Oct. 22, 1957 K. D. SMITH 2,810,863

ELECTRO-OPTICAL SYSTEM

Filed July 17, 1943 2 Sheets-Sheet 1

FIG. 1

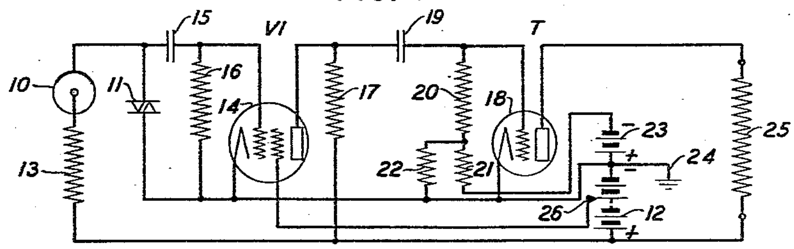

FIG. 2

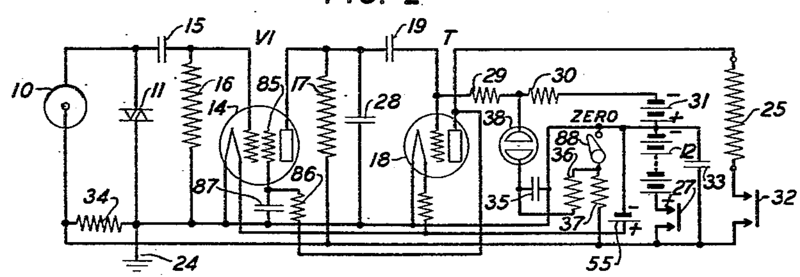

FIG. 3

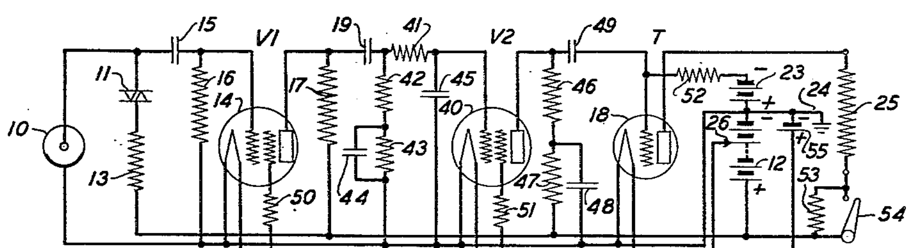

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FIG. 4

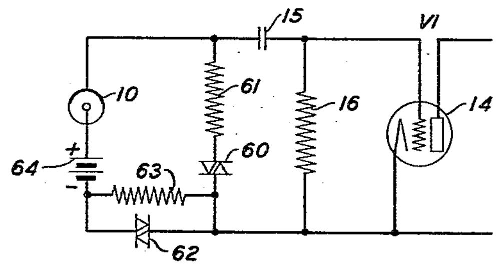
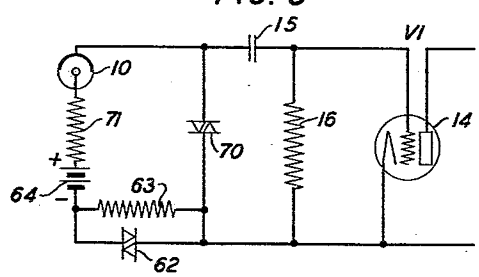


FIG. 5



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ELECTRO-OPTICAL SYSTEM

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19 Claims. (Cl. 315—159)

This invention relates to radiant energy sensitive systems and more particularly to electro-optical systems.

An object of the invention is to provide an improved electro-optical system having a nearly constant percentage sensitivity, that is, a system in which the output voltage is nearly proportional to the percentage modulation of a modulated static condition but is independent of the magnitude of the static condition.

In order to attain this object it is proposed to utilize one or more non-linear resistive elements. A circuit typical of this invention comprises a photoelectric cell, a source of direct current potential and a varistor connected in series to which is coupled a vacuum tube amplifier through a series condenser. By using a properly proportioned varistor or combination of varistors and fixed resistances a nearly uniform sensitivity for a given percentage change in illumination over an extensive range of illuminations may be obtained.

Another object is to provide an improved means in a radiant energy sensitive system for controlling the time of response to the received energy.

A varistor, as the term is used herein, is a non-linear resistance device which may assume a variety of forms but is always a conductive or semiconductive device, never an electron emissive device. Varistor elements suitable for use in embodiments of this invention are discs of a semiceramic material composed of silicon carbide, clay and carbon, pressed and fired. The impedance at any given voltage is inversely proportional to the area of the disc. Therefore almost any desired operating impedance may be realized by a choice of area of the varistor disc. This type of varistor, its composition and method of manufacture, are described in McEachron Patent 1,822,742, issued September 8, 1931.

One use to which this invention can be put is to detonate the explosive charge of a projectile as it moves into proximity to a target due to a reduction in the illumination of the photoelectric cell. The normal or static illumination may be large or small but for any given percentage reduction in the illumination the sensitivity remains practically constant. Thus, as the projectile moves past the target, which may be an airplane, a certain percentage of the illumination of the photoelectric cell is cut off at a given rate, dependent upon the speed of the projectile and the nature of the airplane. However, the sensitivity of the detonating unit is reasonably constant no matter what the absolute intensity of the illumination may have been.

In one circuit arrangement devised for such a use a single-stage vacuum tube amplifier is inserted between the photoelectric cell and varistor circuit and a thyratron stage which on firing causes detonation of the explosive charge. In this arrangement the input circuit of the amplifier is connected across the varistor so that a reduction in illumination of the photoelectric cell tends to make the grid of the thyratron more positive with respect to its cathode.

In another circuit arrangement also devised for such use a two-stage amplifier is inserted between the photoelectric cell and varistor circuit and the thyratron stage. In this second arrangement the input circuit of the first amplifier stage is connected across the photoelectric cell. This connection to the photoelectric cell causes the grid of the thyratron also to become more positive when the illumination on the photoelectric cell is reduced.

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These circuit arrangements consist basically of three parts: (1) the circuit for converting light fluctuations into voltage changes closely proportional to the percentage light fluctuations; (2) a selective amplifier to amplify corresponding voltage fluctuations to a suitable intensity; and (3) a trigger device to supply, when acted upon by the desired signal, sufficient direct current to detonate the explosive charge. Now if we designate the peak pulse voltage necessary to fire the trigger tube by V, the voltage gain ratio of the amplifier by G, and the conversion factor of the input circuit, that is, volts output per percent light fluctuations, by E, then we may indicate the sensitivity of the circuit in percentage change of illumination required to fire the thyratron by the following equation:

$$\text{Sensitivity} = \frac{V}{EG} \qquad (1)$$

To obtain increased sensitivity that is, a lowered percentage change of illumination required to fire the thyratron, we may operate on any or all of the factors V, E and G which are subject to design variations. If we wish to use fewer amplifying tubes, resulting in a lower gain G, we may at least partially compensate for such reduction by reducing the necessary peak pulse voltage V and increasing the conversion factor E.

The peak pulse voltage required is dependent upon the negative bias used on the thyratron. It can be seen from Equation 1 that if V and G are changed in the same ratio the sensitivity is not effected so that if G is reduced, say to one-half its previous value, the lost sensitivity may be regained by reducing the negative bias, therefore permitting reducing V to one-half its previous value. This can be done since the noise disturbances and the signal are amplified together and such modification does not change the signal-to-noise ratio nor make the circuit more susceptible to firing on noise. The amount of allowable reduction of negative bias is dependent upon variations of bias voltage from battery to battery. Consequently, in any practical circuit there is a limit to which the peak pulse voltage V may be reduced.

If we make the assumption that all significant disturbances are present in the amplifier input, then changing the amplifier gain G only changes the sensitivity of the unit. If we economize on circuit elements by leaving out a tube and its associated coupling impedances we will of course broaden the frequency responses but this can be tolerated at the reduced sensitivity.

Using a varistor in combination with a photoelectric cell in accordance with this invention we have almost complete control of the general impedance level of the load circuit. We can make it equal to or greater than that of the photoelectric cell at the usual light intensities and thus obtain a conversion factor which is relatively high. An advantage of this high conversion factor is that it is practicable with one amplifier tube to operate at a sensitivity of about 1 percent. Furthermore, with the better conversion factor and reduced gain, noise and vibration disturbances in the first stage are not so troublesome, resulting in a saving in vacuum tube cost.

The invention will now be described more in detail, having reference to the accompanying drawings.

Fig. 1 is a circuit diagram showing one embodiment of the invention having a single amplifier stage;

Fig. 2 is a circuit diagram of a modified embodiment of the invention;

Fig. 3 is a circuit diagram of another modified embodiment of the invention having a two-stage amplifier;

Figs. 4 and 5 illustrate other embodiments of the invention having a plurality of varistors and fixed resistors.

The same reference characters are used to indicate identical elements in the several figures of the drawings.

An embodiment of the invention having a single amplifier stage will now be described having reference to Fig. 1. A photoelectric cell 10, a varistor 11, a battery 12 and a protective resistor 13 are connected in series. Coupled across the varistor 11 is an amplifier stage V1 to which amplifier stage is coupled a thyratron stage T. The amplifier stage V1 comprises a vacuum tube 14, the control grid of which is connected through a condenser 15 to that terminal of varistor 11 which is connected to the cathode of photoelectric cell 10. The cathode of vacuum tube 14 is connected to the other terminal of varistor 11. The input circuit of amplifier stage V1 is completed by grid leak resistor 16 which is connected between the grid and cathode of vacuum tube 14. The output circuit of vacuum tube 14 is coupled to the input circuit of thyratron 18 by resistor 17, series condenser 19 and a grid leak combination of resistors 20, 21 and 22. A negative bias for the grid of thyratron 18 is supplied by battery 23. Resistors 21 and 22 constitute a voltage divider connected across battery 23 whereby a desired negative bias for the grid of thyratron 18 is obtained. The resistor 25 serves as load for thyratron stage T and in series with battery 12 is connected between the anode and cathode of thyratron 18. The voltage for the screen grid of vacuum tube 14 is supplied from an intermediate tap 26 on battery 12. The negative terminal of battery 12 is grounded by conductor 24.

By reason of the voltage versus current characteristic of varistor 11 approximately equal voltage changes across the terminals of varistor 11 occur for equal percentage changes of illumination on photoelectric cell 10, regardless of the absolute illumination of photoelectric cell 10 within the operable range of illuminations. However, an impulsive reduction of light on photoelectric cell 10 causes an impulsive change of voltage on the grid of vacuum tube 14 which is transmitted to the grid of thyratron 18, causing it to fire and energize load resistor 25.

Resistor 13 protects the photoelectric cell 10 against excessive currents on high illuminations which would otherwise result because of the low resistance of varistor 11 at high current values.

The modified circuit of Fig. 2 is in many respects identical with the circuit of Fig. 1. A photoelectric cell 10, a varistor 11 and a battery 12 are adapted to be connected in a closed series circuit upon the closure of switch 27. Coupled across the varistor 11 is an amplifier stage V1 to which is coupled thyratron stage T. The amplifier stage V1 comprises a vacuum tube 14, the control grid of which is connected through a condenser 15 to that terminal of varistor 11 which is connected to the cathode of photoelectric cell 10. The cathode of vacuum tube 14 is connected to the other terminal of varistor 11. The input circuit of amplifier stage V1 is completed by grid leak resistor 16 which is connected between the grid and cathode of vacuum tube 14. The output circuit of vacuum tube 14 is coupled to the input circuit of thyratron 18 by resistor 17, series condenser 19, shunt condenser 28, a series arrangement of grid leak resistors 29 and 30 and negative biasing battery 31. The resistor 25 serves as load for thyratron stage T and is connected upon closure of switch 32 in series with battery 12 and switch 27 between the cathode and anode of thyratron 18. Battery 12 is shunted by a condenser 33. When thyratron 18 fires, resistor 25 is heated sufficiently to cause detonation of the explosive charge of the projectile which, in a specific embodiment of the invention, is controlled by the arrangement illustrated in Fig. 2.

In the specific embodiment just mentioned, the thyratron 18 is adapted to be fired after a predetermined elapsed time following the closing of switch 27 providing that it has not been fired previously under control of photoelectric cell 10. Such firing of thyratron 18 is effected by the charging of condenser 35 through resistors 36 and 37 in series from battery 12 after switch 27 has been closed. When condenser 35 acquires a predetermined charge, gaseous discharge lamp 38 which may be a neon tube, breaks down placing a sufficient positive voltage on the grid of thyratron 18 through resistance 29 to overcome the negative bias of battery 31 and fire the thyratron, battery 12 having been connected in series with the discharge path between cathode and anode of thyratron 18 by the closure of switch 32.

Various protective features are incorporated in the arrangement of Fig. 2 to prevent premature firing of thyratron 18. Resistor 34 which has a high resistance is connected across condenser 33 to prevent charging of condenser 33 by leakage current across the contacts of switch 27 in its open condition and the consequent charging of condenser 35 to the breakdown potential of discharge lamp 38. The resistance of resistor 34 is so high that the current drain on battery 12 is negligible even when switch 27 is closed.

The screen grid 85 of vacuum tube 14 is connected through resistor 86 to the anode of thyratron 18. Grid 85, therefore, is not energized until switch 32 is closed. Furthermore, condenser 87 which is connected between grid 85 and the negative or zero terminal of battery 12 must be charged through resistor 86 and load resistor 25 before the grid 85 assumes its operating potential. As a result of this arrangement thyratron 18 cannot be fired upon the closing of switch 32 due to parasitic currents in the input circuit of amplifier stage V1 because vacuum tube 14 is blocked when there is no positive voltage on grid 85, as at the instant that switch 32 is closed and for a fraction of a second thereafter or until condenser 87 can be charged by current from battery 12 flowing through resistors 25 and 86.

In the operation of the specific circuit of Fig. 2 when used to detonate the explosive charge of a projectile, switches 27 and 32 are closed under the control of forces of acceleration resulting from the translatory motion of the projectile. Switch 27 is closed first and starts the charging of condenser 35. Shortly thereafter switch 32 is closed, placing positive battery on the anode of thyratron 18 and activating amplifier stage V1 by charging condenser 87 and energizing screen grid 85 of vacuum tube 14. From the instant that amplifier stage V1 is activated until the breakdown of discharge device 38, the firing of thyratron stage T is under control of photoelectric cell 10. This time interval is so chosen that the projectile during that interval is passing through the target zone. If it passes in proximity to a target an impulsive reduction in illumination of the photoelectric cell 10 occurs causing the thyratron 18 to fire. Since the response is approximately constant for any given percentage reduction of illumination, within the operating range of illuminations, this circuit is effective to fire the thyratron 18 whether the illumination be great or small. This is important since the illumination relied upon is natural illumination from the sky in this specific embodiment.

For testing purposes manually operated switch 88 is provided which when closed prevents the charging of condenser 35 to the breakdown potential of discharge tube 38. Resistor 37 prevents undue drain on battery 12 while switch 88 is closed.

The cathodes of vacuum tube 14 and thyratron 18 are energized from battery 55.

The arrangement of Fig. 3 is somewhat like that of Fig. 1. Two stages of amplification are used between the photoelectric cell and the varistor circuit and the thyratron stage T. The photoelectric cell 10, varistor 11, a protective resistor 13 and the battery 12 are connected in a series circuit. Coupled across the photoelectric cell 10 is an amplifier having two stages V1 and V2 to the output of which stage V2 is coupled thyratron stage T. The amplifier stage V1 comprises a vacuum tube 14, the control grid of which is connected through condenser 15 to the anode of photoelectric cell 10 which is connected to one terminal of varistor **11**. The cathode of vacuum tube **14** is connected to the cathode of photoelectric cell **10**. The input circuit of amplifier stage **V1** is completed by grid leak resistor **16**. The output circuit of amplifier stage **V1** is coupled to the input circuit of amplifier stage **V2** by resistor **17**, series condenser **19**, series grid resistor **41**, grid leak resistors **42** and **43**, shunting condenser **44** for resistor **43** and shunt grid condenser **45**. The output circuit of amplifier stage **V2** is coupled to the input circuit of thyratron stage **T** by resistors **46** and **47**, condenser **48** shunting resistor **47** and battery **12**, series condenser **49**, grid leak resistor **52** and negative grid biasing battery **23**. The output circuit of thyratron stage **T** comprises load resistor **25** in series with protective resistor **53** and battery **12**. Resistor **53** may be short-circuited by the closure of switch **54**. With resistor **53** in circuit the anode current of thyratron **18** cannot exceed a very small value, which will not appreciably affect load resistor **25**. Therefore resistor **53** serves as a protective resistance until switch **54** is closed to effectively remove resistor **53** from the circuit. Switch **54** may be controlled manually or automatically as by forces of acceleration in the case where this arrangement is used to detonate an explosive projectile. The cathodes of vacuum tubes **14** and **40** and thyratron **18** are heated by current from battery **55**. The screen grids of vacuum tubes **14** and **40** are energized by a connection from intermediate tap **26** on battery **12** through resistors **50** and **51** respectively.

Vacuum tubes **14** and **40** of Figs. 1, 2 and 3 may be pentode tubes having suppressor grids which are connected to the cathodes.

A reduction in illumination of photoelectric cell **10** in Fig. 3 causes a positive impulse of voltage to be applied through condenser **49** to the grid of thyratron **18** by reason of the voltage across photoelectric cell **10** being applied to the input circuit of amplifier stage **V1** and two stages of amplification being used. Varistor **11** causes changes in this voltage to be of approximately equal amounts for any given percentage change of illumination of the photoelectric cell whether the initial illumination just prior to each change be large or small if it is within the operable range of illuminations.

In the arrangement of Fig. 4 two varistors **60** and **62** are connected in series. Fixed resistor **61** is connected in series with varistor **60**, the input circuit of amplifier stage **V1** including series condenser **15** and grid leak resistor **16** being connected across both the varistor **60** and the resistor **61**. A resistor **63** is connected in shunt of varistor **62**. The primary series circuit, therefore, comprises photoelectric cell **10**, resistor **61**, varistor **60**, varistor **62** shunted by resistor **63** and battery **64**. Suitable values for the fixed resistors are resistor **61**, 2 megohms; resistor **63**, 4 megohms; and resistor **16**, 100 megohms. Any suitable circuit arrangement may be connected to the cathode and anode of tube **14** such as those illustrated in Figs. 1 and 2.

In the arrangement of Fig. 5, two varistors **70** and **62** are connected in series. The input circuit of amplifier **V1**, including condenser **15** and resistor **16**, is connected across varistor **70**. A protective resistor **71** is included in the primary series circuit which includes photoelectric cell **10**, varistor **70**, varistor **62** shunted by resistor **63**, battery **64** and protective resistor **71**. Suitable values for the fixed resistors **63** and **16** are the same as those given for the same resistors of Fig. 4 and for resistor **71**, 3 megohms. As in the case in Fig. 4, any suitable circuit may be connected to the cathode and anode of tube **14** in Fig. 5.

The circuits of Figs. 1, 3 and 5 with their protective resistors **13** and **71** respectively, are particularly useful if the photoelectric cell **10** should become so oriented in flight that it would receive direct illumination from the sun, causing a tremendous pulse of light. The large value of the protective resistances at large light values causes most of the battery voltage to appear across this resistance, leaving only a small voltage to cause current to flow through the photoelectric cell.

Other forms of input circuits may comprise a combination of varistor with positive input tube grid, a combination of varistor and variable negative grid bias, and a combination of varistor and cathode impedance.

What is claimed is:

1. An electro-optical system comprising a primary series circuit including a light sensitive device and a resistor, the resistance of said resistor changing in response to changes of illumination of said device, a vacuum tube amplifier having an input circuit including a series condenser and an output circuit, said input circuit being coupled to a portion of said series circuit across which there is a voltage drop dependent upon the illumination of the light sensitive device, and means connected to the output circuit of said amplifier adapted to be controlled by impulsive changes of light on said light sensitive device.

2. An electro-optical system comprising a primary series circuit including a light sensitive device and a resistor, the resistance of said resistor changing in response to changes of illumination of said device, a vacuum tube amplifier having an input circuit including a series condenser and an output circuit, said input circuit being connected across said resistor, and means connected to the output circuit of said amplifier adapted to be controlled by impulsive changes of light on said light sensitive device.

3. An electro-optical system comprising a primary series circuit including a light sensitive device, a resistor of fixed resistance and a second resistor, the resistance of said second resistor changing in response to changes of illumination of said device, a vacuum tube amplifier having an input circuit including a series condenser and an output circuit, said input circuit being coupled to a portion of said series circuit across which there is a voltage drop dependent upon the illumination of said light sensitive device, and means connected to the output circuit of said amplifier adapted to be controlled by impulsive changes of light on said light sensitive device.

4. An electro-optical system comprising a primary series circuit including a light sensitive device, a resistor of fixed resistance and a second resistor, the resistance of said second resistor changing in response to changes of illumination of said device, a vacuum tube amplifier having an input circuit including a series condenser and an output circuit, said input circuit being connected across said second resistor, and means connected to the output circuit of said amplifier adapted to be controlled by impulsive changes of light on said light sensitive device.

5. An electro-optical system comprising a primary series circuit including a light sensitive device, a resistor of fixed resistance and a second resistor, the resistance of said second resistor changing in response to changes of illumination of said device, a vacuum tube amplifier having an input circuit including a series condenser and an output circuit, said input circuit being connected across both said resistor of fixed resistance and said second resistor, and means connected to the output circuit of said amplifier adapted to be controlled by the impulsive changes of light on said light sensitive device.

6. An electro-optical system comprising a series circuit including a photoelectric cell, a first varistor, a second varistor, a fixed resistor and a source of unidirectional current, and a vacuum tube amplifier having an input circuit including a condenser and an output circuit, said input circuit being connected across a portion of said series circuit including said first varistor.

7. An electro-optical system comprising a series circuit including a photoelectric cell, a first varistor, a second varistor, a fixed resistor and a source of unidirectional current, one terminal of said fixed resistor being connected

to one terminal of said first varistor, and a vacuum tube amplifier having an input circuit including a condenser and an output circuit, said input circuit being connected across a portion of said series circuit including both said first varistor and said fixed resistor.

8. An electro-optical system comprising a series circuit including a photoelectric cell, a first varistor, a second varistor, a fixed resistor and a source of unidirectional current, a vacuum tube amplifier having an input circuit including a condenser and an output circuit, said input circuit being connected across a portion of said series circuit including said first varistor, and a second fixed resistor connected in shunt to said second varistor.

9. An electro-optical system comprising a series circuit including a photoelectric cell, a first varistor, a second varistor, a fixed resistor and a source of unidirectional current, one terminal of said fixed resistor being connected to one terminal of said first varistor, a vacuum tube amplifier having an input circuit including a condenser and an output circuit, said input circuit being connected across a portion of said series circuit including both said first varistor and said fixed resistor, and a second fixed resistor connected in shunt to said second varistor.

10. An electro-optical system comprising a series circuit including a photoelectric cell, a first varistor, a second varistor, a fixed resistor and a source of unidirectional current, and a vacuum tube amplifier having an input circuit including a condenser and an output circuit, said input circuit being connected across said first varistor only.

11. An electro-optical system comprising a series circuit including a photoelectric cell, a first varistor, a second varistor, a fixed resistor and a source of unidirectional current, a vacuum tube amplifier having an input circuit including a condenser and an output circuit, said input circuit being connected across said first varistor only, and a second fixed resistor connected in shunt to said second varistor.

12. An electro-optical system comprising a series circuit including a photoelectric cell, a varistor and a source of unidirectional current, a space discharge tube having a cathode, an anode and a control electrode, a series condenser connected between said control electrode and one terminal of said varistor, a conductive connection between said cathode and the other terminal of said varistor, a fixed resistor connected between said control electrode and said cathode, and means connected between said anode and said cathode controlled by changes in the illumination of said cell.

13. An electro-optical system comprising a series circuit including a photoelectric cell, a varistor and a source of unidirectional current, a space discharge tube having a cathode, an anode and a control electrode, a series condenser connected between said control electrode and one terminal of said varistor, a conductive connection between said cathode and the other terminal of said varistor, a fixed resistor connected between said control electrode and said cathode, said fixed resistor having a resistance at least as large as the maximum resistance of said varistor, and means connected between said anode and said cathode controlled by changes in the illumination of said cell.

14. The combination with a vacuum tube amplifier including a vacuum tube having a cathode, an anode, a first control electrode and a second control electrode of a radiant energy sensitive device, means including said radiant energy sensitive device for impressing signal voltage on said cathode and said first control electrode, means including a load device connected to said cathode and anode, said means including switching means to operably associate said load device with said amplifier, and means for slowly applying an operating potential to said second control electrode only after said switching means is actuated to operably associate said load device with said amplifier.

15. A radiant energy sensitive unit comprising a radiant energy sensitive device, means for producing voltages under control of said device, a vacuum tube amplifier for amplifying voltages produced by said means, said vacuum tube amplifier including a vacuum tube having a cathode, an anode, a control grid and a screen grid, a thyratron coupled to the cathode and anode of said vacuum tube, said thyratron having a cathode, an anode and a control electrode, a load device, a source of unidirectional current, a switch, a series circuit including said load device, source of current and switch connected between the anode and cathode of said thyratron, a condenser connected between the screen grid and cathode of the vacuum tube of said amplifier, and a high resistance connected between said screen grid and a point of said series circuit which is more positive than the cathode of said thyratron and between said switch and said anode.

16. An electronic circuit comprising a space discharge tube having a cathode, an anode and a control electrode, means to apply control voltages between said cathode and control electrode, a load device for said space discharge tube, a source of unidirectional current, a switch, a series circuit including said load device, switch and source connected between said anode and cathode, a condenser connected in shunt of said source and switch, and a high resistance connected in a shunt circuit for said condenser to drain off any charge on said condenser due to leakage current from said source across the terminals of said switch in its open position.

17. A space discharge tube amplifier comprising a space discharge tube having a cathode, an anode and a control electrode, means to apply voltages to be amplified between said cathode and control electrode, a load device for said space discharge tube, a source of unidirectional current, a switch, a series circuit including said load device, switch and source connected between said anode and cathode, a condenser connected in shunt of said source and switch, a high resistance connected in a shunt circuit for said condenser to drain off any charge on said condenser due to leakage current from said source across the terminals of said switch in its open position, and a gaseous discharge tube connected in a circuit from the positive terminal of said condenser to said control electrode.

18. An electro-optical system comprising a photoelectric cell having anode and cathode electrodes, an electrical circuit including a conductive impedance connected between said anode and cathode electrodes, and a condenser of high impedance to desired frequencies produced under control of said photoelectric cell and of low impedance to undesired frequencies higher than said desired frequencies connected to one of said electrodes and in shunt of at least a portion of said conductive impedance.

19. An electro-optical system comprising a photoelectric cell having an anode and a cathode, a conductive impedance connected between said anode and ground, a second conductive impedance connected between said cathode and ground, and a condenser of low impedance to high frequency current connected between said anode and ground.

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