

**Aug. 22, 1961**

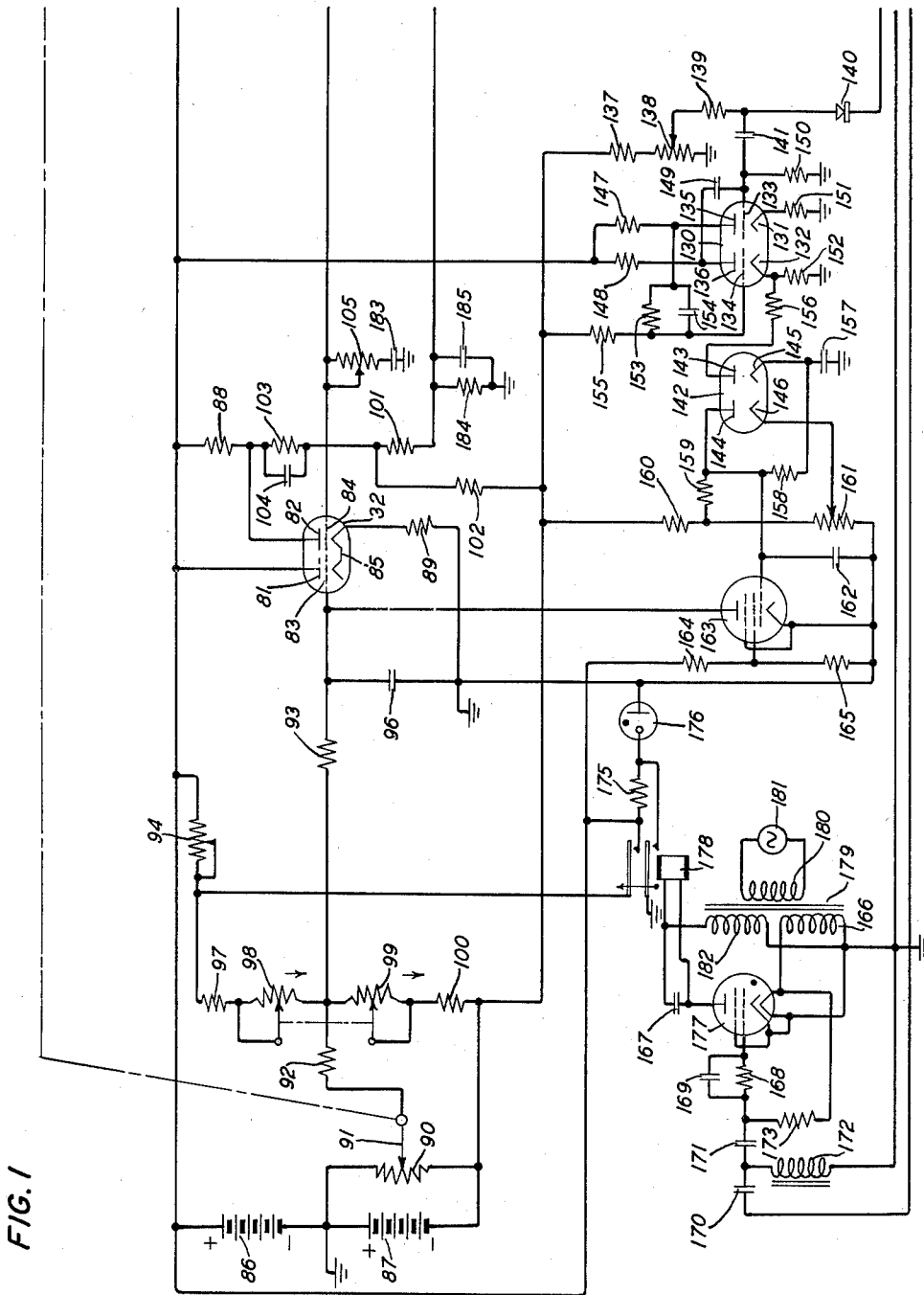
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**2,997,663**

## REGULATED POWER SUPPLY

Filed Nov. 15, 1951

3 Sheets-Sheet 1



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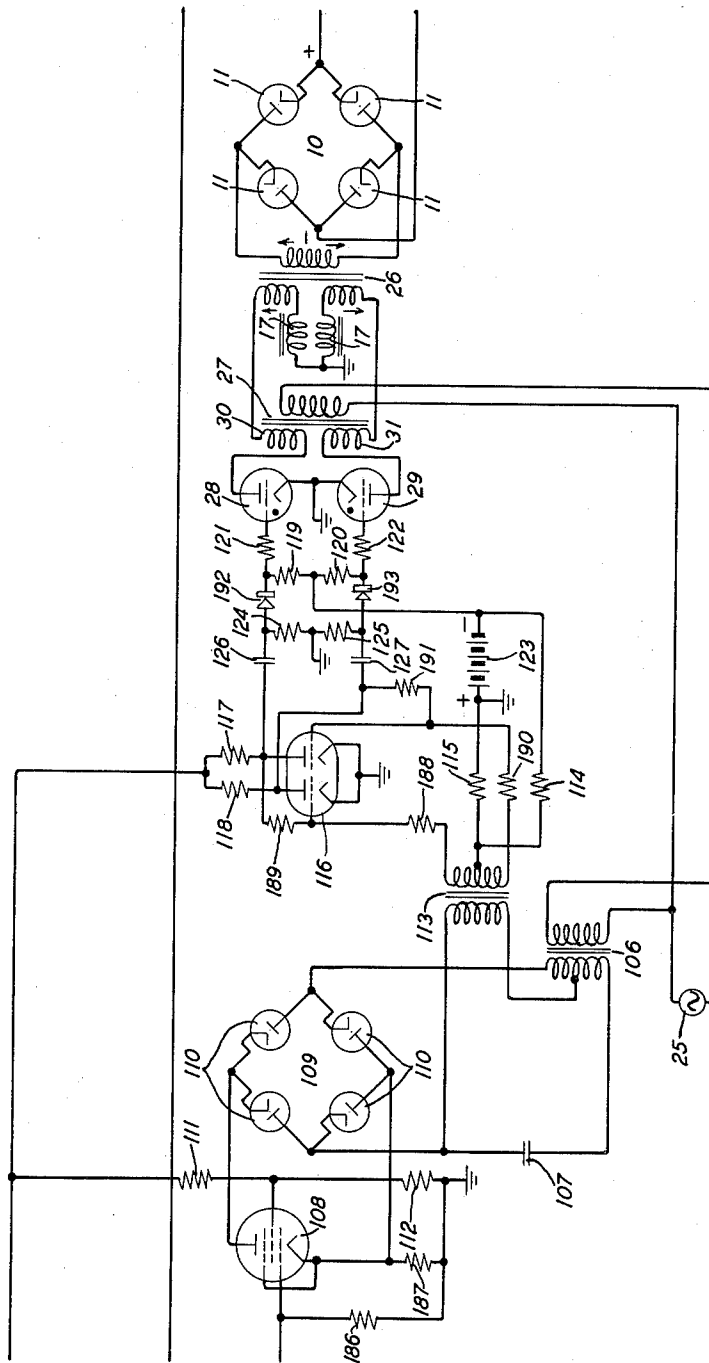
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3 Sheets-Sheet 2



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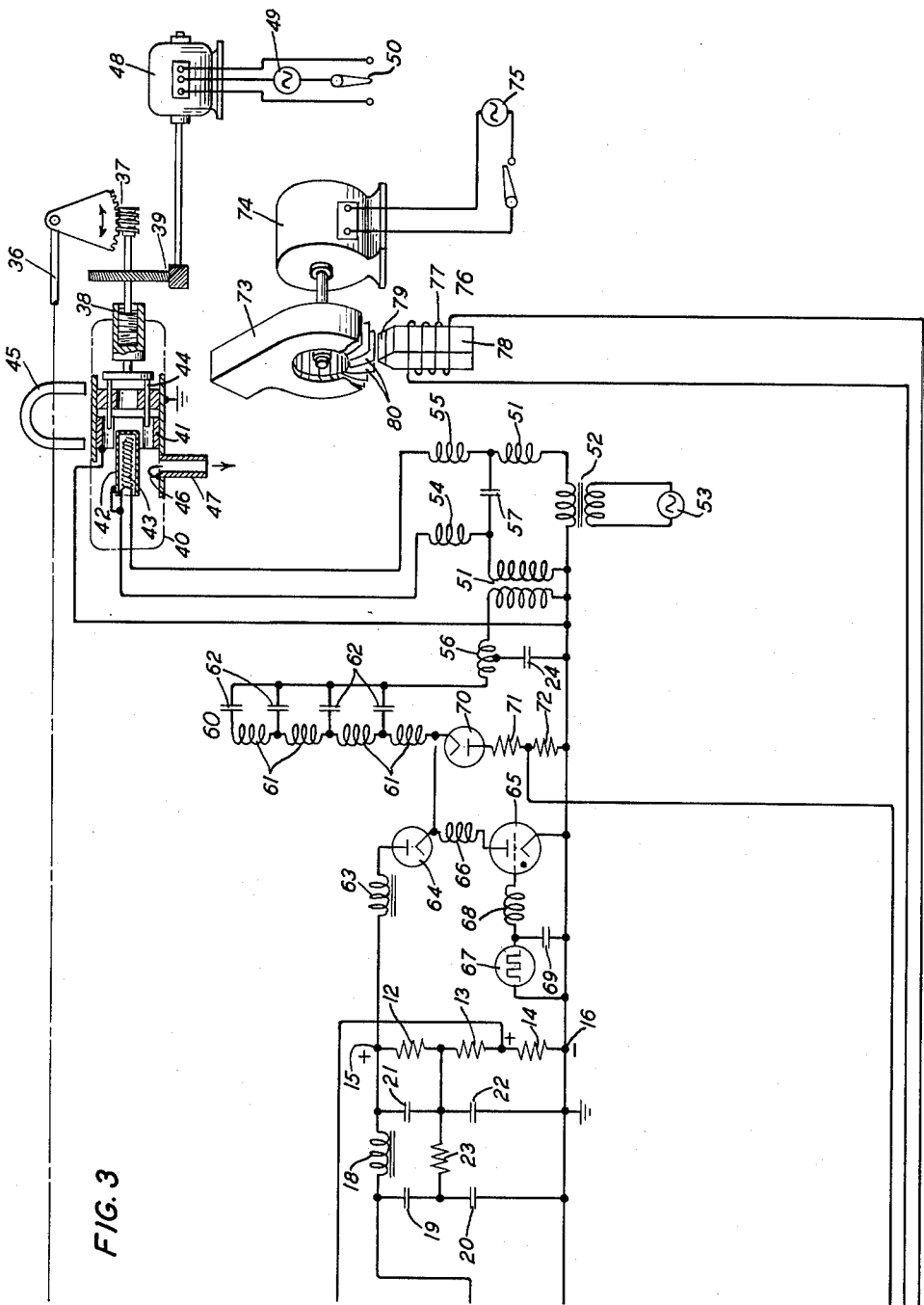
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REGULATED POWER SUPPLY

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3 Sheets-Sheet 3



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2,997,663

## REGULATED POWER SUPPLY

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This invention relates to voltage controlling apparatus and particularly to apparatus for supplying to a space current device of the tunable magnetron type recurring voltage pulses of regulated amplitude.

Magnetrons and, more particularly, tunable magnetrons are disclosed in an article in "The Bell System Technical Journal," Volume XXV, No. 2, April 1946, entitled "The Magnetron as a Generator of Centimeter Waves," by J. B. Fisk, H. D. Hagstrum and P. L. Hartman. In operating a magnetron, the power output of the device may be increased, within an operating range, by increasing the direct space current supplied to the anode-cathode path of the device. Moreover, it has been found that as the tuning of the magnetron is changed in a direction to increase the frequency of the output wave, for example, the anode-cathode impedance of the device increases substantially linearly with frequency so as to decrease the amplitude of the direct current flowing in the anode-cathode path when voltage pulses of fixed peak amplitude are impressed upon the magnetron. It has also been found, however, that the useful life of a magnetron will be considerably shortened when operated at a space current amplitude which is excessively high and also that the operating efficiency of the device decreases as the peak space current increases beyond a certain maximum amplitude.

It is an object of the invention, therefore, to provide means for jointly controlling the tuning of a magnetron oscillation generator and the voltage impressed upon the magnetron for energizing it to maintain a substantially constant peak current through the space current path of the magnetron irrespective of the frequency of the wave generated by the magnetron.

A further object of the invention is to provide means for reducing the voltage impressed upon a magnetron in response to misfiring or arcing between the anode and cathode of the magnetron.

In accordance with a specific embodiment of the invention herein shown and described for the purpose of illustration, there is provided for generating radio frequency waves a tunable, electromagnetic, space current resonator known as a magnetron oscillator having a plurality of coupled resonant cavities and a suitable means for tuning the magnetron by varying either the inductance or the capacitance of the resonant cavities, as described in the article in "Bell System Technical Journal," supra. The tuning control mechanism of the magnetron may be driven through a flexible coupling shaft either by manual control or by a motor which is remotely controlled.

There is provided a regulated rectifying apparatus for producing a high, direct output voltage which is automatically maintained substantially constant under certain fixed, normal operating conditions of the magnetron. Means are provided for deriving from the output voltage of said regulated rectifier under said normal operating conditions recurrent, constant peak amplitude voltage pulses which are impressed upon the anode-cathode path of the magnetron to cause substantially constant amplitude pulses of space current to flow through the space separating the anode and cathode of the magnetron. Means are provided for increasing or decreasing the output voltage of the regulated rectifier and, therefore, the amplitude of the voltage pulses impressed upon the magnetron under control of the driving means for the tuning

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control mechanism of the magnetron. The magnitude of the voltage pulses impressed upon the magnetron is thus increased in response to a frequency increase of the waves generated by the magnetron and vice versa, so as to maintain the peak space current of the device substantially constant irrespective of the frequency to which the magnetron is tuned. In case the magnetron should repeatedly arc or misfire, means are provided for reducing the voltage applied to the magnetron to a low value and for subsequently causing the voltage to rise over a relatively long period.

The invention may be better understood by referring to the following detailed description with reference to the accompanying drawing in which FIGS. 1, 2 and 3, when placed side by side in order with FIG. 1 at the left, are a schematic view of a system for energizing a magnetron type space current device embodying the invention.

Referring to the drawing, there is provided a high voltage, bridge-type rectifier 10 having a space current diode 11 in each of the bridge arms for supplying current to a load when the rectifier is suitably energized. The voltage measured between the output or load terminals 15 and 16 may be of the order of 7.0 kilovolts, for example. Voltage dividing resistors 12, 13 and 14 in series are connected across the output or load terminals 15 and 16, negative terminal 16 being grounded. A ripple filter connected between the output terminals of bridge rectifier 10 and the output terminals 15, 16 comprises a choke coil 18 in series in the lead going from the positive terminal of the bridge rectifier 10 to output terminal 15, condensers 19, 20, 21 and 22 and a resistor 23. Condensers 21 and 22 in series are in a shunt path connecting terminals 15 and 16 and condensers 19 and 20 in series are in a shunt path connecting a common terminal of the bridge rectifier 10 and choke coil 18 to ground.

Current from an alternating current supply source 25 is supplied to the input terminals of rectifier 10 through a circuit comprising transformers 26 and 27, dual reactor 17 and gas-filled, grid-controlled space current devices 28 and 29. The primary winding of transformer 27 is connected to alternating-current supply source 25 while the secondary winding of transformer 26 is connected to the input terminals of rectifier 10. The cathodes of tubes 28 and 29 and a mid-terminal of the dual reactor 17 are connected to ground. Transformer 27 has two secondary windings 30 and 31. During half-cycle periods of one polarity of the current from the supply source 25, the voltage across transformer winding 30 causes current to flow through the space current path of tube 28 and through the upper half of the primary of transformer 26 so as to induce a voltage of one polarity in the secondary of transformer 26. During half-cycle periods of opposite polarity of the current from source 25, the voltage across transformer winding 31 causes current to flow through the space current path of tube 29 and through the lower half of the primary of transformer 26 so as to induce a voltage of opposite polarity in the secondary of transformer 26. As will be further described below, pulses are impressed upon the control electrode-cathode circuits of tubes 28 and 29 alternately to initiate current conduction in the tubes, means being provided for shifting the phase of the pulses to control the conducting periods of the tubes and, therefore, the average current flowing in the primary of transformer 26. The voltage across the secondary of transformer 26 is thus controlled to regulate the rectifier output voltage at terminals 15, 16.

There is provided a tunable, multicavity magnetron oscillator 40, such as described in United States Patent No. 2,459,030 to H. C. Jonas, J. P. Laico and V. L. Ronci, January 11, 1949, comprising an anode 41, a cathode 42, a cathode heater 43, a suitable tuning means 44, a permanent magnet 45 and an output coupling de-

vice 46 for generating pulses of high power, high frequency oscillations which are picked up by the coupling device 46 and transmitted through a wave guide 47 to a suitable utilization apparatus, not shown. There is provided a motor 48 energized by current from a suitable source 49 through a single-pole, double-throw switch 50 or other suitable means for causing the motor to drive the tuning pins 44 through gearing 39 and internally threaded driving member 38 in one direction for increasing the frequency of the oscillations produced by the magnetron or in the other direction for decreasing the frequency. The motor 48 is also coupled to a shaft 36 through gearing 39 and 37. There are provided a transformer 51, having a primary, a secondary and a tertiary winding, through which high voltage pulses are impressed between the cathode 42 and the grounded anode 41 for causing space current to flow through the device and a transformer 52 through which alternating current from a supply source 53 is supplied to the cathode heater 43. The voltage across the secondary of transformer 52 is impressed upon a circuit comprising in series the secondary and tertiary windings of transformer 51, inductance coils 54, 55 and the cathode heater 43, a coupling condenser 57 being provided in a path connecting the common terminal of inductance coil 54 and the secondary of transformer 51 and the common terminal of inductance coil 55 and the tertiary winding of transformer 51.

There are provided a pulse shaping, line network 60 comprising series inductance elements 61 and shunt capacitive elements 62 and means for charging and discharging the network similar to that disclosed in United States Patent No. 2,469,977 to H. Morrison, May 10, 1949. The network 60 is charged through a circuit which may be traced from the positive terminal 15 of the high direct voltage source through an inductor 63, diode 64, the network 60, inductor 56 and the primary of transformer 51 to the negative terminal 16. A condenser 24 is provided in a path connecting a mid-terminal of inductor 56 to ground. A gas-filled, grid-controlled space current device 65 is provided for discharging the network 60 when the device is conductive through a circuit comprising inductors 66 and 56, and the primary of transformer 51. The tube 65 is made conductive intermittently by impressing triggering pulses from a source 67 upon the grid-cathode circuit of the tube 65 through a circuit comprising a shunt condenser 69 and a series inductor 68.

When the voltage from terminals 15, 16 is applied to the circuit, network 60 begins to charge at a rate determined primarily by the inductance of reactor 63 and the combined capacity of condensers 62 of network 60. Except for the fact that the diode 64 in the charging circuit conducts only in one direction, the charging current of network 60 would be oscillatory, the voltage across the network reaching a maximum of nearly twice the voltage at terminals 15, 16. Since the diode 64 prevents current flow in the reverse direction, the network 60 will remain charged to said maximum voltage until discharged through the tube 65 when made conductive. The circuit is designed so that the load connected to the terminals of network 60 is substantially equal to the characteristic impedance of the network. As a result, current flowing in the discharge circuit will cause the network voltage to be divided equally between the terminals of the network and the load presented to the network. Simultaneously, a wave will travel along the network, be reflected at the distant open circuited end and return to the input terminals. During a period equal to about twice the transmission time of the network, the voltage across the load will be maintained at its original value. When the reflected voltage wave reaches the input terminals of the network, the voltage across the network and the load will be reduced substantially to zero and, as a result, conduction in tube 65 will be interrupted.

The network will then be charged again to repeat the cycle of operation.

When arcing occurs in the space current path of the magnetron, the mismatch of the impedance of the network and that of the load caused by the reduction of the load impedance by the arc would result in a residual charge on the network having a polarity such as to make the anode of tube 65 negative with respect to the cathode, if no means were provided to prevent this. The effect of such reverse polarity residual charges would be to raise the voltage to which the network is charged during the next normal charging period and this effect would be cumulative from cycle to cycle. The resulting excessive voltage applied to the magnetron would cause the arcing to continue and the life of the magnetron to be shortened. The charging of the network 60 in the reverse direction is substantially prevented by providing across the space current path of tube 65 and reactor 66 a path for conducting current in a direction opposite from the conducting direction through tube 65, this conducting path comprising a diode 70 and resistors 71 and 72, all in series. With this arrangement, any reverse charge in the network 60 will find a low impedance path through diode 70 for quickly dissipating the charge. Moreover, the voltage across resistor 72 due to current flowing through the diode 70 is utilized to reduce the voltage across terminals 15, 16 in case the magnetron misfires or arcs repeatedly for a predetermined number of times, as will be described below, thus further protecting the magnetron against arcing and increasing its useful life.

There is provided a blower 73 driven by a motor 74 when energized from a current supply source 75, thereby cooling the magnetron to maintain its operating temperature within safe operating limits. The blower is equipped with a magnetic pick-up unit 76 comprising a permanent magnetic core 78 with a soft iron wedge-shaped pole-piece 79 and a winding 77. This unit is mounted in a bracket, not shown, which places the pole-piece 79 in close proximity to the rotating blades 80 of the blower which may be 24 in number, for example. When the blower is running at a speed of 3450 revolutions per minute, for example, the changing flux through the magnetic circuit comprising the magnet 78 and the fan blades causes to be generated in the winding 77 a voltage having a frequency of 1380 cycles per second. This voltage remains nearly constant over a wide range of frequency which varies directly with the blower speed. Means responsive to the frequency reduction of this voltage which results when the blower slows down or fails to operate are provided for reducing the anode-cathode voltage impressed upon the magnetron to thereby prevent overheating of the magnetron, as described below.

The remainder of the voltage supply system shown in the drawing is provided for regulating the voltage supplied to the magnetron. There is provided a space current device 32 having anodes 81 and 82, control grids 83 and 84 and a common cathode 85. Anode 81 is directly connected to the positive terminal of a 300-volt battery 86 while the anode 82 is connected through a resistor 88 to the positive battery terminal. The cathode 85 is connected through a resistor 89 to the grounded negative terminal of battery 86. There is provided a second 300-volt battery 87 having its positive terminal grounded. A potentiometer 90 having a variable tap 91 is connected across battery 87. The variable tap 91 of potentiometer 90 is connected through resistors 92 and 93 to the grid 83 and the grid is further connected by a condenser 96, to ground. A first voltage divider connected from the positive terminal of battery 86 to the negative terminal of battery 87 comprises in series resistor 97, rheostats 98 and 99 and resistor 100, in order, a common terminal of rheostats 98 and 99 being connected to a common terminal of resistors 92 and 93. A second voltage divider across batteries 86 and 87 comprises in series resistors 88, 103 and 102. A resistor

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103 and a condenser 104 in shunt are provided in a path connecting the anode 82 to a voltage divider comprised of series resistor 101 and shunt resistor 184 in parallel with condenser 185. The control grid 84 is connected to the variable tap of a potentiometer 105. Potentiometer 105 is connected in series with condenser 183 and a common terminal of resistors 13 and 14 providing a means for adjusting the phase margin of the voltage regulating loop.

There is provided a phase shifting bridge circuit having half portions of the secondary winding of a transformer 106 in its first and second arms, respectively, and a condenser 107 in its third arm, the primary of transformer 106 being connected to the alternating-current supply source 25. The space current path of a pentode space current device 108 is effectively connected in the fourth arm of the phase shift bridge circuit through a bridge rectifier 109 comprising four space current diodes 110, the rectifier 109 being provided so that the anode of tube 108 will be positive with respect to the cathode for both half-cycle periods of the alternating supply source 25. The common terminal of resistors 101 and 184 is connected to the control electrode of tube 108. A voltage divider comprising resistors 111 and 112 in series is connected across battery 86 and the voltage across resistor 112 is impressed upon the screen grid-cathode circuit of tube 108. The output terminals of the phase shifting circuit are connected to the primary winding of a transformer 113. There is provided a voltage divider comprising resistors 114 and 115 in series connected across a battery 123. A common terminal of resistors 114 and 115 is connected to a mid-terminal of the secondary winding of transformer 113 and the end terminals of this secondary winding are connected through resistors 188 and 190 to the control grids, respectively, of the triodes of a twin-triode space current device 116. The positive terminal of battery 86 is connected through resistors 118 and 117 to the anodes of the triodes, the cathodes of the triodes being connected to ground. Resistors 117 and 118 are thus in the space current paths of the triodes, respectively, of tube 116. The control electrode-cathode circuit of the left-hand triode as viewed in the drawing, may be traced from the anode electrode of the right-hand triode through resistor 189 to the left-hand control electrode thence through resistor 188 through the upper half portion of the secondary of transformer 113 to the common terminal of resistors 114 and 115. The control electrode-cathode circuit of the right-hand triode may be traced from the anode of the left-hand triode through resistor 191 to the right-hand control electrode thence through resistor 190 and the lower half of the secondary transformer 113 to the common terminal of resistors 114 and 115. The gas-filled tubes 28 and 29 are biased beyond cut-off by a voltage equal to the difference of the voltage of battery 123 and the voltage across resistors 119 and 120, respectively, a terminal of resistor 119 being connected through a resistor 121 to the control grid of tube 28, a terminal of resistor 120 being connected through a resistor 122 to the control grid of tube 29, the common terminal of resistors 119 and 120 being connected to the negative terminal of battery 123 and the cathodes of the tubes being grounded. The voltages across resistors 119 and 120 are set up by current from battery 123 flowing through resistor 119, a crystal rectifier 192 and a resistor 124, in series, and by current from battery 123 flowing through resistor 120, a crystal rectifier 193 and a resistor 125, in series. The anode of the right-hand triode of tube 116 is connected through a condenser 126 to the common terminal of resistors 124 and crystal rectifier 192 and the anode of the left-hand triode of tube 116 is connected through a condenser 127 to the common terminal of resistors 125 and crystal rectifier 193. The values of condensers 126 and 127 and of the resistors 124 and 125 are selected to shift the phase by approximately 45 degrees of the waves im-

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pressed upon the grid-cathode circuits of tubes 28 and 29 for repeatedly initiating conduction therein.

Considering the operation of the circuit as thus far described, if the output voltage of rectifier 10 appearing across terminals 15, 16 should increase, for example, the control grid 84 of tube 32 will become relatively more positive with respect to the cathode 85, thereby making the control grid of tube 108 relatively more negative with respect to its cathode. The anode-cathode resistance of tube 108 in one arm of the phase shift bridge circuit is thus increased. The alternating component voltages impressed upon the grid-cathode circuits of the triodes of tube 116 and, therefore, the alternating component voltages impressed upon the grid-cathode circuits of tubes 28 and 29 are thus delayed to cause space current conduction in tubes 28 and 29 to be initiated later in the respective half-cycle periods when the anodes, respectively, are positive with respect to the cathodes. In normal operation the inductance of the dual choke coil 17 provides an inductive load thereby limiting the rate of rise of the current when conduction is initiated in tube 28, for example, and that tube continues to conduct until its anode-cathode potential becomes zero. Delaying the starting of conduction in tubes 28 and 29 has the effect of reducing the average current flowing in opposite directions alternately through the primary winding of transformer 26 and, therefore, of reducing the alternating voltage impressed upon the input of rectifier 10 from the secondary of transformer 26. The output voltage of the rectifier across terminals 15, 16 is thus reduced to cause the initially assumed increase of voltage at terminals 15, 16 to be minimized.

The motor 48 which drives the means 38, 44 for changing the tuning of the magnetron 40 also drives the movable contact 91 of potentiometer 90 which is coupled directly to shaft 36. The voltage requirement at terminals 15, 16 may be approximately 5.8 kilovolts at the lowest magnetron frequency and 6.8 kilovolts at the highest magnetron frequency, for example. When the motor runs in a direction to increase the frequency of the oscillations produced by the magnetron 40, the potentiometer contact 91 is driven in a direction to make the grid 83 of tube 32 relatively more positive with respect to its cathode, thereby increasing the current flowing through cathode resistor 89 and making the grid 84 relatively more negative with respect to the cathode. The control grid of tube 108 is thus made relatively more positive with respect to its cathode to decrease the anode-cathode resistance of tube 108. The output voltage of the phase shifting circuit impressed through transformer 113 upon the grid-cathode circuits of tube 116 is thus advanced in phase to cause the output voltage of rectifier 10 impressed across terminals 15, 16 to be increased with the result that the voltage pulses impressed between the anode and cathode of the magnetron are correspondingly increased in amplitude so as to maintain the space current in the magnetron at a substantially constant amplitude irrespective of the change of tuning of the magnetron.

As previously stated, the voltage across resistor 72 due to current flowing through the diode 70 is utilized to effect a reduction of the voltage at terminals 15, 16 in case the magnetron arcs or misfires ten or more times per second, for example, after which the voltage at terminals 15, 16 will return to normal value over a relatively long period. If the magnetron continues to misfire the voltage at terminals 15, 16 will continue to be cyclically reduced and then increased. For this purpose there is provided a circuit comprising space current devices 130, 142 and 163.

The common terminal of resistors 71 and 72 is connected to the negative terminal of the crystal rectifier 140. The positive terminal of the crystal rectifier 140 connects to the common terminal of resistor 139 and condenser 141. The circuit from the negative battery 87 through resistor 137 and potentiometer 138 provide an adjustable

negative potential at the variable contact of 138 which applied through resistor 139 fixes the level of negative pulses which will pass through the crystal rectifier 140 and be applied through condenser 141 to grid terminal 133 of the dual triode 130. The dual triode 130 operates as a single shot multivibrator in the following manner. In its quiescent condition the dual triode 130 has its 132, 134, 136 section cut off by negative bias supplied to grid 134 from battery 87 through resistor 155 and at the same time section 131, 133, 135 is conducting due to its grid 133 being grounded through resistor 150. Self-bias of this section is provided by resistor 151 connected between cathode 131 and ground. Anode voltage obtained from battery 86 is supplied to anodes 135 and 136 through resistors 147 and 148 respectively. For multivibrator action anode 136 is coupled to control grid 133 by condenser 149 and anode 135 is coupled to control grid 134 by resistor 153 and condenser 154 connected in shunt. With section 131, 133, 135 of the dual triode 130 conducting the potential at the common point of resistors 153 and 155 is sufficiently negative to cut off the space current flow through resistors 148 and 152. When a pulse of abnormal amplitude is applied to the crystal rectifier 140 by an abnormal negative current through resistors 71 and 72, the negative pulse is coupled to grid 133 through condenser 141 causing the space current in that section to be reduced. The reduced space current causes a positive signal to be applied to control grid 134 resulting in space current flow between anode 136 and cathode 132. This increase in space current lowers the potential of anode 136 which is coupled through condenser 149 to grid 133 driving this section to cut-off. This condition is maintained for about 300 microseconds when grid 134 regains control and the circuit returns to its quiescent state. The switched interval is a function of resistors 150, 153, 155 and condensers 149 and 154. When space current flows through resistor 152 a positive potential at cathode 132 causes current to flow through resistor 156, plate 143 to cathode 145 of dual diode 142 and partially charges condenser 157. The potential across condenser 157 is a function of the rate at which abnormal pulses are passed by the crystal rectifier 140 with its peak potential adjustable by the variable arm of potentiometer 161 connected to the diode-cathode 146. A voltage divider circuit is provided by resistors 160 and potentiometer 161 connected across battery 87. A further dividing action is obtained using resistors 159 and 158 connecting the common point between cathode 145 and condenser 157 with the common connection of resistor 160 and potentiometer 161. The common point between resistors 158 and 159 connects with anode terminal 144 of the dual diode 142, by-pass condenser 162, and the control grid of pentode 163. In the absence of pulses at the input to grid 133 of the dual triode 130 condensers 157, 162 and the control grid of the pentode 163 are sufficiently negative as to cut off the anode space current of pentode 163. The anode of pentode 163 is connected to grid 83 of tube 32. The cathode of tube 163 is connected to ground and its screen is connected to the common point of the voltage divider resistors 164 and 165 connected across battery 86.

When an irregularity occurs in the load on transformer 51, negative current pulses through resistor 72 cause abnormal negative pulses to be applied to grid 133 of tube 130. Through the multivibrator action of tube 130 these short negative pulses result in constant amplitude pulse of amplified duration to be applied to condenser 157. When the number of abnormal pulses exceeds for example 10 per second, the increase in positive potential of condenser 157 raises the potential on the control grid of pentode tube 163 causing space current to flow from the common point of rheostats 98 and 99 through resistor 93 and the anode-cathode of pentode 163. The space current flow through resistor 93 reduces the potential at grid 83 of tube 32, thereby making the grid 83 relatively less positive with respect to the cathode and

reducing the current flow through cathode resistor 89. The grid 84 is thus made relatively more positive with respect to the cathode and the grid of tube 108 is made relatively more negative with respect to its cathode to cause the anode-cathode resistance of tube 108 to increase. The alternating voltage impressed from the phase shifting circuit to the grid circuits of tube 116 is thus delayed to cause the voltage at terminals 15, 16 to decrease by a large amount. Current conduction in tube 163 will be interrupted when the control grid voltage of the tube reaches cut-off and condenser 96 will recharge at a rate determined by its capacity and the values of the resistors in the associated charging circuit and the voltage at terminals 15, 16 will rise exponentially. If the arcing of the magnetron should continue, the charging of condenser 157 will be repeated to again cause the voltage at terminals 15, 16 to be lowered. This cyclic decreasing of the voltage at terminals 15, 16 will continue as long as the arcing of the magnetron persists. When the arcing ceases, tube 163 will be maintained in its non-conducting state and the voltage at terminals 15, 16 will be maintained at a substantially constant value.

In case the blower 73 should fail to operate at the required speed for adequately cooling the magnetron, means are provided for reducing the anode voltage applied to the magnetron to prevent overheating and resulting damage to the magnetron. For this purpose there is provided a control circuit comprising a tetrode thyatron 177 and a slow release relay 178. There is provided a transformer 179 having a primary winding 180 connected to an alternating-current supply source 181 and two secondary windings 182 and 166. Current is supplied from winding 166 to the cathode heater of tube 177, the grounded terminal of winding 166 being connected to one terminal of winding 182 and the cathode of tube 177 being connected to one of the end terminals of winding 166. A resistor 168 shunted by a condenser 169 is connected between the grid of tube 177 and the common terminal of resistor 173 and condenser 171. The anode-cathode circuit of tube 177 comprises the winding of relay 178 shunted by a condenser 167 and winding 182 of transformer 179. The grid-cathode circuit comprises resistor 168 shunted by condenser 169, resistor 173 and winding 166. When the polarity of the alternating voltage impressed upon the anode-cathode circuit is such as to make the anode positive with respect to the cathode, the polarity of the voltage from transformer winding 166 impressed upon the grid-cathode circuit is such as to make the grid negative with respect to the cathode. In the absence of a voltage from winding 77, that is, when the blower is not running, tube 177 cannot conduct since during each half cycle of the alternating current when the anode is positive with respect to the cathode, the control grid is made more negative with respect to the cathode.

When the blower 73 is operating at normal speed, a voltage of 1380 cycles per second, for example, generated in the winding 77 is impressed upon the input of a high-pass filter comprising series condensers 170 and 171 and a shunt inductive reactor 172, the output of the filter being terminated in a resistor 173 in series with winding 166 of transformer 177. The alternating voltage at the output of the filter combined with that from winding 166 is applied through condenser 169 and resistor 168 in shunt to the grid of tube 177. The combined signal voltage thus impressed upon the grid-cathode circuit is of sufficient amplitude to cause conduction in tube 177. The relay remains operated due to the charge on condenser 167 during intervals separating successive conducting periods of tube 177, conduction in tube 177 being interrupted when the anode becomes negative with respect to the cathode. The condenser 169 shunted by resistor 168 in series with resistor 173 maintains proper anode-grid phase relation during the turn-on interval. If the blower 73 should slow down so that the frequency of the voltage

generated in winding 77 is reduced to 1150 cycles per second, for example, the alternating voltage across resistor 173 will decrease, and, as a result, the combined alternating voltage will decrease sufficiently to stop conduction in tube 177 thereby deenergizing relay 178. The release of relay 178 will cause the voltage of battery 86 to be applied through rheostat 94 to resistor 97 to make the grid 83 of tube 32 relatively more negative with respect to its cathode, thereby making the grid 84 of the tube relatively more positive with respect to the cathode and the grid of tube 108 relatively more negative with respect to its cathode to increase the resistance of the space current path of tube 108. The resulting delay of the voltage wave impressed upon the grid-cathode circuits of tube 116 causes the voltage at terminals 15, 16 and therefore, the anode-cathode voltage applied to the magnetron 40 to be decreased. Overheating of the magnetron is thus substantially prevented. When the relay 171 is deenergized, current from battery 86 is supplied through a resistor 175 to an indicating lamp 176. Operation of the relay short-circuits the lamp 176 to interrupt its energization to thereby produce an indication that the blower 73 is running at normal speed.

What is claimed is:

1. In combination, a rectifier having output terminals connected to a load, a first transformer having a first and a second primary winding and a secondary winding, said secondary winding being connected to input terminals of said rectifier, a second transformer having a primary winding connected to an alternating-current supply source and a first and a second secondary winding, a first and a second gas-filled space current device each having an anode, a cathode and a control electrode, a circuit comprising said first primary and said first secondary windings for connecting the anode of said first device to its cathode, a circuit comprising said second primary and said second secondary windings for connecting the anode of said second device to its cathode, means for biasing each of said control electrodes negatively with respect to its cathode, a third and a fourth space current device each comprising an anode, a cathode and a control grid, means for coupling the anodes of said third and fourth devices to the control electrodes of said first and second devices respectively, means for coupling the cathodes of said first, second, third and fourth devices, means for impressing upon said anodes of said third and fourth devices with respect to said cathodes a potential for causing the flow of space current in said third and fourth devices, a third transformer having a primary and a secondary winding, means for connecting the end terminals of the secondary of said third transformer to the control grids of said third and fourth devices, means for connecting a mid-terminal of said secondary of said third transformer to said cathodes, means for supplying current from said alternating-current supply source to the primary of said third transformer, and means for shifting the phase of said current

supplied to the primary of said third transformer for controlling the voltage across said load.

2. A combination in accordance with claim 1 in which said load comprises a space current device and in which there is provided means responsive to arcing in said space current device for controlling said phase shifting means to reduce the voltage impressed upon said space current device.

3. A combination in accordance with claim 1 in which said load comprises a space current device having an anode and a cathode and in which there are provided means for deriving from said rectifier output terminals and impressing upon a circuit connecting said anode and said cathode a first series of voltage pulses for causing space current to flow in said device, means responsive to arcing in said space current device for setting up a second series of voltage pulses one for each of the pulses of said first series, and means responsive to the occurrence within a predetermined time period of a plurality of said pulses of said second series for controlling said phase shifting means to reduce the amplitude of said pulses of said first series.

4. A combination in accordance with claim 1 in which there is provided means responsive to the output voltage of said rectifier for controlling said phase shifting means for normally minimizing changes of output voltage of said rectifier.

5. A combination in accordance with claim 4 in which said load comprises an electromagnetic resonator for generating electromagnetic waves having means for changing the tuning of said resonator to change the frequency of said waves and in which there are provided means for impressing upon said resonator for energizing it a voltage derived from said rectifier, and means for controlling said tuning changing means and said phase shifting means simultaneously to maintain a predetermined relationship between the output voltage of said rectifier and the frequency of said generated waves.

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