 10, 11 and 12 are fractional end views of modified forms of pivotal supports for certain of the coils, such, for example, as the feedback coils.

Referring to the drawings, the invention in one form is illustrated in Fig. 1 as comprising a pair of electric valves 10 and 11 connected in a circuit which, in many respects, is similar to a conventional push-pull oscillator. The anodes of the tubes 10 and 11 are respectively connected to a divided output inductor comprising sections 12 and 13. The output tank capacitor 14 is connected in shunt or parallel relation with the inductor 12—13. A suitable source of anode potential is indicated by the terminals marked B+ and B—. The connection from the B+ terminal leading to the midpoint of the inductor 12—13 includes a high frequency choke coil 14a. The respective control grids of the tubes 10 and 11 are connected to spaced points on the inductor 15 of the input tank circuit, which also includes a capacitor 16. The control grid of the tube 10 has in circuit therewith a parasitic suppressing resistor 17, the connection to the inductor 15 being completed by the contactor 18. Similarly, the control grid of the tube 11 has in circuit therewith a parasitic-suppressing resistor 20 with a contactor 21 completing the connection to the inductor 15. The respective grid circuits are completed by way of conductors 22 and 23, resistors 24 and 25, a milliammeter 26, a grid bias battery C, conductors 27, 28 and 29, and thence to the midpoint of the secondary windings of the respective filament transformers 31 and 32.

As well understood in the art, there exists between the anodes and the grids of each of the valves or tubes 10 and 11 a substantial capacitance, substantial in the sense that there is a feeding back or capacitive return to the grid circuit of some of the signal energy appearing in the output circuit. The effect of the anode-grid capacity on each tube is neutralized by means of the criss-cross capacitors 34 and 35 which, it will be observed, are respectively connected from the anode of one tube to the grid of the opposite tube. The neutralizing capacitors 34 and 35 are of a size, or variable in manner, such that the signals fed back through these capacitors to each grid circuit have a magnitude equal to that of the signals fed back through the anode-grid capacity. Since this neutralizing voltage for each tube is derived from the opposite tube of the push-pull combination, it is 180° out of phase with the voltage which is fed back through the anode-grid capacity and hence neutralizes the effect of the latter.

The respective input or grid circuits have in shunt therewith resistors 36 and 37 which provide a better regulated load for the input circuits. The mid-point of these resistors is also connected to the conductor 22. The resistors 36 and 37 may be omitted in some oscillators, but if certain parasitics develop these resistors effectively suppress them.

In accordance with the invention, a divided feedback coil, comprising coil sections 40 and 41, is inductively associated with the output tank inductor 12—13. The feedback coil applies some of the output energy to the divided coil sections 42 and 43. In terms of the output of the oscillator as a whole, the energy fed back to the input circuit is relatively small. It is only enough properly to energize the input tank circuit comprisng the inductor 15 and the capacitor 16.

The load circuit is coupled to the output tank inductor 12—13 by means of an output coil 45. The load circuit also includes a variable tuning coil 46. As shown, the load may consist of plywood bundles 47 and 48, located between the platens 49 and 50 of a press. A central electrode or conducting plate 51 is connected directly to the tuning coil 46. This arrangement provides a return circuit which divides between the plywood bundles 47 and 48. The platens 49 and 50 are connected together as indicated by conductor 52, the return circuit being completed by way of conductor 53. For a more detailed disclosure of the electrode arrangement in the press, reference may be had to my Patent No. 2,307,344, dated January 5, 1943.

In a push-pull oscillator several mesh circuits are present. If there are present in any mesh or loop circuit inductive and capacitive reactance, such circuit will exhibit characteristics of resonance at a particular frequency. If energy is applied to such a circuit, oscillations will occur at that particular frequency. These spurious oscillations at frequencies other than the desired frequency are known as parasitics. Specifically, one parasitic oscillation may arise by a tendency of the tubes to act as though they were connected in push-pull with condenser 14, effectively short-circuiting coils 12 and 13. The frequency of this parasitic may be of the order of ten times the desired frequency. However, in accordance with the invention, it is effectively suppressed by the resistors 17 and 20 connected in series in the respective grid circuits. The resistance necessary for suppression of parasitics of this type is low and may be of the order of only a few ohms. Additionally to suppress the foregoing parasitic and additional parasitics, each side of each filament is connected through resistors 54 and 55 and capacitors 56 and 57 to ground, the common circuit including the conductor 29. These circuits, including both resistance and capacitance, bypass the parasitics through circuits of high loss, thus suppressing same. If desired, these by-pass circuits may be replaced by resistors connected directly in series with each side of each filament. However, the by-pass circuits are preferred. The choke coil 14a in the anode circuit also functions to dampen or suppress parasitics.

There sometimes appears in the grid-cathode circuit a parasitic having a frequency within the audio range. This parasitic is effectively suppressed by means of the resistor 24. The resistor 25 and the capacitor 60 comprise respectively the grid leak resistor and capacitor and provide in manner well understood by those skilled in the art a negative bias on the respective control grids. The "C" battery provides a minimum negative

bias for the respective grids during stand-by periods.

The criss-cross capacitors 34 and 35 neutralize, as has already been explained, the grid-anode capacity of each tube and they respectively overcome the effect of unwanted feed back of energy from the output to the input circuit. In terms of operation this means that if the feed back coil 40—41 is moved out of inductive relation with the inductor 12—13 the oscillator will stop oscillating. Since there will not be a return of energy from the output to the input circuit when the feedback coils are in neutral or non-inductive relation with the inductor 12—13, the oscillator will not oscillate. In this respect the oscillator possesses one desirable characteristic of an amplifier. The advantage of insuring that oscillations will not be generated upon movement of the feedback coil to a neutral position is that the oscillator is quiescent before application of the load thereto. On application of the load the combined oscillator-amplifier can be made to generate oscillations of proper amplitude, thus simplifying the problem of loading and operating the same. In accordance with the present invention the oscillator or high frequency generator is at all times under control and at all times produces high frequency energy at the desired frequency, and with the desired amplitude, and in the substantial absence of parasitics of any consequential magnitude either before or during application of the load.

The present invention differs from push-pull oscillators of the prior art in that the neutralizing capacitors 34 and 35 feed back energy in manner to overcome the capacity feedback through the interelectrode capacity of the tubes 10 and 11, while at the same time the feedback coil 40—41 is arranged inductively to return a portion of the output energy to the tank circuit comprising the inductor 15 and the capacitor 16. These provisions, together with output and input tank circuits of relatively large current-carrying capacities and of high electrical efficiency, stabilize the frequency to an extraordinary degree. Relatively wide changes in the electrical constants of the load circuit do not tend to change appreciably the frequency at which the oscillator as a whole is intended to operate.

If desired, the feedback circuit may be coupled to the output circuit by means of a series tuned circuit instead of being conductively coupled through the closed switches 57 and 58. By opening these switches the capacitors 59 and 60*a* are connected in series in the feedback circuit.

The operation of the oscillator as a whole, as applied to the heating of the plywood bundles 47 and 48, will be described following the discussion of combined electrical and mechanical features.

Referring to Figs. 2–4, the output coupling coil 45 is shown as comprising two turns of pipe or tubing, preferably copper, with the respective ends of the coil supported from a pair of pipes 45*a* and 45*b* which terminate in L-fittings 59 and 60, into which are secured additional lengths of pipe 61 and 62. These additional lengths of pipe are provided with bearings 63 and 64 as shown in Fig. 4. From one of the short sections of pipe there extends an operating arm 65 which is welded or otherwise formed integrally therewith. Resilient contact fingers 66 and 67 extend from each bearing member 63 and 64 into sliding and wiping engagement with the pipes 61 and 62. In this manner good electrical contact is

established to the bearings, from which the further electrical connections are made. Thus, from bearing 63 one connection is completed by a sheet of copper 70, connected to ground and to the steel supporting frame F. This connection corresponds to the one in Fig. 1 where one side of the coil 45 is shown directly connected to ground G. The other connection from coil 45 is by way of a tubular or pipe conductor 68 which is fluid-flow connected with the conductor 62, Fig. 4. The respective bearings 63 and 64 are mounted on electrical insulating blocks 72 and 73 which may be of hardwood and bolted to the channel iron frame F.

In order to rotate the coil 45 from the position shown in Fig. 3 in a clockwise direction about the pivotal axis and toward an electrically coupled position with respect to the coil 12—13, the operating arm 65 is connected by a link 75, Fig. 3, to a disc 76 which may be driven by any suitable means such as by the electric motor 77. For example, as the disc 76 is rotated in a clockwise direction, as viewed in Fig. 3, the link 75 rotates the arm 65 in a clockwise direction to move the output coil 45 into a position of inductive coupling with respect to the tank coil 12—13.

Though additional turns may be provided, each of the sections 40 and 41 of the feedback coil is shown in Fig. 2 as comprising a single turn, the respective ends of which terminate in L-shaped fittings into which there are threaded relatively short lengths of pipe 80 and 81. The corresponding pipe, or tubular conductor 80, from each coil has a second L-fitting on the end thereof, into each of which there extends one end of a horizontal pipe or tubular conductor 82. As best shown in Fig. 5, the horizontal conductor 82 is journalled as at 83 and 84.

Attached to the horizontal pipe or conductor 82 is an operating arm 85, the free end of which is connected to a link 95 for rotation of the conductor 82. In Fig. 5 the coils 40 and 41 have been diagrammatically illustrated above their respective supporting pipes 80 and 81. Thus, it will be observed that the right hand side of coil 40, as viewed in Fig. 5, is connected by the pipe-conductors 80, 82 and 80 to the left hand side of coil 41. The right hand side of coil 41 is connected to the pipe-conductor 81, which in turn is fastened to an arcuate conducting member 87, Fig. 3, carried by an insulating member 88 which in turn is secured to the pipe-conductor 82. The conducting segment 87 has cooperating with it a plurality of resilient contact fingers 89 which are carried by a tubular conductor 93. Similarly, the left hand side of coil 40, as viewed in Fig. 5, is connected to and supported by the pipe conductor 81, which is fastened to a similar arcuate conducting member carried by an insulating segment 91, which is in turn secured to and carried by the conductor 82. Resilient contact members 92 complete the connection from the left hand side of coil 40 to a conductor 90, as viewed in Fig. 5. Thus the conductors 90 and 93 though stationary, are effectively connected to the coils 40 and 41. The arrangement is such that these coils inductively assist each other. That is, the voltage induced in them is cumulative.

As shown in Fig. 3, the free end of the operating arm 85 is connected to one end of a link 95 with the opposite end thereof connected to a disc 96 driven by a motor (not shown). Upon clockwise rotation of the disc 96 as viewed in Fig. 3 the feedback coil comprising the two sections 40 and 41 is moved in a counter-clockwise direction and

into inductively coupled relation with the tank coil 12—13. It will now be seen that the horizontal conductor 82 not only serves to support the feed back coils 40 and 41 but it also serves electrically to connect the end of one coil with the end of the other coil. The conductor 82 also provides the pivotal support about whose axis the coils 40 and 41 may be rotated. Conductor 82 also supports the V-shaped insulating members 88 and 91 which carry the arcuate conducting members through which the opposite ends of the coils are connected to the conductors 90 and 93.

Energy induced in the feed back coil 40—41 flows by way of conductors 101 and 102, Fig. 2, to the input tank circuit. It will be observed that these conductors are also tubular and are respectively connected to the conductors 90 and 93. For example, as shown in Figs. 2 and 5, the conductor 101 by an L-fitting is connected to a vertical conductor 104 which is threaded into an L-fitting, Fig. 5. The connection from the conductor 102 into the conductor 93 is made in like manner by vertical conductor 103.

Cooling water may be circulated through the output coupling coil 45, as by the rubber or insulating hose connection indicated at 106 and the outlet tubular conductor 68, which leads, Fig. 2, to a second tubular conductor 107. From inlet 106, the flow is through the tubular conductor 61, Fig. 4, forming the left hand horizontal support, through the vertical conductor 45*a*, the tubular coil 45, the other vertical conductor 45*b* and thence through the other horizontal pipe 62 to the outlet pipe 68 and to conductor 107. As diagrammatically shown in Fig. 2, the conductor 107 leads to a tuning coil or inductor 107*a*, thence through a concentric line 107*b* to the platen 51 of the press. The fluid outlet is taken from near the end of the inner conductor of the line 107*a* as by insulating hose or tubing 107*c*.

The tank coil 12—13 is also fluid cooled. As shown in Fig. 3, the coil section 13 has an inner flow channel 13*a* and a separate outer flow channel. In other words, the coil sections 12 and 13 are each constructed of double tubing or of a single tube having separate flow channels therein. Electrically the inner and outer sections are of course united. The inlet is indicated at the pipe 108, Fig. 2, and the fluid flow may be traced through the control valve 109, the pipe 110 which leads to a rubber or insulating hose 111 coiled on a suitable insulating support 112 located at the central part of the coil assemblies. The opposite end 111*a* of the insulating hose is connected to the inner fluid channel of the coil 12. The fluid flows through the inner channel and exits by way of pipe 114 in which there is included a T-connection 115 which is plugged so that all fluid flow is by way of the line 116 through the valve 117 and to the lowermost part of the cooling jacket 118 of one of the tubes. The fluid returns by way of the branch lines 119, 120, valve 121 and a pipe line 122 which is located directly below the pipe line 114. The line 122 is connected to the outer flow channel of the coil 12. It may here be observed the upper line 114 is extended beyond the T-fitting 115. This extension provides an electric connection by way of conductor 123 to the anode of the tube cooled by the jacket 118.

Continuing with the description of the flow of the cooling fluid, it flows through the outer flow channel of the coil 12 and from the opposite end of the coil through pipe 124 to the inner flow channel 13*a*, Fig. 3, of the coil 13, from which it exits by a pipe line 125 located directly above

the pipe line 126. The pipe 125 leads to the cooling jacket 118*a* of the other tube. The return circuit is by way of the line 126, Fig. 2, and through the outer flow channel of coil 13, thence through a length of rubber or insulating hose interwound with the hose 111. The cooling fluid or water exits from the system through the line 127, Fig. 2.

While a suitable fluid circulating system has been illustrated it will be understood insofar as the electrical operation of the system is concerned, the coil assemblies may be air cooled, either by circulation of air or by radiation of heat directly into the atmosphere.

The assembly of the stationary coil 12—13 and the pivotally mounted coils 40—41 and 45 is relatively compact and comprises a sub-assembly which is directly incorporated into the mechanical structure forming the system as a whole. If desired, the functions of the pivoted coils may be interchanged, that is, the output coil 45 may be stationary and the tank inductor coil 12—13 mounted for pivotal movement; or coils 40—41 may be interchanged in function with coil 45. The sub-assembly of coils is shown in Fig. 3 to be mounted upon the frame F which comprises vertical channel irons and horizontal crossbars of insulating material, preferably hardwood. The motors which operate the coils 40—41 and 45 are mounted at the base of the frame which also carries the support for the rubber or insulating tubing 111. The axes about which these coils rotate are located so that the respective coils may be rotated or swung into and out of inductive relation with the divided tank coil 12—13.

Again referring to Fig. 2, the connections from the feed back coils 40 and 41 are by way of conductors 101 and 102. These connect directly with an exciting coil 42 comprising a tubular conductor supported directly above the input tank inductor 15. Though a single turn is shown it is understood additional turns may be utilized if desired. The capacitor 16 comprises a series of condenser plates located one above the other, the assembly as a whole being disposed directly beneath the coils or inductors 15 and 42. As best shown in Fig. 6, the coil 42 is supported by means of porcelain insulators 128, corresponding ends of which insulators are attached to coil 42 with the opposite ends thereof attached to insulating cross members 129 and 130 of a supporting frame. These cross members are carried by upright supports 131 and 132. The upright supports 131 for the cross member 129 are provided with a plurality of holes 131*a* and the upright supporting members 132 for the cross member 130 are provided with similar holes 132*a*. It will thus be seen that the cross members 129 and 130 together with the insulators 128 and the coil 42 form a unit which may be held in different predetermined positions depending upon which of the vertically spaced holes 131*a* and 132*a* are utilized to receive the fastening bolts which extend through supporting angle irons carried by the cross members 129 and 130. As shown, the coil 42 is relatively close to the cooperating coil 15. By moving the assembly upwardly, this spacing may be increased thereby to decrease the coupling between the coils 42 and 15. The input tank coil or inductor 15 is constructed of copper pipe or tubing of substantial diameter. For example, in one embodiment of the invention the diameter of the copper pipe was between three and four inches. The inductor 15 comprises two U-shaped sections with the respective arms

thereof extending toward each other. The closed ends 15a and 15b extend slightly beyond the upright supports 131 and 132. The ends of the inwardly extending arms terminate in L-fittings into which there are solder-sweated depending tubular conductors 138—141. These depending tubular conductors are respectively supported on insulators, three of which are shown, the insulators 142—144. The depending conductors 140—141 are interconnected by a shorting bar 145 which by means of clamps 146 and 147 may be secured in any desired position along the lengths of conductors 140 and 141.

Electrically the effect of moving the shorting bar 145 upwardly from the position illustrated is to decrease the inductance of the coil 15. This is desirable for initial adjustment of the oscillator as a whole. The opposite depending conductors 138 and 139 are conveniently located for short electrical connections to the tank capacitor 16. One connection, from the depending conductor 138, is completed by means of a relatively wide band or strap of copper 148. One end is electrically connected to the conductor 138 and at the opposite end is electrically connected to one set of the plates 16a of the capacitor 16. Similarly, a like strap-conductor (not shown) extends from the other depending conductor 139 to the other set of plates 16b of the capacitor 16. In addition to the support by the insulators 142—144 at the bottom of the frame, the coil 15 is supported from lower cross bars 150 and 151 of the frame by means of insulators 152—155. The cross bars and upright support members thus far described may be and are preferably constructed of hardwood having good insulating properties. This superstructure as a whole may be carried by metallic channel irons 156 having their lower ends interconnected by means of a rectangular metallic frame 157.

The plates 16a and 16b which form the capacitor 16 are respectively provided with four rods which carry plate-spacing members. Two of these rods, 170 and 171, for the plates 16a, appear in Fig. 6. One of these rods, 169, for the plates 16b, may be seen in Fig. 6, as well as the ends of the two rods on the opposite side of plates 16b. These rods are carried on cross members. For example, the rods 170 and 171 are bolted to the cross member 172, itself supported on insulators 173 and 174, which in turn are fastened to the frame. Similarly, the insulators 175 and 176 support a similar cross member (not shown) through which the rod 169 and its companion rod (not shown) extend. The rods 170 and 171 extend through and are secured to an upper cross member 174a carried by insulators 166. On the opposite side of the plates 16a like rods extend through the cross member 167 carried by the insulators 165. These insulators are supported from a rectangular frame 160 carried by four bolts, two of which, the bolts 161 and 164, are shown.

The two rods, including the rod 169 for the plates 16b, extend through a cross member 168a carried between the depending insulators 165. The two rods on the opposite side of plate 16b extend through and are fastened to the cross member 168, carried by two depending insulators, only one of which, the insulator 166a, is shown.

It will thus be seen that the capacitor 16 is of rugged construction. It may also be observed that from the frame 160 there extend upwardly supporting members for an insulating cross member 180 which also carries two insulators, 181 and 182, which assist in supporting the ends of conductor 42 from which extend the conductors 101 and 102.

By utilizing the relatively large conductor to form the tank coil or inductor 15, the tank circuit including this coil and the capacitor 16 has a high electrical efficiency. Its resistance is not only low but it also has a large surface from which any heat generated therein is quickly dissipated or lost. In terms of the Q of the circuit, it may be and preferably is of the order of 1000 or more. The grid tank circuit has a high capacitance, an exceedingly low resistance and a relatively low inductance. Electrically the input or grid tank circuit may be isolated from the anode tank circuit. It is inductively coupled thereto through the adjustable feed back coil 40—41. This grid tank circuit functions to store far more energy than is needed to control the grids of the respective tubes 10 and 11, Fig. 1. By storing a relatively large amount of energy as compared with that dissipated in the control of the tubes 10 and 11 the circuit is stable. There is little tendency for the frequency to deviate due to reflected impedance from the load circuit. The rectangular configuration of the tank circuit is advantageous in that relatively short leads may be used between the tank coil and the grids of the tubes. In other words, as shown in Fig. 2, the tube locations are adjacent the opposite ends of the rectangular tank circuit and the leads from the grids to the tank circuit are relatively short. Specifically, one grid may be connected to the closed end 15a and the other grid may be connected to the closed end 15b of the coil 15 as by a suitable clamp or by a soldered or brazed connection such as are well known to those skilled in the art. It may be further observed that the adjustable taps 18 and 21 of Fig. 1 diagrammatically indicate adjustability of the voltage applied to the respective grids of the tubes 10 and 11. While this diagrammatic adjustment may be utilized, the shorting bar 145 of Fig. 6 performs a like electrical function and has the advantage that the input signals to the respective grids are simultaneously adjusted in magnitude depending upon the position of the shorting bar 145 with respect to the depending conductors 140 and 141.

The neutralizing capacitors 44 and 45 of Fig. 1 and the plate circuit capacitor 14 have not been illustrated in Figs. 2 and 6 of the drawings inasmuch as they may be of conventional design. The output capacitor 14 may also be generally similar to the design of the input capacitor 16. The spacing and size of the plates will be selected to meet the voltage-capacity requirements.

Referring to the modified form of the invention as illustrated in Fig. 7, parts corresponding with those of Fig. 1 have been identified with the same reference characters. These parts perform identical functions and the description thereof need not be repeated. In accordance with Fig. 7 the feedback circuit is tuned by means of capacitors 190 and 191. These capacitors are of substantial size so that the closed circuit including the feedback coil 40—41 and the input coil 172 provide for the storage of a relatively large amount of electric energy, and substantially in excess of that required to control the grids of the tubes 10 and 11. In other respects, the system of Fig. 7 operates in the manner already described in connection with Fig. 1.

In accordance with a further modification of the invention, for some applications a simplified circuit of the type shown in Fig. 8 will be satisfactory. In accordance with this system the re-

spective grid circuits of the tubes 10 and 11 are conductively connected to the respective feed back coils 40 and 41. The anode tank circuit comprising tank coil 12—13 and capacitor 14 in this instance, determines the output frequency. As before, the cross-cross capacitors 34 and 35 in combination with the grid biasing means, including the C battery, resistor 25 and the capacitor 60, prevent the generation of oscillations whenever the feed back coils 40 and 41 are moved to their neutral positions with respect to the tank coil 12—13.

A further modification of the invention is shown in Fig. 9. A single electric valve 199 has its anode connected to a tank circuit comprising coils 200, 201, and a capacitor 202. A single feed back coil 40 is conductively connected through the C battery to the grid-cathode of the valve. In order to prevent oscillations when the coupling coil 40 is in the neutral position, a voltage of correct phase to neutralize the interelectrode capacity of the tube 199 is derived through capacitor 203, and fed back to the grid-cathode circuit. It will be observed the source of anode potential is applied from the choke coil 204 to a point intermediate the coils 200 and 201. By so locating the input circuit from the anode source of supply a neutral point is established between the coils 200 and 201. The result is that the instantaneous voltage across the coil 201 is 180° out of phase, with respect to the instantaneous voltage across the coil 200. In this manner a voltage of correct phase is derived, through the capacitor 203, effectively to neutralize the grid-cathode capacity of the tube 199.

In the various modifications of the invention, the principle of rotating the feed back coils with respect to the tank coil is utilized. While this arrangement is desirable it presents mechanical problems, solutions of which have already been presented in connection with the description of the disclosures of Figs. 2–5. A further modification of an adjustable coil-supporting assembly is shown in Fig. 10. If it is desired to rotate the tank coil 12—13, diagrammatically illustrated in Fig. 10, the supporting conductors 45*a* and 45*b* may have insulatingly supported from them a third conductor 210, carried by suitable insulators such as the insulator 211. A flexible conductor may be attached to the conductor 210 by means of a clamp 211*a*, with additional circuit connectors 212 and 213 provided for the connections to the outer end portions of the respective coils 12 and 13.

A modified form of the feed back coil assembly of Fig. 5 is illustrated in Fig. 11. In accordance with this modification of the invention, the frame F has dependent legs 215 and 216, on which are mounted bearing members 217 and 218. These bearing members rotatably support a conductor 219, on the respective ends of which are L-fittings 220 and 221. Into each fitting there extends the respective conductors 222 and 223, which lead directly from coils 224 and 225. These coils are of the "pancake" type, that is, spirally wound turns are all located in the same plane. Connection is made to the inner ends of the respective coils by means of rigid conductors 226 and 227, which terminate in L-shaped fittings 228 and 229. The conductors 222 and 226 are mechanically locked together by insulating members 230. The insulating members 231 perform the same function for the conductors 223 and 227. The respective L-fittings 228 and 229 have extending from them conductors 232 and 233, on which are

mounted additional L-fittings 234 and 235, each of which is provided with a plurality of resilient contact fingers which insure intimate and low resistance electrical contact therewith. The L-shaped fittings 234 and 235 have extending from them additional conductors 236 and 237, to which the feed back conductors 103 and 104 may be connected in manner already described in connection with Figs. 2, 3 and 5. The operating member 238, for operating the respective feed back coils 224 and 225 is in this instance mounted between the bearing members 217 and 218.

Where the supporting frame F is located below the coil assembly the construction of Fig. 12 may be conveniently utilized. The stationary bearing members 240 and 241 rotatably support a relatively large cylindrical conductor 242, to which an operating lever 243 is secured. The conductor 242 has secured to its respective ends T-fittings 244 and 245. Feedback coils 246 and 247 are supported from these T-fittings by means of rigid conductors 248 and 249, which extend therefrom. The inner ends of the coils 246 and 247 are supported by conductors 248*a* and 249*a*, mounted at their lower ends in T-fittings 250 and 251. These T-fittings are rigidly connected to conductors 252 and 253, which extend inwardly and concentrically of the conductor 242. The respective inner ends of the conductors 252 and 253 are rotatably mounted within conductor 242 by means of the insulating bushings 254 and 255. Coupling members 257 and 258 are each provided with a plurality of resilient contact fingers which engage the respective ends of conductors 252 and 253 to complete an electrical connection therewith. From the couplings 257 and 258 there extend conductors 260 and 261 which may lead to feedback conductors, corresponding with the conductors 103 and 104, and 101 and 102, Fig. 2, for the return of energy to the input circuit of the oscillator.

It will be understood these alternate arrangements are equally applicable to the output coupling coil 45, or, if desired, the tank coil 12, 13 may be pivotally mounted for relative movement with respect to its associated coils 40, 41 and 45.

Before reviewing the operation of the system as a whole as applied to the heating of suitable dielectric materials, such as the bundles of plywood 47 and 48 shown in Fig. 1, a brief review of the principles involved in the heating of dielectric material will be presented. Basically, in any electric circuit the power consumed is the product of the voltage times the current times the power factor. In the form of an equation it is:

$$P=EI\cos\theta \qquad (1)$$

where P equals power consumed, E equals voltage, I equals current and the cosine θ equals the power factor.

Where the circuit includes a resistor and a capacitor in series, the current is equal to the voltage divided by the impedance, or mathematically:

$$I=\frac{E}{\sqrt{R^2+X^2}} \qquad (2)$$

where R equals the resistance in ohms and X is equal to the capacitive reactance in ohms.

By simple substitution then,

$$P=\frac{E^2}{\sqrt{R^2+X^2}}\cos\theta \qquad (3)$$

If the resistance is small, as it is with a substan-

tially pure capacitive load, it may be neglected. When neglected, the relationship simplifies to:

$$P=\frac{E^2\cos\theta}{X} \quad (4)$$

Inasmuch as the capacitive reactance X is expressed by the relation

$$X=\frac{1}{\omega C}$$

where ω equals $2\pi f$ (f being the frequency in cycles per second), and C the capacity of the load in farads, Equation 4 may be expressed

$$P=E^2 2\pi f C\cos\theta \quad (5)$$

However, the capacity of a parallel plate condenser is frequently expressed:

$$C=\left[\frac{KA}{d}\right]B \quad (6)$$

where A is the area of one plate in square inches, d the spacing between the plates in inches, B a constant to convert the expression to microfarads and K is the dielectric constant of the dielectric material or load between the electrodes.

Substituting Equation 6 in 5 and multiplying numerator and denominator by d, there is obtained

$$P=\left[\frac{E}{d}\right]^2 2\pi fKADdB\cos\theta \quad (7)$$

The expression

$$\frac{E}{d}$$

represents the applied voltage divided by the spacing of the plates in inches. That relationship defines the voltage gradient G, expressed in volts per inch of the material between the electrodes.

The further substitution may be made with the result:

$$P=G^2 2\pi fKVB\cos\theta \quad (8)$$

In the foregoing V equals the volume which is equal to A times d and inasmuch as the dielectric constant K times the power factor equals the loss factor L. F. the equation may be further simplified and written

$$P=G^2 2\pi fVB(L.\ F.) \quad (9)$$

In other words, neglecting the resistance as shown by the simplified Equation 4, the power consumed in generating heat between the electrodes varies with the square of the voltage gradient. As the voltage is increased, the heating effect is rapidly increased. The heating effect varies directly with the frequency, the volume of material being heated, and with the loss factor.

Equation 9 indicates that any particular heating problem may be approached in the following manner. If a material of a certain volume is to be heated, the first consideration will be the spacing between the plates. An applied voltage as high as will be reasonably safe from the standpoint of flashover and the like is preferred inasmuch as the heating varies with the square of the voltage. Since the higher the voltage the more rapid will be the heating of the dielectric material, the actual voltage utilized thus depends on the physical dimensions of the material to be heated. After this variable has been determined, the only other variable in Equation 9 over which the operator has any control is the frequency. In consequence, a frequency will be selected which will produce the required heating in the desired period of time. For many applications it has been found that frequencies from 1,000,000 to 10,000,000 cycles per second are satisfactory, although there is nothing critical about the frequency. It may be low, thousands of cycles per second, or high, as in megacycles per seconds.

Where the dielectric to be heated presents substantial series resistance, it will be found that certain frequencies may produce greater heating effects than frequencies above and below that frequency. This is due to the fact that the equation, as shown by Equation 3, is not linear. That is, the impedance is a complex expression, the square root of the sum of the respective squares of resistance and reactance. The square of the voltage applied to the electrodes divided by this complex expression and the quotient multiplied by the power factor gives the power consumed or used in heating the material between the electrodes. For such materials, the maximum applied voltage is first selected from the voltage gradient standpoint. Inasmuch as the resistance of the material can be measured, the equation may then be solved for the frequency which will produce the maximum heating. This solution of Equation 3 is conventional and need not be presented here.

Again referring to Fig. 1 or Fig. 7, the tuning coil **46** comprises a relatively large coil, each turn of which may consist of copper tubing of substantial diameter. This tuning coil **46** is adequate to introduce enough inductance in series with the output coil **45** to tune the output circuit to resonance. The capacitance in the output circuit is supplied by the load, the dielectric material comprising the plywood bundles **47** and **48**. The electrodes form in effect two plates of a capacitor separated by the material being heated or treated. By tuning the output circuit to resonance at the applied frequency and adjusting the coupling between coils **12**, **13** and **45**, the load presents to the power generator a resistance of substantially constant magnitude. In this manner, a much greater efficiency is attained, a much greater percent of the power input is converted into heat within the load illustrated as the plywood bundles **47** and **48**. This provision is in contrast with prior practice in which the load consisted of a transmission line terminated at a fixed antenna or radiating terminal. The systems of Fig. 1 or Fig. 7 preferably operate in manner similar to class C amplifiers. That is, the bias as applied by the bias battery C, the resistor **25** and the capacitor **60** is sufficiently negative to prevent anode or plate current flow except during a fraction of the positive half cycle of the grid excitation cycle. This means that the grid bias must be reduced by the input signal to approximately zero before the plate current can flow. At that time an impulse of plate current flows from one or the other of the anodes of the tubes **10** and **11** to the cathode through the tank circuit **12—13—14**. These current impulses through the respective anode or plate circuits of tubes **10** and **11** supply energy to the tank circuit **12—13—14** and produce oscillating current flow therein at a frequency depending upon the relative values of the inductance of coil **12—13**, and of the capacitance of the capacitor **14**. There are inherent losses within the tubes themselves. The principal one is that due to the heating of the anode. Because of the heat developed at the anode it is necessary to provide the fluid cooling system heretofore described. The heating of the anode is proportional to the prod-

uct of the instantaneous anode current times the instantaneous anode-cathode voltage. For most efficient operation, it would be desirable to provide for anode current flow at a time when the anode voltage is at its minimum. While this may be done, the duration of the current impulse must be reduced to such a degree that the total power output is also reduced. Therefore, the preferred operation is with a grid bias such that the anode current flows from a tube during a part of a half cycle, with resultant efficiencies of conversion of the direct current power into high frequency high voltage alternating current power of the order of sixty percent to seventy-five percent.

Inasmuch as the foregoing considerations present the requirements for operation in accordance with this invention, it will now be seen that the foregoing manner of connecting the load to the secondary circuit has many advantages. The voltage applied to the load, by reason of the transformation from the primary winding, the coil 12—13 to the secondary winding comprising the coil 45, may be continuously varied. That voltage may be either greater or less than across the tank condenser 14. By placing the load in the secondary circuit, varying values of resistance may be reflected into the primary circuit. This makes possible the following procedure in loading the power amplifier.

With the respective coils in approximately the positions shown in Fig. 3 and the circuits otherwise energized as indicated in Fig. 1, the motor controlling the feed back coil 40—41 is energized in a direction to move this coil toward the output coil 12—13. A small voltage is thereby induced into the feed back coil 40—41 which of course is transmitted to the coils 42 and 43 at the input side of the amplifier or oscillator. The motor 77, Fig. 3, is then energized in a direction to move the output coil 45 toward the tank coil 12—13. While in a position of loose coupling the secondary circuit including the coil 45 is tuned by the inductor 46 to resonance. Resonance may be obtained by measuring the voltage across the load, that is, between the center platen 51 of the press and ground G. Upon varying the tuning coil or inductor 46, this voltage will rise to a maximum, indicative of a resonant condition. When this is done, the output coil 45 is moved to a position of greater coupling with respect to the coils 12—13. This has the effect of decreasing the voltage across the coils 12—13 and of increasing the direct current input from the B supply. The feed back coil 40—41 is then moved to a position of greater coupling with respect to the coil 12—13, and the greater excitation applied to the input tank circuit 15—16 and to the grids of the tubes produces a rise in the voltage across the output tank coil 12—13, and a rise in the current through the coils. This in turn increases the voltage across the load. The operation is then repeated. The output coil 45 is moved to a position of still greater coupling, followed by adjustment of the feed back coil 40—41 to a position of greater coupling. By measuring the direct current flowing to the circuit from the source of anode supply and the voltage developed across the output coil 12—13 a direct indication is obtained as to the power output. When these two quantities reach predetermined values as determined by the voltage and current load characteristics of the tubes utilized, the operator knows that the oscillator has reached full load, and it is operating with good plate efficiency.

It is to be observed that the foregoing adjustments are made during operation of the oscillator or high-frequency generator. In similar manner, adjustments may be made at any time during the operation of the oscillator. In this way, adjustment of the applied load may be made at any time depending upon the heating requirements as imposed by the character of the material which is being heated.

While embodiments of the invention have been described, it will be understood that further modifications may be made without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. In a high-frequency electrical generator of the push-pull type having a pair of valves each provided with an anode, a cathode, and a control grid, the combination of an output tank circuit connected to said anodes, and an input tank circuit connected to said control grids and including a coil formed by a conductor of large cross-sectional area and of exceedingly low resistance at the operating frequency, said coil having a generally rectangular shape and at its midportion having two pairs of depending legs, an adjustable shorting bar connected across an adjacent pair of said legs, a capacitor disposed between said two pairs of depending legs, one set of plates thereof being electrically connected to one of the other of said pairs of legs and the other set of plates being electrically connected to the remaining one of said legs, an exciting coil of generally like rectangular construction, means including electrical insulators for supporting said exciting coil adjacent to and in inductive relation with said first-named coil, an electrical circuit including said exciting coil and a second coil inductively coupled to said output tank circuit, and means connecting said control grids to separated points on said first-named coil.

2. In a high-frequency generator including at least one electric valve, the combination of an output tank circuit connected to said valve, an input tank circuit connected to said valve and comprising an inductor formed by a conductor of large circumferential area and having a double U-shape, the respective legs of each U-shaped portion extending towards each other and in the same plane, the four ends of the adjacent legs thereof having depending end portions, an adjustable conductor interconnecting two of said depending end portions, a capacitor comprising two sets of plates disposed adjacent said inductor, and means connected one of the remaining depending end portions to one set of plates, and the last of said depending end portions to the other of said sets of plates, means for applying to said input tank circuit energy from said output tank circuit comprising a generally rectangular shaped coil overlying said inductor and inductively coupled therewith, and means for supporting said coil in selected fixed relation therewith.

3. In a high-frequency generator, an input tank circuit comprising a capacitor having two sets of plates spaced one from the other, a pair of upstanding conductors, means electrically connecting one set of plates to one of said conductors, and the other set of plates to the other of said conductors, said upstanding conductors being in a region spaced above said capacitor and extending outwardly from each other and back again towards each other to form a single turn coil, said conductors in the region where they again approach each other having depending end portions, and an adjustable shorting bar slidable

with respect to said depending end portions and electrically connecting them together.

4. An oscillator of the push-pull type comprising a pair of electric valves each provided with an anode, a cathode, and a control grid, an output tank circuit connected to said anodes and including a divided coil forming the inductor thereof, a capacitor in shunt with said inductor for tuning the same to resonance at a desired output frequency, a pair of coils each having ends which extend away from the peripheries thereof, separate conductive means electrically insulated from each other and rigidly connected to the respective ends of said pair of coils forming a pivotal mounting for each of said coils, and means for moving each of said coils between positions of minimum and maximum coupling with respect to said divided coil.

5. In an oscillator, a coil formed of copper tubing, rigid conductive tubes connected to the respective ends of said coil and forming the support therefor, means including one of said rigid tubes forming a pivotal support for said coil, and means connected to said one tube for adjusting the position of said coil.

6. In a high-frequency system having thermionic tubes, the combination of a cooling system which comprises an inductance coil formed in two sections and electrically connected together, each section of said coil having a double flow passage therethrough, means including fluid connections for introducing cooling fluid through a flow passage of one coil and for circulating it around the anode of one of said tubes, returning it through the other flow passage of said one section, thence through a flow passage of the other section, and around the anode of another tube, with a return path through the other flow passage of said other section.

7. In an oscillator, a coil formed of a rigid electrical conductor, rigid supporting conductors respectively connected to the ends of said coil, means for pivotally mounting said coil from the ends of said supporting conductors comprising a bearing extending at right angles to said supporting conductors to provide pivotal support for one of them and an electrical connection thereto, and means mechanically supporting said other supporting conductor and providing an electrical connection thereto.

8. In an oscillator, a divided coil comprising at least two coil sections, rigid supporting conductors mechanically and electrically connected to the respective ends of said coil sections and forming the sole support therefor, pivotal means mechanically and electrically connecting two of said supporting conductors, and electrically separate means mechanically and electrically connected to the remaining conductors to assist in the support of said coil sections without interfering with pivotal movement of said coil about said pivotal means.

9. In an oscillator of the push-pull type having a tubular inductor common to tubes connected in push-pull circuit relation, the combination of means for cooling the anodes thereof, which comprises means for introducing a cooling fluid at the electrical center of said inductor, means for conducting said fluid through a restricted flow passage of one half of said inductor and into cooling relation with one of the anodes of one of the tubes, means for returning said fluid through a separate flow passage of said one half of said inductor to the electrical center thereof, means for passing the fluid so returned through

a flow passage of the other half of said inductor into cooling relation with the anode of the other of said tubes, means for returning the fluid through a separate flow passage of said other half of said inductor to the electrical center thereof, and means for producing forced flow of said fluid through said coil and in cooling relation with said anodes.

10. An inductance system for a self-excited oscillation generator comprising a tank circuit inductor formed in two sections spaced one from the other, each section having a double fluid flow path, means connecting one path of one section in series with one path of the other section, said means also connecting said two sections to form a single electrical path between them, a pair of coils movable into and out of inductive relation with said inductor, means electrically interconnecting said pair of coils and also forming a pivotal mounting for movement thereof about an axis removed from the periphery thereof, an output coil formed of an electrically conducting fluid conduit, supporting means connected to each end of said output coil for pivotally mounting it for movement into and out of inductive relation between said two sections, means for circulating cooling fluid through said supporting means and the turns of said output coil, and means for independently adjusting the positions of said pair of coils and of said output coil with respect to said inductor.

11. An inductance system for a self-excited oscillation generator comprising a tank circuit inductor formed in two sections spaced one from the other, each section having a double fluid flow path, means connecting one path of one section in series with one path of the other section, said means also connecting said two sections to form a single electrical path therebetween, a pair of coils movable into and out of inductive relation with said inductor, means electrically interconnecting said pair of coils and also forming a pivotal mounting for movement thereof about an axis removed from the periphery thereof, an output coil formed of a fluid conduit which is also an electrical conductor, supporting means connected to each end of said output coil for pivotally mounting it for movement into and out of inductive relation between said two sections, means for circulating cooling fluid through said supporting means and the turns of said output coil, means for independently adjusting the positions of said pair of coils and of said output coil with respect to said inductor, and an inductance coil of helical shape connected in fluid and electrical conducting series circuit relation with said output coil.

12. In a high-frequency heating system including an oscillator, an output coupling coil formed of a rigid electrical conductor, rigid supporting conductors respectively connected to the ends of said coil, means for pivotally mounting said coil from the end portion of at least one of said supporting conductors to provide pivotal support therefor, said means comprising a bearing extending at right angles to said supporting conductors, means mechanically and rotatably supporting said other supporting conductor and providing an electrical connection thereto, and means mechanically connected to one of said rigid conductors for adjusting the position of said coil about its said pivotal support.

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