Oct. 31, 1967 T. D. LODE 3,350,653

THERMIONIC ELECTRON TUBE CIRCUIT

Filed Dec. 4, 1964 4 Sheets-Sheet 1

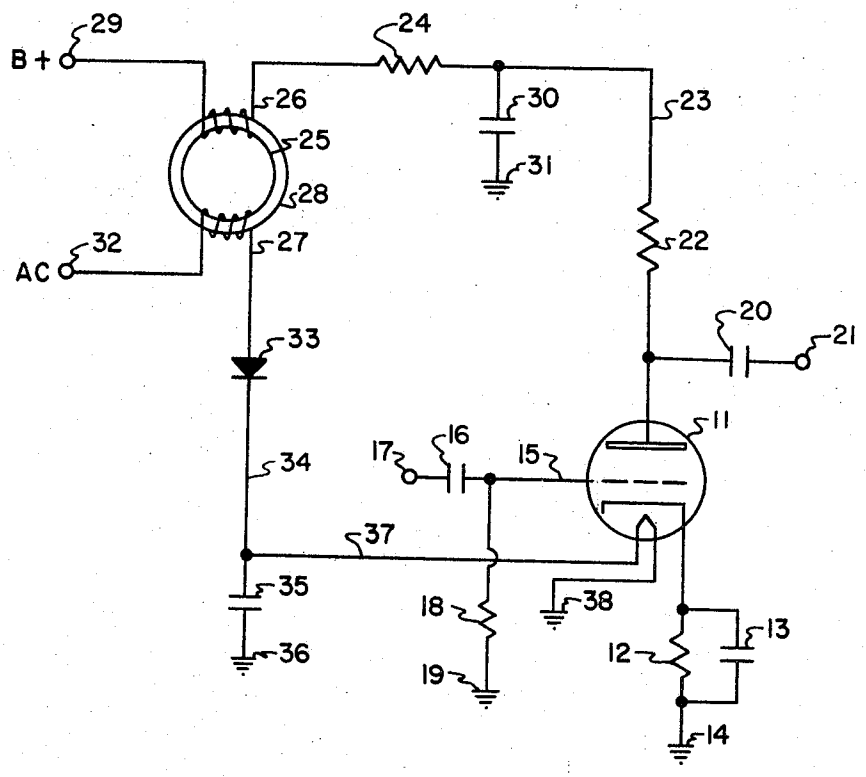


FIG. 1

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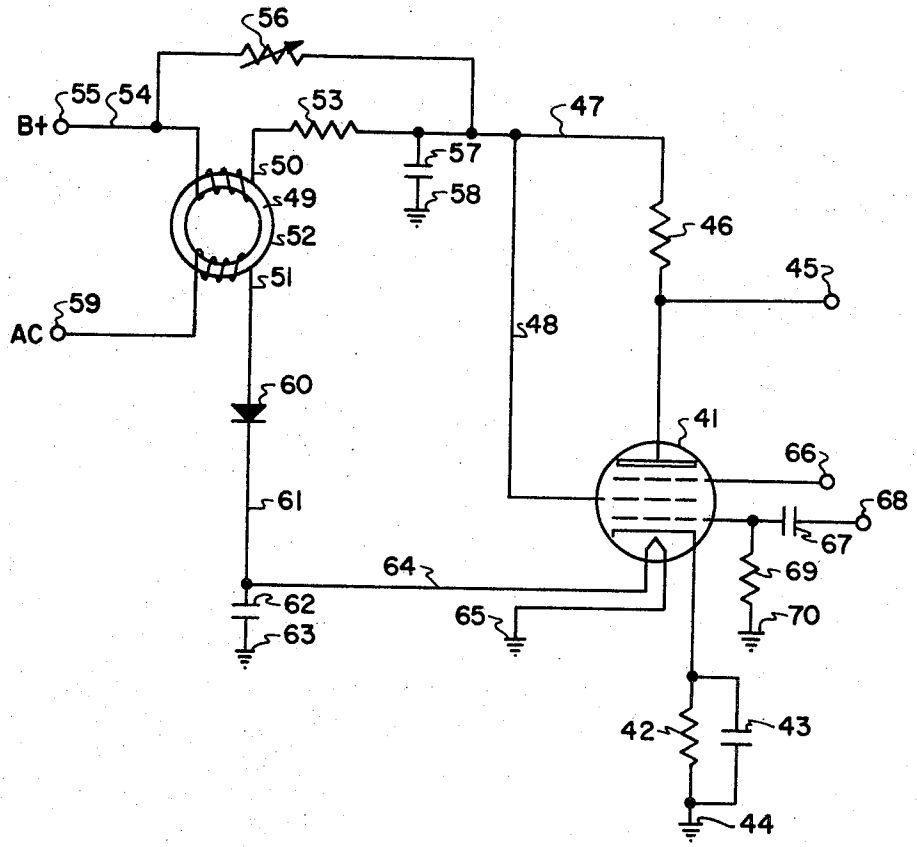


FIG. 2

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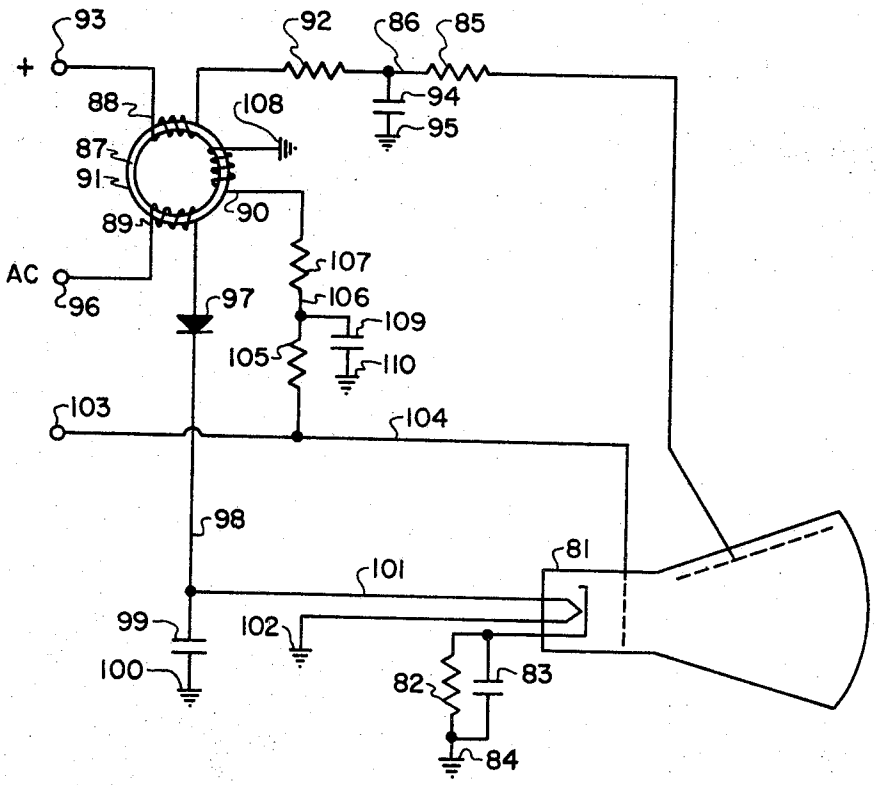


FIG. 3

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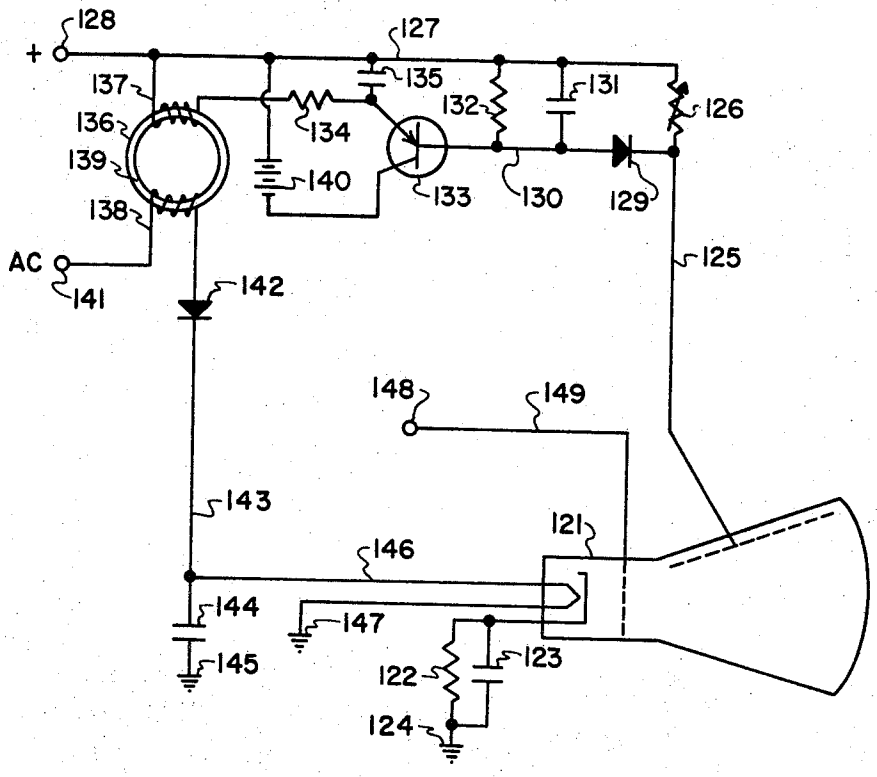


FIG. 4

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THERMIONIC ELECTRON TUBE CIRCUIT

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This invention relates to thermionic electron tubes. More particularly, it relates to the automatic regulation or control of the heater power so as to increase the useful life of a thermionic electron tube.

Thermionic electron tubes, in spite of their advantages and widespread use, have been among the less reliable electronic components. A particular reliability problem is that thermionic tubes are subject not only to gradual deterioration, which allows preventive maintenance and replacement before complete failure. They are also subject to sudden and unexpected failures due to such causes as heater burn-outs and internal short circuits. Such sudden and unexpected tube failures have remained a major source of unreliability in electronic equipment incorporating thermionic electron tubes.

The limited life and unreliability of thermionic electron tubes may be attributed largely to the high internal temperatures which are normally required for their operation. The desirability of lower operating temperatures is well recognized. Various studies have indicated that the probable life may be increased by a factor of two or more by a reduction of heater voltage of approximately 5 percent. Unfortunately, it is not practical to simply reduce the heater voltage to a low value. As an extreme example, it might be pointed out that reducing the heater voltage to zero would greatly extend the life of the tube at the penalty of its not performing a useful task. The heater of a thermionic electron tube is normally designed so as to maintain a cathode temperature which will allow emission of the maximum design cathode current after tube aging and at the minimum heater voltage limit. The penalty which is paid to meet these requirements is a shorter probable life than if the cathode were operated at a temperature just sufficient for the current actually required in the specific application and without a reserve for aging and heater voltage fluctuations.

An object of the present invention is to automatically regulate the heater power so as to maintain the cathode of an electron tube at a temperature just sufficient to provide the required emission current at a particular time. A further object is to increase the probable life of an electron tube and its associated equipment by reducing its average operating temperature.

In a particular form of the present invention, an electron tube is connected in a class A voltage amplifier circuit arranged to amplify alternating voltage signals. The plate current from the electron tube is filtered or smoothed and passed through the control winding of a magnetic amplifier. The output of the magnetic amplifier is connected to the electron tube heater. In operation, the magnetic amplifier will vary the heater voltage so as to maintain a desired average plate current. The required heater voltage will usually be significantly less than the nominal rated heater voltage of the electron tube. The electron tube operating temperatures will be correspondingly lower. Hence, the deteriorating effects of high temperatures and temperature cycling upon the electron tube and its surroundings are greatly reduced.

In the drawings:

FIGURE 1 is a schematic illustration of a first form of the invention, showing a class A amplifier circuit arranged for the amplification of alternating voltage signals;

FIGURE 2 is a schematic illustration of a second form of the invention, showing a circuit arranged for the amplification of both unidirectional and alternating voltage signals;

FIGURE 3 is a schematic illustration of a third form of the invention, showing its application to the control of the average brightness of a cathode ray tube presentation; and

FIGURE 4 is a schematic illustration of a fourth form of the invention, showing its application to the control of the peak brightness of a cathode ray tube presentation.

In FIGURE 1, the cathode of electron tube **11** connects through resistor **12** to ground **14**. Capacitor **13** is connected in parallel with resistor **12**, and serves as an alternating current bypass. The control grid of electron tube **11** connects via line **15** and capacitor **16** to input terminal **17**. Line **15** connects via resistor **18** to ground **19**. The anode of electron tube **11** connects via capacitor **20** to output terminal **21**. The anode of electron tube **11** also connects via resistor **22** to line **23**. Line **23** connects to a first side of resistor **24**. Magnetic amplifier **25** includes control winding **26** and output winding **27**, both wound upon magnetic core **28**. The second side of resistor **24** connects to a first side of control winding **26**, and the second side of control winding **26** connects to terminal **29**. Capacitor **30** is connected between line **23** and ground **31**, and serves as a filter capacitor to isolate the electron tube circuit from alternating voltages developed across winding **26**. Terminal **32** connects to a first side of output winding **27**, whose second side connects to the anode of diode **33**. The cathode of diode **33** connects to line **34**. Capacitor **35** is connected between line **34** and ground **36**. Line **37** connects from line **34** to a first side of the heater of electron tube **11**. The second side of said heater connects to ground **38**.

The circuit of FIGURE 1 is generally that of a conventional thermionic electron tube alternating voltage amplifier, except for the presence of magnetic amplifier **25** and the circuit elements associated therewith. In operation, a source of positive voltage is connected between terminal **29** and ground to provide power for the plate circuit of electron tube **11**. A source of alternating voltage is connected between terminal **32** and ground to provide power for the heater circuit of electron tube **11**. A source of alternating voltage signals which are to be amplified is connected between input terminal **17** and ground. Terminal **21** serves as the signal output terminal for the circuit, and output signals may be measured between terminal **21** and ground.

Magnetic amplifier **25** of FIGURE 1 is of the type known as a flux reset magnetic amplifier. When the circuit of FIGURE 1 is first energized, electron tube **11** will be cold. Except for the transient charging current of capacitors **20** and **30**, essentially no current will flow through control winding **26** of magnetic amplifier **25**. With no current flowing through control winding **26**, output winding **27** will offer little impedance to the flow of current from AC terminal **32** through control winding **27**, diode **33**, into filter capacitor **35** and the heater of electron tube **11**. Thus, the nominal full voltage will be applied to the heater of electron tube **11**. As electron tube **11** warms up, current will begin to flow in its plate circuit and through control winding **26**. As the current through control winding **26** increases, the rectified output of magnetic amplifier **25** and the heater power supplied to electron tube **11** will be reduced.

In a properly designed circuit, the plate current and heater voltage will stabilize at equilibrium values. At equilibrium, the plate current through control winding **26** will generate a magnetic amplifier output, to the heater of electron tube **11**, just sufficient to maintain the desired average electron tube plate current. If the electron tube plate current increases, the heater voltage will be reduced so as to decrease the plate current to its nominal

value. If the plate current decreases, the heater voltage will be increased so as to return the plate current to its nominal value. This regulation also provides a stabilization of the heater voltage with respect to variations of the AC power line voltage. Cathode resistor **12** maintains a small negative grid bias so that the cathode emission and plate current of electron tube **11** are partially limited by the negative potential of the grid with respect to the cathode, as well as being limited by the cathode temperature. A small alternating voltage signal applied to the control grid will cause corresponding fluctuations of the instantaneous plate current of electron tube **11**. A corresponding output signal will appear across plate resistor **22** and at output terminal **21**. In class A–1 operation, in which the tube is not driven to cut off and in which the grid is at all times negative with respect to the cathode, the instantaneous variations of the plate circuit current caused by the alternating signal will not significantly change the average current through control winding **26**. Hence, these variations will not significantly affect the electrical power input to the heater of electron tube **11** or the cathode temperature. Thus, the circuit of FIGURE 1 may be used as an alternating voltage amplifier or control circuit. In a particular experimental model, constructed along the lines of the circuit of FIGURE 1, the magnetic amplifier employed a torroidal core wound from a .002 inch thick tape of a nickel-iron alloy known under the trade name of Deltamax. Such cores have a rectangular hysteresis loop and are particularly suitable for use in magnetic amplifiers. The control winding was wound with a suitable number of turns so that an electron tube plate current of the order of .001 ampere, the desired nominal plate circuit current, would generate a core magnetizing force approximately equal to the coercive force of the core material. The output winding was wound with a number of turns such that it would inductively support a 6.3 volt 60 c.p.s. sinusoidal waveform, with core magnetic flux excursions of approximately ½ to ⅔ of the saturation value. The B+ voltage at a terminal corresponding to terminal **29** of FIGURE 1 was of the order of 250 volts. 6.3 volt AC power, derived from a secondary winding of a transformer connected to a 60 c.p.s. AC power line, was connected between ground and a terminal corresponding to terminal **32**. Resistors **12**, **18**, **22**, and **24** were 1000 ohms, 470,000 ohm, 100,000 ohms and 20,000 ohms respectively. Capacitors **13**, **16**, **20**, **30** and **35** were 50 microfarads, .05 microfarad, .05 microfarad, 8 microfarads, and 1000 microfarads respectively. Capacitors **13**, **30** and **35** were electrolytic types, and capacitors **16** and **20** were of the paper dielectric type. Diode **33** was a conventional semiconductor junction rectifier. The electron tube was a type 6AB4, a miniature triode with a medium amplification factor of approximately 20. The 6AB4 is electrically similar to each of the two triode units in commonly used 12AU7 dual triode, and is rated at a nominal heater voltage of 6.3. The equilibrium plate circuit current of the experimental model was approximately .001 ampere, with a 1 volt negative grid bias due to the voltage drop across resistor **12**. The circuit functioned as a voltage amplifier in the manner described above.

When first connected and turned on, the equilibrium heater voltage for the .001 ampere plate current was 3.4 volts. During the first 100 hours of operation, the equilibrium heater voltage rose slowly to 3.6 volts. It then decreased slowly to 3.2 volts after 300 hours of operation. For a subsequent year and a half of continuous operation, the equilibrium heater voltage remained at 3.2 volts. The tube continued to function as an amplifier and displayed no ill effects from continued operation at a low heater voltage. It is estimated that the cathode temperature was several hundred degrees cooler than when operated at the nominal 6.3 heater voltage. The tube envelope remained relatively cool to the touch.

FIGURE 2 illustrates a second form of the invention which may be used to amplify or control unidirectional or low frequency signals. Electron tube **41** of FIGURE 2 is a dual control pentode in which the third grid is used to divide the cathode current between the second or screen grid and the plate. Such tubes are used as variable gain amplifiers, and as multiple input gates or switches in vacuum tube digital computing and control circuits. The cathode of electron tube **41** connects through resistor **42** to ground **44**. Capacitor **43** is connected across resistor **42**, and serves as an alternating current bypass. The anode of electron tube **41** connects to output terminal **45** and to a first side of resistor **46**. The second side of resistor **46** connects to line **47**. The second or screen grid of electron tube **41** connects via line **48** to line **47**. Magnetic amplifier **49** includes control winding **50** and output winding **51**, both wound upon a magnetic core **52**. Resistor **53** connects from line **47** to a first side of control winding **50**. The second side of control winding **50** connects via line **54** to positive voltage supply terminal **55**. Variable resistor **56** is connected between lines **47** and **54**. Capacitor **57** is connected from line **47** to ground **58**. AC power input terminal **59** is connected to a first side of output winding **51**. The second side of output winding **51** connects to the anode of diode **60**, the cathode of which connects to line **61**. Capacitor **62** connects from line **61** to ground **63**. Line **64** connects from line **61** to a first side of the heater of electron tube **41**. The second side of said heater connects to ground **65**. The third or suppressor grid of electron tube **41** connects to input terminal **66**. The first or control grid of electron tube **41** connects through capacitor **67** to input terminal **68**. This first grid is also connected via resistor **69** to ground **70**.

The circuit of FIGURE 2 generally resembles the circuit of FIGURE 1, except for the substitution of three grid electron tube **41** and the addition of variable resistor **56** as an adjustable current bypass around control winding **50**.

In the circuit of FIGURE 1, the average plate current is controlled by magnetic amplifier **25**. Hence, the circuit of FIGURE 1 is useful primarily to amplify and/or control signals of frequencies which are high with respect to the response time of magnetic amplifier **25** and the heater and cathode of electron tube **11**. Electron tube **41** of FIGURE 2 is a dual control pentode, in which the third grid is used to divide cathode current between the second or screen grid and the plate. Since the average potential of the first grid of electron tube **41** will be near ground, the cathode current of electron tube **41** will be brought to an equilibrium value in the manner described for the circuit of FIGURE 1. If grid #3, connected to terminal **66**, is strongly negative with respect to the cathode, little current will be received by the anode of electron tube **41**. The majority of the cathode current will be collected by the screen grid and will flow through line **48**. If a positive potential is applied to terminal **66** and grid #3, a greater fraction of the cathode current will be collected by the plate and a lesser fraction collected by the screen grid. Since both screen and plate currents pass through the control winding circuit of magnetic amplifier **49**, the control of plate current by the #3 grid of electron tube **41** does not significantly vary the total cathode current as seen by magnetic amplifier **49**. Hence, low frequency or DC signals may be amplified and/or controlled. Variable resistor **56** is an adjustable current bypass around control winding **50**. This adjustable bypass is one means of adjusting the sensitivity of magnetic amplifier **49** and, hence, the equilibrium plate current of electron tube **41**.

If desired, alternating voltage signals may be applied to input terminal **68**. The output voltage at terminal **45** will then be simultaneously affected by signals applied to the first and third grids of electron tube **41**.

FIGURE 3 illustrates a third form of the invention, showing its application to the control of the average brightness of a cathode ray tube presentation. In FIGURE 3, the cathode of cathode ray tube **81** connects via

resistor **82** to ground **84**. Capacitor **83** is connected across resistor **82**. The beam current collection electrode of cathode ray tube **81** connects to a first side of resistor **85** which connects in turn to line **86**. Magnetic amplifier **87** includes first control winding **88**, output winding **89** and second control winding **90**, all wound upon magnetic core **91**. Resistor **92** connects from line **86** to a first side of control winding **88**. The second side of winding **88** connects to terminal **93**. Capacitor **94** connects from line **86** to ground **95**. AC input terminal **96** connects to a first side of output winding **89**, which connects in turn to the anode of diode **97**. The cathode of diode **97** connects to line **98**, which connects through capacitor **99** to ground **100**. Line **98** connects through line **101** to a first side of the heater of cathode ray tube **81**. The second side of said heater connects to ground **102**. Input terminal **103** connects via line **104** to a control grid of cathode ray tube **81**. Line **104** also connects through resistor **105** to line **106**. Line **106** connects through capacitor **109** to ground **110**, and through resistor **107** to a first side of winding **90**. The second side of winding **90** connects to ground **108**.

The operation of the circuit of FIGURE 3 generally resembles the operation of the circuits of FIGURES 1 and 2. The major differences are the use of the invention for the control of the beam current of a cathode ray tube, and the addition of second control winding **90** to magnetic amplifier **87**. A positive high voltage source is connected between terminal **93** and ground to provide the high voltage for the operation of cathode ray tube **81**. An alternating voltage source is connected between terminal **96** and ground to provide power for the heater of cathode ray tube **81**. A signal source, providing an electrical signal in accordance with the desired beam current and spot brightness, is connected between terminal **103** and ground. The beam current from cathode ray tube **81** is passed through control winding **88** of magnetic amplifier **87**. Magnetic amplifier **87** controls the heater voltage applied to cathode ray tube **81** so as to maintain the desired average beam current and, hence, the desired average brightness.

In many instances, it will be desirable to vary the average brightness of a cathode ray display in accordance with a received signal. In the circuit of FIGURE 3, the received signal is applied to a control grid of cathode ray tube **81** so as to vary the instantaneous beam current in the normal manner. In addition, the signal from input terminal **103** is filtered and applied to a second control winding of magnetic amplifier **87**. This will cause the equilibrium beam current and average display brightness to vary in accordance with the average received signal.

FIGURE 4 illustrates a fourth form of the invention, showing its application to the control of the peak beam current and display brightness of a cathode ray tube. In FIGURE 4, the cathode of cathode ray tube **121** connects via resistor **122** to ground **124**. Capacitor **123** is connected across resistor **122**. The beam current collection electrode of tube **121** connects via line **125** to a first side of variable resistor **126**. The second side of variable resistor **126** connects to line **127**, which connects to terminal **128**. Line **125** connects to the cathode of diode **129**, the anode of which connects to line **130**. Capacitor **131** and resistor **132** are connected in parallel between lines **127** and **130**. Line **130** connects to the base of transistor **133**. The emitter of transistor **133** connects to a first side of resistor **134**, and through capacitor **135** to line **127**. Magnetic amplifier **136** includes control winding **137** and output winding **138**, both wound upon magnetic core **139**. The negative terminal of battery **140** connects to the collector of transistor **133**, and the positive terminal to line **127**. Terminal **141** connects to a first side of output winding **138**, the second side of which connects to the anode of diode **142**. The cathode of diode **142** connects to line **143**, which connects in turn through capacitor **144** to ground **145**. Line **146** connects from line **143** to a first side of the heater of cathode ray tube **121**. The second side of said heater is connected to ground **147**.

The operation of the circuit of FIGURE 4 generally resembles the operation of the previously described circuits. The major difference in FIGURE 4 is the addition of circuitry between the beam collection electrode of cathode ray tube **121** and the control winding of magnetic amplifier **136**. This additional circuitry causes magnetic amplifier **136** to respond to the peak beam current, rather than the average beam current. A positive high voltage source is connected from terminal **128** to ground to furnish the high voltage for the operation of cathode ray tube **121**. A source of alternating voltage is connected between terminal **141** and ground to provide power for the heater of tube **121**. An electrical signal to vary the cathode ray tube beam current and spot brightness as desired is connected between terminal **148** and ground.

Variable resistor **126**, diode **129**, capacitor **131** and resistor **132** form a peak holding rectifier circuit in which the stored voltage across capacitor **131** corresponds to the peak current through line **125**. Transistor **133** is connected as an emitter follower to couple the circuit of control winding **137** to capacitor **131** without drawing excessive current. For convenience, the collector supply voltage to transistor **133** is shown as battery **140**. In practice, it may be more desirable to use a non-battery power supply for this circuit. With the addition of this circuitry between line **125** and control winding **137**, magnetic amplifier **136** will control the heater voltage of cathode ray tube **121** so as to maintain a desired peak beam current and peak spot brightness. Varying the magnitude of variable resistor **126** will change the sensitivity of the magnetic amplifier control circuit and the resultant peak beam current of cathode ray tube **121**.

The circuit of FIGURE 4 may be particularly useful for radar display applications in which it is desired to maintain a constant peak brightness, in spite of changes in the average brightness due to factors such as variations in the size and number of displayed targets.

The drawings and the preceding description have shown the control of the cathode temperature and cathode current of 1 and 3 grid thermionic electron tubes, and of grid controlled thermionic cathode ray tubes. Similar techniques may be employed to reduce the operating temperature and increase the reliability and probable life of other forms of thermionic electron tubes such as klystrons, traveling wave tubes, and other thermionic electron devices in which an electron beam may be controlled both by varying the cathode heater power and by using additional electrostatic and/or electromagnetic means.

The preceding description has implied the use of indirectly heated cathodes, electrically separate from the cathode heater element. Similar techniques could be used with directly heated cathodes, such as filament type cathodes. The preceding description has shown the use of a magnetic amplifier to control the heater voltage or power. Other forms of amplifying and controlling means, for example, transistor amplifiers, may be similarly used with similar results.

What is claimed is:

1. An electron tube circuit comprising an electron tube having a thermionic electron emitting cathode, an anode and a control grid, heating means for varying the cathode temperature, means coupled to the heating means for controlling the magnitude of the heating thereby controlling the cathode temperature, power terminals for connecting a direct voltage supply in series with the anode and cathode so that a current may flow from anode to cathode, signal terminals for applying a voltage signal to the control grid, first means responsive to the anode current effecting a first control of the magnitude of the heating, and second means responsive to the voltage at the signal terminals effecting a second control of the magnitude of the heating, whereby the temperature of the cathode is

controlled in part by the anode current and in part by the voltage at the signal terminals.

2. An electron tube circuit for controlling the average brightness of a cathode ray tube presentation in response to a voltage signal comprising, a cathode ray tube having a cathode heater, a cathode, an anode and a control grid, a magnetic amplifier having a first control winding connected to the anode, a second control winding connected to the grid and an output winding connected to the heater, means for passing a current through the output winding and the heater whereby the output winding current is effective in controlling the cathode temperature, means for passing a beam current through the first control winding and between the cathode and anode whereby the beam current affects the output winding current to cause the cathode temperature to vary inversely with beam current, and signal terminals for applying a signal voltage to the grid and a signal current through the second control winding whereby the signal current affects the output winding current to cause the cathode temperature to vary with signal current.

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