UNIT 4: Fundamentals of semiconductor devices and digital circuits

(Lecture 23 to 36 + Tutorial 9)

Prepared By:

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Outcome: Analyze the working of various semiconductor devices and its applications

Fundamentals of semiconductor devices and digital circuits : digital abstraction- voltage levels and the static discipline, boolean logic, combinational gates, fan-in and fan-out of gates, noise margin in details, pn junction and zener diode characteristics and analysis, testing of diodes and its applications, basic operation and testing of BJT, MOSFET representation and its characteristics, handling of integrated circuits-ESD phenomena

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 23
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What is Digital Signal

- A digital **signal** is a signal that can only have discrete values in time
  - Most common are **binary** digital signals, where only two values are allowed often designated as 0 and 1
- The opposite is analog signals that can take infinite values

Analog Signal

Digital Signal

What is Digital

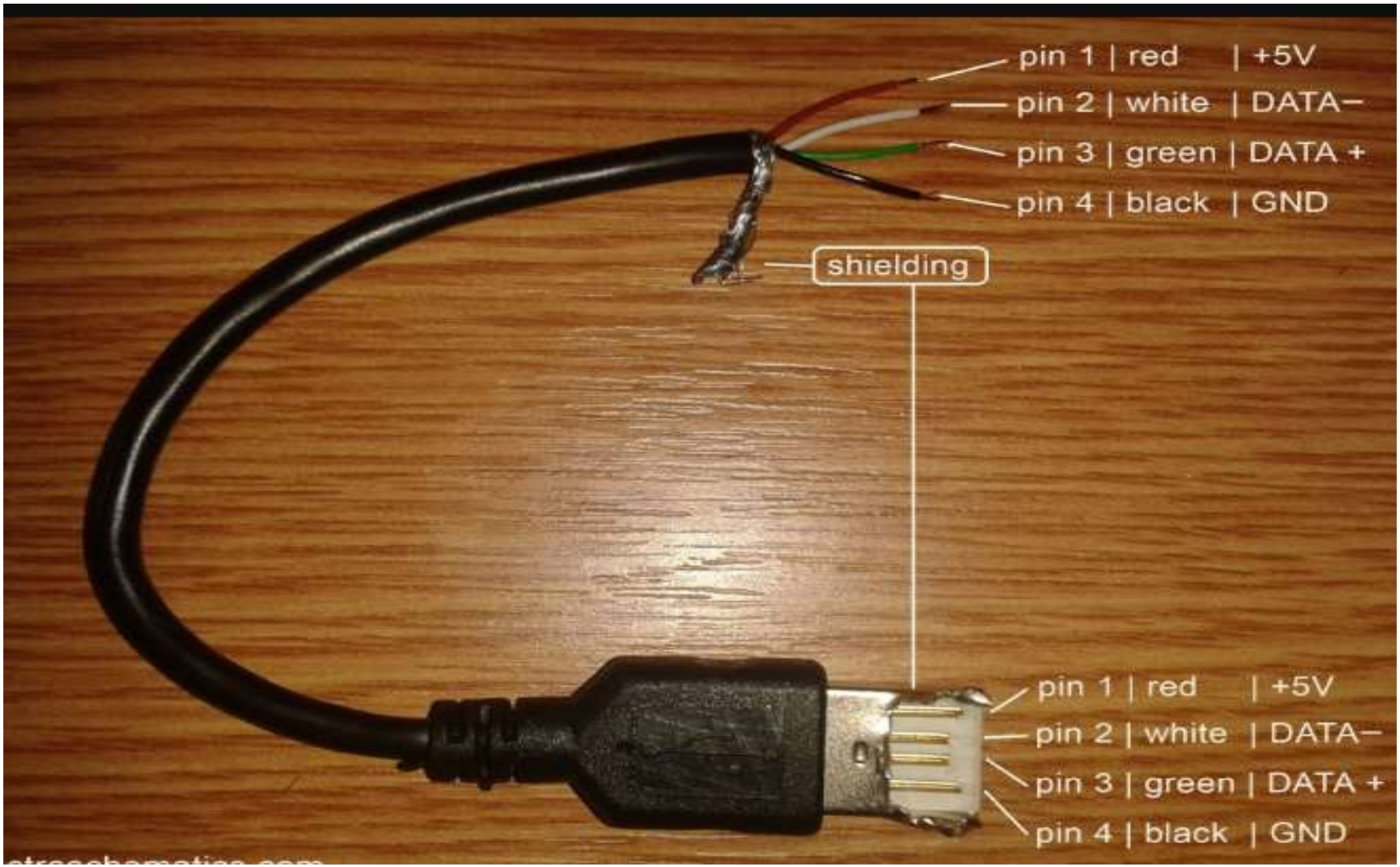
- A digital **system** processes digital signals

- Examples: computer, cellphone, DVD, digital camera, etc.

Okay, what is a signal then?

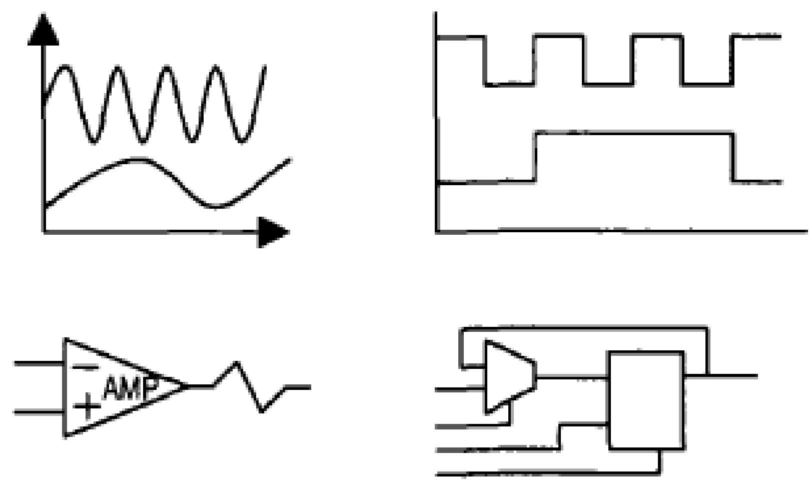
- A signal is a physical quantity (sound, light, voltage, current) that carries **information**
  - The power cable supplies power but no information (not a signal)
  - A USB cable carries information (files)
- Examples of quantities used as digital information signals
  - Voltage: 5V (logic 1), 0V (logic 0) in digital circuits
  - Magnetic field orientation in magnetic hard disks
  - Pits and lands on the CD surface reflect the light from the laser differently, and that difference is encoded as binary data

USB Cable Connections



ANALOG VS DIGITAL

- Analog devices and systems: Process analog signals (time-varying signals that can take any value across a continuous range known as dynamic range)
- Digital devices and systems: Process digital signals (analog signals that are modeled as having at any time one of two discrete values)



a. Analog Circuit. b. Digital Circuit.

Example of analog vs digital system

Digital advantages:

Battery life

Programmability

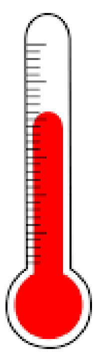
Accuracy

The world is analog

- Few systems like the watch can be completely digital
- Systems that interact with the environment, need to process analog information
- How? Analog signals must first be converted to digital

Example of analog vs digital system

Analog

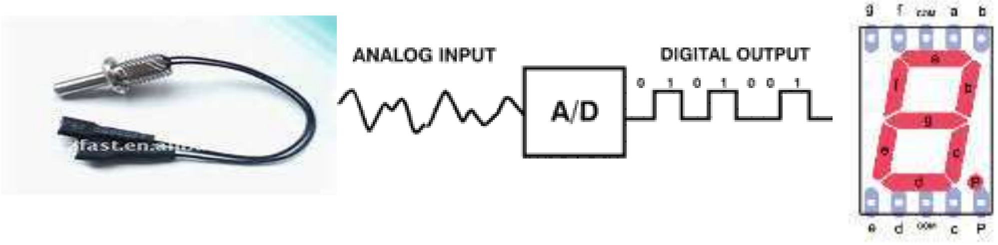


Digital

Temperature sensor (analog)

A/D converter

Display



ANALOG GOES DIGITAL

- Photography
- Video
- Audio
- Automobile applications
- Telephony/Telecomunications
- Traffic lights
- Special effects

WHY DIGITAL?
ADVANTAGES OF DIGITAL PROCESSING

- Reproducibility of results
- Ease of design
- Programmability
- Speed
- Noise tolerance

Quick Quiz (Poll 1)

- **Is this digital or analog?**

A Digital
B Analog

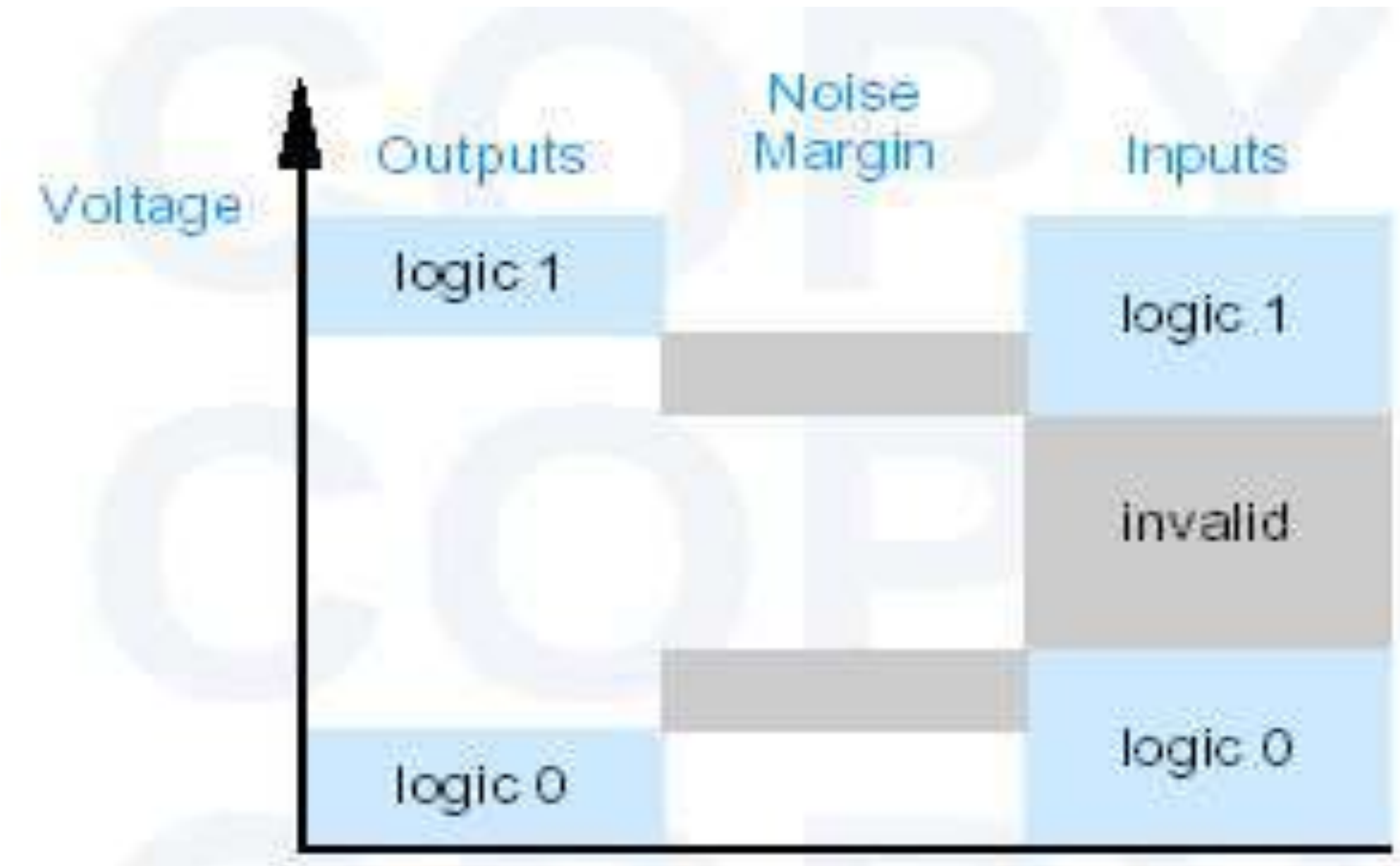
Quick Quiz (Poll 2)

- **An analog signal is sent in discrete pulses in two states, on= 1 or off= 0.**

a) True

b) False

DIGITAL ABSTRACTION



Introduction

Value discretization forms the basis of the *digital abstraction*. The idea is to lump signal values that fall within some interval into a single value (see in Figure) where a voltage signal was discretized into two levels:

- voltage value between 0 volts and 2.5 volts is treated as a ‘‘0,’’ and
- a value between 2.5 volts and 5 volts as a ‘‘1.’’

Correspondingly, to transmit the logical value ‘‘0’’ over a wire, we place the nominal voltage level of 1.25 on the wire. Similarly, to transmit the logical ‘‘1,’’ we place the nominal voltage level of 3.75 volts on the wire (see in Figure)

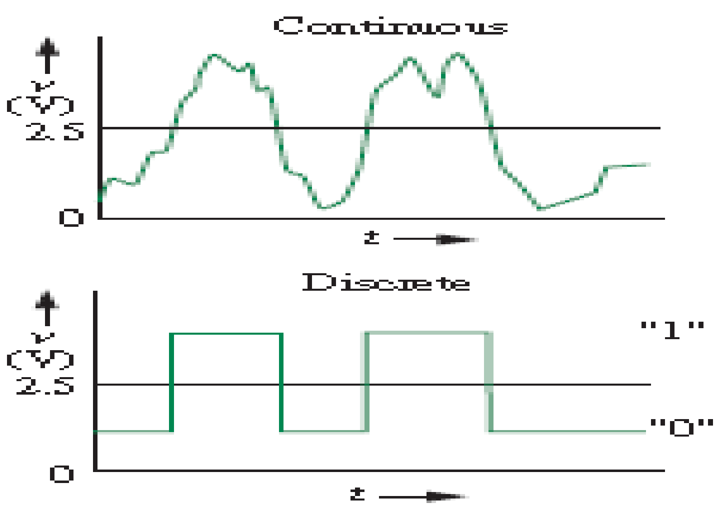


FIGURE Value discretization into two levels.

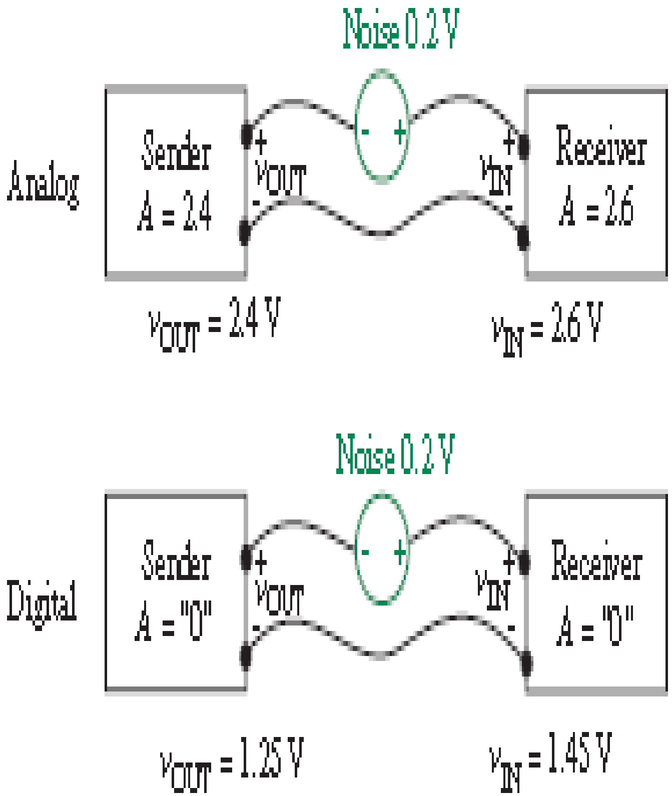
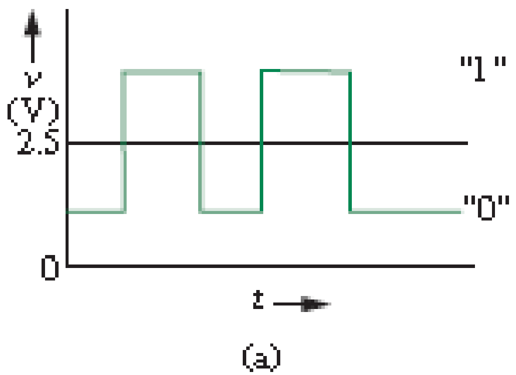


FIGURE 9.2 Signal transmission in the presence of noise. The noise is represented as a series voltage source.

Although the digital approach seems wasteful of signal dynamic range, it has a significant advantage over analog transmission in the presence of noise. Notice, this representation is immune to symmetric noise with a peak to peak value less than 2.5 V. To illustrate, consider the situation depicted in Figure in which a sender desires to transmit a value *A* to a receiver.

In the digital case, suppose that the value *A* is a logical "0." The sender transmits this value of *A* by representing it as a voltage level of 1.25 V on the wire, which is received as a voltage level of 1.45 by the receiver because of the series noise source. In this situation, since the received voltage falls below the 2.5-V threshold, the receiver interprets it correctly as a logical "0." Thus, the sender and receiver were able to communicate without error in the digital case.



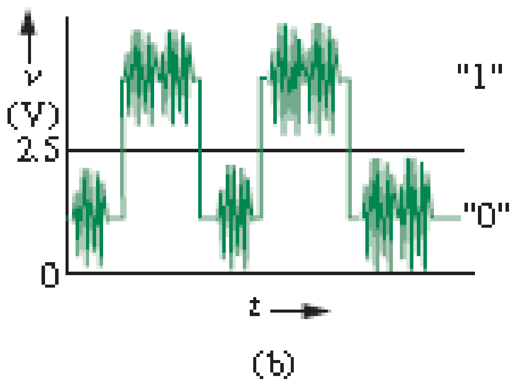


FIGURE 9.3 Noise immunity for discretized signals: (a) a digital signal produced by a sender; (b) the signal received by a receiver following transmission through a noisy environment.

To illustrate further, consider the waveforms in Figure 9.3. Figure 9.3a shows a discretized signal waveform produced by a sender corresponding to a "0," "1," "0," "1," "0" sequence. Figure 9.3b shows the same signal with the
superposition of some amount of noise, possibly during transmission through
a noisy environment.

Two levels of signal precision are sufficient for many applications. As one example, logic computations involve signals that commonly take on one of two values: TRUE or FALSE.

There are other applications that require more levels of precision:

A speech signal processing application might involve speech signals with 256 or more levels of precision.

One approach to achieving more precision is to use coding to create multi-digit numbers. When each digit takes on one of two values, the digit is called a *binary digit*, or bit.

Much as the familiar decimal system uses multiple digits to represent numbers other than 0 through 9, the binary system uses multiple bits to represent numbers other than 0 or 1.

Multi-bit signals are commonly transmitted by allocating multiple wires one for each bit, or occasionally, by time multiplexing multiple bits on a single wire.

The two-level representation is commonly known as the *binary representation*. Virtually all digital circuits use the binary representation because two-level circuits are much easier to build than multilevel circuits. The two levels in the binary representation are variously called

(a) TRUE or FALSE,

(b) ON or OFF,

(c) 1 or 0,

(d) HIGH or LOW.

Quick Quiz (Poll 3)

A signal is a way to transmit ________________ by means of gesture, action, sound, or other means.

a) money
b) information
c) time
d) light

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 24

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Voltage Levels and the static discipline

The representations differed not only in the signal type (for example, current versus voltage), but also in the signal values (for example, 5 V versus 4 V to represent a logical 1).

Because we require that digital devices built by various manufacturers talk to each other, the devices must adhere to a common representation.

The representation must allow for large enough design margins so that devices can be built out of a wide range of technologies.

Furthermore, the representation should be such that the devices operate correctly even in the presence of some amount of noise.

The *static discipline* is a specification for digital devices. The static discipline requires devices to adhere to a common representation, and to guarantee that they interpret correctly inputs that are valid logical signals according to the common representation, and to produce outputs that are valid logical signals provided they receive valid logical inputs.

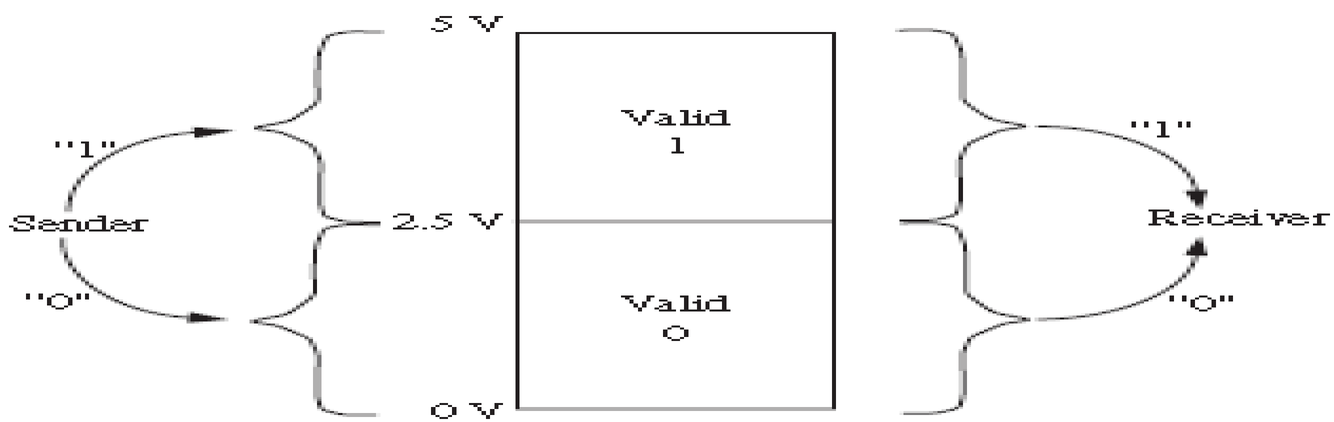
Voltage Levels and the static discipline

One of the representations we saw earlier divided a voltage range into two intervals and associated a logic value with each, namely,

$$\text{Logic } 0: 0.0\text{ V} \leq V < 2.5\text{ V}.$$

$$\text{Logic } 1: 2.5\text{ V} \leq V \leq 5.0\text{ V}.$$

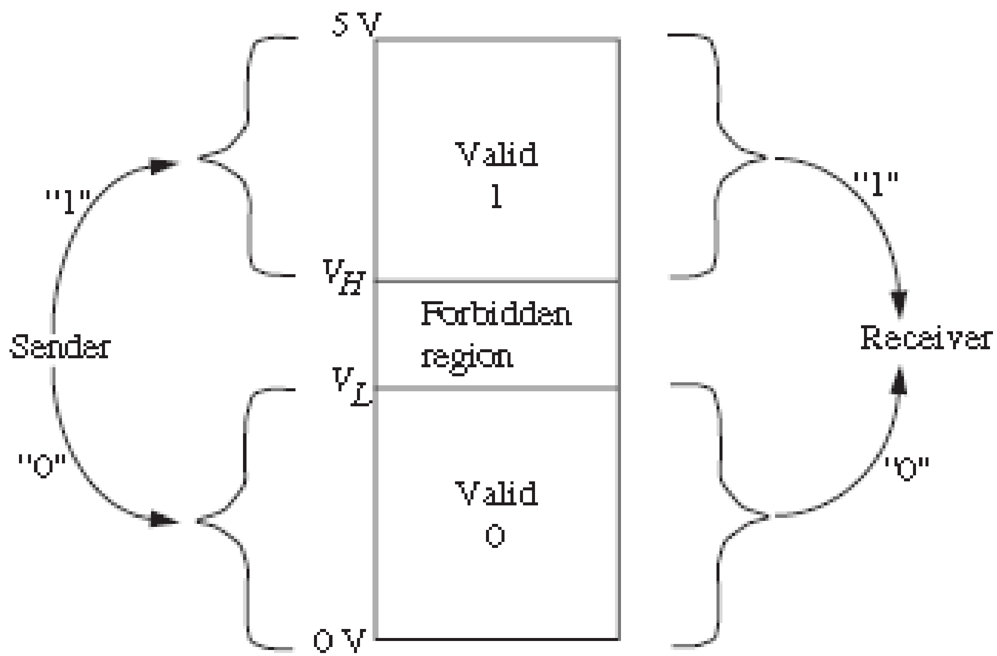
This simple representation is illustrated in Figure. According to this representation, if a receiver saw 2 V on a wire it would interpret it as a 0. Similarly, a receiver would interpret 4 V on a wire as a 1. Assume, for now, that values outside this range are invalid.



There is one problem, however. What does the receiver do if it sees a voltage level of 2.5 V on the wire? Does it interpret this signal value as a logical 0 or as a logical 1?

To eliminate such confusion, we further prescribe a ***forbidden region*** that separates the two valid regions. We further allow the behavior of the receiving device to be undefined if it sees a voltage in the forbidden region.

Thus, the correspondence between voltage levels and logic signals from the viewpoint of a receiver might look like:

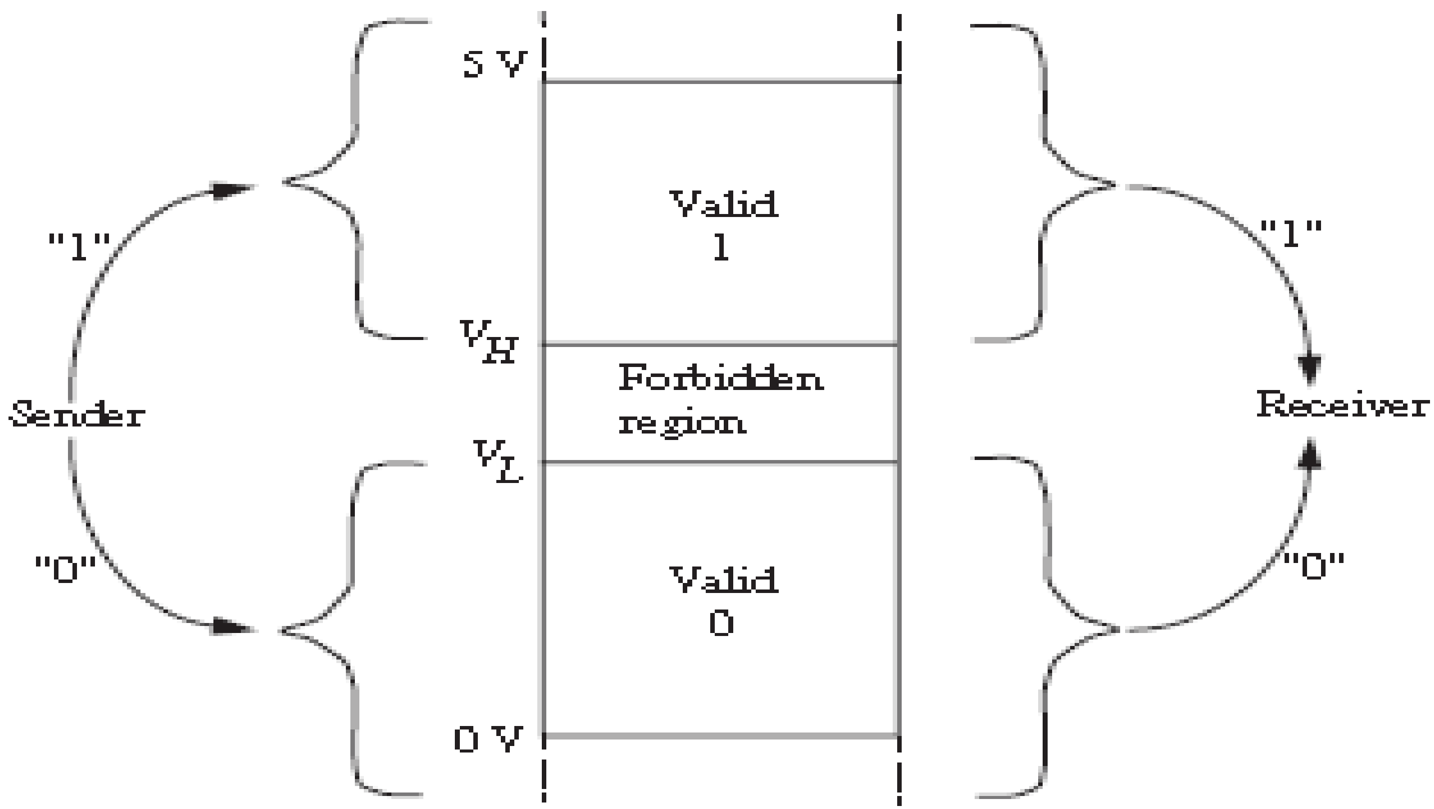


Logic 0 : 0 V ≤ V ≤ 2 V.

Logic 1 : 3 V ≤ V ≤ 5 V.

This representation using a forbidden region is illustrated in Figure. In this representation, a receiver interprets signals above 3 V as a logical 1 and voltages below 2 V as a logical 0. Signal voltages between 2 V and 3 V are invalid.

It often turns out that practical circuits are able to correctly interpret values outside the extremum points (below 0 volts for a logical 0 and above 5 V for a logical 1), within certain limits, of course. When devices can make this interpretation, our representation with the forbidden region allows senders to output any voltage value above V_H for a logical 1. Similarly, senders can output any value below V_L for a logical 0 (see Figure).



There is one other problem with our representations illustrated in previous Figures They do not offer any immunity to noise. As an illustration of the notion of noise margins, consider the two situations in Figure.

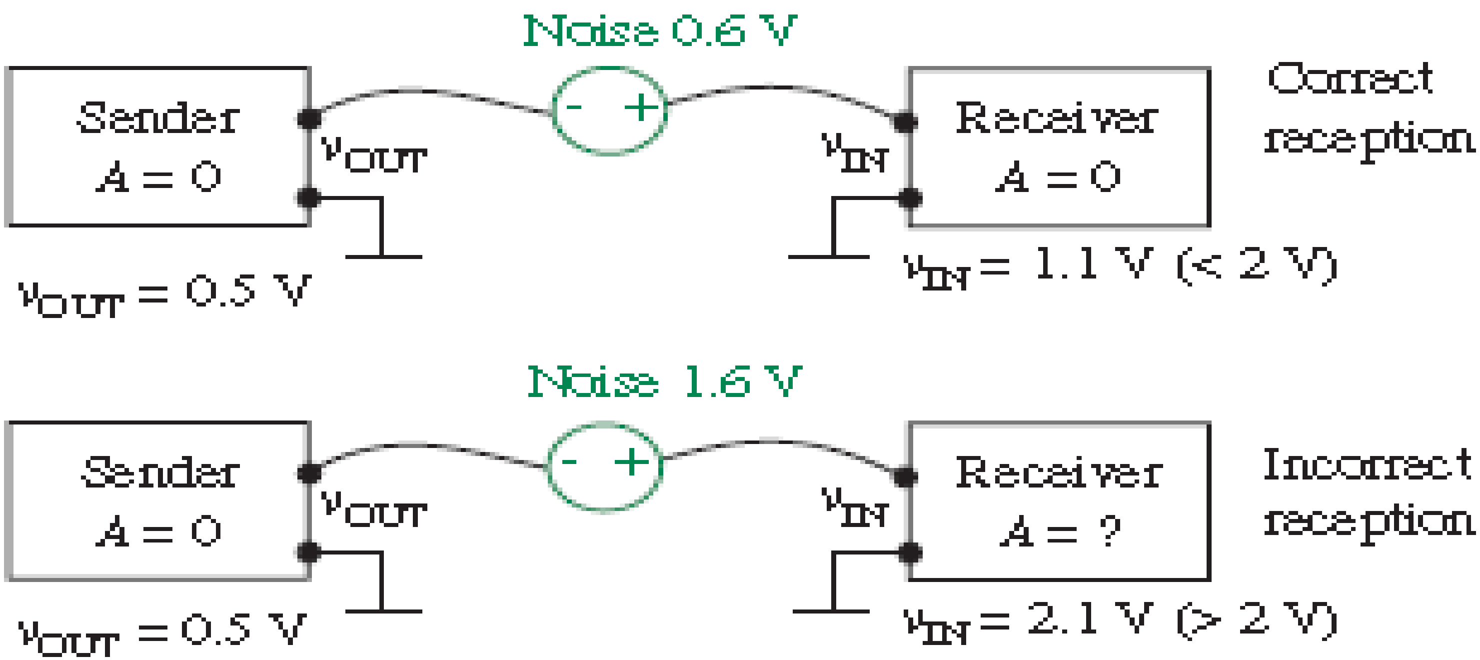
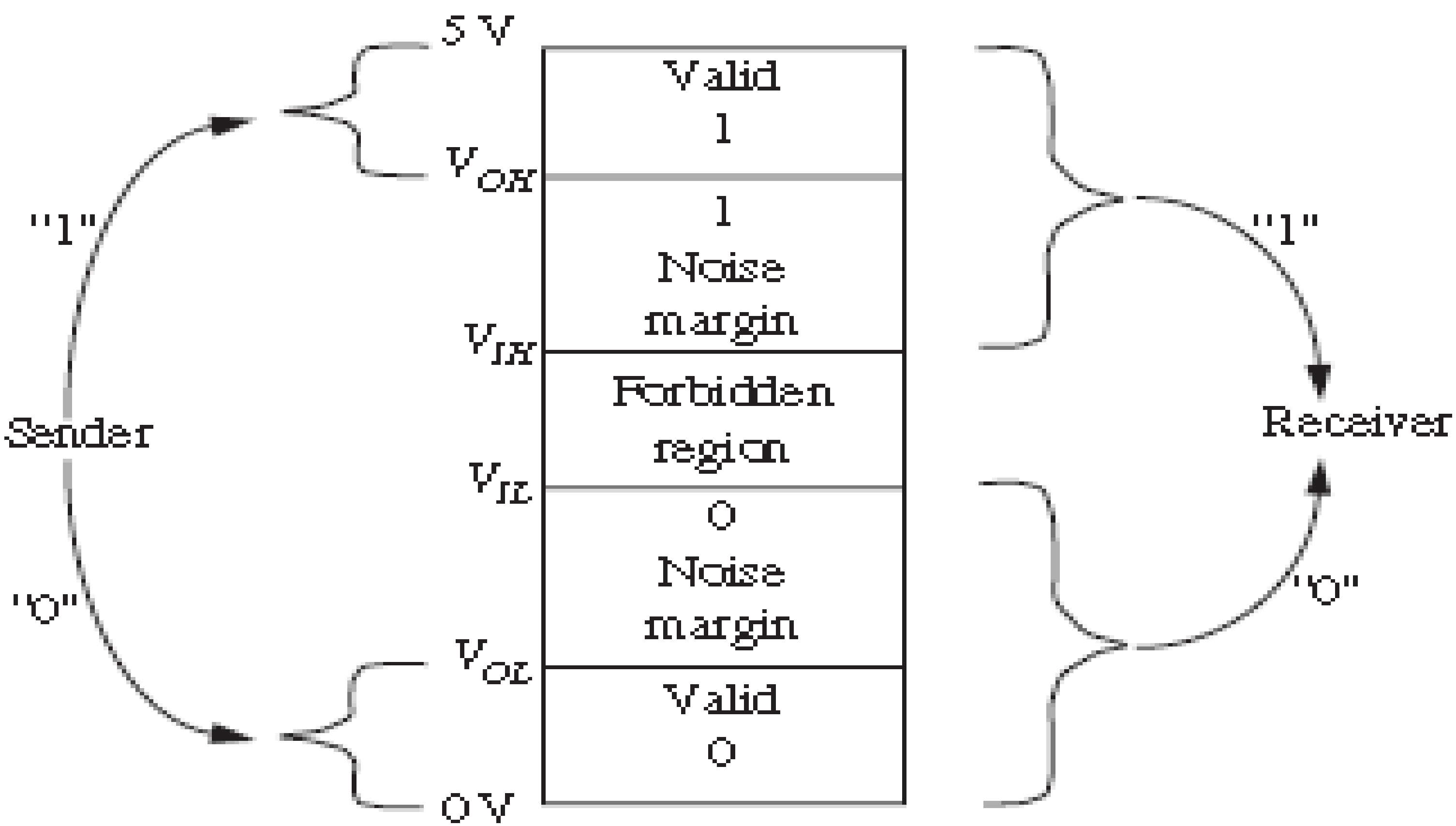


FIGURE Noise margins and signal transmission.

The tighter bounds on the voltage values for a sender compared to those for a receiver result in an asymmetry in input and output voltage thresholds.

This asymmetry is reflected in Figure which shows the correspondence between valid voltage levels and logic signals that is in common use in digital circuits.



To send a logical 0, the sender must produce an *output* voltage value that is less than V_{OL}. Correspondingly, the receiver must interpret *input* voltages below V_{IL} as a logical 0.

Similarly, to send a logical 1, the sender must produce an *output* voltage value that is greater than V_{OH}. Further, the receiver must interpret voltages above V_{IH} as a logical 1.

Quick Quiz (Poll 1)

Noise Margin is:

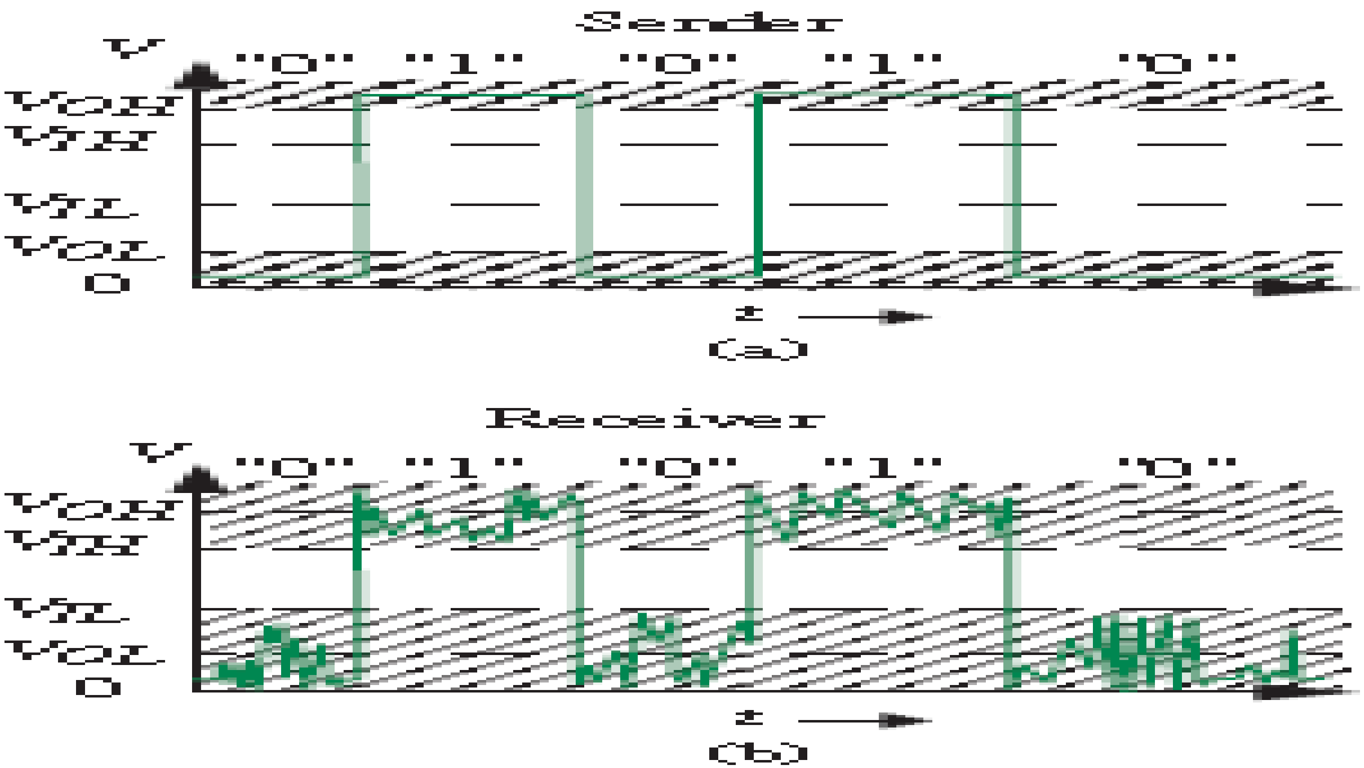
a) Amount of noise the logic circuit can withstand
b) Difference between VOH and VIH
c) Difference between VIL and VOL
d) All of the Mentioned

To allow for a reasonable noise margin, V_{OH} must greater than V_{IH}. We can define both a noise margin for transmitting logical 1's and for transmitting logical 0's.

Noise Margin: The absolute value of the difference between the prescribed output voltage for a given logical value and the corresponding forbidden region voltage threshold for the receiver is called the *noise margin* for that logical value.

Figure a illustrates a scenario in which a sender outputs a 01010 sequence by producing the appropriate output voltage levels (between V_{OH} and 5 V for a logical 1, and between 0 V and V_{OL} for a logical 0).

Provided that the noise does not exceed the noise margins (voltages for a logical 0 do not exceed V_{IL} and voltages for a logical 1 do not fall below V_{IH}), a receiver is able to correctly interpret the signal as illustrated in Figure b.



As illustrated in Figure, the *noise margin for a logical 0* is given by

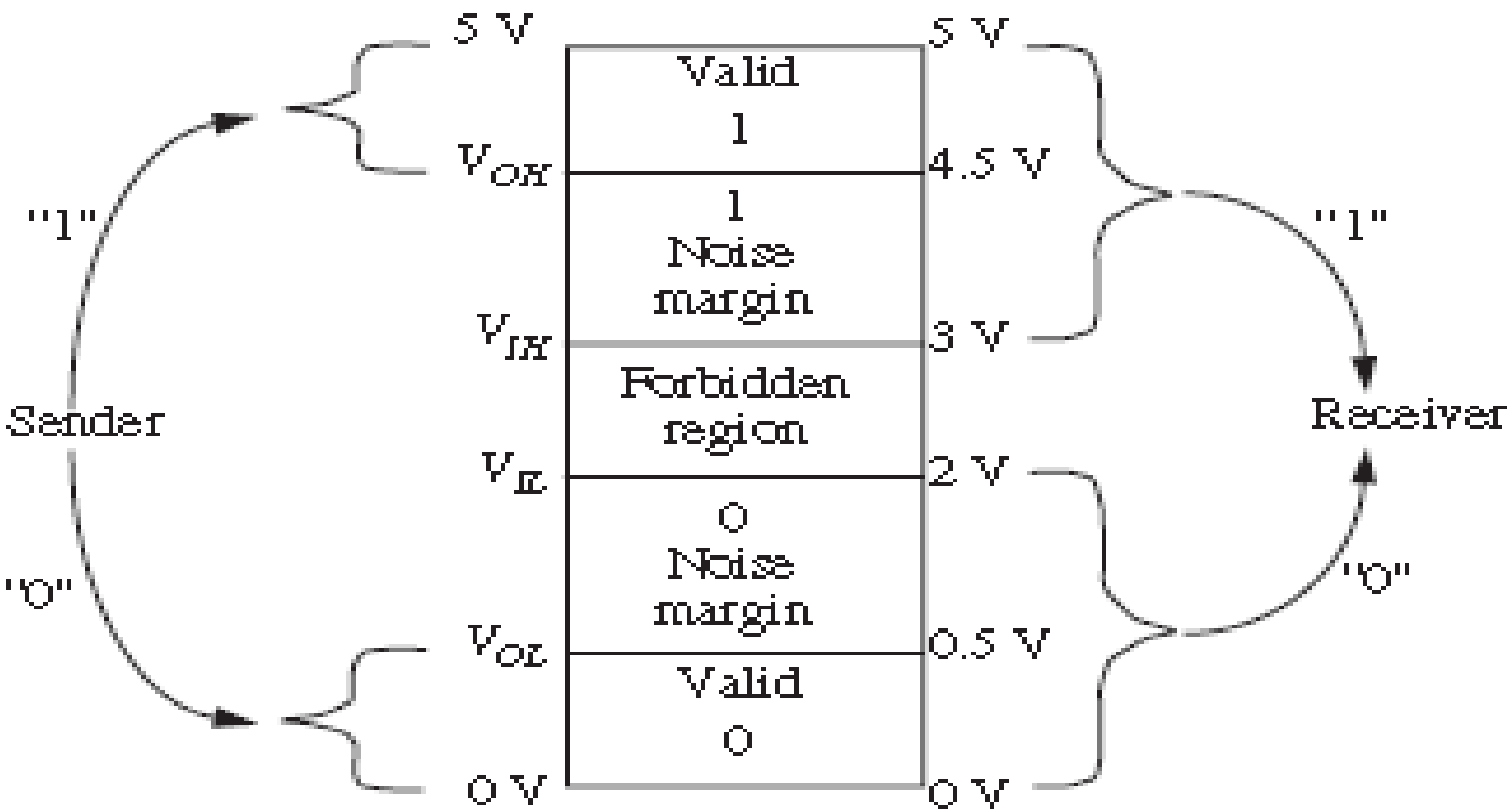
$$NM_0 = V_{IL} - V_{OL}$$

and the *noise margin for a logical 1* is given by

$$NM_1 = V_{OH} - V_{IH}.$$

The region between V_{IL} and V_{IH} is the forbidden region.

Relating the threshold voltage parameters to the numbers used in our example, V_{OH} corresponds to 4.5 V, V_{OL} corresponds to 0.5 V, V_{IH} corresponds to 3 V, and V_{IL} corresponds to 2 V. This mapping is illustrated in Figure .



Quick Quiz (Poll 2)

The noise immunity _______________ with noise margin.

a) Decreases
b) Increases
c) Constant
d) None of the Mentioned

Static discipline The *static discipline* is a specification for digital devices. The static discipline requires devices to interpret correctly voltages that fall within the input thresholds (V_{IL} and V_{IH}). As long as valid inputs are provided to the devices, the discipline also requires the devices to produce valid output voltages that satisfy the output thresholds (V_{OL} and V_{OH}).

When designing logic devices, we are often interested in maximizing the noise margins to achieve maximum noise immunity. Referring to Figure 9.8, the 0 noise margin, NM0 = $V_{IL} - V_{OL}$, can be maximized by maximizing V_{IL} and minimizing V_{OL}. Similarly, the 1 noise margin, NM1 = $V_{OH} - V_{IH}$, can be maximized by maximizing V_{OH} and minimizing V_{IH}.

Quick Quiz (Poll 3)

The Lower Noise Margin is given by:

a) VOL – VIL
b) VIL – VOL
c) VIL ~ VOL(Difference between VIL and VOL, depends on which one is greater)
d) All of the Mentioned

Quick Quiz (Poll 4)

The Higher Noise Margin is given by:

a) VOH – VIH
b) VIH – VOH
c) VIH ~ VOH(Difference between VIH and VOH, depends on which one is greater)
d) All of the mentioned

Quick Quiz (Poll 5)

Input Voltage between VIL and VOL is considered as:

a) Logic Input 1
b) Logic Input 0
c) Uncertain
d) None of the mentioned

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 25

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Introduction

- In the middle of the twentieth century, computers were commonly known as “thinking machines” and “electronic brains.”
  - Many people were fearful of them.
- Nowadays, we rarely ponder the relationship between electronic digital computers and human logic. Computers are accepted as part of our lives.
  - Many people, however, are still fearful of them.
- In this chapter, you will learn the simplicity that constitutes the essence of the machine.

Boolean Algebra

- Boolean algebra is a mathematical system for the manipulation of variables that can have one of two values.
  - In formal logic, these values are "true" and "false."
  - In digital systems, these values are "on" and "off," 1 and 0, or "high" and "low."
- Boolean expressions are created by performing operations on Boolean variables.
  - Common Boolean operators include AND, OR, and NOT.

Boolean Algebra

- A Boolean operator can be completely described using a truth table.
- The truth table for the Boolean operators AND and OR are shown at the right.
- The AND operator is also known as a Boolean product. The OR operator is the Boolean sum.

X AND Y

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1

X OR Y

X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1

Boolean Algebra

- The truth table for the Boolean NOT operator is shown at the right.
- The NOT operation is most often designated by an overbar. It is sometimes indicated by a prime mark (‘) or an “elbow” (¬).

NOT x

x	$\overline{x}$
0	1
1	0

Boolean Algebra

- A Boolean function has:
  - At least one Boolean variable,
  - At least one Boolean operator, and
  - At least one input from the set {0,1}.
- It produces an output that is also a member of the set {0,1}.

Now you know why the binary numbering system is so handy in digital systems.

Quick Quiz (Poll 1)

- Boolean algebra can be used _______________

  a) For designing of the digital computers
  b) In building logic symbols
  c) Circuit theory
  d) Building algebraic functions

Boolean Algebra

- The truth table for the Boolean function:

  $$F(x,y,z) = x\bar{z}+y$$

  is shown at the right.
- To make evaluation of the Boolean function easier, the truth table contains extra (shaded) columns to hold evaluations of subparts of the function.

$$F(x,y,z) = x\bar{z}+y$$

x	y	z	$\bar{z}$	$x\bar{z}$	$x\bar{z}+y$
0	0	0	1	0	0
0	0	1	0	0	0
0	1	0	1	0	1
0	1	1	0	0	1
1	0	0	1	1	1
1	0	1	0	0	0
1	1	0	1	1	1
1	1	1	0	0	1

Boolean Algebra

- As with common arithmetic, Boolean operations have rules of precedence.
- The NOT operator has highest priority, followed by AND and then OR.
- This is how we chose the (shaded) function subparts in our table.

$$F(x,y,z) = x\bar{z}+y$$

x	y	z	$\bar{z}$	$x\bar{z}$	$x\bar{z}+y$
0	0	0	1	0	0
0	0	1	0	0	0
0	1	0	1	0	1
0	1	1	0	0	1
1	0	0	1	1	1
1	0	1	0	0	0
1	1	0	1	1	1
1	1	1	0	0	1

Boolean Algebra

- Digital computers contain circuits that implement Boolean functions.
- The simpler that we can make a Boolean function, the smaller the circuit that will result.
  - Simpler circuits are cheaper to build, consume less power, and run faster than complex circuits.
- With this in mind, we always want to reduce our Boolean functions to their simplest form.
- There are a number of Boolean identities that help us to do this.

Boolean Algebra

- Most Boolean identities have an AND (product) form as well as an OR (sum) form. We give our identities using both forms. Our first group is rather intuitive:

Identity Name	AND Form	OR Form
Identity Law	$1x = x$	$0 + x = x$
Null Law	$0x = 0$	$1 + x = 1$
Idempotent Law	$xx = x$	$x + x = x$
Inverse Law	$x\overline{x} = 0$	$x + \overline{x} = 1$

Boolean Algebra

- Our second group of Boolean identities should be familiar to you from your study of algebra:

Identity Name	AND Form	OR Form
Commutative Law	$xy = yx$	$x+y = y+x$
Associative Law	$(xy)z = x(yz)$	$(x+y)+z = x + (y+z)$
Distributive Law	$x+yz = (x+y)(x+z)$	$x(y+z) = xy+xz$

Boolean Algebra

- Our last group of Boolean identities are perhaps the most useful.
- If you have studied set theory or formal logic, these laws are also familiar to you.

Identity Name	AND Form	OR Form
Absorption Law	$x(x+y) = x$	$x + xy = x$
DeMorgan's Law	$\overline{(xy)} = \overline{x} + \overline{y}$	$\overline{(x+y)} = \overline{x}\,\overline{y}$
Double Complement Law	$\overline{(\overline{x})} = x$	

Boolean Algebra

- We can use Boolean identities to simplify the function:

  as follows: $F(X,Y,Z) = (X + Y)(X + \overline{Y})(\overline{X\overline{Z}})$

$(X + Y)(X + \overline{Y})(\overline{X\overline{Z}})$	Idempotent Law (Rewriting)
$(X + Y)(X + \overline{Y})(\overline{X} + Z)$	DeMorgan's Law
$(XX + X\overline{Y} + XY + Y\overline{Y})(\overline{X} + Z)$	Distributive Law
$((X + Y\overline{Y}) + X(Y + \overline{Y}))(\overline{X} + Z)$	Commutative & Distributive Laws
$((X + 0) + X(1))(\overline{X} + Z)$	Inverse Law
$X(\overline{X} + Z)$	Idempotent Law
$X\overline{X} + XZ$	Distributive Law
$0 + XZ$	Inverse Law
XZ	Idempotent Law

Simplifying Logic Expressions

Find the minimum sum-of-products representation for the boolean function

$$A + \overline{\overline{A}C} + B.$$

We first write the sum-of-products representation:

$$\begin{aligned} A + \overline{\overline{A}C} + B &= A + (\overline{\overline{A}} + \overline{C}) + B \\ &= A + (A + \overline{C}) + B \\ &= A + A + \overline{C} + B \\ &= A + \overline{C} + B. \end{aligned}$$

Here, $A + A + \overline{C} + B$ is in a sum-of-products form. The minimum sum-of-products form, however, is $A + \overline{C} + B$.

Simplifying Logic Expressions

$$Z = \overline{X}\,Y + X\,\overline{Y} + X\,Y.$$

The following sequence of simplifications show that this expression for Z is equivalent to $X + Y$:

$$\begin{aligned} Z &= \overline{X}Y + X\overline{Y} + XY \\ &= \overline{X}Y + X(\overline{Y} + Y) \\ &= \overline{X}Y + X \cdot 1 \\ &= \overline{X}Y + X \\ &= Y + X. \end{aligned}$$

Name	AND form	OR form
Identity law	$1A = A$	$0 + A = A$
Null law	$0A = 0$	$1 + A = 1$
Idempotent law	$AA = A$	$A + A = A$
Inverse law	$A\overline{A} = 0$	$A + \overline{A} = 1$
Commutative law	$AB = BA$	$A + B = B + A$
Associative law	$(AB)C = A(BC)$	$(A + B) + C = A + (B + C)$
Distributive law	$A + BC = (A + B)(A + C)$	$A(B + C) = AB + AC$
Absorption law	$A(A + B) = A$	$A + AB = A$
De Morgan's law	$\overline{AB} = \overline{A} + \overline{B}$	$\overline{A + B} = \overline{A}\,\overline{B}$

Quick Quiz (Poll 2)

Applying DeMorgan's theorem to the expression $\overline{ABC}$, we get ________.

A. $\overline{A} + \overline{B} + \overline{C}$

B. $\overline{A + B + C}$

C. $A + \overline{B} + C\overline{C}$

D. $A(B + C)$

Quick Quiz (Poll 3)

- $AC + ABC = AC$

A True

B False

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 26

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Boolean Algebra

- Sometimes it is more economical to build a circuit using the complement of a function (and complementing its result) than it is to implement the function directly.
- DeMorgan's law provides an easy way of finding the complement of a Boolean function.
- Recall DeMorgan's law states:

$$\overline{(xy)} = \overline{x} + \overline{y} \quad \text{and} \quad \overline{(x+y)} = \overline{x}\,\overline{y}$$

Boolean Algebra

- DeMorgan's law can be extended to any number of variables.
- Replace each variable by its complement and change all ANDs to ORs and all ORs to ANDs.
- Thus, we find the the complement of:

$$F(X,Y,Z) = (XY) + (\overline{X}Z) + (Y\overline{Z})$$

is:

$$\overline{F}(X,Y,Z) = \overline{(XY) + (\overline{X}Z) + (Y\overline{Z})}$$

$$= \overline{(XY)}\,\overline{(\overline{X}Z)}\,\overline{(Y\overline{Z})}$$

$$= (\overline{X}+\overline{Y})(X+\overline{Z})(\overline{Y}+Z)$$

Boolean Algebra

- Through our exercises in simplifying Boolean expressions, we see that there are numerous ways of stating the same Boolean expression.
  - These "synonymous" forms are *logically equivalent.*
  - Logically equivalent expressions have identical truth tables.
- In order to eliminate as much confusion as possible, designers express Boolean functions in *standardized* or *canonical* form.

Boolean Algebra

- There are two canonical forms for Boolean expressions: sum-of-products and product-of-sums.
  - Recall the Boolean product is the AND operation and the Boolean sum is the OR operation.
- In the sum-of-products form, ANDed variables are ORed together.
  - For example: $F(x,y,z) = xy + xz + yz$
- In the product-of-sums form, ORed variables are ANDed together:
  - For example: $F(x,y,z) = (x+y)(x+z)(y+z)$

Boolean Algebra

- It is easy to convert a function to sum-of-products form using its truth table.
- We are interested in the values of the variables that make the function true (=1).
- Using the truth table, we list the values of the variables that result in a true function value.
- Each group of variables is then ORed together.

$F(x,y,z) = x\bar{z}+y$

x	y	z	$x\bar{z}+y$
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

Boolean Algebra

- The sum-of-products form for our function is:

$$F(x,y,z) = \bar{x}y\bar{z}+\bar{x}yz+x\bar{y}\bar{z}+xy\bar{z}+xyz$$

We note that this function is not in simplest terms. Our aim is only to rewrite our function in canonical sum-of-products form.

$$F(x,y,z) = x\bar{z}+y$$

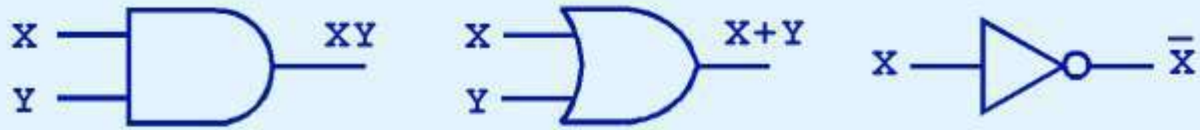
x	y	z	$x\bar{z}+y$
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

Logic Gates

- We have looked at Boolean functions in abstract terms.
- In this section, we see that Boolean functions are implemented in digital computer circuits called gates.
- A gate is an electronic device that produces a result based on two or more input values.
  - In reality, gates consist of one to six transistors, but digital designers think of them as a single unit.
  - Integrated circuits contain collections of gates suited to a particular purpose.

Logic Gates

- The three simplest gates are the AND, OR, and NOT gates.



X AND Y

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1

X OR Y

X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1

NOT X

X	$\overline{X}$
0	1
1	0

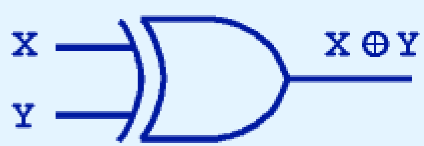
- They correspond directly to their respective Boolean operations, as you can see by their truth tables.

Logic Gates

- Another very useful gate is the exclusive OR (XOR) gate.
- The output of the XOR operation is true only when the values of the inputs differ.

X XOR Y

X	Y	X ⊕ Y
0	0	0
0	1	1
1	0	1
1	1	0



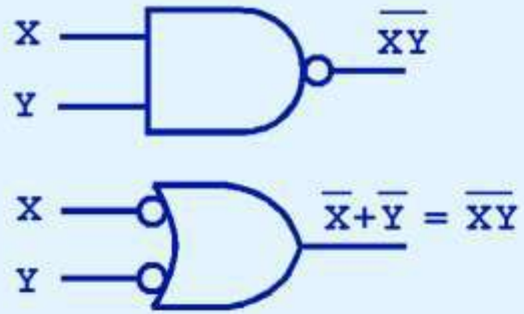
Note the special symbol ⊕ for the XOR operation.

Logic Gates

- NAND and NOR are two very important gates. Their symbols and truth tables are shown at the right.

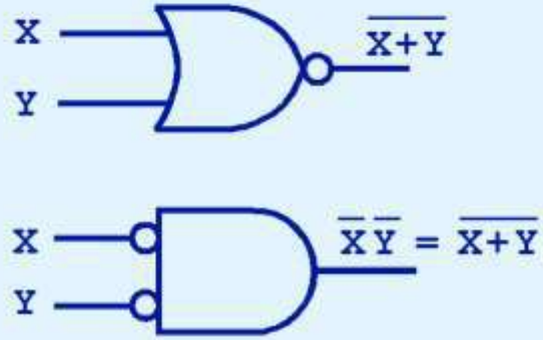
X NAND Y

X	Y	X NAND Y
0	0	1
0	1	1
1	0	1
1	1	0



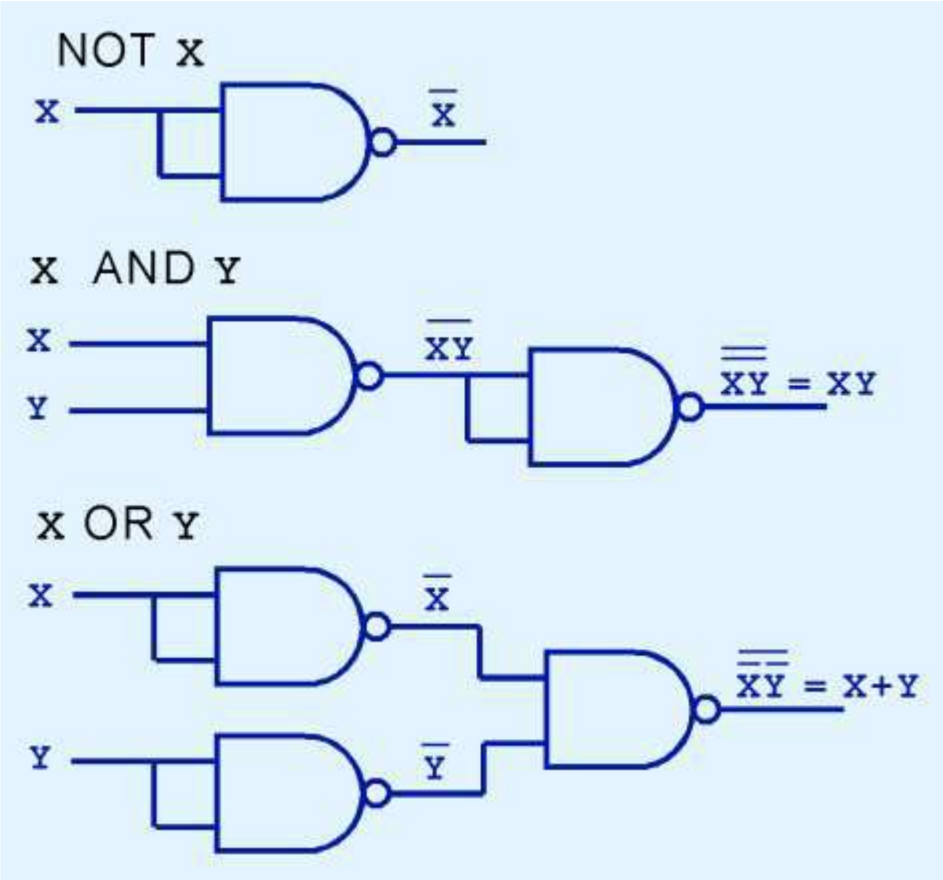
X NOR Y

X	Y	X NOR Y
0	0	1
0	1	0
1	0	0
1	1	0



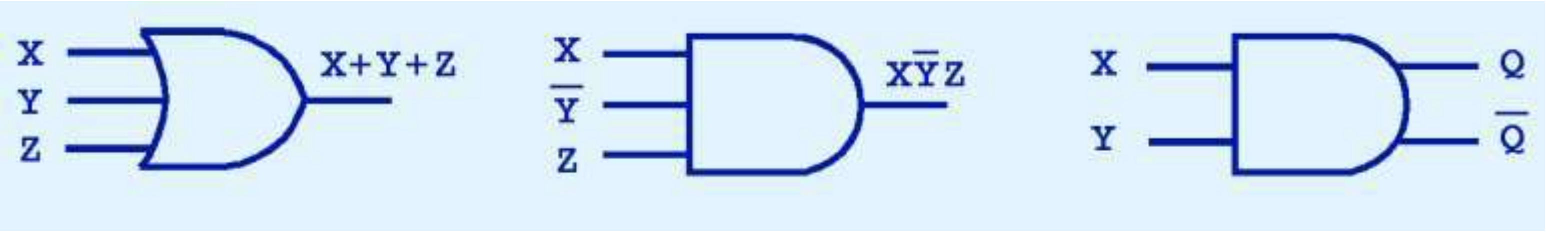
Logic Gates

- NAND and NOR are known as *universal gates* because they are inexpensive to manufacture and any Boolean function can be constructed using only NAND or only NOR gates.



Logic Gates

- Gates can have multiple inputs and more than one output.
  - A second output can be provided for the complement of the operation.
  - We'll see more of this later.



Quick Quiz (Poll 1)

- Electronic circuits that operate on one or more input signals to produce standard output _______

  a) Series circuits
  b) Parallel Circuits
  c) Logic Signals
  d) Logic Gates

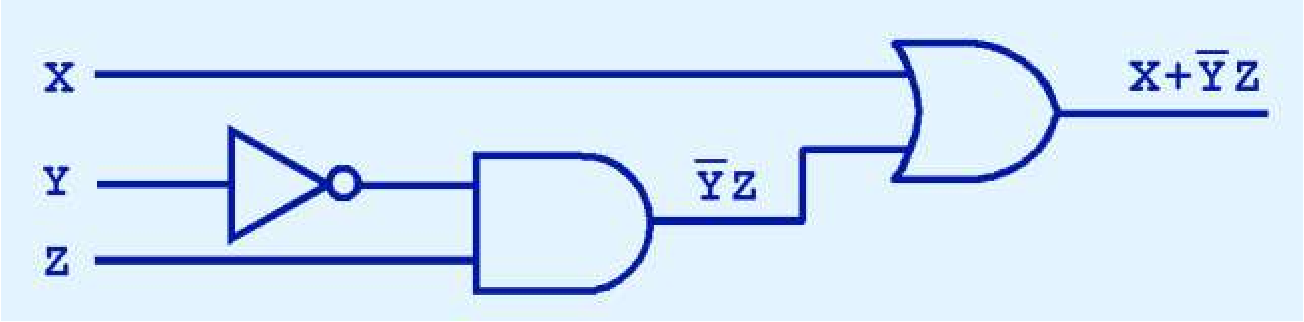
Quick Quiz (Poll 2)

- A ____________ gate gives the output as 1 only if all the inputs signals are 1.

  a) AND
  b) OR
  c) EXOR
  d) NOR

Digital Components

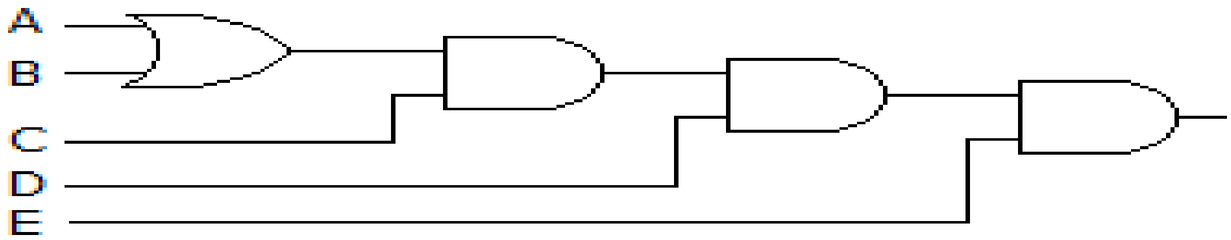
- The main thing to remember is that combinations of gates implement Boolean functions.
- The circuit below implements the Boolean function: $F(X,Y,Z) = X+\overline{Y}Z$



We simplify our Boolean expressions so that we can create simpler circuits.

Quick Quiz (Poll 3)

Derive the Boolean expression for the logic circuit shown below:



A. $C(A + B)DE$

B. $\left[C(A + B)D + \overline{E}\right]$

C. $\left[\left[C(A + B)D\right]\overline{E}\right]$

D. $ABCDE$

Quick Quiz (Poll 4)

- The universal gate that can be used to implement any Boolean expression is ___________

  a) NAND
  b) EXOR
  c) OR
  d) AND

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 27

Prepared By:
Krishan Arora
Assistant Professor and Head

What is a Semiconductor?

What is a Semiconductor?

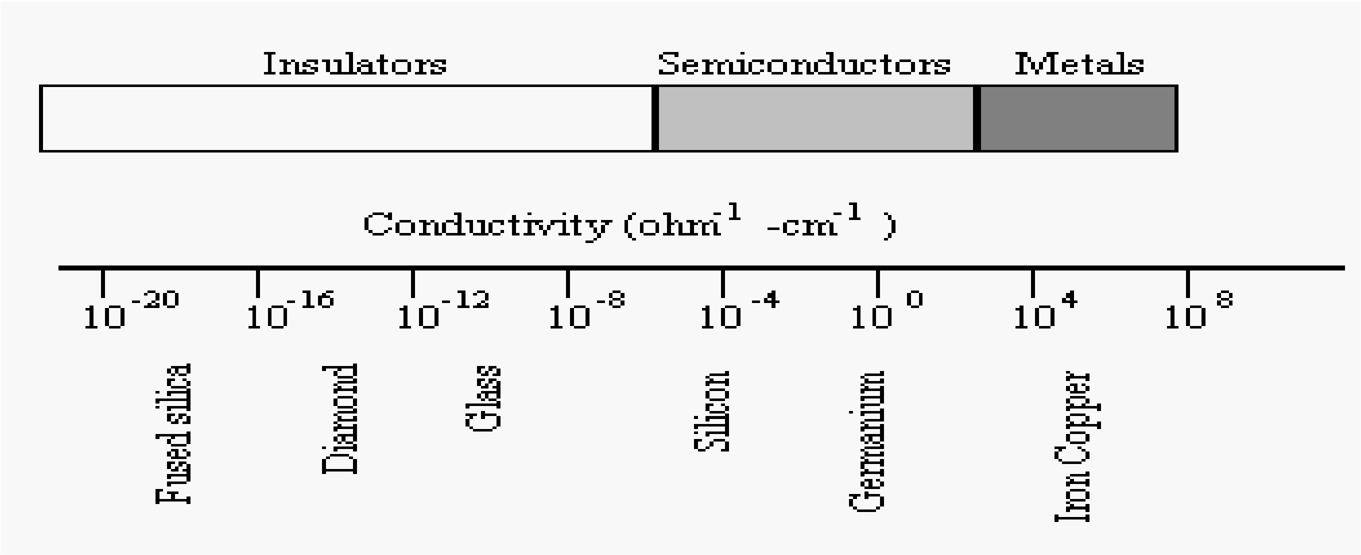
Microprocessors

Transistors

Capacitors

LED

Range of Conduciveness



The semiconductors fall somewhere midway between conductors and insulators.

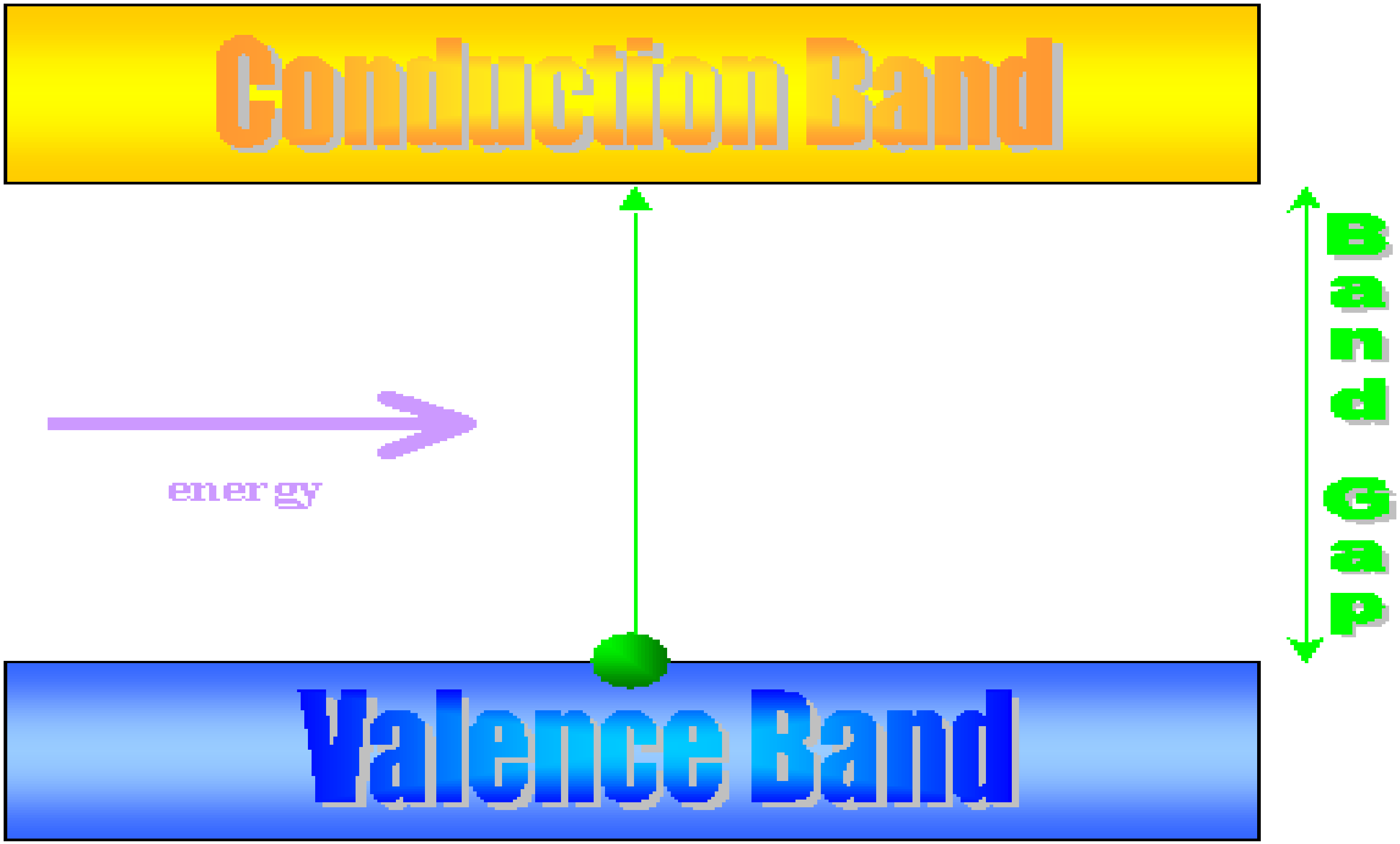
Definition

- Conductors: The materials or the substances that allow the electricity to flow through them are known as conductors. Aluminium is used in cooking utensils, that absorb and store heat, and even they are used in packing the food.

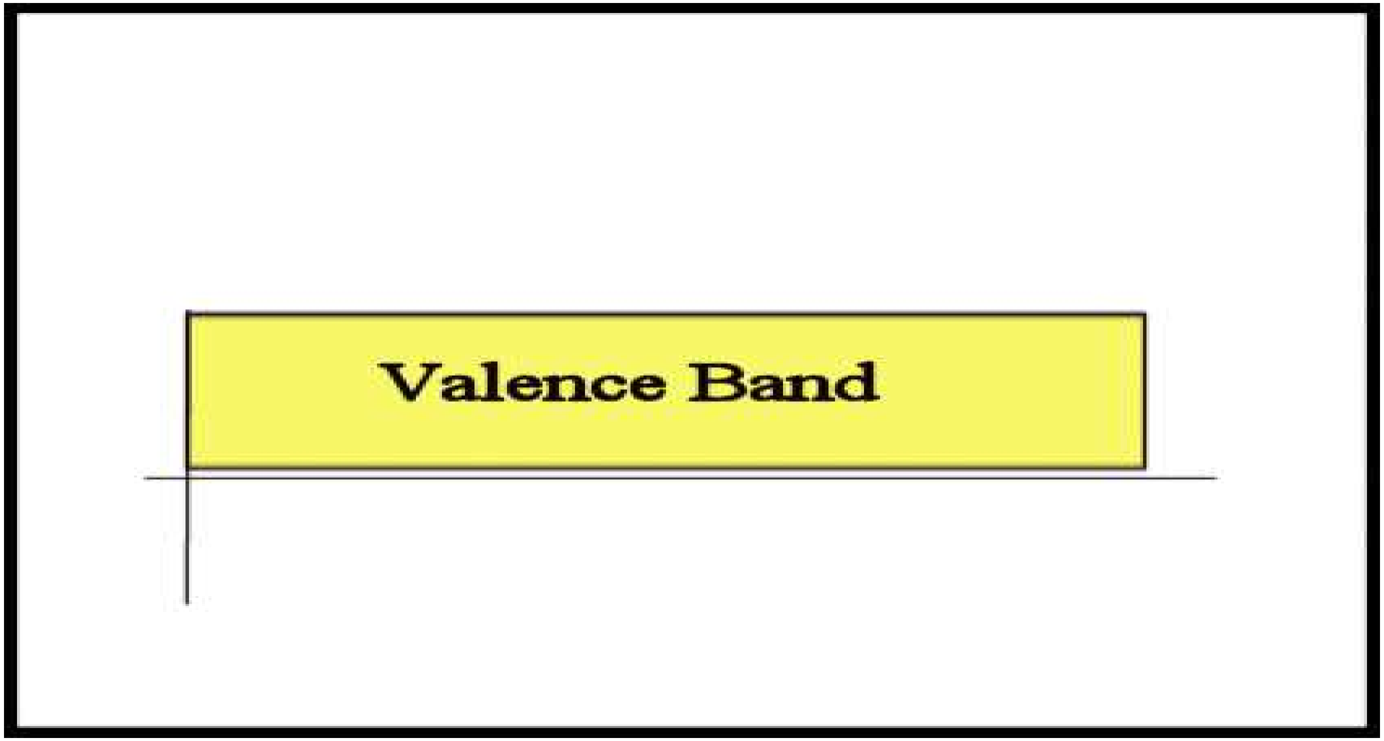
- Semiconductors: Materials that have the characters to behave like conductors, as well as insulators under different conditions, are known as semiconductors. Semiconductors are used in power devices, light emitters (including solid-state lasers), optical sensors.

- Insulators: Insulators are the substances whose characters are different from the conductors, as they do not allow heat or electricity to pass through them. Woollen clothes and blankets that are used in winters to keep the body warm.

Scientific Principle of Conduction

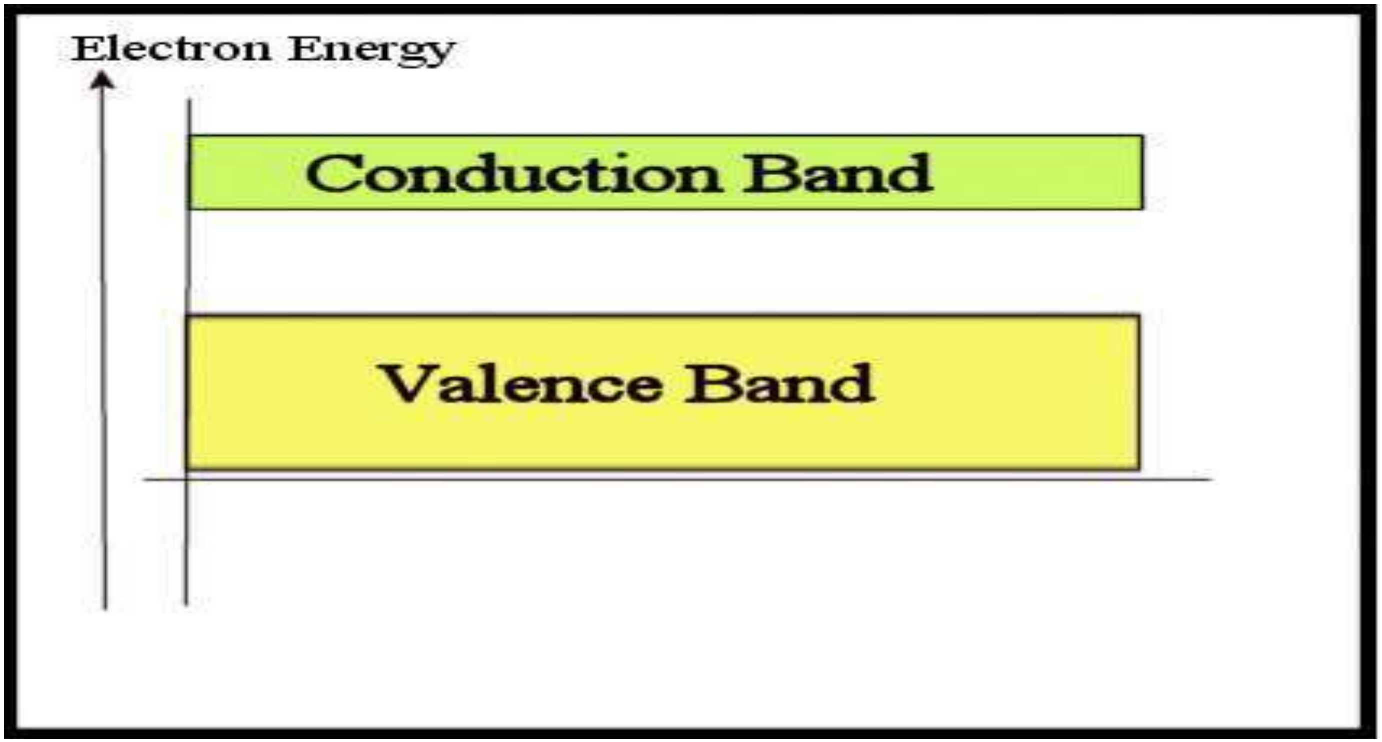


Valence Band



The highest occupied energy band is called the valence band.
Most electrons remain bound to the atoms in this band.

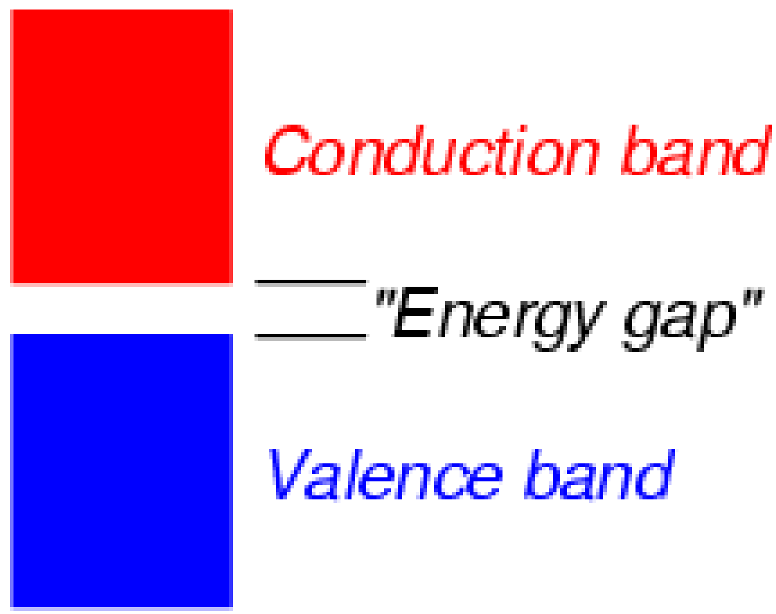
Conduction Band



The conduction band is the band of orbitals that are high in energy and are generally empty.

It is the band that accepts the electrons from the valence band.

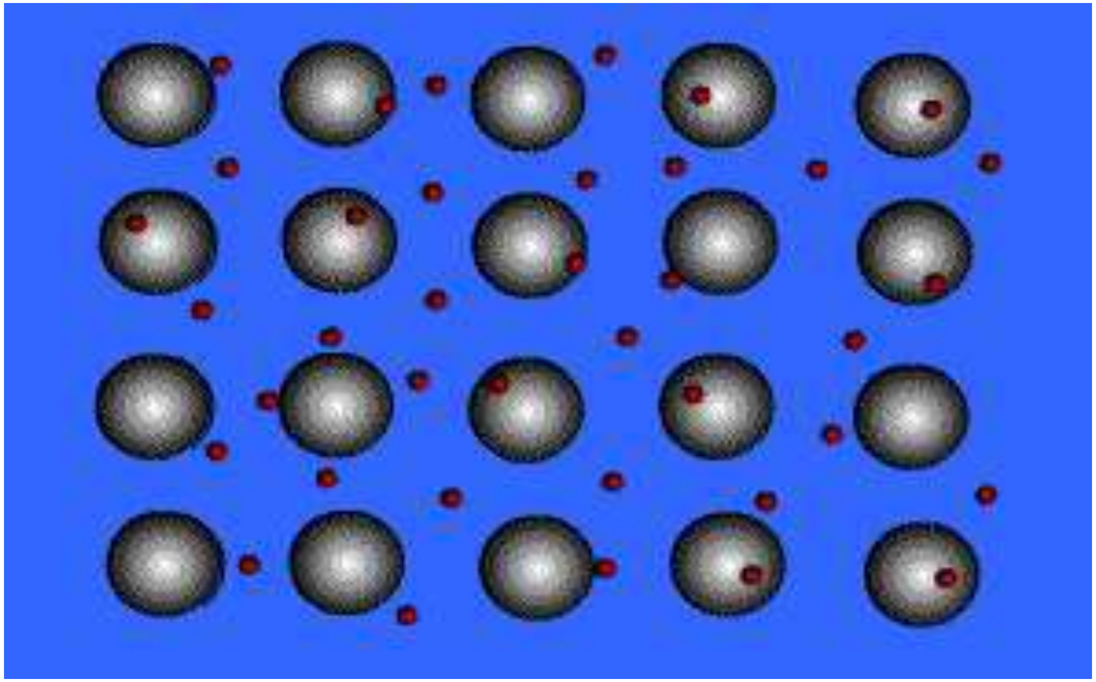
Energy Gap



The "leap" required for electrons from the Valence Band to enter the Conduction Band.

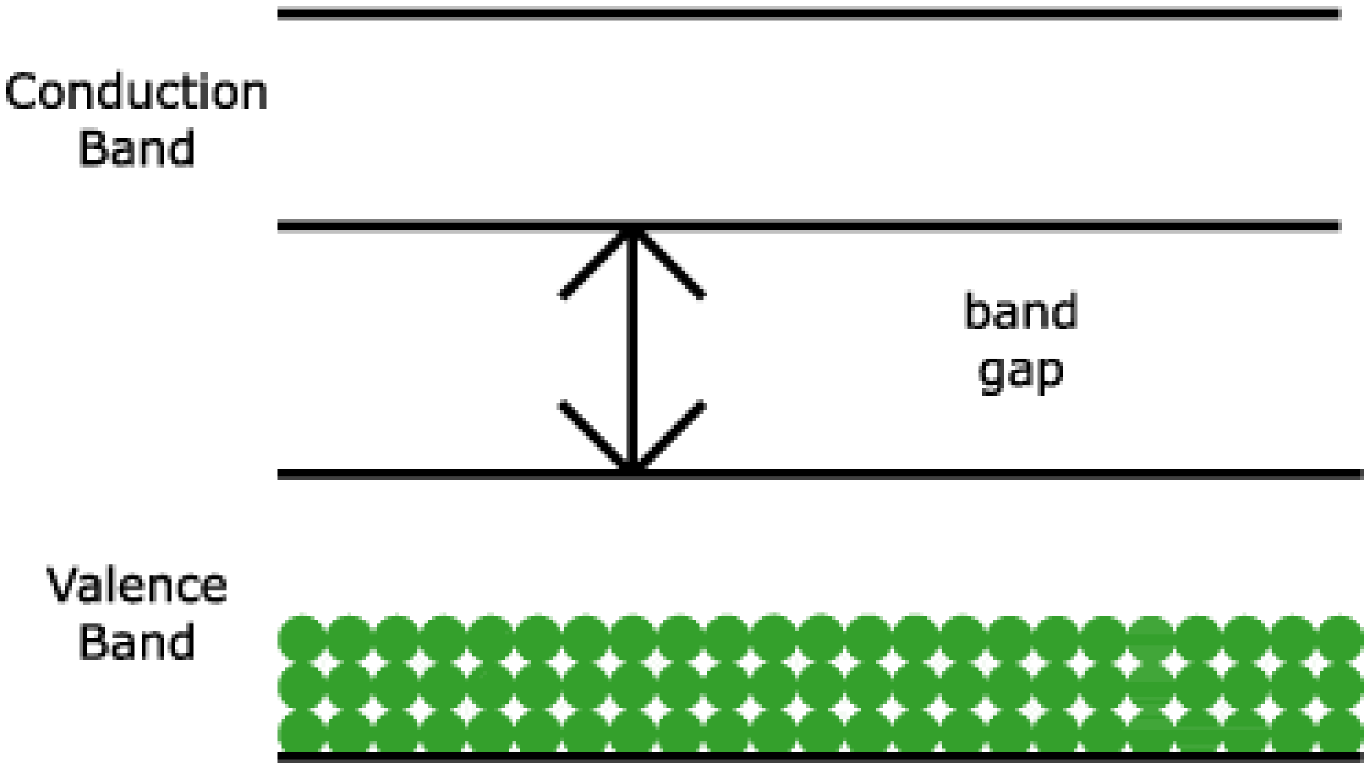

Conduction Band
Band Gap
Valence Band
LongIslandExchange.com

Conductors



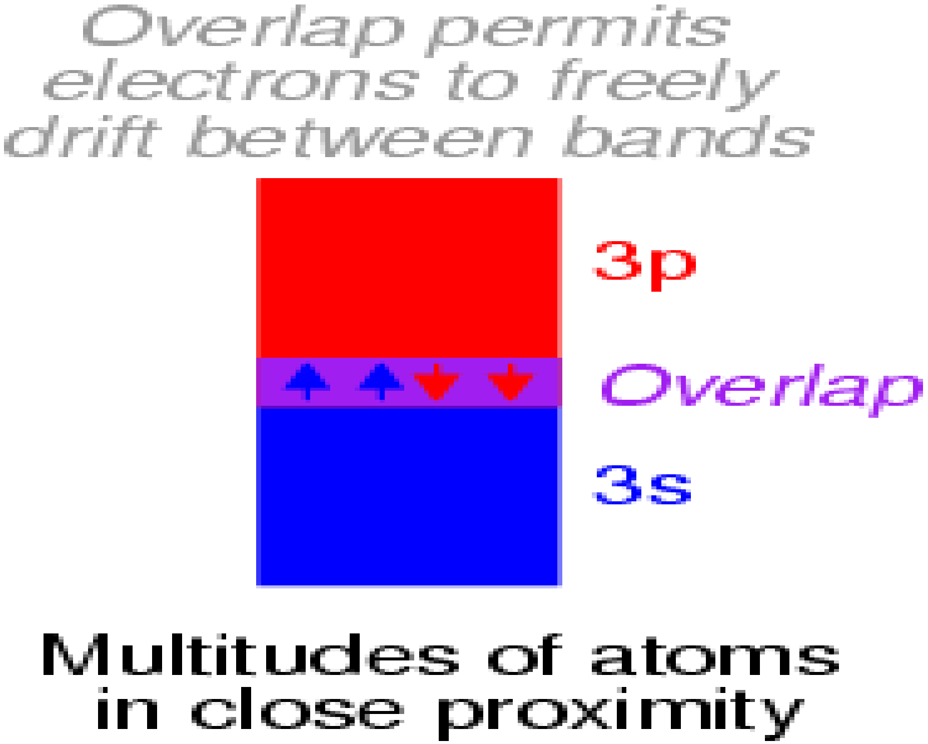
In a conductor, electrons can move freely among these orbitals within an energy band as long as the orbitals are not completely occupied.

Conductors



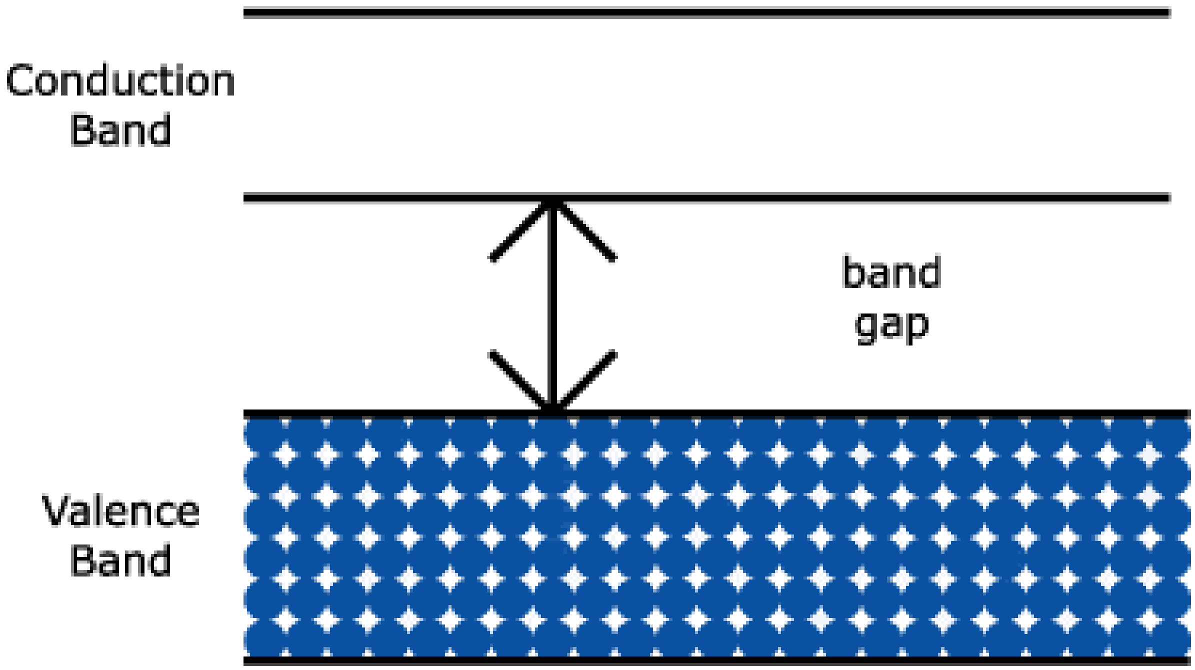
In conductors, the valence band is empty.

Conductors



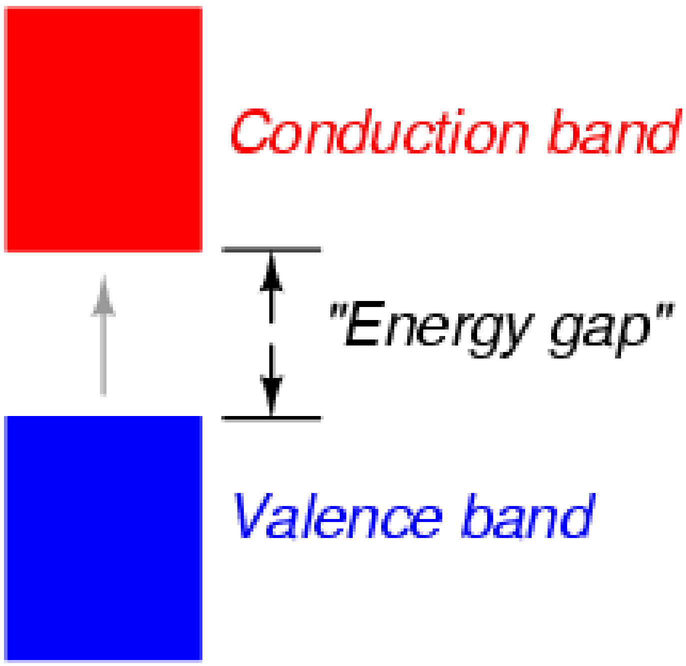
Also in conductors, the energy gap is nonexistent or relatively small.

Insulators



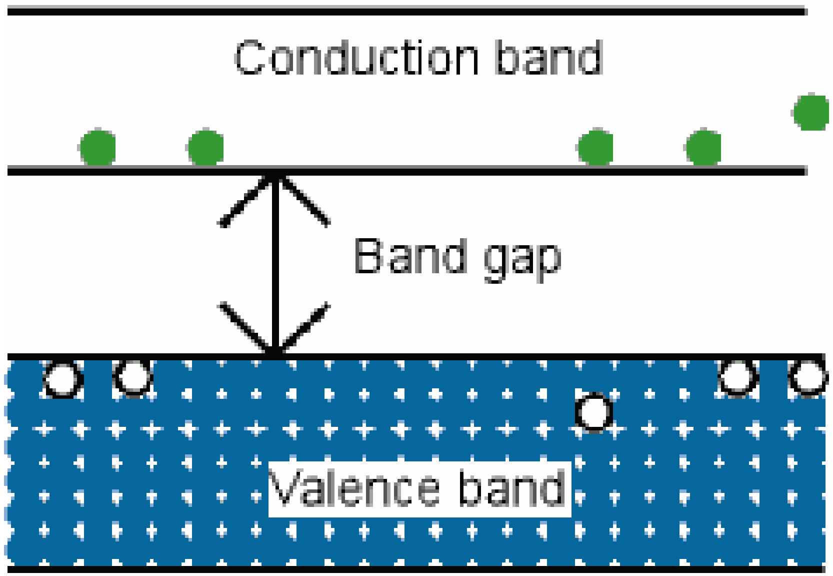
In insulators, the valence band is full.

Insulators



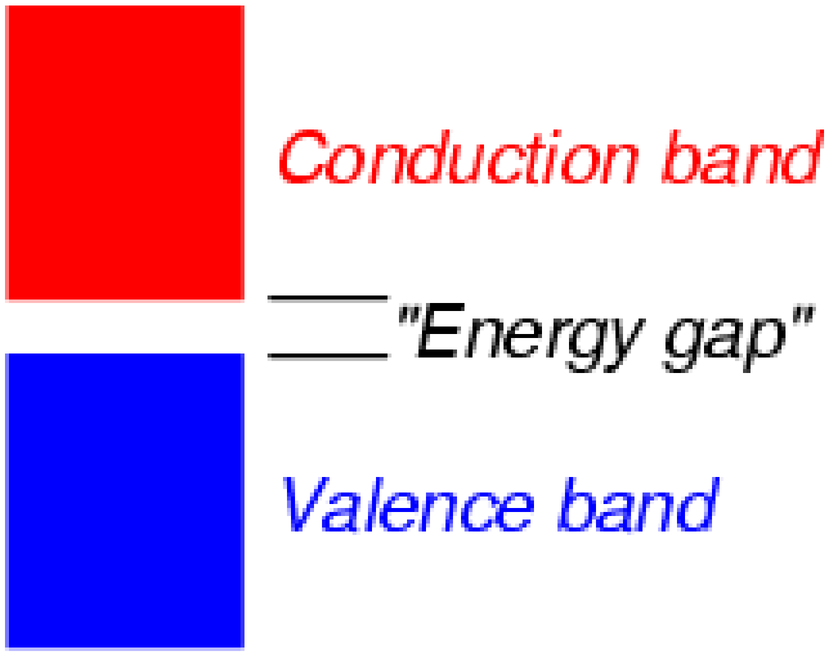
Also in insulators, the energy gap is relatively large.

Semiconductors



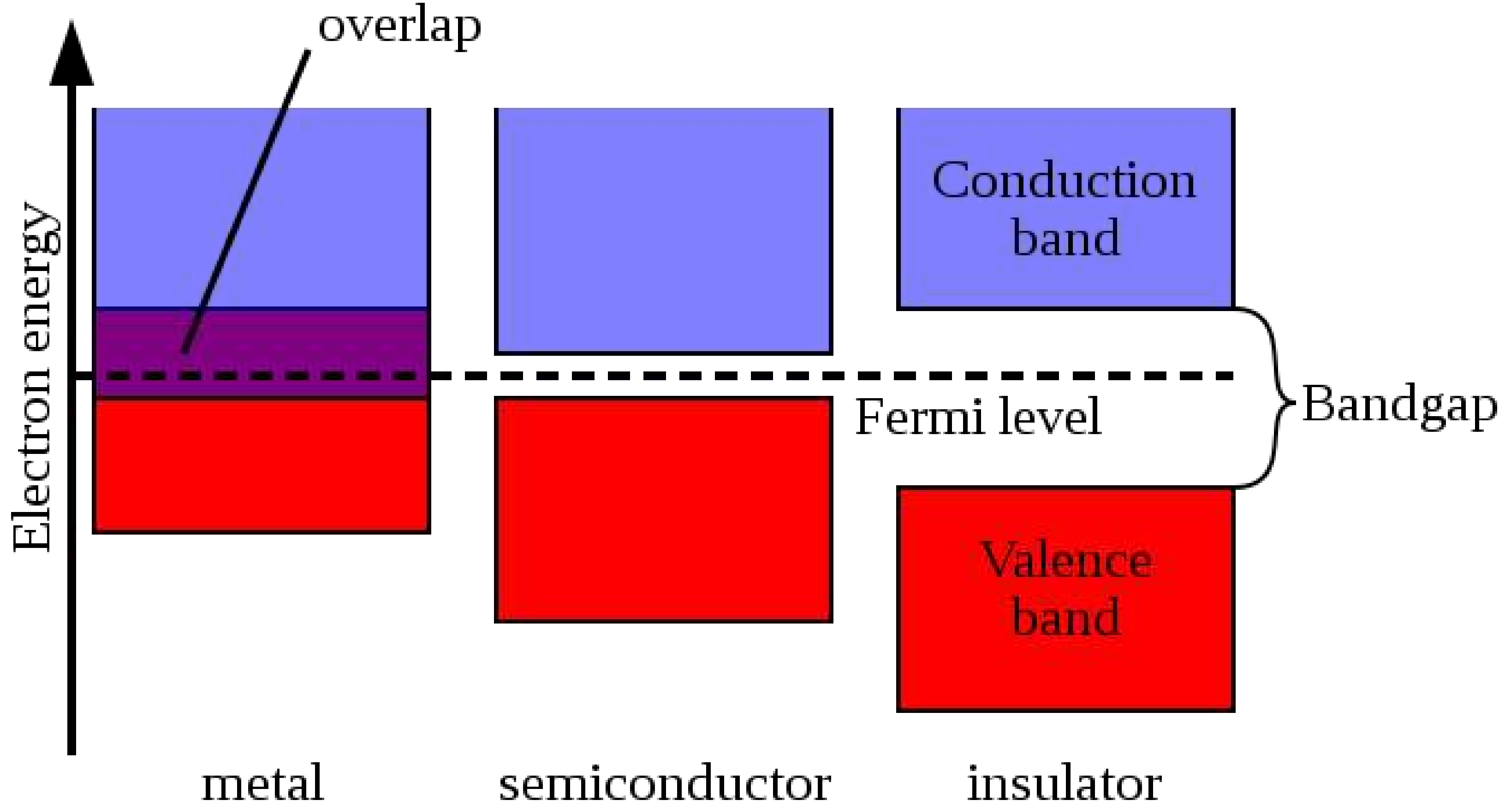
In semiconductors, the valence band is full but the energy gap is intermediate.

Semiconductors



Only a small leap is required for an electron to enter the Conduction Band.

Band Diagrams



Quick Quiz (Poll 1)

The conduction band

A. Is always above the forbidden energy level
B. Is the region of free electrons
C. Concentrates holes for the flow of current
D. Is a range of energies corresponding to the energies of the free electrons

Quick Quiz (Poll 2)

In semiconductor the forbidden energy gap lies

A. Just below the conduction band
B. Just above the conduction band
C. Either above or below the conduction band
D. Between the valence band and conduction band

Quick Quiz (Poll 3)

A semiconductor has generally ……………… valence electrons.

a)2
b)3
c)6
d)4

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

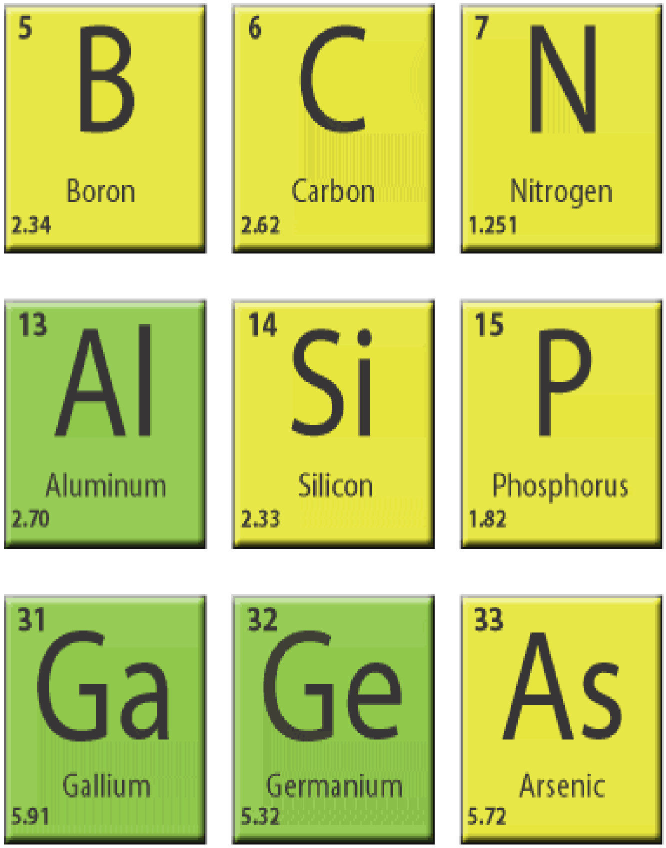
Lecture 28

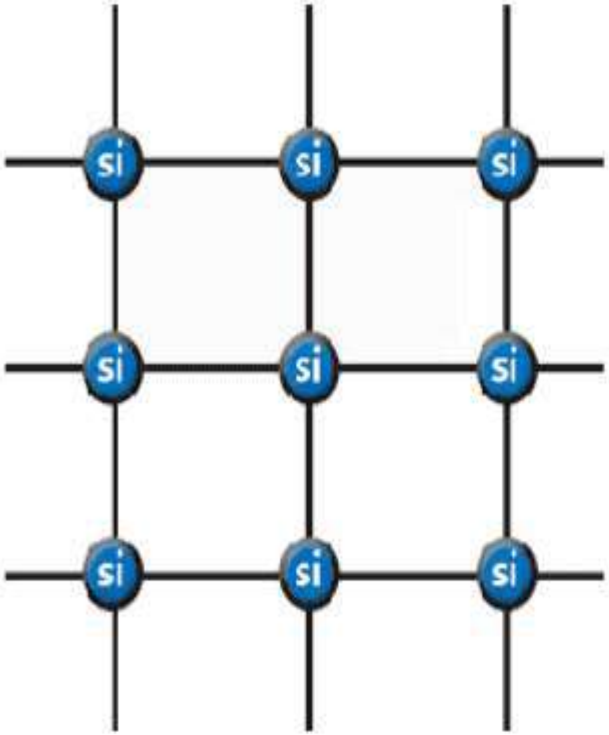
Prepared By:
Krishan Arora
Assistant Professor and Head

What are P-type and N-type ?

- Semiconductors are classified in to P-type and N-type semiconductor
- P-type: A P-type material is one in which holes are majority carriers i.e. they are positively charged materials (++++)
- N-type: A N-type material is one in which electrons are majority charge carriers i.e. they are negatively charged materials (-----)

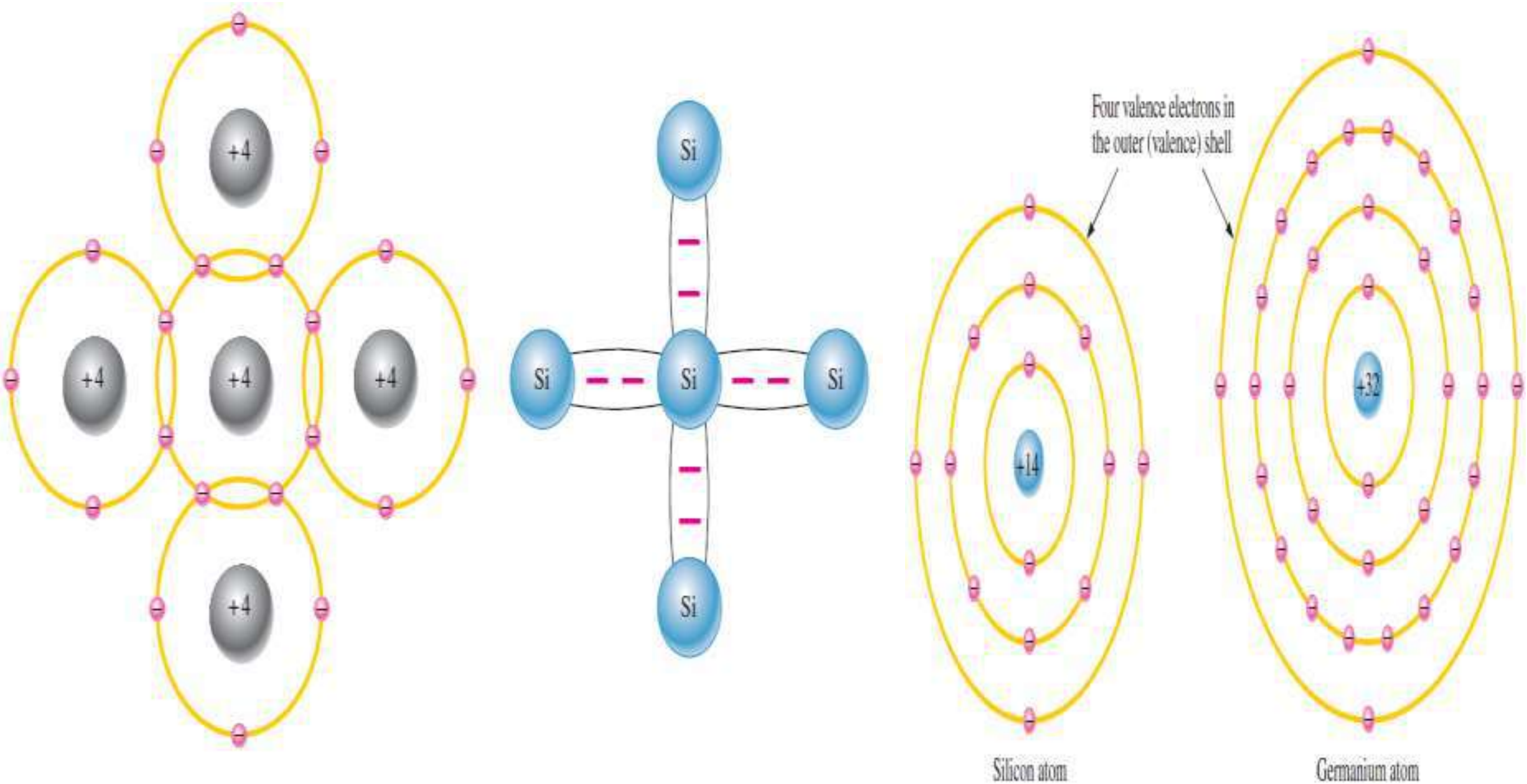
Silicon and Germanium





Silicon is a very common element, the main element in sand & quartz.

Silicon and Germanium



Intrinsic and Extrinsic semiconductor

The pure form of the semiconductor is known as the intrinsic semiconductor and the semiconductor in which intentionally impurities is added for making it conductive is known as the extrinsic semiconductor.

Conduction Electron and Holes.

An intrinsic (pure) silicon crystal at room temperature has sufficient heat energy for some valence electrons to jump the gap from the valence band into the conduction band, becoming free electron called ‘**Conduction Electron**’

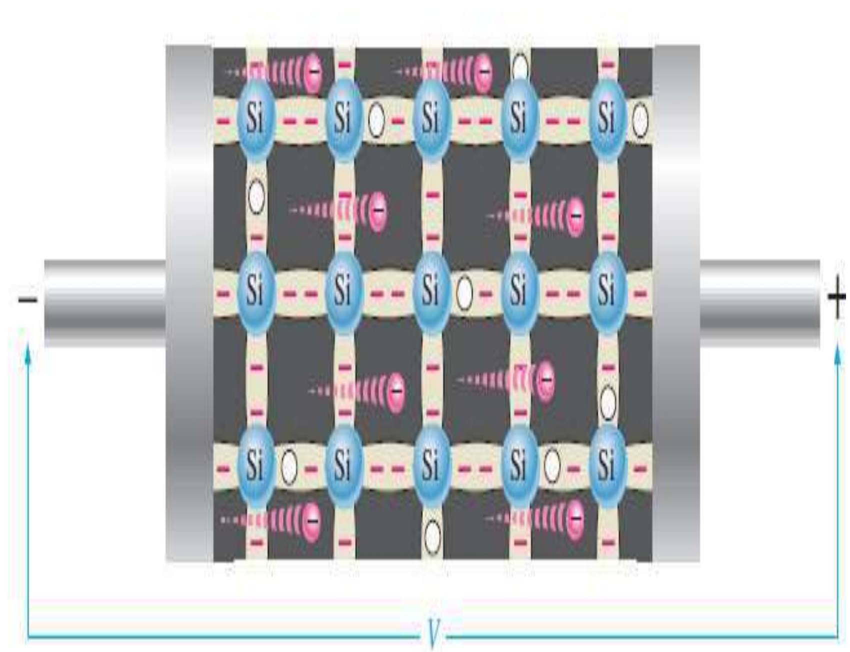
It leaves a vacancy in valance band, called **hole**.

Recombination occurs when a conduction-band electron loses energy and falls back into a hole in the valence band.

Electron Hole Current.

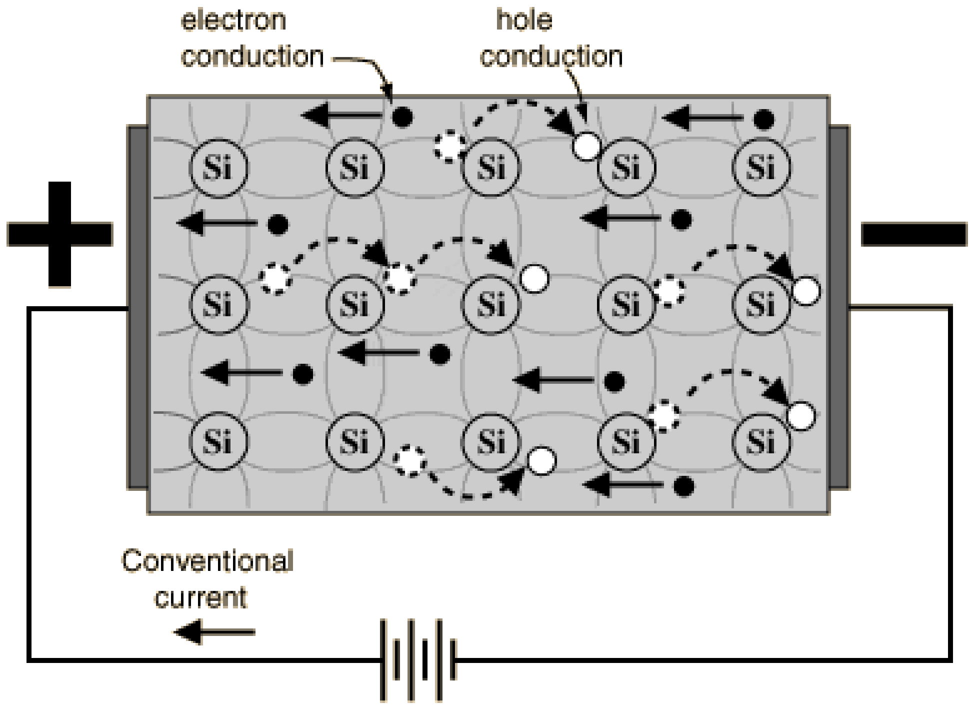
In conduction band : When a voltage is applied across a piece of intrinsic silicon, the thermally generated free electrons in the conduction band, are now easily attracted toward the positive end.

This movement of free electrons is one type of current in a semiconductive material and is called ***electron current.***



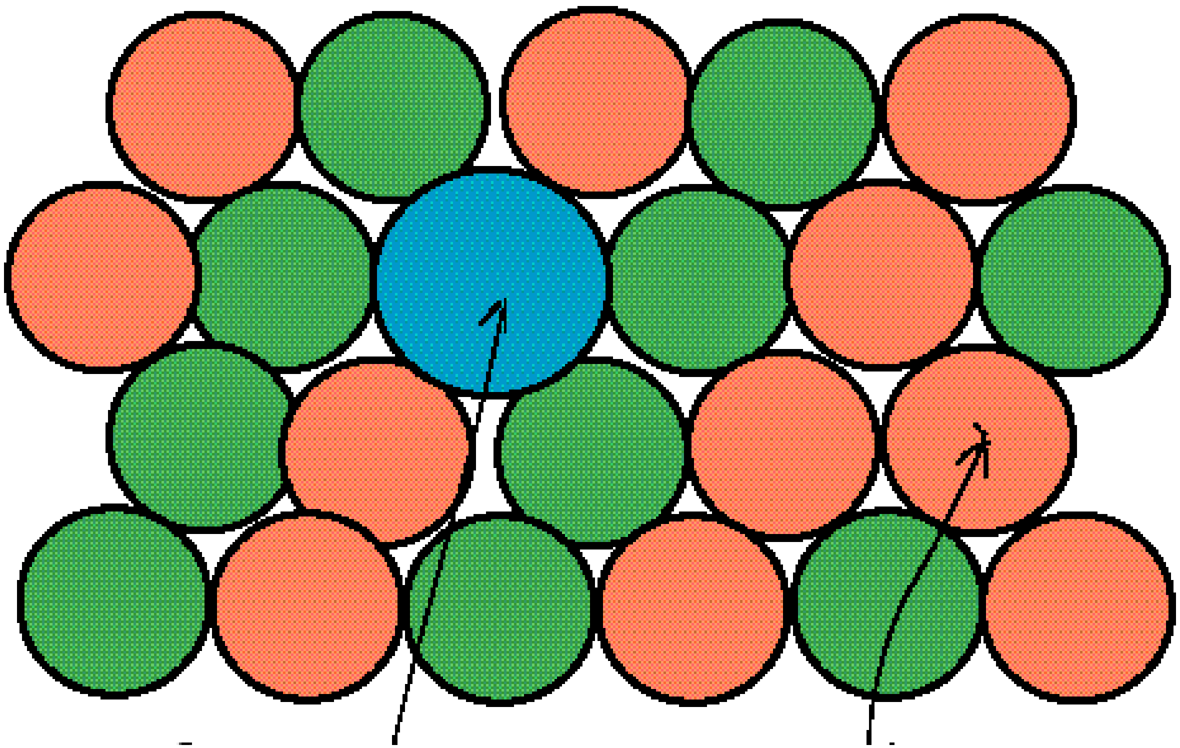
- **In valance band:** In valance band holes generated due to free electrons. Electrons in the valance band are although still attached with atom and not free to move, however they can move into nearby hole with a little change in energy, thus leaving another hole where it came from. Effectively the hole has moved from one place to another in the crystal structure. It is called ***hole current.***

Current Flow

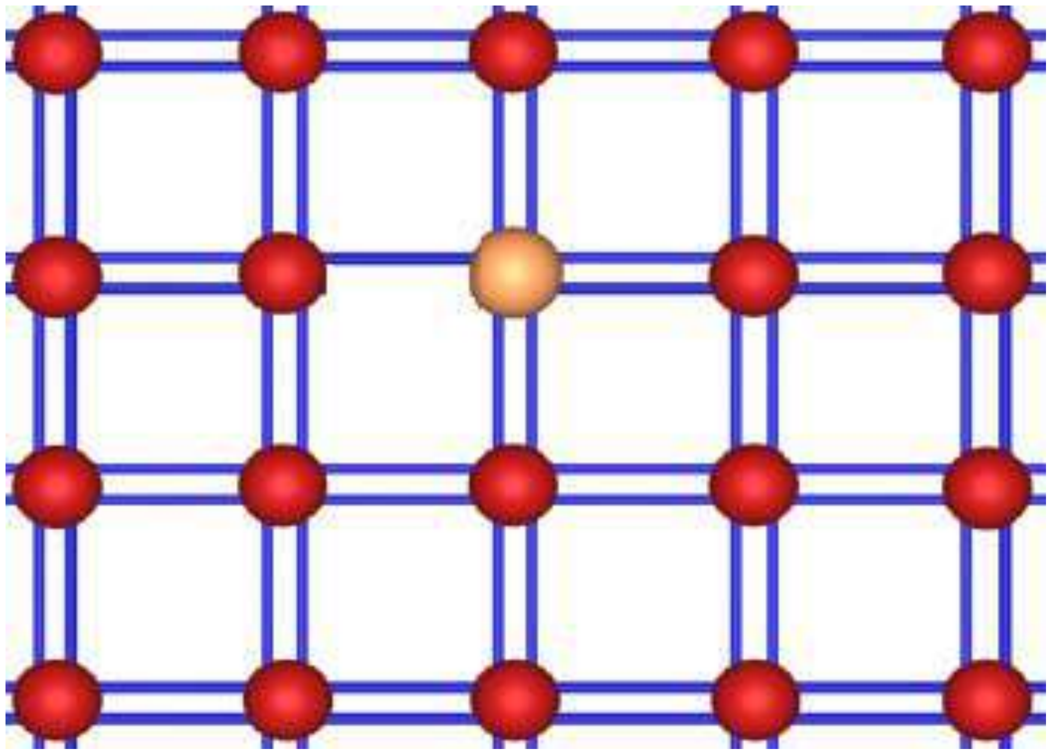


If a voltage is applied, then both the electron and the hole can contribute to a small current flow.

Impurity

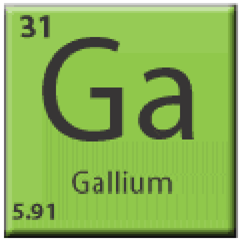


Doping



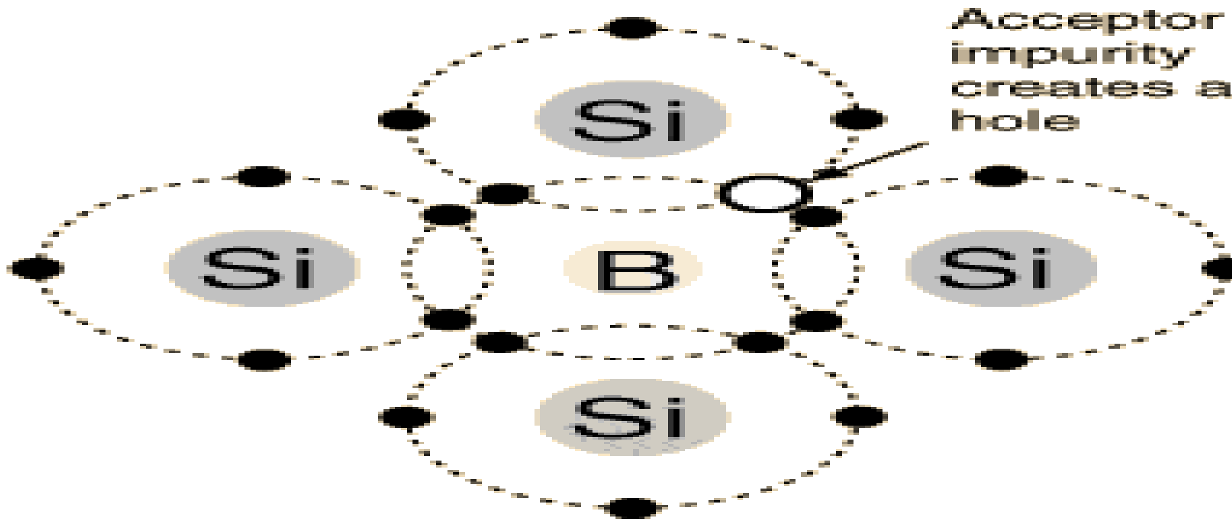
Doping (adding an impurity) can produce 2 types of semi-conductors depending upon the element added.

P-Type Doping



In P-type doping, boron or gallium is the dopant.

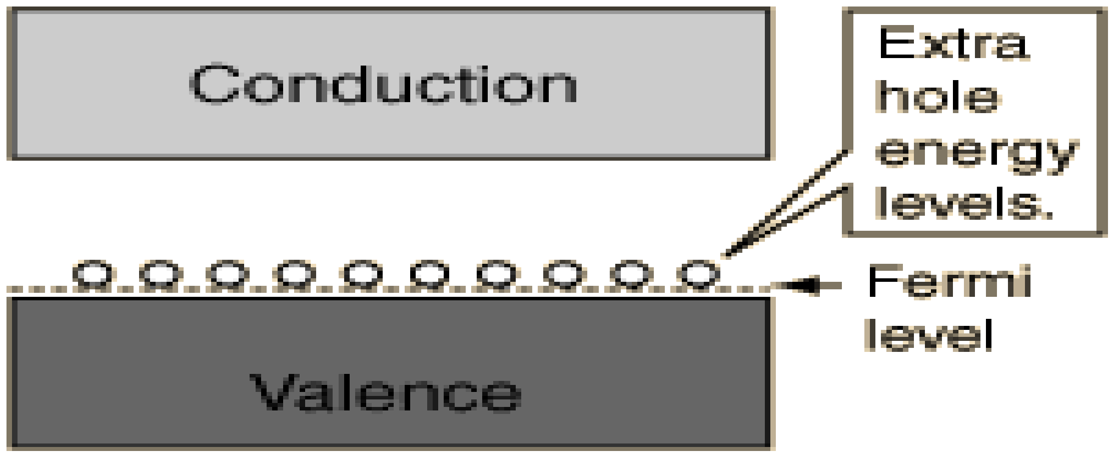
P-Type Doping



Boron and gallium each have only three outer electrons.

When mixed into the silicon lattice, they form "holes" in the lattice where a silicon electron has nothing to bond to.

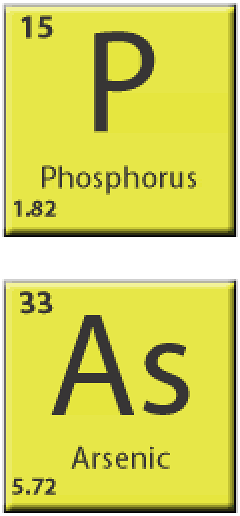
P-Type Doping



The absence of an electron creates the effect of a positive charge, hence the name P-type.

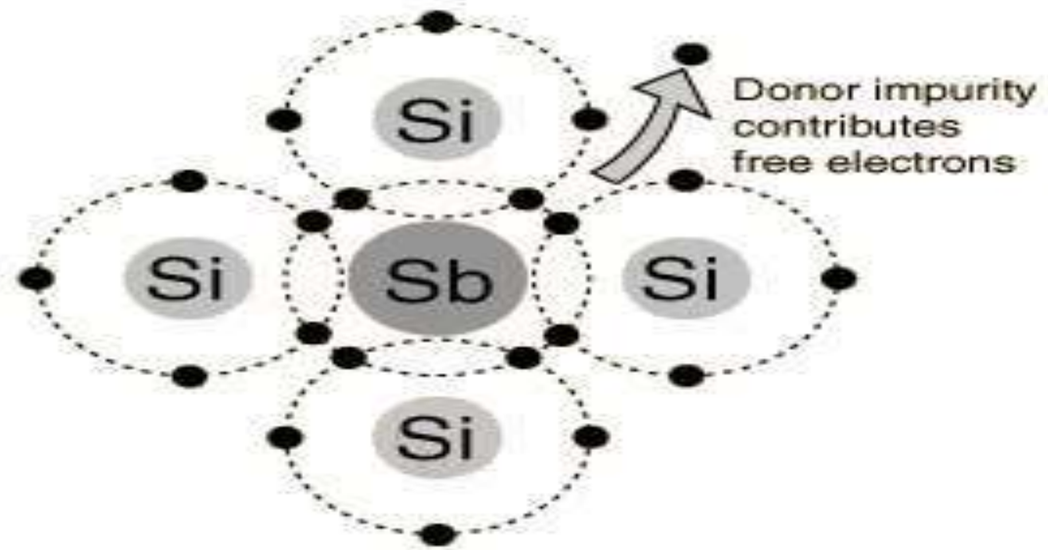
Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.

N-Type



In N-type doping, phosphorus or arsenic is added to the silicon in small quantities.

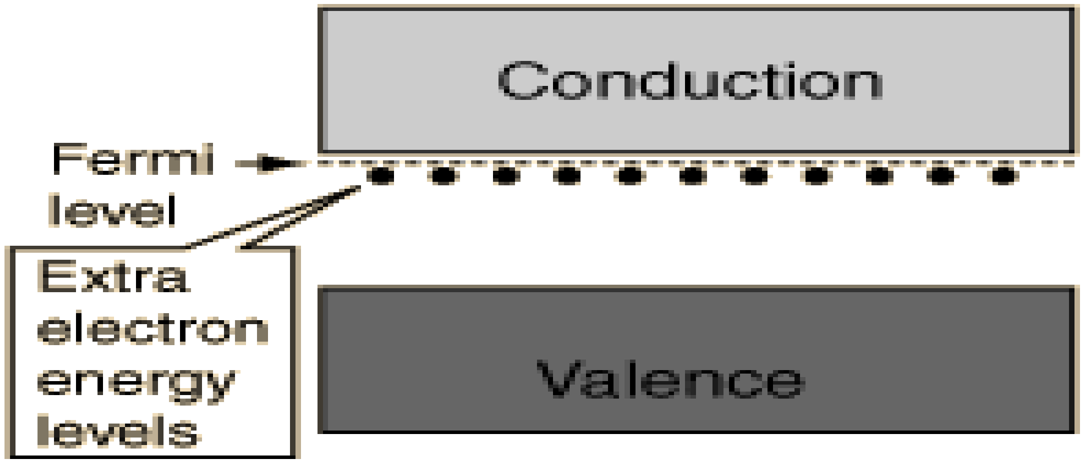
N-Type



Phosphorus and arsenic each have five outer electrons, so they're out of place when they get into the silicon lattice.

The fifth electron has nothing to bond to, so it's free to move around.

N-Type



***It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor*.**

Electrons have a negative charge, hence the name N-type.

Quick Quiz (Poll 1)

When a pentavalent impurity is added to a pure semiconductor, it becomes ………

a) An insulator
b) An intrinsic semiconductor
c) p-type semiconductor
d) n-type semiconductor

Quick Quiz (Poll 2)

A semiconductor is formed by ……… bonds.

a) Covalent
b) Electrovalent
c) Co-ordinate
d) None of the above

Quick Quiz (Poll 3)

The most commonly used semiconductor is ………..

a) Germanium
b) Silicon
c) Carbon
d) Sulphur

Quick Quiz (Poll 4)

The temperature co-efficient of an intrinsic semiconductor is.......

A. Zero
B. Positive
C. Negative
D. None of them

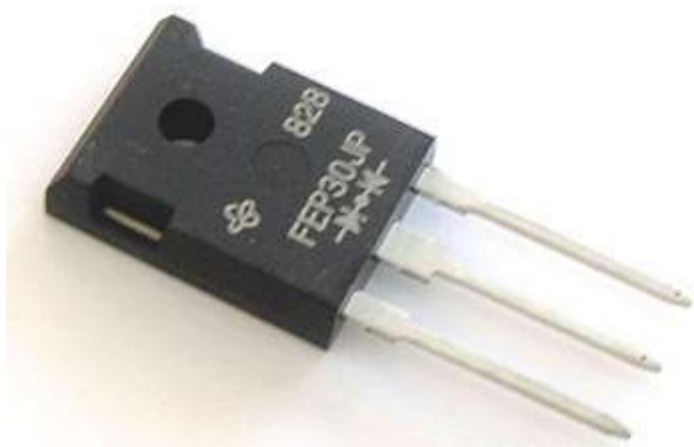
UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 29 A

Prepared By:
Krishan Arora
Assistant Professor and Head

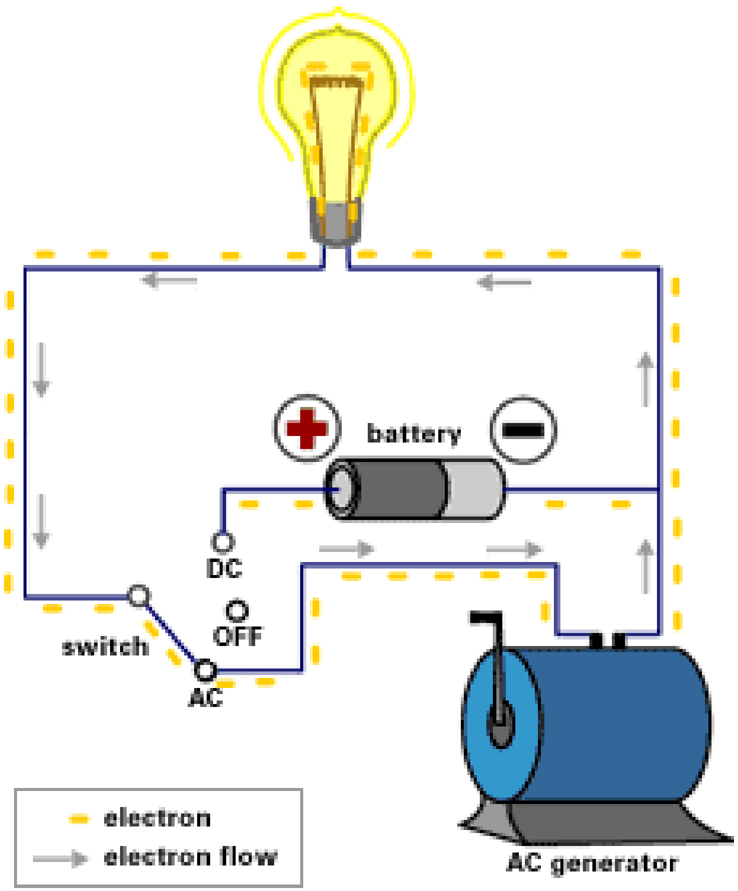
Rectifiers

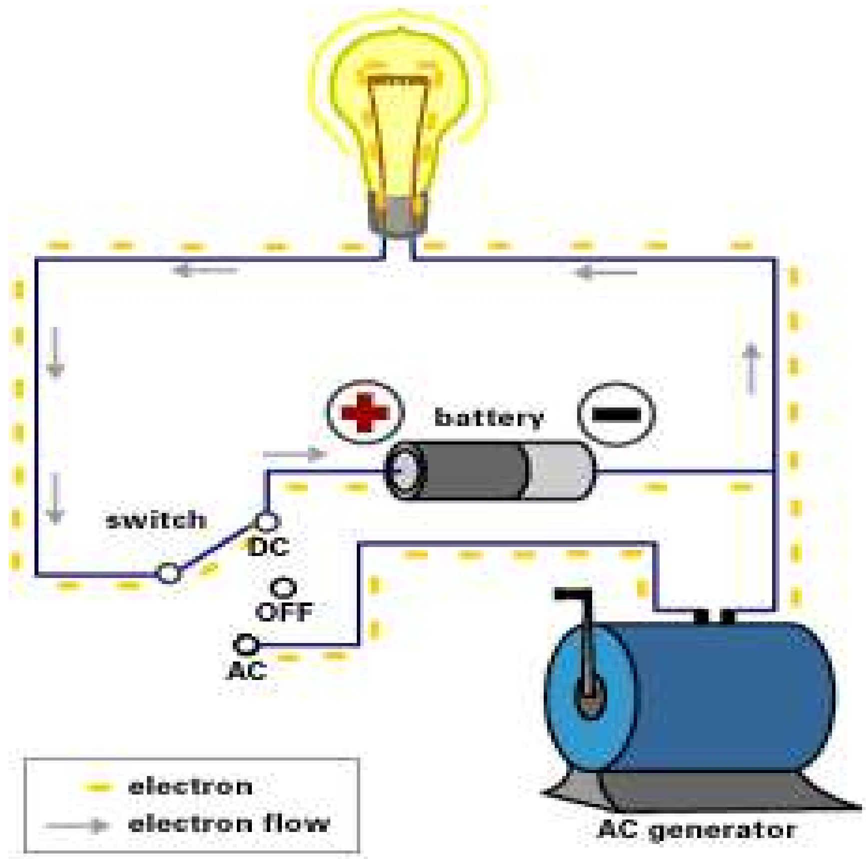


The most popular application of the diode.

Most electronics need a direct current to function, but the standard form of electricity that is transmitted to homes is alternating current.

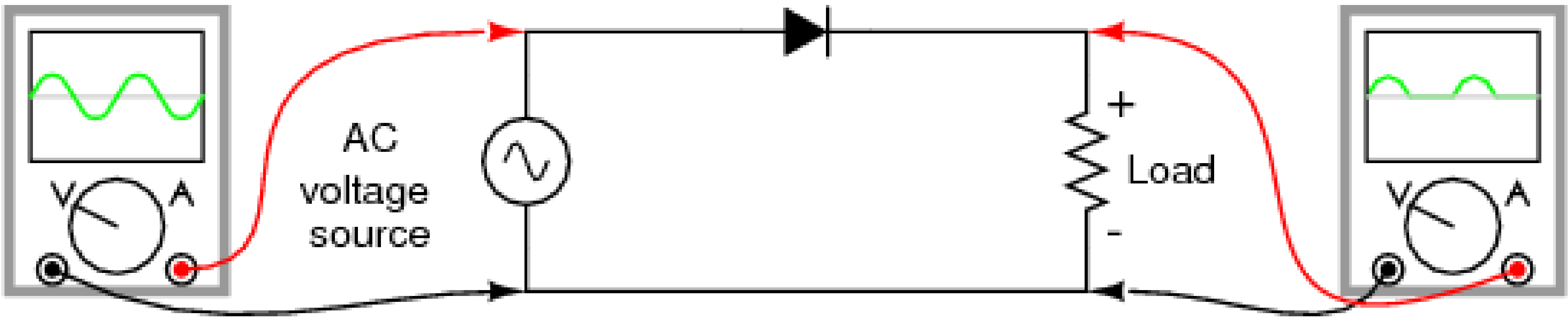
Rectifiers are needed to change the alternating current





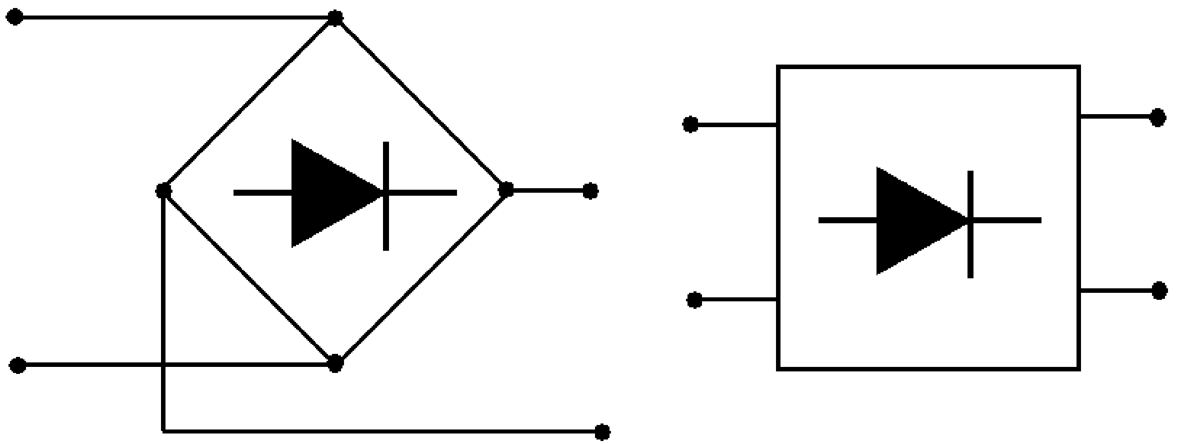
into direct current inside the electronics so that they can function correctly.

Rectification



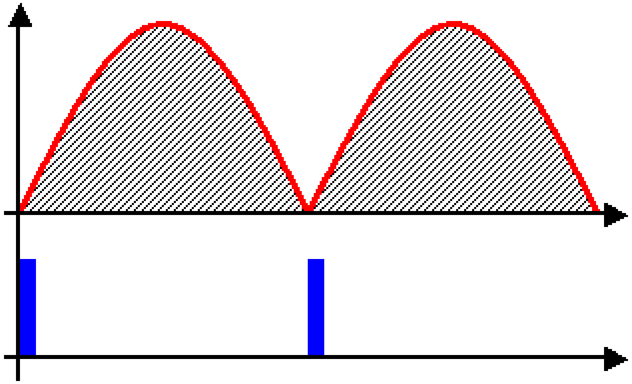
is the conversion of alternating current (AC) to direct current (DC).

Rectifiers



This involves a device that only allows one-way flow of electrons, which is exactly what a semiconductor diode does.

Half-Wave Rectifiers



The simplest kind of rectifier circuit is the half-wave rectifier.

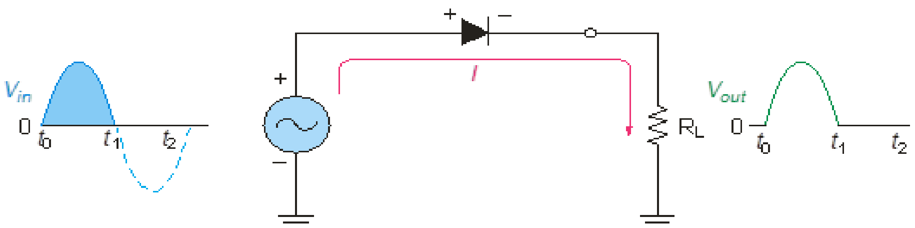
It only allows one half of an AC waveform to pass through to the load.

Half-wave rectification is a very simple way to reduce power to a resistive load.

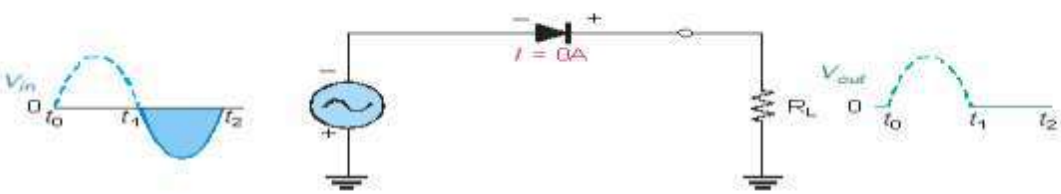
Some two-position lamp dimmer switches apply full AC power to the lamp filament for "full" brightness and then half-wave rectify it for a lesser light output.

Working of Half wave Rectifiers

- As diodes conduct current in one direction and block in other.
- When connected with ac voltage, diode only allows half cycle passing through it and hence convert ac into dc.
- As the half of the wave get rectified, the process called half wave rectification.

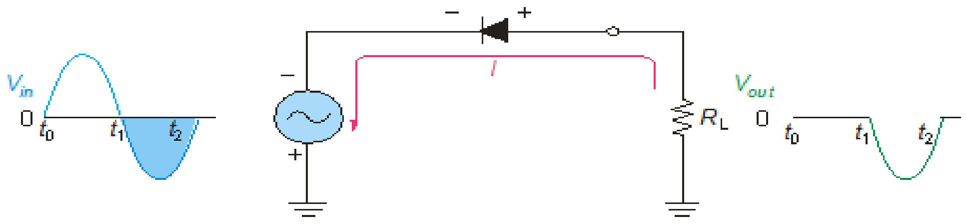


- A diode is connected to an ac source and a load resistor forming a half wave rectifier.
- Positive half cycle causes current through diode, that causes voltage drop across resistor.



Diode as Rectifiers

- Reversing diode.



- Average value of Half wave output voltage:

VAVG = VP / pi

- VAVG is approx 31.8% of Vp

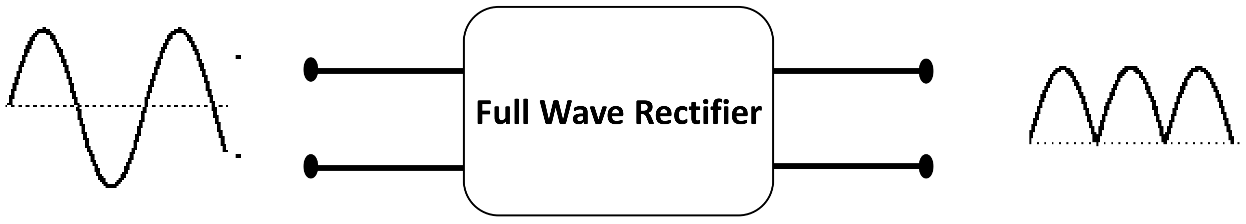
- PIV: Peak Inverse Voltage = Vp

Full wave rectifiers

- When we use a half-wave rectifier, a significant amount of power gets wasted as the only one half of each cycle passes through and the other the cycle gets blocked. Moreover, the half-wave rectifier is not efficient (40.6%) and we can not use it for applications which need a smooth and steady DC output. For more efficient and steady DC, we will use a full wave rectifier.
- A full wave rectifier converts both halves of each cycle of an alternating wave (AC signal) into pulsating DC signal.

Full wave rectifiers

- A full wave rectifier allows unidirectional current through the load during the entire 360 degree of input cycle.



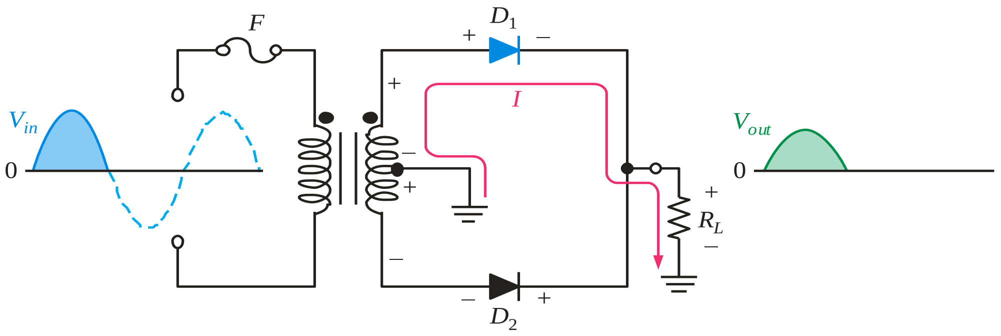
- The output voltage have twice the input frequency.

$$V_{AVG} = 2V_P / pi$$

- V_{AVG} is 63.7% of Vp

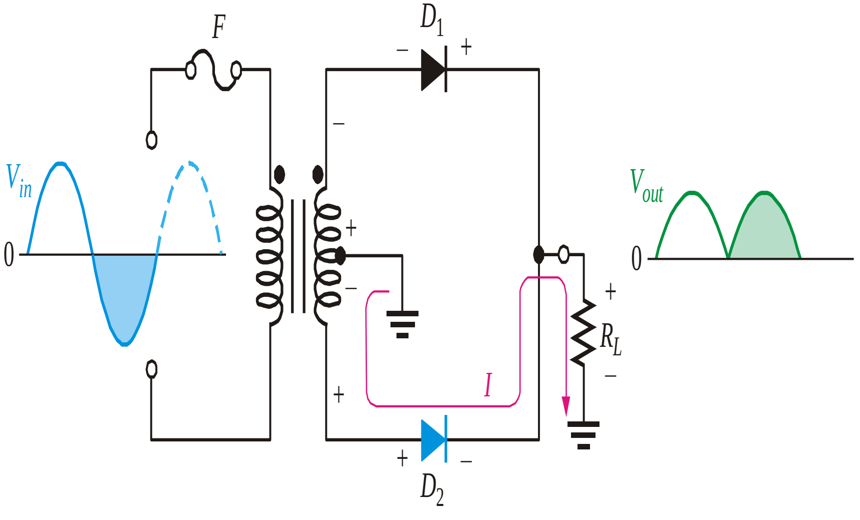
The Center-Tapped Full wave rectifiers

- A center-tapped transformer is used with two diodes that conduct on alternating half-cycles.



During the positive half-cycle, the upper diode is forward-biased and the lower diode is reverse-biased.

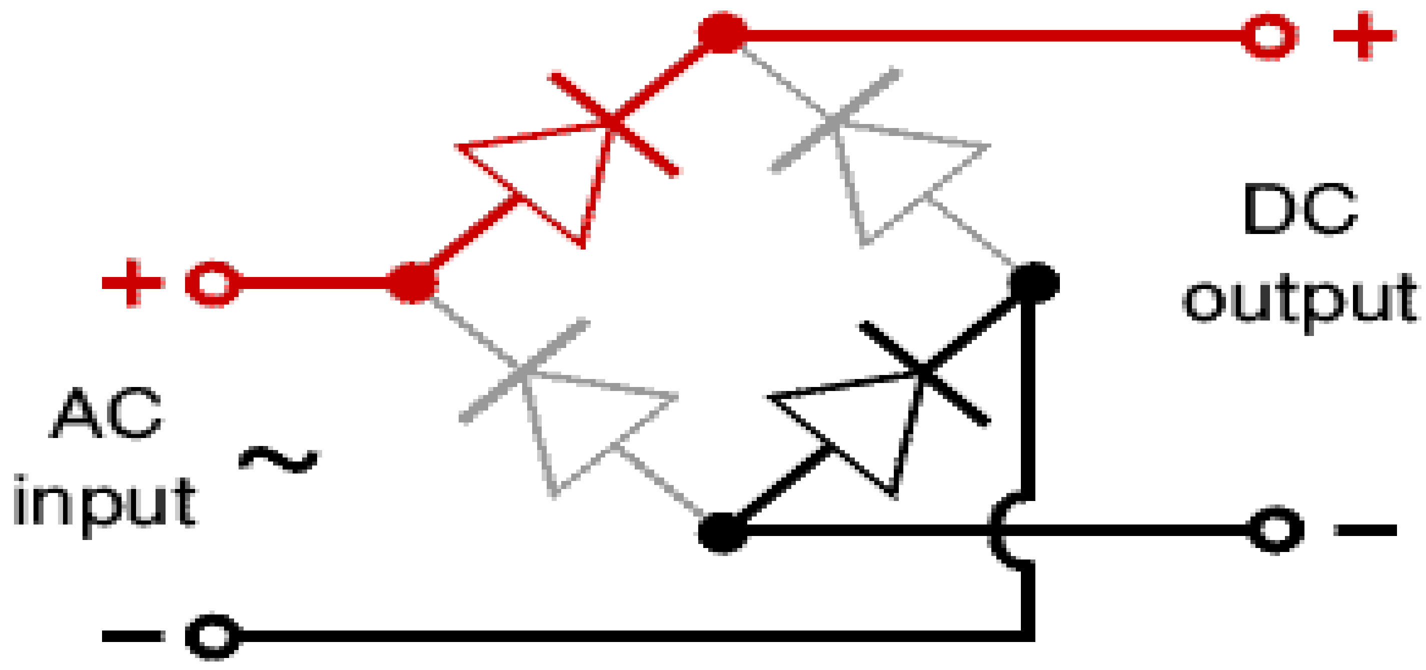
During the negative half-cycle, the lower diode is forward-biased and the upper diode is reverse-biased.



Operation of full wave rectifier

- During positive half cycle diode D1 conducts and D2 will be open circuited.
- Current flow through the load resistance in the direction of forward current through diode.
- Current through RL gives output voltage Vo.
- During negative half cycle D2 conducts and D1 open circuited.
- Current flow through D2 and RL.
- Current through RL give rise to output voltage Vo.

Bridge Rectifiers

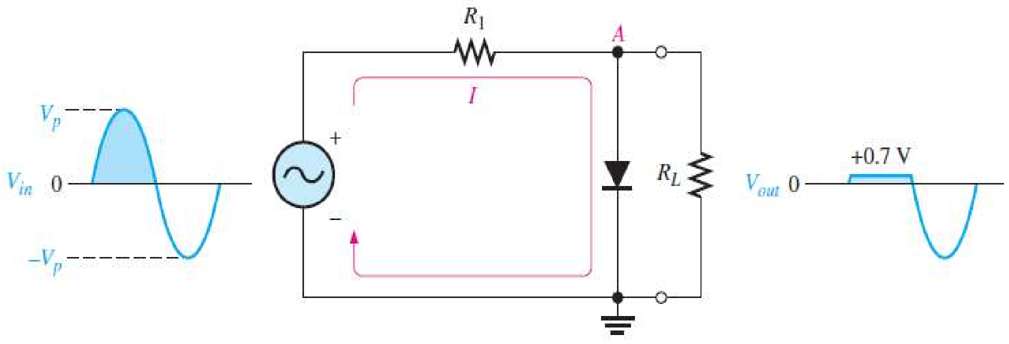


Working

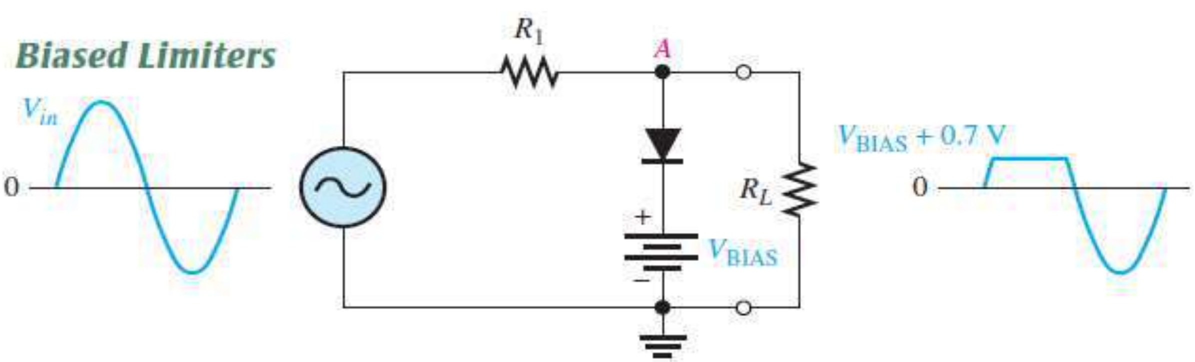
For most electrical demands, a bridge rectifier is used. A rectifier bridge is four diodes configured so that the output always has the same polarity regardless of the polarity of the input. Rectifier bridges are most often used to convert alternating current into full-wave direct current for power supplies and throttles.

Diode Limiters

- Diode circuits, called limiters or clippers, are used to clip off portions of signal voltages above or below certain levels.



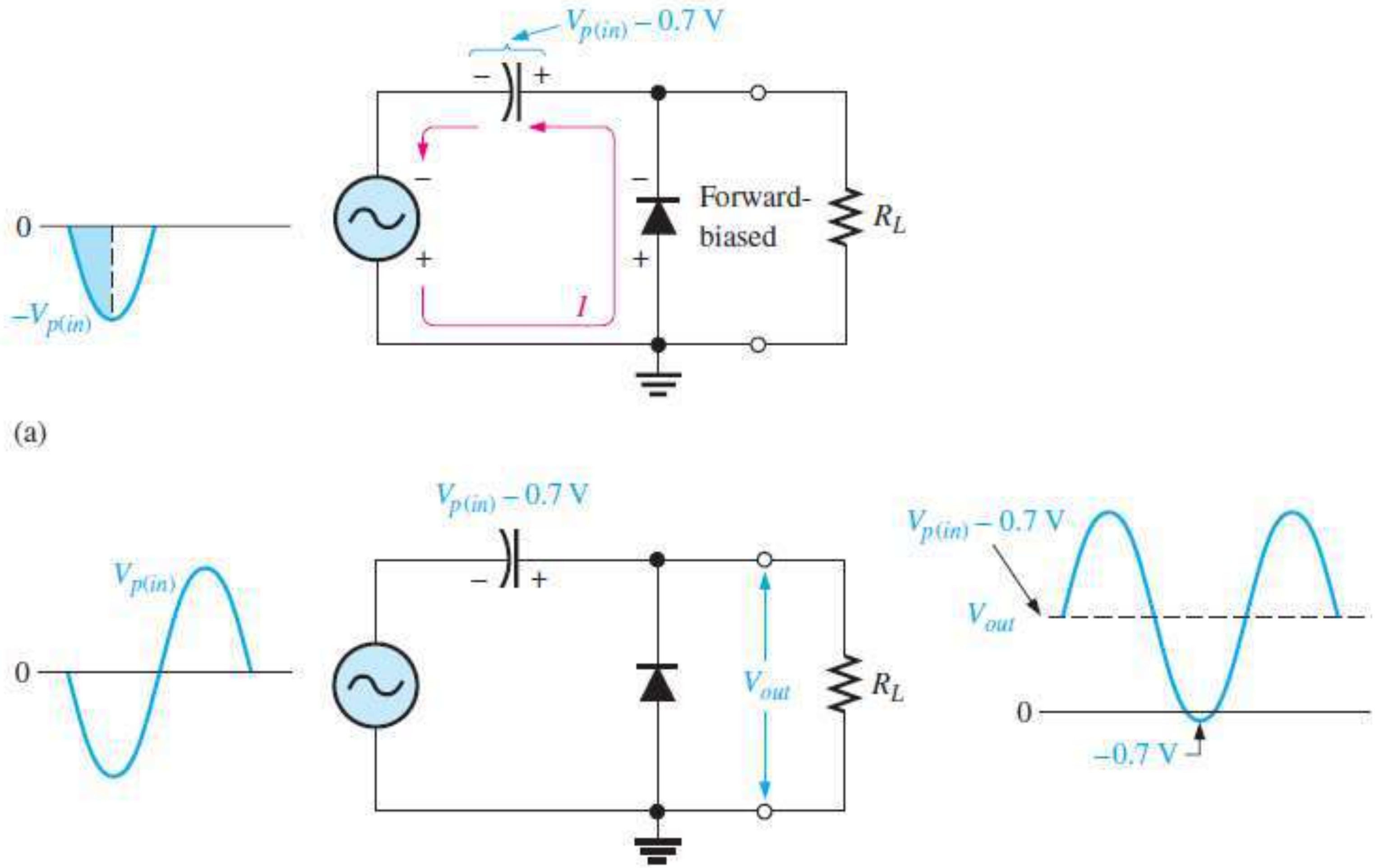
$$V_{out} = \left(\frac{R_L}{R_1 + R_L}\right)V_{in}$$



Diode Limiters

- The **diode limiter** also called Clipper as it is used to limit the input voltage. A basic **diode limiter** circuit is composed of a **diode** and a resistor. Depending upon the circuit configuration and bias, the circuit may clip or eliminate all or part of an input waveform. It limits the output voltage to a specific value.

Diode Clampers



Working of Clamper Circuit

- The positive or negative peak of a signal can be positioned at the desired level by using the clamping circuits. As we can shift the levels of peaks of the signal by using a clamper, hence, it is also called as level shifter.
- The clamper circuit consists of a capacitor and diode connected in parallel across the load. The clamper circuit depends on the change in the time constant of the capacitor. The capacitor must be chosen such that, during the conduction of the diode, the capacitor must be sufficient to charge quickly and during the non conducting period of diode, the capacitor should not discharge drastically.

Quick Quiz (Poll 1)

- Bridge rectifier is an alternative for

  a) Full wave rectifier
  b) Peak rectifier
  c) Half wave rectifier
  d) None of the mentioned

Quick Quiz (Poll 2)

- The mean value of half wave rectified sine wave is

(A) 0.707 i_m

(B) 0.66 i_m

(C) 0.5 i_m

(D) 0.318 i_m

Quick Quiz (Poll 3)

- For full-wave rectified sine wave, mean value is

(A) 0.70 i_m

(B) 0.636 i_m

(C) 0.5 i_m

(D) 0.318 I_m.

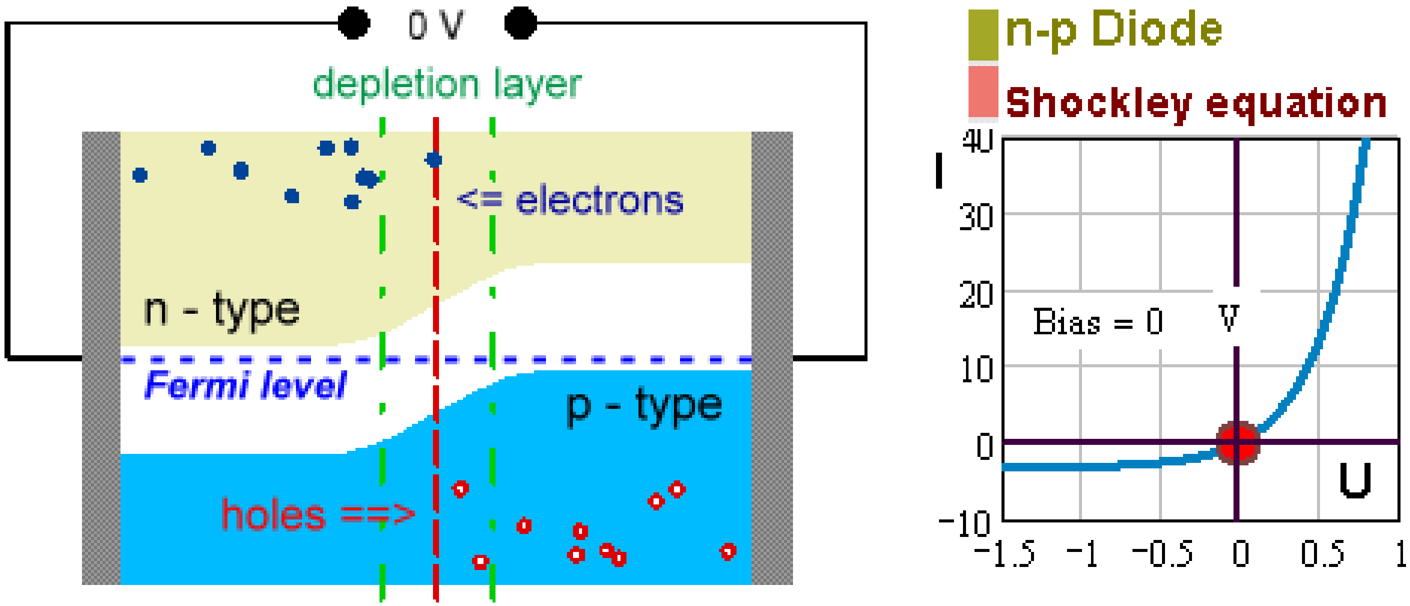
UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 29

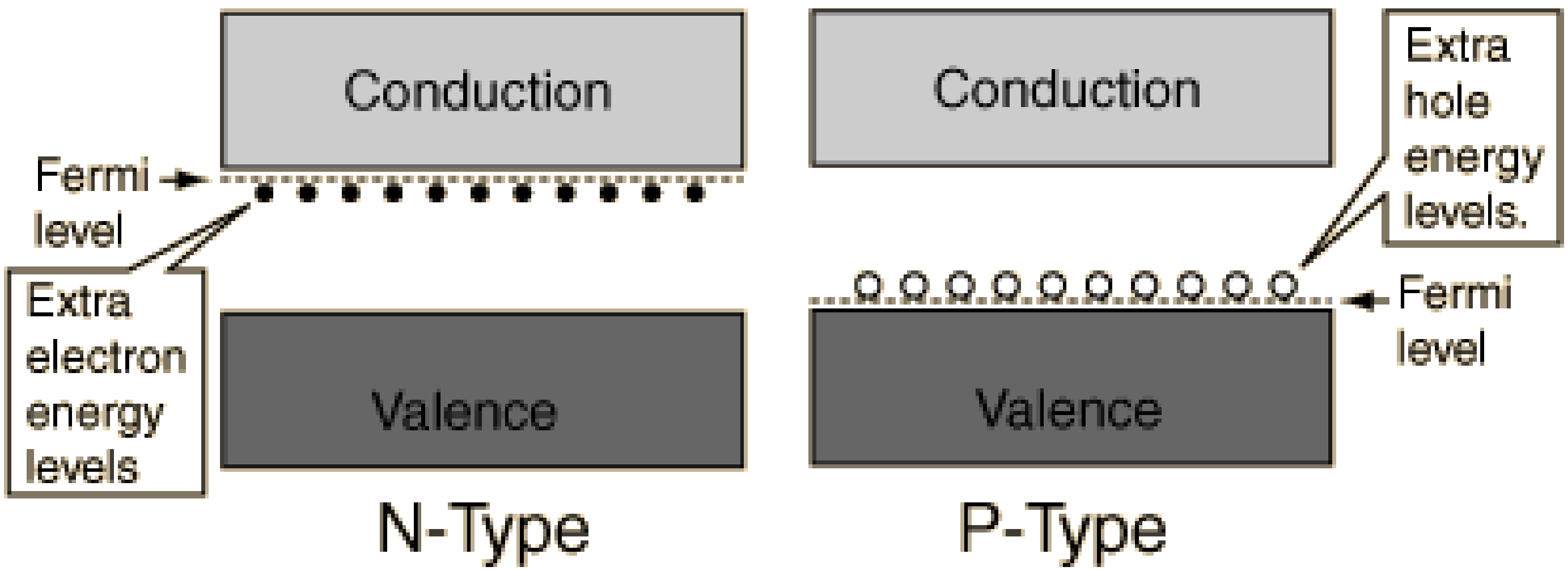
Prepared By:
Krishan Arora
Assistant Professor and Head

P-N Junction



We create a p-n junction by joining together two pieces of semiconductor, one doped n-type, the other p-type.

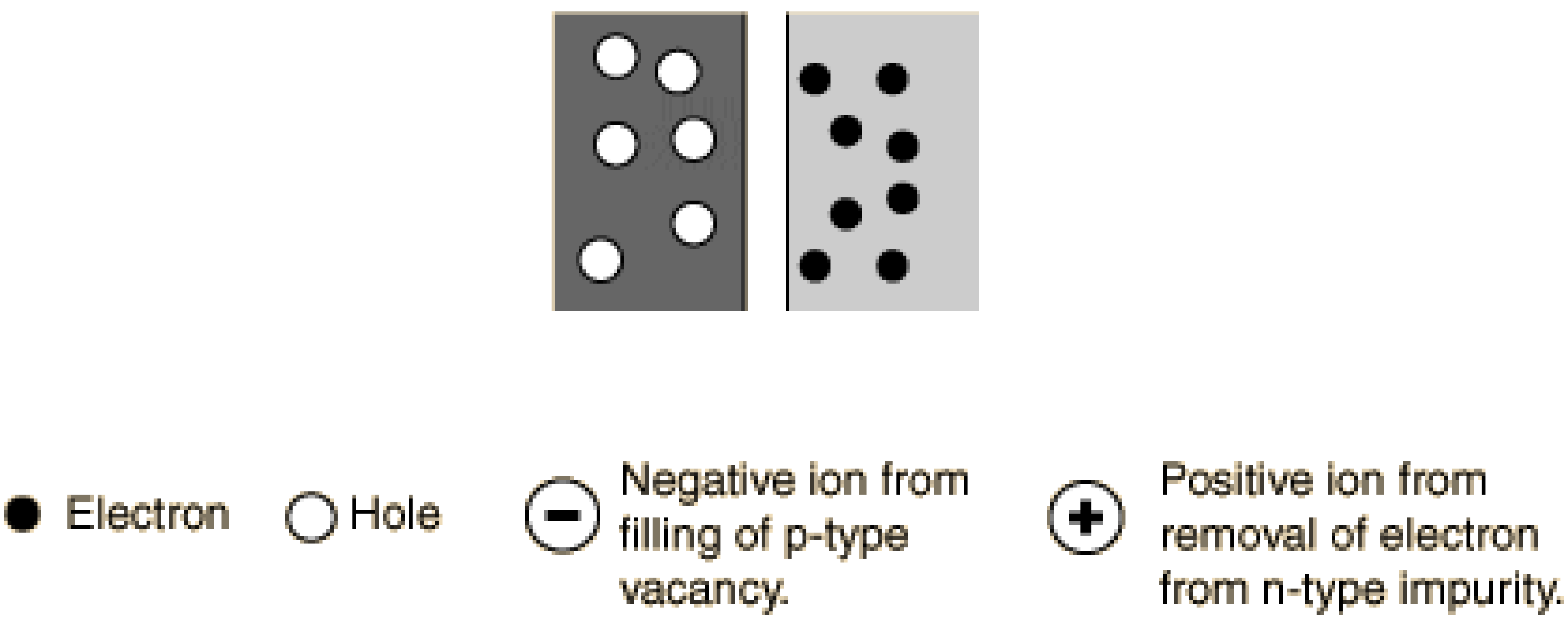
P-N Junction



In the n-type region there are extra electrons and in the p-type region, there are holes from the acceptor impurities .

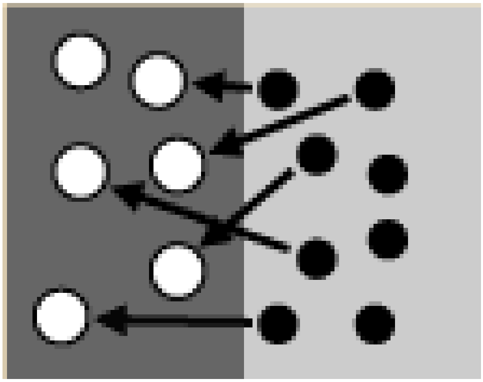
P-N Junction

In the p-type region there are holes from the acceptor impurities and in the n-type region there are extra electrons.



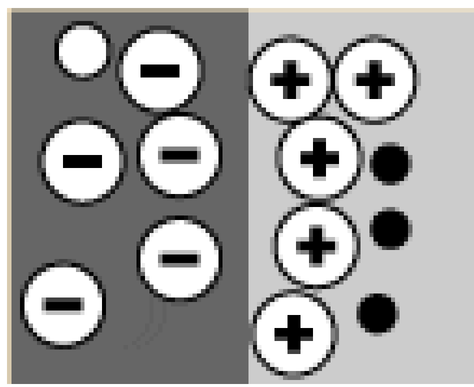
P-N Junction

When a p-n junction is formed, some of the electrons from the n-region which have reached the conduction band are free to diffuse across the junction and combine with holes.



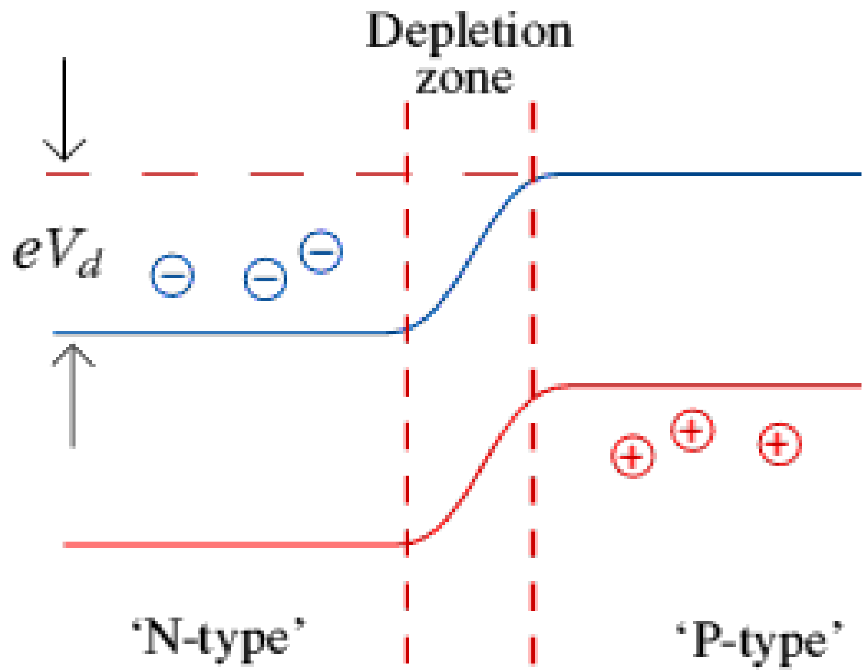
P-N Junction

Filling a hole makes a negative ion and leaves behind a positive ion on the n-side.



A space charge builds up, creating a depletion region.

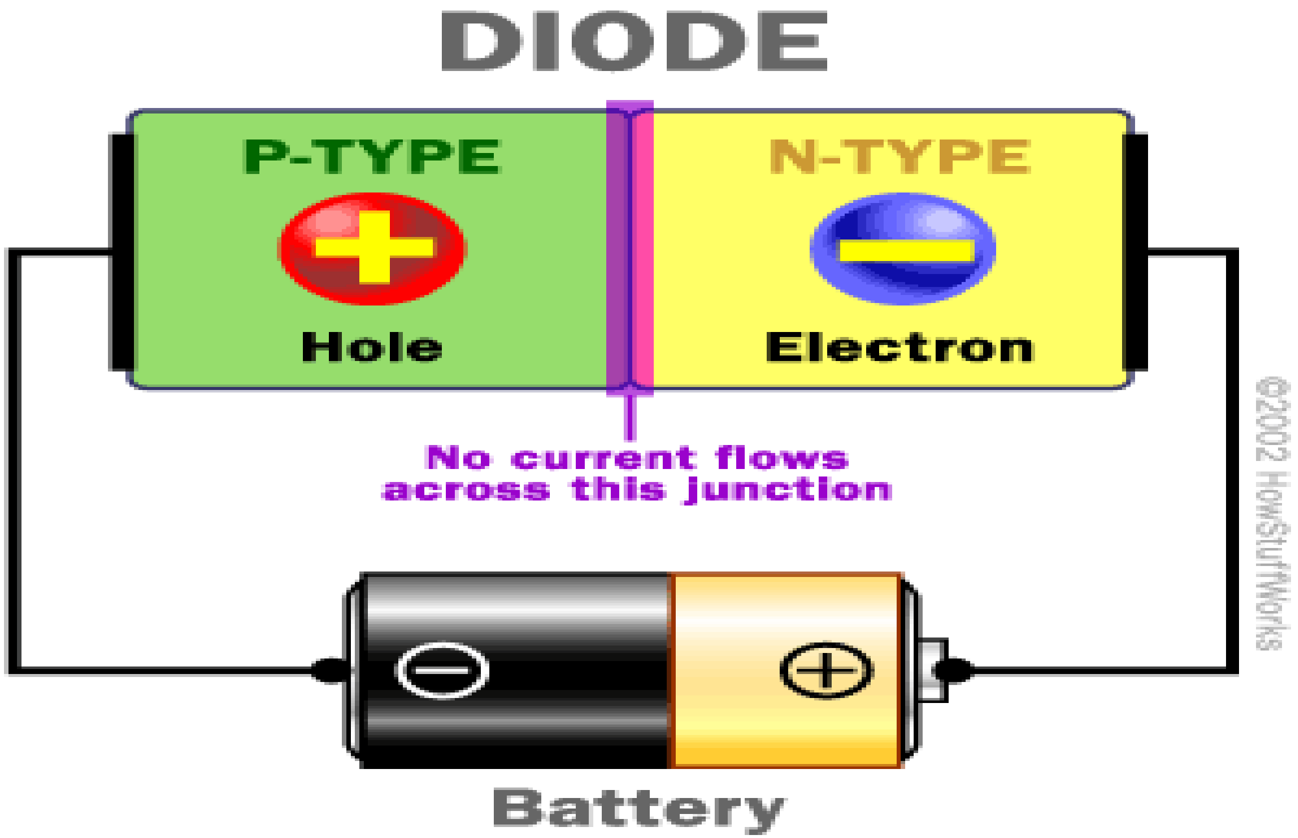
P-N Junction



This causes a depletion zone to form around the junction (the join) between the two materials.

This zone controls the behavior of the diode.

Diode

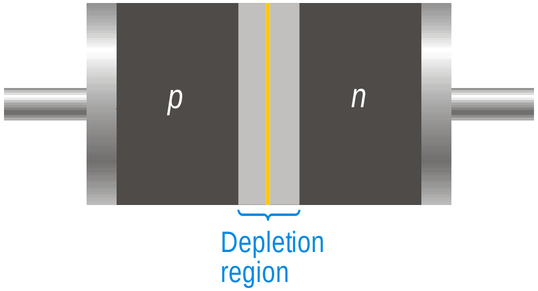


A diode is the simplest possible semiconductor device.

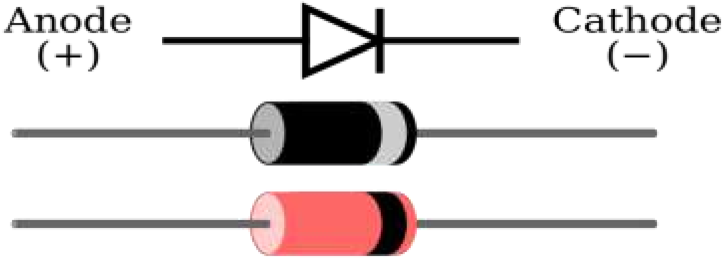
Diodes

- Diode, semiconductor material, such as silicon, in which half is doped as p-region and half is doped as n-region with a pn-junction in between.

- The p region is called **anode** and n type region is called **cathode.**



Diode symbol



One Way Electric "Turnstile"

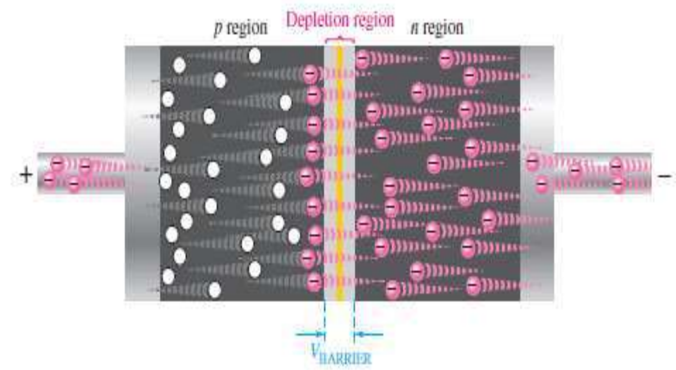
A diode allows current to flow in one direction but not the other.

Jumping

If you apply enough reverse voltage, the junction breaks down and lets current through.

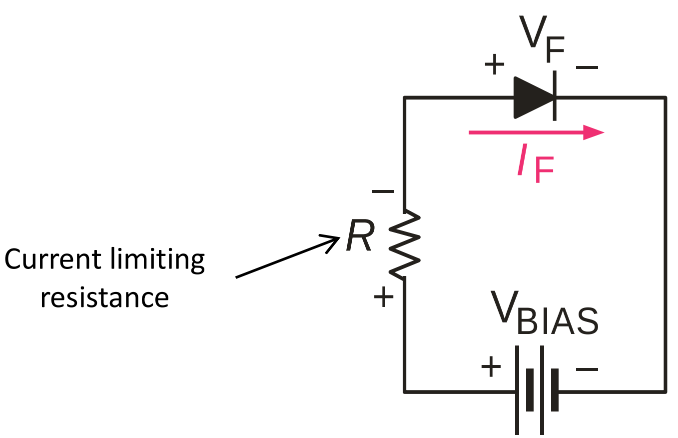
Forward Biased

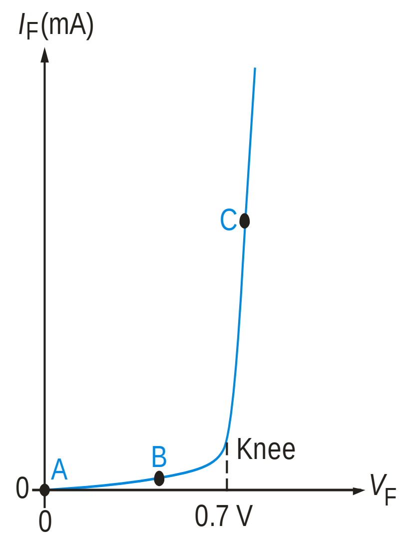
- Forward bias is a condition that allows current through pn junction.
  - A dc voltage (Vbais) is applied to bias a diode.
  - Positive side is connected to p-region (anode) and negative side is connected with n-region.
  - Vbais must be greater than ‘barrier potential’



As more electrons flow into the depletion region reducing the number of positive ions and similarly more holes move in reducing the positive ions.

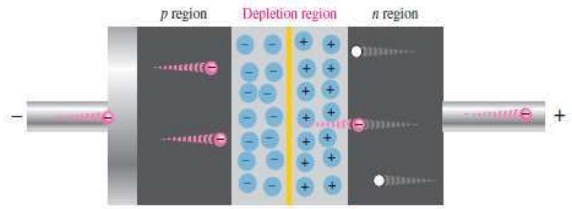
This reduces the width of depletion region.





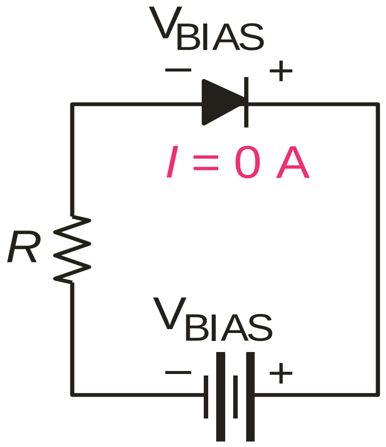
Reverse Biased

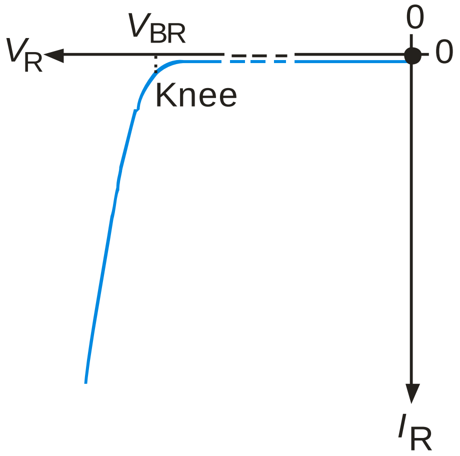
- Reverse bias is a condition that prevents current through junction.
- Positive side of Vbias is connected to the n-region whereas the negative side is connected with p-region.
- Depletion region get wider with this configuration.



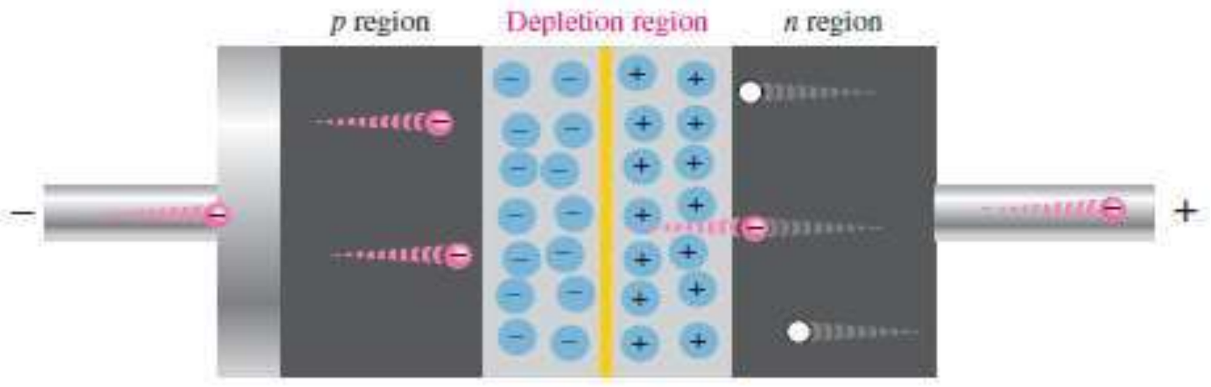
The positive side of bias voltage attracts the majority carriers of n-type creating more positive ions at the junction.

This widens the depletion region.





Reverse Current



- A small amount current is generated due to the minority carriers in p and n regions.
- These minority carriers are produced due to thermally generated hole-electron pairs.
- Minority electrons in p-region pushed towards +ve bias voltage, cross junction and then fall in the holes in n-region and still travel in valance band generating a hole current.

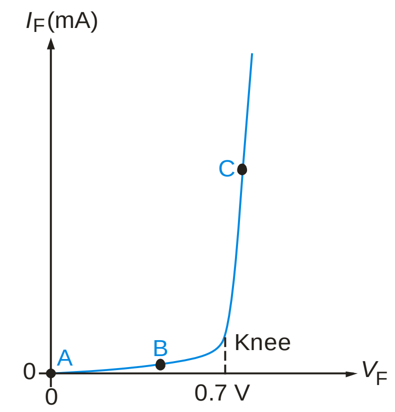
Reverse Breakdown

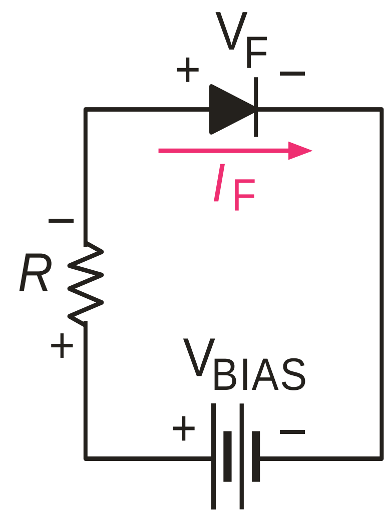
- If the external bias voltage is increased to a value call *breakdown voltage* the reverse current can increase drastically.
- Free minority electrons get enough energy to knock valance electron into the conduction band.
- The newly released electron can further strike with other atoms.
- The process is called ***avalanche effect.***

Diode V-I Characteristic

❖ **VI Characteristic for forward bias.**

- ❖ The current in forward biased called *forward current* and is designated *If*.
- ❖ At 0V (Vbias) across the diode, there is no forward current.
- ❖ With gradual increase of Vbias, the forward voltage and forward current increases.
- ❖ A resistor in series will limit the forward current in order to protect the diode from overheating and permanent damage.
- ❖ A portion of forward-bias voltage drops across the limiting resistor.
- ❖ Continuing increase of Vf causes rapid increase of forward current but only a gradual increase in voltage across diode.

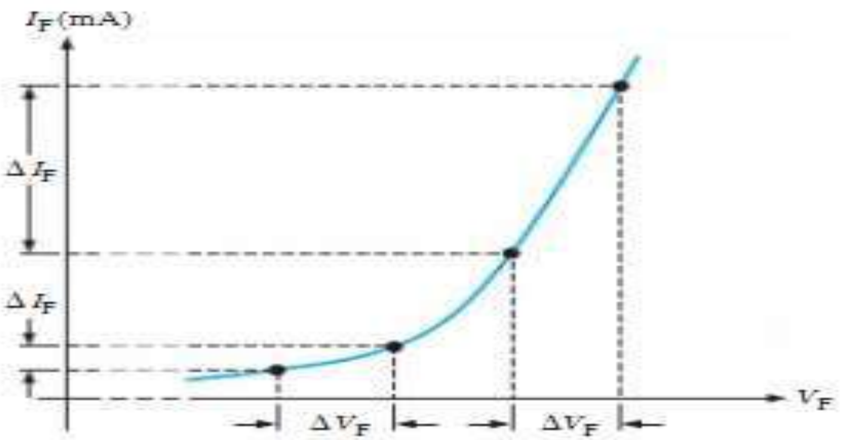




Diode V-I Characteristic

❖ **Dynamic Resistance:**

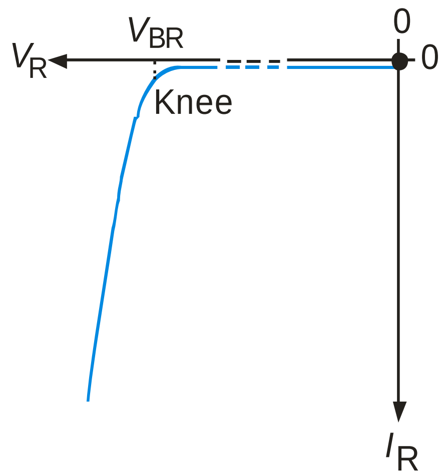
- The resistance of diode is not constant but it changes over the entire curve. So it is called dynamic resistance.



The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

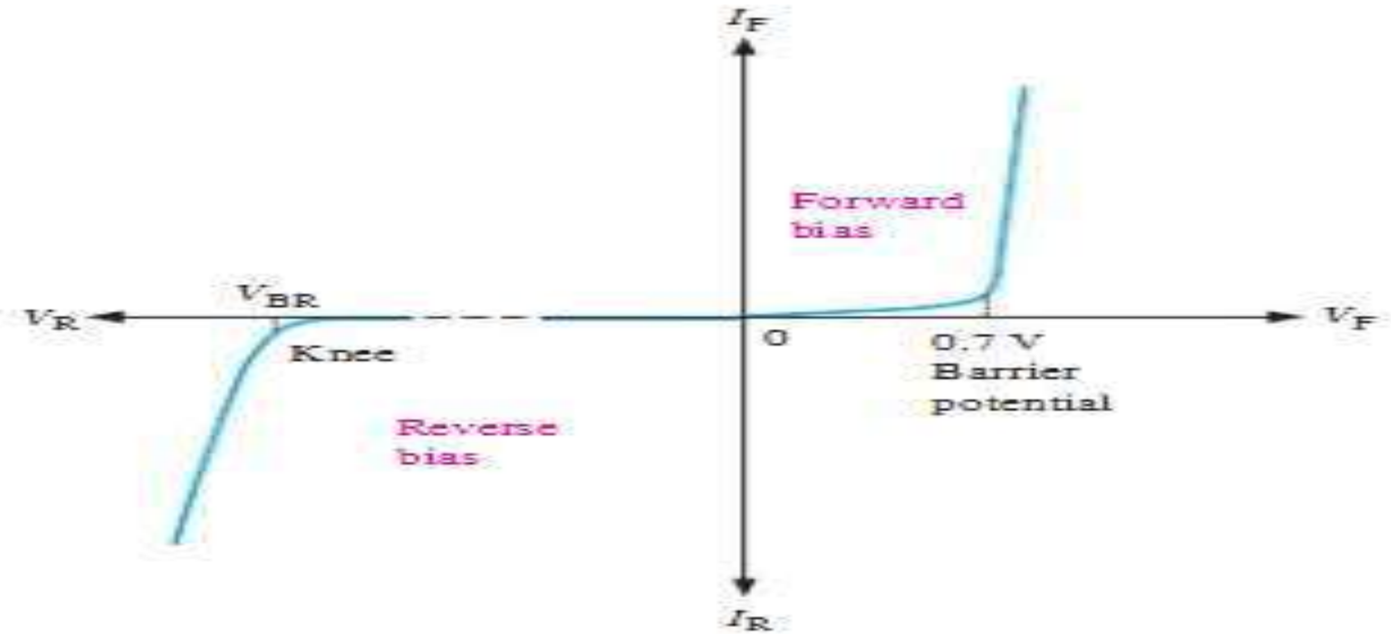
Diode V-I Characteristic

- **VI Characteristic for reverse bias.**
  - With 0V reverse voltage there is no reverse current.
  - There is only a small current through the junction as the reverse voltage increases.
  - At a point, reverse current shoots up with the break down of diode. The voltage called break down voltage. This is not normal mode of operation.
  - After this point the reverse voltage remains at approximately V_{BR} but I_R increase very rapidly.
  - Break down voltage depends on doping level, set by manufacturer.



Diode V-I Characteristic

❖The complete V-I characteristic curve



The complete *V-I* characteristic curve for a diode.

Quick Quiz (Poll 1)

- When PN junction is in forward bias, by increasing the battery voltage

A. Circuit resistance increases

B. Current through P-N junction increases

C. Current through P-N junction decreases

D. None of the above happens

Quick Quiz (Poll 2)

- A reversed-biased PN junction has

  A. Almost zero current
- B. A very narrow depletion layer
- C. A net hole current
- D. A net electron current

Quick Quiz (Poll 3)

- As a PN junction is forward biased

  A. Holes as well as electrons tend to drift away from the junction
- B. The depletion region decreases
- C. The barrier tends to breakdown
- D. None of the above

UNIT-IV

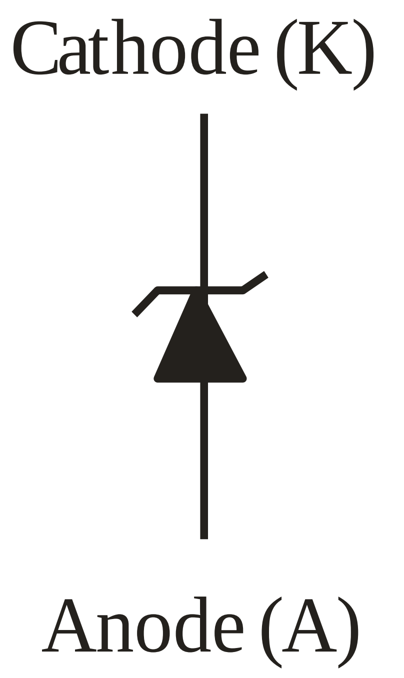
Fundamentals of semiconductor devices and digital circuits

Lecture 30

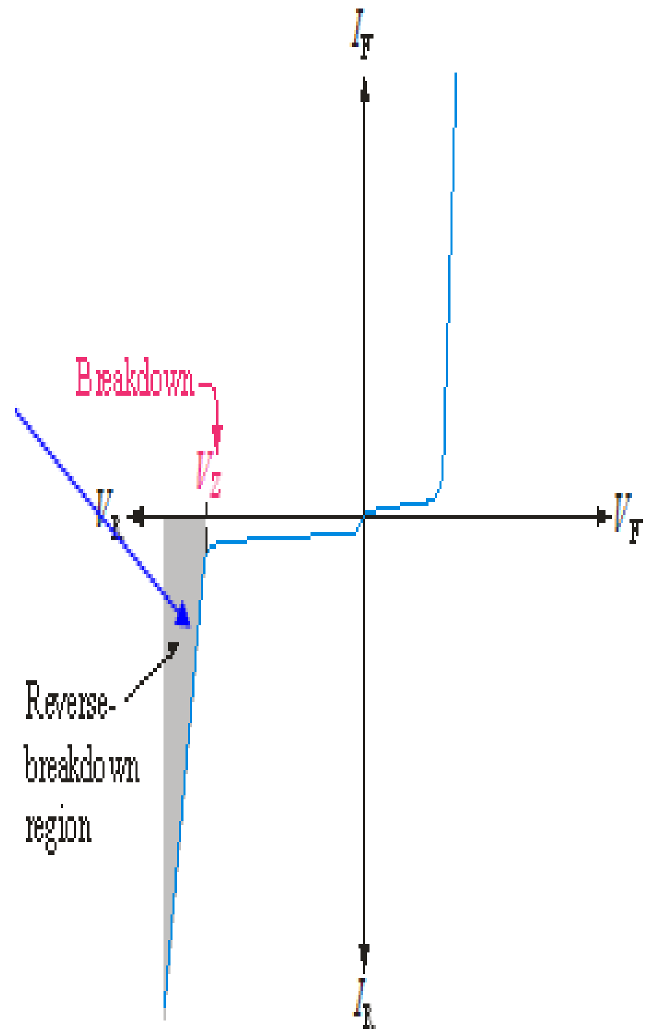
Prepared By:
Krishan Arora
Assistant Professor and Head

Zener Diodes

- A Zener diode is a silicon pn junction that is designed for operation in reverse-breakdown region
- When a diode reaches reverse breakdown, its voltage remains almost constant even though the current changes drastically, and this is key to the Zener diode operation.



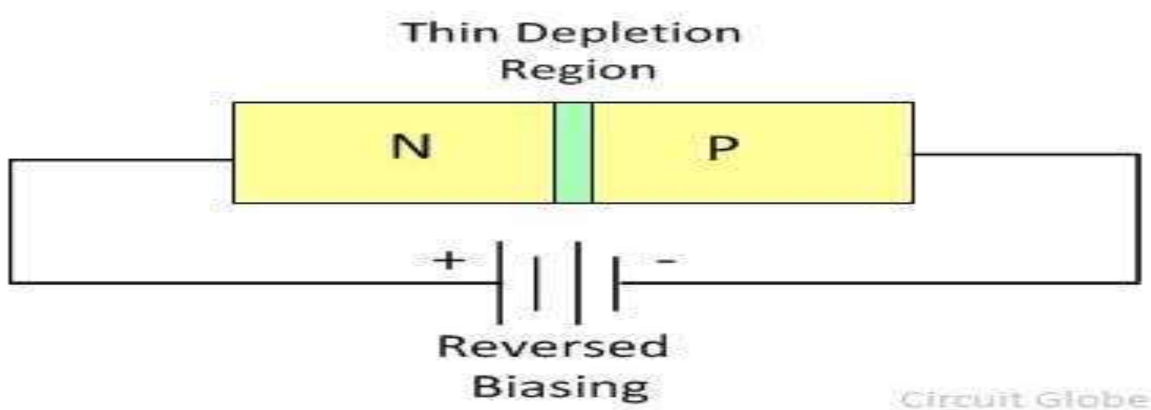
A Zener diode is one of the specially designed diodes that predominately works in reverse biased conditions. They are more heavily doped than ordinary diodes, due to which they have narrow depletion region. While regular diodes get damaged when the voltage across them exceeds the reverse breakdown voltage, Zener diodes work exclusively in this region. The depletion region in Zener diode goes back to its normal state when the reverse voltage gets removed. This particular property of Zener diodes makes it useful as a **voltage regulator**.



Characteristic curve

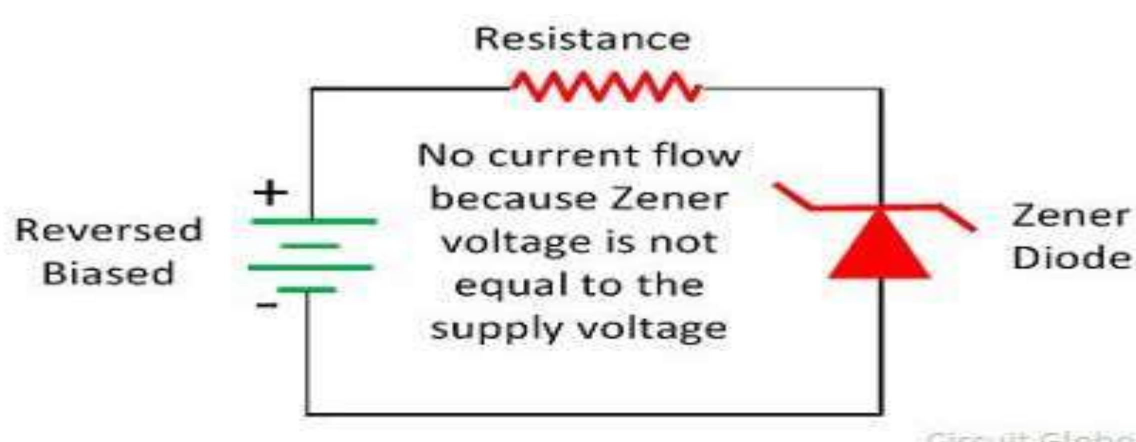
Zener Diode Circuit Diagram

- The circuit diagram of the Zener diode is shown in the figure below. The Zener diode is employed in reverse biasing. The reverse biasing means the n-type material of the diode is connected to the positive terminal of the supply and the P-type material is connected to the negative terminal of the supply. The depletion region of the diode is very thin because it is made of the heavily doped semiconductor material.

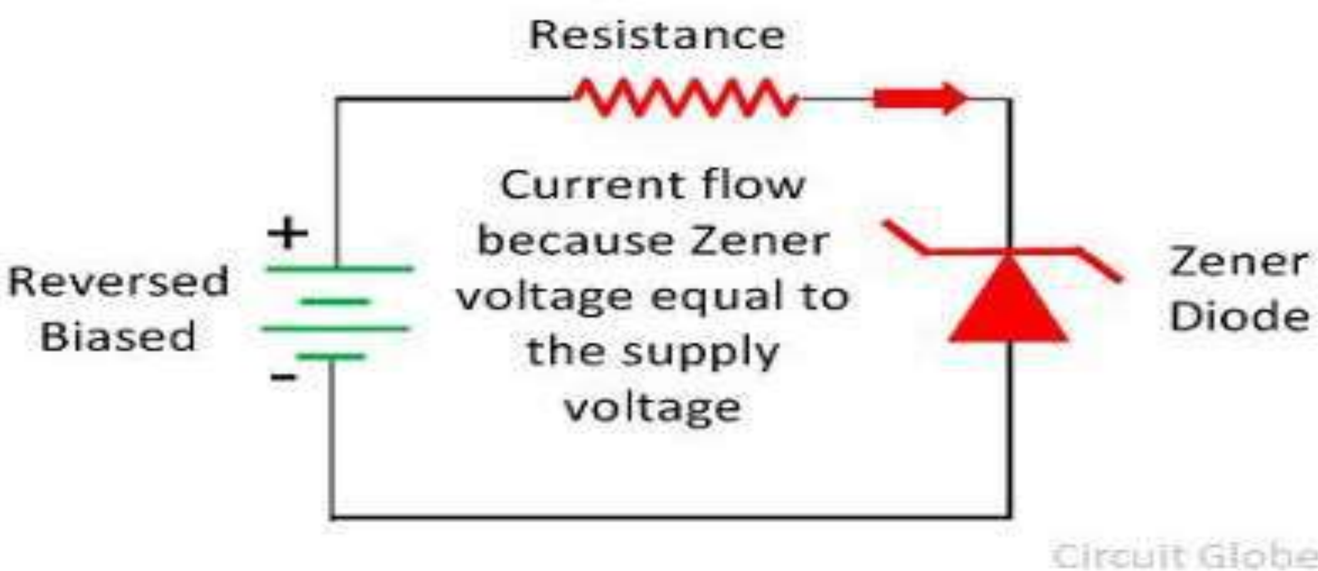


Working of Zener Diode

- When no biasing is applied across the Zener diode, the electrons remains in the valence band of the p-type material and no current flow through the diode. The band in which the valence electrons (outermost orbit electron) place is known as the valence band electron. The electrons of the valence band easily move from one band to another when the external energy is applied across it.



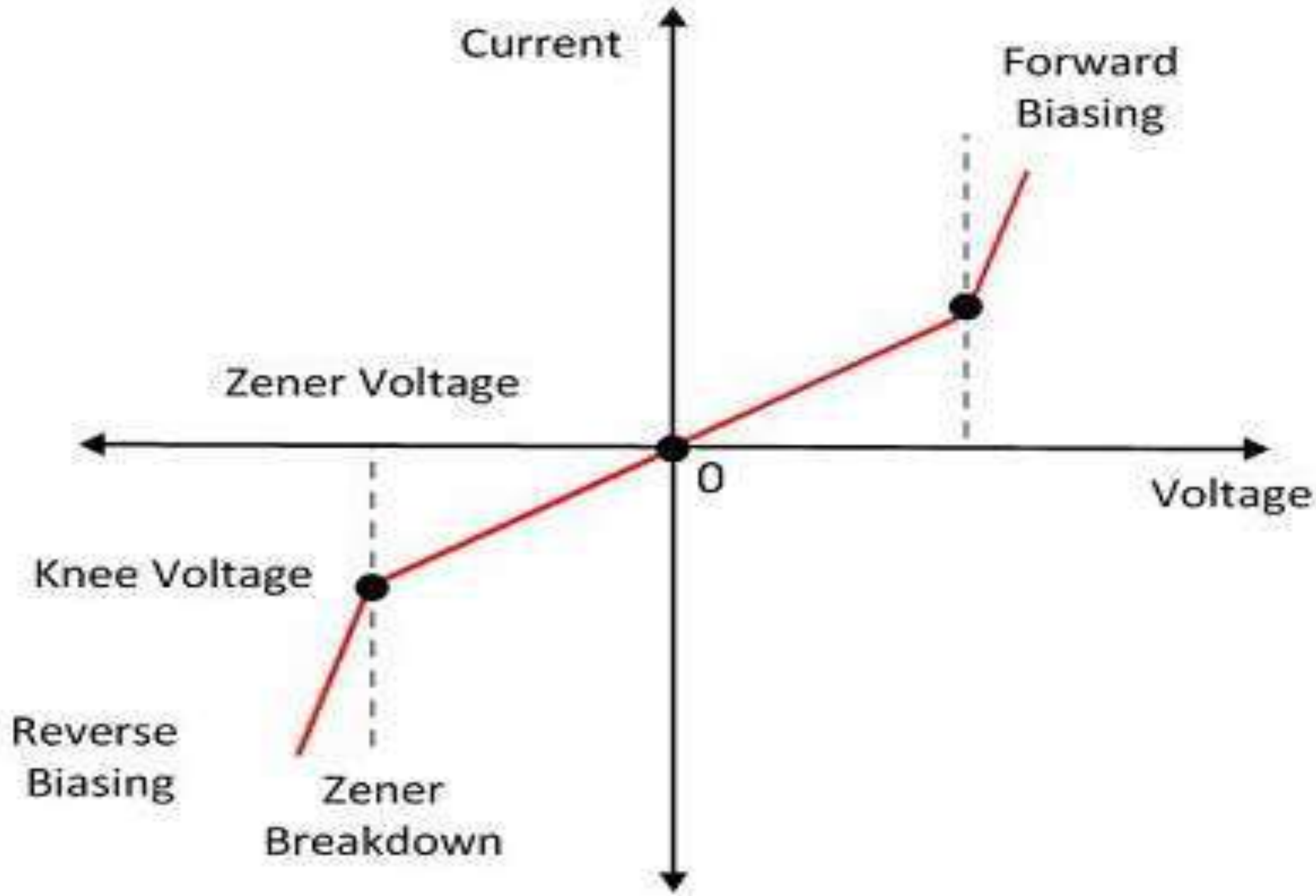
- When the reverse bias applies across the diode and the supply voltage is equal to the Zener voltage then it starts conducting in the reverse bias direction. The Zener voltage is the voltage at which the depletion region completely vanish.



- The reverse bias applies across the diode increases the intensity of electric field across the depletion region.
- Thus, it allows the electrons to move from the valence band of P-type material to the conduction band of N-type material.
- This transferring of valence band electrons to the conduction band reduces the barrier between the p and n-type material.
- When the depletion region become completely vanish the diode starts conducting in the reverse biased.

Zener Breakdown Characteristic

- This curve shows that the Zener diode, when connected in forwarding bias, behaves like an ordinary diode.
- But when the reverse voltage applies across it and the reverse voltage rises beyond the predetermined rating, the Zener breakdown occurs in the diode.
- **As the reverse voltage (VR) increases, the reverse current (IR) remains extremely small up to the knee of the curve.**
- **Reverse current is also called Zener current(Iz).**
- **At knee point the breakdown effect begins, the internal Zener resistance (ZZ) begins to decrease.**
- **The reverse current increase rapidly.**
- **The Zener breakdown (VZ) voltage remains nearly constant.**

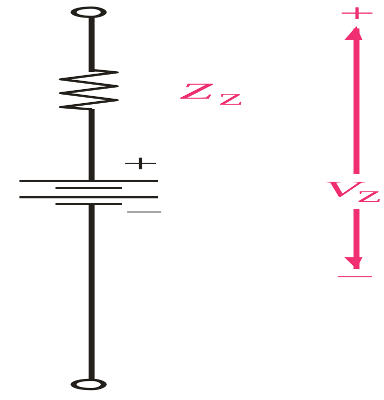


VI Characteristic of Zener Diode

Zener Diode Impedence

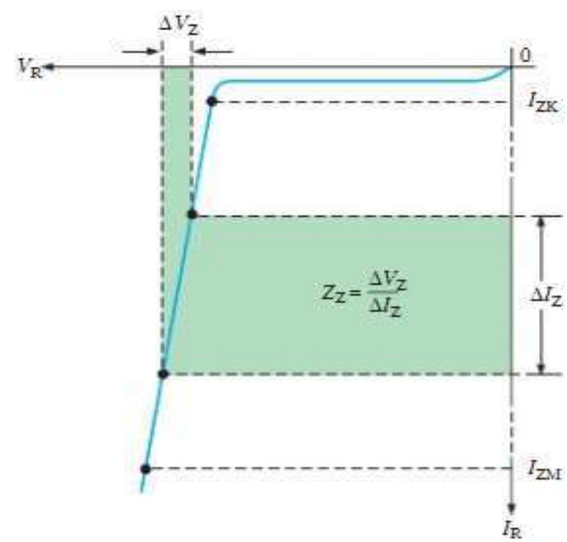
- The zener impedance, Z_Z, is the ratio of a change in voltage in the breakdown region to the corresponding change in current:

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



Practical model

What is the zener impedance if the zener diode voltage changes from 4.79 V to 4.94 V when the current changes from 5.00 mA to 10.0 mA?

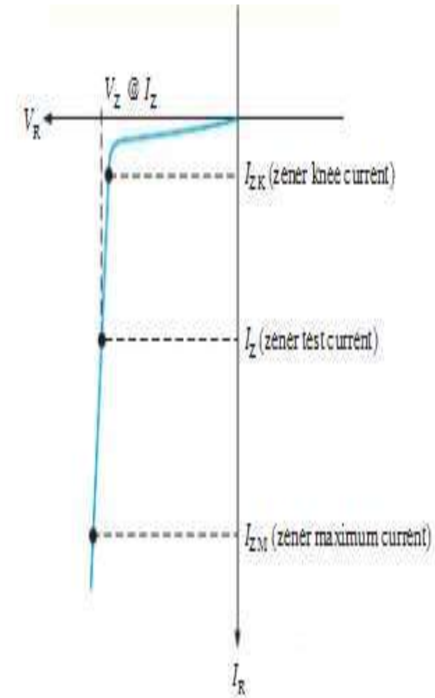


$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z} = \frac{0.15\ \text{V}}{5.0\ \text{mA}} =$$

30 Ω

Zener Regulation

- The ability to keep the reverse voltage constant across its terminal is the key feature of the Zener diode.
- It maintains constant voltage over a range of reverse current values.
- A minimum reverse current IZK must be maintained in order to keep diode in regulation mode. Voltage decreases drastically if the current is reduced below the knee of the curve.
- Above IZM, max current, the Zener may get damaged permanently.

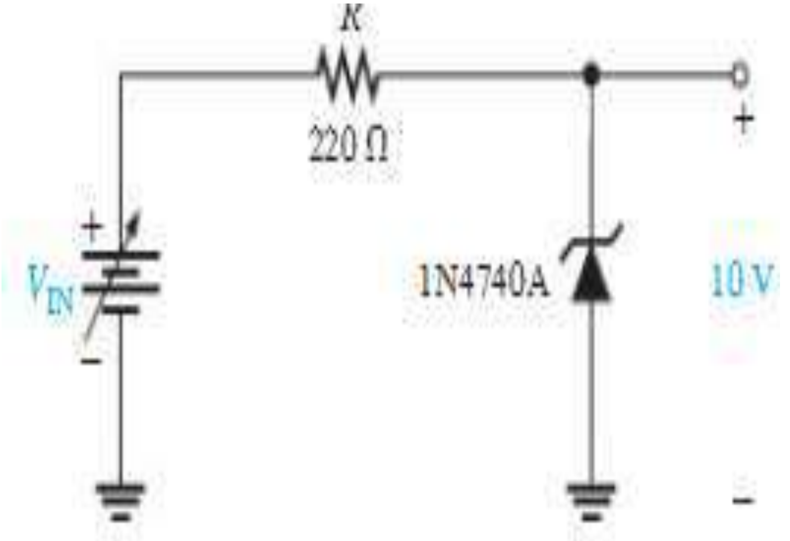


Reverse characteristic of a zener diode. V_Z is usually specified at a value of the zener current known as the test current.

Zener Regulation

❖ Zener Regulation with variable input voltage

- Ideal model of IN4047A
- *IZK* = 0.25mA
- *VZ* = 10V
- *PD(max)* = 1W



Explanation

I_{ZM} = 1W / 10V = 100mA

For the minimum zener current, the voltage across the 220 Ω resistor is

$$V_R = I_{ZK}R = (0.25\text{ mA})(220\ \Omega) = 55\text{ mV}$$

Since $V_R = V_{IN} - V_Z$,

$$V_{IN(min)} = V_R + V_Z = 55\text{ mV} + 10\text{ V} = 10.055\text{ V}$$

For the maximum zener current, the voltage across the 220 Ω resistor is

$$V_R = I_{ZM}R = (100\text{ mA})(220\ \Omega) = 22\text{ V}$$

Therefore,

$$V_{IN(max)} = 22\text{ V} + 10\text{ V} = 32\text{ V}$$

This shows that this zener diode can ideally regulate an input voltage from 10.055 V to 32 V and maintain an approximate 10 V output. The output will vary slightly because of the zener impedance, which has been neglected in these calculations.

Applications of Zener Diodes

- The Zener diode is mostly used in the commercial and industrial applications. The following are the main application of the Zener diode.
- **As Voltage Stabilizer** – The Zener diode is used for regulating the voltage. It provides the constant voltage from the fluctuating voltage source to the load. The Zener diode is connected in parallel across the load and maintain the constant voltage V_Z and hence stabilises the voltage.

- **For Meter Protection** – The Zener diode is generally used in multimeters for controlling the movement of the meter against accidental overloads. It is connected in parallel with the diode. When the overload occurs across the diode most of the current pass through the diode. Thus, protects the meter from damage.
- **For Wave Shaping** – The Zener diode is used for converting the sine wave into the square wave.This can be done by placing the two Zener Diodes in series with the resistance. The diode is connected back to back and in the opposite direction.

Quick Quiz (Poll 1)

- In Zener diode, the breakdown is due to Zener, has doping

  A. Lowest
  B. Moderate
  C. High
  D. Low

Quick Quiz (Poll 2)

- Holes are available in

  A. Valence band
  B. Forbidden gap
  C. Conduction band
  D. None of the above

Quick Quiz (Poll 3)

: In a Zener regulator, when output terminals are open, load current

A. will increase

B. will decrease

C. become zero

D. become infinite

Quick Quiz (Poll 4)

The breakdown voltage of the zener diode is controlled by the

A. impurities
B. doping level
C. voltage
D. Both a and b

UNIT-IV

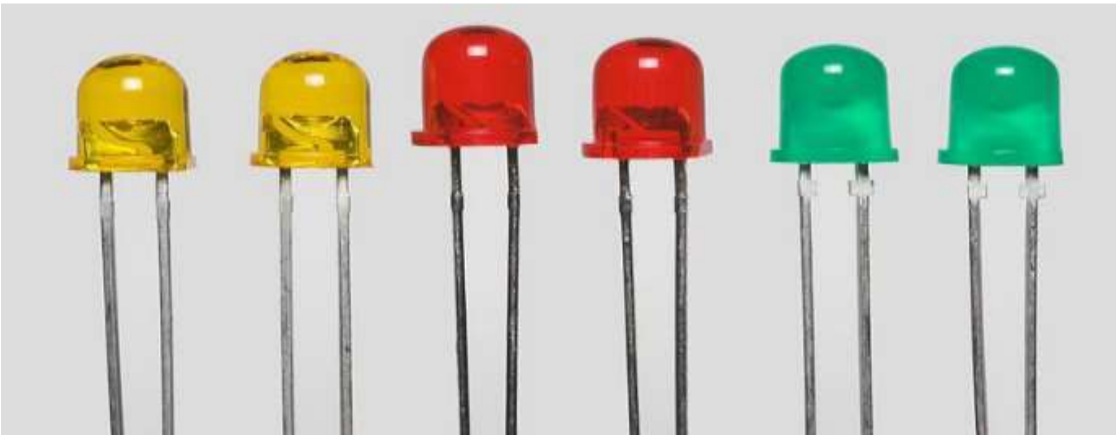
Fundamentals of semiconductor devices and digital circuits

Lecture 31

Prepared By:
Krishan Arora
Assistant Professor and Head

Light Emitting Diode

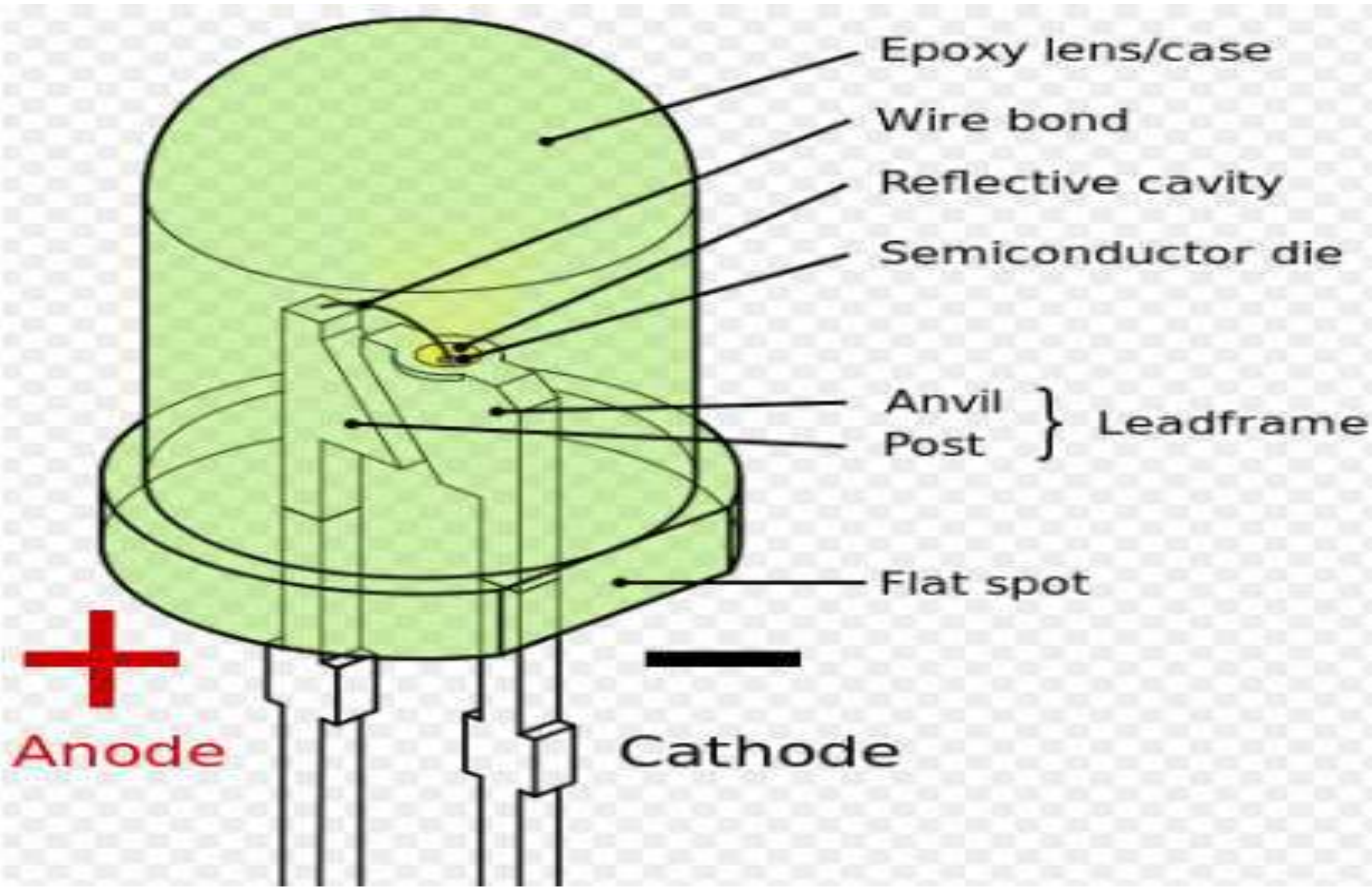
The lighting emitting diode is a p-n junction diode. It is a specially doped diode and made up of a special type of semiconductors. When the light emits in the forward biased, then it is called as a light emitting diode.



History

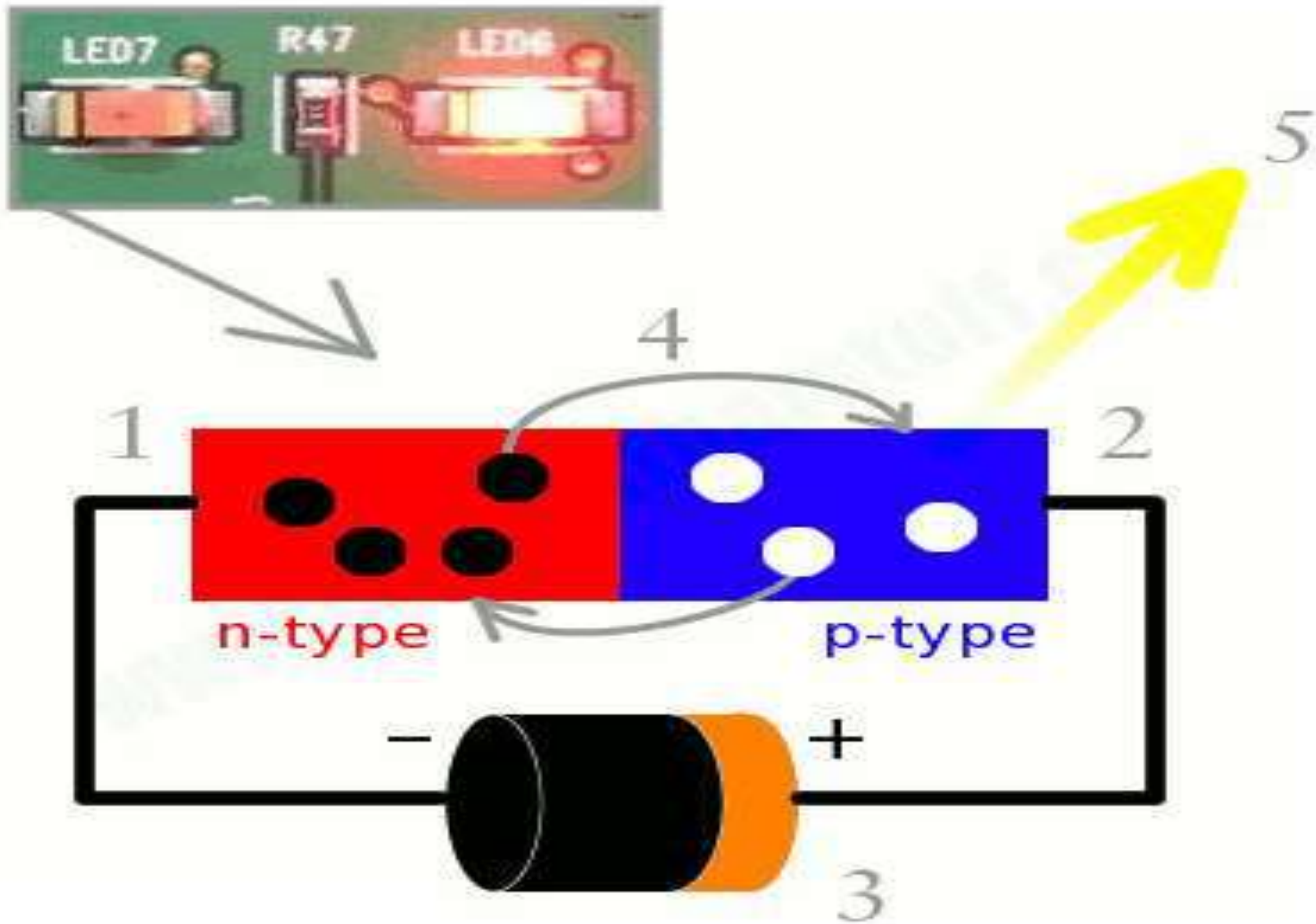
- The Light emitting diode is a two-lead semiconductor light source. In 1962, Nick Holonyak has come up with an idea of light emitting diode, and he was working for the general electric company.
- The LED is a special type of diode and they have similar electrical characteristics of a PN junction diode.
- Hence the LED allows the flow of current in the forward direction and blocks the current in the reverse direction. The LED occupies the small area which is less than the **1 mm^2**.
- The applications of LEDs used to make various electrical and electronic projects.

Internal Structure



How does the Light Emitting Diode work?

- The light emitting diode simply, we know as a diode. When the diode is forward biased, then the electrons & holes are moving fast across the junction and they are combining constantly, removing one another out.
- Soon after the electrons are moving from the n-type to the p-type silicon, it combines with the holes, then it disappears.
- Hence it makes the complete atom & more stable and it gives the little burst of energy in the form of a tiny packet or photon of light.



Working of Light Emitting Diode

- From the diagram, we can observe that the N-type silicon is in red color and it contains the electrons, they are indicated by the black circles.
- The P- type silicon is in the blue color and it contains holes, they are indicated by the white circles.
- The power supply across the p-n junction makes the diode forward biased and pushing the electrons from n-type to p-type. Pushing the holes in the opposite direction.
- Electron and holes at the junction are combined.
- The photons are given off as the electrons and holes are recombined.

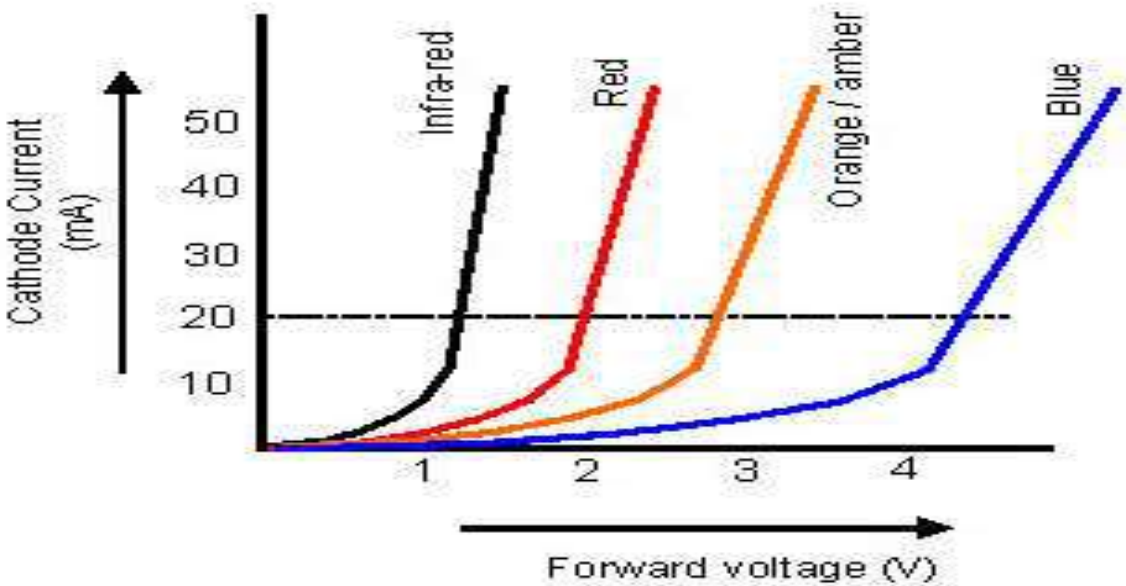
Types of Light Emitting Diodes

- Gallium Arsenide (GaAs) – infra-red
- Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange
- Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow
- Gallium Phosphide (GaP) – red, yellow and green
- Aluminium Gallium Phosphide (AlGaP) – green
- Gallium Nitride (GaN) – green, emerald green
- Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue
- Silicon Carbide (SiC) – blue as a substrate
- Zinc Selenide (ZnSe) – blue
- Aluminium Gallium Nitride (AlGaN) – ultraviolet

I-V Characteristics of LED

- There are different types of light emitting diodes are available in the market and there are different LED characteristics which include the color light, or wavelength radiation, light intensity.
- The important characteristic of the LED is color. In the starting use of LED, there is the only red color. As the use of LED is increased with the help of the semiconductor process and doing the research on the new metals for LED, the different colors were formed.

- The following graph shows the approximate curves between the forward voltage and the current. Each curve in the graph indicates the different color.



I-V Characteristics of LED

Quick Quiz (Poll 1)

- The LEDs made with GaAs emit light in the

  A. Yellow region
- B. Infrared region
- C. Orange region
- D. Red visible region

Lighting System Efficacy

Luminaire Type		Lumens Per Watt	Fixture Efficiency	Usable Lumens Per Watt
Halogen Incandescent		17	45%	8
Compact Fluorescent		45	33%	15
150 W Cobra Head Type II Streetlight (HPS)		91	50%	46
400W HID w/Glass Housing (MH)		70	54%	38
XLamp LED Lighting Fixture		71	***90%***	***64***
T8 Fluorescent Tube		80	77%	62

Current LED Market

Cellphone
(Nokia)

Traffic signals
(Gelcore)

Large Displays
(NASDAQ)

streetlights

TVs (LED DLP^{tm})
(samsung)

Automotive

LEDs in Architectural Lighting

Installation Benjamin Franklin Bridge,
PA, USA (Color Kinetics Inc.)

Lighting Systems by Color Kinetics Inc.
Takarazuka University of Art and Design

AUTOMOBILE LED Headlights

Nissan

Honda

Daimlar Chrysler

Toyota

0.5-1% better fuel efficiency

Air/Water Purification

- Fruit and Vegetable Storage Life Extended 1 week
- Water Purication: UV LED to kill bacteria

Mitsubishi Refrigerator MR-W55H,
UV LED 375 nm, 590 nm

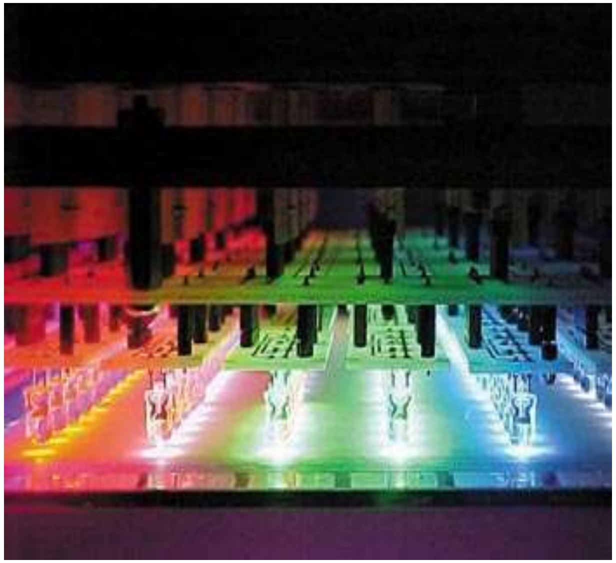
(Credit: Hydro-Photon Inc.)

Applications of Light Emitting Diodes

There are many applications of the LED and some of them are explained below.

- LED is used as a bulb in the homes and industries
- The light emitting diodes are used in the motorcycles and cars
- These are used in the mobile phones to display the message
- At the traffic light signals led’s are used

The Advantage of LED Lighting



Long life – lifetimes can exceed 100,000 hours as compared to 1,000 hrs for tungsten bulbs.

Robustness – no moving parts, no glass, no filaments.

Size – typical package is only 5 mm in diameter.

Energy efficiency – 50- 90% less energy used translates into smaller power supply.

Non-toxicity – no mercury.

Versatility – available in a variety of colors; can be pulsed.

Cool – less heat radiation than Tunsten or incandescent

Quick Quiz (Poll 2)

The colour of emitted light from LED depends on

A. Construction of LED, that is physical dimensions
B. Number of available carriers
C. Type of semiconductor material used
D. Number of recombinations taking place

Quick Quiz (Poll 3)

The advantage of LED is

A. Long life
B. Fast on-off switching
C. Low operating voltage
D. All of the above

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

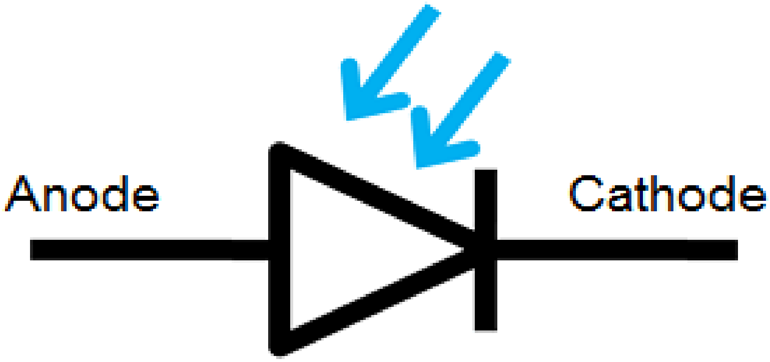
Lecture 32

Prepared By:
Krishan Arora
Assistant Professor and Head

Photodiode

- A photodiode is a PN-junction diode that consumes light energy to produce electric current. Sometimes it is also called as photo-detector, a light detector, and photo-sensor.
- These diodes are particularly designed to work in reverse bias condition, it means that the P-side of the photodiode is associated with the negative terminal of the battery and n-side is connected to the positive terminal of the battery.
- This diode is very complex to light so when light falls on the diode it easily changes light into electric current.
- The solar cell is also branded as large area photodiode because it converts solar energy into electric energy. Though, solar cell works only in bright light.

Photodiode Symbol



Photodiode symbol

Photodiode Symbol

Types of Photodiode

The types of the photodiodes can be classified based on its construction and functions as follows.

- PN Photodiode
- Schottky Photo Diode
- PIN Photodiode
- Avalanche Photodiode

These diodes are widely used in the applications where the detection of the presence of light, color, position, intensity is required.

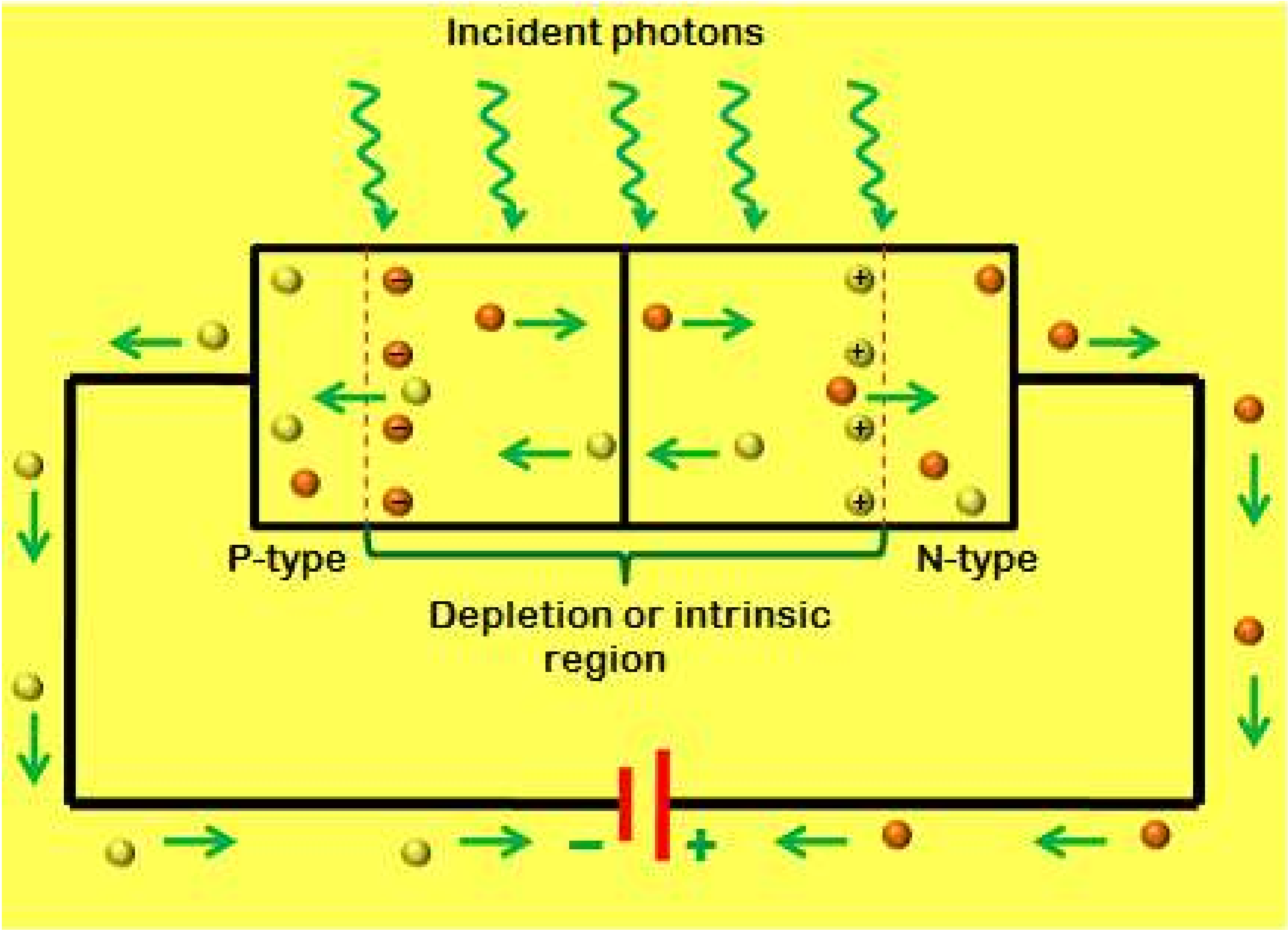
Features of Photodiodes

The main features of these diodes include the following.

- The linearity of the diode is good with respect to incident light
- Noise is low.
- The response is wide spectral
- Rugged mechanically
- Light weight and compact
- Long life

Working of Photodiode

- The working principle of a photodiode is, when a photon of ample energy strikes the diode, it makes a couple of an electron-hole. This mechanism is also called as the inner photoelectric effect.
- If the absorption arises in the depletion region junction, then the carriers are removed from the junction by the inbuilt electric field of the depletion region.
- Therefore, holes in the region move toward the anode, and electrons move toward the cathode, and a photocurrent will be generated.
- The entire current through the diode is the sum of the absence of light and the photocurrent. So the absent current must be reduced to maximize the sensitivity of the device.



Incident photons
P-type
N-type
Depletion or intrinsic
region

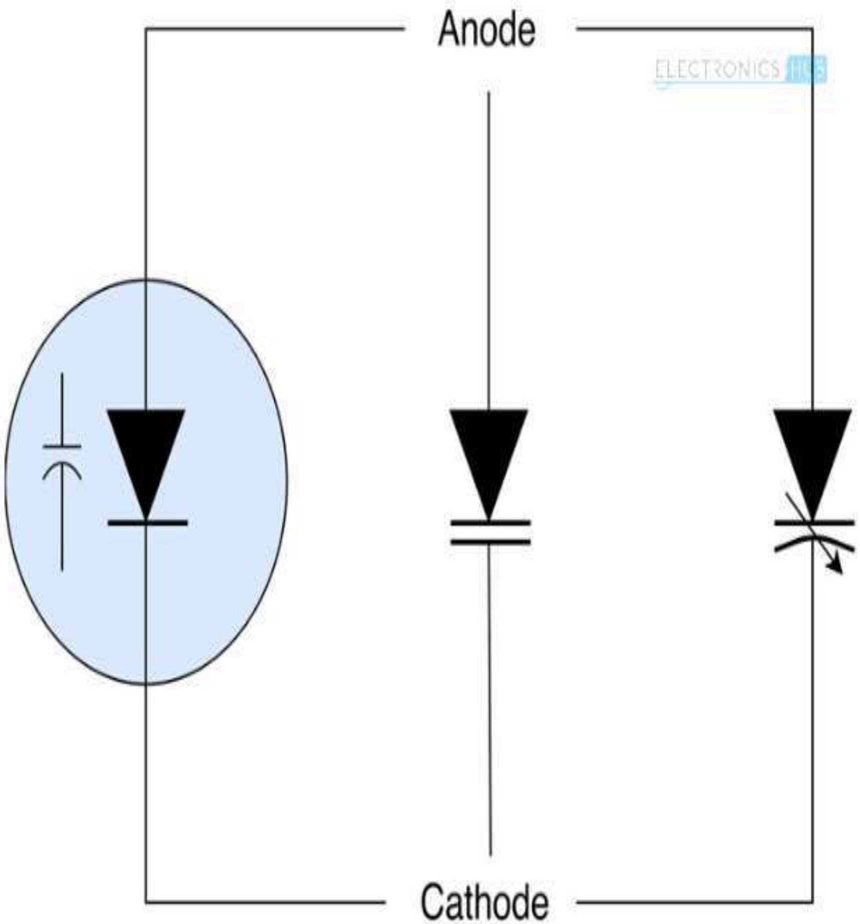
Applications of Photodiode

- These diodes are used in consumer electronics devices like smoke detectors, compact disc players, and televisions and remote controls in VCRs.
- In other consumer devices like clock radios, camera light meters, and street lights, photoconductors are more frequently used rather than photodiodes.
- Photodiodes are frequently used for exact measurement of the intensity of light in science & industry.

Varactor Diode

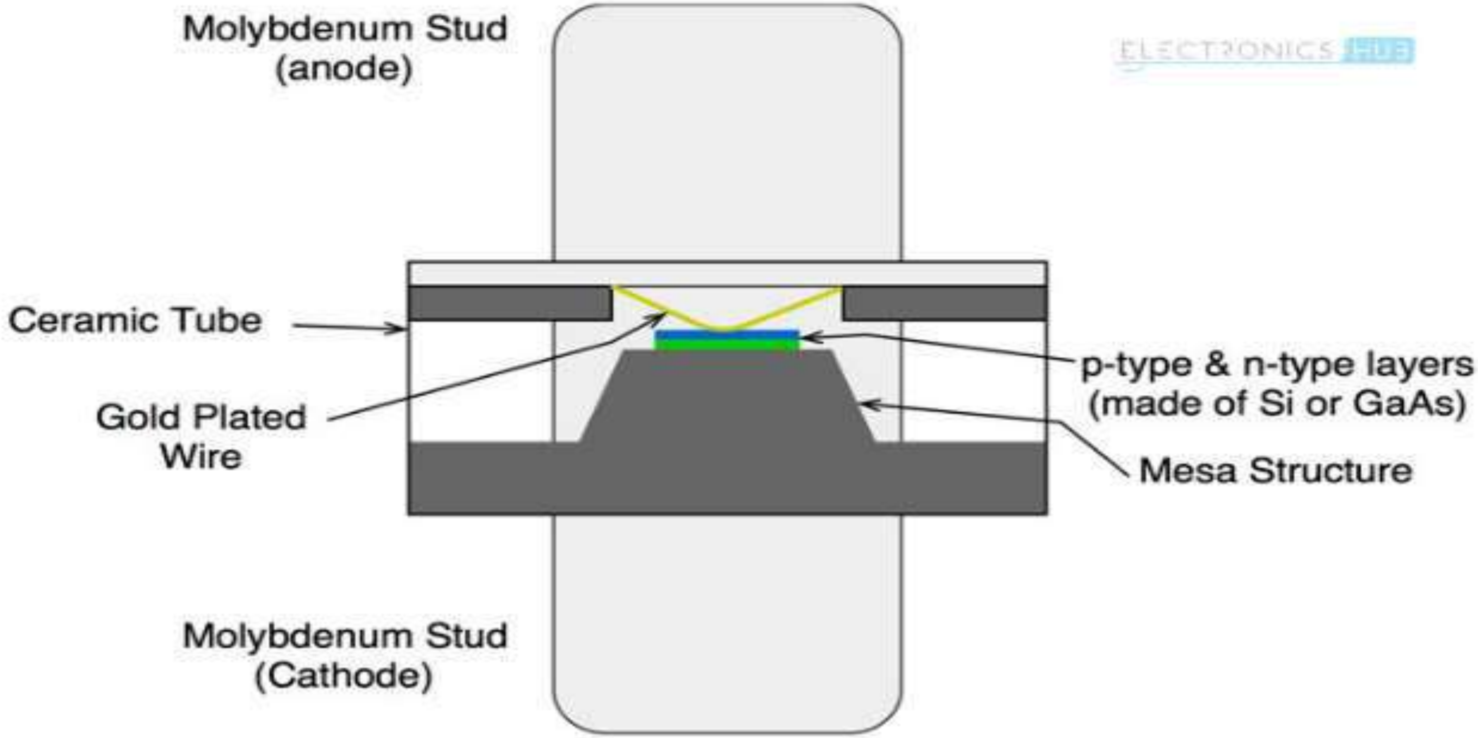
- A Varactor Diode (also known with the names Varicap Diode, Varactor Diode, Tuning Diode) is a p-n junction diode which acts as a variable capacitor under varying reverse bias voltage across its terminals.
- In other words, it is a specially designed semiconductor diode whose capacitance at the p-n semiconductor junction changes with the change in voltage applied across its terminals. And because it is a diode that can behave as a variable capacitor, it is named as a Varactor Diode in short.

Symbols



Construction

- A Varactor Diode consists of p-type and n-type semiconductor layers sandwiched together, with the n-type layer attached to a mesa (table-shaped) structure. A gold plated molybdenum stud is connected to n-type layer via the mesa structure and it acts as cathode terminal.
- The p-type layer is connected to another gold plated molybdenum stud (which acts as anode) via a gold wire. Except for some portion of the molybdenum studs, the entire arrangement is enclosed in a ceramic layer.



- The p-type and n-type layers of the varactor diode are made up of silicon or gallium arsenide depending on the type of application for which it is used. For low frequency applications, silicon is used, and for high-frequency applications gallium arsenide is used.

Applications

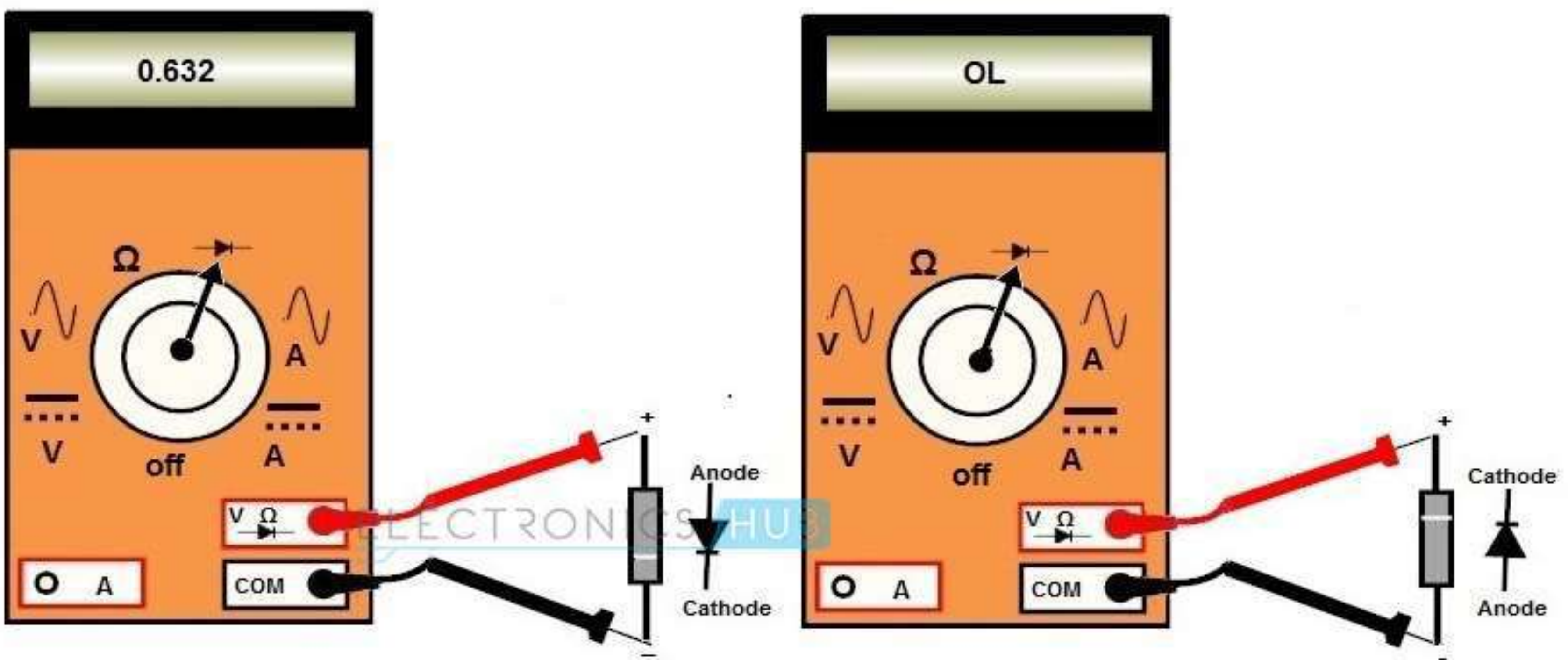
- Some of the applications include:

❖ Automatic Frequency Controllers (AFCs)
❖ Ultra High Frequency Television sets
❖ High frequency Radios
❖ Frequency Multipliers
❖ Band Pass Filters
❖ Harmonic Generators

Testing of diode

How to Test a Diode using a Digital Multimeter

The diode testing using a digital multimeter (DMM) can be carried in two ways because there are two modes available in DMM to check the diode. These modes are diode mode and ohmmeter mode.



Testing of diode

- Identify the terminals anode and cathode of the diode.
- Keep the digital multimeter (DMM) in diode checking mode by rotating the central knob to the place where the diode symbol is indicated. In this mode multimeter is capable to supply a current of 2mA approximately between the test leads.
- Connect the red probe to the anode and black probe to the cathode. This means diode is forward-biased.
- Observe the reading on meter display. If the displayed voltage value is in between 0.6 to 0.7 (since it is silicon diode) then the diode is healthy and perfect. For germanium diodes this value is in between 0.25 to 0.3.
- Now reverse the terminals of the meter that means connect the red probe to cathode and black to anode. This is the reverse biased condition of the diode where no current flows through it. Hence the meter should read OL (which is equivalent to open circuit) if the diode is healthy.

Testing of diode

- If the meter shows irrelevant values to the above two conditions, then the diode is defective. The diode defect can be either open or short. Open diode means diode behaves as an open switch in both reverse and forward-biased conditions. So, no current flows through the diode. Therefore, the meter will indicate OL in both reverse and forward-biased conditions.
- Shorted diode means diode behaves as a closed switch so the current flows through it and the voltage drop across the diode will be zero. Therefore, the multimeter will indicate zero voltage value, but in some cases it will display a very little voltage as the voltage drop across the diode.

Quick Quiz (Poll 1)

- **Photodiode is used in the detection of**

(a) Visible light
(b) Invisible light
(c) No light
(d) Both visible and invisible light

Quick Quiz (Poll 2)

- **When a diode is forward biased, the recombination of free electron and holes produce**

(a) Heat
(b) Light
(c) Radiation
(d) All the above

Quick Quiz (Poll 3)

- The varactor is also known as

  A. Epicap

  B. Varicap

  C. Tuning diode

  D. All of the above

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 33

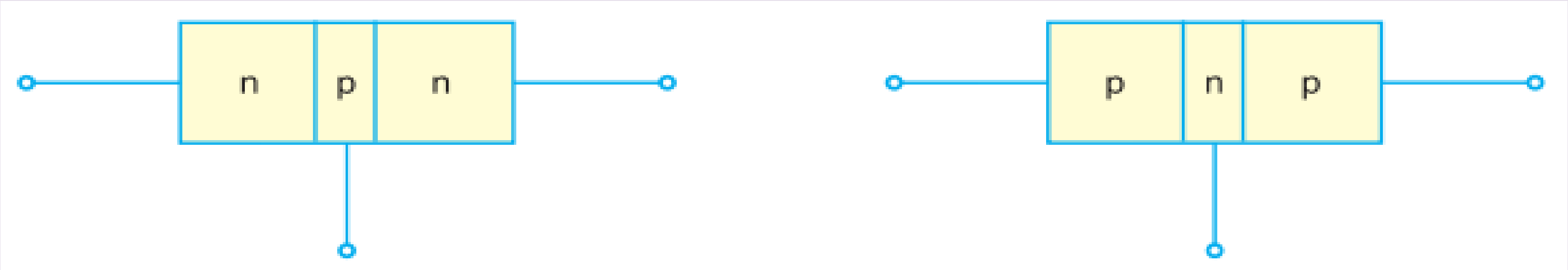
Prepared By:
Krishan Arora
Assistant Professor and Head

Bipolar Junction Transistors

- The transistor is a three-layer semiconductor device consisting of either two n- and one p- type layers of material or two p- and one n- type layers of material.
- The former is called an npn transistor, while the latter is called a pnp transistor
- So, there are two types of BJT-

i) pnp transistor   ii) npn transistor

Bipolar Junction Transistors



In each transistor following points to be noted-

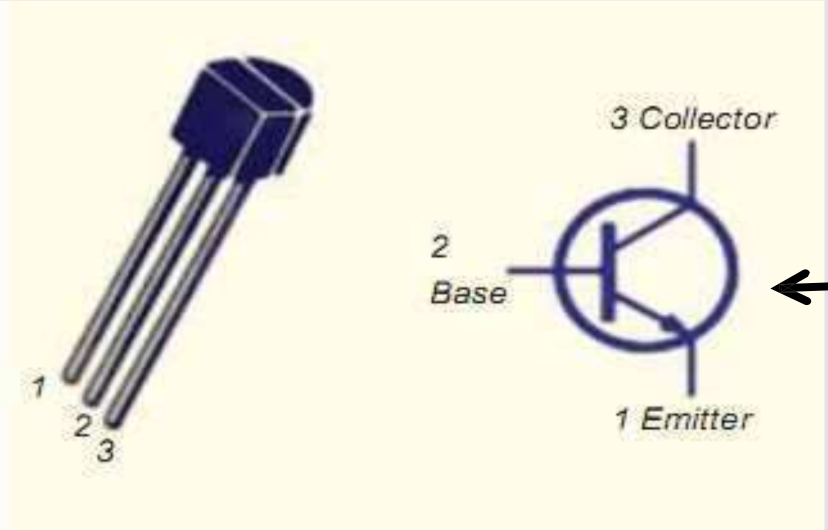
i)There are two junction, so transistor can be considered as two diode connected back to back.

ii)There are three terminals.

iii)The middle section is thin than other.

Naming of Transistor Terminals

- Transistor has three section of doped semiconductor.
- The section one side is called “emitter” and the opposite side is called “collector”.
- The middle section is called “base”.



Transistor symbol

Naming of Transistor Terminals

1) ***<u>Emitter:</u>***

→ The section of one side that supplies carriers is called emitter.

→ Emitter is always forward biased with respect to base so it can supply carrier.

→ For “npn transistor” emitter supply holes to its junction.

→ For “pnp transistor” emitter supply electrons to its junction.

Naming of Transistor Terminals

2) Collector:

→The section on the other side that collects carrier is called collector.

→ The collector is always reversed biased with respect to base.

→For “npn transistor” collector receives holes to its junction.

→ For “pnp transistor” collector receives electrons to its junction.

Naming of Transistor Terminals

3) Base:

→The middle section which forms two pn junction between emitter and collector is called Base.

Some important factors to be remembered-

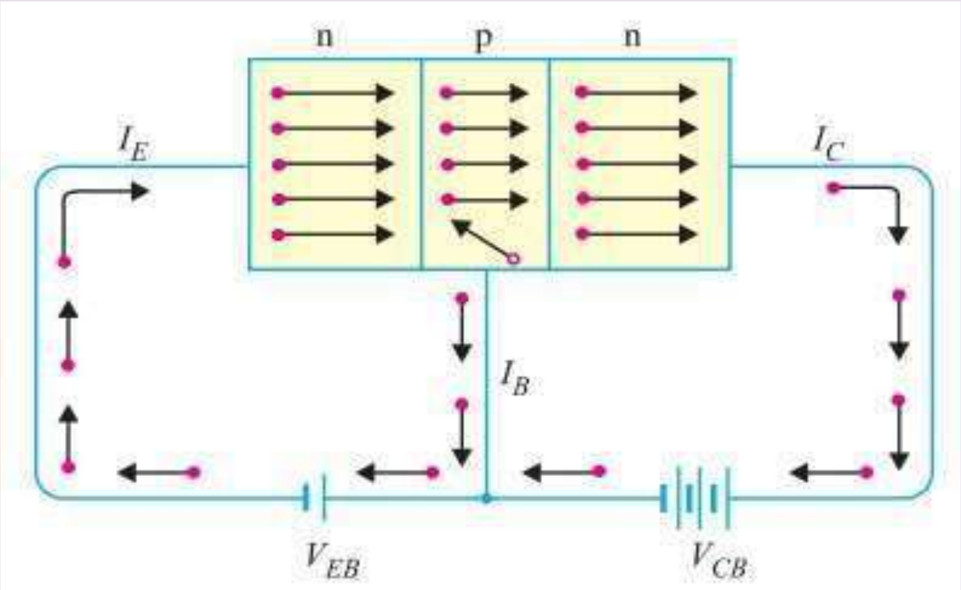
- The transistor has three region named emitter, base and collector.
- The Base is much thinner than other region.
- Emitter is heavily doped so it can inject large amount of carriers into the base.
- Base is lightly doped so it can pass most of the carrier to the collector.
- Collector is moderately doped.

Some important factors to be remembered-

- The junction between emitter and base is called emitter-base junction(emitter diode) and junction between base and collector is called collector-base junction(collector diode).
- The emitter diode is always forward biased and collector diode is reverse biased.
- The resistance of emitter diode is very small(forward) and resistance of collector diode is high(reverse).

Transistor Operation

1) Working of npn transistor:



✓Forward bias Is applied to emitter-base junction and reverse bias is applied to collector-base junction.

✓ The forward bias in the emitter-base junction causes electrons to move toward base. This constitute emitter current, I_E

Transistor Operation

1) Working of npn transistor:

✓As this electrons flow toward p-type base, they try to recombine with holes. As base is lightly doped only few electrons recombine with holes within the base.

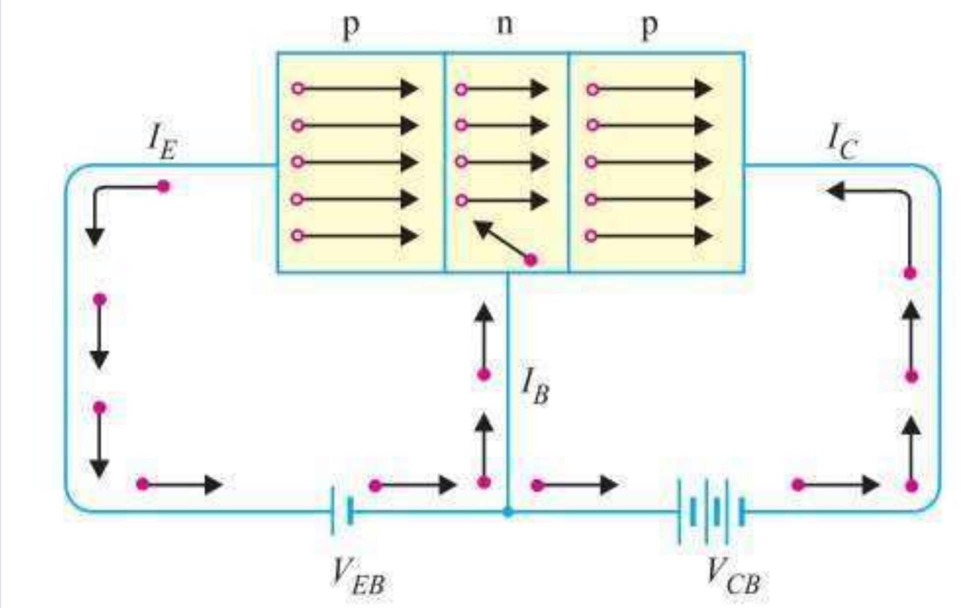
✓These recombined electrons constitute small base current.

✓The remainder electrons crosses base and constitute collector current.

$$I_E = I_B + I_C$$

Transistor Operation

2) Working of pnp transistor:



✓Forward bias is applied to emitter-base junction and reverse bias is applied to collector-base junction.

✓ The forward bias in the emitter-base junction causes holes to move toward base. This constitute emitter current, I_E

Transistor Operation

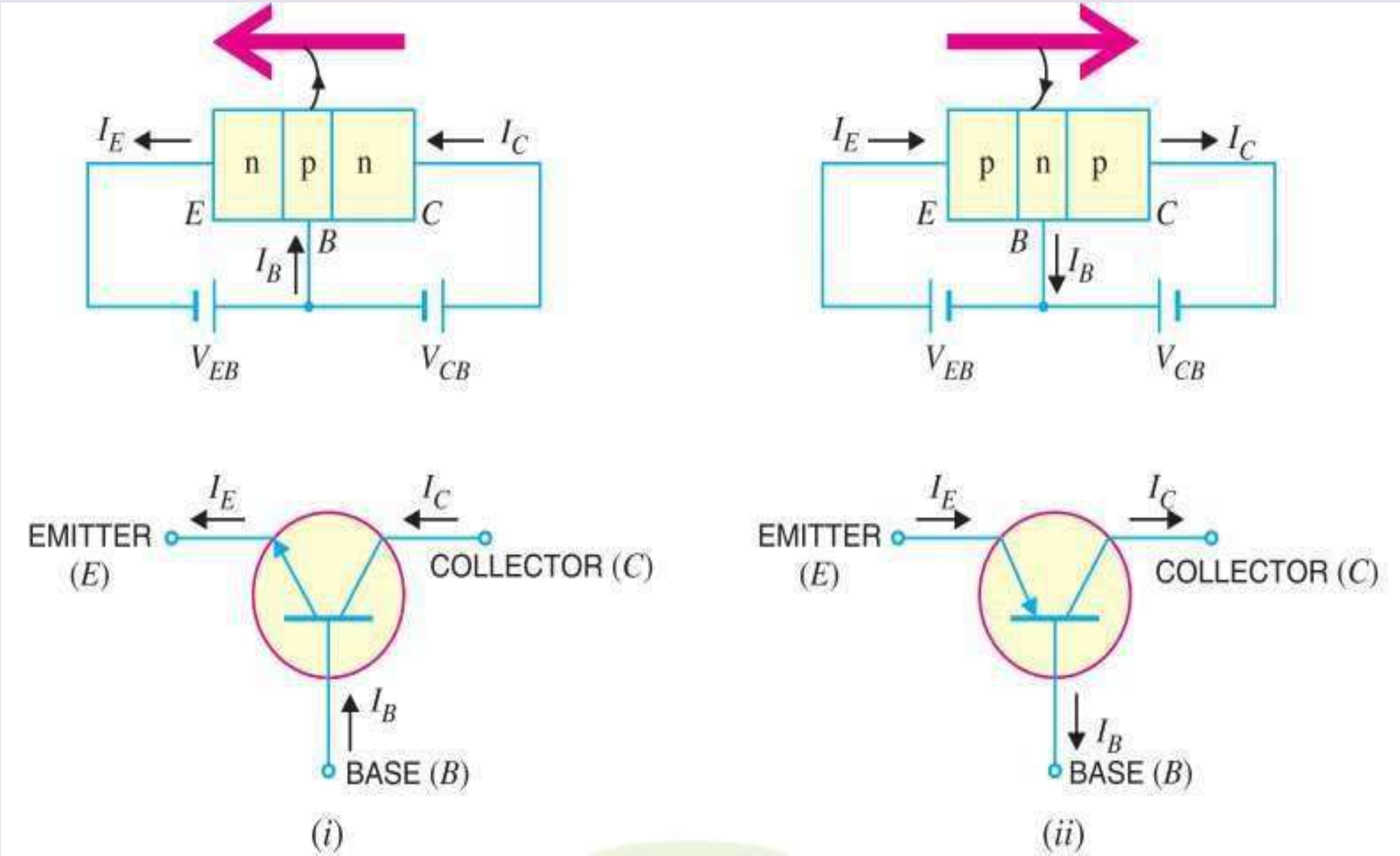
2) Working of pnp transistor:

✓As this holes flow toward n-type base, they try to recombine with electrons. As base is lightly doped only few holes recombine with electrons within the base.

✓These recombined holes constitute small base current.

✓The remainder holes crosses base and constitute collector current.

Transistor Symbol



Transistor Operating Modes

- Active Mode

→ Base- Emitter junction is forward and Base- Collector junction is reverse biased.

- Saturation Mode

→ Base- Emitter junction is forward and Base- Collector junction is forward biased.

- Cut-off Mode

→ Both junctions are reverse biased.

Transistor Connection

- Transistor can be connected in a circuit in following three ways-

1)Common Base

2)Common Emitter

3)Common Collector

Quick Quiz (Poll 1)

- **A transistor has ……………………**

a) one pn junction

b) two pn junctions

c) three pn junctions

d) four pn junctions

Quick Quiz (Poll 2)

- **The element that has the biggest size in a transistor is ……………………..**

a) collector

b) base

c) emitter

d) collector-base-junction

Quick Quiz (Poll 3)

• **Most of the majority carriers from the emitter ……………………**

a) recombine in the base

b) recombine in the emitter

c) pass through the base region to the collector

d) none of the above

Quick Quiz (Poll 4)

- **The emitter of a transistor is …………………… doped**

a) lightly

b) heavily

c) moderately

d) none of the above

UNIT-IV

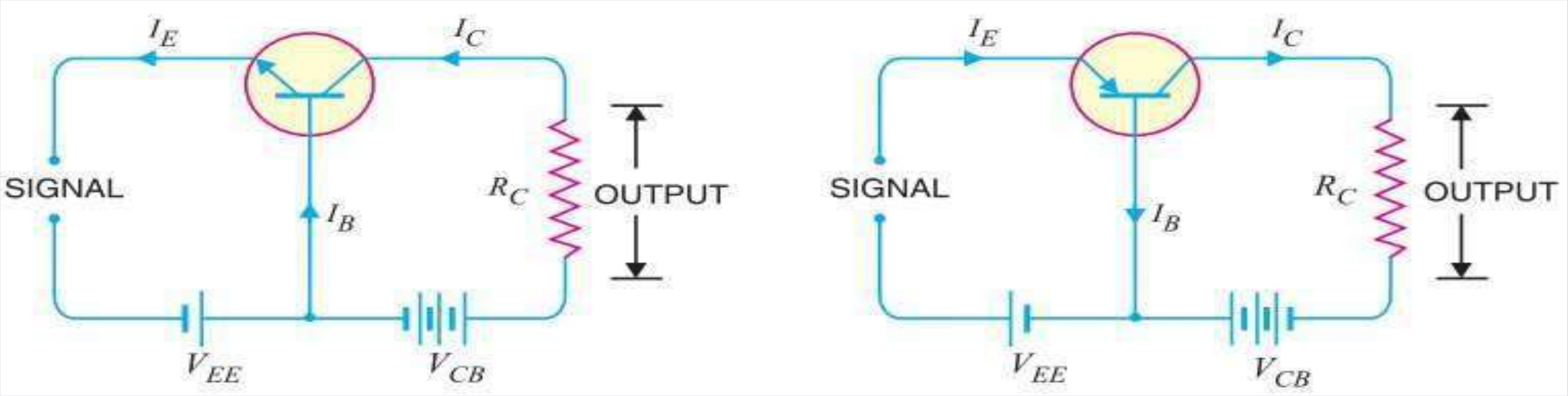
Fundamentals of semiconductor devices and digital circuits

Lecture 34

Prepared By:
Krishan Arora
Assistant Professor and Head

Common Base Connection

- The common-base terminology is derived from the fact that the base is common to both the input and output sides of the configuration.



- First Figure shows common base npn configuration and second figure shows common base pnp configuration.

Common Base Connection

- <u>Current amplification factor (α) :</u>

  The ratio of change in collector current to the change in emitter current at constant V_{CB} is known as current amplification factor,.α

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \ at \ \text{constant} \mathrm{V}_{CB}$$

→ Practical value of α is less than unity, but in the range of 0.9 to 0.99

Expression for Collector Current

→Total emitter current does not reach the collector terminal, because a small portion of it constitute base current. So,

$$I_E = I_C + I_B$$

→Also, collector diode is reverse biased, so very few minority carrier passes the collector-base junction which actually constitute leakage current, I_{CBO}.

→So, collector current constitute of portion of emitter current αIE and leakage current I_{CBO}

$$I_C = \alpha I_E + I_{CB0}$$

Expression for Collector Current

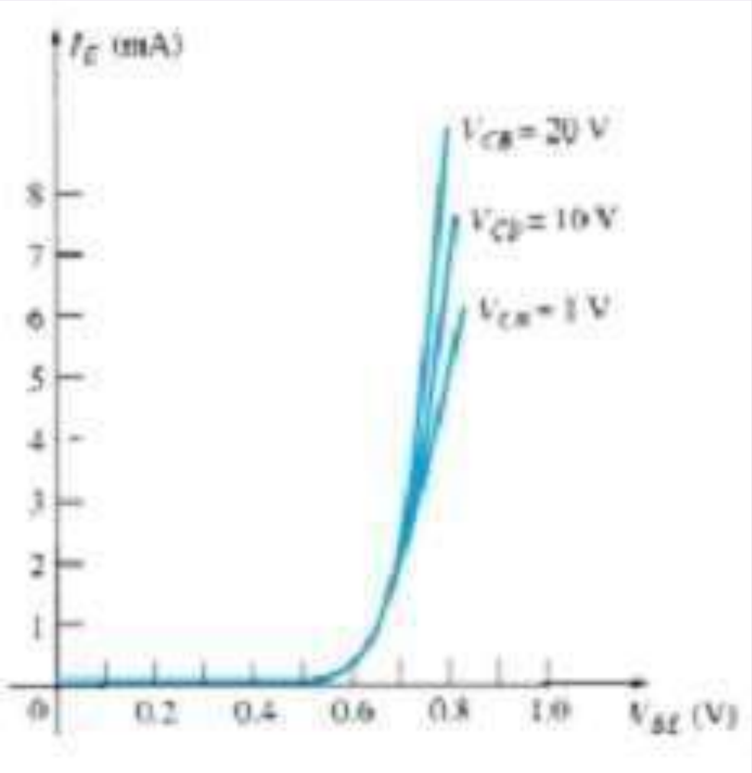
$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

Characteristics of common base configuration

- <u>Input Characteristics:</u>



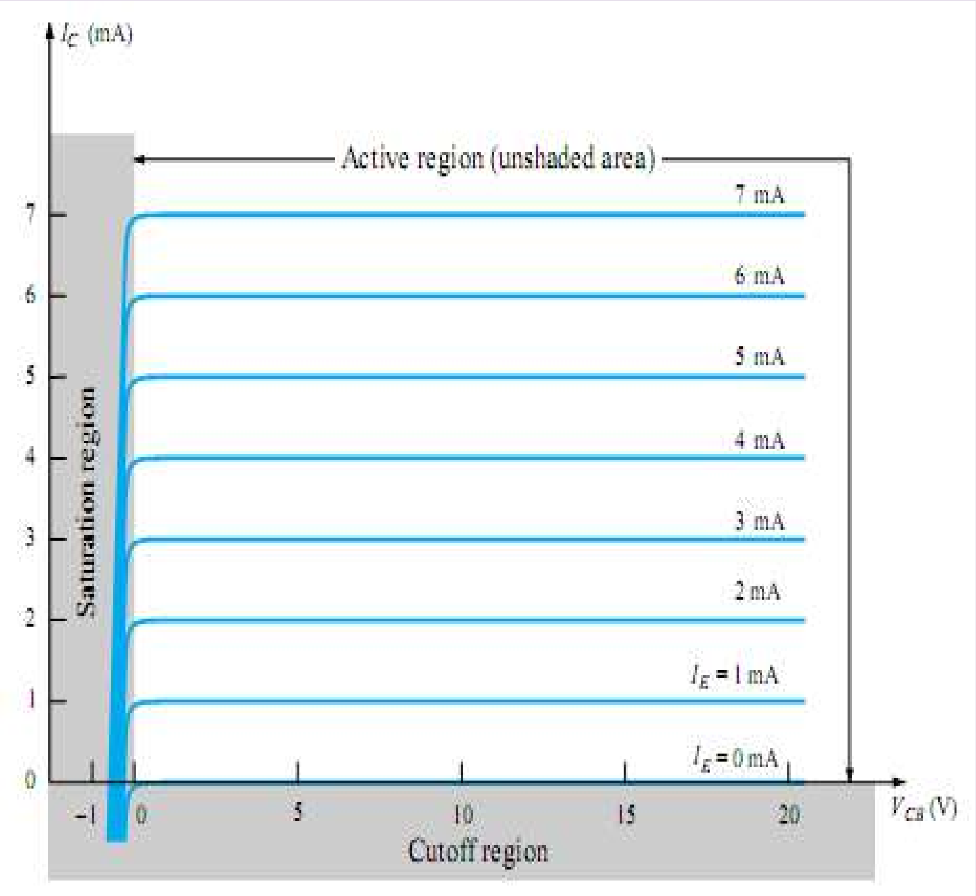
→ V_{BE} vs I_E characteristics is called input characteristics.

→ I_E increases rapidly with V_{BE}. It means input resistance is very small.

→ I_E almost independent of V_{CB}.

Characteristics of common base configuration

Output Characteristics:



→V_{Bc} vs I_c characteristics is called output characteristics.

→ I_C varies linearly with V_{Bc} ,only when V_{Bc} is very small.

→ As, V_{Bc} increases, I_C becomes constant.

Input and Output Resistance of common base conf.

- Input Resistance: The ratio of change in emitter-base voltage to the change in emitter current is called Input Resistance.

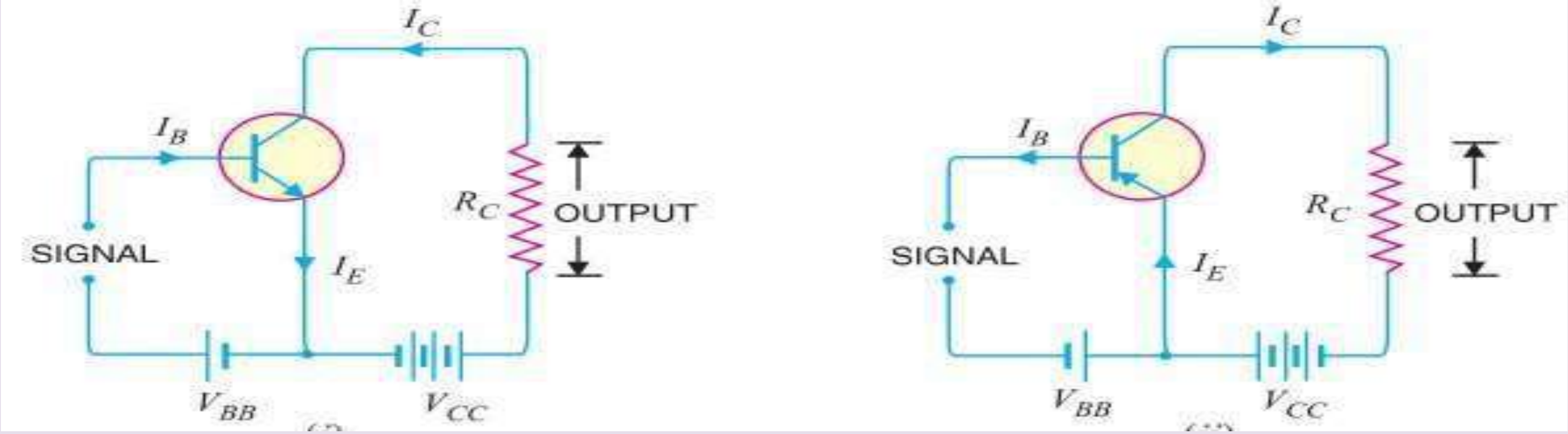
$$r_i = \frac{\Delta V_{BE}}{\Delta I_E}$$

- Output Resistance: The ratio of change in collector-base voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{BC}}{\Delta I_C}$$

Common Emitter Connection

- The common-emitter terminology is derived from the fact that the emitter is common to both the input and output sides of the configuration.



- First Figure shows common emitter npn configuration and second figure shows common emitter pnp configuration.

Common Emitter Connection

- Base Current amplification factor (β) :
- In common emitter connection input current is base current and output current is collector current.
- The ratio of change in collector current to the change in base current is known as base current amplification factor, β.

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

- Normally only 5% of emitter current flows to base, so amplification factor is greater than 20. Usually this range varies from 20 to 500.

Relation Between β and α

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

Expression for Collector Current

$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = I_B + I_C = I_B + (\alpha I_E + I_{CBO})$$

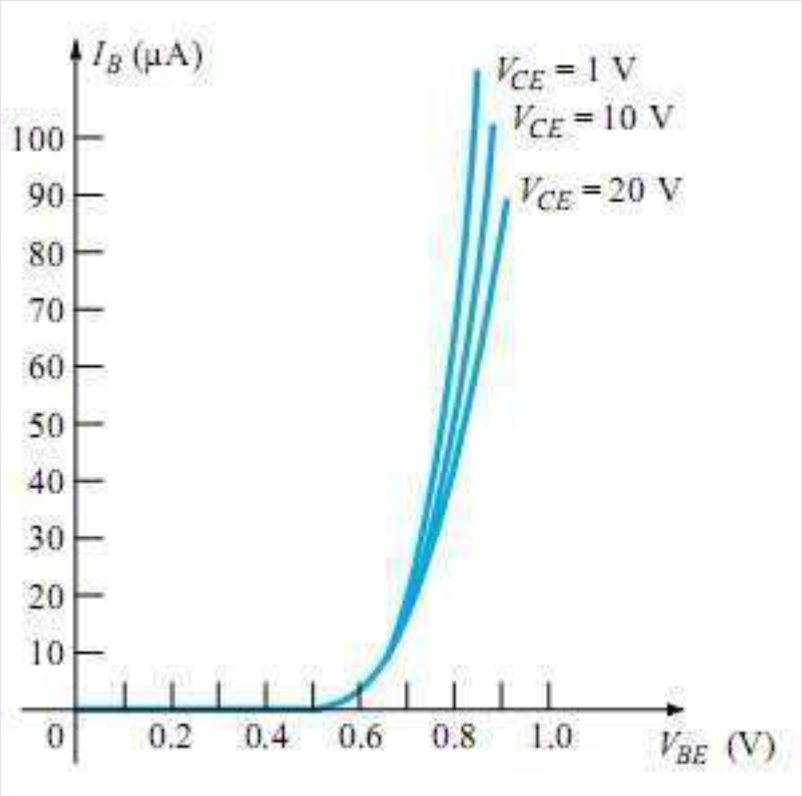
$$I_E(1 - \alpha) = I_B + I_{CBO}$$

$$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

$$I_C \; ; \; I_E = *(\beta + 1) I_B + (\beta + 1) I_{CBO}$$

Characteristics of common emitter configuration

- <u>Input Characteristics:</u>



→ V_{BE} vs I_B characteristics is called input characteristic

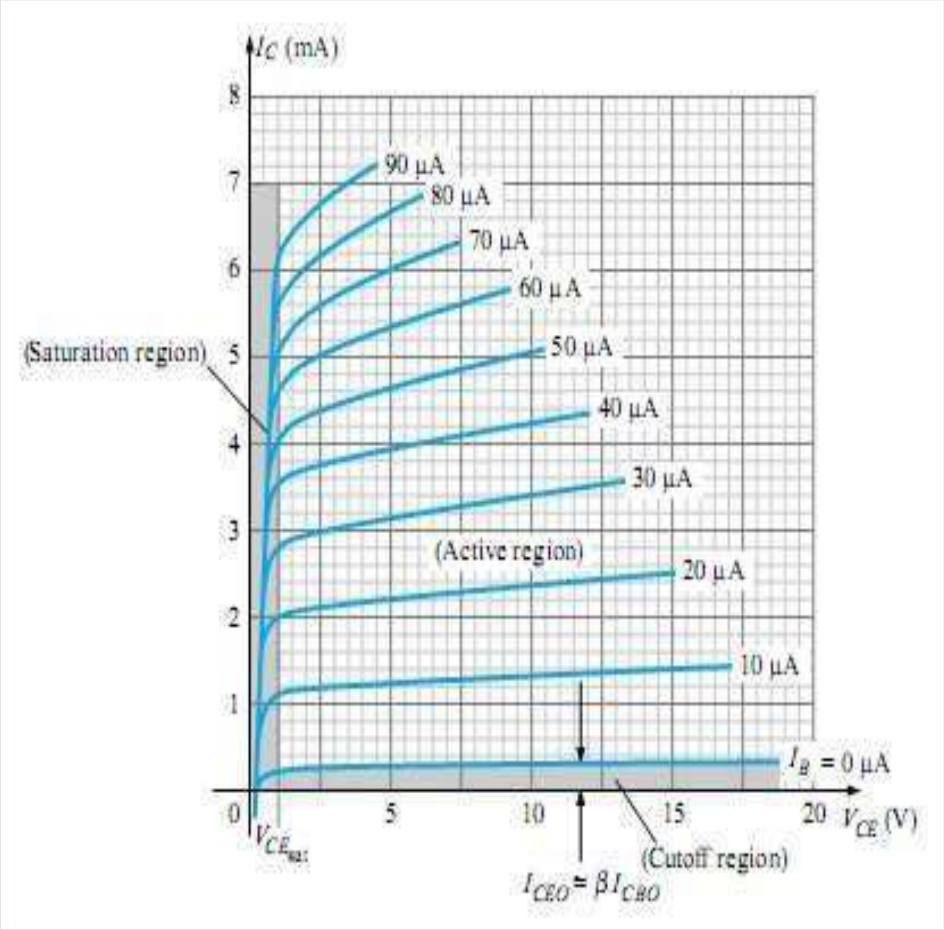
→ I_B increases rapidly with V_{BE}. It means input resistance is very small.

→ I_E almost independent of V_{CE}.

→ I_B is of the range of micro amps.

Characteristics of common emitter configuration

- Output Characteristics:



→ V_{CE} vs I_c characteristics is called output characteristics.

→ I_C varies linearly with V_{CE} ,only when V_{CE} is very small.

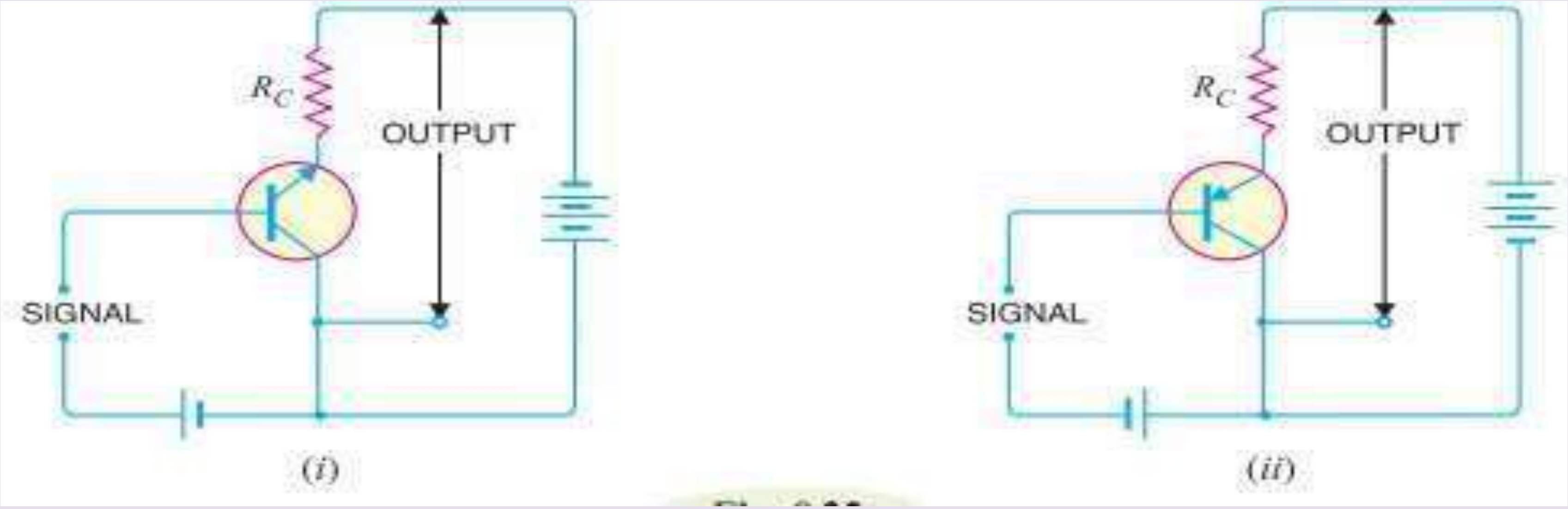
→ As, V_{CE} increases, I_C becomes constant.

Input and Output Resistance of common emitter conf.

- Input Resistance: The ratio of change in emitter-base voltage to the change in base current is called Input Resistance. $r_i = \frac{\Delta V_{BE}}{\Delta I_B}$
- Output Resistance: The ratio of change in collector-emitter voltage to the change in collector current is called Output Resistance. $r_0 = \frac{\Delta V_{CE}}{\Delta I_C}$

Common Collector Configuration

- The common-collector terminology is derived from the fact that the collector is common to both the input and output sides of the configuration.



- First Figure shows common collector npn configuration and second figure shows common collector pnp configuration.

Common Collector Configuration

- Current amplification factor :
- In common emitter connection input current is base current and output current is emitter current.
- The ratio of change in emitter current to the change in base current is known as current amplification factor in common collector configuration.

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

- This circuit provides same gain as CE configuration as $\Delta I_E \approx \Delta I_C$

Relation Between α and γ

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1-\alpha}$$

Expression for Collector Current

$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = I_B + I_C = I_B + (\alpha I_E + I_{CBO})$$

$$I_E(1-\alpha) = I_B + I_{CBO}$$

$$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

$$I_C \; ; \; I_E = *(\beta + 1) I_B + (\beta + 1) I_{CBO}$$

$$\beta = \frac{\alpha}{1-\alpha} \quad \therefore \quad \beta + 1 = \frac{\alpha}{1-\alpha} + 1 = \frac{1}{1-\alpha}$$

Comparison of Transistor Connection

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Quick Quiz (Poll 1)

The relation between β and α is ………….

a) $\beta = 1 / (1 - \alpha)$
b) $\beta = (1 - \alpha) / \alpha$
c) $\beta = \alpha / (1 - \alpha)$
d) $\beta = \alpha / (1 + \alpha)$

Quick Quiz (Poll 2)

The most commonly used transistor arrangement is …………… arrangement

a) common emitter
b) common base
c) common collector
d) none of the above

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 35

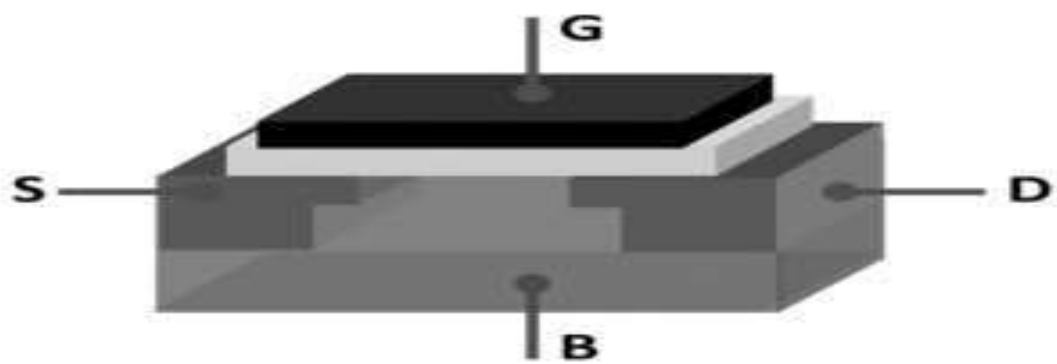
Prepared By:
Krishan Arora
Assistant Professor and Head

What is MOSFET?

- The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device that is widely used for switching purposes and for the amplification of electronic signals in electronic devices. A MOSFET is either a core or integrated circuit where it is designed and fabricated in a single chip because the device is available in very small sizes.

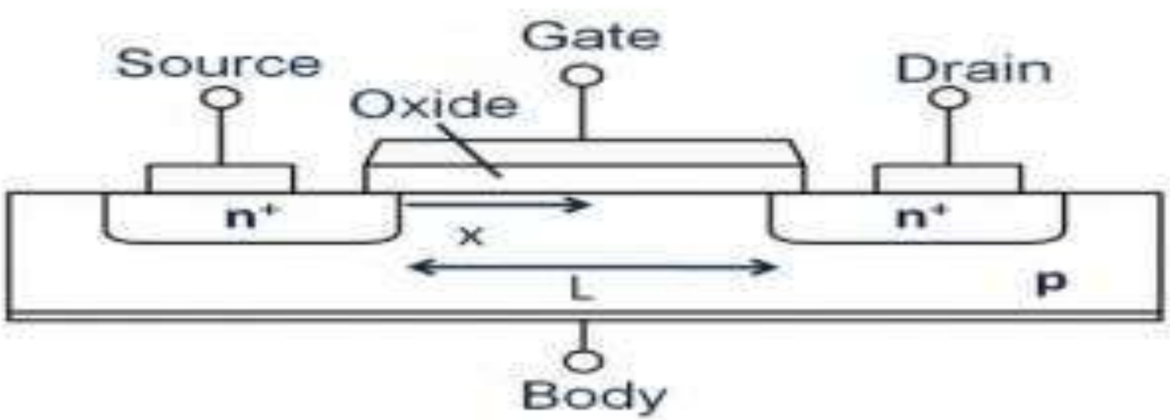
Construction

- A MOSFET is a four-terminal device having source(S), gate (G), drain (D) and body (B) terminals. In general, The body of the MOSFET is in connection with the source terminal thus forming a three-terminal device such as a field-effect transistor. MOSFET is generally considered as a transistor and employed in both the analog and digital circuits. This is the basic **introduction to MOSFET**. And the general structure of this device is as below :



MOSFET

- From the above **MOSFET structure**, the functionality of MOSFET depends on the electrical variations happening in the channel width along with the flow of carriers (either holes or electrons). The charge carriers enter into the channel through the source terminal and exit via the drain.
- The width of the channel is controlled by the voltage on an electrode which is called the gate and it is located in between the source and the drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity that exists in the device is the crucial section where the entire operation is across this.



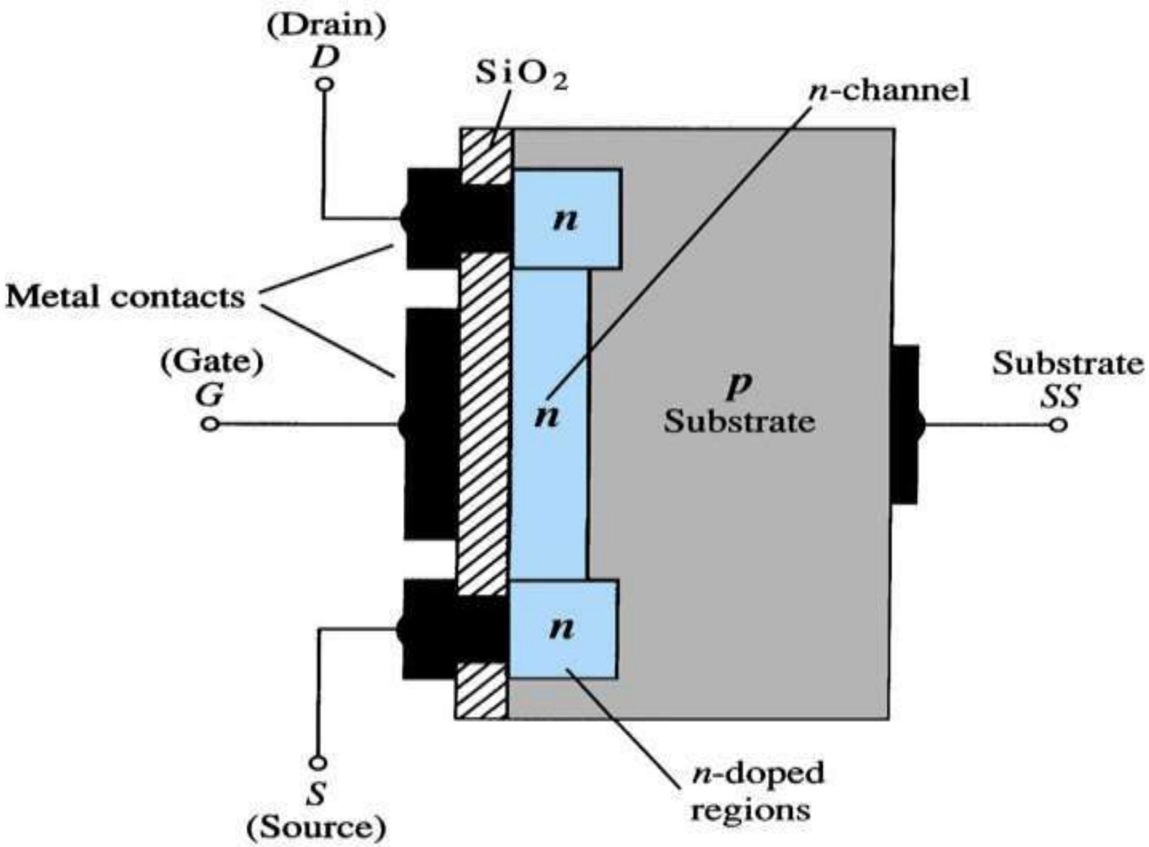
MOSFET With Terminals

- A MOSFET can function in two ways

❖ Depletion Mode

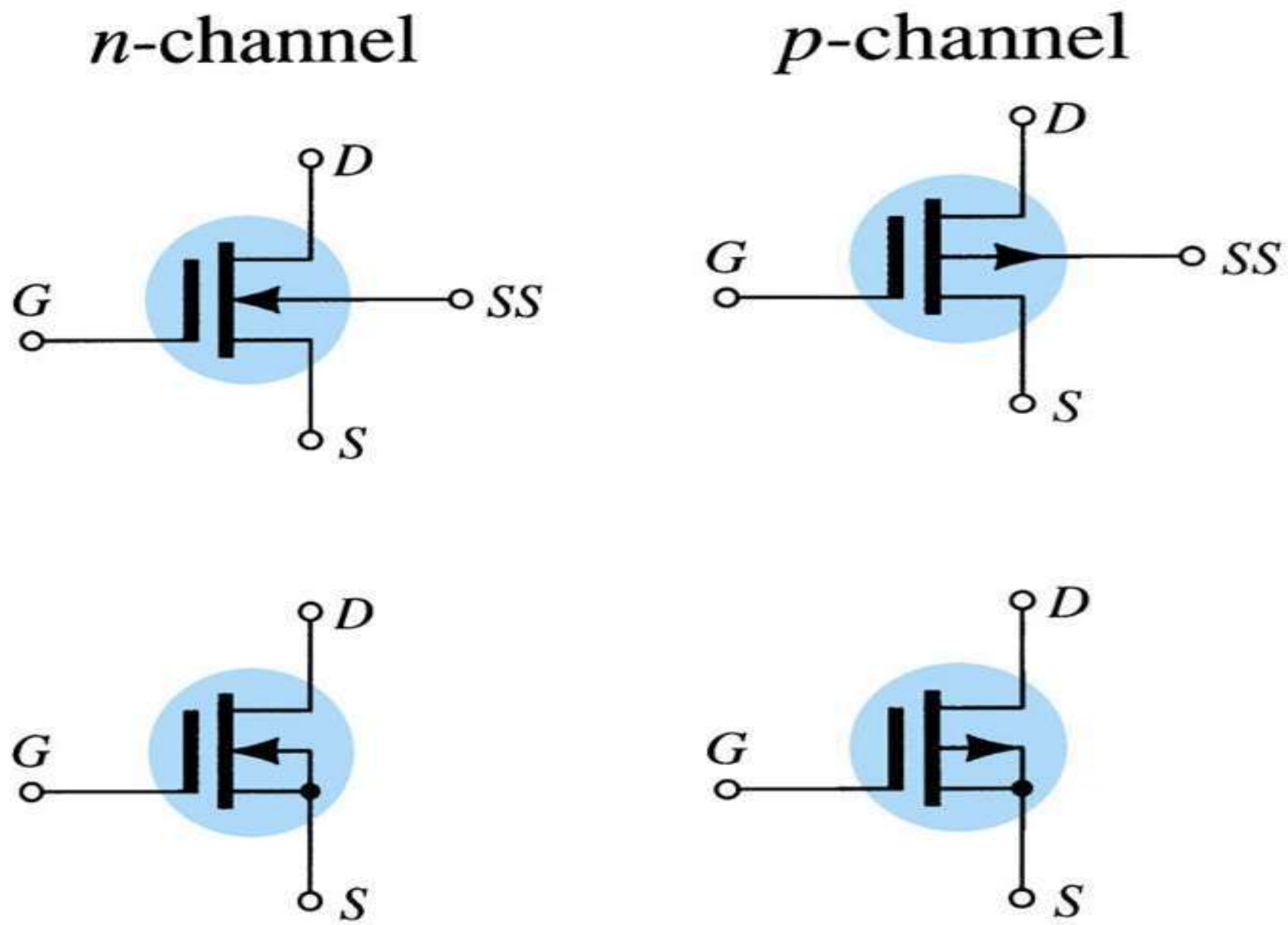
❖ Enhancement Mode

Depletion Mode MOSFET Construction



The Drain (D) and Source (S) leads connect to the to n-doped regions
These N-doped regions are connected via an n-channel
This n-channel is connected to the Gate (G) via a thin insulating layer of SiO_2
The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS

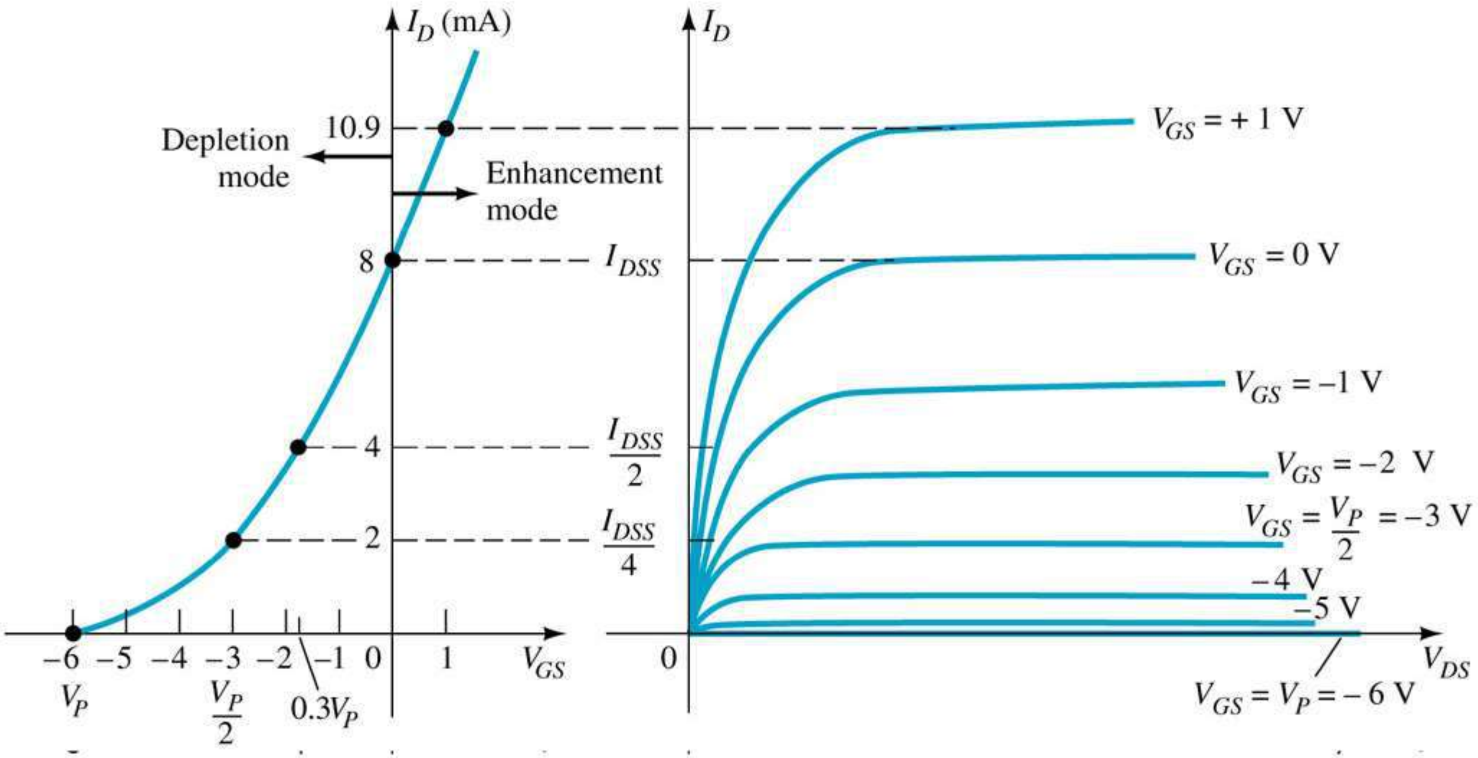
D-MOSFET Symbols



(a)

(b)

D-MOSFET Depletion Mode Operation



The transfer characteristics are similar to the JFET

In Depletion Mode operation:

When $V_{GS} = 0V$, $I_D = I_{DSS}$

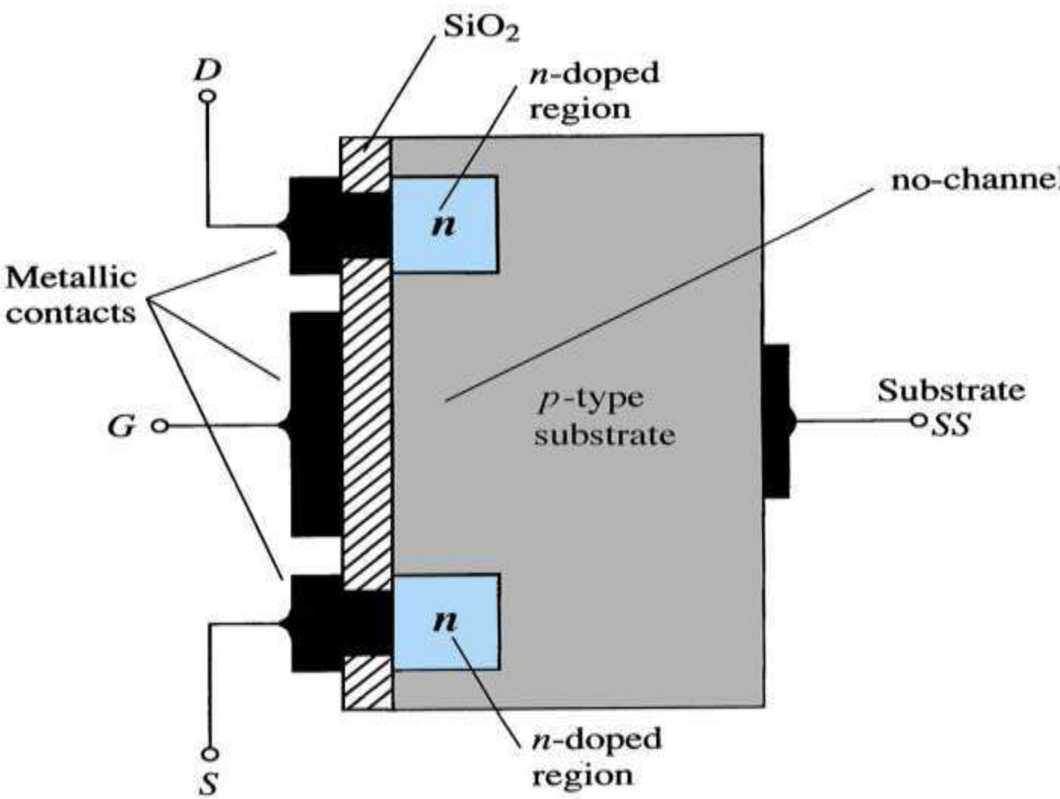
When $V_{GS} < 0V$, $I_D < I_{DSS}$

When $V_{GS} > 0V$, $I_D > I_{DSS}$

The formula used to plot the Transfer Curve, is:

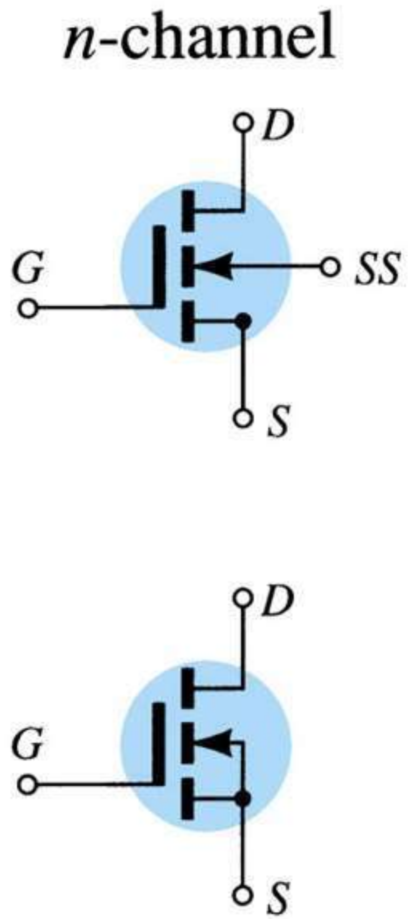
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Enhancement Mode MOSFET Construction



The Drain (D) and Source (S) connect to the to n-doped regions
These n-doped regions are not connected via an n-channel without an external voltage
The Gate (G) connects to the p-doped substrate via a thin insulating layer of SiO_2
The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS

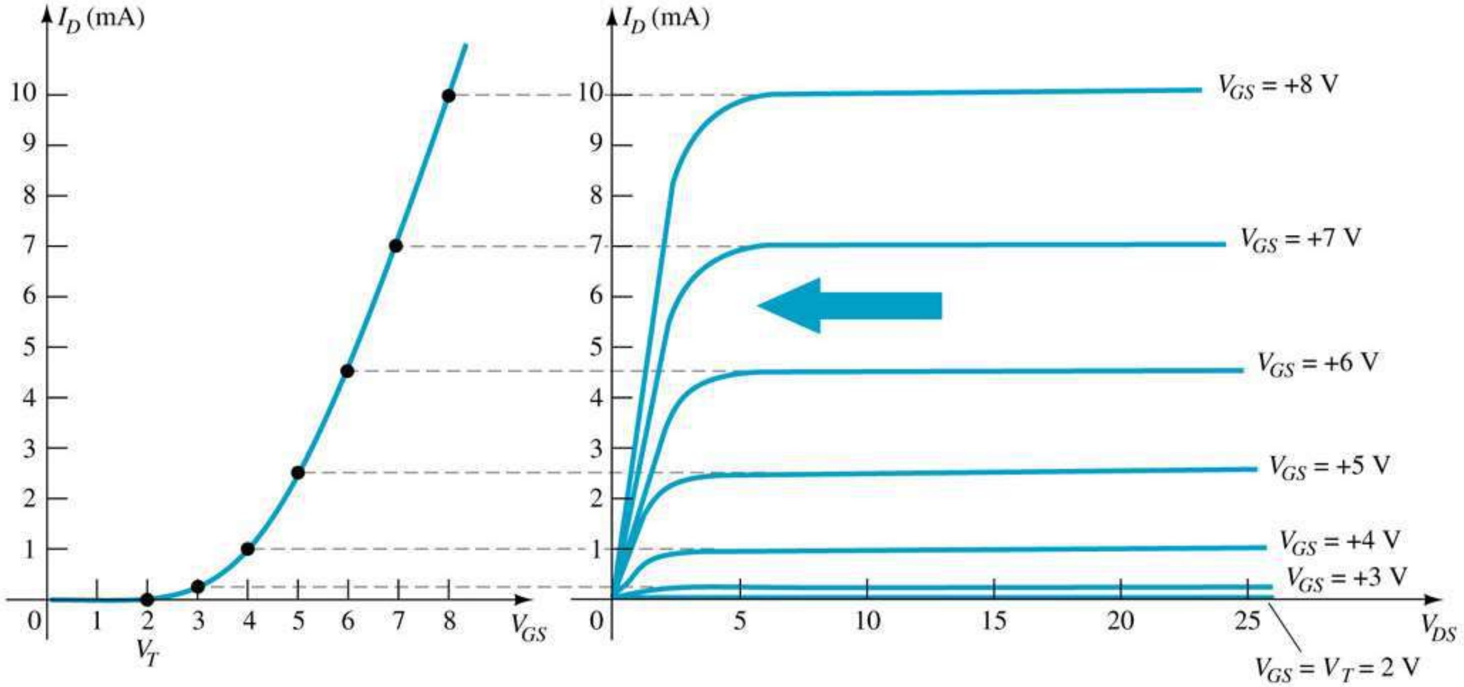
E-MOSFET Symbols



(a)

Basic Operation

The Enhancement mode MOSFET only operates in the enhancement mode.



V_{GS} is always positive

$I_{DSS} = 0$ when $V_{GS} < V_T$

As V_{GS} increases above V_T, I_D increases

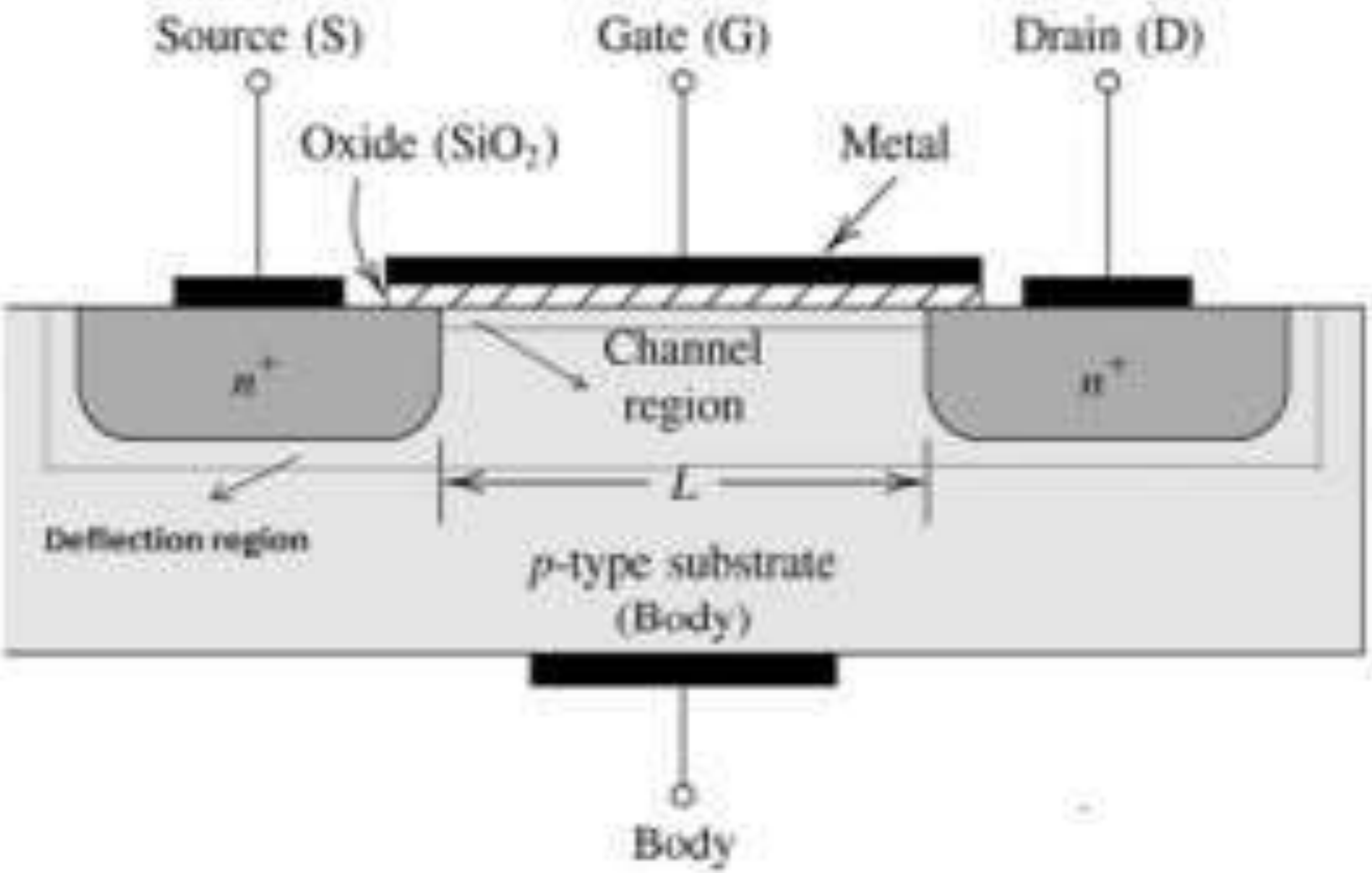
If V_{GS} is kept constant and V_{DS} is increased, then I_D saturates (I_{DSS})

The saturation level, V_{DSsat} is reached.

Working Principle of MOSFET

- The main principle of the MOSFET device is to be able to control the voltage and current flow between the source and drain terminals. It works almost like a switch and the functionality of the device is based on the MOS capacitor. The MOS capacitor is the main part of MOSFET.
- The semiconductor surface at the below oxide layer which is located between the source and drain terminal can be inverted from p-type to n-type by the application of either a positive or negative gate voltages respectively. When we apply a repulsive force for the positive gate voltage, then the holes present beneath the oxide layer are pushed downward with the substrate.

- The depletion region populated by the bound negative charges which are associated with the acceptor atoms. When electrons are reached, a channel is developed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of the positive voltage, if we apply a negative voltage, a hole channel will be formed under the oxide layer.



MOSFET Block Diagram

MOSFET Regions of Operation

- **Cut-off Region –** It is the region where the device will be in the OFF condition and there zero amount of current flow through it. Here, the device functions as a basic switch and is so employed as when they are necessary to operate as electrical switches.
- **Saturation Region –** In this region, the devices will have their drain to source current value as constant without considering the enhancement in the voltage across the drain to source. This happens only once when the voltage across the drain to source terminal increases more than the pinch-off voltage value. In this scenario, the device functions as a closed switch where a saturated level of current across the drain to source terminals flows. Due to this, the saturation region is selected when the devices are supposed to perform switching.
- **Linear/Ohmic Region –** It is the region where the current across the drain to source terminal enhances with the increment in the voltage across the drain to source path. When the MOSFET devices function in this linear region, they perform amplifier functionality.

Advantages

Few of the advantages are :

- It generates enhanced efficiency even when functioning at minimal voltage levels
- There is no presence of gate current this creates more input impedance which further provides increased switching speed for the device
- These devices can function at minimal power levels and uses minimal current

Disadvantages

Few of the disadvantages are :

- When these devices are functioned at overload voltage levels, it creates instability of the device
- As because the devices have a thin oxide layer, this may create damage to the device when stimulated by the electrostatic charges

Applications

The applications of MOSFET are

- Amplifiers made of MOSFET are extremely employed in extensive frequency applications
- The regulation for DC motors are provided by these devices
- As because these have enhanced switching speeds, it acts as perfect for the construction of chopper amplifiers
- Functions as a passive component for various electronic elements.

Quick Quiz (Poll 1)

- Which of the following terminals does not belong to the MOSFET?

  a) Drain
  b) Gate
  c) Base
  d) Source

Quick Quiz (Poll 2)

- The MOSFET combines the areas of ________ & __________

a) field effect & MOS technology
b) semiconductor & TTL
c) mos technology & CMOS technology
d) none of the mentioned

UNIT-IV

Fundamentals of semiconductor devices and digital circuits

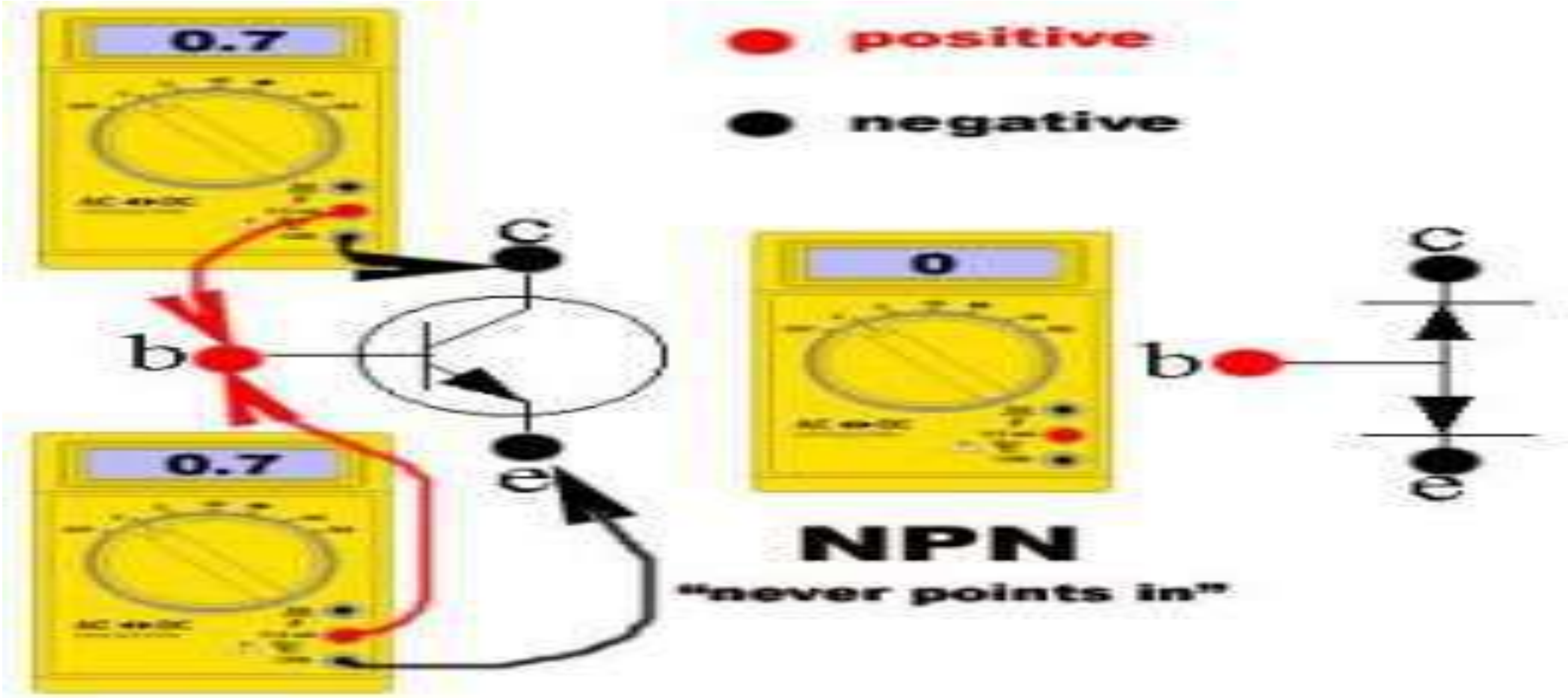
Lecture 36

Prepared By:
Krishan Arora
Assistant Professor and Head

Procedure of a Transistor Tester Using a Digital Multimeter

- A digital multimeter is used to test the base to emitter and base to collector PN junction of the BJT. By using this test, you can also identify the polarity of an unknown device. PNP and NPN transistor can be checked using the digital multimeter.
- The digital multimeter consists of two leads: black and red. Connect the red (positive) lead to the base terminal of the PNP transistor, and the black (negative) lead to the emitter terminal of the transistor. The voltage of a healthy transistor should be 0.7V, and the measurement across the collector should read 0.0V. If the measured voltage is around 1.8V, then the transistor will be dead.

- Similarly, connect the black lead (negative) to the base terminal of the NPN transistor, and red lead (positive) to the emitter terminal of the transistor. The voltage of a healthy transistor should be 0.7V, and the measurement across the collector should read 0.0V. If the measured voltage is around 1.8V, then the transistor will be dead.



Integrated circuits

- An **integrated circuit**, or IC, is small chip that can function as an amplifier, oscillator, timer, microprocessor, or even computer memory. An IC is a small wafer, usually made of silicon, that can hold anywhere from hundreds to millions of transistors, resistors, and capacitors.
- **General types of integrated circuits(ICs) include the following:**
- Logic Circuits. These ICs are designed using logic gates-that work with binary input and output (0 or 1). ...
- Comparators. X. ...
- Switching ICs. ...
- Audio amplifiers. ...
- Operational amplifiers. ...
- Timer ICs.

Why are integrated circuits are important?

- Basically and integrated circuit as the name implies, is one (or many) circuit(s) within a circuit. So the most important thing of the IC is the form factor. Because we can include Millions and Billions of transistors into one Germanium and silicon chip, we can now reduce the size of our electronic devices.

Advantages of IC

- The entire physical size of IC is extremely small than that of discrete circuit.
- The weight of an IC is very less as compared entire discrete circuits.
- It’s more reliable.
- Because of their smaller size it has lower power consumption.
- It can easily replace but it can hardly repair, in case of failure.
- Temperature differences between components of a circuit are small.
- It has suitable for small signal operation.
- The reduction in power consumption is achieved due to extremely small size of IC.

Disadvantages of IC

- Coils or indicators cannot be fabricated.
- It can be handle only limited amount of power.
- High grade P-N-P assembly is not possible.
- It is difficult to be achieved low temperature coefficient.
- The power dissipation is limited to 10 watts.
- Low noise and high voltage operation are not easily obtained.
- Inductors and transformers are needed connecting to exterior to the semiconductor chip as it is not possible to fabricate inductor and transformers on the semiconductor chip surface.
- Inductors cannot be fabricated directly.
- Low noise and high voltage operation are not easily obtained.

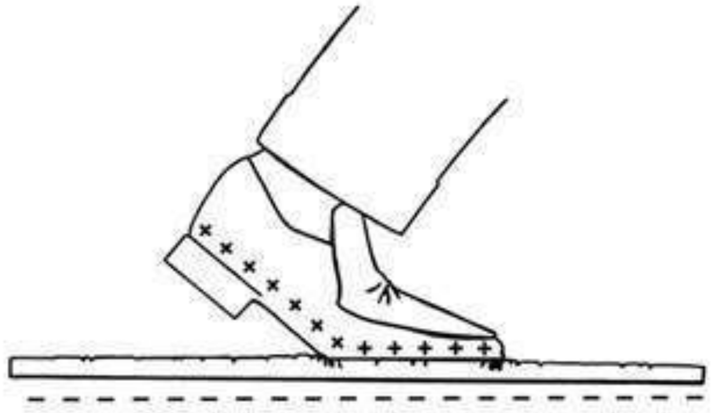
ESD

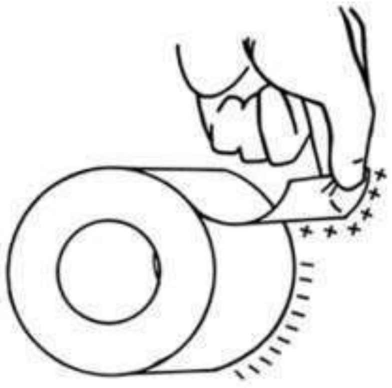
- Electrostatic discharge (**ESD**) is the sudden flow of electricity between two electrically charged objects caused by contact, an electrical short, or dielectric breakdown. A buildup of static electricity can be caused by tribocharging or by electrostatic induction.
- ESD (electrostatic discharge) is defined as the transfer of electric charge, which takes place when two objects which have been charged to different electric potentials are brought in contact with one another or when two objects which have different electric potentials due to static induction are brought in contact .

ESD Definition

ESD – Electrostatic Discharge: The transfer of an electrostatic charge between bodies at different electrical potentials.

- Also referred to as static electricity
- **Electrostatic charge is most commonly created by the contact and separation of two materials which results in Tribocharging**





Sources of ESD

The following items are examples of materials that generate and hold electrostatic charge.

- Vinyl binders
- Equipment covers
- Plastic document holders/sheet protectors
- Post-It™ notes
- Plastic pens
- Bubble wrap
- Plastic housings on equipment
- Paper, schematics, etc.
- Plastic work travelers
- Plastic spray bottles
- Personal items
  - –Purses
  - –Sweaters/jackets
  - –Insulated lunch totes
  - –Combs/brushes
  - –Lotion bottles

Common Causes of ESD

- Opening a common plastic bag
- Removing adhesive tape from a roll or container
- Walking across a floor and grabbing the door knob
- Transporting computer boards or components around in their trays on non- ESD carts
- Sliding circuit boards on a work bench

Why is ESD Important?

Electrostatic Discharge (ESD) can damage sensitive electronic devices, resulting in:

- Higher manufacturing costs
  - Rework
  - Repair
  - Scrap
- Lower production yields
- Unhappy customers
  - Shorter product life
  - Reduce product reliability

Estimates of actual cost of ESD damage to the electronics industry = $$$ Billions annually

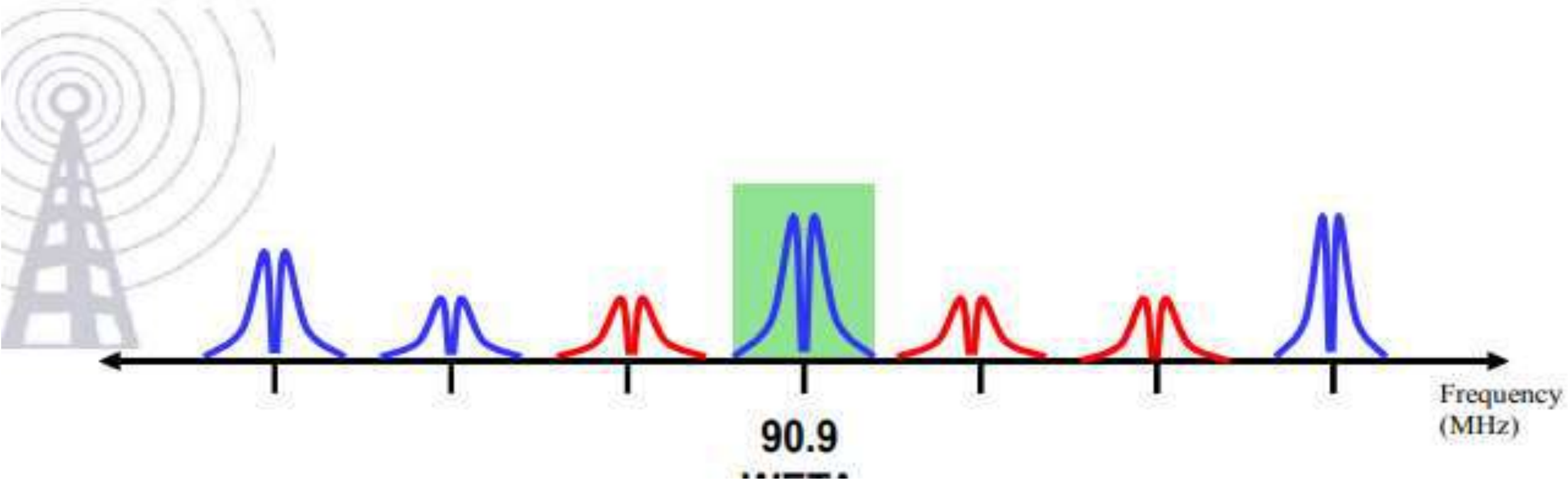
UNIT - V

Tuning a Radio

- Consider tuning in an FM radio station.
- What allows your radio to isolate one station from all of the adjacent stations?

Filters

- A filter is a frequency-selective circuit.
- Filters are designed to pass some frequencies and reject others.



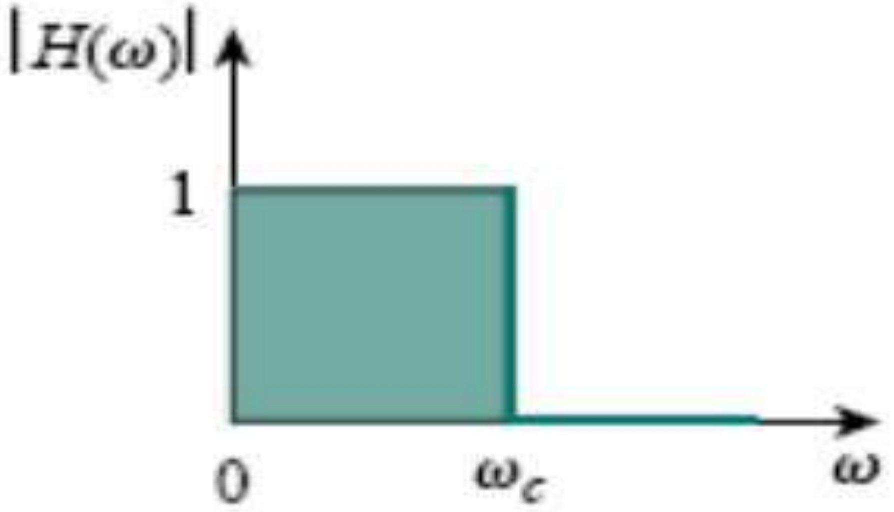
Active and Passive Filters

- Filter circuits depend on the fact that the impedance of capacitors and inductors is a function of frequency

- There are numerous ways to construct filters, but there are two broad categories of filters:
  - Passive filters are composed of only passive components (resistors, capacitors, inductors) and do not provide amplification.
  - Active filters typically employ RC networks and amplifiers (opamps) with feedback and offer a number of advantages.

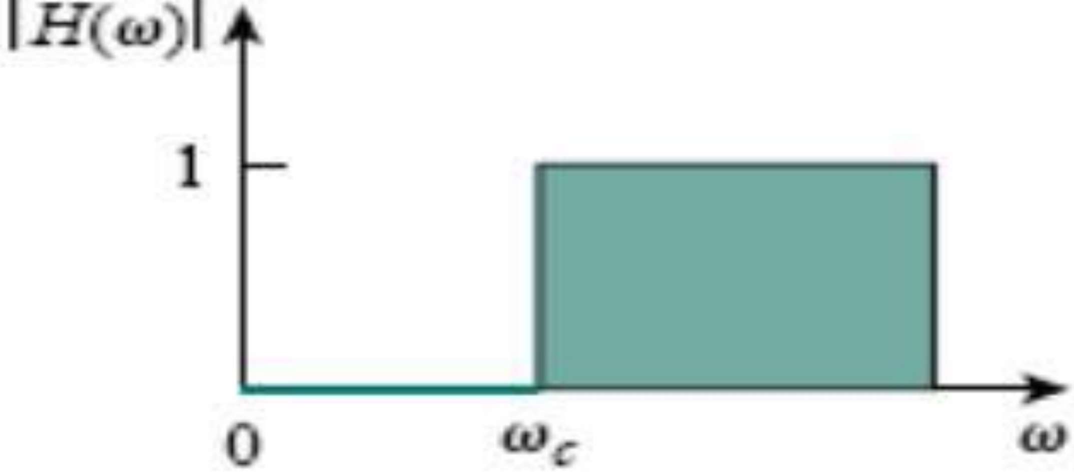
Passive Filters

- There are four basic kinds of filters:
  - **Low-pass filter** - Passes frequencies below a critical frequency, called the *cutoff frequency*, and attenuates those above.



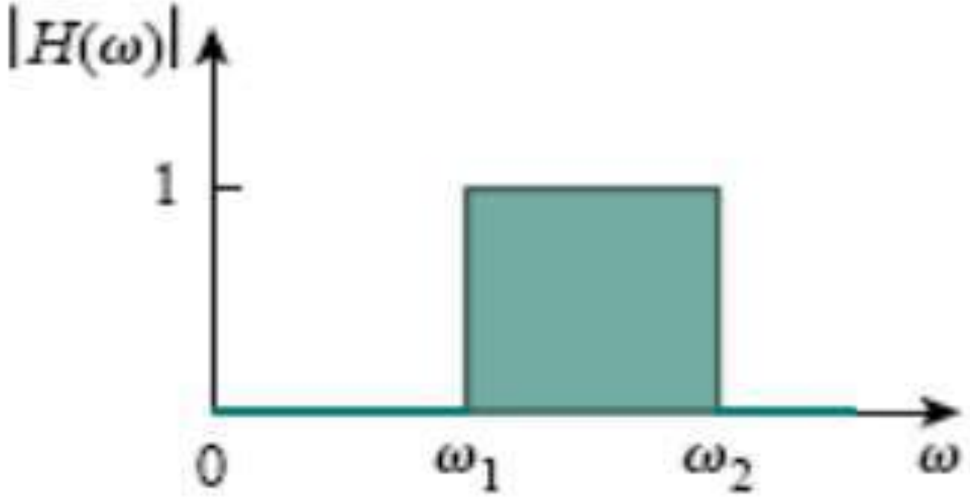
Passive Filters

- There are four basic kinds of filters:
  - **High-pass filter** - Passes frequencies above the critical frequency but rejects those below.



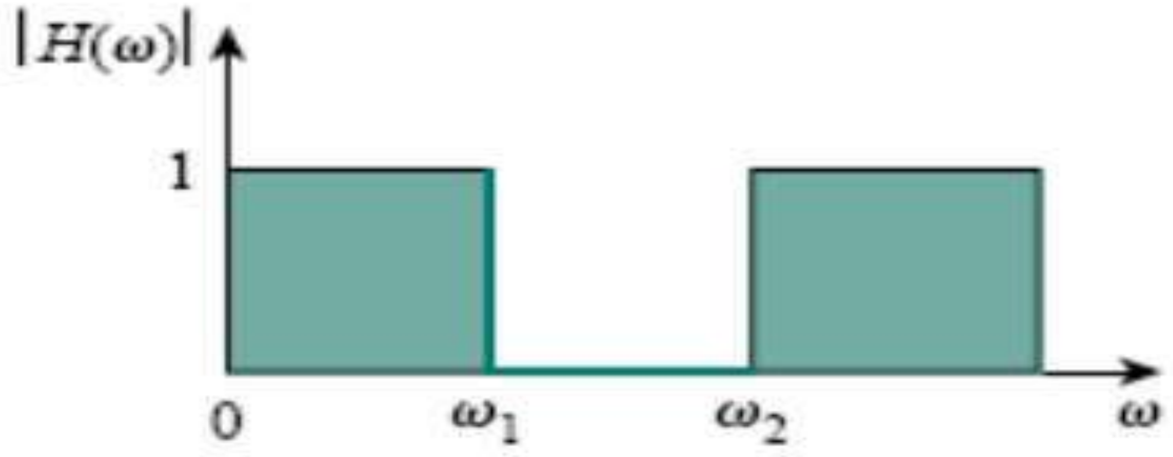
Passive Filters

- There are four basic kinds of filters:
  - **Bandpass filter** - Passes only frequencies in a narrow range between upper and lower cutoff frequencies.

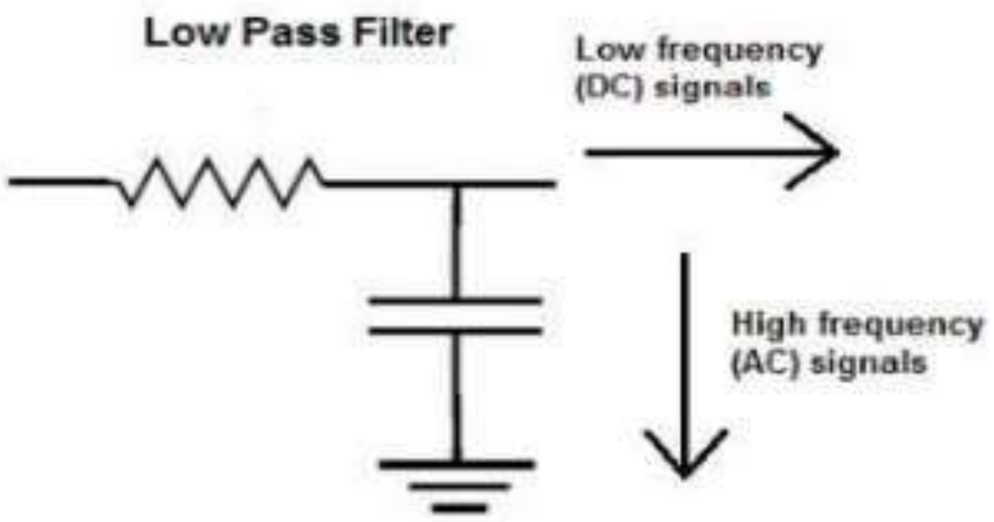


Passive Filters

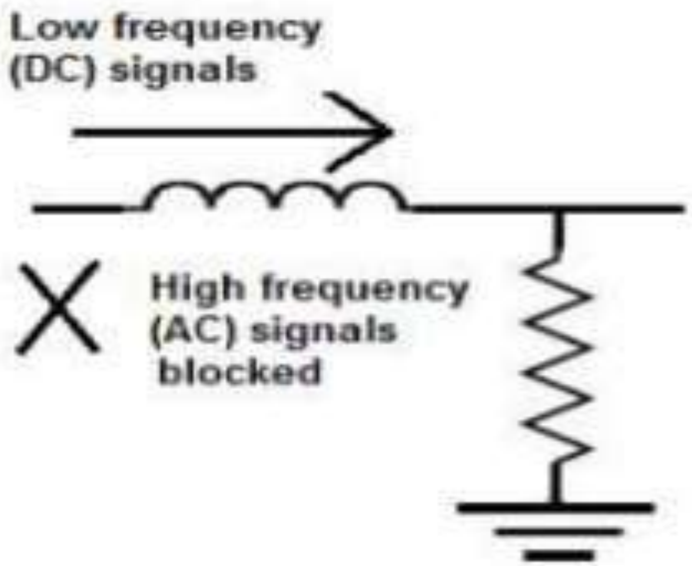
- There are four basic kinds of filters:
  - **Band-reject filter** - Rejects or stops frequencies in a narrow range but passes others.



Low Pass Filters



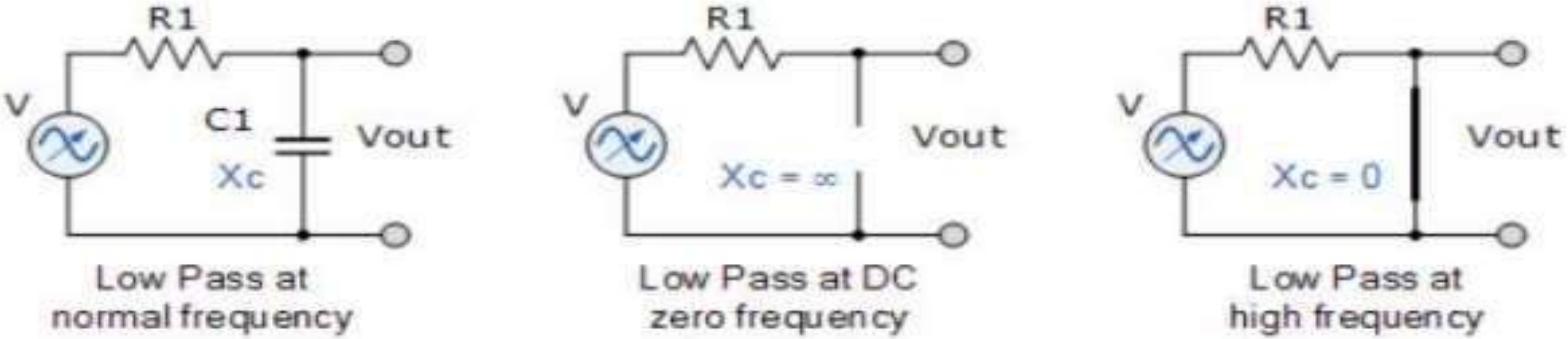
RC low-pass filter



RL low-pass filter

- RC low pass filter works based on the principle of *capacitive reactance*, while RL low pass filter works on the principle of *inductive reactance*

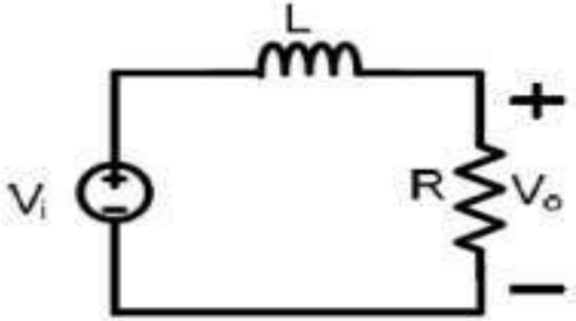
Capacitive Reactance



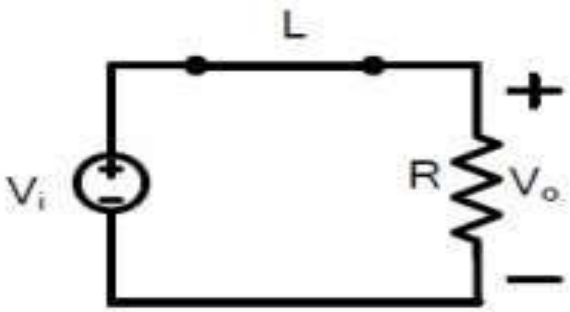
- *Capacitive Reactance (Xc)* varies with the applied frequency.
  - As the frequency applied to the capacitor increases, its effect is to decrease its reactance (measured in ohms).
  - Likewise as the frequency across the capacitor decreases its reactance value increases.

$$(Xc = {}^{1}/_{2\pi f c}) \text{ ohms}$$

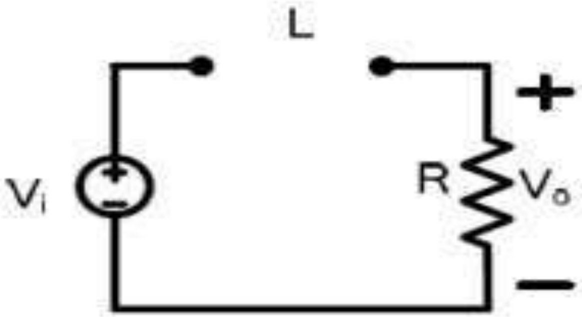
Inductive Reactance



RL low-pass filter



RL low-pass filter at low frequencies $\omega = 0$

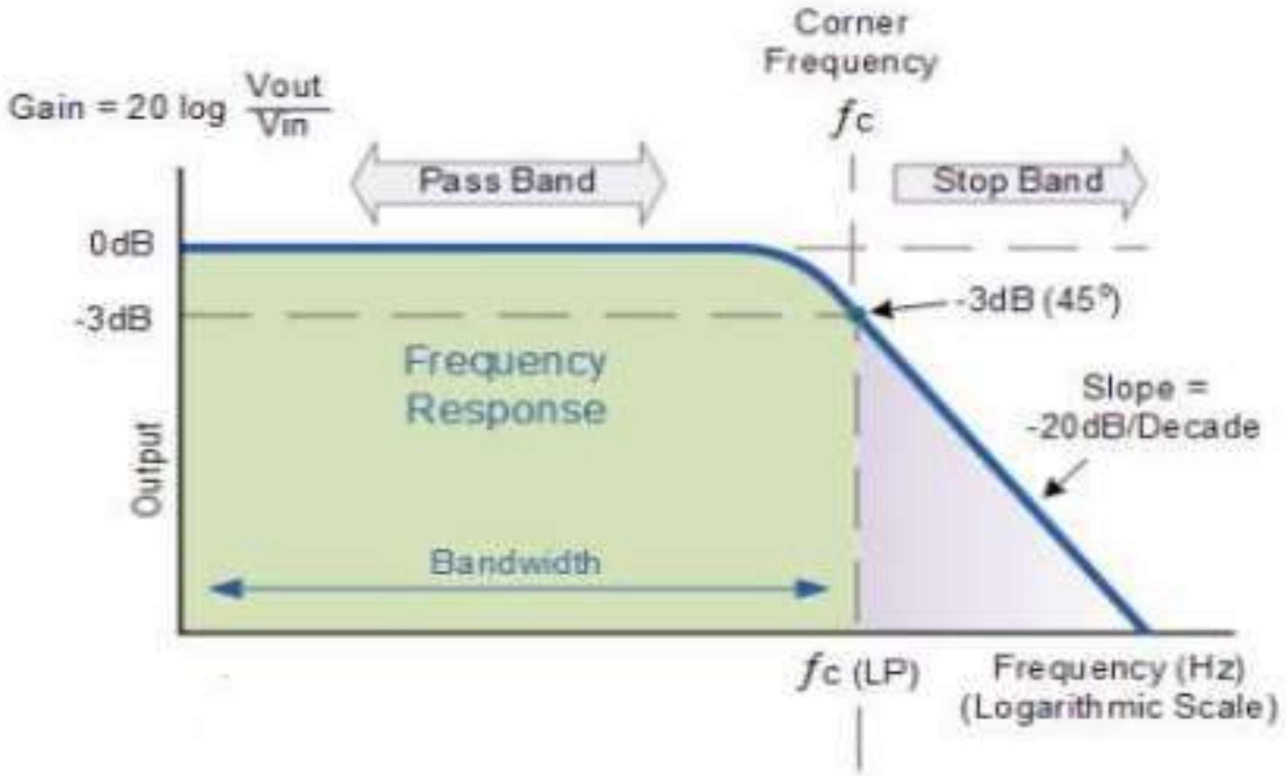


RL low-pass filter at high frequencies $\omega = \infty$

- *Inductive Reactance (X_L)* varies with the applied frequency.
  - To high frequency signals, inductors offer high resistance thus blocks high frequencies
  - As frequencies decrease, the inductor offers low resistance so low frequencies pass

$$X_L = 2\pi f L \text{ ohms}$$

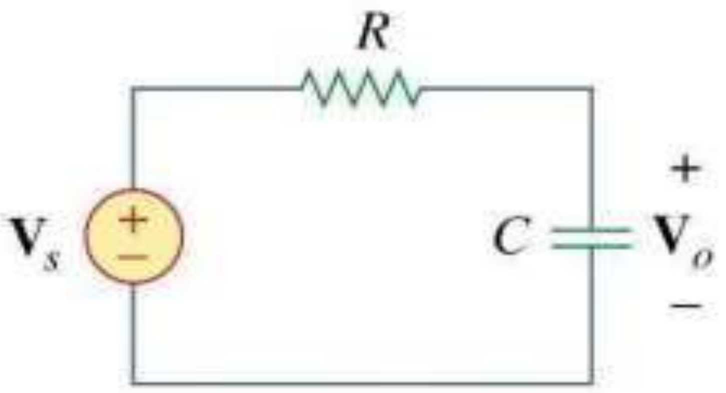
RC Low-Pass Filter – Frequency Response



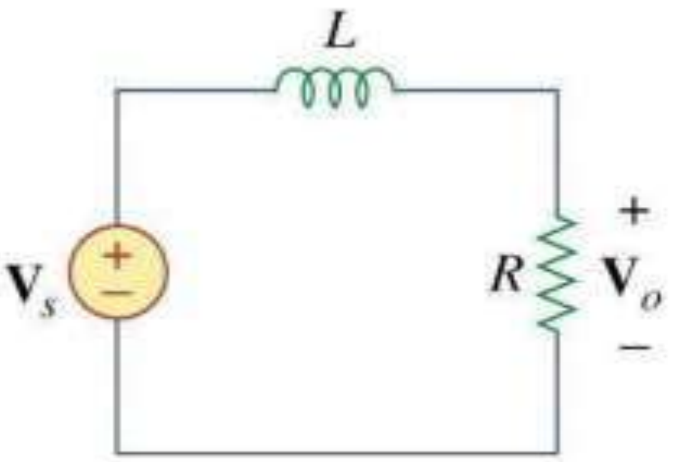
- The cutoff frequency is the frequency at which capacitive reactance and resistance are equal (R = Xc), therefore $f_c = {}^{1}/_{2\pi Rc}$
- At cutoff, the output voltage amplitude is 70.7% of the input value or –3 dB (20 log (Vout/Vin))

Filters

Notice the placement of the elements in RC and RL low-pass filters.



RC low-pass filter

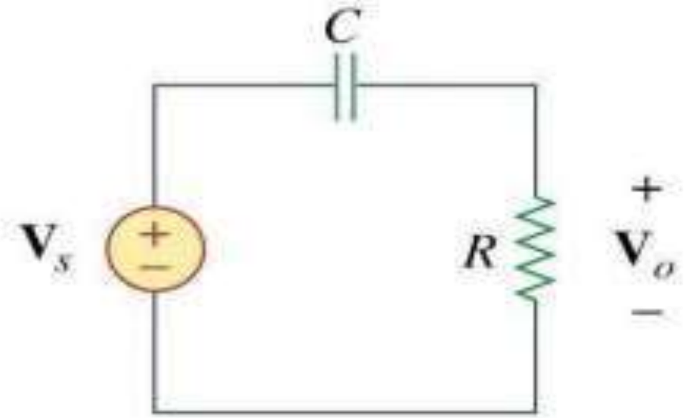


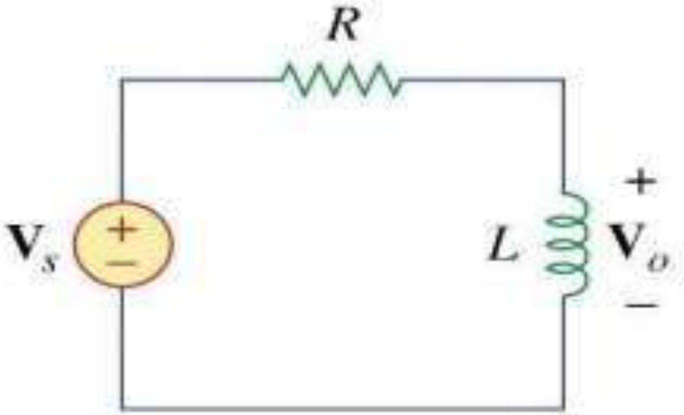
RL low-pass filter

What would result if the position of the elements were switched in each circuit?

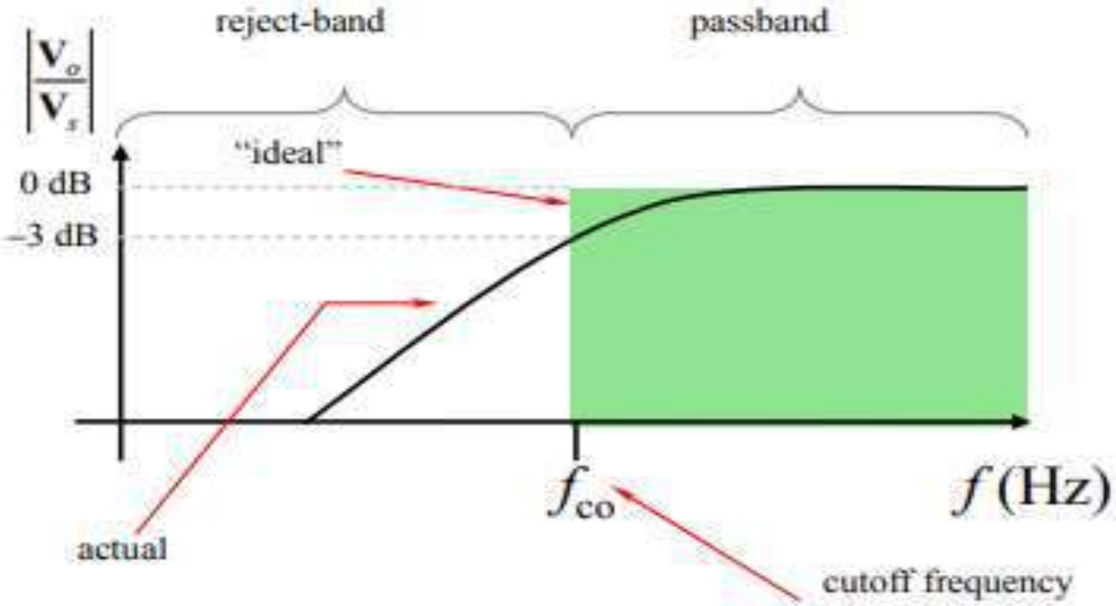
RC and RL High-Pass Filter Circuits

Switching elements results in a **High-Pass Filter**.





$$f_{co} = \frac{1}{2\pi RC} \quad \text{or} \quad f_{co} = \frac{R}{2\pi L} \quad [\text{Hz}]$$



Example

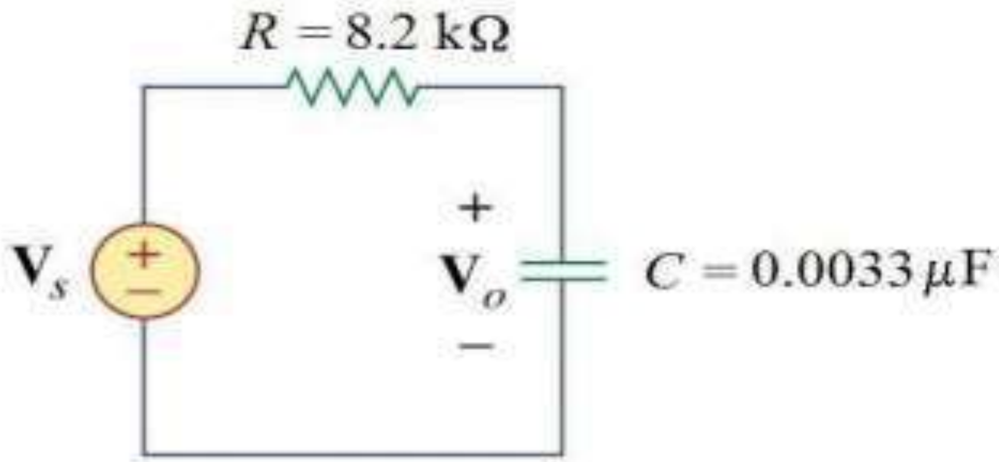
What is the cutoff frequency for this filter?

Given:

$$R = 8.2k\Omega$$
$$C = 0.0033\mu F$$

$$\omega_{co} = \frac{1}{RC}$$

or $$\boxed{f_{co} = \frac{1}{2\pi RC}} \quad [\text{Hz}]$$

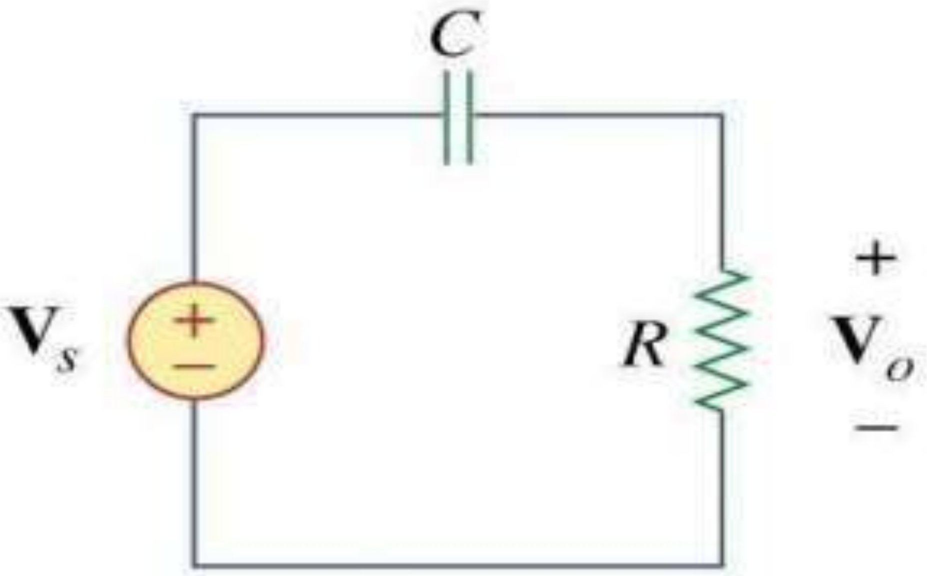


$$f_{co} = 5.88 \text{ kHz}$$

Example

What resistor value R will produce a cutoff frequency of 3.4 kHz with a 0.047 mF capacitor? Is this a high-pass or low-pass filter?

This is a High-Pass Filter



$$f_{co} = \frac{1}{2\pi RC} \quad [\text{Hz}]$$

$$\Rightarrow \text{R} = \frac{1}{2\pi C f_{co}}$$

$$R = 1004\,\Omega$$

Quick Quiz (Poll 1)

- What is a filter?

a) Frequency selective circuit
b) Amplitude selective circuit
c) Frequency damping circuit
d) Amplitude damping circuit

Quick Quiz (Poll 2)

- What are filters created by using resistors and capacitors or inductors and capacitors called?

  a) Active filters
  b) Passive filters
  c) Continuous filters
  d) Differential filters

Tutorial 9

Example 1

- Simplify each Boolean expression

$$A(A+\bar{A})+B$$

Explanation

- $A(A+\bar{A})+B$

$= AA+A\bar{A}+B$ by the distributive law

$= A+0+B$ because $AA = A$ and $A\bar{A} = 0$

$= A+B$ because A + 0 = A

Example 2

Simplify each Boolean expression

$(A+B)(\overline{A}+B)\overline{B}$

Explanation

- $(A+B)(\overline{A}+B)\overline{B}$

$= (A+B)(\overline{A}\overline{B}+B\overline{B})$ by the distributive law

$= (A+B)(\overline{A}\overline{B}+0)$ because $B\overline{B} = 0$

$= (A+B)(\overline{A}\overline{B})$ because $\overline{A}\overline{B}+0 = \overline{A}\overline{B}$

$= A\overline{A}\overline{B} + B\overline{A}\overline{B}$ by the distributive law

$= \overline{B}0 + \overline{A}0$ because $A\overline{A} = 0$ and $B\overline{B} = 0$

$= 0$ because 0 ANDed with anything is 0

Example 3

- Simplify each Boolean expression

(A + B)(A + C)

Explanation

(A + B)(A + C)	
= AA + AC + AB + BC	Distributive law
= A + AC + AB + BC	AA = A
= A(1 + C) + AB + BC	1 + C = 1
= A. 1 + AB + BC	Factoring (distributive law)
= A(1 + B) + BC	1 + B = 1
= A. 1 + BC	A . 1 = A
= A + BC	

Example 4

- Simplify the following expression

$$\overline{A(\overline{B}\,\overline{C} + BC)}$$

Explanation

- Simplification

$$\overline{\mathbf{A}(\overline{\mathbf{B}}\,\overline{\mathbf{C}} + \mathbf{BC})} = \overline{\mathbf{A}} + \overline{(\overline{\mathbf{B}}\,\overline{\mathbf{C}} + \mathbf{BC})}$$

$$= \overline{\mathbf{A}} + (\overline{\overline{\mathbf{B}}\,\overline{\mathbf{C}}})(\overline{\mathbf{BC}})$$

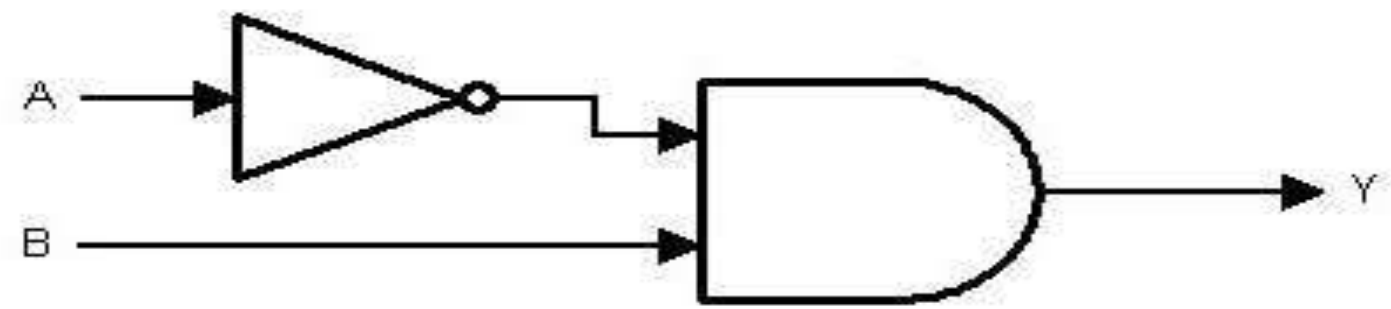
$$= \overline{\mathbf{A}} + (\mathbf{B} + \mathbf{C})(\overline{\mathbf{B}} + \overline{\mathbf{C}})$$

Summary of 2-input Logic Gates

Inputs		Truth Table Outputs For Each Gate					
A	B	AND	NAND	OR	NOR	EX-OR	EX-NOR
0	0	0	1	0	1	0	1
0	1	0	1	1	0	1	0
1	0	0	1	1	0	1	0
1	1	1	0	1	0	0	1

Example 5

- Truth Table of output Y ?

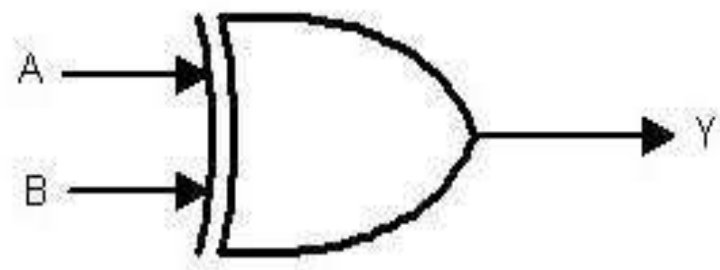


Explanation

A	B	$\bar{A}$	Y
0	0	1	0
0	1	1	1
1	0	0	0
1	1	0	0

Example 6

- Truth Table of output Y ?



Explanation

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

MCQ 1

- How many truth table entries are necessary for a four-input circuit?

  a) 4
  b) 8
  c) 12
  d) 16

MCQ 2

- Which input values will cause an AND logic gate to produce a HIGH output?

a) At least one input is HIGH
b) At least one input is LOW
c) All inputs are HIGH
d) All inputs are LOW

MCQ 3

- The basic logic gate whose output is the complement of the input is the _____________

a) OR gate
b) AND gate
c) INVERTER gate
d) XOR gate

MCQ 4

- The expression for Absorption law is given by _____________

  a) A + AB = A
  b) A + AB = B
  c) AB + AA’ = A
  d) A + B = B + A

MCQ 5

- Which of following are known as universal gates?

  a) NAND & NOR
  b) AND & OR
  c) XOR & OR
  d) EX-NOR & XOR

MCQ 6

- **The output of OR gate is 1**

a) If both inputs are zero
b) If either or both inputs are 1
c) Only if both inputs are 1
d) If either input is zero

MCQ 7

- Which of the following logical operations is represented by the + sign in Boolean algebra?

- **A.**inversion
- **B.**AND
- **C.**OR
- **D.**complementation