Oct. 3, 1961 R. W. KETCHLEDGE 3,003,065

ELECTRON MULTIPLIER TUBE CIRCUITS

Filed May 15, 1957 2 Sheets-Sheet 1

FIG. 2

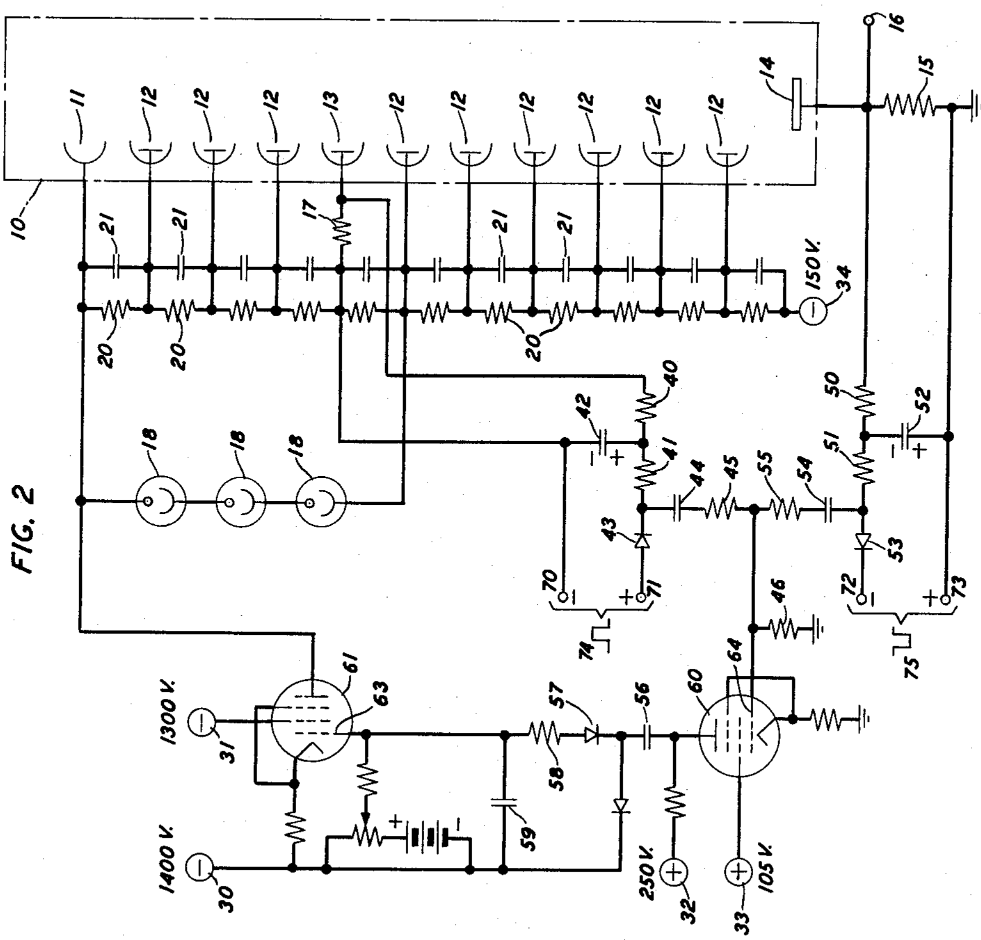
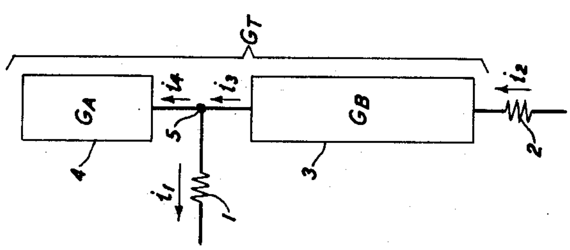


FIG. 1



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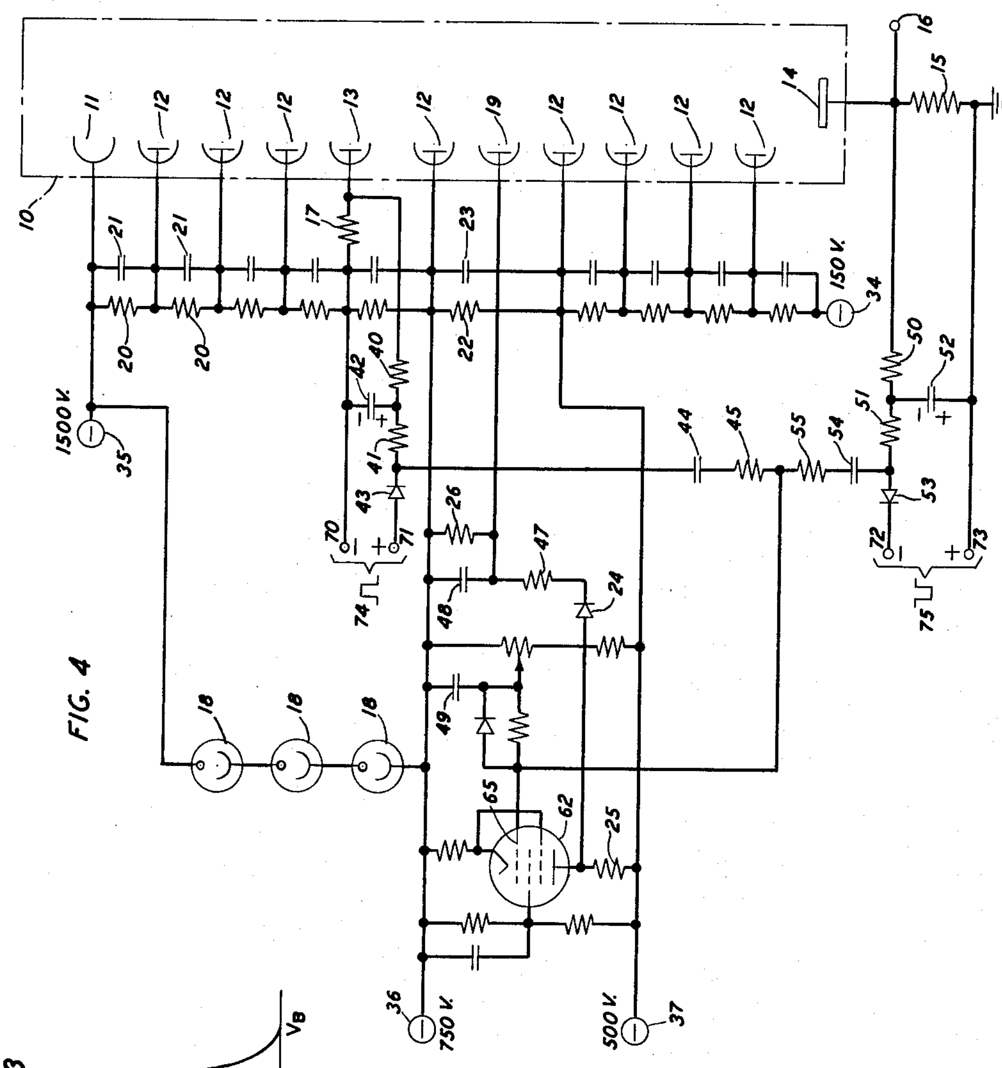

FIG. 4

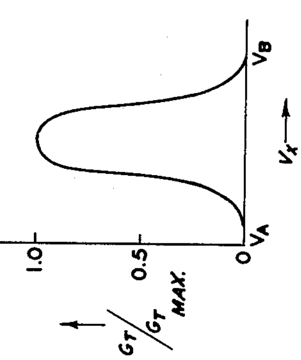

FIG. 3

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ELECTRON MULTIPLIER TUBE CIRCUITS

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15 Claims. (Cl. 250—207)

This invention relates to electron multiplier tube circuits, and more particularly, to gain stabilization of such tubes.

Photomultiplier tubes have received wide usage in recent years where it is desired to convert a light signal to an electrical output. Particularly is this the case where considerable amplification is needed in addition to such conversion. Successful operation of such a tube depends upon a stream of electrons, emitted from an illuminated photocathode, being passed through a series of secondarily emissive electrodes, called dynodes, to an anode. Since each dynode has a ratio of secondary to primary electrons in excess of unity, the electron current is multiplied in its passage through the dynode string. Such is the efficiency of the electron multiplier stages that current gains of the order of one million are readily attainable with this method of amplification.

Unfortunately, the gain of such a device is peculiarly sensitive to variations in dynode voltage, thus necessitating either an extremely stable voltage source or some way of controlling this source to compensate for variations in gain where gain stability is desired. Various methods have been proposed in the past in an attempt to solve this stability problem, many of which rely for their operation upon the utilization of an extremely accurate signal source or special monitoring apparatus for gain comparison purposes.

Furthermore, it is a characteristic of photomultiplier tubes that they are often subject to aging effects, that is, deterioration in gain with use over a period of time. This gain deterioration usually results from a decrease in the secondary emission ratio of the dynodes nearest the anode, since it is here that the highest currents are handled and the most severe usage occurs.

My invention provides a simple way of obtaining a reference for the basis of a gain stabilization system, one which operates upon the normal signals being amplified, thereby eliminating any necessity for special test signals or separate monitoring equipment. In addition, my invention is equally effective in stabilizing the amplification of a photomultiplier tube against short-term variations in gain or those resulting from aging effects over a long period of time.

It is, therefore, a general object of my invention to provide an improved gain stabilization system for electron multiplier amplifiers.

It is a further object of my invention to provide a simplified gain reference in an electron multiplier amplifier circuit with which overall amplification may be compared.

It happens that the amplification of a signal current in the early stages of a photomultiplier tends to be more constant than does that in the later stages. This is particularly true where the voltage applied to these early stages is held at a substantially constant value, as is possible through the utilization of voltage regulator devices such as gas diodes or reverse breakdown semiconductor diodes. In one specific embodiment of my invention the tube current present at the fourth dynode of a photomultiplier tube is detected for use as a reference in a ten-dynode photomultiplier tube amplifier circuit. Both the voltage derived from this reference and the amplified signal voltage at the photomultiplier anode are sampled and compared. The resultant of this comparison is utilized to control a series voltage control tube which regulates the voltage of the amplifying dynodes, thereby compensating for changes in gain between the reference point and the output of the photomultiplier. In another specific embodiment of my invention the output of the comparison circuit is used to control the voltage on a single dynode, thereby compensating for gain variations in the amplifier by changing the gain of this dynode.

It is a feature of this invention that voltages derived from currents at different points in a photomultiplier tube be utilized to provide a gain comparison signal to control a gain stabilization system.

It is a further feature of my invention that the voltage derived from tube current at a particular dynode in a photomultiplier tube be used as a reference for comparing the output of the tube to determine stability of amplification.

Another feature of my invention is the provision of a resistor in series with a particular dynode in a photomultiplier tube to detect the signal level at this point for use as a reference in measuring the degree of amplification through the rest of the tube.

Another feature of one specific embodiment of my invention is the use of a comparison output voltage derived from the matching of signal levels from different points in a photomultiplier tube to regulate the voltage applied to a dynode string in order that amplification through the photomultiplier may be stabilized.

Another feature of another specific embodiment of my invention is the use of a comparison output voltage derived from the matching of signal levels from different points in a photomultiplier tube to control the voltage applied to a single dynode so that amplification through the photomultiplier may be stabilized.

It is a further feature of my invention that both a reference voltage derived from beam current at an intermediate dynode in a photomultiplier tube and a voltage derived from the anode current of such a tube be sampled on a pulse basis so that a comparison of the sampled voltages gives an indication of the degree of gain stability of the tube.

These and other features of my invention may be rendered more apparent by a detailed description of certain specific embodiments schematically depicted in the accompanying drawing in which:

FIG. 1 is a schematic representation of a photomultiplier tube in accordance with this invention;

FIG. 2 is a schematic representation of one specific embodiment of my invention;

FIG. 3 is a diagram of normalized photomultiplier gain versus voltage for a single dynode; and

FIG. 4 is a schematic representation of another specific embodiment of my invention.

In FIG. 1 the photomultiplier tube is shown in block diagram with the electron multiplying stage divided into two sections, one on either side of a selected dynode represented by point 5. To this dynode 5 is connected a resistor 1 carrying a current i_1. The electron multiplying stages prior to the dynode 5 are represented by the block 4 having a gain G_A and the stages following the dynode 5 are represented by a block 3 having a gain of G_B. A resistor 2 carrying a current i_2 is connected to the photomultiplier anode which is included in the block 3. The current i_3 is the beam current flowing to the dynode 5 from the subsequent stage and the current i_4 represents the beam current flowing from the dynode 5 to a previous stage. The gain G_B of the later multiplying stages is equal to the ratio of i_2 divided by i_3. Since i_3 is the sum of i_1 and i_4, i_1 is related to i_3 by the secondary emission ratio of the dynode 5. Thus, a comparison of the two currents i_1 and i_2 can be used to obtain an indication of the gain G_B, including the electron multiplication of the dynode 5 itself. Because the total gain of the photomultiplier, G_T, is equal to the product of the separate gains G_A and G_B and because, as was explained earlier, the gain G_A is maintained substantially constant, the indication of gain variation thus obtained can be used to control a compensating mechanism to adjust the gain G_B to compensate for its earlier variation, thereby maintaining the total gain of the tube constant. In other words, the gain G_A is maintained essentially constant and an output is taken from the dynode 5 to be used as a reference against which the final output of the photomultiplier may be continually compared. This comparison can be accomplished using the normal signals being amplified by the tube without the need for special signals of any kind.

FIG. 2 depicts a circuit embodying my invention in which circuitry is shown for detecting and comparing the tube currents at a particular dynode and at the anode and for using this comparison to control the voltage on the dynode string to adjust the gain. The photomultiplier tube is represented by the outline **10** in which are contained the photocathode **11**, the dynodes **12** and **13**, and the anode **14**. The dynode **13** is the particular dynode which has been selected as the one from which the reference will be obtained. To the anode **14** is connected to resistor **15** which may represent a load, and an output terminal **16**. Voltage for the dynode string is obtained between negative sources **30** and **34** through a series regulator tube **61**.

Positive voltages applied to the control grid **63** of the tube **61** increase the voltage applied across the dynode string, thereby increasing the gain of the photomultiplier amplifier. Voltage regulator diodes **18** are connected between cathode **11** and the fifth dynode **12** thereby maintaining the voltage between these two points substantially constant. Thus, any change in voltage drop across the dynode string is applied only to the last five dynodes. In this way, the gain of the first five dynode stages is maintained substantially constant. The gas diodes **18** could advantageously be replaced by semiconductor reverse breakdown diodes having proper voltage characteristics.

Resistors **20** constitute the direct current bleeder network for the dynode string and the capacitors **21** serve as bypass capacitors for the alternating current signal variations. The reference voltage obtained from dynode **13** is developed across the dynode series resistor **17** and stored by means of the connected dynode integrator network composed of resistor **40** and capacitor **42** with the polarity of voltage across capacitor **42** as shown. A sampling pulse **74** applied to terminals **70** and **71** drives terminal **71** sufficiently positive with respect to terminal **70** that diode **43** becomes biased in a forward direction and develops an output across resistor **41** which is fed through coupling capacitor **44** to the summing network comprising resistors **45**, **46** and **55**. Similarly, the output signal of the photomultiplier is stored in the anode integrator made up of resistor **50** and capacitor **52** with the polarity of voltage across capacitor **52** as is shown. Thus a pulse **75** applied to terminals **72** and **73** drives terminal **72** sufficiently negative that diode **53** becomes biased in the forward direction, developing an output across resistor **51** which is fed through coupling capacitor **54** into the summing network. Both these signals are compared across resistor **46** and the resulting voltage applied to control grid **64** of vacuum tube **60** is amplified and coupled through capacitor **56**, diode **57** and resistor **58** to control grid **63** of tube **61**. These pulses are stored on capacitor **59** to convert the pulse comparison signals to a steady direct current voltage. Thus, if, for example, the gain of the photomultiplier **10** decreases due to a change in gain in the latter portion of the electron multiplier section, the voltage stored in the anode integrator capacitor **52** will decrease while that stored in the dynode integrator capacitor **42** will remain the same for any given level of signal input into the photomultiplier tube. The output of the anode sampling circuit will now increase relative to the output of the dynode sampling circuit because these outputs represent the difference between the sampling pulses and the voltages stored on the respective integrator capacitors. Therefore, the control grid **64** will be driven more negative, decreasing current through the tube **60** and applying a positive signal through capacitor **56**. This permits the negative voltage stored on capacitor **59** to decrease thereby causing control grid **63** to become more positive, reducing the cathode-to-anode resistance of tube **61**, and applying a greater voltage across the dynodes in the latter half of the photomultiplier. This increase in voltage increases the gain of these dynode stages thereby compensating for the original decrease in photomultiplier gain for photomultiplier amplification. Voltage sources **31**, **32**, and **33** are connected as shown to provide proper operating potentials for their associated vacuum tube amplifiers.

FIG. 3 is a diagram of the normalized photomultiplier tube gain

$$\frac{G_T}{G_{T_{max}}}$$

related to the voltage of a particular dynode when it is varied between the potentials of its two adjacent dynodes and will be discussed to explain the operation of a second embodiment of my invention depicted in FIG. 4. This shows that the photomultiplier gain approaches a maximum when the variable potential is approximately midway between those of the two adjacent dynodes and falls off substantially as the variable potential approaches that of either adjacent dynode. Reasons for this are that the secondary emission ratio is related to the potential of a particular dynode with respect to the last previous dynode and also that the electrostatic fields affecting the paths of the secondary electrons within the tube are dependent upon individual dynode voltage. The fact that the gain of a photomultiplier tube varies in this fashion suggests a method for controlling the gain of the photomultiplier amplifier in a gain stability circuit.

FIG. 4 depicts a second specific embodiment of my invention which makes use of the previously described effect of individual dynode voltage upon the gain of a photomultiplier. In this figure, a photomultiplier tube **10** containing a photocathode **11**, dynodes **12**, **13**, and **19**, and an anode **14** is connected in an amplifier circuit. Dynode **13**, as before, is connected to resistor **17** and to a dynode integrator circuit as was described above in connection with FIG. 2. Similarly, the anode **14** connected to output resistor **15** and an output terminal **16**, is further connected to an anode integrator circuit as was depicted in FIG. 2. The bleeder resistors **20** and the bypass capacitors **21** are connected as was shown in FIG. 2 with the exception that the resistor **22** and the capacitor **23** are of such values as to properly determine the voltage between two non-adjacent dynodes. The dynode **19** is the particular dynode to which the feedback control is applied for the purpose of stabilizing the gain in the photomultiplier. As before, voltage regulator devices **18** are provided to maintain constant the gain in the first half of the electron multiplier section. The resultant of the signals fed through resistors **45** and **55** is applied to the control grid **65** of vacuum tube **62**. A capacitor **49** is provided to store the resultant of the sampling pulse circuit and to apply a steady potential to control grid **65**. This signal, amplified and inverted through tube **62**, is then applied through diode **24** and resistor **47** to be stored upon capacitor **48** and applied to the dynode **19**. Thus, a decrease in gain anywhere between dynode **13** and anode **14** in the photomultiplier tube **10** decreases the voltage stored on capacitor **52** relative to that stored on capacitor **42**. The difference between the pulse **75** and the voltage across capacitor **52** thereby increases relative to the difference between pulse 74 and the voltage across capacitor 42. This increase appears as a negative voltage on control grid 65 of tube 62 which, upon amplification and inversion through tube 62, is applied as a more positive potential to dynode 19. This dynode 19 is normally biased, through proper selection of the resistors 25, 47, and 26, so that it is nearer in potential to the dynode preceding it than to the dynode succeeding it. That is, in the diagram of FIG. 3 its potential V_x is to the left of the midpoint between V_A and V_B so that the gain of the tube is less than maximum on the left side of the peak of the gain curve. Thus, as the potential of dynode 19 is made more positive, the gain of the photomultiplier will be increased. In this manner the feedback signal applied to dynode 19 causes this dynode to change the gain of the tube to compensate for original gain variation, thereby stabilizing the photomultiplier tube amplification. Potential sources 34 and 35 supply the voltage to the dynode string. Potential sources 36 and 37 furnish potentials to operate the amplifier circuit including tube 62.

Which particular dynode in the electron multiplier section is to be selected for detecting the tube current depends on the signal level required by the detection and comparison circuitry. The detection is advantageously accomplished as near the electron emission source as is feasible. In a tube having an emitted electron beam of sufficient energy, detection could be effected at the first dynode of the electron multiplier section with an attendant increase in the stability of the reference voltage developed by the detector circuitry.

The values of voltage assigned to the potential sources in FIGS. 2 and 4 are merely typical values selected for the proper operation of the described specific embodiment of the invention. Other potentials may be chosen by those skilled in the art without departing from the nature and scope of this invention.

There are known in the art certain types of electron multipliers making use of one or more control electrodes in addition to the multiplying dynodes. Such control electrodes may be situated adjacent certain of the dynodes. In applying the principles of my invention to such a device in a circuit similar to that depicted in FIG. 4 of the drawing, the feedback voltage supplied to control the gain of the electron multiplier amplifier can advantageously be applied to such a control grid, rather than to the dynode itself, to accomplish the desirable results provided by my invention.

It is to be understood that, while the specific embodiments of my invention contain electron multiplier tubes of the photomultiplier type and the invention has been described in terms of its application to photomultiplier amplifiers, it is equally adaptable to any device employing an electron multiplier structure and the invention is not intended to be limited to a use with electron multiplier tubes of any particular type.

It is to be understood that the above described circuits are merely illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electrical circuit comprising an electron discharge device of the electron multiplier type having at least a plurality of electrodes with secondary electron emitting characteristics and an anode, output means connected to said anode, means for the measurement of current at one of said electrodes, means for comparing said measurement with the output taken from said anode to detect any variation in electron multiplication between said one electrode and said anode, and electron multiplication control means connected to said comparison means.

2. An electrical circuit comprising an electron tube having a cathode and an anode, between said cathode and anode at least one electrode capable of emitting secondary electrons when bombarded by incident electrons, means for making measurements of tube current at points before and after multiplication by said electrode, means for comparing said measurements, and means responsive to said comparison means to alter any variation in the degree of current multiplication.

3. A gain stabilization circuit comprising an electron multiplier device including secondary emission electrodes having the property of emitting secondary electrons upon bombardment by incident electrons, potential divider means connected to said electrodes, output means connected to said device, detection means comprising means for ascertaining the currents within said device at one of said electrodes and at said output of said device, comparison means for indicating any deviation from a constant ratio of said currents, control means for the control of current multiplication within said device, and connecting means applying potentials from said comparison means to said control means.

4. A gain stabilization circuit comprising an electron multiplier device including secondary emission electrodes having the property of emitting secondary electrons upon bombardment by incident electrons, potential divider means connected to said electrodes, output means connected to said device, detection means comprising means for ascertaining the currents within said device at one of said electrodes and at said output of said device, comparison means for indicating any deviation from a constant ratio of said currents, control means for the control of current multiplication within said device, said control means comprising means for varying the potential across said divider means to determine thereby the degree of current multiplication through said electron multiplier device, and connecting means applying potentials from said comparison means to said control means.

5. A gain stabilization circuit comprising an electron multiplier device including secondary emission electrodes having the property of emitting secondary electrons upon bombardment by incident electrons, potential divider means connected to said electrodes, output means connected to said device, detection means comprising means for ascertaining the currents within said device at one of said electrodes and at said output of said device, comparison means for indicating any deviation from a constant ratio of said currents, means for maintaining constant potentials on said electrodes before said one electrode, control means for the control of current multiplication within said device, said control means comprising means for varying the potentials applied to said electrodes between said points of current measurement to determine thereby the degree of current multiplication through a portion of said electron multiplier device, and connecting means applying potentials from said comparison means to said control means.

6. A gain stabilization circuit comprising an electron multiplier device including secondary emission electrodes having the property of emitting secondary electrons upon bombardment by incident electrons, potential divider means connected to said electrodes, output means connected to said device, detection means comprising means for ascertaining the currents within said device at one of said electrodes and at said output of said device, comparison means for indicating any deviation from a constant ratio of said currents, control means for the control of current multiplication within said device, said control means comprising means for varying the potential applied to at least one of said electrodes situated between said points of current measurement relative to the potential of the remainder of said electrodes to determine thereby the degree of current multiplication through a portion of said electron multiplier device, and connecting means applying potentials from said comparison means to said control means.

7. An electrical circuit comprising an electron multi-

plier device having a secondary emission electrode and an anode, means for detecting the magnitude of electric current within said device at said electrode, means for comparing with said detected value of current the current at said anode, and feedback means for compensating for variation in the ratio of said electrode and anode currents to maintain the amplification through said device substantially constant.

8. A gain stabilization circuit comprising an electron multiplier device having secondary emission electrodes and an anode, output means attached to said anode, first capacitive means connected to one of said electrodes to detect the current at said electrode, second capacitive means connected to said anode to detect the current at said anode, comparison means for comparing the voltages stored across said capacitive means, and feedback means utilizing the resultant of said comparison to control the gain of said electron multiplier device.

9. A gain stabilization circuit as in claim 8 in which said feedback means comprises means for controlling the voltage applied to said secondary emission electrodes.

10. A gain stabilization circuit as in claim 9 in which said feedback means comprises means for controlling the voltage applied to a single secondary emission electrode relative to the potential applied to the remainder of said secondary emission electrodes.

11. An electrical circuit comprising a discharge device having an anode and a plurality of secondary emission electrodes, output means connected to said anode, first capacitive means connected to one of said electrodes to detect the current at said electrode, second capacitive means connected to said anode to detect the current at said anode, sampling means comprising first and second pulse sources connected to said first and second capacitive means respectively, resistance means between said sampling means providing a comparison of the sampled outputs of said capacitive means, and feedback means connected to said comparison means to control the amplification of said discharge device at a substantially constant magnitude.

12. A gain stabilization circuit for an electron multiplier device comprising an electron multiplier device having a plurality of electrodes exhibiting secondary emission characteristics and an anode, first means for monitoring the current at one of said electrodes, second means for monitoring the current at said anode, means for comparing said separately monitored currents, means for detecting any variation in the ratio of said currents, and means responsive to a signal from said detecting means to vary the gain of said electron multiplier device and thereby compensate for the original gain variation.

13. A gain stabilization circuit in accordance with claim 12 in which said gain varying means comprises means for varying the potentials applied to said electrodes situated between said one electrode and said anode.

14. A gain stabilization circuit in accordance with claim 12 in which said gain varying means comprises means for varying the potential applied to a particular electrode with respect to the potentials of adjacent electrodes.

15. An electrical circuit comprising an electron multiplier device having electrodes with secondary electron emitting characteristics and an anode, means for applying fixed potentials to said electrodes, output means connected to said anode, means for measuring electron beam current at at least one of said electrodes, means for measuring electron beam current at said anode, means for comparing said measured currents to ascertain any change in electron multiplication intermediate the points of measurement, and means energized by said comparison means for controlling the potentials applied to said electrodes.

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