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# APPLICATION OF CONVENTIONAL VACUUM TUBES IN UNCONVENTIONAL CIRCUITS*

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***Summary***—*This paper describes some out-of-the-ordinary, yet simple and interesting, vacuum tube applications. It illustrates how conventional vacuum tubes can be used in circuits which impose unusual requirements for grid current, noise, and life. Analysis of circuit requirements and knowledge of tube performance characteristics frequently make possible adjustment of operating conditions to give the desired results. A number of circuits to indicate the practicability of this procedure are described, and are used to illustrate simple and logical methods of analyzing circuit operation.*

*1. A two-stage photo amplifier relay circuit operating directly on the alternating-current line and using a voltage divider, one resistor, and three condensers as circuit parts.*

*2. A sensitive photo amplifier circuit using a pentode as the load resistor for a phototube and a standard tube as a reliable and sensitive electrometer tube feeding a low priced indicating instrument.*

*3. A modification of (2) to provide variable-range, variable-sensitivity characteristics.*

*4. A simple vacuum tube circuit in which standard unselected tubes can be used to multiply currents on the order of $10^{-12}$ amperes by a definite factor (fixed by the circuit elements and not by the tubes) to such values that they can be easily read on an insensitive milliammeter.*

*5. A simple capacitance operated relay working on the alternating-current line, using metal tubes and only a few inexpensive circuit parts.*

## I. Introduction

VACUUM tubes are becoming more and more widely used as means of doing things that have, heretofore, been done with difficulty, inconvenience, or not at all.

If we desire our vacuum tubes to operate with the same degree of reliability and length of life that we expect of other mechanical and electrical links in our modern machines, we must use the same factors of safety in the operation of the tubes as in the use of the other mechanical and electrical parts. If we fail to do this and let an electronic device be placed in service after only initial tests to show that it will work, we can expect trouble after the device has been in service for a period of time. The results of this procedure have led many people to be skeptical of the reliability of electronic devices.

When we do consider the requirements of circuits and tube char-

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acteristics and use the same factor of safety in the design of these circuits that we would use in the design of other mechanical or electrical equipment, we will have little to fear from the unreliability or the short life of electronic apparatus.

Simplicity of an electronic device is another important factor in determining its success or failure for a particular application. It seems needless to say that it is uneconomical to replace existing reliable apparatus with complicated new electronic equipment; yet too often we find ourselves so involved in the electronic problems that we lose sight of simpler and more direct methods of accomplishing our purpose.

It is believed that the following circuits will prove of interest to the designer of electronic devices.

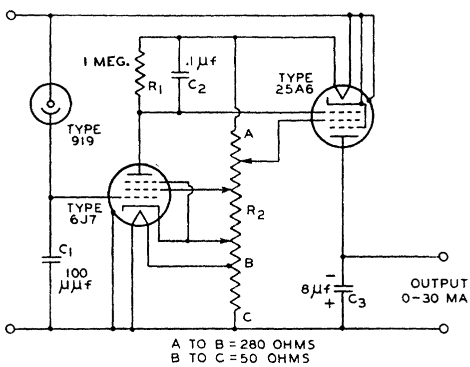
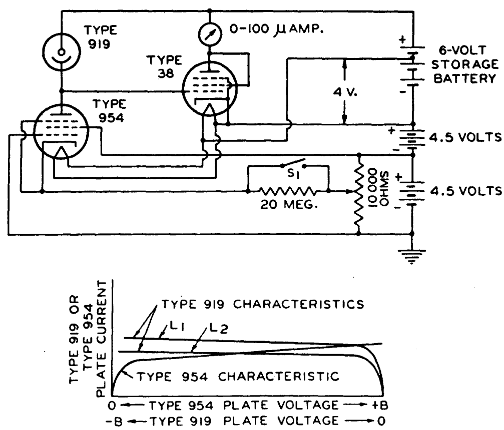



**Fig. 1—A simple two-stage alternating-current operated photo amplifier relay circuit.**

## II. A Simple Two-Stage Alternating-Current Operated Photo Amplifier Relay Circuit

Fig. 1 shows a simple two-stage photo amplifier relay circuit operating directly on the alternating-current line. The simplicity of the circuit is illustrated by the fact that the complete list of circuit parts includes only one voltage divider resistor, one plate load resistor, and three condensers. The circuit shown in Fig. 1 consists of a high impedance phototube feeding through a voltage amplifier or buffer stage into a power output stage. The filament voltage of the buffer stage has been reduced to reduce the temperature of, and, hence, the electron emission from the grid of the buffer tube. The plate current of the buffer stage is kept at a minimum in order to reduce the electron bombardment of the gas molecules within the tube and hence the gas current to the grid. The bias to the grid of the buffer stage is obtained by means of the rectifying action of the grid itself. This method of obtaining the grid bias keeps the effective bias and plate current of the tube constant, regardless of large fluctuations in contact potential between the grid and the cathode. The impedance of the condenser $C_1$ acts as a load impedance for the phototube. Condenser $C_1$ is charged up to a definite negative potential on one half of the alternating-current cycle and is allowed to discharge through the phototube on the other half of the cycle. The amount that is discharged by the phototube deteimines the working potential on the grid of the buffer stage. The size of $C_1$ can be set to any desired value to control the desired sensitivity range of the relay.

As the 6J7 conducts on only one half of the alternating-current cycle, it acts as a rectifier and so a negative direct-current potential




**Figs. 2 and 3—A sensitive light intensity indicator.**

is built up on its plate. This negative direct-current potential is suitable for use as bias and signal for the output stage. The plate of the 6J7 is returned through its load to a point on the voltage divider (one side of the heater of the 25A6) in order to obtain a zero working bias on the grid of the 25A6 output tube without the necessity of having the 6J7 cut off. This allows the 6J7 to be operated about the center of its characteristic. As the output of the 6J7 buffer stage has relatively low impedance, it is suitable for driving the grid of the 25A6 power output stage, which in turn is capable of handling relatively large amounts of power to operate a relay.

This circuit finds its principal use in applications where relatively small amounts of light are available and where the light variations last not less than one tenth of a second.

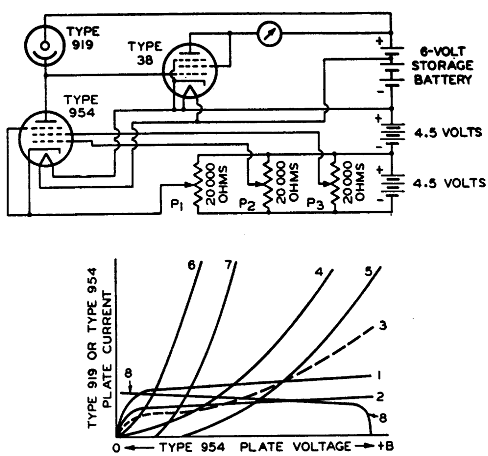
## III. A Sensitive Light Intensity Indicator

Fig. 2 shows a sensitive photo amplifier circuit that can be used for accurately matching the intensities of amounts of light. With this circuit, it is easily possible to indicate light differences or changes which may amount to small parts of one per cent. In this circuit arrangement, the high impedance 954 pentode acts as a load impedance for the 919 high impedance vacuum type phototube. It can be seen by reference to Fig. 3 that the potential of the common connection between the 919 and the 954 is determined by the intersection of the 954 and 919 characteristics. It is also evident that a small change of light on the phototube will result in an output of several volts. This output voltage is applied to the grid of a 38 output tube, the plate current of which is indicated on a 200-microampere meter. Because the phototube with the 954 load has an extremely high output impedance, it is necessary to operate the 38 so that its grid input impedance is extremely high. To reduce the grid emission to a minimum, the voltage to the heaters of the 38 and the 954 is reduced to four volts. The possibility of emission from the heaters to the grid is eliminated by operating the heaters at a potential positive with respect to the plate of the 954 and the grid of the 38. Gas current to the grid of the 38 is kept at a minimum by keeping the potentials within the 38 low so as to minimize the ionization of any gas that may be in the tube. Because all of the high impedance external connections are made to electrodes brought out from the tops of the tubes, external leakages are reduced to a minimum. External leakage can be greatly reduced by carefully cleaning the tubes and coating them with a nonhygroscopic wax. This can be done by dipping the tubes in hot ceresin wax and holding them under the surface of the wax until the greater part of the moisture on the glass is boiled off. Care should be taken not to scorch the wax. Ceresin wax has long been used by research men for reducing the effects of moisture leakages in high impedance direct-current circuits. Dr. Rentschler of the Westinghouse Lamp Company very kindly made available to the writer information on the use of ceresin wax.

This circuit finds application where it is desirable to indicate very small percentage variations of an amount of light. For instance, it can be used to indicate the absorption of light by a fluid and, consequently, to indicate or control the concentration of certain chemicals in suspension or solution. The use of monochromatic light can be used to advantage when it is desired to isolate a particular constituent. This circuit also finds application in color matchers and in indicating small changes of small amounts of light. For instance, when measuring small changes of small amounts of light, it has been demonstrated that a change of light intensity on the order of two millionths of a lumen is sufficient to swing the output meter over its full scale.

## IV. A Variable Range, Variable Sensitivity, Light Variation Indicator

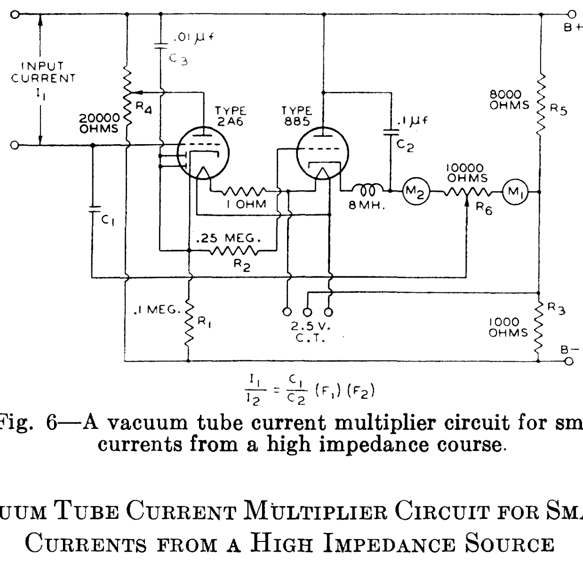
It is sometimes desirable to make the sensitivity of the light intensity meter indicator less for small percentage changes of light. The sensitivity can be reduced to any desired degree by varying the plate characteristics of the 954 between those of a pentode and those of a triode. This variation is produced in the arrangement shown in Fig. 4 by properly adjusting $P_2$ and $P_3$ to control the relative potentials on the control grid and the screen grid. When the No. 2 grid of the 954 is positive with respect to the cathode, the 954 has a high impedance pentode characteristic. Changing the No. 1 grid bias changes




Figs. 4 and 5—A variable range, variable sensitivity, light variation indicator.

the height of the characteristic as shown in Fig. 5 by curves 1 and 2. As the potential of the No. 2 grid is made more negative, the characteristic of the 954 changes to that shown by curve 3. With zero bias on the No. 1 and the No. 2 grids, the characteristic curve is as shown by curve 4. When a negative bias is placed on the No. 2 grid, the shape of the characteristic is unchanged but it is shifted along the voltage axis as shown by curve 5. If the No. 1 grid is biased positively, the slope of the characteristic is increased. Curve 6 shows the effect of positive bias on the No. 1 grid (bias on the No. 2 grid for this curve is zero). Placing a negative bias on the No. 2 grid shifts this characteristic along the axis as shown by curve 7.

From this analysis it can be seen that the 954 phototube load can be adjusted to give practically any desired positive impedance load at any desired current and at any desired voltage across the tube. This means that the full scale reading of the output meter can be made to cover a fraction of a per cent light variation, a 100 per cent light variation, or any desired amount of variation between these two extremes. A photo amplifier such as this finds application as a densitometer for use in connection with the analysis of the photographically recorded spectra and for use in connection with a suitable monochrometer or light filter as a means of measuring the absorption lines or the concentration of certain chemicals in solution. These are but two of a large number of possible applications for this type of circuit.




$$\frac{I_1}{I_2} = \frac{C_1}{C_2} (F_1)(F_2)$$

**Fig. 6—A vacuum tube current multiplier circuit for small currents from a high impedance course.**

## V. A Vacuum Tube Current Multiplier Circuit for Small Direct Currents from a High Impedance Source

Fig. 6 shows a vacuum tube current multiplier circuit that will multiply a small direct current from a high impedance source by a definite factor which is practically unaffected by the tube characteristics or by supply voltage variations. Essentially the operation of the circuit is as follows: The signal current $I_1$ is used to discharge condenser $C_1$; after the charge on $C_1$ has been reduced to a certain value just below the grid current point of the buffer stage, the potential on the grid of the buffer stage will be such as to make the current through the buffer stage just sufficient to cause a certain voltage drop across the cathode load resistor. This drop will decrease the bias on the 885 gas triode sufficiently to cause the tube to "break down." When this occurs, condenser $C_2$ is discharged and then charged in the opposite direction by the action of the inductance in series with the cathode of the 885 gas triode. While condenser $C_2$ is being discharged through the 885, $C_3$ holds the cathode of the buffer stage at an essentially constant potential and $C_1$ is charged to a potential equal to the potential change across $C_2$, modified by a factor $F_1$ determined by the position of the slider on $R_6$. This statement is true when the plate potential of the buffer stage is adjusted so that the 885 breaks down at the instant that the control grid starts to draw grid current. The adjustment of the circuit can be made by varying the slider on $R_4$ until the 885 ceases to relax and then backing off on the control slightly. The output meter $M_1$ reads $I_2+I_1$, and the output meter $M_2$ reads $I_2-I_1$, but because $I_1$ is usually extremely small compared to $I_2$, both $I_1+I_2$ and $I_2-I_1$ can generally be considered equal to $I_2$. Thus, the equation

$$\frac{I_1}{I_2} = \frac{C_1}{C_2} F_1$$

can be written without appreciable error as

$$\frac{I_1}{I_2 + I_1} = \frac{C_1}{C_2} F_1$$

or,

$$\frac{I_1}{I_2 - I_1} = \frac{C_1}{C_2} F_1.$$

These equations hold true only when the actual discharge time for the 885 is extremely small with respect to the time taken to build up the charge on condenser $C_2$ through resistor $R_6$. This is usually the case. Where a high degree of accuracy is required, a correction factor $F_2$ to account for the time required for discharge should be applied to the reading of the output meter. This correction factor, which is slightly less than unity, will apply for all readings of the instrument.

It should be noted here that the grid-to-cathode capacitance as well as the grid-to-plate capacitance of the buffer stage, or any capacities in the input circuit, are not to be considered a part of $C_1$ for the computation of the current ratios in the circuit. When the 885 discharges $C_2$, $C_1$ is charged as explained above to a voltage equal to the voltage change across $C_2$ times $F_1$. After this the charge is allowed to distribute itself between $C_1$ and $C_x$ without changing its actual value. $C_x$ is the sum of all the capacitances from grid to ground; this sum includes the buffer stage capacitances of the grid to plate and the grid to cathode, as well as the capacitances in the signal current source. Since this is true, a definite current will remove this charge in a definite time regardless of the size of $C_x$.

The most accurate form of the expression for current ratios in this circuit is

$$\frac{I_1}{I_2} = \frac{C_1}{C_2}(F_1)(F_2).$$

The accuracy of this formula is probably as great as the accuracy of the reading of the output meter, when $I_2$ is equal to the meter reading $M_1$ minus $I_1$, or $I_2$ is equal to $(M_1+M_2)/2$, when $F_1$ is a correction factor due to the setting of the slider on potentiometer $R_6$, and $F_2$ is a correction factor due to the time of conductance per cycle of the 885. The measured current $I_1$ includes leakages in the setup and the grid current of the buffer stage.

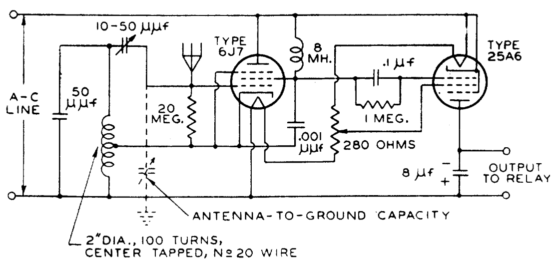



Fig. 7—A metal tube capacitance operated relay operating directly from the alternating-current line.

It is interesting to note that practically all of the time $C_1$ is being discharged by means of $I_1$ the plate current of the buffer stage is zero. This means that there can be no gas current to the grid during this time. The heater voltage of the buffer stage is lowered to reduce the grid emission. The heater is returned to a potential positive with respect to the grid of the buffer stage to avoid the possibility of emission from the heaters to the grid. This type of circuit is capable of measuring currents on the order of $10^{-12}$ amperes. It finds application in the measurement of small phototube currents, of leakage currents, or of any other small currents in high impedance circuits. If test condensers are connected in place of $C_1$, $I_2$ will be inversely proportional to the leakage of the condenser expressed directly in units of resistance per unit of capacity.

## VI. A Simple Capacitance Operated Relay Working Directly on the Alternating-Current Line

Fig. 7 shows a new and simple form of capacitance operated relay that can be made up cheaply from standard radio parts.

In this circuit operating on the alternating-current line, the sensitive element consists of a pentode oscillator, the feedback of which is determined by the difference in ratio between the inductance of the two parts of the oscillator coil and the ratio between $C_1$ and the antenna-to-ground capacitance. Thus, the intensity of oscillation of the oscillator varies rapidly with a change of $C_1$ or a change in the antenna-to-ground capacitance $C_2$. Because the cathode of the oscillator is at a radio-frequency potential, and because the control grid of the output tube is by-passed for high frequencies through suitable by-pass condensers to the cathode, a negative direct voltage equal to the peak radio-frequency voltage on the cathode of the 6J7 is built up across the grid leak and condenser due to the rectifying action of the grid of the 25A6 output tube. This voltage appears on the grid of the 25A6 output tube. The 6J7 oscillator oscillates at high frequency on one half of the alternating-current cycle and builds up the above-mentioned negative charge on the grid of the output tube. During this time, the output tube has negative plate voltage and so is nonconducting. On the other half of the alternating-current cycle, the 6J7 oscillator has negative plate voltage and so ceases oscillating. The negative charge built up on the grid of the output tube does not have time to leak off during this interval and, hence, is effective in controlling the plate current of the output tube during the positive plate voltage interval.

The sensitivity of this circuit to small changes in capacitance can be increased by increasing the resistance of the choke coil feeding the screen of the 6J7. When this resistance is more than about 15,000 ohms, the circuit will become unstable; i.e., the relay will not operate and release on the same value of capacitance. This increase in sensitivity is caused by the fact that as the intensity of oscillation of the 6J7 is increased, its plate current and its screen current decrease. This causes the screen voltage and, hence, the mutual conductance of the 6J7 to increase; the increase, in turn, helps to increase the intensity of oscillation.

This type of circuit finds application in connection with door-openers, counters, etc., and has even been used as a foul-line indicator for bowling alleys.