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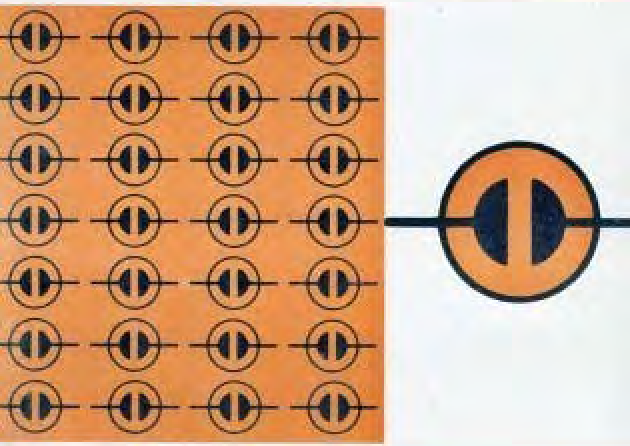

Using and Understanding MINIATURE NEON LAMPS

By
William G. Miller

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Contents

Preface

Miniature glow lamps have been in use for many years and are familiar to most readers as indicators and relaxation oscillators. Practically everyone has seen the inexpensive neon tester, consisting of a neon glow lamp in series with a current-limiting resistor, housed in a neat plastic enclosure terminated with flexible test leads. This forms a convenient and reliable means of testing for the presence of ac or dc voltages.

In electronics, the "state of the art" has progressed rapidly, finding new applications for the glow lamp as a circuit element. Much of this progress results from the increasing use of solid-state devices, many of them, like the transistor, requiring comparatively low currents and voltages for operation.

Some of the characteristics that make the miniature neon lamp particularly appealing to the hobbyist-experimenter are its low cost, long life, dependability, and the ease with which it can be made to work in extremely simple circuits. At the same time, but probably unknown to the majority of persons who work with electronics, the neon lamp can be used in some circuits and applications that are quite sophisticated, complex, or exacting.

This book is offered to present the student, hobbyist, technician, and engineer with a more complete account of the properties of neon lamps and to acquaint them with some of the many ways in which neon lamps can be utilized.

WILLIAM G. MILLER

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The Neon Lamp

The neon lamp is basically a glass envelope filled with gas and containing two or more electrodes. It is also referred to as a gas tube, gas diode, glow tube, and glow lamp.

It might be interesting to note that the neon lamp does not always contain neon alone, but may contain a mixture of gases. Some gas lamps have no neon at all, but are included in this discussion because the design considerations for all types are similar. Long term reliability, low cost, and small power and space requirements help account for its increased popularity.

BASIC OPERATION

The miniature neon lamp is a cold-cathode device and requires no heater. The electrodes are separated by an average distance of ⅛ inch inside the gas-filled envelope.

Under initial conditions, the gas acts as an insulator with a resistance of about 1000 megohms. If a variable voltage is applied across the electrodes (Fig. 1) and increased to approximately 50 volts, there will be essentially no current flow, due to the high insulation resistance of the gas.

Actually the gas atoms are constantly being bombarded and ionized by external forces such as light. The positive ions thus generated are attracted to the cathode, which has a negative charge. The electrons that are liberated in the generation of positive ions are accelerated to the positive anode, striking other atoms as they travel, but they rarely attain enough velocity to dislodge more electrons and create new ions.

This velocity can be attained if an external voltage of sufficient amplitude is applied. When an electron dislodges additional electrons, which in turn create even more ions, the process is referred to as "run-away" or "avalanche," and constitutes current flow. Run-away can be self destructive if uncontrolled, so a series current-limiting resistor (R_s), must be included. The exact value of voltage needed to start the ionizing action is called the breakdown voltage.

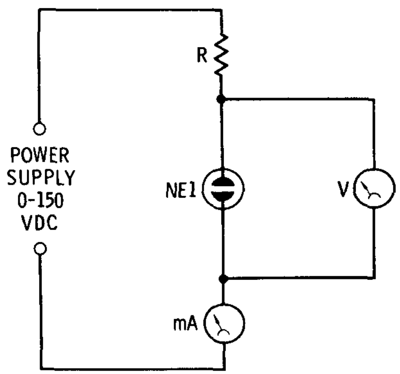

Fig. 1-1. Voltage and current in a neon-lamp circuit.

When breakdown voltage is applied to the circuit in Fig. 1-1 there will be a sharp deflection of the ammeter, and the voltmeter reading will drop to a value known as the maintaining voltage of the lamp. The maintaining voltage of a lamp remains relatively constant over a wide current range.

The actual values of breakdown and maintaining voltage will vary from one gas tube to another. They depend on many factors, such as physical design, external radiation, and circuit design.

The curve in Fig. 1-2 illustrates the characteristics of a typical gas discharge device (glow lamp). It can be seen that dynamic current does not begin to flow until the voltage reaches point A. Breakdown occurs at point B, or 110 volts, and the maintaining voltage is approximately 85 volts (point D). When breakdown occurs, the current flow is said to be self-sustaining. This means that the applied voltage can be lowered to some value above the maintaining voltage and current flow will still continue to increase until the normal glow

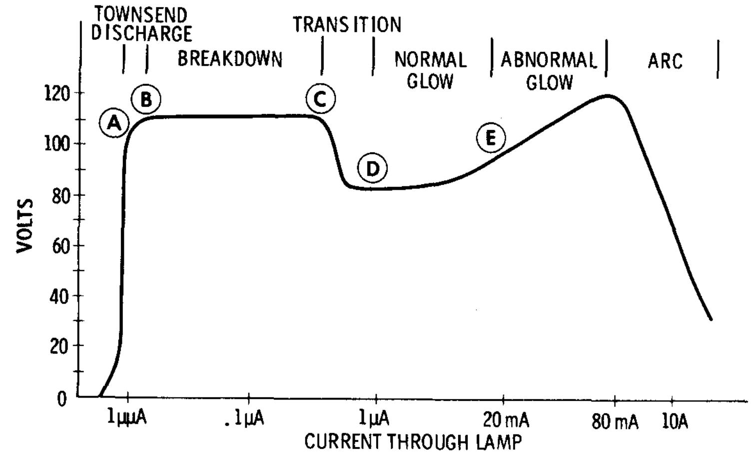

Fig. 1-2. Characteristic curve of a neon lamp.

region is reached. Note that the current scale is not linear, but compressed for convenience.

COROTRONS

Corotron is the name given by the manufacturer to a line of gas-filled diodes that are used to regulate voltages between 850 and 30,000 volts. Unlike the conventional regulator, they do not glow, but operate on the slightly positive slope prior to breakdown.

This is called the "corona mode" of operation and closely resembles the action of a zener diode.

Corotrons are free of voltage jumps, oscillations, and photosensitivity. Current capability is, however, quite small. The maximum figure for T2 types is 100 μA and 3 mA is the limit for even the largest type. Care must be taken never to exceed the peak current rating or breakdown will occur and permanent component damage may result.

PROGRESSIVE EXPLANATION OF TERMS

Ion—An atom with an excess or deficiency of electrons.

Ionization—In glow lamps, the process of separating an electron from an atom, creating a positive charge and a free electron.

This may be caused by collisions between atomic particles, the application of a voltage, an electrostatic field, X rays, ultraviolet rays, cosmic rays, and radioactivity.

Corona—The visible glow of an ionized gas surrounding the cathode.

Breakdown Voltage—Also called ionization voltage, striking voltage, and firing potential. It is the voltage needed to make a lamp glow. This is determined mainly by the type of gas, electrode spacing, pressure, and external ionizing forces, such as light.

Static Breakdown Voltage—The breakdown voltage under controlled conditions, which include: freedom from electrostatic fields, 5 to 50 foot candles of ambient light, and a 24-hour period in a non-conducting state.

Townsend Discharge—An avalanche type of electron flow that occurs just before breakdown voltage is reached. It is not a self-sustained current flow.

Maintaining Voltage—Also called holding voltage. It is the voltage across the lamp after breakdown. This voltage is at its minimum in the normal glow region (Fig. 1-2, point D to E).

Normal Glow—The mode of operation that allows maximum current variation with minimum change in voltage.

Abnormal Glow—A region of operation that is arrived at by increasing the lamp current beyond the normal glow region (Point E, Fig. 1-2).

Extinguishing Voltage—The voltage at which a lamp will cease to glow.

Differential Voltage—The difference between the breakdown voltage and maintaining voltage.

Ionization Time—The time required for a lamp to enter normal glow after application of a voltage that is in excess of the breakdown voltage.

This time may be well under 50 μsec if the applied voltage is 30 percent greater than the breakdown voltage.

Deionization Time—Definition 1: The time it take a lamp to return to its static breakdown voltage after current ceases to flow.

Definition 2: In a dc circuit, if a lamp is extinguished by a rectangular pulse, it is the time which must elapse before 90 percent of the original breakdown voltage can be reapplied and still not cause breakdown.

The first definition is used for most circuit applications, but if higher frequency oscillators and counters are being considered, the latter definition would be more useful.

Deionization time is affected by tube construction, the magnitude of the conduction current, and most of all by the amplitude of the extinguishing voltage.

Dark Effect—The effect that light has on breakdown voltage. Higher ambient light levels produce lower breakdown voltages. If a lamp is to be operated in total darkness, it is usually necessary to simulate ambient light by the addition of a small amount of radioactivity.

Standing Rise—The rise in breakdown voltage that some lamps incur after extended periods of storage. This is mainly caused by the glass and other internal solids releasing gas molecules.

Negative Resistance—An increase in current caused by a decrease in voltage. This can be noted on the characteristic curve of most lamps. In Fig. 1-2 this corresponds to that part of the curve between points C and D.

Design Current—The value of operating current upon which the end-of-life figures are based.

Transmission Time—The time required for an input level change to appear on the output of a lamp already in the conducting state. This is usually less than 8 μsec and is a function of the conducting current.

End-of-Life—A glow lamp that is used for its light output is said to have reached its end-of-life when the light output falls to 50 percent of its original value. If a lamp is used as a circuit component, the end-of-life occurs when the characteristics fall out of specifications. Lamps operated on ac have longer life figures due to shorter duty cycle.

Aging—The process of operating a new lamp at an increased current level for periods in excess of 24 hours in order to stabilize its characteristics.

The aging process varies for different lamps and is usually done in the factory. However, aging is not required for all lamp applications.

Sputtering—A phenomena that occurs when lamps are operated at higher currents. Certain quantities of the metal cathode material will vaporize, and when the vapor comes in contact with the cooler glass envelope, it solidifies. This thin film of sputtered metal is opaque and restricts light output, but it also increases electrical stability.

Polarization—A lamp is said to be polarized when its characteristics change with a reversal of polarity. Lamps that are aged or operated on dc exhibit this effect. Lamps that are aged on dc are coded to designate the anode or positive terminal.

Work Function—A measure of the ability of a material to give up electrons. Molybdenum is said to have a lower work function than nickel because it releases more electrons for a given voltage.

PHYSICAL CONSIDERATIONS

Gases

Gases—The inert or "rare" gases are used in the manufacture of glow lamps. Neon is the basic gas, but other gases may be used in mixtures to achieve special results.

Neon—The basic glow-lamp gas, noted for its high light output, and low breakdown and maintaining voltage. The characteristic color of the neon glow is red-orange.

Helium—A low breakdown, low light-output gas that may be mixed with neon to produce a specific value of breakdown or maintaining voltage.

Argon—This gas has a higher breakdown voltage, but if as little as 0.1 percent is added to neon, the breakdown voltage for the mixture is lower than for either gas alone. Pure argon is used as an ultraviolet light source.

Xenon—A high-breakdown gas that is used to produce a brilliant white light and is also used as a noise source. This gas has not found much application in miniature gas tubes.

Krypton—A gas with qualities similar to argon. It is added to neon to raise the breakdown and maintaining voltages, and is an excellent source of ultraviolet light.

Krypton 85—A radioactive isotope of krypton that is added to neon or other gases to provide partial ionization and stability to compensate for the dark effect.

Electrodes

Material—Nickel and molybdenum are the two common electrode metals. Molybdenum tends to lower the breakdown and maintaining voltage and can carry higher currents.

Spacing—Increased spacing between the electrodes increases breakdown voltage but has little effect on the maintaining voltage.

Coating—Emissive materials such as barium and strontium are used to coat the electrodes and allow the cathode to give up electrons more freely. This results in lower breakdown voltages and higher, more uniform light output. Gas tubes that use emissive material will change their characteristics with time. NE2 lamps are in this class.

Size—The size of an electrode will determine its light radiating area and current carrying ability.

Pressure

Increasing the internal gas pressure will raise the breakdown voltage of the lamp without major changes in the maintaining voltage. Lamps with a high differential between breakdown and maintaining voltage are useful as counters, high power oscillators, and energy transfer diodes.

In general, high-pressure gas tubes will exhibit poor light output and an unstable corona that results in voltage jumps and noise.

Temperature

Gas tubes have a negative temperature coefficient. Most indicator types will drop 50 mV in maintaining voltage for each Celsius (centigrade) degree of increase. Circuit component types and regulators may have a figure as low as −2 mV per degree C.

Radiation

The electrical characteristics, the electrodes, and the gas are relatively unaffected by gamma radiation. The glass, however, will darken and become brittle.

Rf radiation or a strong ac field will ionize the gas directly.

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Indicators

The miniature glow lamp has found widespread use as an indicator in electronic, commercial, and industrial equipment. A brief comparison to the incandescent type is offered to help explain both their popularity and their limitations.

INCANDESCENT VERSUS NEON

A specific lamp must be indicated if the ratings are going to be based on such items as temperature, vibration, shock, or humidity. Both types have indicators that perform well in these areas.

The tungsten filament is basically a low-voltage, high-current device, while the neon requires higher voltages and smaller currents. The efficiency figures of each vary widely, but in comparing the NE2H with CM8-806, which is a Chicago Miniature, 100,000 hour, tungsten-filament lamp, the efficiencies were found to be equal at 2.2 lumens per watt. If life expectancy is plotted against cost, the neon lamp is unparalleled. Even the most economical glow lamps have a life of 20,000 hours.

As a result of efforts to improve the tungsten life figures, several lines of miniature incandescents have appeared on the market with life expectancies of 20, 50, and 100 thousand hours. These lamps are relatively expensive and the life figures are based on "burnout." Since neons do not burn out, their life is calculated on other factors, such as tube darkening. (Envelope darkening can occur with both types.)

When a high-brightness neon is operated at half its design current, it will give over a million hours of use before darkening restricts its light output by 50 percent.

Neon lamps perform poorly at altitudes higher than 70,000 feet, where the lower atmospheric pressures encourage external corona and arcing.

The tungsten-filament lamp can produce high light intensities over a wide range of light frequencies. Filters of paint, plastic, etc., can be used to "color" the incandescent light, but this cannot be done to any usable degree with neon. Colors such as green, seen in outdoor neon signs, are the result of phosphors or a combination of helium and mercury vapor used with noviol or uranium glass. Helium and mercury vapor are usually considered unsuitable for use in miniature lamps.

As a result of the preceding comparison, it would be reasonable to assume that cost and life expectancy are the main reasons for selecting a neon as an indicator. Actually, all but a very few glow lamps can be called indicators because they emit light. There are, however, three basic types that are designed specifically for their light radiating ability.

STANDARD BRIGHTNESS

The NE2 is in this category and is the most popular of all the lamps. It has the lowest current requirements and exhibits a gradual change in characteristics with extended operation. The light output falls off at a uniform rate, due to sputtering, and the breakdown voltage rises slightly.

If you double the design current, you will double the light output, but its life expectancy should be divided by 8. The inverse holds true if design current is halved. Light output will be halved, but life figures can be multiplied by 8.

HIGH BRIGHTNESS

The NE2H is a lamp of this type and differs from the standard-brightness variety in several ways. It has a higher initial breakdown voltage, and when it reaches its end of life, the breakdown rises to a point that is higher than the peak line voltage (160V), and the lamp will no longer ignite.

The high-brightness lamp has 10 times the light output of a standard brightness unit and can carry more current. It maintains a fairly steady characteristic until it reaches its end of life. The maintaining voltage of this type of lamp is unstable. "Voltage jumps" and high noise levels are not uncommon, so this restricts its use as a circuit element.

As in the case of the standard-brightness lamp, if the design current is doubled or halved, the light output will also be doubled or halved, but the life figures will have to be multiplied or divided by 64 instead of 8.

ULTRAVIOLET

Gas tubes filled with argon fall into this category. They emit a deep blue light, and are used primarily for their color. Very little true ultraviolet radiation is able to penetrate the glass envelope so they are relatively safe to work with. The AR9 is an example of this type.

CONSTRUCTION

American and foreign companies have made efforts in recent years to change the physical design of the lamps, either for esthetic and space requirements or to increase the light output.

General Electric has a complete line of lamps that have formed tips instead of the standard drawn tip. These lamps not only look better but increase the light output when viewed end-on.

Tech-Neon, Signalite and GE all offer acid-frost lamps, which give a pleasing, uniform light output.

The British, French, Belgian, and Italian companies offer some lamps that are exotic by American standards. Most of these companies manufacture a line of lamps with a lens that is an integral part of the envelope. They also produce lamps with axial leads. One European manufacturer even produces a lamp that glows green. This is done by coating the inside with green phosphor and filling the envelope with argon. All of these lamps are expensive, and for that reason the American companies hesitate to produce them. There is also a major glow-lamp manufacturer in Canada that offers essentially the same products as the American companies.

The recent trend by many equipment manufacturers has been to use lamps that have been encapsulated in plastic along with the ballast or series resistor. This improves the appearance and greatly simplifies mounting. Many domestic and foreign companies, including Japanese, offer this type of indicator.

PRACTICAL INDICATORS

Some lamps come with a series or current-limiting resistor attached, but, if not, its value may be calculated. The glow lamp specification sheet will recommend a particular value for standard line voltages, but the designer may have a wide range of voltages to contend with.

Example: It is necessary to have a visual indication that power has been supplied to the circuit in Fig. 2-1. For illustra-

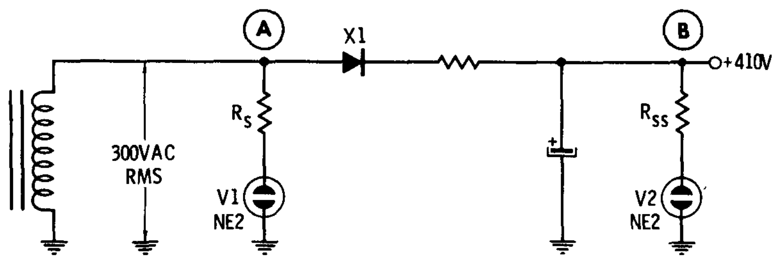


Fig. 2-1. Neon indicators in a power supply.

tion, we chose point A and B as possible locations. The formula for both resistors is the same, but they are handled differently. The formula is:

$$R_s = \frac{E_{app} - E_{maint}}{I_{design}}$$

In other words the resistor has to drop the difference between the applied voltage and the maintaining voltage of the lamp at the design current.

Solution for I1:

$$R_s = \frac{300 - 39}{.0005}$$

$$R_s = 510k$$

Solution for I2:

$$R_{ss} = \frac{410 - 55}{.0005}$$

$$R_{ss} = 680k$$

Resistors are to the closest 10% EIA value.

Since I1 is in an ac circuit, rms values were used. Location B will provide a positive indication of B+ but only one electrode will glow. The total measured light output from both lamps is approximately equal.

The indicator in Fig. 2-2 will ionize only when E_{app} or supply voltage has reached 150 Vdc. The value of R_s is solved in the usual manner and forms part of a voltage divider with R_d. R_d was selected to provide the maximum rated breakdown voltage (90) at point A, when the supply reaches 150 volts. Greater accuracy can be had if the exact value of breakdown is known. I1 in Fig. 2-3 will give a visible indication of voltages throughout the range shown. The circuit functions in the usual manner down to about 500V at which point C, I1, and R_s will switch to relaxation oscillations and the lamp will flash brightly.

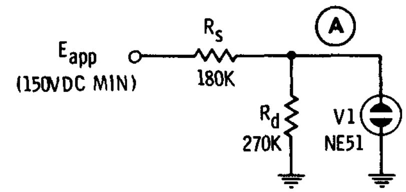


Fig. 2-2. Voltage level indicator.

Fig. 2-3. Wide-range indicator.

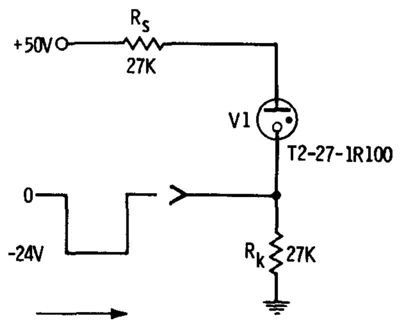


Fig. 2-4. Nonlatching indicator.

The simple nonlatching circuit in Fig. 2-4 is useful when operation is required from a low voltage source (24V), such as a transistor collector. The value of the supply voltage is less than the lamp's lowest rated extinguishing voltage. A negative 24-volt pulse is added algebraically to the supply voltage to total 74 volts, which equals the highest rated breakdown voltage for the lamp. The lamp can remain on only when the negative pulse is present on the cathode.

Fig. 2-5 shows another nonlatching circuit that features use of low voltage transistors (18V) and even lower control voltages (+1V). Q1 is normally saturated so the 62V developed by the zener diode is not enough to ionize the 5AGA. When Q1 is cut off by a +1V pulse or by grounding the base, the −18V

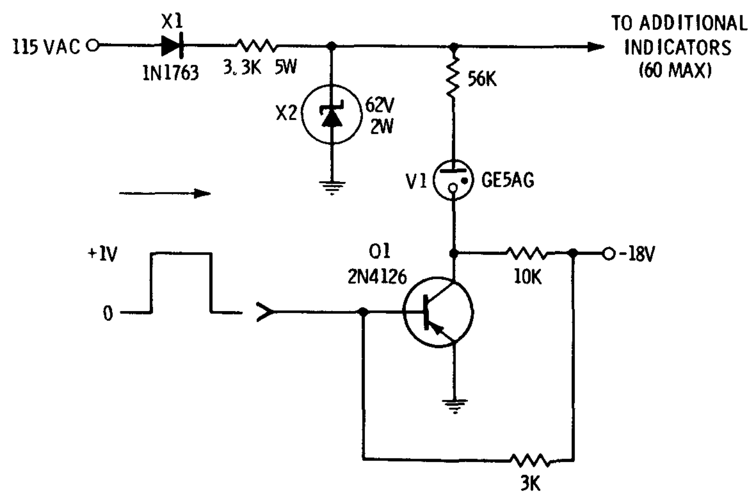
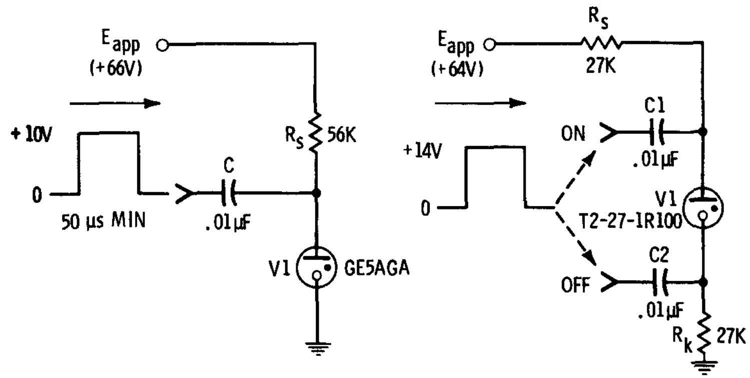


Fig. 2-5. Nonlatching indicators using low-voltage transistors.

will be felt at the cathode of the lamp through the 10k resistor. This voltage which is added to the zener voltage should exceed the lamp's maximum rated firing voltage. The lamp is extinguished 60 times a second by the ac input so there is no need for a separate turn-off circuit.

The power supply voltages in Fig. 2-6 are selected to be lower than the minimum rated breakdown voltage and higher than the maximum rated maintaining voltage. The input pulse is added to E_{app} to cause breakdown and the supply will support ionization at the maintaining voltage. Fig. 2-6B illustrates how the same principle may be used to extinguish the lamp.



(A) ON action only. (B) ON-OFF action.

Fig. 2-6. Latching indicators, low-voltage drive.

Availability of high-quality, low-leakage transistors at prices considerably less than a dollar has made direct operation of neon lamps economically practical.

The transistor selected for the type of circuit shown in Fig. 2-7 must be able to withstand voltages that are equal to E_{app} minus the lowest rated maintaining voltage of the neon lamp. The 1.2K resistor prevents false starting by minimizing leakage effects.

In computer technology and other related fields, it is sometimes necessary to have a visual indication of a very short pulse. Since pulses shorter than 50 μs rarely can cause ionization, special circuits are required. The circuit in Fig. 2-8 will respond to pulses shorter than 1 μs and cause the neon lamp to glow. The incoming pulse charges C through the dynamic

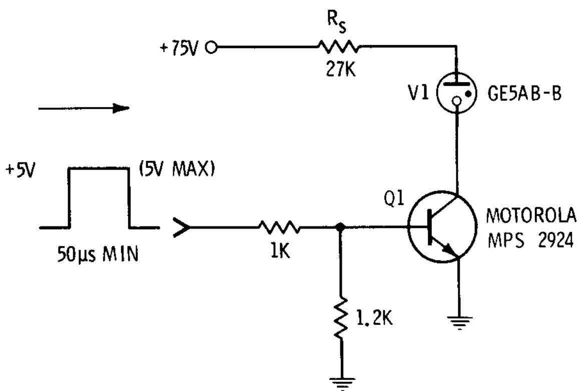


Fig. 2-7. Direct transistor operation.

impedance (50Ω) of the 1N38. This switches the 2N337 on and fires the neon lamp. Since C cannot discharge through the diode, the transistor will remain on until C discharges through R_k and Q1. Increasing the value of C will allow the lamp to remain on longer but will decrease the input sensitivity.

Five different conditions may be represented by a single lamp as shown in Fig. 2-9. In position 4, R_o is too large to support ionization so RC oscillations will result from the charging and discharging of the .01 μF capacitor. Fig. 2-10A shows a circuit that will indicate a blown line fuse and Fig. 2-10B will indicate a good fuse.

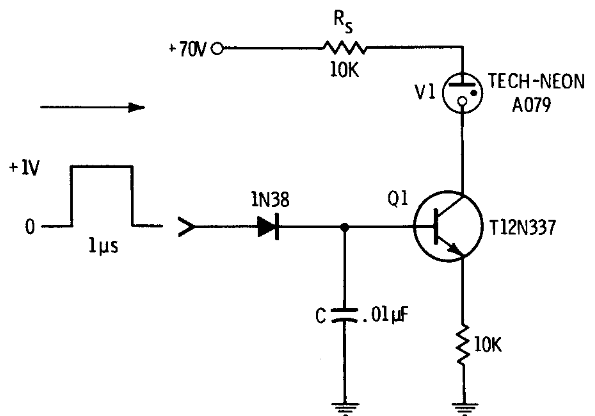


Fig. 2-8. Short-pulse indicator.

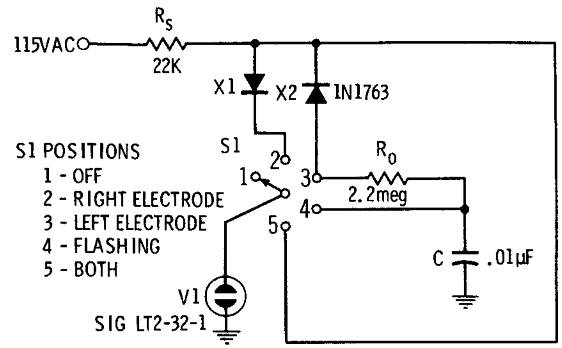
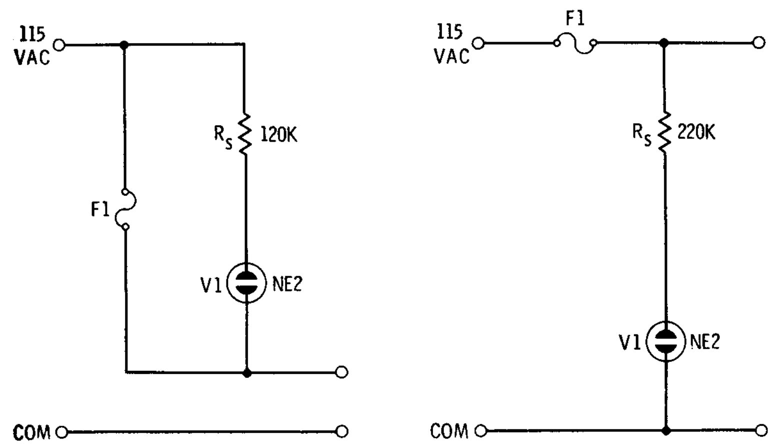


Fig. 2-9. Five-state indicator.



(A) Blown-fuse indicator.

(B) Good-fuse indicator.

Fig. 2-10. Fuse indicators.

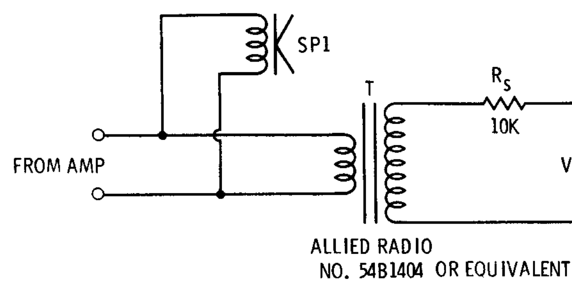


Fig. 2-11. Speaker operation indicator.

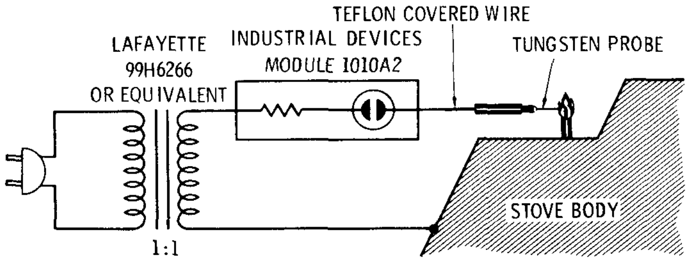


Fig. 2-12. Pilot flame monitor.

In remote or multiple speaker installations, it is sometimes desirable to have a visible indication of operation. A small audio output transformer, with the low impedance side connected to the speaker terminals as in Fig. 2-11, will step up the small audio voltage to a value that will operate the neon lamp. The transformer is not critical, but the brightness of the lamp will be affected by the Z or turns ratio, as well as the amplifier output.

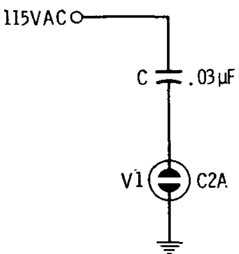


Fig. 2-13. High-efficiency one-million hour circuit.

The novel circuit in Fig. 2-12 utilizes the flame as a high Z conductor to keep the neon lamp lit. When the pilot light goes out, the random concentrations of cold gas will act as an open circuit.

When extremely long life and low power dissipation are required, the circuit in Fig. 2-13 might be considered. Instead of resistance, X_c is used to limit the current to the desired value. In this example the C2A (NE2H) is operated at half its design current, so its life figures are increased by a factor of 64.

3

Voltage Regulators and References

DESCRIPTION

Recent technology and manufacturing techniques have produced a miniature voltage regulator that has the physical dimensions of other neon lamps, but is capable of current variation over ranges as wide as 15 mA. Its maintaining voltage will change less than one volt, and life figures are in excess of 20,000 hours. These gas diodes can replace the older 7- and 8-pin "tube" type regulators in all but a few applications. They are ideally suited for printed circuit boards, encapsulation, and other modern fabrication methods.

APPLICATION

In many cases, the same gas tube may be used both as a regulator and as a reference. The GE 5AB lamp, for instance, is used extensively as a voltage reference, but also provides excellent regulation of vacuum-tube screen-grid voltages. This lamp is simply an aged NE2 with a small amount of radioactivity added for the reduction of the "dark effect." The electrodes have an oxide coating and accordingly the lamp's characteristics will change slightly with use. This effect can be disregarded in many applications such as the reference voltage in series-regulated vacuum-tube power supplies, where gradual change over a period of months can be tolerated.

On the other hand, applications such as voltage calibrators and unmanned communication sites may require not only good regulation, but a specific voltage value over extended periods of time.

REGULATOR CONSTRUCTION

The high-current regulators achieve their characteristics by several means. The electrodes are made longer and larger in diameter to increase the current carrying ability. European manufacturers use an anode that is somewhat smaller than the cathode. American firms favor identical electrodes and there appears to be some controversy as to which one produces the best results.

Both designs utilize electrodes that can carry current loads in excess of 60 mA. The limiting factors are the bulb temperature and the point at which the tube will arc.

The electrodes of a high-current regulator are pure metal and contain no oxide coatings. This is a necessary condition for a wide current range and long-term stability. They also are aged at higher currents for longer periods than the reference type diode.

Extended aging is needed to sputter or vaporize the cathode surface metal that may have trapped gas atoms during manufacture. This process, sometimes referred to as "cleaning up," is essential for reliable operation. These gas tubes can be recognized by their characteristic black or silver appearance, which is caused by the deposit of sputtered cathode material on the wall of the lamp.

CIRCUIT DESIGN CONSIDERATIONS

Since it is not the purpose of this book to present an exacting mathematical analysis of neon-lamp circuits, certain assumptions have been made that are not necessarily so.

The formulas, for instance, have omitted resistor tolerances, temperature coefficients, and the dynamic impedance of the conducting gas tube. All formulas have been reduced to the simplest possible form and, in some cases, expressed literally

rather than mathematically. Selection of resistors was done by choosing the standard EIA value that was closest to the calculated value.

PRACTICAL REGULATOR AND REFERENCE CIRCUITS

The circuit in Fig. 3-1 is the basic and most widely used method of obtaining a reference voltage. The supply voltage (E_{app}), must exceed the rated breakdown voltage and is applied to V1 through the current-limiting resistor R_s. This causes the lamp to ionize and its characteristic maintaining voltage (E_{maint}) will appear at point A. Once the correct tube has been selected, only the value of series resistance must be calculated.

$$R_s = \frac{E_{app} - E_{maint}}{I_{design}}$$

The maintaining voltage and the design current can readily be obtained from the specifications sheet.

The foregoing formula will hold true as long as R_x remains relatively high. It can be seen that R_x forms a voltage divider with R_s, and under initial conditions breakdown or "firing" voltage must appear at point A or V1 will not ionize. Once the gas tube conducts, the value of R_x must remain high enough to sustain ionization. Voltage-divider action is still present at point A and if this voltage drops below the maintaining voltage the lamp will be extinguished. In other words, if the circuit in Fig. 3-1 is used, the load current cannot exceed the design current.

Fig. 3-2 illustrates a circuit that compensates for unusually wide variations of input voltage. V1 is rated to regulate over a 15 mA range. R_s was chosen to cause 1 mA to flow at +140 V. The minimum load resistance is calculated by determining

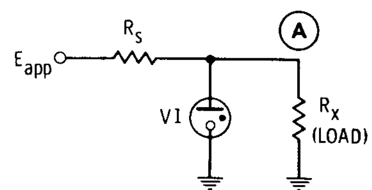


Fig. 3-1. Basic voltage-reference circuit.

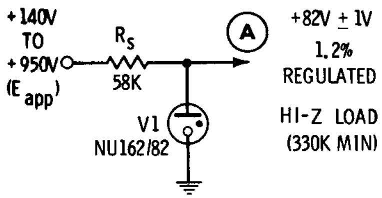


Fig. 3-2. Voltage regulator for input variations.

what value R, in series with R_s, is necessary to cause the maximum rated E_{bkdwn} (118V) to appear at point A when the minimum voltage (+140V) is applied.

It can be seen in Fig. 3-3 that the same gas tube can be used to compensate for changing load conditions. If the NU 162/82 regulator is operated at its maximum rated current, a regulated 0-5.5 mA output is realized. Actually this circuit would be capable of a regulated 15 mA output, except that under initial conditions the value of R_x would be so low as to prevent breakdown voltage from appearing at point A.

The simple circuit in Fig. 3-4 compensates for both input and output voltage variations. It represents a compromise of the circuits shown in Figs. 3-2 and 3-3.

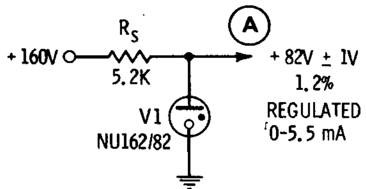


Fig. 3-3. Voltage regulator for load variations.

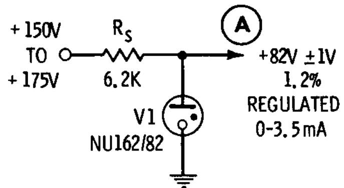


Fig. 3-4. General-purpose voltage regulator.

The voltage divider limitations of Figs. 3-2, 3-3, and 3-4 are overcome by the addition of a replacement-grade silicon diode X1, and a "firing" resistor (R_f), as shown in Fig. 3-5.

Under initial conditions, the load may draw 15 mA and the voltage at point A will never reach breakdown. This "low" voltage is isolated from the gas tube by diode X1, so that V1 may be ionized by the current through R_f. After ionization point A will be positive with respect to point B, so X1 will conduct and operation will be the same as in previous circuits. The value of R_f is calculated in the same manner as R_s except that the value of I is small. Current through R_f must be large

enough to sustain ionization, but can be considerably smaller than the .5 mA arbitrarily chosen in Fig. 3-5.

A stable higher voltage reference is achieved in Fig. 3-6 by operating two gas tubes in series. The reference voltage is the sum of the two maintaining voltages and E_{app} must exceed the sum of the two breakdown voltages.

Fig. 3-7 illustrates a useful circuit that produces a high reference voltage with relatively small supply voltage. In this instance, the series breakdown voltages exceed E_{app}. E_{app} may drop as low as +130V and still deliver a precise 124-volt reference. This is done by diode isolation and shunt starting as in Fig. 3-5. R_f fires V2 and R_{ff} fires V1. R_s is calculated as in previous circuits.

The 300-volt regulator shown in Fig. 3-8 can be contained in a space the size of a 20-watt resistor and can deliver 3.6 watts of power to the load. Since the total breakdown of the three gas tubes in series equals 450 volts, R_f and R_{ff} must be used to initiate ionization. R_f fires V3 and R_{ff} fires V1. V2 will then ionize because of the potential difference between points B and C.

Parallel starting can be used for any number of tubes. Fig. 3-9 shows two methods for an identical 4-tube supply. In Fig. 3-9A, the use of a single resistor, R_f, enables the minimum applied voltage to be reduced from 600V to 500V. Two additional resistors, R_f and R_{ff} in Fig. 3-9B, further reduce the voltage requirements to 450V. Fig. 3-9B is usually the preferred method, as the starting resistors are ¼-watt 20-percent components, and the main savings are realized in applied power and the power dissipated by R_s.

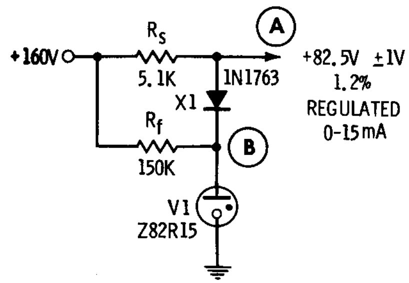


Fig. 3-5. Shunt starting regulator with diode isolation.

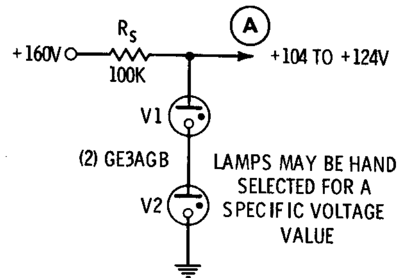


Fig. 3-6. Series starting, series operation voltage reference.

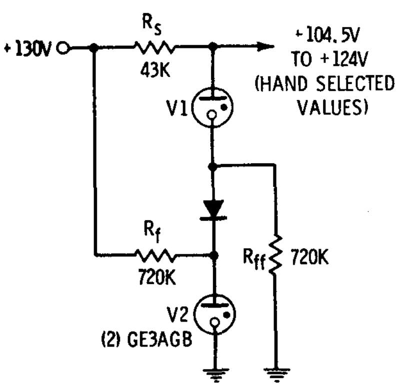


Fig. 3-7. Shunt starting, series operation voltage reference.

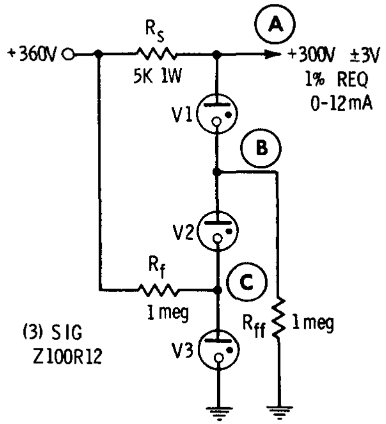
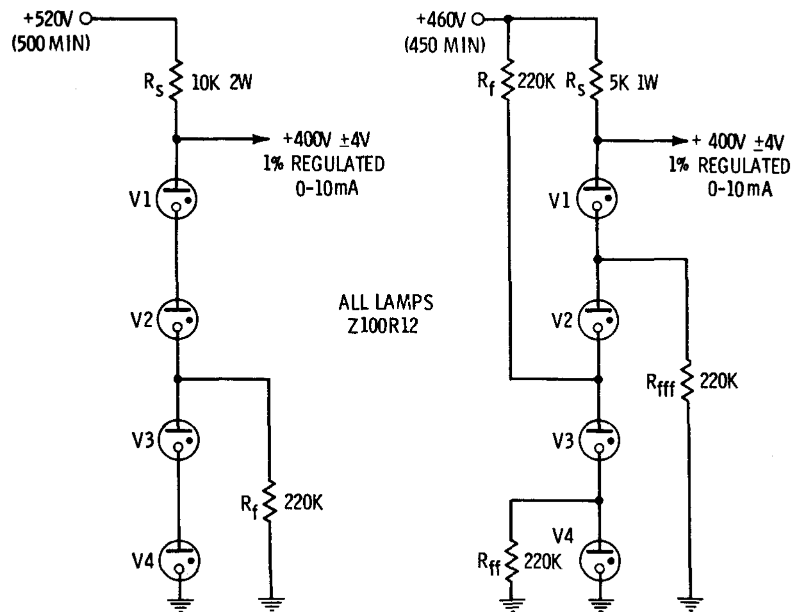


Fig. 3-8. Shunt starting, series operation high-voltage regulator.

Small capacitors may also be used in place of the firing resistors. "Capacitive starting" is usually more expensive and requires more space, but these circuits dissipate less heat and require less current.



(A) Using one shunt resistor.

(B) Using three shunt resistors.

Fig. 3-9. Shunt starting, series operation four-tube regulators.

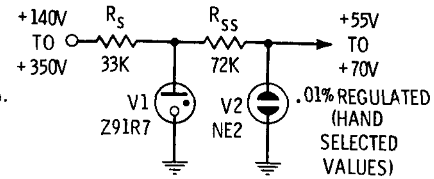
A cascaded reference is used when an extreme degree of regulation is required. In Fig. 3-10 a change of 100V at the source will produce a change of less than 1 part in 10,000 at the output. The maintaining voltage (E_{maint}) of V1 must exceed the E_{bkdwn} of V2. R_s and R_{ss} are found by the formulas:

$$R_s = \frac{E_{app}(min) - E_{maint}(V1)}{I(V1min) + I(V2)}$$

$$R_{ss} = \frac{E_{maint}(V1) - E_{maint}(V2)}{I(V2)}$$

V1 may be a more economical lamp and still provide a reliable circuit.

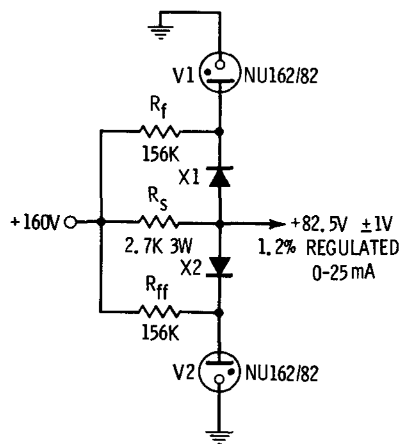
Fig. 3-10. High-stability cascaded reference.



The maintaining voltages of V1 and V2 in Fig. 3-11 are close enough to make parallel operation practical. Diodes X1 and X2 isolate the load from R_f and R_{ff} for initial ionization and also serve to isolate V1 from V2. The value of R_s is found by treating V1 and 2 as one gas diode with twice the current rating. X1 and X2 are replacement-grade silicon diodes.

The novel circuit shown in Fig. 3-12 may be used to establish precise low-voltage references. The output voltage is the

Fig. 3-11. High-current parallel regulator.



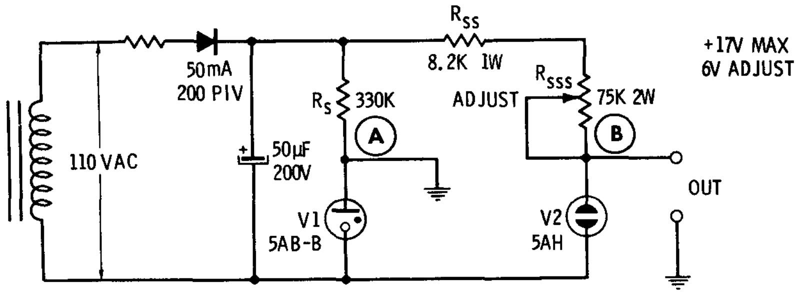


Fig. 3-12. Differential low-voltage reference.

difference between the maintaining voltages at points A and B.

The high-current regulator in Fig. 3-13 appears to be a conventional shunt starting circuit, but a closer look at the values and performance figures will indicate a different mode of operation.

Most circuit designers will agree that the load current should rarely exceed the rated tube current and this premise is true if you do not place any limitation on the minimum amount of current that may be drawn by the load. If the "zener diode" approach is used, the load current may be many times the tube's maximum rated value.

This is possible if we consider that when a gas diode regulator is rated at 12 mA, that means it will stay within specification over this range. It does not mean that 12 mA will be delivered to the load. Tube V1 is still regulating 100V ± 1V over a 12-mA range, but at a 110-mA level. If the supply voltage is held at a constant 160V, the load may vary between 100 to 120 mA and still be within 2 percent of 100V. The important limitation of this circuit is that there is a minimum current the load must draw. Fuse F1 is included to protect V1, if the load is reduced or removed.

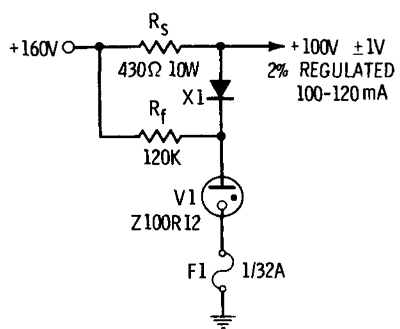


Fig. 3-13. High-current, high-voltage regulator.

Design procedure for Fig. 3-13:

1. Select regulator tube after determining the maintaining voltage required and range of regulation.
2. Let R_f be 120K unless the supply voltage is over 200 volts, then double or triple this value. (Not critical.)
3. Let X1 be any 400-PIV, 200-mA diode or better.
4. Find $I_t = I_x + I\ (V1)$

   Find $R_t = \dfrac{E_{app}}{I_t}$

   Find $R_x = \dfrac{E_{maint}}{I_x}$

Solution:

$$R_s = R_t - R_x$$

where,

E_{app} is the supply voltage,
I_x is the minimum current required by load,
I(V1) is the maximum rated lamp current,
R_x is the load resistance,
R_t is the total circuit resistance,
I_t is the total circuit current,
R_s is the series limiting resistor,
E_{maint} is the maintaining voltage.

Fig. 3-14 is one variation of a popular circuit. The wide variety of screen-grid voltages and currents makes a standard circuit impractical. The voltage needed at point A is usually high enough to require two or more lamps in series. R_s, V1, and V2 comprise the regulator system, but any of the systems previously discussed may be used. I_{design} is the maximum screen-grid current.

Algebraic addition can provide a regulated low-voltage, wide-temperature-range supply as shown in Fig. 3-15. The negative 100 volts developed by V1 is added to the positive 82 volts of V2 at point A and the result is a negative 18 volts. V1 is rated at 10 mA but R_s had to be increased to 18K in order to sustain ionization of V2. C1 is an example of capacitive starting and is included to ensure that point A will reach

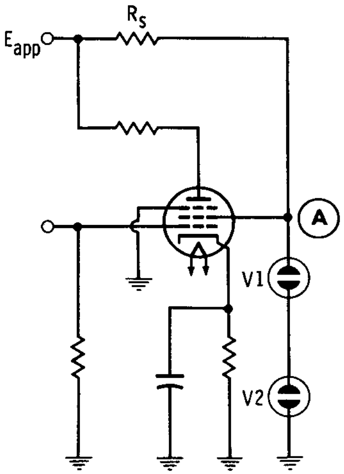


Fig. 3-14. Vacuum-tube screen-grid regulator.

the breakdown voltage of V2. The filter capacitors may be lower in value and if 220 Vac is used, C1 may be omitted, R_s and R_{ss} may be calculated for full tube current, and regulation will occur over a 10 mA range.

The circuit in Fig. 3-15 has one advantage over other low-voltage types in that it has a common ground. In all differential or algebraic circuits, the tolerances will add, so the final performance figures will be half that for a single tube.

V1 in Fig. 3-16 is a voltage reference for V2. In this series-pass voltage regulator, current carrying ability and regulation are the prime considerations—an AO57B would be a suitable

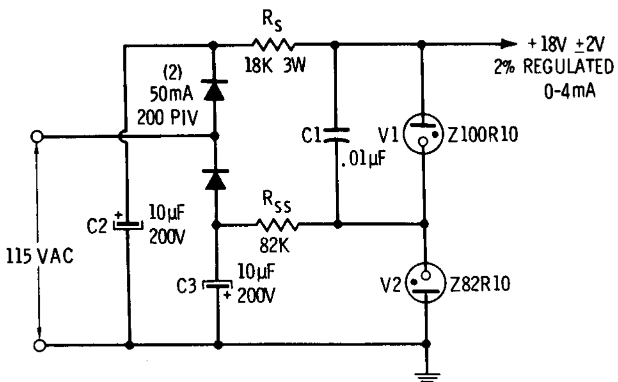


Fig. 3-15. Algebraic low-voltage regulator.

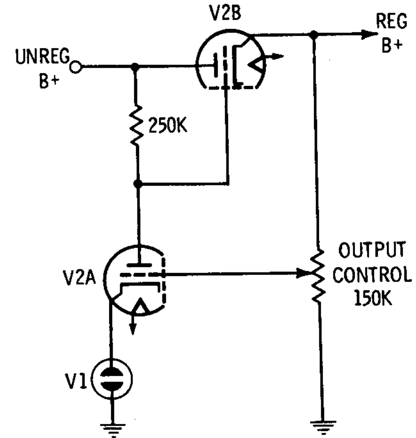


Fig. 3-16. Series-pass regulated reference.

choice. The maintaining voltage of V1 will determine the low-voltage limits of the regulator. V2 can be any miniature dual-triode that meets voltage and current requirements.

High voltage and high current are both available from the circuit illustrated in Fig. 3-17. This circuit can be constructed for less than \$2.00 at present list prices and is physically small. If better regulation for input variations is required, the T2-32-1 lamps should be pre-aged at 10 mA for 24 hours. The sum of the two maintaining voltages minus the junction drop (0.6V) will determine the exact output voltage.

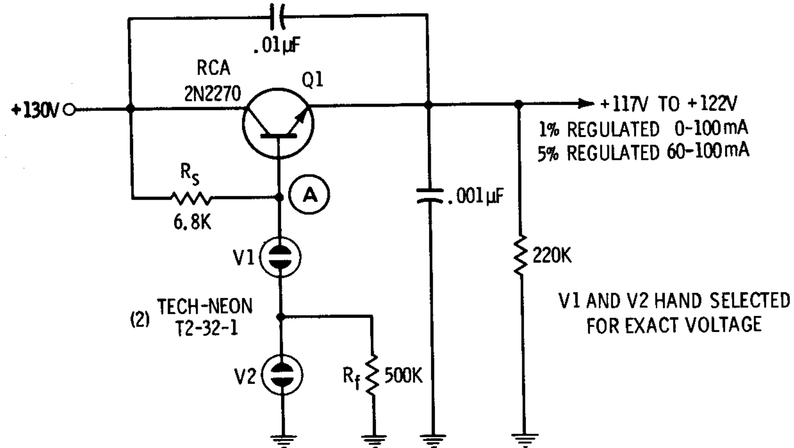


Fig. 3-17. Transistorized series voltage regulator.

T4½ to S14 Gas Lamps

Designation NE	USAS	Other	Bulb Type	DC B'kdown Volts	NOTES	DC Maint. Volts	NOTES	Exting. Volts	NOTES	Des. I mA.	Life Avg. Hours	NOTES	M.O.L. in.	Base	Max. Bulb Dia.	Notes
NE7	B4A		T-4 1/2	70 avg.	13	59 avg.	13	---		2.	7,500	7	1 1/4	1 1/8" Wire	9/16"	
NE16		7AA	T-4 1/2	67- 87		53-65		---		1.5		66	1 1/2	DC Bayonet	9/16"	6, 66
NE17	B5A		T-4 1/2	70 avg.	13	59 avg.	13	---		2.	7,500	7	1 1/2	DC Bayonet	9/16"	
		LNE17	T-4 1/2	100-124		68-95		---		3.5	5,000	7	1 1/2	DC Bayonet	9/16"	8
NE21	B6A		T-4 1/2	70 avg.	13	59 avg.	13	---		2.	7,500	7	1 1/2	SC Bayonet	9/16"	
NE30	J5A		S-11	85 max.		---		---		12.	10,000	7	2 1/4	Med. Screw	1 3/8"	64, 67
NE30AO	J7A		S-11	85 max.		---		---		12.	10,000	7	2 1/4	Med. Screw	1 3/8"	67, 68
NE30R	J8A		S-11	85 max.		---		---		12.	10,000	7	2 1/4	Med. Screw	1 3/8"	67, 69
NE31	L9A		G-10	90 max.		---		---		12.	10,000	7	2 7/16	Cand. Skirted	1 1/4"	67
NE32	L5A		G-10	66 avg.	13	61 avg.	13	---		10.	3,000	2	2 1/8	DC Bayonet	1 1/4"	
NE34	R2A		S-14	90 max.		---		---		18.	10,000	7	3 1/2	Med. Screw	1 3/4"	64
NE34AO	R3A		S-14	90 max.		---		---		18.	10,000	7	3 1/2	Med. Screw	1 3/4"	64, 68
NE34R	R4A		S-14	90 max.		---		---		18.	10,000	7	3 1/2	Med. Screw	1 3/4"	64, 69
NE36	R5A		S-14	90 max.		---		---		18.	10,000	7	3 15/16	DC Bay. Skirted	1 3/4"	
NE40	R6A		S-14	90 max.		---		---		30.	10,000	7	3 1/2	Med. Screw	1 3/4"	64, 70
NE40AO	R7A		S-14	90 max.		---		---		30.	10,000	7	3 1/2	Med. Screw	1 3/4"	64, 68, 70
NE40R	R8A		S-14	90 max.		---		---		30.	10,000	7	3 1/2	Med. Screw	1 3/4"	64, 69, 70
NE42	R9A		S-14	90 max.		---		---		60.	10,000	7	3 15/16	DC Bay. Skirted	1 3/4"	
NE45	B7A		T-4 1/2	90 max.		---		---		2.	7,500	7	1 17/32	Cand. Screw	9/16"	64
		LNE45	T-4 1/2	100 max. ac		---		---		4.	5,000	7	1 17/32	Cand. Screw	9/16"	8, 64
NE47	B8A		T-4 1/2	81 avg.	13	69 avg.	13	---		2.	7,500	7	1 1/2	SC Bayonet	9/16"	
		LNE47	T-4 1/2	100 max. ac		---		---		4.	5,000	7	1 1/2	SC Bayonet	9/16"	8
NE48	B9A		T-4 1/2	81 avg.	13	67 avg.	13	---		1.5	1,000	2	1 1/2	DC Bayonet	9/16"	
		LNE48	T-4 1/2	120-142		80-90		---		4.	5,000	7	1 1/2	DC Bayonet	9/16"	8
NE49	F1A		T-4 1/2	90 max.		---		---		2.	7,500	7	1 3/4	Min. Bay. Skirted	9/16"	
NE50	B3A		T-3 1/4	90 max.		---	27	---		.3	15,000	7	1 3/16	Min. Bayonet	13/32"	6
NE51	B1A		T-3 1/4	90 max.		---	27	---		.3	15,000	7	1 3/16	Min. Bayonet	13/32"	
NE51A			T-3 1/4	90 max.		65-75		51 min.	49	.3	10,000	55	1 3/16	Min. Bayonet	13/32"	63
NE51B			T-3 1/4	80 max.		55-62		51 min.	49	.3	10,000	55	1 3/16	Min. Bayonet	13/32"	63
NE51C			T-3 1/4	90 max.		65-75		54 min.	49	.3	10,000	55	1 3/16	Min. Bayonet	13/32"	63
NE51H	B2A	LNE51	T-3 1/4	135 max.		---	24	---		1.2	25,000	7	1 3/16	Min. Bayonet	13/32"	8, 6
NE51S			T-3 1/4	64 avg.		55 avg.		50min.	1	.2	1,000	55	1 3/16	Min. Bayonet	13/32"	
NE54	F2A		T-4 1/2	90 max.		---		---		2.	7,500	7	1 1/4	1 1/8" Wire	9/16"	
NE56	J9A		S-11	85 max.		---		---		5.	10,000	7	2 1/4	Med. Screw	1 3/8"	65, 67
NE56AO	L2A		S-11	85 max.		---		---		5.	10,000	7	2 1/4	Med. Screw	1 3/8"	65, 67, 68
NE56R	L3A		S-11	85 max.		---		---		5.	10,000	7	2 1/4	Med. Screw	1 3/8"	65, 67, 69
NE57	F3A		T-4 1/2	85 max.		---		---		2.	7,500	7	1 17/32	Cand. Screw	9/16"	64, 67
		LNE57	T-4 1/2	100 max. ac		---		---		3.5	5,000	7	1 17/32	Cand. Screw	9/16"	8, 64
NE58	F4A		T-4 1/2	90 max.		---		---		2.	7,500	7	1 17/32	Cand. Screw	9/16"	65
NE66	F5A		T-4 1/2	90 max.		---		---		10.	25	7	1 17/32	Cand. Screw	9/16"	64
NE67		6AC	T-3 1/4	55- 90		56 avg.	13	---		.2	1,000	2	1 3/16	Min. Bayonet	13/32"	5
NE71	L7A		G-10	85 max.		---		---		12.	10,000	7	1.3	Med. Screw	1 1/4"	64
NE73	L8A		G-10	85 max.		---		---		12.	10,000	7	1.3	Med. Screw	1 1/4"	65
NE79	R1A		S-7	85 max.		---		---		12.	10,000	7	2	DC Bayonet	7/8"	
AR1	W1A		S-14	115 max.		---		---		18.	1,000	30	3 1/2	Med. Screw	1 3/4"	32, 64
AR2	W2A		S-14	115 max.		---		---		18.	1,000	30	3 15/16	DC Bay. Skirted	1 3/4"	32
AR3	J2A		T-4 1/2	115 max.		---		---		3.5	150	30	1 17/32	Cand. Screw	9/16"	32, 64
AR4	J3A		T-4 1/2	115 max.		---		---		3.5	150	30	1 1/2	DC Bayonet	9/16"	32
AR5			--	115 max.		---		---		3.5	2,000	7	1 7/16	Tel. Slide	--	32, 64, 71
AR6			--	115 max.		---		---		3.5	2,000	7	1 7/16	Tel. Slide	--	32
HA3	L4A		S-11	85 max.		---		---		12.	1,000	7	2 1/4	Med. Screw	1 3/8"	33, 64
HA7			T-3 1/4	90 max.		---		---		.3	1,000	31	1 3/16	Min. Bayonet	13/32"	33
HA8	J4A		T-4 1/2	90 max.		---		---		2.	5,000	7	1 1/2	DC Bayonet	9/16"	33
		LNE58	T-4 1/2	100 max. ac		---		---		4.	5,000		1 17/32	Cand. Screw	9/16"	65, 8