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PDS

Electronics Basic

Diode Zenner

Acknowledgement

I want to express my gratitude to Prentice Hall giving me the permission to use instructor's material for developing this module. I would like to thank the Department of Electrical Engineering. I hope this module is helpful to enhance our students' academic performance.

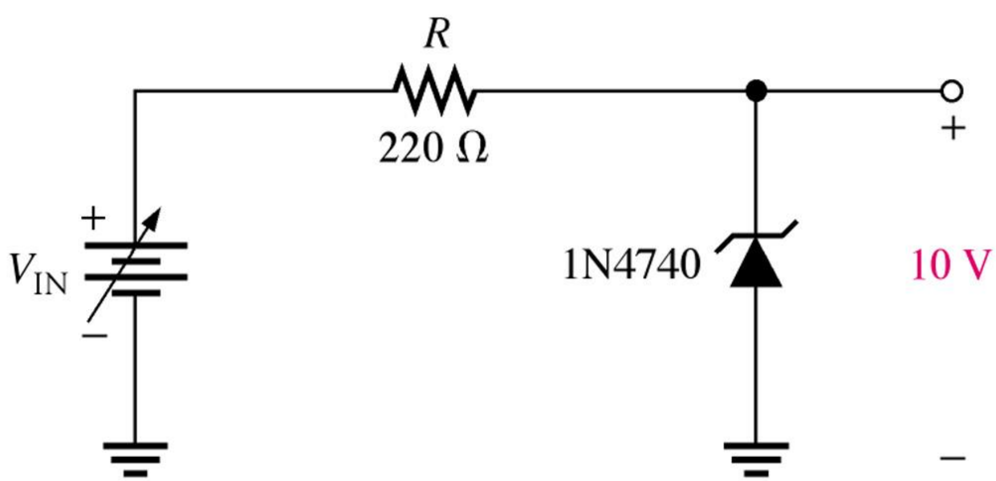
Outlines

- **Introduction to Zener Diode**
- **Voltage regulation and limiting**
- **The varactor diode**
- **LEDs and photodiodes**
- **Special Diodes**

Key Words: Zener Diode, Voltage Regulation, LED, Photodiode, Special Diode

Introduction

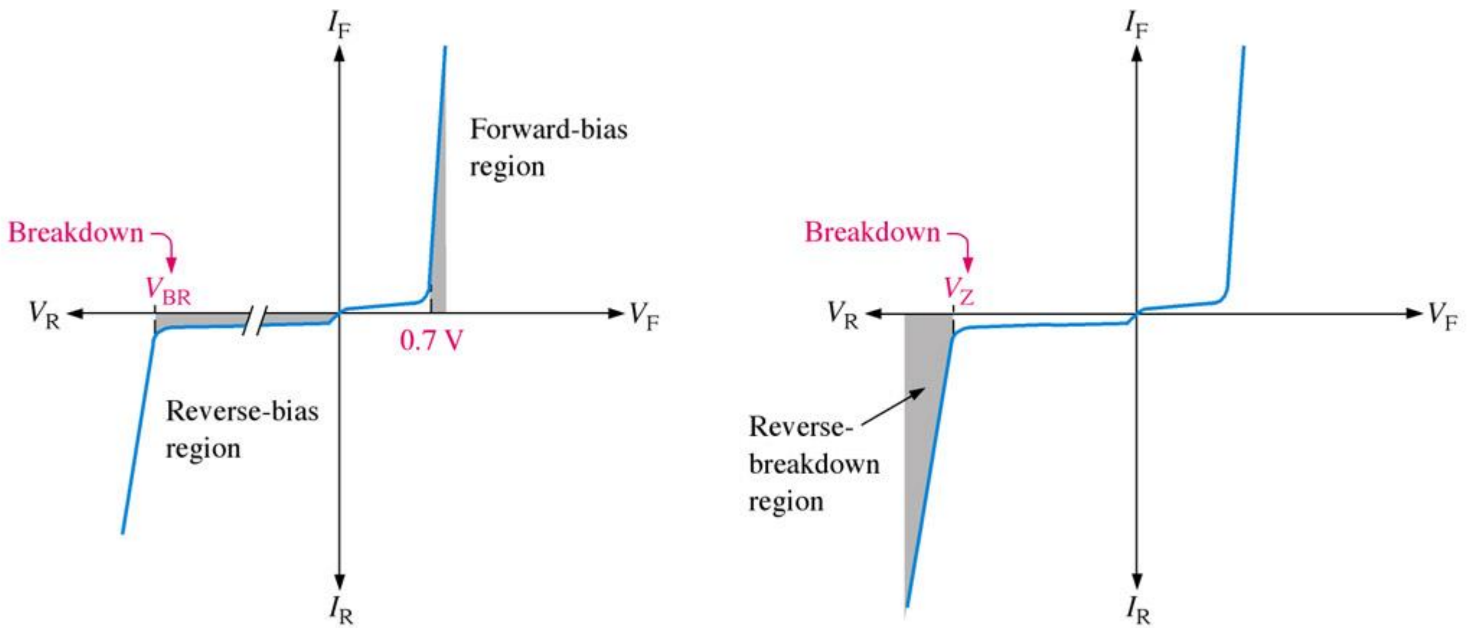
The **zener diode** is a silicon pn junction devices that differs from rectifier diodes because *it is designed for operation in the reverse-breakdown region*. The breakdown voltage of a zener diode is set by carefully controlling the level during manufacture. The basic function of **zener diode** is to maintain a specific voltage across it's terminals within given limits of line or load change. Typically it is used for providing a stable reference voltage for use in power supplies and other equipment.



This particular zener circuit will work to maintain 10 V across the load.

Zener Diodes

A **zener diode** is much like a normal diode. The exception being is that it is placed in the circuit in reverse bias and operates in reverse breakdown. This typical characteristic curve illustrates the operating range for a zener. Note that it's forward characteristics are just like a normal diode.



(a) The normal operating regions for a rectifier diode are shown as shaded areas.

(b) The normal operating region for a zener diode is shaded.

Volt-ampere characteristic is shown in this Figure with normal operating regions for rectifier diodes and for zener diodes shown as shaded areas.

Zener Breakdown

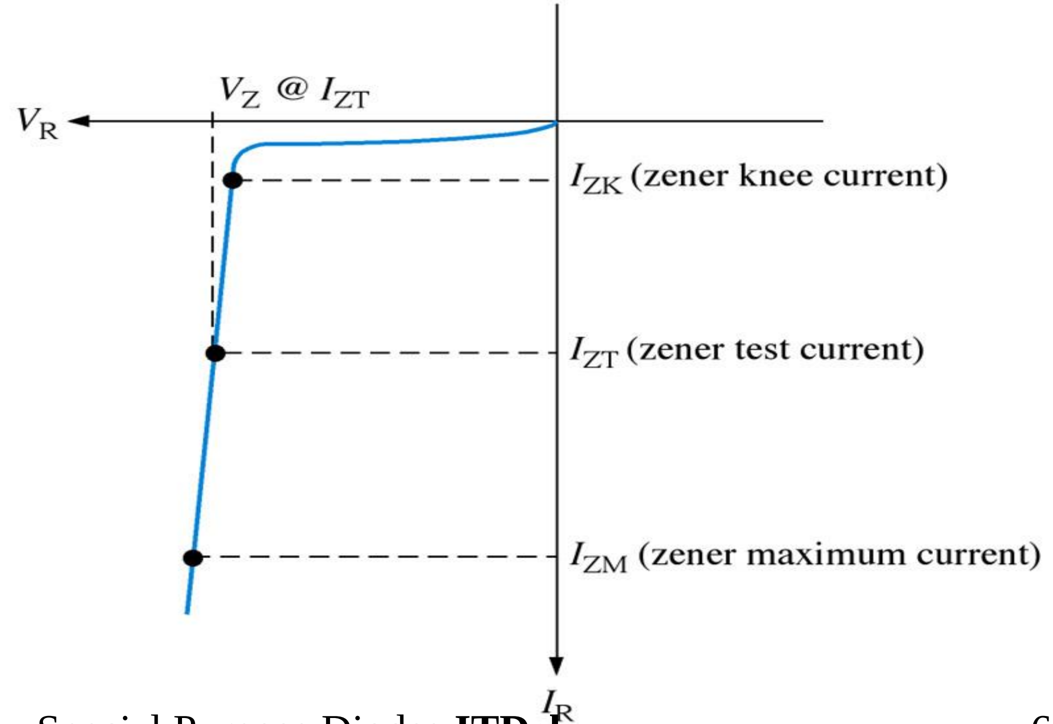
Zener diodes are designed to operate in reverse breakdown. Two types of reverse breakdown in a zener diode are *avalanche* and *zener*. The avalanche break down occurs in both rectifier and zener diodes at a sufficiently high reverse voltage. **Zener breakdown** occurs in a zener diode at low reverse voltages.

A zener diode is heavily doped to reduced the breakdown voltage. This causes a very thin depletion region. As a result, an intense electric field exists within the depletion region. Near the zener breakdown voltage (V_z), the field is intense enough to pull electrons from their valence bands and create current. The zener diodes breakdown characteristics are determined by the doping process

Low voltage zeners less than 5V operate in the zener breakdown range. Those designed to operate more than 5 V operate mostly in **avalanche breakdown** range. Zeners are commercially available with voltage breakdowns of **1.8 V to 200 V**.

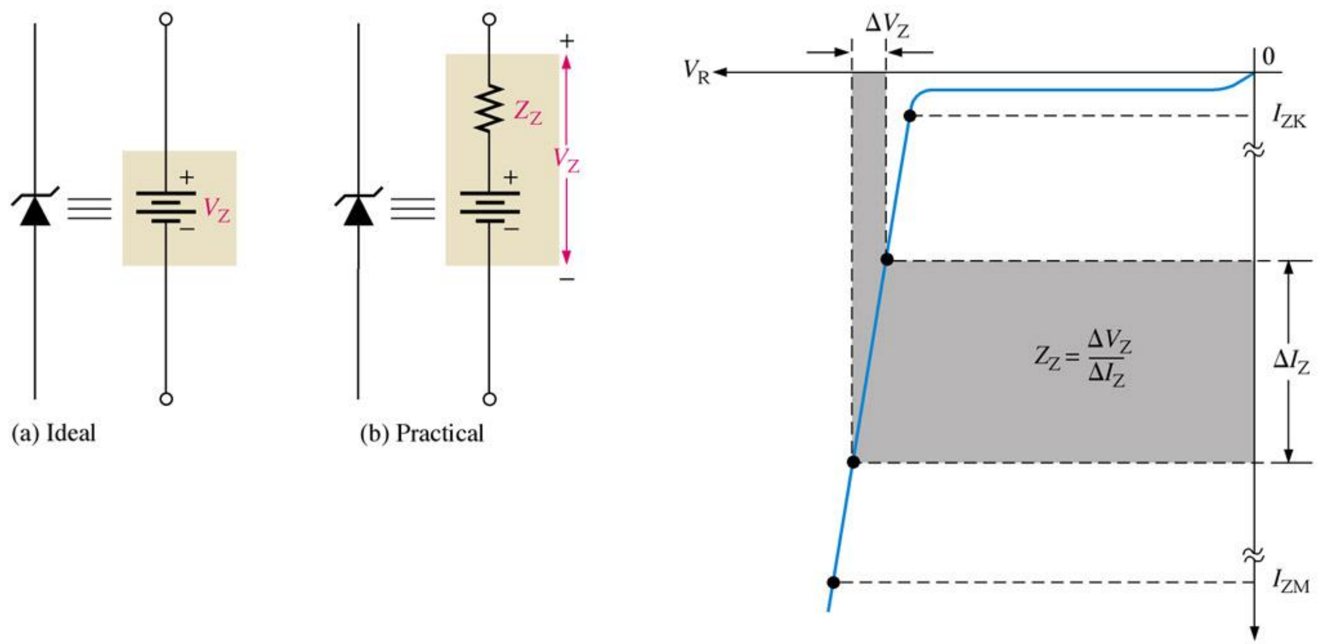
Breakdown Characteristics

Figure shows the reverse portion of a zener diode’s characteristic curve. As the reverse voltage (V_R) is increased, the reverse current (I_R) remains extremely small up to the “knee” of the curve. The reverse current is also called the zener current, I_Z. At this point, the breakdown effect begins; the internal zener resistance, also called zener impedance (Z_Z), begins to decrease as reverse current increases rapidly.



Zener Equivalent Circuit

Figure (b) represents the practical model of a zener diode, where the zener impedance (Z_Z) is included. Since the actual voltage curve is not ideally vertical, a change in zener current (ΔI_Z) produces a small change in zener voltage (ΔV_Z), as illustrated in Figure (c).

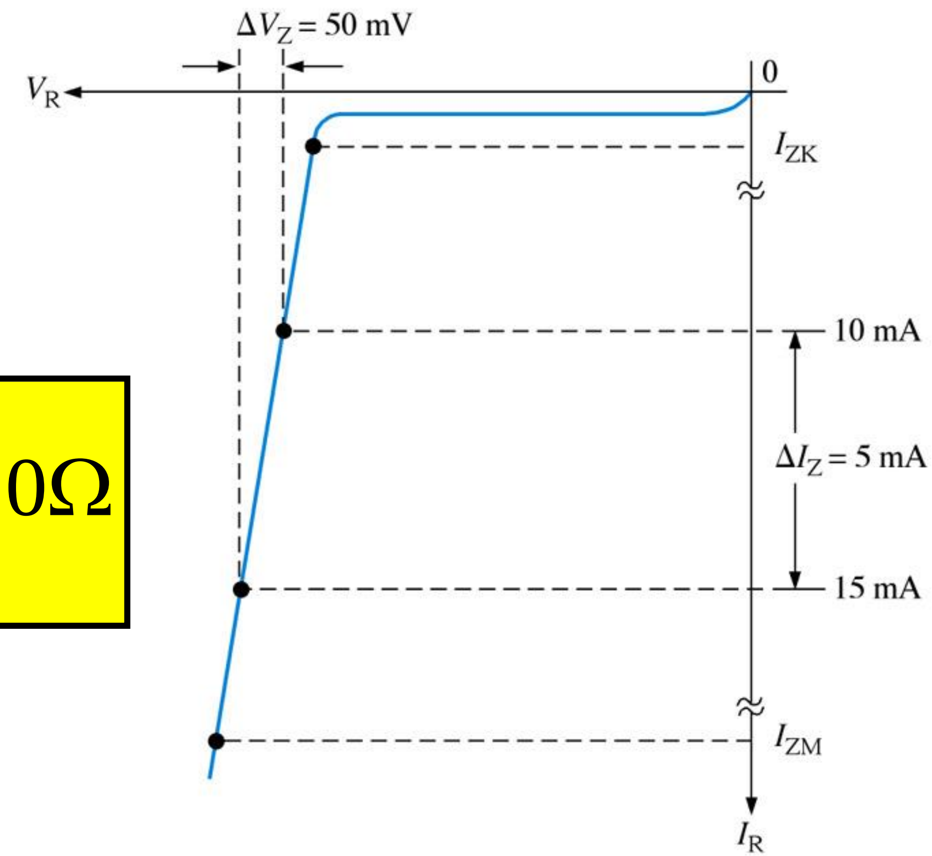


(a) Ideal (b) Practical (c) Characteristic curve

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

Zener diode equivalent circuit models and the characteristic curve illustrating Z_Z.

Ex 5-1 A zener diode exhibits a certain change in V_Z for a certain change in I_Z on a portion of the linear characteristic curve between I_{ZK} and I_{ZM} as illustrated in Figure. What is the zener impedance?



$$Z_Z = \frac{V_Z}{I_Z} = \frac{50mV}{5mV} = 10\Omega$$

Zener diode Data Sheet Information

Maximum Ratings

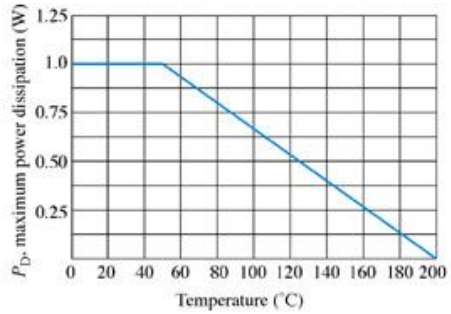
Rating	Symbol	Value	Unit
DC power dissipation @ $T_A = 50°C$ Derate above 50°C	P_D	1.0 6.67	Watt mW/°C
Operating and storage junction Temperature range	T_J, T_{stg}	–65 to +200	°C

Electrical Characteristics ($T_A = 25°C$ unless otherwise noted) $V_F = 1.2$ V max, $I_F = 200$ mA for all types.

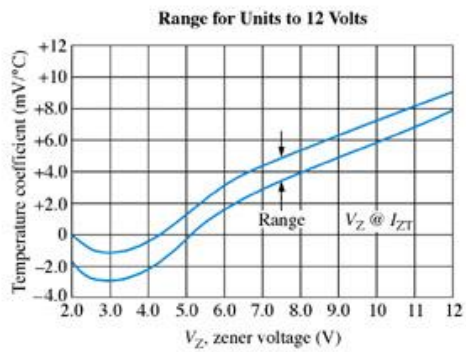
JEDEC Type No. (Note 1)	Nominal Zener Voltage V_Z @ I_{ZT} Volts	Test Current I_{ZT} mA	Maximum Zener Impedance Z_{ZT} @ I_{ZT} Ohms	Z_{ZK} @ I_{ZK} Ohms	I_{ZK} mA	Leakage Current I_R µA Max	V_R Volts
1N4728	3.3	76	10	400	1.0	100	1.0
1N4729	3.6	69	10	400	1.0	100	1.0
1N4730	3.9	64	9.0	400	1.0	50	1.0
1N4731	4.3	58	9.0	400	1.0	10	1.0
1N4732	4.7	53	8.0	500	1.0	10	1.0
1N4733	5.1	49	7.0	550	1.0	10	1.0
1N4734	5.6	45	5.0	600	1.0	10	2.0
1N4735	6.2	41	2.0	700	1.0	10	3.0
1N4736	6.8	37	3.5	700	1.0	10	4.0
1N4737	7.5	34	4.0	700	0.5	10	5.0
1N4738	8.2	31	4.5	700	0.5	10	6.0
1N4739	9.1	28	5.0	700	0.5	10	7.0
1N4740	10	25	7.0	700	0.25	10	7.6
1N4741	11	23	8.0	700	0.25	5.0	8.4
1N4742	12	21	9.0	700	0.25	5.0	9.1
1N4743	13	19	10	700	0.25	5.0	9.9
1N4744	15	17	14	700	0.25	5.0	11.4
1N4745	16	15.5	16	700	0.25	5.0	12.2
1N4746	18	14	20	750	0.25	5.0	13.7
1N4747	20	12.5	22	750	0.25	5.0	15.2
1N4748	22	11.5	23	750	0.25	5.0	16.7
1N4749	24	10.5	25	750	0.25	5.0	18.2
1N4750	27	9.5	35	750	0.25	5.0	20.6
1N4751	30	8.5	40	1000	0.25	5.0	22.8
1N4752	33	7.5	45	1000	0.25	5.0	25.1
1N4753	36	7.0	50	1000	0.25	5.0	27.4
1N4754	39	6.5	60	1000	0.25	5.0	29.7
1N4755	43	6.0	70	1500	0.25	5.0	32.7
1N4756	47	5.5	80	1500	0.25	5.0	35.8
1N4757	51	5.0	95	1500	0.25	5.0	38.8
1N4758	56	4.5	110	2000	0.25	5.0	42.6
1N4759	62	4.0	125	2000	0.25	5.0	47.1
1N4760	68	3.7	150	2000	0.25	5.0	51.7
1N4761	75	3.3	175	2000	0.25	5.0	56.0
1N4762	82	3.0	200	3000	0.25	5.0	62.2
1N4763	91	2.8	250	3000	0.25	5.0	69.2
1N4764	100	2.5	350	3000	0.25	5.0	76.0

NOTE 1 — Tolerance and Type Number Designation. The JEDEC type numbers listed have a standard tolerance on the nominal zener voltage of ±10%. A standard tolerance of ±5% on individual units is also available and is indicated by suffixing "A" to the standard type number. C for ±2.0%, D for ±1.0%.

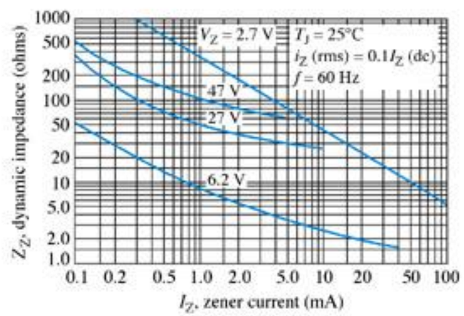
(a) Electrical characteristics



(b) Power derating



(c) Temperature coefficient



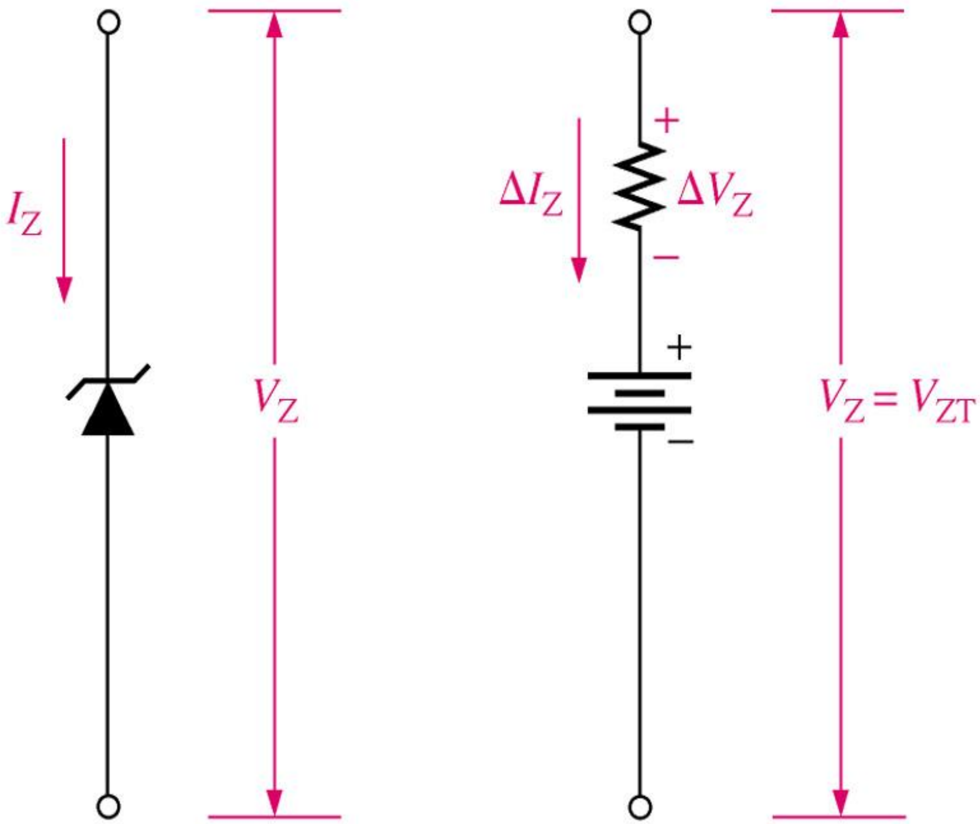
(d) Effect of zener current on zener impedance

As with most devices, zener diodes have given characteristics such as temperature coefficients and power ratings that have to be considered. The data sheet provides this information.

- V_Z: zener voltage
- I_{ZT}: zener test current
- Z_{ZT}: zener Impedance
- I_{ZK}: zener knee current
- I_{ZM}: maximum zener current

Partial data sheet for the 1N4728-1N4764 series 1 W zener diodes.

Ex 5-2 A IN4756 zener diode has a Z_{ZT} of 5.5 Ω. The data sheet gives V_{ZT} = 6.8 V at I_{ZT} = 57 mA and I_{ZK} = 1 mA. What is the voltage across the zener terminals when the current is 50 mA? When the current is 25 mA?



$\Delta I_Z = I_Z - I_{ZT} = +\ 15$ mA

$\Delta V_Z = \Delta I_Z\, Z_{ZT} = (15\ \text{mA})(5.5\ \Omega)$
$= +45.5\text{mV}$

$V_Z = 6.8\ \text{V} + \Delta V_Z$
$= 6.8\ \text{V} + 45.5\ \text{mV} = 6.85\text{V}$

$\Delta I_Z = -\ 12$ mA

$\Delta V_Z = \Delta I_Z\, Z_{ZT}$
$= (-12\ \text{mA})(5.5\ \Omega)$
$= -\ 42$ mV

$V_Z = 6.8\ \text{V} - \Delta V_Z = 6.8\ \text{V} - 42\ \text{mV} = 6.76\text{V}$

The **temperature coefficient** specifies the percent change in zener voltage for each ^{o}C change in temperature. For example, a 12 V zener diode with a positive temperature coefficient of $0.01\%/^{o}C$ will exhibit a 1.2 mV increase in V_Z when the junction temperature increases one Celsius degree.

$$\Delta V_Z = V_Z \times TC \times \Delta T$$

Where V_Z is the nominal zener voltage at 25 ^{o}C, TC is the temperature coefficient, and ΔT is the change in temperature.

Ex 5-5 An 8.2 V zener diode (8.2 V at 25 ^{o}C) has a positive temperature coefficient of 0.05 $\%/^{o}C$. What is the zener voltage at 60 ^{o}C?

The change in zener voltage is

$$\Delta V_Z = V_Z \times TC \times \Delta T = (8.2\ V)(0.05\ \%/^{o}C)(60\ ^{o}C - 25\ ^{o}C)$$

$$= (8.2\ V)(0.0005/^{o}C)(55\ ^{o}C) = 144\ mV$$

Notice that $0.05\%/^{o}C$ was converted to $0.0005/^{o}C$. The zener voltage at 60 ^{o}C is

$$V_Z + \Delta V_Z = 8.2\ V + 144\ mV = 8.54\ V$$

Zener Power Dissipating and Derating

Zener diodes are specified to operate at a maximum power called the maximum dc power dissipation, $P_{D(max)}$.

$$P_D = V_Z I_Z$$

The maximum power dissipation of a zener diode is typically specified for temperature at or below a certain value (50 °C, for example). The derating factor is expressed in mW/°C. The maximum derated power can be determined with the following formula:

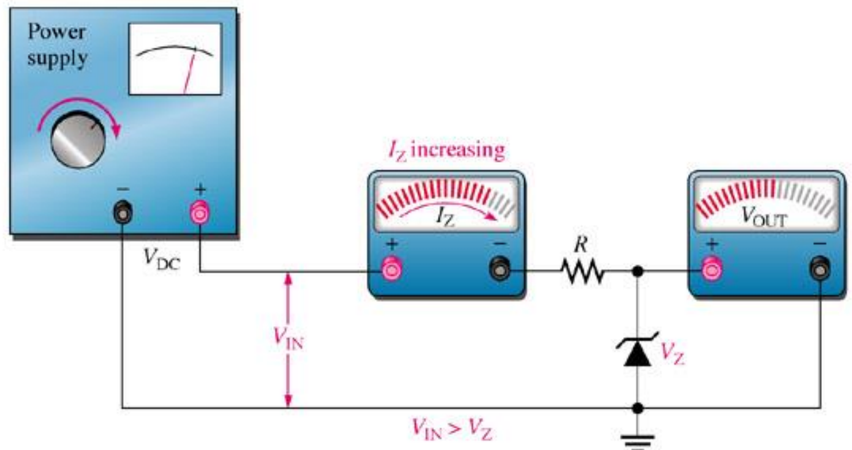
$$P_{D(derated)} = P_{D(max)} - (mW/^{o}C)\Delta T$$

Ex 5-4 A certain zener diode has a maximum power rating of 400 mW at 50 °C and a derating factor of 5.2 mW/°C. Determine the maximum power the zener can dissipate at a temperature of 90 °C.

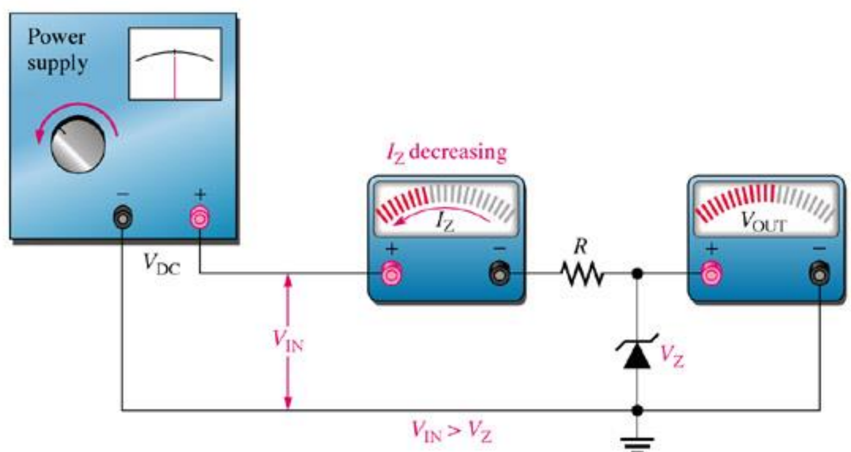
$$\begin{aligned} P_{D(derated)} &= P_{D(max)} - (mW/^{o}C)\Delta T \\ &= 400\text{ mW} - (5.2\text{ mW}/^{o}C)(90^{o}C - 50\ ^{o}C) \\ &= 400\text{ mW} - 128\text{ mW} = 272\text{ mW} \end{aligned}$$

Zener Diode Applications –

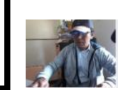
Zener Regulation with a Varying Input Voltage



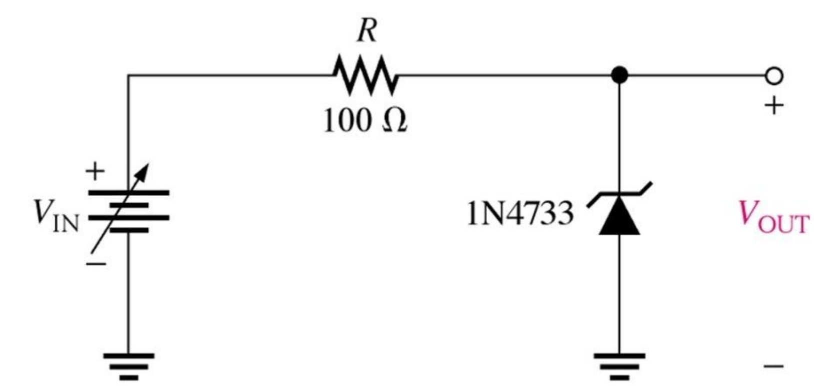
(a) As the input voltage increases, the output voltage remains constant ($I_{ZK} < I_Z < I_{ZM}$).



(b) As the input voltage decreases, the output voltage remains constant ($I_{ZK} < I_Z < I_{ZM}$).



Ex 5-5 Determine the minimum and the maximum input voltages that can be regulated by the zener diode in Figure.



From the data sheet in Figure, the following information for the IN4755 is obtained:
V_Z = 5.1 V at I_{ZT} = 49 mA, I_{ZK} = 1 mA, and Z_Z = 7 Ω at I_{ZT}.

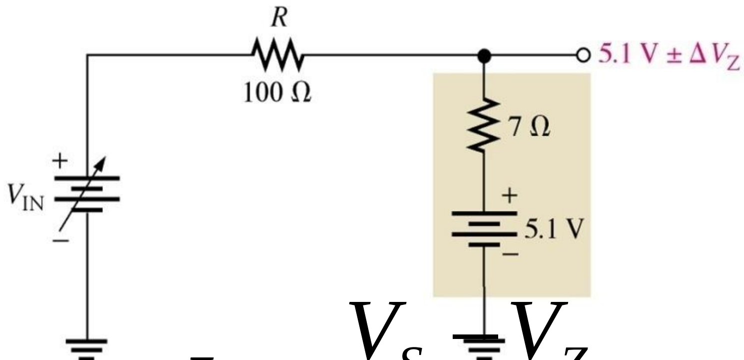
$V_{OUT} \approx 5.1V - \Delta V_Z = 5.1\text{ V} - (I_{ZT} - I_{ZK})Z_Z$
$= 5.1\text{ V} - (48\text{ mA})(7\ \Omega) = 5.1\text{ V} - 0.556\text{ V}$
$= 4.76\text{ V}$

$V_{IN(min)} = I_{ZK}R + V_{OUT}$
$= (1\text{ mA})(100\ \Omega) + 4.76\text{ V} = 4.86\text{ V}$

$$I_{ZM} = \frac{P_{D(\max)}}{V_z} = \frac{1W}{5.1V} = 196\,mA$$

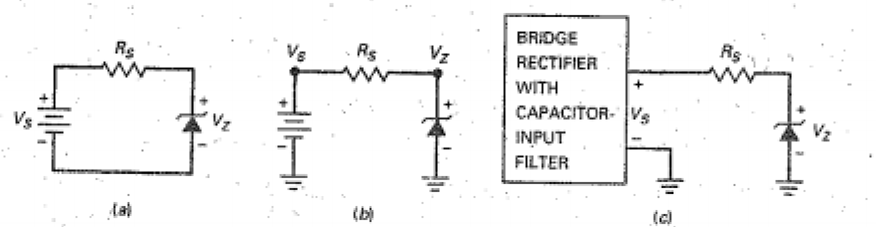
$V_{OUT} \approx 5.1V - \Delta V_Z = 5.1\text{ V} + (I_{ZM} - I_{ZT})Z_Z$
$= 5.1\text{ V} + (147\text{ mA})(7\ \Omega) = 5.1\text{ V} + 1.05\text{ V}$
$= 6.15\text{ V}$

$V_{IN(min)} = I_{ZM}R + V_{OUT}$
$= (196\text{ mA})(100\ \Omega) + 6.15\text{ V} = 25.7\text{ V}$



$$I_S = \frac{V_S - V_Z}{R}$$

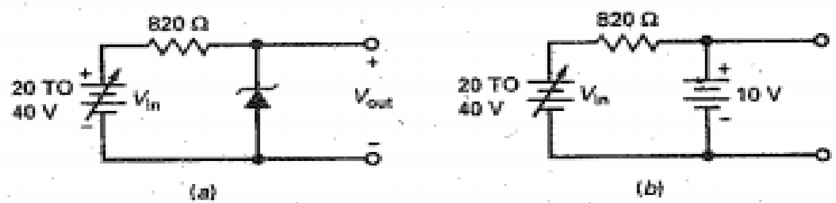
Figure 5-2 Zener regulator. (a) Basic circuit; (b) same circuit with grounds; (c) power supply drives regulator.



Example 5-1

Suppose the zener diode of Fig. 5-4*a* has a breakdown voltage of 10 V. What are the minimum and maximum zener currents?

Figure 5-4 Example.



SOLUTION The applied voltage may vary from 20 to 40 V. Ideally, a zener diode acts like the battery shown in Fig. 5-4*b*. Therefore, the output voltage is 10 V for any source voltage between 20 and 40 V.

The minimum current occurs when the source voltage is minimum. Visualize 20 V on the left end of the resistor and 10 V on the right end. Then you can see that the voltage across the resistor is 20 V − 10 V, or 10 V. The rest is Ohm's law:

$$I_S = \frac{10\ \text{V}}{820\ \Omega} = 12.2\ \text{mA}$$

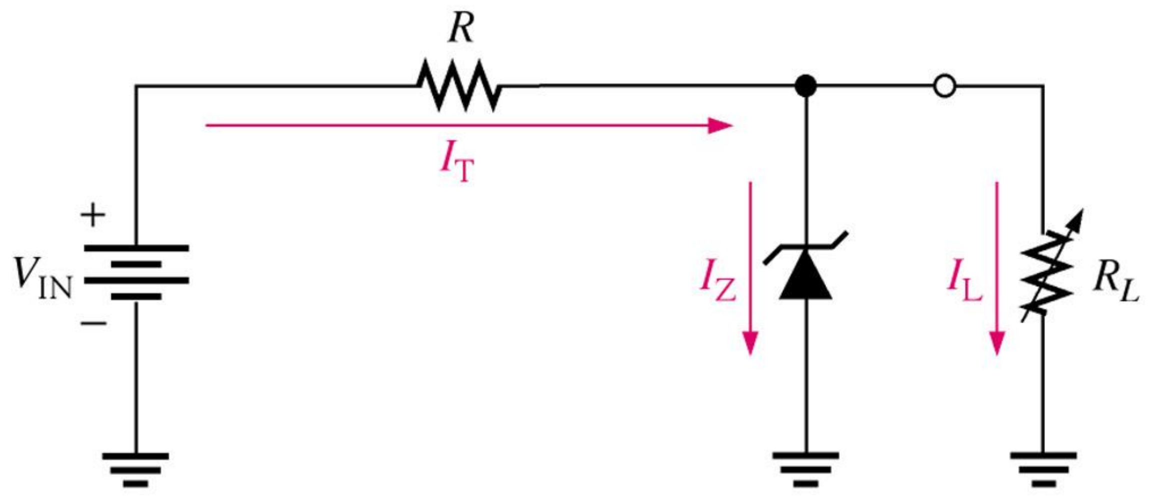
The maximum current occurs when the source voltage is 40 V. In this case, the voltage across the resistor is 30 V, which gives a current of

$$I_S = \frac{30\ \text{V}}{820\ \Omega} = 36.6\ \text{mA}$$

In a voltage regulator like Fig. 5-4*a*, the output voltage is held constant at 10 V, despite the change in source voltage from 20 to 40 V. The larger source voltage produces more zener current, but the output voltage holds rock-solid at 10 V. (If the zener resistance is included, the output voltage increases slightly when the source voltage increases.)

Zener Regulation with a Variable Load

In this simple illustration of zener regulation circuit, the zener diode will "adjust" its impedance based on varying input voltages and loads (R_L) to be able to maintain its designated zener voltage. ***Zener current will increase or decrease directly with voltage input changes***. The zener current will increase or decrease inversely with varying loads. Again, the zener has a finite range of operation.



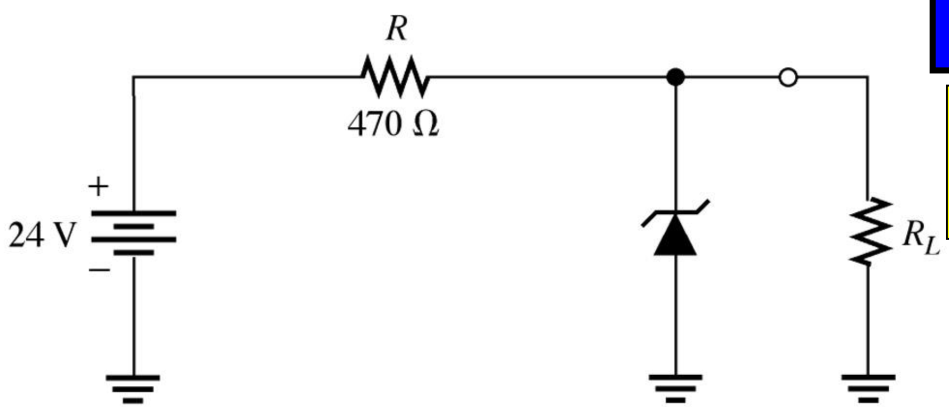
$$V_L = V_Z$$

$$I_L = \frac{V_L}{R_L}$$

$$I_s = I_Z - I_L$$

$$I_Z = I_S - I_L$$

Ex 5-6 Determine the minimum and the maximum load currents for which the zener diode in Figure will maintain regulation. What is the minimum R_L that can be used? V_Z = 12 V, I_{ZK} = 1 mA, and I_{ZM} = 50 mA. Assume Z_Z = 0 Ω and V_Z remains a constant 12 V over the range of current values, for simplicity.



When I_L = 0 A ($R_L = \infty$), I_Z is maximum

$$I_{Z(\max)} = I_T = \frac{V_{IN} - V_Z}{R}$$

$$= \frac{24V - 12V}{470\Omega} = 25.5mA$$

Since $I_{Z(max)}$ is less than I_{ZM}, 0 A is an acceptable minimum value for I_L because the zener can handle all of the 25.5 mA. **$I_{L(min)}$ = 0 A**

The maximum value of I_L occurs when I_Z is minimum ($I_Z = I_{ZK}$),

$I_{L(max)} = I_T - I_{ZK}$ = 25.5 mA – 1mA = 24.5 mA

The minimum value of RL is

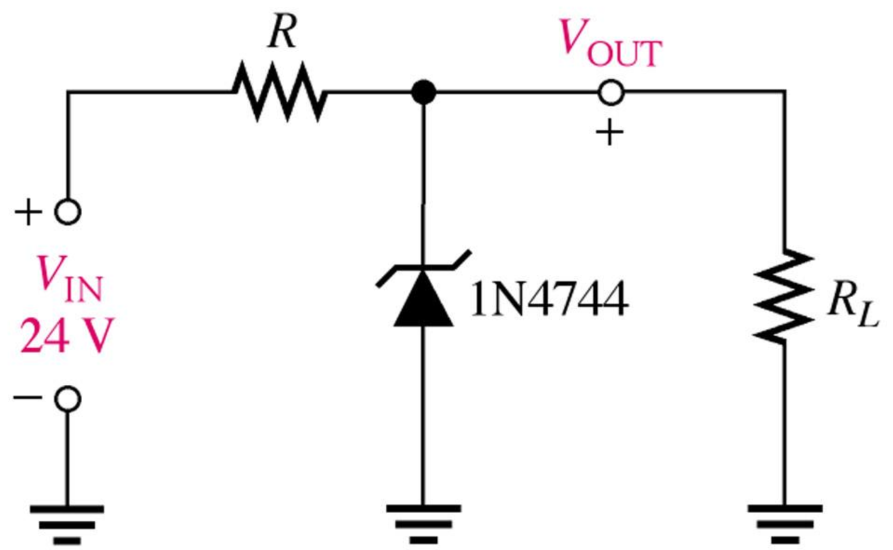
$R_{L(min)} = V_Z/I_{L(max)}$ = 12 V/24.5 mA = 490 Ω

Ex 5-7 For the circuit in Figure:

(a) Determine V_{OUT} at I_{ZK} and I_{ZM}.

(b) Calculate the value of R that should be used.

(c) Determine the minimum value of R_L that can be used.



(a) For I_{ZK}:

$$V_{OUT} = V_Z = 15\text{ V} - \Delta I_Z Z_{ZT}$$
$$= 15\text{ V} - (I_{ZT} - I_{ZK})Z_{ZT}$$
$$= 15\text{ V} - (16.75\text{ mA})(14\Omega)$$
$$= 15\text{ V} - 0.255\text{ V} = 14.76\text{ V}$$

Calculate the zener maximum current. The power dissipation is 1 W.

$$I_{ZM} = \frac{P_{D(\max)}}{V_Z} = \frac{1W}{15V} = 66.7mA$$

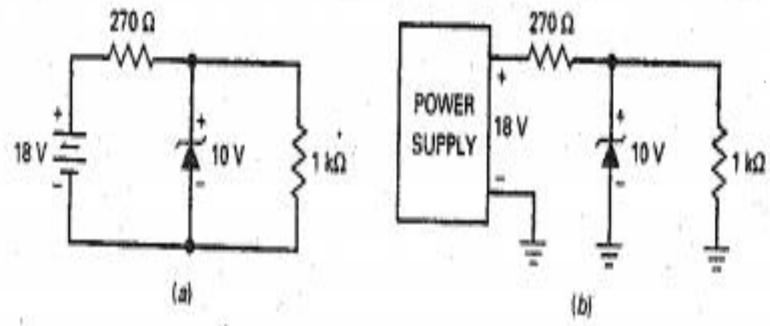
For I_{ZM}:

$$V_{OUT} = V_Z = 15\text{ V} + \Delta I_Z Z_{ZT} = 15\text{ V} + (I_{ZM} - I_{ZT})Z_{ZT}$$
$$= 15\text{ V} + (49.7\text{ mA})(14\Omega) = 15.7\text{ V}$$

Example 5-2

Is the zener diode of Fig. 5-6*a* operating in the breakdown region?

Figure 5-6 Example.



SOLUTION With Eq. (5-2):

$$V_{TH} = \frac{1\ \text{k}\Omega}{270\ \Omega + 1\ \text{k}\Omega}(18\ \text{V}) = 14.2\ \text{V}$$

Since this Thevenin voltage is greater than the zener voltage, the zener diode is operating in the breakdown region.

Example 5-3

MultiSim

What does the zener current equal in Fig. 5-6*b*?

SOLUTION You are given the voltage on both ends of the series resistor. Subtract the voltages, and you can see that 8 V is across the series resistor. Then Ohm's law gives:

$$I_S = \frac{8\ \text{V}}{270\ \Omega} = 29.6\ \text{mA}$$

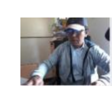
Since the load voltage is 10 V, the load current is:

$$I_L = \frac{10\ \text{V}}{1\ \text{k}\Omega} = 10\ \text{mA}$$

The zener current is the difference between the two currents:

$$I_Z = 29.6\ \text{mA} - 10\ \text{mA} = 19.6\ \text{mA}$$

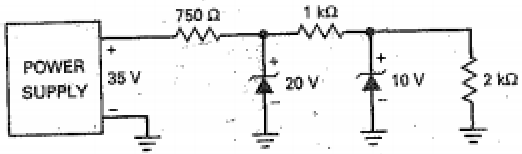
PRACTICE PROBLEM 5-3 Using Fig. 5-6*b*, change the power supply to 15 V and calculate I_S, I_L, and I_Z.



Example 5-4

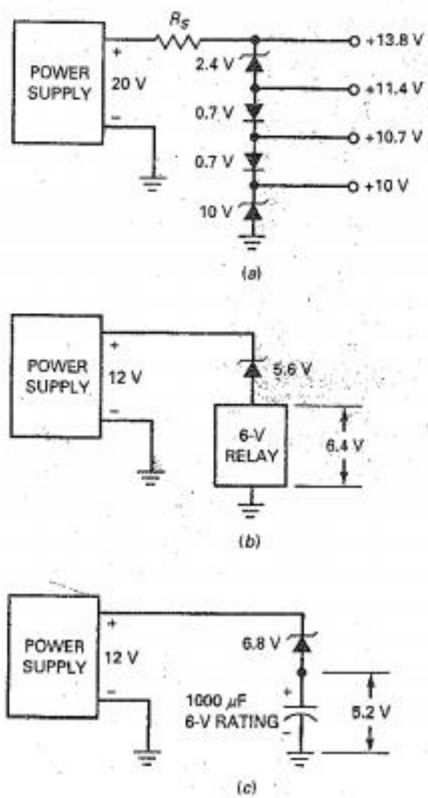
What does the circuit of Fig. 5-7 do?

Figure 5-7 Example.



SOLUTION This is an example of a **preregulator** (the first zener diode) driving a zener regulator (the second zener diode). First, notice that the preregulator has an output voltage of 20 V. This is the input to the second zener regulator, whose output is 10 V. The basic idea is to provide the second regulator with a well-regulated input, so that the final output is extremely well regulated.

Figure 5-9 Zener applications. (*a*) Producing nonstandard output voltages; (*b*) using a 6-V relay in a 12-V system; (*c*) using a 6-V capacitor in a 12-V system.



(b) The value of R is calculated for the maximum zener current that occurs when there is no load as shown in Figure (a).

$$R = \frac{V_{IN} - V_Z}{I_{ZM}} = \frac{24V - 15.7V}{66.7mA} = 124\Omega$$

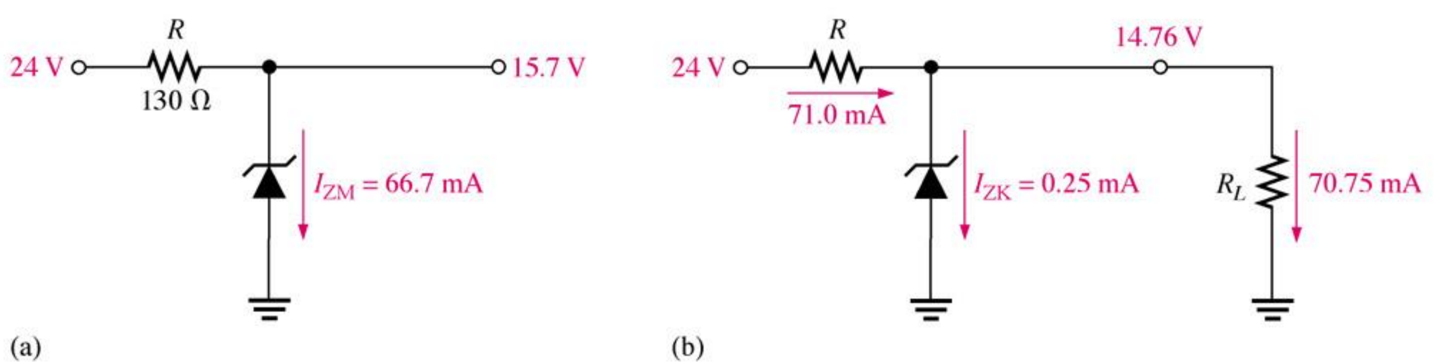
R = 150 Ω (nearest larger standard value).

(c) For the minimum load resistance (maximum load current), the zener current is minimum (I_{ZK} = 0.25 mA) as shown in Figure (b).

$$I_T = \frac{V_{IN} - V_{OUT}}{R} = \frac{24V - 14.76V}{130\Omega} = 71.0mA$$

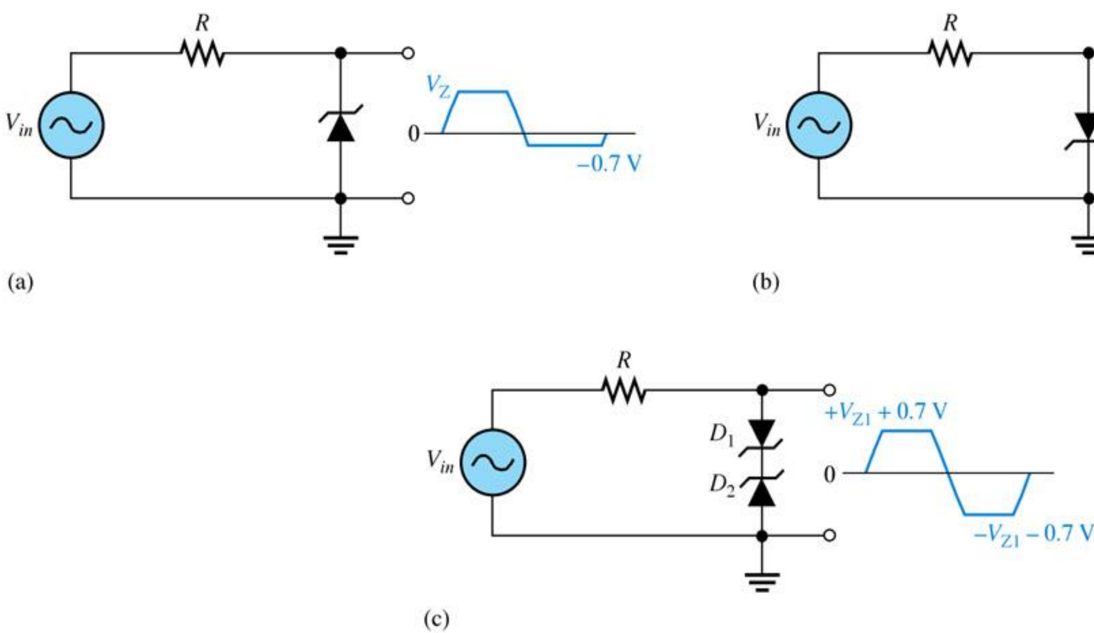
$$I_L = I_T - I_{ZK} = 71.0mA - 0.25mA = 70.75mA$$

$$R_{L(\min)} = \frac{V_{OUT}}{I_L} = \frac{14.76V}{70.75mA} = 209\Omega$$

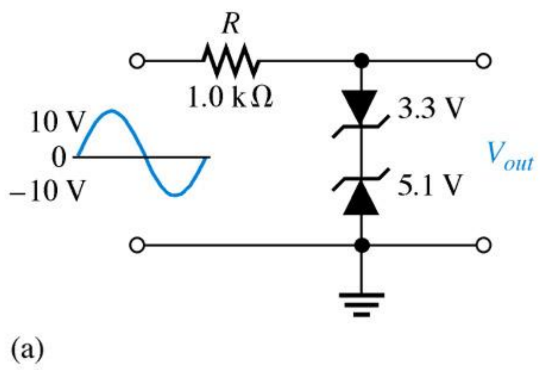


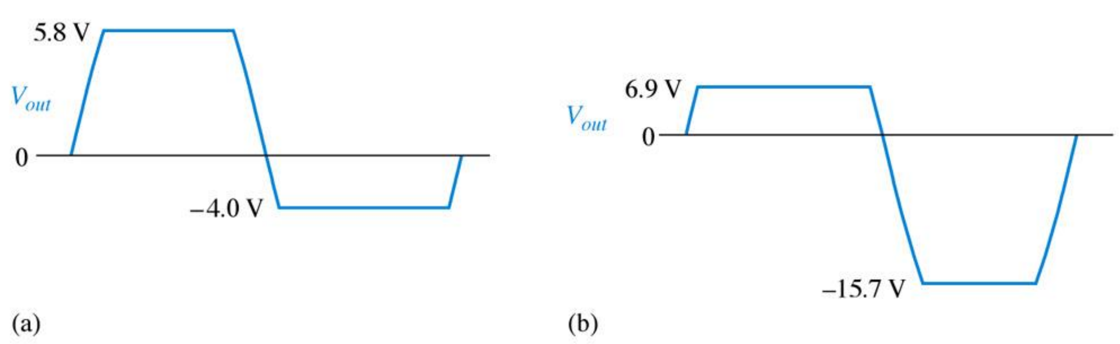
Zener Limiting

Zener diodes can used in ***ac applications to limit voltage swings to desired levels***. Part (a) shows a zener used to limit the positive peak of a signal voltage to the selected voltage. When the zener is turned around, as in part (b), the negative peak is limited by zener action and the positive voltage is limited to + 0.7 V.



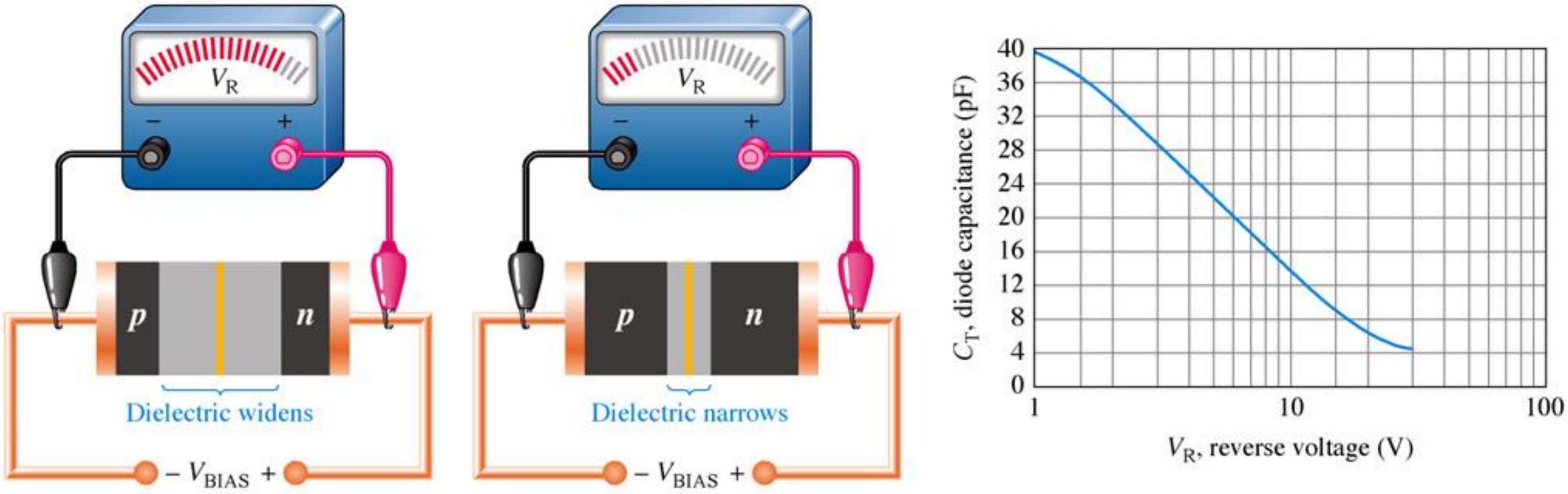
Ex 5-8 Determine the output voltage for each zener limiting circuit in Figure.





Varactor Diodes

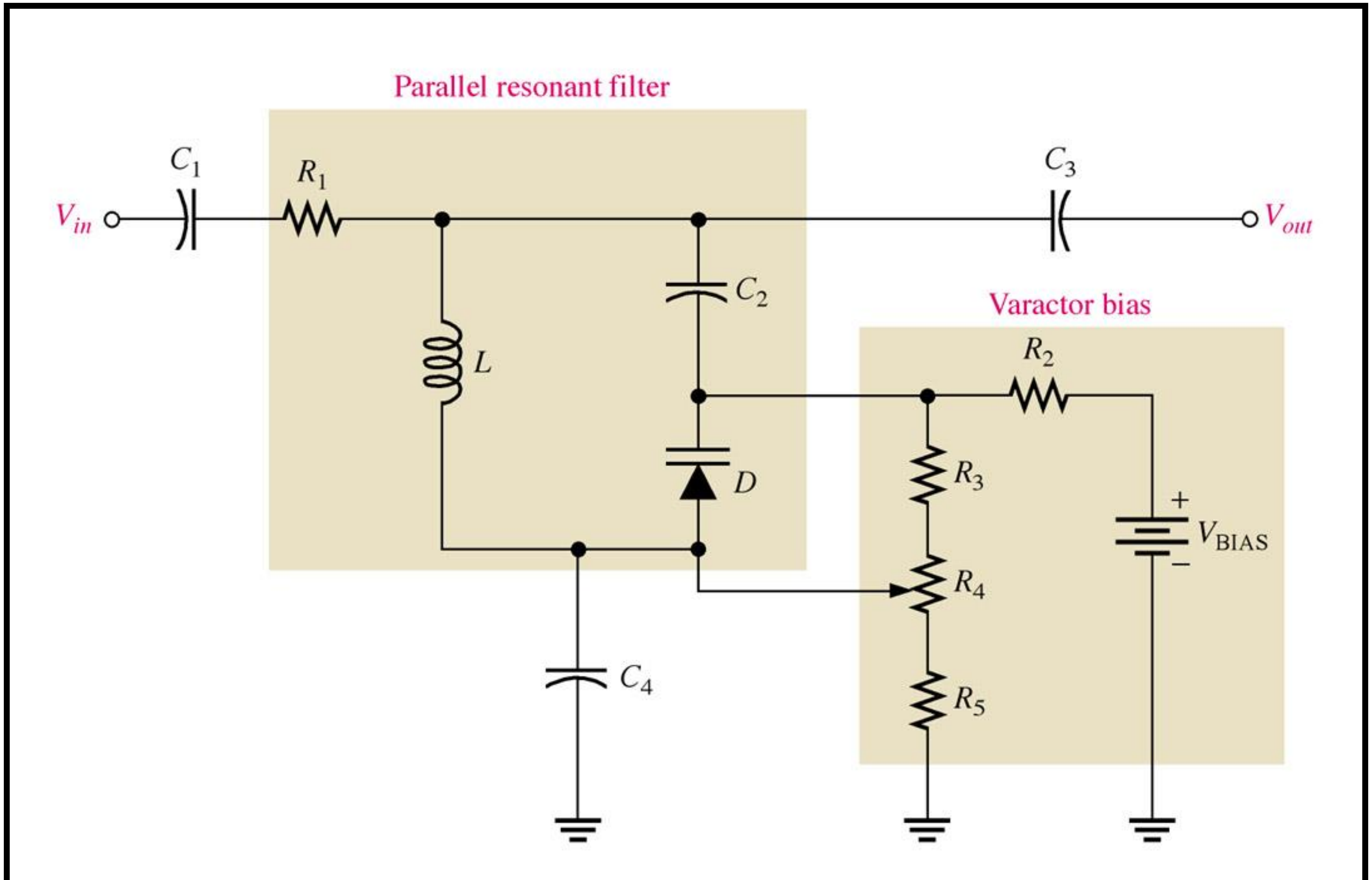
A **varactor diode** is best explained as a variable capacitor. Think of the depletion region a variable dielectric. The diode is placed in reverse bias. The dielectric is "adjusted" by bias changes.



(a) Greater reverse bias, less capacitance (b) Less reverse bias, greater capacitance (c) Graph of diode capacitance versus reverse voltage

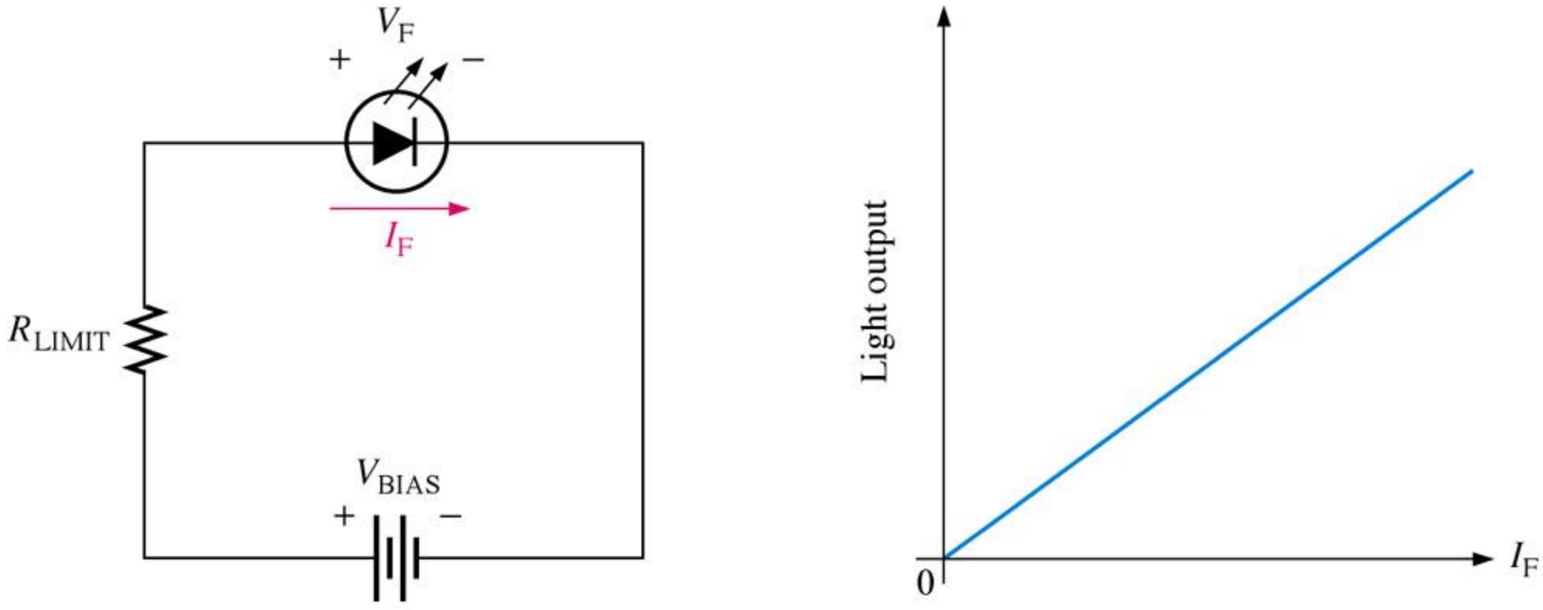
Varactor Diodes

The varactor diode can be useful in filter circuits as the adjustable component.



Optical Diodes

The **light-emitting diode** (LED) emits photons as visible light. It's purpose is for indication and other intelligible displays. Various impurities are added during the doping process to vary the color output.

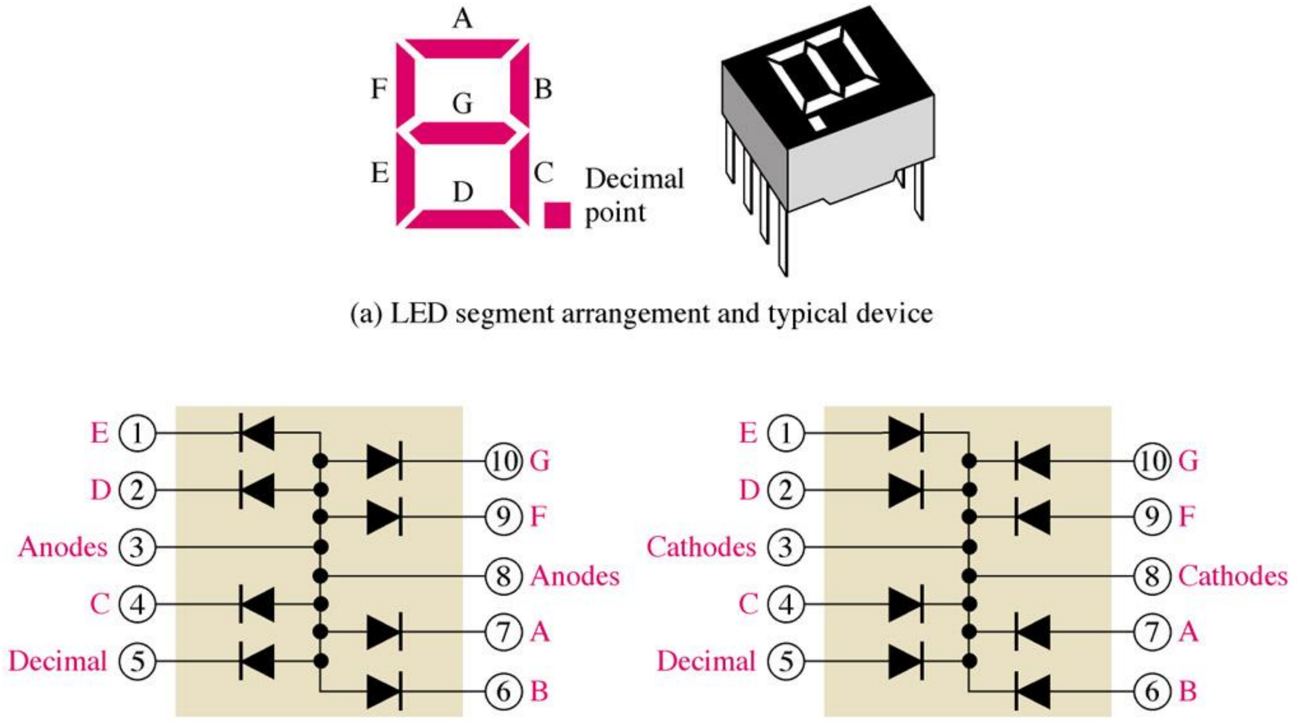


(a) Forward-biased operation

(b) General light output versus forward current

Optical Diodes

The seven segment display is an example of LEDs use for display of decimal digits.



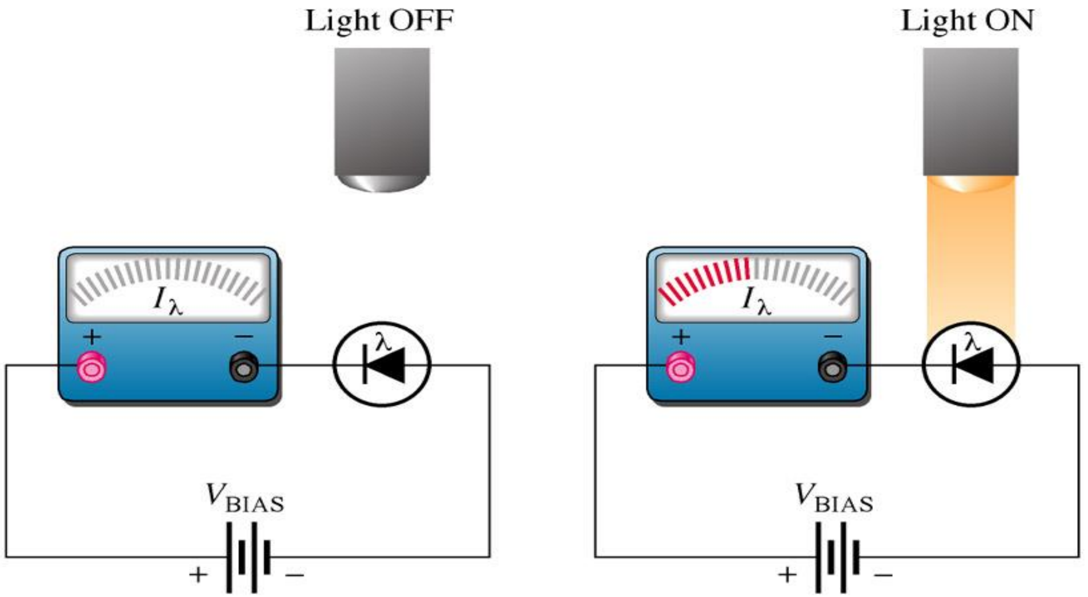
(a) LED segment arrangement and typical device

(b) Common anode

(c) Common cathode

Optical Diodes

The **photodiode** is used to vary current by the amount of light that strikes it. It is placed in the circuit in reverse bias. As with most diodes when in reverse bias, no current flows when in reverse bias, but when light strikes the exposed junction through a tiny window, reverse current increases proportional to light intensity.

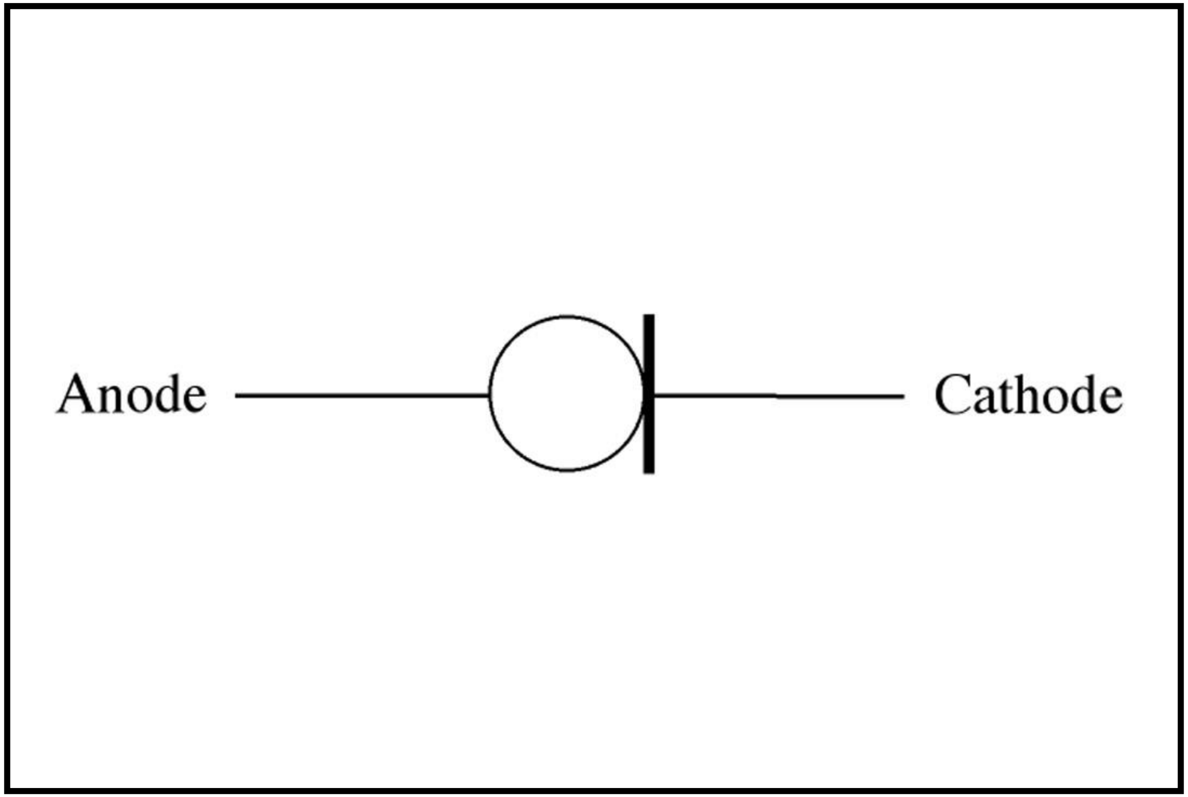


(a) No light, no current except negligible dark current

(b) Where there is incident light, resistance decreases and there is reverse current.

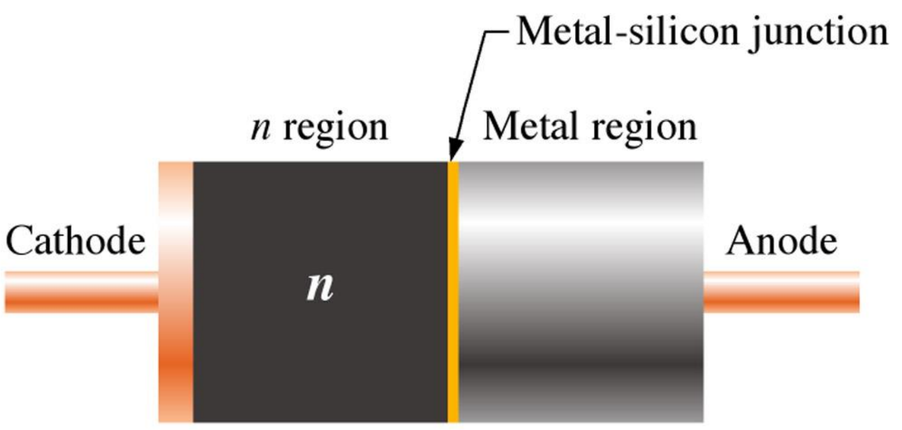
Other Diode Types

Current regulator diodes keeps a constant current value over a specified range of forward voltages ranging from about 1.5 V to 6 V.



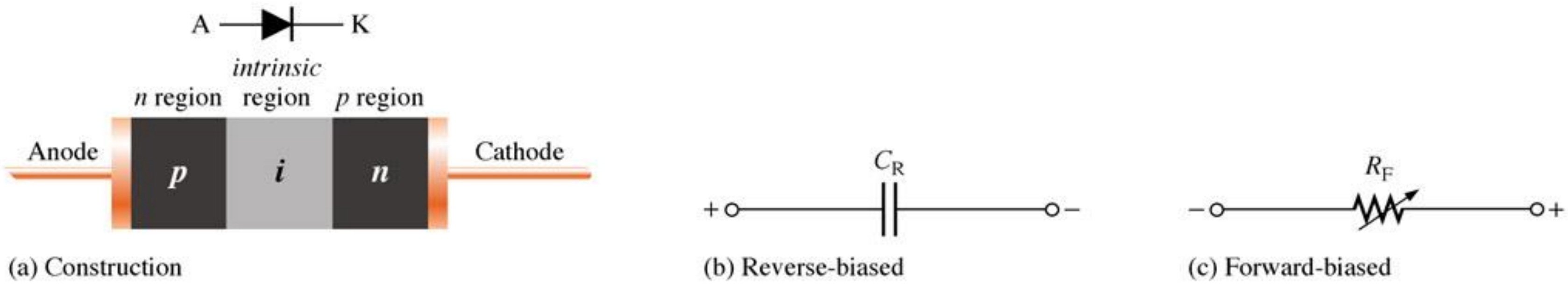
Other Diode Types

The **Schottky diode's** significant characteristic is it's fast switching speed. This is useful for high frequencies and digital applications. It is not a typical diode in the fact that it does not have a p-n junction, instead it consists of a heavily doped n-material and metal bound together.



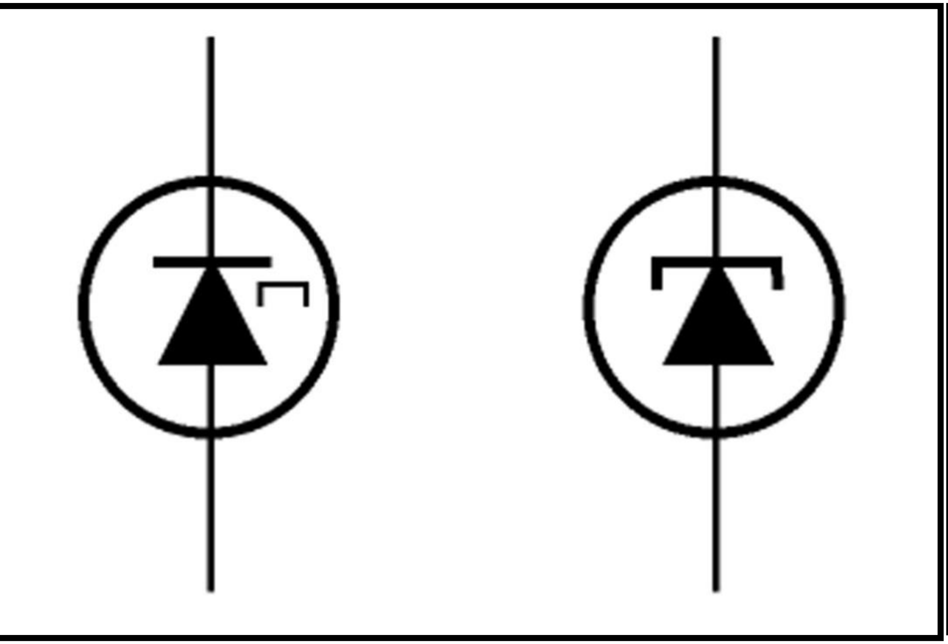
Other Diode Types

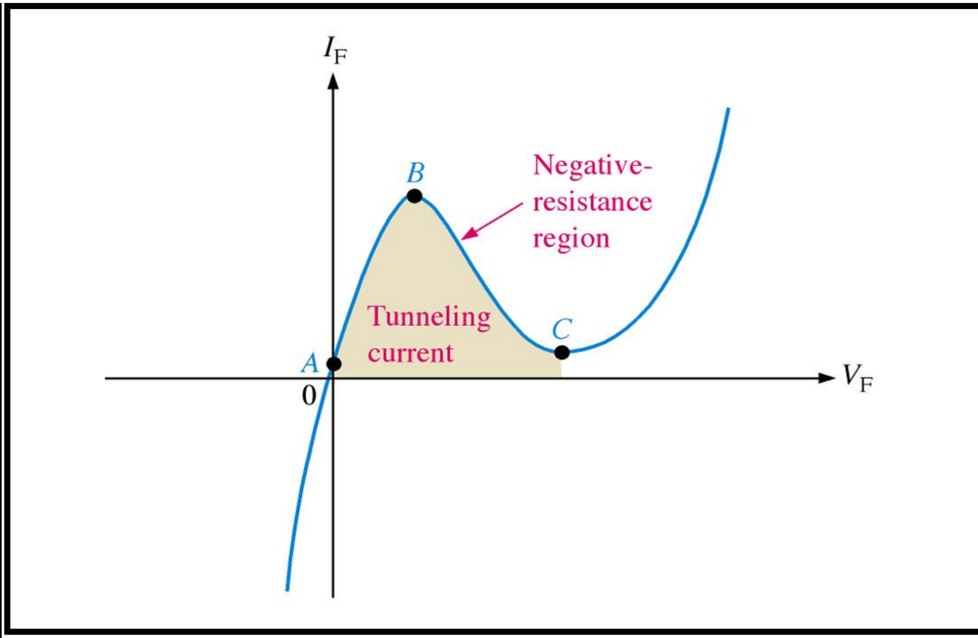
The ***pin* diode** is also used in mostly microwave frequency applications. It's variable forward series resistance characteristic is used for attenuation, modulation, and switching. In reverse bias exhibits a nearly constant capacitance.



Other Diode Types

The **step-recovery diode** is also used for fast switching applications. This is achieved by reduced doping at the junction.



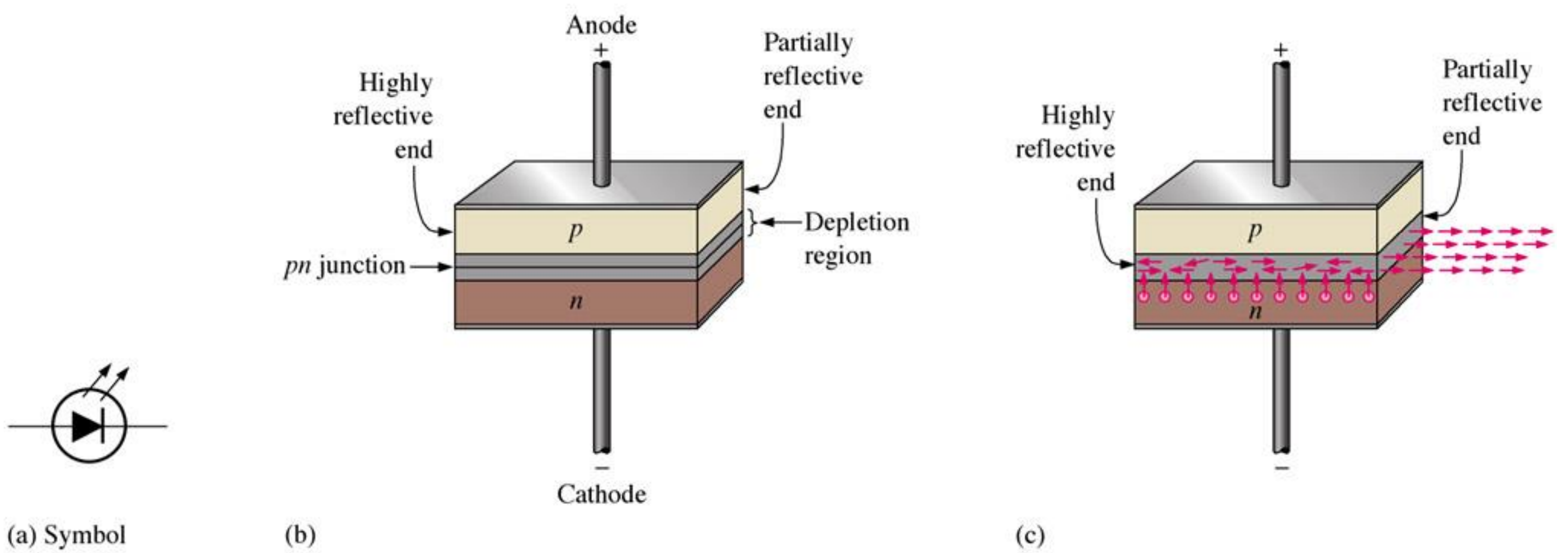


Other Diode Types

The **tunnel diode** has negative resistance. It will actually conduct well with low forward bias. With further increases in bias it reaches the negative resistance range where current will actually go down. This is achieved by heavily doped p and n materials that creates a very thin depletion region.

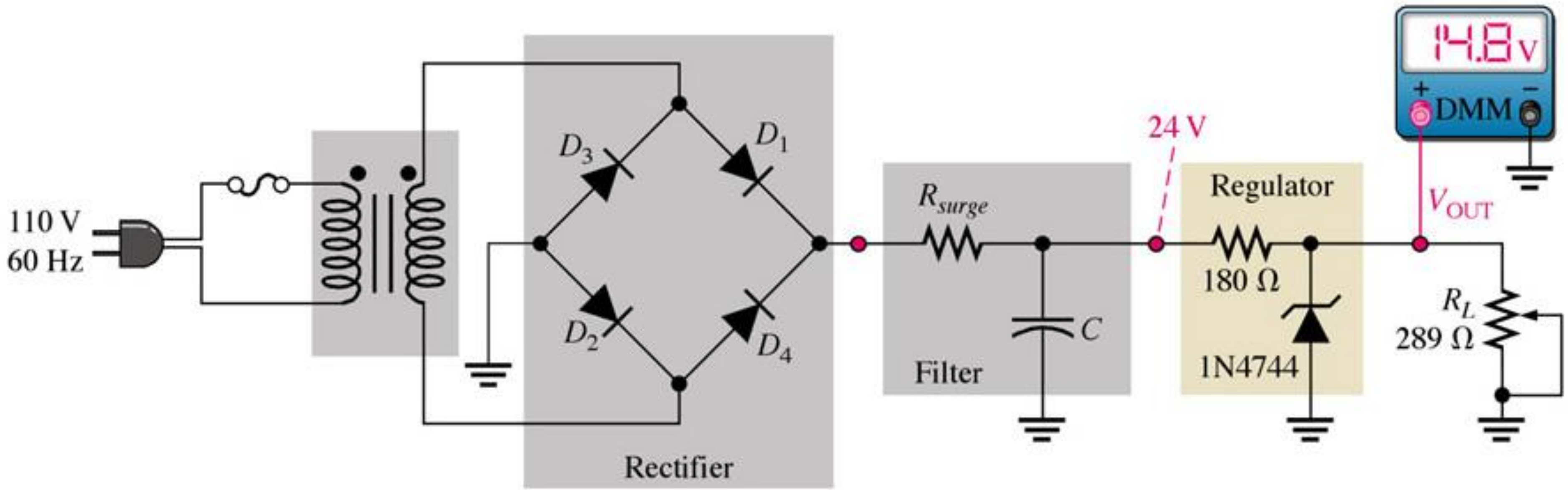
Other Diode Types

The **laser diode** (**l**ight **a**mplification by **s**timulated **e**mission of **r**adiation) produces a monochromatic (single color) light. Laser diodes in conjunction with photodiodes are used to retrieve data from compact discs.



Troubleshooting

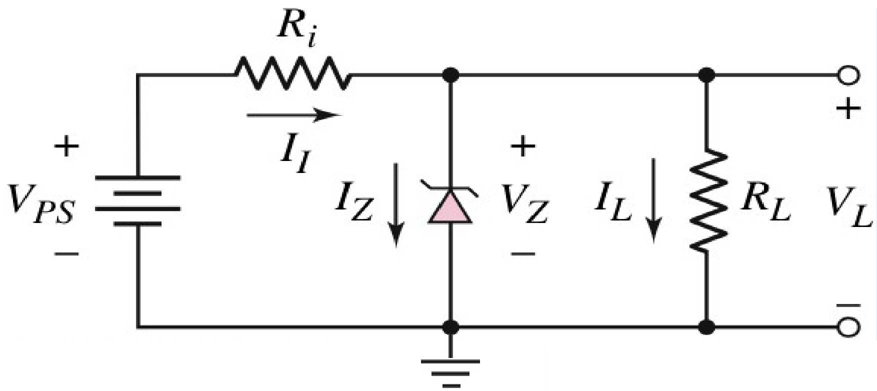
Although precise power supplies typically use IC type regulators, zener diodes can be used alone as a voltage regulator. As with all troubleshooting techniques we must know what is normal.



(b) Correct output voltage with full load

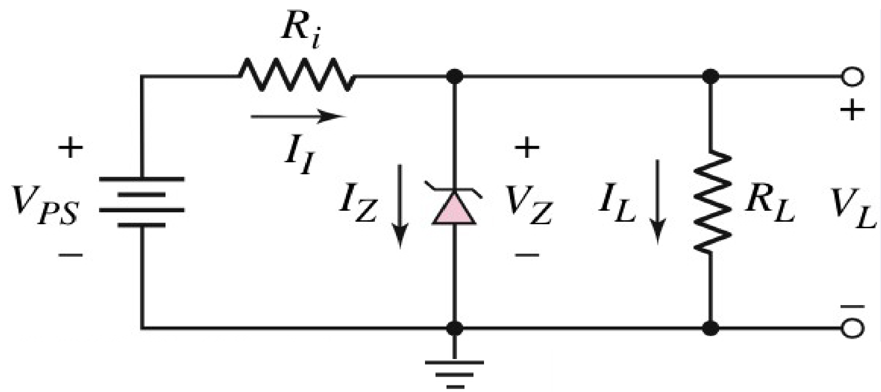
A properly functioning zener will work to maintain the output voltage within certain limits despite changes in load.

Example



A Zener diode is connected in a voltage regulator circuit. It is given that V_{PS} = 20V, the Zener voltage, V_Z = 10V, R_i = 222 Ω and $P_{Z(\max)}$ = 400 mW.

a. Determine the values of I_L, I_Z and I_I if R_L = 580 Ω.
b. Determine the value of R_L that will establish $P_{Z(\max)}$ = 400 mW in the diode.



For proper function the circuit the following conditions must be satisfied the following conditions.

1. The power dissipation in the Zener diode is less than the rated value

2. When the power supply is a minimum, $V_{PS}(\text{min})$, there must be minimum current in the zener diode $I_Z(\text{min})$, hence the load current is a maximum, $I_L(\text{max})$,

3. When the power supply is a maximum, $V_{PS}(\text{max})$, the current in the diode is a maximum, $I_Z(\text{max})$, hence the load current is a minimum, $I_L(\text{min})$

$R_i = \dfrac{V_{PS}(\text{min}) - V_Z}{I_Z(\text{min}) + I_L(\text{max})}$ **AND** $R_i = \dfrac{V_{PS}(\text{max}) - V_Z}{I_Z(\text{max}) + I_L(\text{min})}$ Or, we can write

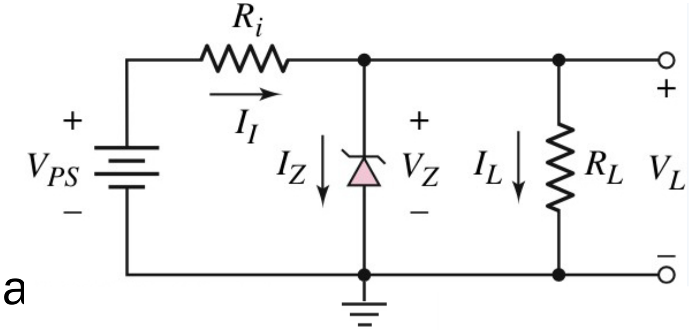
$$[V_{PS}(\text{min}) - V_Z] \,.\, [I_Z(\text{max}) + I_L(\text{min})] = [V_{PS}(\text{max}) - V_Z].\, [I_Z(\text{min}) + I_L(\text{max})]$$

For general thumb of rule for design this circuit is, so from the last Equation

$$I_Z(\max) = \frac{I_L(\max).[V_{PS}(\max) - V_Z] - I_L(\min).[V_{PS}(\min) - V_Z]}{V_{PS}(\min) - 0.9V_Z - 0.1V_{PS}(\max)}$$

Maximum power dispassion in the Zener diode is

$$P_Z(\max) = I_Z(\max) \times V_Z$$



simple Zener diode voltage regulator circuit

EXAMPLE 1 (Example 5.5 from textbook)

Design a Zener diode voltage regulator circuit a shown
in Figure . Consider voltage regulator is used to power the cell phone at 2.5 V from the lithium ion battery, which voltage may vary between 5 and 5.6 V. The current in the phone will vary 0 (off) to 100 mA(when talking).

Solution:
The stabilized voltage V_L = 2.5 V, so the Zener diode voltage must be V_Z = 2.5 V.
The maximum Zener diode current is

$$I_Z(\max) = \frac{I_L(\max).[V_{PS}(\max) - V_Z] - I_L(\min).[V_{PS}(\min) - V_Z]}{V_{PS}(\min) - 0.9V_Z - 0.1V_{PS}(\max)}$$

Or, $$I_Z(\max) = \frac{100 \times [3.6 - 2.5] - 0 \times [3 - 2.5]}{3 - 0.9 \times 2.5 - 0.1 \times 3.6} = 282.05 \text{ mA}$$

The maximum power dispassion in the Zener diode is

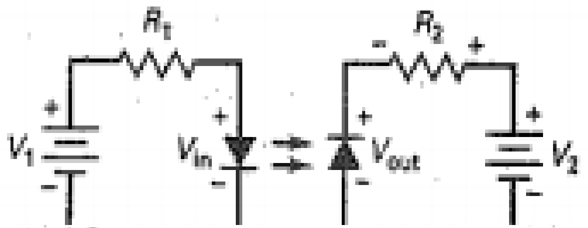
$$P_Z(\max) = I_Z(\max) \times V_Z = 282.05 \times 2.5 = 705.13 \text{ mW}$$

The value of the current limiting resistance is

$$R_i = \frac{V_{PS}(\max) - V_Z}{I_Z(\max) + I_L(\min)} = \frac{3.6 - 2.5}{282.05 + 0} \approx 3.9\ \Omega$$

Optocoupler

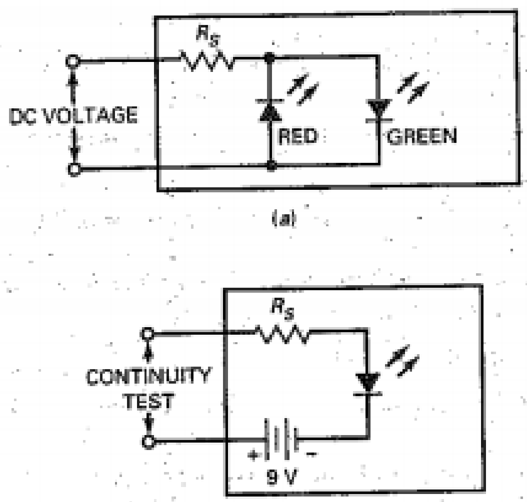
Figure 5-22 Optocoupler combines an LED and a photodiode.



Example 5-12

Figure 5-23*a* shows a voltage-polarity tester. It can be used to test a dc voltage of unknown polarity. When the dc voltage is positive, the green LED lights up. When the dc voltage is negative, the red LED lights up. What is the approximate LED current if the dc input voltage is 50 V and the series resistance is 2.2 kΩ?

Figure 5-23 (*a*) Polarity indicator; (*b*) continuity tester.



SOLUTION We will use a forward voltage of approximately 2 V for either LED. With Eq. (5-13):

$$I_S = \frac{50\text{ V} - 2\text{ V}}{2.2\text{ k}\Omega} = 21.8\text{ mA}$$

Example 5-13

MultiSim

Figure 5-23*b* is a continuity tester. After you turn off all the power in a circuit under test, you can use this circuit to check for the continuity of cables, connectors, and switches. How much LED current is there if the series resistance is 470 Ω?

SOLUTION When the input terminals are shorted (continuity), the internal 9-V battery produces an LED current of:

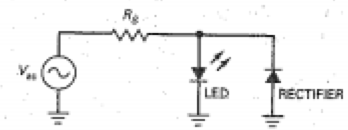
$$I_S = \frac{9\text{ V} - 2\text{ V}}{470\ \Omega} = 14.9\text{ mA}$$

PRACTICE PROBLEM 5-13 Using Fig. 5-23, what value series resistor should be used to produce 21 mA of LED current?

Example 5-14

LEDs are often used to indicate the existence of ac voltages. Figure 5-24 shows an ac voltage source driving an LED indicator. When there is ac voltage, there is LED current on the positive half cycles. On the negative half cycles, the rectifier diode turns on and protects the LED from too much reverse voltage. If the ac source voltage is 20 V rms and the series resistance is 680 Ω, what is the average LED current? Also, calculate the approximate power dissipation in the series resistor.

Figure 5-24 Low ac voltage indicator.



SOLUTION The LED current is a rectified half-wave signal. The peak source voltage is 1.414 × 20 V, which is approximately 28 V. Ignoring the LED voltage drop, the approximate peak current is:

$$I_S = \frac{28\text{ V}}{680\ \Omega} = 41.2\text{ mA}$$

The average of the half-wave current through the LED is:

$$I_S = \frac{41.2\text{ mA}}{\pi} = 13.1\text{ mA}$$

Ignore the diode drops in Fig. 5-24; this is equivalent to saying that there is a short to ground on the right end of the series resistor. Then the power dissipation in the series resistor equals the square of the source voltage divided by the resistance:

$$P = \frac{(20\text{ V})^2}{680\ \Omega} = 0.588\text{ W}$$

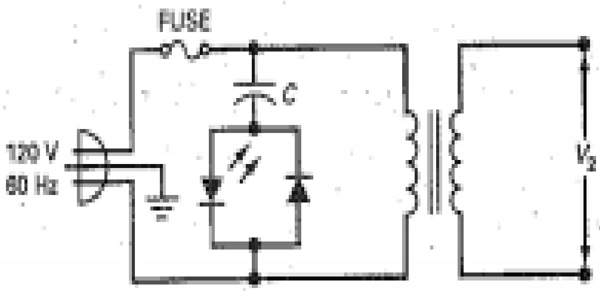
As the source voltage in Fig. 5-24 increases, the power dissipation in the series resistor may increase to several watts. This is a disadvantage because a high-wattage resistor is too bulky and wasteful for most applications.

PRACTICE PROBLEM 5-14 If the ac input voltage of Fig. 5-24 is 120 V and the series resistance is 2 kΩ, find the average LED current and approximate series resistor power dissipation.

Example 5-15

The circuit of Fig. 5-25 shows an LED indicator for the ac power line. The idea is basically the same as in Fig. 5-24, except that we use a capacitor instead of a resistor. If the capacitance is 0.68 μF, what is the average LED current?

Figure 5-25 High ac voltage indicator.



SOLUTION Calculate the capacitive reactance:

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(60\text{ Hz})(0.68\ \mu\text{F})} = 3.9\text{ k}\Omega$$

Ignoring the LED voltage drop, the approximate peak LED current is:

$$I_p = \frac{170\text{ V}}{3.9\text{ k}\Omega} = 43.6\text{ mA}$$

The average LED current is:

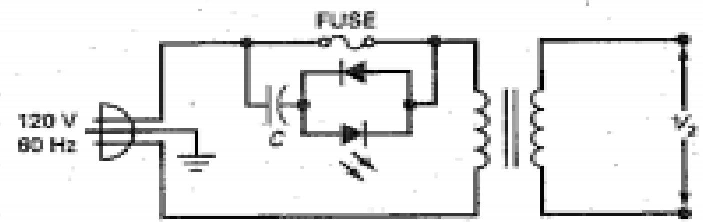
$$I_p = \frac{43.6\text{ mA}}{\pi} = 13.9\text{ mA}$$

What advantage does a series capacitor have over a series resistor? Since the voltage and current in a capacitor are 90° out of phase, there is no power dissipation in the capacitor. If a 3.9-kΩ resistor were used instead of a capacitor, it would have a power dissipation of approximately 3.69 W. Most designers would prefer to use a capacitor, since it's smaller and ideally produces no heat.

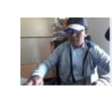
Example 5-16

What does the circuit of Fig. 5-26 do?

Figure 5-26 Blown-fuse indicator.

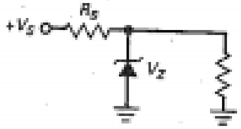


SOLUTION This is a *blown-fuse indicator.* If the fuse is OK, the LED is off because there is approximately zero voltage across the LED indicator. On the other hand, if the fuse is open, some of the line voltage appears across the LED indicator and the LED lights up.



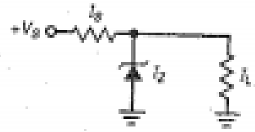
Derivations

(5-3) Series current:



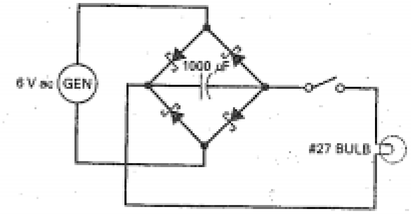
$$I_S = \frac{V_S - V_Z}{R_S}$$

(5-6) Zener current:

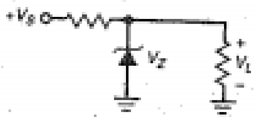


$$I_Z = I_S - I_L$$

Figure 5-43

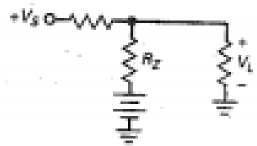


(5-4) Load voltage:



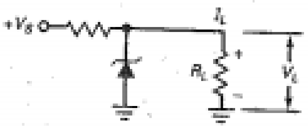
$$V_L = V_Z$$

(5-7) Change in load voltage:



$$\Delta V_L = I_Z R_Z$$

(5-5) Load current:

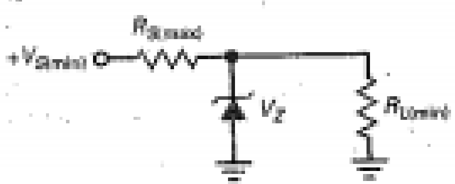


$$I_L = \frac{V_L}{R_L}$$

(5-8) Output ripple:

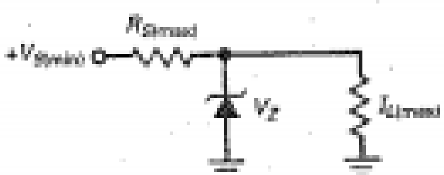
$$V_{R(out)} = \frac{R_Z}{R_S} V_{R(in)}$$

(5-9) Maximum series resistance:



$$R_{S(max)} = \left(\frac{V_{S(min)}}{V_Z} - 1\right) R_{L(min)}$$

(5-10) Maximum series resistance:

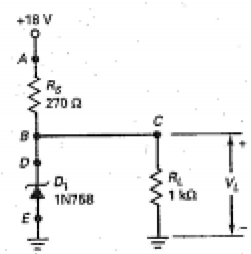


$$R_{S(max)} = \frac{V_{S(min)} - V_Z}{I_{L(max)}}$$

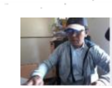
(5-13) LED current:

$$I_S = \frac{V_S - V_D}{R_S}$$

Figure 5-44 Troubleshooting.



	V_A	V_B	V_C	V_D	D_1
OK	18	10.3	10.3	10.3	OK
T1	18	0	0	0	OK
T2	18	14.2	14.2	0	OK
T3	18	14.2	14.2	14.2	∞
T4	18	18	18	18	∞
T5	0	0	0	0	OK
T6	18	10.5	10.5	10.5	OK
T7	18	14.2	14.2	14.2	OK
T8	18	0	0	0	0



1332105 Dasar Elektronika

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Electronic Basic

Analisis Zener Diode

Next

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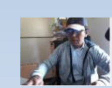
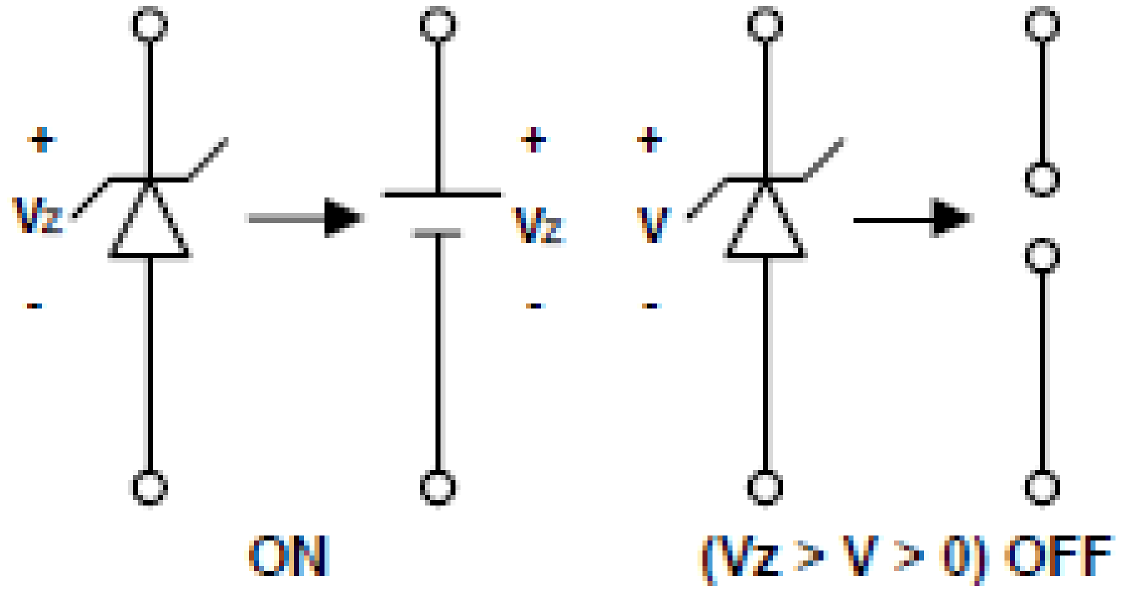


Analisis

Dioda Zener

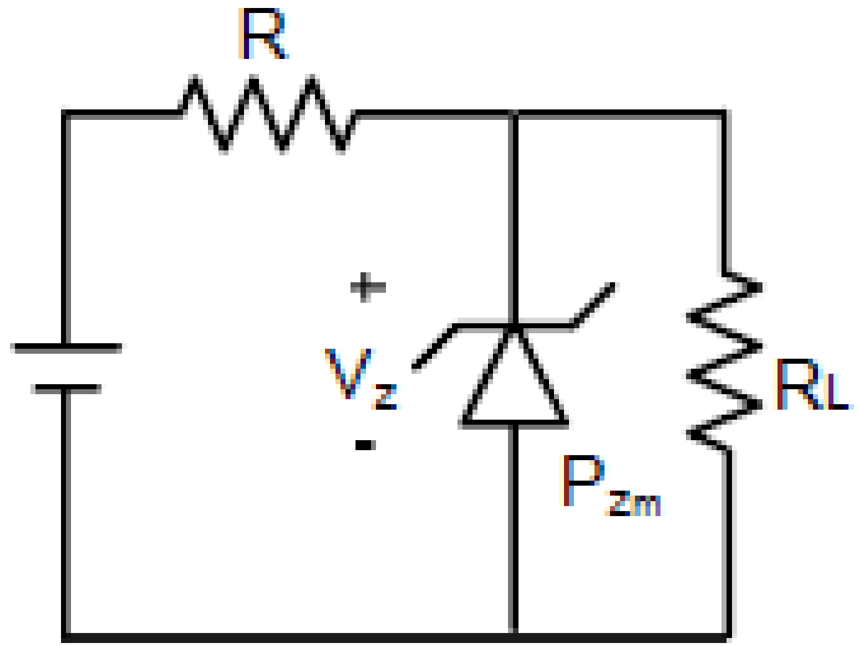
Dalam menganalisis zener, kita dapat menggunakan cara menganalisis dioda pada bagian sebelumnya. Ketika zener diindikasikan ON, rangkaian penggantinya adalah sumber tegangan Vz, sedangkan jika zener OFF rangkaian penggantinya adalah saklar terbuka

Rangkaian pengganti Dioda Zener



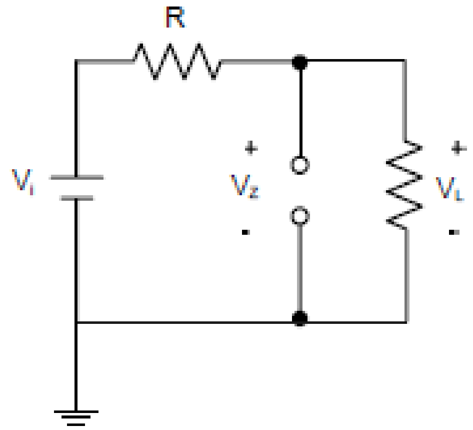
Vi dan R tetap

- Rangkaian Dasar Regulator dengan Zener



Analisa rangkaian zener dapat dilakukan dengan langkah berikut:

a. Tentukan kondisi zener dengan melepasnya dari rangkaian dan
menghitung tegangan pada untai terhubung.

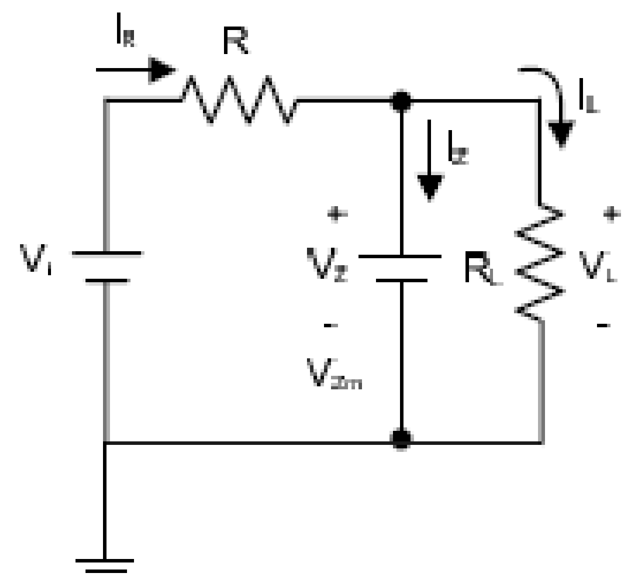


$$V = V_L = \frac{R_L V_i}{R + R_L}$$

- Jika $V \geq V_Z$, zener → ON. Zener dapat diganti dengan rangkaian penggantinya. Sebaliknya jika $V \leq V_Z$ maka zener→ OFF dapat digantikan dengan saklar terbuka

Rangkaian Ekivalen Zener ON

b. Ganti Zener dengan rangkaian ekivalennya



- Dari gambar zener ON, arus yang mengalir pada zener dapat ditentukan dengan KCL

$$I_R = I_Z + I_L$$

$$I_Z = I_R - I_L$$

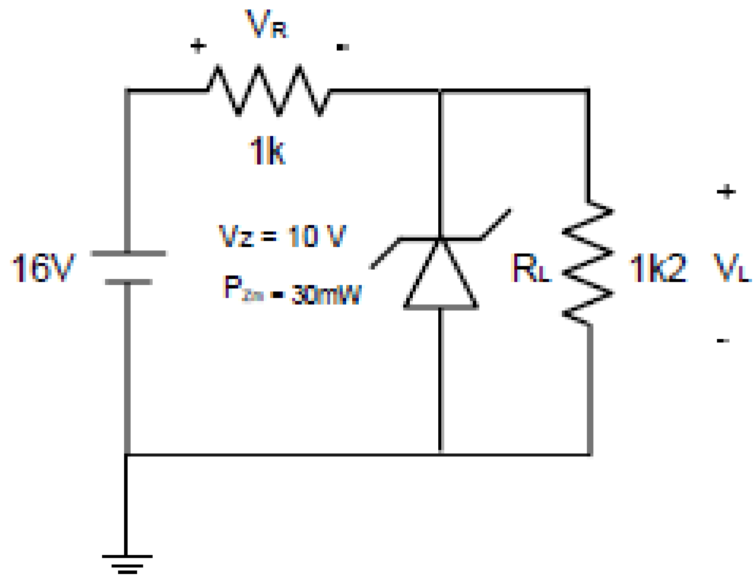
$$I_L = \frac{V_L}{R_L} \quad \text{dan} \quad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

- Dimana,

$$P_Z = V_Z I_Z$$

- Daya yang diserap zener:

Contoh Soal



- Tentukan V_L, V_R, I_Z, dan P_Z
- Ulangi soal (a) dengan $R_L = 3k\Omega$

Jawab

a) Terapkan prosedur sebelumnya

- Lepaskan zener dari rangkaian

$$V = V_L = \frac{R_L V_i}{R + R_L} = \frac{1.2k(16V)}{1k + 1.2k} = 8.73V$$

$$V < V_Z \rightarrow \text{Zener OFF}$$

- Ganti zener dengan saklar terbuka

$$V_R = V_i - V_L = 16 - 8.73V = 7.27V$$

$$I_Z = 0A$$

$$P_Z = V_Z I_Z = 0W$$

b) Lepaskan zener dari rangkaian

$$V = V_L = \frac{R_L V_i}{R + R_L} = 12V$$

$V \geq V_Z$ → Zener ON

- Ganti zener dengan rangkaian ekivalen untuk zener ON

$$V_L = V_Z = 10V$$

$$V_R = V_i - V_L = 16V - 10V = 6V$$

$$I_L = \frac{V_L}{R_L} = \frac{10V}{3k\Omega} = 3.33mA$$

$$I_R = \frac{V_R}{R} = \frac{6V}{1k\Omega} = 6mA$$

$$I_Z = I_R - I_L$$

$$= 6mA - 3.33mA$$

$$= 2.67mA$$

- Daya yang diserap zener

$$P_Z = V_Z I_Z = (10)(2.67mA) = 26.7mW$$

Vi Tetap dan R_L Variabel

- ON/OFF-nya zener tergantung pada interval nilai R_L. R_L yang terlalu kecil akan mengakibatkan zener OFF. Nilai minimum R_L dapat ditentukan sebagai berikut:

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$R_{L\min} = \frac{R V_Z}{V_i - V_Z} \quad ..$$

- Jika R_L yang dipilih > R_L min, maka zener ON. Selanjutnya ganti dengan rar alen zener ON.

$$I_{L\max} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L\min}}$$

$$V_R = V_i - V_Z$$

- R_L min akan meni I_L max

$$I_R = \frac{V_R}{R}$$

$$I_Z = I_R - I_L$$

- Tegangan pada R

$$I_{L\min} = I_R - I_{Z\max}$$

$$R_{L\max} = \frac{V_Z}{I_{L\min}}$$

- $I_{Z\,min}$ dicapai pada $I_{L\,max}$ dan sebaliknya

R_L Tetap dan V_i Variabel

- Untuk nilai R_L yang tetap, tegangan V_i harus cukup besar untuk dapat mengakibatkan zener ON.
- Tegangan V_i minimum ditentukan oleh:

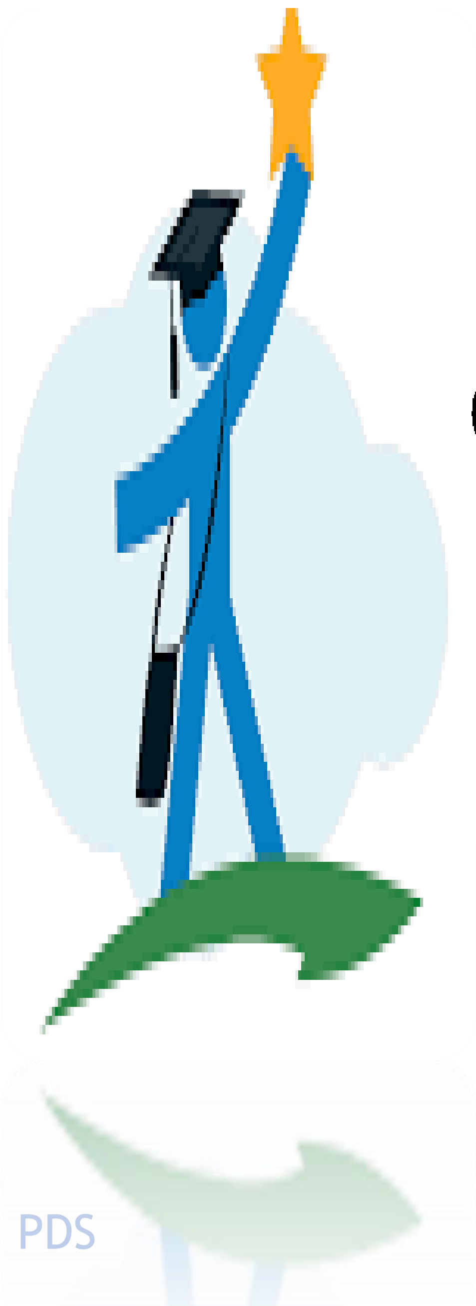
$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$V_{L\min} = \frac{(R_L + R)V_Z}{R_L}$$

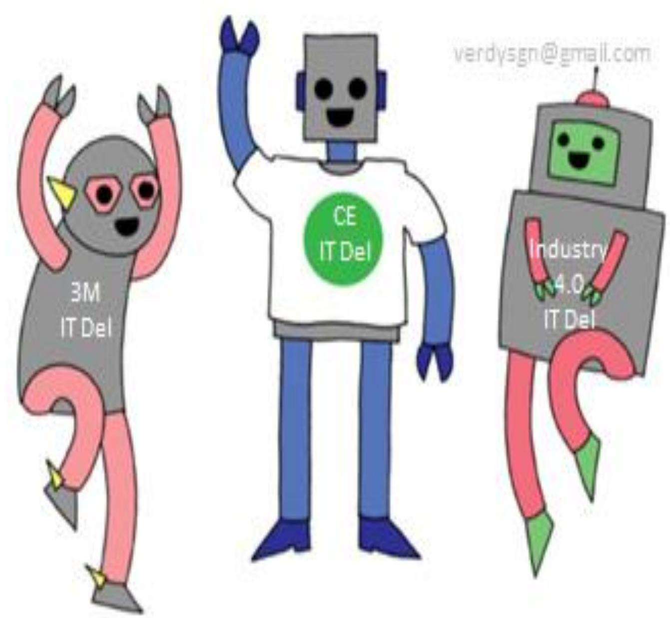
$$I_{R\max} = I_{Z\max} - I_L$$

$$V_{i\max} = V_{R\max} + V_Z$$

$$V_{i\max} = I_{R\max} R + V_Z$$




Thanks!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