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INTRODUCTION

By definition, a Voltage Regulator Zener diode is a two electrode device which utilizes a semiconductor P-N junction's reverse breakdown characteristics. The name honors Dr. Carl Zener, who, some time ago, explored the breakdown mechanism of diodes and was responsible for much of the initial work on breakdown mechanism theory. In view of their mode of operation, they are also called *breakdown diodes* and, sometimes identified schematically by a conventional diode symbol with the letter "B" added. Other names for the devices are... *avalanche diodes,* which is more descriptive of the actual breakdown mechanism, and *voltage-reference diodes*, a term descriptive of one of their major applications. The popular symbol used is

and the best accepted name is "Voltage Reference Diode." The word "Zener" is however still popular and therefore used generally in this booklet.

(a) Fig. 1 (b)

Referring to Fig. 1(a), if a DC voltage is applied to bias a diode in its forward, or "conducting," direction (anode positive), very little current will flow until the bias voltage exceeds the diode's barrier potential. In most cases, however, this is but a small fraction of a volt, and once the barrier potential is reached, the forward current increases rapidly in a more or less linear fashion. A plot of forward current (I_f) vs. forward voltage (E_f) represents the diode's *forward characteristics*.

If the polarity of the voltage source is reversed, as shown in Fig. 1(b), the diode is biased in its reverse direction. Under these conditions, the diode presents a high impedance to the applied voltage and only a minute "leakage" current can flow. As the reverse voltage is increased still further a point will be reached, eventually, where the diode junction "breaks down." When this happens, there is a sudden and substantial increase in reverse current flow. The change from a small "leakage" current is so abrupt, in fact, that the reverse voltage (at the breakdown point) is essentially constant for relatively large changes in current. A plot of reverse current (I_r) vs. reverse voltage (E_r) represents the diode's *reverse characteristics*. The point at which junction breakdown takes place is known as the *Zener voltage*. This may be from as little as three to four volts to as high as two hundred volts, depending on the characteristics of the individual diode.

The *forward* and *reverse* characteristics of a typical diode are plotted in Fig. 2. Although the exact slope of the horizontal and vertical portions of the curve may vary somewhat, as well as the voltage values at which current changes take place, the general *shape* of the curve is the same for all standard diodes...whether general purpose, rectifier, fast switching, detector, or Zener types.

All semiconductor diodes exhibit a reverse breakdown characteristic, but not all diodes may be used as Zeners. All Zener diodes may within limitations however be used as conventional (rectifier) diodes.

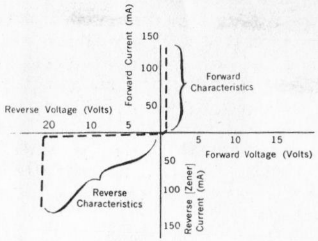


Fig. 2

Circuitwise, Zener diodes may be employed in a wide variety of applications. Typically, they may be used as voltage regulators and reference elements, as surge and overvoltage protective devices, as coupling and biasing elements, as limiters, square-wave generators, clippers and slicers, and as temperature sensors and control elements. From an equipment view point, Zener diodes may be used in computers, test instruments, radio and TV transmitters and receivers, industrial control equipment, telephone systems, medical instruments, Radar gear, alarm systems, Hi–Fi and PA amplifiers, amateur radio gear, power converters...and, in fact, in any electrical or electronic equipment in which voltage or current control or measurement is important.

HOW ZENER DIODES WORK

The Zener diode's distinguishing feature is its reverse breakdown characteristic. Before we can examine the breakdown mechanism, however, we must first review basic semiconductor theory. The internal electric current flow in a semiconductor differs from that in a conductor in that it is made up of two different types of *current carriers* ...negatively-charged free *electrons* (as in metals) and positively-charged *holes*. A "hole" is simple the absence of an electron in a molecular structure; it behaves, however, as if it were a real positive particle and can drift from one molecule to another through the crystalline structure of a semiconductor. As far as any given semiconductor material is concerned, the predominating current carrier, whether holes or electrons, is called the *majority* carrier but both types of carrier may be present at the same time.

In a P-type semiconductor, the positive holes predominate and any free electrons present are termed, appropriately enough, *minority* carriers. Conversely, holes are minority carriers in N-type semiconductors, where free electrons are the predominating type.

When a P-N diode junction is biased in its forward direction, the respective majority carriers congregate at the junction, thus permitting an easy transfer of current across the junction. It is this action which accounts for the low forward resistance of diodes.

On the other hand, when a reverse bias is applied to the diode, the majority carriers move away from the junction. Under these conditions, current transfer across the junction is very difficult and the diode acts as a high resistance. There are still minority carriers present in both semiconductor materials, however, and these, congregating near the junction, permit a small "leakage" current to flow.

According to current theories, the minority carriers, accelerated across the junction by the reverse bias voltage, acquire more and more energy as the reverse bias is increased. Eventually the minority carriers acquire sufficient energy to be able to "knock" valence bound electrons out of atoms. Each time this occurs, a *pair* of current carriers is produced – a free electron and a hole (where the electron belonged). The result, of course, is a very sudden increase in the number of current carriers present and a corresponding large increase in reverse current flow.

ZENER DIODE SPECIFICATIONS

Common terms used in discussing Zener diode operation are defined in Table 1. Zener diodes generally are described in terms of three basic characteristics...*Wattage Rating, Zener Voltage,* and *Tolerance.*

A Zener diode's wattage rating determines the amount of reverse current that it can handle safely without damage at a given voltage. For example, an INTERNATIONAL RECTIFIER type Z1102 Zener diode has a 1 watt rating and can handle a maximum reverse current of 200 ma. at 4.7 volts. A type Z1302, with a 10 watt rating, can handle 2 amp. at the same voltage.

As would be expected, the maximum current which can be handled by a Zener diode of any given wattage rating becomes less as the voltage rating is increased. Thus, the 1 watt Z1102 can handle, as we have seen, 200 ma. at 4.7 volts. The type Z1120, a similar 1 watt unit, can handle only 37 ma. at its rating of 27 volts.

The nominal Zener voltage is the voltage at which reverse breakdown occurs. From a commercial viewpoint, and in order to insure consistency, this value generally is given at a specific reverse (or Zener) current for each type.

A Zener diode's tolerance is given in terms of standard percentages, and refers to the device's Zener voltage rating. The diodes in the Z series and furnished in the K-546 Kit have a ± 10% tolerance rating. Thus, a nominally rated 3.9 volt diode may have an actual Zener voltage of from 3.51

volts (3.9 - 10%) to 4.29 volts (3.9 + 10%). Standard INTERNATIONAL RECTIFIER Zener diodes are available with 5%, 10% and 20% tolerance rating, and very close tolerance units are available on special order at premium prices.

In addition to the three basic electrical specifications other data may be given as an aid to design engineers and more advanced workers. For example, a diode's typical *impedance* (Z_Z) in ohms may be given at a specific test current (I_Z). The voltage *temperature coefficient* may be listed in terms of percentage variation per degree Centigrade (%/°C). Finally, *derating* curves may be provided to permit the designer to determine the safe power limits at higher operating temperatures; in general, the higher the operating temperature, the lower a semiconductor device's rated power dissipation.

ZENER DIODE APPLICATIONS

From a practical viewpoint, the only real limitations on the ways in which Zener diodes may be used are the imagination and skill of the circuit designer. Although of specific value in voltage regulator and reference applications, two or more Zener diodes may be interconnected for special jobs or the units may be combined with other semiconductor devices, such as transistors, to extend their range and increase their versatility.

Typical circuits illustrated in Figs. 3, 4 and 6 should serve to spark the imagination of students and experimenters alike.

DC APPLICATIONS: Typical direct current applications are illustrated schematically in Fig. 3. Of the circuits shown, Figs. 3(a) and 3(b) illustrate the diode's basic application as a shunt or series voltage regulator, respectively, while the other circuits represent special applications for the device.

Since Fig. 3(a) represents the Zener diode's basic application as a regulator element, let us examine this circuit in some detail. Referring to the schematic diagram, the Zener diode Z_1 is used to provide a regulated DC voltage to a *load.* The load may be a critical oscillator circuit, precision amplifier, or test instrument. The source voltage *(DC input)* is unregulated. The diode used is chosen on the basis of load voltage and current requirements, while the series resistor, R_S, is chosen to limit the maximum current through the diode to a safe value.

Let us assume that DC input may vary from 12.0 to 12.8 volts and that the load requires from 40 to 60 ma at 6.8 volts. With this information, we choose an INTERNATIONAL RECTIFIER type Z1106 diode, for this device is rated at 6.8 volts, with a maximum Zener current of 140 ma. (This being a one watt type).

In order to calculate the resistor's (R_S) value and wattage rating, we'll assume "worst-state" conditions...that is, that the load current is at a *minimum* (40 ma.) and supply voltage is at a *maximum* (12.8 volts). Under these conditions, the difference between the supply and load voltages is

$E = 12.8 - 6.8 = 6.0$ volts.

The current through the series resistor would be...

$I =$ (Zener current) + (load current)

$= 140 + 40 = 180$ ma.

Using Ohm's law, then, the resistor's value would be...

$R = E/I = 6.0/0.18 = 34$ ohms, and the power dissipated by the resistor would be...

$P = EI = 6.0 \times 0.18 = 1.08$ watts.

Allowing an ample safety factor, a 3 to 5 watt resistor would be used, and the final component specifications would be for

Fig. 3(a) under the assumed conditions...

Z_1 – INTERNATIONAL RECTIFIER type Z1106

R_s – 33 ohms (nearest standard value) @ 5 watt

In operation, if the load current increased (we assumed minimum current in our calculations) *or* the source voltage decreased (we assumed it to be at a maximum), the Zener current would *decrease*. Thus, if the load current increased to its maximum of 60 ma., the Zener current would drop to 90 ma., maintaining a current of 150 ma. through the series resistor and, therefore, a voltage drop of 6.0 volts, and the load voltage would remain at its regulated value of 6.8 volts. If, on the other hand, the source voltage dropped to 12.0 volts, the Zener current would drop in proportion, reducing the voltage drop across R_s, and again maintaining 6.8 volts across the load.

The shunt regulator circuit, Fig. 3(a), is used where a relatively large voltage drop between the unregulated source and regulated load voltage is needed. If the difference between the source and load voltages is small, then the series regulator circuit shown in Fig. 3(b) could be used. For example, if a 28.0 source is used to supply a load requiring 22.4 volts, a Zener diode rated at 5.6 volts could be used in the series configuration (28.0 = 22.4 + 5.6). As before, the resistor (R_s) is included to assist in voltage regulation. The series circuit has one major disadvantage...both the load and resistor currents must pass through the diode, hence a fairly large Zener diode must be used in most applications.

If it is necessary to regulate a voltage for which the exact Zener diode is not available, two or more Zener diodes may be connected in series, as shown in Fig. 3(c). The diodes used in such an arrangement need not have equal breakdown voltages since the circuit is self-equalizing, but the current ranges and power handling capability should be similar. The same type of circuit may be used as a regulated voltage-divider by providing "taps" between the individual diodes, as indicated by the dotted lines.

Occasionally it is necessary to regulate a voltage to a value lower than that normally available with Zener diodes. When this is the case, the difference regulator circuit shown in Fig. 3(d) may be used. Here, the output voltage equals the *difference* between the two Zener voltages. For example, if Z_1 were rated at 3.9 volts and Z_2 at 5.6 volts, the output would be 1.7 volts (5.6 − 3.9 = 1.7).

A modified version of the differential regulator is illustrated in Fig. 3(e). This circuit provides an *adjustable* regulated output voltage. In operation, the first diode (Z_1) serves as a pre-regulator. With the arrangement shown, the output voltage can be varied from Z2's value to Z1's value by adjusting R_a.

If relatively large currents are to be regulated, a Zener diode may be used in conjunction with a transistor, as shown in Fig. 3(f). In this shunt regulator configuration, only the transistor's base current flows through the Zener diode. The col-

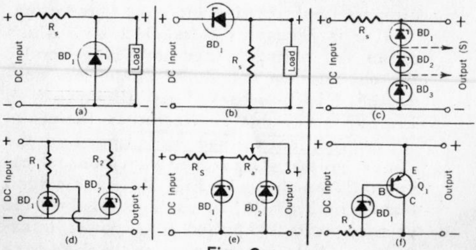


Fig. 3

lector current, of course, is many times this value, depending on the transistor's current gain (beta). In addition to multiplying the current handling capability (and, hence, effective power rating) of the Zener diode, the transistor also serves to improve the regulating factor.

AC APPLICATIONS: Zener diodes may be used effectively in AC circuits. Typical applications are illustrated in Fig. 4, with the basic AC shunt regulator shown in Fig. 4(a). As will be observed, the basic circuit is almost identical to that of the basic DC shunt regulator. The difference between the two lies in the mode of operation, for when AC is applied to a single Zener diode, the device conducts on alternate half-cycles ...that is, when biased in its forward direction. The result is that alternate "halves" of the applied signal are stripped away, as shown by the waveform sketch given in Fig. 5(a). Zener breakdown action takes place only when the reverse bias peak exceeds the diode's rated voltage; in this case, the output waveform assumes the shape illustrated in Fig. 5(b)...essentially an unsymmetrical square-wave with slightly curved sides. The function of the series resistor, R_S, is the same as in the DC regulator circuit discussed earlier. Modified versions of the basic circuit...Fig. 4(a)... may be used not only as regulators but as clippers and rectangular-wave generators.

If it is necessary to regulate both peaks of an AC voltage...and this is generally the case...then two Zener diodes are connected "back-to-back," as illustrated in Fig. 4(b). With this configuration, the peaks of the applied voltage are clipped to the Zener voltages and the waveform is essentially as shown in Fig. 5(c). The circuit shown in Fig. 4(b) is used to regulate the primary voltage applied to a power transformer (T_1), but a similar back-to-back arrangement may be used to regulate secondary voltage, as shown in Fig. 4(c). In both cases, the usual series resistor (Rs) must be included to insure proper operation.

The applications of either primary or secondary voltage regulators are virtually unlimited. Primary regulators may be used to protect test equipment and other critical apparatus from line surges or to insure an accurate supply voltage to precision instruments. Secondary regulators may be used in similar applications and, in addition, are used often to regulate the filament voltage of oscillator tubes in VFOs and signal generators to insure maximum frequency stability.

Back-to-back Zener diodes may be used in other than regulator applications. When connected across the voice coil winding of a Hi-Fi loudspeaker or PA driver, for example, such a circuit will protect the equipment against damaging overloads and transient peaks. Back-to-back arrangements are excellent also for use as limiters in FM receivers, as clippers in computer circuits, and as wave-shaping networks.

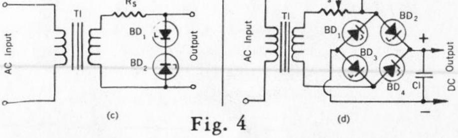


Fig. 4

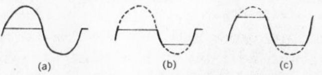


Fig. 5

Another interesting and useful Zener diode application is illustrated in Fig. 4(d). Here, four Zener diodes (Z_1, Z_2, Z_3 and Z_4) are connected in a bridge arrangement as part of an AC-powered regulated DC supply. In operation, the Zener diodes act as clippers in conjunction with R_a, limiting the voltage to which the output capacitor, C_1, is charged. At the same time, the Zeners serve as ordinary rectifiers. This type of circuit is especially valuable where only a modest degree of regulation is required.

SPECIAL ZENER DIODE APPLICATIONS: Four additional Zener diode circuits are illustrated in Fig. 6. These were chosen not only to illustrate the Zener diode's versatility but because they have particular appeal to experimenters and hobbyists.

Often, a meter is used in applications where readings over the upper portion of the scale are the only ones of interest. One example might be a meter used to check the output of a battery charger. In such applications, more accurate and meaningful readings can be obtained if the lower portion of the scale is suppressed. A circuit for accomplishing this is illustrated in Fig. 6(a). Here, the Zener diode acts as an open circuit until the applied voltage exceeds its breakdown voltage, thus "expanding" the meter's scale. Calibration is achieved by means of R_s and by adjusting the meter's needle below the normal "O" reading.

Whenever power to an inductive load (e.g. relay or solenoid coil) is interrupted a considerable voltage can be built up by the load's collapsing magnetic field. Often this is sufficient to weld contacts or cause arcing which, in turn, can lead to rapid contact deterioration.

A rectifier diode may be connected across the coil and will provide a path for circulating current which will prevent the buildup of damaging voltage. However, the presence of this circulating current can cause undesirable effects such as making relay operations sluggish.

The addition of a Zener diode in series with the rectifier diode as shown in Fig. 6(b) will interrupt the flow of such circulating current a short time after the switch opens, minimizing the bad effects of the circulating current and still allowing the stored energy in the coil to be dissipated harmlessly without damage to contacts,

An interesting communications application for Zener diodes is shown schematically in Fig. 6(c). Here, a pair of Zeners are connected back-to-back in a simple *speech clipper.* Used in conjunction with the speech amplifier of an amateur radiotelephone transmitter, such a circuit can effectively raise the energy content of a modulated radio signal by removing sharp low energy peaks from the voice signal. The actual clipping is accomplished by the pair of Zener diodes, while the L-C circuit (C2-L1-C3) is included simply to remove the undesirable high frequency harmonics introduced by the clipping action.

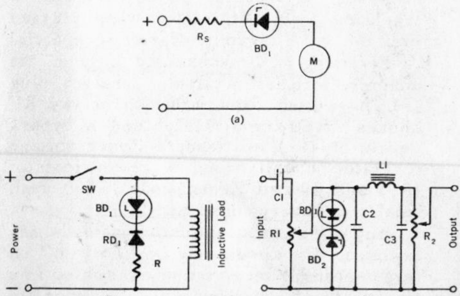


Fig. 6

HOBBYIST ZENER PROJECTS

The basic circuits described and illustrated in Figs. 3, 4 and 6 may be adapted to a variety of projects and equipment designs. Engineers, technicians, advanced students and experimenters should have little or no difficulty in modifying the circuits shown and in selecting component values to meet their individual requirements. There are, however, a number of hobbyists who prefer to tackle specific construction projects. As an aid to these, then, a number of easily-built projects featuring INTERNATIONAL RECTIFIER Zener diodes are illustrated schematically in Figs. 7 through 11.

TRANSISTOR RADIO AUTO ADAPTOR:

The relatively simple unit illustrated schematically in Fig. 7(a) may be used to power small transistor receivers from an automobile's power supply, thus saving the radio's built-in dry battery. A majority of small transistor receivers employ 9-volt batteries. Most automobile electrical systems, on the other hand, supply approximately 12.6 volts DC, but may furnish as high as 14 to 16 volts under some conditions. The adaptor shown supplies a regulated 9-volt DC output when plugged into the car's cigarette lighter receptacle.

Referring to the schematic diagram, the adaptor includes a lighter charger plug (PL_1), a hash filter made up of two RF chokes (RFC_1 and RFC_2) and a bypass capacitor (C_1), a standard Zener voltage regulator circuit using a power resistor (R_1) and 10-watt Zener diode (BD_1), and, finally, a battery connector (BC_1).

Any of several construction methods may be used. The circuit may be "built-in" on larger portable receivers or assembled in a small aluminum *Minibox* as a separate accessory. Some builders may prefer to assemble the unit in a small case and install it under the car dash, providing a 9-volt DC outlet; in the latter case, the plug may be eliminated, but a simple SPST switch should be connected in series with the "hot" side of the 12-volt line. If assembled as a separate accessory, the plug should be connected to a moderately long dual conductor cord...from 2 to 6 feet.

The "hash" filter may not be needed in all cases. If cost is a factor, the basic regulator circuit (R_1 and BD_1) may be assembled first and tried with a transistor radio, with the filter circuit (RFC_1, RFC_2 and C_1) added only if needed to reduce engine noise.

Although the circuit is non-critical, a few precautions must be observed. First, DC polarity is extremely important and a prior check should be made to see if the car has a negative or positive ground system. Plug connections are shown for a *positive ground* system. If the car has a negative ground system, connections to the plug (PL_1) should be reversed. Second, the type of battery connector (BC) chosen should match the one in the transistor radio with which the adaptor is used...a suitable connector may be obtained by removing the plug plate from a discarded 9-volt battery.

In operation, the hash filter removes engine and generator noise, while the regulator circuit, R_1-BD_1, reduces the battery voltage to 9-volts. Since a 10-watt Zener is used, up to several hundred milliamperes can be supplied...this is more than ample tor small transistor portables.

HEADPHONE "BLAST" ELIMINATOR:

SWLs, hams, and others who use headphones may avoid "blasting" as strong signals are picked up by adding the low-cost accessory shown schematically in

Fig. 7(b) to their receivers. Essentially a simple peak voltage limiter, the unit prevents the application of excessively strong signals to the headphones.

Consisting of a series limiting resistor, R_1, and back-to-back connected Zener diodes, BD_1 and BD_2, the "Blast" Eliminator may be wired directly on a receiver's chassis or in a small case as a separate accessory. If permanently installed, the 'phone plug (PL_1) is not needed. R_1's size is not critical, and values from 4.7K to 10K may be used. For best results, the two Zener diodes should have identical voltage ratings, but they may be either 3/4 or 1-watt units. The voltage values used will depend on the maximum headphone level desired. Good results can be obtained with 3.9-volt diodes, but 4.7, 5.6 or 6.8 volt units may be used; they will deliver greater output volume before limiting takes place.

In use, the 'phone plug (PL_1) is inserted in the "Blast" Eliminator's output jack (J_1). One Zener conducts on positive peaks in excess of its voltage rating, the other on negative peaks, dropping the excessive voltage across R_1. The unit is designed for use with high impedance magnetic or crystal headphones.

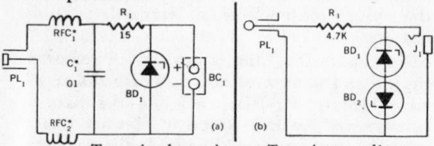


FIG. 7: Two simple projects: *Transistor radio auto adaptor* (a), and a *Headphone "Blast" Eliminator* (b).

*Optional, refer to text

In use, the phone plug (PL_1) is inserted in the receivers phone jack, while the headphone's plug is inserted in the "Blast" Eliminator's output jack (J_1). One Zener conducts on positive peaks in excess of its voltage rating, the other on negative peaks, dropping the excessive voltage across R_1. The unit is designed for use with high impedance magnetic or crystal headphones.

MULTI-OUTPUT POWER SUPPLY:

A DC power supply Fig. 8 providing six discrete, regulated output voltages which may be used separately or in combination, the device is useful for calibration and testing of DC voltmeters or similar instruments, as a bias supply, or as a source of DC power for checking breadboarded transistor stages. It can supply adequate power for the average one or two-stage small-signal circuit.

Referring to the schematic diagram, the circuit consists of a standard DC power supply and filter to which a series Zener regulator has been added. In operation, T_1 supplies an AC voltage to half-wave rectifier RD_1. R_1 serves as a surge limiting resistor to protect the diode. C_1, L_1 and C_2 form a conventional "pi" type ripple filter. Finally, the regulator network is made up of six Zener diodes (BD_1 through BD_6) and an adjustable current limiting resistor, R_2.

The circuit is not critical and several design changes may be made to meet individual needs. T_1's primary circuit may be fused, if desired, or, if cost is a factor, the pilot lamp assembly (LP_1) may be eliminated. Since a brute-force filter is used, larger (or smaller) filter capacitor values may be employed. Typically, C_1 may have values from 20 to 60 mfd. and C_2 from 30 to 80 mfd. Finally, almost any assortment of Zener diodes may be used, provided the total of their voltage ratings is approximately 95 to 100 volts. Suggested values are 27 to 32 volts for BD_1, 22 for BD_2, 18 for BD_3, 12 for BD_4, 9.1 for BD_5, and 6.8 for BD_6. Zener wattage ratings are not overly critical; if one watt units are used, the supply can deliver up to 15 ma. from any pair of terminals. If higher current output is desired, 10 watt Zener diodes should be used for the higher voltage devices.

Once the unit is assembled and checked, R_2 should be set to its maximum resistance value. Afterwards, R_2's connection to BD_1 should be opened and a suitable milliampmeter connected to measure Zener current. With the power "On," R_2's value should be adjusted until the total Zener current is *less* than the maximum current rating of any Zener diode in the series string...for 1 watt Zeners this generally will be on the order of 25 Ma. With R_2 adjusted, the meter may be disconnected and removed, with R_2 reconnected to BD_1.

In use, the desired output voltage is obtained by connecting to a selected pair of output terminals. Assuming the Zener voltage values suggested above, an output of 6.8 volts could be obtained by connecting across BD_6, or an output of 9.1 volts by connecting across BD_5. Other voltages may be obtained by connecting across two or more Zeners...for example, 40 volts could be obtained by connecting across BD_2 and BD_3 or 52 volts by connecting across BD_2, BD_3 and BD_4. When used as a power source rather than for bias or calibration applications, the load current should be limited to a maximum of about 15 ma, when the Zener diodes used are all rated one watt.

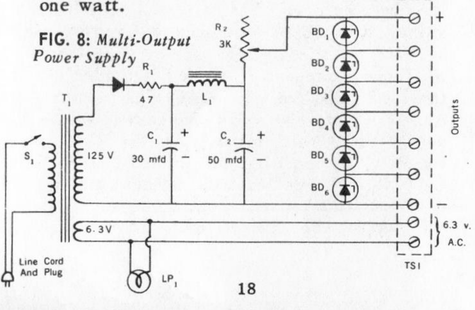


FIG. 8: *Multi-Output Power Supply*

OSCILLOSCOPE CALIBRATOR:

Another low-cost, easily assembled experimenter's laboratory instrument is illustrated schematically in Fig. 9. Supplying a 60 cps square-wave signal of known peak-to-peak amplitude, the instrument is useful for 'Scope Calibration but also may be used for checking the operation of peak-to-peak voltmeters or similar units.

In operation, an isolated A.C. voltage obtained from T_1's secondary is applied through current limiting resistor R_1 to a pair of Zener diodes, BD_1 and BD_2, connected back-to-back. One diode "clips" the positive peaks, the other the negative peaks, so that the resulting output signal is approximately a square-wave with a peak-to-peak voltage equal to the sum of the Zener voltages.

A standard power transformer, as specified, is used for T_1, although the filament winding is not needed unless the builder wishes to add a pilot lamp assembly. Either 3/4 or 1-watt Zeners may be used and, ideally, BD_1 and BD_2 should have identical values, but this is not critical. BD_1, for example, may be rated at 3.9 volts and BD_2 at 5.6 volts...in this case, the output voltage would be 9.5 volts.

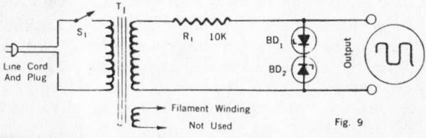


FIG. 9: A low-cost *'Scope Calibrator.*

REMOTE CONTROL:

Zener diodes may be used to provide a variety of discrete control functions over a pair of control lines. Used in this manner, Zeners permit an interesting array of applications in the remote control of electromechanical equipment, models, lamps or other devices. Since the potential applications are virtually unlimited, it is difficult to outline a specific project using these devices...each project must be "tailor-made" to fit individual needs. However, one possible arrangement, illustrated schematically in Fig. 10, is given as an example.

Referring to the diagram, the controlled devices include two similar relays, RY_1 and RY_2, a small DC motor, M_1, and a lamp bulb, LP. An adjustable DC voltage is used for control purposes and the Zener diodes, BD_1 through BD_4, are chosen in accordance with the desired sequence of operation. For example, let us assume that BD_1 is rated at 3.9 volts, BD_2 at 4.7 volts, BD_3 at 5.6 Volts, and BD_4 at 6.8 volts, and that the control voltage may be adjusted from 0 to, say, 9 volts.

In operation, all of the controlled devices would remain inactive as long as the line voltage remained less than 3.9 volts. As the voltage is raised in excess of 3.9 volts (but less than 4.7), BD_1 would conduct, permitting RY_1 to close. The relay's contacts, in turn, could be used to actuate other equipment. When the control voltage is raised still further...to over 4.7 volts... BD_2 conducts, closing RY_2. Continuing, raising the control voltage to over 5.6 volts permits BD_3 to conduct, supplying power to the motor (M_1). Finally, as the voltage is raised in excess of 6.8 volts, the last diode, BD_4, conducts, and power is furnished to the lamp bulb. Thus, a sequence of four separate control functions are performed over the single pair of lines simply by changing the D C level.

In practice, the controlled devices and Zener wattage ratings must be chosen in such a way that the loads serve to limit the Zener currents to safe values. In addition, best results are obtained when the loads can tolerate. . .and function. . .over a moderately broad voltage range. Typically, RY_1 and RY_2 in the circuit shown would be high-resistance, sensitive relays; the motor would be designed to operate with from 1 to 3 volts, and the lamp would be designed to furnish adequate illumination at 2 to 2.5 volts. As a general rule, low-wattage Zeners would be used to control sensitive relays, higher wattage units to control small motors, lamps or solenoids.

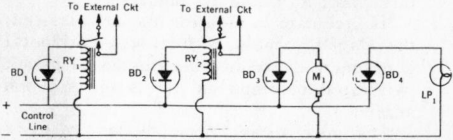


FIG. 10:

Using Zener diodes for *remote control* applications.

OSCILLOSCOPE DEMONSTRATION:

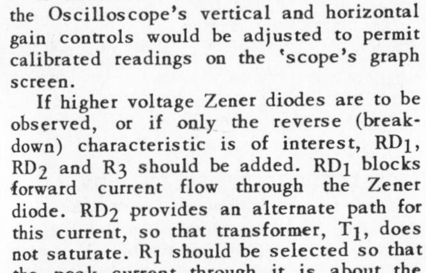
Students, teachers and experimenters alike will find the circuit shown in Fig. 11 useful for providing a display of Zener diode characteristics on a cathode-ray Oscilloscope.

In operation, the 'scope's vertical deflection is made proportional to Zener current and its horizontal deflection proportional to Zener voltage. This is accomplished by connecting the instrument's "H" input terminals across the Zener and by using a small resistor (R_1) to develop a signal voltage proportional to Zener current. . .this, in turn, is connected to the 'scope's "V" input terminals. Note that with the connections shown a positive voltage across the Zener diode causes a horizontal deflection to the left.

Referring to the diagram, T_1 supplies an A.C. voltage greater than the Zener diode's (BD_1) rating, R_1 is a small resistor, and R_2 is the familiar series current limiting resistor. For Zener diodes rated 10 volts and below RD_1, RD_2 and R_3 may be omitted. In this case R_2's value is chosen to limit both forward and reverse currents to a safe value but, under some circumstances, it may be eliminated entirely. In a typical set-up, for example, T_1 could be a 6.3-volt filament transformer (or the filament winding of a power transformer), R_1 a 10 ohm, 10-watt resistor, and Z_1 a 3.9 or 4.7-volt, 3 watt Zener diode...in this case, R_2 would not be needed.

If accurate measurements are desired, the Oscilloscope's vertical and horizontal gain controls would be adjusted to permit calibrated readings on the 'scope's graph screen.

If higher voltage Zener diodes are to be observed, or if only the reverse (breakdown) characteristic is of interest, RD_1, RD_2 and R_3 should be added. RD_1 blocks forward current flow through the Zener diode. RD_2 provides an alternate path for this current, so that transformer, T_1, does not saturate. R_1 should be selected so that the peak current through it is about the same as the peak Zener (reverse) current through the Zener diode, BD_1.



*Optional, refer to text

FIG. 11:

An interesting demonstration...using an Oscilloscope to observe Zener diode characteristics.

PARTS LISTS

Transistor Radio Auto Adaptor (Fig. 7a):

RFC_1*, RCF_2* – R.F. Choke, *National* type R-60, 2 required.
C_1* – 0.01 Mfd., 200 volt disc ceramic capacitor.
R_1 – 15 ohm, ±10% 10 watt wirewound resistor.
BD_1 – Zener diode, 9.1 volts, 10 watt (IR No. Z1310).
BC_1 – Battery connector – to suit radio used.
PL_1 – Cigarette lighter charger plug (*Schauer* No. A-8412).
MISC. – Small *Minibox*, terminal strip, wire, solder, screws, nuts.

*These components are used in the "hash" filter and may not be needed in all cases.

Headphone "Blast" Eliminator (Fig. 7b):

R_1 – 4.7K, ½ watt resistor.
RD_1, BD_2 – 3/4 or 1 watt Zener diodes, 3.9 to 6.8 volt, exact size not critical, but two should be same value.
PL_1 – 'Phone plug.
J_1 – Open circuit jack.
MISC. – Small *Minibox*, terminal strip, wire, solder, hdwe.

Oscilloscope Calibrator (Fig. 9):

R_1 – 10K, 5 watt wirewound resistor.
T_1 – Power transformer, 100 to 125 volt secondary, filament winding not needed (*Knight* 61 G 411 or Triad R30X as specified above, may be used).
S_1 – SPST toggle switch.
BD_1, BD_2 – 3/4 or 1 watt Zener diodes 3.9 to 6.8 volts.
MISC. – Small chassis or case, line cord and plug, two-terminal screw-type terminal strip (or two binding posts), wire; solder, screws, nuts.

Remote control circuits (Fig. 10) and *Oscilloscope Demonstration* (Fig. 11) – see text.

Multi-Output Power Supply (Fig. 8):

R_1 – 47 ohm, ½ watt resistor.
R_2 – 3K, 10 watt wirewound adjustable resistor.
C_1 – 30 Mfd., 200 volt tubular or can type electrolytic.

C_2 – 50 Mfd., 200 volt tubular or can type electrolytic.
T_1 – Power transformer; 117 volt primary, secondaries 125 volt @ 50 ma and 6.3 volt @ 2 a. (*Knight* 61 G 411 Triad R30X or equivalent).
L_1 – Filter choke, 8.5 Hy @ 50 ma, 400 ohm (*Stancor* C1279) or equivalent.
S_1 – SPST toggle switch.
TS_1 – 9-terminal screw-type terminal strip.
LP_1 – Pilot lamp, 6.3 volts...to fit socket used.
RD_1 – Rectifier (*IR* type SD500 or 5A4D)
RD_1, BD_2, BD_3, BD_4, BD_5, BD_6 – Zener diodes, suggest values of 27 or 32, 22, 18, 12, 9.1, and 6.8 volts, respectively. 1 watt units suitable for most situations, but higher voltage units should be 10-watt rating if more than 15 ma output current is desired.
MISC. – Small chassis, line cord and plug, terminal strips, screws and nuts, pilot lamp socket and jewel assembly, wire; solder.

SYMBOL	DEFINITION
V_f or E_f	Forward voltage – the value of voltage applied to a diode in its "forward" or conducting direction.
I_f	Forward current – the value of current flowing through a diode when biased in its conducting direction.
V_r or	Reverse voltage – the value of voltage applied to a diode in its "reverse" (sometimes, *inverse*) or "non-conducting" direction.
I_r	Reverse current – the value of current flowing through a diode when biased in its non-conducting direction. This remains close to zero until the Zener voltage is reached.
V_z or E_z	Zener voltage – essentially, the value of reverse voltage at which diode "breakdown" occurs, with a corresponding large increase in I_r. When listed as a specification, it may refer to the voltage at a specific (or test) Zener current.
I_z	Zener current – the diode's reverse current after the Zener voltage has been reached or exceeded.
Z_z	Zener impedance – an AC characteristic given in ohms; this value is determined by dividing an applied AC voltage by the corresponding AC current when the diode is reverse biased for a specific Zener current.
I_{zt}	Zener test current – Zener current at which parameter such as Zener voltage or Zener impedance is specified. May be referred to simply as I_z.

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