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[54] **ELECTRON DISCHARGE DEVICE WITH INTEGRAL VOLTAGE BRIDGE AND METHOD OF SETTING SAME**
8 Claims, 2 Drawing Figs.

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[50] **Field of Search** .... 323/40, 75 (N), 75 (F); 324/57 (B); 315/3.5, 3.6; 330/43

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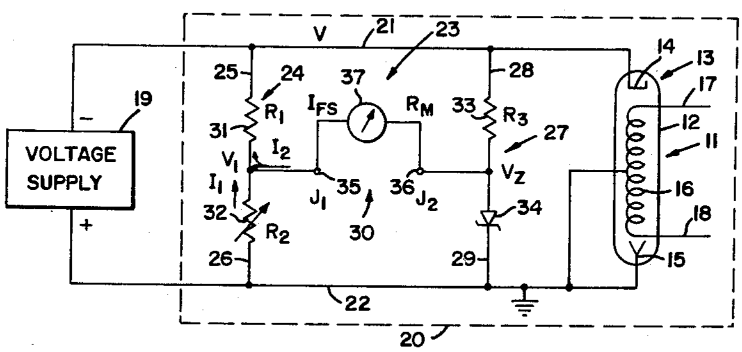
ABSTRACT: An internal voltage bridge is connected between the cathode and slow wave structure of a traveling-wave tube whereby the voltage applied between the cathode and slow wave structure can be adjusted to a predetermined value by adjustment until no reading occurs in a current measuring device connected in the bridge portion of the bridge circuit. An internal anode voltage divider is provided by connecting anode electrodes to adjustable potentiometers in one leg of the voltage bridge whereby proper setting of the cathode to slow wave structure voltage establishes the desired voltage at the respective anode electrodes.



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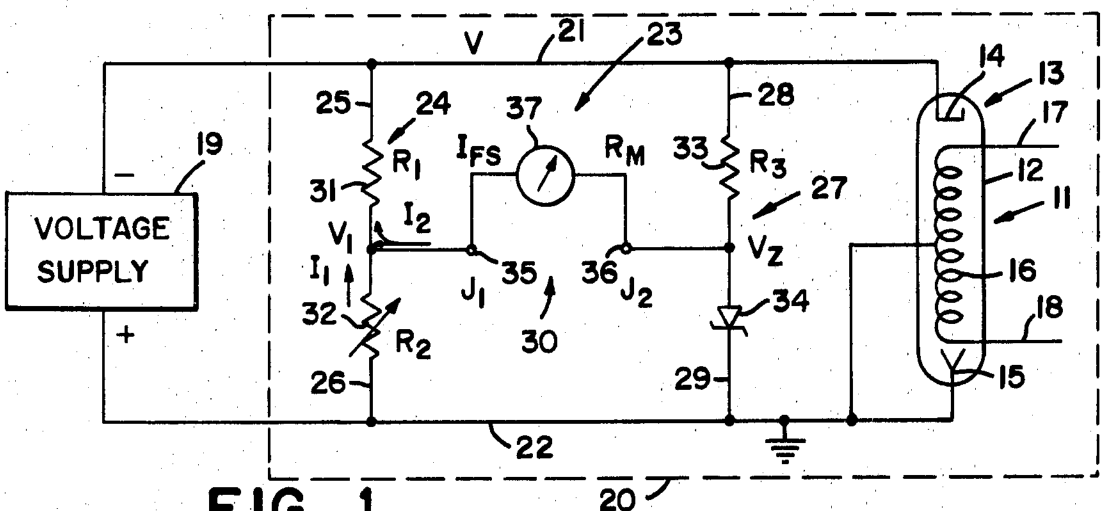

FIG_1

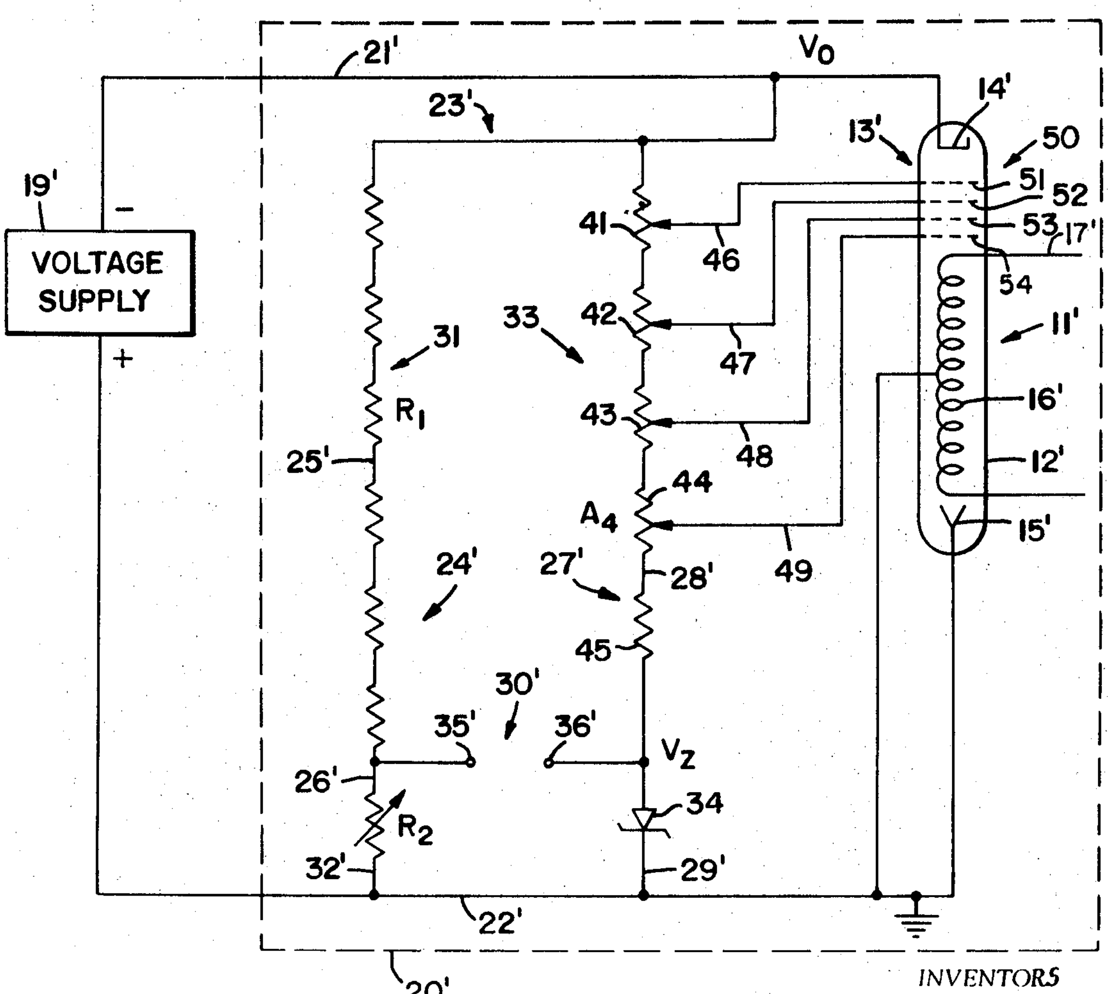

FIG_2

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ELECTRON DISCHARGE DEVICE WITH INTEGRAL VOLTAGE BRIDGE AND METHOD OF SETTING SAME

The present invention relates in general to electron discharge devices and more particularly to an integral voltage bridge for a traveling-wave tube for easy accurate adjustment of the cathode to slow wave structure voltage in in the field.

Many complex electronics systems utilize one or more electron discharge devices as traveling-wave tubes and, in general, these traveling-wave tubes are field replaceable; i.e., a tube is replaced directly in the field whenever it fails to meet specifications. However, because the performance of a traveling-wave tube, particularly a low noise traveling-wave tube, is critically dependent upon the high electrode voltages such as in the range of thousands of volts, supplied by the power supplies in the system, and because it is not unusual to find the regulation of the system power supply just barely within the regulation limits permitted by the traveling-wave tube specification, operation of the traveling-wave tube within specified performance can be achieved only if the error in setting the electrode voltages is extremely small. The typical cathode-to-helix voltage regulation specification for a low noise traveling-wave tube with a helix slow wave structure is at most ±0.5 percent.

Presently, the most common method in field adjustment of low noise traveling-wave tubes is to adjust the cathode-to-helix voltage for optimum small-signal gain at the highest operating frequency. This method has the advantage of not requiring an accurate voltmeter since the voltage is not even measured; however, it does require much more skill in setting the voltage. Furthermore, the design of the equipment may require certain modifications to permit a small-signal gain measurement. Another difficulty is that many low noise traveling-wave tubes exhibit optimum performance at a voltage different from that producing maximum gain at the highest operating frequency. Finally, this procedure does not provide a method accurately setting the various anode voltages, necessary in low noise traveling-wave tubes, without use of an accurate voltmeter which has a very high internal impedance.

As a general rule voltmeters with the required accuracy for setting the electrode voltage are not available in the field. Therefore, optimum performance is seldom achieved in replacement traveling-wave tubes. Even when accurate voltmeters are available in the field, they require frequent calibration checks which are often logistically impossible. Additionally, required accuracy is difficult to achieve even if the particular meter setting happens to be a full scale reading, and danger to the operator exists even in setting up such a meter to read a high voltage.

Replacement of the traveling-wave tube and power supply together is not economical and an integrated traveling-wave tube and power supply is not a practical solution in retrofitting traveling-wave tubes in most existing systems, because the power supply usually cannot be accommodated within the available space.

Coupled with the problem of proper setting of the cathode-to-helix voltage in low noise traveling-wave tubes is the setting of various anode voltages for multiple-anode electron guns present in all low noise traveling-wave tubes. The required anode voltages are determined by the particular design of the low noise gun. Because of manufacturing tolerances there is rather a wide variation in anode voltages from tube to tube, but the tolerance within which these voltages must be set in order to achieve the desired noise figure is only about ±0.1 percent of the nominal values. Thus, the problems encountered in setting the anode voltages are similar to, and as difficult as, those encountered in setting the cathode-helix voltage.

The object of the present invention is to provide an integral voltage bridge for an electron discharge device whereby the voltage applied to an electron discharge device can be easily and accurately adjusted in the field.

Another object of the present invention is to provide such an adjustment method and apparatus whereby proper voltage adjustment between two electrodes of the electron discharge device sets the desired voltage applied to other electrodes of the discharge device.

Broadly stated, the present invention to be described in greater detail below, is directed to a method and apparatus wherein an integral voltage bridge network is connected between two electrodes of an electron discharge device, such as between the cathode and slow wave structure of a traveling-wave tube, and wherein the bridge network is set by the manufacturer such that a reading can be made in the field across the bridge of the bridge network and the voltage applied between the electrodes adjusted until a null reading exists in the measuring device at which point a desired predetermined voltage exists between the electrodes.

This invention enables easy accurate adjustment of the applied voltage in the field without requirement of an expensive measuring instrument such as a high impedance voltmeter and avoids the necessity for using a measuring device that needs to be continually calibrated.

In accordance with another aspect of the present invention, one of the arms of the bridge is subdivided with a plurality of potentiometers and the center taps of the potentiometers connected to intermediate voltage auxiliary electrodes, such as the multiple anodes in a low noise electron gun, whereby the potentiometers can be factory adjusted to the desired auxiliary electrode voltage when the desired predetermined voltage is accurately applied to the device so that when the proper voltage is determined in the field with a null reading on the bridge of the bridge network, the desired voltages are applied to the auxiliary electrodes. With this construction and method continued adjustment of the auxiliary electrode voltages is avoided and desired auxiliary electrode voltages is avoided and desired auxiliary electrode voltages established with certainty in the field by one adjustment easily and accurately made with inexpensive instruments that need not be recalibrated periodically.

In accordance with one specific embodiment of the present invention, an integral voltage bridge is provided for traveling-wave tubes to control and set the applied voltage between the cathode and slow wave structure of the device utilizing a bridge network connected between the cathode and slow wave structure with high resistances provided in the branches of the bridge network between the tube cathode and bridge of the network and with a low voltage Zener diode in one branch between the bridge and the slow wave structure and a factory adjustable resistance in the other branch between the bridge and the slow wave structure. With this construction the desired predetermined voltage accurately measured is applied between the cathode and slow wave structure by the tube manufacturer and the adjustable resistor adjusted to provide a null reading in a microammeter connected in the bridge of the bridge network. Subsequent application of voltages to the traveling-wave tube in the field can be adjusted to provide the precise predetermined voltage by connection of a microammeter in the bridge of the bridge network in the field and application and adjustment of voltage between the cathode and the slow wave structure until a null reading appears in the microammeter. With this construction the contacts for application of the microammeter in the bridge of the bridge network can be the only two points that are accessible externally and although existing at a voltage above ground voltage are maintained only at a voltage above ground by the value of the Zener voltage. Therefore, a high degree of safety is afforded the technician in setting up the cathode to slow wave structure voltage. Furthermore, the internal voltage bridge operating properly cannot be damaged by shorting out or grounding the contacts, a feature which insures reliability against accidental grounding or shorts while setting the voltage.

In accordance with still another aspect of the present invention, an integral voltage bridge as described in the last preceding paragraph is provided in the one branch between the cathode and the bridge with a plurality of potentiometers the center taps of which are respectively connected to auxiliary electrodes which serve as anodes in a low noise electron gun. By adjusting the potentiometers when the precise desired predetermined voltage is applied between the cathode and slow wave structure by the tube manufacturer so that desired voltages are applied to the respective anodes, the proper anode voltages are assured when the tube is adjusted in the field to establish the predetermined cathode to slow wave structure voltage using the null reading technique.

Other objects and advantages of this invention will become apparent when reading the following description and referring to the accompanying drawings in which similar characters of reference represent corresponding parts in each of the several views.

In the drawings:

FIG. **1** is a schematic circuit diagram of an integral voltage bridge in accordance with the present invention; and

FIG. **2** is a schematic circuit diagram of an integral voltage bridge in accordance with another aspect of the present invention.

As pointed out above, the present invention is broadly directed to an integral voltage bridge for use in electron discharge devices whereby the proper predetermined voltage between selected electrodes can be achieved in the field utilizing inexpensive available microammeters. While it will be appreciated that the present invention can be applied to various different types of electron discharge devices, the invention will be described for purposes of illustration as applied to a traveling-wave tube for which the invention is ideally suited.

Referring now to the drawings, with particular reference to FIG. **1**, there is shown a schematic diagram of an integral voltage bridge in accordance with the present invention as applied to a traveling-wave tube **11**. The traveling-wave tube **11** of conventional construction includes an envelope **12** provided with a beam generating assembly **13** including a cathode **14** at one end position of the envelope **12** for generating and projecting a beam of electrons longitudinally of the envelope **12** to a collector assembly **15**. A slow wave structure **16** such as a helix is positioned between the beam generating assembly **13** and the collector assembly **15** for providing wave-beam interaction between an RF electromagnetic wave traveling along the slow wave structure **16** from an input waveguide **17** to an output waveguide **18**. While the present invention is schematically illustrated and will be described for purposes of illustration as applied to a low power traveling-wave tube utilizing a helix slow wave structure, it will be appreciated that the invention is applicable to the use with other types of slow wave structures.

The traveling-wave tube is operated with application of a high voltage between the cathode and the slow wave structure such as from an adjustable voltage power supply **19** to the cathode **14** on a line **21** and from the collector **15** and ground via a line **22**.

In accordance with the present invention an integral voltage bridge **23** is connected between the cathode and line **21** and the slow wave circuit and line **22** for easily and accurately adjusting the voltage from the supply **19** applied to the traveling-wave tube **11** in the field. Typically, the traveling-wave tube **11** and voltage bridge **23** are sold and shipped as an integral unit **20** for connection in the field to the voltage supply **19**.

The voltage bridge **23** includes a first branch **24** having first and second arms **25** and **26** respectively, connected end to end between lines **21** and **22**, a second branch **27** including third and fourth arms **28** and **29**, respectively, also connected end to end between lines **21** and **22**, and a bridge **30** for connecting the junction of first and second arms **25** and **26** with the junction of third and fourth arms **28** and **29**. A high resistance **31** with value R_1 is provided in arm **25**; a variable resistor **32** with value R_2 is provided in arm **26**; a high resistance **33** with value R_3 is provided in arm **28**; and a Zener diode **34** giving a reference voltage V_Z is provided in arm **29**. A pair of jacks **35** and **36** is provided in the bridge **30** of the voltage bridge **23** permitting connection of a microammeter **37** having meter resistance R_M and full scale meter current I_{FS}. The jacks **35** and **36** are the only two points of the circuit assembly that are externally accessible.

The integral unit **20** is factory adjusted whereby the voltage bridge **23** provides a means for setting the cathode-to-helix voltage within ±0.1 percent under service conditions using only an uncalibrated microammeter which is readily available in the most commonly used multimeters. In the factory, the predetermined cathode-to-helix voltage is supplied to the unit **20** from an adjustable voltage supply utilizing a precision voltmeter. A microammeter is connected to jacks **35** and **36** and variable resistance **32** adjusted to achieve zero current through the microammeter and resistance **32** permanently set at this adjustment. The tube is then in condition for delivery to a field installation where a precision voltmeter is not required.

In the field, the unit **20** is connected to the voltage supply **19** and the microammeter **37** connected to jacks **35** and **36**. The voltage of the supply **19** is adjusted to achieve zero current through the microammeter **37**. Under these adjusted conditions, the precise predetermined voltage is applied between cathode and helix.

In the circuit as shown in FIG. **1** with the voltage V in line **21** and the voltages V_1 and V_z at the bridge connections of the branches **24** and **27**, respectively, the Zener diode serves as a reference voltage which is compared to the voltage V_1 which itself is proportional to the cathode voltage V. The cathode voltage V is related to the parameters of the bridge as follows:

$$V=(R_1+R_2)\,I_1+R_1I_2 \tag{1}$$

The variation of currents I_1 in arm **26** and I_2 through bridge **30** with V is

$$\Delta V=(R_1+R_2)\,\Delta I_1+R_1\Delta I_2 \tag{2}$$

Another relationship is

$$V_1=R\,2I_1=AQV_z+R_mI_2 \tag{3}$$

where R_m is the internal resistance of the microammeter. Relying upon the fact that the variation of V_z with small changes in microammeter current I_2 is negligible, then

$$R_2\Delta I_1=R_m\Delta I_2 \tag{4}$$

and substituting this result in eqn. (2) and rearranging

$$\frac{\Delta V}{\Delta I_2}=R_1+R_m\left(\frac{R_1}{R_2}+1\right) \tag{5}$$

When the bridge is balanced $I_2=0$ and $V=V_o$, the desired cathode voltage, and

$$I_{1(o)}=\frac{V_z}{R_2}=\frac{V_o-V_z}{R_1} \tag{6}$$

or

$$\frac{R_1}{R_2}=\frac{V_o}{V_z}-1 \tag{7}$$

Substituting eqn. (7) into eqn. (5)

$$\frac{\Delta V}{\Delta I_2}=R_1+R_m\frac{V_o}{V_z} \tag{8}$$

Equation (8) gives R_1 in terms of parameters for expected application.

The total bridge current I_{TO} when the bridge is balanced is given by

$$I_{T0}=\frac{V_z}{R_2}+\frac{V_o-V_z}{R_3}$$

or

$$R_3=\frac{V_o-V_z}{I_{T0}-V_z/R_2} \tag{9}$$

For a given application once having calculated R_1 from eqn. (8), R_2 and R_3 can be calculated from eqns. (7) and (9).

The values for the bridge elements for a given application can be determined from the above equations and practical considerations.

While the present invention has been described above in sufficient detail to enable a person skilled in the art to practice the invention, an operative illustrative example of use of the present invention will be given.

Proceeding on the assumption that the cathode voltage be set within the ±0.1 percent range mentioned above and that an ordinary multimeter, such as Simpson Model 260, would be used, these assumptions, together with the parameters of the traveling-wave tube, specify the meter current sensitivity to cathode voltage variations $\Delta V/\Delta I$, the meter resistance R_m, the full-scale meter current I_{FS}, and the cathode voltage V_o. It then remains to specify the Zener diode voltage V_z and the total bridge current I_{TO}.

For a specific traveling-wave tube with nominal cathode voltage V_o=3,250 and current characteristics such that total bridge current cannot exceed 2.0 ma.; the total bridge current I_{TO} of 1.5 ma. is chosen. For the type of meter suggested, I_{FS}= 50 μa. on the most sensitive scale, and $R_m \cong 100$ ohms. It is reasonable to assume that the minimum discernible meter deflection is one percent of full scale, and at this deflection the maximum tolerance on cathode voltage of 0.1 percent is not exceeded. Then,

$$\Delta V/\Delta I_z = 0.001\times 3250/(0.001\times 50\times 10^{16}) = 6.5\times 10^{6} \quad (10)$$

The choice of Zener diode voltage is dictated by the desire for a high Zener voltage for increased sensitivity on one hand, and a low Zener voltage for a low temperature coefficient on the other hand. A good compromise is V_z=11.7. Then the following bridge parameters are calculated from equations (8), (7) and (6), respectively, to be:

$$R_1 = 6.45\times 10^{6} \text{ ohms}$$
$$R_2 = 23.3\times 10^{3} \text{ ohms} \quad (11)$$
$$I_{1(o)}\text{Q}x0.5 \text{ ma.}$$

A voltage bridge-tube unit **20** was constructed using these values, and the cathode-to-helix voltage V_o was set at 3,250 volts using a precision voltmeter (J-Omega Model 415A). Variable resistor **32** was then adjusted to achieve zero current through a microammeter (Simpson Model 260). Next, the cathode-helix voltage was repeatedly readjusted to obtain zero meter current, and at each setting the voltage was recorded from the precision voltmeter. A total of **20** readings were taken, and the maximum deviation from the nominal value of 3,250 volts was ±2.0 volts. Seventeen of the **20** readings were within ±1.0 volt of the nominal value.

In accordance with another aspect of the present invention, an auxiliary electrode or anode voltage divider network is incorporated into the integral voltage bridge for providing precise predetermined voltages to other tube electrodes when the cathode-to-slow wave structure voltage is set utilizing the voltage bridge **23** described above with reference to FIG. **1**.

Thus, with reference to FIG. **2**, the resistance R3 or **33'** in arm **28'** of branch **27'** of the voltage bridge **23'** is made up of a plurality of resistors **41—45** connected in series of which resistors **41—44** are portions of potentiometers. The center taps of these potentiometers **41—44** are connected via lines **46-—49** respectively, to the anodes **51—54**, positioned between the cathode **14'** and slow wave circuit **16'** and form with cathode **14'** a low noise electron gun **50**.

When the cathode-to-helix voltage is applied to the unit **20'** at the factory, and the variable resistor **32'** of the voltage bridge **23'** adjusted to provide a null reading in bridge **30'**, the center taps of the potentiometers **41—44** are adjusted and set to establish the desired anode voltages on anodes **51—54**. The incorporation of this anode voltage divider into resistance **33'** of the voltage bridge has no effect on the accuracy of setting the cathode-to-helix voltage by balancing the bridge. Furthermore, the total current required by this arrangement including the anode voltage divider is no greater than that required for the integral voltage bridge alone.

When unit **20'** as shown in FIG. **2** is installed in the field and a null reading achieved in bridge **30'** of the voltage bridge **23'**, the appropriate anode voltages are applied automatically to the low noise gun.

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it is understood that certain changes and modifications may be practiced within the spirit of the invention as limited only by the scope of the appended claims.

We claim:

1. In an electron tube circuit a voltage bridge for setting a predetermined cathode-to-electrode voltage comprising:
- a first branch of first and second arms connected end to end between said cathode and said electrode; and
- a second branch of third and fourth arms connected end to end and between said cathode and said electrode;
- a resistance provided in said first arm;
- a selectively adjusted resistance provided in said second arm;
- a resistance provided in said third arm;
- a reference voltage device provided in said fourth arm;
- means for applying a voltage between said cathode and said electrode; and means for measuring current between said branches at the junction of said first and second arms and the junction of said third and fourth arms, said resistances in said first, second and third arms and said voltage device having values such that substantially no current is measured by said measuring means when said predetermined voltage is applied between said cathode and said electrode.

2. In an electron tube circuit in accordance with claim **1** wherein the resistance provided in said third arm includes a plurality of potentiometers in series, the tap of each potentiometer connected to an auxiliary electrode maintained by the potentiometer resistance in said third arm at a voltage intermediate the voltage applied between said cathode and said electrode.

3. A traveling-wave tube circuit comprising:
- a vacuum envelope;
- a beam generating assembly for generating and projecting a beam of electrons from one position within said envelope to another position therein and including a cathode;
- a collector assembly located at said other position for collecting said beam of electrons;
- a slow wave structure located between said positions for providing interaction between said beam and a radio frequency wave propagating along said slow wave structure; and
- bridge network means for establishing a predetermined voltage between said cathode and said collector assembly including
  - a first branch of first and second arms connected end to end between said cathode and said slow wave structure,
  - a second branch of third and fourth arms connected end to end between said cathode and said slow wave structure,
  - a resistance provided in said first arm,
  - a selectively adjusted resistance provided in said second arm,
  - a resistance provided in said third arm,
  - a reference voltage device provided in said fourth arm,
- means for applying a voltage between said cathode and said slow wave structure; and
- means for measuring current between said branches at the junction of said first and second arms and the junction of said third and fourth arms, said resistance in said first, second and third arms and said reference voltage device having values such that substantially no current is measured by said measuring means when said predetermined voltage is applied between said cathode and said electrode.

4. A traveling-wave tube in accordance with claim **3** wherein said beam generating assembly includes a plurality of anode electrodes positioned between said cathode and said slow wave structure, and said resistance provided in said third arms includes a plurality of potentiometers, the center tap of each potentiometer connected to one of said anode electrodes for providing the desired voltage on each of said anode electrodes when the predetermined voltage is applied between said cathode and said slow wave structure.

5. A traveling-wave tube comprising in combination:
- a vacuum envelope;
- a beam generating assembly located at one position within said envelope and including a cathode and anode means for generating and projecting a beam of electrons to another position within said envelope;
- a collector assembly located at said other position within said envelope for collecting said beam of electrons;
- a slow wave structure located between said first and second positions for providing beam-wave interaction between said beam of electrons and an electromagnetic wave propagating along said slow wave structure; and
- voltage bridge means for establishing a predetermined voltage between said cathode and said slow wave structure including
  - a first branch of first and second arms connected end to end between said cathode and said slow wave structure,
  - a second branch of third and fourth arms connected end to end between said cathode and said slow wave structure,
  - a high resistance provided in said first arm, a selectively adjusted low resistance provided in said second arm,
  - a high resistance provided in said third arm, a low voltage Zener diode provided in said fourth arm,
  - means for applying a high voltage between said cathode and said slow wave structure,
  - a connection to said first branch at the junction of said first and second arms; and a connection to said second branch at the junction of said third and fourth arms for connecting a current measuring device between said connections,
  - said resistances in said first and third arms having resistance values, said Zener diode having a voltage value, and said resistance in said second arm adjusted to a value with the predetermined voltage applied between said cathode and said slow wave structure so that no current flows through a current measuring device connected between said connections when said predetermined voltage exists between said cathode and said slow wave structure.

6. The traveling-wave tube in accordance with claim 5 wherein said beam generating assembly includes:
- a plurality of anode electrodes progressively positioned between said cathode and said slow wave structure for establishing progressively increasing voltages from said cathode to said slow wave structure; and
- said resistance provided in said third arm includes a plurality of potentiometers, the center taps of said potentiometers connected to respectively positioned anode electrodes whereby proper setting of said voltage applying means such that no current flows in a measuring device connected between said connections establishes desired predetermined voltages to said anode electrodes.

7. The method of setting the cathode-to-slow wave structure voltage of a traveling-wave tube comprising the steps of:
- connecting the branches of a bridge network between the cathode and the slow wave structure of a traveling-wave tube with high resistances in the branches between the cathode and the bridge, and a reference voltage device in one branch between the bridge and the slow wave structure;
- applying the desired cathode-to-slow wave structure voltage between said cathode and said show wave structure;
- adjusting a resistance in the other branch of the bridge network between the bridge and the slow wave structure to reduce the current in the bridge substantially to zero;
- subsequently adjusting the voltage applied between said cathode and said slow wave structure until substantially no current flows in said bridge.

8. The method in accordance with claim 7 including the step of subdividing the voltage in the one branch between said cathode and said bridge with connections to a progression of anode electrodes, and selecting the connections along said subdivided portion to apply desired potentials to said progression of anode electrodes when the predetermined voltage is applied between said cathode and said slow wave structure whereby adjustment of the voltage between the cathode and said slow wave structure until substantially no current flows in said bridge, adjusts the voltages applied to said anodes to the desired values.