Chapter VI

VOLTAGE REGULATION AND REFERENCE

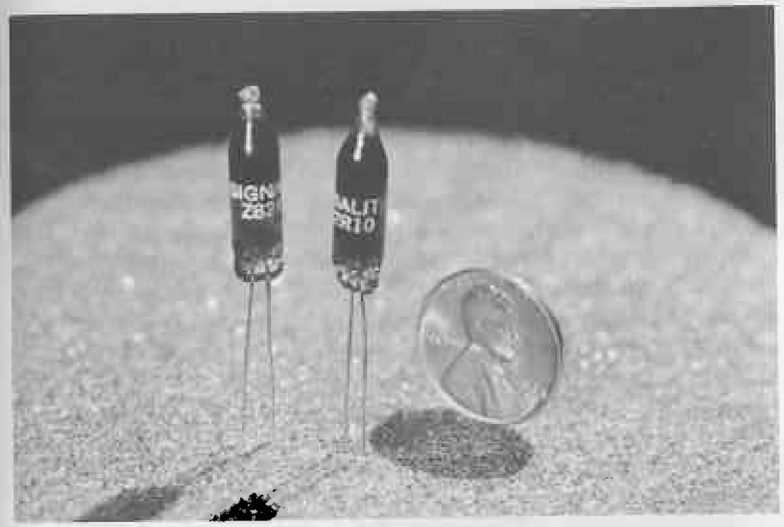
Most electronic systems being designed today use some form of voltage regulation to ensure circuit stability regardless of changes in load current or supply voltage. In addition to being a requisite for proper circuit operation, many times the circuit design can be simplified with resultant cost reductions if it is based on using a regulated supply. The degree of accuracy that the voltage regulator must provide varies considerably with the function performed by the electronics. As a result there are many different methods for providing the regulation available to the designer.

For many years neon glow lamps have been used to provide voltage regulation. This is because the characteristic maintaining voltage of these gas discharge tubes remains fairly constant over a relatively wide range of operating currents. Thus, they can absorb any reasonable voltage or current fluctuations occurring in normal operation, keeping the load voltage fairly constant.

For many applications, however, the degree of control required by the system and its components is so close that standard neon glow lamps, originally designed for indicator use, can not be used. Consequently, where regulation of voltage has to be held within limits less than ±5 volts, it has been necessary in the past to use other means such as complex circuitry for regulating the power supply itself or installing large gas tube regulators or zener diodes, all of which are fairly expensive.

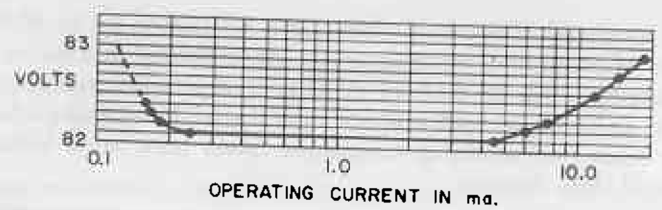
Recently, a major improvement was made in the design and manufacture of cold cathode tubes by Signalite whereby the breakdown and maintaining voltage characteristics could be held to extremely close tolerances. As a result a new family of cold cathode voltage regulators was evolved which could be used to provide regulation, predictably and reliably, to within ±0.5 volts. Compared to other methods for regulating voltage, these tubes are small, inexpensive, simple to install, rugged,

and longlived. They hold their close tolerances up to 30,000 hours of continuous operation, and are relatively insensitive to vibration, shock or thermal cycling. Temperature coefficients range as low as minus 2 millivolts per degree Centigrade which is at least two orders of magnitude lower than same voltage in solid state devices.



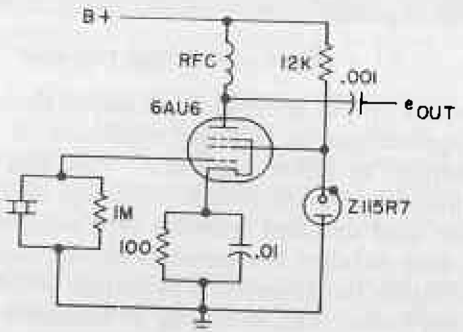
6-1 **Photo neon voltage regulators**

The precise output of these tubes makes them equally suitable for applications as voltage regulators or for reference voltage sources. In either application they can be depended upon to provide accurate output. Although in the past many people have used standard indicator type neon lamps for these purposes, their stability, low current carrying capacity, and degree of variation has imposed a limitation which has necessitated a compromise with precision or reliability. It should be noted that the tubes discussed in this chapter are not standard indicator lamps. The tubes under consideration here represent a whole new class of component which should be compared to the highest quality gas tube regulators, zener diodes and other methods for achieving close regulation. (See Figure 6-2)



6-2 Typical regulation curve for cold cathode voltage regulator

Many circuits in today's electronic equipment require the maintenance of precise voltage levels for proper operation. Variations in the E_B voltages can cause shifts in amplifier gain or can produce significant distortion. These changes in power supply voltage can result in malfunction of the equipment in less serious cases, or in catastrophic failure in the more severe cases. Lack of proper regulation in the screen voltage of a crystal oscillator, for example, can cause the frequency to drift in spite of the crystal control and can change the output level. A typical application for neon cold cathode voltage regulators for this application is shown in Figure 6-3.



6-3 Voltage regulation for crystal oscillator

One of the more common devices that is particularly sensitive to the stability of the power supply voltage is the photo-

multiplier.[1] Development in recent years of semiconductors and solid state technology has precipitated an unparalleled progress in photosensitive cathodes. This is because the semiconductor materials have a quantum efficiency in the visible spectrum that exceeds that of the metals by a significantly higher ratio, up to 30 percent for semiconductors versus up to 0.1 percent for metals.

Although photoelectric emission is a relatively efficient process on a per quantum basis, the primary photocurrent for low light levels is so small that secondary electron emission is necessary to provide current amplification high enough to be useful. In the photomultiplier tube photon energy impinging on a photocathode causes an emission of electrons. These are directed to a secondary emitting surface called a dynode. Impingement of the primary electron on the dynode causes 3 to 6 secondary electrons to be emitted per primary electron. These secondary electrons are directed to a second dynode where the process is repeated. Photomultiplier tubes may have as many as 14 dynodes. The last dynode in any case is followed by an anode which collects the electrons and provides the output signal.

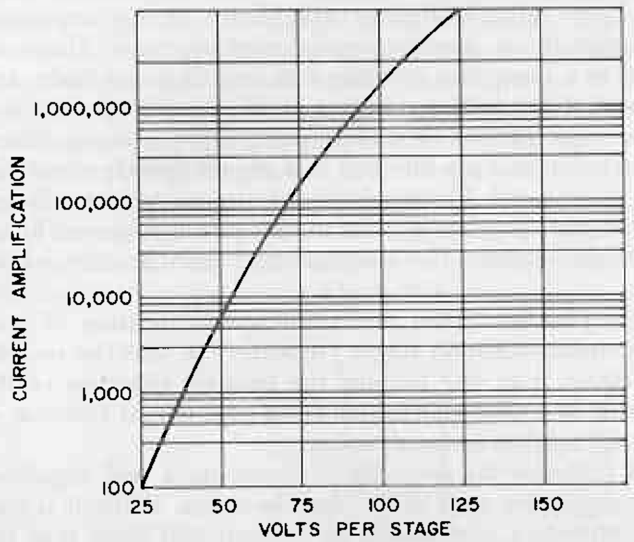
In the photomultiplier the coupling and focusing of multiple secondary-emission stages (dynodes) so that the secondary electrons from one become the primary electrons of the next result in a total gain which is an exponential function of the voltage applied to the dynodes.

This indicates the necessity of providing a well regulated voltage supply for each of the dynode stages. While it is possible to operate a photomultiplier so that each stage is at the voltage required for maximum secondary emission, such a condition would require in the vicinity of 500 volts per stage. The more conventional and practical approach is to operate each dynode at the voltage which produces the maximum gain per volt. While this voltage varies from tube to tube, it is generally

1. Bauman, Edward, Signalite Inc. — "A New Method for Precise Voltage Regulation for Use With Photomultipliers," *Signalite Application News*, Vol. 3, No. 2, and "Precise Voltage Regulation for Photomultipliers," *Electronic Industries*, February 1966.

in the vicinity of 70 to 100 volts. Thus, we see the need for closely regulated voltage supplies.

Depending on the method by which electrons are directed from dynode to dynode, photomultiplier structures may be classified as unfocused, electrostatically focused, and electromagnetically focused. In unfocused structures such as the grid, Venetian-blind and box types, electrons are simply accelerated from dynode to dynode by means of grids. In electrostatically focused photomultipliers a portion of each dynode serves to



6-4 **Variation of amplification factor with voltage per stage**

shape the electric field between dynodes in such a manner that secondary emission from one dynode is focused upon the optimum area of the following dynode. Mutually perpendicular electric and magnetic fields provide similar focusing of secondary electrons in electromagnetically focused photomultipliers.

A typical electrostatically focused photomultiplier with nine dynode stages before the collector anode may result in an overall gain of approximately one million at 100 volts per dynode stage. Variation of the amplification factor with the voltage per stage is shown in Figure 6-4 for a typical 931-A tube.

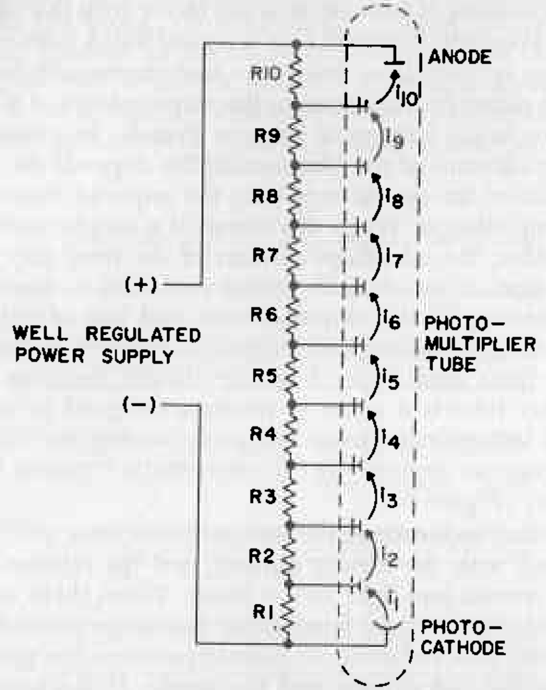
It can be seen from this curve that photomultiplier gain is affected either by variations in the stage voltage of all the dynodes, or in the voltage of just one dynode. In practice, then, the amplification of the photomultiplier depends on the characteristics of the circuit supplying the required inter-electrode operating voltages. When this circuit is a simple resistive voltage divider, the interstage currents of the tube may alter the distribution of the dynode voltages in such a manner as to cause limiting of the output current and loss of gain due to electrostatic defocusing and electron skipping of dynode stages.

The most usual type of voltage divider used for a photomultiplier tube is a series of resistors designed to divide the applied voltage equally or unequally among the various dynode stages as required by the electrostatic focusing system of the tube. (Figure 6-5)

In some applications the interstage currents are negligible compared with the divider current, and the relation between output current and light flux is linear. When there are significant variations in light level, these interstage currents are not negligible. This reduction in current produces the greatest loss between the last dynode and the anode. If the total applied voltage is maintained constant, the voltage lost in the output stages is redistributed among the preceding stages in a nonuniform manner. This causes unequal changes in the gain of the affected stages and may cause electrostatic defocusing, electron skipping of stages, and other effects.

Regulation of the voltage applied to the dynodes may be accomplished by either of the two following methods. One of these is to have a very tightly regulated power supply in the 1000 to 1500 volt class, and to have a high current bleeder so as to supply a low source impedance voltage to each dynode. The disadvantage of this method is that for most applications it is complex, costly and may present a severe maintenance problem.

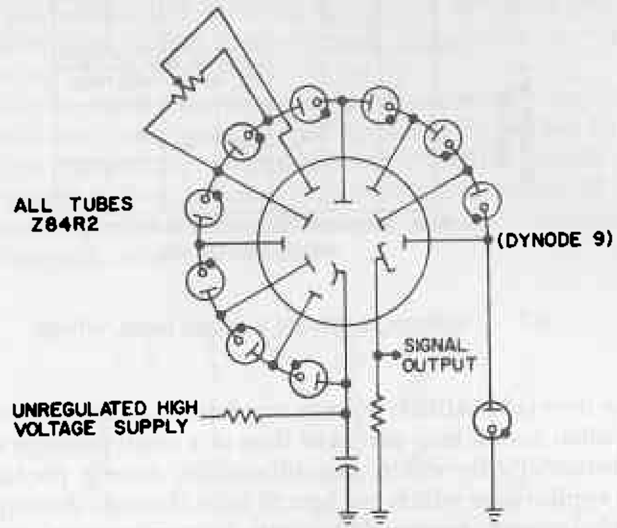
The second method is to regulate the voltage at each dynode. Several methods have been proposed and used to accomplish this. One is to use zener diodes, which exhibit good



6-5 **Resistive-type voltage divider for photomultiplier**

characteristics in regulation. However, they can only be used in applications where they will not be adversely affected by their poor temperature coefficients. Cost is also a factor in their selection because high voltage, close tolerance zeners tend to be prohibitively expensive.

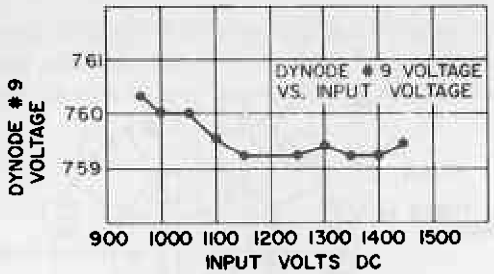
The use of large gas tube regulators for each dynode also tends to be expensive. Frequently, they do not exhibit a close enough regulation to maintain the dynode voltage within tight limits. Occasionally, they exhibit jump voltage characteristics. In some applications their size prohibits their use.



6-6 **Cold cathode voltage regulators with photomultiplier tube**

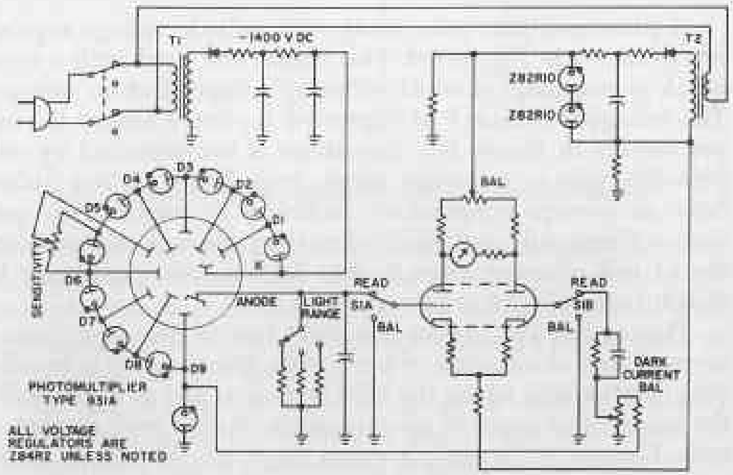
A photomultiplier tube using cold cathode voltage regulators is shown in Figure 6-6. This circuit was used with a type 931-A photomultiplier which is critically dependent on voltage. The voltage at dynode 9 of Figure 6-6 is plotted against the input voltage in Figure 6-7. Regulation is accomplished by ten Signalite voltage reference tubes, type Z84R2. These tubes have an average temperature coefficient of minus 2 mv per degree Centigrade and exhibit less than one volt change from the 84 volt reference from 0.15 to 2.0 ma. Life expectancy is 30,000 hours of continuous operation.

Photomultipliers are an important tool in detection, measurement and observation where human visual acuity is insufficient, particularly where the light level is so low as to preclude the use of other types of photosensitive devices such as photocells. Because in these applications the effects of noise or transit time can materially affect the required results, accurate regulation of voltages to the dynodes is of critical importance.



6-7 Voltage at dynode 9 versus input voltage

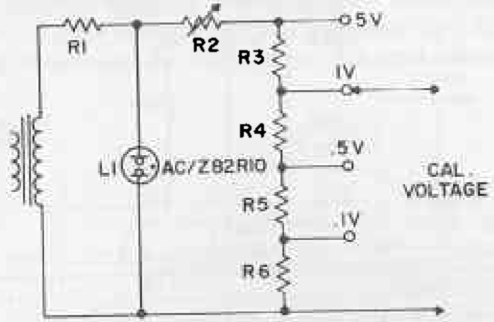
These new cold cathode voltage regulators can provide reliable regulation over a long period of time in a small package and at a substantially favorable cost differential. Among photomultiplier applications which can benefit from this new development are photometry, spectrophotometric instrumentation, scintillation counters, gamma ray spectrometers, Cerenkov radiation measurement, particle size measurement, smoke detectors, ce-



6-9 Calibrator circuit

lestial navigation, star tracking, flying-spot television pick-up, laser detection, timing measurement, and others. A typical photometer circuit is shown in Figure 6-8.

A circuit which uses these cold cathode voltage regulators for a calibrator in an oscilloscope is shown in Figure 6-9. In this circuit the maintaining voltage of the AC/Z82R10 tube is used as the reference line. Accuracy is maintained to within .2% over an extended period of time. The output voltage is specified as a peak-to-peak reference voltage.



6-8 Typical photometer circuit

R_1, L_1 and R_2 are mounted internally. R_2 is adjusted once initially to match the voltage regulator being used. Recalibration is not necessary since these voltage regulator tubes maintain their close tolerances for an extremely long time.

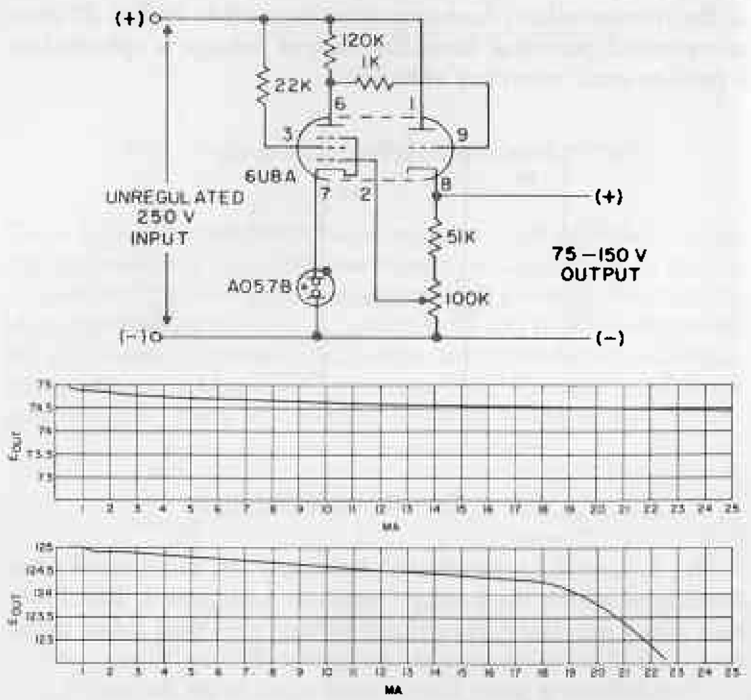
The following procedure is used to calibrate the unit:

1. Connect a calibrated oscilloscope to the highest reference voltage tap, that is, the junction of R_2 and R_3.

2. Adjust R_2 until the oscilloscope reads exactly 5 volts peak-to-peak. Then, if the resistors (R_3, R_4, R_5 and R_6) are accurate, the output voltages should be as specified.

This circuit may be used with ac voltage or dc voltage simply by choosing the appropriate voltage regulator tube.

A simple method for regulating the voltage of low-power power supplies used in electronic equipment is shown in Figure 6-10. The potentiometer permits output voltage to be set at any value between 75 and 150 volts. The neon tube is used to set the reference level, and its maintaining voltage establishes the lower limit for voltage regulation.

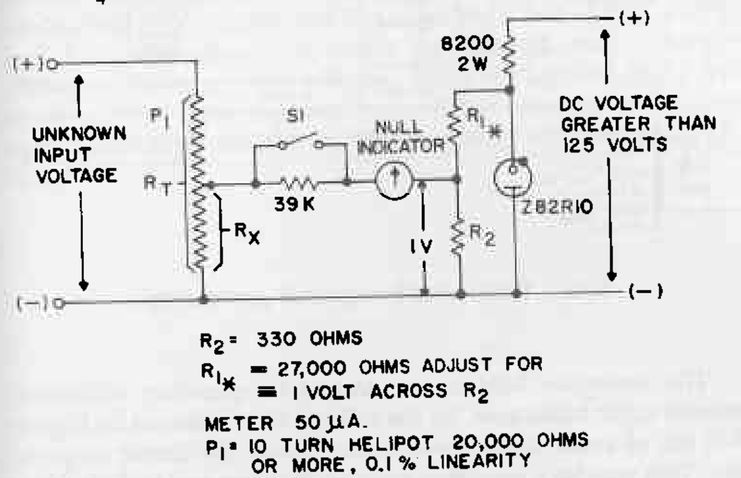


6-10 Power supply regulation

Use of the neon cold cathode voltage regulator tube as a stable voltage reference source for comparison purposes is shown in Figure 6-11. While this example indicates a simple digital voltmeter, a similar approach may also be used to make a suppressed zero meter.

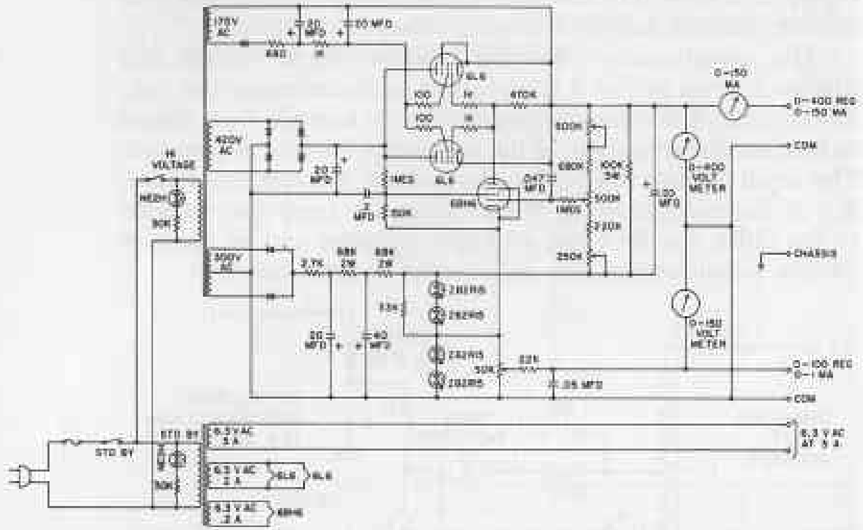
This circuit uses a precision Z82R10 voltage regulator for supplying an accurate 82 volts, and permits this value to be divided down to an absolute 1 volt. The accuracy of the voltage regulator is to within one volt. Consequently, the accuracy of the one volt will hold to .012 volts versus line conditions.

The potentiometer takes the unknown input voltage and divides it down so that it is compared to the reference one volt. As the ratio of the division comes close to balance, S_1 is closed to increase the sensitivity of the null meter for final adjustment. The input voltage is equal to the ratio of the total resistance, R_T, of the potentiometer to the resistance from the common to the slider, R_X. By using a 10-turn indicator and an accurate 10-turn potentiometer, the voltage can be read directly.



6-11 Potentiometer bridge voltmeter

Another example of a regulated power supply is shown in Figure 6-12. This is an electronically regulated power supply which uses the subminiature Z82R10 voltage regulators for a reference source. The output voltage is zero to 400 volts, regulated, up to 125 ma. Bias is zero to 100 volts. Output impedance is less than 10 ohms.

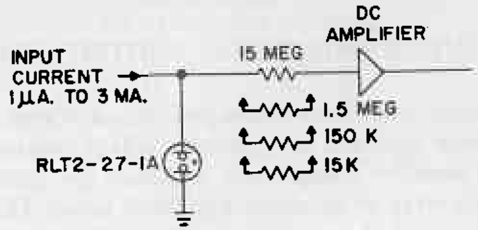


6-12 Electronically regulated power supply

The aerospace field is accustomed to operating within extremely tight tolerances. In the critical circuit shown in Figure 6-13 use of zener diodes would have made the circuit inoperative. This was for a sounding rocket nose cone and included five cold cathode ionization gauges. The microamp signal from the gauges was amplified in a dc amplifier as shown in Figure 6-13.

For low currents the input resistance of the amplifier was 15 megohms. But for higher currents an automatic range switching circuit inserted 1.5 megohms or 150K or 15K as required in place of the original 15 megohm input resistor.

In this program if the input current changed abruptly to a high value, for example 3 ma, when the 15 megohm resistor was on the input, the input voltage would be 3 times 15, or



6-13 Voltage limiter circuit

45 KV. To prevent this, a voltage limiter was required. Zener diodes had been considered but their high leakage at +85°C ($<0.1\,\mu a$) introduced too much input signal error. Leakage current of the neon tube was low, firing voltage was high, and input voltage clamping was assured by using a neon lamp which has a high breakdown voltage rating, such as the RLT2-27-1A.