Chapter 8
ZENER VOLTAGE SENSING CIRCUITS AND APPLICATIONS

BASIC CONCEPTS OF VOLTAGE SENSING

Numerous electronic circuits require a signal or voltage level to be sensed for circuit actuation, function control, or circuit protection. The circuit may alter its mode of operation whenever an interdependent signal reaches a particular magnitude (either higher or lower than a specified value). These sensing functions may be accomplished by incorporating a voltage dependent device in the system creating a switching action that controls the overall operation of the circuit.

The zener diode is ideally suited for most sensing applications because of its voltage dependent characteristics. The following sections are some of the more common applications and techniques that utilize the zener in a voltage sensing capacity.

TRANSISTOR-ZENER SENSING CIRCUITS

The zener diode probably finds its greatest use in sensing applications in conjunction with other semiconductor devices. Two basic widely used techniques are illustrated in Figures 1a and 1b.

In both of these circuits the output is a function of the input voltage level. As the input goes from low to high, the output will switch from either high to low (base sense circuit) or low to high (emitter sense circuit), (see Figure 2).

The base sense circuit of Figure 1a operates as follows: When the input voltage is low, the voltage dropped across R_2 is not sufficient to bias the zener diode and base emitter junction into conduction, therefore, the transistor will not conduct. This causes a high voltage from collector to emitter. When the input becomes high, the zener is biased into conduction, the transistor turns on, and the collector to emitter voltage, which is the output, drops to a low value.

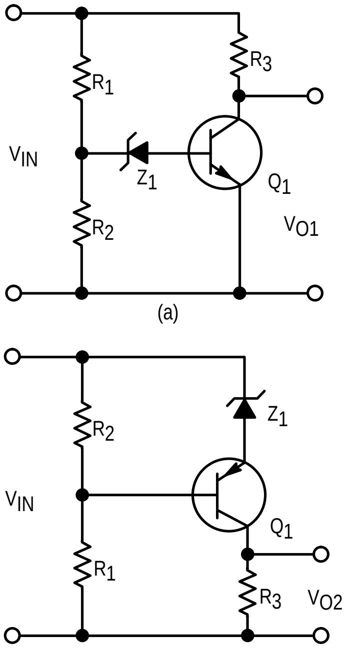


Figure 1. Basic Transistor-Zener Diode Sensing Circuits

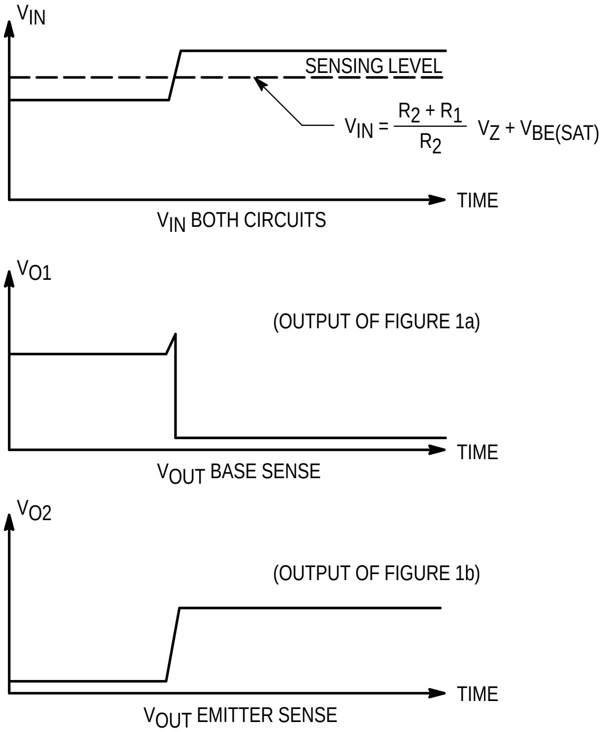


Figure 2. Outputs of Transistor-Zener Voltage Sensing Circuits

The emitter sense circuit of Figure 1b operates as follows: When the input is low the voltage drop across R_3 (the output) is negligible. As the input voltage increases the voltage drop across R_2 biases the zener into conduction and forward biases the base-emitter junction. A large voltage drop across R_3 (the output voltage) is equal to the product of the collector current times the resistance, R_3. The following relationships indicate the basic operating conditions for the circuits in Figure 1.

Circuit Output

$$\text{1a} \quad \left\{ \begin{array}{l} \text{High} \\ V_{OUT} = V_{IN} - I_{CO}R_3 \cong V_{IN} \\ \text{Low} \\ V_{OUT} = V_{IN} - I_C R_3 = V_{CE(sat)} \end{array} \right.$$

$$\text{1b} \quad \left\{ \begin{array}{l} \text{Low} \\ V_{OUT} = V_{IN} - V_Z - V_{CE(off)} = I_{CO}R_3 \\ \text{High} \\ V_{OUT} = V_{IN} - V_{CE(sat)} = I_C R_3 \end{array} \right.$$

In addition, the basic circuits of Figure 1 can be rearranged to provide inverse output.

AUTOMOTIVE ALTERNATOR VOLTAGE REGULATOR

Electromechanical devices have been employed for many years as voltage regulators, however, the regulation setting of these devices tend to change and have mechanical contact problems. A solid state regulator that controls the charge rate by sensing the battery voltage is inherently more accurate and reliable. A schematic of a simplified solid state voltage regulator is shown in Figure 3.

The purpose of an alternator regulator is to control the battery charging current from the alternator. The charge level of the battery is proportional to the battery voltage level. Consequently, the regulator must monitor the battery voltage level allowing charging current to pass when the battery voltage is low. When the battery has attained the proper charge the charging current is switched off. In the case of the solid state regulator of Figure 3, the charging current is controlled by switching the alternator field current on and off with a series transistor switch, Q_2. The switching action of Q_2 is controlled by a voltage sensing circuit that is identical to the base sense circuit of Figure 1a. When under-charged, the zener Z_1 does not conduct keeping Q_1 off. The collector-emitter voltage of Q_1 supplies a forward bias to the base-emitter of Q_2, turning it on. With Q_2 turned on, the alternator field is energized allowing a charging current to be delivered to the battery. When the battery attains a proper charge level, the zener conducts causing Q_1 to turn on, and effectively shorting out the base-emitter junction of Q_2. This short circuit cuts off Q_2, turns off the current flowing in the field coil which consequently, reduces the output of the alternator. Diode D_1 acts as a field suppressor preventing the build up of a high induced voltage across the coil when the coil current is interrupted.

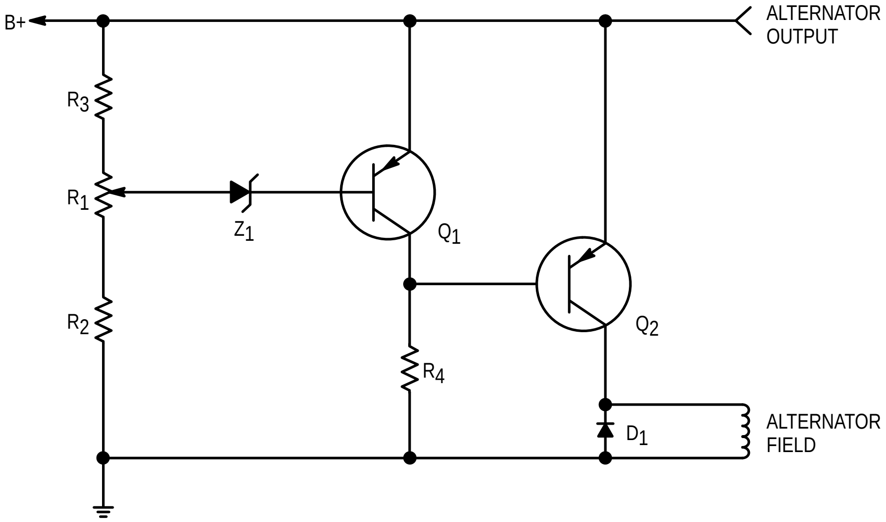


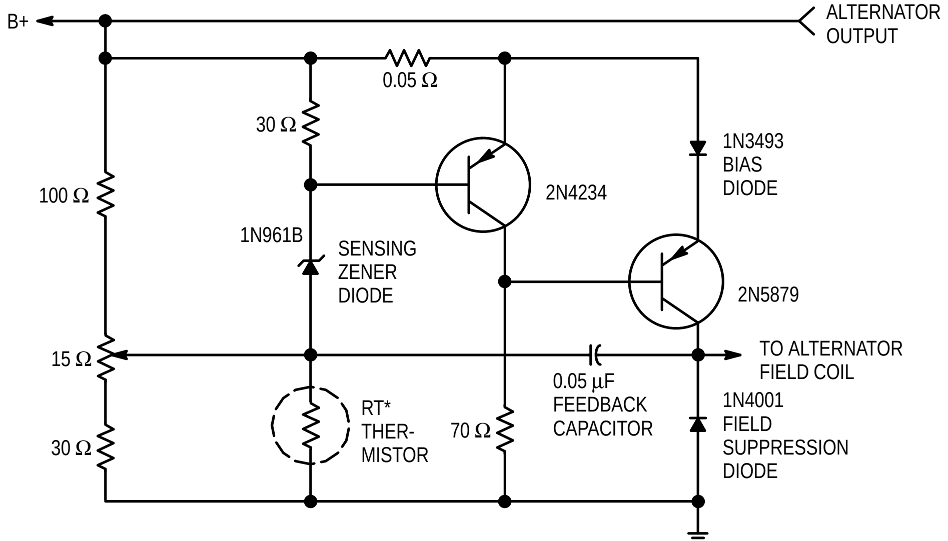
Figure 3. Simplified Solid State Voltage Regulator

In actual operation, this switching action occurs many times each second, depending upon the current drain from the battery. The battery charge, therefore, remains essentially constant and at the maximum value for optimum operation.

A schematic of a complete alternator voltage regulator is shown in Figure 4.

It is also possible to perform the alternator regulation function with the sensing element in the emitter of the control transistor as shown in Figure 5.

In this configuration, the sensing circuit is composed of Z_1 and Q_1 with biasing components. It is similar to the sensing circuit shown in Figure 1b. The potentiometer R_1 adjusts the conduction point of Q_1 establishing the proper charge level. When the battery has reached the desired level, Q_1 begins to conduct. This draws Q_2 into conduction, and therefore shorts off Q_3 which is supplying power to the alternator field. This type of regulator offers greater sensitivity with an increase in cost.



*THE VALUE OF RT DEPENDS ON THE SLOPE OF THE VOLTAGE REGULATION VERSUS TEMPERATURE CURVE.

Figure 4. Complete Solid State Alternator Voltage Regulator

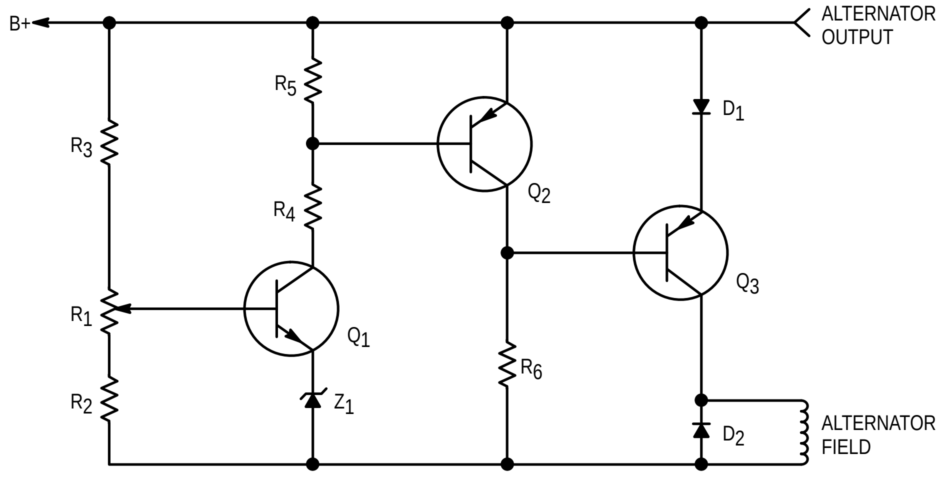


Figure 5. Alternator Regulator with Emitter Sensor

UNIJUNCTION-ZENER SENSE CIRCUITS

Unijunction transistor oscillator circuits can be made GO-NO GO voltage sensitive by incorporating a zener diode clamp. The UJT operates on the criterion: under proper biasing conditions the emitter-base one junction will breakover when the emitter voltage reaches a specific value given by the equation:

$$V_p = \eta V_{BB} + V_D \qquad (1)$$

where:

V_p = peak point emitter voltage
η = intrinsic stand-off ratio for the device
V_{BB} = interbase voltage, from base two to base one
V_D = emitter to base one diode forward junction drop.

Obviously, if we provide a voltage clamp in the circuit such that the conditions of equation 1 are met only with restriction on the input, the circuit becomes voltage sensitive. There are two basic techniques used in clamping UJT relaxation oscillators. They are shown in Figure 6 and Figure 7.

The circuit in Figure 6 is that of a clamped emitter type. As long as the input voltage V_{IN} is low enough so that V_p does not exceed the Zener voltage V_Z, the circuit will generate output pulses. At some given point, the required V_p for triggering will exceed V_Z. Since V_p is clamped at V_Z, the circuit will not oscillate. This, in essence, means the circuit is GO as long as V_{IN} is below a certain level, and NO GO above the critical clamp point.

The circuit of Figure 7, is a clamped base UJT oscillator. In this circuit V_{BB} is clamped at a voltage V_Z and the emitter tied to a voltage dividing network by a diode D_1. When the input voltage is low, the voltage drop across R_2 is less than V_p. The forward biased diode holds the emitter below the trigger level. As the input increases, the R_2 voltage drop approaches V_p. The diode D_1 becomes reversed biased and, the UJT triggers. This phenomenon establishes the operating criterion that the circuit is NO GO at a low input and GO at an input higher than the clamp voltage. Therefore, the circuits in Figures 6 and 7 are both input voltage sensitive, but have opposite input requirements for a GO condition. To illustrate the usefulness of the clamped UJT relaxation oscillators, the following two sections show them being used in practical applications.

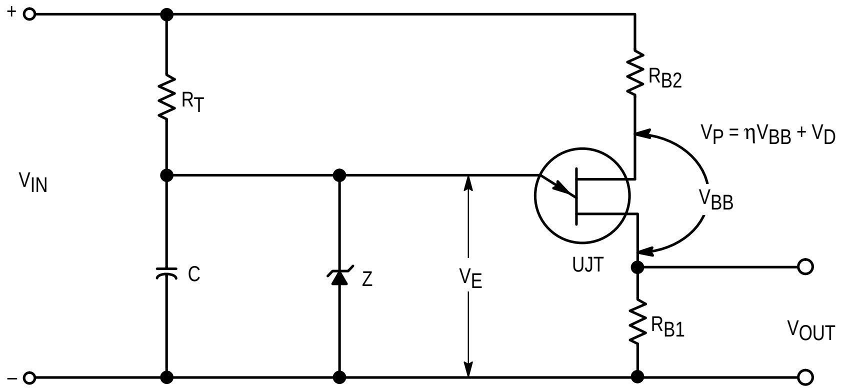


Figure 6. UJT Oscillator, GO — NO GO Output, GO for Low V_{IN} — NO GO for High V_{IN}

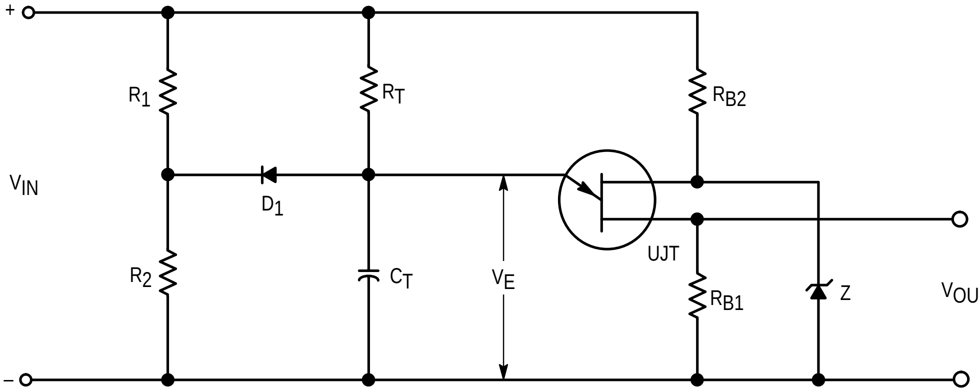


Figure 7. UJT — NO GO Output, NO GO for Low V_{IN} — GO for High V_{IN}

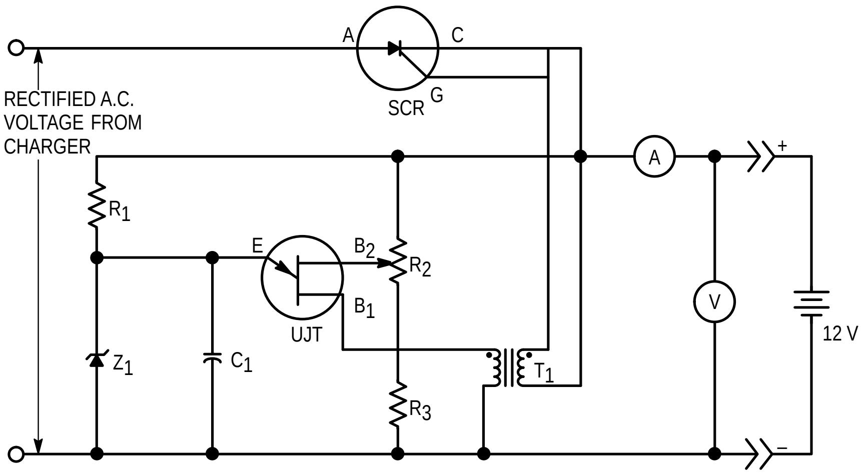
BATTERY VOLTAGE SENSITIVE SCR CHARGER

A clamped emitter unijunction sensing circuit of the type shown in Figure 6 makes a very good battery charger (illustrated in Figure 8). This circuit will not operate until the battery to be charged is properly connected to the charger. The battery voltage controls the charger and will dictate its operation. When the battery is properly charged, the charger will cease operation.

The battery charging current is obtained through the controlled rectifier. Triggering pulses for the controlled rectifier are generated by unijunction transistor relaxation oscillator (Figure 9). This oscillator is activated when the battery voltage is low.

While operating, the oscillator will produce pulses in the pulse transformer connected across the resistance, R_{GC} (R_{GC} represents the gate-to-cathode resistance of the controlled rectifier), at a frequency determined by the resistance, capacitance, R.C. time delay circuit.

Since the base-to-base voltage on the unijunction transistor is derived from the charging battery, it will increase as the battery charges. The increase in base-to-base voltage of the unijunction transistor causes its peak point voltage (switching voltage) to increase. These waveforms are sketched in Figure 9 (this voltage increase will tend to change the pulse repetition rate, but this is not important).



R_1 — 3.9K, 1/2 W
R_2 — 1K, POT.
R_3 — 5.1K, 1/2 W

C_1 — .25 µf
Z_1 — 1N753, 6.2 V
SCR — MCR3813

UJT — 2N2646
T_1 — PR_1, 30_T, no. 22
SEC, 45T, NO. 22
CORE: FERROX CUBE
203F181-303

Figure 8. 12 Volt Battery Charger Control

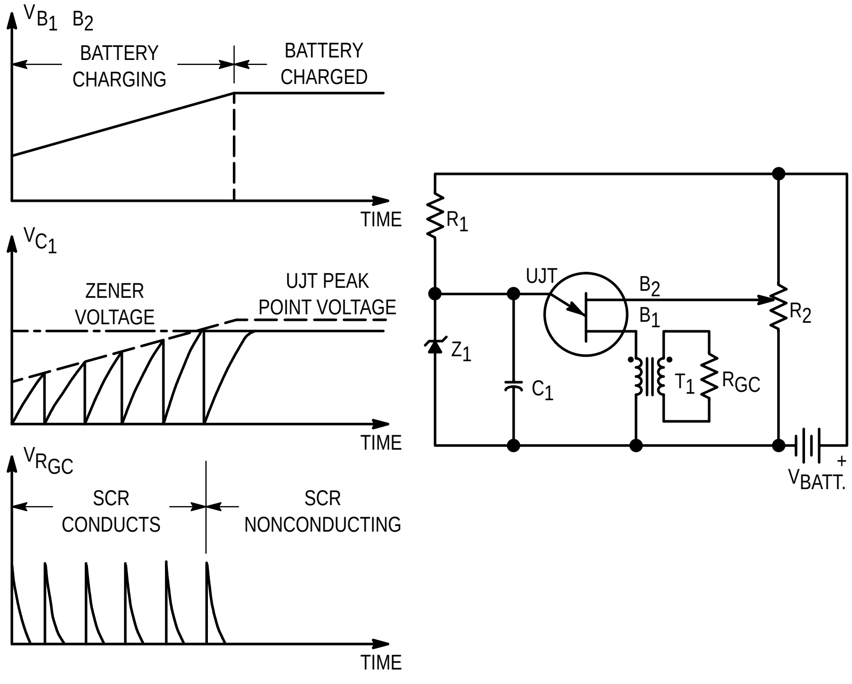


Figure 9. UJT Relaxation Oscillator Operation

When the peak point voltage (switching voltage) of the unijunction transistor exceeds the breakdown voltage of the Zener diode, Z_1, connected across the delay circuit capacitor, C_1, the unijunction transistor ceases to oscillate. If the relaxation oscillator does not operate, the controlled rectifier will not receive trigger pulses and will not conduct. This indicates that the battery has attained its desired charge as set by R_2.

The unijunction cannot oscillate unless a voltage somewhere between 3 volts and the cutoff setting is present at the output terminals with polarity as indicated. Therefore, the SCR cannot conduct under conditions of a short circuit, an open circuit, or a reverse polarity connection to the battery.

ALTERNATOR REGULATOR FOR PERMANENT MAGNET FIELD

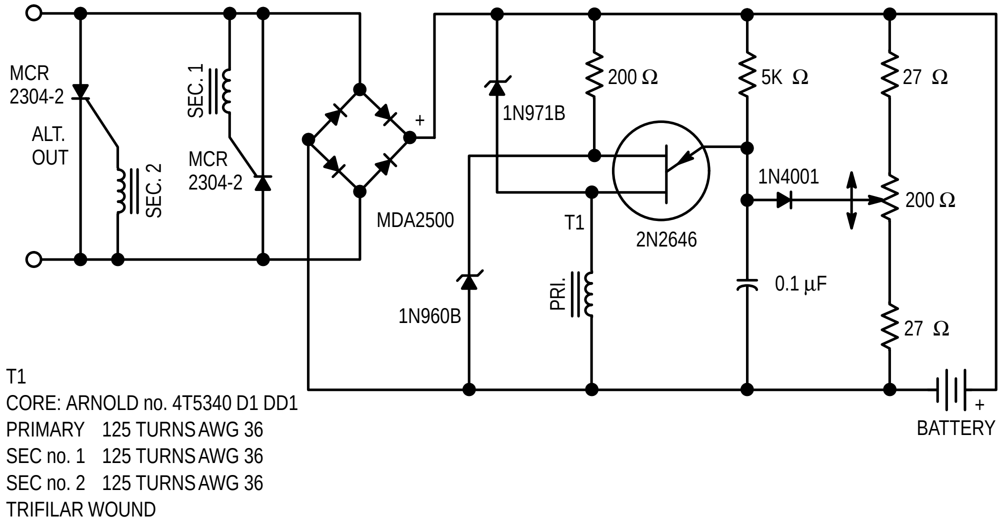
In alternator circuits such as those of an outboard engine, the field may be composed of a permanent magnet. This increases the problem of regulating the output by limiting the control function to opening or shorting the output. Because of the high reactance source of most alternators, opening the output circuit will generally stress the bridge rectifiers to a very high voltage level. It is, therefore, apparent that the best control function would be shorting the output of the alternator for regulation of the charge to the battery.

Figure 10 shows a permanent magnet alternator regulator designed to regulate a 15 ampere output. The two SCRs are connected on the ac side of the bridge, and short out the alternator when triggered by the unijunction voltage sensitive triggering circuit. The sensing circuit is of the type shown in Figure 7. The shorted output does not appreciably increase the maximum output current level.

A single SCR could be designed into the dc side of the bridge. However, the rapid turn-off requirement of this type of circuit at high alternator speeds makes this circuit impractical.

The unijunction circuit in Figure 10 will not oscillate until the input voltage level reaches the voltage determined by the intrinsic standoff ratio. The adjustable voltage divider will calibrate the circuit. The series diode in the voltage divider circuit will compensate for the emitter-base-one diode temperature change, consequently, temperature compensation is necessary only for the zener diode temperature changes.

Due to the delay in charging the unijunction capacitor, when the battery is disconnected the alternator voltage will produce high stress voltage on all components before the SCRs will be fired. The 1N971B Zener was included in the circuit to provide a trigger pulse to the SCRs as soon as the alternator output voltage level approaches 30 volts.



T1
CORE: ARNOLD no. 4T5340 D1 DD1
PRIMARY 125 TURNS AWG 36
SEC no. 1 125 TURNS AWG 36
SEC no. 2 125 TURNS AWG 36
TRIFILAR WOUND

Figure 10. Permanent Magnet Field Alternator Regulator

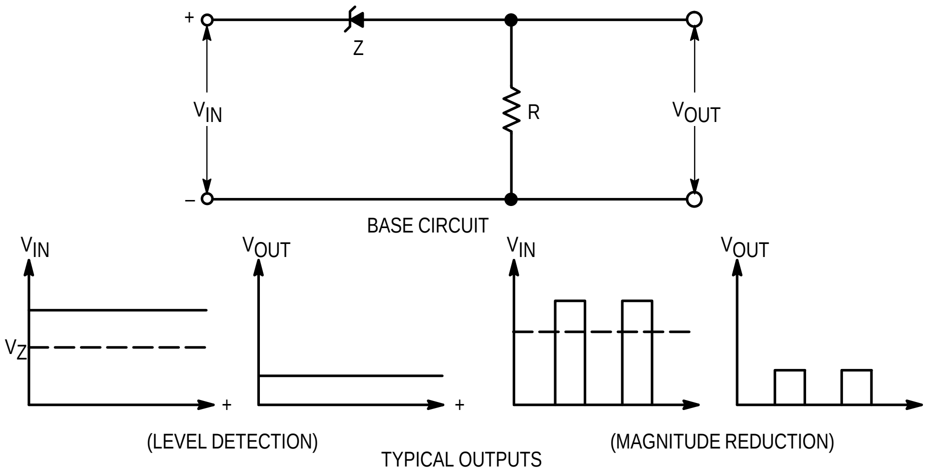


Figure 11. Zener-Resistor Voltage Sensitive Circuit

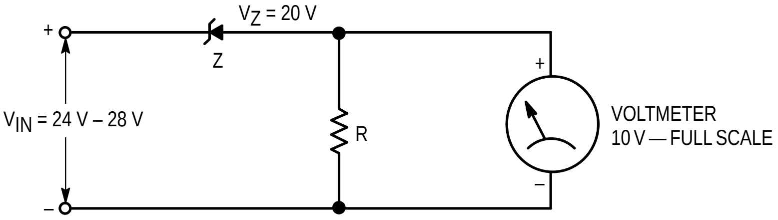


Figure 12. Improving Meter Resolution

ZENER-RESISTOR VOLTAGE SENSING

A simple but useful sense circuit can be made from just a Zener diode and resistor such as shown in Figure 11.

Whenever the applied signal exceeds the specific Zener voltage V_Z, the difference appears across the dropping resistor R. This level dependent differential voltage can be used for level detection, magnitude reduction, wave shaping, etc. An illustrative application of the simple series Zener sensor is shown in Figure 12, where the resistor drop is monitored with a voltmeter.

If, for example, the input is variable from 24 to 28 volts, a 30 voltmeter would normally be required. Unfortunately, a 4 volt range of values on a 30 volt scale utilizes only 13.3% of the meter movement — greatly limiting the accuracy with which the meter can be read. By employing a 20 volt zener, one can use a 10 voltmeter instead of the 30 volt unit, thereby utilizing 40% of the meter movement instead of 13.3% with a corresponding increase in accuracy and readability. For ultimate accuracy a 24 volt zener could be combined with a 5 voltmeter. This combination would have the disadvantage of providing little room for voltage fluctuations, however.

In Figure 13, a number of sequentially higher-voltage Zener sense circuits are cascaded to actuate transistor switches. As each goes into avalanche its respective switching transistor is turned on, actuating the indicator light for that particular voltage level. This technique can be expanded and modified to use the zener sensors to actuate some form of logic system.

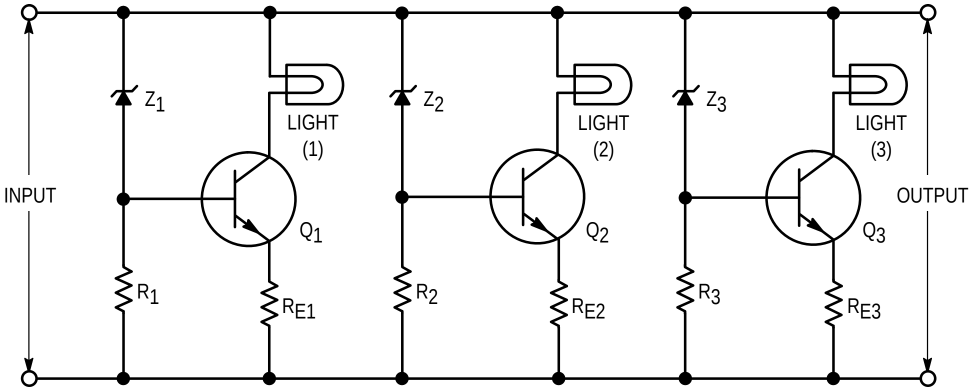


Figure 13. Sequential Voltage Level Indicator