Readers comment

Counting functions

To the Editor: In your interview with Charles Clough, Texas Instruments' vice president for semiconductor marketing ["Everybody's popping circuits," *Electronics,* March 21, p. 66], he estimates that "the average [U.S.] home now has 3,000 transistor functions."

We would be very much obliged if you could tell us how Mr. Clough has come to this conclusion, which is far beyond all of our estimates for TV and radio sets, two cars, anti-burglar systems, and air-conditioning.

J. Hieke
Siemens Aktiengesellschaft
Munich, Germany

- *Mr. Clough has since increased his estimate to 30,000 transistor functions. The key word is "functions." A simple calculator chip has 6,000 functions, and it's logical that a calculator, several solid-state television sets, a car or two, and radio could easily boost the total that high.*

Protecting with zeners

To the Editor: The idea presented by your Engineer's newsletter, "Zener diodes can give you fast protection" [May 2, p. 118], is not as effective as claimed. This item states that a zener-diode clamp will be made much faster by the addition of a compensating junction. While this does add a small junction capacitance in series with the large zener capacitance, it does not provide the order-of-magnitude reduction in clamp capacitance, as claimed.

The total clamp capacitance is not the series combination of the junction and zener capacitances. To demonstrate this, the required connection from A to B is added to the diagram of the clamp. Note that the voltage that must be developed on each capacitance is determined by the diode it shunts. Addition of the compensating junction does not reduce the voltage to which the zener capacitance C_Z must be charged, so the charge required by C_Z is still $q_Z = C_Z V_Z$. In addition, the capacitance of the compensating diode C_F must be charged with $q_F = C_F V_F$. Thus, the total equivalent clamp capacitance is

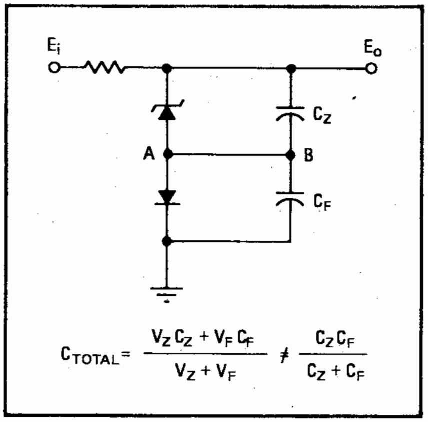
$$C = q/V$$

$$C_{\mathrm{TOTAL}} = (V_Z C_Z + V_F C_F)/(V_Z + V_F) \neq (C_Z C_F)/(C_Z + C_F)$$

For a 6-V zener diode,

$$C_{\mathrm{TOTAL}} = 0.9C_Z + 0.1C_F \neq 0.1C_Z$$

While the above total capacitance is about 9% less than C_Z, the clamp voltage is increased around 10% by the added junction. Thus, the time to reach the clamp level is increased—not decreased—by addition of a compensating junction.



Jerald Graeme
Burr-Brown Research Corp.
Tucson, Ariz.

Microwaves for rails

To the Editor: This office is engaged in feasibility studies for future transportation systems in the Adelaide, South Australia, urban area. It has occurred to us that microwave communications systems could be used for train-signaling control. We request information on such a system that could satisfy our needs.

Preliminary analysis indicates that the system should have immunity to power-frequency interference from electric trains, the ability to confine signals to railway property, immunity to copper thieves, and ability to measure each individual train's location and velocity at any instant.

Any information on such a system may be forwarded to:

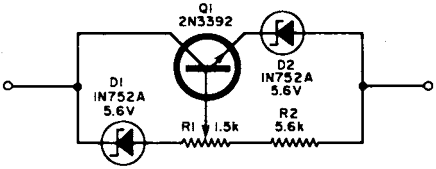
Roger M. Pullem
Director-General
of Transport's Office
Box 1599, G. P. O.
Adelaide, South Australia 5001

Variable Replacement For Zener Diode

By DONALD H. ROGERS
Sr. Adv. Development Engineer
Jerrold Electronics Corp.

The circuit designer often needs a precise or special value of zener voltage for reference or regulation. Suitable zener diodes can be procured, but rarely from stock. A substitute which can be put together from available components is attractive, especially if it can be adjusted at the last minute.

In the circuit shown (which is connected in place of the zener), the input voltage to transistor Q1 is the difference between the applied voltage across the two terminals and the sum of the drops across D1 and D2. When this difference exceeds the semiconductor drop in the base-emitter junction, the transistor begins to conduct, with a very rapid rise in current.



A sample was put together with two random 1N752A's and a 2N3392 with a d.c. beta of 200, and the dynamic impedance was less than 13 ohms throughout the range from 5 to 30 mA. The terminal voltage was adjustable from 11 to 13 volts. ▲

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Zener Diode Voltage-Regulator Nomograms

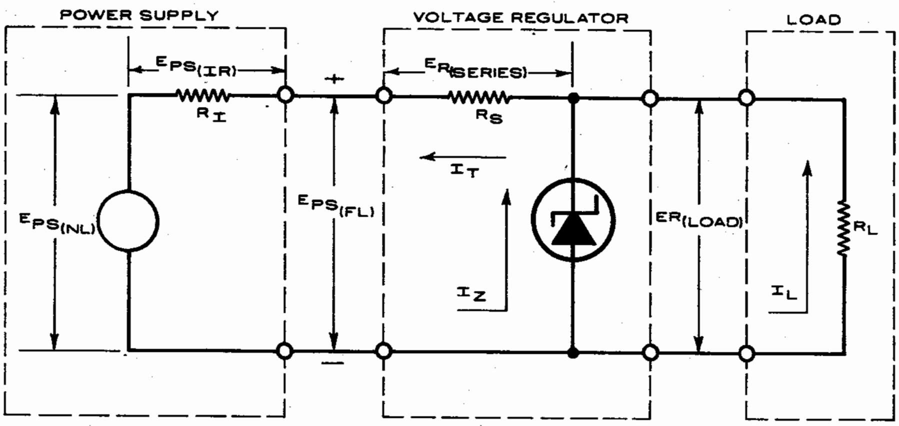


Fig. 1. Basic circuit diagram of the zener-diode regulator.

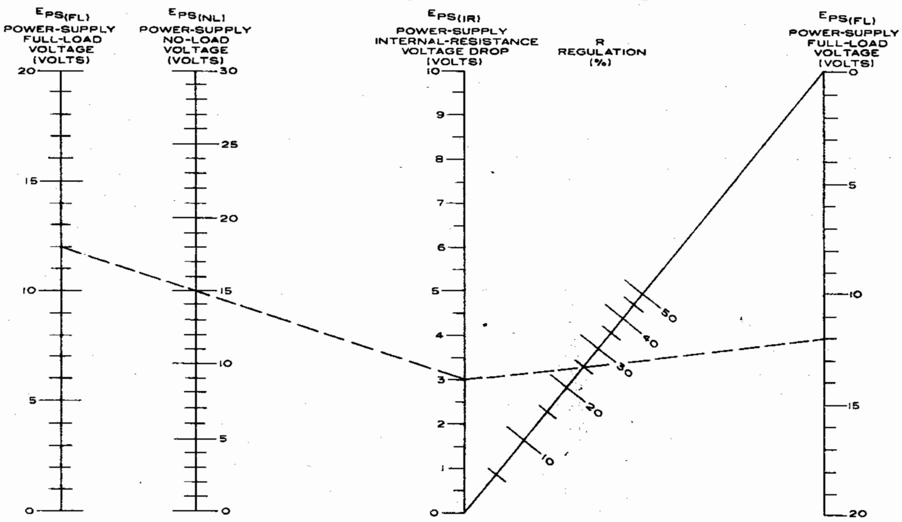
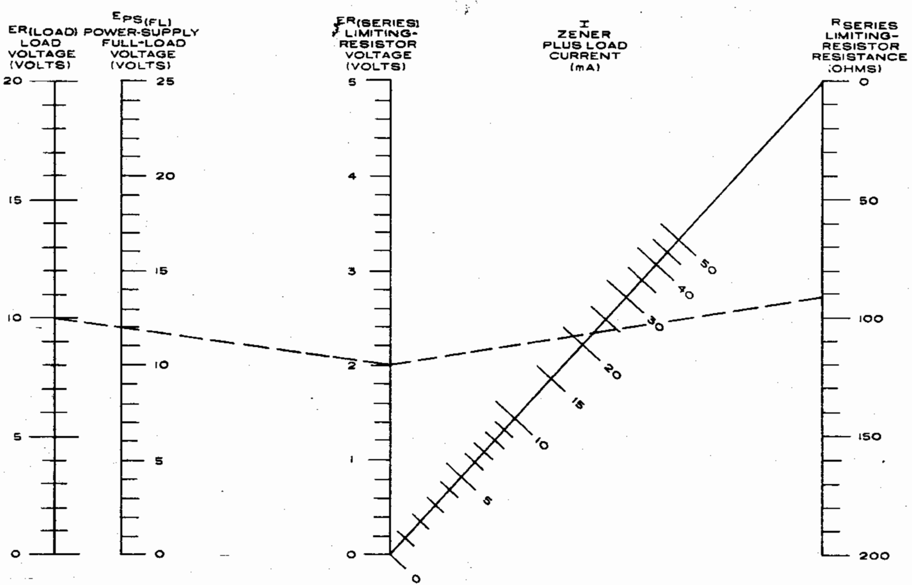


Fig.2. This voltage-regulator design nomogram is used to determine percentage regulation of zener-supply voltage.

Fig.3. The second voltage-regulator design nomogram is used to determine the parameters of the series limiting resistor.



Editor's Note: Although some of the nomograms shown in the following article are used to solve some fairly simple calculations, they do serve to demonstrate the use of nomograms in design work. In most cases, nomograms serve to speed up tedious, time-consuming calculations simply by the user placing a straightedge over the scales of the chart.

THE silicon zener diode is the workhorse of solid-state voltage regulators and simple circuits like that of Fig. 1 are easy to design. Although the regulating action is similar to that of the VR tube, zeners are quite temperature-sensitive so additional calculations are necessary. Four design nomograms have been developed that will help make regulator design fairly routine.

Any voltage-regulator design begins with the load requirements and determination of the voltage variations to be supplied to the regulator from the basic power supply. The nomogram of Fig. 2 shows how the regulation of the supply can be determined. First the no-load voltage is determined analytically or measured. Then a dummy load can be placed across it equal to the full load and the new voltage measured. Regulation is determined by the internal resistance drop and can be expressed by the equation:

$$R = \frac{E_{PS(NL)} - E_{PS(FL)}}{E_{PS(FL)}} \times 100$$

where: R is percentage regulation, $E_{PS(NL)}$ is output voltage of power supply with no load, $E_{PS(FL)}$ is output voltage of power supply with full load, and:

$$E_{PS(NL)} - E_{PS(FL)} = E_{PS(IR)}$$

where: $E_{PS(IR)}$ is voltage drop across the internal resistance of the power supply. These three voltage are shown in Fig. 1 to the left.

The first three scales on the left of Fig. 2 determine the numerator of the first equation and the "Z" scales on the right use the numerator to calculate the regulation.

For example, if an unregulated supply furnishes 15 volts under no-load condition and 12 volts under full dummy load, we have a 3-volt internal resistance drop. If we draw a line between the 3-volt point to the right to a 12-volt point on the fifth scale, we cross the Regulation scale at 25%.

By CHESTER W. YOUNG

Four design charts that can be used to simplify selection of components for a solid-state voltage-regulator circuit.

The second nomogram (Fig. 3) takes the next step and starts with the power-supply full-load voltage. This is combined with the current requirements of the load and the zener to determine the series limiting resistor value. The three scales to the left determine the voltage drop involved and the "Z" scales on the right determine the required resistance. Two equations are:

$$E_{R(series)} = E_{PS(FL)} - E_{R\,(load)}$$

where: $E_{R(series)}$ is voltage across series-dropping resistor, $E_{PS(FL)}$ is voltage output of the power supply under full load, $E_{R(load)}$ is voltage to be maintained across the load by zener diode and:

$$R_{series} = E_{R(series)} / I$$

where: R_{series} is required resistance of the series-dropping resistor and I is the total current to be drawn under regulating conditions.

For example, if we assume that we have been designing for a load that requires 10 volts at 20 milliamperes, we enter the nomogram on the second scale at 12 volts (our power supply full-load voltage) and connect a line to the first scale at the required 10-volt point. Extending this line to the third scale on our right we determine the voltage drop across the resistor to be 2 volts. The "Z" chart on the right helps determine the resistance value if the load current (20 mA) and the zener current (usually 10% of required load current, 2 mA) are known. In this case the total would be 22 mA drawn through the dropping resistor. A line extending from the 2-volt point (3rd scale) to the far-right scale passing through the 22-mA point of the middle "Z" scale would intersect at 91 ohms. This solves the fraction 2/0.022.

The selection of the series resistor is determined by the resistance value just calculated and the maximum current to be drawn through it. The nomogram in Fig. 4 determines the power (center scale) from either of the formulas: $W = EI$ or $W = I^2R$, where W is power (in watts) dissipated in either resistor or zener diode, E is volts across resistor or zener, and I is current through resistor or zener.

For example, we have just determined the series-resistor value to be 91 ohms so we enter this on the second scale from the left. We also know the total load and zener current is 22 mA. This value is entered on the second scale from the right (I^2) at 22 mA. Joining these two points with the solid line,

(Continued on page 75)

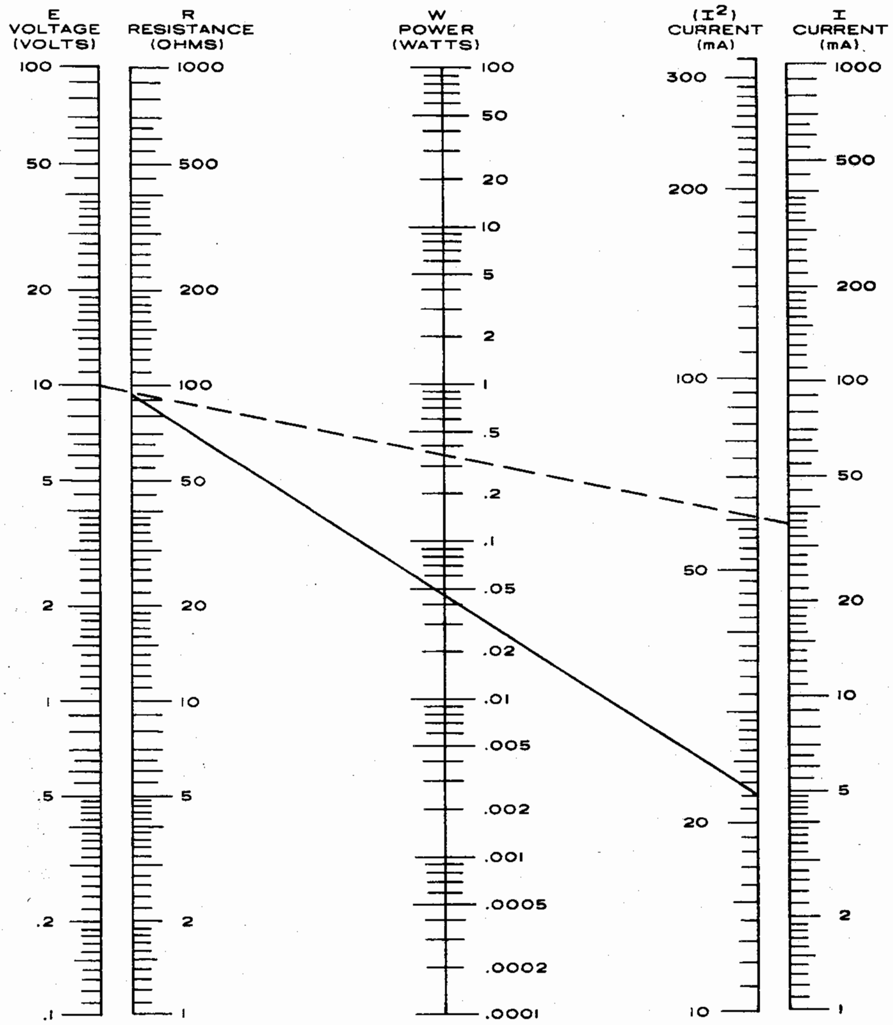
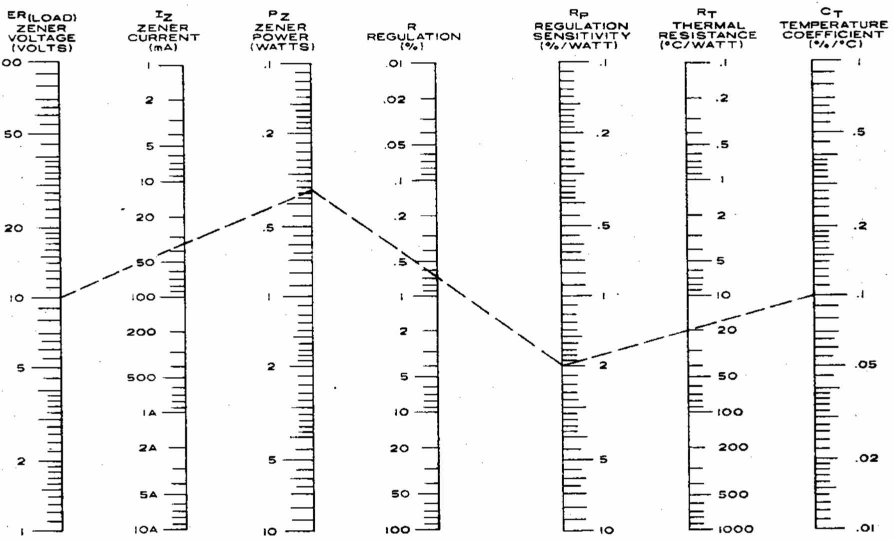


Fig. 4. The third design nomogram is employed to find the power requirements of the series resistor and zener diode.

Fig. 5. This fourth nomogram is used to relate the various zener-diode parameters in order to provide circuit trade-offs.



Regulator Nomograms

(Continued from page 33)

we cross the center (W) scale at 0.044 watt. A half-watt resistor would be more than adequate.

Since we have a 10-volt zener, we enter this value on the first scale on the left. Since the zener will hold the voltage on one side of the series-dropping resistor at 10 volts, then the 15-volt no-load voltage of our power supply will drop 5 volts across the series resistor. This can produce a 55-mA current through the resistor of which 20 mA will be required in the load, leaving 35 mA through the zener. Entering the far-right scale at 35 mA and joining the far-right and far-left scales with a dashed line, we find the zener power to be 0.35 watt. If we assume that it is possible for the load to be disconnected, the latter two numbers could be 55 mA for the zener and 0.55-watt dissipation. Hence, in either case a 1-watt zener would probably provide an adequate safety factor.

The fourth nomogram, Fig. 5, can provide trade-offs to determine the regulation to be expected or can help to determine the parameters necessary to select a zener for a given performance. The first three scales on the left are power-calculation scales using the familiar:

$$P_Z = E_{R(load)} I_Z$$

where: P_Z is zener power consumption, $E_{R(load)}$ is zener and load voltage, and I_Z is zener current.

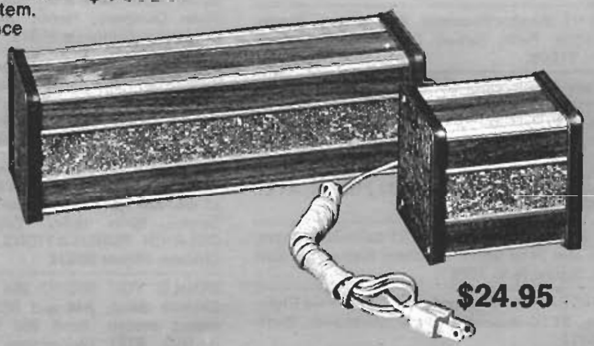
The three scales on the right make use of the manufacturer's data on the zener temperature sensitivity. The two scales on either side of the center (R) scale, P_Z and R_P, are used to determine the final regulation to be expected from our system. These three scales are used with the equation:

$$R_P = C_T R_T$$

where: R_P is regulation sensitivity in percent per watt, C_T is temperature coefficient in percent per °C, and R_T is thermal resistance in °C per watt.

For example, repeating the zener power calculations of the last nomogram using $E = 10$ volts on the left scale, $I = 35$ mA on the second scale, we reach $P = 0.35$ watt on the third scale.

Then if the manufacturer gives the temperature coefficient as 0.10%/°C for the zener we are considering, this value is entered on the far-right scale. If this particular zener also has a thermal resistance of 20°C/watt, this is entered on the R_T scale. A line joining these points and extending to the left will intersect the R_P scale at 2.0%/watt. Now a line joining this point with 0.35 watt on the P_Z scale crosses the R scale at 0.7% which is the over-all expected regulation. ▲



A TAILOR-MADE ZENER DIODE

BY JAMES E. McALISTER

Design your own variable-voltage zener

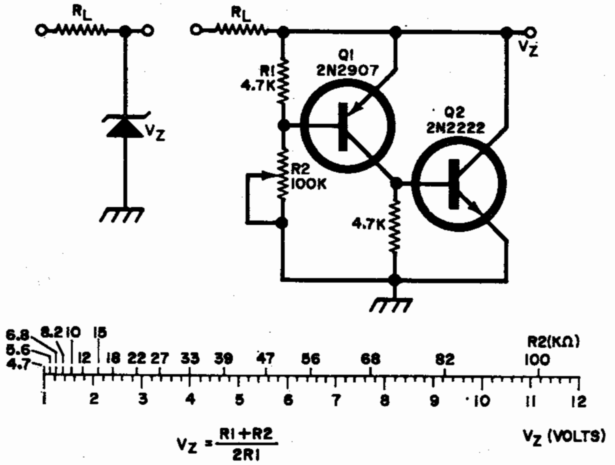
ZENER diodes are powerful circuit elements (as pointed out in "Design Your Own Voltage Regulator," in the April 1973 issue); unfortunately, they are available only in discrete, fixed values of voltage. In some cases, a variable voltage is needed, and a zener will not suffice. In addition, zeners are not commonly available at levels below about 3 volts. This makes it difficult to design simple 1.5-volt regulators for battery replacement.

With only a handful of components, a transistor equivalent of a zener diode can be built for use in any circuit calling for a zener. The output voltage from the "equivalent zener" is variable and can be adjusted to values down to as low as 1 volt and below.

The circuit, shown in the figure, is quite simple. Transistor *Q1*, begins to conduct when the voltage across *R1* reaches approximately 0.5 volt. This causes *Q2* to conduct, but *Q2* draws only enough current through the load resistor to maintain conduction in both *Q1* and *Q2*. The voltage drop across the load resistor is thus the output voltage.

Transistor *Q1* can be almost any silicon pnp transistor, but one with a high current gain is preferable. The parameters of *Q2* are not critical either. The power dissipating capability of the equivalent zener is primarily determined by the power dissipation rating of *Q2*, however, so *Q2* should be selected accordingly. The equivalent zener diode can be used in any circuit where a regular zener would apply.

Resistor *R2* is shown as a variable, but fixed values of resistance may be used if desired. The chart in the figure shows how to determine the resistance for a desired output voltage. Since the voltage does depend to some extent on the characteristics of the transistors, the value of *R2* chosen from the chart may not give the exact desired output, but it will be close. The chart (and the accompanying equation) assumes that *R1* is 4700 ohms. ◆



$$V_Z = \frac{R1 + R2}{2R1}$$

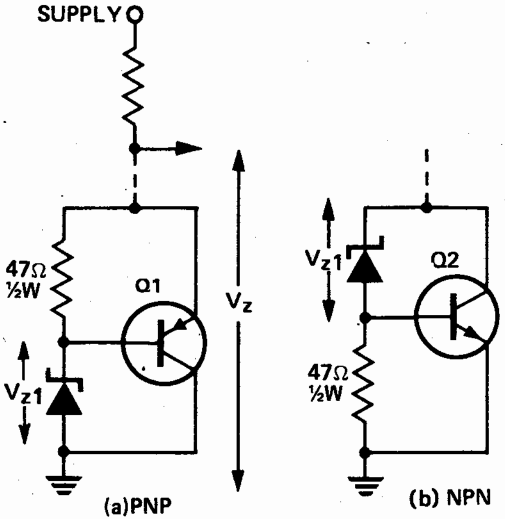
The right-hand circuit, with transistors, simulates the diode circuit at left. Use the chart and the equation to determine the value of R2 to give desired voltage.

HIGH-POWER ZENERED VOLTAGE FROM LOW POWER SOURCES

A power transistor can be used to provide a high power zenered voltage from a low wattage zener. A 400 mW zener can be used where a 10 watt zener is required or a 1 W zener can be used where a 50 to 80 watt zener is required, by using appropriate transistors for Q1 and Q2 in the circuits shown.

Where low rating is required Q1 would be a ASZ 15 (germanium) or an AY9140 (silicon). Q2 could be a 2N3054 (silicon). For higher powers Q1 could be an ASZ18 (germanium) or a 2N2955 (silicon) and Q2 a 2N3055 (silicon) or an AY8149 (silicon).

A heatsink on the transistor is required. The circuit in (a) has the advantage that power transistors can be bolted directly on to a chassis which may serve as a heatsink.



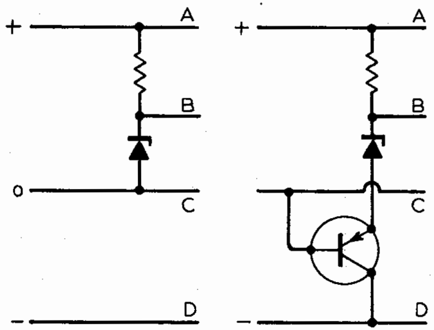
$V_{z1} = V_z - V_{be}$

Q1, Q2 – GERMANIUM OR SILICON POWER TRANSISTOR

V_{be} – GERMANIUM = 0.3V
V_{be} – SILICON = 0.7V

Zero current zener reference

Left-most circuit illustrates a commonly used circuit feature where a zener diode establishes a potential at B with reference to a centre rail C. In certain circuitry it is essential that the zener current be prevented from passing into any load connected between the centre rail, C, and the common rail, D. The circuit arrangement on the right illustrates a means of ensuring that the zener current is bypassed to the common rail D.



$$V_{BC} = V_Z - V_{be}$$

A typical application is where the potential CD is a voltage-regulated supply used to feed a low current into a capacitive load and where the source voltage CD is liable, even if only under transient conditions, to be open-circuited such that the zener current if not by-passed could affect an over-voltage condition at CD.

J. Double
Bangor.

7

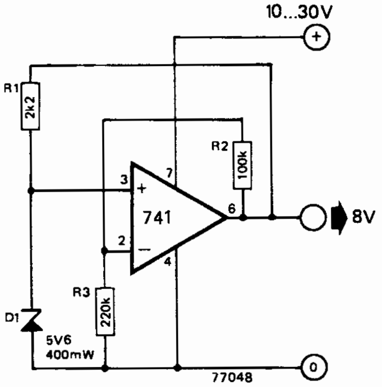
super zener

This circuit is intended primarily to produce a stable reference voltage in battery operated equipment designed for minimum current consumption. Despite the fact that only 1 mA flows through the zener the output voltage showed a fluctuation of less than 1 mV for supply voltage variations of 10 to 30 volts.

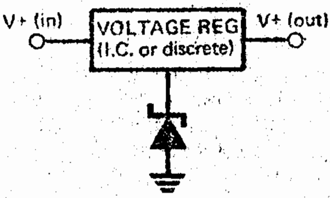
The reference voltage from the zener is applied to the non-inverting input of a 741 op-amp, and the output voltage is the zener voltage multiplied by the op-amp gain i.e. $V_O = V_Z \times \frac{R_2 + R_3}{R_3}$

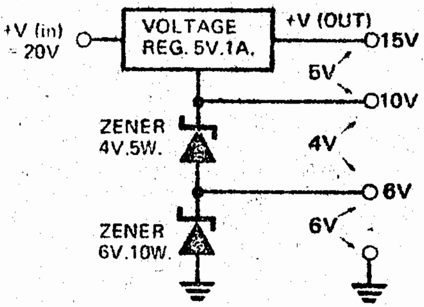
This approach has two advantages. Firstly, a low temperature coefficient zener (5.6 V) can be used to provide any desired reference voltage simply by altering the op-amp gain. Secondly, since no significant current is 'robbed' from the zener by the op-amp input, the zener need only be fed by a small current. So that the resistance of the zener does not affect the output voltage the zener current must be fairly constant. This is achieved by feeding the zener via R1 from the output of the op-amp. The zener current is $\frac{V_O - V_Z}{R_1}$, so R1 should be chosen to give a zener current of about 1 mA. The reference voltage obtained from the op-amp output can supply currents of up to 15 mA.

One point to note when using this circuit is that the supply voltage must be at least 2 V greater than the output voltage of the circuit.



ZENER BOOSTS OUTPUT VOLTAGE OF REGULATOR





In this circuit the zener diode raises all voltages — with respect to earth — by the zener voltage, i.e.

Vin (max) ≏ voltage regulator Vin (max) + zener voltage

Vin (working min) ≏ voltage regulator Vin (min) + zener voltage

Vout = voltage regulator Vout + zener voltage

As the voltage regulator dissipates all excess power while the zener merely clamps the output voltage above its own voltage, a low wattage zener (250 mW) should be adequate — unless lower voltage taps are used, as in the second example in which the total output is one amp.

For other value zeners, wattages can be worked out by the formula W = zener voltage X current.