Nov. 1, 1960 G. M. W. BADGER ET AL 2,958,804

ELECTRON BEAM TUBE AND CIRCUIT

Filed May 19, 1958 4 Sheets-Sheet 1

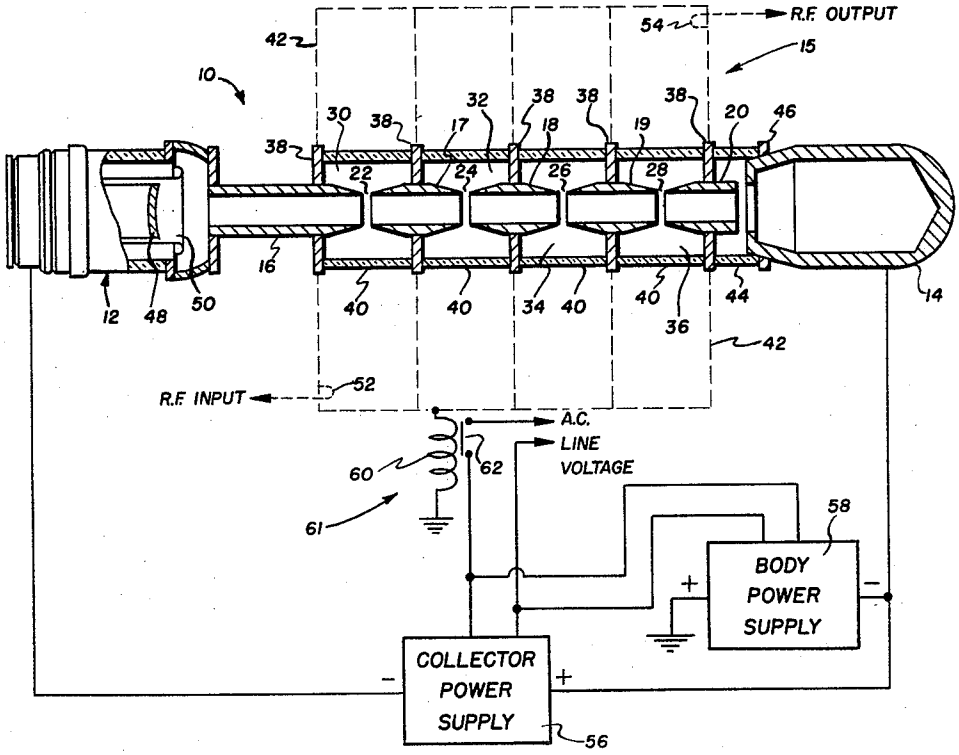


FIG. 1

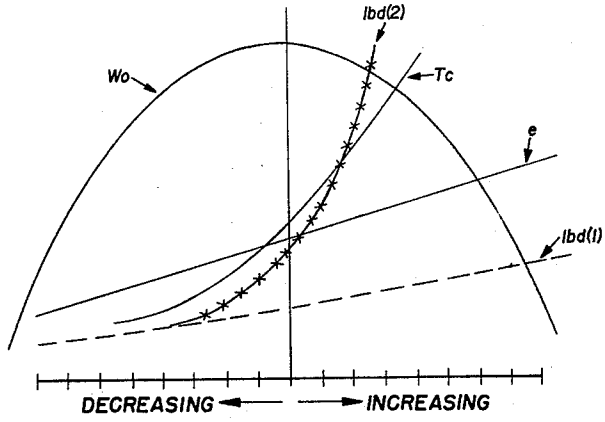


FIG. 2

INVENTOR.
GEORGE M.W. BADGER
DONALD H. PREIST

BY

Leon F. Herbert

ATTORNEY

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ELECTRON BEAM TUBE AND CIRCUIT

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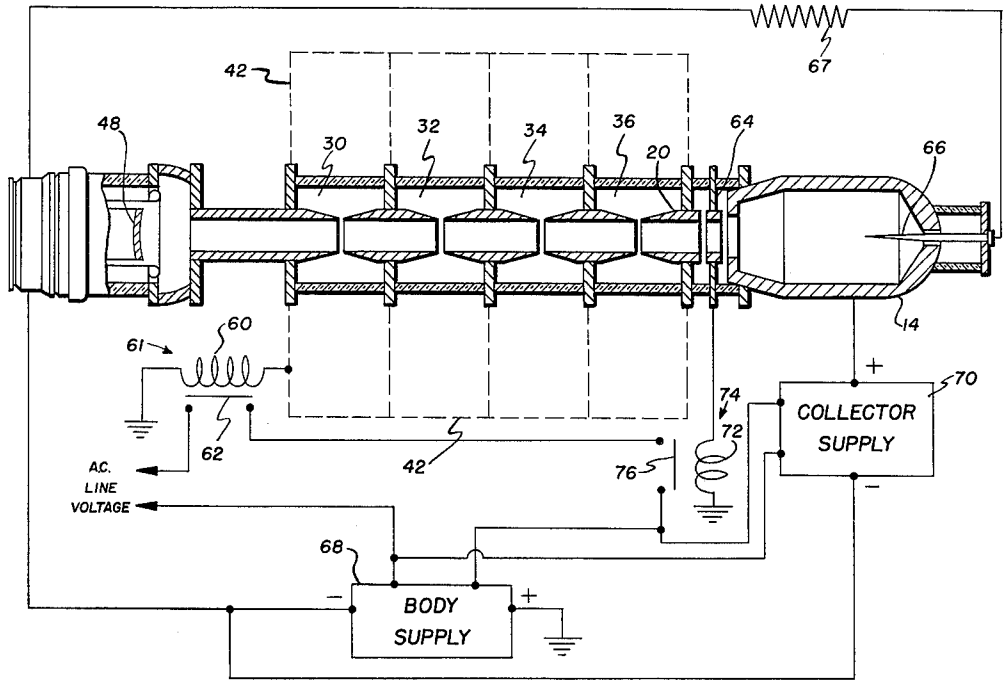


FIG. 3

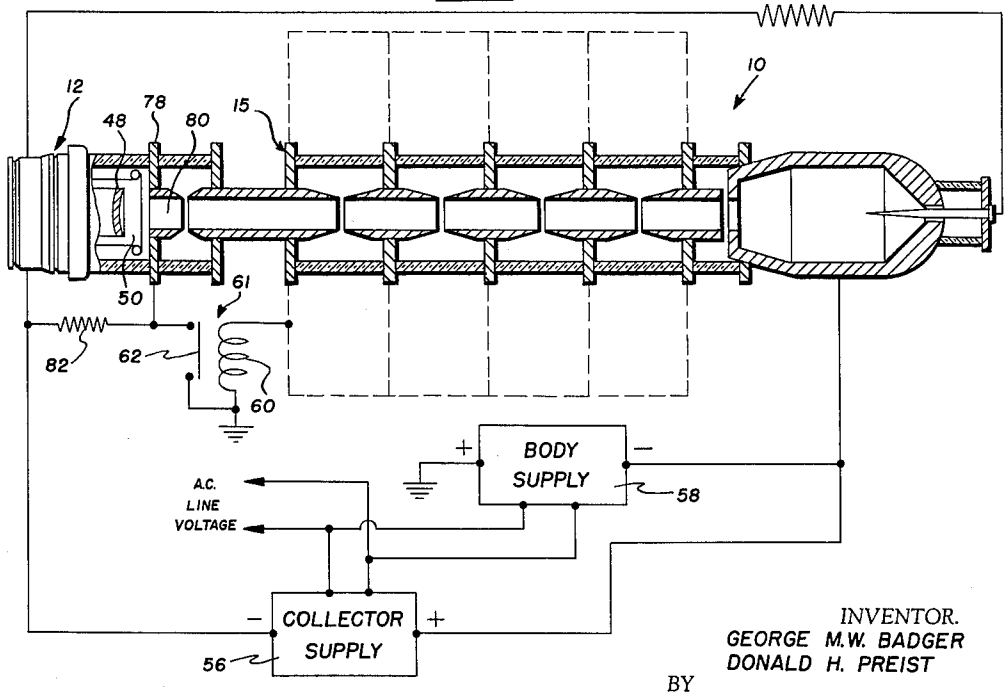


FIG. 4

INVENTOR.
GEORGE M.W. BADGER
DONALD H. PREIST

BY

Leon F. Herbert

ATTORNEY

Nov. 1, 1960 G. M. W. BADGER ET AL 2,958,804

ELECTRON BEAM TUBE AND CIRCUIT

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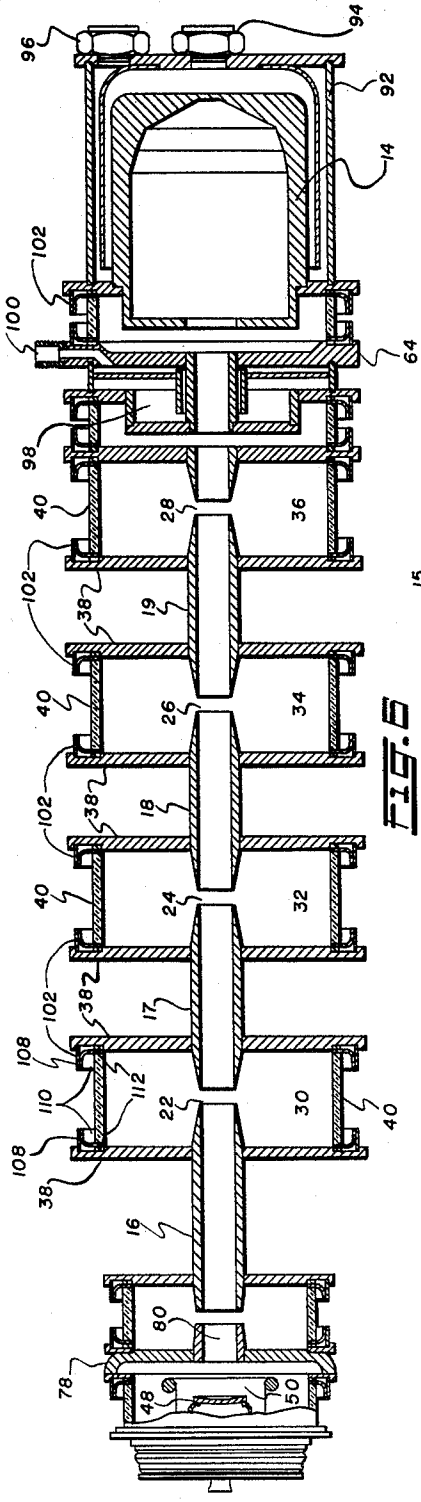


FIG. 5

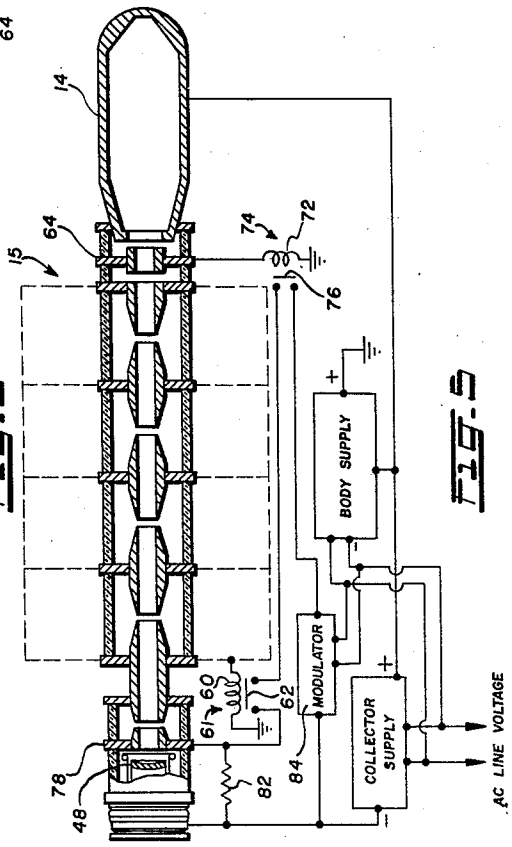


FIG. 6

INVENTOR.
GEORGE M.W. BADGER
DONALD H. PREIST

BY

Leon F. Herbert

ATTORNEY

Nov. 1, 1960 G. M. W. BADGER ET AL 2,958,804

ELECTRON BEAM TUBE AND CIRCUIT

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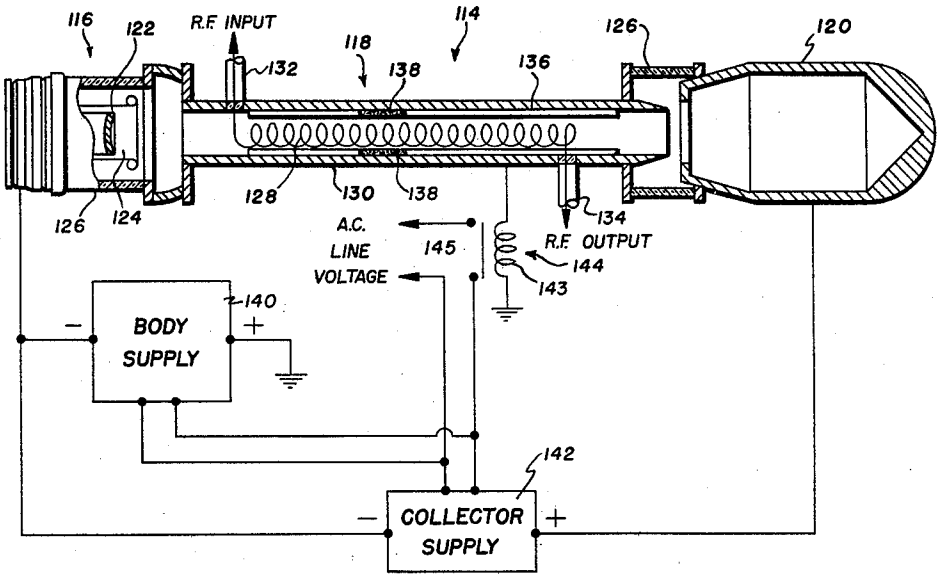


FIG. 7

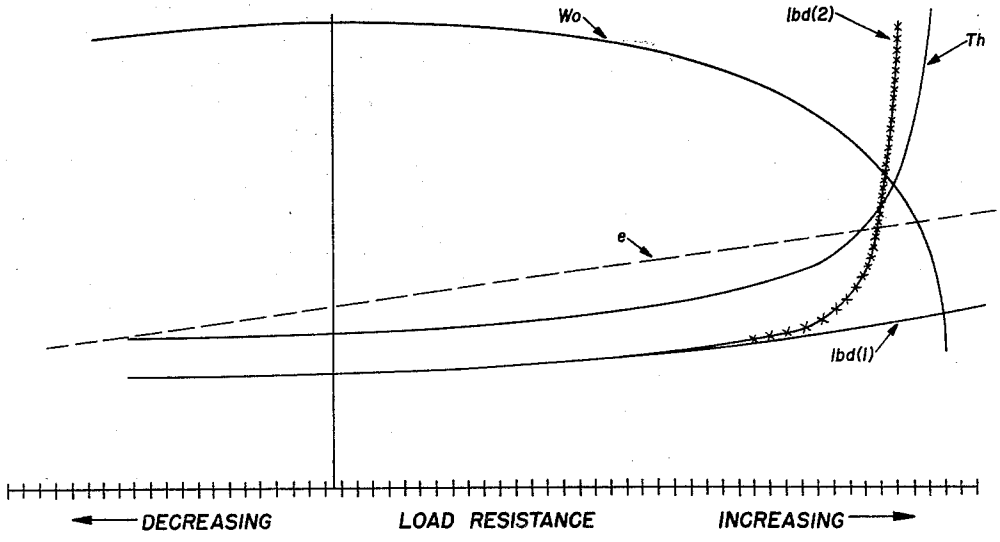


FIG. 8

INVENTOR.
GEORGE M.W. BADGER
DONALD H. PREIST

BY

Leon F. Herbert

ATTORNEY

United States Patent Office 2,958,804 Patented Nov. 1, 1960

2,958,804

ELECTRON BEAM TUBE AND CIRCUIT

George M. W. Badger, Menlo Park, and Donald H. Preist, Mill Valley, Calif., assignors to Eitel-McCullough, Inc., San Bruno, Calif., a corporation of California

Filed May 19, 1958, Ser. No. 736,205

17 Claims. (Cl. 315—5.39)

This invention relates to electron tubes and to methods of and means for operating electron tubes. In particular, this invention relates to methods of and means for protecting beam tubes, such as klystrons and traveling wave tubes, from destruction due to improper operation.

In the operation of high power klystrons and traveling wave tubes one of the important problems is the self destruction of the tube due to improper utilization of energy therefrom. In a klystron, for example, if insufficient power is coupled from the output cavity to the load (i.e., if the klystron is improperly matched to its load, as by undercoupling) the output cavity will tend to become overheated, which may result in destructive thermal effects such as melting of seals or cracking of insulating envelope parts. Similarly, if a traveling wave tube is improperly matched to its load the power reflected due to such mismatch will tend to result in overheating of the helix and ultimate destruction of the tube.

Mismatch between a klystron and its load may occur for a number of reasons. For example, when the circuit in which the klystron is to be operated is being tuned to obtain optimum performance of the klystron, frequency variations will occur which will change the amount of coupling to the load. Similarly, during operation of either klystrons or traveling wave tubes, the load on the tube may be wholly or partially lost. For example, the output circuit into which the tube is operating may be shorted, or ice may form on an antenna to which the tube is connected. Such loss of load will cause improper utilization of energy from the tube and may produce destructive overheating of the tube.

Therefore, it is an object of this invention to provide means for protecting a klystron or a traveling wave tube from destruction due to improper utilization of energy therefrom.

It is another object of this invention to provide a klystron or a traveling wave tube which is particularly designed to be used with a circuit which will protect it from destruction due to improper utilization of energy therefrom.

It is yet another object of this invention to provide a circuit capable of protecting a klystron or a traveling wave tube against destruction due to improper utilization of energy therefrom.

Briefly, an electron tube according to one embodiment of this invention comprises an envelope containing an electron gun, a radio-frequency interaction means, and a collector electrode, the collector being adapted to operate at a lower direct current potential with respect to the cathode than that of the radio-frequency interaction means. The electron tube is operated in a circuit comprising a power supply means providing a first potential difference which is applied between the cathode and the collector of the tube and a second potential difference, greater than the first, which is applied between the cathode and the radio-frequency interaction means of the tube through a current responsive device. The current responsive device is adapted to interrupt the flow of beam current in the tube in response to a given current flow between the cathode and radio-frequency interaction means.

The invention possesses other objects and features of advantage, some of which, with the foregoing, will be set forth in the following description of our invention. It is to be understood that we do not limit ourselves to this disclosure of species of our invention, as we may adopt variant embodiments thereof within the scope of the claims.

Referring to the drawing:

Figure 1 is a simplified plan view in cross-section of a klystron and schematic representation of a circuit according to one embodiment of this invention;

Figure 2 is a graphical representation of certain electrical characteristics of a klystron in operation, showing the advantages of this invention over the prior art;

Figure 3 is a simplified plan view in cross-section of a klystron and a schematic representation of a circuit according to another embodiment of this invention;

Figure 4 is a simplified plan view in cross-section of a klystron and a schematic representation of a circuit according to still another embodiment of this invention;

Figure 5 is a simplified plan view in cross-section of a klystron and a schematic representation of a circuit according to a still further embodiment of this invention;

Figure 6 is a detailed plan view in cross-section of the type of klystron shown in Figure 5;

Figure 7 is a simplified plan view in cross-section of a traveling wave tube and a schematic representation of a circuit according to this invention;

Figure 8 is a graphical representation of certain electrical characteristics of a traveling wave tube in operation showing the advantages of this invention over the prior art.

Referring to Figure 1, a klystron **10** has been chosen for illustration in connection with the basic principles of the subject invention since the greatest amount of experimentation has been done with klystrons. The klystron **10** comprises an electron gun **12** forming one end of an elongated envelope and a collector electrode **14** forming the other end of the envelope. The intermediate portion of the envelope is formed by the radio-frequency interaction means or body **15** of the tube which comprises a plurality of drift tube sections **16, 17, 18, 19** and **20** spaced from each other to form interaction gaps **22, 24, 26** and **28**, and a plurality of cavity resonator portions **30, 32, 34** and **36** bridging the interaction gaps **22, 24, 26** and **28**.

The cavity resonator portions each comprise two metal end walls **38** and a ceramic cylinder **40** sealed between the end walls **38**. The ceramic cylinders **40** provide vacuum tight envelope walls and radio-frequency windows through which radio-frequency oscillations may pass into the exterior non-evacuated portions of the resonant cavities represented by dotted lines **42**. Such exterior portions of the resonant cavities are conductive, thus electrically interconnecting the drift tube sections and completing the R.F. interaction means or body **15** of the tube.

A ceramic cylinder **44** is sealed between an end wall **38** of the resonant cavity portion **36** adjacent the collector electrode **14** and a metallic flange **46** on the collector electrode **14**, thus insulating the collector electrode from the remainder of the klystron **10**.

The electron gun **12** of the klystron **10** comprises a cathode **48** and a focusing electrode **50**. In order to produce a beam of electrons the focusing electrode **50** is maintained at a zero or slightly negative potential

with respect to the cathode 48. This, along with the curvature of the cathode 48, will focus the electrons from the cathode into a beam of slightly smaller diameter than the inner diameter of the drift tube sections. A positive potential applied to both the body 15 and the collector 14 with respect to the cathode 48 will cause the beam to pass axially through the drift tube sections and into the collector. A conventional magnetic system (not shown) is used to prevent the beam from spreading. All of the electrons in the beam will tend to have a constant velocity which is determined by the potential applied to the body and collector with respect to the cathode if no velocity modulation is applied to the tube and nearly all of the power in the beam will be dissipated at the collector in the form of heat.

As is well known in the klystron art, radio-frequency oscillations may be introduced into the resonant cavity adjacent the electron gun 12 (as by means of an inductive loop 52, for example) which oscillations will produce a varying electrostatic field across the interaction gap 22 associated with such resonant cavity to modulate the velocity of the electrons in the beam as they cross the interaction gap 22. Such modulation of the velocity of electrons in the beam results in bunching of the electrons as they proceed along the drift tube. The bunches of electrons thus obtained cause varying electrostatic fields at each of the succeeding interaction gaps 24, 26 and 28 as they pass thereacross, thus inducing oscillations in the cavities 32, 34 and 36 associated with such gaps. Such oscillations will reinforce the electrostatic field at each of the gaps which will further increase the bunching of the electrons as they proceed along the drift tube. The oscillations produced in the cavity 36 adjacent the collector electrode 14 will be of the greatest intensity and may be coupled out of the cavity, by means of another induction loop 54, for example, as the power output of the tube. The electrons proceed on into the collector electrode 14 where their residual energy is dissipated in the form of heat.

Figure 2 is a graph of certain operational characteristics of a klystron. Since a klystron is designed to operate in resonant circuits, the load on a klystron will be essentially resistive. Thus, the base line or abscissa of the graph of Figure 2 is divided into arbitrary units of load resistance. With a klystron, as with any other power source, optimum power in the load is obtained when the load resistance is equal to the equivalent internal resistance thereof. Therefore a point at the center of the base line or abscissa has been selected as that value of resistance which equals the equivalent internal resistance of the klystron and a vertical line has been drawn through such point. Values to the right of such line represent increasing load resistance and values to the left of such line represent decreasing load resistance. By definition and as shown by the curve labeled (W_0), the power delivered to the load will be maximum at the value of load resistance represented by such line and will decrease for either increasing or decreasing values of load resistance.

If the radio-frequency voltage in the output cavity of a klystron is plotted on the graph described above (as shown by the curve labeled *e* in Figure 2) it will be seen to decrease from some given value at optimum load resistance as the load resistance decreases and to increase from such value as the load resistance increases. This is well known in the art and is as would be expected by analogy to other types of power sources.

In a klystron of the construction shown in Figure 1, the ceramic cylinder 40 in the output cavity 36 acts as a shunt impedance, across the output circuit of the klystron. Thus, such ceramic cylinder introduces power losses into the output circuit, such losses taking the form of heating of the ceramic cylinder. The heating of the ceramic cylinder is represented on the graph by the curve labeled T_c and is seen to increase rapidly as the load resistance increases. The rapid increase in heating of the ceramic cylinder is due to a number of effects. In the first place, the power loss in the ceramic cylinder will increase with the square of the voltage thereacross. Secondly, the dielectric loss factor of the ceramic cylinder tends to increase as its temperature goes up, the power loss or heating of the ceramic cylinder increasing accordingly.

A further contribution to the heating of the ceramic cylinder is made by the bombardment thereof by secondary electrons. Such secondary electrons are produced by the impingement of primary electrons from the beam on the end or tip of the drift tube section 20 adjacent the output gap 28 due to the beam spreading action of the output gap in extracting power from the beam. The action of the output gap is such that the impingement of the primary electrons on the end of the drift tube section adjacent thereto will increase rapidly as the peak value of the radio-frequency voltage in the output cavity approaches the D.C. voltage between cathode and R.F. interaction section.

Furthermore, the number and velocity of the secondary electrons produced by such impingement of primary electrons will increase in proportion to the number of impinging primary electrons and therefore with the R.F. voltage across the gap.

Thus, since the radio-frequency voltage in the output cavity increases as the load resistance increases, the bombardment of the ceramic cylinder by secondary electrons and the heating of the ceramic cylinder due to such bombardment will increase rapidly as the load resistance increases.

The variations in load resistance which are responsible for such overheating and destruction are largely due to coupling problems. A variation in coupling has the effect of varying the resistive load on the klystron and thus "coupling" may be substituted for "load resistance" on the abscissas of the graph of Figure 2. The vertical line would then represent both optimum load resistance and optimum coupling. Lesser degrees of coupling would lie to the right of such vertical line and would have the effect of increasing load resistance. Greater degrees of coupling would lie to the left of the vertical line and would have the effect of decreasing load resistance.

It will be seen that if a klystron is undercoupled to its load the effective load resistance will increase, causing the output ceramic to overheat and possibly resulting in destruction of the tube. For this reason most klystrons are usually operated slightly over-coupled in order to provide some degree of protection against destruction due to under coupling.

However, coupling cannot always be accurately controlled. For example, a slight change in the orientation of a coupling loop can produce a large change in coupling. In addition, variations in operating frequency, as, for example, when the klystron and circuit are being tuned to obtain optimum power output, can produce very erratic variations in coupling. Furthermore, a broken output line or some similar physical occurrence can cause a complete loss of load which is the ultimate of undercoupled conditions. Thus, a protective means is needed which will react to an undercoupling condition or loss of load to protect the tube from destruction.

In the operation of a klystron according to the prior art, there was no practical means of protecting a beam tube from destruction due to undercoupling conditions. Referring to the graph of Figure 2, it will be seen that either undercoupling or overcoupling will produce the same variation in power output. Furthermore, a comparatively small change in power output due to undercoupling corresponds to a radical increase in ceramic heating. Thus, monitoring of the power output of the tube will not provide a reliable indication of the coupling condition thereof. Similarly, although the radio-frequency voltage in the output cavity increases with undercoupling, the rate of such increase is so small compared

to the radical increase in ceramic heating that monitoring of such radio-frequency voltage is impractical as a means of providing protection against destruction due to undercoupling.

However, according to this invention, undercoupling conditions may be quickly and accurately detected. This is accomplished by operating the klystron with the collector at a lower positive potential with respect to the cathode than the potential of the body with respect to the cathode and monitoring the current flow between the body and the cathode.

Referring again to the graph of Figure 2, the curve marked $Ibd_{(1)}$ represents the current flow between the body of a klystron and the cathode thereof, when the collector and the body of the klystron are at the same potential with respect to the cathode. Ideally, there should be no current flow between the body of the klystron and the cathode thereof, since all of the electrons from the cathode are supposed to be focused into a beam of slightly smaller diameter than the diameter of the drift tube sections. Thus, under ideal conditions, all of the electrons emitted by the cathode would pass through the drift tube sections and impinge upon the collector. However, in actual practice, it is found that a certain small percentage of the electrons emitted by the cathode will not reach the collector but will impinge upon the body of the klystron. The impingement of electrons on the body of the tube occurs for a variety of reasons, among which are thermal effects and the beam-spreading action of the various interaction gaps.

It will be seen that the body current $Ibd_{(1)}$ described above increases slightly when the tube is undercoupled. The increase in body current is due to the increase in the radio-frequency voltage of the output gap **28** when the tube is undercoupled. However, such increase in body current is so small in comparison to the radical increase in ceramic heating (T_c) that it would be impractical to attempt to monitor the body current as a means of providing protection against destruction due to undercoupling.

Thus, according to this invention, the collector is "depressed," or in other words the tube is operated with the collector at a lower potential with respect to the cathode than the potential of the body with respect to the cathode. With the collector depressed, undercoupling causes the body current to increase just as radically as the temperature of the ceramic cylinder increases, as shown by the curve labeled Ibd_2.

The rapid increase in body current with increasing load impedance (or undercoupling) when the collector is depressed is due to the increase in R.F. voltage in the output cavity (curve *e*) which is also responsible for the increased ceramic heating, as described above. For this reason the amount of body current is always representative of the ceramic heating. It will be seen that the increase in R.F. voltage swing across the output gap will have an increased effect on the electrons as they pass across such gap. Thus, certain of the electrons will be slowed down to such an extent that they will not possess sufficient velocity to get into the collector due to its low potential. Instead, they will be attracted back to the end of the body adjacent the collector due to its high positive potential and will contribute to the body current. With specific reference to Figure 1, the slow electrons will not enter collector **14** but will return to the drift tube section **20**.

Referring again to Figure 1, there is shown a circuit according to this invention for protecting a klystron against damage due to undercoupling. A first power supply represented schematically at **56** is electrically connected between the cathode and the collector and provides a given potential difference therebetween (6 kv., for example). A second power supply represented schematically at **58** (4 kv., for example) is electrically connected between the collector and the ground, the positive terminal of the supply being grounded. The R.F. interaction means or body **15** of the tube comprising the interior cavity resonator portions **30, 32, 34, 36** and the external portions represented by the dotted lines **42** are connected to ground through the coil **60** of a current responsive device **61**. Therefore, it will be seen that the cathode and collector are at negative potential with respect to ground, the cathode being more negative than the collector, while the body of the tube is at ground potential. It should be understood that direct connections could be made without grounding any portion of the circuit or that the cathode or the collector could be grounded instead of the body. The arrangement described, with the body grounded, is preferred since it is believed to be less dangerous to human life.

The switch contacts **62** associated with the coil of the current responsive device are placed in the input power lines to the power supplies **56** and **58**. The switch contacts **62** are normally closed, thus energizing the power supplies **56** and **58**. However, the current responsive means **61** is adjusted so that when a predetermined current flows through the coil **60** the switch contacts **62** will be opened, thus disconnecting the power supplies from the power source and inactivating the tube. Thus, since the collector is at a lower potential than the body of the tube, if the tube is undercoupled or the load impedance increases for any reason the body current will increase rapidly as described above. The resulting increased current flow through the coil of the current responsive device **61** will open the contacts **62** and inactivate the tube before overheating of the ceramic can occur. The action of the current responsive device **61** may be adjusted to be rapid or slow depending on the needs of a particular tube or of the particular circuit in which such tube is to be used. It should be understood that current responsive devices other than that specifically described herein, such as bi-metallic resistance elements, for example, might be used, but that regardless of the type of current responsive device used, it is preferably one which is manually resettable.

The circuit described above also provides protection against other malfunctioning such as misalignment of the beam or failure of the magnetic focusing equipment. Misalignment of the beam, for example, will result in increased body current due to the increased impingement of the beam on one or more of the drift tube sections. Such increased body current will flow through the coil **60** opening the contacts **62** and inactivating the tube.

However, the use of a lesser positive potential on the collector than the body of the tube, as described above, produces other problems. For example, the bombardment of the collector by the beam will produce secondary electrons. Such secondary electrons will tend to be attracted away from the collector to the highly positive body. Some of such secondaries may be accelerated into the drift tube and will tend to cross the output interaction gap in the reverse direction and out of phase with the electrons of the beam, thus interfering with the operation of the tube.

The problem of secondaries may be satisfactorily overcome through the use of a so-called "flytrap" collector. Such collector, as shown in Figure 1, comprises a hollow member having a comparatively large volume with respect to the size of the opening through which the beam passes. Thus, the secondary electrons which are produced by the impingement of the beam on the interior of such member are shielded from the high positive field of the body and are "trapped" within the collector. In other words, in a flytrap collector the angle which the secondary electrons see for escape will be greatly reduced since the cross-sectional area of the collector is large in comparison to the area of the opening into the collector.

The use of a depressed collector has an advantage in

addition to that of causing the body current to increase rapidly with undercoupling. This additional advantage is that the electron beam may be collected at a lower potential. Thus, if the collector is depressed, a substantial power savings may be realized. In a typical klystron of this kind best results have been obtained through the use of collector depression of approximately 40%. In other words, the potential of the collector with respect to the cathode is 60% of the potential of the body with respect to the cathode. However, the collector may be depressed to a lesser or greater extent within the scope of the subject invention.

Referring to Figure 3, another embodiment of this invention is shown. The tube according to the embodiment shown in Figure 3 is identical to that shown in Figure 1 except that an auxiliary collector electrode **64** is interposed between the end of the last drift tube section **20** and the collector **14** and is insulated from both the drift tube section **20** and the collector **14**, and further that a probe **66** is placed in the collector and insulated therefrom.

The probe **66** within the collector **14** is connected to the cathode **48** through a resistor **67** so that it tends to assume the same potential as the cathode. The purpose of the probe within the collector is to aid in the suppression of secondary electrons within the collector. Furthermore, the probe has been found to be particularly desirable in depressed collector operation since it tends to remove any positive ions which may be trapped within the collector. The presence of such positive ions is undesirable in the collector since they will tend to perform a focusing action on the beam within the collector. Such focusing action may cause the beam to be concentrated on one spot on the interior surface of the collector, producing a hot spot, and may actually result in melting of a small area on the collector wall releasing gases or perhaps even puncturing the collector. Therefore, the embodiment shown in Figure 6 represents a still further improvement on the flytrap collector.

According to the embodiment shown in Figure 3, the cathode is connected to ground through a high voltage power supply **68** (10 kv., for example) and to the collector through a lower voltage power supply **70** (6 kv., for example), the negative terminal of each supply being connected to the cathode. As in the embodiment shown in Figure 1, the body of the tube comprising the interconnected internal resonator portions **30**, **32**, **34**, **36** and the external resonator portions represented by dotted lines **42** are connected to ground through the coil **60** of a current responsive device **61**, the switch contacts **62** being placed in the input power line to the power supplies **68** and **70**.

Similarly, the auxiliary collector is connected to ground through the coil **72** of a second current responsive device **74**. The contacts **76** of such second current responsive device **74** are also placed in the input lines to the power supplies **68** and **70**. Under normal operating conditions the contacts **62** and **76** of both current responsive devices **61** and **74** are closed. However, if excess current flows through either current responsive device **61** or **74** the contacts will be opened, disconnecting the power supplies from the power source and inactivating the tube.

The embodiment of the invention shown in Figure 3 is specifically designed to take advantage of the fact that the rapid increase in body current due to undercoupling in depressed collector operation, as shown by the curve Ibd_2 in Figure 2, as compared to the slight increase in body current under nondepressed collector conditions, as shown by the curve Ibd_1, is due almost entirely to the electrons of the beam which do not enter the collector but instead return to and impinge upon the end of the last drift tube section **20**. By interposing the auxiliary collector **64** between the collector **14** and the last drift tube section **20**, such electrons are intercepted by the auxiliary collector **64**. Thus, under normal operating conditions substantially no current will flow through the current responsive device **74** connected to the auxiliary collector. However, when an undercoupled condition occurs, a very high current will immediately result through the current responsive device **74** connected to the auxiliary collector. Thus, it will be seen that the current responsive device **74** connected to the auxiliary collector need only discriminate between substantially no current and a high current, whereas, referring to the embodiment of the invention shown in Figure 1, the current responsive device **61** must distinguish between a certain appreciable normal current flow and a higher current flow. Thus, the embodiment of the invention shown in Figure 3 enables a much finer control of the heating of the ceramic due to undercoupling.

The current responsive device **61** shown connected between the body of the tube and ground in Figure 3 will not respond in any way to undercoupling since the auxiliary collector will receive all of the electrons which tend to return to the body due to an undercoupled condition. Instead, the current responsive device **61** will provide protection against malfunctions of the tube such as misalignment of the beam or failure of the magnetic focusing system, as was mentioned with respect to the embodiment shown in Figure 1. Thus, all of the protective features of the embodiment of this invention shown in Figure 1 are provided by the embodiment shown in Figure 3 and in addition the response of the embodiment shown in Figure 3 to undercoupling is more discriminate.

Referring to Figure 4, still another embodiment of the subject invention is shown. The klystron used according to the embodiment shown in Figure 4 differs from that shown in Figure 3 in that it has a modulating anode **78**. Otherwise the tube is the same as was described with respect to Figure 3. The modulating anode **78** comprises an apertured electrode adjacent the cathode which is insulated from both the electron gun **12** and the body **15** of the tube **10**. The aperture **80** of the modulating anode may have a diameter approximately equal to the diameter of the drift tube sections and is of sufficient length to shield the cathode **48** completely from the electric field of the body **15** of the tube. Thus, the emission of electrons from the cathode **48** is controlled entirely by the potential difference between the cathode and the modulating anode **78** and is entirely independent of the potential difference between the cathode and the body **15**. If the modulating anode is at cathode potential (or negative potential with respect to the cathode) no electrons will be emitted by the cathode and thus there will be no electron beam. If a positive potential is applied to the modulating anode with respect to the cathode, electrons will be emitted by the cathode, formed into a beam by the focusing electrode **50**, and accelerated into the drift tube. Due to the action of the focusing electrode, substantially no electrons will impinge upon the modulating anode **78** even though it is at a very high positive potential with respect to the cathode **48**. Since the quantity of electrons emitted by the cathode, or, in other words, the beam current will increase as the positive potential on the modulating anode increases and no electrons impinge upon such modulating anode, an effective modulating means is provided which requires very low driving power.

The circuit according to the embodiment shown in Figure 4 is the same as that of the embodiment shown in Figure 1 except that the switch contacts **62** of the current responsive device **61** are not placed in the input power line of the power supplies **56** and **58**. Instead, the switch contacts **62** are placed in the modulating anode circuit and function to apply a cut-off voltage to the modulating anode **78** if undercoupling occurs. In other words, under normal operating conditions the modulating anode **78** is connected to ground through the contacts of the current responsive device. The modulating anode **78** is also connected to the cathode through a resistor **32**.

Thus, the full voltage applied to the body of the klystron is developed across the resistor **82** between the cathode and the modulating anode, placing the modulating anode at body potential with respect to the cathode, thus producing full beam current. However, if an undercoupled condition should occur, electrons returning to the body **15** of the electron discharge device would pass through coil **60** of the current responsive device **61**, tending to open the contacts **62**. As soon as the contacts are opened, the high voltage between modulating anode and the cathode will discharge through the resistor **82** and the modulating anode will assume cathode potential, completely cutting off the electron beam and thus inactivating the klystron. As has been pointed out heretofore, the current responsive device may be of the manually resettable type so that it may be reset and the tube returned to operation when the difficulty has been corrected.

It will be seen that according to the embodiment shown in Figure 4 the input to the power supplies is never interrupted even under undercoupled conditions. This arrangement may be particularly desirable in applications where it is desired to place the klystron back into operation as soon as possible after the undercoupled condition is rectified or where momentary undercoupling may be expected to occur. Since the power supplies are not turned off, the klystron will be ready for operation as soon as the undercoupled condition has been corrected and the switch contacts **62** have been manually reset.

Referring to Figure 5, yet another embodiment of the subject invention is shown. The klystron according to the embodiment shown in Figure 5 is a combination of the klystron shown in Figure 3 with that shown in Figure 4 in that it includes both an auxiliary collector **64** between the body **15** and the collector **14** and a modulating anode **78** between the cathode **48** and the body **15**. According to this embodiment of the invention, as in the embodiment shown in Figure 4, the modulating anode **78** is connected to the cathode **48** through a resistor **82**. In addition, a source **84** of modulating voltage is connected between the cathode **48** and modulating anode **78** through the switch contacts **62** and **76** of two current responsive devices **62** and **74**. The coil **72** of one **74** of such current responsive devices is connected between the auxiliary collector **64** and ground and the coil **60** of the **61** other of such current responsive devices is connected between the body **15** of the klystron and ground, as is described in connection with the embodiment shown in Figure 3. Thus, under normal operating conditions the modulating anode **78** may be utilized to modulate the beam of the klystron as desired. However, if an undercoupled condition occurs, electrons will be returned to the auxiliary collector **64**, causing a current flow through the coil **72** of current responsive device **74** opening its switch contacts **76**, and thereby disconnecting the modulator **84** and placing the modulating anode **78** at cathode potential which will cut off the beam. Similarly, if, due to some malfunction of the tube or circuit, excess electrons from the beam impinge upon the body **15** of the klystron, current will flow through the coil **60** of the current responsive device **61** connected between the body and ground, opening its switch contacts **62** and placing the modulating anode **78** at cathode potential to cut off the beam. This embodiment of the invention combines all of the advantageous features of the embodiments heretofore described.

Referring to Figure 6, the structural details of an electron tube according to the embodiment of Figure 5 are shown. The klystron shown in Figure 6 is specifically designed for high power operation. For example, the collector **14** of the klystron is provided with a cooling jacket **92** having inlet **94** and outlet **96** connections whereby cooling fluid may be circulated about such collector. In addition, the auxiliary collector **64** is adapted to be liquid cooled by having a passageway **98** formed therein with inlet and outlet connections **100** so that cooling fluid may be circulated therethrough.

Among the other structural features of interest shown in Figure 6 are the vacuum tight seals **102** between the ceramic cylinders **40** and the metal end walls **38**. Each of such seals comprises a first metallic sealing ring **108** having one end sealed to an associated metal end wall **38** as by brazing. A second sealing ring **110** is adapted to fit snugly within the first sealing ring **108** and has a flange which extends inwardly across one end of an associated ceramic cylinder **40** and is sealed to the end of the ceramic cylinder **40** as by brazing to a metallic coating on the end of such cylinder **40**. A ceramic backing ring **112** is brazed to the opposite surface of the inwardly extending flange of the second sealing ring **110** from the ceramic cylinder **40** and is in sliding abutment with the metal end wall **38**. The free ends of the sealing rings **108** and **110** are sealed to each other as by brazing or welding to complete the vacuum tight joint. It will be seen that any stresses caused by the difference in radial expansion between a ceramic cylinder **40** and the associated metal end wall **38** which may occur due to thermal effects will be minimized by flexure of the sealing rings **108** and **110**. The ceramic backing ring **112** provides for free sliding movement and at the same time supports the full axial stress exerted on the seal **102**.

Referring to Figure 7, an embodiment of this invention as applied to a traveling wave tube **114** is shown. As with the klystron heretofore described, the traveling wave tube **114** comprises an electron gun **116** for producing a beam of electrons, a body section **118** for radio frequency interaction with the beam, and a collector **120** for receiving the electron beam after it has passed through the body **118**. The electron gun **116** comprises a cathode **122** which emits electrons and a focus electrode **124** which forms such electrons into a beam. The collector **120** is of the "flytrap" design, similar to that shown in the klystron **10** of Figure 1, so that collector depression, as described hereinabove, may be employed.

The body **118** of the traveling wave tube **114** is insulated from both the electron gun **116** and the collector **120** by means of ceramic cylinders **126**, for example, and comprises a slow wave structure **128** supported within a conductive shell **130**. As shown in Figure 7, the slow wave structure **128** is a helix arranged to surround the electron beam. A radio-frequency wave is applied to the helix at the end thereof adjacent the electron gun, as indicated at **132**, and the helix is designed so that the wave is propagated along it at a velocity corresponding to the velocity of the electron beam which passes axially through it. Thus, the wave interacts with the electron beam throughout the length of the helix, tending to velocity modulate the electrons of the beam to produce bunches of electrons in the beam, which bunches in turn tend to reinforce the wave. The reinforced beam is extraced from the helix at the end thereof adjacent the collector, as shown at **134**. The conductive shell **130** serves to shield the helix and electron beam from the influence of any external electric fields and the helix is supported within such shell **130** by insulating means **136** such as quartz rods spread about the outer periphery of the helix between the helix and the shell **130**.

It should be understood that the slow wave structure **128** may take a variety of forms other than the helix shown in Figure 7. For example, traveling wave tubes utilizing disc loaded wave guides, or interdigited conductive structures, or filter networks as the slow wave structure **128** are well known in the art. In addition, traveling wave tubes which make use of the backward wave which is propagated in a reverse direction along the slow wave structure are known. It is believed that the subject invention is applicable to all of the traveling wave tube structures mentioned above, including those which make use of the backward wave. According to the embodiment

shown in Figure 7, resistive elements **138** are placed between the helix **128** and the shell **130** toward the gun end of the tube. Such resistive elements **138** serve to attenuate the backward wave which is propagated along the helix and would tend to interfere with the desired operation of the tube by producing oscillations, etc.

The circuit according to the embodiment of the invention shown in Figure 7 comprises high voltage (e.g., 10 kv.) power supply **140** connected between the cathode **122** and ground and a lower voltage (e.g., 6 kv.) power supply **142** connected between the cathode **122** and the collector **120**. The shell **130** and the helix of the tube are connected to ground through the coil **143** of a current responsive device **144**. Thus, it will be seen that the body **118** of the tube is at ground potential, the collector is at a negative potential with respect to the body, and the cathode is at a higher negative potential with respect to the body. In other words, the circuit is designed for depressed collector operation of the tube. The switch contacts **145** of the current responsive device **144** are placed in the input power line to the high voltage supplies **140** and **142**. Under normal operating conditions such switch contacts **145** are closed, but if excess current flows through the coil **143** of the current responsive device **144** the contacts **145** will be opened, disconnecting the power supplies and inactivating the tube.

Figure 8 is a graph similar to the graph of Figure 2, but showing certain operational characteristics of traveling wave tubes. Since a traveling wave tube is inherently a much broader band device than a klystron, the power output (curve W_o) of a traveling wave tube probably does not vary so radically with load resistance as does the power output of a klystron. Nevertheless, there is an optimum load resistance, as represented by the vertical line in Figure 8, and if the load resistance decreases to zero as with a shorted load, or increases to infinity, as when the load is lost due to the rupture of the output line, the power output of the tube will decrease rapidly. Although the tube is not endangered by the shorting of the load to produce zero load resistance, it has been found that if the load resistance increases to high values approximating infinity, as when an output line breaks, the helix will be intensely heated at the output end thereof, as is shown by the curve *Th*. Such heating of the helix is not fully understood but is believed to be due to the increase in voltage which will occur at the output end of the helix, as indicated by the curve *e*. Such increased voltage will cause increased bombardment of the last few turns of the helix by electrons from the beam. Although the body current of a traveling wave tube under non-depressed collector does not increase appreciably (as shown by the curve Ibd_1) due to such bombardment, it is believed that secondary electrons are produced which may rebound between the last few turns of the helix, due to the rapidly changing electric fields present, to cause the excessive heating thereof.

However, by operating the tube with the collector depressed (i.e., with the collector at a lower potential than the body) the body current may be caused to increase rapidly as the load resistance approaches infinity, as shown by the curve Ibd_2. The body current increases rapidly due to the fact that certain of the electrons of the beam will not have sufficient velocity to enter the collector due to its reduced potential, but will return to the shell **130** and helix **128** of the tube, producing an increased current flow through the coil **143** of the current responsive device **144**, opening the contacts **145** thereof and inactivating the tube.

Thus, it will be seen that according to the subject invention novel circuits are provided for the protection of beam tubes such as klystrons and traveling wave tubes during operation thereof. Furthermore, a novel structure for beam tubes is provided, which construction enhances the protective operation of the circuits. It should be understood that the current responsive device, described hereinabove as an electro-magnetic device, could take other forms such as a bi-metallic element, for example, which will respond to excess current flow. In addition, it should be realized that a modulating anode or an auxiliary collector or both, as described with respect to Figures 3, 4 and 5, could be used in the traveling wave tube embodiment shown in Figure 7. Also, changes can be made in the circuitry described hereinabove which will not depart from the fundamental teaching of the invention.

What is claimed is:

1. In combination an electron tube comprising an elongated envelope, an electron gun including a cathode at one end of said envelope, a collector electrode at the other end of said envelope, and a radio frequency interaction means interposed between said electron gun and said collector; and a circuit comprising a high voltage power supply means providing a given positive voltage and a higher positive voltage, means connecting said given positive voltage to said collector with respect to said cathode, and other means connecting said higher positive voltage to said radio frequency interaction means with respect to said cathode, said other means including a current responsive device adapted to interrupt the flow of beam current through said electron tube in response to a given current flow between said interaction means and said cathode.

2. In combination an electron tube comprising an elongated envelope, an electron gun including a cathode at one end of said envelope, a collector electrode at the other end of said envelope, and a radio frequency interaction means interposed between said electron gun and said collector; and a circuit comprising a high voltage power supply means providing a given positive voltage and a higher positive voltage, and a current responsive device comprising an actuating means and an actuated means, said actuated means including a switch, said given positive voltage being directly connected to said collector electrode with respect to said cathode, said higher positive voltage being connected to said radio frequency interaction means with respect to said cathode through said actuating means of said current responsive device, said switch of said actuated means of said current responsive device being interposed in the input power line to said power supply means whereby said current responsive device is adapted to interrupt the operation of said power supply means in response to a given current flow between said radio frequency interaction means and said cathode.

3. An electron tube apparatus comprising an elongated envelope, an electron gun including a cathode at one end of said envelope, a collector electrode at the other end of said envelope, a radio frequency interaction means in said envelope interposed between said electron gun and said collector electrode, high voltage power supply means connected to said cathode, to said radio frequency interaction means and to said collector, said power supply means providing a given positive potential to said collector with respect to said cathode and another positive potential to said interaction means with respect to said cathode which is higher than said given positive potential, an electro-magnetic switch comprising a coil, a switch arm adapted to be actuated by said coil to move away from a contact, said coil being electrically interposed between said radio frequency interaction means and said power supply, and said switch arm and contact being interposed in a power input line to said power supply means, whereby a predetermined current flow through said coil will move said switch arm away from said contact and open the power input line to said power supply means.

4. In combination an electron tube comprising an elongated envelope, an electron gun including a cathode at one end of said envelope, a collector electrode at the other end of said envelope, a radio frequency interaction means interposed between said electron gun and said

collector, and an auxiliary collector electrode interposed between said radio frequency interaction means and said collector electrode; and a circuit comprising a high voltage power supply means providing a given positive voltage and a higher positive voltage, means connecting said given positive voltage to said collector with respect to said cathode, other means connecting said higher positive voltage to said radio frequency interaction means with respect to said cathode, and a current responsive device electrically connecting said higher positive voltage to said auxiliary collector electrode with respect to said cathode, said current responsive device being adapted to interrupt the flow of beam current through said electron tube in response to a given current flow between said auxiliary collector electrode and said cathode.

5. In combination an electron tube comprising an elongated envelope, an electron gun including a cathode at one end of said envelope, a collector electrode at the other end of said envelope, a radio frequency interaction means interposed between said electron gun and said collector electrode, and an auxiliary electrode interposed between said radio frequency interaction means and said collector electrode; and a circuit comprising a high voltage power supply means providing a given positive voltage and a higher positive voltage, means connecting said given positive voltage to said collector with respect to said cathode, a first current responsive device connecting said higher positive voltage to said radio frequency interaction means with respect to said cathode, and a second current responsive device connecting said higher positive voltage to said auxiliary electrode with respect to said cathode, each of said current responsive devices being adapted to interrupt the flow of beam current through said electron tube in response to a given current flow therethrough.

6. A combination as claimed in claim 4 wherein said current responsive devices comprise an actuating means and an actuated means, said actuated means including a switch, said higher positive potential being connected through said actuating means, and said switch of said actuated means being interposed in the input power line to said power supply means, whereby said current responsive devices are adapted to interrupt the operation of said power supply means in response to a given current flow through the actuating means thereof.

7. In combination an electron tube and a circuit, said electron tube comprising an elongated envelope, an electron gun at one end of said envelope including a cathode, a collector electrode at the other end of said envelope, a radio frequency interaction means interposed between said electron gun and said collector, and a beam modulating electrode interposed between said electron gun and said radio frequency interaction means, said circuit comprising a high voltage power supply means providing a given positive voltage and a higher positive voltage, a current responsive device comprising an actuating means and an actuated means, said actuated means including a switch, said given positive potential being directly connected to said collector electrode with respect to said cathode, said higher positive voltage being connected to said radio frequency interaction means with respect to said cathode through said actuating means of said current responsive device, said higher positive potential being also connected to said beam modulating electrode with respect to said cathode through said switch of said actuated means of said current responsive device, and said beam modulating electrode being connected to said cathode through a resistor, whereby a given current flow through said actuating means of said current responsive device will open said switch of said actuated means thereof reducing said beam modulating means to cathode voltage.

8. In combination an electron tube and circuit, said electron tube comprising an elongated envelope, an electron gun including a cathode at one end of said envelope, a collector electrode at the other end of said envelope, a radio frequency interaction means interposed between said electron gun and said collector, a beam modulating electrode interposed between said electron gun and said radio frequency interaction means, and an auxiliary collector electrode interposed between said radio frequency interaction means and said collector electrode; and a circuit comprising a high voltage power supply means providing a given positive voltage and a higher positive voltage, a current responsive device comprising an actuating means and an actuated means, said actuated means including a switch, said given positive voltage being directly connected to said collector electrode with respect to said cathode, said higher positive voltage being connected to said radio frequency interaction means with respect to said cathode, said higher positive potential being also connected to the auxiliary collector electrode with respect to the cathode through the actuating means of the current responsive device and to the beam modulating electrode with respect to the cathode through the switch of the actuated means of the current responsive device, and said beam modulating electrode being connected to said cathode through a resistor, whereby a given current flow through said actuating means of said current responsive device will open said switch thereof reducing said beam modulating means to cathode voltage.

9. A combination as claimed in claim 8 wherein said circuit includes a second current responsive device, said actuating means of said second current responsive device being interposed between said power supply means and said radio frequency interaction means, and said switch of said actuated means of said second current responsive device is interposed between said beam modulating electrode and said power supply.

10. A combination as claimed in claim 7 wherein said circuit includes a means supplying modulating voltage connected between said cathode and said beam modulating electrode through said switches of said actuated means of said current responsive devices.

11. An electron tube comprising an elongated envelope, an electron gun at one end of said envelope for generating a beam of electrons, a collector electrode at the other end of said envelope for receiving said beam of electrons, a radio frequency interaction means interposed between said gun and said collector electrode for interaction with said beam of electrons, and an auxiliary electrode interposed between said radio frequency interaction means and said collector electrode, said auxiliary electrode comprising an apertured plate through which said beam passes in its travel from the radio frequency interaction means toward said collector.

12. An electron tube comprising an elongated envelope, an electron gun at one end of said envelope for generating a beam of electrons, a collector electrode at the other end of said envelope for receiving said beam, said collector electrode comprising a hollow member having an enclosed volume and an opening through which said beam enters said enclosed volume, a radio frequency interaction means interposed between said gun and said collector for interaction with said beam, and an auxiliary collector electrode interposed between said radio frequency interaction means and said collector electrode, said auxiliary collector electrode comprising a metallic member having an aperture therein through which said beam passes in its travel from the radio frequency interaction means toward said collector, electrons returning from said collector impinging upon said metallic member, said metallic member having passageway formed therein through which a cooling fluid may be circulated.

13. A combination as claimed in claim 5 wherein said current responsive devices comprise an actuating means and an actuated means, said actuated means including a switch, said higher positive potential being connected through said actuating means, and said switch of said actuated means being interposed in the input power line

to said power supply means, whereby said current responsive devices are adapted to interrupt the operation of said power supply means in response to a given current flow through the actuating means thereof.

14. A combination as claimed in claim 8 wherein said circuit includes a means supplying modulating voltage connected between said cathode and said beam modulating electrode through said switches of said actuated means of said current responsive devices.

15. A combination as claimed in claim 9 wherein said circuit includes a means supplying modulating voltage connected between said cathode and said beam modulating electrode through said switches of said actuated means of said current responsive devices.

16. The combination according to claim 3, in which said collector electrode comprises a hollow member having an enclosed volume constituting a hollow interior and an opening through which the beam enters said hollow interior, the length of said hollow interior being about five times the diameter of said opening, whereby said collector electrode may be operated at a lower positive potential than said radio frequency interaction means with respect to said cathode.

17. The combination according to claim 16, in which a metallic probe is insulatingly mounted on the collector electrode opposite said opening and projects into the hollow interior of said collector electrode, said circuit including a resistor connecting said probe to the cathode.

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UNITED STATES PATENT OFFICE

CERTIFICATION OF CORRECTION

Patent No. 2,958,804 November 1, 1960

George M. W. Badger et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 15, line 15, for the claim reference numeral "3" read -- 1 --.

Signed and sealed this 25th day of April 1961.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents

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