Tishk International University
Engineering Faculty
Mechatronics Engineering Department
Lecture 6

Electronics Principles and Devices
Zener Diode

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Outline

- Introduction of Zener Diode
- Voltage-Current Characteristics for Zener Diode
- Zener Diode Breakdown
- Zener Diode Equivalent Circuit
- Examples
- Next Lecture

Zener Diode

- A Zener diode is a type of diode that permits current to flow in the ***forward*** direction like a normal diode, but also in the ***reverse*** direction if the voltage is larger than the breakdown voltage known as ***Zener knee voltage*** (***Zener voltage***).
- The device was named after ***Clarence Melvin Zener***, who discovered the ***Zener effect***.
- **Clarence Melvin Zener**, an American physicist, was born in Indianapolis and earned his PhD from Harvard in 1930. He was the first to describe the properties of reverse breakdown that are exploited by the zener diode. As a result, Bell Labs, where the device was developed, named the diode after him.

Zener Diode

The breakdown voltage of a zener diode is set by carefully controlling the doping level during manufacture.

The symbol for a zener diode is shown in Figure 1. instead of a straight line representing the cathode, the zener diode has a bent line that reminds you of the letter Z (for zener).

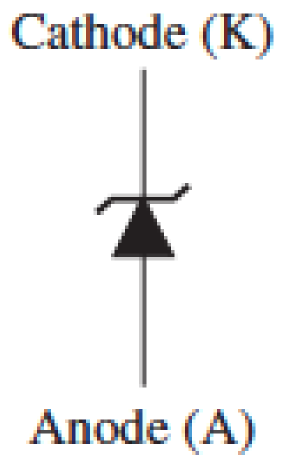


Figure 1: Zener Diode Symbol

Voltage-Current Characteristics for Zener Diode

Similar to the normal diode, at the forward characteristics when the diode reaches the potential across the diode, the voltage remain constant and the current increased gradually, as shown in Figure 2.

However at the reverse region, when a diode reaches reverse breakdown, its voltage remains almost constant even though the current changes drastically, and this is the key to zener diode operation, as shown in Figure 2.

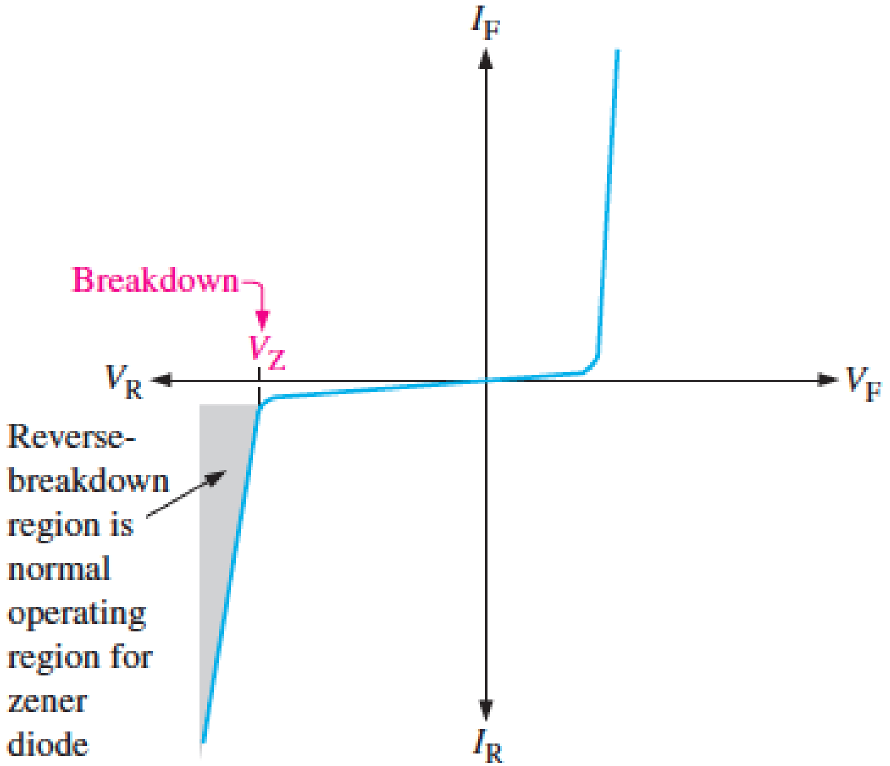


Figure 2: V-I characteristic with the normal operating region for zener diodes.

Zener Diode Breakdown

A zener diode is heavily doped to reduce the breakdown voltage. This causes a very thin depletion region (*pn* junction). As a result, an intense electric field exists within the depletion region.

Zener diodes are designed to operate in reverse breakdown. Two types of reverse breakdown in a zener diode are ***avalanche*** and ***zener.***

Near the zener breakdown voltage (V_Z), the field is intense enough to pull electrons from their valence bands and create current. Zener diodes with breakdown voltages of **less than** approximately 5 V operate mostly in ***zener breakdown***. Those with breakdown voltages **greater than** approximately 5 V operate mostly in ***avalanche breakdown***. Both types, however, are called zener diodes.

Zeners are commercially available with breakdown voltages from less than 1 V to more than 250 V with specified tolerances from 1% to 20%.

Zener Diode Breakdown

Figure 3 shows the reverse portion of a zener diode's characteristic curve. 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 the reverse current increases rapidly. From the bottom of the knee, the zener breakdown voltage (V_Z) remains essentially constant although it increases slightly as the zener current, I_Z, increases.

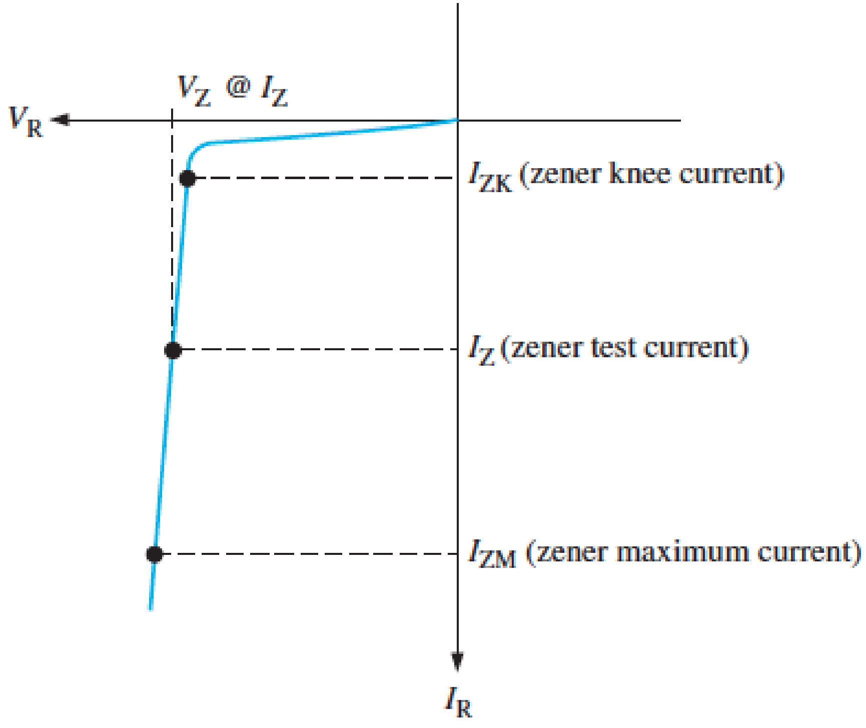


Figure 3: Reverse characteristic of a zener diode.

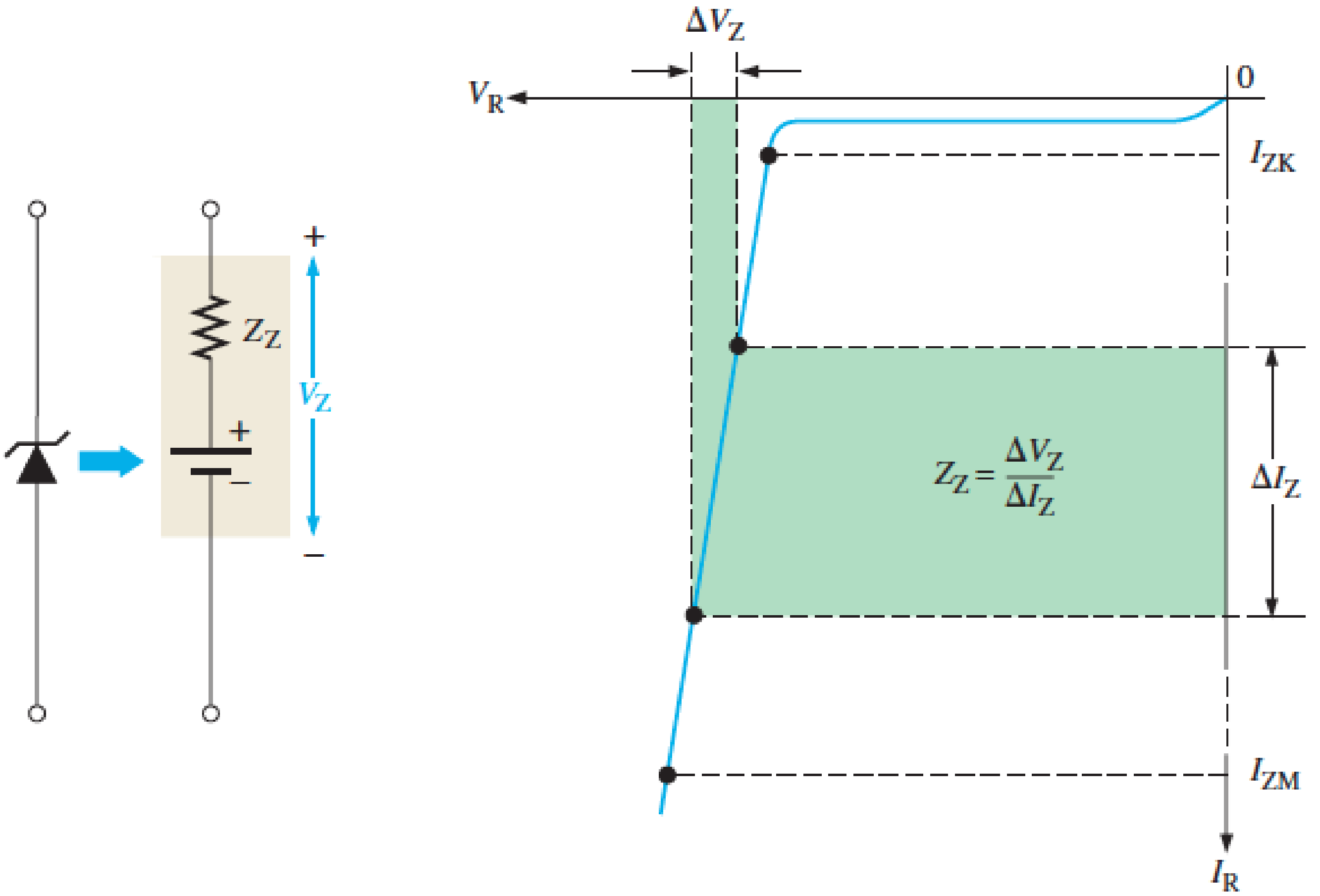
Zener Diode Equivalent Circuit

Figure 4(a) represents the practical model (second approximation) of a zener diode, where the zener impedance (resistance), Z_Z, is included. Since the actual voltage curve is not ideally vertical, a change in zener current produces a small change in zener voltage as illustrated in Figure 4(b). By Ohm's law, the ratio of ΔV_Z to ΔI_Z is the impedance, as expressed in the following equation:

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

Normally, Z_Z is specified at the zener test current. In most cases, you can assume that Z_Z is a small constant over the full range of zener current values and is purely resistive. It is best to avoid operating a zener diode near the knee of the curve because the impedance changes dramatically in that area.

Zener Diode Equivalent Circuit



(a) Practical model (b) Characteristic curve. The slope is exaggerated for illustration.

Figure 4: Practical zener diode equivalent circuit and the characteristic curve illustrating Z_Z.

Datasheet Information for 1N4728A - 1N4764A Zeners

FAIRCHILD SEMICONDUCTOR®

January 2005

1N4728A - 1N4764A
Zeners

DO-41 Glass case
COLOR BAND DENOTES CATHODE

Absolute Maximum Ratings * $T_a = 25°C$ unless otherwise noted

Symbol	Parameter	Value	Units
P_D	Power Dissipation @ TL ≤ 50°C, Lead Length = 3/8"	1.0	W
	Derate above 50°C	6.67	mW/°C
T_J, T_{STG}	Operating and Storage Temperature Range	-65 to +200	°C

* These ratings are limiting values above which the serviceability of the diode may be impaired.

Electrical Characteristics $T_a = 25°C$ unless otherwise noted

Device	V_Z (V) @ I_Z (Note 1)			Test Current	Max. Zener Impedance			Leakage Current	
	Min.	Typ.	Max.	I_Z (mA)	Z_Z @ I_Z (Ω)	Z_{ZK} @ I_{ZK} (Ω)	I_{ZK} (mA)	I_R (μA)	V_R (V)
1N4728A	3.315	3.3	3.465	76	10	400	1	100	1
1N4729A	3.42	3.6	3.78	69	10	400	1	100	1
1N4730A	3.705	3.9	4.095	64	9	400	1	50	1
1N4731A	4.085	4.3	4.515	58	9	400	1	10	1
1N4732A	4.465	4.7	4.935	53	8	500	1	10	1
1N4733A	4.845	5.1	5.355	49	7	550	1	10	1
1N4734A	5.32	5.6	5.88	45	5	600	1	10	2
1N4735A	5.89	6.2	6.51	41	2	700	1	10	3
1N4736A	6.46	6.8	7.14	37	3.5	700	1	10	4
1N4737A	7.125	7.5	7.875	34	4	700	0.5	10	5
1N4738A	7.79	8.2	8.61	31	4.5	700	0.5	10	6
1N4739A	8.645	9.1	9.555	28	5	700	0.5	10	7
1N4740A	9.5	10	10.5	25	7	700	0.25	10	7.6
1N4741A	10.45	11	11.55	23	8	700	0.25	5	8.4
1N4742A	11.4	12	12.6	21	9	700	0.25	5	9.1
1N4743A	12.35	13	13.65	19	10	700	0.25	5	9.9
1N4744A	14.25	15	15.75	17	14	700	0.25	5	11.4
1N4745A	15.2	16	16.8	15.5	16	700	0.25	5	12.2
1N4746A	17.1	18	18.9	14	20	750	0.25	5	13.7
1N4747A	19	20	21	12.5	22	750	0.25	5	15.2

Example 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 5. What is the zener impedance?

Solution:

$Zz = \Delta V_Z / \Delta I_Z$ = (50mV)/(15mA - 10mA)

= 10 Ω

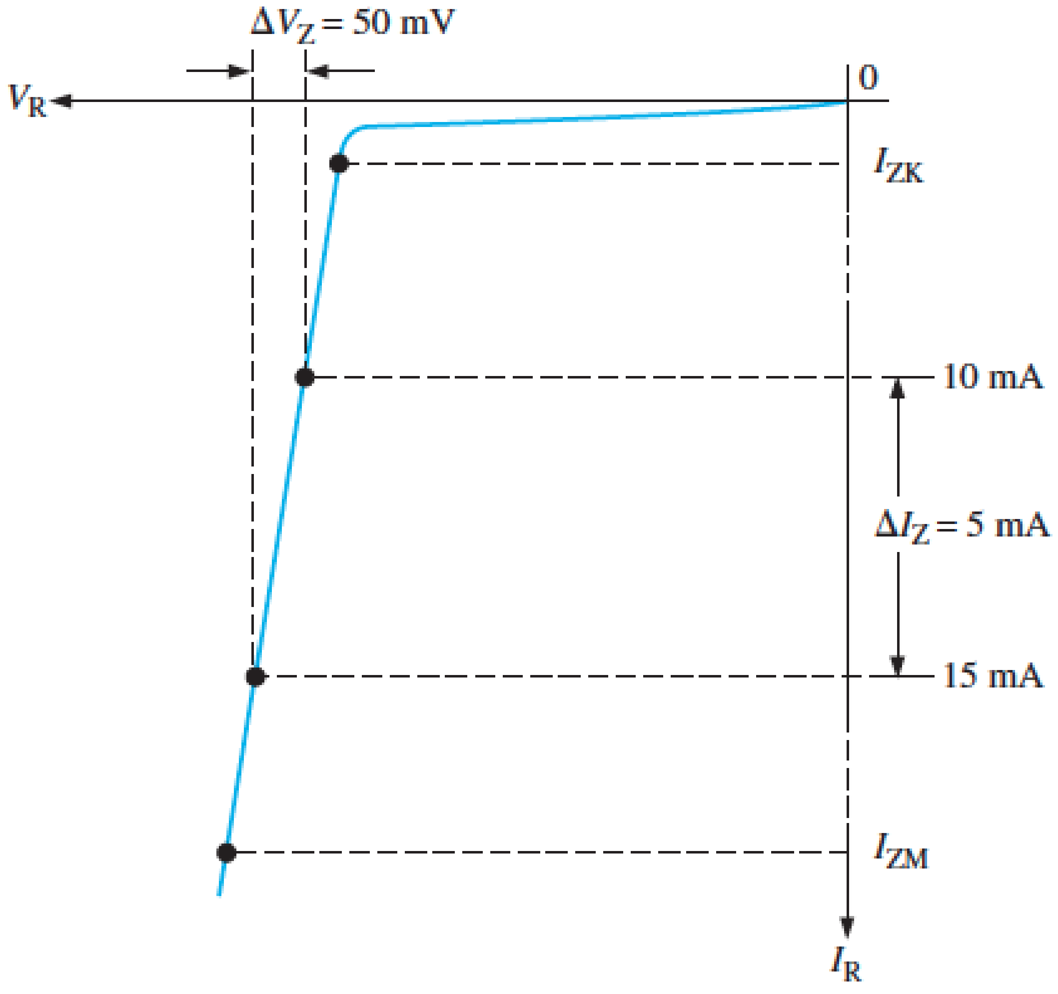


Figure 5

Example 2

Calculate the zener impedance if the change in zener voltage is 100 mV for a 20 mA change in zener current on the linear portion of the characteristic curve.

Solution:

$Zz = \Delta V_Z / \Delta I_Z$ = (100mV)/(20mA)

= 5 Ω

Example 3

From the datasheet a zener diode has a Z_Z of 3.5Ω. The datasheet gives V_Z 6.8 V at a test current, I_Z, of 37 mA. What is the voltage across the zener terminals when the current is 50 mA? When the current is 25 mA? Figure 6 represents the zener diode.

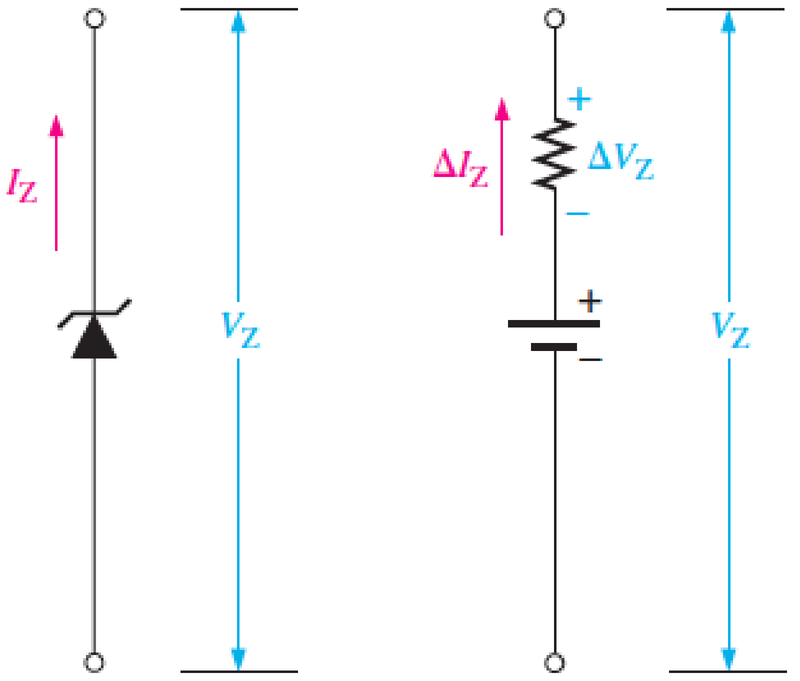


Figure 6

Solution of Example 3

- When the current equal to 50mA

  $\Delta I_Z = I_Z - 37mA = 50mA - 37mA = 13mA$

  $\Delta V_Z = \Delta I_Z * Z_Z = 45.5mV$

  $\Delta V_Z = V_{Z2} - V_{Z1}$ then $V_{Z2} = \Delta V_Z + V_{Z1} = 6.8\ V + 45.5\ mV = 6.85\ V$

- When the current equal to 25mA

  $\Delta I_Z = I_Z - 37mA = 25mA - 37mA = -12mA$

  $\Delta V_Z = \Delta I_Z * Z_Z = -42\ mV$

  $\Delta V_Z = V_{Z2} - V_{Z1}$ then $V_{Z2} = \Delta V_Z + V_{Z1} = 6.8\ V - 42\ mV = 6.758\ V$

Exercise 1

From the datasheet a zener diode has a Z_Z of 9Ω. The datasheet gives V_Z 12 V at a test current, I_Z, of 21 mA. What is the voltage across the zener terminals when the current is 10 mA and When the current is 30 mA?.