GENERAL ELECTRIC

PHOTOTUBES

DESCRIPTION

The phototube is an electronic device that controls a flow of electrons by means of changes in light. Technically, a "phototube is a vacuum tube in which one of the electrodes is irradiated for the purpose of causing electron emission." (IRE Definition).

When a voltage in series with a resistance is applied to the anode and cathode of a phototube and the cathode is illuminated by some light source, a current will flow in this circuit proportional to the amount of light striking the cathode.

A phototube may be used in any application where a current change due to a light intensity change can be utilized for control purposes.

FUNDAMENTALS

Phototubes consist essentially of two electrodes in an evacuated container in which there may be either a vacuum or an inert gas at low pressure.

There are three general types of phototubes, vacuum, gas, and electron multiplier. The last mentioned tube consists of the two usual electrodes, cathode and anode, as well as a series of electrodes called dynodes which amplify the electron current from the cathode by means of secondary emission.

The cathode has the property of emitting electrons under the action of light. A potential of from 15 to 25 volts applied to the anode is sufficient to attract all the electrons emitted from the cathode by the action of the light.

An increase of anode voltage above this value will cause little or no increase in current in the vacuum-type tube. However, when a low pressure of an inert gas is present, the original current is increased by the ionization of the gas.

The amount of ionization increases rapidly as the anode voltage is increased, until a point is reached at which the discharge breaks into a glow. Since this glow discharge will destroy the tube, it is always necessary to limit the anode voltage to a point well below this value.

In the multiplier-type tube, increases in anode and dynode voltages cause greater electron flow due to secondary emission than in either of the other types.

In general, the vacuum types are the more stable in their characteristics and give an output directly proportional to the light flux incident on the cathode. The gas-filled tubes have the advantage of greater output per unit of light flux because of the ionization of the gas.

The color sensitivity of phototubes, which varies depending upon the type of light-sensitive material and glass envelope used, is quite different from that of the human eye. General Electric manufactures phototubes covering the following color ranges: Red-infrared, violet-green, blue, ultraviolet-blue, ultraviolet, violet-red.

Whenever it is desirable to have a device with a special color sensitivity, a standard phototube should be used in conjunction with a light filter with the proper transmission characteristics.

RATINGS

Phototubes are rated in terms of the following:

Spectral Response—expressed as a symbol composed of the letter "S" followed by a number, as S-1, S-2, etc. These symbols represent various curves of output versus light wavelength, and are standardized in accordance with RMA standards.

Luminous Sensitivity—usually expressed as the current in microamperes per lumen of light flux. Measurements are usually made at 0.1 lumen, the light source being a tungsten lamp operating at 2870° K. The ultraviolet-sensitive tubes are tested by means of ultraviolet lamps rather than the tungsten lamp.

Static Sensitivity—the ratio of anode direct current to a constant luminous flux.

Dynamic Sensitivity—the ratio of the variation in anode current to the variation of a varying luminous flux.

Leakage Resistance or Dark Current—a measure of the output impedance of the phototube. It is given either as a resistance in megohms or a current in microamperes through a given resistance. In the latter case, the cathode is in complete darkness.

Gas Ratio—the ratio of the current when ionization exists, to the current due to primary electrons alone. This ratio is obtained by comparing the luminous sensitivities at two voltages, usually 90 and 25 volts.

Maximum Anode Voltage—the maximum instantaneous value of voltage that should be impressed on the tube.

Maximum Anode Current—the maximum instantaneous value of current that should be allowed to pass through the tube.

Maximum Ambient Temperature—the maximum temperature to which the tube should be subjected.

CLASSES OF PHOTOTUBES

Although phototubes are made in a variety of styles and sizes, there are two general methods of classification—by size and by style. There are two general sizes:

large—PJ-22
small—GL-929

There are several special sizes, of which the FJ-405 is one example. The size classes may be divided into three styles, vacuum, gas, and multiplier, the second method of classification. All styles do not exist in each size, as the multiplier type comes in only one size. In the large size tubes, GL-868/PJ-23 is the gas tube and the PJ-22 the vacuum tube.

APPLICATIONS

Phototubes can be divided into three general classes of use: control and safety, amusement and sound reproduction, inspection and measurement.

Under control and safety come such applications as:

1. Opening doors automatically
2. Burglar alarm systems
3. Automatic switching of street-lighting systems

Amusement and sound reproduction includes:

1. Pin-ball games
2. Theater sound systems
3. Horse race timers

Inspection and measurement uses include:

1. Color temperature pyrometers
2. Pinhole detection in sheet metal
3. Daytime measurements of cloud heights

These are but a few of the many applications in each of these categories and are given merely as an indication of some of the better known uses to which phototubes have been applied.

For most control applications ample illumination is provided by a lamp used as a source of light. In these cases, it is desirable to use a gas phototube of high sensitivity. This obviates the necessity of high-gain amplifier stages following the phototube.

For measurement applications, where a very small amount of light is available, a fairly high output impedance is desirable. Leakage currents become important in this case. Phototubes with low leakage are the GL-917 and GL-919.

In applications requiring a stable phototube, the vacuum phototube is recommended. For best operation the anode voltage should be kept below 25 volts. It is also desirable to illuminate as much of the cathode area as possible, to avoid minor differences in sensitivity of various sections of the cathode.

Where extreme amplification is required the multiplier tube should be used. In comparison to a vacuum phototube, the multiplier phototube has an amplification factor approaching 1,000,000.

APPLICATION CIRCUITS#

Fig. 1 shows an elementary circuit diagram of a phototube and amplifier. P is any phototube and T any triode. Changes in light on the phototube will cause a change in the current through the load resistance R_3.

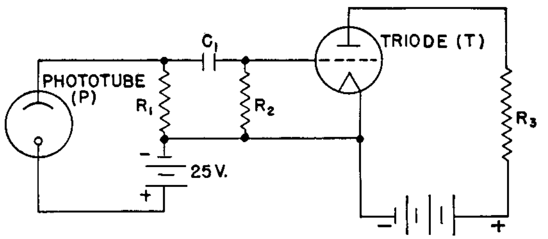

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Fig. 1—Elementary Circuit Diagram of a Phototube and Amplifier

A variation of the elementary diagram is shown in Fig. 2. Here the phototube controls a double-grid thyratron, the thyratron conducting when the light level on the phototube decreases. The GL-868/PJ-23 phototube and the FG-97 thyratron are used in this circuit. This type of circuit provides an on-off arrangement, actuated by a phototube and is particularly suitable for applications requiring a high speed of response, where the values of current required are within the rating of the thyratron tube.

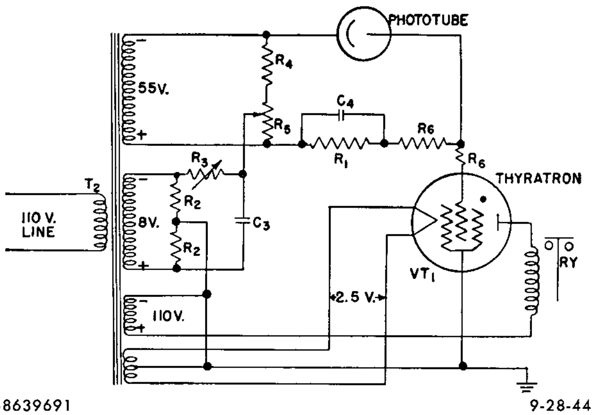

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Fig. 2—Phototube Double-Grid Thyratron Relay Control Circuit

The circuit in Fig. 3 demonstrates the use of the GL-868/PJ-23 phototube as an audio-frequency pickup tube. Any audio-fluctuation of a light

#Circuits shown in ETI-177 are examples of possible tube applications and the description and illustration of them does not convey to the purchaser of tubes any license under patent rights of General Electric Company.

APPLICATION CIRCUITS (CONT'D)

source will be picked up on the phototube and amplified. This type of circuit is used commercially in talking motion pictures, to change the variations along the sound track on the film, back into actual sound and music as heard in our modern theatres. Such a circuit is also suitable for use in "Narrowcasting" with a beam of light where it is desirable to focus the direction of signals to make sure they are not read from other sources.

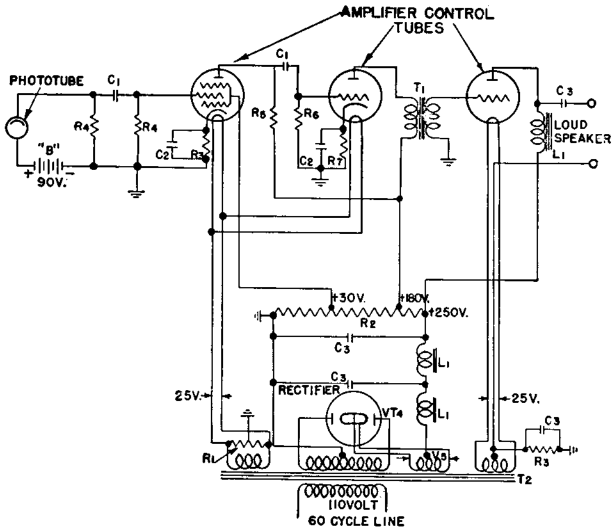

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Fig. 3—High-Gain Phototube Amplifier Circuit

Figs. 4 through 10 illustrate some of the many circuits for specific applications where phototubes are particularly advantageous for measurement and control work. The circuit shown in Fig. 4 may be used for measuring and recording

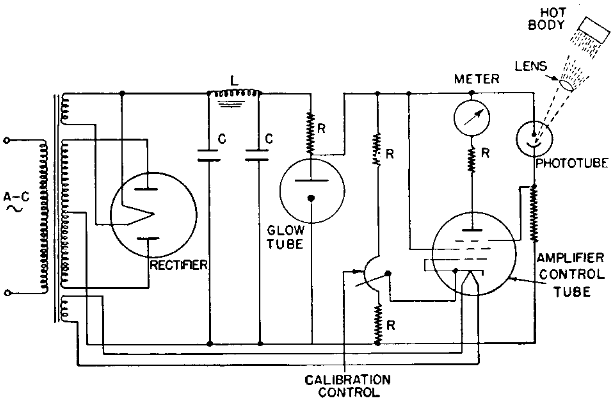

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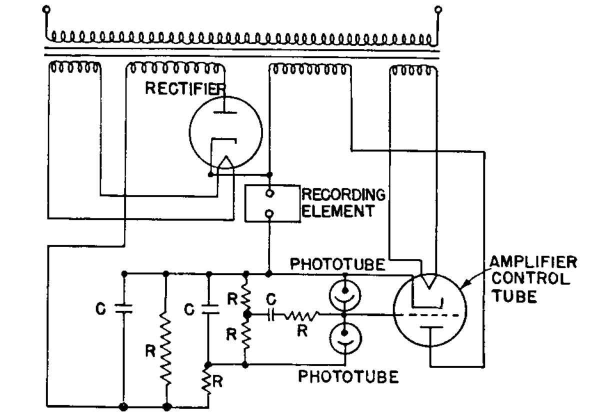
*Fig. 4—Phototube Pyrometer Circuit

high temperatures where the heat is at a visible temperature.

The circuit shown in Fig. 5 has a high impedance input and is adapted for use where the continuous recording of small currents is desired.



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†Fig. 5—Recorder Circuit Using Phototubes, Rectifier and High-Vacuum Amplifier

Fig. 6 is a circuit used for the measurement of illumination. This circuit may be employed in applications which require the measurement of the output of different light levels.

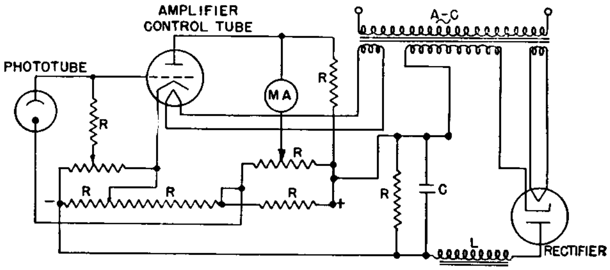

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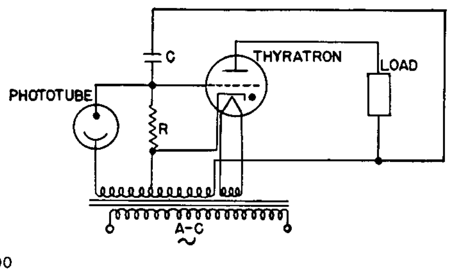
Fig. 6—Phototube Circuit for the Measurement of Illumination

The circuit shown in Fig. 7 is suitable for counting, for on-off operation and similar uses. The voltage source in this circuit is a-c rather than d-c.



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‡Fig. 7—Thyratron Phase-Control Circuit Employing a Phototube

*Fig. 4—King, W. R., General Electric Review, Vol. 39

†Fig. 5—Henney, Electron Tubes in Industry, P-418 McGraw-Hill Book Co. Inc., 1937

‡Fig. 7—Reich, H. J., Theory and Application of Electron Tubes, P-508 McGraw-Hill Book Co., 1939

APPLICATION CIRCUITS (CONT'D)

A circuit for regulating the voltage output from a generator by changing the field supply voltage is shown in Fig. 8.

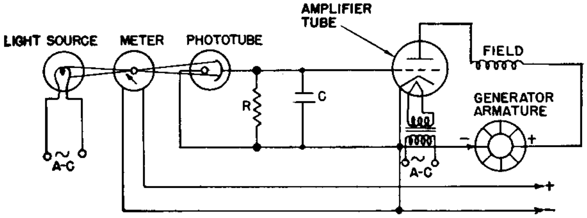

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Fig. 8—Voltage Regulation Circuit Using Hole in Meter

The circuits illustrated in Figs. 9 and 10 are used for operating relays, for counters, or for on-off and limit-control applications. The circuit shown in Fig. 9 is applicable in cases where relay operation is desired with an increase in light level.

The circuit in Fig. 10 may be used in applications where it is desired to operate the relay with a decrease in light level.

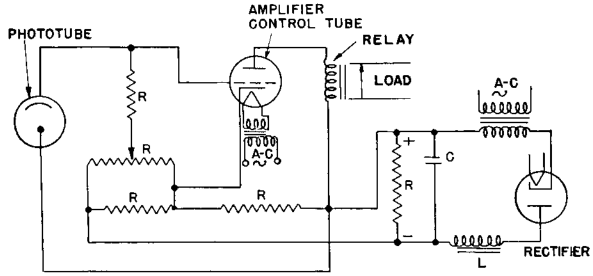

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Fig. 9—Forward D-c Photoelectric Relay Circuit

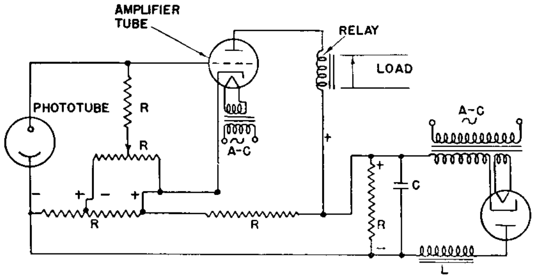

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Fig. 10—Reverse D-c Photoelectric Relay Circuit

INSTALLATION AND OPERATION

Phototubes may be mounted in any position, but a shock-absorbing mounting must be used if the tubes are to be subjected to vibration or shock.

Tubes should never be used in an ambient temperature higher than that given under the Technical Information for the specific tube.

Care should be exercised in wiring to insure high insulation resistance and low capacitance in all parts of the circuit.

It is desirable to operate phototubes at as low a voltage and illumination as possible, as the life will be increased and better stability of operation will result. A high light level is harmful when the tube is disconnected as well as when it is in operation.

For high-frequency operation it is important that leads be kept short to reduce output capacitance.

The average amplifier circuit employing a phototube makes use of standard radio receiver tubes. These radio tubes are rated for approximately 10 megohms maximum d-c resistance between grid and cathode. Therefore 10 megohms is recommended as the maximum phototube load resistance.

If it is necessary to use a higher output impedance for the phototube, it is requisite to operate the radio tube at greatly reduced voltages. By using low plate and screen voltages, and a reduced filament voltage, gas ionization is decreased, and the radio tube will be comparatively stable.

PHOTOMETRIC TERMS AND FORMULAS

Some photometric terms often used in phototube work are given below for reference.

Luminous Flux—The rate of passage of radiant energy evaluated by reference to the luminous sensation produced by it is luminous flux.

Lumen—The unit of luminous flux is the lumen. It is equal to the flux emitted in a unit solid angle by a uniform point source of one international candle.

Luminous Intensity—The luminous intensity of a point source in any direction is the luminous flux per unit solid angle emitted by that source in that direction.

Point Source of Light—The flux emanating from a light source whose dimensions are negligible in comparison with the distance from which it is observed may be considered as coming from a point.

International Candle—The unit of luminous intensity is the international candle.

Illumination—The illumination at a point of a surface is the density of the luminous flux incident

PHOTOMETRIC TERMS AND FORMULAS (CONT'D)

at that point or the quotient of the incident flux by the area of the surface when the latter is uniformly illuminated.

Foot-Candle—Taking the foot as the unit of length, the unit of illumination is the lumen per square foot; it is known as the foot-candle.

Brightness—The brightness in a given direction of a surface emitting light is the quotient of the luminous intensity measured in that direction by the area of this surface projected on a plane perpendicular to the direction considered.

Unit of Brightness—The practice recognized internationally is to express brightness in international candles per unit area of surface.

$$1 \text{ Candle Power} = 4\pi \text{ Lumens}$$

$$1 \text{ Foot Candle} = 1 \text{ Lumen per square foot}$$

$$1 \text{ Lumen} = \frac{\text{Candle Power (Area)}}{(\text{Distance})^2}$$

$$1 \text{ Lumen} = \text{Foot Candle (Area)}$$

$$\text{Foot Candle} = \frac{\text{Candle Power}}{(\text{Distance})^2}$$

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