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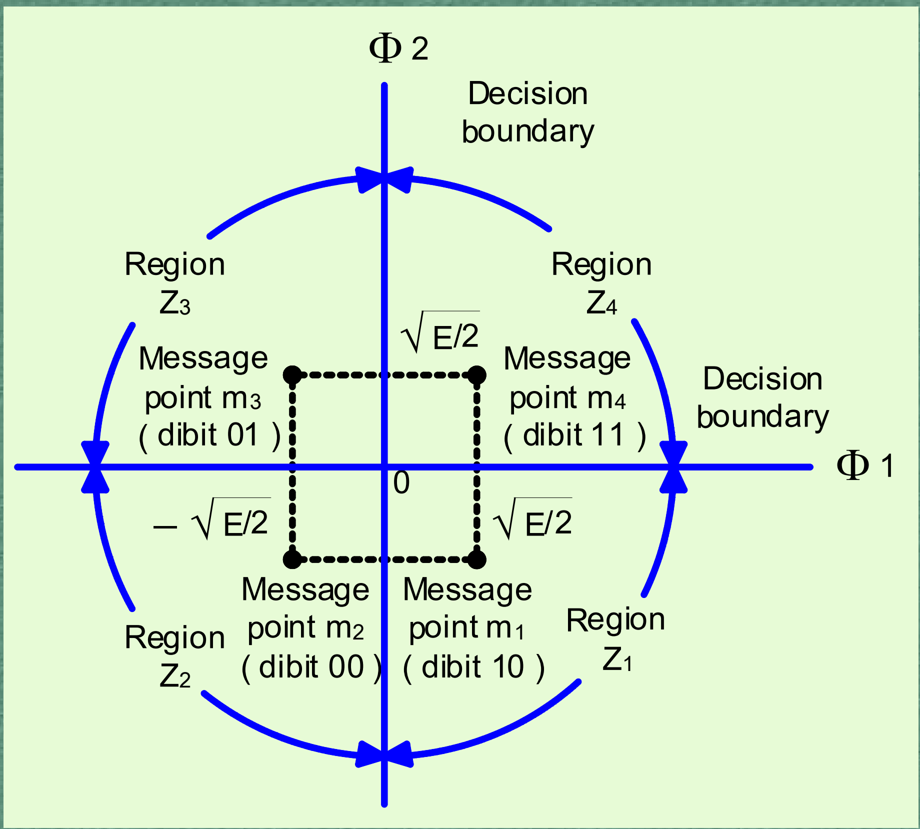
DIGITAL MODULATION TECHNIQUES



Indian Railways Institute of
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SECUNDERABAD - 500 017

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INDIAN RAILWAYS INSTITUTE OF SIGNAL ENGINEERING & TELECOMMUNICATIONS, SECUNDERABAD - 500 017

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CONTENTS

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CHAPTER 1

DIGITAL MODULATION TECHNIQUES

1.1 Introduction to Digital Communication system.

In Digital communication systems, relatively high frequency analog carriers are modulated by relatively low frequency digital information signals and systems involving the transmission of digital pulses.

1.2 Types of Digital Modulation.

1) Digital Amplitude modulation or Amplitude Shift Keying (ASK)
2) Frequency Shift Keying (FSK)
3) Phase Shift Keying (PSK)

1.2.1 Digital Amplitude modulation or Amplitude Shift Keying (ASK)

Amplitude Shift Keying (ASK) involves the process of switching the carrier either **ON or OFF,** in correspondence to a sequence of digital pulses that constitute the information signal. One binary digit is represented by the presence of a carrier; the other binary digit is represented by the absence of a carrier. The Frequency of the carrier remains fixed.

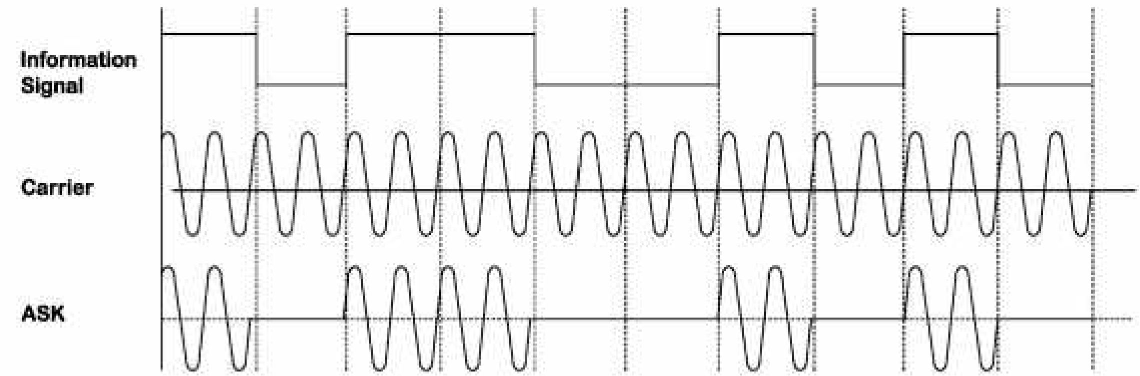


Fig 1.1 Amplitude Shift Keying (ASK) wave form

Mathematically, Digital Amplitude modulation or Amplitude Shift Keying (ASK) can be represented by

$$V_{am}(t) = [1+ V_m(t)] \left[A/2 \cos(\omega_c\ t)\right] \ldots\ldots\ldots\ldots 1$$

Where,

$V_{am}(t)$ = Digital Amplitude modulated wave.

A/2 = UN modulated carrier amplitude (volts)

$V_m(t)$ = Modulating Binary Signal. (Volts)

ω_c = Carrier Radian frequency (radians per second).

In equation 1, the modulating signal $V_{am}(t)$ *is* a binary wave form, *where* +1 V = logic 1 and -1V = logic 0. Therefore for a logic 1 input $V_m(t)$ = +1 and the equation reduces to

$$V_{am}(t) = [1+ 1] \left[A/2 \cos(\omega_c\ t)\right] = A \cos(\omega_c\ t).$$

And for the logic 0 input $V_m(t) = -1$ and the equation reduces to

$$V_{am}(t) = [1-1]\left[A/2 \, Cos(\omega_c \, t)\right] = 0$$

Thus, for 100% modulation $V_{am}(t)$ *is* either A Cos $(\omega_c \, t)$ or 0.

Hence, the carrier is either on or off for that reason Amplitude Shift Keying (ASK) is commonly referred as ***on – off keying (OOK)***

Amplitude Shift Keying (ASK) is sometimes called as continuous wave (CW), because when the carrier is being transmitted (i.e., ON), it has a constant amplitude constant frequency, and constant phase.

Amplitude Shift Keying (ASK) is used to transport digital information at a relatively low quality; it is therefore seldom use in high capacity, high performance communication systems.

Application of ASK

- It is used in multichannel telegraph systems.
- Simple ASK is no longer used in digital communication systems due to noise problems.

1.2.2 Frequency Shift Keying (FSK)

The Frequency Shift Keying (FSK) involves the process of varying the frequency of a carrier wave by choosing one of two frequencies (binary FSK) in correspondence to a sequence of digital pulses that constitute the information signal. Two binary digits are represented by two frequencies around the carrier frequency. Amplitude remains fixed. It is similar to conventional frequency modulation (F M) except that the modulating signal is a binary signal that varies between two discrete voltage levels rather than a continuously changing analog waveform

The general expression for Frequency Shift Keying is.

$$V_{fsk}(t) = V_c \, Cos \, [2\pi \, \{f_c + V_m(t) \, \Delta f\} \, t] \ldots\ldots\ldots 2$$

Where,

$V_{fsk}(t)$ = FSK Wave form
V_c = Peak carrier Amplitude (volts)
f_c = center carrier frequency (Hertz)
Δf = Peak frequency deviation (Hertz)
$V_m(t)$ = Modulation signal at the input. (+/- 1)

In the equation 2, the peak shift in the carrier frequency Δf is proportional to the amplitude and the polarity of the binary input signal .The modulating signal $V_m(t)$ is a normalized binary wave form where logic 1 = +1 and logic 0 = -1 . Thus for logic 1 input, $V_m(t) = +1$ and the equation 2 can be rewritten as …..

$$V_{fsk}(t) = V_c \, Cos \, [2\pi \, \{f_c + \Delta f\} \, t]$$

For a logic 0 input, $V_m(t) = -1$ and the equation 2 becomes

$$V_{fsk}(t) = V_c \, Cos \, [2\pi \, \{f_c - \Delta f\} \, t]$$

So with binary FSK, the carrier frequency is shifted (deviated) by the binary input signal. As the binary input signal changes from logic 0 to logic 1 and vice versa, the output frequency shifts between two frequencies: a mark or logic 1 frequency (fm) and a space or logic 0 frequencies (fs)

The mark and space frequencies are separated from the carrier frequencies by the peak frequency deviation (i.e. fc +/- Δf).

It is important to note that the mark and space frequencies are arbitrarily assigned, depending on the system design as shown in the figure 1.2

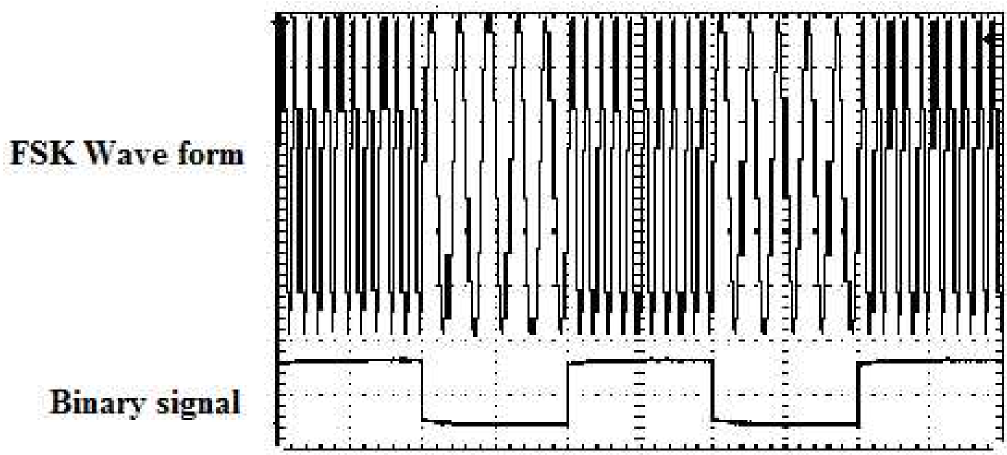


Fig: 1.2 Frequency Shift Keying wave form generation

Application of FSK

- FSK signaling schemes are used mainly for low-speed digital data transmissions.

Advantages of FSK over ASK

- ASK needs automatic gain control (AGC) to overcome fading effect.
- Relatively easy for FSK generation
- The constant amplitude property for the carrier signal does not waste power and does produce some immunity to noise.

1.2.3 PHASE SHIFT KEYING

Phase shift keying (PSK) is another form of angle modulated, constant amplitude digital modulation. PSK is similar to conventional phase modulation except that with PSK, the input signal is a binary digital signal and a limited number of output phases are possible.

1.3 BINARY PHASE SHIFT KEYING

In binary phase shift keying (BPSK), the binary modulating signals, shifts the phase of the carrier signal as per the logic condition of the modulating signal.

The output of the modulated carrier signal is either at in phase (0 Phase) or at 180° out of phase. When the modulating signal is at +1V that represents logic 1, the phase of the modulated carrier will be +1 sin $\omega_c t$ (0 °). When the modulating signal is at –1V that represents logic 0, the phase of the modulated carrier will be -1 sin $\omega_c t$ (180 °).

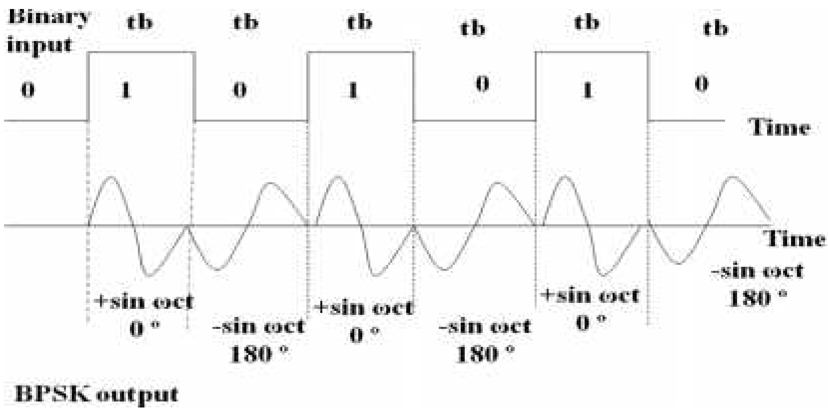


FIG: 1.3 BPSK wave form

Fig 1.3 shows the output phase versus time relationship for BPSK waveform. The output spectrum from a BPSK modulator is simply a double sideband suppressed carrier signal where the upper and lower side frequencies are separated from the carrier frequencies by a value equal to the one half the bit rate.

1.4 BPSK Transmitter:

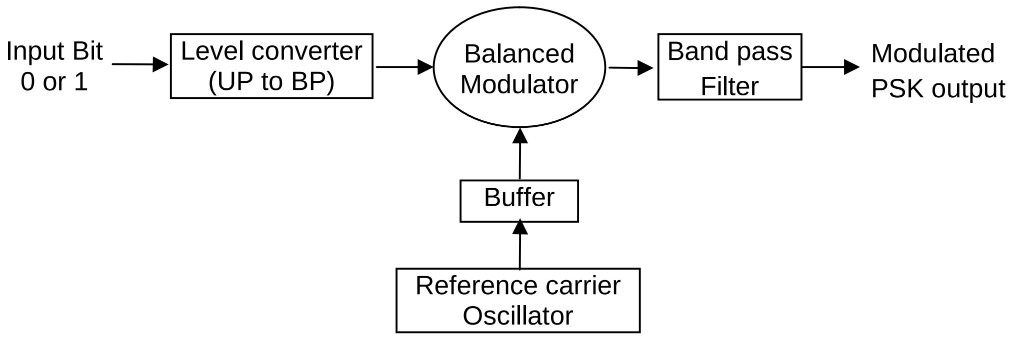


Fig: 1.4 BPSK Transmitters

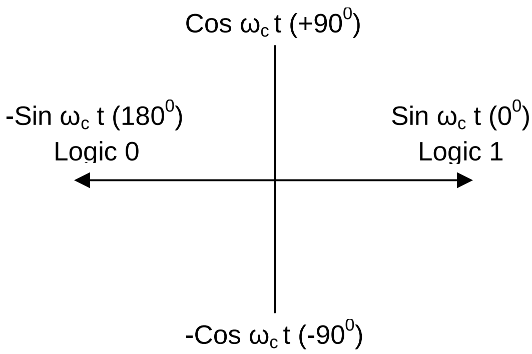
The Fig 1.4 above shows the simplified block diagram of BPSK Transmitter. The Balanced Modulator acts as phase reversing switch. Depending on the logic condition of the digital input, the carrier is transferred to the output either in phase or 180 ^{0} out of phase with the reference carrier oscillator. Fig 1.5(a), (b) &(c) show the Truth Table, Phasor Diagram and constellation diagram for BPSK modulator respectively. A constellation diagram which is sometimes called as signal space diagram is similar to the Phasor diagram except that the entire Phasor is not drawn. In a constellation diagram, only the relative positions of the peaks of the phasors are shown.

Binary Inputs	Output Phases
Logic 0	180^0
Logic 1	0^0

Fig 1.5 (a) Truth Table

1.5 What is a Constellation diagram?

A **constellation diagram** is a representation of a signal modulated by a digital modulation scheme such as quadrature amplitude modulation or phase-shift keying. It displays the signal as a two-dimensional scatter diagram in the complex plane at symbol sampling instants. In a more abstract sense, it represents the possible symbols that may be selected by a given modulation scheme as points in the complex plane. Measured constellation diagrams can be used to recognize the type of interference and distortion in a signal.



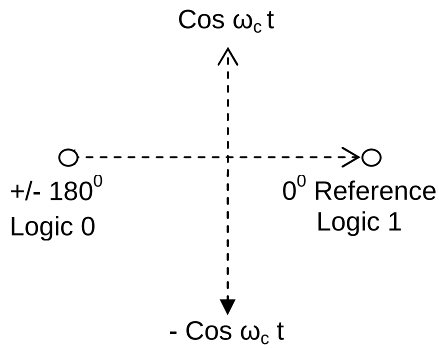


Fig 1.5 (b) Phasor Diagram **Fig 1.5 (c) Constellation Diagram**

1.6 BPSK Receiver

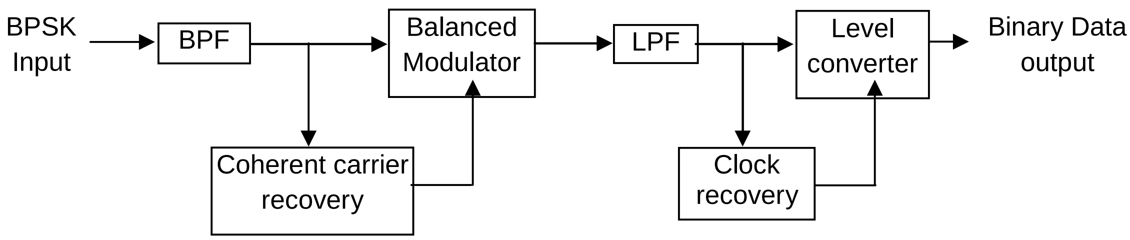


Fig: 1.6 Block Diagram of BPSK Receiver

Fig 1.6 shows the block diagram of a BPSK receiver. The input signal may be + sin ω_c t or – sin ω_c t. The coherent carrier recovery circuit detects and regenerates a carrier signal that is both frequency and phase coherent with the original transmit carrier. The Balance modulator is a product detector, the output is the product of the two inputs (the BPSK signal and the recovered carrier). The low pass filter (LPF) separates the recovered binary data from the complex demodulated signal.

Mathematically the demodulation process is as follows.

For a BPSK input signal of + sin ω_c t (logic 1), the output of the balanced modulator is

$(\sin \omega_c t)(\sin \omega_c t) \quad = \quad \sin^2 \omega_c t$

or, $\quad \sin^2 \omega_c t \quad = \quad ½ (1 - \cos 2\omega_c t)$

$\quad = \quad ½ - ½ \cos 2\omega_c t \rightarrow$ (filtered out)

Leaving output = + ½ V = logic 1

We know that the output of the balanced modulator contains a positive voltage [+ ½ V] and a cosine wave at twice the carrier frequency (2 ω_c). The LPF has a cutoff frequency much lower than (2 ω_c) and thus blocks the second harmonic of the carrier and passes only the positive constant component. A positive voltage represents a demodulated logic1

For a BPSK input signal of - sin ω_c t (logic 0), the output of the balanced modulator is

Output = (- sin ω_c t) (sin ω_c t) = - sin ^{2} ω_c t

- Sin ^{2} ω_c t = - ½ (1- cos 2 ωc t) = -½ +½ cos 2 ωc t → (filtered out)

Leaving output = - ½ V = logic 0

The output of the balanced modulator contains a positive voltage [- ½ V] and a cosine wave at twice the carrier frequency (2 ω_c). Again the LPF has a cutoff frequency much lower than (2 ω_c) and thus blocks the second harmonic of the carrier and passes only the negative constant component. A negative voltage represents a demodulated logic 0.

1.7 2 to L level converter

In order to understand how the M-Ary QAM, or M-Ary PSK modulators and demodulators operate, a review of the operation of a base band 2 to L level converter is necessary. Consider a 2 to 4 level converter shown in figure 1.7.

Basically, what occurs is the grouping of digital bit stream into two bit blocks, or dibit, as shown in Figure 1.7. The coding is such that 10 represent a voltage of +V_2, dibit 11 represents a voltage level of +V_1, dibit 01 becomes –V_1, and dibit 00 becomes -V_2. Thus it can be seen that for four levels, only $\log_2 4$ = 2 binary bits or dibit is required to produce four distinct base band voltage levels. For L levels, blocks of $\log_2 L$ bits are required to assist in the binary coding of each of L levels. For a 16 QAM or 16 PSK, 4 bits are required to assist in the binary coding. BPSK and QPSK are subsets of M - ary PSK, where the output can assume one of M discrete phase states.

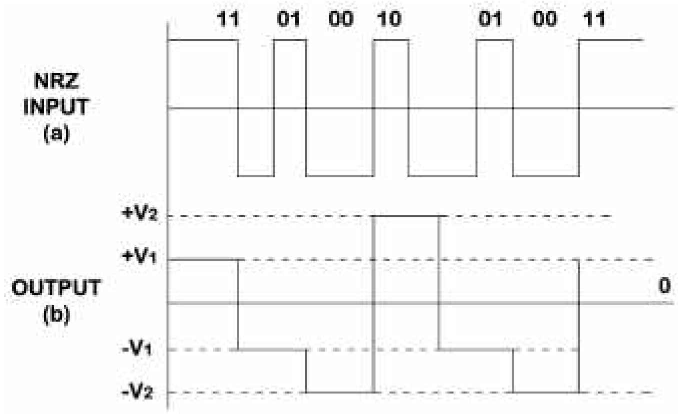


Figure 1.7 2 to 4 level converter

In case of M-ary system M = 2^N where,

M = No. of allowable phase states.

N= No. of binary bits needed to quantize (in blocks) M

Also symbol rate $r_s = r_b / \log_2 M$ where r_b is bit rate.

This means signaling rate can be reduced in an M - Ary system by a factor N. Also, since the maximum rate of symbols through a channel is proportional to its bandwidth, the reduced rate reduces the bandwidth. Hence, the M-Ary systems are termed as bandwidth efficient. But as the level of modulation i.e., the value of M increases, the signal space reduces and the phase vectors get crowded resulting in the increase in the probability of error due to unavoidable phase distortion in the demodulation and synchronization process.

Hence, for a given transmit power, the demodulator need more and more E_b/N_o for required BER of the demodulated data, when the level of modulation becomes higher. In practice, the QPSK (4 level system) is found optimum for achieving bandwidth efficiency without sacrificing the implementation margin.

QPSK has four different phase states (45^0, 135^0, 225^0, & 315^0). To encode these phase angles, two bits are needed. That is why the data signals are transformed into dibit (which are binary coded) by series to parallel conversion. This combination of each two bit to a symbol, the bit rate is reduced by factor 2. To realize a QPSK modulator two double balanced mixers are fed with quadrature offset local oscillator and switched by base band signals. The outputs from mixers are combined to form a QPSK signal.

1. 8 QUATERNARY PHASE SHIFT KEYING (QPSK)

In QPSK, the data bits to be modulated are grouped into **symbols**, each containing two bits also called **dibit,** and each symbol can take on one of four possible values: 00, 01, 10, or 11. During each symbol interval, the modulator shifts the carrier to one of four possible phases corresponding to the four possible values of the input symbol. In the ideal case, the phases are each 90 degrees apart, and these phases are usually selected such that the signal constellation matches the configuration and four different phase values (i.e. 45, 135, 225 and 315 degrees) are used, as shown in Figure 1.8

As the serial data is taken 2 bits at a time to form the symbol; the symbol rate is half the bit-rate. So we can say that QPSK would only require half the bandwidth of BPSK for the same bit rate as its symbol-rate is half.

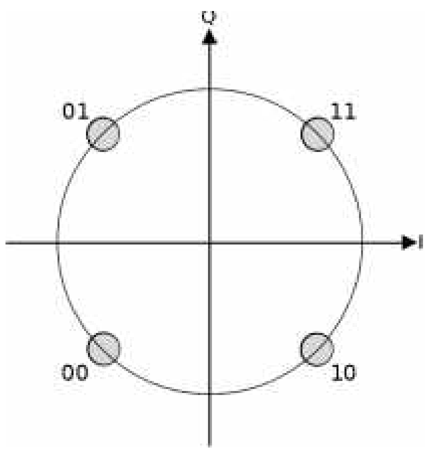


Fig 1.8: Constellation diagram of QPSK

1.9 QPSK Transmitter:

A block diagram of QPSK modulator is shown in figure 1.9. Two bits (**DIBIT**) are fed into bit splitter. After both bits have been serially inputted, they are simultaneously parallel outputted. One bit is directed towards **I** channel and the other to the **Q** channel. The **I** bit modulates the carrier that is in phase with the reference oscillator and the **Q** bit modulates a carrier that is 90^0 out of phase or Quadrature with the reference carrier.

It is seen, that once a dibit has been split into the **I** and **Q** channels, the operation is the same as in a BPSK modulator. Essentially, a QPSK modulator is two BPSK modulators combined in parallel. Again, for a logic 1 = +1V and a logic 0 = -1 V , two phases are possible at the output of the **I** balanced modulator ($+\sin\omega_c t$ and $-\sin\omega_c t$) , and two phases are possible at the output of the **Q** balanced modulator ($+\text{Cos}\ \omega_c t$ and $-\text{Cos}\ \omega_c t$) . When the linear summer combines the two quadrature (90^0 out of phase) signals , there are four possible resultant phasors given by these expressions ($+\sin\omega_c t + \text{Cos}\ \omega_c t$, $+\sin\omega_c t - \text{Cos}\ \omega_c t$, $-\sin\omega_c t + \text{Cos}\ \omega_c t$ and $-\sin\omega_c t - \text{Cos}\ \omega_c t$) .

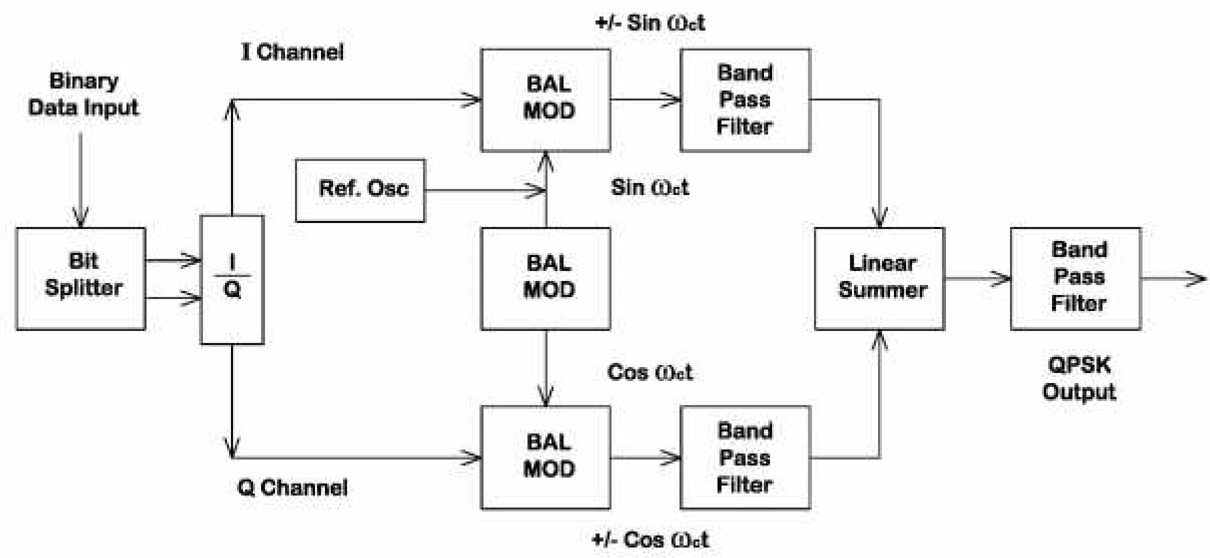


Fig: 1.9 Block Diagram of QPSK Modulator

These Phasors has exactly the same amplitude. Therefore, a QPSK signal can undergo almost $+45^0$ or -45^0 shifts in phase during transmission and still retain the correct encoded information when demodulated at the receiver.

1.10 Band width consideration of QPSK

With QPSK, as the input data are divided into two channels, the bit rate in either the **I** or the **Q** channel is equal to one half the input data rate ($f_b/2$). (Essentially the bit splitter stretches the **I** and **Q** bits to twice their input bit length). Consequently, the highest fundamental frequency present at the data input to the I or Q balanced modulator is equal to the one fourth of the input data rate (one half of $f_b/2 = f_b/4$). As a result, the output of the **I** and **Q** balance modulators requires a minimum ,double sided Nyquist band width equal to one half of the incoming bit rate (f_n = twice $f_b/4 = f_b/2$).

Thus with QPSK, a band width compression is realized (the minimum bandwidth is less than the incoming bit rate).

The output of the balanced modulators can be expressed mathematically as,

Output = $(\sin \omega_a t)(\sin \omega_c t)$

Where $\omega_a t = 2\pi f_b/4\, t$ and $\omega_c = 2\pi f_c t$
Modulating Phase UN modulated Carrier Phase

Thus, output $= (\sin 2\pi f_b/4\, t)\ (\sin 2\pi f_c t)$

$= \frac{1}{2}\cos 2\pi(f_c - f_b/4)t - \frac{1}{2}\cos 2\pi(f_c + f_b/4)t$

The output frequency spectrum extends from $f_c + f_b/4$ to $f_c - f_b/4$ and the minimum band width (f_N) is

$$(f_c + f_b/4) - (f_c - f_b/4) = 2 f_b/4 = f_b\mathbf{/2}$$

So it is seen that for a given input bit rate the minimum bandwidth required to pass the output of the QPSK modulator is equal to the one Half of that required for the BPSK modulator.

1.11 QPSK Receiver

The bock diagram of QPSK receiver is shown in the fig 1.10. The input signal is split into **I** and **Q** and is fed to the product detectors and the carrier recovery circuits. The carrier recovery circuits reproduces the original transmit carrier oscillator signal. The recovered carrier must be frequency and phase coherent with the transmit reference carrier .The QPSK signal is demodulated in the **I** and **Q** product demodulator, which generates the original **I** and **Q** data bits. The output of the product detectors are fed to the bit combining circuits or multiplexer where they are converted from parallel **I** and **Q** data channels to a single binary output data stream.

Mathematically, the demodulation process is as follows.

The receive QPSK signal ($-\sin \omega_c t + \cos \omega_c t$) is one of the inputs to the **I** product detector.

The other input is the recovered carrier ($\sin \omega_c t$). The output of the I product detector is

$$I = \underbrace{(-\sin \omega_c t + \cos \omega c\, t)}_{\text{QPSK input signal}}\ \underbrace{(\sin \omega_c t)}_{\text{carrier}}$$

$$= (-\sin \omega_c t)(\sin \omega_c t) + (\cos \omega_c t)(\sin \omega_c t)$$

$$= -\sin^2 \omega_c t + (\cos \omega_c t)(\sin \omega_c t)$$

$$= -\tfrac{1}{2}(1 - \cos 2\omega_c t) + \tfrac{1}{2}\sin(\omega_c + \omega_c)t + \tfrac{1}{2}\sin(\omega_c - \omega_c)t$$

$$= -\tfrac{1}{2} + \underbrace{\tfrac{1}{2}\cos 2\omega_c t + \tfrac{1}{2}\sin 2\omega_c t}_{\text{(Filtered out)}} + \underbrace{\tfrac{1}{2}\sin 0}_{\text{(Equal to 0)}} = -\tfrac{1}{2}\ \mathbf{V\ (logic\ 0)}$$

Again the receive QPSK signal ($-\sin \omega_c t + \cos \omega_c t$) is one of the inputs to the Q product detector. The other input is the recovered carrier shifted by 90^0 ($\cos \omega c\, t$). The output of the Q product detector is

$Q = (-\sin \omega_c t + \cos \omega_c t)(\cos \omega_c t)$
QPSK input signal carrier

$= \cos^2 \omega_c t - (\sin \omega_c t)(\cos \omega_c t)$

$= \frac{1}{2}(1 + \cos 2\omega_c t) - \frac{1}{2}\sin(\omega_c + \omega_c)t + \frac{1}{2}\sin(\omega_c - \omega_c)t$

$$= \underbrace{\tfrac{1}{2} + \tfrac{1}{2}\cos 2\omega_c t - \tfrac{1}{2}\sin 2\omega_c t}_{\text{(Filtered out)}} + \underbrace{\tfrac{1}{2}\sin 0}_{\text{(Equal to 0)}} \quad = \quad \mathbf{\tfrac{1}{2}\,V\ (logic\ 1)}$$

The demodulated I and Q bits (0 and 1 respectively) correspond to the constellation diagram and truth table.

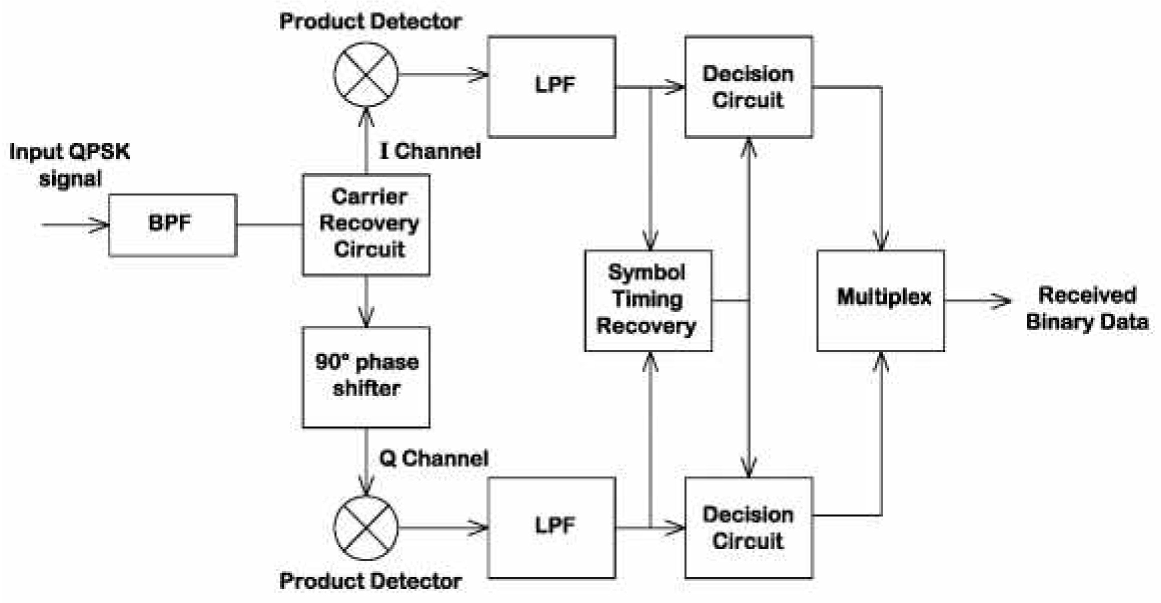


Fig 1.10: Block Diagram of QPSK Receiver

1.12 OFFSET QPSK or OQPSK

Offset QPSK **(**OQPSK) is a modified form of QPSK where the bit waveform on the I and Q channels are offset or shifted in phase from each other by one half of a bit time. The amplitude of a QPSK signal is ideally constant. In Offset QPSK, the transitions on the I and Q channels are staggered. In OQPSK constellation diagram shown that Phase transitions are therefore limited to 90 degree.

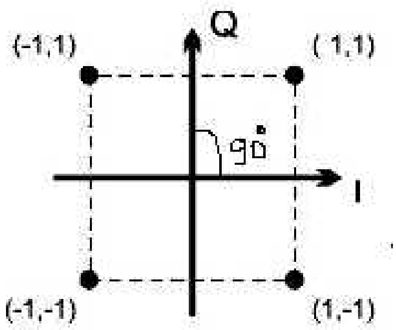


Fig 1.11: OQPSK constellation diagram

The spectrum of an OQPSK signal is identical to that of a QPSK signal; hence both signals occupy the same bandwidth. The staggered alignment of the even and odd bit streams does not change the nature of the spectrum. OQPSK retains its band limited nature even after nonlinear amplification, and therefore is very attractive for mobile communication systems where bandwidth efficiency and efficient nonlinear amplifiers are critical for low power drain. Further, OQPSK signals also appear to perform better than QPSK in the presence of phase jitter due to noisy reference signals at the receiver. OQPSK (offset QPSK) is a special version of QPSK in which the transmitted signal has no amplitude modulation. This disadvantage of an amplitude modulation is a result of 180° shifting in the phase. In OQPSK the incoming signal is divided in the modulator into two portions in-phase(I) and quadrature (Q)which are then transmitted shifted by a half symbol duration. In figure 1.12 shows that, a block diagram of OQPSK transmitter. The information bit stream is split up into in-phase (I-channel) and quadrature (Q-channel) via serial to parallel Converter. After, the signal is fed to the pulse shaping. In-phase signal is go to mixer but the quadrature signal is delay and then goes to the mixer. Finally, the two channels I and Q are summing get the output OQPSK signal.

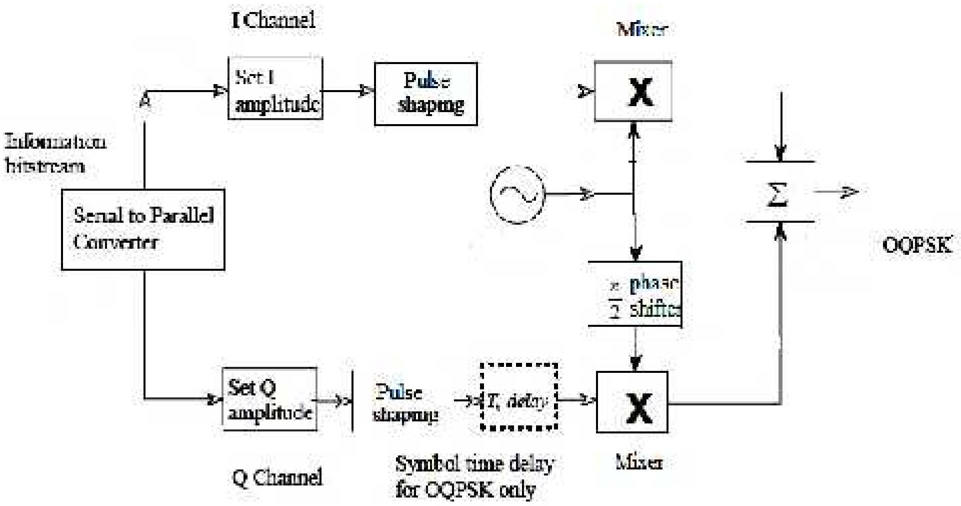


Fig 1.12: Block diagram of OQPSK transmitter

1.13 Eight Phase PSK (8PSK)

Eight Phase PSK (8PSK) is an M- ary encoding technique where M = 8. With an 8-PSK modulator, there are eight possible output phases, to encode eight different phases the incoming bits are considered in groups of three bits called tribits (2^3=8).

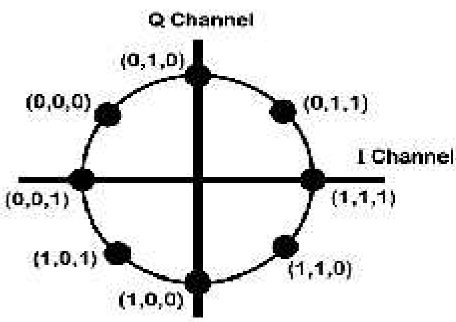


Fig 1.13 Constellation diagram of 8PSK

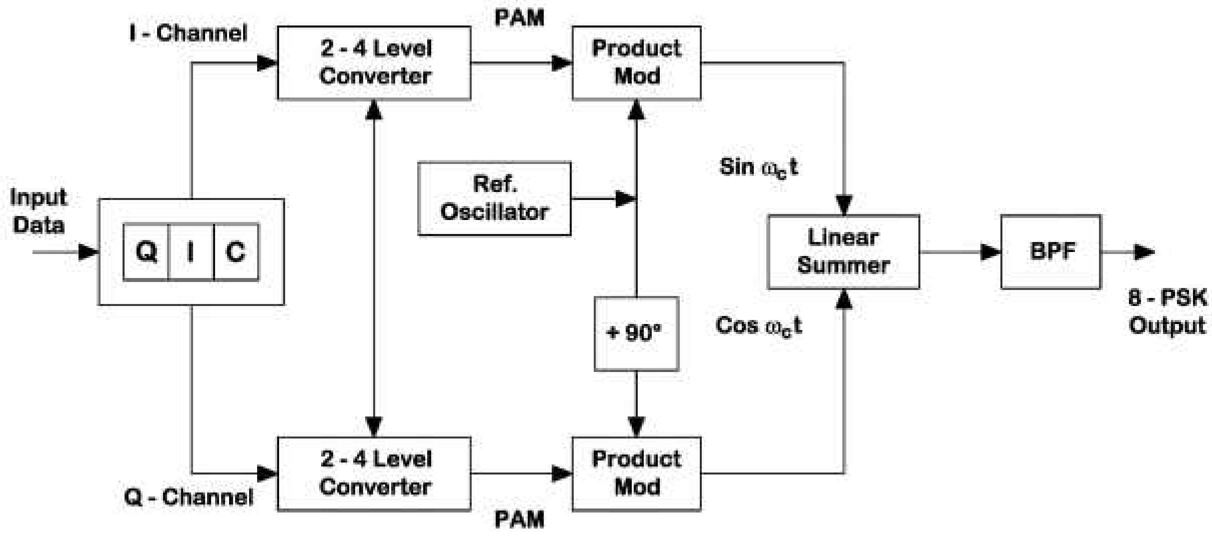


Fig 1.14 Block diagram of 8PSK Transmitter

A block diagram of an 8 PSK modulator is shown in figure 1.14 .The incoming bit stream enters the bit splitter, where it is converted to a parallel , three channel output (I = in phase channel,, Q=quadrature channel, and C is control channel) .Consequently ,the bit rate in each of the three channel is $f_b/3$. The bits in the I and C channels enters the 2-4 level converter, and the bits in the Q and C bar channels enter the Q channel 2-4 level converter. Essentially the 2-4 level converters are parallel input digital to analog converters which generates PAM signals. Now this is fed to Product modulator where it modulates with a reference carrier. The linear summer combines the two quadratures to produce 8 PSK output signals.

It is to be noted that the tribit code between any two adjacent phase's changes by only one bit, this type of code is called Grey code. This code is used to reduce the number of transmission errors.

1.14 8- PSK Receiver

Fig 1.15 shows the block diagram of 8 PSK receivers. The power splitter directs the input 8-PSK signal to the I and Q product detectors and the carrier recovery circuits. The carrier recovery circuit reproduces the original reference oscillator signal. The incoming 8 PSK signal is mixed with the recovered carrier in the I product detector and with a quadrature carrier in the Q product detector. The output of the product detectors are 4 levels PAM signals that are fed to the 4 to 2 level analog to digital convertors. The outputs from the I channel 4 to 2 level convertors are the I and C bits, where as the outputs from the Q channel 4 to 2 – level converters are the Q and C bar bits. The parallel to serial logic circuit converts the I/C and Q/C bar bits pair to serial I, Q and C output data streams.

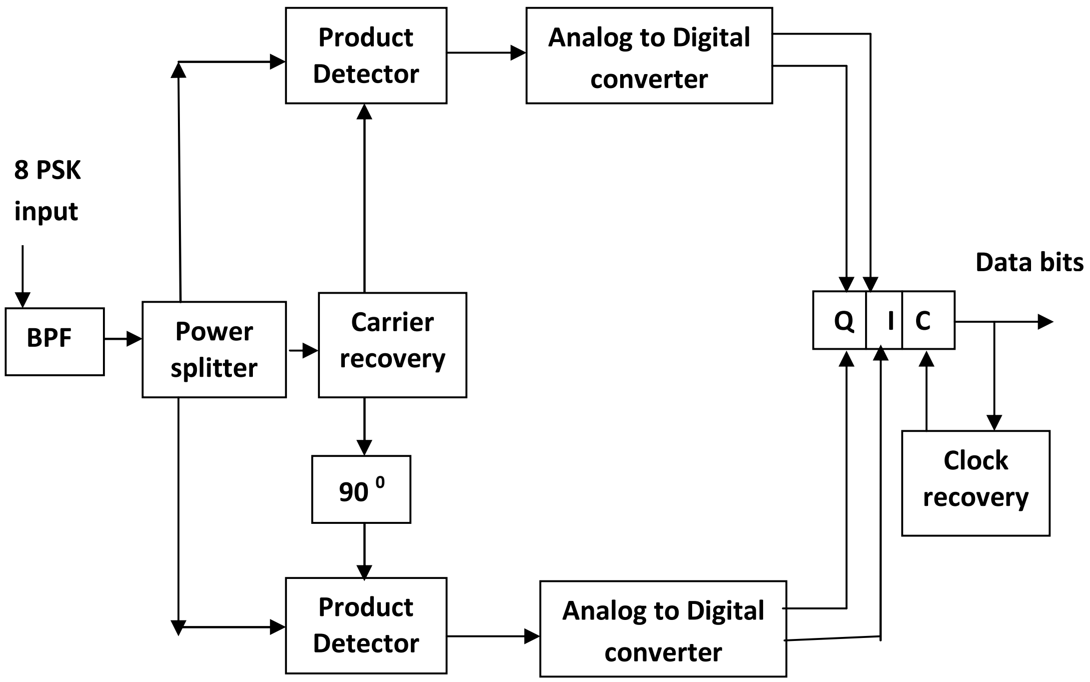


Fig 1.15 Block Diagram of 8 PSK Receivers

1.15 QUADRATURE AMPLITUDE MODULATION

Quadrature amplitude modulation (QAM) is a form of digital modulation, where the digital information is contained in both the amplitude and phase of the transmitted carrier. They are being increasingly used for data communications often within radio communications systems. Radio communications systems ranging from cellular technology through wireless systems including WIMAX, and Wi-Fi 802.11 use a variety of forms of QAM, and the use of QAM will only increase within the field of radio communications.

1.16 QAM advantages and disadvantages

Although QAM appears to increase the efficiency of transmission for radio communications systems by utilizing both amplitude and phase variations, it has a number of drawbacks. The first is that it is more susceptible to noise because the states are closer together so that a lower level of noise is needed to move the signal to a different decision point. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance. This is not the case with QAM.

The second limitation is also associated with the amplitude component of the signal. When a phase or frequency modulated signal is amplified in a radio transmitter, there is no need to use linear amplifiers, whereas when using QAM that contains an amplitude component, linearity must be maintained. Unfortunately linear amplifiers are less efficient and consume more power, and this makes them less attractive for mobile applications.

1.17 QAM applications

QAM is in many radio communications and data delivery applications. However some specific variants of QAM are used in some specific applications and standards.

For domestic broadcast applications for example, 64 QAM and 256 QAM are often used in digital cable television and cable modem applications. In the UK, 16 QAM and 64 QAM are currently used for digital terrestrial television using DVB - Digital Video Broadcasting. In the US, 64 QAM and 256 QAM are the mandated modulation schemes for digital cable as standardized by the SCTE in the standard ANSI/SCTE 07 2000. In addition to this, variants of QAM are also used for many wireless and cellular technology applications.

1.18 Constellation diagrams for QAM

The constellation diagrams show the different positions for the states within different forms of QAM, quadrature amplitude modulation. As the order of the modulation increases, so does the number of points on the QAM constellation diagram?

The diagrams below show constellation diagrams for a variety of formats of modulation:

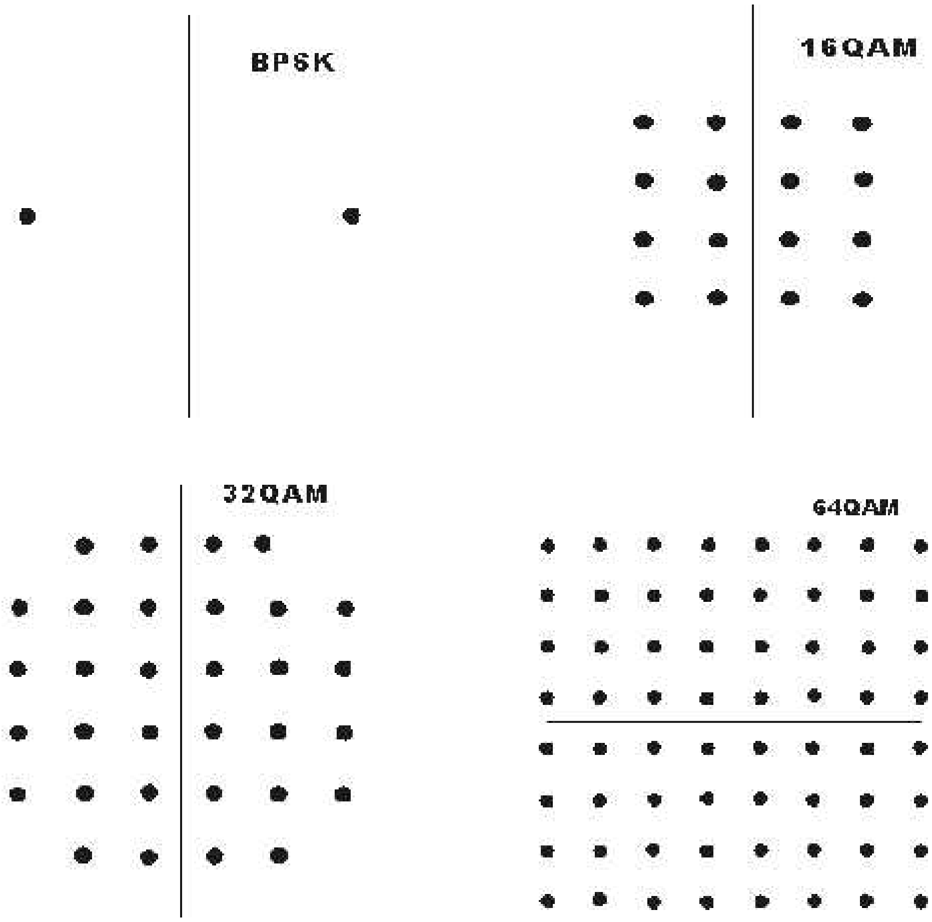


Fig 1.16: Constellation diagrams for QAM

1.19 QAM bits per symbol

The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol. By selecting a higher order format of QAM, the data rate of a link can be increased.

The table below gives a summary of the bit rates of different forms of QAM and PSK.

Modulation	Bits per symbol	Symbol Rate
BPSK	1	1 x bit rate
QPSK	2	1/2 bit rate
8PSK	3	1/3 bit rate
16QAM	4	1/4 bit rate
32QAM	5	1/5 bit rate
64QAM	6	1/6 bit rate

1.20 QAM noise margin

While higher order modulation rates are able to offer much faster data rates and higher levels of spectral efficiency for the radio communications system, this comes at a price. The higher order modulation schemes are considerably less resilient to noise and interference.

As a result of this, many radio communications systems now use dynamic adaptive modulation techniques. They sense the channel conditions and adapt the modulation scheme to obtain the highest data rate for the given conditions. As signal to noise ratios decrease errors will increase along with re-sends of the data, thereby slowing throughput. By reverting to a lower order modulation scheme the link can be made more reliable with fewer data errors and re-sends.

1.21 Eight QAM (8 QAM)

Eight QAM (8- QAM) is an M – ary encoding technique where M = 8. Unlike 8 PSK, the output signal from an 8 QAM transmitter is not a constant amplitude signal.

1.22 8 - QAM Transmitter

The block diagram of an 8 – QAM transmitter is shown fig 1.17, as we can observe the only difference between the 8 - QAM transmitter and the 8- PSK transmitter is the omission of the inverter between the C- channel and the Q product modulator. As with 8-PSK , the incoming data are divided into groups of three bits (tribits) ; the I.Q, and C bit streams, each with a bit rate equal to one third of the incoming data rate . Again the I and Q bits determine the polarity of the PAM signal at the output of the 2 to – 4 level converters, and the C channel determines the magnitude. Because the C bit is fed un inverted to both the I and Q channel 2- to -4 level converters, the magnitudes of the I and Q PAM signals are always equal. Their polarities depend on the logic condition of the I and Q bits and, therefore may be different.

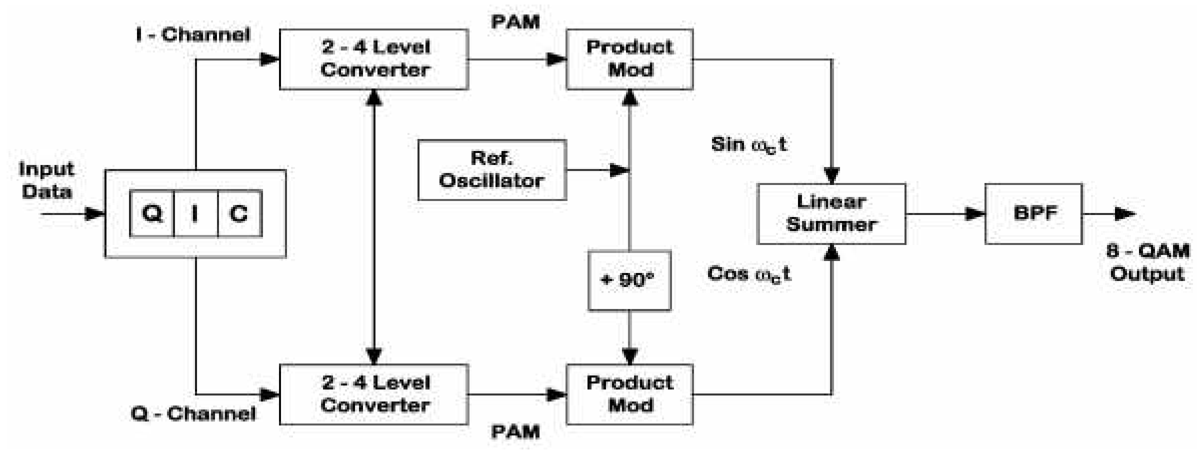


Fig 1 .17: Block Diagram of 8- QAM Transmitter

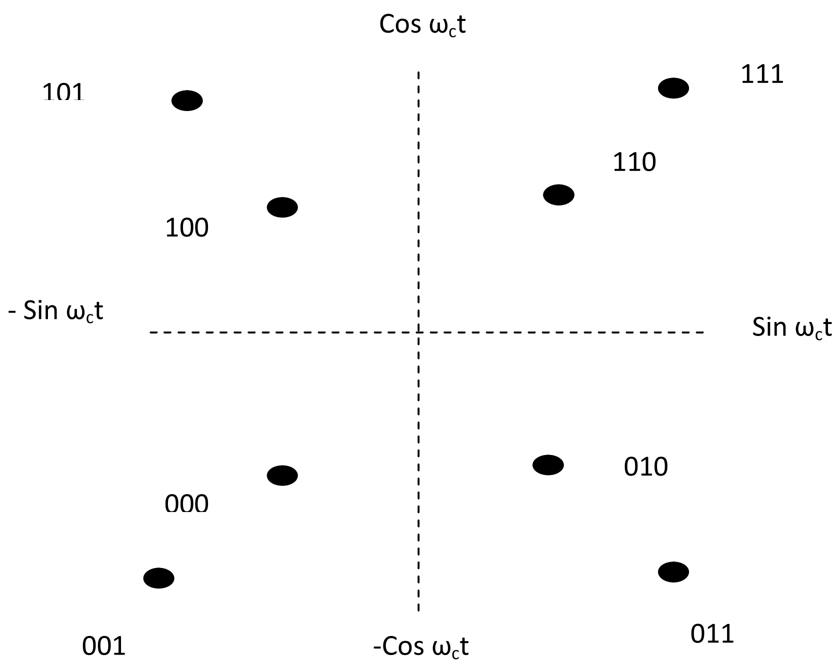


Fig 1.18: Constellation diagrams for 8- QAM

1.23 8 QAM receivers:

8 QAM receivers are almost identical to the 8 PSK receiver .The differences are the PAM levels at the output of the product detectors and the binary signals at the output of the analog to digital converters. because there are two transmit amplitudes possible with 8 –QAM that are different from those achievable with 8-PSK , the four demodulated PAM levels in 8- QAM are different from those in 8- PSK . Therefore, the conversion factor for the ADC must also be different. Also, with 8- QAM the binary output signals from the I channel ADC are the I and C bits, and the binary output signals from the Q channel ADC are the Q and C bits.

1.24 SIXTEEN QAM (16 QAM)

As with the 16 PSK, 16 QAM is an M-ary system, where M =16. The input data are acted on in groups of four ($2^4 = 16$). As with 8 – QAM, both the phase and amplitude of the transmit carrier are varied.

1.25 16 - QAM Transmitter

The block diagram for 16 QAM transmitters is shown in fig 1.19. The input binary data are divided into four channels; I, I /, Q and Q/. The bit rate in each channel is equal to one-fourth of the input bit rate. Four bits are serially clocked into the bit splitter, and then they are outputted simultaneously and in parallel with the I, I/, Q and Q/ channels .The I and Q bits determine the polarity at the output of the 2-4 level converters. The, I/ & Q/ determine the magnitude .Consequently, the 2-4 level converters generate a 4 level PAM signal. The PAM signal modulates the in phase and quadrature carriers in the product modulators.

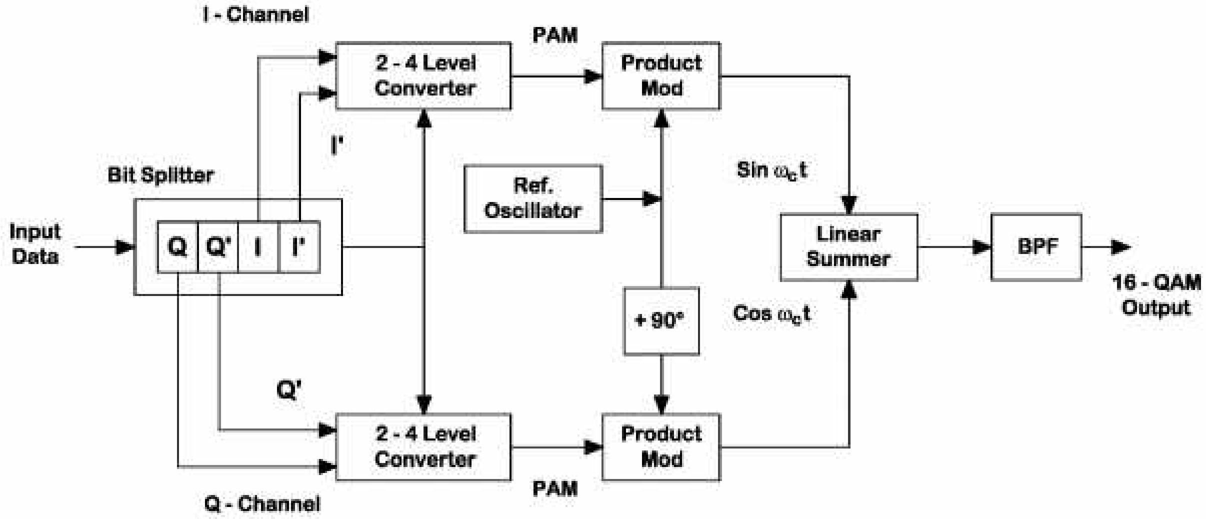


Fig 1.19 Block diagram of 16 QAM Transmitter

1.26 QAM Highlight

Quadrature Amplitude Modulation or QAM is a form of modulation which is widely used for modulating data signals onto a carrier used for radio communications. It is widely used because it offers advantages over other forms of data modulation such as PSK, although many forms of data modulation operate alongside each other.

Quadrature Amplitude Modulation, QAM is a signal in which two carriers shifted in phase by 90^0 are modulated and the resultant output consists of both amplitude and phase variations. In view of the fact that both amplitude and phase variations are present in it may also be considered as a mixture of amplitude and phase modulation.

1.27 Minimum Shift Keying, MSK

Minimum shift keying, MSK, is a form of phase shift keying, PSK, that is used in a number of applications. A variant of MSK modulation, known as Gaussian filtered Minimum Shift Keying, GMSK, is used for a number of radio communications applications including in the GSM cellular telecommunications system. In addition to this, MSK has advantages over other forms of PSK and as a result it is used in a number of radio communications systems.

1.28 Reason for Minimum Shift Keying, MSK

It is found that binary data consisting of sharp transitions between "one" and "zero" states and vice versa which potentially creates signals that have sidebands extending out a long way from the carrier, and this creates problems for many radio communications systems, as any sidebands outside the allowed bandwidth cause interference to adjacent channels and any radio communications links that may be using them.

1.29 Minimum Shift Keying, MSK basics

The problem can be overcome in part by filtering the signal, but is found that the transitions in the data become progressively less sharp as the level of filtering is increased and the bandwidth reduced. To overcome this problem GMSK is often used and this is based on Minimum Shift Keying, MSK modulation. The advantage of which is what is known as a continuous phase scheme. Here there are no phase discontinuities because the frequency changes occur at the carrier zero crossing points.

When looking at a plot of a signal using MSK modulation, it can be seen that the modulating data signal changes the frequency of the signal and there are no phase discontinuities. This arises as a result of the unique factor of MSK that the frequency difference between the logical one and logical zero states is always equal to half the data rate. This can be expressed in terms of the modulation index, and it is always equal to 0.5.

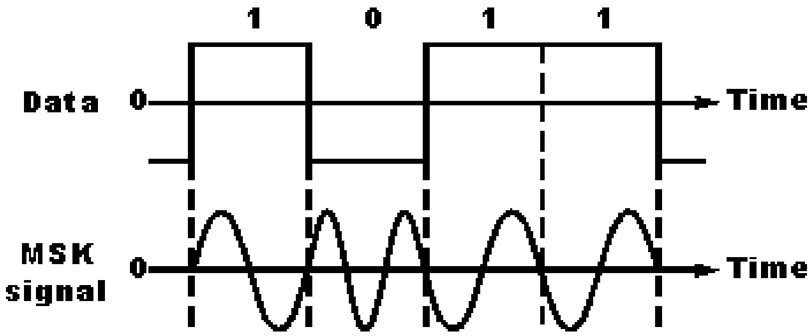


Fig 1.20 Signal using MSK modulation

MSK – How does It Work? The baseband modulation starts with a bit stream of 0's and 1's and a bit-clock. The baseband signal is generated by first transforming the 0/1 encoded bits into -1/1 using an NRZ filter. This signal is then frequency modulated to produce the complete MSK signal. The amount of overlap that occurs between bits will contribute to the inter-symbol interference

Phase shift keying, PSK, is widely used these days within a whole raft of radio communications systems. It is particularly well suited to the growing area of data communications. PSK, phase shift keying enables data to be carried on a radio communications signal in a more efficient manner than Frequency Shift Keying, FSK, and some other forms of modulation.

With more forms of communications transferring from analogue formats to digital formats, data communications is growing in importance and along with it the various forms of modulation that can be used to carry data.

There are several flavors of phase shift keying, PSK that are available for use. Each form has its own advantages and disadvantages, and a choice of the optimum format has to be made for each radio communications system that is designed. To make the right choice it is necessary to have a knowledge and understanding of the way in which PSK works.

1.30 Overview

Phase shift keying, PSK, is a particularly important form of modulation these days. With most of the traffic on the newer radio communications systems and radio communications links being carried as data and using forms of phase shift keying, PSK, it is of particular importance

Gaussian Minimum Shift Keying, or to give it its full title Gaussian filtered Minimum Shift Keying, GMSK, is a form of modulation used in a variety of digital radio communications systems. It has advantages of being able to carry digital modulation while still using the spectrum efficiently. One of the problems with other forms of phase shift keying is that the sidebands extend outwards from the main carrier and these can cause interference to other radio communications systems using nearby channels.

In view of the efficient use of the spectrum in this way, GMSK modulation has been used in a number of radio communications applications. Possibly the most widely used is the GSM cellular technology which is used worldwide and has well over 3 billion subscribers.

1.31 GMSK basics

MSK and also GMSK modulation are known as a continuous phase scheme and also continuous frequency shift keying. The on-off binary signal is first transformed to a polar binary signal. The polar binary signal is filtered such that a Gaussian-shaped signal is produced. Then Frequency modulation is then applied to the signal

Here there are no phase discontinuities because the frequency changes occur at the carrier zero crossing points. This arises as a result of the unique factor of MSK that the frequency difference between the logical one and logical zero states is always equal to half the data rate. This can be expressed in terms of the modulation index, and it is always equal to 0.5.

A plot of the spectrum of an MSK signal shows fig 1.20 sidebands extending well beyond a bandwidth equal to the data rate. This can be reduced by passing the modulating signal through a low pass filter prior to applying it to the carrier. The requirements for the filter are that it should have a sharp cut-off, narrow bandwidth and its impulse response should show no overshoot. The ideal filter is known as a Gaussian filter which has a Gaussian shaped response to an impulse and no ringing. In this way the basic MSK signal is converted to GMSK modulation.

1.32 Generating GMSK modulation

There are two main ways in which GMSK modulation can be generated. The most obvious way is to filter the modulating signal using a Gaussian filter and then apply this to a frequency modulator where the modulation index is set to 0.5 as shown in fig 1.21. This method is very simple and straightforward but it has the drawback that the modulation index must exactly equal 0.5. In practice this analogue method is not suitable because component tolerances drift and cannot be set exactly.

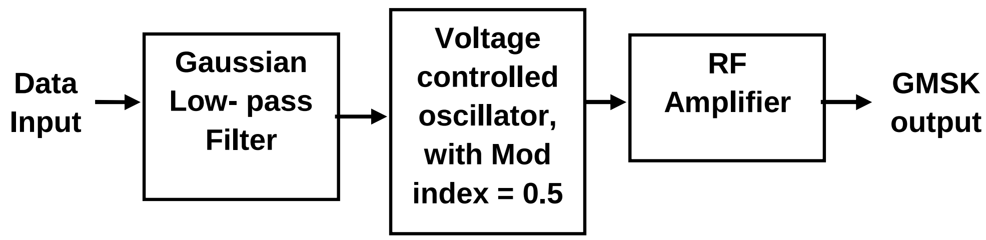


Fig 1.21 Generating GMSK using a Gaussian filter and VCO

A second method is more widely used. Here what is known as a quadrature modulator is used as shown in fig 1.22. The term quadrature means that the phase of a signal is in quadrature or 90^0 to another one. The quadrature modulator uses one signal that is said to be in-phase and another that is in quadrature to this. In view of the in-phase and quadrature elements this type of modulator is often said to be an I-Q modulator. Using this type of modulator the modulation index can be maintained at exactly 0.5 without the need for any settings or adjustments. This makes it much easier to use, and capable of providing the required level of performance without the need for adjustments. For demodulation the technique can be used in reverse.

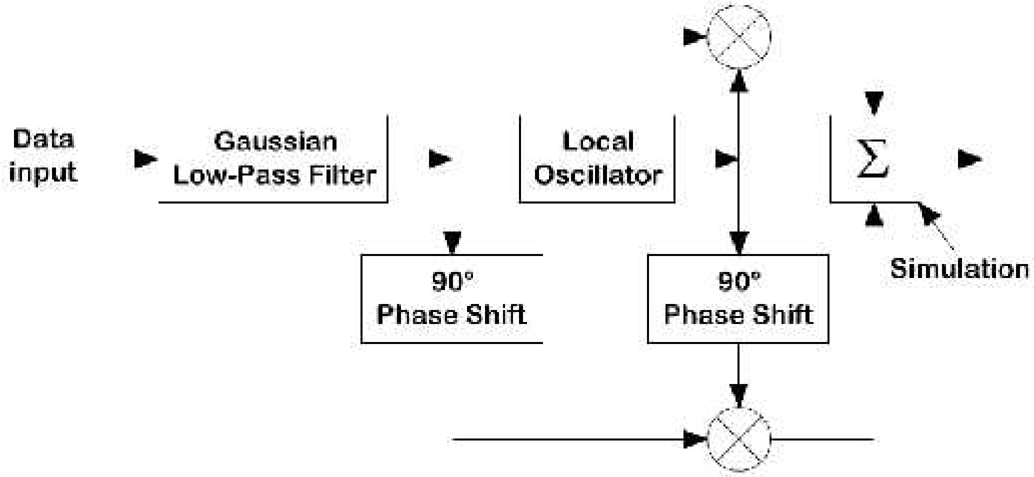


Fig 1.22 Block diagram of I-Q modulator used to create GMSK

1.33 Advantages of GMSK modulation

There are several advantages to the use of GMSK modulation for a radio communications system. One is obviously the improved spectral efficiency when compared to other phase shift keyed modes.

A further advantage of GMSK is that it can be amplified by a non-linear amplifier and remain undistorted .This is because there are no elements of the signal that are carried as amplitude variations. This advantage is of particular importance when using small portable transmitters, such as those required by cellular technology. Non-linear amplifiers are more efficient in terms of the DC power input from the power that they convert into a radio frequency signal.

This implies that the power consumption for a given output is much less and this results in lower levels of battery consumption; a very important factor for cell phones.

A further advantage of GMSK modulation again arises from the fact that none of the information is carried as amplitude variations. This means that is immune to amplitude variations and therefore more resilient to noise, than some other forms of modulation, because most noise is mainly amplitude based.

1.34 GMSK highlights

GMSK modulation is a highly successful form of modulation, being used in GSM cellular technology, and as a result, its use is particularly widespread. It is also used in other radio communications applications because of its advantages in terms of spectral efficiency, resilience to noise and its ability to allow the use of efficient transmitter final amplifiers. Even though other radio communications systems utilize other forms of modulation, GMSK is an ideal choice for many applications.

Objective:

1) ASK is no longer used in digital communication systems due to --------- problems. (Noise)

2) FSK signaling schemes are used mainly for ---------speed digital data transmissions. (Low)

3) The output spectrum from a BPSK modulator is simply a -------------- –sideband suppressed carrier (Double)

4) -------------------- represents the possible symbols that may be selected by a given modulation scheme as points in the complex plane. (constellation diagram)

5) --------------- has four different phase states (45^0, 135^0, 225^0, & 315^0). (OQPSK)

6) In QPSK, the data bits to be modulated are grouped into symbols, each containing --------- bits also called --------- (Two, Dibit)

7) In Offset QPSK the bit waveform on the I and Q channels are offset or shifted in phase from each other by ------------- of a bit time (one half)

8) Eight Phase PSK (8PSK) is an M- ary encoding technique where M = ----------- (8)

9) Quadrature amplitude modulation (QAM) is a form of digital modulation where the digital information is contained in both the -------------of the transmitted carrier. (Amplitude and phase)

10) By selecting a higher order format of----------modulation, the data rate of a link can be increased. (QAM)

11) GMSK modulation is also known as ------------------------ (continuous phase scheme)

Subjective:

1. Explain QAM with the help of a diagram.

2. What is the need for QPSK in digital modulation

3. Draw the block diagram of QPSK transmitter and briefly explain.

4. Draw the block diagram of QPSK receiver and briefly explain

5. Write short notes on :
   a. 8 PSK
   b. Constellation diagram
   c. OQPSK
   d. QAM
   e. MSK
   f. GMSK

ANEXURE A

PASSIVE DEVICES

A.1.0 Hybrid

Any device, which provides impedance matching between certain circuits and isolation between other circuits, may be referred as a ’Hybrid’. It may be a transformer, a resistance bridge, or a wave-guide device for Microwave Frequencies

A.1.1 Transformer Hybrid

A **hybrid coil** (or **bridge transformer**, or sometimes **hybrid**) is a transformer that has three windings, and which is designed to be configured as a circuit having four branches, (i.e. ports) that are conjugate in pairs. A signal arriving on one branch is divided between the two adjacent branches but does not appear at the opposite branch. In the schematic diagram, the signal into W splits between X and Z, and no signal passes to Y. Similarly, signals into X split to W and Y with none to Z, etc.

Correct operation requires matched characteristic impedance at all four ports.

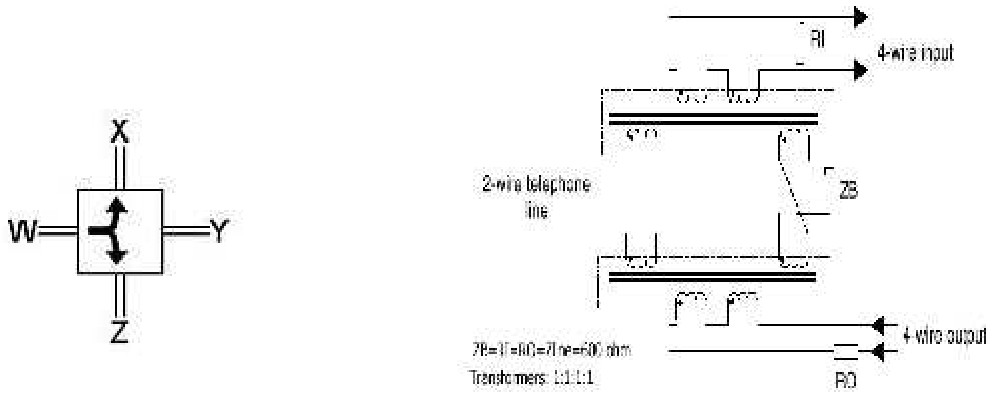


Fig A.1.1 (a) W and Y, X and Z are conjugate pair b) basic hybrid configuration

The primary use of a voice band hybrid coil is to convert between 2-wire and 4-wire operation in sequential sections of a communications circuit, for example in a four-wire terminating set. Such conversion was necessary when repeaters were introduced in a 2-wire circuit, a frequent practice at early 20th century telephony. Without hybrids, the output of one amplifier feeds directly into the input of the other, resulting in a howling situation (see Fig A.1.1 (c)). By using hybrids, the outputs and inputs are isolated, resulting in correct 2-wire repeater operation. Late in the century, this practice became rare but hybrids continued in use in line cards.

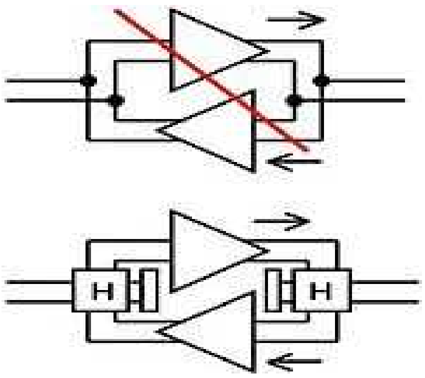


Fig A.1.1 (c) Using hybrids for bidirectional amplification

A.1.2 Resistance Hybrid

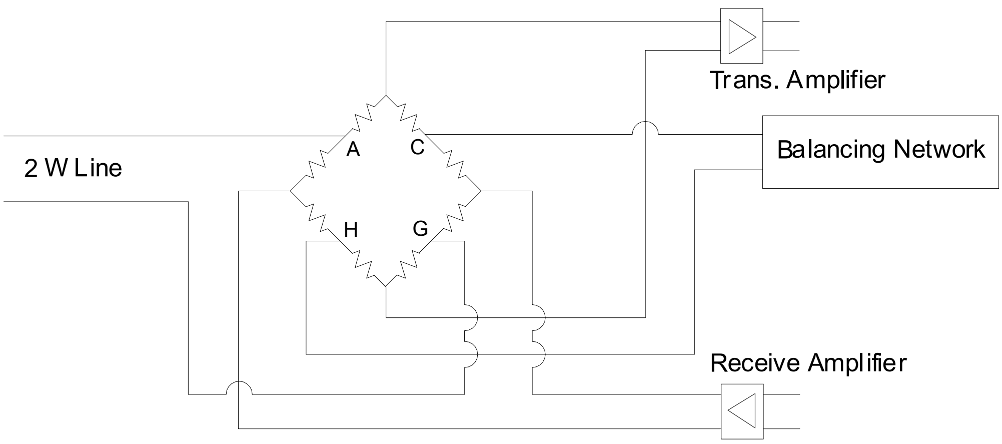


Fig A.1.2 Resistance Hybrid

It consists of 4 equal center tapped resistors. It does not give as precise a balance as the Hybrid transformers can give. For voice frequency (300 - 3400 HZ) applications, the transmission loss of a resistance hybrid is 6db to 9.5 dB. In this frequency range the transformer hybrid is widely used because it introduces less loss (3.5 dB) as compared to resistance hybrid (6 dB minimum). But for frequencies above 1 MHz, the transformer losses increase and resistance hybrid is preferable. For this reason, in Microwave Radio equipments the resistance hybrids are widely used.

A.1.3 Applications

1. Hybrids are used in telephones to reduce the side tone, or volume of microphone output that was fed back to the earpiece. Without this, the phone users own voice would be louder in the earpiece than the other party's.
2. Hybrids also had their windings so arranged as to act as an impedance matching transformer. Today, the transformer version of the hybrid has been replaced by resistor networks and compact IC versions, which uses integrated circuit electronics to do the job of the hybrid coil.
3. Radio-frequency hybrids are used to split radio signals, including television. The splitter divides the antenna signal to feed multiple receivers.

A.2.0 ATTENUATORS

An attenuator is a resistive network designed to introduce a known loss in a signal transmission path. To prevent attenuation distortion, attenuator networks are designed using purely resistive components**.** In a number of applications a need comes to introduce a specified loss between source and a matched load without altering impedance relationship. Hence, attenuator serves two purposes; one is introducing known attenuation (loss) and other one is impedance matching between input and output circuits.

Generally a transformer is used for impedance matching purposes. But a transformer introduces attenuation distortion (all frequencies are not attenuated to the same degree) in carrier frequency circuits.

These resistive attenuator networks will introduce no phase shift. Hence, in case of attenuator networks, the phase constant (β) will be zero, and the propagation constant (γ) will simply be equal to the attenuation constant (α).

Attenuators can be fixed or variable. A fixed Attenuator of constant attenuation is called a **Pad**. An attenuator network uses resistances to which the input and output impedances are matched.

The decrease in power due to insertion of an attenuator is expressed in decibels.

Attenuation in dB, $\mathbf{D = 10 \log_{10} (P_1/P_2)}$

Where P_1 is the input power and P_2 is the output power.

Basic attenuators are pi pads (π-type) and T pads. These may be required to be balanced or unbalanced networks depending on whether the line geometry with which they are to be used is balanced or unbalanced. For instance, attenuators used with coaxial lines would be the unbalanced form while attenuators for use with twisted pair are required to be the balanced form

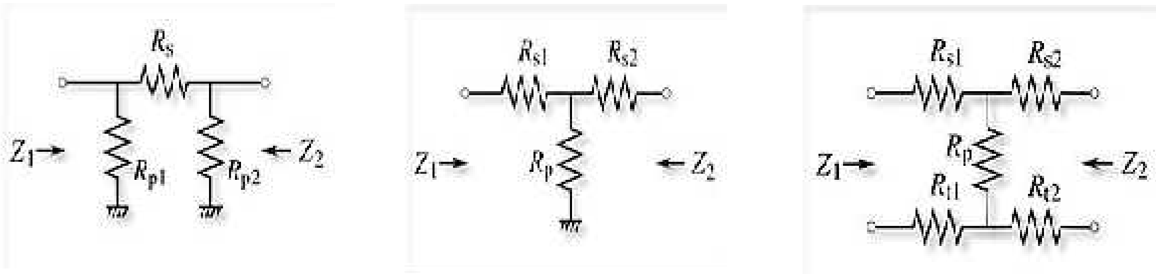


Fig A.2.1 (a) π- type balanced attenuator (b) T-type unbalanced attenuator (c) T-type balanced attenuator

A.2.1 Applications

In a number of applications a need comes to introduce a specified loss between source and a matched load without altering impedance relationship. Hence, attenuator serves two purposes; one is introducing known attenuation (loss) and other one is impedance matching between input and output circuits

A.2.2 RF attenuators

Radio frequency attenuators are typically coaxial in structure with precision connectors as ports and coaxial, micro strip or thin-film internal structure. The size and shape of the attenuator depends on its ability to dissipate power. RF attenuators are used as loads for and as known attenuations and protective dissipations of power in measuring RF signals.

Fig A.2.2 30dB 5W RF-attenuator, DC-18GHz, with N-type coaxial connectors

A.2.3 Optical attenuator

An optical attenuator is a device used to reduce the power level of an optical signal, either in free space or in an optical fiber. The basic types of optical attenuators are fixed, step-wise variable, and continuously variable.

Applications

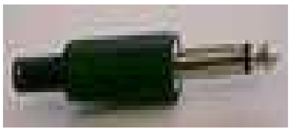
Attenuators are commonly used in fiber optic communications, either to test power level margins by temporarily adding a calibrated amount of signal loss, or installed permanently to properly match transmitter and receiver levels.

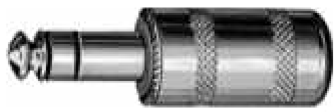
A.3.0 Connectors

Interconnections, between sub-units or modules, are needed in every electronic system for two main purposes. First purpose is for the system’s own functioning as single and complete system. The second purpose is for making measurements and conducting tests on the system for both maintenance and restoration.

A.3.1 TYPES OF CONNECTORS: a) Audio Connectors b) Coaxial Connectors

A.3.1.1 Audio Connectors: Two of the most common connectors used for professional audio are *3-pin XLR*, *RCA*, and 1/4" Phone Connector *(6.5mm jacks)*. Both *3-pin XLR* and *6.5mm jacks* are used with balanced cables whereas *RCA* connector is used with unbalanced cables.



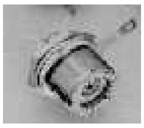
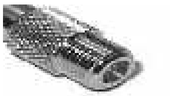
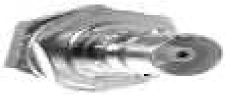
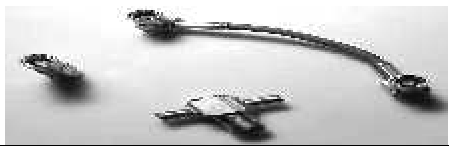


3-pin XLR Male 3-pin XLR Female
1/4" Mono Connector 1/4" Stereo

RCA Connector (Male)

Frequency of operation: Max. Up to 10 MHz

A.3.1.2 Coaxial Connectors (RF connectors)

Sl.No.	Type of connector	Frequency of operation
1.	  UHF Connector	300MHz or less
2.	F Connector  	250MHz to 1GHz
3.	Type N Connector 	12 GHz or more
4.	C Connector**:** It is called Concelman's connector 	12GHz
5.	BNC Connector: The "Bayonet Neil-Concelman"connector. 	2GHz or higher
6.	SMA Connector (Sub-Miniature A'.) Very popular, small, threaded connectors.  	12 to 18GHz
6(a).	SMC Connector**:** A push-on version of the SMA  	
6(b).	SMB Connector**:** A very small version of the SMC 	

ANNEXURE B

FUNDAMENTAL OF ELECTRONICS

B.1.0 SEMICONDUCTORS

A semiconductor is a material that has intermediate conductivity between a conductor and an insulator. It means that it has unique physical properties somewhere in between a conductor like aluminum and an insulator like glass. In a process called **doping**, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material. Examples for semiconductors include **silicon**, the basic material used in the integrated circuit, and **germanium**, the semiconductor used for the first transistors

Semiconductors may be divided as Intrinsic (pure) and extrinsic (impure). Again extrinsic semiconductor is classified as N-type and P-type.

N-type semiconductors are materials which have Pentavalent **impurity** atoms (e.g. Antimony) (donor) added and conducts by "**electron"** movement.

P-type are materials which have Trivalent impurity atoms (e.g. Boron) (Acceptors) added and conduct by "hole" movement and are called, P-type Semiconductors

A diode is one of the simplest semiconductor devices, which has the characteristic of passing current in one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential I-V relationship and therefore we cannot described its operation by simply using an equation such as Ohm’s law.

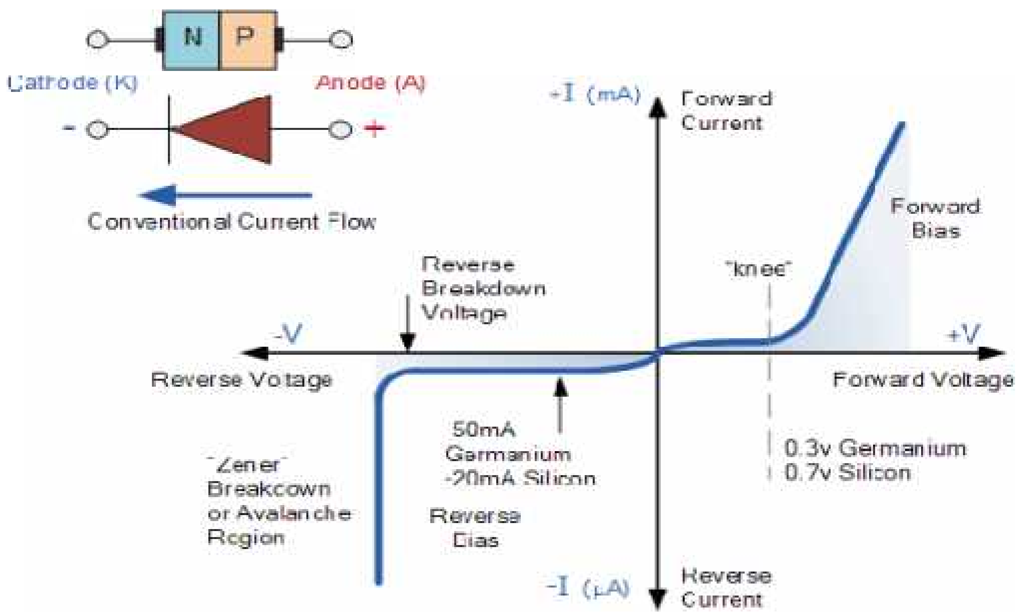


Fig B.1.1 Junction Diode Symbol and Static I-V Characteristics

B.1.1 PN junction region of a Junction Diode has the following important characteristics

Semiconductors contain two types of mobile charge carriers, **Holes** and **Electrons**. The holes are positively charged while the electrons negatively charged. The junction region itself has no charge carriers and is known as the depletion region. The junction (depletion) region has a physical thickness that varies with the applied voltage. When a diode is **Zero Biased** no external energy source is applied and a natural **Potential Barrier** is developed across a depletion layer which is approximately 0.5 to 0.7v for silicon diodes and approximately 0.3 of a volt for germanium diodes. When a junction diode is **Forward Biased,** the thickness of the depletion region reduces and the diode acts like a short circuit allowing full current to flow and if junction diode is **Reverse Biased,** the thickness of the depletion region increases and the diode acts like an open circuit blocking any current flow, (only a very small leakage current).

B.2.0 TRANSISTORS

A **TRANSISTOR** is a three or more element solid-state device that amplifies by controlling the flow of current carriers through its semiconductor materials. The three elements of a transistor is (1) the EMITTER, which gives off current carriers, (2) the BASE, which controls the carriers, and (3) the COLLECTOR, which collects the carriers.

B.2.1 BASIC TYPES OF TRANSISTORS are the NPN and PNP. The only difference is the symbols between the two transistors are the direction of the arrow on the emitter. If the arrow points in, it is a PNP transistor and if it points outward, it is an NPN transistor.

Fig B.2.1 Schematic symbols for PNP- and NPN-type BJTs.

B.2.2 PROPER BIASING OF A TRANSISTOR enables the transistor to be used as an amplifier. To function in this capacity, the emitter-to-base junction of the transistor is forward biased, while the base-to-collector junction is reverse biased.

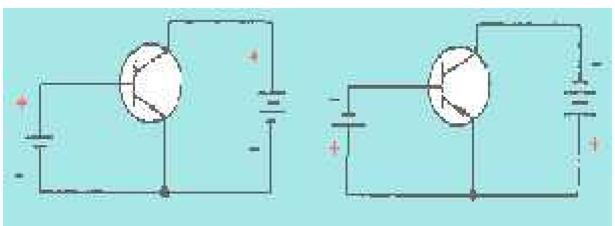


Fig B.2.2 PROPER BIASING OF A TRANSISTOR

NPN TRANSISTOR OPERATION is basically the action of a relatively small emitter-base bias voltage controlling a relatively large emitter-to-collector current.

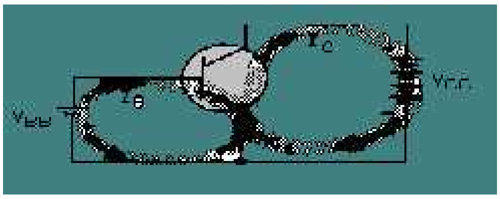


Fig B.2.3 NPN TRANSISTOR OPERATION

PNP TRANSISTOR OPERATION is essentially the same as the NPN operation except the majority current carriers is holes and the bias batteries are reversed.

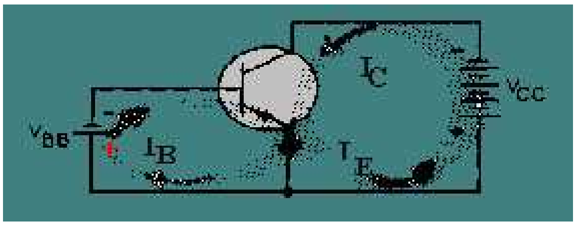


Fig B.2.4 PNP TRANSISTOR OPERATION

CUTOFF occurs when the base-to-emitter bias prevents current from flowing in the emitter circuit. For example, in the PNP transistor, if the base becomes positive with respect to the emitter, holes are repelled at the emitter-base junction. This prevents current from flowing in the collector circuit.

SATURATION occurs in a PNP transistor when the base becomes so negative, with respect to the emitter, that changes in the signal are not reflected in collector-current flow.

B.2.3 TRANSISTOR CONFIGURATION is the particular way a transistor is connected in a circuit. A transistor may be connected in any one of three different configurations: common emitter (CE), common base (CB), and common collector (CC).

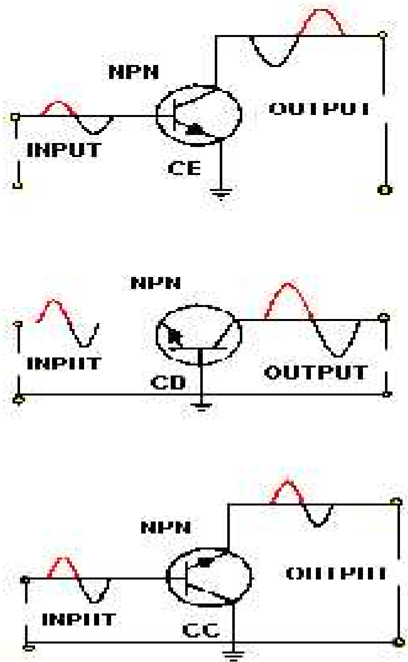


Fig B.2.5 TRANSISTOR CONFIGURATION

B.2.3.1 COMMON-EMITTER CONFIGURATION (CE) is the most frequently used configuration in practical amplifier circuits, since it provides good voltage, current, and power gain. The input to the CE is applied to the base-emitter circuit and the output is taken from the collector-emitter circuit, making the emitter the element "common" to both input and output. The CE is set apart from the other configurations, because it is the only configuration that provides a phase reversal between input and output signals.

B.2.3.2 COMMON-BASE CONFIGURATION (CB) is mainly used for impedance matching, since it has a low input resistance and a high output resistance. It also has a current gain of less than 1. In the CB, the input is applied to the emitter, the output is taken from the collector, and the base is the element common to both input and output.

B.2.3.3 COMMON-COLLECTOR CONFIGURATION (CC) is used as a current driver for impedance matching and is particularly useful in switching circuits. The CC is also referred to as an emitter-follower and is equivalent to the electron-tube cathode follower. Both have high input impedance and low output impedance.

In the CC, the input is applied to the base, the output is taken from the emitter, and the collector is the element common to both input and output.

GAIN is a term used to describe the amplification capabilities of an amplifier. It is basically a ratio of output to input. The current gain for the three transistor configurations (CB, CE, and CC) are ALPHA **(~),** BETA **( )**, and GAMMA **(¥)**, respectively.

B.2.4 TRANSISTOR CONFIGURATION COMPARISON CHART gives a rundown of the different properties of the three configurations.

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT/OUTPUT PHASE RELATIONSHIP	0°	180°	0°
VOLTAGE GAIN	500 to 800	300 to 600	Less than 1
CURRENT GAIN	Less than 1 0.95-0.99	30 to 300	30-300
POWER GAIN	LOW	HIGH	MEDIUM
INPUT RESISTANCE	50 to 200Ω	500 to 1000Ω	20K Ω to 100K Ω
OUTPUT RESISTANCE	300K Ω	50K Ω	500 Ω

B.2.5 Applications

Transistors are used as

1. Building blocks of logic gates, which are fundamental in the design of digital circuits. In digital circuits like microprocessors, transistors act as on-off switches; in the MOSFET, for instance, the voltage applied to the gate determines whether the switch is on or off.
2. Amplifiers and oscillators in common analog circuits.
3. mixed-signal circuits that interface or translate between digital circuits and analog circuits
4. Power semiconductor devices in high current or high voltage applications.

B.3.0 Field Effect Transistor (FET)

The **FET** is a three terminal unipolar semiconductor device that has, high efficiency, instant operation, robust and cheap and can be used in most electronic circuit applications to replace their equivalent bipolar junction transistors (BJT)

The FET however, uses the voltage that is applied to their input terminal, called the Gate to control the current flowing through them resulting in the output current being proportional to the input voltage. As their operation relies on an electric field (hence the name field effect) generated by the input Gate voltage, this then makes the FET a "VOLTAGE" operated device.

FETs can be made much smaller than an equivalent BJT transistor and along with their low power consumption and power dissipation makes them ideal for use in integrated circuits such as the CMOS range of digital logic chips.

B.3.1Types of FET

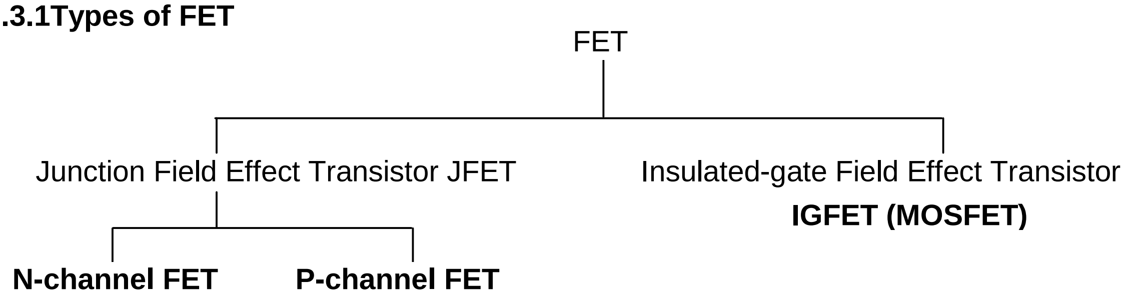
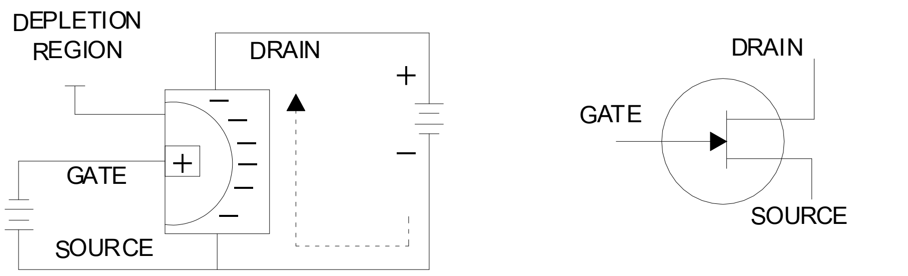


Fig B.3.1

B.3.1.1 JFET is a three terminal device that is constructed with no PN-junctions within the main current carrying path between the Drain and the Source terminals. The current path between these two terminals is called the "channel" which may be made of either a P-type or an N-type semiconductor material.

The control of current flowing in this channel is achieved by varying the voltage applied to the Gate. The FET being a "Unipolar" device depends only on the conduction of electrons (N-channel) or holes (P-channel).



(A) CONSTRUCTION (B) SCHEMATIC SYMBOL

Fig B.3.2 N – CHANNEL JFET

The **FET** has one major advantage over its BJT, in that their input impedance, (Rin) is very high, (thousands of Ohms), while the BJT is comparatively low. This very high input impedance makes them very sensitive to input voltage signals, but the price of this high sensitivity also means that they can be easily damaged by static electricity.

B.3.1.2 Metal Oxide Semiconductor Field Effect Transistor (MOSFET): The MOSFET differs from the JFET by the addition of a silicon dioxide layer over the JFET and then a layer of silicon nitride. The result is a device which has even higher input impedance (.order of 10^{15} ohms.) The goal of extremely high input impedance allows an amplifier to sample some signal with minimal "loading" or interference with the signal source

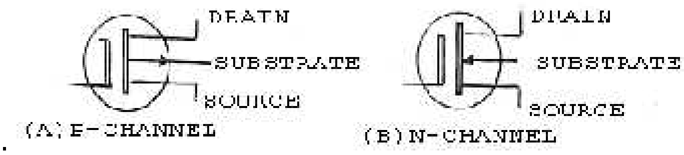


Fig B.3.3 MOSFET SYMBOLS

B.4.0 Zener Diode

A **Zener Diode** is a special kind of diode which permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value - the **breakdown voltage** known as the **Zener voltage**.

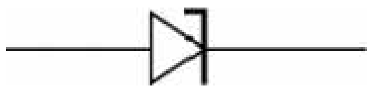


Fig B.4.1 Zener diode symbol

The **Zener voltage** of a standard diode is high, but if a reverse current above that value is allowed to pass through it, the diode is permanently damaged. **Zener diodes** are designed so that their zener voltage is much lower - for example just 2.4 Volts. When a reverse current above the Zener voltage passes through a Zener diode, there is a controlled *breakdown* which does not damage the diode. The voltage drop across the Zener diode is equal to the Zener voltage of that diode no matter how high the reverse bias voltage is above the Zener voltage.

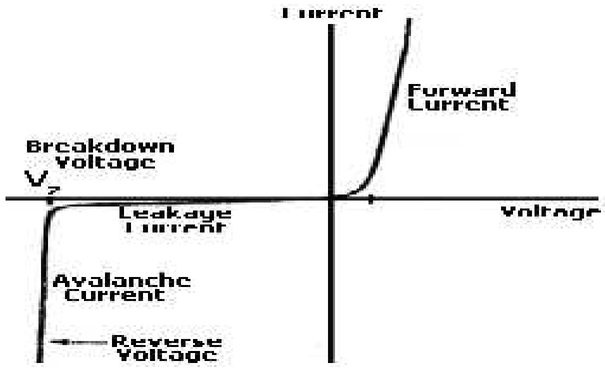


Fig B.4.2 Zener diode Current vs. Voltage graph

The illustration above shows this phenomenon in a Current vs. Voltage graph. With a zener diode connected in the forward direction, it behaves exactly the same as a standard **diode** - i.e. a small voltage drop of 0.3 to 0.7V with current flowing through pretty much unrestricted. In the reverse direction however there is a very small leakage current between 0V and the Zener voltage - i.e. just a tiny amount of current is able to flow. Then, when the voltage reaches the **breakdown voltage** (Vz), suddenly current can flow freely through it.

Since the voltage dropped across a **Zener Diode** is a known and fixed value, Zener diodes are typically used to regulate the voltage in electric circuits. Using a **resistor** to ensure that the current passing through the Zener diode is at least 5mA (0.005 Amps), the circuit designer knows that the voltage drop across the diode is exactly equal to the **Zener voltage** of the diode.

B.4.1 Applications

1. A **Zener diode** can be used to make a simple **voltage regulation** circuit as shown below. The output voltage is fixed at the zener voltage of the zener diode used and so can be used to power devices requiring a fixed voltage

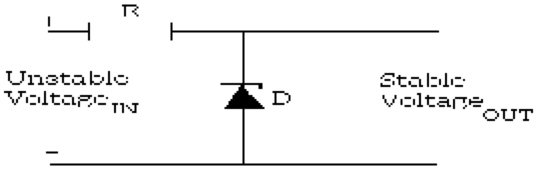


Fig B.4.3 Zener Diode Voltage Regulator Circuit

2. Another interesting application is the **Zener diode clipper** shown in Fig.

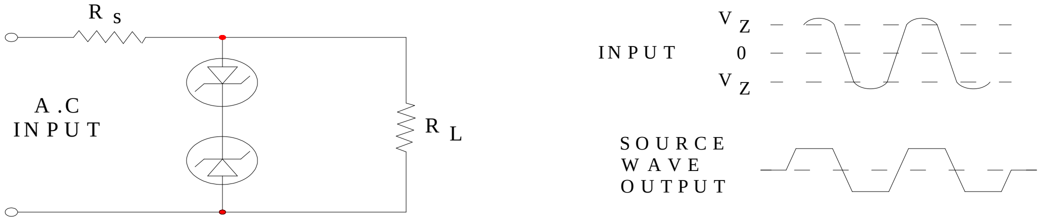


Fig B.4.4 ZENER DIODE CLIPPER

3. ZENER DIODE LIMITER

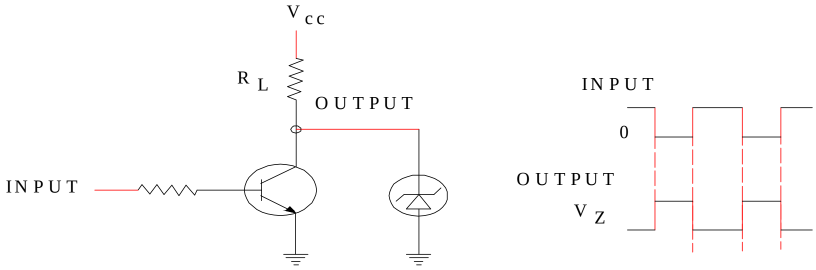
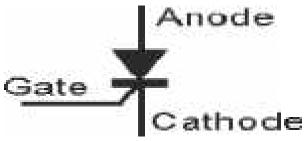


Fig B.4.5 ZENER DIODE LIMITER

B.5.0 Silicon Controlled Rectifier (SCR)

The silicon controlled rectifier (SCR) is multilayered semiconductor device consisting of two P-type materials alternated with two N-type, materials. The device is called a rectifier because it has a forward direction that has low resistance and thus passes current, and, a reverse direction that has a high resistance and blocks, current. The forward direction is not always a low resistance, but rather under the control of a turn on gate. The controlled rectifier is not always used to perform the usual rectifier functions. Applications making use of the controlling feature have been developed to make fullest use of its capabilities.



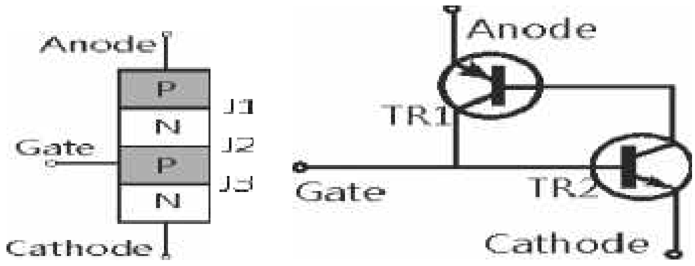


Fig B.5.1 (a) Symbol for SCR (b) Equivalent circuit of a silicon controlled rectifier (SCR)

The term SCR or silicon controlled rectifier is often used synonymously with that of thyristor - the SCR or silicon controlled rectifier is actually a trade name used by General Electric for a thyristor.

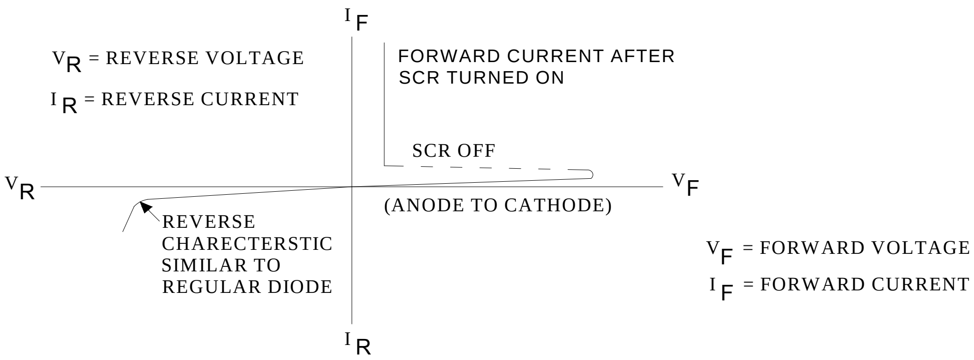


Fig B.5.2 SCR CHARACTERISTIC CURVE

B.5.1 Applications

SCRs are used in many areas of electronics where they find uses in a variety of different applications.

1. AC power control (including lights, motors, etc).
2. Overvoltage protection crowbar for power supplies
3. AC power switching.
4. Control elements in phase angle triggered controllers.
5. within photographic flash lights where they act as the switch to discharge a stored voltage through the flash lamp, and then cut it off at the required time.

B 6.0 UNI junction transistor (UJT)

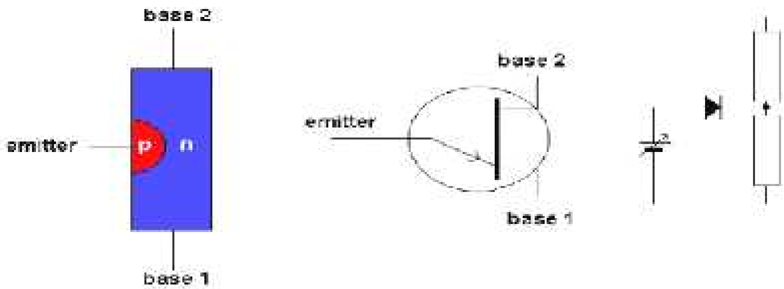


Fig B 6.0 : UJT Structure & Symbol

The uni junction transistor (UJT) is made of a bar of N type material with a P type junction (the emitter) near the centre. Base 1 is connected to zero volts and base 2 to the positive supply. The resistance between the two bases (the INTERBASE RESISTANCE) is typically 10k. With the emitter unconnected, the bar acts as a potential divider, and about 0.5 volts appears at the emitter. If a voltage is connected to the emitter, as long as it is less than 0.5 volts, nothing happens, as the P-N junction is reversed biased. When the emitter voltage exceeds 0.5 volts, the junction is forward biased and emitter current will flow. This increase in current is equal to a reduction of resistance between base 1 and the emitter. This causes the emitter voltage to fall.

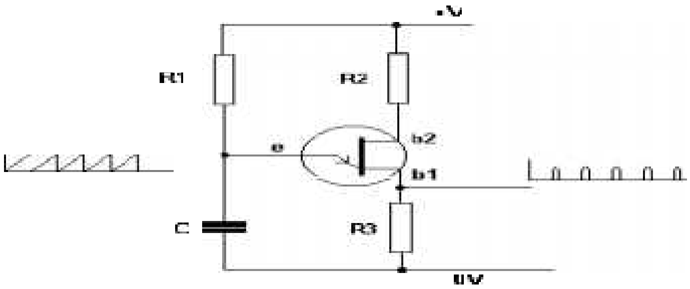


Fig 6.01 : Relaxation Oscillator

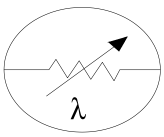
In the circuit, C charges via R1. When the voltage across C exceeds 0.6 volts, the b1/emitter junction goes low resistance and discharges C. The result is a saw tooth waveform across C. There is also a pulse of current through R3, giving a pulse of voltage across it. This circuit is called a relaxation oscillator. The voltage across C charges up slowly then suddenly relaxes. The circuit is often used to trigger thyristor circuits.

B.7.0 SPECIAL DEVICES

B.7.1 Photo resistors It is a semiconductor device where resistance varies inversely with the intensity of light that falls on the device (photosensitive area). These are constructed with cadmium compounds, such as cadmium sulphide or cadmium selenide. They are more responsive to a particular wavelength of light.

CdS - about 7000 A^0
CdSe - about 5500 A^0

When no light is incident on the device the cell resistance is maximum and this is called the dark resistance. The resistance decreases with light intensity falling on the device as shown in graph



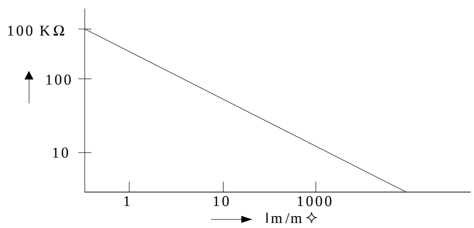
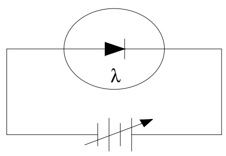


Fig. B.7.1 (a) SYMBOL OF PHOTO TRANSISTOR (b) CHARACTERISTICS

B.7.2 Photo Diodes Photo diode is a p-n junction device that operates in reverse bias. The symbol of photo diode is as shown in Fig. The p-n junction of the device has a small window such that light can strike the junction.

When no light is incident on it, a very small leakage current flow because of reverse bias just like an ordinary diode) as shown. This current is very small called the dark current. When light is incident, depending on the amount of light energy the reverse current changes (i.e., an increase in the amount of light energy produces an increase in, reverse current). It can be used as a variable resistance device controlled by light intensity.



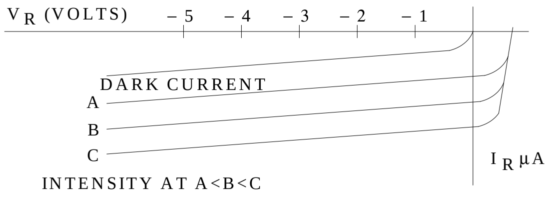


Fig B.7.2 (a) SYMBOL (b) CHARACTERISTICS OF PHOTODIODE

B.7.3 Light Emitting Diode (LED)

As the name indicates, it is a forward biased P-N junction which emits visible light when energized. Charge carrier recombination takes place when electrons from N-side cross the junction and recombine with the holes on the P-side. Now, the electrons are in the higher conduction band on the N-side where as the holes are in the lower valence band on P-side. During the recombination, some of this energy difference is given up n the form of heat and light (i.e., photons). For Silicon and Germanium junctions, greater percentage of this energy is given up in the form of heat so that the amount of emitted light is insignificant. But in the case of other semiconductor materials like gallium arsenide (GaAs),gallium-phosphide (GaP) and gallium-arsenide-phosphide (GaAsP), a percentage of energy is released during recombination is given out in the form of light. Depending on the type of material used the colour of light (frequencies) is emitted.

GaAsP - Red light
GaP - Yellow to green light
GaAs - Infra red radiation

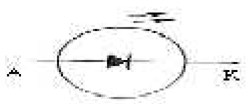


FIG B.7.3 SYMBOL OF LED

B.7.3.1 Applications

1. Used as small indicator lamps.
2. They were also used in alphanumeric displays
3. With recent developments light emitting diodes are being used instead of incandescent lamps for illumination.

B.7.4 Laser Diodes

The *laser diode* is a further development upon the regular light-emitting diode, or LED. The term "laser" it is actually an acronym, despite the fact it's often written in lower-case letters. "Laser" stands for Light Amplification by Stimulated Emission of Radiation, and refers to another strange quantum process whereby characteristic light emitted by electrons falling from high-level to low-level energy states in a material stimulate other electrons in a substance to make similar "jumps," the result being a synchronized output of light from the material. This synchronization extends to the actual *phase* of the emitted light, so that all light waves emitted from a "lasing" material are not just the same frequency (color), but also the same phase as each other, so that they reinforce one another and are able to travel in a very tightly-confined, non dispersing beam. This is why laser light stays so remarkably focused over long distances: each and every light wave coming from the laser is in step with each other.

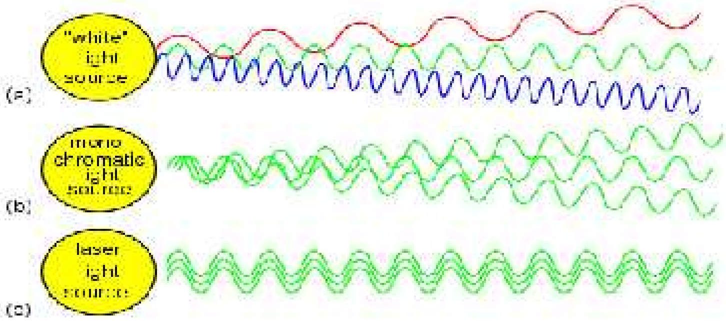


Fig B.7.4 a) White light of many wavelengths. (b) Mono-chromatic LED light, a single wavelength. (c) Phase coherent laser light.

Incandescent lamps produce "white" (mixed-frequency, or mixed-color) light as in Figure above (a). Regular LEDs produce monochromatic light: same frequency (color), but different phases, resulting in similar beam dispersion in Figure above (b). Laser LEDs produce coherent light: light that is both monochromatic (single-color) and mono phase (single-phase), resulting in precise beam confinement as in Figure above (c).

B.7.4.1 Applications

Laser light finds wide application in the modern world: everything from surveying, where a straight and non dispersing light beam is very useful for precise sighting of measurement markers, to the reading and writing of optical disks, where only the narrowness of a focused laser beam is able to resolve the microscopic "pits" in the disk's surface comprising the binary 1's and 0's of digital information.

Some laser diodes require special high-power "pulsing" circuits to deliver large quantities of voltage and current in short bursts. Other laser diodes may be operated continuously at lower power. In the continuous laser, laser action occurs only within a certain range of diode current, necessitating some form of current-regulator circuit. As laser diodes age, their power requirements may change (more current required for less output power), but it should be remembered that low-power laser diodes, like LEDs, are fairly long-lived devices, with typical service lives in the tens of thousands of hours.

B.7.5 Opto Coupler

It is a device where light energy is converted to electrical energy. This device enables information (Electrical Signal) to pass from one circuit to another even though the circuits are isolated.

An opto coupler (typical) which is mounted with a six pin dual in line package is shown in the figure. To identify the pin numbers a dot (spot) is on the top of the package. The package has an LED and a transistor. The LED emits infra-red radiation when biased properly (biased voltage). These radiations fall on the photo transistor and change the collector current (depending on the intensity of radiation). The quality of an optocoupler depends on: -

1. Good Isolation 2.Current transfer ratio & 3.Switching speed.

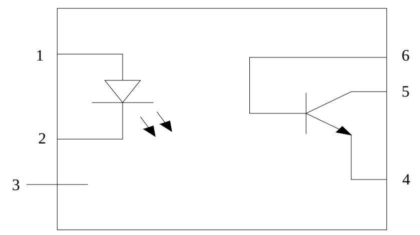


Fig B.7.5 OPTO COUPLER

B.8.0 SEMICONDUCTOR MICROWAVE DEVICES

B.8.1 Varactor Diode

The Varactor diode is a semiconductor, voltage-dependent variable capacitor also known as VARICAP diode. Basically it is just a reverse biased diode whose mode of operation depends on its transition capacitance (C_T). As we know that a reverse biased junctions behave like capacitors whose capacitance $\alpha 1/ (V_R)^n$ where n varies from 1/3 to ½. As reverse voltage V_R is increased, the depletion layer widens thereby decreasing the junction capacitance. Hence, we can change diode capacitance by simply changing $V_{R.}$ Silicon diodes which are optimized for this variable capacitance effect are called Varactors.

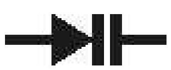


Fig B.8.1 Varactor diode circuit symbol

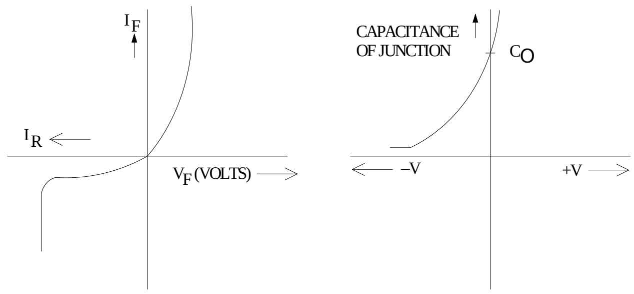


Fig. B 8.1.1 VARACTER DIODE CHARACTERISTICS

B.8.1.1 Applications

1. Automatic frequency control device
2. FM Modulator
3. Adjustable band -pass filter
4. Parametric amplifier (RF application)
5. Frequency multiplication: Since the capacitance of a varactor diode varies with the applied reverse bias, the diode acts as a non linear capacitance, (like a non linear resistance) and this property is used to produce frequency multiplications. Frequency multiplier using diode requires no power other than the input signal to be multiplied and they are highly efficient compared to conventional multiplier.

B.8.2 Schottky barrier diode

This diode uses a metal like gold, silver on one side of the junctions and doped silicon (usually n type) on the other side. Since there are no minority carriers, it is a unipolar device and no reverse current with back bias. The electrons flowing from the semiconductor to the metal have a higher energy level than electrons in the metal. Mostly silicon and GaAs are used.

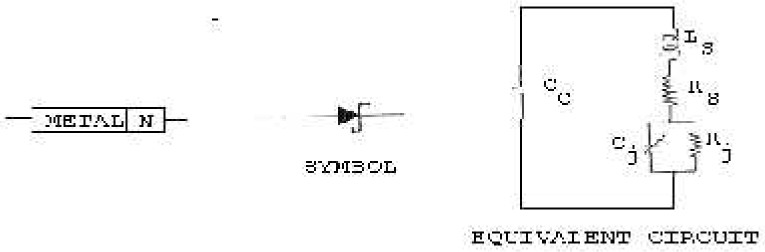


Fig B.8.2 SCHOTTKY DIODE

B.8.2.1 Applications

1. Widely used for radio frequency (RF) applications as a mixer or detector diode.
2. used in power applications as a rectifier, again because of its low forward voltage drop leading to lower levels of power loss compared to ordinary PN junction diodes.
3. Used as a clamp diode in a transistor circuit to speed the operation when used as a switch.

B.8.3 Step Recovery Diode, SRD

It is another type of Varactor diode having a graded doping profile where doping density decreases near the junction .This results in the production of strong electric fields on both sides of the junction. The step recovery diode or SRD is a form of semiconductor diode that can be used as a charge controlled switch and it has the ability to generate very sharp pulses. In view of its method of operation, it is also called the "Snap-off" diode, "charge storage" diode or "memory varactor".

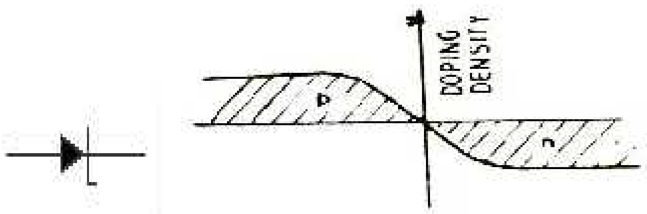


Fig B.8.3 (a) Symbol of SRD (b) Doping Profile of SRD

B.8.3.1 Applications

1. In microwave radio frequency electronics as pulse generator or parametric amplifier.
2. As very short pulse generator, ultra fast waveform generator.
3. As a high order frequency multiplier
4. Capable of working at moderate power levels, and this gives it a distinct advantage over some other radio frequency technologies that are available.

B.8.4 PIN diode

The PIN diode can be shown diagrammatically as being a PN junction, but with an intrinsic layer between the PN and layers. The intrinsic layer of the PIN diode is a layer without doping, and as a result this increases the size of the depletion region this change in the structure gives the PIN diode its unique properties.

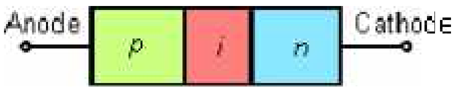


Fig B.8.4 Basic PIN diode structure

The PIN diode operates in exactly the same way as a normal diode. The only real difference is that the depletion region that normally exists between the P and N regions in an unbiased or reverse biased diode is larger.

When the diode is forward biased, the carrier concentration, i.e. holes and electrons is very much higher than the intrinsic level carrier concentration. Due to this high level injection level, the electric field extends deeply (almost the entire length) into the region. This electric field helps in speeding up of the transport of charge carriers from p to n region, which results in faster operation of the diode, making it a suitable device for high frequency operations.

The PIN diode is an ideal component to provide electronics switching in many areas of electronics. It is particularly useful for RF design applications and for providing the switching, or attenuating element in RF switches and RF attenuators. The PIN diode is able to provide much higher levels of reliability than RF relays that are often the only other alternative.

B.8.4.1 Applications

- **High voltage rectifier:** The PIN diode can be used as a high voltage rectifier.
- **RF switch:** The PIN diode makes an ideal RF switch.
- **Photo detector:** As the conversion of light into current takes place within the depletion region of a photodiode, increasing the depletion region by adding the intrinsic layer improves the performance by increasing he volume in which light conversion occurs.

B.8.5 Gunn diode

The Gunn diode is a unique component - even though it is called a diode, it does not contain a PN diode junction. The Gunn diode can be termed a diode because it does have two electrodes. It depends upon the bulk material properties rather than that of a PN junction. The Gunn diode operation depends on the fact that it has a voltage controlled negative resistance.

Fig B.8.5 (a) Gunn diode symbol

A Gunn diode oscillator or transferred electron device oscillator generally consists of a diode with a DC bias applied and a tuned circuit.

The Gunn diode oscillator circuit or transferred electron oscillator uses the negative resistance over a portion of the V/I curve of the Gunn diode, combined with the timing properties within the device to allow the construction of an RF relaxation oscillator. When a suitable current is passed through the device it will start to oscillator.

The negative resistance created by the V/I characteristic will cancel out any real resistance in the circuit so that any oscillation will build up and will be maintained indefinitely while DC is applied. The amplitude will be limited by the limits of the negative resistance region of the Gunn diode.

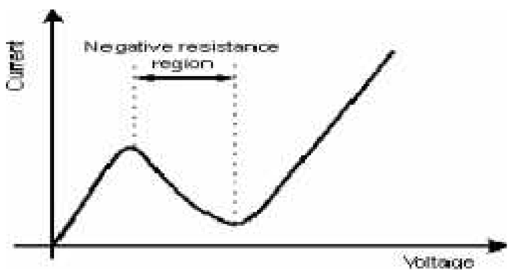


Fig B.8.5 (b) Gunn diode characteristic

B.8.5.1 Applications

1. Gunn diodes are widely used in microwave RF applications for generating frequencies between 1 and 100 GHz.
2. Gunn diode may also be used for an amplifier in what may be known as a transferred electron amplifier or TEA.
3. As Gunn diodes are easy to use, they form a relatively low cost method for generating microwave RF signals.

B.8.6 IMPATT diode

IMPact Avalanche Transit Time(IMPATT) diode is a high power radio frequency (RF) generator operating from 3 to 100 GHz. IMPATT diodes are fabricated from silicon, gallium arsenide, or silicon carbide.

It is reverse biased above the breakdown voltage. The high doping levels produce a thin depletion region. The resulting high electric field rapidly accelerates carriers which free other carriers in collisions with the crystal lattice. Holes are swept into the P_+ region. Electrons drift toward the N regions. The cascading effect creates an avalanche current which increases even as voltage across the junction decreases. The pulses of current lag the voltage peak across the junction. A “negative resistance” effect in conjunction with a resonant circuit produces oscillations at high power levels (high for semiconductors).

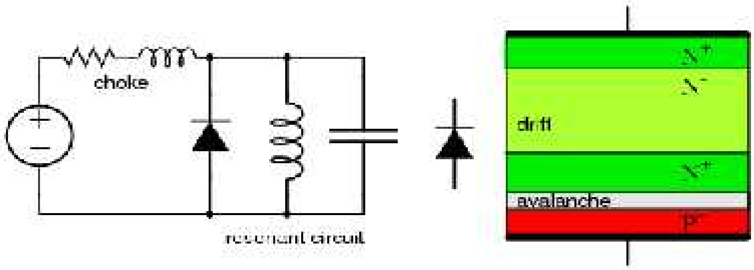


Fig B.8.6 IMPATT diode: (a) Oscillator circuit (b) symbol (c) heavily doped P and N layers.

The resonant circuit in the schematic diagram of Figure above is the lumped circuit equivalent of a waveguide section, where the IMPATT diode is mounted. DC reverse bias is applied through a choke which keeps RF from being lost in the bias supply. This may be a section of waveguide known as a bias Tee. Low power RADAR transmitters may use an IMPATT diode as a power source. They are too noisy for use in the receiver.

B.8.6.1 Applications

1. IMPATT diodes are used in a variety of applications from low power radar systems to alarms.
2. IMPATT diodes are ideal where small cost effective microwave radio sources are needed. & make excellent signal sources for many RF microwave applications

ANNEXURE C

APPLIED ELECTRONICS

C.1.0 AMPLIFIER

It is the device that provides amplification without appreciably altering the original signal.

C.1.1 BASIC TRANSISTOR AMPLIFIER amplifies by producing a large change in collector current for a small change in base current. This action results in voltage amplification because the load resistor placed in series with the collector reacts to these large changes in collector current which, in turn, results in large variations in the output voltage.

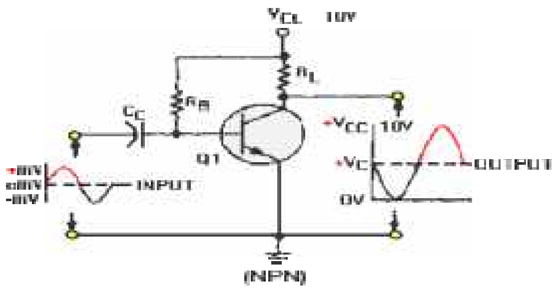


Fig C.1.1 BASIC TRANSISTOR AMPLIFIER

The three types of **BIAS** used to properly bias a transistor are base-current bias (fixed bias), self-bias, and combination bias.

Combination bias is the one most widely used because it improves circuit stability and at the same time overcomes some of the disadvantages of base-current bias and self-bias.

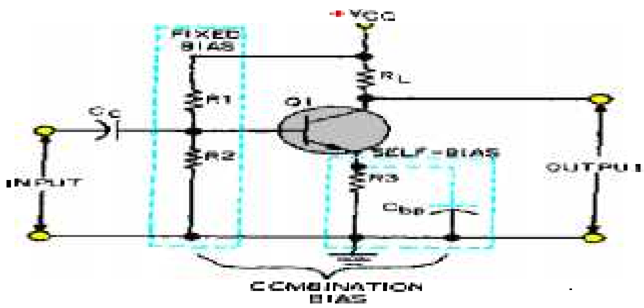


Fig C.1.2 Combination bias

C.1.2 CLASS OF AMPLIFIER OPERATION is determined by the portion of the input signal for which there is an output.

There are four classes of amplifier operations: class A, class AB, class B, and class C.

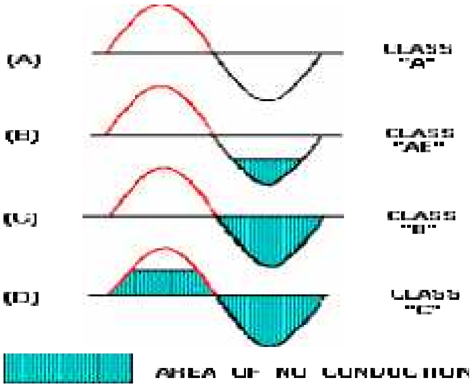


Fig C.1.3 classes of amplifier operations

C.1.2.1 CLASS A AMPLIFIER is biased so that variations in input signal polarities occur within the limits of cutoff and saturation. Biasing an amplifier in this manner allows collector current to flow during the complete cycle (360 degrees) of the input signal, thus providing an output which is a replica of the input but 180 degrees out of phase.

Applications: Class A amplifiers are used as audio- and radio-frequency amplifiers in radio, radar, and sound systems.

C.1.2.2 CLASS AB AMPLIFIERS are biased so that collector current is zero (cutoff) for a portion of one alternation of the input signal. Therefore, collector current will flow for more than 180 degrees but less than 360 degrees of the input signal.

Applications: The class AB amplifier is commonly used as a push-pull amplifier to overcome a side effect of class B operations.

C.1.2.3 CLASS B AMPLIFIERS are biased so that collector current is cut off during one-half of the input signal. Thus, for a class B operation, collector current will flow for approximately 180 degrees (half) of the input signal.

Applications: The class B operated amplifier is used as an audio amplifier and sometimes as the driver- and power-amplifier stage of transmitters.

C.1.2.4 CLASS C AMPLIFIERS are biased so that collector current flows for less than one-half cycle of the input signal.

Applications: The class C operated amplifier is used as a radio-frequency amplifier in transmitters.

C.1.3 FIDELITY and **EFFICIENCY** are two terms used in conjunction with amplifiers. Fidelity is the faithful reproduction of a signal, while efficiency is the ratio of output signal power compared to the total input power.

The class A amplifier has the highest degree of fidelity, but the class C amplifier has the highest efficiency.

C.2.0 RECTIFIERS

A **rectifier** is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as **rectification**.

C.2.1 Types of Rectifiers

C.2.1.1 Half wave rectifier circuit: This is the simplest form of rectifier. Often using only a single diode is blocks half the cycle and allows through the other. As such only half of the waveform is used. While the advantage of this circuit is its simplicity, the drawback is the fact that there is longer between successive peaks of the rectified signal. This makes smoothing less effective and more difficult to achieve high levels ripple rejection.

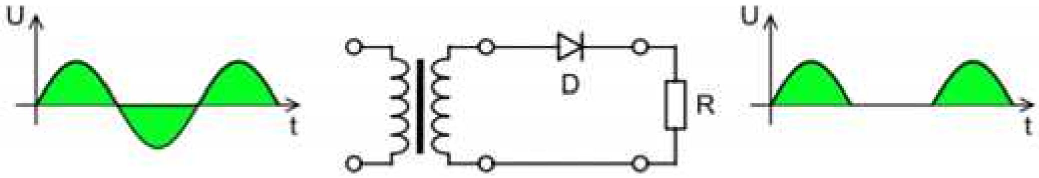


Fig C.2.1 Half wave rectifier circuit

C.2.1.2 **Full wave rectifier circuit:** This form of rectifier circuit uses both halves of the waveform. This makes this form of rectifier more effective, and as there is conduction over both halves of the cycle, smoothing becomes much easier and more effective.

The two diode version of the full wave rectifier circuit requires a centre tap in the transformer. When vacuum tubes / thermionic valves were used, this option was widely used in view of the cost of the valves. However with semiconductors, a four diode bridge circuit saves on the cost of the centre tapped transformer and is equally effective.

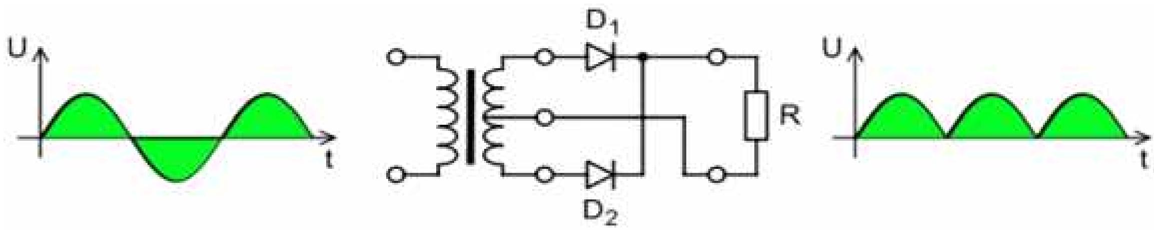


Fig C.2.2 Full wave rectifier circuit

C.2.1.3 **Bridge rectifier circuit*:*** This is a specific form of full wave rectifier that utilizes four diodes in a bridge topology. Bridge rectifiers are widely used, especially for power rectification, and they can be obtained as a single component contains the four diodes connected in the bridge format.AC input

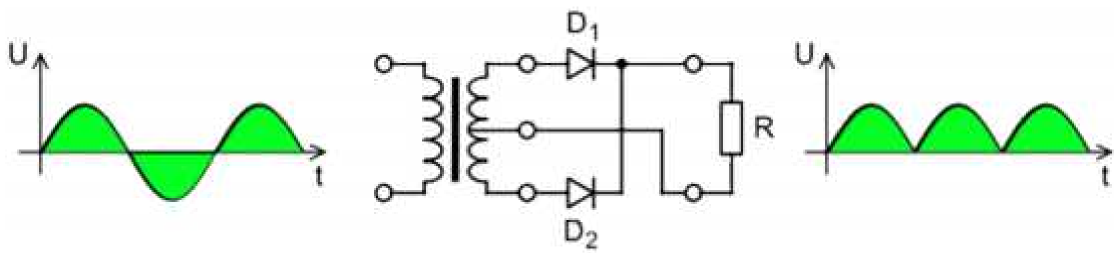


Fig C.2.3 Bridge rectifier circuit

The choice of diode rectifier circuit depends on the application. While the full wave rectifier circuits, and in particular the bridge rectifier circuits are possible the most widely used, half wave rectifier circuits may offer a better option in some circumstances.

C.2.2 Applications

1. The primary application of rectifiers is to derive DC power from an AC supply. Virtually all electronic devices require DC, so rectifiers are used inside the power supplies of virtually all electronic equipment.
2. Rectifiers are used in DC –DC convertors
3. Rectifiers are used for detection of amplitude modulated radio signals
4. Rectifiers are used to supply polarized voltage for welding. In such circuits control of the output current is required; this is sometimes achieved by replacing some of the diodes in a bridge rectifier with thyristors, effectively diodes whose voltage output can be regulated by switching on and off with phase fired controllers.

C.2.3 Comparison of Rectifier Circuits

Type of Rectifier	No of diodes	PIV	Type of transformer	DC output voltage	Ripple factor	efficiency
Half wave	1	V_m	Single winding	$0.318V_m$	1.21	40.6%
Full wave	2	$2\ V_m$	Centre tap	$0.636V_m$	0.482	81.2%
Bridge	4	V_m	Single winding	$0.636V_m$	0.482	81.2%

C.3.0 FILTERS

To remove the AC components or filter them out in a rectifier circuit, a filter circuit is used. A filter circuit is a device to remove the A.C components of the rectified output, but allows the D.C components to reach the load. A filter circuit is in general a combination of inductor (L) and Capacitor (C) called LC filter circuit. A capacitor allows A.C only and inductor allows D.C only to pass. So a suitable L and C network can effectively filter out the A.C component from rectified wave.

Types of Filters

- Inductor Filter
- Capacitor Filter
- LC Filter
- π Filter

Inductor Filter

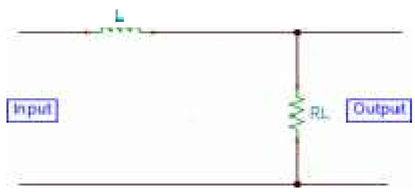


Fig C.3.1 Inductor Filter

This type of filter is also called choke filter. It consists of an inductor L which is inserted between the rectifier and the load resistance R_L. The rectifier contains A.C components as well as D.C components. When the output passes through the inductor, it offers a high resistance to the A.C component and no resistance to D.C components. Therefore, A.C components of the rectified output are blocked and only D.C components reached at the load.

Capacitor Filter

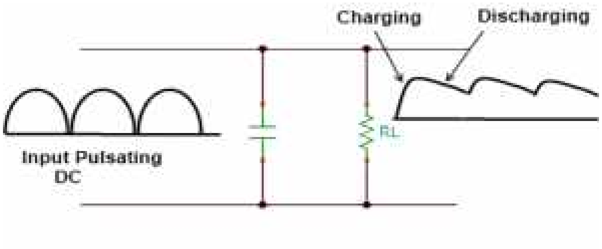


Fig C.3.2 Capacitor Filter

In this filter a capacitor is connected across the load during the rise of voltage cycle it gets charge and this charge is supply to the load during the fall in the voltage cycle. This process is repeated for each cycle and thus the ripple is reduced across the load. It is shown in the above Figure. It is popular, because of its low cost, small size, less weight and good characteristics.

LC Filter

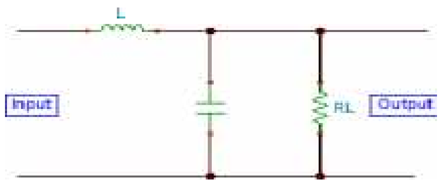


Fig C.3.3 LC Filter

In inductor filter, the ripple factor is directly proportional to the load resistance. On the other hand in a capacitor filter, it is varying inversely with the load resistance. Hence if we combine the inductor filter with the capacitor the ripple factor will become almost independent of the load filter. It is also known as inductor input filter, choke input filter, L input or LC-section.

In this circuit a choke is connected in series with the load. It offers high resistances to the AC components and allows DC component to flow through the load. The capacitor across the load is connected in parallel which filter out any AC component flowing through the choke. In this way the ripples are rectified and a smooth DC is provided through the load

Pie Filter

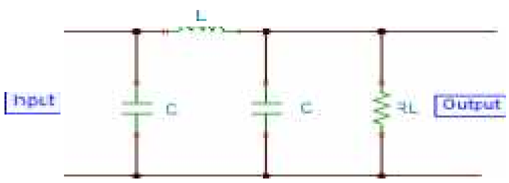


Fig C.3.4 Pie Filter

It consists of one inductor and two capacitor connected across its each end. The three components are arranged in shape of Greek letter Pi. It is also called capacitor input Pi filter. The input capacitor C_1 is selected to offer very low reactance to the repel frequency hence major parts of filtering is done by C_1. Most of the remaining repels are removed by the combining action of L and C_2. This circuit gives much better filter then LC filter. However C_1 is still directly connected across the supply and would need high pulse of current if load current is large. This filter is used for the low current equipment's.

C.4.0 Oscillators

An **electronic oscillator** is an electronic circuit that produces a repetitive, oscillating electronic signal, often a sine wave or a square wave. Oscillators convert direct current (DC) from a power supply to an alternating current signal. They are widely used in many electronic devices. Oscillators are often characterized by the frequency of their output signal:

An audio oscillator produces frequencies in the audio range, about 16 Hz to 20 kHz. An RF oscillator produces signals in the radio frequency (RF) range of about 100 kHz to 100 GHz.

A low-frequency oscillator (LFO) is an electronic oscillator that generates a frequency below ≈20 Hz. This term is typically used in the field of audio synthesizers, to distinguish it from an audio frequency oscillator.

C.4.1 Types of electronic oscillator: (1) Linear or harmonic oscillator (2) Nonlinear or relaxation oscillator.

C.4.1.1 LINEAR OSCILLATOR

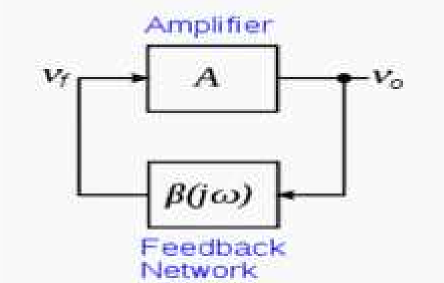


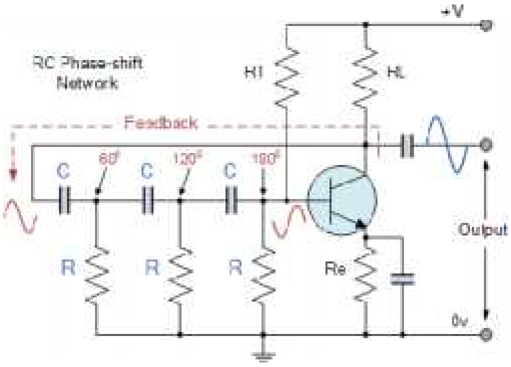
Fig C.4.1 Block diagram of a feedback oscillator

The harmonic, or *linear*, oscillator produces a sinusoidal output.

Feedback oscillator The most common form of linear oscillator is an electronic amplifier such as a transistor or op amp connected in a feedback loop with its output fed back into its input through a frequency selective electronic filter to provide positive feedback. When the power supply to the amplifier is first switched on, electronic noise in the circuit provides a signal to get oscillations started. The noise travels around the loop and is amplified and filtered until very quickly it becomes a sine wave at a single frequency.

Feedback oscillator circuits can be classified according to the type of frequency selective filter they use in the feedback loop

1. In an *RC oscillator* circuit, the filter is a network of resistors and capacitors. RC oscillators are mostly used to generate lower frequencies, for example in the audio range. Common types of RC oscillator circuits are the phase shift oscillator and the Wien bridge oscillator.



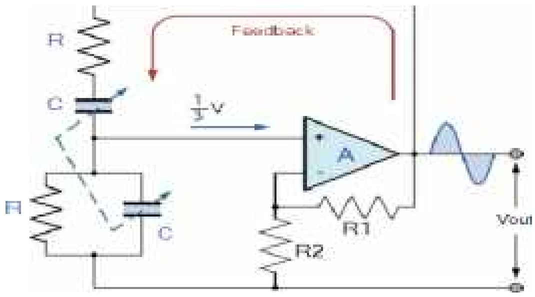
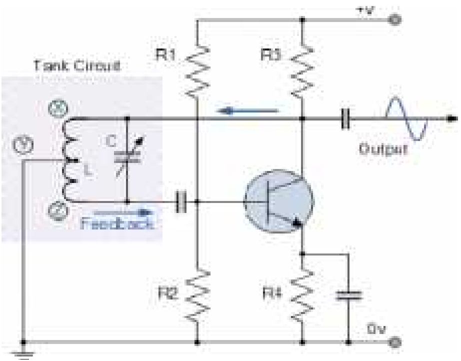


Fig.C.4.2 (a) Phase Shift Oscillator (b) Wien Bridge Oscillator.

2. In an *LC oscillator* circuit, the filter is a tuned circuit (often called a *tank circuit*) consisting of an inductor (L) and capacitor (C) connected together. Charge flows back and forth between the capacitor's plates through the inductor, so the tuned circuit can store electrical energy oscillating at its resonant. There are small losses in the tank circuit, but the amplifier compensates for those losses and supplies the power for the output signal.LC oscillators are used at radio frequencies, when a tunable frequency source is necessary, such as in signal generators, tunable radio transmitters and the local oscillators in radio receivers. Typical LC oscillator circuits are the Hartley, Colpitts and Clapp circuits.



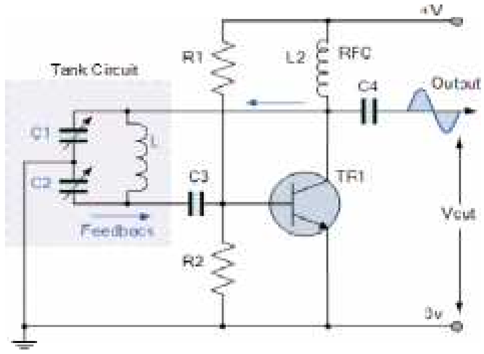


Fig C.4.3 (a) Hartley Oscillator (b) Colpitts Oscillator

4. Crystal oscillators often use the same circuits as LC oscillators, with the crystal replacing the tuned circuit; the oscillator circuit is commonly used. Quartz crystals are generally limited to frequencies of 30 MHz or below. Surface acoustic wave (SAW) devices are another kind of piezoelectric resonator used in crystal oscillators, which can achieve much higher frequencies. They are used in specialized applications which require a high frequency reference, for example, in cellular telephones.

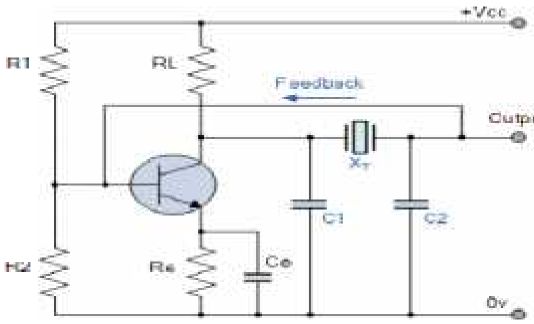


Fig C.4.4 Crystal oscillator

C.4.1.2 Nonlinear or Relaxation oscillator

A nonlinear or relaxation oscillator produces a non-sinusoidal output, such as a square, saw tooth or triangle wave. It contains an energy-storing element (a capacitor or, more rarely, an inductor) and a nonlinear switching circuit (a latch, Schmitt trigger, or negative resistance element) that periodically charges and discharges the energy stored in the storage element thus causing abrupt changes in the output waveform.

Square-wave relaxation oscillators are used to provide the clock signal for sequential logic circuits such as timers and counters, although crystal oscillators are often preferred for their greater stability. Triangle wave or saw tooth oscillators are used in the time base circuits that generate the horizontal deflection signals for cathode ray tubes in analogue oscilloscopes and television sets. In function generators, this triangle wave may then be further shaped into a close approximation of a sine wave

C.5.0 Operational Amplifiers (OP-AMP)

The **Operational Amplifier**, or Op-amp as it is most commonly called, is an ideal amplifier with infinite Gain and Bandwidth when used in the Open-loop mode with typical D.C. gains of well over 100,000, or 100dB.

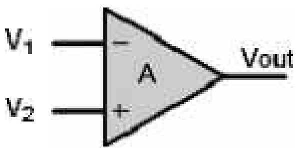
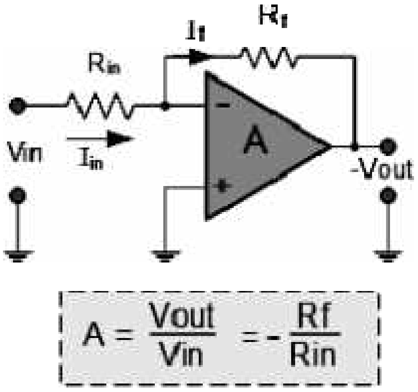


Fig C.5.1 Op-amp Symbol

- The basic Op-amp construction is of a 3-terminal device, 2-inputs and 1-output.
- An Operational Amplifier operates from either a dual positive (+V) and a corresponding negative (-V) supply, or they can operate from a single DC supply voltage.
- The two main laws associated with the operational amplifier are that it has an infinite input impedance, (Z_∞) resulting in "**No current flowing into either of its two inputs**" and zero input offset voltage "**V1 = V2**".
- An operational amplifier also has zero output impedance, (Z = 0).
- Op-amps sense the difference between the voltage signals applied to their two input terminals and then multiply it by some pre-determined Gain, (A).
- This Gain, (A) is often referred to as the amplifiers "Open-loop Gain".
- Closing the open loop by connecting a resistive or reactive component between the output and one input terminal of the op-amp greatly reduces and controls this open-loop gain.
- Op-amps can be connected into two basic configurations, **Inverting** and **Non-inverting**.

C.5.1 Two Basic Operational Amplifier Circuits



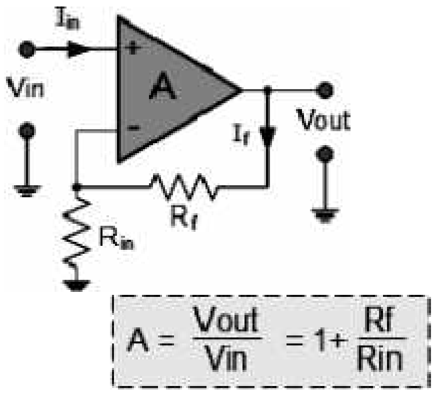


Fig 5.2 Inverting OPAMP Non Inverting OPAMP

By the use of a suitable feedback resistor, (Rf) the overall gain of the amplifier can be accurately controlled.

Negative Feedback is the process of "feeding back" a fraction of the output signal back to the input, but to make the feedback negative, we must feed it back to the negative or "inverting input" terminal of the op-amp using an external **Feedback Resistor** called Rf. This feedback connection between the output and the inverting input terminal forces the differential input voltage towards zero.

For **positive feedback**, were the fed-back voltage is in "Phase" with the input the overall gain of the amplifier is increased.

C.5.2 Voltage Follower

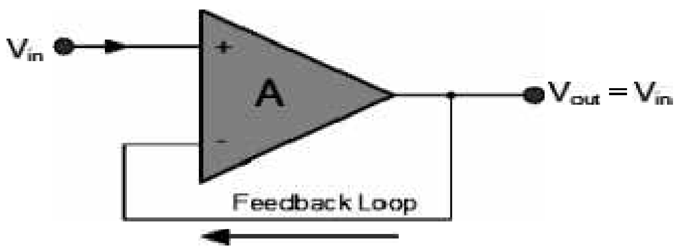
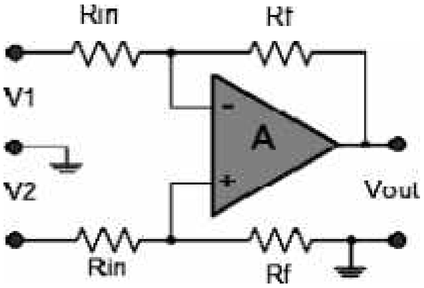


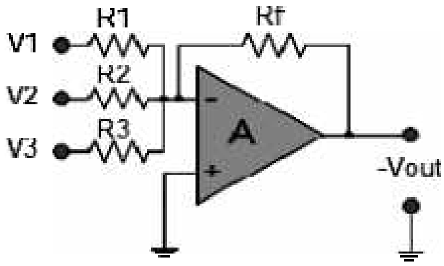
Fig C.5.3 Voltage Follower

By connecting the output directly back to the negative input terminal, 100% feedback is achieved resulting in a **Voltage Follower** (buffer) circuit with a constant gain of 1 (Unity).

C.5.3 Differential and Summing Operational Amplifier Circuits



$$Vout = \frac{Rf}{Rin}(V2 - V1)$$

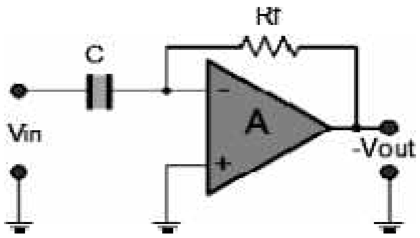


$$Vout = -\left(\frac{Rf}{R1}V1 + \frac{Rf}{R2}V2 + \frac{Rf}{R3}V3\right)$$

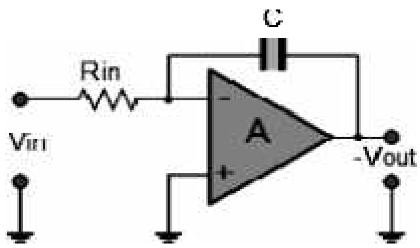
Fig C.5.4 Differential OPAMP Summing OPAMP

- Changing the fixed feedback resistor (Rf) for a Potentiometer, the circuit will have Adjustable Gain.
- The **Differential Amplifier** produces an output that is proportional to the difference between the 2 input voltages.
- Adding more input resistor to either the inverting or non-inverting inputs **Voltage Adders** or **summers** can be made.
- Voltage follower op-amps can be added to the inputs of Differential amplifiers to produce high impedance Instrumentation amplifiers.
- useful application of a **Summing Amplifier** is as a weighted sum digital-to-analogue converter

C.5.4 Differentiator and Integrator Operational Amplifier Circuits



$$Vout = -Rf\ C\ \frac{dVin}{dt}$$



$$Vout = -\frac{1}{j\omega RinC}Vin$$

Fig C.5.5 Differentiator OPAMP Integrator OPAMP

- The **Integrator Amplifier** produces an output that is the mathematical operation of integration.
- The **Differentiator Amplifier** produces an output that is the mathematical operation of differentiation.
- Both the Integrator and Differentiator Amplifiers have a resistor and capacitor connected across the op-amp and is affected by its RC time constant.
- In their basic form, Differentiator Amplifiers suffer from instability and noise but additional components can be added to reduce the overall closed-loop gain.