312en29

29

APPLICATIONS OF SEMICONDUCTOR DEVICES

In the last lesson, you learnt the working principle of semiconductor devices like *p-n* junction diode, Zener diode, LED, solar cells and transistors. Due to their miniature size and special electrical properties, these devices find applications in almost every household appliances and gadgets like gas lighter, security alarm, radio, TV, telephone, tape recorder, CD player, computer, fan regulator, emergency lights etc. All control mechanisms in big industries and flight control equipments in an aeroplane and power systems in satellites use semiconductor devices. In a way, it is now difficult to imagine life without these.

In this lesson you will learn some simple applications of diodes and transistors. This discussion is followed by an introduction to elements of **digital electronics.** This branch of electronics handles special types of signals/waveforms, which can assume only two values, 0 and 1. Digital electronics is based on the concept of **logic gates.** These gates accept input in digital form and give output according to the logic operation it is supposed to perform. You will learn about logic gates, their symbols and circuit implementation in this lesson.

OBJECTIVES

After studying this lesson, you should be able to:

- *explain the use of diode as a half-wave and a full-wave rectifier;*
- *explain the use of Zener diode as voltage regulator;*
- *describe the uses of a transistor as an amplifier, a switch and an oscillator;*
- *explain the logic gates with their Truth Tables; and*
- *realize logic gates using simple circuit elements.*

29.1 APPLICATIONS OF *p-n* JUNCTION DIODES

You now know that a *p–n* junction exhibits asymmetric electrical conduction, i.e., its resistance in forward bias is different from that in reverse bias. This property of a diode is used in rectification, i.e., conversion of an ac signal into a dc signal (of constant magnitude). In every day life, we may need it to charge a cell phone, laptop etc. Let us now learn about it.

29.1.1 *p-n* Junction Diode as a Rectifier

You have learnt in Lessons of Module 5 that the electricity supply in our homes provides us ac voltage. It is a sinusoidal signal of frequency 50 Hz . It means that voltage (or current) becomes zero twice in one cycle, i.e., the waveform has one positive and other negative half cycle varying symmetrically around zero voltage level. The average voltage of such a wave is zero. Let us now learn the mechanism to convert an ac into dc.

(a) Half-Wave Rectification

Refer to Fig. 29.1. The signal from ac mains is fed into a step down transformer T which makes it available at the terminals X and Y. The load resistance R_L is connected to these terminals through a *p-n* junction diode D. You may now like to ask : Why have we used a step down transformer? This is done due to the fact that most devices require voltage levels lower than 220V. The stepped down ac signal is obtained at the output of stepdown transformer. The potential at terminal X with respect to Y will vary as a sine function with time, as shown in Fig. 29.2(a). In the positive half cycle, during the time interval 0 to $T/2$, diode D will be forward biased and conduct, i.e., current flows through R_L from A to B. However, during the negative half cycle, i.e., in the interval $T/2$ to T, D is reverse biased and the junction will not conduct, i.e. no current flows through R_L. This is shown in Fig. 29.2(b). Since the *p-n* junction conducts only in one-half cycle of the sine wave, it acts as a half-wave rectifier.

During the non-conducting half cycle, the maximum reverse voltage appearing across the diode is equal to the peak ac voltage V_m. The maximum reverse voltage that a diode can oppose without breakdown is called its **Peak Inverse Voltage(PIV)**. For rectification, we must choose a diode having PIV greater than the peak ac voltage to be rectified by it; otherwise it will get damaged. The dc voltage, V_{dc} across R_L, as measured by voltmeter in case of half-wave rectifier, is given by

$$V_{dc} = V_m/\pi \qquad (29.1)$$

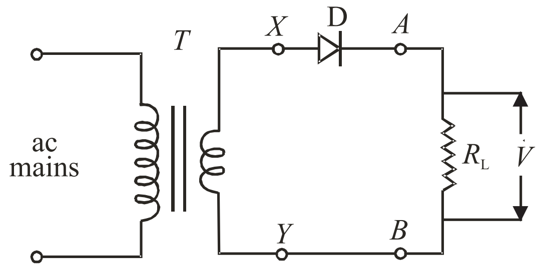


Fig. 29.1: Half wave rectifier circuit

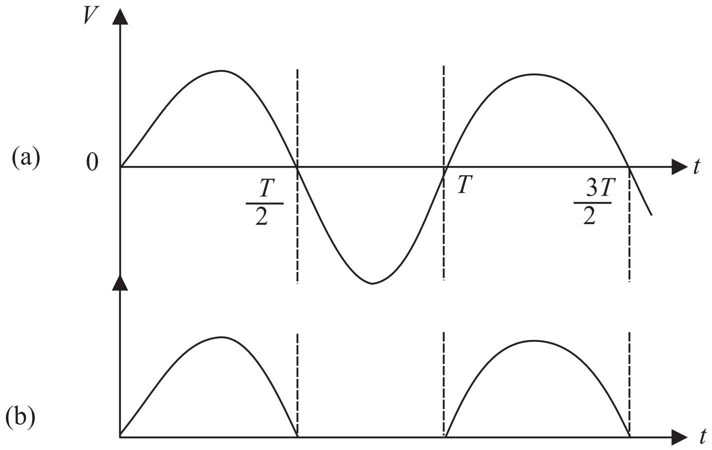


Fig. 29.2: (a) Input ac voltage, and **b)** half-wave rectified output

where V_m is the peak ac voltage. The dc current I_{dc} through the load resistance R_L is given by

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi R_L} \qquad (29.2)$$

Note that in this case, we are utilizing only half of the input power and obviously it is not an efficient way of obtaining dc. You may logically think that instead of one, we should use two diodes in such a way that they conduct in alternate cycles. This is known as full-wave rectification. Let us learn about it now.

(b) Full-Wave Rectification

For full-wave rectification, we feed the input signal in a centre tapped step down transformer. (It has two identical secondary windings connected in series.) D_1 and D_2 are two *p-n* junction diodes, as shown in Fig. 29.3. One end of the load resistance R_L is connected to the central point Y of the secondary windings and the other end is connected to the cathode terminals of the diodes D_1 and D_2. The anodes of these diodes are connected respectively to the ends X and Z of the secondary windings. The potentials at the ends X and Z are in opposite phase with respect to Y, i.e., when potential of X is positive, Z will be negative and vice versa. It is shown graphically in Fig. 29.4 (a) and (b).

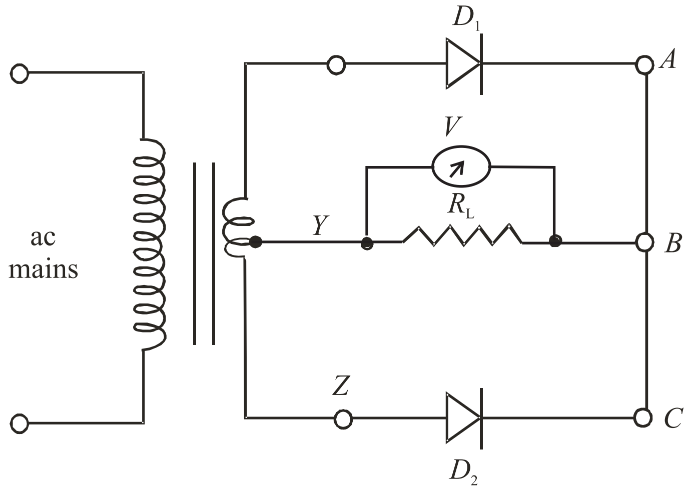


Fig. 29.3 : A full-wave rectifier circuit using two diodes

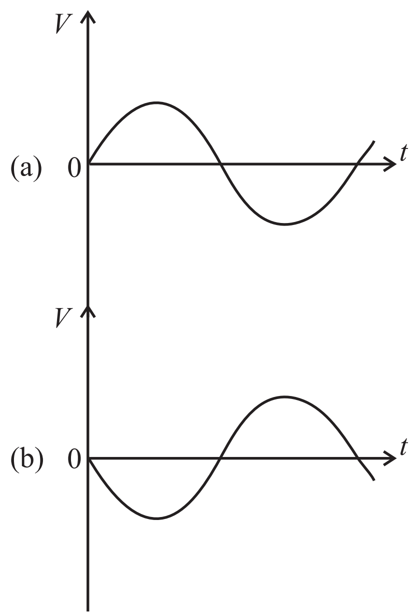


Fig. 29.4 : (a) Potential at point *X* is positive with respect to *Y*, and **(b)** potential of point *Z* is negative with resptect to *Y*

Suppose that to start with, terminal *X* is positive and *Z* is negative with respect to *Y*. In this condition, diode D_1 will conduct but D_2 will not conduct. The current will flow through the load from *B* to *Y* and the output voltage across R_L is as shown in Fig 29.5(a). During the next half cycle, terminal *X* will be negative and *Z* will be positive. Under this condition, diode D_2 conducts and current will again pass through the load resistance in the same direction, that is from *B* to *Y* . The corresponding waveform is shown in Fig. 29.5(b).And the net output across R_L is pulsating , as shown in Fig. 29.5(c).

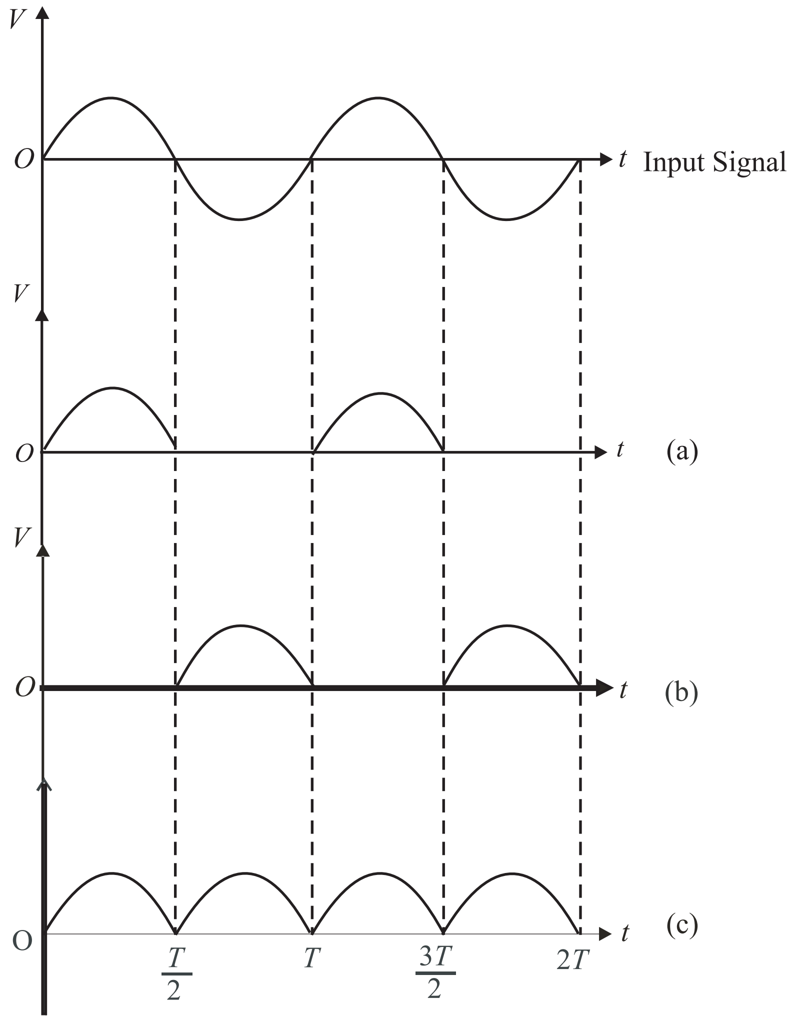


Fig. 29.5 : Voltage across R_L **a)** when D_1 conducts, **b)** D_2 conducts, **c)** net output of full wave rectifier

Since current through the load now flows over the entire cycle of the sine wave, this is called full-wave rectification. The dc voltage V_{dc} and dc current I_{dc} are given by

$$V_{dc} = 2 \times V_m/\pi \tag{29.3}$$

and

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} \tag{29.4}$$

Note that the unidirectional current flowing through the load resistance after full-wave rectification pulsates from maximum to minimum (zero) and is not useful for any practical application. To reduce the fluctuating component and obtain more steady current, we filter the pulsating part. You may be eager to know as to how do we achieve this. Let us now discover answer to this important question.

Filtering

We recall that impedance offered by a capacitor to the flow of ac depends on its freqeuncy. Therefore, a capacitor C connected across the load resistance, as shown in Fig. 29.6, filters out high frequency component.

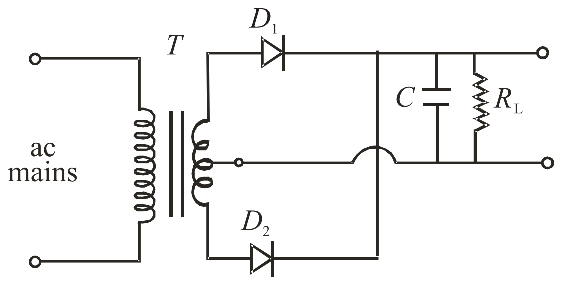


Fig. 29.6 : Circuit diagram for *capcitor*-filter in full-wave rectification

The capacitor gets charged to nearly maximum potential V_m when diode D_1 conducts for period $t = T/4$. When the current tends to decrease for $T/4 < t < T/2$, the capacitor discharges itself and tries to maintain current through the load, reducing fluctuations considerably, as shown in Fig. 29.7. The larger the value of capacitor and the load resistance, the lower will be the fluctuations in the rectified dc. The capacitor C connected across the load to reduce fluctuations is called a *filter capacitor*. In a power supply, we use LC and C-L-C (or π) filters to reduce the rippling effect. You will learn about these in detail in your higher classes.

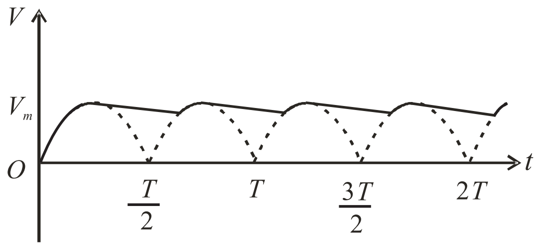


Fig 29.7: Output voltage when capacitor is used to filter ac

In high quality power supplies combination of inductors and capacitor $L - C - L$ or $C - L - C$ is used. Depending on the way, these components are connected these filters are called 'T' or 'Π'.

Special p-n junction, called Zener diode, acts as voltage regulator in reverse bias. You will now study about it.

29.1.2 Zener Diode as a Voltage Regulator

The half-and full-wave rectifiers with filters are the simplest type of power supplies. These provide almost pure dc but have one deficiency. When load current is increased by decreasing resistance, the output voltage drops. This is because, when large current is drawn, the filter capacitor gets discharged more and its voltage across the load resistor reduces. Similarly, if the ac input changes, the dc output voltage also varies. Obviously, a supply with varying output voltage affects the performance of different devices being operated with it. For example, if we operate an amplifier, the quality of sound reproduced by it will get deteriorated.

To remove this deficiency, a Zener diode is used with simple power supplies which gives constant dc voltage. Such a circuit is called regulated power supply.

The Zener regulated voltage supply circuit is shown in Fig. 29.8. It consists of a Zener diode with breakdown voltage V_z. This will be equal to the stabilized output voltage V_O A suitable series resistance R_s is included to control circuit current and dissipate excess voltage. The anode of Zener diode is connected to the negative terminal of input supply, and the cathode is connected in series with R_s to positive terminal of input supply, that is, the Zener is connected in reverse bias condition. The load resistance is connected across the Zener diode. The Zener regulator will only operate if the input supply voltage to the regulator, V_i is greater than V_z . After breakdown, the voltage across it remains nearly constant and is independent of the current passing through it. The current I_s flowing passing through R_s is given by the equation

$$I_s = (V_i - V_z)/R_s \tag{29.5}$$

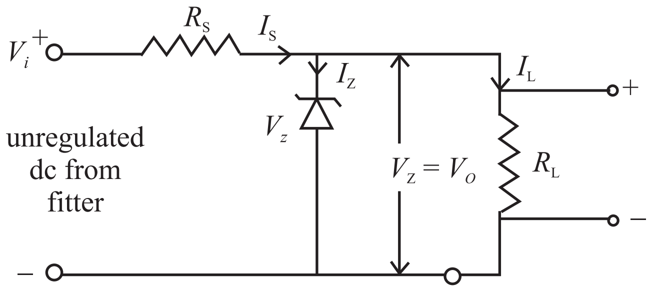


Fig. 29.8 : Zener diode as a stabilizer

This current divides in two parts: the Zener current I_z and load current I_L. Applying Kirchoff's law, we can write

$$I_s = I_z + I_L$$

or $$I_z = I_s - I_L \tag{29.6}$$

For Zener diode to operate, some current $I_{Z_{\min}}$ should always flow through it. Therefore, the load current I_L should always be less than the main current I_s. Typical value of $I_{Z_{\min}}$ may range from 5 mA to 20 mA.

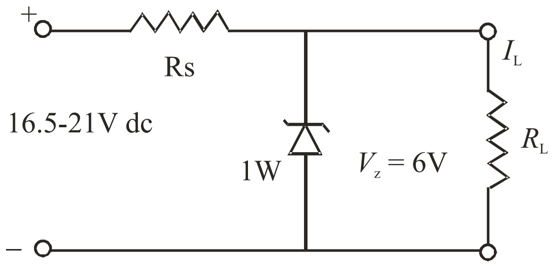
If load current is zero, the entire I_s will pass through Zener diode and output voltage V_O will be equal to V_z. When some load current is drawn, say I_L, the Zener current will decrease by the same amount but the output voltage will remain V_z. Similarly, if the ac main voltage increases or decreases, the input voltage, V_i will increase or decrease accordingly. It will result in change of I_s given by Eqn.(29.5). Due to change in I_s, the change in V_i will appear as a drop across the series resistance R_s. The Zener voltage V_z and hence V_O will remain unchanged. Thus we see that the output voltage has been stabilized against the variations in the current and the input voltage.

The power dissipation in Zener diode is given by the relation

$$P_d = V_z \times I_z \qquad (29.7)$$

This dissipation should not exceed the maximum power dissipation rating recommended by the manufacturer for Zener diode. Let us now understand the design of a Zener regulated power supply with one example.

Example 29.1: The load current varies from 0 to 100 mA and input supply voltage varies from 16.5 V to 21 V in a circuit. Design a circuit for stabilized dc supply of 6 V.



Solution: We choose a Zener diode of 6 V. Let $I_{Z_{min}}$ be 5 mA. The maximum current will flow through the Zener when there is no load current. Its magnitude will be (100+5) mA= 0.105A.

The value of R_s is determined by the minimum input voltage and maximum required current:

$$R_s = \frac{V_{Z_{min}} - V_z}{I_{max}} = \frac{16.5\text{V} - 6\text{V}}{105\text{mA}} = 100\ \Omega$$

The current through the Zener diode will be maximum when the input voltage is maximum, that is 21 V and $I_L = 0$. Therefore, the maximum Zener current I_{max} = (21V– 6V)/100 Ω $\simeq$ 0.15 A.

The maximum power dissipation in the diode is 6V × 0.15A= 0.9W.

It means that we should use a Zener diode of 6 V, 1 W and resistance Rs. of 100Ω. It should be connected in the circuit as shown above. It will give a stable output of 6 V for the specified ranges of load and input variation.

INTEXT QUESTIONS 29.1

1. Draw a circuit of full-wave rectifier with a filter capacitor.
2. What will be the output voltage, if you connect a Zener diode in forward bias instead of reverse bias in the regulator circuit of Example 29.1?

29.2 TRANSISTOR APPLICATIONS

You learnt the working principle of transistor in detail in the last lesson. Normally, the collector is reverse biased and no current flows in collector-emitter circuit. If we pass a very small current in the base circuit, a very large current starts flowing in the collector circuit. This property has made a transistor indispensable for vast electronic applications. But here we have discussed its applications as an amplifier, as a switch, and as an oscillator (frequency generator).

29.2.1 Transistor as an Amplifier

An electrical signal is voltage or current, which is coded with some useful information. For example, when we speak in front of a microphone, its diaphragm vibrates and induces a very small voltage in its coil, depending on the intensity of sound. This induced voltage appears as a weak signal and can not operate a loudspeaker to reproduce sound. To make it intelligible, it is fed into a device called amplifier. The amplifier increases the level of input signal and gives out magnified output. If V_i is the input signal voltage fed to the amplifier and V_O denotes the amplified output, their ratio is called *voltage gain.*

i.e.,
$$A_V = \frac{V_O}{V_i} \tag{29.8}$$

Similarly, we can define the current gain and power gain as

$$A_I = \frac{i_O}{i_i} \tag{29.10}$$

$$A_p = \frac{P_O}{P_i} \tag{29.11}$$

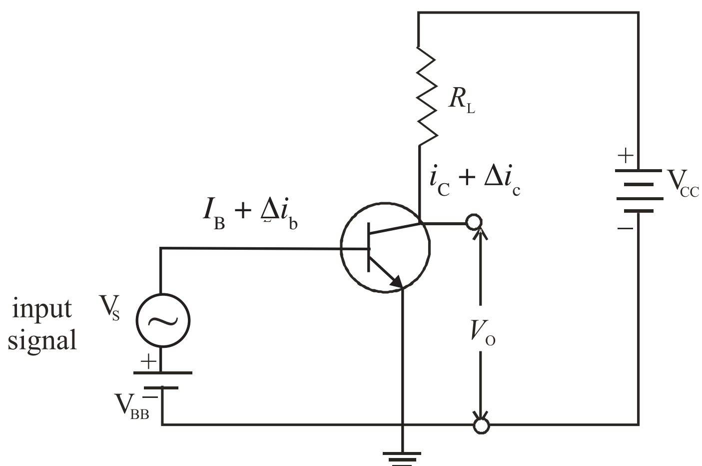


Fig. 29.9: Basic amplifier circuit using a *n-p-n* transistor in *CE* mode

The circuit for transistor as an amplifier is shown in Fig. 29.9. Here an *n-p-n* transistor is used in CE mode. Its collector is reverse biased through the load resistance R_L by the battery V_{CE}. When a base current I_B flows, some collector current I_C will start flowing. On decreasing I_B, a stage will be reached when I_C becomes almost zero. This is the lower limit of variation of I_B. Similarly, on increasing I_B again, a stage of saturation is reached and I_C stops increasing. This corresponds to the upper limit of variation of I_B. For faithful amplification of input signal, a base current equal to the mean of these two limiting values of I_B is passed through the base by forward biasing it with battery V_{BB}. We can choose the operating point in the centre of linear operating range of the transistor. This is called biasing of the base. A signal source providing an input signal υ_S is connected in series with υ_{BB}.

Due to addition of oscillating signal voltage υ_S to υ_{BB}, the base current changes by an amount Δi_b around the dc biasing current I_B. The signal voltage is kept low so that the signal current Δi_b if added and subtracted from I_B does not cross the upper and lower limits of the base current variation. Otherwise, the transistor will go into cut off or saturation region and the amplified output will be highly distorted and noisy. Note that signal current

$$\Delta i_b = \upsilon_S / r_i \qquad (29.12)$$

where r_i is the input impedance. This change in base current Δi_b results in a large change in collector current, say Δi_c given by

$$\Delta i_c = \beta \Delta i_b = \beta \upsilon_s / r_i \qquad (29.13)$$

where β is the ac current amplification factor, equal to $\Delta i_c / \Delta i_b$. From (Eqn. 29.13) we get

$$\upsilon_s = \Delta i_c \times r_i / \beta \qquad (29.14)$$

By applying Kirchhoff's law to the output circuit in Fig. 29.9, we have

$$V_{CC} = V_{CE} + I_C R_L \qquad (29.15)$$

On differentiating Eqn. (29.15), we get

$$dV_{CC} = dV_{CE} + dI_C \times R_L \qquad (29.16)$$

Since V_{CC} is constant, $dV_{CC} = 0$. Therefore, we get

$$dV_{CE} = -\, dI_C \times R_L$$

But dV_{CE} is the change in output $\Delta \upsilon_0$ and dI_C in i_c. Therefore,

$$\Delta \upsilon_0 = -\, \Delta i_c \times R_L$$

The voltage gain A_v of the amplifier is given by

$$A_V = \upsilon_0 / \upsilon_S = -\, (\Delta i_c \times R_L)/(\Delta i_c \times r_i / \beta)$$

$$= -\beta \times R_L / r_i \qquad (29.17)$$

The ratio β/r_i is called **transconductance** of transistor and is denoted by g_m. Hence Eqn. (29.17) can be written as

$$A_V = -g_m \times R_L \qquad (29.18)$$

The negative sign indicates that input and output are in opposite phase, i.e. they differ in phase by 180°. The power gain is given by

$$A_P = A_I \times A_V = \beta \times A_V \qquad (29.19)$$

Note that power gain does not mean that the law of conservation of energy is violated in an amplifier. The ac power output of the amplifier is more than the ac input signal power but this gain is achieved at the cost of dc power supplied by the voltage source.

John Bardeen
(1908 – 1991)

John Bardeen is the only researcher in history of science who received two Nobel Prizes in Physics. He was born in Madison, Wisconcin USA, in a highly educated family. He was so bright a kid that his parents moved him from third grade to Junior high school. He did his graduation in Electrical Engineering. But, he also had to struggle for his career. After spending three years as geophysicist with Gulf Oil Company, he went to Princeton for his Ph.D. in Mathematical Physics. After a brief stint at Harvard and Minnesota and in Naval Ordnance Labs, he joined William Shockley's research group at Bell Laboratories. With Walter Brattain, he devloped the first transistor for which Bardeen, Brattain and Shockley were conferred the 1956 Nobel Prize in Physics.

Bardeen shared his second Nobel in 1972 with Leon C Cooper and R Schieffer for their theoretical work on superconductivity.

INTEXT QUESTION 29.2

1. For a *CE* mode amplifier, υ_i is 20 mV and υ_o is one volt. Calculate voltage gain.

2. The P_0 of an amplifier is 200 times that P_i. Calculate the power gain.

3. For a CE amplifier, $R_L = 2000\ \Omega$, $r_i = 500\ \Omega$ and $\beta = 50$. Calculate voltage gain and power gain.

29.2.2 Transistor as a switch

In day-to-day life, we use electrical switches to put the gadgets like lamps, fans, machines on or off manually. Note that the switch has two distinct states, viz on and off. In electronics, we come across situations where we need to apply an input to some device in the form of two distinct voltage levels. This is as if we were operating a switch. When switch is on, one voltage level is applied but when switch is off, the other one is applied. Typically, such voltage levels are used in computers, where digital signals are employed. This is done by using a trasistor in the non-linear region of its operation. In the transister characteristics shown in Fig 29.10, we see two extreme regions: *cut-off region and saturation region*. The (jagged) region below the zero base (I_B = 0) signifies the *cut off* regions. The transistor does not conduct and entire supply voltage V_{CC} appears across the transistor between the collector and the emitter (V_{CE}). That is, the output voltage at the collector is V_{CC}.

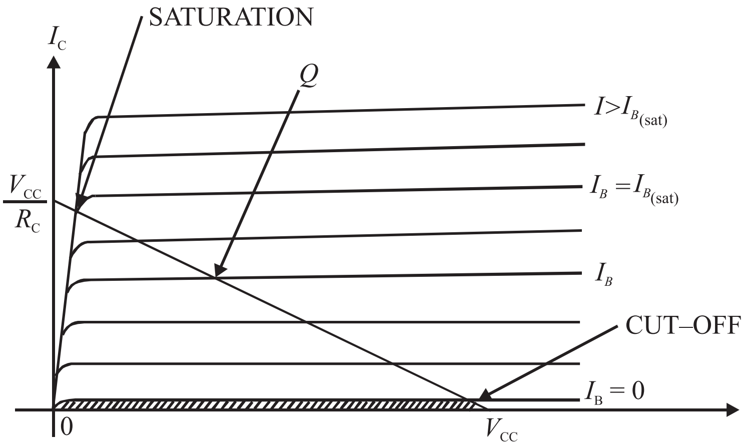


Fig. 29.10 : Transistor output characteristics

When the base current I_B is greater than its saturation value, the transistor conductor fully and collector-emitter voltage V_{CE} is almost zero. In such a case, the output voltage obtained between collector and ground is zero and entire voltage drop appears across R_L. That is , the collector current $I_C = \frac{V_{CC}}{R_L}$.

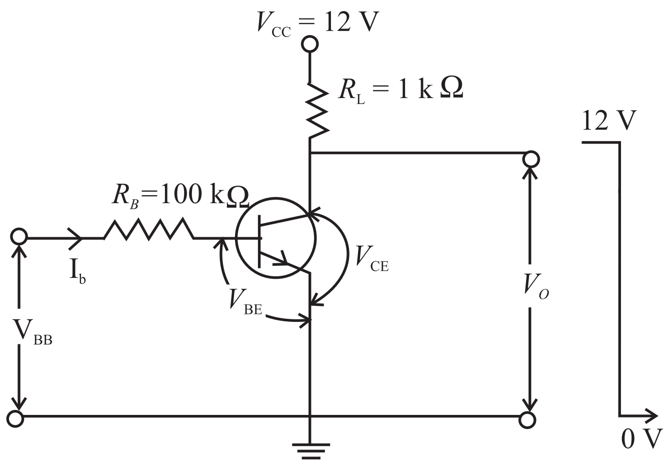


Fig. 29.11: Transistor as a switch

Fig 29.11 shows a typical circuit of transistor as a switch. The control signal for switching the transistor on or off is given in the form of V_{BB}. For the input loop, we can write

$$I_B R_B + V_{BE} - V_{BB} = 0$$

When $V_{BB} = 0$, we get

$$I_B = -\frac{V_{BE}}{R_B} \qquad (29.20)$$

Since I_B is less than zero, the transistor is cut off, and

$$V_0 = V_{CC} \qquad (29.21)$$

If $V_{BB} = 5V$, and $V_{BE} = 0.7$ V for the chosen transistor, from Eqn. (29.20) we get

$$I_B\ (100\ k\Omega) + 0.7V - 5\ V = 0.$$

$$\therefore \qquad I_B = \frac{5V - 0.7V}{100k\Omega} = 43\ \mu A$$

For normal transistors, this value of base current is enough to drive the transistor to full saturation. In this case, $V_O = V_{CE_{sat}} = 0$ and the collector current

$$I_C = \frac{V_{CC}}{R_L} = \frac{12V}{1K\Omega} = 12mA.$$

This kind of switch can also be used as an indicator in displays. For example, if we connect an LED is series with the collector resistor, as shown in Fig 29.12, the collector current drives the LED on for high (+5V) input, and it lights up. Whenever input is zero, the LED is off because no collector current flows through the circuit.

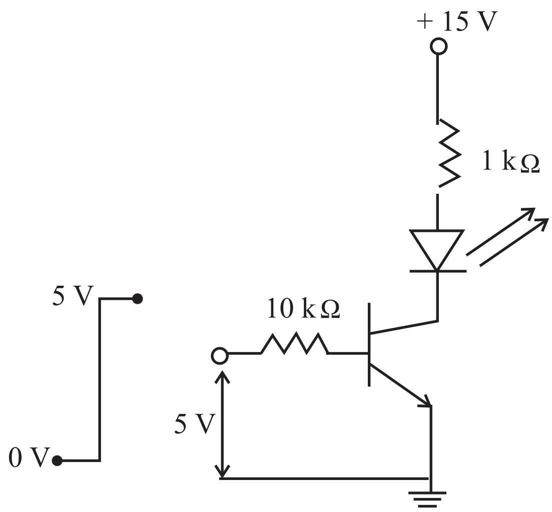


Fig. 29.12: LED indicator using transistor switch

Another major application of transistors is to generate an oscillating signal of desired frequency. This is done by a special circuit called an **oscillator**. The oscillators find many applications, particularly in radio transmitters to generate the carrier wave frequency. These are also used in clock generators, electronic watches and computers etc. There are various types of oscillators. We here discuss a typical oscillator circuit using a transistor.

29.2.3 Transistor as an Oscillator

An electronic oscillator is a device which generates continuous electrical oscillations. In a simple oscillator circuit, a parallel *LC* circuit is used as resonant circuit and an amplifier is used to feed energy to the resonant circuit. It can generate frequencies from audio to radio range depending on the choice of *L* and *C*.

We know that when a charged capacitor is connected across an inductor, the charge oscillates. But due to loss of energy by radiation and heating of wires, the energy is lost and the amplitude of oscillations decays with time. To build a sinusoidal oscillator, where the oscillations are sustained (i.e. they do not decay), we need an amplifier with positive feedback. The basic idea is to feed a part of output signal in input signal. By adjusting the gain of the circuit and the phase of the feedback signal, energy dissipated in each cycle is replenished to get sustained oscillations of desired frequency.

Schematically, we can depict an oscillator to be made up of two main blocks: an amplifier with gain *A,* and a feedback circuit with feedback factor β, as shown in Fig 29.13.

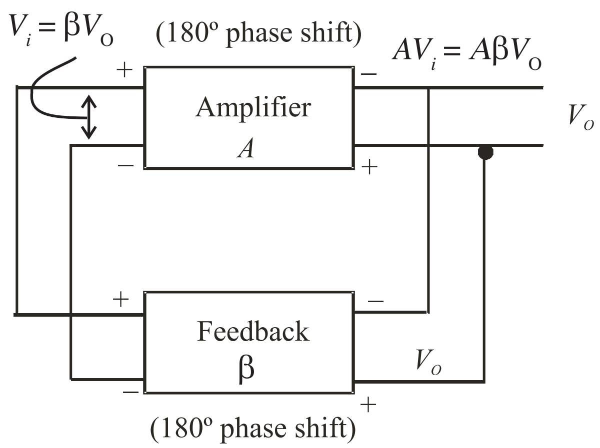


Fig. 29.13: Schematic diagram of an oscillator

In case, $A\beta < 1$, V_O decreases continuously. On the other hand, if $A\beta > 1$, V_0 increases gradually.But if $A\beta = 1$, we get constant value of V_0 leading to sustained oscillations.

Now, we consider a *CE* amplifier, like the one discussed in Sec. 29.2.1. It has 180º phase difference between the input and output, i.e. it has negative gain (–*A*). To keep the total feedback gain $A\beta = 1$, we require that β is also negative; equal to $-A^{-1}$. That is, it is necessary to introduce a phase shift of 180º in the feedback circuit as well.

In Fig. 29.14, we have shown a circuit diagram of an oscillator using *LC* tank circuit and a transistor amplifier in *CE* mode. This is called Colpitt's Oscillator.

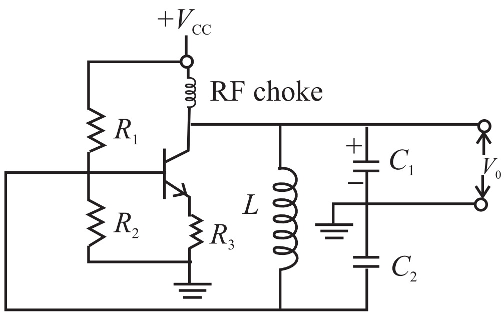


Fig. 29.14 : Colpitt's Oscillator

In this circuit C_1, C_2 and L form the tank circuit. The oscillating current is generated in this circuit, which is at its resonant frequency. The output is obtained across C_1, the feedback is provided across C_2 connected to the base of the transistor amplifier in *CE* mode. In this case 180° is introduced by the amplifier and another 180° phase shift is provided by the capacitor C_2 which is connected between ground and other end of the inductor coil. Hence, the total loop gain is positive. When the gain of transistor amplifier is sufficiently large at the resonant frequency, we obtain sustained oscillations at the output.

29.3 LOGIC GATES

In electronics, we come across mainly two types of waveforms. The information carried by these waveforms is called signal. When the signal takes any value within a range of amplitude at any instant of time, it is called a continuous signal. When the signal takes the value only at certain times, it is called a discrete signal. When the signal takes only particular finite number of amplitude values, it is called a **digital signal** (Fig. 29.15).

The digital signal varies in steps and typically has only two widely separated values '0' and '1'. These are called bits. Normally 0V corresponds to bit '0' and 5 V corresponds to bit '1'. Since the levels are so widely separated, any noise riding on the signal within the range of almost 2V, [(0V + 2 V) for level '0' and (5V – 2V) for level '1', does not affect the signal value, Hence these signals are immune to noise. The signals used in a computer are digital. The information is coded in the form of digital signals by a series of bits arranged in different order. Each bit is a pulse of fixed time duration.

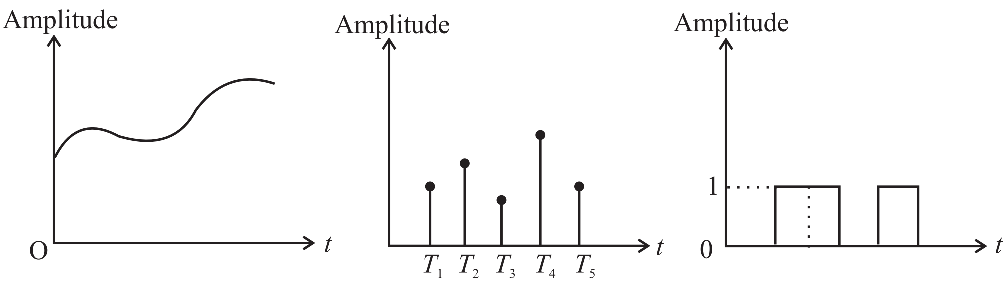


Fig. 29.15: a) continuous signal, **b)** discrete signal, and **c)** digital signal

Different mathematical operations can be performed on the digital signal. The mathematics governing these operations is called Boolean algebra.

In Boolean algebra, the basic operations are addition and multiplication. If it is a digital data that takes value 0 or 1, the following identities hold:

$$A \times 0 = 0 \tag{29.22}$$

$$A + 1 = 1 \tag{29.23}$$

The circuits which perform these operations are called *logic gates*. Let us now learn about basic logic gates.

29.3.1 Basic Logic Gates

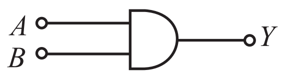
Logic gates are devices which have one or more inputs and one output. They give different output when the input bits differ in their arrangement. The output produced by these gates follows the laws of Boolean logic. There are three basic types of logic gates :

1. AND Gate, 2. OR Gate, 3. NOT Gate

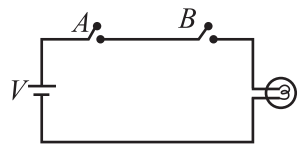
These gates perform multiplication, addition and inversion (negation) operations, respectively. Let us now learn the working of these logic gates.

1. AND Gate

An AND gate can have two or more inputs but only one output. The logic symbol of a two input AND gate is given Fig 29.16(a). We can understand the behaviour of an AND gate by considering a number of electrical switches connected in series. For examples, switches A and B are two inputs of the gate and the bulb gives the output Y. The ON switch stands for logic input '1' and OFF switch stands for logic input '0'. In this case, the bulb will glow only if it is connected to the supply voltage. This will happen only if both A and B switches are simultaneously ON (or '1'). The behaviour of output Y at various values of A and B is shown in Table in Fig. 29.16(c). This table is called *Truth Table*.



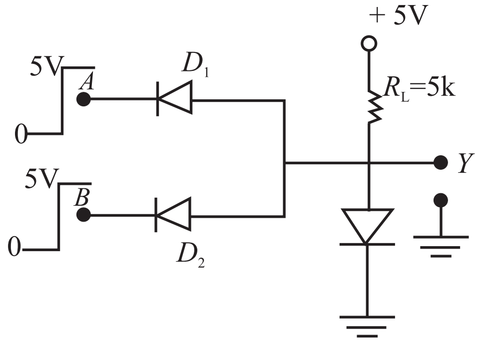
(a)



(b)

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

(c)



(d)

Fig 29.16: a) Symbol of AND gate, **b)** switch implementation of AND gate, **c)** Truth Table of AND Gate, and d) diode implementation of AND gate.

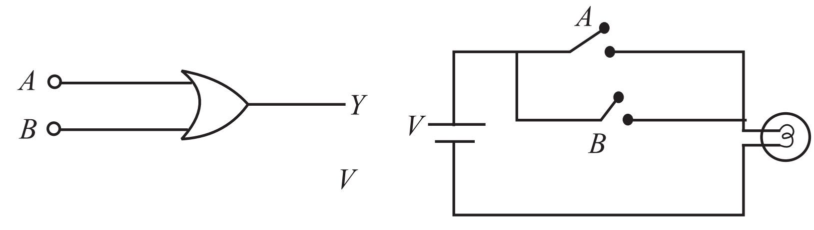
The Boolean expression for the AND operation is represented as

$Y = A.B = AB = A \times B$ and read as A AND B.

Realization of AND Gate : The logic gate realized by using diodes is called a DDL Gate (Diode–Diode Logic Gate). The diode implementation of a two-input AND gate is shown in Fig.29.16 (d). The anodes of two diodes D_1 and D_2 connected in parallel are forward biased by a 5 V battery through a 5 kΩ resistance. The output is taken from the anode. Cathode wires A and B serve as input terminals. When either A or B or both the terminals are grounded, the respective diode will conduct and a potential drop will develop across the resistance and output will be 0.7 V, i.e. logic '0'. When both the terminals are connected to 5V (i.e. for input 1, 1), neither of the diodes will conduct and output will be 5 V, i.e. logic '1'

2 OR Gate

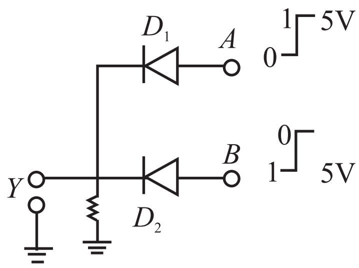
The OR gate can have two or more inputs and only one output. The logic symbol of a two input OR gate is given in Fig 29.17(a). We can explain the behaviour of an OR gate with the help of a number of electrical switches connected in parallel. For a two input OR gate, two switches are connected, as shown in Fig.29.17(b). The switch A and B are the two inputs of the gate and the bulb gives output Y. The ON switch stands for logic input '1' and OFF switch stands for logic input '0'. The glowing bulb stands for logic output '1' and the non-glowing bulb for logic output '0'. In this case, when either A OR B or both the switches are ON, the supply voltage reaches the output and the bulb glows. The input-output correlation for an OR gate is shown in the Truth Table given in Fig. 29.17(c).



(a) (b)

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

(c)



(d)

Fig 29.17: a) Symbol of OR gate, **b)** switch implementation of OR gate, **c)** Truth Table of OR gate, and **d)** diode implementation of OR gate

The Boolean expression for an OR operation is represented as

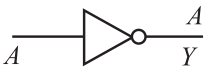
$Y = A + B$ and read as A or B.

Realization of OR Gate: The diode implementation of a two-input OR gate is shown in Fig. 29.17 (d). The cathodes of diodes D_1 and D_2 connected in parallel are grounded through a 5 kΩ resistance. The output is taken from the cathode and the two anode wires A and B serve as input terminals. When either A or B or both the terminals are connected to the positive terminal of the 5 V battery, the respective diode/diodes will conduct and potential at the output will be bout 5V i.e. logic ‘1’. When both the switches are open, output will be 0 V i.e. logic ‘0’.

3 NOT Gate

Another important gate used in digital signal handling is the **NOT** gate, which inverts the signal, i.e., if input is ‘1’ then output of NOT gate is ‘0’ and for ‘0’ input, the output is ‘1’.

The symbol for NOT gate is shown in Fig. 29.18(a). The Truth Table of NOT gate is shown in fig. 29.18(b).



(a)

A	$Y = A$
0	1
1	0

(b)

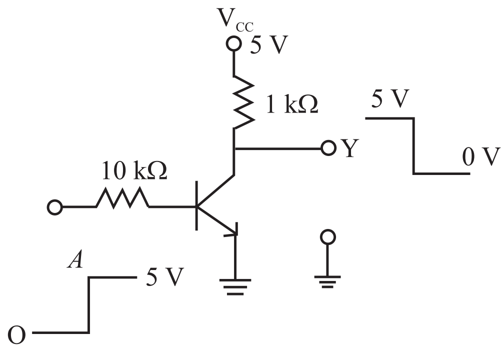


Fig. 29 18: (a) Symbol of NOT gate, (b) Truth Table of NOT gate, and (c) circuit implementation of NOT gate

The circuit to implement a NOT gate is identical to that used for a transistor as a switch. This is shown in Fig. 29.18(c). When input A is at ' 0' level, transistor is off and the entire V_{CC} voltage (5V) appears at the output Y. When input A is '1' (5V), the transistor conducts and output voltage Y is '0'.

The inversion operation is indicated by a bar on the top of the symbol of the input e.g. in the Truth Table we can write, $Y = \text{NOT}\ (A) = \overline{A}$

So far we have discussed basic logic gates. You may now ask: Can we combine these to develop other logic gates? You will discover answer to this question in the following section.

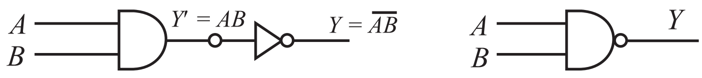
29.3.2 Combination Logic Gates

Two most important gates formed by combination of logic gates are (1) NAND [NOT+AND] and (2) NOR [NOT+OR] gates. In digital electronics, a NAND gate or a NOR gate serves as a building block because use of multiple number of either of these gates allows us to obtain OR, AND and NOT gates. For this reason, these are called universal gates. Let us now learn about combination logic gates.

1. NAND Gate

The NAND Gate is obtained by combining AND gate and NOT gate, as shown in Fig. 29.19 (a). Here the output Y of AND gate is inverted by the NOT gate to get the final output Y. The logic symbol of a NAND gate is shown in Fig. 29.19(b). The Truth Table of a NAND gate is given in Fig. 29.19(c). It can be obtained by inverting the output of an AND gate. The truth table of a NAND gate shows that it gives output '1' when at least one of the inputs is '0' The Boolean expression of a NAND operation is represented as

$$Y = A.B = A \times B = AB$$



(a) (b)

A	B	$Y' = AB$	$Y = \overline{AB}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

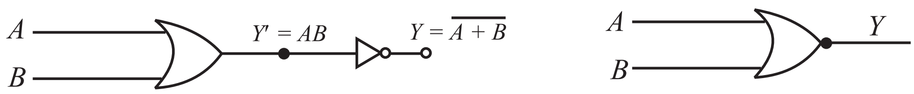
(c)

Fig. 29.19 : a) NAND as combination logic gate, **b)** symbol of NAND GATE, and **c)** Truth Table of a NAND gate

2. NOR Gate

The NOR gate, obtained by combining an OR gate and NOT gate, is shown in Fig. 29.20(a) Here the output of OR gate, Y', is inverted by the NOT gate to get the final output Y. The logic symbol of a NOR gate is given in Fig. 29.20(b). The Truth Table of a NOR gate given in Fig. 29.20(c), can be arrived at by inverting the output of an OR gate. The Truth Table of a NOR gate shows that it gives output '1' only when both the inputs are '0'

The Boolean expression for a NOR operation is represented as $Y = \overline{A + B}$.



(a) (b)

A	B	$Y' = A+B$	$Y = \overline{A + B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

Fig. 29.20 : a) NOR as combination logic gate, **b)** symbol of NOR gate, and **c)** Truth Table of NOR gate

As mentioned earlier, the NAND and NOR gates are basic building blocks of all the logic gates. Let us now see, how we can obtain the three basic gates AND, OR and NOT by using NAND gates.

29.3.3 Realization of Basic Gates from NAND Gate

The NAND gate is considered to be the universal gate because all other gates can be realized by using this gate.

(a) Realization of a NOT gate : If two input leads of a NAND gate are shorted together, as shown in Fig. 29.21, the resulting gate is a NOT gate. You can convince yourself about this by writing its truth table.

Here we have $A = B$

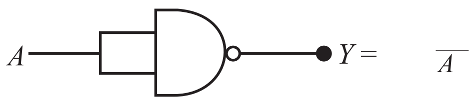
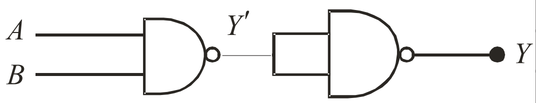


Fig. 29.21 : NAND gate as NOT gate

(b) **Realization of an AND gate** : The AND gate can be realized by using two NAND gates. The output of one NAND gate is inverted by the second NAND gate used as NOT gate as shown in Fig 29.22(a). The combination acts as an AND gate, as is clear from the Truth Table given in Fig. 29.22(b).



A	B	$Y' = \overline{AB}$	$Y = AB$
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

(b)

Fig. 29. 22: a) NAND gates connected to implement AND gate and **b)** Truth Table of AND gate using NAND gate

c) **Realization of an OR gate :** The OR gate can be realized by using three NAND gates. Two NAND gates are connected as inverters and their outputs are fed to the two inputs of a NAND gate, as shown in Fig. 29.23. The combination acts as an OR gate.

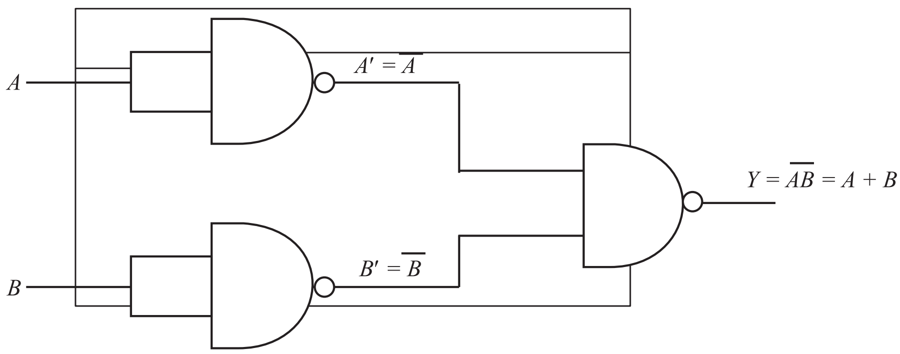


Fig. 29.23 : Three NAND gates connected as OR gate

INTEXT QUESTIONS 29.3

Complete the following table from Fig. 29.23 to prove that it is an OR gate.

A	*B*	*A′*	*B′*	*Y*
0	0	–	–	–
0	1	–	–	–
1	0	–	–	–
1	1	–	–	–

WHAT YOU HAVE LEARNT

- A *p-n* junction diode can be used as a rectifier to convert ac into dc.
- A half-wave rectified dc contains more ac component than the full-wave rectified dc.
- A Zener diode stablizes the output of a power supply.
- In a stabilizer, the Zener diode dissipates more power when the current taken by the load is less.
- For amplification, a transistor needs input current.
- Transistor can be used as a switch by biasing it into saturation and cut-off regions.
- There are three basic logic gates: AND,OR and NOT.
- NAND gate is a universal gate because it can be used to implement other gates easily.

TERMINAL QUESTION

1. Why the Peak Inverse Voltage (PIV) of a *p-n* junction diode in half-wave rectifier with filter capacitor is double of that without the capacitor?
2. Explain how a Zener diode helps to stabilize dc against load variation.
3. What should be the range of variation of amplitude of input signal for proper working of an amplifier?
4. Draw a circuit using diodes and transistors to implement a NOR gate.

ANSWERS TO INTEXT QUESTIONS

29.1

1. See Fig.29.6

2. In case of full wave rectifier, both diodes D_1 and D_2 charge C to maximum voltage of V_{max} in alternate half cycles. Hence, the PIV of the diodes should be $2 \times V_{max}$.

3. $R_z = 100\,\Omega$, $R_s = 100\,\Omega$ and $R = R_z + R_s = 200\,\Omega$
Hence,

$$I = \frac{21}{200} = 0.105\text{A}$$

and $V = IR = 0.105 \times 100$
$= 10.5\text{V}$

29.2

1. $|A_v| = \frac{V_0}{V_i} = \frac{1\text{V}}{20\text{ mV}} = 50$.

2. $A_p = \frac{P_0}{P_i} = 200$.

3. $$|A_v| = \frac{\beta \times R_L}{r_i} = \frac{50 \times 2000\Omega}{500\Omega} = 200$$

$$A_p = \beta A_v = 50 \times 200 = 10000.$$

29.3

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