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ELECTROPHYSIOTHERAPEUTIC APPARATUS

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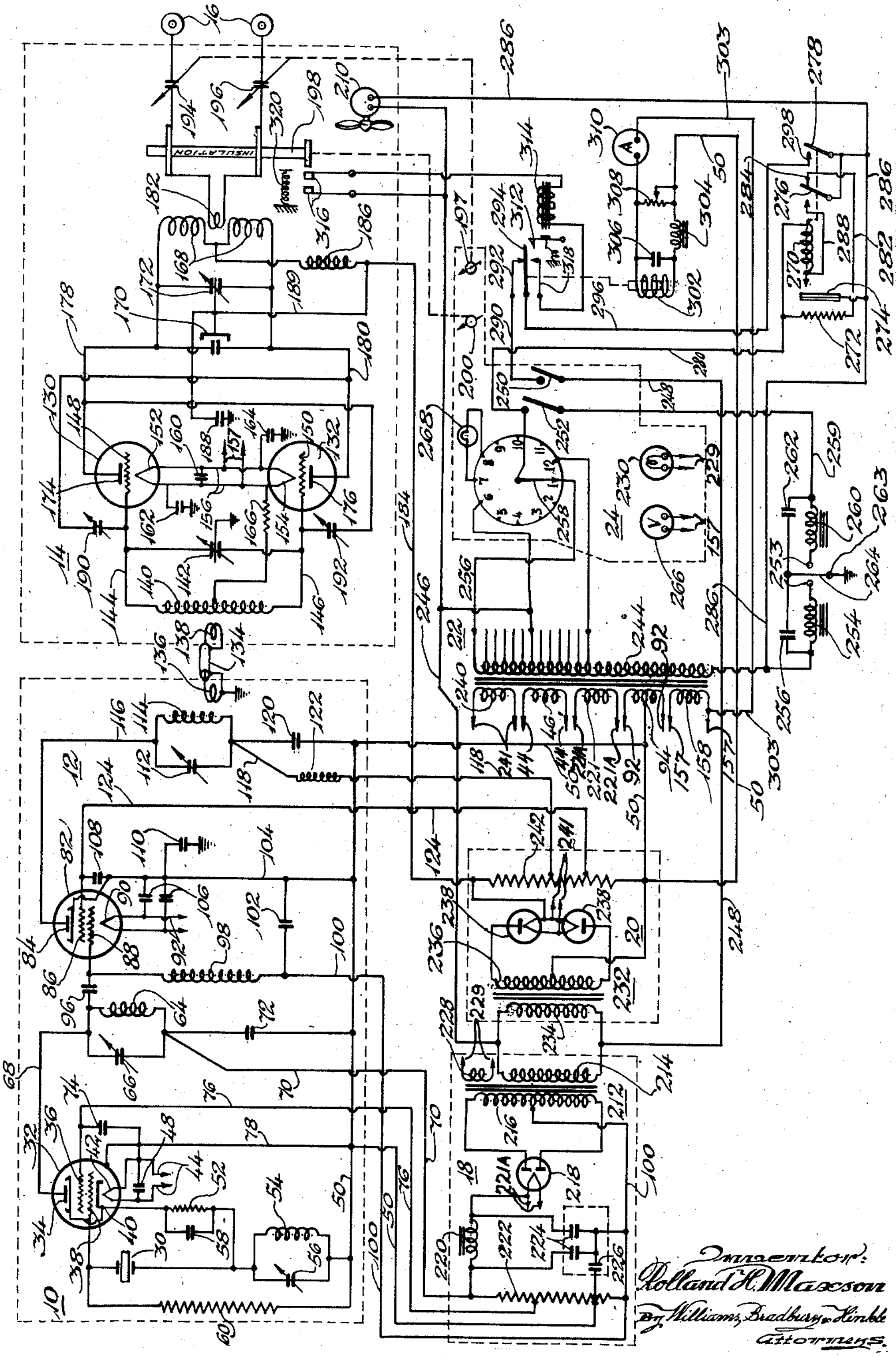

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ELECTROPHYSIOTHERAPEUTIC APPARATUS

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The present invention relates to electro-physiotherapeutic apparatus, and has for its primary object the provision of new and improved apparatus of this type which will not interfere with radio communication and which will operate satisfactorily and be safe under extreme operating conditions. The apparatus of the present invention operates at a specified frequency and within certain tolerance limits, and also in a specified frequency channel.

The electro-physiotherapeutic apparatus, or diathermy equipment as it may be called, of the prior art transmitted electromagnetic waves into space to a degree depending on a considerable number of complicated conditions difficult to control. As a result, the equipment has at least the potential, if not the actual, ability of transmitting signals which can be heard on radio receivers tuned to the diathermy frequency. The equipment includes what is essentially a high powered self-excited oscillator generating a frequency which may vary over a range of about 5% to 80%, causing interference in a great number of communication channels.

Most of the frequency shift in the prior art apparatus using oscillators of the self-excited type, is caused by the change in reactance of the plate tank circuit, i. e., the resonant circuit determining the frequency of oscillation. This change in reactance is due to variations in reactance of a patient's circuit coupled to the plate tank circuit, which reactance is reflected back into the tank circuit. A self-excited oscillator automatically adjusts its frequency to the value that causes capacitive and inductive reactance components to be equal. The resulting adjustment or shift in oscillation frequency is great because the reactance of the patient's circuit varies greatly with the wide range of patient applications.

The apparatus of the present invention includes a crystal controlled oscillator, preferably of the harmonic type, the output of which is supplied to an intermediate amplifier driving a final amplifier and isolating the final amplifier from the oscillator. In some respects the apparatus of the present invention may be compared to a crystal controlled radio transmitter, but while such a comparison can be made, there are many problems present in diathermy equipment which are not present in radio transmitters. For instance, in a transmitter the final amplifier feeds energy into a load having a constant resistance and with all reactance substantially tuned out. In contrast, the final amplifier of the present apparatus supplies energy to a load whose resistance as well as reactance varies over a wide range (because of the different positions of the applicator relative to the patient) and which reactance may or may not be tuned out of the circuit. If a conventional type of radio transmitter final amplifier were used, the reflected reactance in the tank circuit would not change the oscillator frequency, contrary to what takes place in the conventional self-excited oscillator type diathermy equipment, as heretofore set forth. However, even though a conventional radio transmitter final amplifier were used, the change in reflected reactance would cause an increased plate input at a lower plate efficiency and thereby overload the tubes. The reason for this is that the frequency cannot adjust itself to cause equality and cancellation of capacitive and inductive reactances in the plate tank circuit so that the reflected reactance in the tank circuit decreases the tank impedance and increases the plate input at a lower plate efficiency, the lowered plate efficiency being caused by a phase shift in the radio frequency plate current resulting from the reflected reactance. Thus the instantaneous radio frequency plate voltage is not 180° out of phase with the instantaneous radio frequency grid voltage. The tube space current thus flows at a higher value of plate voltage and produces an increased plate dissipation which might well be in excess of the tube's rated value, even though no energy whatever is being transmitted to the patient. This condition might arise when the reflected reactance was sufficiently high, as in the case where the applicator, which may take the form of a treatment drum, supplied by the apparatus is not in contact with the patient and is not "tuned to resonance" but is closely coupled to the final amplifier.

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It is, therefore, one of the primary objects of the present invention to minimize changes in plate tank circuit reactance due to reflected reactance from the load or patient's circuit. According to the instant invention, this is accomplished by (1) connecting the patient's circuit to the plate tank circuit of the final amplifier by means of a loose and variable coupling; (2) utilizing a plate tank circuit having a very high full load effective Q; and (3) preventing thermal deformation of elements of the tank circuit. The coupling to the plate tank circuit has associated with it a pair of series variable condensers whereby tuning out of the reactance in the patient's circuit can be effected. The coupling is variable, and while the coupling to the plate tank circuit is loose, it is sufficient to provide the requisite energy transfer to the patient. There is, however, a limit to the extent to which the coupling can be reduced and still have sufficient coupling to provide the requisite energy transfer to the patient. There exists also a probability the operator may not always accurately tune the patient's circuit (by means of the series condensers) so that some reactance will be reflected into the plate tank circuit. Accordingly, the present invention provides a further minimization of the effect of the reflected reactance upon the plate tank circuit by utilizing tank circuit elements having very low capacitive and inductive reactances, i. e., reactances that are relatively small compared to the shunt reflected reactance. The plate tank capacitance is made large and the inductance small in value, with the result that the tank circuit has a very high full load effective Q. For instance, the apparatus of the present invention may have at full load an effective Q preferably of about 85 as compared with value of about 10 to 20 for radio transmitters.

While the use of a plate tank circuit having a very high full load Q is effective in minimizing tank reactance changes due to reflected load reactance, it produces an increase in the effective radio frequency current circulating in the plate tank circuit. In accordance with another feature of the present invention, the effect of this increased current to nullify the stabilizing effect produced by the high Q circuit is prevented by maintaining the circuit at an even temperature.

It may be seen, therefore, that an object of the present invention is to provide a new and improved diathermy equipment producing an adequate energy input to the patient under all conditions without exceeding the rated plate dissipation of the electronic tubes even under the worst conditions of "out of resonance" operation of an unloaded applicator with full coupling, and wherein it is not necessary substantially continuously to adjust the resonance of the patient's circuit or the final amplifier plate tank circuit.

Another object of the present invention is the provision of a new and improved diathermy equipment of the type wherein the transfer of energy to the patient is effected electromagnetically through the use of a low impedance cable or applicator drum inductively coupled, as by a pick-up coil, to the plate tank circuit of an amplifier supplied with high frequency oscillations by a crystal controlled oscillator having the advantages set forth in the preceding paragraph.

Further objects and advantages of the present invention will become apparent from the ensuing description, in the course of which reference is had to the single figure of the accompanying drawing illustrating schematically one embodiment of the invention.

It may be well briefly to refer to the primary components of one embodiment of the apparatus of the present invention before proceeding with a detailed description thereof. The apparatus comprises, in the main, an oscillation generator and electron coupled amplifier **10**, the output of which is supplied to an exciter amplifier **12** supplying a final amplifier **14** having a pair of output or patient's terminals **16**. In the embodiment of the invention illustrated, these terminals are adapted to receive an applicator drum or a cable of a type commonly used with high frequency therapeutic apparatus, which has not been illustrated. The apparatus includes, in addition, a low voltage power supply unit **18**, a high voltage power supply unit **20**, a combination filament and voltage adjusting auto transformer **22**, and a control unit **24**.

The main elements referred to, and also other components to be referred to hereinafter, are all mounted in and upon a suitable portable cabinet which is preferably, but not necessarily, made of metal.

The oscillation generator and electron coupled amplifier **10** is piezoelectric crystal controlled and of the harmonic type. It is preferred that the crystal, indicated by the reference character **30**, be a quartz crystal and that the output of the oscillator be taken at the second harmonic of the crystal frequency. In the instant embodiment, the crystal has a frequency of 6.830 megacycles and a very low frequency drift with temperature. The oscillation generator and electron coupled amplifier comprises an electron tube **32** (preferably of the RCA type 6L6, a metal beam tetrode) including an anode **34**, a screen grid **36**, a control grid **38**, a cathode **40**, and a cathode heater **42** connected by conductors **44** to a secondary winding **46** of transformer **22**. A high frequency by-pass condenser **48** is connected across the terminals of the heater **42**.

The cathode of tube **32** is connected to a ground (at ground for radio frequency only) bus wire **50** through a self-biasing resistor **52**, shunted by a radio frequency by-pass condenser **58**, and a cathode reactance tank circuit comprising inductance coil **54** and an adjustable air spaced condenser **56** tuned to a frequency approximately halfway between the crystal frequency and the second harmonic, i. e. to a frequency of about 10.245 megacycles. This tank circuit provides plate impedance and radio frequency excitation (or feedback) to the control grid **38**. The crystal **30**, which is in the grid circuit, acts as a very high Q oscillation circuit and determines the oscillator frequency. Grid bias is furnished to the tube by the cathode resistor **52** and the grid leak resistor **60** connected across the ground conductor **50**. The plate and screen grid currents of the tube **32** produce a voltage drop across the bias resistor **52** and the rectified radio frequency grid current produces a direct current voltage drop across the resistor **60**, with the result that the two voltage drops bias the grid.

The electron coupled output circuit of the oscillator tube includes a plate tank circuit comprising inductance coil **64** and a variable air spaced condenser **66** tuned to a frequency of about 13,660 megacycles, i. e., the second harmonic of the crystal frequency. It is preferred that this tank circuit be tuned slightly off resonance in order to decrease the voltage applied to the grid of the tube of the exciter amplifier **12**. The tank circuit is connected to the plate **34** by conductor **68** and to the positive terminal of the plate supply voltage (to be described in detail hereinafter) by conductor **70**. A radio frequency by-pass condenser **72** is connected between the tank circuit and ground conductor **50**. The screen grid is also by-passed to ground for radio frequencies by a by-pass condenser **74** connected across the screen voltage supply conductor **76** and a conductor **78** leading to the ground conductor **50**. The conductor **78** is connected also to one of the terminals of the heater **42**.

The tube **32** should have a very small grid-to-plate capacitance (as is the case with the type of tube mentioned) in order that there be negligible energy fed back from the plate to the grid.

Furthermore, the plate and screen currents are limited well below the tube ratings by using relatively low plate and screen voltages and by applying a suitable grid bias through the use of the cathode bias resistor **52**.

The exciter amplifier **12** comprises a tube **82** (of the G. E. type GL-814, a transmitting beam tetrode power amplifier) having an anode **84**, a screen **86**, a control grid **88** and a filamentary cathode **90**. The cathode is connected by conductors **92** to the secondary winding **94** of the transformer **22** having its center tap connected to the ground wire **50**. The tube is operated as a class C power amplifier and it is loosely coupled to the oscillation generator through a relatively small coupling condenser **96** connected to the plate end of the plate tank circuit **64**, **66** and a grid reactor **98** connected to the grid and to a source of biasing voltage (to be described in greater detail hereinafter) by a conductor **100**. The loose coupling afforded by condenser **96** cuts down the excitation of exciter amplifier **12** applied to it from the oscillator, the oscillator being made relatively powerful to render it more stable. The radio frequency input circuit for the amplifier tube is completed by a by-pass condenser **102** connected across conductors **100** and **104**, the latter of which is connected to conductor **50** and to the cathode **90** through the by-pass condensers **106**. The screen grid **86** of tube **82** is by-passed to ground through a radio frequency by-pass condenser **108**. The ground conductor **50**, it should be noted, is connected to the chassis of the exciter amplifier and thus to the metal cabinet through a radio frequency by-pass condenser **110**. This connection should be made at a location having a zero or minimum radio frequency voltage.

The negative terminal of the plate supply is preferably not grounded to the chassis upon which the apparatus is mounted and the cabinet, which is conductively connected to it, for safety reasons. There is less danger of accidental contact with high voltages by a person working on the apparatus if the negative plate voltage is insulated from the cabinet and chassis. The negative plate supply circuit and the chassis are, however, maintained at ground with respect to radio frequency by the by-pass condenser **110** and other condensers hereinafter to be referred to. The condenser **110** is connected across the negative plate supply or ground conductor **50** and the chassis, while the chassis and cabinet are connected to a good ground.

The exciter amplifier output or plate circuit includes a tank circuit consisting of a variable air spaced condenser **112** and an inductance coil **114** tuned to a frequency of 13.660 megacycles. One terminal of the tank circuit is connected to the anode **84** by a conductor **116**, and the other is connected to a plate voltage supply through conductor **118** and to ground through a radio frequency by-pass condenser **120**. The plate voltage supply conductor **118** has a radio frequency choke **122** interposed therein isolating the direct current plate voltage from radio frequency voltages. The screen grid **86** of the tube is connected to a source of screen voltage through a conductor **124**.

The amplifier is prevented from self-oscillating because the screen grid is by-passed to the beam-forming plates of the tube and to ground by the condenser **108**, and because the grid circuit is shielded from the plate circuit to prevent any external plate-to-grid coupling. In addition, both terminals of the filament are held at ground potential, in so far as radio frequency is concerned, by the condensers **106** and **110**.

The fixed grid bias applied to the grid **88** of tube **82** through conductor **100** is sufficient to limit the plate current to a value such that the plate and screen dissipation will be well below their rated values when radio frequency grid excitation is removed as by removal of or damage to the crystal **30**.

The tubes of the final amplifier **14**, which are operated as class C amplifiers, are preferably of a low impedance type operable at relatively high direct current plate voltages. In the present embodiment, the two tubes **130** and **132** (type G. E. FP-265) of the final amplifier have a high grid-plate transconductance (6,000 micro mhos), a high mu (amplification factor, of about 75), operate at a direct current plate voltage of about 1500 volts, and are connected to provide push-pull amplification. The high mu characteristics of the tubes provide sufficient plate current cut-off at zero bias, when no radio frequency voltage is supplied to the amplifier, so that the plate dissipation rating is not exceeded even when grid excitation is missing, as would happen if the crystal were removed or damaged.

The output of amplifier **12** is supplied to the final amplifier through a radio frequency transmission line **134** of the concentric cable type. The line is of low impedance and grounded and terminates at each end with two turn coils **136** and **138**. The former is inductively coupled to coil **114** of the amplifier plate tank circuit, and the latter is inductively coupled to a center tapped inductance coil **140** forming part of a grid tank circuit including also a dual section variable air spaced condenser **142**, the center plate of which is connected to the chassis. The terminals of the tank circuit are connected by conductors **144** and **146** to the grids **148** and **150** of the tubes **130** and **132**, respectively. The filamentary cathodes **152** and **154** of the tubes are connected in parallel by the conductors **156** which are connected by conductors **157** to the secondary winding **158** of the filament transformer **22**. A radio frequency by-pass condenser **160** is connected across conductors **156** and the separate conductors are connected to the chassis by the radio frequency by-pass condensers **162** and **164** symmetrically arranged relative to conductors **156**. These condensers provide return circuits for the radio frequency grid and plate currents and keep the filaments at ground for radio frequency currents.

Grid bias is supplied to the grids **148** and **150** of the two amplifier tubes by a grid leak resistor **166** connected to one of the conductors **156** and to the center tap of inductance coil **140**. A rectified radio frequency grid current flows through the resistor **166**, thereby setting up a direct current voltage providing bias for the grids.

The final amplifier includes also the plate tank circuit having, in accordance with one of the features of the present invention, a very high full load effective Q, and comprising a two-part inductance coil **168**, a condenser **170** of the fixed air spaced type, and a trimmer condenser **172** also of the air spaced type and preferably constructed to have but a limited range of adjustment. Coil **168** and condenser **170** are preferably constructed and arranged so as to be symmetrically located relative to each other and ground, i. e., the chassis. The plate tank circuit is connected to the anodes **174** and **176** of tubes **130** and **132** through conductors **178** and **180**. The trimmer condenser 172 is adjusted with the patient circuit coupling coil 182 set for zero coupling, in a manner to be described in greater detail hereinafter. Plate voltage for the two tubes is supplied by a conductor 184 connected to the midpoint of inductance coil 168 and having interposed therein a radio frequency choke coil 186. A by-pass condenser 188 serves, together with the coil 186, as a filter to isolate the direct plate current voltage from the radio frequency voltage. The condenser 188 also maintains the plate circuit at ground potential with respect to radio frequency and it is symmetrically located relative to condensers 162 and 164. The plates of the condensers 170 and 172 are connected to each other and by conductor 189 to the plate voltage supply line 184 so that there is no high direct current potential between said plates and so that the only voltage across the capacitors is the radio frequency voltage appearing across the tank circuit.

Self-oscillation of the final amplifier is prevented by neutralizing the feedback voltages due to the internal plate-to-grid capacitance of the tube by the variable condensers 190 and 192. The former connects the plate 176 of tube 132 to the grid 148 of tube 130, and the latter connects the plate 174 of tube 130 to the grid 150 of tube 132. The self-oscillation is further prevented by shielding and isolation of the external plate and grid circuits to prevent plate-to-grid coupling.

The patient's circuit, including a cable (not shown, or an applicator drum, also not shown) adapted to be connected to the conductor terminals 16, comprises the previously mentioned two-turn pickup coil 182. The output circuit includes also a pair of variable air spaced tuning condensers 194 and 196 interposed between the terminals 16 and opposite terminals of the pickup coil and adapted to be adjusted to tune the patient's circuit into resonance with the final amplifier. The condensers are mounted on a common shaft and are adjustable, as by means of a control knob 197 suitably connected to the shaft, as through reduction gearing, to provide an accurate control.

The amount of energy transferred to the patient may be varied by adjusting the coupling between the pickup coil 182 and the coil 168 of the final amplifier plate tank circuit. This adjustment is effected by movement of a support 198 upon which the pickup coil 182 may be suitably mounted. The support is preferably made of insulating material, and it may be moved in some suitable manner (not shown) by movement of a knob 200 or other device having an indicating pointer and operatively connected to the support 198.

One of the important features of the present invention is the provision of an apparatus which is capable of providing an adequate energy input to the patient under all conditions, in which excessive plate dissipation of the tubes is prevented even under the worst condition of "out of resonance operation" of the unloaded applicator with full coupling between the final amplifier and the patient's circuit, and which does not require substantially continuous adjustment of resonance of the patient's circuit and of the final amplifier plate tank circuit. These desirable characteristics are attained by utilizing (1) a loose coupling between the patient's circuit and the plate tank circuit of the final amplifier, (2) a final amplifier plate tank circuit having a very high full load effective Q, and (3) preventing deformation of the tank circuit elements as a result of temperature changes.

The patient's circuit, as heretofore brought out, is not coupled to a self-excited oscillator, but is coupled to the oscillator through several stages of amplification. The push-pull final amplifier feeds the high frequency energy to the patient's terminals and thence through a cable or other applicator device to a patient. The patient and applicator constitute a load whose resistance and reactance vary over a wide range, and which reactance may or may not be tuned out of the circuit. The reflected reactance in the tank circuit will not, however, change the frequency of the oscillation generator by reason of the interposition of the amplifiers between the patient's terminal and the oscillation generator. Variations in the plate tank reactance due to the reflected reactance from the patient's circuit are minimized by reducing the coupling between the plate tank circuit and the patient's circuit. The reflected reactance is in effect in shunt to the plate tank reactance and is proportional to the degree of coupling between the tank circuit and patient's circuit.

Since there is a limit to the amount the maximum coupling can be reduced and still have enough coupling to provide sufficient energy transfer to the patient, and because of the possibility that an operator may not always properly tune the patient's circuit by adjustment of condensers 194 and 196, there exists a possibility that some reactance will be reflected into the plate circuit. Further to minimize the reactance change in plate circuit, the capacitive and inductive reactance components of the plate tank circuit are designed with very low reactance values, i. e., reactances having a very small value as compared with the reflected reactance,which is in effect in shunt with the tank reactance. In other words, the plate tank capacitance is made large and the inductance small in value, thereby to provide a tank circuit having a very high full load effective Q.

In an apparatus utilizing electromagnetic transfer of energy to a patient through a cable or drum, i. e., apparatus of the character herein illustrating one embodiment of the present invention, it is preferable to use a low impedance cable or drum so that high current can be obtained at low voltage. The low impedance, while preferable from the foregoing standpoint, creates greater difficulties because the reflected reactance variations have a greater effect on the plate tank circuit, but even these difficulties are obviated by the plate tank circuit having a very high full load effective Q of the present invention. The present invention may be utilized also in apparatus wherein the transfer of energy to the patient is effected by the use of condenser plates. Such apparatus would preferably be operated at a higher frequency and utilize a high impedance patient's circuit so as to provide a higher voltage for more effective energy transfer.

The coupling between the final amplifier plate tank circuit and the patient's circuit is preferably electromagnetic and provided by the tank coil 168 and the two-turn pickup loop 182, which is connected to the cable or drum through condensers 194 and 196. A tank coil found satisfactory consists of two sections of slightly less than three turns each (a total of about five and three-quarters turns) of 20 guage copper tubing having an outside diameter of three-eighths inch. The mean loop diameter is three inches and the space between tube centers is five-eighth inch, and the two sections are spaced two and one-quarter inches apart. A satisfactory pickup loop **182** is made of two turns of one-eighth inch outside diameter copper tubing, having a mean loop diameter of one and three-eighths inches and spaced three-eighths of an inch apart. The cable is preferably about twelve feet long and made of flexible braided copper tubing (384 strand, #36, tinned) surrounding a rope center and covered by flexible rubber insulation. If a drum be used, it may be connected to the terminals by short lengths of the above described cable and it may be made of copper tubing like that used in the construction of the tank coil, the total length of cable and tubing being about twelve feet. The tubing is preferably wound spirally and placed within a Bakelite receptacle. With the cable and drum described, the condensers **194** and **196** preferably have values of about 100 mmf, these values being determined primarily by the inductance of the cable or drum and of the pickup loop, the inductance of which is kept low, as by using but two turns. In the case of a condenser applicator the pickup loop would preferably consist of more turns and additional inductances would be placed in series with the connections between the loop and terminals.

The plate tank capacitance of the final amplifier **14** comprises the parallel capacitances of condensers **170** (77 mmf.) and **172** (8.5 mmf.), and of condensers **190** (18 mmf.) and **192** (18 mmf.) in series with the plate-to-grid capacitances of the tubes, the series capacitances of the plates to the filaments to the tubes, and the distributed capacitance of inductance coil **168**, totaling, with the values given, about 103 mmf. The condenser values are illustrative only, and for those given the inductance of the tank circuit is equal to about 1.315 micro-henries at the resonant frequency.

It is known that for a tank circuit of the character of that here under consideration,

$$q=\frac{E^2_{t\text{-}rms}}{2\pi fLP}=\frac{2\pi fCE^2_{t\text{-}rms}}{P}=\frac{I_{t\text{-}rms}E_{t\text{-}rms}}{P}$$

where

Q=effective Q of plate tank circuit with full load (i. e., with tubes operating at full rated input)

$E_{t\text{-}rms}$=effective R. F. voltage across plate tank circuit

C=capacity of the circuit

L=inductance of the circuit

f=the resonance frequency

P=power in watts delivered to tank circuit from tubes

$I_{t\text{-}rms}$=effective R. F. current circulating in plate tank circuit, at full load

In the instant case, the full load effective Q is about 85, a value considerably higher than the effective values of Q in the tank circuits of radio transmitters, which range from 10 to 20. From the calculations given above, it may be noted that with fixed voltage and power, an increase in Q causes an increase in the circulating tank current. The increased current would, if the high Q plate tank circuit contemplated by the present invention is used, reach a value causing excessive heating (if not prevented, as explained hereinafter) of the tank coil **168** and condenser **170** that would actually deform these enough to change the reactance of the tank circuit, thereby tending to nullify the stabilizing effect produced by the high Q of the circuit. This excessive heating is, however, prevented from occurring by means of an air blower indicated generally by reference character **210**, which is of the exhaust type and creates a flow of air past the tank circuit elements which are, like the blower, mounted within a suitable cabinet. The blower is arranged to be operative whenever a main switch is closed, as will be described hereinafter.

By thus minimizing changes in the plate circuit reactance as a result of variations in the reflected reactance, the space current and plate load of the amplifier tubes are maintained more constant and maintained within the rated dissipation values of the tubes. Furthermore, the instantaneous radio frequency plate voltage is prevented from materially shifting from its proper position (180° out of phase with the instantaneous radio frequency grid voltage) so that the tube space current flows at a lower value of plate supply voltage.

The low voltage power supply unit **18** includes a transformer **212** having a primary winding **214** and a center tapped secondary winding **216** connected in conventional manner to a full wave rectifier tube **218** (RCA type 5Y3), the filament of which is connected to the plate voltage supply conductor **70** through a low frequency choke coil **220** and to the secondary winding **221** of the filament transformer **22** by conductors **221**—A. The center tap of transformer **216** is connected directly to the grid bias supply conductor **100**. A voltage divider resistor **222** is connected across conductors **70** and **100** and intermediate points thereof are connected to conductors **50** and **76**, so that conductor **100** is at a more negative potential than ground conductor **50** and conductor **76** is at a potential intermediate ground and that of conductor **70**. The choke coil **220** has associated with it the two conventional by-pass condensers **224** constituting, with the choke coil, a filter. An additional filter condenser **226** is connected between conductor **50** and conductor **100**. Transformer **212** includes also a second secondary winding **228** supplying power through conductors **229** to a pilot light **230** (which may be red), which therefore glows whenever the transformer is energized.

As heretofore indicated, the power supply unit **18** delivers a low voltage. In actual practice the maximum voltage appearing across the voltage divider **222** is about 285 volts.

The high voltage supply unit **20** includes a transformer **232** having a primary winding **234** and a center tapped secondary winding **236** connected in conventional manner to the pair of rectifier tubes **238** (of the RCA type 866A), the filaments of which are supplied with current from the secondary winding **240** of the filament transformer **22** through conductors **241**. The output of the rectifier is connected directly to a voltage divider resistor **242**, across which there thus appears a pulsating direct current voltage. The negative terminal of the voltage divider is also connected to the ground conductor **50**, while the positive terminal is connected to the plate supply conductor **184**. Conductors **118** and **124** are connected to intermediate portions of the voltage divider.

The high voltage power supply unit is constructed and arranged to deliver a maximum voltage of about 1500 volts across the terminals of the voltage divider resistor **242**.

The transformers **212** and **232** are supplied with energy from the combined voltage adjusting auto and filament transformer 22, their primary windings 214 and 234 being adapted to be connected in parallel to a portion of the primary winding 244 of transformer 22 through the conductors 246 and 248 and upon closure of a switch 250, hereinafter to be called the oscillator switch. The conductor 246 is connected to a tap on the winding 244, whereas the conductor 248 is adapted to be connected to the lower terminal of the winding upon closure of switch 250, the closure of which, however, will not complete the energizing circuit unless a main switch 252 has been closed for a certain length of time.

Power is supplied to the transformer 22 from a suitable alternating current source, which may be connected to the terminals 253 of a plug type connector. The supply of power to the primary winding 244 is under the control of the main switch 252, illustrated diagrammatically as a simple knife switch (but which is preferably a circuit breaker type of switch capable of opening under predetermined overload conditions). One terminal of the primary winding 244 (the lower one) is connected to one of the terminals 253 through a radio frequency choke coil 254 constituting, with condenser 256, a power line filter. The other terminal of winding 244 is shown connected by conductor 256 and a rotatable voltage adjuster arm 258 to the other terminal 253 through the switch 252, conductor 259 and a radio frequency choke coil 260 constituting, with condenser 262, a second power line filter. Adjacent terminals of condensers 256 and 262 are connected to a third terminal 263 by conductor 264. Terminal 263 is also connected to the cabinet and chassis and is adapted to be connected to a good ground, such as a water pipe, through a suitable conductor which may be the third wire of a three-wire cable.

The voltage adjusting arm 258 is provided so that the apparatus may be operated at designed voltage irrespective of the line voltage. To enable the operator to ascertain that the proper adjustment has been made, there is provided a volt meter 266 supplied with energy from the filament secondary winding 157 through conductors 157. Twelve voltage adjustments are obtainable, each constituted by a connection from a fixed contact associated with the movable contact arm 258 and connected to a suitable tap on the transformer winding 244 (the taps being spaced at suitable intervals such as 2½ volts). Only three of these connections are shown—the first, middle, and last—the others being omitted for the sake of clarity of disclosure. A pilot light 268 is connected across two of the contacts of the voltage adjuster, and thereby across a small portion of the winding 244, in order to provide an indication of the energization of the primary winding of transformer 22.

The closure of the main power switch 252 energizes a time delay relay conditioning the rectifiers for operation after a time interval and upon closure of the oscillator switch 250. The time delay is provided by a thermal time delay relay including a coil 270, a resistance heater 272 energizable upon closure of main switch 252, and three movable switch blades 274, 276 and 278, of which the last two mentioned are operable by the coil. The switch blade 274 is a bimetallic switch blade adapted, when heated by resistance heater 272, to move to the right to close an energizing circuit through coil 270, preferably after a delay of about 15 seconds. Resistance heater

272 is energized immediately upon closure of main switch 252 through a circuit including a terminal 253, conductor 259, the switch 252, conductor 280 connected to the heater, conductor 282, contact 284, the movable switch blade 276 in engagement with contact 284, and conductor 286 leading to the other terminal 253. The energizing circuit for coil 270 closed by the bimetallic switch blade 274 is the same as that for the heater circuit to conductor 280, which is also connected to coil 270, the circuit from coil 270 to the other power terminal being completed through switch blade 274 and conductor 286. When coil 270 is energized it completes a holding circuit for itself through conductor 288 and switch blade 276 in its operated position. The heater 272 is deenergized by movement of switch blade 276 to its operated position.

When oscillator switch 250 is closed after operation of relay 270, conductor 248 is connected to the lower terminal of transformer winding 244, with the result that the primary windings 214 and 234 are energized because the other terminals of the two windings are connected to winding 244 through conductor 246. Conductor 248 is connected to the lower terminal of winding 244 through a circuit including oscillator switch 250, conductor 290, switch blade 292 of an overload relay mechanism including a movable switch blade 294, conductor 296, switch blade 298 of the time delay relay, movable switch blade 278 in contact with it, and conductor 286. It is apparent, therefore, that closure of the oscillator switch 250 will not render the power supply units operative unless the main power switch has been closed to energize transformer 22 for a short period of time.

In order to obtain sufficient energy transfer when high impedance patient loads are connected to the terminals 16, it is necessary to have a closer coupling between the pickup coil 182 and the plate tank coil 168 of the final amplifier than is the case when low impedance patient loads are connected to the terminals. Thus, when the apparatus is constructed to provide the requisite close coupling under these conditions, then when a very low impedance load is connected to the terminal 16, there is a possibility that overcoupling will occur and result in the plate current of the final amplifier tubes exceeding the ratings of the tubes.

The apparatus includes an overload relay mechanism to cut off the plate voltage when the plate current exceeds a predetermined maximum value, such as the rated maximum value, as disclosed and claimed in my copending divisional application Serial No. 741,769, filed April 16, 1947. According to this arrangement the plate voltage is cut off until the relay mechanism is reset by adjusting the coupling between the pickup coil 182 and the tank coil 168 to a minimum value, such as the "zero" point of the power control 200 or preferably slightly below this point. Accordingly, the plate voltage cannot be restored until the overcoupled condition causing the overload no longer exists.

The overload mechanism includes an overload relay coil 302 connected in the plate-cathode circuit of the final amplifier tubes 130 and 132. More specifically, the relay coil is in circuit between the ground conductor 50 and the filament transformer 158 connected to the cathodes 152 and 154 of the tubes. The circuit from the coil to the transformer winding 158 includes conductor 303 and the circuit from the transformer winding 158 to the cathodes includes conductors 157. The coil has associated with it a low frequency filter constituted by a low frequency choke coil 304 in series and a by-pass condenser 306 connected in shunt with it. The filter smooths the pulsating direct current flowing in the plate circuit of the final amplifier, thereby preventing chattering of the relay. The value of current at which the relay operates is adjustable by a resistor 308 also connected in shunt with coil 302.

The plate current of the final amplifier is measured by a direct current milliammeter 310, also in the plate-cathode circuit of the two final amplifier tubes. After the final amplifier has been operating for a few minutes to allow the final amplifier tank circuit elements to reach their normal operating temperatures, and with the reactance in the patient's circuit tuned out by capacitors 194 and 196, the plate current is proportional to the power output of the amplifier. Under these conditions the milliammeter can be used as an output meter to enable the operator to judge relative dosage.

The overload relay operates the previously mentioned switch 294 so that when the switch 294 is operated upon an overload the energizing circuit for the rectifier transformers 212 and 232 is broken. When the switch 294 is operated it is latched in its operated position by a spring biased latch 312.

In order to reset switch 294 it is necessary to adjust the coupling to slightly below the zero point. When this is done the latch 312 is retracted by a solenoid 314, the circuit for which can be closed through a pair of contacts 316 associated with the pickup coil support 198. These contacts are so arranged that they can be closed only when the pickup coil is manually held slightly beyond the zero setting. At this time solenoid 314 is energized from the winding 244 of transformer 22 through a circuit including conductor 246, the contacts 316, solenoid 314, switch 294 in engagement with fixed contact 318, conductor 296, fixed contact 298, movable switch 278 in engagement therewith, and conductor 286. When the solenoid 314 is energized, the latch 312 is retracted to permit the return of switch blade 294 to its indicated position (to which it may be spring biased) to engage contact 292. When this happens the primary windings of transformers 212 and 232 are again energized.

In order to prevent intermittent on-and-off action of the overload relay under conditions in which the overload was not caused by overcoupling, as when the plate tank circuit may be out of resonance because of an improper adjustment of the tank circuit trimmer condenser 172, the pickup coil support 198 and the contacts 316 are so constructed and arranged that the contacts are not closed except when the support is adjusted to move the pickup coil slightly beyond a zero coupling position. Immediately the support 198 is released, as by releasing the power control knob 200, a spring 320 returns the pickup coil support and coil to their zero positions.

The blower 210 is adapted to be energized simultaneously with the energization of transformer 22 by connection thereof across conductors 246 and 286. While the main function of the blower is to maintain constant the temperature of the final amplifier tank circuit elements to prevent change in tank reactance as a result of temperature variations, it also serves the purpose of cooling other parts of the apparatus, such as the transformers.

After the unit has been assembled and all the tubes have been installed and the ground connection 264 made, it is desirable to check the apparatus prior to operation. This check includes the following steps:

(1) Make certain that neither a cable nor an applicator drum are connected to terminals 16, and that the resonance control 197 and power control 200 are at their zero positions.

(2) Turn on the main switch 252 and adjust the voltage adjusted arms 258 so that the volt meter 266 registers as close as possible to the intended operating voltage, which may be suitably indicated on the volt meter dial.

(3) Turn on the oscillator switch 250 and observe the plate current milliammeter 310. This meter should indicate a certain current flow (approximately 130 milliamperes in an apparatus of the character described, or possibly higher). This current should, however, immediately start to decrease and reach a minimum value (of approximately 90 milliamperes or less) in about four minutes. The trimmer condenser 172 should be adjusted if any of the following results are observed:

(*a*) The plate current exceeds a certain maximum value (about 150 milliamperes).

(*b*) The plate current does not reach the minimum value even after operating ten minutes.

(*c*) The plate current increases instead of decreasing.

(4) Should adjustment of the trimmer condenser 172 be necessary, this is done as follows: With both the power and resonance controls at zero and with nothing plugged in the terminals 16, the unit is operated with the oscillator switch 250 in its closed position for at least ten minutes, after which the trimmer condenser 172 is adjusted to produce minimum plate current. This adjustment is rather critical and should be done carefully. In the event the plate current should be quite high, it is best then to make a preliminary adjustment and then a final adjustment after an interval of about ten minutes.

(5) If it is not possible to obtain the minimum plate current reading, or if the overload relay 302 operates whenever the oscillator switch is turned on, it will be necessary to check the tubes and neutralization.

(6) If at any later time the "no load" plate current does not decrease to its minimum value or less in four minutes after turning on the oscillator switch, then the trimmer condenser should be adjusted as indicated above.

After the apparatus has been adjusted as above indicated, it is ready for operation. The first step in the operation is to connect either a cable or drum or other type applicator to the terminals 16 and properly place it relative to the patient, and this is done in accordance with conventional modes of application of these devices. The main switch 252 is then closed, with the result that the transformer 22 is energized, as is the exhaust blower 210. Energization of the transformer is indicated by the pilot light (white) 268. The transformer immediately supplies current to the filaments of all the tubes, including the rectifier tubes, to condition these for operation. At the same time the volt meter 266 indicates the voltage appearing across the transformer winding 158. In the event of line voltage changes, the volt adjuster 258 may have to be adjusted. This adjustment is also usually necessary, when treatment is started, because of line voltage drop. Closure of the main power switch also effects energization of the resistance heater 272 and energization of coil 270 after a time interval, through bimetallic switch blade 274, so that transformers 212 and 232 of the two power supply units may be thereafter energized upon closure of oscillator switch 250. Energization of the transformers results in the application of voltages to the oscillation generator 10, the exciter amplifier 12 and the final amplifier 14, to render these operative. At the same time, pilot light 230 is energized to indicate the placing of the apparatus into full operation. Full operation of the device is also indicated by the reading of the milliammeter 310, which, it may be remembered, indicates the plate current of the final amplifier stage. At this time it is preferable to operate the apparatus for a period of several minutes in order to allow the final amplifier to reach an operating temperture at which the plate current decreases to its minimum value.

With the apparatus in full operation, the next step is the adjustment of the resonance control 197 to tune the patient's circuit into resonance with the plate tank circuit of the final amplifier. This is done with the power control 200 advanced to one of its minimum coupling positions. The resonance control should always be adjusted to give maximum plate current, the indication of resonance. Adjustment of control knob 197, it may be remembered, adjusts the condensers 194 and 196 to effect this tuning. The position of the adjustment depends on the particular application given to the patient. The resonance control does not act the same as the power control because, after resonance has been obtained, further change in the resonance control causes a reduction in plate current, i. e., such adjustment causes detuning of the circuit.

The energy transferred to the patient is controlled by the power control 200, which adjusts the coupling between the pickup coil 182 and the inductance coil 168 of the final amplifier plate tank circuit. The energy transfer is indicated by the plate current milliammeter 310. Should the control be turned too high, i. e., to couple too closely the coils, then under certain conditions the overload relay coil 302 may be energized sufficiently to operate switch 294 from its indicated position into contact with fixed contact 318. This, as heretofore described in detail, results in the termination of the supply of voltage to the oscillation generator, the exciter amplifier and final amplifier tubes, because transformers 212 and 232 are deenergized by movement of switch blade 294 away from contact 292. The apparatus can be restored to operative condition only by adjusting the power control 200 to a minimum coupling position, in which it has to be held and from which it is returned to "zero" coupling position by the spring 320 acting upon the pickup coil support 198. Such turning of the power control results in the energization of the rest solenoid 314, which withdraws latch 312 to enable contact arm 294 to move into its indicated position.

The milliammeter 310 indicates the direct plate current of the final amplifier, which is directly proportional to the radio frequency power transferred from the oscillator to the patient's circuit, provided that the unit has been in operation with the power and resonance controls at zero for a time long enough to enable the plate current to reach a minimum value before starting treatment, and provided that the resonance control is tuned for maximum plate current during treatment. In other words, the reading of this meter is an arbitrary guide to the amount of energy generated.

The operation of overload mechanism is indicated by the pilot light 230. This pilot light is supplied with energy from the transformer winding 228 so that it is lighted whenever the oscillator switch 250 is closed and the apparatus is in operation. Should the overload mechanism operate with the switch 250 closed, then the transformer winding 228 is deenergized and the light 230 extinguished. Thus, the extinguishment of pilot light 230 with the oscillator switch 250 closed indicates operation of overload mechanism.

While there has been described but a single preferred embodiment of my invention, many modifications may be made without departing from the spirit of the invention, as indicated herein and otherwise, and I do not wish to be limited to the precise details of construction set forth, but desire to avail myself of all changes within the scope of the appended claims.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent of the United States, is:

1. An electro-therapeutic apparatus of the type comprising an oscillation generator and a patient's circuit, including an amplifier coupled to said generator and patient's circuit, the coupling between the amplifier and patient's circuit comprising an amplifier plate tank circuit having a very high full load effective Q.

2. An electro-therapeutic apparatus of the type comprising an oscillation generator and a patient's circuit, including a class C amplifier between the generator and circuit and having a plate tank circuit coupled to the patient's circuit, said tank circuit having a very high full load effective Q.

3. An electro-therapeutic apparatus of the type comprising an oscillation generator and a patient's circuit, including a coupling between the oscillation generator and patient's circuit comprising a generator output plate tank circuit having a very high full load effective Q, and temperature changing means for preventing thermal deformation of elements of said tank circuit.

4. An electro-therapeutic apparatus of the type comprising an oscillation generator and a patient's circuit, including an amplifier having a plate tank circuit coupled to the patient's circuit, said tank circuit having a very high full load effective Q, and means for cooling the elements of said tank circuit to prevent thermal deformation of elements of said tank circuit.

5. An electro-therapeutic apparatus of the type comprising a crystal controlled oscillation generator and a patient's circuit, including a class C amplifier coupled to the generator and patient's circuit, the coupling between the amplifier and patient's circuit comprising an amplifier plate tank circuit having a very high full load effective Q and comprising an inductance coil, and a coupling coil in said patient's circuit loosely coupled to said inductance coil.

6. An electro-therapeutic apparatus of the type comprising a crystal controlled oscillation generator and a patient's circuit, including a class C amplifier coupled to the generator and patient's circuit, the coupling between the ampli-

fier and patient's circuit comprising an amplifier plate tank circuit having a very high full load effective Q and comprising an inductance coil, a coupling coil in said patient's circuit loosely coupled to said inductance coil, said patient's circuit having a low impedance, and temperature changing means for preventing thermal deformation of elements of said resonant circuit.

7. An electro-therapeutic apparatus of the type comprising an oscillation generator and a patient's circuit, including a coupling between the oscillation generator and patient's circuit comprising a resonant circuit adapted when the generator is operative to be heated to an extent such as to cause thermal deformation of its elements, temperature changing means for preventing thermal deformation of elements of said resonant circuit, and a switch operable to condition said generator for operation and for placing said temperature changing means in operation.

8. An electro-therapeutic apparatus of the type comprising an oscillation generator and a patient's circuit, including in combination, an amplifier coupled to the generator and having a plate tank circuit coupled to the patient's circuit, said tank circuit having a very high full load effective Q, and means loosely coupling said patient's circuit to said tank circuit, said patient's circuit having a low impedance.

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Certificate of Correction

Patent No. 2,448,540. September 7, 1948.

ROLLAND H. MAXSON

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

Column 4, line 54, for "about 13,660" read *about 13.660*; column 11, line 47, for "winding 157" read *winding 158*; column 14, line 13, for the word "adjusted" read *adjuster*; column 18, line 19, list of references cited, for the date "Nov. 12, 1937" read *Nov. 2, 1937*;

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 7th day of December, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.

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