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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COMMUNICAITON SYSTEMS – SEC1303

UNIT – 1

TELEPHONE COMMUNICATION

1. TELEPHONE COMMUNICATION

Telephones - Standard Telephone and local loop - Electronics Telephone - Telephone System- Cordless Telephone -Telephone Facsimile - Fax Machine Operation - Paging System -Cellular Telephone system - Digital cellular Telephone system - ISDN.

1.1 Introduction

Telecommunication means "communications at a distance". Tele in Greek means at a distance Electrical communications by wire, radio, or light (fiber optics).

1.2 Telephones

The telephone system was designed for full-duplex analog communication of voice signals. Today, this system is still primarily used for voice, but it employs mostly digital techniques, not only in signal transmission but also in control operations. The telephone system permits any telephone to connect with any other telephone in the world.

A telephone line or telephone circuit (or just line or circuit within the industry) is a single-user circuit on a telephone communication system. This is the physical wire or other signaling medium connecting the user's telephone apparatus to the telecommunications network, and usually also implies a single telephone number for billing purposes reserved for that user. Telephone lines are used to deliver landline telephone service and Digital subscriber line (DSL) phone cable service to the premises.

1.3 dB Communication

The db (decibel) is a relative unit of measurement commonly used in communications for providing a reference for input and output levels. Power gain or loss. Decibels are used to specify measured and calculated values in audio systems, microwave system gain calculations, satellite system link-budget analysis, antenna power gain, and light-budget calculations and in many other communication system measurements. In each case the dB value is calculated with respect to a standard or specified reference.

1.4 Local loop

The Local Loop in a telephone network (sometimes referred to as the "last mile" of the network) is the bit that connects home to local telephone exchange. It refers literally to the copper cables that run from home to the telephone exchange. Standard telephones are connected to the telephone system by way of a two-wire, twisted-pair cable that terminates at the local exchange or central office. As many as 10,000 telephone lines can be connected to a single central office. The two-wire, twisted-pair connection between the telephone and central office is referred to as the local loop or subscriber loop. The circuits in the telephone and at the central office form a complete electric circuit, or loop.

1.5 Basic Telephone System

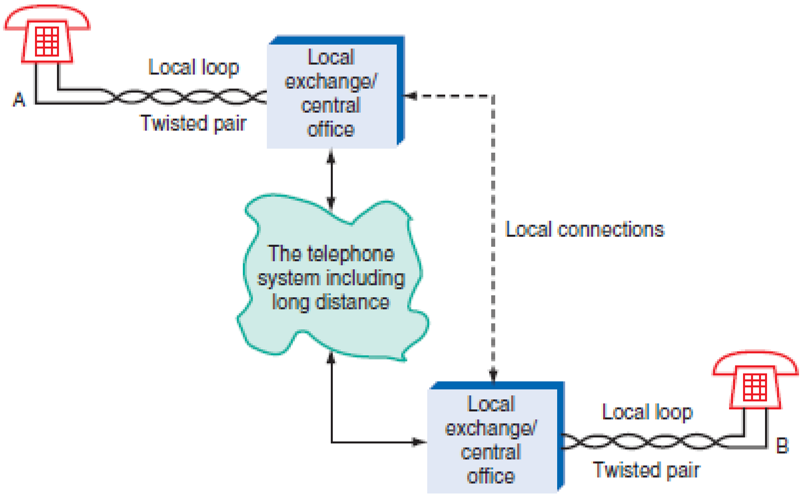

Figure 1.1 Basic Telephone System

A basic telephone or telephone set is an analog baseband transceiver. It consists of the following:

The ringer is either a bell or electronic oscillator connected to a speaker. A switch hook is a double-pole mechanical switch that is usually controlled by a mechanism actuated by the telephone handset. The dialing circuits provide a way for entering the telephone number to be called. Most telephones use the dual-tone multi frequency (DTMF) system. The handset contains a microphone for the transmitter and a speaker or receiver.

A combination of 350 Hz and 440 Hz sine waves sent to the Telephone from the central office (CO) indicating that the network is ready to receive calling instructions.

The hybrid is a special transformer used to convert signals from the four wires from the transmitter and receiver into a signal suitable for a single two-line pair to the local loop.

1.6 Basic Telephone Set

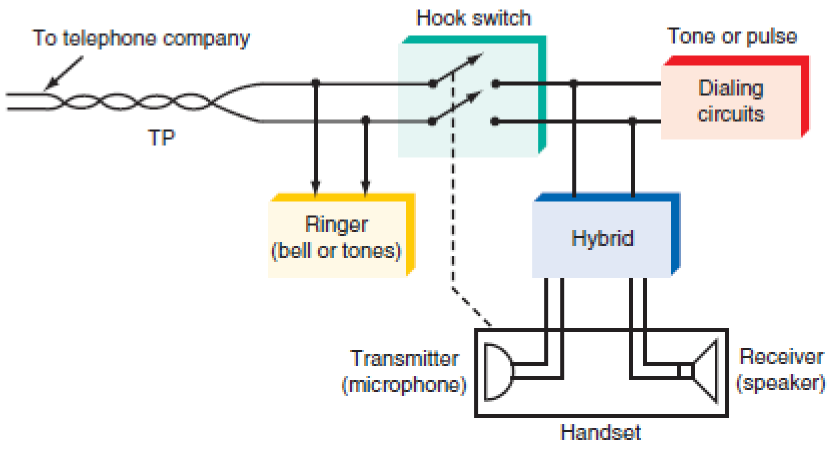

Figure 1.2 Basic Telephone Set

It also contains a ringer and a dialing mechanism. Overall, the telephone set fulfills the following basic functions.

The receive mode provides:

1. An incoming signal that rings a bell or produces an audio tone indicating that a call is being received
2. A signal to the telephone system indicating that the signal has been answered
3. Transducers to convert voice to electric signals and electric signals to voice

The transmit mode:

1. Indicates to the telephone system that a call is to be made when the handset is lifted
2. Indicates that the telephone system is ready to use by generating a signal called the dial tone
3. Provides a way of transmitting the telephone number to be called to the telephone system
4. Receives an indication that the call is being made by receiving a ringing tone
5. Provides a means of receiving a special tone indicating that the called line is busy
6. Provides a means of signaling the telephone system that the call is complete

All telephone sets provide these basic functions. Some of the more advanced electronic telephones have other features such as multiple line selection, hold, speaker phone, call waiting, and caller ID.

Figure shows a basic block diagram of a telephone set. The function of each block is described below. Detailed circuits for each of the blocks and their operation are described later when the standard and electronic telephones are discussed in detail.

Ringer: The ringer is either a bell or an electronic oscillator connected to a speaker. It is continuously connected to the twisted pair of the local loop back to the central office. When an incoming call is received, a signal from the central office causes the bell or ringer to produce a tone.

Switch Hook: A switch hook is a double-pole mechanical switch that is usually controlled by a mechanism actuated by the telephone handset. When the handset is "on the hook," the hook switch is open, thereby isolating all the telephone circuitry from the central office local loop. When a call is to be made or to be received, the handset is taken off the hook. This closes the switch and connects the telephone circuitry to the local loop. The direct current from the central office is then connected to the telephone, closing its circuits to operate.

Dialing Circuits: The dialing circuits provide a way for entering the telephone number to be called. In older telephones, a pulse dialing system was used. A rotary dial connected to a switch produced a number of on/off pulses corresponding to the digit dialed. These on/off pulses formed a simple binary code for signaling the central office.

In most modern telephones, a tone dialing system is used. Known as the dual-tone multifrequency (DTMF) system, this dialing method uses a number of pushbuttons that generate pairs of audio tones that indicate the digits called. Whether pulse dialing or tone dialing is used, circuits in the central office recognize the signals and make the proper connections to the dialed telephone.

Handset: This unit contains a microphone for the transmitter and a speaker or receiver. When speak into the transmitter, it generates an electric signal representing the voice. When a received electric voice signal occurs on the line, the receiver translates it to sound waves. The transmitter and receiver are independent units, and each has two wires connecting to the telephone circuit. Both connect to a special device known as the hybrid.

Hybrid: The hybrid circuit is a special transformer used to convert signals from the four wires from the transmitter and receiver to a signal suitable for a single two-line pair to the local loop. The hybrid permits full duplex, i.e., simultaneous send and receive, analog communication on the two-wire line. The hybrid also provides a side tone from the transmitter to the receiver so that the speaker can hear her or his voice in the receiver. This feedback permits automatic voice-level adjustment.

1.7 Conventional Telephone system

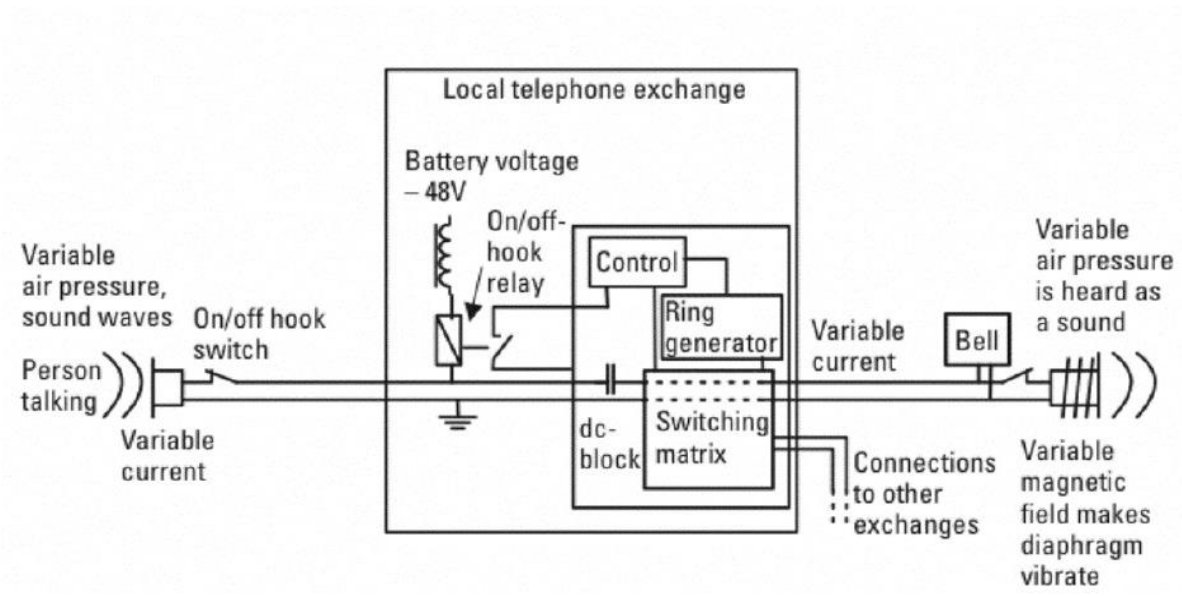

Figure 1.3 Conventional Telephone

There are some components associated with telephone systems that deserve special consideration.

Standard Telephone

Figure shows that the schematic diagram of a conventional telephone and the local loop connections back to the central office. The circuitry at the central office is discussed in greater detail later. For now, note that the central office applies a dc voltage over the

twisted-pair line to the telephone. This dc voltage is approximately 248 V with respect to ground in the open-circuit condition. When a subscriber picks up the telephone, the switch hook closes, connecting the circuitry to the telephone line. The load represented by the telephone circuitry causes current to low in the local loop and the voltage inside the telephone to drop to approximately 5 to 6 V.

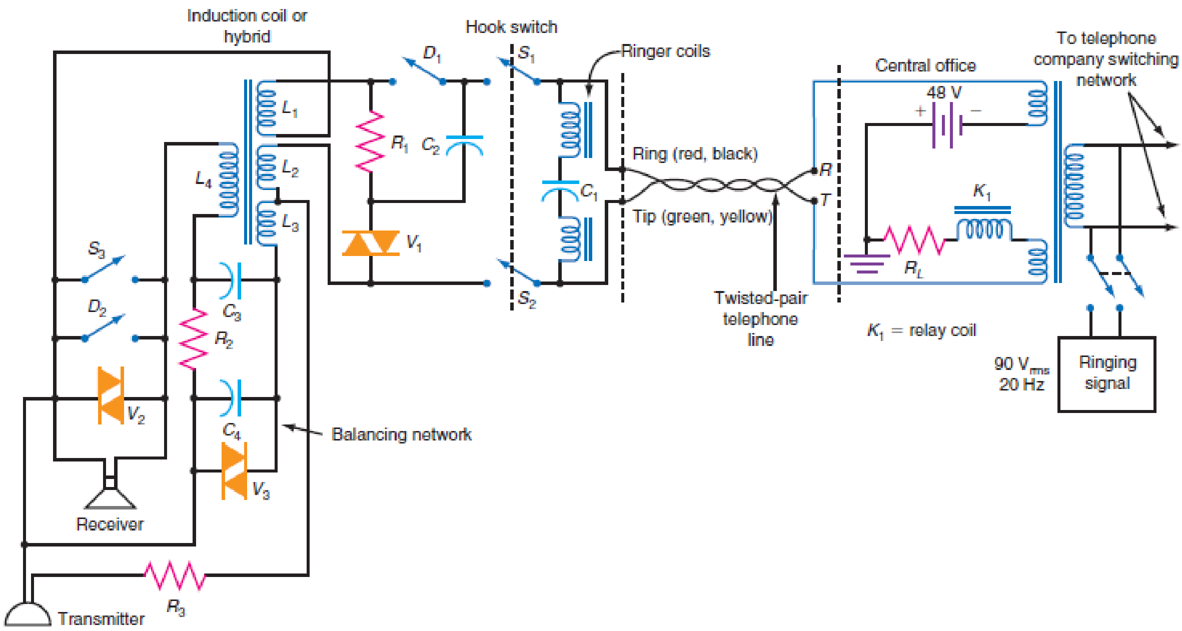

Figure 1.4 Standard telephone circuit diagram showing connection to central office

The amount of current l owing in the local loop depends upon a number of factors. The dc voltage supplied by the central office may not be exactly 248 V. It can, in fact, vary many volts above or below the 48-V normal value. Figure shows, the central office also inserts some resistance RL to limit the total current low if a short circuit occurs on the line. This resistance can range from about 350 to 800 V. In Fig., the total resistance is approximately 400 V.

The resistance of the telephone itself also varies over a relatively wide range. It can be as low as 100 V and as high as 400 V, depending upon the circuitry. The resistance varies because of the resistance of the transmitter element and because of the variable resistors called varistors used in the circuit to provide automatic adjustment of line level.

The local loop resistance depends considerably on the length of the twisted pair between the telephone and the central office. Although the resistance of copper wire in the twisted pair is relatively low, the length of the wire between the telephone and the central office can be many miles long. Thus the resistance of the local loop can be

anywhere from 1000 to 1800 V, depending upon the distance. The local loop length can vary from a few thousand feet up to about 18,000 ft.

Finally, the frequency response of the local loop is approximately 300 to 3400 Hz. This is sufficient to pass voice frequencies that produce full intelligibility. An unloaded twisted pair has an upper cutoff frequency of about 4000 Hz. But this cutoff varies considerably depending upon the overall length of the cable. When long runs of cable are used, special loading coils are inserted into the line to compensate for excessive roll-off at the higher frequencies.

The two wires used to connect telephones are labeled tip and ring. These designations refer to the plug used to connect telephones to one another at the central office. At one time, large groups of telephone operators at the central office used plugs and jacks at a switchboard to connect one telephone to another manually.

The tip wire is green and is usually connected to ground; the ring wire is red. Many telephone cables into a home or an office also contain a second twisted pair if a separate telephone line is to be installed. These wires are usually color-coded black and yellow. Black and yellow correspond to ring and tip, respectively, where yellow is ground. Other color combinations are used in telephone wiring.

Ringer circuitry connected directly to the tip and ring local loop wires is the ringer. The ringer in most older telephones is an electromechanical bell. A pair of electromagnetic coils is used to operate a small hammer that alternately strikes two small metallic bells. When an incoming call is received, a voltage from the central office operates the electromagnetic coils, which in turn operate the hammer to ring the bells. The bells make the familiar tone produced by most standard telephones. In Figure the ringing coils are connected in series with a capacitor C1. This allows the ac ringing voltage to be applied to the coils but blocks the 48 V of direct current, thus minimizing the current drain on the 48 V of power supplied at the central office. The ringing voltage supplied by the central office is a sine wave of approximately 90 Vrms at a frequency of about 20 Hz. These are the nominal values, because the actual ringing voltage can vary from approximately 80 to 100 Vrms with a frequency somewhere in the 15- to 30-Hz range. This ac signal is supplied by a generator at the central office.

The ringing voltage is applied in series with the 248-V dc signal from the central office power supply. The ringing signal is connected to the local loop line by way of a transformer T1. The transformer couples the ringing signal into its secondary winding where it appears in series with the 48-V dc supply voltage.

The standard ringing sequence is shown in Figure. In U.S. telephones, the ringing voltage occurs for 1 s followed by a 3-s interval. Telephones in other parts of the world use different ringing sequences. For example, in the United Kingdom, the standard ring sequence is a higher-frequency tone occurring more frequently, and it consists of two ringing pulses 400 ms long, separated by 200 ms. This is followed by a 2-s interval of quiet before the tone sequence repeats.

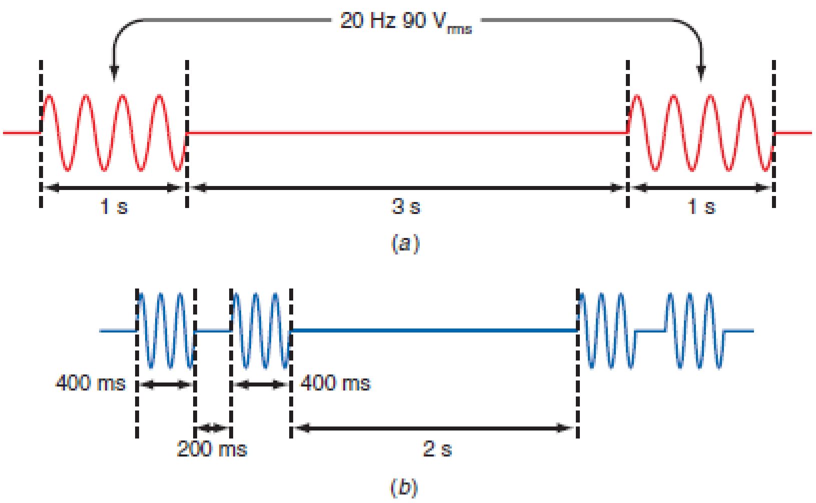

Figure 1.5 Telephone ringing sequence. (a) United States and Europe. (b) United Kingdom

Transmitter:

The transmitter is the microphone into which speak during a telephone call. In a standard telephone, this microphone uses a carbon element that effectively translates acoustical vibrations into resistance changes. The resistance changes, in turn, produce current variations in the local loop representing the speaker's voice. A dc voltage must be applied to the transmitter so that current flows through it during operation. The 48 V from the central office is used in this case to operate the transmitter. The resulting ac voice signal produced on the telephone line is approximately 1 to 2 Vrms.

Receiver: The receiver, or earpiece, is basically a small permanent-magnet speaker. A thin metallic diaphragm is physically attached to a coil that rests inside a permanent

magnet. Whenever a voice signal comes down a telephone line, it develops a current in the receiver coil. The coil produces a magnetic field that interacts with the permanent-magnet field. The result is vibration of the diaphragm in the receiver, which converts the electric signal to the acoustic energy that supplies the voice to the ear. As it comes in over the local loop lines, the voice signal has an amplitude of approximately 0.5 to 1 Vrms.

Hybrid:

The hybrid is a transformer like device that is used to simultaneously transmit and receive on a single pair of wires. The hybrid, which is also sometimes referred to as an induction coil, is really several transformers combined into a single unit. The windings on the transformers are connected in such a way that signals produced by the transmitter are put on the two-wire local loop but do not occur in the receiver. In the same way, the transformer windings permit a signal to be sent to the receiver, but the resulting voltage is not applied to the transmitter.

In practice, the hybrid windings are set up so that a small amount of the voice signal produced by the transmitter does occur in the receiver. This provides feedback to the speaker so that she or he may speak with normal loudness. The feedback from the transmitter to the receiver is referred to as the side tone. If the side tone were not provided, there would be no signal in the receiver and the person speaking would have the sensation that the telephone line was dead. By hearing his or her own voice in the receiver at a moderate level, the caller can speak at a normal level. Without the side tone, the speaker tends to speak more loudly, which is unnecessary.

Automatic Voice Level Adjustment: Because of the wide variation in the different loop lengths of the two telephones connected to each other, the circuit resistances will vary considerably, thereby causing a wide variation in the transmitted and received voice signal levels. All telephones contain some type of component or circuit that provides automatic voice level adjustment so that the signal levels are approximately the same regardless of the loop lengths. In the standard telephone, this automatic loop length adjustment is handled by components called varistors. These are labeled V1, V2, and V3 in Figure.

A varistor is a nonlinear resistance element whose resistance changes depending upon the amount of current passing through it. When the current passing through the

varistor increases, its resistance decreases. A decrease in current causes the resistance to increase.

The varistors are usually connected across the line. In Figure, varistor V1 is connected in series with resistor R1. This varistor automatically shunts some of the current away from the transmitter and the receiver. If the loop is long, the current will be relatively low and the voltage at the telephone will be low. This causes the resistance of the varistor to increase, thus shunting less current away from the transmitter and receiver. On short local loops, the current will be high and the voltage at the telephone will be high. This causes the varistor resistance to decrease; thus more current is shunted away from the transmitter and receiver. The result is a relatively constant level of transmitted or received speech. Note that a second varistor V3 is used in the balancing network. The balancing network (C3, C4, R2) works in conjunction with the hybrid to provide the side tone discussed earlier. The varistor adjusts the level of the side tone automatically.

Pulse Dialing:

The term dialing is used to describe the process of entering a telephone number to be called. In older telephones, a rotary dial was used. In more modern telephones, pushbuttons that generate electronic tones are used for "dialing."

The use of a rotary dialing mechanism produces what is known as pulse dialing. Rotating the dial and releasing it cause a switch contact to open and close at a fixed rate, producing current pulses in the local loop. These current pulses are detected by the central office and used to operate the switches that connect the dialing telephone to the called telephone. While most telephone companies still support pulse dialing, most dial phones have been long retired. Pulse dialing is no longer widely used.

Tone Dialing:

Although some dial telephones are still in use and all central offices can accommodate them, most modern telephones use a dialing system known as Touch- Tone. It uses pairs of audio tones to create signals representing the numbers to be dialed. This dialing system is referred to as the dual-tone multifrequency (DTMF) system. A typical DTMF keyboard on a telephone is shown in Fig. 18-5. Most telephones use a standard

keypad with 12 buttons or switches for the numbers 0 through 9 and the special symbols * and #. The DTMF system also accommodates four additional keys for special applications.

In Figure numbers represent audio frequencies associated with each row and column of pushbuttons. For example, the upper horizontal row containing the keys for 1, 2, and 3 is labeled 697, which means that when any one of these three keys is depressed, a sine wave of 697 Hz is produced. Each of the four horizontal rows produces a different frequency. The horizontal rows generate what is generally known as the low group of frequencies.

A higher group of frequencies is associated with the vertical columns of keys. For example, the keys for the numbers 2, 5, 8, and 0 produce a frequency of 1336 Hz when depressed.

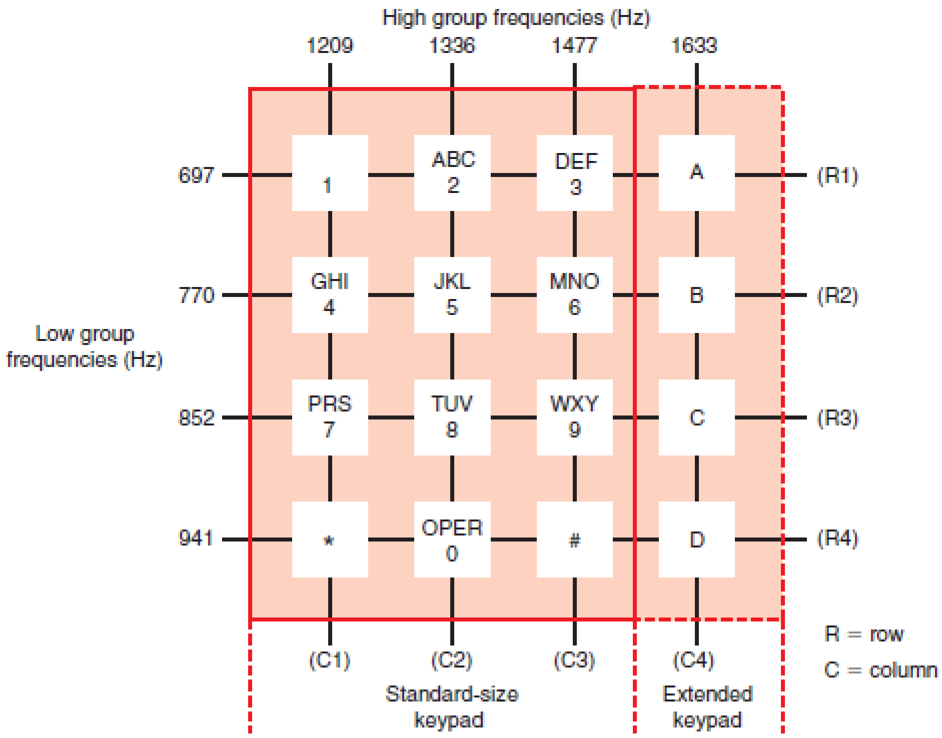

Figure 1.6 DTMF keypad

If the number 2 is depressed, two sine waves are generated simultaneously, one at 697 Hz and the other at 1336 Hz. These two tones are linearly mixed. This combination produces a unique sound and is easily detected and recognized at the central office as the signal representing the dialed digit 2. The tolerance on the generated frequencies is usually within (plus or minus1.5 percent.)

1.8 Telephone System

Most of us take telephone service for granted, as we do other so-called utilities, e.g., electric power. In the United States, telephone service is excellent. But this is certainly not the case in many other countries in the world.

When we refer to the telephone system, we are talking about the organizations and facilities involved in connecting telephone to the called telephone regardless of where it might be in United States or anywhere else in the world. The telephone system is called the Public Switched Telephone Network (PSTN). The telephone system referred to as the Plain Old Telephone Service (POTS). A number of different companies are involved in long-distance calls, although a single company is usually responsible for local calls in a given area. These companies make up the telephone system, and they design, build, maintain, and operate all the facilities and equipment used in providing universal telephone service. A vast array of equipment and technology are employed. Practically every conceivable type of electronic technology is used to implement worldwide telephone service, and that continues to change as Internet calling known as Voice over Internet Protocol (VoIP) grows.

The telephone, a small but relatively complex entity, is nothing compared to the massive system that backs it up. The telephone system can connect any two telephones in the world, and most people can only speculate on the method by which this connection takes place. It takes place on many levels and involves an incredible array of systems and technology. Obviously, it is difficult to describe such a massive system here. However, in this brief section, we attempt to describe the technical complexities of interconnecting telephones, the central office and the subscriber line interface that connect each user to the telephone system, the hierarchy of interconnections within the telephone system, and the major elements and general operation of the telephone system. Long-distance operation and special telephone interconnection systems such as the PBX are also discussed. VoIP is introduced.

Subscriber Interface Most telephones are connected to a local central office by way of the two-line, twisted pair local loop cable. The central office contains all the equipment that operates the telephone and connects it to the telephone system that makes the connection to any other telephone.

Each telephone connected to the central office is provided with a group of basic circuits that power the telephone and provide all the basic functions, such as ringing, dial tone, and dialing supervision. These circuits are collectively referred to as the subscriber interface or the subscriber line interface circuit (SLIC). In older central office systems, the subscriber interface circuits used discrete components. Today, most functions of the subscriber line interface are implemented by one or perhaps two integrated circuits plus supporting equipment. The subscriber line interface is also referred to as the line side interface.

The SLIC provides seven basic functions generally referred to as BORSCHT.
The (telephone) line interface is often referred to as a BORSCHT circuit.
This acronym describes the functional requirements of a standard telephone line interface. The tip and ring leads of the telephone set are wired through some protection devices to the line interface located in the peripheral module. This interface must perform the following functions:

B Battery feed

O Over voltage protection

R Ringing

S Supervision & Signaling

C Coding

H Hybrid

T Test

Line Cards

Line cards are the single most common component in a telephone office. It is a very complex device that contains a wide range of technologies.

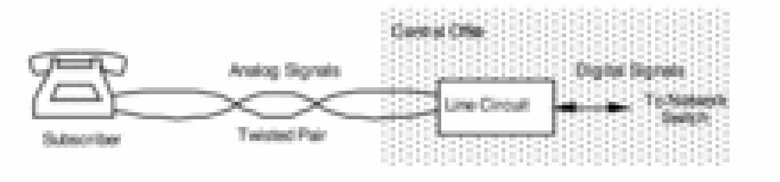

Figure 1.7 SLIC

Many of these functions can be integrated into a single IC, often called a SLIC chip (subscriber line interface chip). SLICs have been available for the PBX market for over a decade. Recently however, they have also become available for the central office environment as well.

B - Battery Feed

Most domestic appliances are powered from an electric utility grid. The notable exception to this is the telephone. This is because the telephone should still operate in the event of a power failure. Indeed, the telephone is vital in case of disaster or emergency.

The telephone office provides a nominal -48 volt dc feed to power the phone. This magnitude is considered the maximum safe dc operating potential. It would not be in the telephone company's best interest to provide a dc voltage, which could electrocute its customers, or it's own employees. A negative potential was chosen to reduce corrosive action on buried cables.

Multi-function telephones cannot always be powered from the telephone exchange and often require an alternate power source. For this reason, sophisticated line interfaces such as ISDN SAA interfaces have a 'fail to POTS' mode. If the electric power fails, the complex phone cannot function to full capacity. The telephone exchange can sense the local power outage through the telephone loop and switches to POTS only service.

The POTS loop requires a nominal -48 v at 20 – 100 ma dc to maintain a voice and signaling path. The earpiece in the handset does not require biasing, but the carbon microphone does. Subscriber signaling is performed by temporarily placing a short circuit on the loop thus changing the loop current, which is then sensed at the central office.

Figure 1.8 POTS Loop

There are several ways to provide loop current, the simplest being a resistor in series with a battery.

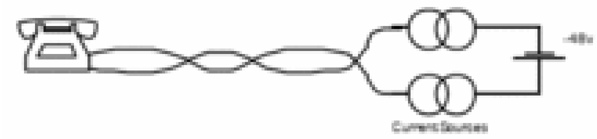

Figure 1.9 Loop current

Another way to provide loop current is by an electronic current source.

Although this method is quite complex, it has become quite popular with the advent of high voltage bipolar technology. One of the more difficult requirements to meet is the 60-dB longitudinal line balance requirement. To achieve this, the impedance to ground on each side of the loop, must match within 0.1%. This is easy to do with laser trimmed thick film resistors, but a bit tricky with current sources.

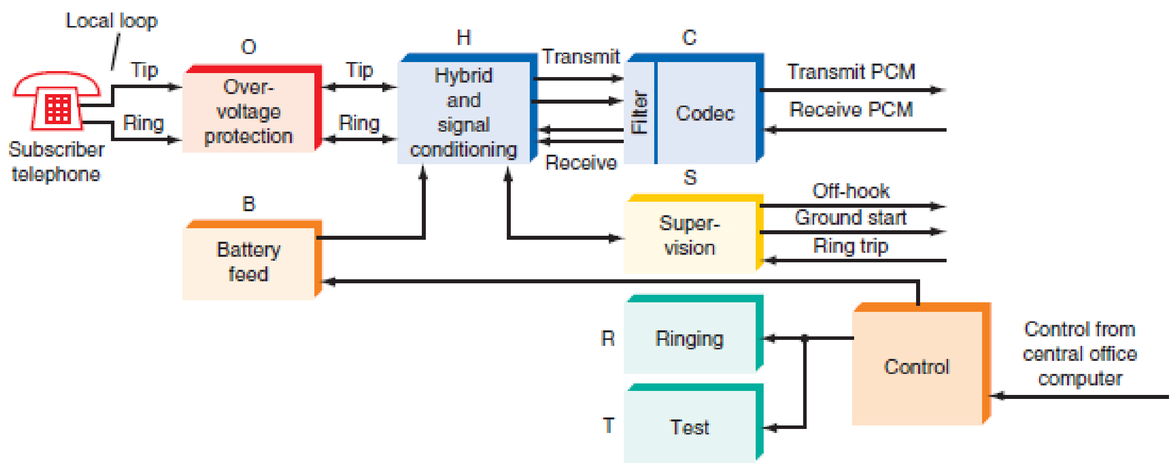

Figure 1.10 BORSCHT functions in the subscriber line interface at the central office

A standard telephone requires a minimum of about 20 ma. This means that the maximum possible loop resistance is about 2000 . In actual practice, the loop is generally limited to 1250 W. The maximum loop length is determined by the wire gauge.

O - Over-voltage Protection

The two major types of over-voltage that can occur are lightning strikes and power line contact. In both cases, the circuit must either recover or fail-safe. Under no circumstances can a surge be allowed to propagate further into the system, or create a fire.

Initial surge protection is provided at the MDF by gas tubes and/or carbon blocks, which arc if the applied voltage exceeds a few hundred volts. Since these devices take a finite time to respond, high-speed diodes are also used at the line circuit inputs.

R - Ringing

Ringing is often provided by means of a dedicated ringing generator that is connected onto the loop by means of a relay. It is possible to generate ringing voltages at the line interface if the current generators have a high enough voltage source available to them. Or alternately, a switching converter with step up capability can be place on the interface.

S - Supervision & Signaling

The central office must supervise the loop in order to identify customer requests for service. A request for service is initiated by going off-hook. This simply draws loop current from the CO. Loop current at the far-end is monitored during ringing to enable the CO to disconnect the ringing generator when the phone is answered. The office continues to monitor the loop current at both ends of the connection throughout the call, to determine when the call is terminated by hanging up.

Signaling is a way to inform the CO what the customer wants. The two basic signaling methods used in customer loops are dial pulse and touch-tone. It is interesting to note that preferred customer loop signaling method in analog exchanges is digital, while the preferred method in digital exchanges is analog.

MF Signaling Tones

Two tones are used to perform the signaling function to eliminate the possibility that speech be interpreted as a signal. At one time DTMF decoders were costly and bulky devices located in a common equipment bay, but today with the advent of LSI technology, this function can be performed on a chip. An example is the Mitel MT8865 DTMF filter, and MT8860 DTMF decoder.

Positions 11 to 14 are not presently being used.

C - Coding

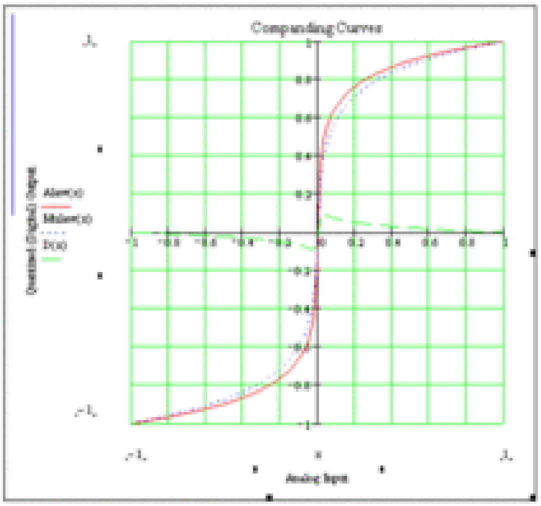

Figure 1.11 Companding curve

Telecommunications signals are seldom linearly encoded, but rather are companded (a combination of compression & expansion). This allows for a more uniform S/N ratio over the entire range of signal sizes. Without companding, a 12 bit linear encoding scheme would be needed to obtain the same S/N ratio at low volume levels. It also reduces the noise and crosstalk levels at the receiver.

Since the highest frequency passed is about 3.4 kHz, a great deal of ingenuity is required to pass data at 4.8, 9.6 kbps or even higher. Note that these are well above the Nyquist rate but considerably below the Shannon-Hartley limit.

All modern telephone systems today employ codecs in the BORSCHT interface to digitize the incoming analog signals. It is ironic that although the telephone system has been updated to digital technology, the telephone set and loop has remained analog.

By international agreement, all voice codecs use an 8 kHz sampling rate. Since each transmitted sample is 8 bits long, the analog voice signal is encoded into a 64 kbps binary steam. This rate determines the basic channel data rate of most other digital communications systems.

By bypassing the codec, it is possible to send 64 kbps customer data through the telephone system. However, because of old style signaling schemes still in use, digital data rates are often limited to 56 kbps.

H – Hybrid

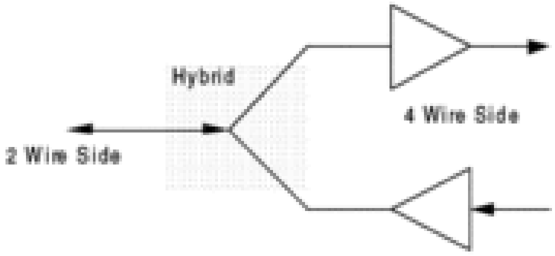

Figure 1.12 Hybrid

A diplexer performs a bi-directional 2-wire to 4-wire conversion. It allows two unidirectional electrical paths to be combined into a single bi-directional one, and vice versa. It is advantageous to separate transmit and receive portions of the signal since it is easier to make unidirectional amplifiers, filters, and logic devices.

One of the simplest ways to create an audio band hybrid is to use a transformer hybrid.

Single Core Transformer Hybrid

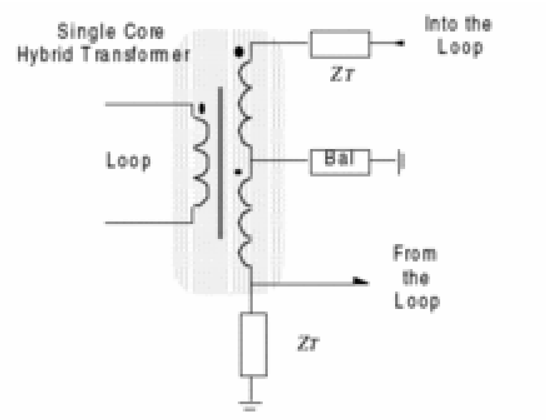

Figure 1.13 Single Core Transformer Hybrid

There are several ways to split transmit and receive paths, the simplest method uses a single core hybrid transformer.

The basic defining transformer equations are:

$$\frac{V_1}{n_1} = \frac{V_2}{n_2} = \frac{V_3}{n_3} = \cdots \qquad and \qquad I_1 n_1 + I_2 n_2 + I_3 n_3 + \cdots = 0$$

For a single core hybrid with a center-tapped secondary, the impedance relationships for proper operation (conjugate matching) are:

$$for \qquad n_2 = n_3 \qquad Z_2 = Z_3 = 2Z_4 \qquad and \qquad Z_1 = \left(\frac{n_2}{n_1}\right)^2 Z_4$$

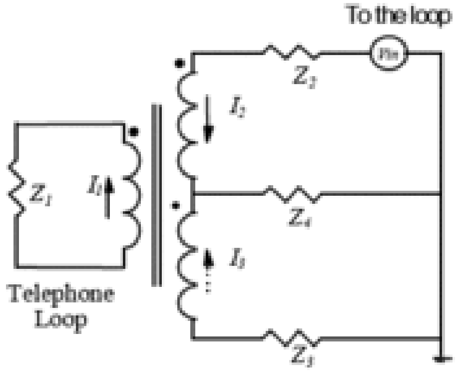

Figure 1.14 Transformer

Note what happens if the transformer is driven from one of the secondary windings:

$$let \qquad n_1 = n_2 = n_3 \qquad \therefore I_3 = -I_1 - I_2$$

But I1 and I2 flow in the opposite directions, therefor:

$$I_3 = -\left(-I\right)_1 - I_2 \qquad and\, if \qquad |I_1| = |I_2| \qquad then \qquad I_3 = 0$$

This last requirement can be satisfied by adjusting the impedances Z1 - Z4 to make the currents equal. From this,observe that signals injected into any port emerge only at adjacent ports but not at the opposite one.

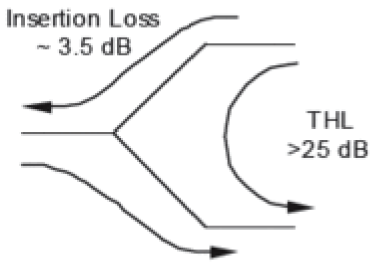

Figure 1.15 Insertion loss

In a properly balanced single core hybrid the typical throughput or insertion loss is about 3.5 dB and the THL (trans hybrid loss) is about 25 dB.

Double Core Hybrid

When properly balanced, a 2-core network can achieve a THL of 50 dB while the insertion loss remains at about 3.5 dB. It has better performance than the single core device, but is bulkier and more expensive.

Balancing Networks :

All telecom equipment is tested and characterized against standard impedance terminations. These impedances are based on line surveys and are approximate equivalent circuit representations of the outside cabling plant.

T – Testing: In order to maintain a high degree of service (99.999%), the equipment must be capable of detecting and repairing faults before the customer is even aware that there may be a problem. As a result, a separate test buss and access relay is provided on a line interface. Tests may be performed in a bridged mode or with the loop and line card disconnected from each other. Testing can be done in three basic directions:

- **From the line interface looking out towards the subscriber loop**
- **From the loop connection looking into the line card**
- **From the central office side of the line card .These tests are generally automated and are conducted late at night when there is little chance that the customer will request service, thus interrupting the test. Some of the scheduled tests may include:**
    - **Transmit and receive levels**
    - **Transmit and receive frequency response**
    - **Insertion loss**
    - **Trans-hybrid loss**
    - **Quantization distortion**
- **Aliasing distortion Some other tests that may be performed when commissioning a line or when a complaint is lodged, include:**
    - **Impulse noise test**
    - **C-message noise**
    - **Longitudinal balance**

Repeaters

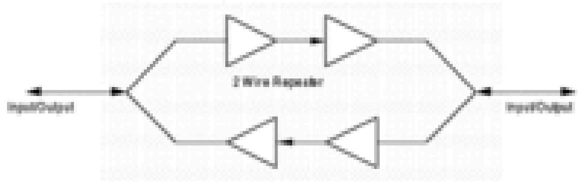

Figure 1.16 Repeaters

By placing two hybrids back to back, it is possible to create a bidirectional amplifier or repeater. The total gain in the 4-wire path within the repeater must not exceed the combined trans hybrid loss of the transformers. If this happens, the circuit will oscillate or sing. The total gain in the 4-wire path within the repeater must not exceed the combined trans hybrid loss of the transformers. If this happens, the circuit will oscillate or sing.

1.9 Telephone Hierarchy

Whenever make a telephone call, voice is connected through local exchange to the telephone system. From there it passes through at least one other local exchange, which is connected to the telephone calling. Several other facilities may provide switching, multiplexing, and other services required to transmit voice signal.

The telephone system is referred to as the public switchod telephone network (PSTN).The organization of this hierarchy in the United States is discussed in the next sections.

Central Office:

The central office or local exchange is the facility to which the telephone is directly connected by a twisted-pair cable. Also known as an end office (EO), the local exchange can serve up to 10,000 subscribers, each of whom is identified by a four-digit number from 0000 through 9999 (the last four digits of the telephone number). The local exchange also has an exchange number. These are the three additional digits that make up a telephone number. Obviously, there can be as many as 1000 exchanges with numbers from 000 through 999. These exchanges become part of an area code region, which is defined by an additional three-digit number. Each area code is fully contained within one of the geographic areas assigned to one of the regional operating companies. These companies are called local exchange carriers, or local exchange companies (LECs).

Operational Relationships:

The LECs provide telephone services to designated geographic areas referred to as local access and transport areas (LATAs). The United States is divided into approximately 200 LATAs. The LATAs are defined within the individual states making up the seven operating regions. The LECs provide the telephone service for the LATAs within their regions but do not provide long-distance service for the LATAs. Long-distance service is provided by long-distance carriers known as interexchange carriers (IXCs). The IXCs are the familiar long-distance carriers, such as AT&T, Verizon and Sprint. Long-distance carriers must be used for the interconnection for any inter- LATA connections. The LECs can provide telephone service within the LATAs that are part of their operating region, but links between LATAs within a region, even though they may be directly adjacent to one another, must be made through an IXC.

Each LATA contains a serving, or point-of-presence (POP), office that is used to provide the interconnections to the IXCs. The local exchanges communicate with one another via individual trunks. And all local exchanges connect to an LEC central offi ce, which provides trunks to the POP. At the POP, the long-distance carriers can make their interface connections. The POPs must provide equal access for any long-distance carrier desiring to connect. Many POPs are connected to multiple IXCs, but in many areas, only one IXC serves a POP.

Figure summarizes the hierarchy just discussed. Individual telephones within a LATA connect to the local exchange or central office by way of the two-wire local loop. The central offices within an LATA are connected to one another by trunks. These trunks may be standard baseband twisted-pair cables run underground or on telephone poles, but they may also be coaxial cable, fiber-optic cable, or microwave radio links. In some areas, two or more central offices are located in the same building or physical facility.

Trunk interconnections are usually made by cables. The local exchanges are also connected to an LEC central office when a connection cannot be made between two local exchanges that are not directly trunked. The call passes from the local exchange to the LEC central office, where the connection is made to the other local exchange. The LEC central office is also connected to the POP. Depending upon the organization of the LEC within the LATA, the LEC central office may contain the POP. Note in Figure that the POP provides the connections to the long-distance carriers, or IXCs. The "cloud"

represents the long-distance networks of the IXCs. The long-distance network connects to the remote POPs, which in turn are connected to other central offices and local exchanges.

Most other long-distance carriers have their own specific hierarchical arrangements. A variety of switching offices across the country are linked by trunks using fiber-optic cable or microwave relay links. Multiplexing techniques are used throughout to provide many simultaneous paths for telephone calls.

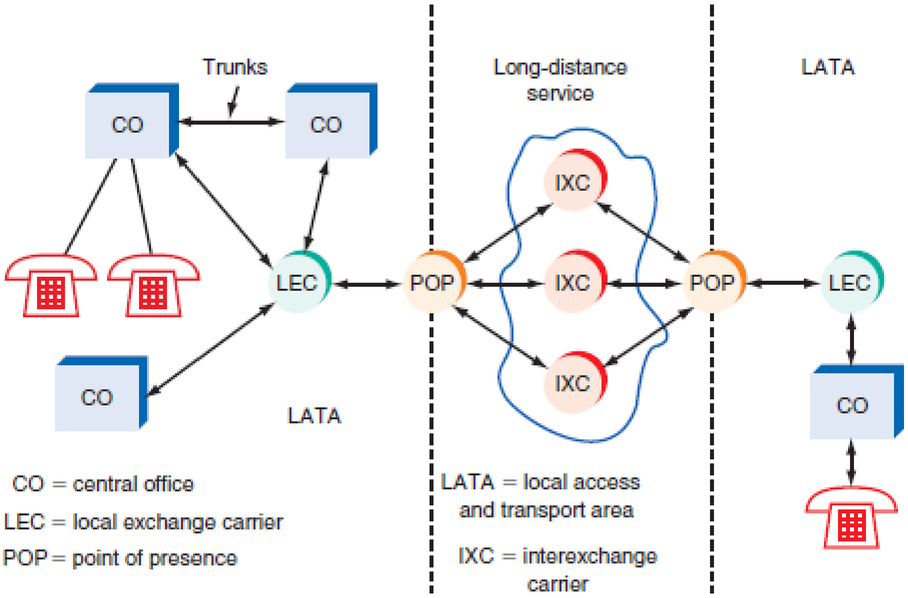

Figure 1.17 Organization of Telephone in US

In all cases, the various central offices and routing centers provide switching services. The whole idea is to permit any one telephone to directly connect with any other specific telephone. The purpose of all the different levels in the telephone system hierarchy is to provide the interconnecting trunk lines as well as switching equipment that makes the desired interconnection. The transmission method in long distance is fiber-optic cable using protocols known as the asynchronous transfer mode (ATM), the synchronous optical network (SONET), and the optical transport network (OTN).

Private Telephone System

Telephone service provided to companies or large organizations with many employees and many telephones is considerably different from basic local loop service provided for individuals. Depending upon the size of the organization, there may be

dozens, hundreds, or even thousands of telephones required. It is simply not economical to provide each telephone in the organization with its own separate local loop connection to the central office. It is also an inefficient use of expensive facilities to use a remote central office for intercompany communication. For example, an individual in one office often may need to make an intercompany call to a person in another office, which may be only a few doors down the hall or a couple of floors away. Making this connection through the local exchange is wasteful.

This problem is solved by the use of private telephone systems within a company or organization. Private telephone systems implement telephone service among the telephones in the organization and provide one or more local loop connections to the central office. The two basic types of private telephone systems are known as key systems and private branch exchanges.

Key Systems:

Key systems are small telephone systems designed to serve from 2 to 50 user telephones within an organization. Commercially available systems usually have provisions for 6, 10, 12, or 50 telephones. Simple key telephone systems are made up of the individual telephone units generally referred to as stations, all of which are connected to a central answering station. The central answering station is connected to one or more local loop lines known as trunks back to the local exchange. Most systems also contain a central electronic switching unit that makes all the internal and external connections.

The telephone sets in a key system typically have a group of pushbuttons that allow each telephone to select two or more outgoing trunking lines. Phone calls are made in the usual way.

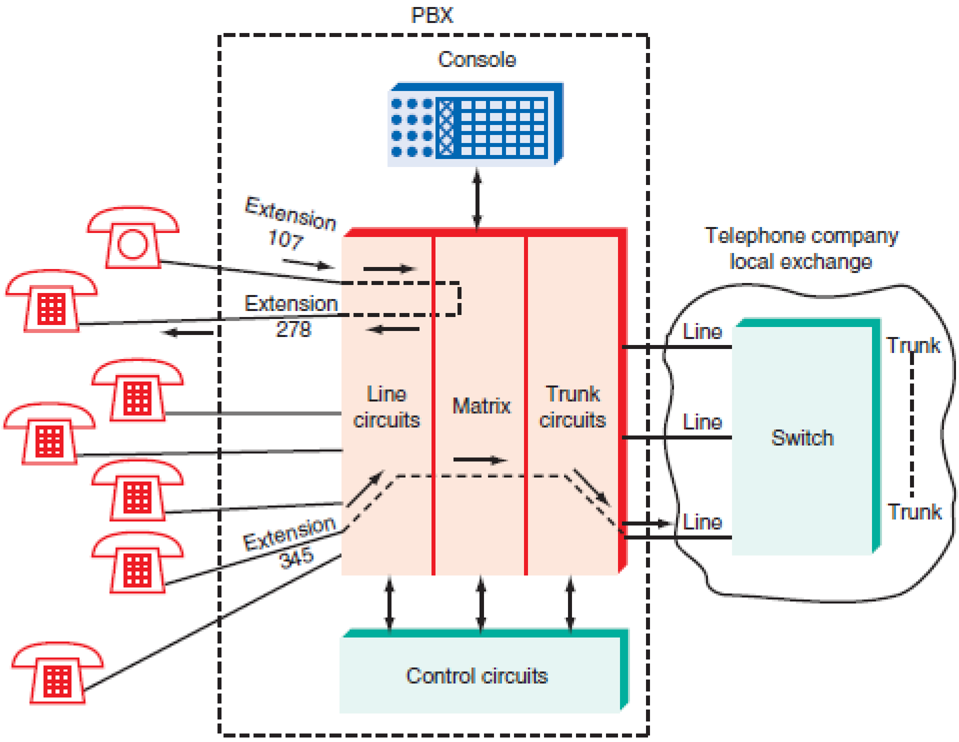

Figure 1.18 A PBX

Private Branch Exchange:

A private branch exchange, or PBX, as it is known, is a private telephone system for larger organizations. Most PBXs are set up to handle 50 or more telephone interconnections. They can handle thousands of individual telephones within an organization. These systems may also be referred to as private automatic branch exchanges (PABXs) or computer branch exchanges (CPXs). Of the three terms, the expression PBX is the most widely known and used.

A PBX, in effect, a miniature complete telephone system. It provides baseband interconnections to all the telephones in an organization. All the telephones connect to a central switching system that makes intercompany connections as well as external connections to multiple trunk lines to the central office. Like the key system, the PBX offers the advantages of efficiency and cost reduction when many telephones are required. Interoffice calls can be completed by the PBX system without accessing the local exchange. Furthermore, it is more economical to limit the number of trunk lines to the central office, for not all telephones in the organization will be attempting to access an outside line at one time. The modern PBX is usually fully automated by computer control. Although no operator is required, most large organizations have one or more operators,

answer incoming telephone calls and route them appropriately with a control console. However, some PBXs are automated so that the individual user's telephone whose extension is the last four digits of the telephone number can be called directly from outside.

From the figure, the PBX is made up of line circuits that are similar to the subscriber line interface circuits discussed earlier. The matrix is the electronic switch that connects any phone to any other phone in the system. It also permits conference calls. The trunk circuits interface to the local loop lines to the central office. All the circuits are under the control of a central computer dedicated to the operation of the PBX.

An alternative to the PBX is known as Centrex. This service, normally provided by the local telephone company, performs the function of a PBX but uses special equipment, and most of the switching is carried out by the local exchange switching equipment over special trunk lines. Its advantage over a standard PBX is that the high initial cost of PBX equipment can be avoided by leasing the Centrex equipment from the telephone company.

Electronic Telephones

Today, all new telephones are electronic, and they use integrated circuit technology. The development of the microprocessor has also affected telephone design. Although simple electronic telephones do not contain a microprocessor, most multiple-line and full-feature telephones do. A built-in microprocessor permits automatic control of the telephone's functions and provides features such as telephone number storage and automatic dialing and redialing that are not possible in conventional telephones.

IC Electronic Telephone: The major components of a typical electronic telephone circuit are shown in Figure. Most of the functions are implemented with circuits contained within a single IC. In the Figure, note that the Touch Tone keypad drives a DTMF tone generator circuit. An external crystal or ceramic resonator provides an accurate frequency reference for generating the dual dialing tones.

The tone ringer is driven by the 20-Hz ringing signal from the phone line and drives a piezoelectric sound element. The IC also contains a built-in line voltage regulator. It takes the dc voltage from the local loop and stabilizes it to provide a constant voltage

to the internal electronic circuits. An external zener diode and transistor provide bias to the electret microphone.

The internal speech network contains a number of amplifiers and related circuits that fully duplicate the function of a hybrid in a standard telephone. This IC also contains a microcomputer interface. The box labeled MPU is a single-chip microprocessing unit. Although it is not necessary to use a microprocessor, if automatic dialing and other functions are implemented, this circuit is capable of accommodating them.

Finally, note the bridge rectifier and hook switch circuit. The twisted pair from the local loop is connected to the tip and ring. Both the 48-V dc and 20-Hz ring voltages will be applied to this bridge rectifier. For direct current, the bridge rectifier provides polarity protection for the circuit, ensuring that the bridge output voltage is always positive. When the ac ringing voltage is applied, the bridge rectifier it into a pulsating dc voltage. The hook switch is shown with the telephone on the hook or in the "hung-up" position. Thus the dc voltage is not connected to the circuit at this time.

However, the ac ringing voltage will be coupled through the resistor and capacitor to the bridge, where it will be rectified and applied to the two zener diodes D1 and D2 that drive the tone ringer circuit.

When the telephone is taken off the hook, the hook switch closes, providing a dc path around the resistor and capacitor R1 and C1. The path to the tone ringer is broken, and the output of the bridge rectifier is connected to zener diode D3 and the line voltage regulator. Thus the circuits inside the IC are powered up, and calls may be received or made.

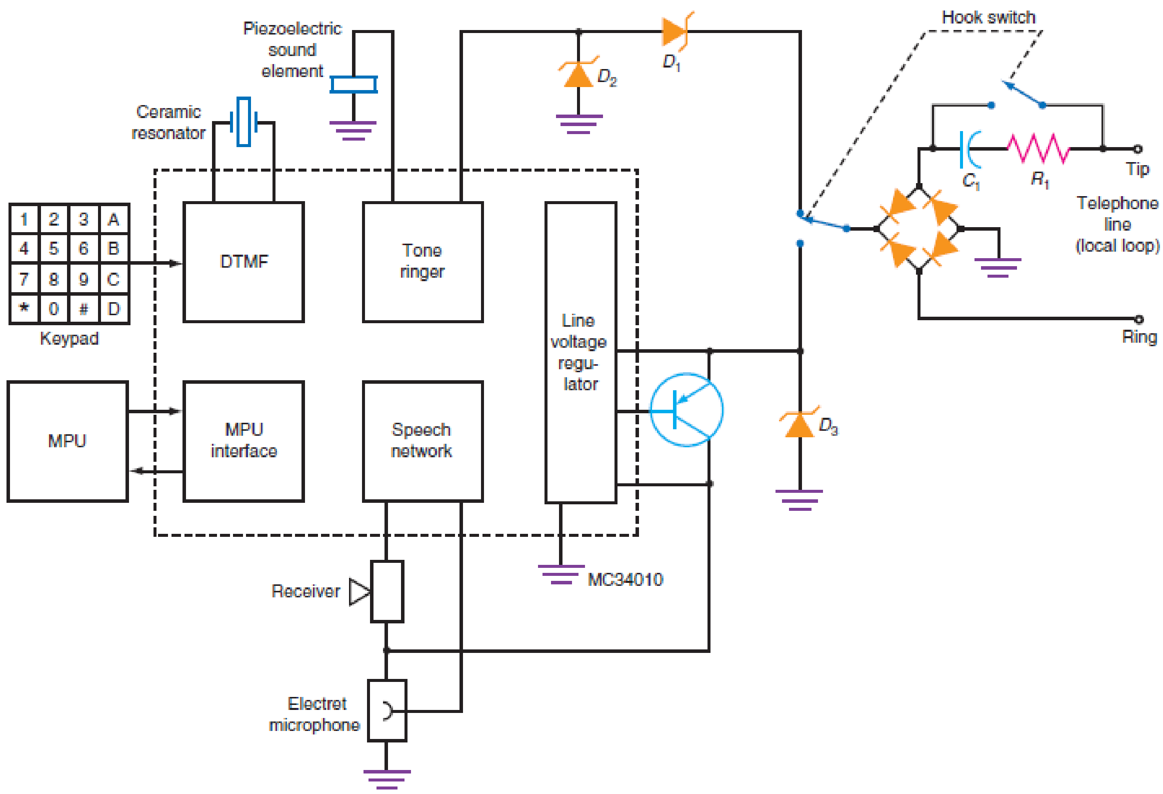

Figure 1.19 Single-chip electronic telephone

Microprocessor Control:

All modern electronic telephones contain a built-in microcontroller. Like any microcontroller, it consists of the CPU, a ROM in which a control program is stored, a small amount of random access read-write memory, and I/O circuits. The microcontroller, usually a single-chip IC, may be directly connected to the telephone IC, or some type of intermediate interface circuit may be used.

The functions performed by the microcomputer include operating the keyboard and any LCD display, if present. Some other functions involve storing telephone numbers and automatically redialing. Many advanced telephones have the capability of storing 10 or more commonly called numbers. The user puts the telephone into a program mode and uses the Touch Tone keypad to enter the most frequently dialed numbers. These are stored in the microcontroller's RAM. To automatically dial one of the numbers, the user depresses a pushbutton on the front of the telephone. This may be one of the Touch Tone pushbuttons, or it may be a separate set of pushbuttons provided for the purpose.

When one of the push buttons is depressed, the microcontroller supplies a preprogrammed set of binary codes to the DTMF circuitry in the telephone IC. Thus the

number is automatically dialed. Other features implemented by the microcontroller are caller ID and an answering machine.

Voice Mail. Previously called an answering machine, this feature is implemented on most electronic phones. The microcontroller automatically answers the call after a preprogrammed number of rings and saves the voice message. In older answering machines, the message was recorded on a tape cassette. But in modern phones, the voice message is digitized, compressed, and then stored in a small l ash ROM ready for replay. The outgoing message is also stored there.

Caller ID:

Caller ID, also known as the calling line identification service, is a feature that is now widely implemented on most electronic telephones. With this feature, any calling number will be displayed on an LCD readout when the phone is ringing. This allows to identify the caller. The caller ID service sends a digitized version of the calling number to phone during the first and second rings. The data transmitted includes the date, time, and calling number. Data is transmitted by FSK, where a binary 1 (mark) is a 1200-Hz tone and a binary 0 (space) is a 2200-Hz tone. The data rate is 1200 bps.

There are two message formats in use, the single-data message format (SDMF) and the multiple-data message format (MDMF). The SDMF is illustrated in Figure. One-half second after the first ring, 80 bytes of alternating 0s and 1s (hex 05) is transmitted for 250 ms followed by 70 ms of mark symbols. These two signals provide initialization and synchronization of the caller ID circuitry in the phone. This is followed by 1 byte describing the message type. This is usually a binary 4 (00000100), indicating the SDMF.

This is followed by a byte containing the message length, usually the number of digits in the calling number. Next the data is transmitted. This is the date, time, and the 10-digit phone number transmitted as ASCII bytes with the least significant digit first. The data format is 2 digits for the month, 2 digits for the day, 2 digits for the hour (military time), 2 digits for the minutes, and up to 10 digits for the calling number. For example, if the date is February 14, the time is 3:37 p.m., and the calling number is 512-499-0033, the data sequence would be 021415375124990033. The final byte in the message

is the checksum that is used for error detection. The checksum is the 2s complement sum (XOR) of all the data bytes not including the initialization and sync signals.

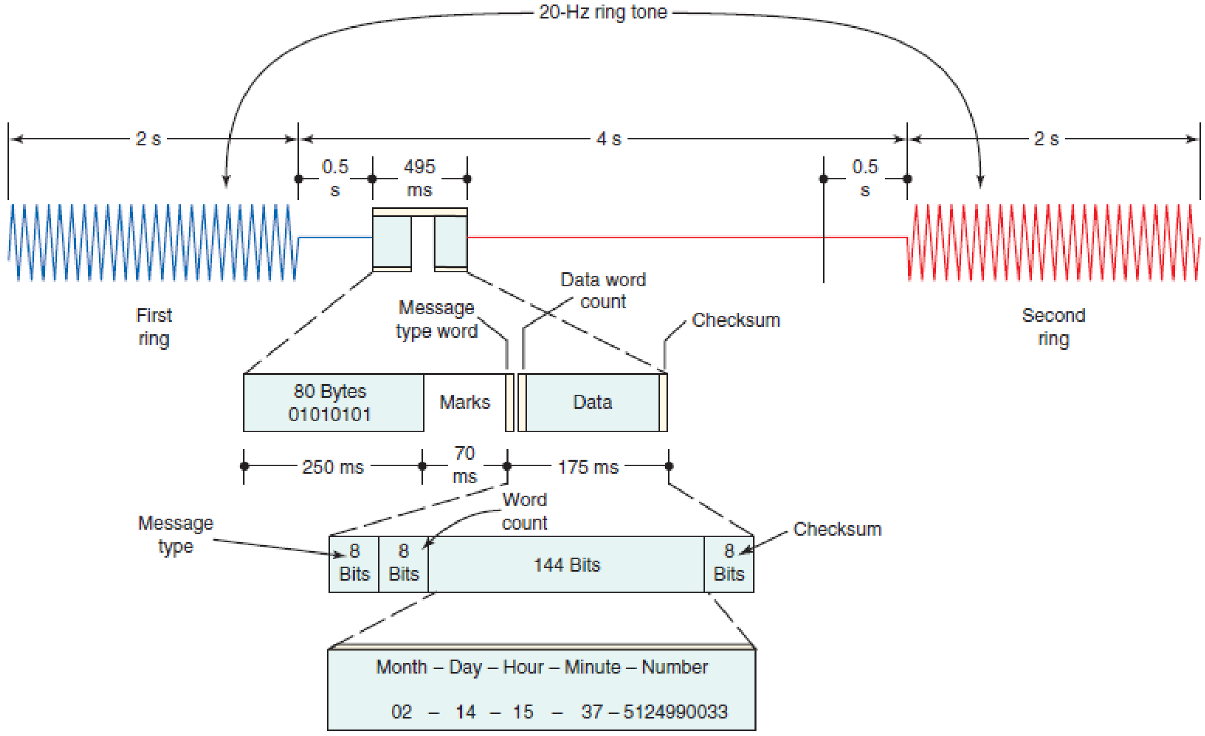

Figure 1.20 The caller ID transmission format

If the calling number is outside the calling area, the system will display an O on the LCD rather than the calling number. Furthermore, a caller may also have his or her number blocked. This can be done by setting it up with the service provider in advance or by dialing *67 prior to making the call. This will cause a P to be displayed on the LCD instead of the calling number. A more advanced data format is the MDMF. It is similar to the SDMF but includes an extra field for the name of the calling party plus additional identification bytes.

Line Interface: Most telephones are connected by way of a thin multiwire cable to a wall jack. A special connector on the cable, called an RJ-11 modular connector, plugs into the matching wall jack. Two local loops are available if needed. The wall jack is connected by way of wiring inside the walls to a central wiring point called the subscriber interface. Also known as the wiring block or modular interface, this is a small plastic housing containing all the wiring that connects the line from the telephone company to all the telephone wires in the house. Many houses and apartments are wired so that there is a wall jack in every room.

The line from the telephone company usually passes through a protector that provides lightning protection. It then terminates at the interface box. An RJ-11 jack and plug are provided to connect to the rest of the wiring. This gives the telephone company a way to disconnect the incoming line from the rest of the house wiring and makes testing and troubleshooting easier.

All the wiring is made by way of screw terminals. For a single-line house, the green and red tip and ring connections terminate at the terminals, and all wiring to the room wall jacks is connected in parallel at these terminals. If a second line is installed, the black and yellow wires, which are the tip and ring connections, are also terminated at screw terminals. They are then connected to the inside house wiring.

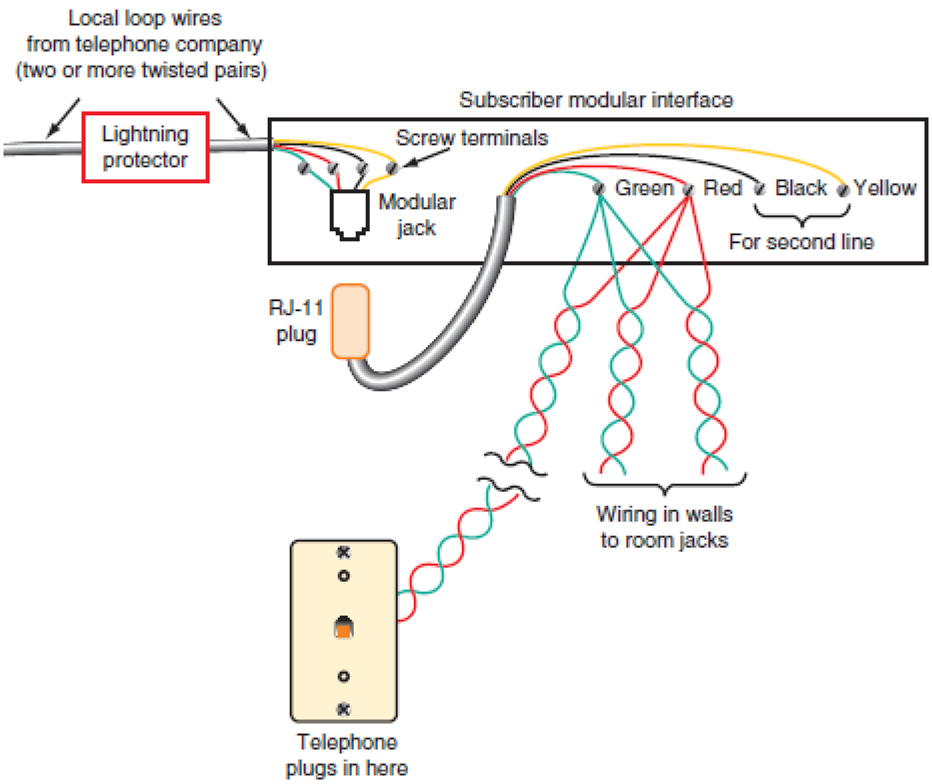

Figure 1.21 Subscriber interface

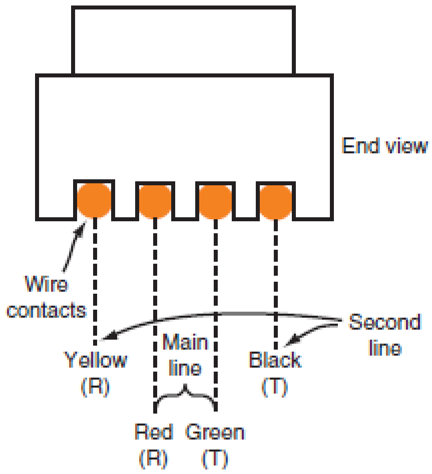

Figure 1.22 Connections to modular plug

Connections on the RJ-11 connector are shown in Figure. The red and green wires terminate at the two center connections, and the black and yellow wires terminate at the two outside connections. Most telephone wire and RJ-11 connectors have four wires and connections. Some cables have only the two inner wires. With four wires a two-line phone can be accommodated.

1.10 Cordless Telephone Concepts

A cordless telephone or portable telephone replaces the handset cord with a radio link. The handset communicates with a base station connected to a fixed telephone line. The range is limited, usually to the same building or some short distance from the base station. The base station attaches to the telephone network the same way a corded telephone does. Cordless" originates from the technique that made it possible for subscribers to connect a small base station to their telephones, thereby attaining a limited degree of mobility It is full duplex communication systems that use radio to connect a portable handset and a dedicated Base Station, which is then connected to a dedicated telephone line with a specific telephone number on a Public Switched Telephone Network (PSTN).

Cordless telephone is a telephone with a wireless handset that communicates via radio waves with a base station connected to a fixed telephone line, usually within a limited range of its base station (which has the handset cradle).

There are various generations of cordless system CT0,CT1,CT2,DECT and PHP

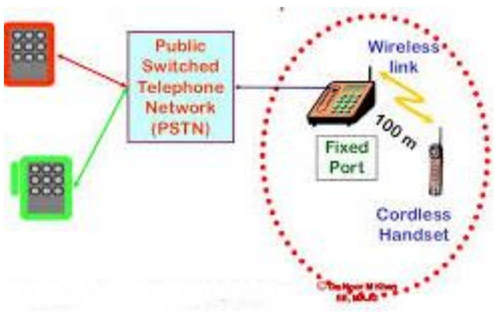

Figure 1.23 Cordless Telephone

A cordless telephone is a two-way radio system made up of two units, the portable unit or handset and the base unit. The base unit is wired to the telephone line by way of a modular connector. It receives its power from the AC line. The base unit is a complete transceiver in that it contains a transmitter that sends the received audio signal to the portable unit and receives signals transmitted and retransmits on the telephone line.

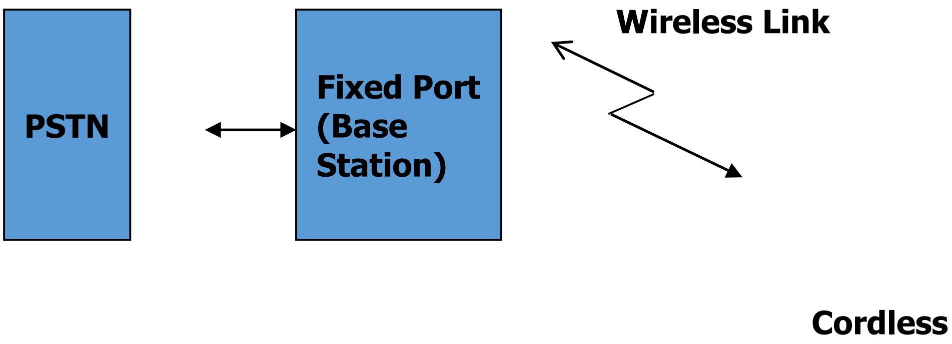

Figure 1.24 Cordless

The base unit contains a battery charger that rejuvenates the battery in the handheld unit. The portable unit is also a battery-powered transceiver. Both units have an antenna. The transceivers in both the portable and the base units use full-duplex operation. In the United States, seven frequency bands have been allocated by the Federal Communications Commission for uses that include cordless phones. These are:

- **1.7 MHz (1.64–1.78 MHz, up to 5 channels, AM modulation**
- **27 MHz, interspersed with Citizens Band (CB) Radio**
- **43–50 MHz (Base: 43.72–46.97 MHz, Handset: 48.76–49.99 MHz, allocated in November 1984 for 10 channels, and later 25 channels, FM modulation)**
- **900 MHz (902–928 MHz, allocated in 1993)**
- **1.9 GHz (1880–1900 MHz, used for DECT communications outside the US)**

- 1.9 GHz (1920–1930 MHz, developed in 1993 and allocated in October 2005, especially with DECT 6.0)
- 5.8 GHz (5725–5875 MHz, allocated in 2003 due to crowding on the 2.4 GHz band)

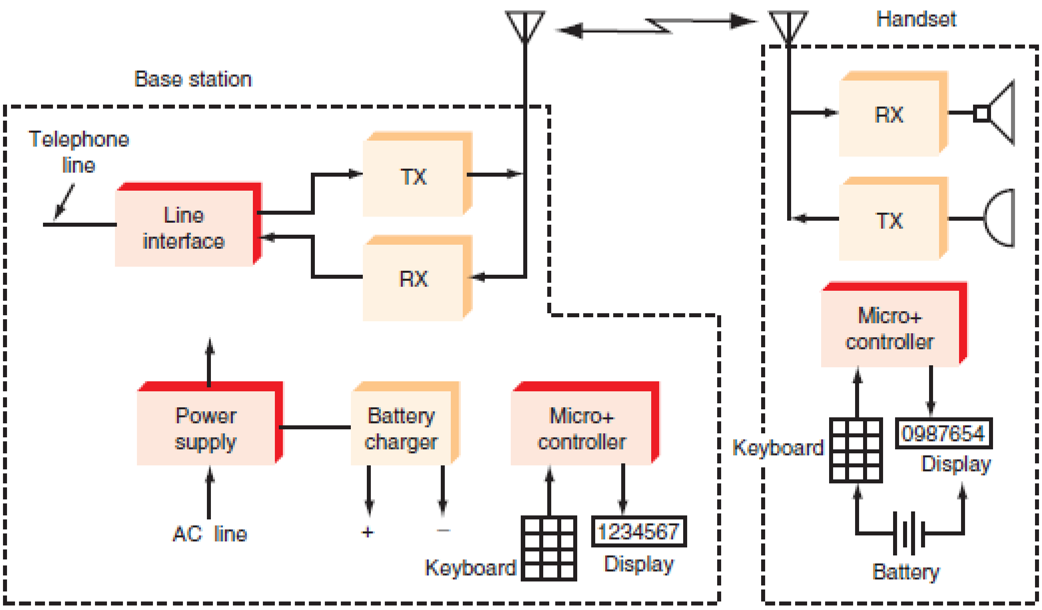

Figure 1.25 General block diagram of a cordless telephone

Figure shows simplified block diagrams of the base and portable units of a typical cordless telephone. Both the base unit and the handset contain an embedded microcontroller that controls all operations, including the keyboard and display. A high percentage of cordless units also contain a caller ID function, and many contain a voicemail feature. An analog-to-digital converter translates a received voice message to digital; it is compressed by the microcontroller and then stored in a l ash memory connected to the microcontroller.

Cordless Phone Features, Capabilities, and Limitations.

The frequency range defines the three basic classes of cordless telephones available today, but there are other considerations. Here is a summary of the three basic types. The simplest and least expensive cordless phones use the 43- to 50-MHz range. They are analog phones using frequency modulation. The transmitter output power is limited to 500 mW, and this, in turn, limits the transmission range to a maximum of about

1000 ft, depending upon the environment. The FCC created these limitations deliberately to reduce the amount of interference with nearby cordless telephones as well as the many wireless baby monitors and toy walkie-talkies using the same frequencies. While some 43- to 50-MHz phones are still available, for the most part they have been replaced by the newer digital phones.

Although these older phones work well enough, they are susceptible to noise and their range is limited. If higher quality and longer range are desired, phones in the 900-MHz, 2.4-GHz, or 5.8-GHz range can be used. Three types of 900-MHz phones are available. These are analog, digital, and spread spectrum. The analog phones use FM. Although they can transmit over a longer distance, they are still susceptible to noise. A digital 900-MHz phone is also available. It uses Gaussian FSK (GFSK) modulation. The best 900-MHz phones use direct- sequence spread spectrum (DSSS). With a power of up to 1 W, the transmission distance is a maximum of about 5000 to 7000 ft, depending on the environment and terrain. Both types of digital phones are highly immune to noise.

The newer and perhaps the best cordless phones use DSSS in the 2.4-GHz or5.8-GHz bands. Their maximum range is nearly 7000 ft, and they are virtually immune to local noise. Although these phones are far more expensive, they offer the highest- quality sound and greatest reliability.

For the most part, cordless phones in the United State have used proprietary designs rather than those conforming to a particular standard. Since the phones are only intended to work in a home or small office setting and there is no requirement that the phone interoperate with other cordless phones, any technology will work as long as it meets the FCC's frequency and operating mode guidelines. The situation is different in Europe where standards for cordless phones have existed for many years. The newest standard created by the European Telecommunications Standards Institute (ETSI), called Digital Enhanced Cordless Telecommunications (DECT) has now been approved for use in the United States. DECT works in the 1.8- to 1.9-GHz band for U.S. use. The DECT phones are digital, using Gaussian FSK modulation. Instead of using frequency-division duplexing (FDD) with two channels, DECT uses only a single channel and time-division duplexing (TTD). In a single channel, time-division multiplexing permits 12 users per channels. Typically 10 channels are available. The raw data rate is 1.152 Mbps. The

latest version of the DECT phone is 6.0, and these phones are available in the United States.

Facsimile Machine

It scans the contents of a document (as an image, not text) to create electronic signals. Scanning is done electronically and the scanned signal is converted into a binary signal. These signals are then sent to the destination (another FAX machine) in an orderly manner using telephone lines. At the destination, the signals are reconverted into a replica of the original document. Note that FAX provides image of a static document unlike the image provided by television of objects that might be dynamic. Today's modern fax machine is a high-tech electro- optical machine. Digital transmission with standard modem techniques is used.

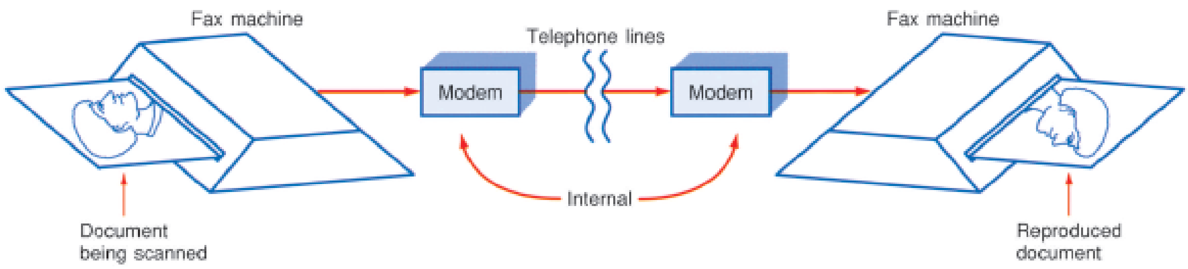

Figure 1.26 Components of a facsimile system

Figure shows how a printed letter might have been scanned. Assume that the letter F is black on a white background. The output of a photodetector as it scans across line a is shown in Fig. (a). The output voltage is high for white and low for black. The output of the photodetector is also shown for scan lines b and c. The output of the photodetector is used to modulate a carrier, and the resulting signal is put on the telephone line. The resolution of the transmission is determined by the number of scan lines per vertical inch. The greater the number of lines scanned, the higher the detail transmitted and the higher the quality of reproduction. Older systems had a resolution of 96 lines per inch (LPI), and the new systems have 200 LPI.

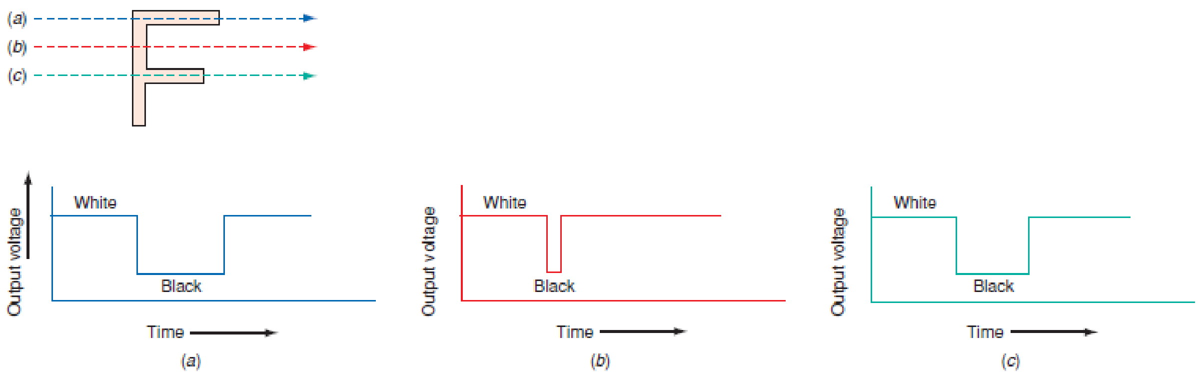

Figure 1.27 Output of a photosensitive detector during different scans

Facsimile Operation

A facsimile (commonly referred to as a fax) is a production of an exact copy of a document by electronic scanning, and the subsequent transmission of the resulting data.

Faxes are transmitted over ordinary phone lines using fax machines. In a typical fax transmission, the document to be faxed is placed in the document feeder of a fax machine and the telephone number of the destination fax machine is dialed. In a very short time, a replica of the document is received at the destination fax machine. By their very nature, faxes can contain any information that appears in written form. As such, faxes will often contain information that is personal, or otherwise confidential.

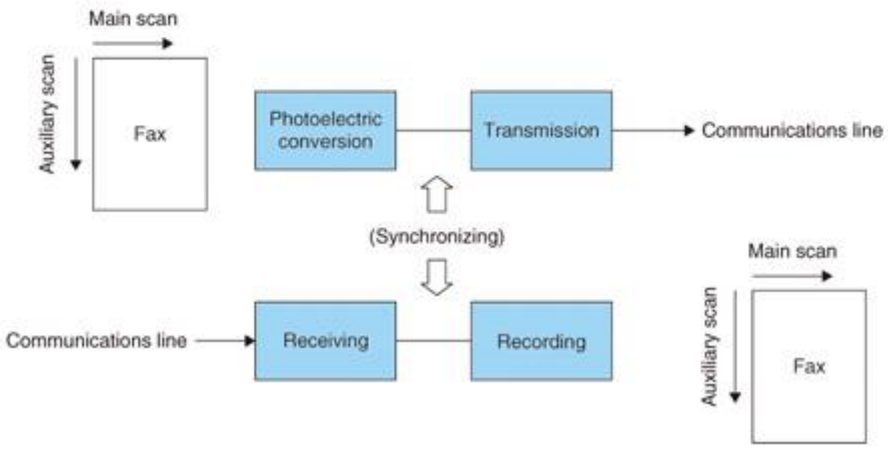

Figure 1.28 Facsimile operation

The process begins with an image scanner that converts the document into hundreds of horizontal scan lines. Many techniques are used, but they all incorporate a photo-(light) sensitive device to convert light variations along one scanned line into an electric voltage. The resulting signal is then processed in various ways to make the data

smaller and faster to transmit. The resulting signal is sent to a modem where it modulates a carrier set to the middle of the telephone voice spectrum bandwidth. The signal is then transmitted to the receiving fax machine over the public-switched telephone network. The receiving machine's modem demodulates the signal that is then processed to recover the original data.

Modem fax machine

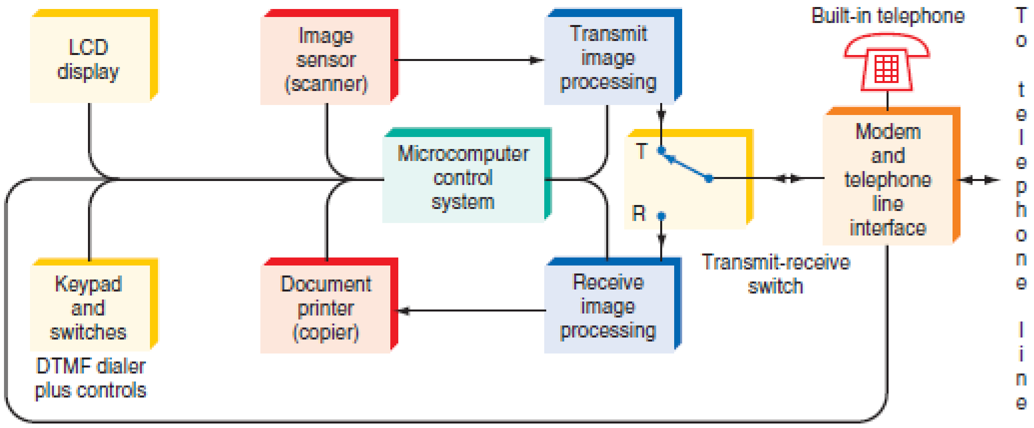

Figure 1.29 Block diagram of modem fax machine

A device can attach to a personal computer that enables to transmit and receive electronic documents as faxes. A fax modem is like a regular modem except that it is designed to transmit documents to a fax machine or to another fax modem. Some, but not all, fax modems do double duty as regular modems. As with regular modems, fax modems can be either internal or external. Internal fax modems are often called fax boards. Documents sent through a fax modem must already be in an electronic form (that is, in a disk file), and the documents receive are likewise stored in files on disk. To create fax documents from images on paper, need an optical scanner. Fax modems come with communications software similar to communications software for regular modems. This software can give the fax modem many capabilities that are not available withstand-alone fax machines. For example, broadcast a fax document to several sites at once.

Figure shows a block diagram of a modern fax machine. The transmission process begins with an image scanner that converts the document to hundreds of horizontal scan lines. Many different techniques are used, but they all incorporate a photo- (light-) sensitive device to convert light variations along one scanned line into an electrical voltage.

The resulting signal is then processed in various ways to make the data smaller and thus faster to transmit. The resulting signal is sent to a modem where it modulates a carrier set to the middle of the telephone voice spectrum bandwidth. The signal is then transmitted to the receiving fax machine over the public switched telephone network. The receiving fax machine's modem demodulates the signal that is then processed to recover the original data. The data is decompressed and then sent to a printer, which reproduces the document. Because all fax machines can transmit as well as receive, they are referred to as transceivers. The transmission is half duplex because only one machine may transmit or receive at a time.

Most fax machines have a built-in telephone, and the printer can also be used as a copy machine. An embedded microcomputer handles all control and operation, including paper handling. Most fax machines use charged coupled devices (CCDs) for scanning. A CCD is a light-sensitive semiconductor device that converts varying light amplitudes into an electrical signal.

Data compression is a digital data processing technique that looks for redundancy in the transmitted signal. . Every fax machine contains a built-in modem that is similar to a conventional data modem for computers.

Image Processing

Most fax machines use charge-coupled devices (CCDs) for scanning. A CCD is a light sensitive semiconductor device that converts varying light amplitudes to an electric signal. The typical CCD is made up of many tiny reverse-biased diodes that act as capacitors, which are manufactured in a matrix on a silicon chip The base forms one large plate of a capacitor that is electrically separated by a dielectric from many thousands of tiny capacitor plates, as shown. When the CCD is exposed to light, the CCD capacitors charge to a value proportional to the light intensity. The capacitors are then scanned or sampled electronically to determine their charge. This creates an analog output signal that accurately depicts the image focused on the CCD. A CCD is actually a device that breaks up any scene or picture into individual picture elements, or pixels. The greater the number of CCD capacitors, or pixels, the higher the resolution and the more faithfully a scene, photograph, or document can be reproduced. CCDs are available with a matrix of many thousands of pixels, thereby permitting very high-resolution picture transmission. CCDs are widely used in modern video cameras in place of the more delicate and more

expensive vidicon tubes. In the video camera (camcorder), the lens focuses the entire scene on a CCD matrix. This same approach is used in some fax machines. In one type of fax machine, the document to be transmitted is placed face down as it might be in a copy machine. The document is then illuminated with brilliant light from a xenon or fluorescent bulb. A lens system focuses the reflected light on a CCD. The CCD is then scanned, and the resulting output is an analog signal whose amplitude is proportional to the amplitude of the reflected light.

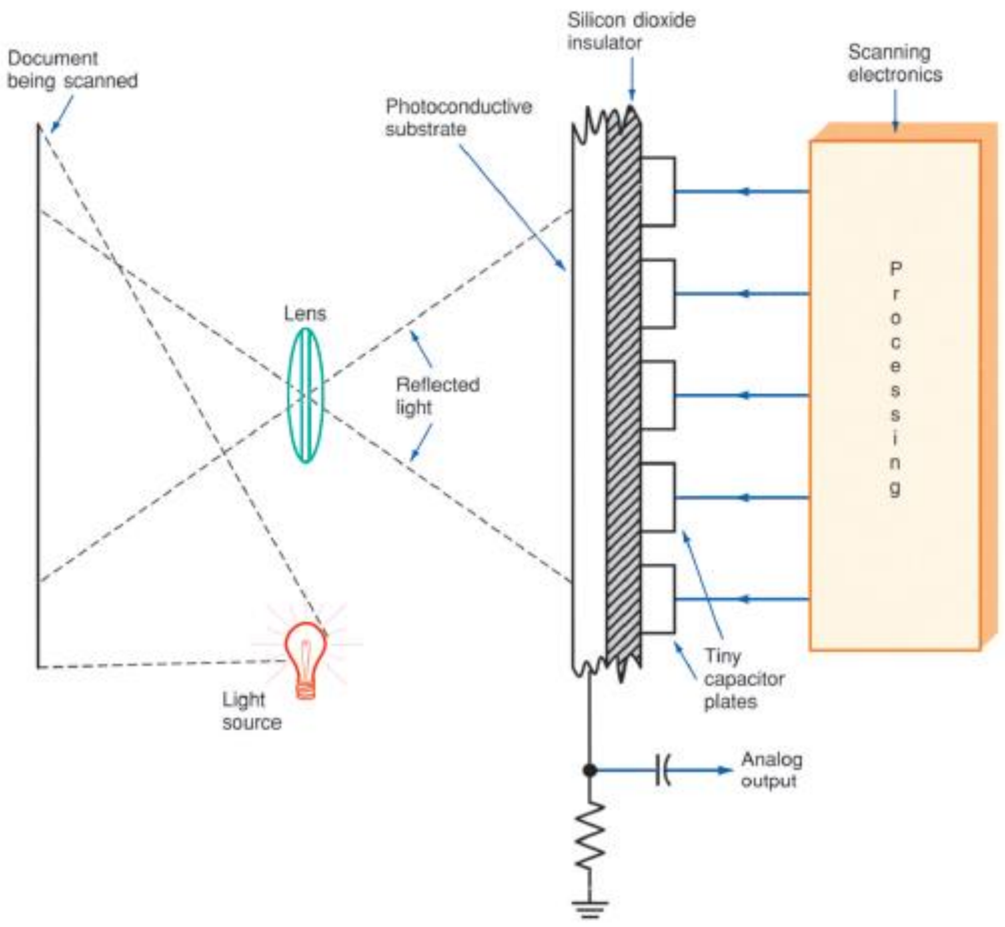

Figure 1.30 A charge-coupled device is used to scan documents in modern fax machines-Cross section

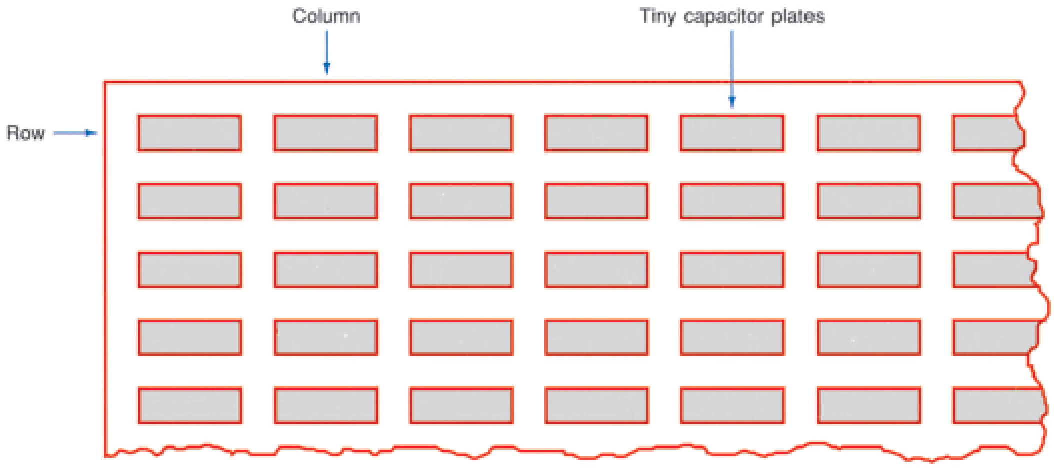

Figure 1.31 Detail of capacitor matrix

In most desktop fax machines, the entire document is not focused on a single CCD. Instead, only a narrow portion of the document is lighted and examined as it is moved through the fax machine with rollers. A complex system of mirrors is used to focus the lighted area on the CCD.

The more modern fax machines use another type of scanning mechanism that does not use lenses. The scanning mechanism is an assembly made up of an LED array and a CCD array. These are arranged so that the entire width of a standard 81⁄2 3 11 in page is scanned simultaneously one line at a time. The LED array illuminates a narrow portion of the document. The reflected light is picked up by the CCD scanner. A typical scanner has 2048 light sensors forming one scan line. Fig. 18-19 shows a side view of the scanning mechanism. The 2048 pixels of light are converted to voltages proportional to the light variations on one scanned line. These voltages are converted from a parallel format to a serial voltage signal. The resulting analog signal is amplified and sent to an AGC circuit and an S/H amplifier. The signal is then sent to an A/D converter where the light signals are translated to binary data words for transmission.

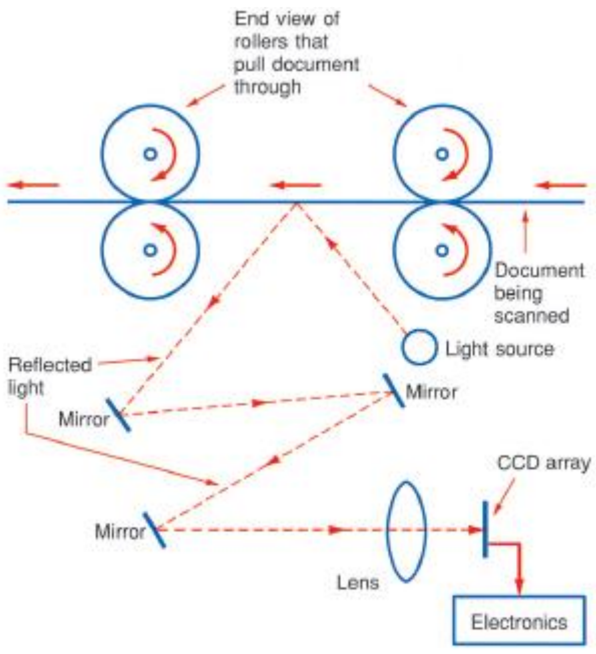

Figure 1.32 Scanning mechanism in a fax machine

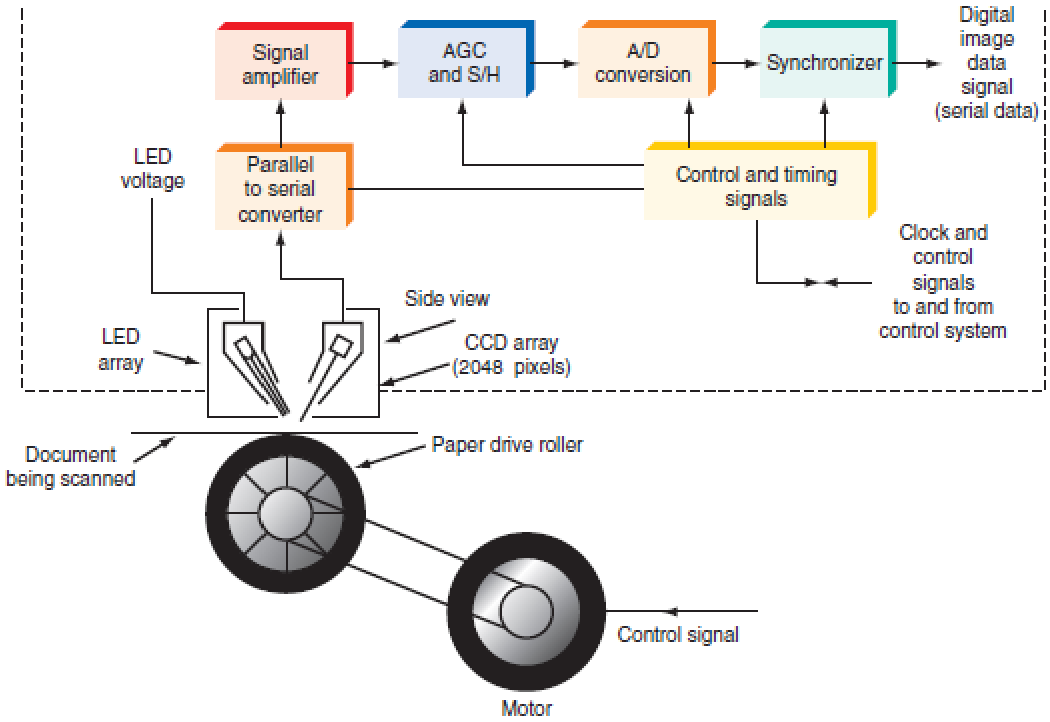

Figure 1.33 LED/CCD scanner mechanism in a modern fax machine

1.11 Data Compression

An enormous amount of data is generated by scanning one page of a document. A typical 81⁄2 3 11 in page represents about 40,000 bytes of data. This can be shortened by a factor of 10 or more with data compression techniques. Furthermore, because of the narrow bandwidth of telephone lines, data rates are limited. That is why it takes so long to transmit one page of data. Developments in high-speed modems have helped reduce the transmission time, but the most important developments are data compression techniques that reduce the overall amount of data, which significantly decreases the transmission time and telephone charges.

Data compression is a digital data processing technique that looks for redundancy in the transmitted signal. White space or continuous segments of the page that are the same shade produce continuous strings of data words that are the same. These can be eliminated and transmitted as a special digital code that is significantly faster to transmit. Other forms of data compression use various mathematical algorithms to reduce the amount of data to be transmitted.

The data compression is carried out by a digital signal processing (DSP) chip. This is a high-speed microprocessor with embedded ROM containing the compression program. The digital data from the A/D converter is passed through the DSP chip, from which comes a significantly shorter string of data that represents the scanned image. This is what is transmitted, and in far less time than the original data could be transmitted. At the receiving end, the demodulated signal is decompressed. Again, this is done through a DSP chip especially programmed for this function. The original data signal is recovered and sent to the printer.

Modems

Every fax machine contains a built-in modem that is similar to a conventional data modem for computers. These modems are optimized for fax transmission and reception. And they follow international standards so that any fax machine can communicate with any other fax machine. A number of different modulation schemes are used in fax systems. Analog fax systems use AM or FM.

Digital fax uses PSK or QAM. To ensure compatibility between fax machines of different manufacturers, facsimile standards have been developed for speed, modulation

methods, and resolution by the International Telegraph and Telephone Consultative Committee, better known by its French abbreviation, CCITT. The CCITT is now known as the ITU-T, or International Telecommunications Union. The ITU-T fax standards are divided into four groups:

1. Group 1 (G1 or GI): Analog transmission using frequency modulation where white is 1300 Hz and black is 2100 Hz. Most North American equipment uses 1500 Hz for white and 2300 Hz for black. The scanning resolution is 96 lines per inch (LPI). Average transmission speed is 6 minutes per page (81⁄2 3 11 in or A4 metric size, which is slightly longer than 11 in).

2. Group 2 (G2 or GII): Analog transmission using FM or vestigial sideband AM. The vestigial sideband AM uses a 2100-Hz carrier. The lower sideband and part of the upper sideband are transmitted. Resolution is 96 LPI. Transmission speed is 3 min or less for an 81⁄2 3 11 in or A4 page.

3. Group 3 (G3 or GIII): Digital transmission using PCM black and white only or upto 32 shades of gray. PSK or QAM to achieve transmission speeds of up to 9600 Bd. Resolution's 200 LPI. Transmission speed is less than 1 minute per page, with 15 to 30 s being typical.

4. Group 4 (G4 or GIV): Digital transmission, 56 kbps, resolution up to 400 LPI, and speed of transmission less than 5 s. The older G1 and G2 machines are no longer used. The most common configuration is group 3. Most G3 machines can also read the G2 format.

The G4 machines are not yet widely used. They are designed to use digital transmission only with no modem over very wideband dedicated digital-grade telephone lines. Both G3 and G4 formats also employ digital data compression methods that shorten the binary data stream considerably, thereby speeding up page transmission. This is important because shorter transmission times cut long-distance telephone charges and reduce operating costs.

Fax Machine Operation

Figure shows simplified block diagram of the transmitting circuits in a modern G3 fax transceiver. The analog output from the CCD array is serialized and fed to an A/D converter that translates the continuously varying light intensity into a stream of binary

numbers. Sixteen gray scale values between white and black are typical. The binary data is sent to a DSP digital data compression circuit as described earlier. The binary output in serial data format is used to modulate a carrier that is transmitted over the telephone lines. The techniques are similar to those employed in modems. Speeds of 2400/4800 and 7200/9600 Bd are common.

Most systems use some form of PSK or QAM to achieve very high data rates on voice-grade lines. In the receiving portion of the fax machine, the received signal is demodulated and then sent to DSP circuits, where the data compression is removed and the binary signals are restored to their original form. The signal is then applied to a printing mechanism. The most common fax printer today is an ink jet printer like those popularly used with PCs. In the high-priced machines, laser scanning of an electrosensitive drum, similar to the drum used in laser printers, produces output copies by using the proven techniques of xerography. The control logic in Figure is usually an embedded microcomputer.

Besides all the internal control functions it implements, it is used for "handshaking" between the two machines that will communicate. This ensures compatibility. Handshaking is usually carried out by exchanging different audio tones. The called machine responds with tones designating its capability. The calling machine compares this to its own standards and then either initiates the transmission or terminates it because of incompatibility. If the transmission proceeds, the calling machine sends synchronizing signals to ensure that both machines start at the same time.

The called machine acknowledges the receipt of the sync signal, and transmission begins. All the protocols for establishing communication and sending and receiving the data are standardized by the ITU-T. Transmission is half duplex. As improvements have been made in picture resolution quality, transmission speed, and cost, facsimile machines have become much more popular. The units can be easily attached with standard RJ-11 modular connectors to any telephone system. In most business applications, the fax machine is typically dedicated to a single line. Most fax machines feature fully automatic operation with microprocessor-based control. A document can be sent to a fax machine automatically. The sending machine simply dials the receiving machine and initiates the transmission. The receiving machine answers the initial call and then reproduces the document before hanging up.

Most fax machines have a built-in telephone and are designed to share a single line with conventional voice transmission. The built-in telephone usually features Touch-Tone dialing and number memory plus automatic redial and other modern telephone features. Most fax machines also have automatic send and receive features for fully unattended operation. Fax machines are slowly fading away as technology changes. Today, most computer printers incorporate a scanner and a printer. The fax function including a data-only telephone with RJ-11 connection is built into the printer. A scanned document the digitized and sent using the fax procedures described earlier.

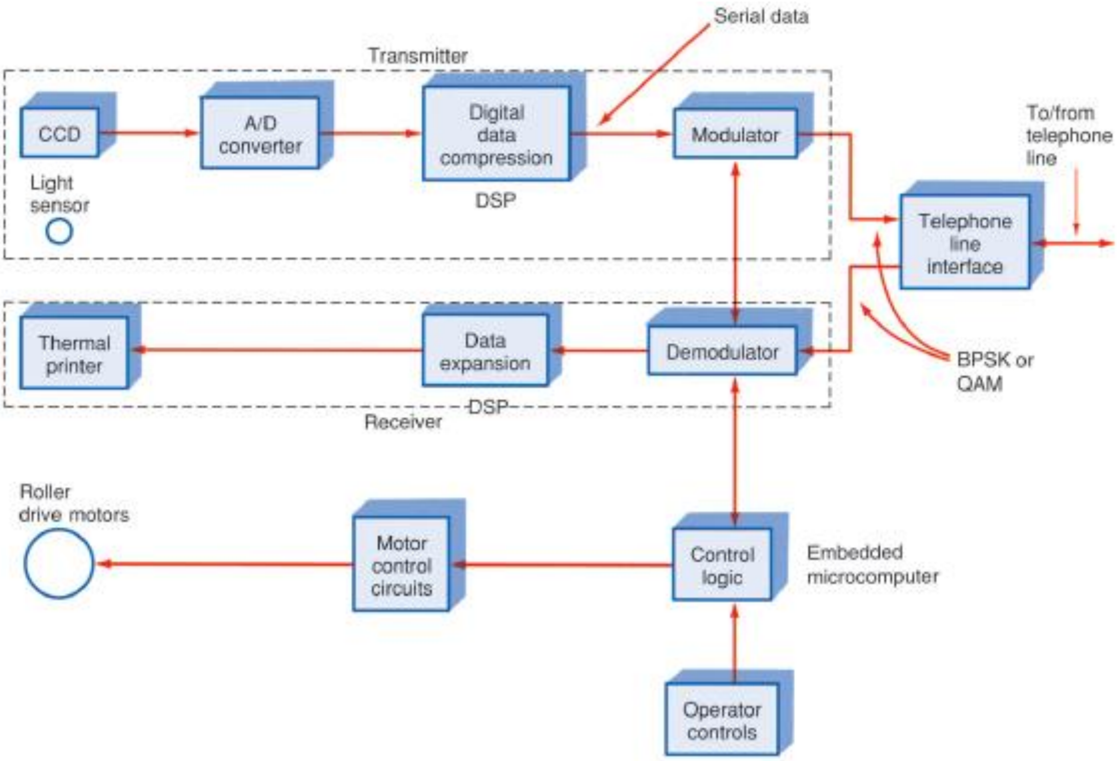

Figure 1.34 Block diagram of a facsimile machine

CCD: An analog shift register, that enables the transportation of analog signals (electric charges) through successive stages (pixels) controlled by a clock signal.

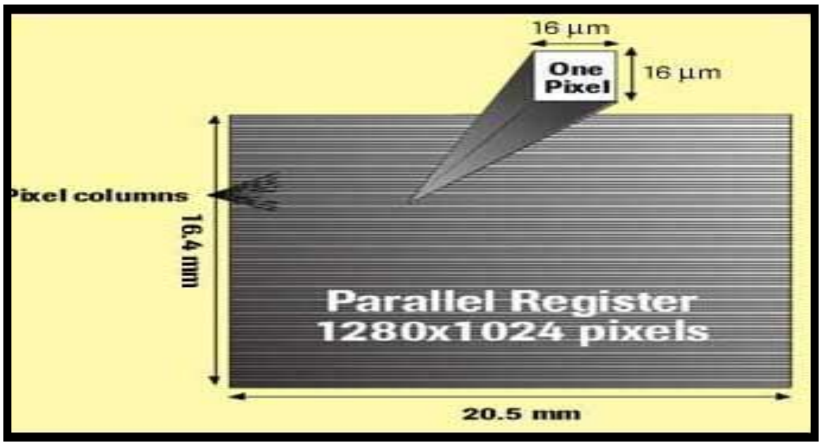

Figure 1.35 CCD

The CCD

- comprised of many individual signal capture units (photo sites, capacitors, pixels)

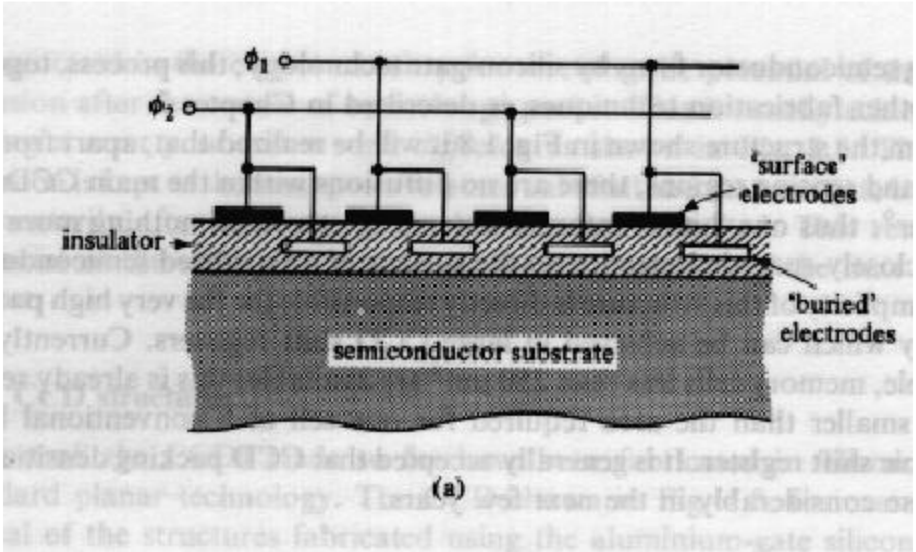

Figure 1.36 CCD Chip

A CCD chip is a metal oxide semiconductor (MOS) device. This means that its base, which is constructed of a material which is a good conductor under certain conditions, is topped with a layer of a metal oxide. In the case of the CCD, usually silicon is used as the base material and silicon dioxide is used as the coating. The final, top layer is also made of silicon - polysilicon

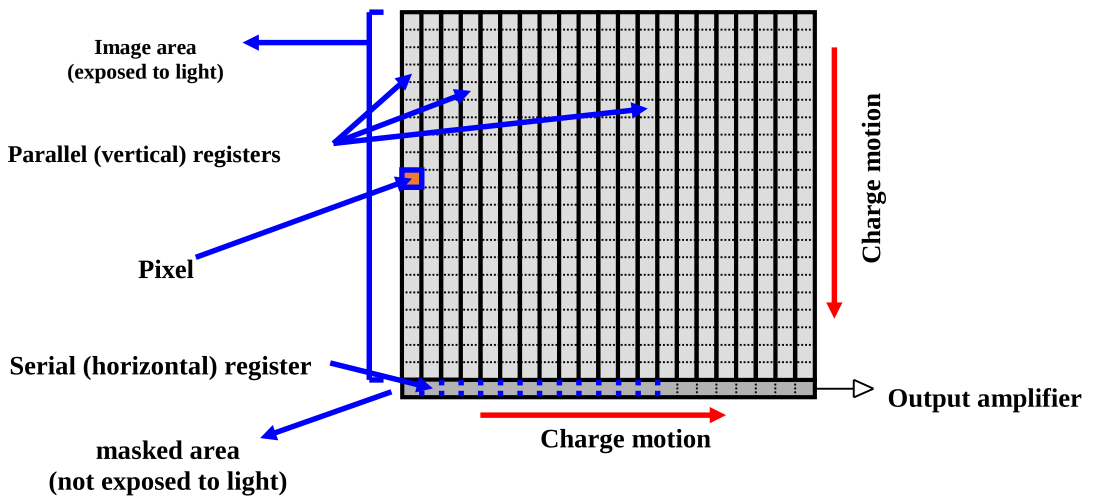

Figure 1.37 Charging area

Fundamentally, a charge coupled device (CCD) is an integrated circuit etched onto a silicon surface forming light sensitive elements called pixels. Photons incident on this surface generate charge that can be read by electronics and turned into a digital copy of the light patterns falling on the device. CCDs come in a wide variety of sizes and types and are used in many applications from cell phone cameras to high-end scientific applications.

Primary uses of CCD:

- **Memory**
- **Delaying samples of analog signals**
- **In an array of photoelectric light sensors (image sensors)**
- **Digital Photography**
- **Astronomy**
- **Sensors**
- **Electron Microscopy**
- **Medical Fluoroscopy**
- **Optical and UV Spectroscopy**

Paging Systems

Paging is a radio communication system designed to signal individuals wherever they may be. Paging systems operate in the simplex mode, for they broadcast signals or

messages to individuals who carry small battery-operated receivers. A paging company will send a radio signal that will be received by the pager.

The paging receiver has a built-in audible signaling device or silent vibrator that inform the person that he or she is being paged. Paging System Operation To contact a person via a pager, an individual dials the telephone number assigned to that person. The call is received at the office of the paging company. The paging company responds with one or more signaling tones that tell the caller to enter the telephone number the paged person should call. Once the number is entered, the caller presses the pound sign key to signal the end of the telephone entry.

The paging system records the telephone number in a computer and translates this number into a serial binary-coded message. The message is transmitted as a data bit stream to the paging receiver. Paging systems usually operate in the VHF and UHF frequency ranges. Most paging systems can locate an individual within a 30-mi radius.

The Paging Process

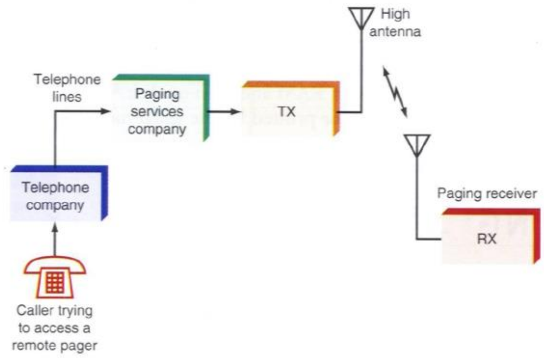

Figure 1.38 Paging system

Each paging receiver is assigned a special code called a cap code, which is a sequence of numbers or a combination of letters and numbers. The cap code is broadcast

over a paging region and if the pager is in the region, it will pick up and recognize its unique code.

Paging systems are operated by commercial carriers, often as a subscription service, and they are also operated directly by end users as private systems. Commercial carrier systems tend to cover a larger geographical area than private systems, while private systems tend to cover their limited area more thoroughly and deliver messages faster than commercial systems.

In all systems, clients send messages to pagers, an activity commonly referred to as paging. System operators often assign unique phone numbers or email addresses to pagers (and pre-defined groups of pagers), enabling clients to page by telephone call, e-mail, and SMS. Paging systems also support various types of direct connection protocols, which sacrifice global addressing and accessibility for a dedicated communications link. Automated monitoring and escalation software clients, often used in hospitals, IT departments, and alarm companies, tend to prefer direct connections because of the increased reliability. Small paging systems, such as those used in restaurant and retail establishments, often integrate a keyboard and paging system into a single box, reducing both cost and complexity.

Paging systems support several popular direct connection protocols, including TAP, TNPP, SNPP, and WCTP, as well as proprietary modem- and socket-based protocols. Additionally, organizations often integrate paging systems with their Voice-mail and PBX systems, conceptually attaching pagers to a telephone extensions, and they set up web portals to integrate pagers into other parts of their enterprise. A paging system alerts a pager (or group of pagers) by transmitting information over an RF channel, including an address and message information. This information is formatted using a paging protocol, such as 2-tone, 5/6-tone, GOLAY, POCSAG, FLEX, ERMES, or NTT. Two-way pagers and response pagers typically use the ReFLEX protocol.

Pagers themselves vary from very cheap and simple beepers, to more complex personal communications equipment, falling into eight main categories:

- **Beepers or Tone-only Pagers are the simplest form of paging. They were named beepers because they originally made a beeping noise, but current pagers in this category use other forms of alert as well. Some use audio signals,**

others light up and some vibrate, often used in combination. The majority of restaurant pagers fall into this category.

- **Voice/Tone pagers provide the ability to listen to a recorded voice message when an alert is received.**
- **Numeric Pagers contain a numeric LCD display capable of displaying the calling phone number or other numeric information generally up to 10 digits. The display can also convey pager codes, a set of number codes corresponding to mutually understood pre-defined messages.**
- **Alphanumeric Pagers contain a more sophisticated LCD capable of displaying text and icons. These devices receive text messages, often through email or direct connection to the paging system.**
- **Response Pagers are alphanumeric pagers equipped with built-in transmitters, with the ability to acknowledge/confirm messages. They also allow the user to reply to messages by way of a multiple-choice response list, and to initiate canned messages from pre-programmed address and message lists. These devices are sometimes called "1.5-way pagers" or "1.7-way pagers" depending on capabilities.**
- **Two-way Pagers are response pagers with built-in QWERTY keyboards. These pagers allow the user reply to messages, originate messages, and forward messages using free-form text as well as canned responses.**
- **One-way Modems are controllers with integrated paging receivers, which are capable of taking local action based on messages and data they receive.**
- **Two-way Modems have capabilities similar to one-way modems, and can also confirm messages and transmit their own messages and data.**

Modern paging systems typically use multiple base transmitters to modulate the same signal on the same RF channel, a design approach called simulcast. This type of design enables pagers to select the strongest signal from several candidate transmitters using FM capture, thereby improving overall system performance. Simulcast systems often use satellite to distribute identical information to multiple transmitters, and GPS at each transmitter to precisely time its modulation relative to other transmitters. The coverage overlap, combined with use of satellite communications, can make paging systems more reliable than terrestrial based cellular networks in some cases, including

during natural and man-made disaster. This resilience has led public safety agencies to adopt pagers over cellular and other commercial services for critical messaging

Paging Receiver

- **A paging receiver is a small battery-powered super heterodyne receiver.**
- **Most pagers use a single-chip IC receiver.**
- **Single- and double-conversion models are available.**
- **Direct conversion receivers (ZIF) are also used.**
- **Most basic paging systems use some form of frequency modulation.**

FLEX Receiver

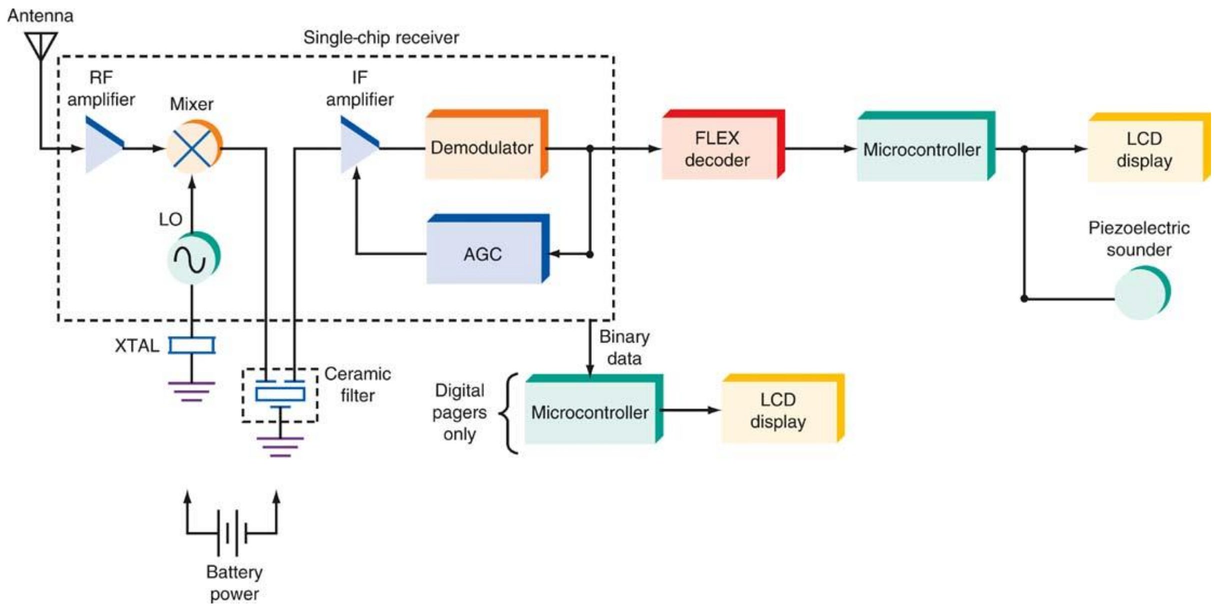

Figure 1.39 FLEX Receiver

1.12 Cellular Telephone system

In a cellular network, cells are generally organized in groups of seven to form a cluster. There is a “cell site” or “base station” at the centre of each cell, which houses the transmitter/receiver antennae and switching equipment. The size of a cell depends on the density of subscribers in an area: for instance, in a densely populated area, the capacity of the network can be improved by reducing the size of a cell or by adding more overlapping cells. This increases the number of channels available without increasing the

actual number of frequencies being used. All base stations of each cell are connected to a central point, called the Mobile Switching Office (MSO), either by fixed lines or microwave. The MSO is generally connected to the PSTN (Public Switched Telephone Network):

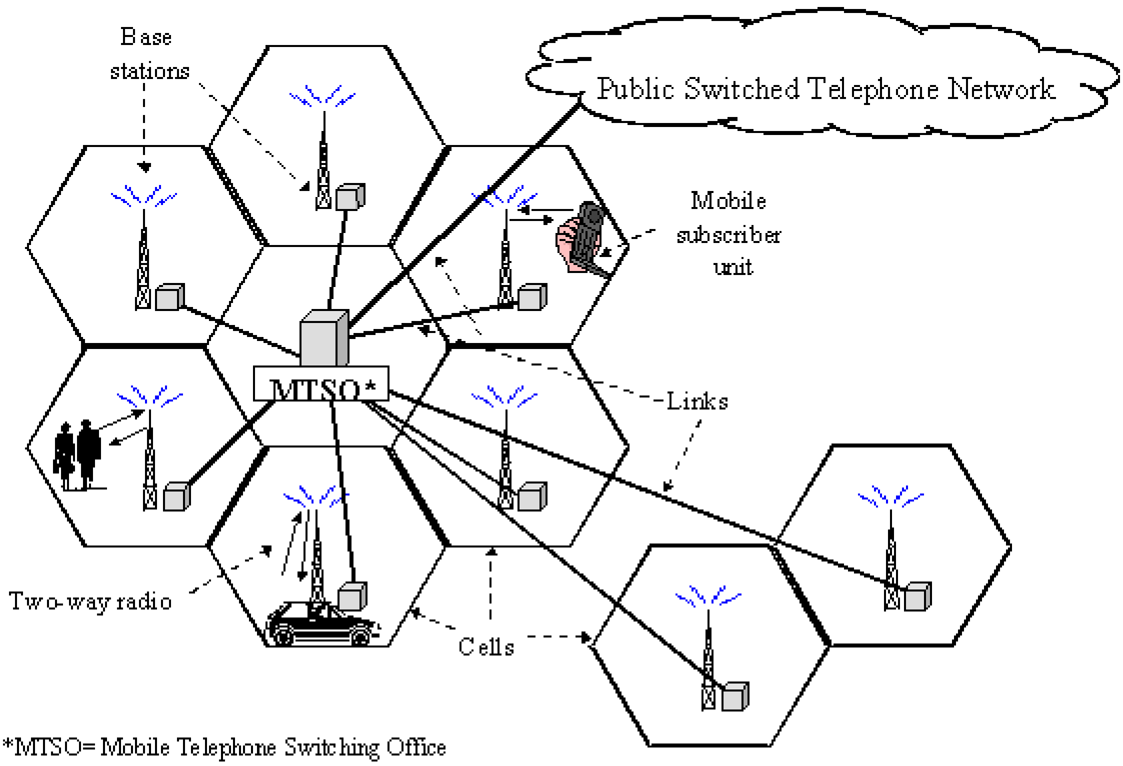

Figure 1.40 Cellular Telephone System

Cellular technology allows the " hand-off" of subscribers from one cell to another as they travel around. This is the key feature which allows the mobility of users. A computer constantly tracks mobile subscribers of units within a cell, and when a user reaches the border of a call, the computer automatically hands-off the call and the call is assigned a new channel in a different cell.

International roaming arrangements govern the subscriber's ability to make and receive calls the home network's coverage area.

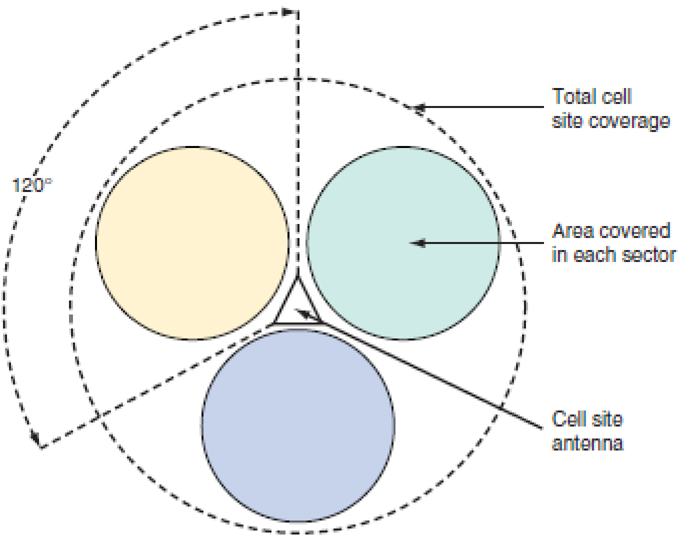

Figure 1.41 Horizontal antenna radiation pattern of a common cell site showing 120° sectors that permit frequency reuse

A cellular system comprises of the following basic components: Mobile Stations (MS): Mobile handsets, which is used by an user to communicate with• another user Cell: Each cellular service area is divided into small regions called cell (5 to 20 Km)• Base Stations (BS): Each cell contains an antenna, which is controlled by a small office.• Mobile Switching Center (MSC): Each base station is controlled by a switching office,• called mobile switching center

1.13 Digital cellular Telephone system

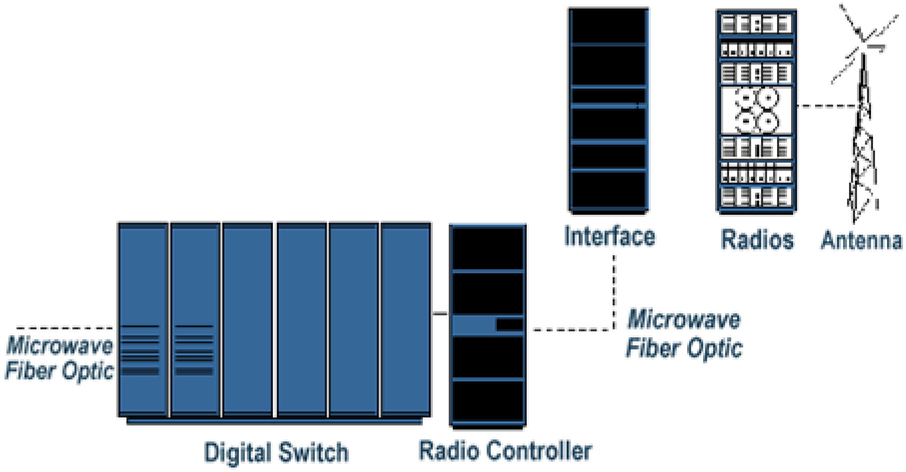

Figure 1.42 Digital Cellular Telephone

While the description of the analog telephone system provides an accurate overview of the principles of current telephone systems, it is a fact that most telephone calls today are really digital telephone calls.

In a digital telephone system, the two ends of the call are analog, and the middle section is digital. Conversions from analog to digital (A/D), and back to analog (D/A), are made in such a way that it is essentially impossible to determine that they were made at all. Although the analog telephone system is gradually being converted to digital, the input and output of the system still remains analog because the eventual use is for humans that are able to process analog information.

At present, most telephone calls are analog from the telephone at home to the first switching office, so the A/D and D/A conversion is made at this office. In the future, as telephone systems become all digital, this conversion from A/D and from D/A will be made within the telephone set at home. The A/D conversion process was explained in the previous lectures- The voice signal- an analog waveform was sampled at a sampling frequency, and quantized to a number of levels. These values were then assigned binary codes to complete the conversion process from analog to digital

The D/A process was also explained briefly. The bits were decoded into their quantized values, and a waveform similar to the original analog waveform was obtained. For voice, remember that the standard sampling frequency is 8000Hz. The standard number of quantization levels for audio signals is 256, requiring 8 bits. So, the bit rate for a digital

telephone call is: 8,000x8=64,000 bits per second (64 Kbps). This is the bit rate that would reach the central office if the A/D conversion was being done inside the telephone at home Since many calls arrive at the central office, they can all be combined, and switched to another center to be routed to the destination Combining many channels and sending them simultaneously through a single transmission line is called multiplexing.

1.14 Multiple Access

Multiple access refers to how the subscribers are allocated to the assigned frequency spectrum. Access methods are the ways in which many users share a limited amount of spectrum. The techniques include frequency reuse, frequency-division multiple access (FDMA), time-division multiple access (TDMA), code-division multiple access (CDMA), and spatial-division multiple access (SDMA).

Frequency Reuse. In frequency reuse, individual frequency bands are shared by multiple base stations and users. This is possible by ensuring that one subscriber or base station does not interfere with any others. This is achieved by controlling such factors as transmission power, base station spacing, and antenna height and radiation patterns. With low-power and lower-height antennas, the range of a signal is restricted to only a mile or so. Furthermore, most base stations use sectorized antennas with 1208 radiation patterns that transmit and receive over only a portion of the area they cover. In any given city, the same frequencies are used over and over simply by keeping cell site base stations isolated from one another.

Frequency-Division Multiple Access

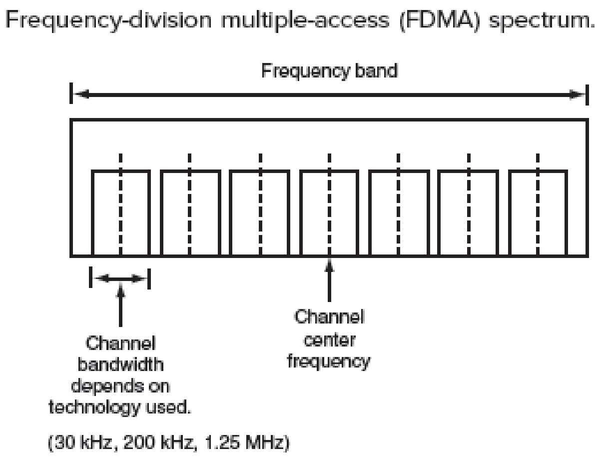

Figure 1.43 FDMA spectrum

FDMA systems are like frequency- division multiplexing in that they allow many users to share a block of spectrum by simply dividing it up into many smaller channels. Each channel of a band is given an assigned number or is designated by the center frequency of the channel. One subscriber is assigned to each channel. Typical channel widths are 30 kHz, 200 kHz, 1.25 MHz, and 5 MHz. There are usually two similar bands, one for uplink and the other for downlink.

Time-Division Multiple Access: TDMA relies on digital signals and operates on a single channel. Multiple users use different time slots. Because the audio signal is sampled at a rapid rate, the data words can be interleaved into different time slots, Of the two common TDMA systems in use, one allows three users per frequency channel and the other allows eight users per channel.

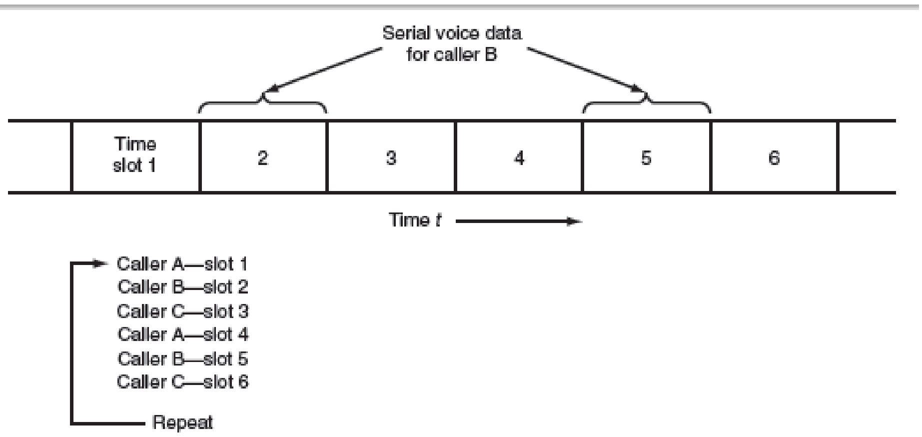

Figure 1.44 TDMA

Code-Division Multiple Access

Code-division multiple access (CDMA). (*a*) Spreading the signal. (*b*) Resulting bandwidth.

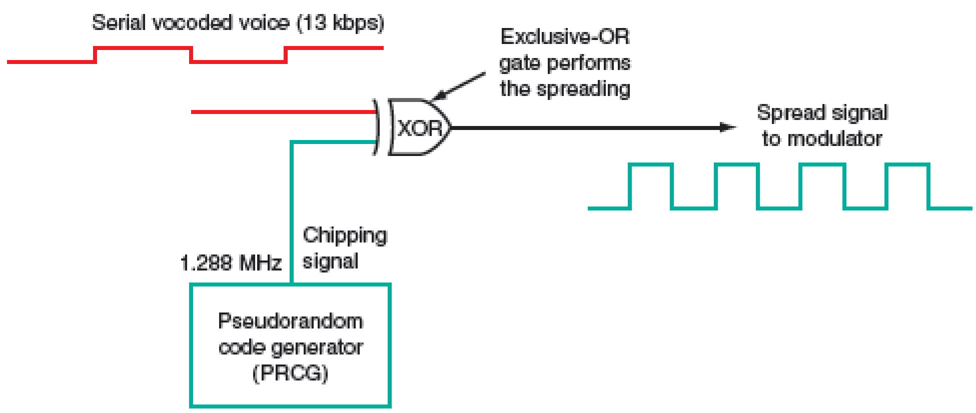

Figure 1.45 CDMA

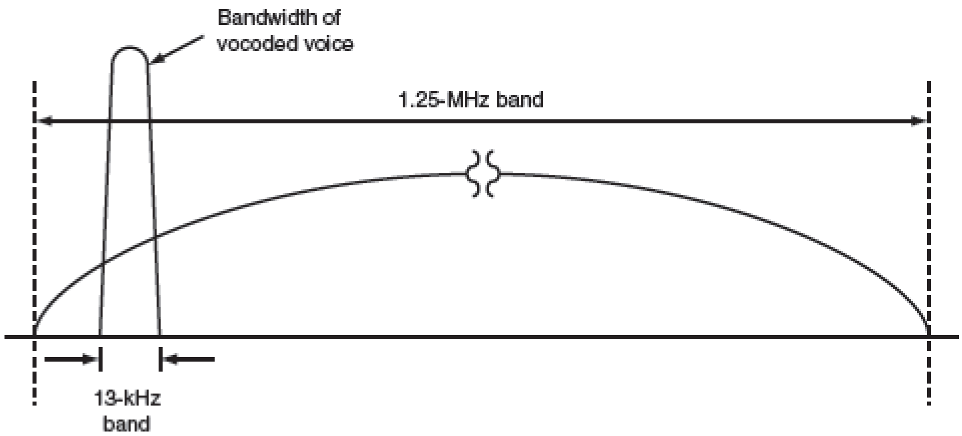

Figure 1.46 Spectrum

CDMA is just another name for spread spectrum. A high percentage of cell phone systems use direct sequence spread spectrum (DSSS). Here the digital audio signals are encoded in a circuit called a vocoder to produce a 13-kbps serial digital compressed voice signal. It is then combined with a higher-frequency chipping signal. One system uses a 1.288-Mbps chipping signal to encode the audio, spreading the signal over a 1.25-MHz channel. See Fig. 20-8. With unique coding, up to 64 subscribers can share a 1.25-MHz channel. A similar technique is used with the wideband CDMA system of third-generation cellphones. A 3.84-Mbps chipping rate is used in a 5-MHz channel to accommodate multiple users.

Orthogonal Frequency Division Multiplexing Access (OFDMA).

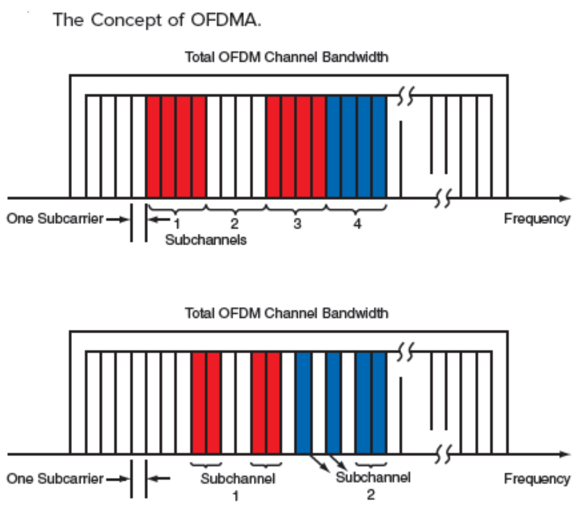

Figure 1.47 OFDMA

OFDMA is the access method used with OFDM. OFDM uses hundreds, even thousands, of subcarriers in a wideband channel. This large number of subcarriers can be subdivided into smaller groups, and each group can be assigned to an individual user. In this way, many users can use the wideband channel assigned to the OFDM signal.

1.15 Integrated Services Digital Network

Integrated Services Digital Network (ISDN) is comprised of digital telephony and data-transport services offered by regional telephone carriers. ISDN involves the digitization of the telephone network, which permits voice, data, text, graphics, music, video, and other source material to be transmitted over existing telephone wires. The emergence of ISDN represents an effort to standardize subscriber services, user/network interfaces, and network and internetwork capabilities. ISDN applications include high-speed image applications (such as Group IV facsimile), additional telephone lines in homes to serve the telecommuting industry, high-speed file transfer, and videoconferencing. Voice service is also an application for ISDN.

ISDN specifies a number of reference points that define logical interfaces between functional groups, such as TAs and NT1s. ISDN reference points include the following:

- **R—The reference point between non-ISDN equipment and a TA.**
- **S—The reference point between user terminals and the NT2.**
- **T—The reference point between NT1 and NT2 devices.**
- **U—The reference point between NT1 devices and line-termination equipment in the carrier network.**

The U reference point is relevant only in North America, where the NT1 function is not provided by the carrier network. Sample ISDN configuration shows three devices attached to an ISDN switch at the central office. Two of these devices are ISDN-compatible, so they can be attached through an S reference point to NT2 devices. The third device (a standard, non-ISDN telephone) attaches through the reference point to a TA. Any of these devices also could attach to an NT1/2 device, which would replace both the NT1 and the NT2. In addition, although they are not shown, similar user stations are attached to the far-right ISDN switch.

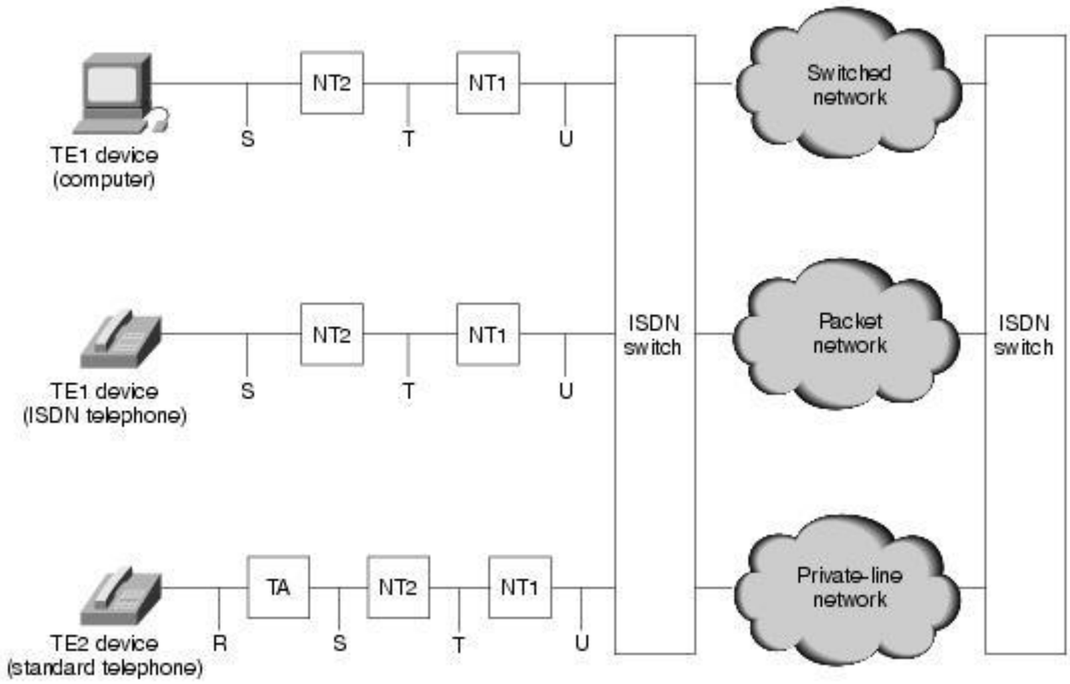

Figure 1.48 ISDN

Sample ISDN configuration

SDN Specifications This section describes the various ISDN specifications for Layer 1, Layer 2, and Layer 3. Layer 1 ISDN physical layer (Layer 1) frame formats differ depending on whether the frame is outbound (from terminal to network) or inbound (from network to terminal). Both physical layer interfaces are shown in Figure.

The frames are 48 bits long, of which 36 bits represent data. The bits of an ISDN physical layer frame are used as follows:

- **F—Provides synchronization**
- **L—Adjusts the average bit value**
- **E—Ensures contention resolution when several terminals on a passive bus contend for a channel**
- **A—Activates devices**
- **S—Is unassigned**
- **B1, B2, and D—Handle user data**

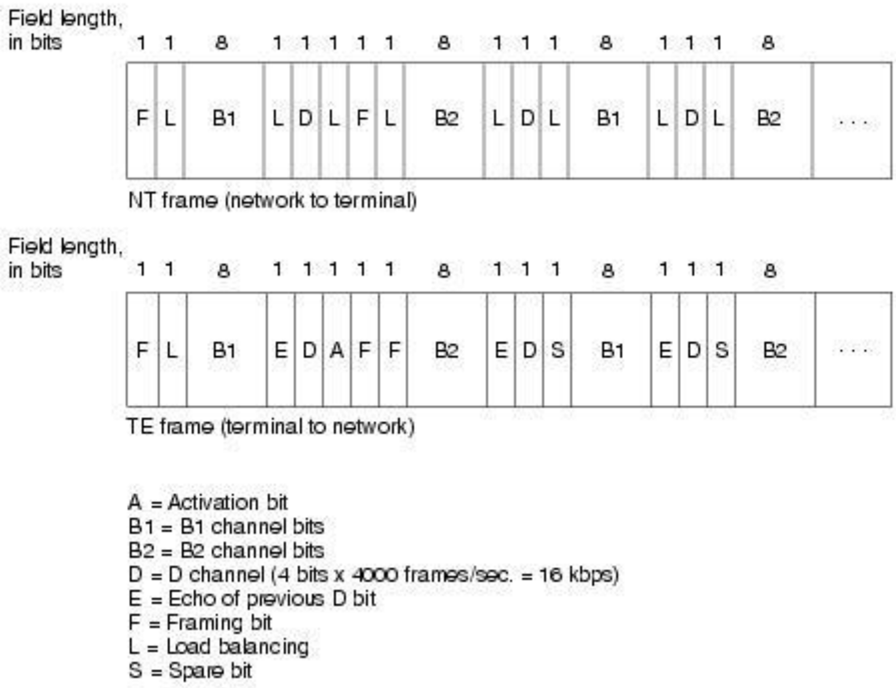

Figure 1.49 ISDN data

Part A: Two Marks:

1. **Define Local Loop.**
2. **What is meant by DTMF system?**
3. **What is the frequency response of the local loop?**
4. **State the ringing voltage and ringing frequency.**
5. **State the function of automatic level adjustment.**
6. **What is the function of MPU in electronic telephone?**
7. **State the elements in MPU.**
8. **What are the main units in a cordless telephone?**
9. **State the frequencies of cordless telephone.**
10. **What is the power rating of cordless phones?**
11. **Define CCD.**
12. **Define pixel.**
13. **Define data compression.**

14. **Define modem.**
15. **State FAX standards.**
16. **State the scanning rate of FAX machines.**

Part B:

1. **Explain the operation of a telephone circuit.**
2. **Explain the construction and operation of the electronic telephone and cordless phones with suitable diagrams.**
3. **Explain the operation of fax machine with suitable diagrams.**
4. **Explain the operation of cellular telephone unit.**
5. **Explain the construction and operation of paging system.**
6. **Explain in detail about ISDN.**

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COMMUNICAITON SYSTEMS – SEC1303

UNIT – 2

TELEVISION COMMUNICATION

2. TELEVISION COMMUNICATION

Television - Basic Principles - Scanning - Camera tubes - band width consideration - generation of composite video signals - monochrome and color transmitter - Picture tubes - receivers - Flat screen TV - Digital TV - HDTV - Set top box

2.1 TELEVISION

The aim of a television system is to extend the sense of sight beyond its natural limits and to transmit sound associated with the scene. The picture signal is generated by a TV camera and sound signal by a microphone. In the 625 line CCIR monochrome and PAL-B colour TV systems adopted by India, the picture signal is amplitude modulated and sound signal frequency modulated before transmission. The two carrier frequencies are suitably spaced and their modulation products radiated through a common antenna. As in radio communication, each television station is allotted different carrier frequencies to enable selection of desired station at the receiving end. The TV receiver has tuned circuits in its input section called 'tuner'. It selects desired channel signal out of the many picked up by the antenna. The selected RF band is converted to a common fixed IF band for convenience of providing large amplification to it. The amplified IF signals are detected to obtain video (picture) and audio (sound) signals. The video signal after large amplification drives the picture tube to reconstruct the televised picture on the receiver screen. Similarly, the audio signal is amplified and fed to the loudspeaker to produce sound output associated with the scene.

2.2 PICTURE TRANSMISSION

The picture information is optical in character and may be thought of as an assemblage of a large number of tiny areas representing picture details. These elementary areas into which picture details may be broken up are known as 'picture elements' or 'pixels', which when viewed together represent visual information of the scene. Thus, at any instant there are almost an infinite number of pieces of information that need to be picked up simultaneously for transmitting picture details. However, simultaneous pick-up is not practicable because it is not feasible to provide a separate signal path (channel) for the signal obtained from each picture element. In practice, this problem is solved by a method known as 'scanning' where conversion of optical information to electrical form

is carried out element by element, one at a time and in a sequential manner to cover the entire picture. Besides, scanning is done at a very fast rate and repeated a large number of times per second to create an illusion (impression at the eye) of simultaneous reception from all the elements, though using only one signal path. Black and White Pictures In a monochrome (black and white) picture, each element is either bright, some shade of grey or dark.

A TV camera, the heart of which is a camera tube, is used to convert this optical information into corresponding electrical signal, the amplitude of which varies in accordance with variations of brightness. Fig. 2.1 shows very elementary details of one type of camera tube (vidicon) and associated components to illustrate the principle. An optical image of the scene to be transmitted is focused by a lens assembly on the rectangular glass face-plate of the camera tube. The inner side of the glass face-plate has a transparent conductive coating on which is laid a very thin layer of photoconductive material. The photo layer has very high resistance when no light falls on it, but decreases depending on the intensity of light falling on it. Thus depending on light intensity variations in the focused optical image, the conductivity of each element of photo layer changes accordingly. An electron beam is used to pick-up picture information now available on the target plate in terms of varying resistance at each point.

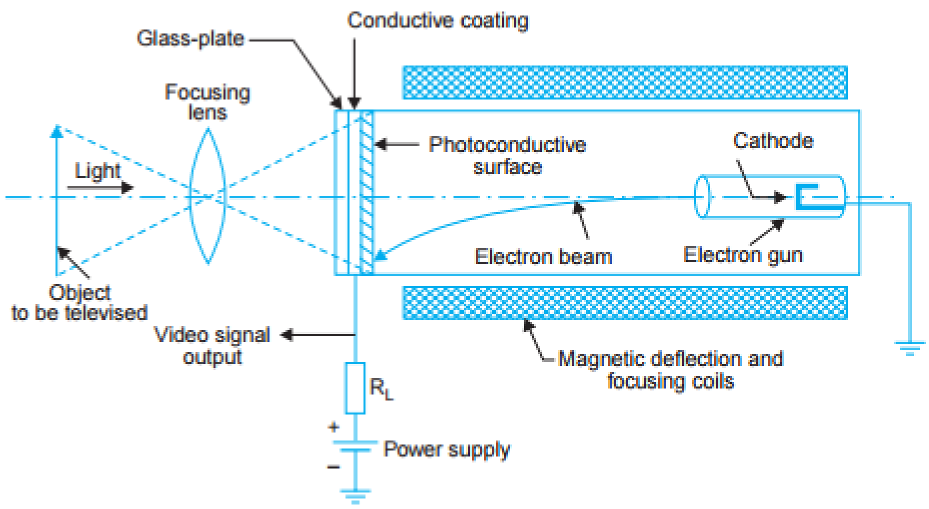


Figure 2.1 Simplified cross-sectional view of a Vidicon camera tube and associated components

The beam is formed by an electron gun in the TV camera tube. On its way to the inner side of glass face-plate, it is deflected by a pair of deflecting coils mounted on the glass envelope and kept mutually perpendicular to each other to achieve scanning of the entire target area. Scanning is done in the same way as one reads a written page to cover all the words in one line and all the lines on the page (see Fig. 2.2). To achieve this, the deflecting coils are fed separately from two sweep oscillators which continuously generate suitable waveform voltages, each operating at a different desired frequency. Magnetic deflection caused by the current in one coil gives horizontal motion to the beam from left to right at uniform rate and then brings it quickly to the left side to commence trace of the next line. The other coil is used to deflect the beam from top to bottom at a uniform rate and for its quick retrace back to the top of the plate to start this process over again. Two simultaneous motions are thus given to the beam, one from left to right across the target plate and the other from top to bottom thereby covering entire area on which electrical image of the picture is available. As the beam moves from element to element, it encounters a different resistance across the target-plate, depending on the resistance of photoconductive coating. The result is a flow of current which varies in magnitude as the elements are scanned. This current passes through a load resistance RL, connected to the conductive coating on one side and to a dc supply source on the other. Depending on the magnitude of current, a varying voltage appears across resistance RL and this corresponds to optical information of the picture.

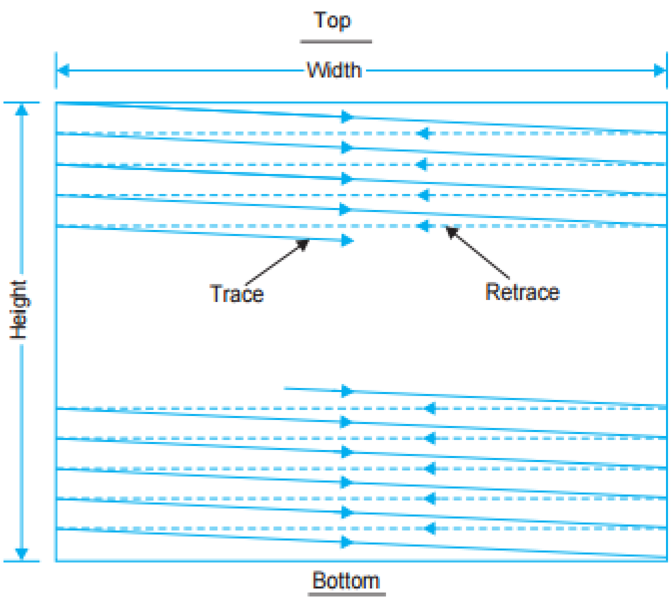


Figure 2.2 Path of scanning beam in covering picture area

If the scanning beam moves at such a rate that any portion of the scene content does not have time to change perceptibly in the time required for one complete scan of the image, the resultant electrical signal contains true information existing in the picture during the time of scan. The desired information is now in the form of a signal varying with time and scanning may thus be identified as a particular process which permits conversion of information existing in space and time co-ordinates into time variations only. The electrical information thus obtained from the TV camera tube is generally referred to as video signal (video is Latin for 'see').

2.3 COLOUR PICTURES

It is possible to create any colour including white by additive mixing of red, green and blue colour lights in suitable proportions. For example, yellow can be obtained by mixing red and green colour lights in intensity ratio of 30 : 59. Similarly, light reflected from any colour picture element can be synthesized (broken up) into red, green and blue colour light constituents. This forms the basis of colour television where Red (R), Green (G) and Blue (B) colours are called primary colours and those formed by mixing any two of the three primaries as complementary colours. A colour camera, the elements of which are shown in Fig. 2.3, is used to develop signal voltages proportional to the intensity of each primary colour light.

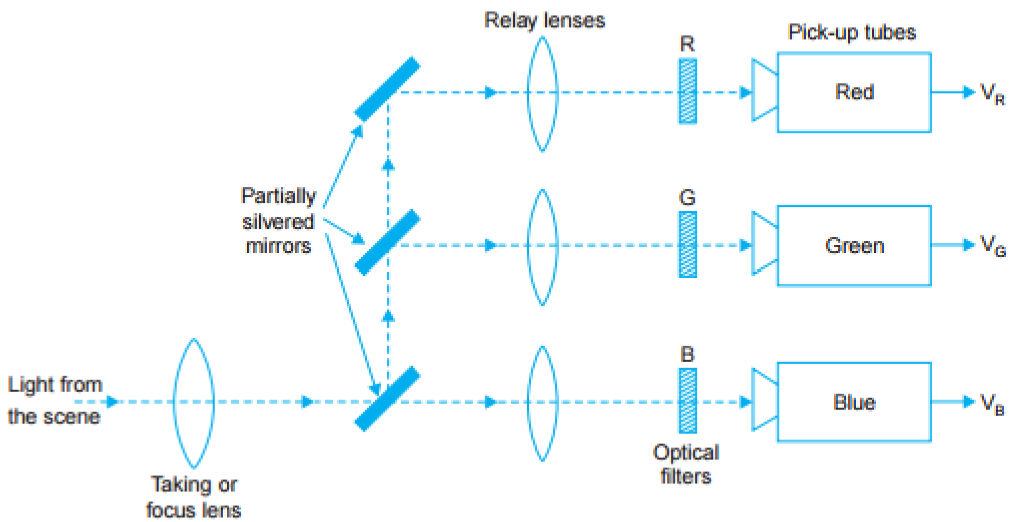


Figure 2.3 Simplified block diagram of a colour camera

It contains three camera tubes (vidicons) where each pick-up tube receives light of only one primary colour. Light from the scene falls on the focus lens and through that on special mirrors. Colour filters that receive reflected light via relay lenses split it into R, G and B colour lights. Thus, each vidicon receives a single colour light and develops a voltage proportional to the intensity of one of the primary colours. If any primary colour is not present in any part of the picture, the corresponding vidicon does not develop any output when that picture area is scanned. The electron beams of all the three camera tubes are kept in step (synchronism) by deflecting them horizontally and vertically from common driving sources. Any colour light has a certain intensity of brightness. Therefore, light reflected from any colour element of a picture also carries information about its brightness called luminance. A signal voltage (Y) proportional to luminance at various parts of the picture is obtained by adding definite proportions of VR, VG and VB (30:59:11). This then is the same as would be developed by a monochrome (black and white) camera when made to scan the same colour scene. This i.e., the luminance (Y) signal is also transmitted along with colour information and used at picture tube in the receiver for reconstructing the colour picture with brightness levels as in the televised picture.

2.4 TELEVISION TRANSMITTER

An oversimplified block diagram of a monochrome TV transmitter is shown in Fig. 2.4. The luminance signal from the camera is amplified and synchronizing pulses added before feeding it to the modulating amplifier. Synchronizing pulses are transmitted to keep the camera and picture tube beams in step. The allotted picture carrier frequency is generated by a crystal controlled oscillator. The continuous wave (CW) sine wave output is given large amplification before feeding to the power amplifier where its amplitude is made to vary (AM) in accordance with the modulating signal received from the modulating amplifier. The modulated output is combined (see Fig. 2.4) with the frequency modulated (FM) sound signal in the combining network and then fed to the transmitting antenna for radiation.

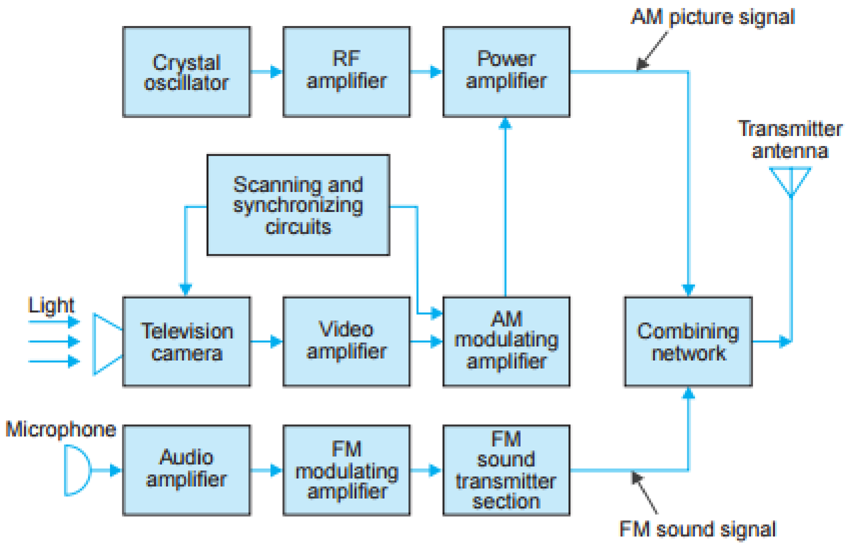


Figure 2.4. Elementary block diagram of a monochrome television transmitter

2.5 COLOUR TRANSMITTER

A colour TV transmitter is essentially the same as the monochrome transmitter except for the additional need that colour (Chroma) information is also to be transmitted. Any colour system is made compatible with the corresponding monochrome system. Compatibility means that the colour TV signal must produce a normal black and white picture on a monochrome receiver and a colour receiver must be able to produce a normal black and white picture from a monochrome TV signal. For this, the luminance (brightness) signal is transmitted in a colour system in the same way as in the monochrome system and with the same bandwidth. However, to ensure compatibility, the colour camera outputs are modified to obtain (B-Y) and (R-Y) signals. These are modulated on the colour sub-carrier, the value of which is so chosen that on combining with the luminance signal, the sidebands of the two do not interfere with each other i.e., the luminance and colour signals are correctly interleaved. A colour sync signal called ‘colour burst’ is also transmitted for correct reproduction of colours.

2.6 SOUND TRANSMISSION

There is no difference in sound transmission between monochrome and colour TV systems. The microphone converts the sound associated with the picture being televised into proportionate electrical signal, which is normally a voltage. This electrical output, regardless of the complexity of its waveform, is a single valued function of time and so needs a single channel for its transmission. The audio signal from the microphone after amplification is frequency modulated, employing the assigned carrier frequency. In FM, the amplitude of carrier signal is held constant, whereas its frequency is varied in accordance with amplitude variations of the modulating signal. As shown in Fig. 2.4, output of the sound FM transmitter is finally combined with the AM picture transmitter output, through a combining network, and fed to a common antenna for radiation of energy in the form of electromagnetic waves.

2.7 TELEVISION RECEIVER

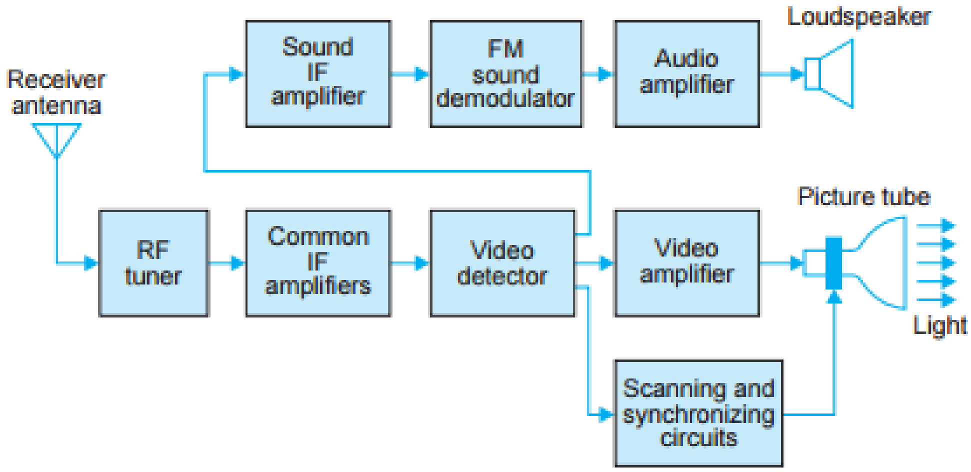


Figure 2.5 Simplified block diagram of a black and white TV receiver

A simplified block diagram of a black and white TV receiver is shown in Fig. 2.5. The receiving antenna intercepts radiated RF signals and the tuner selects desired channel's frequency band and converts it to the common IF band of frequencies. The receiver employs two or three stages of intermediate frequency (IF) amplifiers. The output from the last IF stage is demodulated to recover the video signal. This signal that carries picture information is amplified and coupled to the picture tube which converts the electrical signal back into picture elements of the same degree of black and white.

The picture tube shown in Fig. 2.6 is very similar to the cathode-ray tube used in an oscilloscope. The glass envelope contains an electron-gun structure that produces a beam of electrons aimed at the fluorescent screen. When the electron beam strikes the

screen, light is emitted. The beam is deflected by a pair of deflecting coils mounted on the neck of picture tube in the same way as the beam of camera tube scans the target plate. The amplitudes of currents in the horizontal and vertical deflecting coils are so adjusted that the entire screen, called raster, gets illuminated because of the fast rate of scanning.

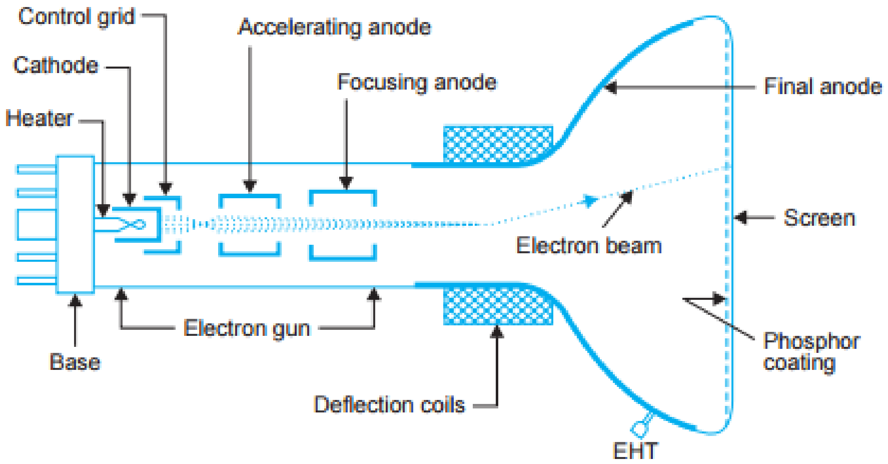


Figure 2.6 Elements of a picture tube

The video signal is fed to the grid or cathode of picture tube. When the varying signal voltage makes the control grid less negative, the beam current is increased, making the spot of light on the screen brighter. More negative grid voltage reduces brightness. If the grid voltage is negative enough to cut-off the electron beam current at the picture tube, there will be no light. This state corresponds to black. Thus the video signal illuminates the fluorescent screen from white to black through various shades of grey depending on its amplitude at any instant. This corresponds to brightness changes encountered by the electron beam of the camera tube while scanning picture details element by element. The rate at which the spot of light moves is so fast that the eye is unable to follow it and so a complete picture is seen because of storage capability of the human eye.

2.8 SOUND RECEPTION

The path of sound signal is common with the picture signal from antenna to video detector section of the receiver. Here the two signals are separated and fed to their

respective channels. The frequency modulated audio signal is demodulated after at least one stage of amplification. The audio output from the FM detector is given due amplification before feeding it to the loudspeaker.

2.9 COLOUR RECEIVER

A colour receiver is similar to the black and white receiver as shown in Fig. 2.7. The main difference between the two is the need of a colour or Chroma subsystem. It accepts only the colour signal and processes it to recover (B-Y) and (R-Y) signals. These are combined with the Y signal to obtain VR, VG and VB signals as developed by the camera at the transmitting end. VG becomes available as it is contained in the Y signal. The three colour signals are fed after sufficient amplification to the colour picture tube to produce a colour picture on its screen.

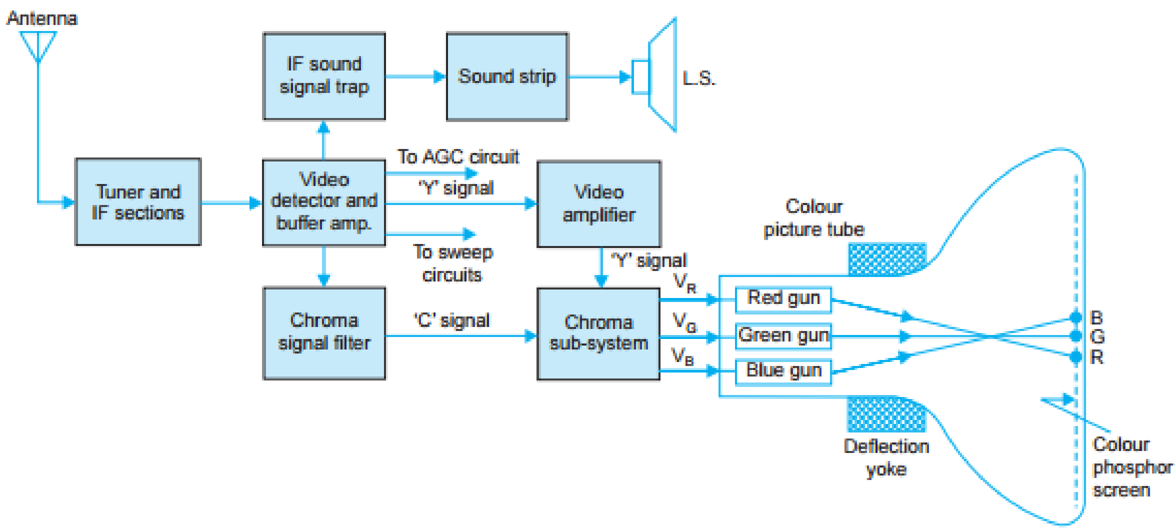


Figure 2.7. An oversimplified block diagram of a colour receiver

As shown in Fig. 2.7, the colour picture tube has three guns corresponding to the three pick-up tubes in the colour camera. The screen of this tube has red, green and blue phosphors arranged in alternate stripes. Each gun produces an electron beam to illuminate corresponding colour phosphor separately on the fluorescent screen. The eye then integrates the red, green and blue colour information and their luminance to

perceive actual colour and brightness of the picture being televised. The sound signal is decoded in the same way as in a monochrome receiver.

2.10 SYNCHRONIZATION

It is essential that the same co-ordinates be scanned at any instant both at the camera tube target plate and at the raster of picture tube, otherwise, the picture details would split and get distorted. To ensure perfect synchronization between the scenes being televised and the picture produced on the raster, synchronizing pulses are transmitted during the retrace, i.e., fly-back intervals of horizontal and vertical motions of the camera scanning beam. Thus, in addition to carrying picture details, the radiated signal at the transmitter also contains synchronizing pulses. These pulses which are distinct for horizontal and vertical motion control, are processed at the receiver and fed to the picture tube sweep circuitry thus ensuring that the receiver picture tube beam is in step with the transmitter camera tube beam.

As stated earlier, in a colour TV system additional sync pulses called colour burst are transmitted along with horizontal sync pulses. These are separated at the input of Chroma section and used to synchronize the colour demodulator carrier generator. This ensures correct reproduction of colours in the otherwise black and white picture.

2.11 RECEIVER CONTROLS

Most black and white receivers have on their front panel (i) channel selector, (ii) fine tuning, (iii) brightness, (iv) contrast, (v) horizontal hold and (vi) volume controls besides an ON-OFF switch. Some receivers also provide a tone control. The channel selector switch is used for selecting the desired channel. The fine tuning control is provided for obtaining best picture details in the selected channel. The hold control is used to get a steady picture in case it rolls up or down. The brightness control varies beam intensity of the picture tube and is set for optimum average brightness of the picture. The contrast control is actually gain control of the video amplifier. This can be varied to obtain desired contrast between white and black contents of the reproduced picture. The volume and tone controls form part of the audio amplifier in sound section, and are used for setting volume and tonal quality of the sound output from the loudspeaker.

In colour receivers there is an additional control called 'colour' or 'saturation' control. It is used to vary intensity or amount of colours in the reproduced picture. In modern colour receivers that employ integrated circuits in most sections of the receiver, the hold control is not necessary and hence usually not provided.

FLAT PANEL DISPLAY

- **Current display technology for TV business is flat panel displays (FPD).**
- **FPD can be investigated in two common groups depending to their display technology. LCD displays are the first and plasma displays are the second FPD technology.**
- **The basic difference is, LCD displays light source at backside of the panel and pixels which are formed by red, green and blue sub pixels act as valve which defines the output light level and color.**
- **In plasma display devices each pixel which are also formed by sub pixels RGB act as a separate lamp defining color and brightness level at that pixel point, plasma display pixels are light emitting devices separately.**
- **Liquid Crystal is the material which is used as valve in LCD displays and plasma cells are the building block of plasma displays.**

TFT-LCD Displays

- **TFT (Thin Film Transistor) and LCD (Liquid Crystal Display)**
- **Liquid Crystal is the material used as a valve for adjusting the light level output from panel and TFT is the control circuitry of this liquid crystal material.**
- **Depending to the voltage level on the crystal, light intensity varies and the voltage level on crystal is controlled by transistors for each sub pixel.**

LCD Basics

- **Friedrich Reinitzer is the first person who observed the liquid crystal state.**
- **Crystals have perfect flat surfaces because of their molecular structures.**

- **Crystals, such as quartz, are formed when molecules form a three-dimensional matrix by attaching each other in a regular pattern.**
- **Crystal are the solid materials actually, but the term "liquid crystal" is used to describe a substance which is in a state between a liquid and a crystal but exhibits properties similar to both.**

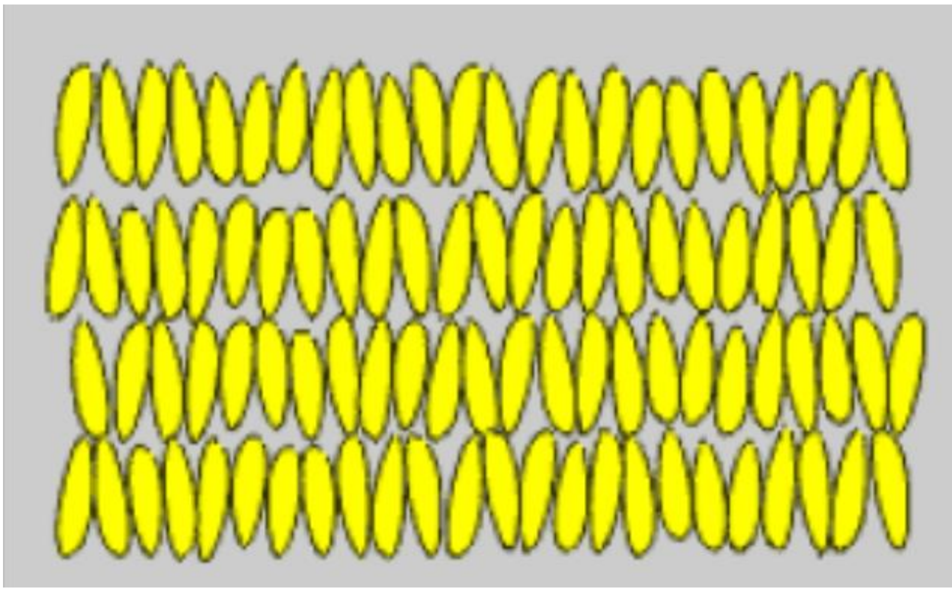


Figure 2.8. Molecular structure of Liquid Crystal

- **After heating a sample of material it changed into a milky fluid.**
- **As the temperature increased further, the fluid changed into a transparent liquid.**
- **Many chemical compounds exists which has the liquid crystal state, with cooling liquid or heating solid material liquid crystal state can be observed for special materials.**
- **Depending to temperature molecular structure change of liquid crystal material is shown in Figure 2.9.**

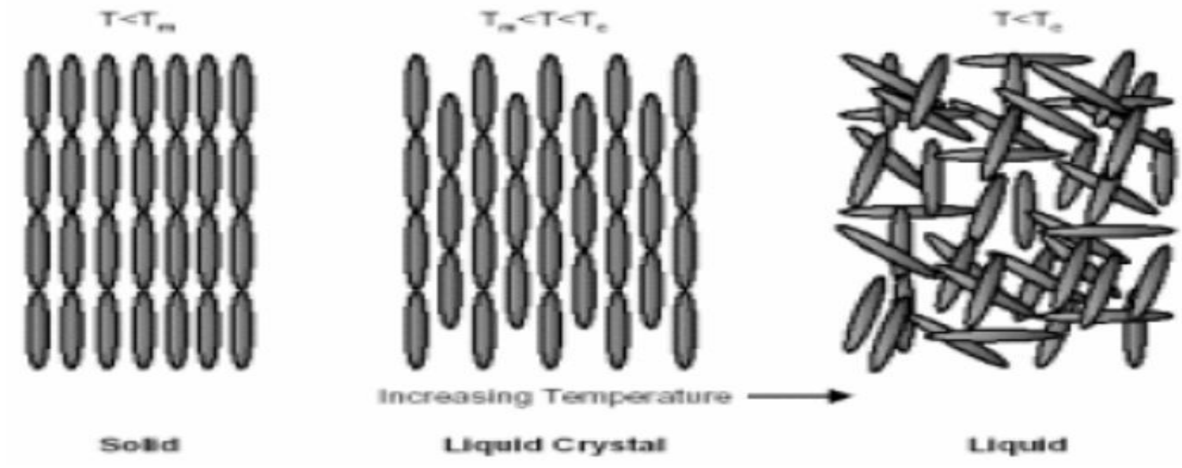
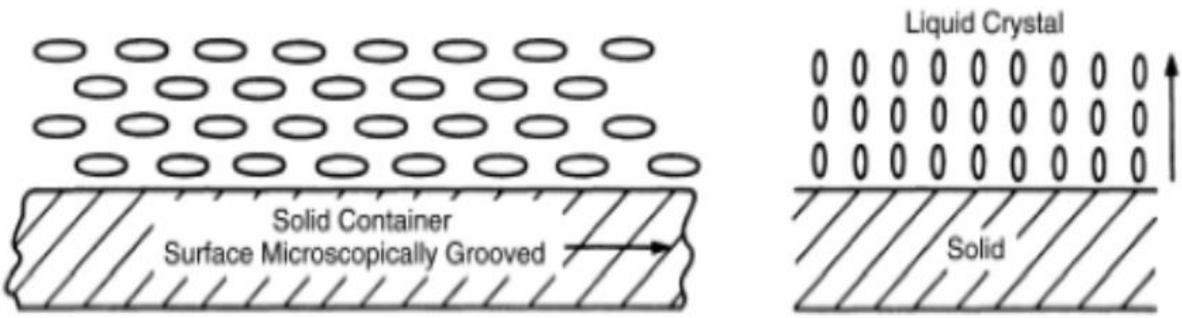


Figure 2.9 Molecular structure of LC depending to temperature

Principles of LCD Display Operation

- **LCD displays are used in several products ranging from small size displays used in mobile phones to large size displays used in TV sets.**
- **Although there are several types of liquid crystal material, nematic crystals are most commonly used in display devices.**
- **Nematic material is rod physical shaped and the alignment of the crystal varies depending to electric field.**
- **The alignment of the cell without and under electric field is shown in Figure. 2.10**



a) No Electric field **b) Under Electric field**

Figure 2.10 Alignment of LC depending on electric field

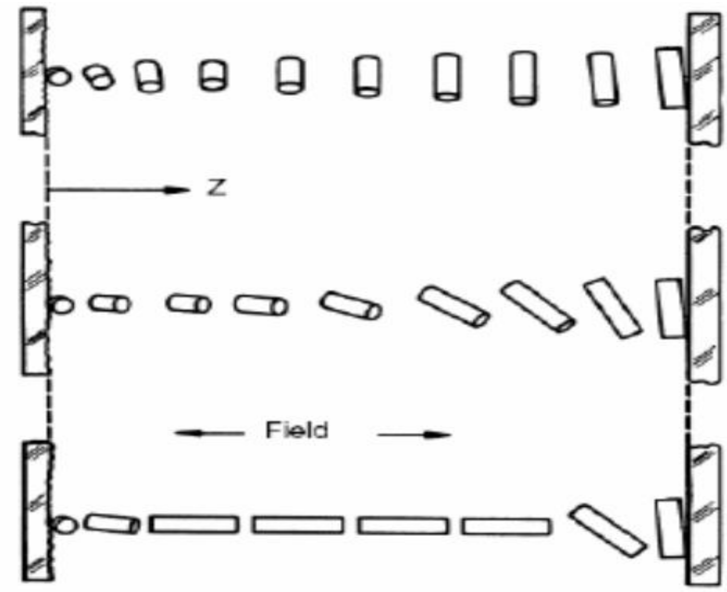


Figure 2.11 Alignment of rods under increasing electric field

- **Vertical alignment varies with electric field and the horizontal alignment of rods is defined by groove direction of the solid plate at the top and bottom side.**
- **Twisted nematic architecture uses this feature. The top and bottom plates are grooved orthogonally and the horizontal position of nematic is ninety degree shifted between plates.**
- **Twisted nematic structure between grooved plates is given in Figure 2.12.**

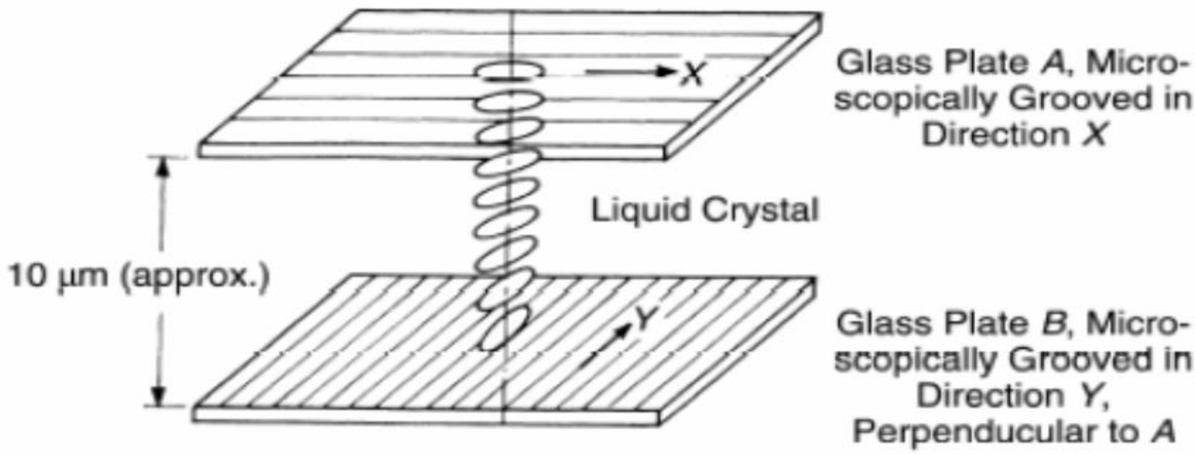


Figure 2.12 Twisted nematic architecture between grooved plates

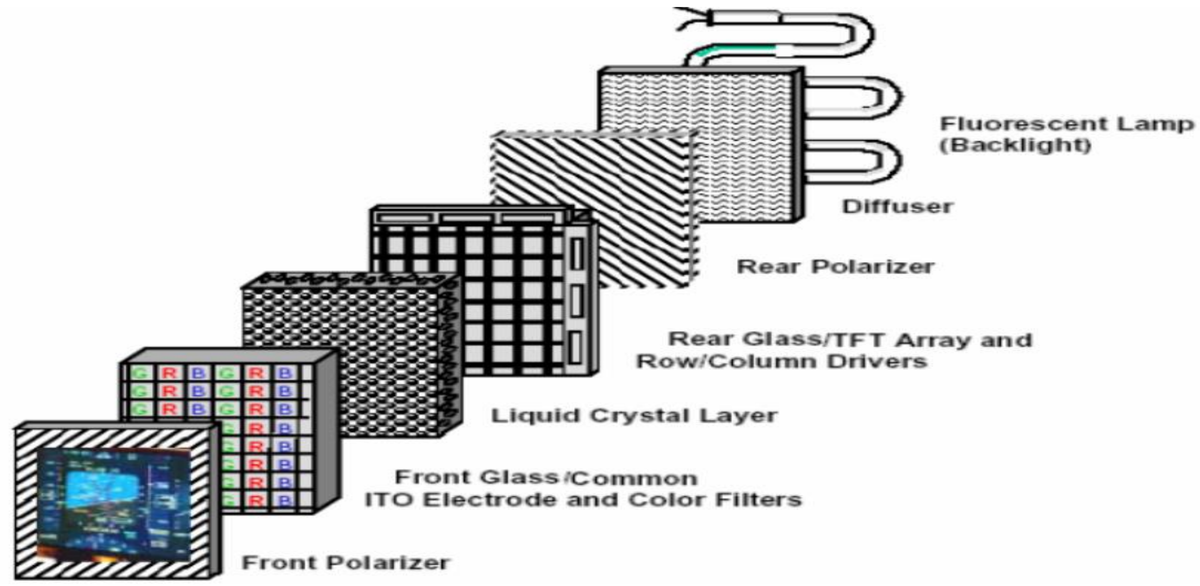


Figure 2.13 Operation of LCD display

- **First element is fluorescent lamp which is always on state.**
- **Diffuser is used as the second element to distribute light to whole display equally and uniformly.**
- **After diffuser light is polarized at rear part in twisted nematic architecture which is the third element.**
- **Fourth layer of the LCD display is the TFT arrays used for addressing and as driving circuitry of LCD panels.**
- **TFT arrays are the driving circuitry of the matrix structure based on rows and columns.**
- **Liquid crystal layer is the fifth element, LCD material is placed between two planes which are grooved orthogonally for twisted nematic architecture.**
- **Liquid crystal layer defines the output light level by shifting the angle of the polarized light.**
- **The front polarizer is in the same polarization with rear polarizer.**
- **When electric field applied to TN the shifting angle increase which means both horizontal and vertical polarization exist but only one of them in the same polarization with the front polarizer can pass through and displayed on screen.**

Plasma Display

- **Plasma displays are formed by plasma cells which control electron motion, in colored plasma display each pixel is formed by three R, G and B sub cells.**
- **Cell control electron motion less than 1uS, and 8 bit level can be realized**
- **The response time, contrast characteristic of plasma display is better than LCD displays.**
- **The operation of plasma cell is similar to lamp, depending to duty cycle cells luminance output varies.**

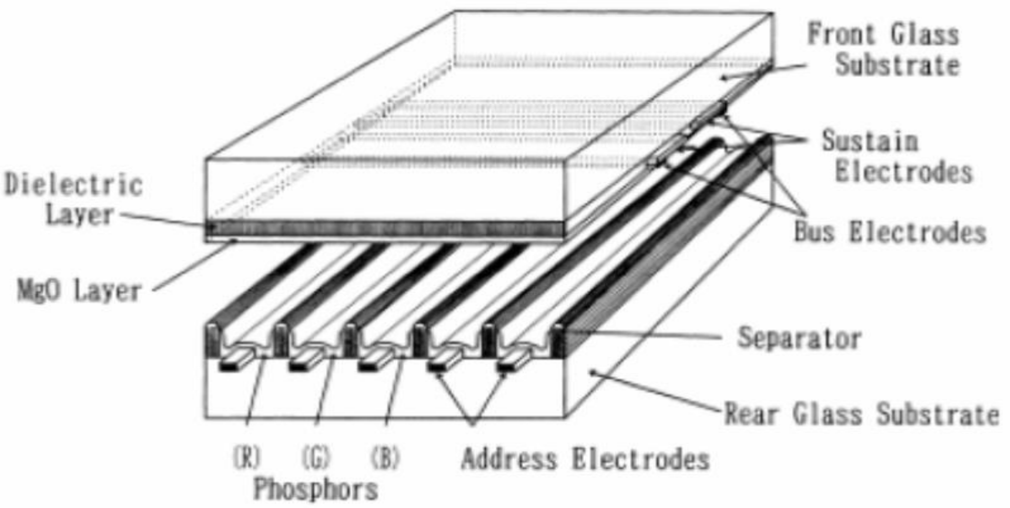


Figure 2.14 Full color Plasma display cell

2.12 Digital Television and HDTV

- **High-definition TV (HDTV), one type of Digital TV (DTV), was designed to replace the National Television Standards Committee (NTSC) system.**
- **The goal of HDTV is to greatly improve the picture and sound quality.**
- **The HDTV system is an extremely complex collection of digital, communication, and computer techniques.**

HDTV Standards

- **HDTV uses the scanning concept to present a picture on the CRT.**
- **The HDTV screen is made up of thousands of tiny dots of light called pixels.**
- **The greater the number of pixels on the screen, the greater the resolution and the finer the detail that can be represented.**

- **HDTV uses progressive line scanning, in which each line is scanned one at a time from top to bottom.**

HDTV Transmission Concepts

- **In HDTV both the video and the audio signals must be digitized by A/D converters and transmitted serially to the receiver.**
- **Because of the very high frequency of video signals, special techniques must be used to transmit the video signal over a standard 6-MHz bandwidth TV channel.**
- **Multiplexing techniques must be used because both video and audio must be transmitted over the same channel.**

HDTV Transmission Concepts: HDTV Transmitter

- **In an HDTV transmitter, the video from the camera consists of the R, G, and B signals that are converted to the luminance and chrominance signals.**
- **These are digitized by A/D converters.**
- **The resulting signals are serialized and sent to a data compressor.**
- **MPEG-2 is the data compression method used in HDTV.**
- **The signal is next sent to a data randomizer.**
- **The random serial signal is passed through a Reed-Solomon (RS) error detection and correction circuit.**
- **The signal is next fed to a trellis encoder.**
- **Each audio channel is sampled at a 48-kbps rate.**
- **The video and audio data streams are packetized.**
- **The packets are multiplexed with some synchronizing signals to form the final signal to be transmitted.**
- **The modulation scheme used in HDTV is 8-VSB.**
- **The modulated signal is up-converted by a mixer to the final transmission frequency, which is one of the standard TV channels in the VHF or UHF range.**
- **A linear power amplifier is used to boost the signal level prior to transmission by the antenna.**

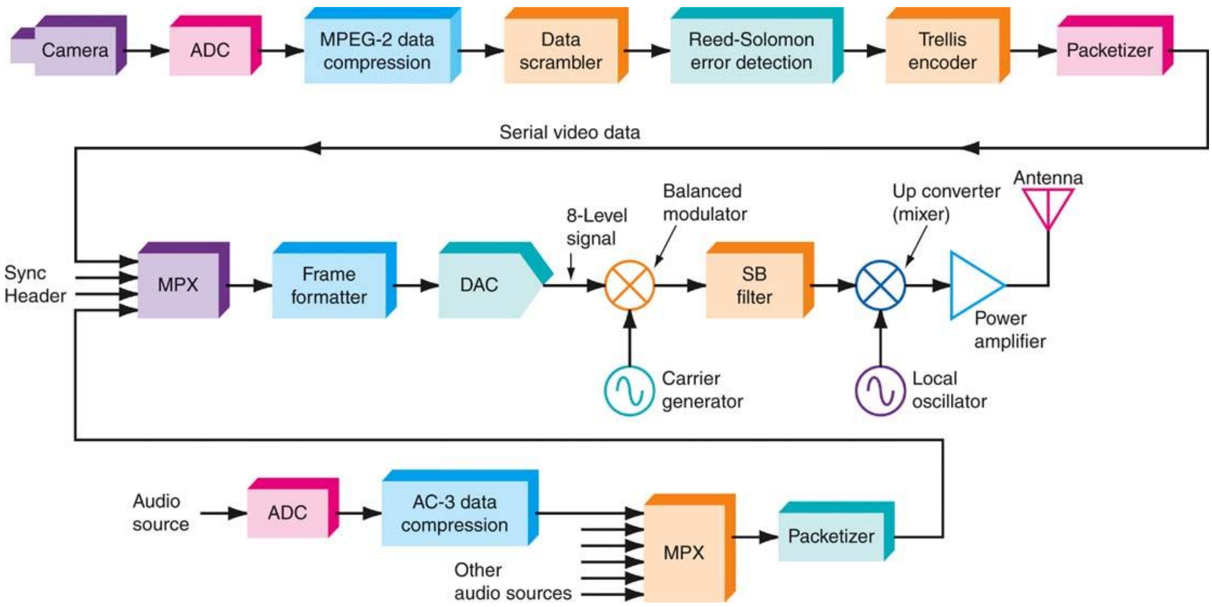


Figure 2.15 HDTV Transmitter

HDTV Transmission Concepts: HDTV Receiver

- **In an HDTV receiver, the tuner and IF systems are similar to those in a standard TV receiver.**
- **The 8-VSB signal is demodulated into the original bit stream.**
- **The signal then passes through an NTSC filter and an equalizer circuit.**
- **The signals are demultiplexed into the video and audio bit streams.**
- **The trellis decoder and RS decoder correct any errors.**
- **The signal is descrambled and decompressed.**
- **The video signal is converted back to the digital signals that will drive the D/A converters that, in turn, drive the red, green, and blue electron guns in the CRT.**
- **The audio signal is demultiplexed and fed to AC-3 decoders.**
- **The resulting digital signals are fed to D/A converters that create the analog audio for each of the six audio channels.**

2.13 SET TOP BOX

An interactive device which integrates the video and audio decoding capabilities of television with a multimedia application execution environment. It provides a user

friendly interface offering personalized multimedia services and regular cable TV service.

Digital video networks(DVN)

- **Digital television advantage.**
- **Digital video delivery requirements**
  - **High bandwidth.**
  - **Fibre cable, satellite, broadcast and computer networks can be used.**
- **Traditional cable networks analogue systems and their drawbacks.**
- **Satellite and terrestrial networks.**
- **Internet suitability for interactive network and drawback.**

DVN need to deliver a high bandwidth stream into consumer homes and a low bandwidth communication layer for interaction between the STB user and the service provider.

- **Cable operators approach for DVN.**
  - **Need to extend unidirectional coaxial networking with a communication path from subscriber home to cable service gateways that can control the content being sent to subscriber.**
  - **Advantage of video compression technology.**
  - **Constraints with cable networks.**
- **Telephone companies approach.**
  - **Advantage with telephone companies.**
    - **Already have set up for P2P and technology for control and service gateways to manage wide area switched star networks.**
  - **Drawback.**
    - **Low bandwidth between head end equipment and consumer's home.**

Set Top Box Hardware Architecture.

- **Requirements based on functionality.**
  - **Should have MPEG-2 sub-system to decode MPEG-2 video and audio.**
  - **Should enable user to download custom applications and execute them on the STB which requires a general purpose microprocessor in the STB with an architecture that supports control of the different devices.**

- **Various hardware components.**

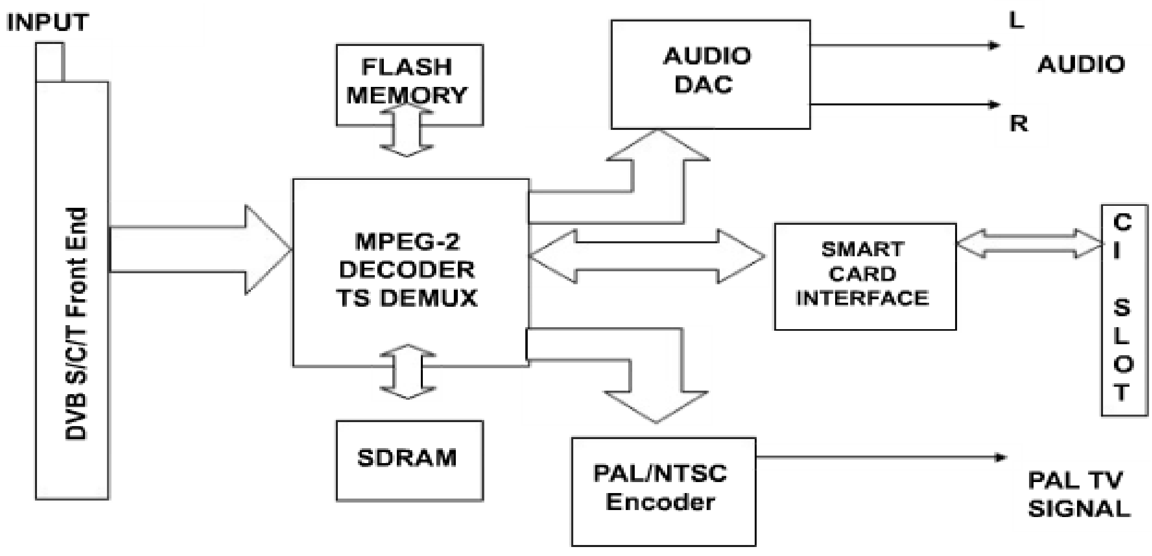


Figure 2.16 Block Diagram of SET TOP Box (IRD) With CI SLOT

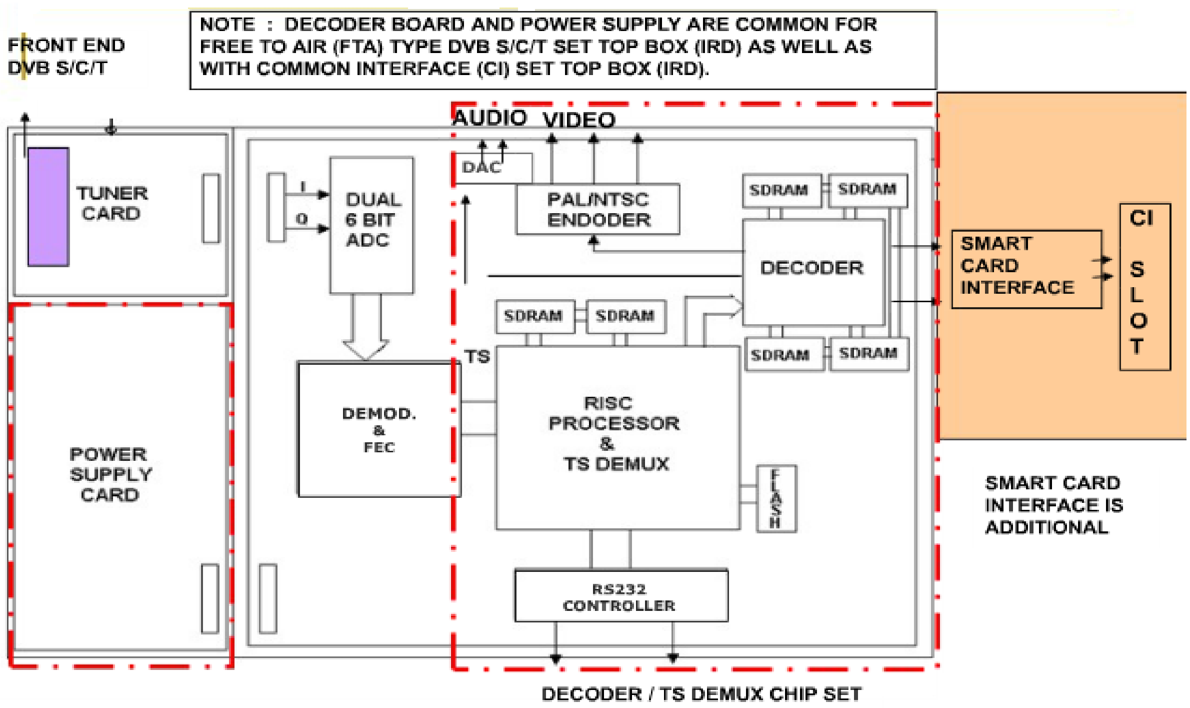


Figure 2.17 Detailed Block Diagram of SET TOP Box (IRD) With CI SLOT

STB software architecture

For personalized interactive services, a set top box should be addressable in the video dial-tone network, thus providing P2P communication between a video and

information provider and a user. It should also have the ability to download client applications and execute them locally.

The control software on the set top box ties together all the hardware components into a functioning unit.

- **STB software has two parts.**
  - **System software which provides the DAVID application programming interface.**
  - **Application software that provides cable TV functionality or some other personalized multimedia service.**
- **DAVID system software includes.**
  - **Operating system (os-9) kernel.**
  - **Device drivers.**
  - **File manager.**

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COMMUNICAITON SYSTEMS – SEC1303

UNIT – 3

SATELLITE COMMUNICATION

3. SATELLITE COMMUNICATION

Satellite basics - Orbit dynamics - Types of Satellite Orbits - Satellite system - System calculation - satellite subsystem and earth station subsystem - Satellite Frequency band - Satellite Applications - Noise in satellite communication system - multiple access method - FDMA and TDMA system.

3.1 Satellite Basics

- **A satellite is a manmade object that orbits another large object like planet.**
- **A communication satellite is a station in space that is used for telecommunication, radio and television signals.**
- **Passive Satellite - A passive satellite only reflects received radio signals back to earth.**
- **Active Satellite - An active satellite acts as a REPEATER; it amplifies signals received and then retransmits them back to earth.**
- **The advantages of satellite communication over terrestrial communication are:**
  - **The coverage area of a satellite greatly exceeds that of a terrestrial system.**
  - **Transmission cost of a satellite is independent of the distance from the center of the coverage area.**
  - **Satellite to Satellite communication is very precise.**
  - **Higher Bandwidths are available for use.**
- **The disadvantages of satellite communication:**
  - **Launching satellites into orbit is costly.**
  - **Satellite bandwidth is gradually becoming used up.**
  - **There is a larger propagation delay in satellite communication than in terrestrial communication**
- **Satellite communications are comprised of 2 main Components**

1. The Satellite

- **This is the earth segment. The ground station's job is two-fold.**
- **In the case of transmitting station, terrestrial data in the form of baseband signals, is passed through a baseband processor, an up converter, a high powered amplifier, and through a parabolic dish antenna up to an orbiting satellite.**
- **In receiving station, works in the reverse fashion, ultimately converting signals received through the parabolic antenna to base band signal.**

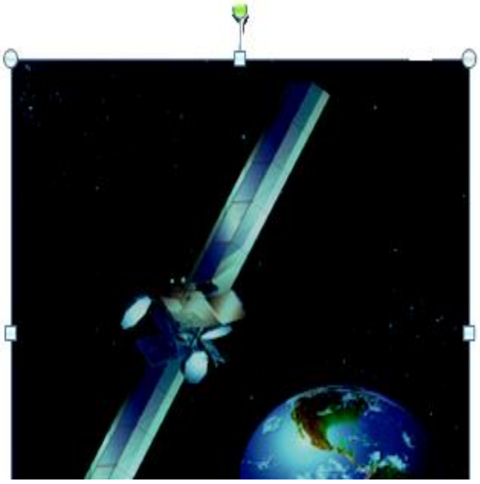

Figure 3.1: Satellite

2. The Ground Station

Figure 3.2: Ground Station

- **This is the earth segment. The ground station's job is two-fold.**
- **In the case of transmitting station, terrestrial data in the form of baseband signals, is passed through a baseband processor, an up converter, a high powered amplifier, and through a parabolic dish antenna up to an orbiting satellite.**
- **In receiving station, works in the reverse fashion, ultimately converting signals received through the parabolic antenna to base band signal.**

- **Satellite work**
    - **Two Stations on Earth want to communicate through radio broadcast but are too far away to use conventional means.**
    - **The two stations can use a satellite as a relay station for their communication**
    - **One Earth Station sends a transmission to the satellite. This is called a Uplink.**
    - **The satellite Transponder converts the signal and sends it down to the second earth station. This is called a Downlink**

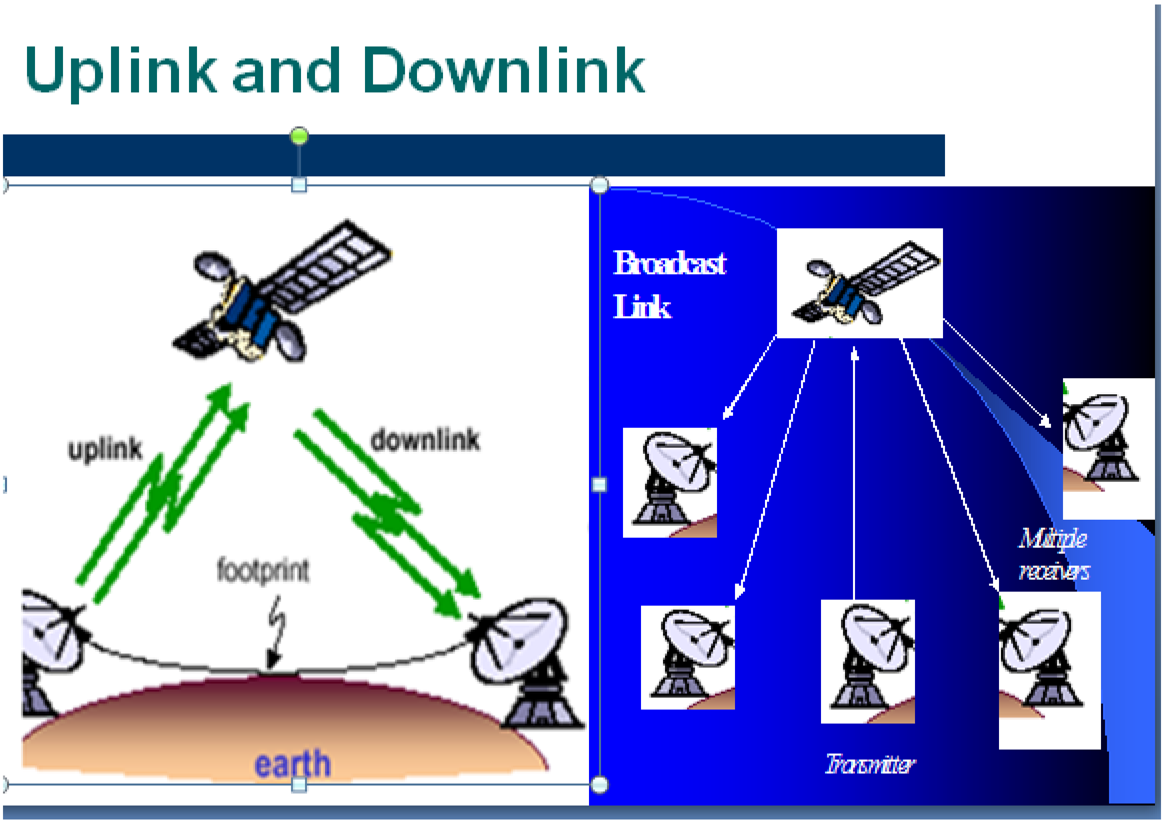

Figure 3.3: Uplink and Downlink

3.2 Satellite Orbit dynamics

The ability to launch a satellite and keep it in orbit depends upon following well-known physical and mathematical laws that are referred to collectively as orbital dynamics.

Principles of Satellite Orbits and Positioning

- **For the satellite to go into orbit around the earth, it is given both vertical and forward motion.**
- **However, gravity tends to pull the satellite toward the earth.**

- **The inertia of the satellite is equalized by the earth's gravitational pull.**
- **The goal is to give the satellite acceleration and speed that will exactly balance the gravitational pull.**
- **The closer the satellite is to earth, the stronger the effect of the earth's gravitational pull. So in low orbits, the satellite must travel faster to avoid falling back to earth. The lowest practical earth orbit is approximately 100 mi, the satellite's speed must be about 17,500 mi/h to keep the satellite in orbit. At this speed, the satellite orbits the earth in approximately 11⁄2 h.**
- **Communication satellites are usually much farther from earth. A typical distance is 22,300 mi. A satellite need travel only about 6800 mi/h to stay in orbit at that distance. At this speed, the satellite rotates about the earth in approximately 24 h, the earth's own rotational time.**
- **A satellite rotates about the earth in either a circular or an elliptical path, as shown in Fig. 3.4**

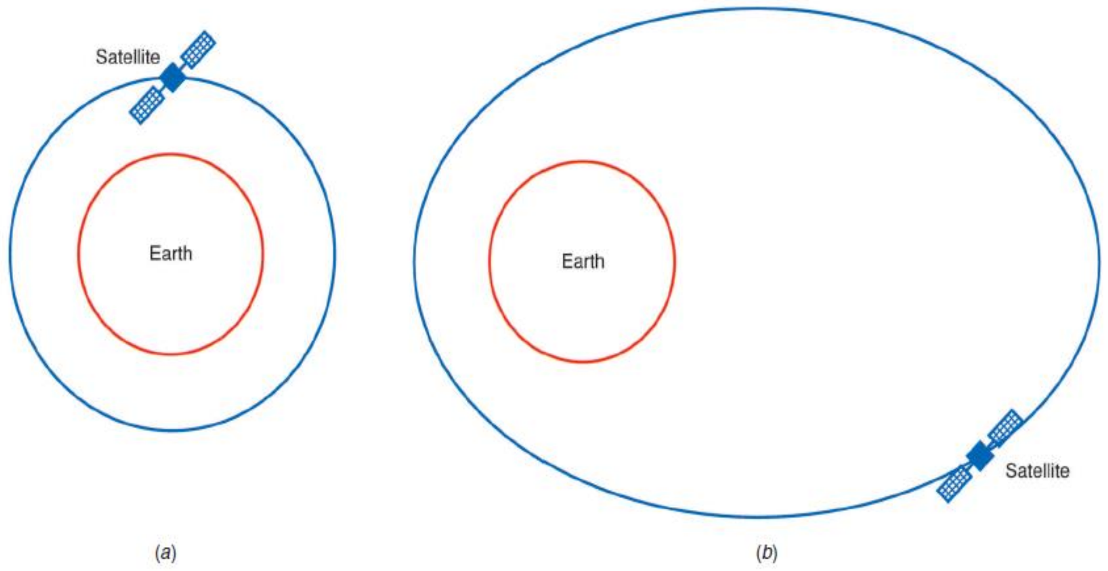

Figure 3.4: Satellite orbits (a) Circular orbit (b) Elliptical orbit

- **Geocenter : The center of gravity of the earth**
- **Orbit plane : A satellite rotates in an orbit that forms a plane passing through geocenter**

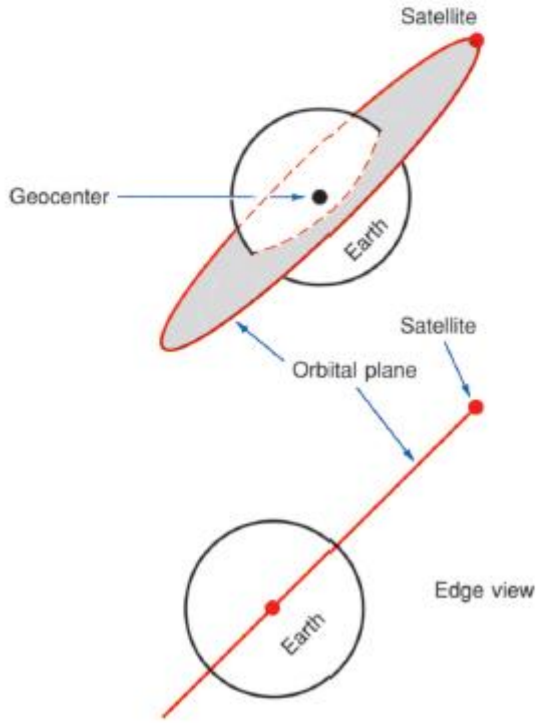

Figure 3.5: The orbital plane passes through the geocenter

- **Satellite Height**
  - **In a circular orbit, the height is the distance of the satellite from the earth. In geometric calculations, the height is the distance between the center of the earth and the satellite.**

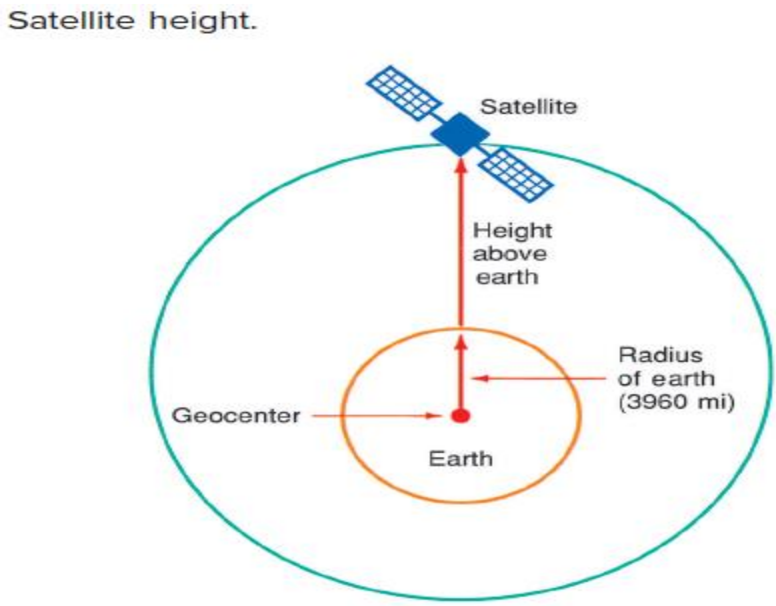

Figure 3.6: Satellite height

- **When the satellite is an elliptical orbit, the center of the earth is one of the focal points of the ellipse.**

The two points of greatest interest are the highest point above the earth (the apogee) and the lowest point (the perigee).

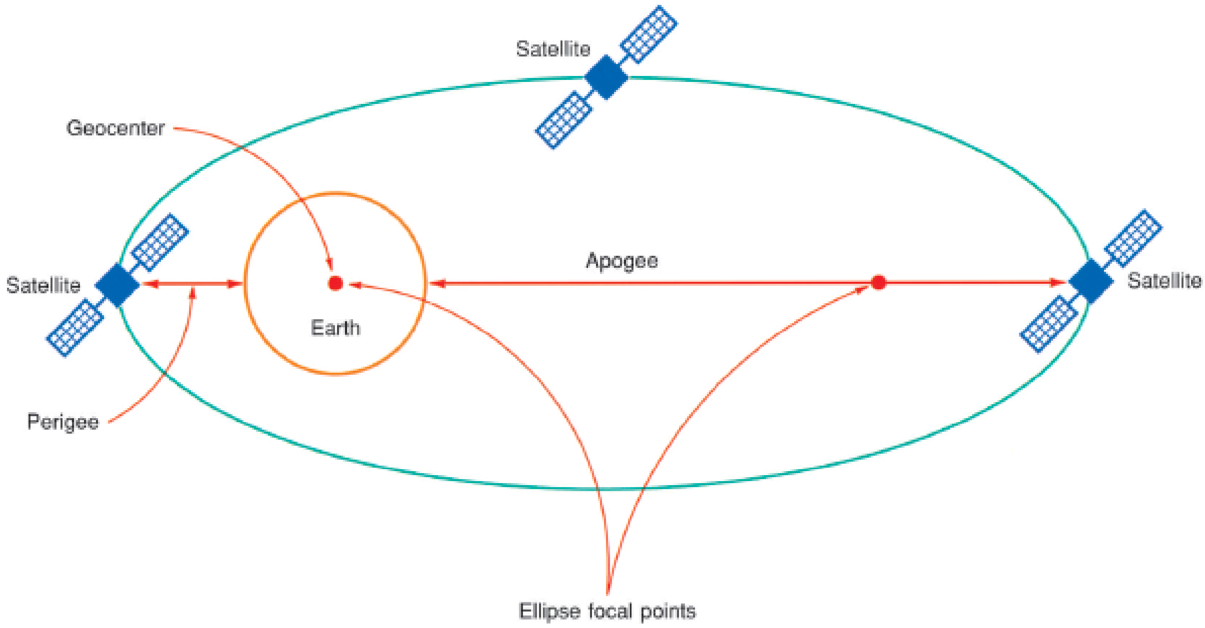

Figure 3.7: Elliptical orbit showing apogee and perigee

- **Satellite Speed**
  - **Satellite speed varies depending upon the distance of the satellite from the earth.**
  - **For a circular orbit the speed is constant, but for an elliptical orbit the speed varies depending upon the height.**
  - **Low earth satellites of about 100 mi in height have a speed of about 17,500 mi/hr.**
  - **Very high satellites such as communication satellites typically travel at speeds of about 6800 mi/hr.**

- **Angle of Inclination**
  - **The angle of inclination of a satellite orbit is the angle formed between the line that passes through the center of the earth and the north pole, and a line that passes through the center of the earth but that is also perpendicular to the orbital plane.**
  - **It is also defined as the angle between the equatorial plane and the satellite orbital plane as the satellite enters the northern hemisphere.**
  - **When the satellite has an angle of inclination, the orbit is said to be ascending or descending.**
  - **Angle of inclination is 0 ° then satellite directly above equator**

– **Angle of inclination is 90 ° then satellite passes over both N and S poles once for each orbit**
– **Ascending orbit-satellite moves from S to N and crosses equator**
– **Descending orbit-satellite moves from N to s and across equator**

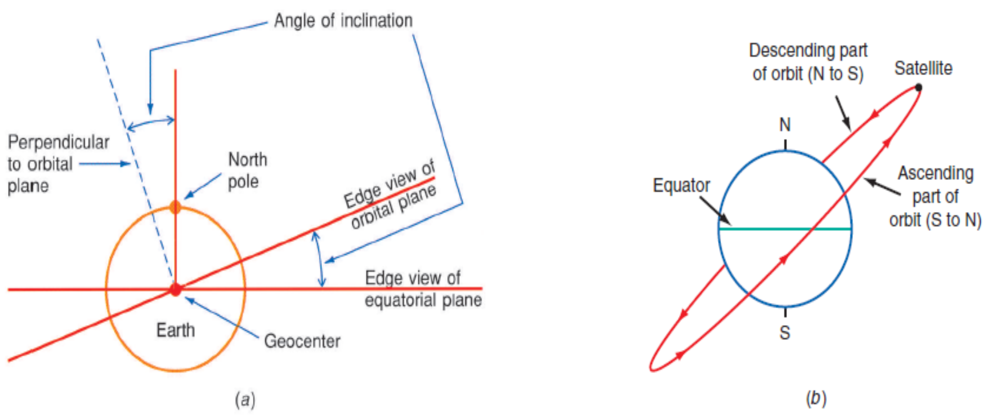

Figure 3.8 : (a) Angle of Inclination (b)Ascending and descending orbits

- **Angle of Elevation**
  – **The angle of elevation of a satellite is the angle that appears between the line from the earth station's antenna to the satellite and the line between the earth station's antenna and the earth's horizon.**
  – **Noise in the atmosphere contributes to poor performance.**
  – **The minimum practical angle of elevation for good satellite performance is 5°.**
  – **The higher the angle of elevation, the better.**

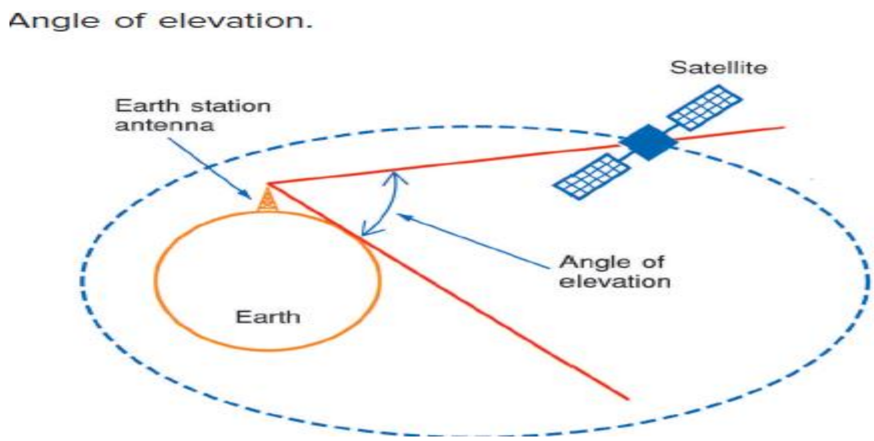

Figure 3.9 : Angle of elevation

Azimuth

Azimuth is defined as the horizontal pointing angle of an antenna. It is measured in a clockwise direction in degrees from true north. The angle of elevation and the azimuth both depend on the latitude of the earth station and the longitude of both the earth station and the orbiting satellite.

3.3 Applications of Satellites

3.3.1) Weather Forecasting

Certain satellites are specifically designed to monitor the climatic conditions of earth. They continuously monitor the assigned areas of earth and predict the weather conditions of that region. This is done by taking images of earth from the satellite. These images are transferred using assigned radio frequency to the earth station. (Earth Station: it’s a radio station located on the earth and used for relaying signals from satellites.) These satellites are exceptionally useful in predicting disasters like hurricanes, and monitor the changes in the Earth's vegetation, sea state, ocean color, and ice fields.

3.3.2) Radio and TV Broadcast

These dedicated satellites are responsible for making 100s of channels across the globe available for everyone. They are also responsible for broadcasting live matches, news, world-wide radio services. These satellites require a 30-40 cm sized dish to make these channels available globally.

3.3.3) Military Satellites

These satellites are often used for gathering intelligence, as a communications satellite used for military purposes, or as a military weapon. A satellite by itself is neither military nor civil. It is the kind of payload it carries that enables one to arrive at a decision regarding its military or civilian character.

3.3.4) Navigation Satellites

The system allows for precise localization world-wide, and with some additional techniques, the precision is in the range of some meters. Ships and aircraft rely on GPS as an addition to traditional navigation systems. Many vehicles come with installed GPS

receivers. This system is also used, e.g., for fleet management of trucks or for vehicle localization in case of theft.

3.3.5) Global Telephone

One of the first applications of satellites for communication was the establishment of international telephone backbones. Instead of using cables it was sometimes faster to launch a new satellite. But, fiber optic cables are still replacing satellite communication across long distance as in fiber optic cable, light is used instead of radio frequency, hence making the communication much faster (and of course, reducing the delay caused due to the amount of distance a signal needs to travel before reaching the destination.). Using satellites, to typically reach a distance approximately 10,000 kms away, the signal needs to travel almost 72,000 kms, that is, sending data from ground to satellite and (mostly) from satellite to another location on earth. This causes substantial amount of delay and this delay becomes more prominent for users during voice calls.

3.3.6) Connecting Remote Areas

Due to their geographical location many places all over the world do not have direct wired connection to the telephone network or the internet (e.g., researchers on Antarctica) or because of the current state of the infrastructure of a country. Here the satellite provides a complete coverage and (generally) there is one satellite always present across a horizon.

3.3.7) Global Mobile Communication

The basic purpose of satellites for mobile communication is to extend the area of coverage. Cellular phone systems, such as AMPS and GSM (and their successors) do not cover all parts of a country. Areas that are not covered usually have low population where it is too expensive to install a base station. With the integration of satellite communication, however, the mobile phone can switch to satellites offering world-wide connectivity to a customer. Satellites cover a certain area on the earth. This area is termed as a „footprint" of that satellite. Within the footprint, communication with that satellite is possible for mobile users. These users communicate using a Mobile-User-Link (MUL). The base-stations communicate with satellites using a Gateway-Link (GWL). Sometimes it becomes necessary for satellite to create a communication link between users belonging to two

different footprints. Here the satellites send signals to each other and this is done using Inter-Satellite-Link (ISL).

3.4 Frequency Allocation for Satellite

VARIOUS SATELLITE SERVICES:

- **Fixed satellite service: Provides Links for existing Telephone Networks Used for transmitting television signals to cable companies**
- **Broadcasting satellite service: Provides Direct Broadcast to homes. E.g. Live Cricket matches etc**
- **Mobile satellite services: This includes services for Land Mobile Maritime Mobile Aeronautical mobile**
- **Navigational satellite services : Include Global Positioning systems**
- **Meteorological satellite services: They are often used to perform Search and Rescue service**

Band	Frequency Range	Total Bandwidth	General Application
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS military, terrestrial earth exploration, and meteorological satellites
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite service (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

Table 3.1 Frequency allocation

3.5.1 Types of Satellites (Based On Orbits)

1) Geostationary or geosynchronous earth orbit (GEO)

GEO satellites are synchronous with respect to earth. Looking from a fixed point from Earth, these satellites appear to be stationary. These satellites are placed in the space in such a way that only three satellites are sufficient to provide connection throughout the surface of the Earth (that is; their footprint is covering almost 1/3rd of the Earth). The orbit of these satellites is circular.

There are three conditions which lead to geostationary satellites. Lifetime expectancy of these satellites is 15 years.

1) The satellite should be placed 37,786 kms (approximated to 36,000 kms) above the surface of the earth.

2) These satellites must travel in the rotational speed of earth, and in the direction of motion of earth, that is eastward.

3) The inclination of satellite with respect to earth must be 00.

Geostationary satellite in practical is termed as geosynchronous as there are multiple factors which make these satellites shift from the ideal geostationary condition.

1) Gravitational pull of sun and moon makes these satellites deviate from their orbit. Over the period of time, they go through a drag. (Earth"s gravitational force has no effect on these satellites due to their distance from the surface of the Earth.)

2) These satellites experience the centrifugal force due to the rotation of Earth, making them deviate from their orbit.

3) The non-circular shape of the earth leads to continuous adjustment of speed of satellite from the earth station.

These satellites are used for TV and radio broadcast, weather forecast and also, these satellites are operating as backbones for the telephone networks.

Disadvantages of GEO: Northern or southern regions of the Earth (poles) have more problems receiving these satellites due to the low elevation above a latitude of 60°, i.e., larger antennas are needed in this case. Shading of the signals is seen in cities due to high buildings and the low elevation further away from the equator limit transmission

quality. The transmit power needed is relatively high which causes problems for battery powered devices. These satellites cannot be used for small mobile phones. The biggest problem for voice and also data communication is the high latency as without having any handovers, the signal has to at least travel 72,000 kms. Due to the large footprint, either frequencies cannot be reused or the GEO satellite needs special antennas focusing on a smaller footprint. Transferring a GEO into orbit is very expensive.

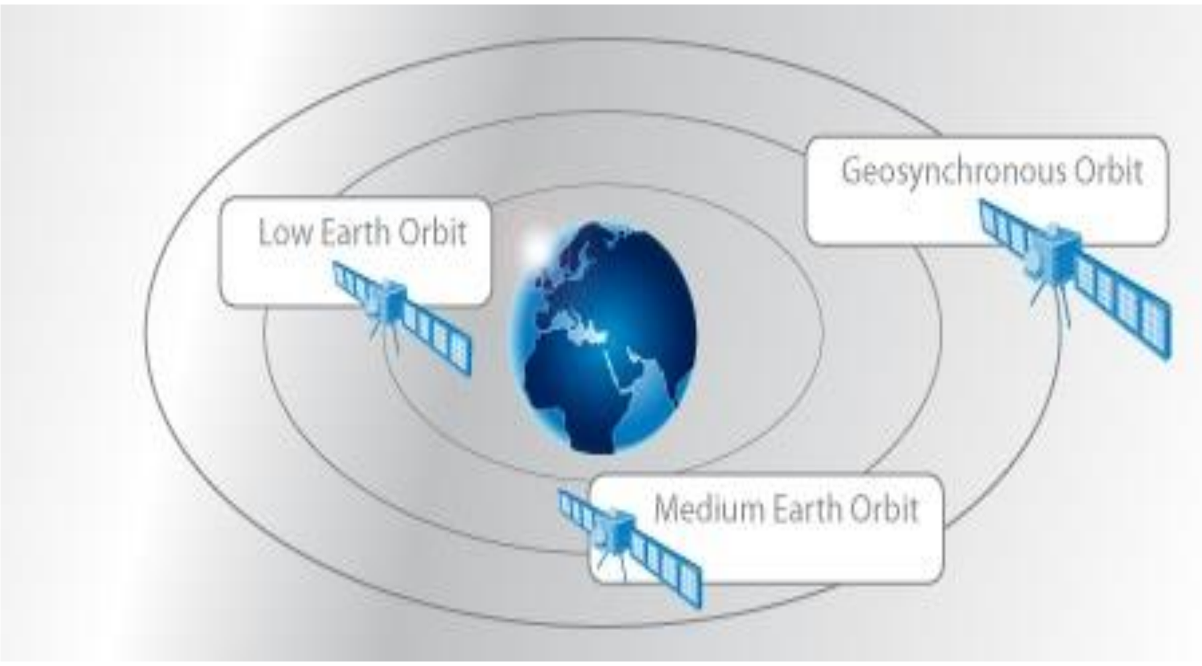

Figure 3.10 Satellite orbits

2. Low Earth Orbit (LEO)

- **LEO satellites are much closer to the earth than GEO satellites, ranging from 500 to 1,500 km above the surface.**
- **LEO satellites don't stay in fixed position relative to the surface, and are only visible for 15 to 20 minutes each pass.**
- **A LEO orbit can also be used to cover a polar region, which the GEO cannot accomplish.**
- **Advantages**
  - **A LEO satellite's proximity to earth compared to a GEO satellite gives it a better signal strength and less of a time delay, which makes it better for point to point communication.**

A LEO satellite's smaller area of coverage is less of a waste of bandwidth

- **Disadvantages**
  - **A network of LEO satellites is needed, which can be costly**
  - **LEO satellites have to compensate for Doppler shifts cause by their relative movement.**
  - **Atmospheric drag effects LEO satellites, causing gradual orbital deterioration.**

3. Medium Earth Orbit (MEO)

- **A MEO satellite is in orbit somewhere between 8,000 km and 18,000 km above the earth's surface.**
- **MEO satellites are similar to LEO satellites in functionality.**
- **MEO satellites are visible for much longer periods of time than LEO satellites, usually between 2 to 8 hours.**
- **MEO satellites have a larger coverage area than LEO satellites.**
- **Advantage**
  - **A MEO satellite's longer duration of visibility and wider footprint means fewer satellites are needed in a MEO network than a LEO network.**
- **Disadvantage**
  - **A MEO satellite's distance gives it a longer time delay and weaker signal than a LEO satellite, though not as bad as a GEO satellite.**

4. Molniya Orbit Satellites

- **Used by Russia for decades.**
- **Molniya Orbit is an elliptical orbit. The satellite remains in a nearly fixed position relative to earth for eight hours.**
- **A series of three Molniya satellites can act like a GEO satellite.**
- **Useful in near polar regions.**

5. High Altitude Platform (HAP)

- **One of the newest ideas in satellite communication.**
- **A blimp or plane around 20 km above the earth's surface is used as a satellite.**
- **HAPs would have very small coverage area, but would have a comparatively strong signal.**

Cheaper to put in position, but would require a lot of them in a network

6. Prograde orbit: This orbit is with an inclination of less than 90°. Its direction is the same as the direction as the rotation of the primary (planet).

7. Retrograde orbit:

This orbit is with an inclination of more than 90°. Its direction is counter to the direction of rotation of the planet. Only few satellites are launched into retrograde orbit because the quantity of fuel required to launch them is much greater than for a prograde orbit. This is because when the rocket starts out on the ground, it already has an eastward component of velocity equal to the rotational velocity of the planet at its launch latitude.

8. Polar Orbits

This orbit passes above or nearly above both poles (north and south pole) of the planet on each of its revolutions. Therefore it has an inclination of (or very close to) 90 degrees. These orbits are highly inclined in shape

3.6 Multiple Access Techniques

Multiple accesses is defined as the technique where in more than one pair of earth stations can simultaneously use a satellite transponder. It is a technique used to explore the satellite's geometric advantages and is at the core of satellite networking. In a wireless communication system, radio resources must be provided in each cell to assure the interchange of data between the mobile terminal and the base station. Uplink is from the mobile users to the base station and downlink is from the base station to the mobile users. Each transmitting terminal employs different resources of the cell. A multiple access scheme is a method used to distinguish among different simultaneous transmissions in a cell. A radio resource can be a different time interval, a frequency interval or a code with a suitable power level.

a) FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

FDMA is a channel access method used in multiple-access protocols as a channelization protocol. FDMA gives users an individual allocation of one or several frequency bands, or channels. Multiple Access systems coordinate access between multiple users.

Key features of FDMA are:

- **FDMA requires high-performing filters in the radio hardware, in contrast to TDMA and CDMA.**
- **FDMA is not vulnerable to the timing problems that TDMA has. Since a predetermined frequency band is available for the entire period of communication, stream data (a continuous flow of data that may not be packetized) can easily be used with FDMA.**
- **Due to the frequency filtering, FDMA is not sensitive to near-far problem which is pronounced for CDMA.**
- **Each user transmits and receives at different frequencies as each user gets a unique frequency slot**
- **It is important to distinguish between FDMA and frequency-division duplexing (FDD). While FDMA allows multiple users simultaneous access to a certain system, FDD refers to how the radio channel is shared between the uplink and downlink (for instance, the traffic going back and forth between a mobile-phone and a base-station).**
- **Furthermore, frequency-division multiplexing (FDM) should not be confused with FDMA. The former is a physical layer technique that combines and transmits low-bandwidth channels through a high-bandwidth channel. FDMA, on the other hand, is an access method in the data link layer.**
- **FDMA also supports demand assignment in addition to fixed assignment. Demand assignment allows all users apparently continuous access of the radio spectrum by assigning carrier frequencies on a temporary basis using a statistical assignment process. The first FDMA demand-assignment system for satellite was developed by COMSAT for use on the Intelsat series IVA and V satellites.**

- **In this scheme, a bandwidth is assigned to an earth station and is divided into n segments to manage the network traffic.**

Advantages of FDMA:

- **Uses existing hardware and hence this technology is cost efficient**
- **Network timing is not required, hence making the system less complex.**
- **No restrictions regarding the type of baseband type of modulation is there.**

Disadvantage of FDMA

- **Inter modulation noise in the transponder leads to interference with other links sharing new spectrum and thus reduces the capacity of satellite.**
- **Flexibility in channel allocation is less (as seen in MCPC, but not in SCPC).**
- **Uplink power control is required to maintain the link quality.**
- **As strong and weak carriers, both are used, weak carriers are often suppressed.**

b) TIME DIVISION MULTIPLE ACCESS (TDMA)

Time division multiple access (TDMA) is a channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. The users transmit in rapid succession, one after the other, each using his own time slot. This allows multiple stations to share the same transmission medium (e.g. radio frequency channel) while using only a part of its channel capacity.

TDMA is a type of Time-division multiplexing, with the special point that instead of having one transmitter connected to one receiver, there are multiple transmitters. In the case of the uplink from a mobile phone to a base station this becomes particularly difficult because the mobile phone can move around and vary the timing advance required to make its transmission match the gap in transmission from its peers.

Features of TDMA

- **Shares single carrier frequency with multiple users**
- **Non-continuous transmission makes handoff simpler**
- **Slots can be assigned on demand in dynamic TDMA**
- **Less stringent power control than CDMA due to reduced intra cell interference**
- **Higher synchronization overhead than CDMA**
- **Advanced equalization may be necessary for high data rates if the channel is "frequency selective" and creates inter-symbol interference**
- **Cell breathing (borrowing resources from adjacent cells) is more complicated than in CDMA**
- **Frequency/slot allocation complexity**
- **Pulsating power envelop: Interference with other devices**
- **For satellite communication TDMA works in the following manner.**
- **TDMA systems are used in commercial satellite applications. The first system type is the classic TDMA implementation employing a single modulated carrier occupying the full transponder's bandwidth.**
- **This system is most common for TDMA networks and is also most efficient from a capacity standards point.**
- **Each user is allocated a specific time slot for transmission due to which overlapping is avoided.**
- **System capacity is increased as only a single carrier is present at any given time.**
- **Disadvantage is that the messages need to be stored, compressed and transmitted during one or more specific time slots. At network level, all transmissions must be synchronized to avoid collision between the bursts.**
- **(Burst: It is a term used in a number of information technology contexts to mean a specific amount of data sent or received in one intermittent time.)**
- **An earth station has a full access to a transponder during its allocated time slot.**
- **Transmissions are in frame format.**
- **On receiving al the bursts, earth station removes the data addresses from it.**
- **Guard time is used to separate time-slots. The time-slot size depends on the traffic requirements.**
- **TDMA also works on demand- assign method.**

Advantages:

- **Here, satellite power utilizations can be maximized as inter modulation noise is minimum.**
- **Uplink power control is not required.**
- **Transmission plans and capacity management is done by the satellite are very flexible.**
- **The digital format of TDMA allows utilization of all advantages of digital techniques.**

Disadvantages

- **It requires a network wide time synchronization which makes the entire system very complex.**
- **Analog of digital conversions are required.**
- **Interface with analog terrestrial plan is expected.**

FDMA & TDMA

- **In situations where connectivity is required between multiple spot beams, then routing of signal to an appropriate beam is done by having frequency-to-beam correspondence.**
- **Sub-bands are made and each of them provides a unique route between two spot beams.**
- **Here transponders can be accessed in FDMA or TDMA mode. As each earth station have to hop between transponders to route the traffic to the desired spot beam this technique is called transponder hopping.**
- **For n spot beams, n2transponders are required.**
- **To make this work, flexibility in altering the frequency bands is required. This is done by using switchable routing method.**
- **In switchable routing method, channels are switched as desired in order to change the available bandwidth of each beam.**
- **A programmable switch located on the satellite router bursts to spot beams according to a set plan.**
- **The earth station can direct its transmission to any spot by transmitting in the appropriate time slot.**

- **Beams are arranged in non-overlapping time-slots.**

c) CODE DIVISION MULTIPLE ACCESS (CDMA)

- **CDMA uses a modulation technique called spread spectrum. Here all the users transmit signals simultaneously on the multiple access schemes.(Spread Spectrum: It refers to a modulation technique that converts the baseband signal to a modulated signal with a spectrum bandwidth that covers or is spread over the band orders of magnitude larger than that normally necessary to transmit the baseband signal itself.)**
- **It could be used as a multiple access system by giving each user a unique pseudo random code rather than a unique carrier frequency or time slot.**
- **All the users contribute to the noise background.**
- **To detect the desired signal in the presence of all the interferences, the composite signal is cross-correlated with the known pseudo random number spreading sequence.**
- **The net performance is improved essentially by the ration of the un-spread signal bandwidth.**

Features of CDMA are:

- **Highly resistant to interferences and thus satellite spacing could be reduced considerably without causing unacceptable degradation in the received signal quality.**
- **Spread spectrum sequences are resistant to multiple noises present in the mobile terminals.**
- **Small antennas can be used without any interference issues from the neighboring**
- **CDMA is a very secure form of communication.**

Implementing CDMA

- **CDMA technique could be implemented in two forms: Direct sequence spread spectrum and Frequency hopping spread spectrum.**
- **The property of pseudo random sequences is used by CDMA.**

i) Pseudo-Random Sequences

- **They are a set of signals which appear ti be a set of random sequences. They are repeated over a time interval, say of Tr.**
- **In order to use such pseudo (false) random sequences signals in digital form, shift registers are required. These shift registers could be used for maximum length of code of the value p=(2m-1),where m-bit register is used.**
- **This is also called maximum length linear shift register sequence.**
- **These sequences have 2m-1 ones and 2m-1-1zeros that are places randomly, thus making the entire sequence look random.**

ii) Direct Sequence Spread Spectrum (DSSS)

- **Definition: Direct sequence spread spectrum is a modulation technique where the transmitted signal takes up more bandwidth then the information signal that is being modulated.**
- **Direct sequence spread spectrum transmissions multiply the data being transmitted by a „noise" signal.**
- **The noise signal is the pseudo random sequence and has a frequency much higher than that of the original signal. It thus spreads the energy of the original signal into a much wider band**
- **The resultant signal appears like noise which could be reconstructed to the original signal at the receiving end by multiplying it by the same pseudo random sequence. This process is known as de-spreading. For de-spreading to work correctly, the transmitter and receiver must be synchronized.**
- **Sometimes while sending the signal from the transmitter"s end, other noises like inter modulation noise and thermal noise are transmitted to the receiver. This is also called as narrow-band interference.**
- **The receiving signal is given as:**
- **Rx (t) = C1 (t) + C2 (t) + …. + Cn (t) Where: Cn (t) is the received signal from the nth transmitter n (t) is the system noise**

iii) Frequency Hopping Spread Spectrum (FHSS)

- **It is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using the pseudo random sequences (which are known to both transmitter and receiver).**

- **Frequency hopping spread spectrum offers three main advantages over fixed frequency transmission techniques:**
    - **Spread spectrum signals are highly resistant to narrow band interferences. The process of re-collecting a spread signal spreads out the interfering signal, causing t to recede into the background.**
    - **Spread spectrum signals are difficult to intercept. Frequency hopping spread spectrum signals simply appears as an increase in the background noise to a narrow band receiver.**
    - **Spread spectrum transmission can share a frequency band with many types of conventional transmissions with minimal interference.**
- **Interference in frequency hopping spread spectrum is caused at instants when an unwanted signal appears within the pass band of the desired signal. It can occur under following conditions:**

i) Transmission of other users of multiple-access channel falls within the range of receiver"s pass band.

ii) Inter modulation noise can be generated due to non-linearities of receiver"s channels.

ii) Interference is noise like when hopping rate is much higher than the information rate. Interference is coherent when hopping rate is smaller than the information rate.

3.7 Satellite Communication Systems

Communication satellites are not originators of information to be transmitted. Instead, these satellites are relay stations for earth sources.

If a transmitting station cannot communicate directly with one or more receiving stations because of line-of-sight restrictions, a satellite can be used. The transmitting station sends the information to the satellite, which in turn retransmits it to the receiving stations. The satellite in this application is what is generally known as a repeater.

Repeaters

- **An earth station transmits information to the satellite. The satellite contains a receiver that picks up the transmitted signal, amplii es it, and translates it on another frequency. The signal on the new frequency is then retransmitted to the receiving stations on earth.**
- **The original signal being transmitted from the earth station to the satellite is called the uplink,**
- **And the retransmitted signal from the satellite to the receiving stations is called the downlink.**
- **Usually the downlink frequency is lower than the uplink frequency.**
- **A typical uplink frequency is 6 GHz, and a common downlink frequency is 4 GHz.**

Transponders

- **The transmitter-receiver combination in the satellite is known as a transponder**
- **The basic functions of a transponder are amplification and frequency translation**
- **The reason for frequency translation is that the transponder cannot transmit and receive on the same frequency**
- **The transmitter's strong signal would overload, or "desensitize," the receiver and block out the very small uplink signal, thereby prohibiting any communication**
- **Widely spaced transmit and receive frequencies prevent interference**

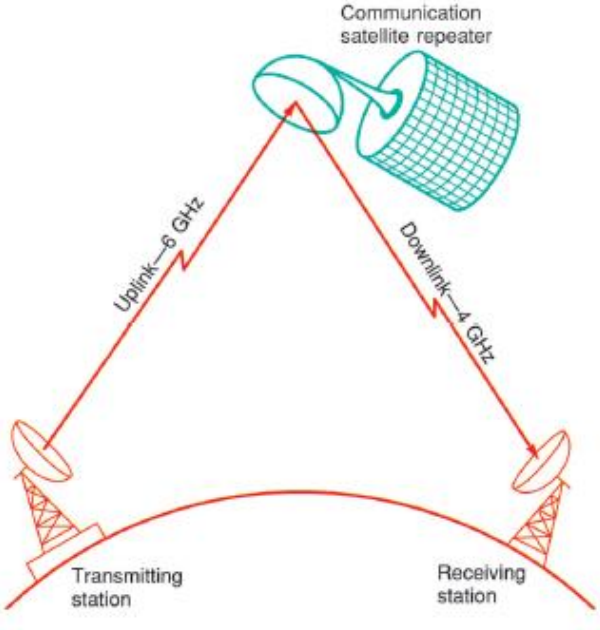

Figure 3.11 Using a Satellite as a microwave relay link

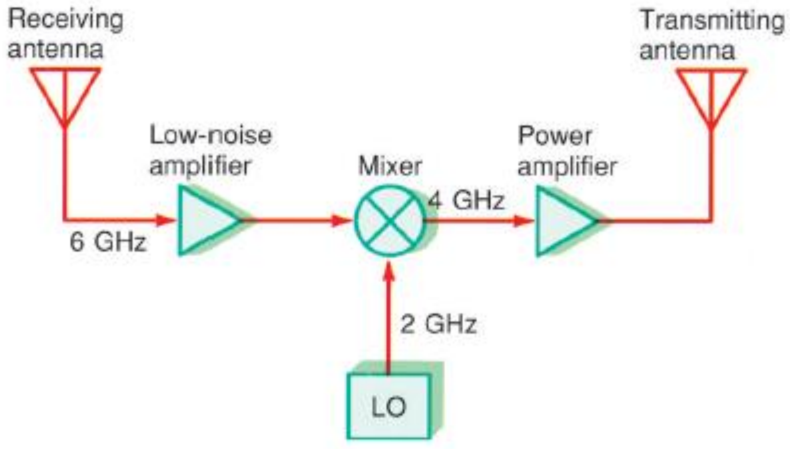

Figure 3.12 Satellite transponder

- **Although the typical transponder has a wide bandwidth, it is used with only one uplink or downlink signal to minimize interference and improve communication reliability.**
- **To be economically feasible, a satellite must be capable of handling several channels. As a result, most satellites contain multiple transponders, each operating at a different frequency.**
- **For example, a communication satellite may have 24 channels, 12 vertically polarized and 12 horizontally polarized. Each transponder represents an individual communication channel.**
- **Various multiple-access schemes are used so that each channel can carry multiple information transmissions.**

SPECTRUM USAGE

Frequency Allocations

- **Most communication satellites operate in the microwave frequency spectrum.**
- **Many military satellites operate in the 200- to 400-VHF/UHF range. Also, the amateur radio OSCAR**
- **Satellites operate in the VHF/UHF range.**
- **VHF, UHF, and microwave signals penetrate the ionosphere with little or no attenuation and are not refracted to earth, as are lower frequency signals in the 3- to 30-MHz range.**

- **Most widely used satellite communication bands is the C band. The uplink frequencies are 5.925 to 6.425 GHz. In any general discussion of the C band, the uplink is generally said to be 6 GHz. The downlink is in the 3.7- to 4.2-GHz range. But again, in any general discussion of the C band, the downlink is nominally said to be 4 GHz. Occasionally, the C band is referred to by the designation 6/4 GHz**
- **Currently, the Ku band is receiving the most attention. The uplinks are in the 14- to 14.5-GHz range, and the downlinks are from 11.7 to 12.2 GHz. You will see the Ku band designated as 14/12 GHz.**
- **Use of the Ka band is also increasing. Most new communication satellites will operate in the Ku band**
- **Two other bands of interest are the X and L bands. The military uses the X band for its satellites and radar. The L band is used for navigation as well as marine and aeronautical communication and radar.**
- **Numerous techniques have been developed to effectively increase the bandwidth and signal-carrying capacity of the satellite. Two of these techniques are known as frequency reuse and spatial isolation.**

Frequency Reuse.

One system for effectively doubling the bandwidth and information carrying capacity of a satellite is known as frequency reuse.

- **When an allocated frequency band is filled, additional capacity can be achieved by reuse of the frequency spectrum. By increasing the size of an antenna (i.e.. increasing the antenna gain) the beamwidth of the antenna is also reduced. Thus different beams of the same frequency can be directed to different geographical areas of the earth. This is called frequency reuse.**
- **In this system, a communication satellite is provided with two identical sets of 12 transponders. The first channel in one transponder operates on the same channel as the first transponder in the other set, and so on. The two systems, although operating on exactly the same frequencies, are isolated from each other by the use of special antenna techniques.**
- **One technique for keeping transmissions separate is to use different antenna polarizations.**

- **For example, a vertically polarized antenna will not respond to a horizontally polarized signal and vice versa. Or a left-hand circularly polarized (LHCP) antenna will not respond to a right-hand circularly polarized (RHCP) signal and vice versa.**
- **Another technique is to use spatial isolation. By using narrow beam or spot beam antennas, the area on the earth covered by the satellite can be divided up into smaller segments. Earth stations in each segment may actually use the same frequency, but because of the very narrow beam widths of the antennas, there is no interference between adjacent segments. This technique is referred to a spatial-division multiple access (SDMA) in that access to the satellite depends on location and not frequency.**

3.8 Satellite Subsystems

- **All satellite communication systems consist of two basic parts, the satellite or spacecraft and two or more earth stations.**
- **The satellite performs the function of a radio repeater or relay station.**
- **Two or more earth stations may communicate with one another through the satellite rather than directly point-to-point on the earth.**

1. **communication subsystem -The heart of a communication satellite**
2. **The following are essential to the self-sustaining nature of the satellite.**
3. **The power subsystem**
4. **The telemetry tracking and command subsystems**
5. **The antenna subsytem**
6. **The propulsion subsystem**
7. **The attitude stabilization subsystems.**

- **The solar panels supply the electric power for the spacecraft. They drive regulators that distribute dc power to all other subsystems. And they charge the batteries that operate the satellite during eclipse periods. And ac-to-dc converters and dc-to-ac inverters are used to supply special voltages to some subsystems.**

Total power capability runs from a few hundred watts in the smaller units to several kilowatts in the largest systems.

- **The communication subsystem consists of multiple transponders. These receive the uplink signals, amplify them, translate them in frequency, and amplify them again for retransmission as downlink signals. A transponder is a repeater that implements a wideband communication channel that can carry many simultaneous communication transmissions. The transponders share an antenna subsystem for both reception and transmission**
- **The telemetry, tracking, and command (TT&C) subsystem monitors onboard conditions such as temperature and battery voltage and transmits this data back to a ground station for analysis. The ground station may then issue orders to the satellite by transmitting a signal to the command subsystem, which then is used to control many spacecraft functions such as i ring the jet thrusters.**
- **The jet thrusters and the apogee kick motor (AKM) are part of the propulsion subsystem. They are controlled by commands from the ground.**
- **The attitude control subsystem provides stabilization in orbit and senses changes in orientation. It fires the jet thrusters to perform attitude adjustment and station-keeping maneuvers that keep the satellite in its assigned orbital position.**

3.8.1 Communication Subsystems

- **Main payload on a communication satellite**
- **It performs the function of a repeater or space relay station**
- **An earth station takes the signals to be transmitted, known as baseband signals, voice, video, and computer data. and modulates a microwave carrier.**

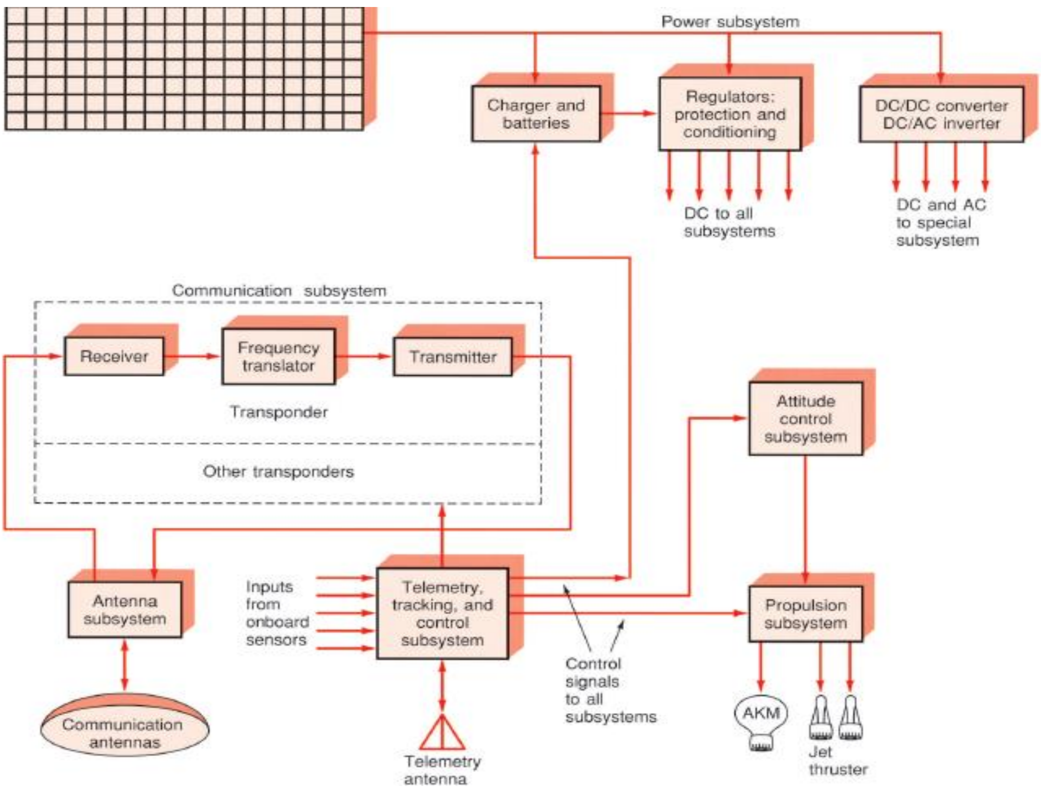

Figure 3.13 General block diagram of a communication satellite

- **transponder :where uplink signals are then amplified, translated in frequency, and retransmitted on the downlink to one or more earth stations.(rejuvenate the uplink signal and retransmit it over the downlink)**
- **Most modern communication satellites contain at least 12 transponders. More advanced satellites contain many more**
- **The receiver and transmitter in the satellite transponder are designed to operate at separate frequencies. In this way, they will not interfere with each other. The frequency spacing is made as wide as practical to minimize the effect of the transmitter desensitizing the receiver.**
- **These transponders operate in the microwave frequency range.**
- **Three basic transponder configurations are used in communication satellites.**
- **A single-conversion transponder uses a single mixer to translate the uplink signal to the downlink frequency.**
- **A dual-conversion transponder makes the frequency translation in two steps with two mixers. No demodulation occurs.**

- **A regenerative repeater demodulates the uplink signal after the frequency is translated to some lower intermediate frequency. The recovered baseband signal is then used to modulate the downlink signal**

Multichannel Configurations.

Virtually all modern communication satellites contain multiple transponders. This permits many more signals to be received and transmitted. There are two basic multichannel architectures in use in communication satellites.

1.Broadband System

2.The Fully channelized system

1.1 Broadband System

- **A typical communication satellite spectrum is 500 MHz wide. This is typically divided into 12 separate channels, each with a bandwidth of 36 MHz. The center frequency spacing between adjacent channels is 40 MHz, thereby providing a 4-MHz spacing between channels to minimize adjacent channel interference**
- **A wideband repeater (Fig.) is designed to receive any signal transmitted within the 500-MHz total bandwidth.**
- **The receive antenna is connected to a low-noise amplifier (LNA) as in every transponder.**
- **Very wideband tuned circuits are used so that the entire 500-MHz bandwidth is received and amplified.**
- **A low-noise amplifier, usually a GaAs FET, provides gain.**
- **A mixer translates all incoming signals to their equivalent lower downlink frequencies.**
- **In a C-band communication satellite, the incoming signals are located between 5.925 and 6.425 MHz.**
- **A local oscillator operating at the frequency of 2.225 GHz is used to translate the inputs to the 3.7- to 4.2-GHz range.**
- **A wideband amplifier following the mixer amplifies this entire spectrum**

1.2 Channelization Process

- The channelization process occurs in the remainder of the transponder. To achieve the high power levels, the channelization process is used.
- For example, in a 12-channel satellite, 12 bandpass filters, each centered on one of the 12 channels, are used to separate all the various received signals.
- Fig. shows the 12 basic channels with their center frequencies, each having a bandwidth of 36 MHz. The bandpass filters separate out the unwanted mixer output signals and retain only the difference signals.
- Then individual high-power amplifiers (HPAs) are used to increase the signal level.
- The high-power amplifiers in most transponders are traveling-wave tubes that inherently have limited bandwidth. They operate well over a small range but cannot deal with the entire 500-MHz bandwidth allocated to a satellite.

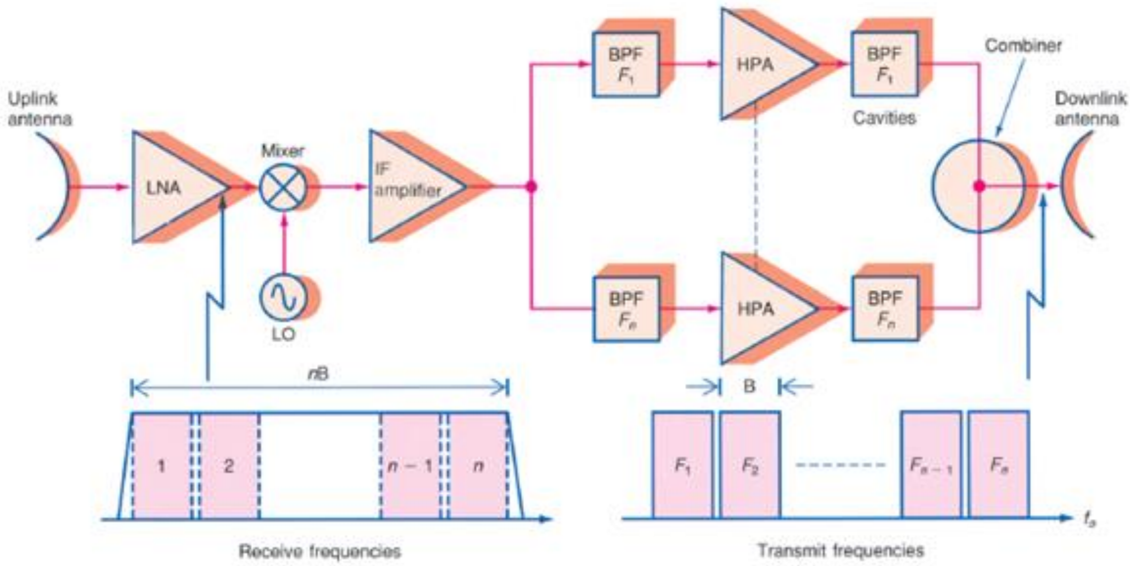

Figure 3.14 A broadband multiple-channel repeater

3.8.2 Power Subsystem

- Today virtually every satellite uses solar panels for its basic power source.
- Solar panels are large arrays of photocells connected in various series and parallel circuits to create a powerful source of direct current.

- **Early solar panels could generate hundreds of watts of power. Today huge solar panels are capable of generating many kilowatts.**
- **A key requirement is that the solar panels always be pointed toward the sun.**
- **Solar panels generate a direct current that is used to operate the various components of the satellite.**
- **However, the dc power is typically used to charge secondary batteries that act as a buffer. When a satellite goes into an eclipse or when the solar panels are not properly positioned, the batteries take over temporarily and keep the satellite operating**
- **Special dc-to-dc converters are used to translate the lower dc voltage of the solar panels to the**
- **higher dc voltage required by the TWTs.**
- **Manipulated with various controls to ensure that they are correctly oriented with respect to the sun**

3.8.3 Telemetry, Command, and Control Subsystems

All satellites have a telemetry, command, and control (TC&C) subsystem that allows a ground station to monitor and control conditions in the satellite

The telemetry system:

- **Report the status of the onboard subsystems to the ground station**
- **Typically consists of various electronic sensors for measuring temperatures, radiation levels, power supply voltages, and other key operating characteristics**
- **Both analog and digital sensors may be used. The sensors are selected by a multiplexer and then converted to a digital signal, which then modulates an internal transmitter**
- **This transmitter sends the telemetry information back to the earth station, where it is recorded and monitored.**
- **With this information, the ground station then determines the operational status of the satellite at all times**

A command and control system:

- **Permits the ground station to control the satellite**
- **Typically, the satellite contains a command receiver that receives control signals from an earth station transmitter**
- **The control signals are made up of various digital codes that tell the satellite what to do**
- **Various commands may initiate a telemetry sequence, activate thrusters for attitude correction, reorient an antenna, or perform other operations as required by the special equipment specific to the mission. Usually, the control signals are processed by an onboard computer**
- **Most satellites contain a small digital computer, usually microprocessor-based, that acts as a central control unit for the entire satellite**

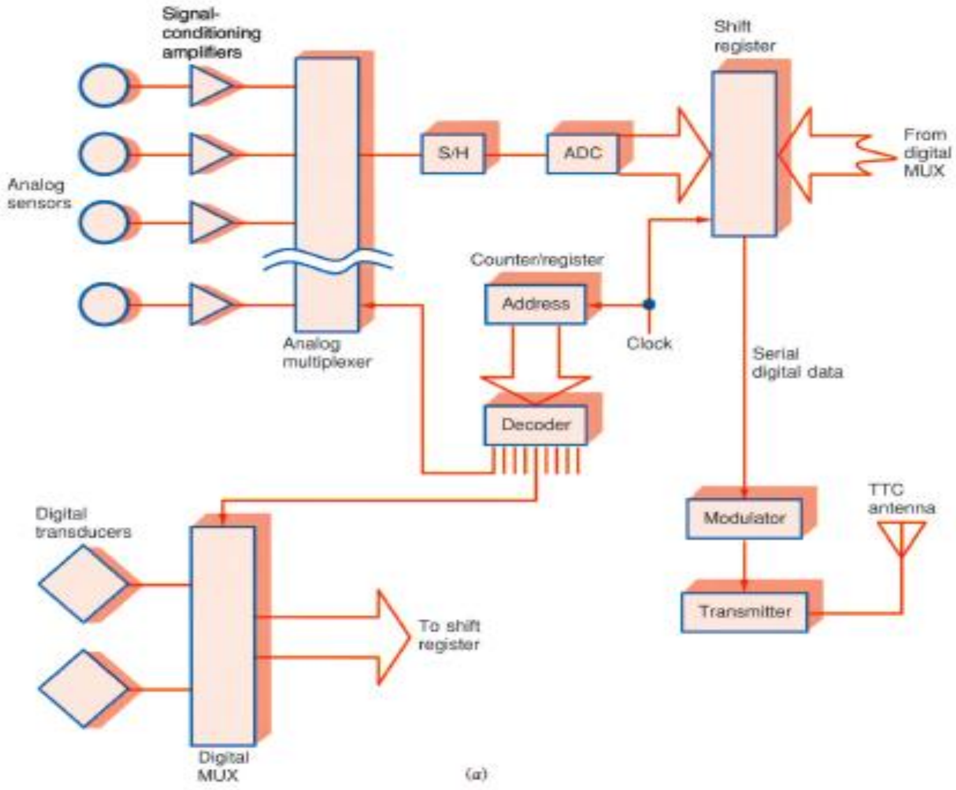

Figure 3.15 General block diagram of a satellite telemetry unit

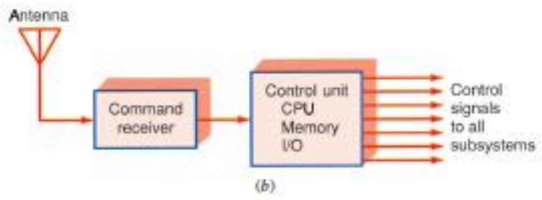

Figure 3.16 The command receiver and controller

3.8.4 Applications Subsystems

- **The applications subsystem is made up of the special components that enable the satellite to fulfill its intended purpose.**
- **For a communication satellite, this subsystem is made up of the transponders.**
- **An observation satellite such as those used for intelligence gathering or weather monitoring may use TV cameras or infrared sensors to pick up various conditions on earth and in the atmosphere. This information is then transmitted back to earth by a special transmitter designed for this purpose.**
- **The Global Positioning System (GPS) for satellites is an example of a subsystem, the application payload for which is used for navigation.**

1.9 Ground Stations

- **The ground station, or earth station, is the terrestrial base of the system**
- **The ground station communicates with the satellite to carry out the designated mission**
- **The earth station may be located at the end user's facilities or may be located remotely with ground-based intercommunication links between the earth station and the end user**
- **Like the satellite, the earth station is made up of a number of different subsystems**
    1. **The antenna subsystem**
    2. **The receive subsystem**
    3. **The transmit subsystem**
    4. **The ground control equipment (GCE) subsystem**
    5. **The power subsystem**

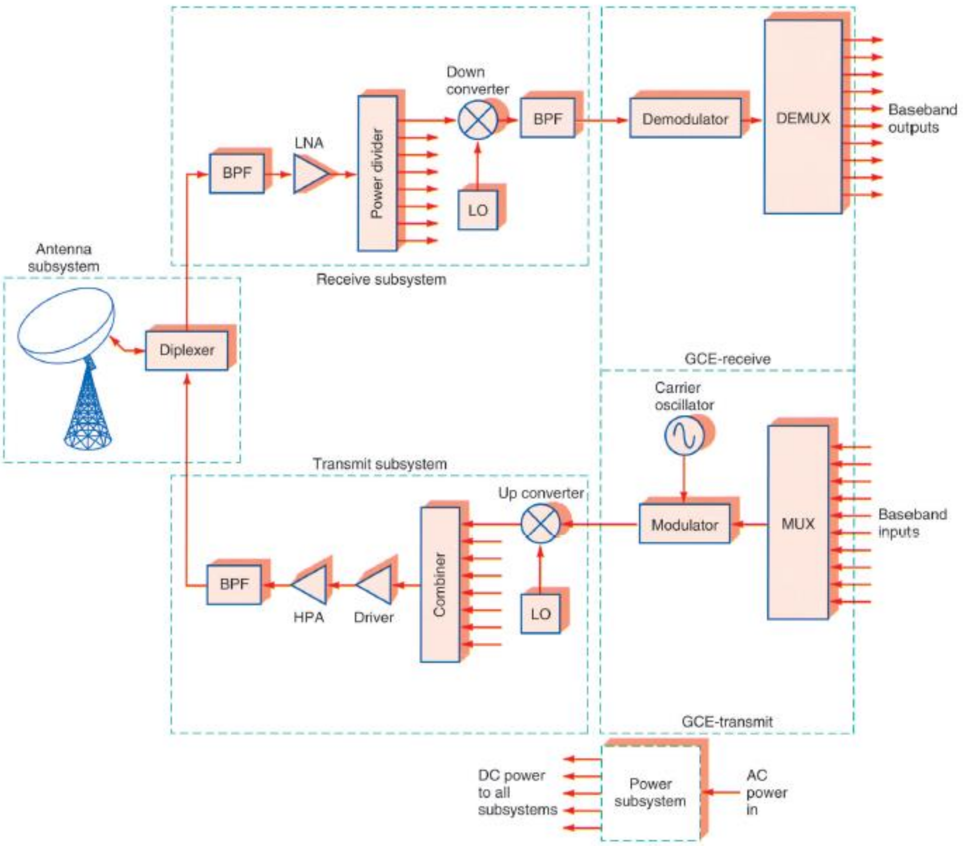

Figure 3.17 General block diagram of an earth station

3.9.1 Antenna Subsystems

- **All earth stations have a relatively large parabolic dish antenna that is used for sending and receiving signals to and from the satellite**
- **Early satellite systems, Huge high-gain antennas were required to pick up minute signals from the satellite. The earth station dishes were 80 to 100 ft or more in diameter. Antennas of this size are still used in some satellite systems today, and even larger antennas have been used for deep-space probes**
- **Modern satellites now transmit with much more power. Advances have also been made in receiver components and circuitry**
- **For that reason, smaller earth station antennas are now practical. In some applications, antennas having as small as 18-in diameter can be used**
- **The antenna in an earth station must be possible to adjust its azimuth and elevation so that the antenna can be properly aligned with the satellite. Earth stations supporting geosynchronous satellites can generally be fixed in position,**

however. Azimuth and elevation adjustments are necessary to initially pinpoint the satellite and to permit minor adjustments over the satellite's life

3.9.2 Receive Subsystems

The downlink is the receive subsystem of the earth station

Receiver Circuits.

- **The receive subsystem consists of the LNA, down converters, and related components.**
- **The purpose of the receive subsystem is to amplify the downlink satellite signal and translate it to a suitable intermediate frequency. From that point, the IF signal is demodulated and demultiplexed as necessary to generate the original baseband signals.**
- **Fig. (a) shows a typical dual-conversion down converter.**
- **The input bandpass filter passes the entire 500-MHz satellite signal. This is fed to a mixer along with a local oscillator.**
- **The output of the mixer is an IF signal, usually 770 MHz. This is passed through a bandpass filter at that frequency with a bandwidth of 36 MHz.**
- **The signal is then applied to another mixer. When combined with the local-oscillator frequency, the mixer output is the standard 70-MHz IF value. An IF of 140 MHz is used in some systems.**
- **A 36-MHz-wide bandpass filter positioned after the mixer passes the desired channel.**
- **In dual-conversion down converters, two different tuning or channel selection arrangements are used. One is referred to as RF tuning, and the other is referred to as IF tuning.**
- **In RF tuning, shown in Fig.(a), the first local oscillator is made adjustable while the second oscillator is fixed**
- **In IF tuning, shown in Fig.(b), the second local oscillator is made adjustable while the first oscillator is fixed**

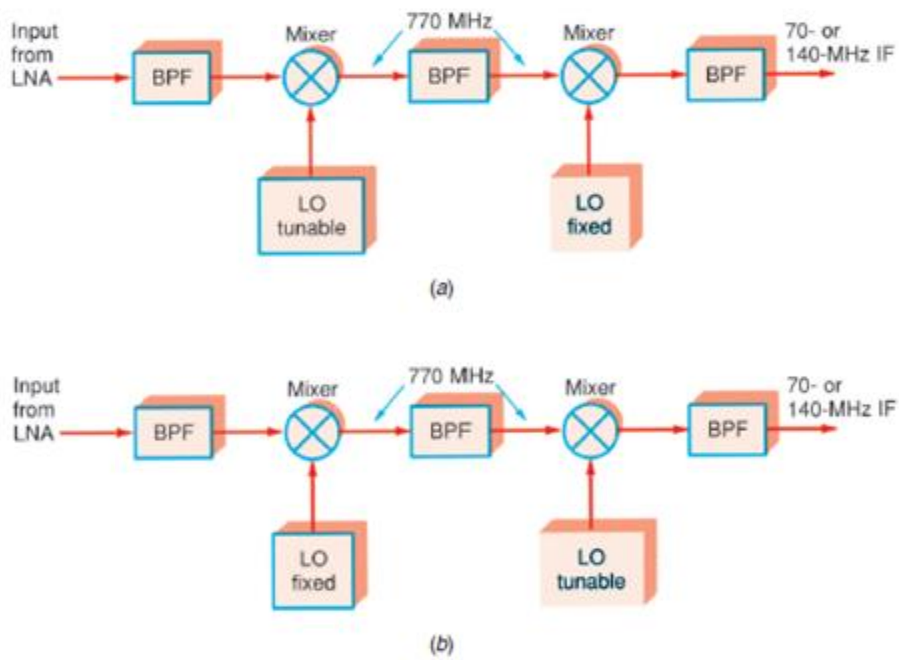

Figure 3.18 Dual-conversion down converters (a) RF tuning (b) IF tuning

Receiver Ground Control Equipment.

- **The receiver ground control equipment (GCE) consists of one or more racks of equipment used for demodulating and demultiplexing the received signals.**
- **The down converters provide initial channelization by transponder, and the demodulators and demultiplexing equipment process the 70-MHz IF signal into the original baseband signals**
- **The outputs from the down converters are interconnected via coaxial cables to the demodulators.**
- **Many identical demodulators are provided that demodulate the IF signal.**
- **In FDM systems, each demodulator is an FM detector. The most commonly used type is the phase-locked loop discriminator.**
- **Equalization and deemphasis are also taken care of in the demodulator.**
- **In systems using TDM, the demodulators are typically used to detect four-phase, or quadrature, PSK at 60 or 120 Mbps. The IF is usually at 140 MHz.**

3.9.3 Transmitter Subsystems

- **The uplink is the transmitting subsystem of the earth station.**
- **It consists of all the electronic equipment that takes the signal to be transmitted, amplifies it(TWT), and sends it to the antenna.**

- **The transmit subsystem consists of two basic parts, the up converters and the power amplifiers.**
- **The up converters translate the baseband signals modulated on to carriers upto the final uplink microwave frequencies.**
- **The power amplifiers generate the high-power signals that are applied to the antenna.**
- **The modulated carriers are created in the transmit GCE.**

Transmit Ground Control Equipment.

- **The transmit subsystem begins with the baseband signals. These are first fed to a multiplexer, if multiple signals are to be carried by a single transponder**
- **Frequency- or time-division multiplexers are used to assemble the composite signal. The multiplexer output is then fed to a modulator.**
- **In analog systems, a wideband frequency modulator is normally used. It operates at a carrier frequency of 70 MHz with a maximum deviation of +/-18 M Hz.**
- **Video signals are fed directly to the modulator; they are not multiplexed.**
- **In digital systems, analog signals are first digitized with PCM converters. The resulting serial digital output is then used to modulate a QPSK modulator.**

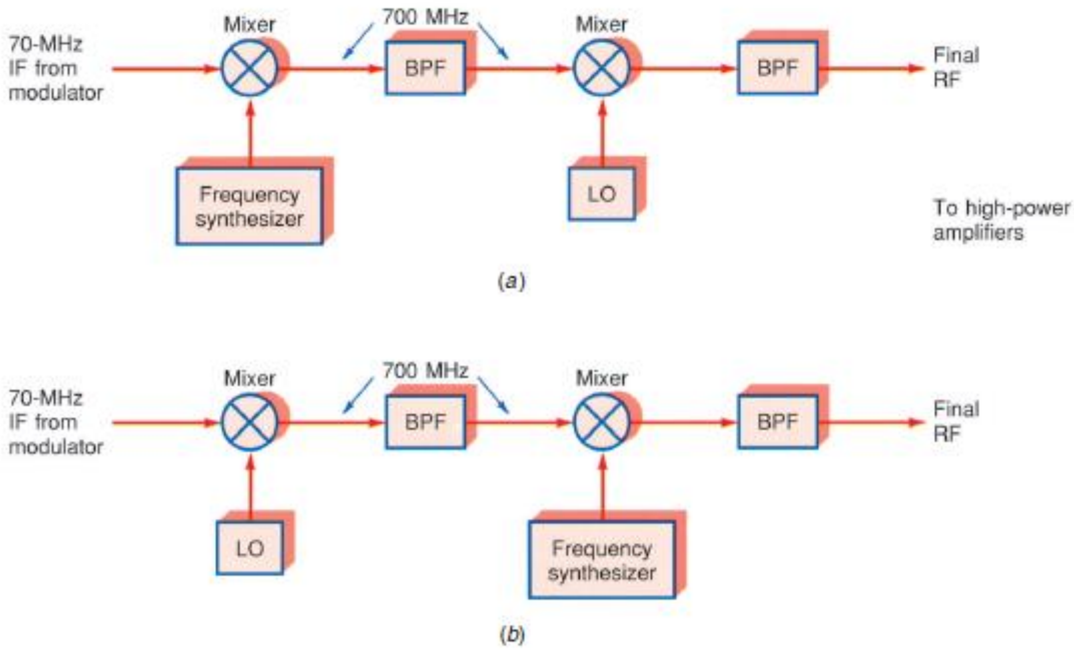

Figure 3.19 Typical up converter circuits (a) IF tuning (b) RF tuning

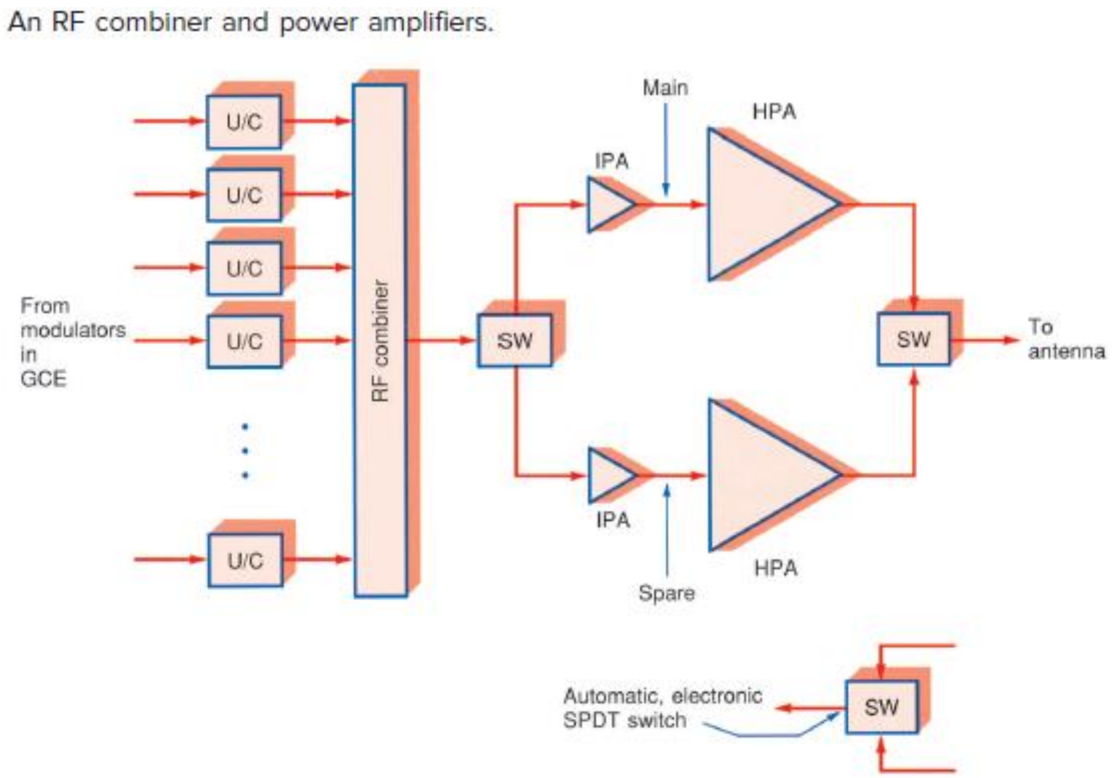

Figure 3.20 RF combiner and power amplifiers

- **In most systems, however, individual up converters are used on each modulated channel. At the output of the up converters, all the signals are combined in a microwave combiner, which produces a single output signal that is fed to the signal amplifiers. This arrangement is illustrated in above Fig. 3.20**
- **The final combined signal to be transmitted to the satellite appears at the output of the RF combiner. But it must first be amplified considerably before being sent to the antenna. This is done by the power amplifier.**
- **The power amplifier usually begins with an initial stage called the intermediate-power amplifier (IPA). This provides sufficient drive to the final high-power amplifier (HPA).**
- **Three types of power amplifiers are used in earth stations: transistor, traveling-wavetube (TWT), and klystron.**
- **Transistor power amplifiers are used in small and medium earth stations with low power. Powers up to 50 W are common.**
- **Most medium- and high-power earth stations use either TWTs or klystrons for the power amplifiers**

3.9.4 Power Subsystems

- **Most earth stations receive their power from the normal ac mains.**
- **Standard power supplies convert the ac power to the dc voltages required to operate all subsystems.**
- **This subsystem operates power supplies that distribute a variety of dc voltages to the other equipment However, most earth stations have backup power supplies.**
- **Smaller systems may use uninterruptible power supplies (UPS), which derive their main power from batteries.**
- **Large battery arrays drive dc-to-ac inverters that produce the ac voltages for the system.**

3.9.5 Telemetry and Control Subsystems

- **The telemetry equipment consists of a receiver and the recorders and indicators that display the telemetry signals.**
- **The signal may be received by the main antenna or a separate telemetry antenna.**
- **A separate receiver on a frequency different from that of the communication channels is used for telemetry purposes.**
- **The telemetry signals from the various sensors and transducers in the satellite are multiplexed onto a single carrier and are sent to the earth station.**
- **The earth station receiver demodulates and demultiplexes the telemetry signals into the individual outputs.**
- **These are then recorded and sent to various indicators, such as strip chart recorders, meters, and digital displays.**
- **Signals may be in digital form or converted to digital. They can be sent to a computer where they can be further processed and stored.**
- **The control subsystem permits the ground station to control the satellite. This system usually contains a computer for entering the commands that modulate a carrier that is amplified and fed to the main antenna.**

- **The command signals can make adjustments in the satellite attitude, turn transponders off and on, actuate redundant circuits if the circuits they are backing up fail, and so on.**
- **The instrumentation subsystem is in effect an extension of the telemetry system. Besides relaying information about the satellite itself, the telemetry system may be used to send back information related to various scientific experiments being conducted on the satellite**

3.9.6 Very Small-Aperture Terminal

- **A very small-aperture terminal (VSAT) is a miniature low-cost satellite ground station.**
- **In the past, most ground stations were large and expensive. But over the years, semiconductor and other technology breakthroughs have greatly reduced the size and cost of ground stations.**
- **The VSAT is one result. These units are extremely small and mount on the top or side of a building and in some versions even fit into a suitcase.**
- **A VSAT is a full receive-transmit earth station. Receive-only (RO) VSATs are also available for special applications such as digital video broadcasts (DVBs).**
- **The most common application of VSATs today is in connecting many remote company or organization sites to a main computer system. For example, most gas stations and retail stores use VSATs as point-of-sale (PoS) terminals to transmit sales transaction information to the home office, check customer credit cards, and relay inventory data.**
- **Companies such as Shell, Wal-Mart, and Barnes & Noble all use VSATs.**
- **Most stores that sell lottery tickets use a VSAT as do most tollbooths using SpeedPass and other radio-frequency identification (RFID) of vehicles for tolls.**
- **Broadcast companies like Fox, CNN, ABC, CBS, NBC, and others use VSATs for remote news gathering and reporting.**
- **A good example of a RO VSAT is the settop box receiver used by consumers for Direct Broadcast Satellite (DBS) TV reception.**

3.10 Satellite Stabilization

Satellite Stabilization

The satellite once placed in its orbit, experiences various perturbing torques. These include gravitational forces from other bodies like solar and lunar attraction, magnetic field interaction, solar radiation pressure, etc. Due to these factors, the satellite orbit tends to drift and its orientation also changes. The satellite's position thus needs to be controlled both in the east-west as well as the north-south directions. The east-west location needs to be maintained to prevent radio frequency (RF) interference from neighboring satellites. It may be mentioned here that in the case of a geostationary satellite, a 10 drift in the east or west direction is equivalent to a drift of about 735 km along the orbit. The north-south orientation has to be maintained to have proper satellite inclination. The attitude and orbit control system maintains the satellite position and its orientation and keeps the antenna correctly pointed in the desired direction. The orbit control is performed by firing thrusters in the desired direction or by releasing a jet of gas. It is also referred to as station keeping.

Commonly employed techniques for satellite attitude control include:

1. Spin stabilization

2. Three-axis or body stabilization

Spin Stabilization

With spin stabilization, the entire spacecraft rotates around its own vertical axis, spinning like a top. This keeps the spacecraft's orientation in space under control. The advantage of spin stabilization is that it is a very simple way to keep the spacecraft pointed in a certain direction. The spinning spacecraft resists perturbing forces, which tend to be small in space, just like a gyroscope or a top

In a spin-stabilized satellite, the satellite body is spun at a rate between 30 and 100 rpm about an axis perpendicular to the orbital plane. Like a spinning top, the rotating body offers inertial stiffness, which prevents the satellite from drifting from its desired orientation. Spin-stabilized satellites are generally cylindrical in shape. For stability, the satellite should be spun about its major axis, having a maximum moment of inertia. To

maintain stability, the moment of inertia about the desired spin axis should at least be 10 % greater than the moment of inertia about the transverse axis.

A disadvantage to this type of stabilization is that the satellite cannot use large solar arrays to obtain power from the Sun. Thus, it requires large amounts of battery power. Another disadvantage of spin stabilization is that the instruments or antennas also must perform “despin” maneuvers so that antennas or optical instruments point at their desired targets. Spin stabilization was used for NASA's Pioneer 10 and 11 spacecraft, the Lunar Prospector, and the Galileo Jupiter orbiter.

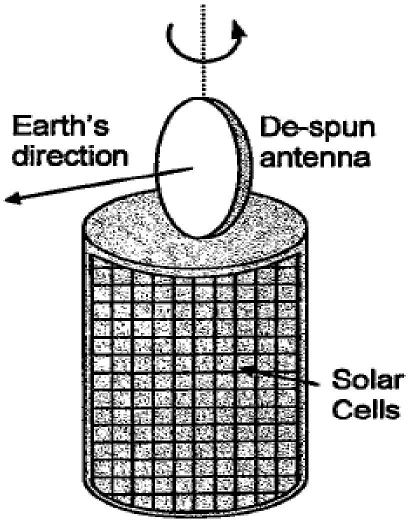

Figure 3.21 Spin stabilization

There are two types of spinning configurations employed in spin-stabilized satellites. These include the simple spinner configuration and the dual spinner configuration. In the simple spinner configuration, the satellite payload and other subsystems are placed in the spinning section, while the antenna and the feed are placed in the de-spun platform. The de-spun platform is spun in a direction opposite to that of the spinning satellite body. In the dual spinner configuration, the entire payload along with the antenna and the feed is placed on the de-spun platform and the other subsystems are located on the spinning body. In both configurations, solar cells are mounted on the cylindrical body of the satellite.

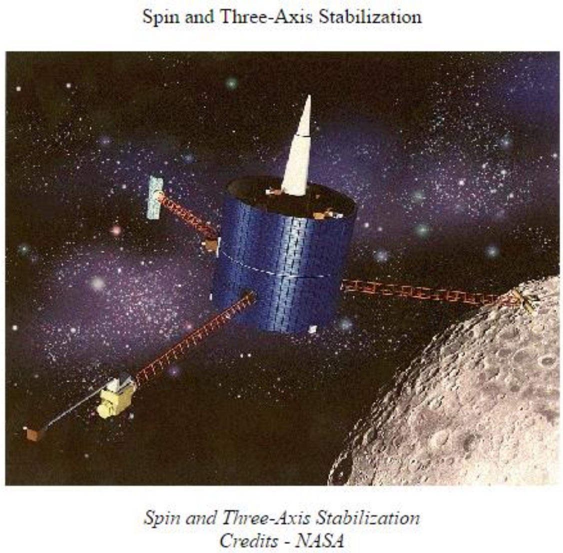

Figure 3.22 Satellite

Three-axis or Body Stabilization:

In the case of three-axis stabilization, also known as body stabilization, the stabilization is achieved by controlling the movement of the satellite along the three axes, i.e. yaw, pitch and roll, with respect to a reference. The system uses reaction wheels or momentum wheels to correct orbit perturbations. The stability of the three-axis system is provided by the active control system, which applies small corrective forces on the wheels to correct the undesirable changes in the satellite orbit.

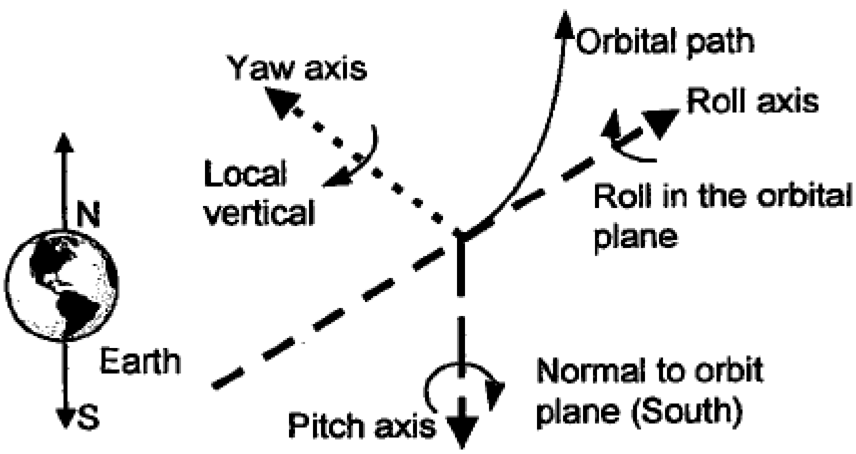

Figure 3.23 Three-axis stabilization

Most three-axis stabilized satellites use momentum wheels. The basic control technique used here is to speed up or slow down the momentum wheel depending upon

the direction in which the satellite is perturbed. The satellite rotates in a direction opposite to that of speed change of the wheel. For example, an increase in speed of the wheel in the clockwise direction will make the satellite rotate in a counterclockwise direction. The momentum wheels rotate in one direction and can be twisted by a gimbal motor to provide the required dynamic force on the satellite.

An alternative approach is to use reaction wheels. Three reaction wheels are used, one for each axis. They can be rotated in either direction depending upon the active correction force. The satellite body is generally box shaped for three-axis stabilized satellites. Antennae are mounted on the Earth-facing side and on the lateral sides adjacent to it. These satellites use flat solar panels mounted above and below the satellite body in such a way that they always point towards the sun, which is an obvious requirement.

An advantage of 3-axis stabilization is that optical instruments and antennas can point at desired targets without having to perform "despin" maneuvers.

Comparison between Spin-stabilized and Three-axis Stabilized Satellites

1. In comparison to spin-stabilized satellites, three-axis stabilized satellites have more power generation capability and more additional mounting area available for complex antennae structures.

2. Spin-stabilized satellites are simpler in design and less expensive than three-axis stabilized satellites.

3. Three-axis stabilized satellites have the disadvantage that the extendible solar array used in these satellites is unable to provide power when the satellite is in the transfer orbit. As the array is still stored inside the satellite during this time.

Station Keeping

Station keeping is the process of maintenance of the satellite's orbit against different factors that can cause temporal drift. Satellites need to have their orbits adjusted from time to time because the satellite, even though initially placed in the correct orbit, can undergo a progressive drift due to some natural forces such as minor

gravitational perturbations due to the sun and moon, solar radiation pressure, Earth being an imperfect sphere, etc. The orbital adjustments are usually made by releasing jets of gas or by firing small rockets tied to the body of the satellite. In the case of spin-stabilized satellites, station keeping in the north-south direction is maintained by firing thrusters parallel to the spin axis in a continuous mode. The east-west station keeping is obtained by firing thruster's perpendicular to the spin axis. In the case of three-axis stabilization, station keeping is achieved by firing thrusters in the east-west or the north-south direction in a continuous mode.

3.11 Noise in satellite system

Equivalent Isotropic Radiated Power

A key parameter in link budget calculations is the equivalent isotropic radiated power, conventionally denoted as EIRP. The Maximum power flux density at some distance r from a transmitting antenna of gain G is

$$\psi_M = \frac{GP_S}{4\pi r^2}$$

An isotropic radiator with an input power equal to GPS would produce the same flux density. Hence this product is referred to as the equivalent isotropic radiated power, or

$$EIRP = GP_S$$

EIRP is often expressed in decibels relative to one watt, or dBW. Let PS be in watts; then

$$[EIRP] = [P_S] + [G]\ dBW$$

where [PS] is also in dBW and [G] is in dB.

The isotropic gain for a paraboloidal antenna is

$$G = \eta(10.472 fD)^2$$

Where,
f is the carrier frequency
D is the reflector diameter
n is the aperture efficiency

The Link-Power Budget Estimation

Losses for clear sky conditions are

$$[LOSSES] = [FSL] + [RFL] + [AML] + [AA] + [PL]$$

The decibel equation for the received power is

$$[P_R] = [EIRP] + [G_R] - [LOSSES]$$

where

[PR] = received power, dBW

[EIRP] = equivalent isotropic radiated power, dBW

[FSL] = free-space spreading loss, dB
[RFL] = receiver feeder loss, dB
[AML] = antenna misalignment loss, dB
[AA] = atmospheric absorption loss, dB
[PL] = polarization mismatch loss, dB

System Noise

The major source of electrical noise in equipment is from the random thermal motion of electrons in various resistive and active devices in the receiver.

Thermal noise is also generated in the lossy components of antennas, and thermal-like noise is picked up by the antennas as radiation.

The available noise power from a thermal noise source is given by

$$P_N = kT_N B_N$$

Where

T_N = equivalent noise temperature (K)

B_N = equivalent noise bandwidth (Hz)

k = $1.38\text{x}10^{-23}$ (Boltzmann's constant)

For thermal noise, noise power per unit bandwidth, N0, is constant (a.k.a noise energy)

$$N_0 = \frac{P_N}{B_N} = kT_N \ \ joules$$

In addition to thermal noise, intermodulation distortion in high-power amplifiers result in signal products which appear as noise, that is intermodulation noise.

Carrier-to-Noise Ratio

A measure of the performance of a satellite link is the ratio of carrier power to noise power at the receiver input.

Conventionally, the ratio is denoted by C/ N (or CNR), which is equivalent to PR/PN.

In terms of decibels,

$$\left[\frac{C}{N}\right] = [P_R] - [P_N]$$

Equations (12.17) and (12.18) may be used for [PR] and [PN], resulting in

$$\left[\frac{C}{N}\right] = [EIRP] + [G_R] - [LOSSES] - [k] - [T_S] - [B_N]$$

The G/ T ratio is a key parameter in specifying the receiving system performance

$$\left[\frac{G}{T}\right] = [G_R] - [T_S] dBK^{-1}$$

Since $P_N = kT_N B_N = N_o B_N$, then

$$\left[\frac{C}{N}\right] = \left[\frac{C}{N_o B_N}\right]$$

$$= \left[\frac{C}{N_o}\right] - [B_N]$$

therefore

$$\left[\frac{C}{N_o}\right] = \left[\frac{C}{N}\right] + [B_N]$$

The final expresion is

$$\left[\frac{C}{N_0}\right] = [EIRP] + \left[\frac{G}{T}\right] - [LOSSES] - [k]\ dBHz \quad \text{---(1)}$$

Case(i) :The Uplink

The uplink earth station is transmitting the signal and the satellite is receiving it. Equation (1)

can be applied to the uplink, but with subscript U denotes that the uplink is being considered.

$$\left[\frac{C}{N_0}\right]_U = [EIRP]_U + \left[\frac{G}{T}\right]_U - [LOSSES]_U - [k] \quad \text{--(2)}$$

Eq (2) contains: the earth station EIRP, the satellite receiver feeder losses, and satellite receiver G/T. The freespace loss and other losses which are frequency-dependent are calculated for the uplink frequency. The resulting carrier-to-noise density ratio given by Eq. (2) is that which appears at the satellite receiver.

Case(ii): Downlink

The downlink the satellite is transmitting the signal and the earth station is receiving it. Equation

(1) can be applied to the downlink, but with subscript D to denote that the downlink is being considered.

$$\left[\frac{C}{N_0}\right]_D = [EIRP]_D + \left[\frac{G}{T}\right]_D - [LOSSES]_D - [k] \quad \text{--(3)}$$

Eq. (3) contains: the satellite EIRP, the earth station receiver feeder losses, and the earth station receiver G/T. The free-space and other losses are calculated for the downlink frequency.

The resulting carrier-to-noise density ratio given by Eq. (3) is that which appears at the detector of the earth station receiver. Where the carrier-to-noise ratio is the specified quantity rather than carrier-to-noise density ratio, Eq. (1) is used. On assuming that the signal bandwidth B is equal to the noise bandwidth BN, we obtain:

$$\left[\frac{C}{N}\right]_D = [EIRP]_D + \left[\frac{G}{T}\right]_D - [LOSSES]_D - [k] - [B] \quad \text{--(4)}$$

Case(iii); Combined Uplink and Downlink C/N Ratio

The complete satellite circuit consists of an uplink and a downlink, as sketched in Fig 3.24

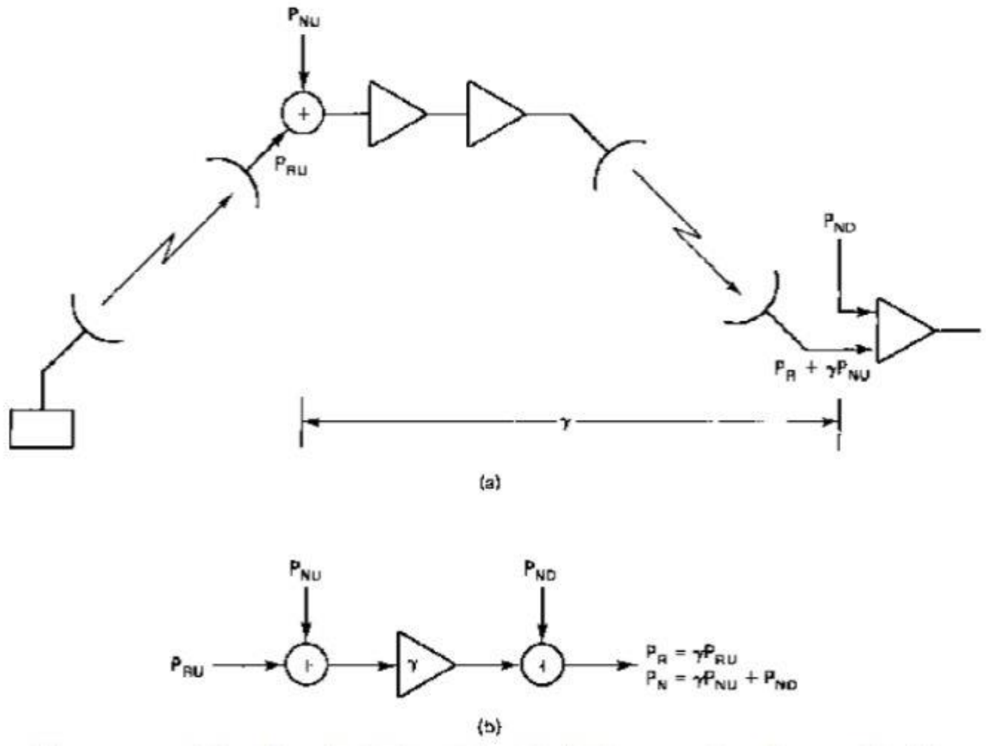

Figure 3.24 (a) combined uplink and downlink

(b) power flow diagram

Noise will be introduced on the uplink at the satellite receiver input.

PNU = noise power per unit bandwidth

PRU = average carrier at the same point

The carrier-to-noise ratio on the uplink is

$$(C/N_o)_U = (P_{RU}/P_{NU}).$$

Note that power levels, and not decibels, are being used.

PR = carrier power at the end of the space link

= the received carrier power for the downlink.

= K x the carrier power input at the satellite

Where

K = the system power gain from satellite input to earth station input. This includes the satellite transponder and transmit antenna gains, the downlink losses, and the earth station receive antenna gain and feeder losses.

The noise at the satellite input also appears at the earth station input multiplied by K, and in addition, the earth station introduces its own noise, denoted by PND. Thus the end-of-link noise is KPNU + PND.

The C/No ratio for the downlink alone, not counting the KPNU contribution, is PR/PND, and the combined C/No ratio at the ground receiver is PR/(KPNU + PND).

The power flow diagram is shown in Fig 3.24

The combined carrier-to-noise ratio can be determined in terms of the individual link values. To show this, it is more convenient to work with the noise-to-carrier ratios rather than the carrier-to noise ratios, and these must be expressed as power ratios, not decibels.

Denoting the combined noise-to-carrier ratio value by No/C, the uplink value by (No/C)U, and the downlink value by (No/C)D then,

$$
\begin{aligned}
\frac{N_o}{C} &= \frac{P_N}{P_R} \\
&= \frac{\gamma P_{NU} + P_{ND}}{P_R} \\
&= \frac{\gamma P_{NU}}{P_R} + \frac{P_{ND}}{P_R} \\
&= \frac{\gamma P_{NU}}{} + \frac{P_{ND}}{P_R} \\
&= \left(\frac{N_o}{C}\right)_U + \left(\frac{N_o}{C}\right)_D \qquad \text{--(4)}
\end{aligned}
$$

Equation (4) shows that to obtain the combined value of C/N0, the reciprocals of the individual values must be added to obtain the N0/C ratio and then the reciprocal of this taken to get C/N0.

The reason for this reciprocal of the sum of the reciprocals method is that a single signal power is being transferred through the system, while the various noise powers which are present are additive.

Similar reasoning applies to the carrier-to-noise ratio, C/ N.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COMMUNICAITON SYSTEMS – SEC1303

UNIT – 4

RADAR COMMUNICATION

4. RADAR COMMUNICATION

RADAR basics - RADAR block diagram and operation - Range equation - RADAR scanning system - Types of RADAR - Doppler effect - CW radar - FM CW radar - MTI radar Pulsed radar – tracking - detection of radar signals in noise correlation detection.

4.1 Introduction

RADAR is an electromagnetic based detection system that works by radiating electromagnetic waves and then studying the echo or the reflected back waves. The full form of RADAR is RAdio Detection and Ranging. Detection refers to whether the target is present or not. The target can be stationary or movable, i.e., non-stationary. Ranging refers to the distance between the Radar and the target.

Radars can be used for various applications on ground, on sea and in space. The applications of Radars are listed below.

- **(i) Controlling the Air Traffic**
- **(ii) Ship safety**
- **(iii) Sensing the remote places**
- **(iv) Military applications**

In any application of Radar, the basic principle remains the same. Let us now discuss the principle of radar.

4.2 Basic Principle of RADAR

Radar is used for detecting the objects and finding their location. We can understand the basic principle of Radar from the following figure.

As shown in the figure, Radar mainly consists of a transmitter and a receiver. It uses the same Antenna for both transmitting and receiving the signals. The function of the transmitter is to transmit the Radar signal in the direction of the target present. Target reflects this received signal in various directions. The signal, which is reflected back towards the Antenna gets received by the receiver.

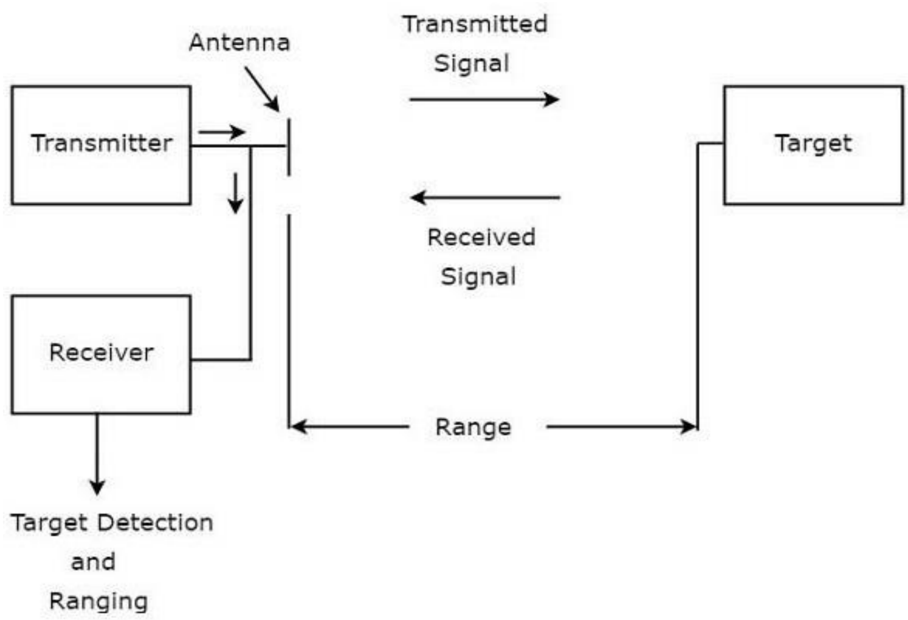

Figure 4.1 Basic Radar System

Target reflects this received signal in various directions. The signal, which is reflected back towards the Antenna gets received by the receiver.

4.3 Pulse Repetition Frequency

Radar signals should be transmitted at every clock pulse. The duration between the two clock pulses should be properly chosen in such a way that the echo signal corresponding to present clock pulse should be received before the next clock pulse. A typical Radar wave form is shown in the following figure.

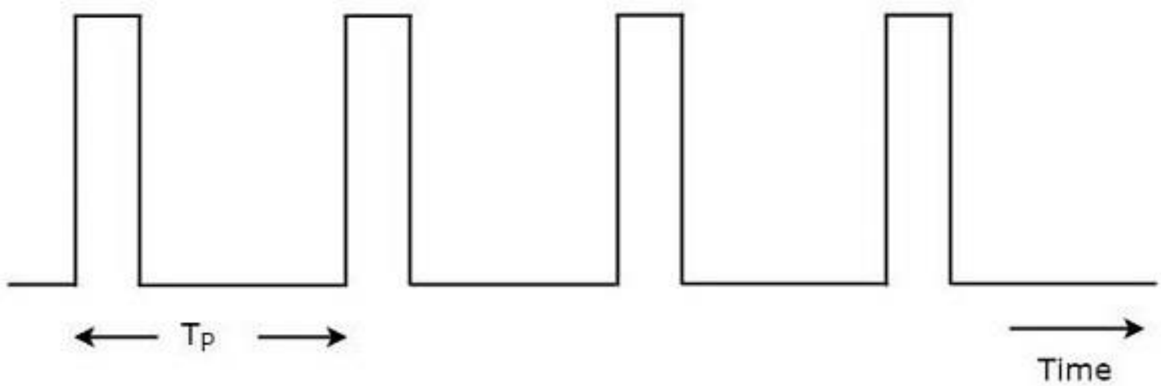

Figure 4.2 Pulse Repetition Frequency

As shown in the figure, Radar transmits a periodic signal. It is having a series of narrow rectangular shaped pulses. The time interval between the successive clock pulses is called pulse repetition time, T_P

4.4 Types of Radar

This topic provides the information briefly about the types of Radars. Radars can be classified into the following two types based on the type of signal with which Radar can be operated.

1. **Pulse Radar**
2. **Continuous Wave Radar**

4.5 Pulse Radar:

The Radar, which operates with pulse signal is called the Pulse Radar. Pulse Radars can be classified into the following two types based on the type of the target it detects.

1. **Basic Pulse Radar**
2. **Moving Target Indication Radar**

4.5.1 Basic Pulse Radar :

The Radar, which operates with pulse signal for detecting stationary targets, is called the Basic Pulse Radar or simply, Pulse Radar. It uses single Antenna for both transmitting and receiving signals with the help of Duplexer. Antenna will transmit a pulse signal at every clock pulse. The duration between the two clock pulses should be chosen in such a way that the echo signal corresponding to the present clock pulse should be received before the next clock pulse.

4.5.2 Moving Target Indication Radar:

The Radar, which operates with pulse signal for detecting non-stationary targets, is called Moving Target Indication Radar or simply, MTI Radar. It uses single Antenna for both transmission and reception of signals with the help of Duplexer. MTI Radar uses the principle of Doppler effect for distinguishing the non-stationary targets from stationary objects.

4.6 Continuous Wave Radar:

The Radar, which operates with continuous signal or wave is called Continuous Wave Radar. They use Doppler Effect for detecting non-stationary targets. Continuous Wave Radars can be classified into the following two types.

1. **Unmodulated Continuous Wave Radar**
2. **Frequency Modulated Continuous Wave Radar**

4.6.1 Unmodulated Continuous Wave Radar:

The Radar, which operates with continuous signal (wave) for detecting non-stationary targets is called Unmodulated Continuous Wave Radar or simply, CW Radar. It is also called CW Doppler Radar. This Radar requires two Antennas. Of these two antennas, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures only the speed of the target but not the distance of the target from the Radar.

4.6.2 Frequency Modulated Continuous Wave Radar:

If CW Doppler Radar uses the Frequency Modulation, then that Radar is called the Frequency Modulated Continuous Wave (FMCW) Radar or FMCW Doppler Radar. It is also called Continuous Wave Frequency Modulated Radar or CWFM Radar. This Radar requires two Antennas. Among which, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures not only the speed of the target but also the distance of the target from the Radar.

4.7 Pulse Radar

The Radar, which operates with pulse signal for detecting stationary targets is called Basic Pulse Radar or simply, Pulse Radar. Pulse Radar uses single Antenna for both transmitting and receiving of signals with the help of Duplexer. Following is the block diagram of Pulse Radar

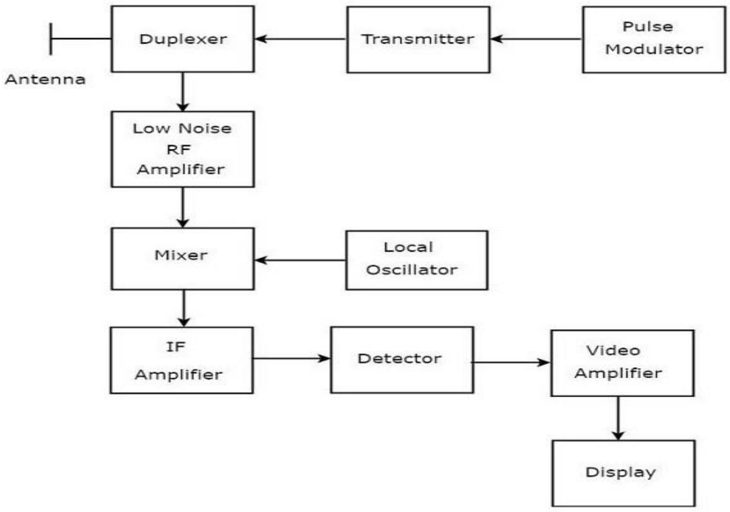

Figure 4.3 Block Diagram of Pulse Radar

Let us now see the function of each block of Pulse Radar ,

Pulse Modulator − It produces a pulse-modulated signal and it is applied to the Transmitter.

Transmitter − It transmits the pulse-modulated signal, which is a train of repetitive pulses.

Duplexer − It is a microwave switch, which connects the Antenna to both transmitter section and receiver section alternately. Antenna transmits the pulse-modulated signal, when the duplexer connects the Antenna to the transmitter. Similarly, the signal, which is received by Antenna will be given to Low Noise RF Amplifier, when the duplexer connects the Antenna to Low Noise RF Amplifier.

Low Noise RF Amplifier − It amplifies the weak RF signal, which is received by Antenna. The output of this amplifier is connected to Mixer.

Local Oscillator − It produces a signal having stable frequency. The output of Local Oscillator is connected to Mixer.

Mixer − We know that Mixer can produce both sum and difference of the frequencies that are applied to it. Among which, the difference of the frequencies will be of Intermediate Frequency (IF) type.

IF Amplifier − IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure allows only the Intermediate Frequency, which is obtained from Mixer and amplifies it. It improves the Signal to Noise Ratio at output.

Detector − It demodulates the signal, which is obtained at the output of the IF Amplifier.

Video Amplifier − As the name suggests, it amplifies the video signal, which is obtained at the output of detector.

Display − In general, it displays the amplified video signal on CRT screen.

4.8 Doppler Effect

If the target is not stationary, then there will be a change in the frequency of the signal that is transmitted from the Radar and that is received by the Radar. This effect is known as the Doppler effect. According to the Doppler effect, we will get the following two possible cases.

1. The frequency of the received signal will increase, when the target moves towards the direction of the Radar.

2. The frequency of the received signal will decrease, when the target moves away from the Radar.

4.8.1 Derivation of Doppler Frequency

The distance between Radar and target is nothing but the Range of the target or simply range, R. Therefore, the total distance between the Radar and target in a two-way communication path will be 2R, since Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar.

If λ is one wave length, then the number of wave lengths N that are present in a two-way communication path between the Radar and target will be equal to $2R/\lambda$.

We know that one wave length λ corresponds to an angular excursion of 2π radians. So, the total angle of excursion made by the electromagnetic wave during the two-way communication path between the Radar and target will be equal to $4\pi R/\lambda$ radians.

Following is the mathematical formula for angular frequency, ω

$$\omega = 2\pi f \qquad \text{Eq 4.1}$$

Following equation shows the mathematical relationship between the angular frequency ω and phase angle ϕ,

$$\omega = d\phi/dt \qquad \text{Eq 4.2}$$

Equate the right hand side terms of Eq 4.1 and Eq 4.2 since the left hand side terms of those two equations are same.

$$2\pi f = d\phi/dt$$

$$f = (1/2\pi)\ d\phi/dt \qquad \text{Eq 4.3}$$

Substitute, $f = f_d$ and $\phi = 4\pi R/\lambda$ in Eq 4.3

$$f_d = 1/2\pi * d/dt(4\pi R/\lambda)$$

$$\Rightarrow f_d = (1/2\pi) * (4\pi/\lambda)\ dR/dt$$

$$f_d = 2V_r/\lambda \qquad \text{Eq 4.4}$$

Where, f_d is the Doppler frequency V_r is the relative velocity.

We can find the value of Doppler frequency f_d by substituting the values of V_r and λ in Eq 4.4

Substitute, $\lambda = C/f$ in Eq4.4

$$f_d = (2Vr) / (C/f)$$

$$f_d = (2Vrf) / C \qquad \text{Eq 4.5}$$

where, f is the frequency of transmitted signal ,C is the speed of light and it is equal to 3×108m/sec .We can find the value of Doppler frequency, fd by substituting the values of Vr, f and C in Eq 4.5.

Note: Both Eq 4.4 and Eq 4.5 show the formulae of Doppler frequency, f_d. We can use either Eq 4.4 or Eq 4.5 for finding Doppler frequency, f_d based on the given data.

4.9 Continuous Wave Radar

The Radar, which operates with continuous signal (wave) for detecting non-stationary targets, is called Continuous Wave Radar or simply CW Radar. This Radar

requires two Antennas. Among which, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal.

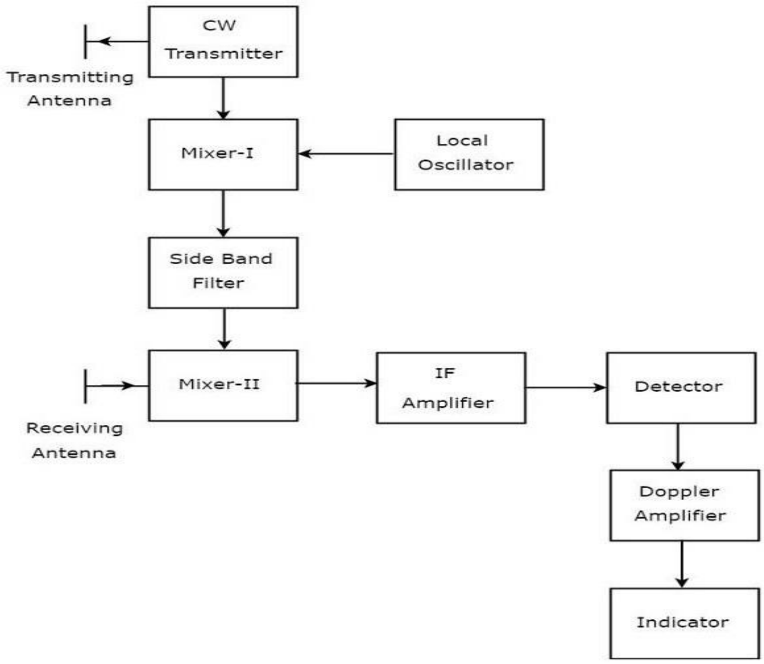

Figure 4.4 Block Diagram of Continuous Wave Radar

The block diagram of CW Doppler Radar contains a set of blocks and the function of each block is mentioned below.

CW Transmitter − It produces an analog signal having a frequency of f_o. The output of CW Transmitter is connected to both transmitting Antenna and Mixer-I.

Local Oscillator − It produces a signal having a frequency of f_l. The output of Local Oscillator is connected to Mixer-I.

Mixer-I − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of f_o and f_l are applied to Mixer-I. So, the Mixer-I will produce the output having frequencies f_o+f_l or f_o-f_l.

Side Band Filter − As the name suggests, side band filter allows a particular side band frequencies − either upper side band frequencies or lower side band frequencies. The side band filter shown in the above figure produces only upper side band frequency, i.e., f_o+f_l.

Mixer-II − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of f_o+f_l and $f_o \pm f_d$ are applied to Mixer-II. So, the Mixer-II will produce the output having frequencies of $2f_o+f_l \pm f_d$ or $f_l \pm f_d$.

IF Amplifier − IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure allows only the Intermediate Frequency, fl±fd and amplifies it.

Detector − It detects the signal, which is having Doppler frequency, f_d.

Doppler Amplifier − As the name suggests, Doppler amplifier amplifies the signal, which is having Doppler frequency, f_d.

Indicator − It indicates the information related relative velocity and whether the target is inbound or outbound. CW Doppler Radars give accurate measurement of relative velocities. Hence, these are used mostly, where the information of velocity is more important than the actual range.

4.10 FMCW Doppler Radar

If CW Doppler Radar uses the Frequency Modulation, then that Radar is called FMCW Doppler Radar or simply, FMCW Radar. It is also called Continuous Wave Frequency Modulated Radar or CWFM Radar. It measures not only the speed of the target but also the distance of the target from the Radar.

FMCW Radar is mostly used as Radar Altimeter in order to measure the exact height while landing the aircraft. The following figure shows the block diagram of FMCW Radar,

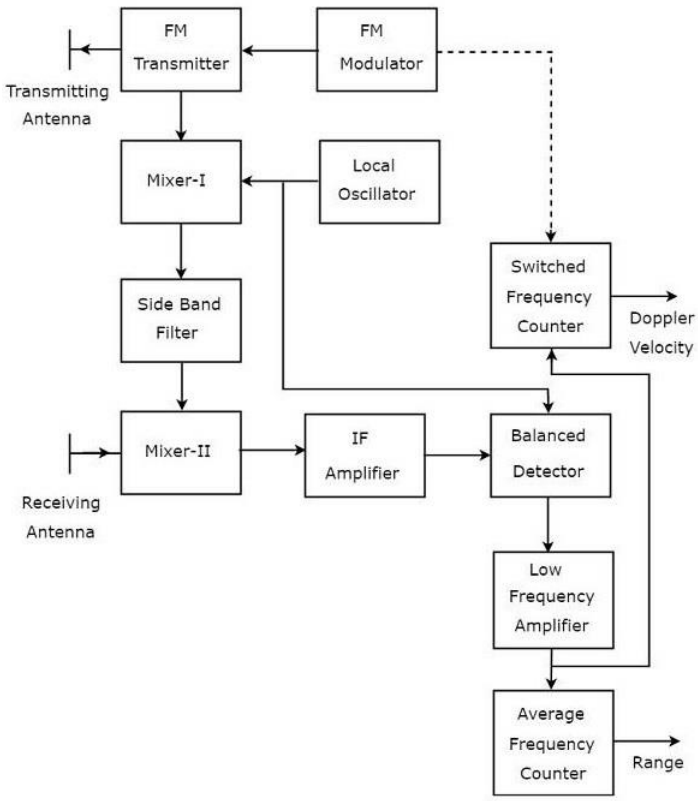

Figure 4.5 Block Diagram of FMCW Doppler Radar

FMCW Radar contains two Antennas − transmitting Antenna and receiving Antenna as shown in the figure. The transmitting Antenna transmits the signal and the receiving Antenna receives the echo signal. The block diagram of the FMCW Radar looks similar to the block diagram of CW Radar. It contains few modified blocks and some other blocks in addition to the blocks that are present in the block diagram of CW Radar. The function of each block of FMCW Radar is mentioned below.

FM Modulator − It produces a Frequency Modulated (FM) signal having variable frequency, $f_0(t)$ and it is applied to the FM transmitter.

FM Transmitter − It transmits the FM signal with the help of transmitting Antenna. The output of FM Transmitter is also connected to Mixer-I.

Local Oscillator − In general, Local Oscillator is used to produce an RF signal. But, here it is used to produce a signal having an Intermediate Frequency, f_{IF}. The output of Local Oscillator is connected to both Mixer-I and Balanced Detector.

Mixer-I − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of $f_o(t)$ and f_{IF} are applied to Mixer-I. So, the Mixer-I will produce the output having frequency either $f_o(t)+f_{IF}$ or $f_o(t)-f_{IF}$.

Side Band Filter − It allows only one side band frequencies, i.e., either upper side band frequencies or lower side band frequencies. The side band filter shown in the figure produces only lower side band frequency. i.e., $f_o(t)-f_{IF}$.

Mixer-II − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of $f_o(t)-f_{IF}$ and $f_o(t-T)$ are applied to Mixer-II. So, the Mixer-II will produce the output having frequency either $f_o(t-T)+f_o(t)-f_{IF}$ or $f_o(t-T)-f_o(t)+f_{IF}$.

IF Amplifier − IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure amplifies the signal having frequency of $f_o(t-T)-f_o(t)+f_{IF}$. This amplified signal is applied as an input to the Balanced detector.

Balanced Detector − It is used to produce the output signal having frequency of $f_o(t-T)-f_o(t)$ from the applied two input signals, which are having frequencies of $f_o(t-T)-f_o(t)+f_{IF}$ and f_{IF}. The output of Balanced detector is applied as an input to Low Frequency Amplifier.

Low Frequency Amplifier − It amplifies the output of Balanced detector to the required level. The output of Low Frequency Amplifier is applied to both switched frequency counter and average frequency counter.

Switched Frequency Counter − It is useful for getting the value of Doppler velocity.

Average Frequency Counter − It is useful for getting the value of Range.

4.11 Moving Target Indication(MTI) Radar:

If the Radar is used for detecting the movable target, then the Radar should receive only the echo signal due to that movable target. This echo signal is the desired one. However, in practical applications, Radar receives the echo signals due to stationary objects in addition to the echo signal due to that movable target. The echo signals due to stationary objects (places) such as land and sea are called clutters because these are unwanted signals. Therefore, we have to choose the Radar in such a way that it considers only the echo signal due to movable target but not the clutters. For this purpose, Radar

uses the principle of Doppler Effect for distinguishing the non-stationary targets from stationary objects. This type of Radar is called Moving Target Indicator Radar or simply, MTI Radar. According to Doppler effect, the frequency of the received signal will increase if the target is moving towards the direction of Radar. Similarly, the frequency of the received signal will decrease if the target is moving away from the Radar.

4.11.1 Types of MTI Radars:

We can classify the MTI Radars into the following two types based on the type of transmitter that has been used.

1. **MTI Radar with Power Amplifier Transmitter**
2. **MTI Radar with Power Oscillator Transmitter**

MTI Radar with Power Amplifier Transmitter:

MTI Radar uses single Antenna for both transmission and reception of signals with the help of Duplexer. The block diagram of MTI Radar with power amplifier transmitter is shown in the following figure.

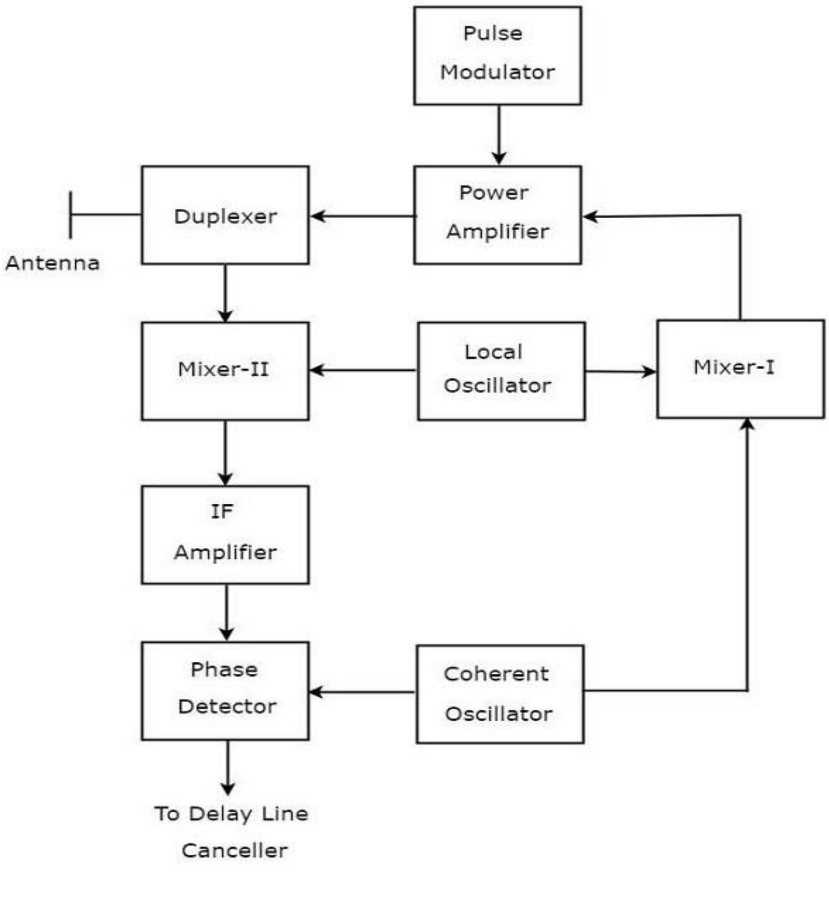

Figure 4.6 Block Diagram of MTI Radar with Power Amplifier Transmitter

The function of each block of MTI Radar with power amplifier transmitter is mentioned below.

Pulse Modulator − It produces a pulse modulated signal and it is applied to Power Amplifier.

Power Amplifier − It amplifies the power levels of the pulse modulated signal.

Local Oscillator − It produces a signal having stable frequency f_l. Hence, it is also called stable Local Oscillator. The output of Local Oscillator is applied to both Mixer-I and Mixer-II.

Coherent Oscillator − It produces a signal having an Intermediate Frequency, fc. This signal is used as the reference signal. The output of Coherent Oscillator is applied to both Mixer-I and Phase Detector.

Mixer-I − Mixer can produce either sum or difference of the frequencies that are applied to it. The signals having frequencies of f_l and f_c are applied to Mixer-I. Here, the Mixer-I is used for producing the output, which is having the frequency f_l+f_c.

Duplexer − It is a microwave switch, which connects the Antenna to either the transmitter section or the receiver section based on the requirement. Antenna transmits the signal having frequency f_l+f_c when the duplexer connects the Antenna to power amplifier. Similarly, Antenna receives the signal having frequency of $f_l+f_c\pm f_d$ when the duplexer connects the Antenna to Mixer-II.

Mixer-II − Mixer can produce either sum or difference of the frequencies that are applied to it. The signals having frequencies $f_l+f_c\pm f_d$ and f_l are applied to Mixer-II. Here, the Mixer-II is used for producing the output, which is having the frequency $f_c\pm f_d$.

IF Amplifier − IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure amplifies the signal having frequency f_c+f_d. This amplified signal is applied as an input to Phase detector.

Phase Detector − It is used to produce the output signal having frequency f_d from the applied two input signals, which are having the frequencies of f_c+f_d and f_c. The output of phase detector can be connected to Delay line canceller.

MTI Radar with Power Oscillator Transmitter:

The block diagram of MTI Radar with power oscillator transmitter looks similar to the block diagram of MTI Radar with power amplifier transmitter. The blocks corresponding to the receiver section will be same in both the block diagrams. Whereas, the blocks corresponding to the transmitter section may differ in both the block diagrams. The block diagram of MTI Radar with power oscillator transmitter is shown in the following figure.

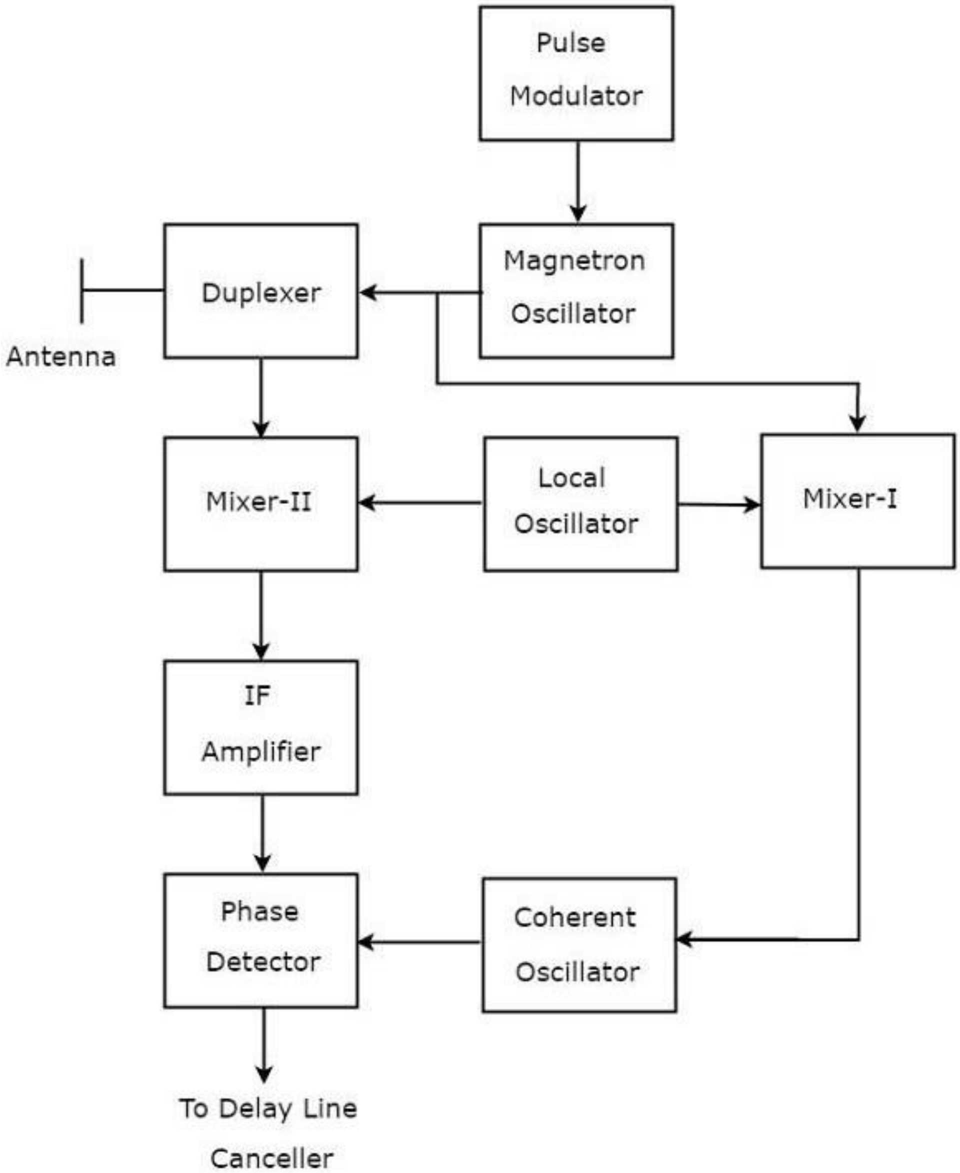

Figure 4.7 Block Diagram of MTI Radar with Power Oscillator Transmitter

As shown in the figure, MTI Radar uses the single Antenna for both transmission and reception of signals with the help of Duplexer. The operation of MTI Radar with

power oscillator transmitter is mentioned below. The output of Magnetron Oscillator and the output of Local Oscillator are applied to Mixer-I. This will further produce an IF signal, the phase of which is directly related to the phase of the transmitted signal. The output of Mixer-I is applied to the Coherent Oscillator. Therefore, the phase of Coherent Oscillator output will be locked to the phase of IF signal. This means, the phase of Coherent Oscillator output will also directly relate to the phase of the transmitted signal. So, the output of Coherent Oscillator can be used as reference signal for comparing the received echo signal with the corresponding transmitted signal using phase detector. The above tasks will be repeated for every newly transmitted signal.

4.12 Delay Line Cancellers

As the name suggests, delay line introduces a certain amount of delay. So, the delay line is mainly used in Delay line canceller in order to introduce a delay of pulse repetition time. Delay line canceller is a filter, which eliminates the DC components of echo signals received from stationary targets. This means, it allows the AC components of echo signals received from non-stationary targets, i.e., moving targets.

Types of Delay Line Cancellers:

Delay line cancellers can be classified into the following two types based on the number of delay lines that are present in it.

1. **Single Delay Line Canceller**
2. **Double Delay Line Canceller**

Single Delay Line Canceller: The combination of a delay line and a subtractor is known as Delay line canceller. It is also called single Delay line canceller. The block diagram of MTI receiver with single Delay line canceller is shown in the figure below.

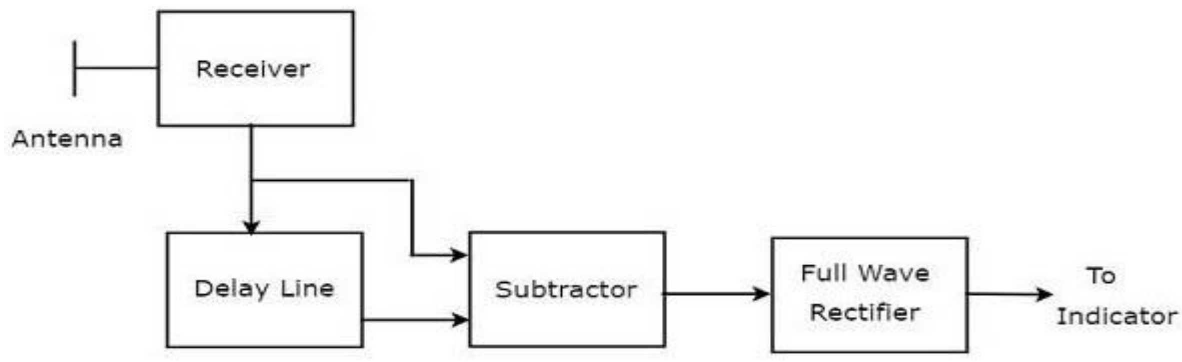

Figure 4.8 Single Delay Line Cancellor

Double Delay Line Canceller: We know that a single delay line canceller consists of a delay line and a subtractor. If two such delay line cancellers are cascaded together, then that combination is called Double delay line canceller. The block diagram of Double delay line canceller is shown in the following figure.

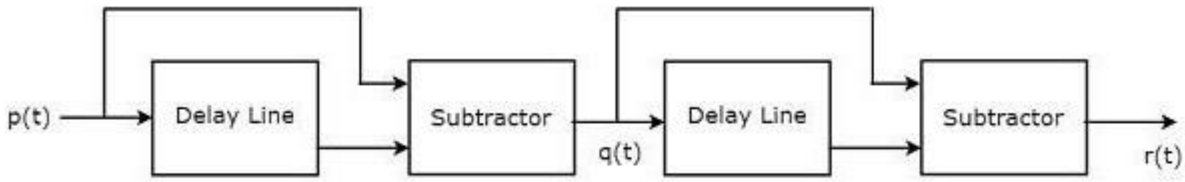

Figure 4.9 Double Delay Line Cancellor

4.13 Tracking Radar

The Radar, which is used to track the path of one or more targets is known as Tracking Radar. In general, it performs the following functions before it starts the tracking activity. Target detection Range of the target Finding elevation and azimuth angles Finding Doppler frequency shift So, Tracking Radar tracks the target by tracking one of the three parameters — range, angle, Doppler frequency shift. Most of the Tracking Radars use the principle of tracking in angle.

Angular Tracking: The pencil beams of Radar Antenna perform tracking in angle. The axis of Radar Antenna is considered as the reference direction. If the direction of the target and reference direction is not same, then there will be angular error, which is nothing but the difference between the two directions. If the angular error signal is applied to a servo control system, then it will move the axis of the Radar Antenna towards the direction of target. Both the axis of Radar Antenna and the direction of target will coincide when the angular error is zero. There exists a feedback mechanism in the Tracking Radar, which works until the angular error becomes zero.

4.14 Radar Displays

An electronic instrument, which is used for displaying the data visually is known as display. So, the electronic instrument which displays the information about Radar's target visually is known as Radar display. It shows the echo signal information visually on the screen.

Types of Radar Displays:

In this section, we will learn about the different types of Radar Displays. The Radar Displays can be classified into the following types.

A-Scope It is a two dimensional Radar display. The horizontal and vertical coordinates represent the range and echo amplitude of the target respectively. In A-Scope, the deflection modulation takes place. It is more suitable for manually tracking Radar.

B-Scope It is a two dimensional Radar display. The horizontal and vertical coordinates represent the azimuth angle and the range of the target respectively. In B-Scope, intensity modulation takes place. It is more suitable for military Radars.

C-Scope It is a two-dimensional Radar display. The horizontal and vertical coordinates represent the azimuth angle and elevation angle respectively. In C-Scope, intensity modulation takes place.

D-Scope If the electron beam is deflected or the intensity-modulated spot appears on the Radar display due to the presence of target, then it is known as blip. C-Scope becomes D-Scope, when the blips extend vertically in order to provide the distance.

E-Scope It is a two-dimensional Radar display. The horizontal and vertical coordinates represent the distance and elevation angle respectively. In E-Scope, intensity modulation takes place.

F-Scope If the Radar Antenna is aimed at the target, then F-Scope displays the target as a centralized blip. So, the horizontal and vertical displacements of the blip represent the horizontal and vertical aiming errors respectively.

G-Scope If the Radar Antenna is aimed at the target, then G-Scope displays the target as laterally centralized blip. The horizontal and vertical displacements of the blip represent the horizontal and vertical aiming errors respectively.

H-Scope It is the modified version of B-Scope in order to provide the information about elevation angle of the target. It displays the target as two blips, which are closely spaced. This can be approximated to a short bright line and the slope of this line will be proportional to the sine of the elevation angle.

I-Scope If the Radar Antenna is aimed at the target, then I-Scope displays the target as a circle. The radius of this circle will be proportional to the distance of the target. If the Radar Antenna is aimed at the target incorrectly, then I-Scope displays the target as a segment instead of circle. The arc length of that segment will be inversely proportional to the magnitude of pointing error.

J-Scope It is the modified version of A-Scope. It displays the target as radial deflection from time base.

K-Scope It is the modified version of A-Scope. If the Radar Antenna is aimed at the target, then K-Scope displays the target as a pair of vertical deflections, which are having equal height. If the Radar Antenna is aimed at the target incorrectly, then there will be pointing error. So, the magnitude and the direction of the pointing error depends on the difference between the two vertical deflections.

L-Scope If the Radar Antenna is aimed at the target, then L-Scope displays the target as two horizontal blips having equal amplitude. One horizontal blip lies to the right of central vertical time base and the other one lies to the left of central vertical time base.

M-Scope It is the modified version of A-Scope. An adjustable pedestal signal has to be moved along the baseline till it coincides the signal deflections, which are coming from the horizontal position of the target. In this way, the target's distance can be determined.

N-Scope It is the modified version of K-Scope. An adjustable pedestal signal is used for measuring distance.

O-Scope It is the modified version of A-Scope. We will get O-Scope, by including an adjustable notch to A-Scope for measuring distance.

P-Scope It is a Radar display, which uses intensity modulation. It displays the information of echo signal as plan view. Range and azimuth angle are displayed in polar coordinates. Hence, it is called the Plan Position Indicator or the PPI display.

R-Scope It is a Radar display, which uses intensity modulation. The horizontal and vertical coordinates represent the range and height of the target respectively. Hence, it is called Range-Height Indicator or RHI display.

4.15 Radar Range Equation

Radar range equation is useful to know the range of the target theoretically.

Derivation of Radar Range Equation

The standard form of Radar range equation is also called as simple form of Radar range equation. Now, let us derive the standard form of Radar range equation.

We know that power density is nothing but the ratio of power and area. So, the power density, P_{di} at a distance, R from the Radar can be mathematically represented as –

$$P_{di} = \frac{P_t}{4\,\pi R^2} \qquad \text{……………..Eq: 1}$$

Where,

P_t is the amount of power transmitted by the Radar transmitter

The above power density is valid for an isotropic Antenna. In general, Radars use directional Antennas. Therefore, the power density, P_{dd} due to directional Antenna will be –

$$P_{dd} = \frac{P_t G}{4\,\pi R^2} \qquad \text{……………..Eq: 2}$$

Target radiates the power in different directions from the received input power. The amount of power, which is reflected back towards the Radar depends on its cross section. So, the power density P_{de} of echo signal at Radar can be mathematically represented as –

$$P_{de} = \quad P_{dd}\left(\frac{\sigma}{4\,\pi R^2}\right) \qquad \text{……………..Eq: 3}$$

Substitute, Equation 2 (P_{dd}) in Equation 3.

$$P_{de} = \frac{P_t G}{4\,\pi R^2}\left(\frac{\sigma}{4\,\pi R^2}\right) \qquad \text{……………..Eq: 4}$$

The amount of power, P_r received by the Radar depends on the effective aperture, A_e of the receiving Antenna.

$$P_r = P_{de}\,A_e \qquad \text{……………..Eq: 5}$$

Substitute, Equation 4 (P_{de}) in Equation 5.

$$P_r = \left(\frac{P_t G\sigma\, A_e}{(4\pi)^2 R^4}\right)$$

$$R^4 = \left[\frac{P_t G\sigma\, A_e}{(4\pi)^2\, P_r}\right]$$

$$R \quad = \left[\frac{P_t G\sigma\, A_e}{(4\pi)^2\, P_r}\right]^{1/4} \text{……………..Eq: 6}$$

Standard Form of Radar Range Equation

- **If the echo signal is having the power less than the power of the minimum detectable signal, then Radar cannot detect the target since it is beyond the maximum limit of the Radar's range**
- **Therefore, the range of the target is said to be maximum range when the received echo signal is having the power equal to that of minimum detectable signal**
- **The following equation is obtained, by substituting $R = R_{Max}$ and $P_r = S_{Min}$ in Equation 6**

$$R_{Max} = \left[\frac{P_t G\sigma\, A_e}{(4\pi)^2\, S_{Min}}\right]^{1/4} \quad \text{……………..Eq: 7}$$

- **Equation 7 represents the standard form of Radar range equation.**
- **By using the above equation, we can find the maximum range of the target.**

Modified Forms of Radar Range Equation

The relation between the Gain of directional Antenna, G and effective aperture, A_e.

$$G = \frac{4\pi A_e}{\lambda^2} \quad Equation\ 8$$

Substitute, Equation 8 in Equation 7.

$$R_{Max} = \left[\frac{P_t \sigma A_e}{(4\pi)^2 S_{min}} \left(\frac{4\pi A_e}{\lambda^2}\right)\right]^{1/4}$$

$$\Rightarrow R_{Max} = \left[\frac{P_t G \sigma {A_e}^2}{4\pi \lambda^2 S_{min}}\right]^{1/4} \quad Equation\, 9$$

Equation 9 represents the modified form of Radar range equation.

By using the above equation, we can find the maximum range of the target.

The following relation is obtained between effective aperture, Ae and the Gain of directional Antenna, G from Equation 8.

$$A_e = \frac{G\lambda^2}{4\pi} \quad Equation\, 10$$

Substitute, Equation 10 in Equation 7.

$$R_{Max} = \left[\frac{P_t G \sigma}{(4\pi)^2 S_{min}} (\frac{G\lambda^2}{4\pi})\right]^{1/4}$$

$$\Rightarrow R_{Max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^2 S_{min}}\right]^{1/4} \quad Equation\, 11$$

Equation 11 represents another modified form of Radar range equation.

By using the above equation, we can find the maximum range of the target.

Problem 1

Calculate the maximum range of Radar for the following specifications −

- **Peak power transmitted by the Radar, P_t=250KW**
- **Gain of transmitting Antenna, G=4000**
- **Effective aperture of the receiving Antenna, A_e=4m^2**
- **Radar cross section of the target, σ=25m^2**
- **Power of minimum detectable signal, S_{min}=10^{-12}W**

Solution

We can use the following standard form of Radar range equation in order to calculate the maximum range of Radar for given specifications.

$$R_{Max}=[P_tG\sigma A_e(4\pi)2Smin]^{1/4}$$

Substitute all the given parameters in above equation.

$$R_{Max}=[(250\times103)(4000)(25)(4)(4\pi)2(10-12)]^{1/4}$$

$$\Rightarrow R_{Max}=158\ KM$$

Therefore, the maximum range of Radar for given specifications is 158 KM.

Problem 2

Calculate the maximum range of Radar for the following specifications.

- **Operating frequency, f=10 GHZ**
- **Peak power transmitted by the Radar, P_t=400KW**
- **Effective aperture of the receiving Antenna, A_e=5m^2**
- **Radar cross section of the target, σ=30m^2**
- **Power of minimum detectable signal, S_{min}=10^{-10}W**

Solution

We know the following formula for operating wavelength, λλ in terms of operating frequency, f.

$$\Lambda = Cf$$

Substitute, C=3×10^8 m/sec and f=10 GHZ in above equation.

$$\lambda=3\times10^{8} / 10\times10^{9}$$

$$\Rightarrow\lambda=0.03m$$

So, the operating wavelength, λ is equal to 0.03m, when the operating frequency, ff is 10GHZ.

We can use the following modified form of Radar range equation in order to calculate the maximum range of Radar for given specifications.

$$R_{Max}=[Pt\sigma A_e^2 / 4\pi\lambda^2 S_{min}]^{1/4}$$

Substitute, the given parameters in the above equation.

$$R_{Max}=[(400\times10^3)(30)(5^2) / 4\pi(0.003)^2(10)^{-10}]^{1/4}$$

$$\Rightarrow RMax=128\ KM$$

Therefore, the maximum range of Radar for given specifications is 128KM.

Part A: Two Marks:

1. **What is radar?**
2. **List the applications of RADAR.**
3. **Investigate Doppler effect or Doppler shift.**
4. **Interpret the main reasons for the failure of the simple form of the radar equation?**
5. **Evaluate the operation of duplexer?**
6. **Interpret the Radar range equation and mention the factors that influence the range of radar system.**
7. **Test the assumptions. Do we have to make in formulating the radar range equation? Study the maximum unambiguous range?**
8. **Compare primary and secondary radars.**
9. **List the merits and demerits of CW radar?**
10. **Quote the applications of FMCW Radar?**
11. **Compare CW Radar and pulsed Radar.**
12. **Summarize various scanning system used in Radar.**
13. **Draw the block diagram of Pulsed radar.**

14. List out the types of display systems used in RADAR.

15. Figure out the features of PPI display?

16. Resolve the function of COHO & STALO in MTI Radar?

17. Analyse the expression for peak power, average power and echo power.

Part B:

1. **Investigate about the basic functional units of a Radar and its working principle in detecting targets.**
2. **Attribute an expression for the Radar range equation and discuss the factors that affects range of radar**
3. **Interpret the working principle of pulsed radar and compare its performance with CW radar.**
4. **Articulate the idea of Moving Target Indicator radar. What is the significance of echo canceller?**
5. **Consider the following i) Doppler effect used in CW radar and ii) CFAR receiver**
6. **Investigate the principle and working of unmodulated CW Radar and Frequency Modulated CW Radar**
7. **Draw the block diagram of MTI radar and explain in detail.**
8. **Resolve the criteria used to analyse the performance of RADAR systems.**
9. **Analyse the importance of digital signal processing techniques in the performance of RADAR.**

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COMMUNICAITON SYSTEMS – SEC1303

UNIT – 5

WIRELESS COMMUNICATION

5. WIRELESS COMMUNICATION

Review of IEEE standards – Bluetooth – Piconet - Bluetooth Usage models - Bluetooth Architecture – IR – Ultrasonic - Ultrasonic Production - Applications of Ultrasonic – RF - WiFi- ZigBee - ZigBee Architecture - ZigBee Network Topologies.

5.1 Introduction

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. The most common wireless technologies use radio. With radio waves distances can be short, such as a few meters for television or as far as thousands or even millions of kilometers for deep-space radio communications. It encompasses various types of fixed, mobile, and portable applications, including two-way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of applications of radio wireless technology include GPS units, garage door openers, wireless computer mouse, keyboards and headsets, headphones, radioreceivers, satellite, television, broadcast television and cordless telephones. Somewhat less common methods of achieving wireless communications include the use of other electromagnetic wireless technologies, such as light, magnetic, or electric fields or the use of sound.

Wireless communication has the following advantages:

i. **Communication has enhanced to convey the information quickly to the consumers.**
ii. **Working professionals can work and access Internet anywhere and anytime without carrying cables or wires wherever they go. This also helps to complete the work anywhere on time and improves the productivity.**
iii. **Doctors, workers and other professionals working in remote areas can be in touch with medical centres through wireless communication.**
iv. **iv. Urgent situation can be alerted through wireless communication. The affected regions can be provided help and support with the help of these alerts through wireless communication.**
v. **Wireless networks are cheaper to install and maintain.**

Disadvantages:

The growth of wireless network has enabled us to use personal devices anywhere and anytime. This has helped mankind to improve in every field of life but this has led many threats as well. Wireless network has led to many security threats to mankind. It is very easy for the hackers to grab the wireless signals that are spread in the air. It is very important to secure the wireless network so that the information cannot be exploited by the unauthorized users. This also increases the risk to lose information. Strong security protocols must be created to secure the wireless signals like WPA and WPA2. Another way to secure the wireless network is to have wireless intrusion prevention system.

5.2 Types of wireless communication:

The different types of wireless communication technologies include:

Infrared (IR) wireless communication:

IR wireless communication communicates data or information in devices or systems through infrared (IR) radiation. Infrared is electromagnetic energy at a wavelength that is longer than that of red light.

Working: IR wireless is used for short and medium-range communications and security control. For IR communication to work, the systems mostly operate inline-of-sight mode which means that there must be no obstruction between the transmitter (source) and receiver (destination). Infrared is used in television remote controls and security systems. In the electromagnetic spectrum, infrared radiation lies between microwaves and visible light, therefore, they can be used as a source of communication. A photo LED transmitter and a photodiode receptor are required for successful IR communication. The LED transmitter transmits the infrared signal in the form of non-visible light, which is captured and retrieved as information by the photo receptor. In this way, the information between the source and the target is transferred. The source and/or destination can be laptops, mobile phones, televisions, security systems and any other device that supports wireless communication.

Review of IEEE standards:

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a

consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards. IEEE had close to 900 active standards, with 500 standards under development. One of the more notable are the IEEE 802 LAN/MAN group of standards, with the widely used computer networking standards for both wired (ethernet, aka IEEE 802.3) and wireless (IEEE 802.11 and IEEE 802.16) networks.

Wireless Local Area Networks (W-LAN)

IEEE 802.11 WLAN uses ISM band (5.275-5.825GHz). Uses 11Mcps DS-SS spreading and 2Mbps user data rates (will fallback to 1Mbps in noisy conditions). IEEE 802.11a standard provides up to 54Mbps throughput in the 5GHz band. The DS-SS IEEE 802.11b has been called Wi-Fi which has limited range. A typical Wi-Fi home router using 802.11b or 802.11g with a stock antenna might have a range of 32 m (120 ft) indoors and 95 m (300 ft) outdoors. Range also varies with frequency band. IEEE 802.11g uses Complementary Code Keying Orthogonal Frequency Division Multiplexing (CCK-OFDM) standards in both 2.4GHz and 5GHz bands.

WiMax

Provides upto 70 Mb/sec symmetric broadband speed without the need for cables. The technology is based on the IEEE 802.16 standard (also called WirelessMAN). WiMAX can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations. In contrast, the WiFi/802.11 wireless local area network standard is limited in most cases to only 100 - 300 feet (30 - 100m). The 802.16 specification applies across a wide range of the RF spectrum, and WiMAX could function on any frequency below 66 GHz (higher frequencies would decrease the range of a Base Station to a few hundred meters in an urban environment).

5.3 IEEE Standards:

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board.

Table: 5.1 IEEE Standards

IEEE 255	**Standard Letter Symbols for Semiconductor Devices, IEEE-255-1963**
IEEE 260	**Standard Letter Symbols for Units of Measurement, IEEE-260-1978 (now 260.1-2004)**
IEEE 488	**Standard Digital Interface for Programmable Instrumentation, IEEE-488-1978 (now 488.1)**
IEEE 610	**Standard Glossary of Software Engineering Terminology**
IEEE 754	**Floating point arithmetic specifications**
IEEE 802	**LAN/MAN**
IEEE 802.1	**Standards for LAN/MAN bridging and management and remote media access control (MAC) bridging**
IEEE 802.2	**Standards for Logical Link Control (LLC) standards for connectivity**
IEEE 802.3	**Ethernet Standards for Carrier Sense Multiple Access with Collision Detection (CSMA/CD)**
IEEE 802.4	**Standards for token passing bus access**

IEEE 802.5	**Standards for token ring access and for communications between LANs and MANs**
IEEE 802.6	**Standards for information exchange between systems**
IEEE 802.7	**Standards for broadband LAN cabling**
IEEE 802.8	**Fiber-optic connection**
IEEE 802.9	**Standards for integrated services, like voice and data**
IEEE 802.10	**Standards for LAN/MAN security implementations**
IEEE 802.11	**Wireless Networking – "WiFi"**
IEEE 802.12	**Standards for demand priority access method**
IEEE 802.14	**Standards for cable television broadband communications**
IEEE 802.15.2	**Bluetooth and Wi-Fi coexistence mechanism**
IEEE 802.15.4	**Wireless Sensor/Control Networks – "ZigBee"**
IEEE 802.15.6	**Wireless Body Area Network[16] (BAN) – (e.g. Bluetooth low energy)**
IEEE 802.16	**Wireless Networking – "WiMAX"**

5.4 IR or Infrared:

Communication Infrared (IR) is a wireless mobile technology used for device communication over short ranges. IR communication has major limitations because it requires line-of-sight, has a short transmission range and is unable to

penetrate walls. IR transceivers are quite cheap and serve as short-range communication solutions. Because of IR's limitations, communication interception is difficult. The IR detector is only looking for infrared that's flashing on and off 38,500 times per second. It has built-in optical filters that allow very little light except the 980 nm infrared. It also has an electronic filter that only allows signals around 38.5 kHz to pass through. This is the type of signal produced by the remote control. This prevents IR interference from common sources such as sunlight and indoor lighting. IR, or infrared, communication is a common, inexpensive, and easy to use wireless communication technology. IR light is very similar to visible light, except that it has a slightltly longer wavelength. This means IR is undetectable to the human eye - perfect for wireless communication. IR radiation is simply light that we cannot see, which makes it great for communication. IR sources are all around us. The sun, light bulbs, or any anything with heat is very bright in the IR spectrum. The IR signal is modulated. Modulating a signal is like assigning a pattern to data, so that the receiver knows to listen. A common modulation scheme for IR communication is something called 38 kHz modulation. There are very few natural sources that have the regularity of a 38 kHz signal, so an IR transmitter sending data at that frequency would stand out among the ambient IR. 38 kHz modulated IR data is the most common, but other frequencies can be used.

5.5 Bluetooth:

BWT-enabled devices operate in the unrestricted 2.4-gigahertz (GHz) Industrial, Science, Medical (ISM) band. The ISM band ranges between 2.400 GHz and 2.483 GHz. BWT-enabled devices use seventy-nine 1-megahertz frequencies (from 2.402 to 2.480 GHz) in the ISM band as shown in Fig. 10. BWT-enabled devices use a technique called frequency hopping to minimize eavesdropping and interference from other networks that use the ISM band. With frequency hopping, the data is divided into small pieces called packets. The transmitter and receiver exchange a data packet at one frequency, and then they hop to another frequency to exchange another packet. They repeat this process until all the data is transmitted. BWT devices randomly hop between frequencies up to 1600 times per second—much faster than other types of devices that use the ISM band. This means that if another device, such as a 2.4-GHz cordless phone, interferes with a BWT

network at a particular frequency, the interference only lasts for about 1/1600 of a second until the BWT devices hop to another frequency. This gives BWT networks a high immunity to interference from other 2.4-GHz devices. There are three classes of BWT radio devices, each with a different maximum range: Class 1 (100 meters); Class 2 (50 meters); and Class 3 (10 meters).

Topology:

There are two types of topology for Bluetooth – Piconet, Scatternet. The Piconet is a small ad hoc network of devices (normally 8 stations) as shown in Figure 5.1. It has the following features:

- **One is called Master and the others are called Slaves o All slave stations synchronizes their clocks with the master.**
- **Possible communication - One-to-one or one-to-many**
- **There may be one station in parked state**
- **Each piconet has a unique hopping pattern/ID**
- **Each master can connect to 7 simultaneous or 200+ inactive (parked) slaves per piconet.**

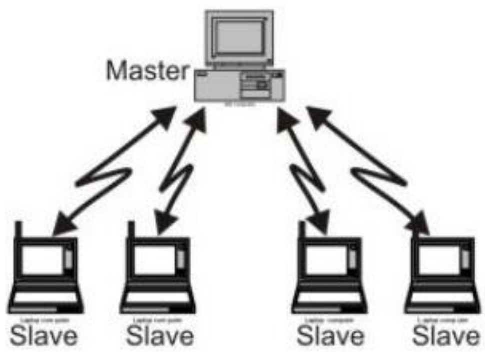

Figure 5.1 Piconet

By making one slave as master of another Piconet, Scatternet is formed by combining several Piconets as shown in Figure 5.2. Key features of the scatternet topology are mentioned below:

- **A Scatternet is the linking of multiple co-located piconets through the sharing of common master or slave devices.**
- **A device can be both a master and a slave.**

- Radios are symmetric (same radio can be master or slave).
- High capacity system, each piconet has maximum capacity (720 Kbps)

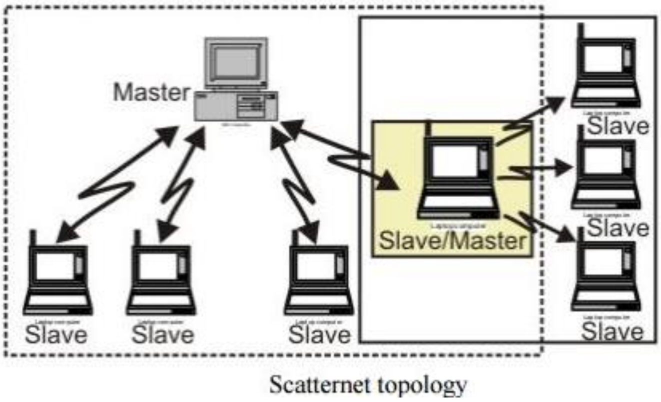

Figure 5.2 Scatternet Topology

5.5.1 Bluetooth Architecture:

The Bluetooth architecture, showing all the major layers in the Bluetooth system, are depicted in the Figure 5.3. The layers below can be considered to be different hurdles in an obstacle course. This is because all the layers function one after the other. One layer comes into play only after the data has been through the previous layer.

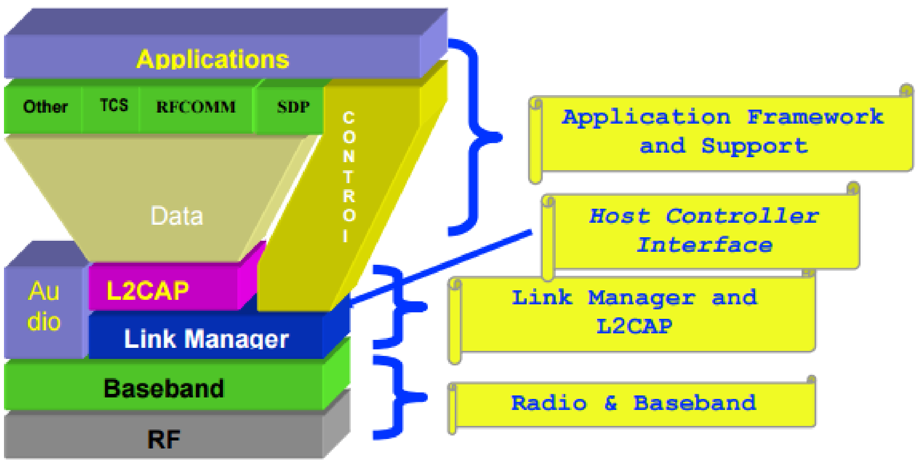

Figure 5.3: Bluetooth Architecture

- **Radio:** The Radio layer defines the requirements for a Bluetooth transceiver operating in the 2.4 GHz ISM band.

- **Baseband: The Baseband layer describes the specification of the Bluetooth Link Controller (LC), which carries out the baseband protocols and other low-level link routines. It specifies Piconet/Channel definition, "Low-level" packet definition, Channel sharing.**
- **LMP: The Link Manager Protocol (LMP) is used by the Link Managers (on either side) for link set-up and control.**
- **HCI: The Host Controller Interface (HCI) provides a command interface to the Baseband Link Controller and Link Manager, and access to hardware status and control registers.**
- **L2CAP: Logical Link Control and Adaptation Protocol (L2CAP) supports higher level protocol multiplexing, packet segmentation and reassembly, and the conveying of quality of service information.**
- **RFCOMM: The RFCOMM protocol provides emulation of serial ports over the L2CAP protocol. The protocol is based on the ETSI standard TS 07.10.**
- **SDP: The Service Discovery Protocol (SDP) provides a means for applications to discover, which services are provided by or available through a Bluetooth device. It also allows applications to determine the characteristics of those available services.**

Bluetooth Layers Layer 1:

Radio Layer This is the lowest layer in the Bluetooth protocol stack. Bluetooth uses a technique called frequency hopping, as explained in the context of wireless LANs, in establishing radio links with other Bluetooth devices. Suppose we have a data packet then the whole packet is never transmitted at the same frequency. It is always split into different parts and transmitted at different frequencies. This is the frequency hopping technique. This partly gives the necessary protection to the transmitted data and avoids tampering. Standard hop values are 79 hops, which are spaced at an interval of 1 MHz. Transmitter characteristics: Each device is classified into 3 power classes, Power Class 1, 2 & 3.

• Power Class 1: is designed for long range (~100m) devices, with a max output power of 20 dBm,

• Power Class 2: for ordinary range devices (~10m) devices, with a max output power of 4 dBm,

• Power Class 3: for short range devices (~10cm) devices, with a max output power of 0 dBm. The Bluetooth radio interface is based on a nominal antenna power of 0dBm. Each device can optionally vary its transmitted power. Equipment with power control capability optimizes the output power in a link with LMP commands (see Link Manager Protocol). It is done by measuring RSSI and reporting it back, if the power is required to be increased or decreased. Modulation Characteristics: The Bluetooth radio module uses GFSK (Gaussian Frequency Shift Keying) where a binary one is represented by a positive frequency deviation and a binary zero by a negative frequency deviation. BT is set to 0.5 and the modulation index must be between 0.28 and 0.35. Radio Frequency Tolerance: The transmitted initial center frequency accuracy must be ±75 kHz from Fc. The initial frequency accuracy is defined as being the frequency accuracy before any information is transmitted. Note that the frequency drift requirement is not included in the ±75 kHz. Receiver Characteristics: The receiver must have a sensitivity level for which the bit error rate (BER) 0.1% is met. For Bluetooth this means an actual sensitivity level of 70dBm or better.

Layer 2: Baseband Layer:

The baseband is the digital engine of a Bluetooth system. It is responsible for constructing and decoding packets, encoding and managing error correction, encrypting and decrypting for secure communications, calculating radio transmission frequency patterns, maintaining synchronization, controlling the radio, and all of the other low level details necessary to realize Bluetooth communications. Bluetooth operates in the 2.4 GHz ISM band. In the US and Europe, a band of 83.5 MHz width is available; in this band, 79 RF channels spaced 1 MHz apart are defined. The channel is represented by a pseudo-random hopping sequence hopping through the 79 or 23 RF channels. Two or more Bluetooth devices using the same channel form a piconet. The hopping sequence is unique for the piconet and is determined by the Bluetooth device address (BD_ADDR) of the master; the phase in the hopping sequence is determined by the Bluetooth clock of the master. The channel is divided into time slots where each slot corresponds to an RF hop frequency. Consecutive hops correspond to different RF hop frequencies. Figure 5.4 shows the communication between the master and a slave. In this case, the master uses even numbered slots and the slave communicates in the odd numbered slots in a half-duplex mode.

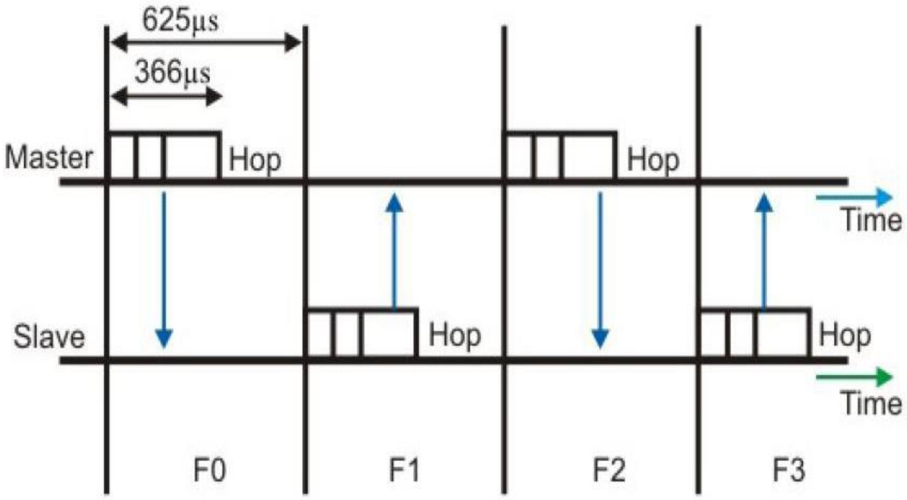

Figure 5.4 Master Slave Communication

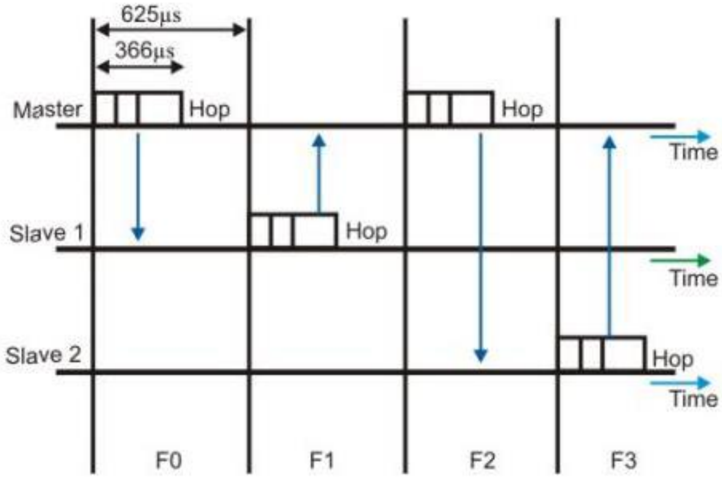

Figure 5.5 Master Slave Multi Communication

The data exchange takes place with every clock tick. The clock synchronization is with respect to that of the master. Transmission takes place by way of TIME DIVISION DUPLEXING (TDD). The channel is divided into time slots, each 625 µs in length. The time slots are numbered according to the Bluetooth clock of the piconet master. A TDD scheme is used where master and slave alternatively transmit. The master shall start its transmission in even-numbered time slots only, and the slave shall start its transmission in odd-numbered time slots only. The packet start shall be aligned with the slot start.

The slave has to always adjust itself to the whims of its master'. If a slave is to establish a connection with the master, then the slave has to synchronize its own clock

according to that of the master. In the multiple-slave scenario, the slave uses even numbered slots, but only one slave communicates in the next odd-numbered slot if the packet in the previous slot was addressed to it. This is shown in Figure 5.5.

The Baseband handles three types of links: SCO (Synchronous Connection-Oriented): The SCO link is a symmetric point to-point link between a master and a single slave in the piconet. The master maintains the SCO link by using reserved slots at regular intervals (circuit switched type). The SCO link mainly carries voice information. The master can support up to three simultaneous SCO links while slaves can support two or three SCO links. SCO packets are never retransmitted. SCO packets are used for 64 kB/s speech transmission. Polling-based (TDD) packet transmissions: In this link type one slot is of 0.625msec (max 1600 slots/sec) and master/slave slots (even-/odd-numbered slots) ACL (Asynchronous Connection-Less) link: The ACL link is a point-tomultipoint link between the master and all the slaves participating on the piconet. In the slots not reserved for the SCO links, the master can establish an ACL link on a per-slot basis to any slave, including the slave already engaged in an SCO link (packet switched type). Only a single ACL link can exist. For most ACL packets, packet retransmission is applied.

Device Addressing: Four possible types of addresses can be assigned to bluetooth units.

• BD_ADDR: Bluetooth Device Address: Each Bluetooth transceiver is allocated a unique 48-bit device address. It is divided into a 24-bit LAP field, a 16-bit NAP field and a 8-bit UAP field.

• AM_ADDR: Active Member Address: It is a 3-bit number. It is only valid as long as the slave is active on the channel. It is also sometimes called the MAC address of a Bluetooth unit.

• PM_ADDR: Parked Member Address: It is a 8-bit member (master-local) address that separates the parked slaves. The PM_ADDR is only valid as long as the slave is parked.

• AR_ADDR: Access Request Address: This is used by the parked slave to determine the slave-to master half slot in the access window it is allowed to send access request messages in. It is only valid as long as the slave is parked and is not necessarily unique.

Layer 3: Link Manager Protocol:

The Link Manager is responsible for managing the physical details for Bluetooth connections. It is responsible for creating the links, monitoring their health, and terminating them gracefully upon command or failure. The link manager is implemented in a mix of hardware and software. The Link Manager carries out link setup, authentication, link configuration and other protocols. It discovers other remote LM's and communicates with them via the Link Manager Protocol (LMP). To perform its service provider role, the LM uses the services of the underlying Link Controller (LC). The Link Manager Protocol essentially consists of a number of PDU (protocol Data Units), which are sent from one device to another, determined by the AM_ADDR in the packet header.

Layer 4: Host Controller Interface:

This is the layer of the stack that contains the firmware i.e. the software that actually controls all the activities happening in the Baseband and Radio layers. It provides a common interface between the Bluetooth host and a Bluetooth module. It manages the hardware links with the scatternets. It also contains the drivers for the hardware devices used in the connection. Basically the BIOS is loaded in the HCI Layer.

Logical Link Control and Adaptation Protocol:

The Logical Link Control and Adaptation Layer Protocol (L2CAP) is layered over the Baseband Protocol and resides in the data link layer.The L2CAP is the big picture brains of a Bluetooth system. It manages the high level aspects of each connection (who is connected to who, whether to use encryption or not, what level of performance is required, etc.). In addition it is responsible for converting the format of data as necessary between the APIs and the lower level Bluetooth protocols. The L2CAP is implemented in software and can execute either on the host system processor or on a local processor in the Bluetooth system. L2CAP provides connection oriented and connectionless data services to upper layer protocols with protocol multiplexing capability, segmentation and reassembly operation, and group abstractions. L2CAP permits higher-level protocols and applications to transmit and receive L2CAP data packets up to 64 kilobytes in length. Two link types are supported for the Baseband layer: Synchronous Connection-Oriented (SCO) links and Asynchronous Connection-Less (ACL) links. SCO links support realtime

voice traffic using reserved bandwidth. ACL links support best effort traffic. The L2CAP Specification is defined for only ACL links and no support for SCO links is planned.

Layer 6: Radio Frequency Communication (RFCOMM):

This is the most important layer in the Bluetooth architecture. RFCOMM takes care of the communication channel between two devices or between a master and a slave. It connects the serial ports of all the devices according to the requirement. RFCOMM basically has to accommodate two kinds of devices:

1. Communication end-points such as computers or printers.

2. Devices that are a part of communication channel such as Modems.

RFCOMM protocol is not aware of the distinction between these two kinds of devices. Hence to prevent any loss of data, it passes on all the information to both the devices. The devices in turn distinguish between the data and filter it out. Layer 7: Service Discovery Protocol The service discovery protocol (SDP) provides a means for applications to discover which services are available and to determine the characteristics of those available services. A specific Service Discovery protocol is needed in the Bluetooth environment, as the set of services that are available changes dynamically based on the RF proximity of devices in motion, qualitatively different from service discovery in traditional network-based environments. The service discovery protocol defined in the Bluetooth specification is intended to address the unique characteristics of the Bluetooth environment. Bluetooth is basically a universal protocol. Manufacturers may embed Bluetooth ports in their devices. SDP is very important when devices from different companies and from different parts of the world are brought together. The devices try to recognize each other through SDP. Telephony Control Protocol Spec (TCS) Basic function of this layer is call control (setup & release) and group management for gateway serving multiple devices. Application Program Interface (API) libraries These are software modules which connect the host application program to the Bluetooth communications system. As such they reside and execute on the same processing resource as the host system application.

5.6 Introduction to Ultrasonics

The word ultrasonic combines the Latin roots ultra, meaning 'beyond' and sonic, or sound. The sound waves having frequencies above the audible range i.e. above 20,000Hz are called ultrasonic waves. Generally these waves are called as high frequency waves. The field of ultrasonics have wide applications in imaging, detection and navigation. The broad sectors of society that regularly apply ultrasonic technology are the medical community, industry, the military and private citizens.

Ultrasound can be modulated to carry an audio signal (like radio signals are modulated). This is often used to carry messages underwater, in underwater diving communicators, and short-range (under five miles) communication with submarines; the received ultrasound signal is decoded into audible sound by a modulated-ultrasound receiver. A modulated ultrasound receiver is a device that receives a modulated ultrasound signal and decodes it for use as sound, navigational-position information, etc. Its function is somewhat like that of a radio receiver Ultrasound imaging is a direct, non-reconstructive form of imaging where image formation is obtained by localizing an ultrasonic wave to a small volume in 3D space. Two dimension of localization are performed by diffraction (focusing), as in optics. One dimension is performed by pulsing, as in RADAR. The ultrasonic wave is produced by electrical excitation of a piezoelectric transducer, which is usually transmitted to the body through an impedance matching gel. Ultrasonic waves are detected by the same transducer and converted into an electrical signal for processing and display.

5.6.1 Properties of ultrasonic waves

- **They have a high energy content.**
- **Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed.**
- **They can be transmitted over longer distances with no appreciable loss of energy.**
- **If an arrangement is made to form stationary waves of ultrasonics in a liquid, it serves as a diffraction grating. It is called an acoustic grating.**
- **They produce intense heating effect when passed through a substance.**

5.6.2 Production of Ultrasonics

There are different methods for the production of ultrasonics. However, the most commonly used methods are as below:

1. **Mechanical method**
2. **Magnetostriction generator**
3. **Piezoelectric generator**

Mechanical Method

This is one of the earliest methods for producing ultrasonic waves of frequencies up to 100 kHz with the help of Galton's whistle. The mechanical method is rarely used due to its limited frequency range.

Magnetostriction Generator

Principle: Magnetostriction effect

When a ferromagnetic rod like iron or nickel is placed in a magnetic field parallel to its length, the rod experiences a small change in its length. This is called magnetostricion effect.

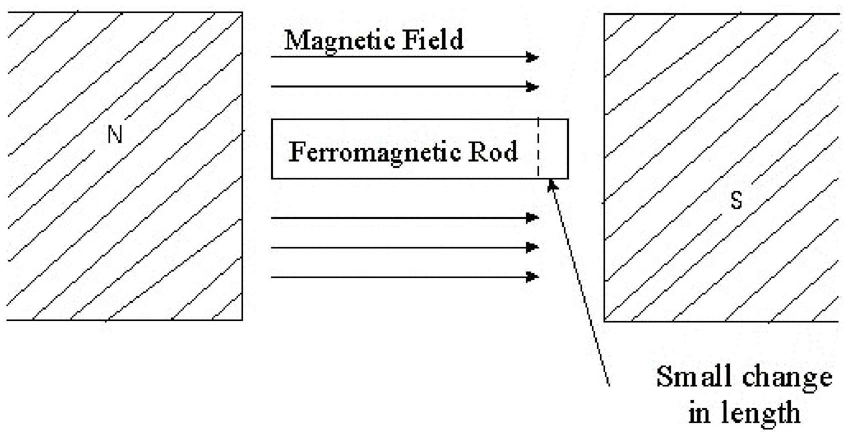

Figure 5.6: Magnetostricion effect

The change in length (increase or decrease) produced in the rod depends upon the strength of the magnetic field, the nature of the materials and is independent of the direction of the magnetic field applied.

The experimental arrangement is shown in Figure for Magneto-striction oscillator. XY is a rod of ferromagnetic materials like iron or nickel. The rod is clamped in the middle. The alternating magnetic field is generated by electronic oscillator. The coil L1 wound on the right hand portion of the rod along with a variable capacitor C. This forms the resonant circuit of the collector tuned oscillator. The frequency of oscillator is controlled by the variable capacitor. The coil L2 wound on the left hand portion of the rod is connected to the base circuit. The coil L2 acts as feed –back loop.

Magnetostriction oscillator operation

- **XY is a rod of ferromagnetic materials like iron or nickel. The rod is clamped in the middle**
- **The alternating magnetic field is generated by electronic oscillator**
- **The coil L1 wound on the right hand portion of the rod along with a variable capacitor C**
- **This forms the resonant circuit of the collector tuned oscillator. The frequency of oscillator is controlled by the variable capacitor**
- **The coil L2 wound on the left hand portion of the rod is connected to the base circuit. The coil L2 acts as feed–back loop**

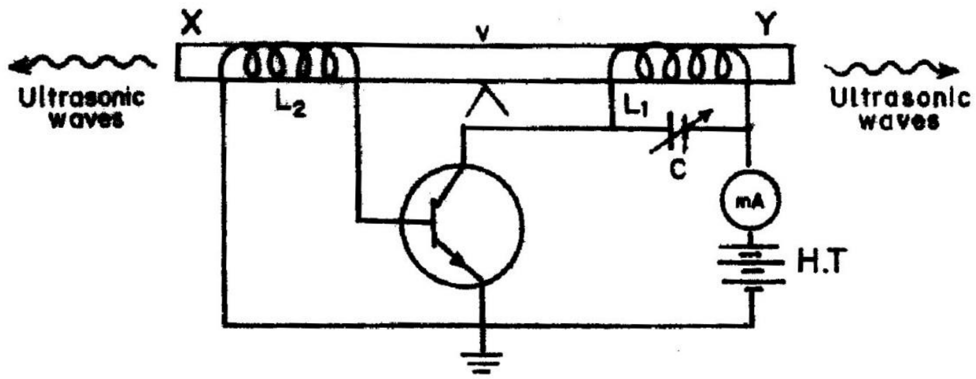

Figure 5.7 Magnetostricion Oscillator Experimental arrangement

Magnetostriction oscillator operation

When High Tension (H.T) battery is switched on, the collector circuit oscillates with a frequency,

$$f = \frac{1}{2\pi\sqrt{L_1 C}}$$

This alternating current flowing through the coil L1 produces an alternating magnetic field along the length of the rod. The result is that the rod starts vibrating due to magnetostrictive effect.

The frequency of vibration of the rod is given by

$$n = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$

where l **= length of the rod**

Y **= Young's modulus of the rod material and**

ρ **= density of rod material**

The capacitor C is adjusted so that the frequency of the oscillatory circuit is equal to natural frequency of the rod and thus resonance takes place.

Now the rod vibrates longitudinally with maximum amplitude and generates ultrasonic waves of high frequency from its ends.

Advantages

- **The design of this oscillator is very simple and its production cost is low.**
- **At low ultrasonic frequencies, the large power output can be produced without the risk of damage of the oscillatory circuit.**

Disadvantages

- **It has low upper frequency limit and cannot generate ultrasonic frequency above 3000 kHz (ie. 3MHz).**
- **The frequency of oscillations depends on temperature.**
- **There will be losses of energy due to hysteresis and eddy current.**

5.6.3 Inverse piezo electric effect

If mechanical pressure is applied to one pair of opposite faces of certain crystals like quartz, equal and opposite electrical charges appear across its other faces. This is called as piezo-electric effect. The converse of piezo electric effect is also true. If an electric field is applied to one pair of faces, the corresponding changes in the dimensions of the other pair of faces of the crystal are produced. This is known as inverse piezo electric effect or electrostriction.

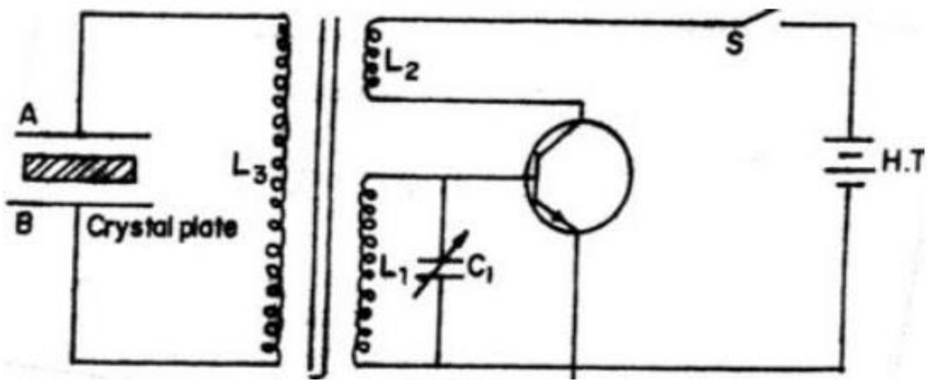

Figure 5.7 Piezo electric oscillator circuit diagram

The quartz crystal is placed between two metal plates A and B. The plates are connected to the primary (L3) of a transformer which is inductively coupled to the electronics oscillator. The electronic oscillator circuit is a base tuned oscillator circuit. The coils L1 and L2 of oscillator circuit are taken from the secondary of a transformer T. The collector coil L2 is inductively coupled to base coil L1. The coil L1 and variable capacitor C1 form the tank circuit of the oscillator.

When H.T. battery is switched on, the oscillator produces high frequency alternating voltages with a frequency.

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

Due to the transformer action, an oscillatory E.M.F. is induced in the coil L3. This high frequency alternating voltages are fed on the plates A and B.

Inverse piezo-electric effect takes place and the crystal contracts and expands alternatively. The crystal is set into mechanical vibrations. The frequency of the vibration is given by

$$n = \frac{P}{2l}\sqrt{\frac{Y}{\rho}}$$

where P = 1,2,3,4 … etc. for fundamental, first over tone, second over tone etc.,

Y = Young's modulus of the crystal and

ρ = density of the crystal

The variable condenser C1 is adjusted such that the frequency of the applied AC voltage is equal to the natural frequency of the quartz crystal, and thus resonance takes place. The vibrating crystal produces longitudinal ultrasonic waves of large amplitude.

Advantages

1. Ultrasonic frequencies as high as 5 x 108Hz or 500 MHz can be obtained with this arrangement.

2. The output of this oscillator is very high.

3. It is not affected by temperature and humidity.

Disadvantages

1. The cost of piezo electric quartz is very high

2. The cutting and shaping of quartz crystal are very complex.

5.6.4 Applications of Ultrasonic Waves in Engineering

(1) Detection of flaws in metals (Non Destructive Testing –NDT)

Principle

Ultrasonic waves are used to detect the presence of flaws or defects in the form of cracks, blowholes porosity etc., in the internal structure of a material.

By sending out ultrasonic beam and by measuring the time interval of the reflected beam, flaws in the metal block can be determined.

Experimental setup

It consists of an ultrasonic frequency generator and a cathode ray oscilloscope (CRO),transmitting transducer(A), receiving transducer(B) and an amplifier.

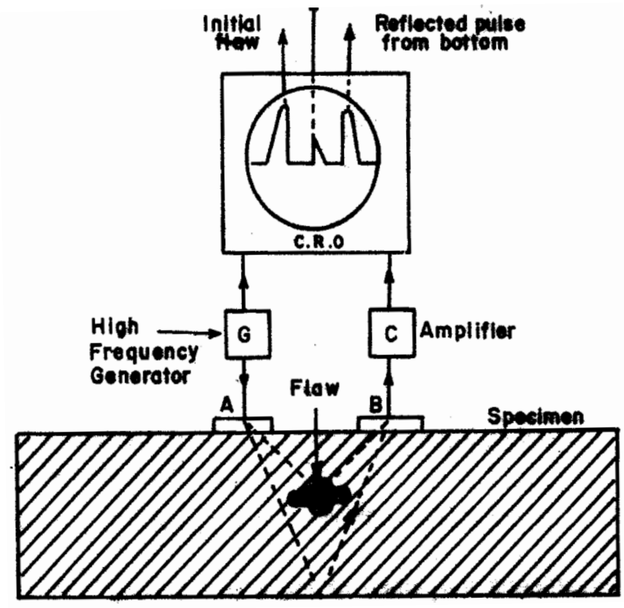

Figure 5.8: Non Destructive Testing Experimental setup

Working

In flaws, there is a change of medium and this produces reflection of ultrasonic at the cavities or cracks.

The reflected beam (echoes) is recorded by using cathode ray oscilloscope.

The time interval between initial and flaw echoes depends on the range of flaw.

By examining echoes on CRO, flaws can be detected and their sizes can be estimated.

Features

This method is used to detect flaws in all common structural metals and other materials like rubber tyres etc.

The method is very cheap and of high speed of operation.

It is more accurate than radiography.

(2) Ultrasonic Drilling

Ultrasonics are used for making holes in very hard materials like glass, diamond etc.

For this purpose, a suitable drilling tool bit is fixed at the end of a powerful ultrasonic generator.

Some slurry (a thin paste of carborundum powder and water) is made to flow between the bit and the plate in which the hole is to be made

Ultrasonic generator causes the tool bit to move up and down very quickly and the slurry particles below the bit just remove some material from the plate.

This process continues and a hole is drilled in the plate.

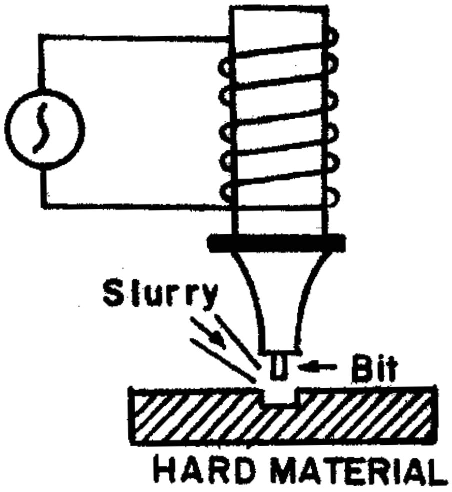

Figure 5.8: Ultrasonic Drilling

(3) Ultrasonic welding

The properties of some metals change on heating and therefore, such metals cannot be welded by electric or gas welding.

In such cases, the metallic sheets are welded together at room temperature by using ultrasonic waves.

For this purpose, a hammer H is attached to a powerful ultrasonic generator as shown in Figure 5.9.

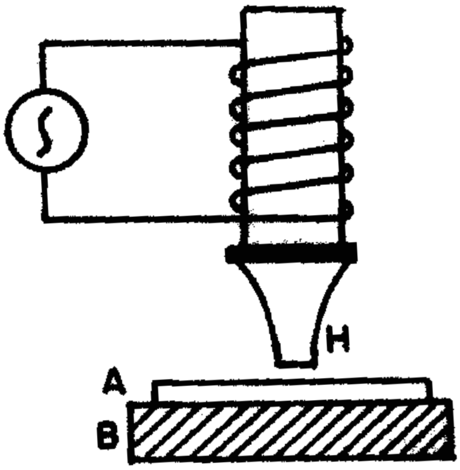

Figure 5.8: Ultrasonic welding

(4) Ultrasonic soldering

Metals like aluminium cannot be directly soldered. However, it is possible to solder such metals by ultrasonic waves.

An ultrasonic soldering iron consists of an ultrasonic generator having a tip fixed at its end which can be heated by an electrical heating element.

The tip of the soldering iron melts solder on the aluminium and the ultrasonic vibrator removes the aluminium oxide layer.

The solder thus gets fastened to clear metal without any difficulty.

(5) Ultrasonic cutting and machining

Ultrasonic waves are used for cutting and machining.

(6) Ultrasonic cleaning

It is the most cheap technique employed for cleaning various parts of the machine, electronic assembles, armatures, watches etc., which cannot be easily cleaned by other methods.

(7) SONAR

SONAR is a technique which stands for Sound Navigation and Ranging.

It uses ultrasonics for the detection and identification of under water objects.

The method consists of sending a powerful beam of ultrasonics in the suspected direction in water. By noting the time interval between the emission and receipt of beam after reflection, the distance of the object can be easily calculated.

The change in frequency of the echo signal due to the Doppler effect helps to determine the velocity of the body and its direction. Measuring the time interval (t) between the transmitted pulses and the received pulse, the distance between the transmitter and the remote object is determined using the formula., where v is the velocity of sound in sea water. The same principle is used to find the depth of the sea.

Applications of SONAR

Sonar is used in the location of shipwrecks and submarines on the bottom of the sea.

It is used for fish-finding application.

It is used for seismic survey.

Worked Problem

A quartz crystal of thickness 1 mm is vibrating at resonance. Calculate the fundamental frequency. Given Y for quartz = 7.9 x 1010 Nm^{-2} and ρ for quartz = 2650 kg m^{-3}.

The frequency of the vibration

$$f = \frac{P}{2t}\sqrt{\frac{Y}{\rho}}$$

Here P = 1

$$f = \frac{1}{2 \times 0.001}\sqrt{\frac{7.9 \times 10^{10}}{2650}}$$

= 2.72998 x 106 Hz

The fundamental frequency of the quartz crystal = 2.730 x 106 Hz = 2.73 MHz.

5.7 RF Characteristics

All RF waves have characteristics that vary to define the wave. Some of these properties can be modified to modulate information onto the wave. These properties are wavelength, frequency, amplitude, and phase.

Wavelength

The wavelength of an RF wave is calculated as the distance between two adjacent identical points on the wave. For example, Figure.1 shows a standard sine wave. Point A and Point B mark two identical points on the wave, and the distance between them is defined as the wavelength. The wavelength is frequently measured as the distance from one crest of the wave to the next. The wavelength dictates the optimum size of the receiving antenna, and it determines how the RF wave will interact with its environment. For example, an RF wave will react differently when it strikes an object that is large in comparison to the wavelength from when it strikes an object that is small in comparison to the wavelength. The wavelength and the frequency are interrelated. In fact for a given medium, if wavelength is known, the frequency can be calculated and if frequency is known, wavelength can be calculated. One of the great discoveries in the history of electromagnetism is that electromagnetic waves travel at the speed of light. Since the speed of light is 299,792,458 meters per second, and this is the speed at which

electromagnetic waves travel in a vacuum. This was theorized by James Clerk Maxwell and proved through experimentation by Heinrich Hertz.

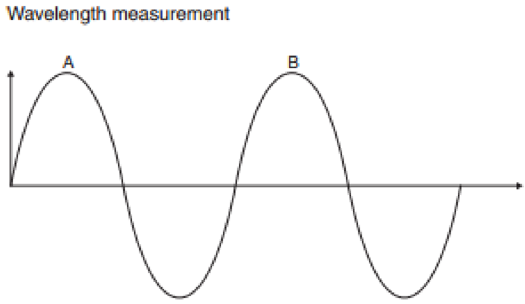

Figure 5.9: Wavelength Measurement

Frequency

Frequency refers to the number of wave cycles that occur in a given window of time. Usually measured in second intervals, a frequency of 1 kilohertz (KHz) would represent 1000 cycles of the wave in 1 second. The wave cycles frequently and just how frequently it cycles determines its frequency. Since all electromagnetic waves, including radio waves, move at the speed of light, the frequency is related to the wavelength. In other words, the wavelength, frequency, and medium are interdependent. Higher frequencies have longer wavelengths. The concept of frequency is used in sound engineering as well as RF engineering.

Amplitude

At greater distances, shorter-wavelength waves are more difficult to detect as the waveform spreads ever wider (though this may be more a factor of the antenna used than of the waveform itself). The characteristic that defines the volume is known as amplitude. In sound wave engineering, an increase in amplitude is equivalent to an increase in volume; hence, an amplifier adds to the volume, or makes the sound louder. While the frequency affects the distance a sound wave can travel, the amplitude affects the ability to detect (hear) the sound wave at that distance.

An RF wave with greater amplitude is easier to detect than an RF wave with lesser amplitude, assuming all other factors are equal. In other words, in a vacuum, an RF wave has better quality at a distance if it has greater amplitude. Realize that RF waves travel, theoretically, forever. This being the case, the detectability of the wave is greater at certain distances when the wave starts with greater amplitude. A wave with a lesser

amplitude may not be detectable due to the noise floor. The noise floor can be defined as a measure of the level of background noise. In other words, there is a point in space where an RF wave still exists, but it cannot be distinguished from the electromagnetic noise in the environment. In effect, both the high-amplitude and low-amplitude waves exist at that point, but only the high-amplitude wave can be detected. This means that both waves have traveled the distance, but only the high-amplitude wave is useful. For this reason, in common usage, engineers often say that an increase in amplitude will extend the range of the RF wave. What is meant by this is that the RF wave's useful range has been extended. Figure 5.10 shows an RF signal with original, increased, and decreased amplitudes.

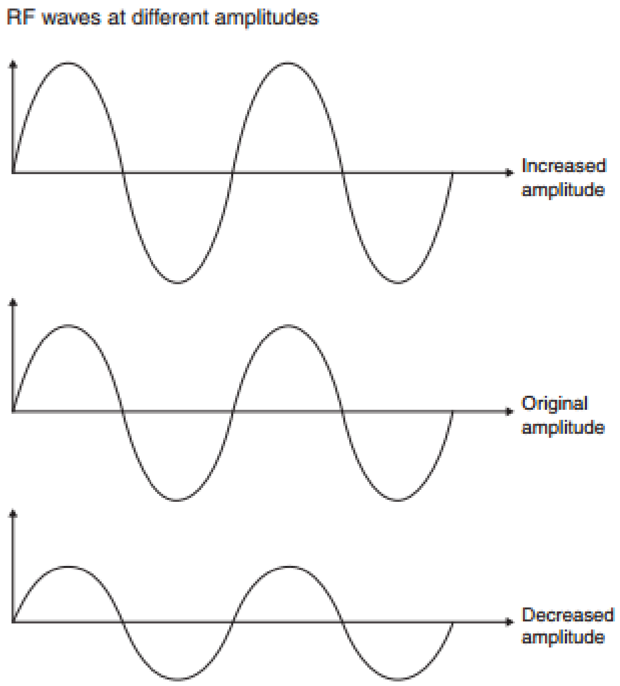

Figure 5.10: RF waves at different amplitudes

Phase

Unlike wavelength, frequency, and amplitude, phase is not a characteristic of a single RF wave but is instead a comparison between two RF waves. If two copies of the same RF wave arrive at a receiving antenna at the same time, their phase state will impact how the composite wave is able to be used. When the waves are in phase, they strengthen each other, and when the waves are out of phase, they sometimes strengthen and sometimes cancel each other. In specific out-of-phase cases, they only cancel each other. Phase is measured in degrees, though real-world analysis usually benefits only from the knowledge of whether the waves are in phase or out of phase. Two waves that are

completely out of phase would be 180 degrees out of phase, while two waves that are completely in phase would be 0 degrees out of phase. Fig. 5.11 shows a main wave signal, another in-phase signal, and an out-of-phase signal. Phase is used for many modern RF modulation algorithms. When troubleshooting wireless networks, the phase of duplicate RF signals is mostly an implication of reflection or scattering in an area that may cause dead zones due to the out-of-phase signals.

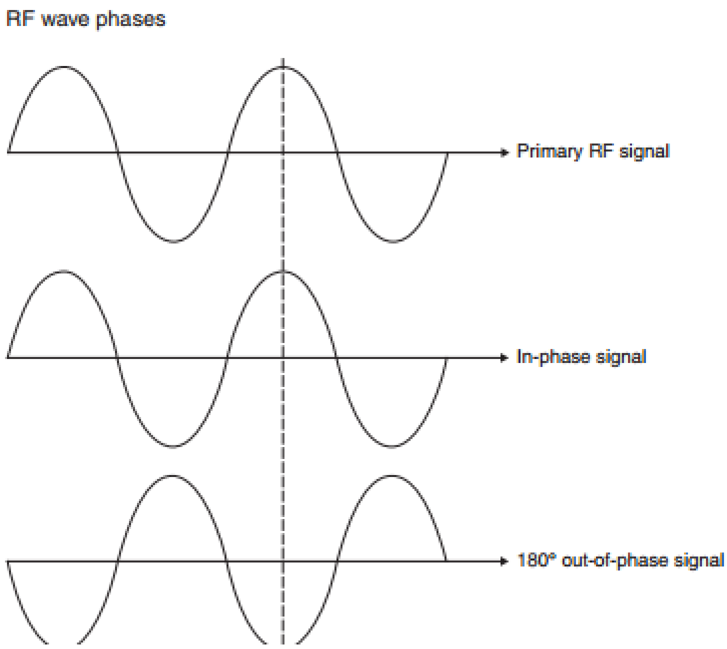

Figure 5.11: RF Wave Phases

RF Behavior

RF waves that have been modulated to contain information are called RF signals. These RF signals have behaviors that can be predicted and detected. They become stronger, and they become weaker. They react to different materials differently, and they can interfere with other signals. The following sections introduce you to the major RF signal behaviors and their implications, including

- **Gain**
- **Loss**
- **Reflection**
- **Refraction**
- **Diffraction**

- **Scattering**
- **Absorption**
- **VSWR**
- **Return**
- **Amplification and Attenuation**
- **Wave Propagation**
- **Free Space Path Loss**
- **Delay Spread**

Gain

Gain is defined as the positive relative amplitude difference between two RF wave signals (hereinafter known as only RF signals). Amplification is an active process used to increase an RF signal's amplitude and, therefore, results in gain. There are two basic types of gain: active and passive. Both types can be intentional, and passive gain can also be unintentional. Fig.3 shows an example of a signal that demonstrates both gain and loss.

Active Gain

Active gain is achieved by placing an amplifier in-line between the RF signal generator (such as an access point) and the propagating antenna. Usually measure the gain is measured in decibel (dB). For example, an amplifier may provide 6 dB of gain to the incoming RF signal. To determine the actual power of the signal after passing through the amplifier, the original power of the signal should be known from the RF generator and then perform the appropriate RF math.

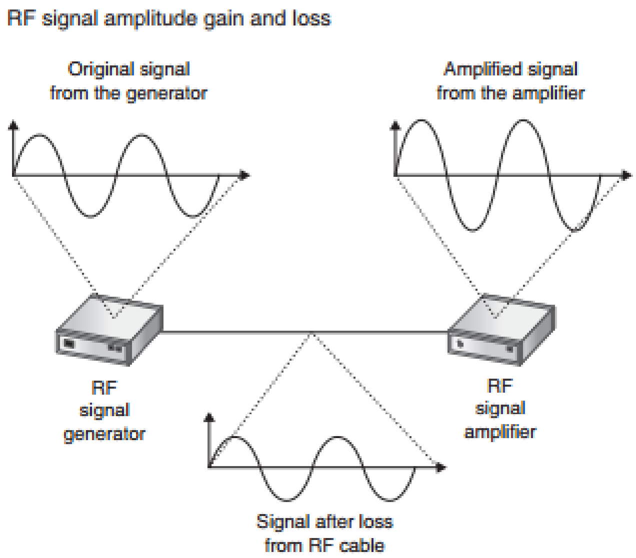

Figure 5.12: RF Signal Amplitude Gain and Loss

Passive Gain

Passive gain is not an actual increase in the amplitude of the signal delivered to the intentional radiator, but it is an increase in the amplitude of the signal, in a favored direction, by focusing or directing the output power. Passive gain can be either intentional or unintentional.

Intentional Passive Gain

Intentional passive gain is directing the sound waves, intentionally, toward that targeted location. This is intentional passive gain. Antennas are used to provide intentional passive gain in wireless networks using RF signals. The antenna propagates more of the RF signal's energy in a desired direction than in other directions. The RF signal is said to have gain in that direction.

Unintentional Passive Gain

Unintentional passive gain happens because of reflection and scattering in a coverage area. When the RF signal leaves the transmitting antenna, the primary signal travels out from the antenna according to the propagation patterns for which the antenna is designed. However, this signal may encounter objects that cause reflection and scattering, resulting in multiple copies of the same signal arriving at the receiving

antenna. If these signals arrive in phase, they can cause the signal strength to actually increase and this would be a form of unintentional passive gain; however, some RF engineers doubt that RF energy, once scattered, is ever joined with other signal paths to produce passive gain of any measurable value.

Loss

Loss is defined as the negative relative amplitude difference between two RF signals. Like gain, loss can be either intentional or unintentional (referenced as natural in this section).

Intentional

Due to FCC regulations and the regulations of other regulatory domains, you will have to ensure that the output powers of your wireless devices are within specified constraints. Depending on the radios, amplifiers, cables, and antennas you are using, you may have to intentionally cause loss in the RF signal. This means that you are

reducing the RF signal's amplitude, and this is accomplished with an attenuator. Attenuation, the process that causes loss, is discussed in greater detail in the later section "Attenuation."

Natural

In addition to the intentional loss that is imposed on an RF signal to comply with regulatory demands, natural or unintentional losses can occur. This kind of loss happens because of the natural process of RF propagation, which involves spreading, reflection, refraction, scattering, diffraction, and absorption.

Reflection

When an RF signal bounces off of a smooth, nonabsorptive surface, changing the direction of the signal, it is said to reflect and the process is known as reflection. RF signals also reflect off objects that are smooth and larger than the waves that carry the signals. Earlier it was noted that the wavelength impacts the behavior of the RF wave as it propagates through space. This is the first example of the relationship of the wavelength and the space through which the wave travels. If the space were empty, there would be no reflection, but since all space we operate in (Earth and its atmosphere) contains some elements of matter, reflection, refraction, scattering, diffraction, and

absorption are expected. Since the object that causes reflection will normally be smooth and larger than the wavelength and since waves used by IEEE 802.11–compliant radios are between 5 and 13 centimeters, it follows that the objects will be greater than 5 centimeters in size (for 5 GHz U-NII bands) or 13 centimeters in size (for the 2.4 GHz ISM band) and smooth. Such objects include metal roofs, metal or aluminum wall coverings, elevators, and other larger smooth objects. Fig.4 shows the traditional diagram of RF signal reflection. It is important to remember that reflected signals are usually weaker after reflection. This is because some of the RF energy is usually absorbed by the reflecting material.

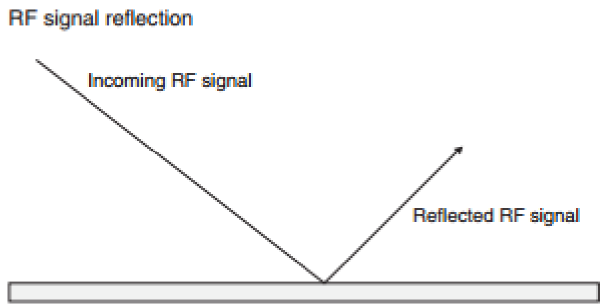

Figure 5.13: RF Signal Reflection

Refraction

Refraction occurs when an RF signal changes speed and is bent while moving between media of different densities. Different mediums, such as drywall, wood, or plastic, will have different refraction indexes. The refraction index helps in determining how much refraction will occur. Fig.5.14 shows an RF signal being refracted. When refraction occurs with RF signals, some of the signal is reflected and some is refracted as it passes through the medium. Of course, as with all mediums, some of the signal will be absorbed as well. RF signal refraction is usually the result of a change in atmospheric conditions. For this reason, refraction is not usually an issue within a building, but it may introduce problems in wireless site-to-site links outdoors. Common causes of refraction include changes in temperature, changes in air pressure, or the existence of water vapor. If the RF signal changes from the intended direction as it are traveling from the transmitter to the receiver, the receiver may not be able to detect and process the signal. This can

result in a broken connection or in increased error rates if the refraction is temporary or sporadic due to fluctuations in the weather around the area of the link.

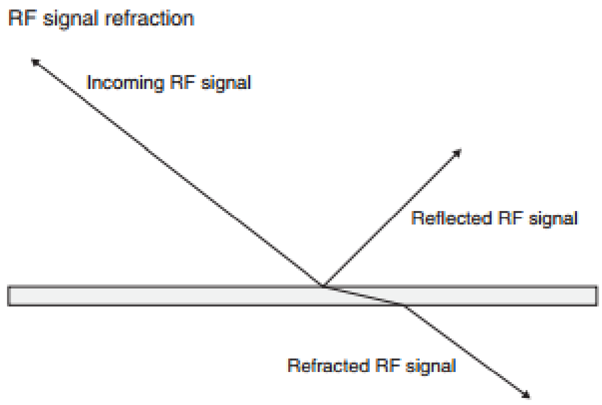

Figure 5.14: RF Signal Reflection

Diffraction

Diffraction is defined as a change in the direction and/or intensity of a wave as it passes by the edge of an obstacle. As from Fig.6, this can cause the signal's direction to change, and it can also result in areas of RF shadow. Instead of bending as it passes into or out of an obstacle, as in the case of refraction, light is diffracted as it travels around the obstacle. Diffraction occurs because the RF signal slows down as it encounters the obstacle and this causes the wave front to change directions. Diffraction is often caused by buildings, small hills, and other larger objects in the path of the propagating RF signal.

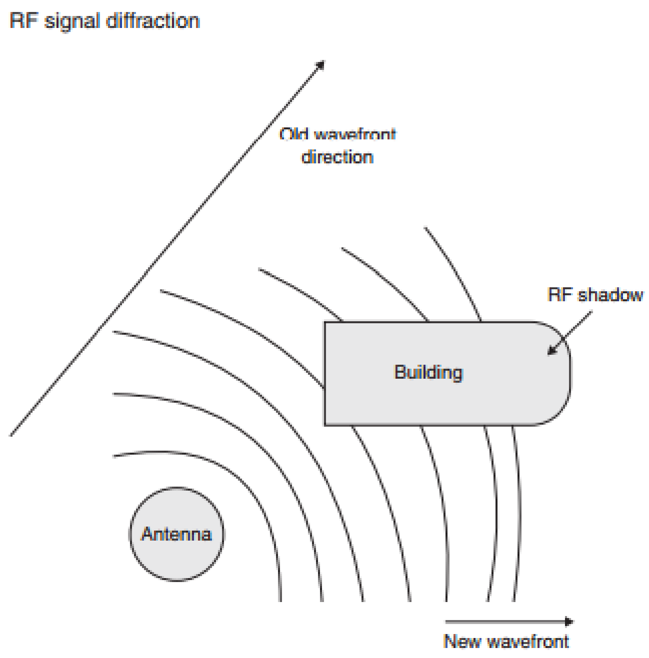

Figure 5.15: RF Signal Diffraction

Scattering

Scattering happens when an RF signal strikes an uneven surface (a surface with inhomogeneities) causing the signal to be scattered instead of absorbed so that the resulting signals are less significant than the original signal. Another way to define scattering is to say that it is multiple reflections. Fig.5.16 illustrates this. Scattering can happen in a minor, almost undetectable way, when an RF signal passes through a medium that contains small particles. These small particles can cause scattering. Smog is an example of such a medium. The more common and more impactful occurrence is that caused when RF signals encounter things like rocky terrain, leafy trees, or chain link fencing. Rain and dust can cause scattering as well.

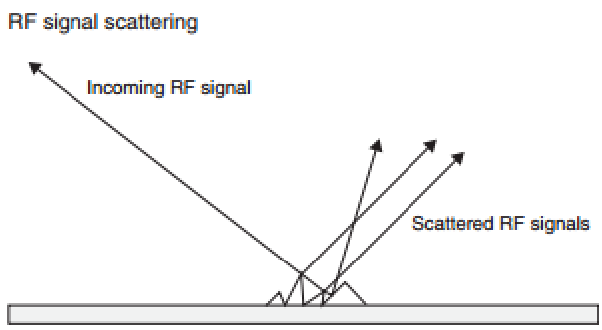

Figure 5.16: RF Signal Scattering

Absorption

Absorption is the conversion of the RF signal energy into heat. This happens because the molecules in the medium through which the RF signal is passing cannot move fast enough to "keep up" with the RF waves. Many materials absorb RF signals in the 2.4 GHz ISM spectrum. These include water, drywall, wood, and even humans. Fig.8 shows RF signal absorption. Different materials have different absorption rates. Table1 provides a breakdown of some of the more common types of materials and the absorption rates associated with them. When performing a site survey or troubleshooting a communications problem, you should certainly consider the effects of these types of materials.

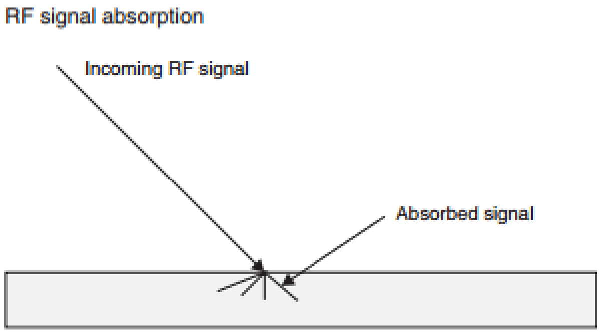

Figure 5.17: RF Signal Absorption

Amplification

Amplification is an increase of the amplitude of an RF signal. Passive gain, is an amplification of an RF signal up to the intentional radiator. Passive gain is a focusing or directing of an RF signal. Amplification is achieved through active gain and is accomplished with an amplifier. Many access points contain variable power output settings, and while this capability is not technically an amplifier, these settings will impact the amplitude of the RF signal that is generated. Therefore, the changing of this setting to higher setting results in a stronger RF signal from the access point.

Attenuation

Attenuation is the process of reducing an RF signal's amplitude. This is occasionally done intentionally with attenuators to reduce a signal's strength to fall within a regulatory domain's imposed constraints. Loss is the result of attenuation, and gain is the result of amplification. RF cables, connectors, and devices may have some level of

imposed attenuation, and this attenuation is usually stated in decibels and is often stated as loss in decibels per foot—this is also known as insertion loss. Insertion loss is the loss incurred by simply inserting the object (cable, connector, etc.) into the path of the RF signal between the source and the intentional radiator.

Wave Propagation

The way RF waves move through an environment is known as wave propagation. Attenuation occurs as RF signals propagate through an environment. When the RF signal leaves the transmitting antenna, it will begin propagation through the local environment and continue on, theoretically, forever. The signal cannot be detected after a certain distance, and this becomes the usable range of the signal. This is because attenuation occurs as the signal propagates through the environment. Some of the signal strength is lost through absorption by materials encountered by the RF signal, however, even without any materials in the path of the signal, the amplitude will be lessened. This is due to a phenomenon known as free space path loss.

Free Space Path Loss

Free space path loss, sometimes called free space loss (FSL) or just path loss, is a weakening of the RF signal due to a broadening of the wave front. This broadening of the wave front is known as signal dispersion.

Multipath and Delay Spread

When signals bounce around in an environment through reflection, refraction, diffraction, and scattering, they create an effect known as multipath. Multipath occurs when multiple paths of the signal, understood as multiple signals, arrive at the receiving antenna at the same time or within a small fraction of a second (nanoseconds) of each other. Multipath can also occur outdoors when signals reflect off of large objects in the RF link path, as is shown in Fig.5.18 Multipath occurs very frequently indoors and is so common an occurrence that many access point vendors include multiple antennas for dealing with this phenomenon. Fig.5.18 suggests the potential for multipath indoors. As the, file cabinets, walls, desks, and doors— among other things—can cause RF propagation patterns that result in multiple paths arriving at the receiving antenna. In an indoor environment, there is often no direct signal path between the transmitter and the receiver (or the access point and the client station). This means that all signals

reaching the client station will have arrived via the RF propagation patterns similar to those in Fig.5.18. The difference in time between the first and second signals arriving at the receiver in a multipath occurrence is known as the delay spread. These signals arriving at the receiver with a delay spread of nearly 0 will complement each other and cause signal upfade. In other words, the received signal will be stronger at the receiver than it would have been without the multipath occurrence. When the delay spread is greater, so that the signals arrive out of phase, the signal will either be downfaded, corrupted, or nullified.

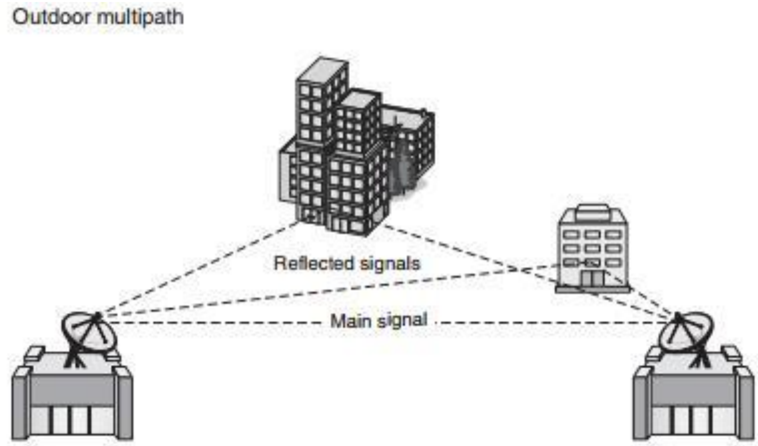

Figure 5.18: Outdoor multipath

5.8 ZigBee

ZigBee is the commercial name for another PAN network technology based on the IEEE

802.15.4 wireless standard. Like Bluetooth, it is a short-range technology with networking capability. It was designed primarily for commercial, industrial, and home monitoring and control applications. The 802.15.4 standard defines the so-called air interface, which is the physical layer (PHY or layer 1 of the OSI standard) and the media access control (MAC or layer 2) of the system. The ZigBee Alliance, an organization of chip, software, and equipment vendors of ZigBee products, specifies additional higher levels of layers including networking and security.

ZigBee is designed to operate in the license-free spectrum available in the world. This is defined by the FCC Part 15 in the United States.

Even though the data rates are low, this is not usually an issue, because most applications are simply transmitting sensor data or making simple on/off operations.

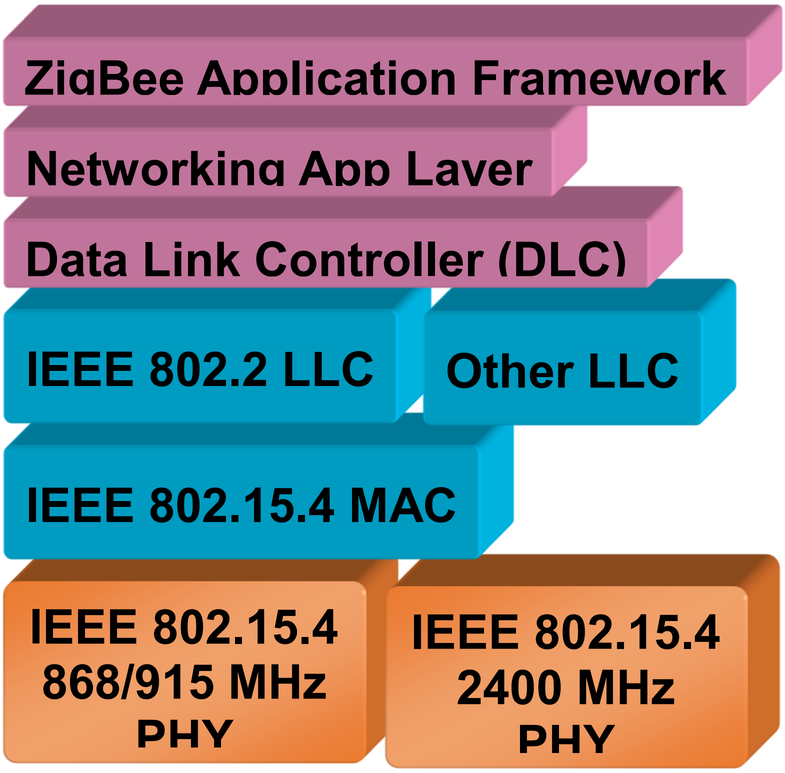

Figure 5.19: IEEE 802.15.4 Architecture

Transmission is by packets with a maximum size of 128 bytes, 104 of which is data. Both 16- and 64-bit addressing modes are available, although the maximum is considered to be up to 65,536 total nodes. The access method as with Wi-Fi is CSMA/CA. The most widely used version is the one operating in the 2.4-GHz band. As for range, it varies considerably with the application and the environment. Using 2.4 GHz, the typical maximum indoor range is about 30 m. That can extend to 400 m outdoors with a clear line of sight. Maximum range is obtained at 868 or 900 MHz and can be as much as 1000 m with a line-of-sight path.

ZigBee's virtue is its versatile networking capability. The standard supports three topologies: star, mesh, and cluster tree. The most commonly used are the star and mesh, illustrated in Fig. 16. These network topologies are made up of three types of ZigBeenodes: a ZigBee coordinator (ZC), a ZigBee router (ZR), and ZigBee end device (ZED).The ZC initiates a network formation. There is only one ZC per network. The ZR servesas monitor or control device that observes a sensor or initiates off/on operations on some end device. It also serves as a router as it can receive data from other nodes and retransmit it to other nodes. The ZED is simply an end monitor or control device that only receives data or transmits it. It does not repeat or route. The ZC and ZR nodes are called full-function devices (FFDs), and the ZED is known as a reduced-function device (RFD).The star coniguration in Fig. 16(a) is the most common, where a centrally located ZR accepts data from or distributes control data to other ZRs or ZEDs. The central ZR then communicates back to the ZC, which serves as the master controller for the system.

In the mesh topology, most of the nodes are ZRs, which can serve as monitor and control points but also can repeat or route data to and from other nodes. The value of the mesh topology is that it can greatly extend the range of the network. If a node lacks the power or position to reach the desired node, it can transmit its data through adjacent nodes that pass along the data until the desired location is reached. While the maximum range between nodes may be only 30 m or less, the range is multiplied by passing data from node to node over a much longer range and wider area.

An additional feature of the mesh topology is network reliability or robustness. If one node is disabled, data can still be routed through other nodes over alternate paths. With redundant paths back to the ZC, a ZigBee mesh ensures that data reaches its destination regardless of unfavorable conditions. Many critical applications require this levelof reliability.

As for applications, ZigBee can address a wide range of wireless needs. It was designed primarily for monitoring and control. Monitoring refers to looking at a wide range of physical conditions, especially temperature, humidity, pressure, the presence of light, speed, and position information. Sensors generate an analog signal representing the physical variable that is amplii ed and otherwise conditioned and then converted to digital data that is transmitted back to the central monitoring location where decisions are made. This characteristic makes ZigBee a superior short-range telemetry system in what is being called wireless sensor networks.

Control refers to the sending of command signals to initiate some action. Typically commands are used to turn things off and on. Some examples are lights, motors, solenoids, relays, and other devices that perform some type of function. Some popular applications include monitoring and controlling lights; heating, ventilating, and air conditioning (HVAC) systems in large buildings; and industrial monitoring and control in factories, chemical plants, and manufacturing operations. Automatic electric and gas meter reading is a major application. Other applications include medical uses such as wireless patient monitoring, automotive sensor systems, military battlefield monitoring, and a whole host of consumer applications such as home monitoring and control, remote control of other objects, and security. Because ZigBee is so low-cost and battery-operated, it can be used in a wide range of situations, most of which probably have not been discovered yet.

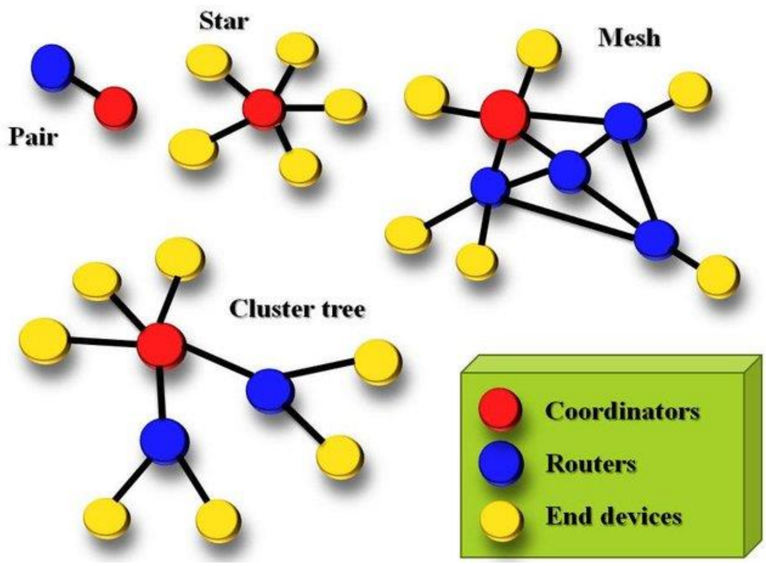

Figure 5.19: ZigBee network topologies

5.9 Wi-Fi

Wi-Fi is the wireless local area network (WLAN) technology widely used throughout the world to implement Internet connections. Virtually all smart phones contain a Wi-Fi transceiver, and many include two antennas for MIMO. The Wi-Fi capability permits smart phones to connect to any available access point or hot spot, including wireless routers that are part of many home broadband Internet connections today.

Wi-Fi Characteristics

This section describes basic characteristics that are common to all Wi-Fi networks.

Operating Frequency

There are two signaling frequencies currently used by Wi-Fi networks:

• 2.4 GHz - Comprises 14 channels, each with a bandwidth of approximately 20 to 22 MHz operating in the ISM band. 802.11b/g networks operate in the 2.4 GHz band. It is a crowded frequency because many devices other than 802.11 devices operate in it. For example, Bluetooth as well as many consumer products such as microwaves, telephones, garage door openers, baby monitors, etc.

• 5 GHz - Comprises 13 channels, each with a bandwidth of approximately 20 MHz operating in the U-NII band. 802.11a networks operate in the 5 GHz band. Currently, this band is less crowded than 2.4 GHz, but this is likely to change as the wireless market continues to grow.

Higher frequency signals have higher attenuation passing through obstacles than do lower frequency signals. This is because some of the energy of the electromagnetic field transfers into the material of the obstacle (cement walls, foliage, etc.) which reduces the strength of the signal.

Signal Strength and Range

Received signal strength is a function of the power output of the transmitter, the frequency used, the distance travelled by the signal, and the path loss that occurs before the signal is received.

Received signal strength, and thus usable range, can vary from moment to moment because propagation characteristics are dynamic and unpredictable. This means that small changes in the environment can result in huge changes to Rx signal strength. The critical thing is received signal-to-noise ratio. Noise is a function of interfering source strength, proximity, and bandwidth. Additionally, all receivers contain an inherent noise source caused by fundamental physical processes such as random thermal motion of charge carriers. In practice, Rx signal-to-noise ratio (SNR) is required for higher transmission speed. SNR is more important than absolute Rx signal strength.

Data Rate and Throughput

802.11 requires positive and timely acknowledgement of each frame transmitted. Unlike wired Ethernet, where the chance of interference is relatively small, 802.11 anticipates a high probability of interference.

There are several things to consider in order to determine the throughput needed by an application.

- **What type of traffic will traverse the network?**
- **Is the traffic steady or intermittent?**
- **Does the application require low latency?**
- **What error rate is acceptable?**

The table given below lists the data rates supported by the IEEE 802.11 standards. The initial 802.11 specification defined two data rates: 1 and 2 Mbps. These low rates were inadequate for some applications, which spurred the development of 802.11 standards with faster data rates. The 1 Mbps data is the most robust data rate for industrial applications in general.

Data Rates Supported by IEEE 802.11 Standards

802.11 Extension	Supported Data Rates
802.11	1, 2 Mbps
802.11a	6, 9, 12, 18, 24, 36, 48, 54 Mbps 6, 12, and 24 Mbps are mandatory
802.11b	1, 2, 5.5, 11 Mbps
802.11g	1, 2, 5.5, 11, 6, 9, 12, 18, 22, 24, 33, 36, 48, 54 Mbps 1, 2, 5.5, 11, 6, 12 and 24 Mbps are mandatory 22 and 33 Mbps are typically not supported
802.11n	1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48, 54, 121.5, 130, 144.44, 270, 300 Mbps

Speed Needs

Though faster speeds are available when using Rabbit hardware, most applications can meet their requirements with the slower speeds. Consider the following statements about the relatively slow speed of the 1 Mbps data rate:

• latency hardly different from higher rates for short packets

• most robust

• never gets slower

• fast enough for most sensor/control applications

• universally supported by old equipment

Channels

Direct communication between wireless stations, whether it be in an ad-hoc network or an infrastructure network, happens on a channel: a specified frequency band for the travel of electromagnetic signals. Rabbit products (like the RCM4400W) support the 2.4 GHz range of the ISM band. As shown in the figure, there are three non-overlapping channels available in North America: 1, 6 and 11. Non-overlapping allows for simultaneous use of the channels in the same physical area without causing interference.

Figure 5.20: Wi-Fi

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