UNIT - IV

4 | Satellite Access and Coding Methods

Syllabus

Modulation and Multiplexing : Voice, Data, Video, Analog - digital transmission system, Digital video Broadcast, multiple access : FDMA, TDMA, CDMA, DAMA Assignment Methods, compression - encryption, Coding Schemes.

Contents

4.1 Modulation and Multiplexing

4.1.1 Frequency Modulation (FM)

- Frequency modulation is a form of analog angle modulation in which the base-band information carrying signal, called information or message signal m(t), varies the frequency of a carrier wave.

- Digital signals may be transmitted using a frequency modulation scheme using Frequency Shift Keying (FSK). But in satellite communication Phase Shift Keying (PSK) is preferred because of its lower BER.

- In FM the information is carried by changes in carrier frequency called frequency deviation. The instantaneous frequency f_i of FM wave is expressed by linear relationship.

$$f_i = f_c + \Delta f$$
$$= f_c + k_f \cdot m(t)$$

where,　　f_c is carrier frequency

　　　　Δf is frequency deviation

　　　　m(t) is modulating voltage

　　　　k_f is modulator constant (hertz/volt)

- The recovered baseband signal v(t) is given by -

$$v(t) = \Delta f \times \frac{1}{k_f}$$

$$= k_f \cdot m(t) \times \frac{1}{k_f} = m(t)$$

- FM radio link has unity gain between transmitter baseband and receiver baseband.

Waveform equation for FM

- FM signal is expressed by :

$$V_{FM}(t) = A \cos\omega_c t + \int_0^t ([2\pi k_f m(t)]dt + \phi_0) \text{ volts}$$

Bandwidth of FM signals (Carson's Rule)

- Carson's rule states that the bandwidth required for FM signal transmission is given by -

$$B = 2(\Delta f_{pk} + f_{max}) \text{ Hz}$$

where,　　Δf_{pk} is peak frequency deviation

　　　　f_{max} is highest frequency in modulating signal.

Baseband S/N ratio for FM signal

- C/N ratio at output of IF amplifier is given as -

$$\frac{C}{N} = \left(\frac{A^2}{2}\right)\Big/(N_0 B) \qquad\qquad \because \text{ Power } C = \frac{A^2}{2}$$

$$\frac{C}{N} = \frac{A^2}{2 N_0 B_n} \qquad\qquad \text{Noise Power} = N_0 \cdot B$$

where, B_n is noise bandwidth (Hz)

A is amplitude of sine wave (V)

N_0 is single sided noise power spectral density

- The baseband signal power (S) is given as -

$$S = \frac{1}{2}(K \Delta f_{peak})^2$$

$$S = (K \Delta f_{rms})^2 \text{ watts}$$

where, K is voltage conversion constant $\left(K = \frac{1}{k_f}\right)$

- Noise power at the demodulator output is

$$N_{out} = 2N_0\left[\frac{K}{A}\right]^2 \int_{f_1}^{f_2} f^2 df$$

$$N_{out} = 2N_0\left[\frac{K}{A}\right]^2 \cdot \frac{(f_2^3 - f_1^3)}{3}$$

- Expression for signal to noise power at output is -

$$\left(\frac{S}{N}\right)_{out} = \left(\frac{C}{N}\right) \times \frac{3}{2} \times \left(\frac{B}{f_{max}}\right) \times \left(\frac{\Delta f_{peak}}{f_{max}}\right)^2$$

- The S/N ratio expression in dB form is given by -

$$\left(\frac{S}{N}\right)_{out} = \frac{C}{N} + 10 \log_{10}\left(\frac{B_{RF}}{f_{max}}\right) + 20 \log_{10}\left(\frac{\Delta f_{peak}}{f_{max}}\right) + 1.8 \text{ dB}$$

where, B_{RF} is IF bandwidth of receiver

Δf_{peak} is peak frequency deviation at transmitter

f_{max} is receiver baseband bandwidth 1.8 dB is equivalent of $\frac{3}{2}$

- The $\dfrac{S}{N}$ ratio can be improved by using large deviation ratio D.

$$D \;=\; \dfrac{\Delta f_{peak}}{f_{max}}$$

- Pre-emphasis and de-emphasis are used in FM transmission to improve $\dfrac{S}{N}$ ratio.

4.1.2 De-emphasis

- De-emphasis flattens the noise power curve that reduces the baseband noise and improves baseband $\dfrac{S}{N}$ ratio.

- The noise power of output of FM demodulator is proportional to the square of the baseband frequency.

- The rms noise voltage V_n is expressed as

$$V_n \;=\; a \, V_{nrms} \, f_b$$

where, V_{nrms} is the rms noise voltage at input of FM demodulator.

a is constant across the IF bandwidth.

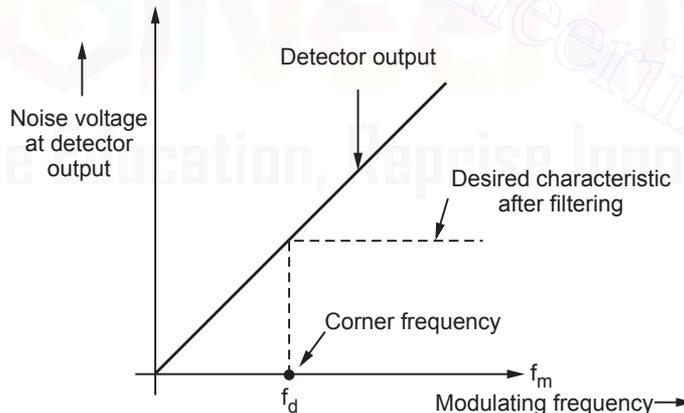- Fig. 4.1.1 shows noise voltage at FM detector output.

Fig. 4.1.1 FM detector output

- The function of de-emphasis circuit is to flatten the Noise Power Spectral Density (NPSD).

- The de-emphasis circuit has transfer function $G_{de}(f)$ which is proportional to $\dfrac{1}{f_b}$ after the demodulators.

$$G_{de}(f) = \frac{b}{f_b}$$

where, b is constant

- The output of de-emphasis circuit is expressed by -

$$V_{n0} = a \cdot V_{nrms} f_b \times \left(\frac{b}{f_b} \right)$$

$$\boxed{V_{n0} = a \cdot b \cdot V_{nrms}}$$

where, ab is constant.

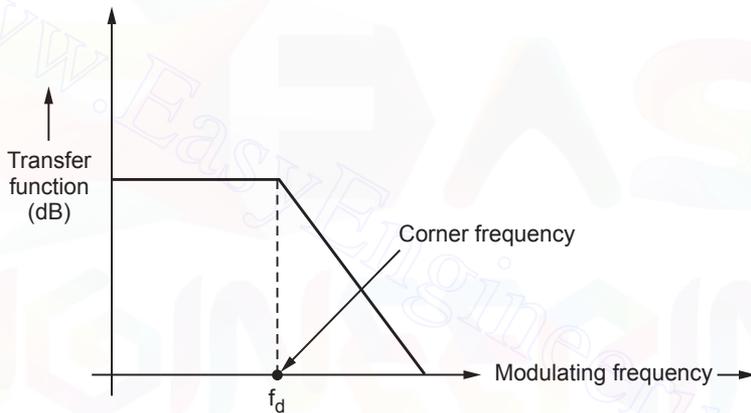- Fig. 4.1.2 shows de-emphasis circuit characteristic.

Fig. 4.1.2 De-emphasis characteristics

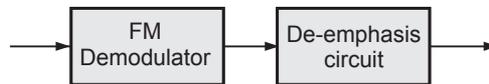- The de-emphasis circuit is placed after FM demodulator as shown in Fig. 4.1.3.

Fig. 4.1.3 De-emphasis filter

- The gain offered by de-emphasis circuit is constant up to its corner frequency f_d and then the required gain proportional to $\frac{1}{F_b}$ (inverse of baseband frequency).

4.1.3 Pre-emphasis

- The de-emphasis circuit at FM receiver is a low pass filter that blocks all high frequencies of signal.

- At transmitter, a complementary circuit to counteract the effect of de-emphasis circuit is required. This is called a **pre-emphasis circuit.**

- The pre-emphasis circuit has a transfer function $G_{pe}(f)$ proportional to frequency.

$$G_{pe}(f) = \frac{1}{b} \cdot f_b$$

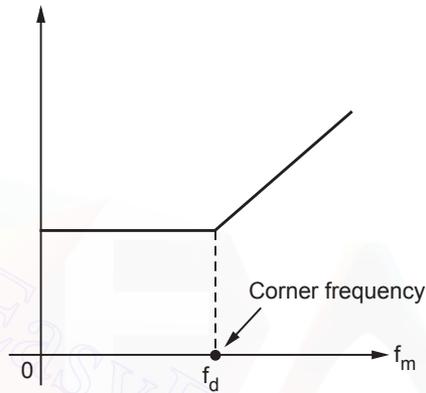- Fig. 4.1.4 shows pre-emphasis filter characteristic.

Fig. 4.1.4 Pre-emphasis filter characteristic

- The $\dfrac{S}{N}$ ratio at baseband is increased by a factor P dB with de-emphasis in the receiver.

- Value of P is different for voice and video signal, typically values are 5 to 10 dB.

- Pre-emphasis amplifies the high frequencies more than low frequencies hence adding extra power to baseband signal.

4.1.4 $\dfrac{S}{N}$ Ratios for FM Video Transmission

- The $\dfrac{S}{N}$ ratio in baseband channel of an FM satellite TV receiver is given by -

$$\left(\frac{S}{N}\right)_w = \frac{C}{N} + 10\log_{10}\left(\frac{B_{RF}}{f_{max}}\right) + 20\log_{10}\left(\frac{\Delta f_{pk}}{f_{max}}\right) + 1.8 + P + Q \text{ dB}$$

where,

Q is called subjective improvement (weighing) factor.

Effect-1

- The calculation of $\dfrac{S}{N}$ ratio is based on sine wave signals, which gives a pessimistic result for video signal.

Effect-2

- The noise from FM receiver appears on screen.

FM demodulator

- Because FM demodulator has low baseband noise power at low frequencies, the FM noise is less annoying compared to white noise.
- The subjective factor Q is added to counter these effects.
- Typical value of Q in NTSC TV receiver is 8 dB.

4.2 Digital Transmission

- Digital modulation is the natural choice for satellite transmission of signals that originate in digital form and that are used by digital devices.
- All signals sent via satellites are digital. Examples are data transmissions to and from the Internet communications between remote terminals and computers, digital telephony, and TV signals in digital form, such as HDTV and DBS-TV.
- Digital transmission uses Time Division Multiplexing (TDM) and Time Division Multiple Access (TDMA).
- Analog signals that are transmitted digitally can share channels with digital data.
- A digital satellite link can carry a mix of telephone and data signals that varies with traffic demand.
- All digital links are designed using a specific symbol rate, and specific filters that minimize Inter Symbol Interference (ISI).
- A symbol in a baseband link is a pulse of current or voltage. In a satellite link, a symbol is almost always a phase state (BPSKU and QPSK) or a phase and amplitude state (QAM).
- Digital links are designed for a specific symbol rate, but one symbol can carry more than one bit. It is important to distinguish between symbols and bits.
- In modulations, such as BPSK, the symbol rate and bit rate are the same. Symbol rates are given in baud or in symbols per second (sps).
- Symbols per second is used because the difference between symbols per second and bits per second is more obvious, because the baud as the unit of transmission rate equal to symbols per second is still in widespread use.

- The unit baud, is derived from the name Baudot, who was an early French pioneer of the telegraph.

4.2.1 Baseband Digital Signals

- The baseband digital signals are transmitted as serially transmitted logical ones and zeroes.

- Whereas in computer circuitry a logical zero may be represented by a low voltage (nominally zero) and a logical one may be represented by a high voltage (e.g., 5 V), this arrangement is inconvenient for transmission over any significant distance and is not used.

- To understand this, imagine a transmission line carrying a bit stream encoded this way and containing approximately equal numbers of ones and zeroes. About half the time the line voltage will be 5 V and about half the time it will be 0 V; hence the line signal will have a 2.5 V DC component. All circuits that carry this signal must have a frequency response that extends to DC, and this is difficult to achieve since many communication circuits contain transformers.

- To avoid this situation, digital modulators accept their input in a polar non-returnto-zero (NRZ) format : logical ones and zeroes are transmitted as plus or minus a stated value.

- Therefore a logical one might be transmitted as + 1 V and a logical zero might be transmitted as – 1 V. Zero volts is not transmitted except as a transient value.

4.2.2 Baseband Transmission of Digital Data

- Satellite links always carry RF signals, which require that data be modulated on to a radio frequency carrier for transmission.

- Considering the case of a baseband data link, the frequency response of the link is assumed to extend from DC to an upper limit f_{max}, where f_{max} is equal to the bandwidth of the link, B Hz.

- Data is transmitted in the form of polar pulses; in a binary system, the pulses have amplitudes + V and – V volts, where V can take any value. The average number of + V and – V pulses is made equal so that the average DC voltage on the transmission line is zero.

Analysis of baseband Links
- Firstly the conditions under which inter-symbol interference can be minimized are determined.

- A random sequence of rectangular binary pulses has a power spectral density given by :

$$G(f) \ = \ T_s \left[\frac{\sin(\pi f T_s)}{\pi f T_s} \right]^2$$

where, T_s is the duration of the pulse.
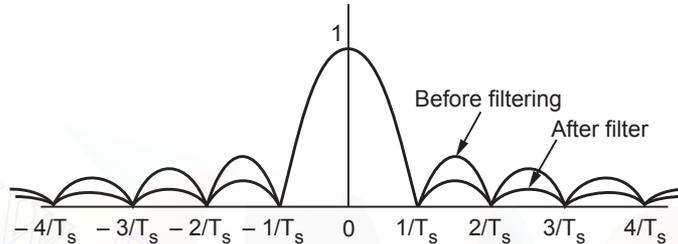
- The spectrum is shown in Fig. 4.2.1.

Fig. 4.2.1 Spectrum of bandlimited NRZ pulse train

- The familiar $\sin \frac{x}{x}$ (also called sinc) spectrum shows that energy exists at all frequencies; to retain the rectangular pulse shape would require an infinite transmission bandwidth.

- Practical communication systems are always bandwidth limited. Interference in radio links determines that a communication system should use the smallest possible bandwidth, and this is usually one of the design criteria of a communication system.

- In any digital communication system, a symbol is defined by the rate at which information is sent over the link, in the form of pulses at baseband, or changes in phase angle of a carrier, for example, in PSK system.

- Analysis of digital transmission systems will be based on symbols, rather than bits, because to send more than one bit per symbol in an RF system conserves the bandwidth.s

- Popular modulations that transmit more than one bit per symbol are QPSK (two bits/symbol) and QAM (up to 10 bits/symbol).

- QPSK is widely used on satellite links, including direct broadcast satellite television. High-speed modems designed for telephone lines use QAM to send a high bit rate in a small bandwidth (e.g. 28.8 kbps in 4 kHz bandwidth).

- Nyquist criteria for zero ISI, which forms the design basis for every digital transmission system, is based on the use of square Root Raised Cosine (RRC) filters and a specified symbol rate on the satellite link.

- If the transmission is binary, the symbol is a bit, and the symbol has two states. When two bits are sent per symbol, the symbols have four possible states and the system is denoted as quaternary, hence the Q in QPSK.

- If a symbol represents more than one bit, the system is known generically as m-ary, with one symbol having m states.

- QAM is a modulation that combines the four phase states of QPSK with multiple pulse amplitudes as in m-ASK. For example, 256-QAM is a modulation in which each symbol represents 8 bits and has 256 possible states. There are four phase states and pulses can have $2^6 = 64$ possible amplitude levels.

- For random pulse train shown in Fig. 4.2.2 (a) and band limit it by passing the pulses through a low pass filter, the pulse shape will be altered. As an example, consider the effect of passing the rectangular pulse train through a single RC section, representing a very simple low pass filter. The resulting waveform, shown in Fig. 4.2.2 (b), has been delayed and pulses are smeared in time-the decaying pulse from one transition extends into the next pulse interval.
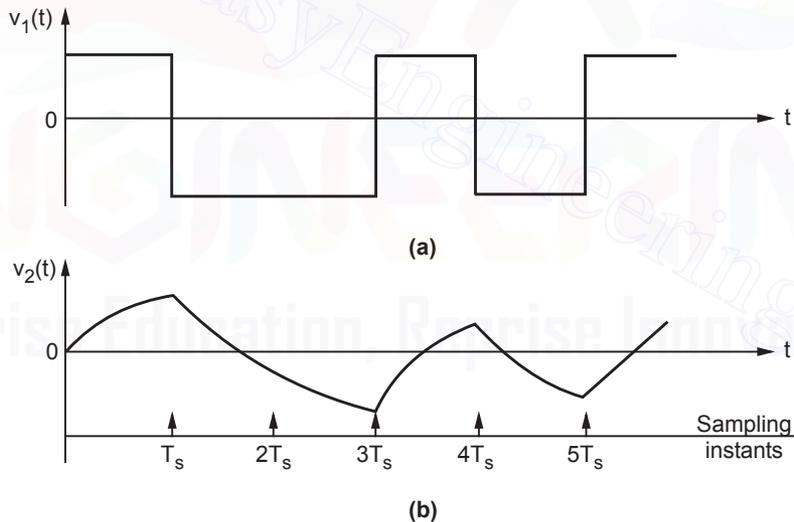

Fig. 4.2.2 Effect of low pass filtering on an NRZ signal

- The pulse pattern is 10 or 01, the amplitude the second pulse at the sampling instant shown in Fig. 4.2.3 has been reduced by the presence of a delayed portion of the preceding pulse. This is called **Inter Symbol Interference (ISI)**.

- The ISI is likely to occur whenever a digital signal is passed through a band-limiting filter. When noise is added to the waveform, ISI increases the likelihood that the receiver will detect a bit incorrectly, causing a bit error. In a baseband system, ISI can be avoided by an appropriate choice of low pass filter.

- Nyquist proposed a technique that can theoretically produce zero ISI, now known as the Nyquist criteria. The objective is to create in the receiver a pulse that resembles the sin x/x shape, crossing the axis at intervals of T_s, where T_s, is the symbol period. This is shown in Fig. 4.2.3.
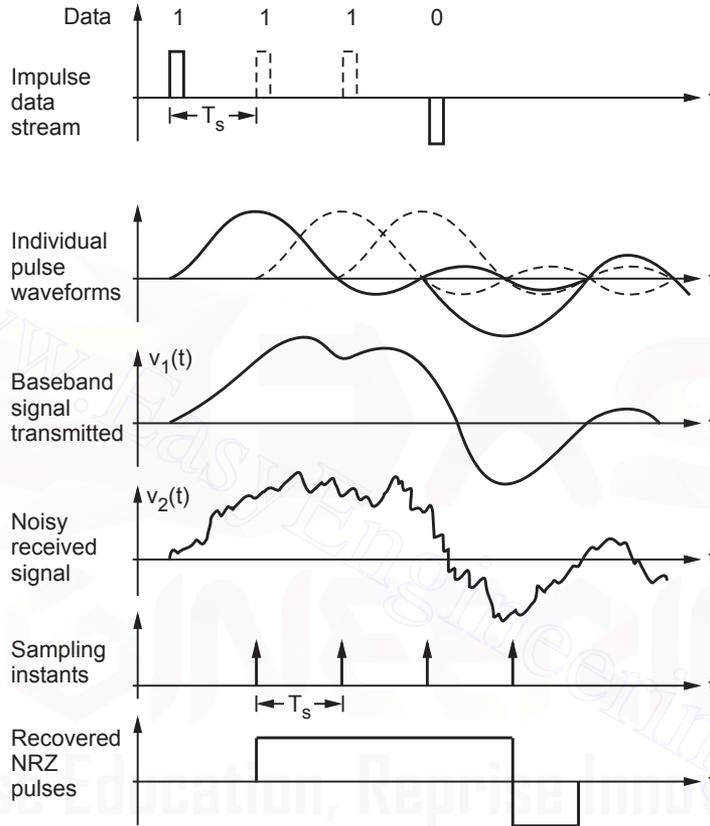

Fig. 4.2.3 Transmission and reception of baseband zero-ISI pulses

- The receiver samples the incoming wave at intervals of T_s, so that at the instant one pulse is sampled, the "tails" from all preceding pulses have zero value. Thus previous pulses cause zero inter-symbol interference (zero ISI) at each sampling instant.

- Filters that produce the required zero ISI waveform in the receiver can be realized in several ways. The baseband transfer function proposed by Nyquist was the raised cosine function, $V_{NQ}(f)$, which has a normalized two-sided frequency characteristic given by,

$$V_{NQ}(f) = 1 \qquad \text{for } |f| < \frac{R_s}{2}(1-\alpha)$$

$$V_{NQ}(f) = \cos^2\left\{\frac{\pi}{2\alpha R_s}\left[|f| - \frac{R_s}{2}(1-\alpha)\right]\right\} \quad \text{for} \quad \frac{R_s}{2}(1-\alpha) \le |f| \le \frac{R_s}{2}(1+\alpha)$$

$$V_{NQ}(f) \;=\; 0 \qquad\qquad \text{for } |f| > \frac{R_s}{2}(1+\alpha)$$

where,

$0 < \alpha < 1$ and $R_s = 1/T_s$ is the symbol rate in symbols per second.

- The entire communication link must have this transfer function to ensure zero ISI. The pulse shape generated at the output of the link is $U_{NQ}(t)$, the required zero ISI waveform, when the filter input is driven by an impulse, $\delta(t)$.

- The waveform $U_{NQ}(t)$ is obtained as the inverse Fourier transform of the output from the Nyquist raised cosine transfer function, which is simply the spectrum of the input pulse multiplied by the frequency response of the system.

$$U_{NQ}(t) \;=\; F^{-1}[\,V_{NQ}(f) \times S(f)\,]$$

where,

$F^{-1}[\;]$ indicates the inverse Fourier transform and $S(f)$ is the spectrum of the input pulse.

- The shape of several raised cosine function characteristics for values of α between 0 and 1, and the corresponding waveforms generated by the impulse response of these filters.

- For $\alpha = 0$ yields a rectangular function with a bandwidth of $R_s/2$. This is the minimum bandwidth through which a signal with a symbol rate R_s can be transmitted while still satisfying the zero ISI condition.

4.3 Multiple Access

- Multiple access is the technique of sharing or dividing channel (transmission medium) amongst number of stations sharing it. Three most commonly used multiple access methods are -

    1. Frequency Division Multiple Access (FDMA)

    2. Time Division Multiple Access (TDMA)

    3. Code Division Multiple Access (CDMA)

- The uplink and downlink carriers of the satellite are required to be modulated by the signal to be transmitted. The modulation can be analog or digital. In the earlier satellites analog modulations were dominant and therefore they were used in communication satellites. The analog voice and video transmission systems use frequency modulation and frequency division multiplexing techniques. Since the frequency modulation techniques has no amplitude fluctuation, the transmitter could be operated efficiently at full power capacity.

- The bandwidths of the satellite systems are from 500 MHz to upto 5 GHz, this complete bandwidth is not needed for the single channel. Thus the complete satellite bandwidth can be used by several channels. Each channel is given a frequency slot in the satellite bandwidth. Thus it is possible to transmit and receive several channels simultaneously through these frequency slots. The channels are transmitted continuously. This is called Frequency Division Multiplexing (FDM).

- The modern communication satellites use digital modulation methods. Since the signals to be transmitted using digital modulation are sampled in time, multiplexing in time can be used. Digital modulation has been very attractive since the availability of fast speed and advanced computers.
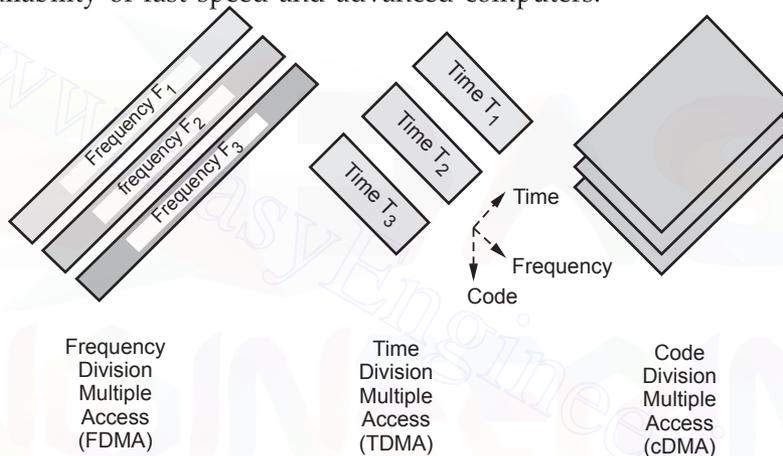

Fig. 4.3.1 Multiple access methods using the three dimensions of frequency, time and code

- If the proportion of the resource (frequency, time, code) is allocated in advance, it is called **Pre-Assigned Multiple Access** or **Fixed Multiple Access.**

- If the proportion of the resource is allocated in response to traffic conditions in a dynamic manner it is called **Demand Assigned Multiple Access - DAMA.**

- Multiple access has many advantages -
  1. Increases efficiency for provider
  2. Reduces costs to user
 3. Enhances network control
  4. Enables more flexible designs

4.4 Frequency Division Multiple Access (FDMA)

- In FDMA the available bandwidth is divided into m number of smaller frequency bands called subbands. Each station transmits its information continuously on an assigned subband. To reduce co-channel interference guard band between two subbands is provided.

If   W = Available bandwidth of channel.

             R = Data rate of channel.

             M = Number of stations.

Then the transmit rate of each station is R/M bits/sec.

- For analog communication, frequency modulation is used in the satellites. Several users share satellite link so that many signals from the earth station are transmitted. These FM signals are in FDM. For digital modulation, the satellite link uses Time Division Multiplexing (TDM). Fig. 4.4.1 shows the FDM scheme for C-Band of the satellite. The receiver in the satellite transponder covers the complete uplink range of that band.

- Fig. 4.4.1 (a) shows that the uplink frequency range of 5.925 MHz to 6.425 MHz of C-Band has 12 channels. The receiver receives all these 12 channels. Each channel is allotted the bandwidth of 36 MHz with 4 MHz spacing between the channels. Thus 12 channels take 480 MHz bandwidth of the satellite. Remaining 20 MHz is used for transmission of command and control of telemetry channel.

- The transponder converts the uplink frequencies to downlink frequencies. The channels has same bandwidth of 36 MHz and spacing of 4 MHz, as shown in Fig. 4.4.1 (b).
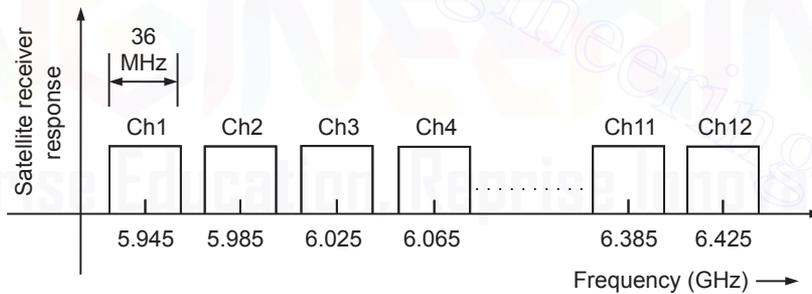
(a) Satellite receiver channels
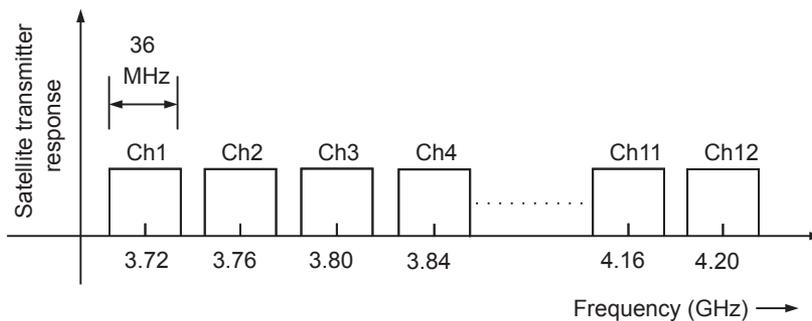
(b) Satellite transmitter channels

Fig. 4.4.1 Frequency division multiplexing in satellite

- The advantage of frequency division multiplexing is that the power required for the transmission at satellite as well as earth station is dependent on the number of channels being transmitted. The signal to noise ratio of frequency modulation is improved, but it needs wider bandwidth. Therefore the number of channels to be accommodated in the band of satellite are reduced.

- FDMA is not suited for bursty traffic conditions because of insufficient use of transmission resources.

- FDMA may be implemented with various modulation-multiplexing methods, the most common being :
  1. FDM-FM (analogue), in which carriers are frequency-modulated by a frequency division multiplexed baseband signal.

  2. TDM-PSK (digital), in which carriers are PSK modulated by a time division multiplexed baseband signal.

  3. SCPC (for earth stations with small traffic), in which each individual telephone (or data) channel modulates the carrier, either by FM (analogue) or PSK (digital).

Forms of FDMA

- Two forms of FDMA are possible :
  1. **Fixed-Assignment Multiple Access (FAMA) :** The assignment of capacity within the overall satellite channel is distributed in a fixed manner among multiple stations. This often results in significant underuse of the capacity, as demand may   fluctuate.

  2. **Demand-Assignment Multiple Access (DAMA) :** The capacity assignment is changed as needed to respond optimally to demand changes among the multiple stations.

- The number of sub-channels provided within a satellite channel via FDMA is limited by three factors :
  1. Thermal noise

  2. Intermodulation noise

  3. Crosstalk

4.4.1 Pre-Assigned / Fix-Assignment FDMA

- Frequency channels or slots are pre-assigned to analog and digital signals. Consider analog signals in the FDM/FM/FDMA format it means the signals are frequency division multiplexed, Frequency Modulated (FM), with FDMA to the satellite.

- In FAMA, the overall capacity of satellite channels are allocated in fixed manner among multiple stations.

- Consider an example, uplink capacity of 36 MHz is shared among 7 earth stations A to G. Stations A, B, C, D, E, F and G can transmit 60, 132, 60, 96, 24, 24 and 24 Voice Frequency (VF) channels respectively.

- Station A is assigned 5 MHz bandwidth from 6237.5 to 6242.5 MHz for 60 VF channels using FDM-FM. It means FDM is used for multiplexing and FM is used to modulate the channels on to carrier frequency of 6240 MHz.
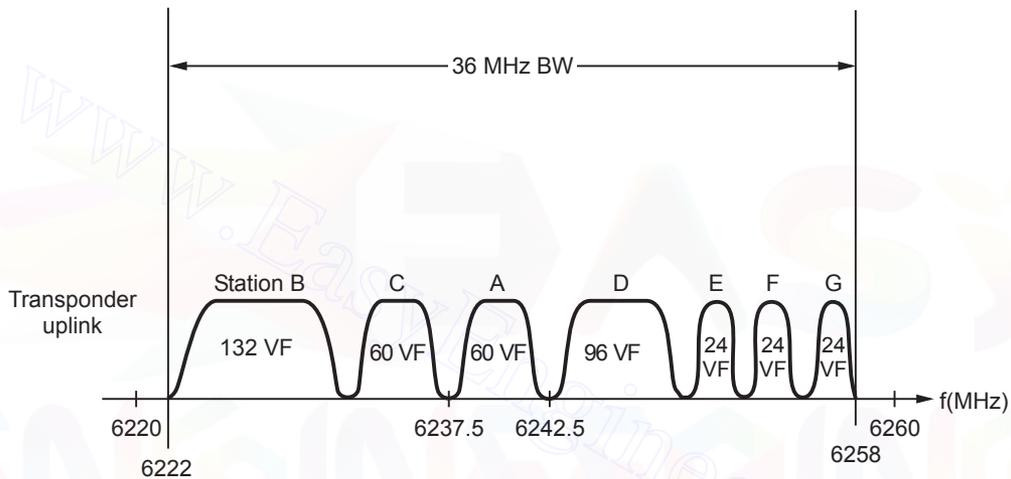

Fig. 4.4.2 Frequency allocation for transmitted spectrum

- Station A has traffic for other stations :
  - − channels to B ⎤
  - − channels to D ⎬ Total 60 VF channels
  - − channels to E ⎦

  - − remaining 36 MHz channel is divided among the other earth stations.
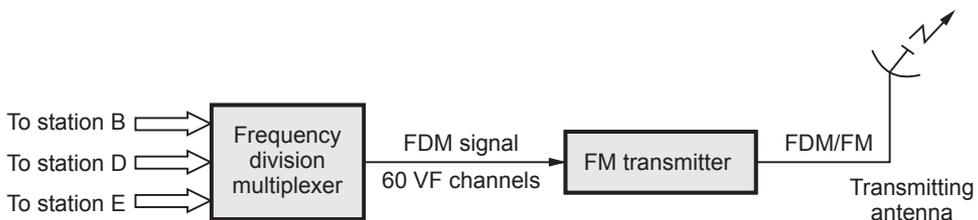

Fig. 4.4.3

- FAMA refers to the fact that logical links between stations are preassigned. FDMA refers to the fact that multiple stations are accessing the satellite link by using different frequency bands.

4.4.2 Demand Assignment Multiple Access (DAMA)

- In DAMA, the channel capacity changes optimally as per the demand amongs multiple stations.
- In DAMA, entire 36 MHz bandwidth is divided in a specific voice channels instead of grouping altogether. This technique is called Single Channel Per Channel (SCPC).
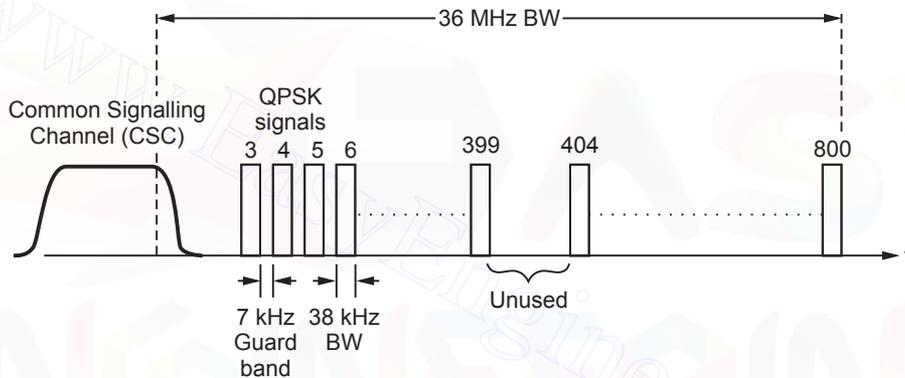

Fig. 4.4.4 Frequency allocation in SCPC

- SCPC is provided in C-band. A single channel of 36 MHz is subdivided into 800 analog channels of 45 kHz each using FM. Digital SCPC is possible with QPSK which provides 64 kbps service in 45 kHz bandwidth.
- SCPC is preferred in remote areas where there are few user stations. SCPC is more efficient of BW than FDMA. First commercially available DAMA SCPC system was SPADE (Single channel per carrier. Pulse code modulation, multiple access demand assignment equipment).

4.4.3 SPADE

- SPADE is one of the demand access systems. The satellite capacity of all the stations in FDMA network is pooled and it is used on SCPC basis. When the call is to be made, a pair of frequencies is assigned to the duplex circuit (i.e. two channels). This is called SCPC demand access method. The SCPC demand access method is used in the networks where there are many small stations and the total traffic on each station is very light.

- The Single channel per carrier Pulse code modulation multiple Access Demand assignment Equipment (SPADE) system is basically SCPC demand access network that uses distributed control. This system allows circuits to be selected by an terminal on demand. The circuits are not permanently associated with the terminals. They are assigned from the satellite channel pool as required. Each channel of the voice circuit occupies 45 kHz bandwidth in SPADE. There are two channels per circuit. Hence there are paired RF carriers for these channels corresponding to one circuit. These RF carriers are separated by 18.045 MHz. There is a Common Signaling Channel (CSC). It occupies 16 kHz of RF bandwidth.
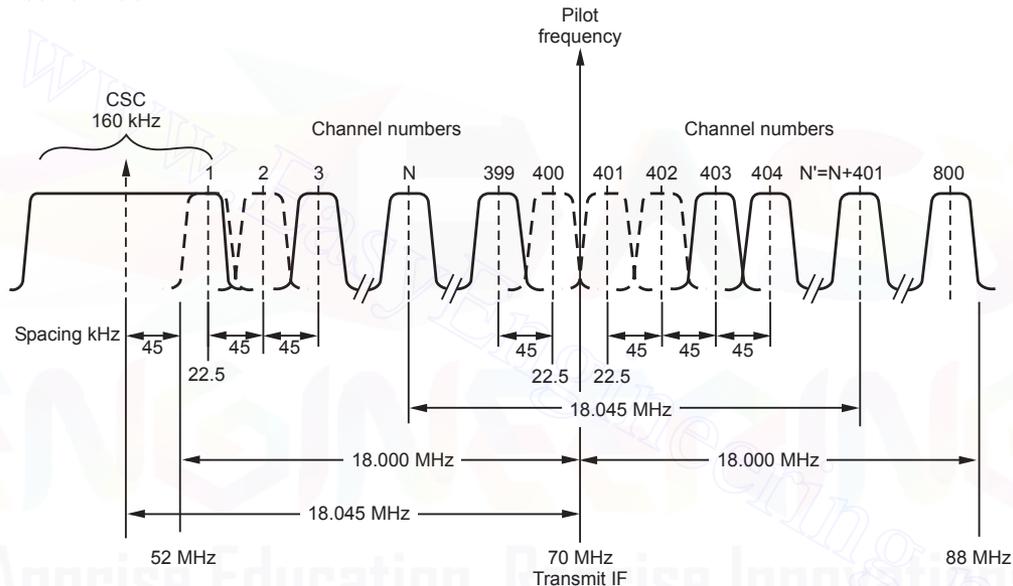

Fig. 4.4.5 SPADE frequency plan

- Fig. 4.4.5 shows the SPADE frequency plan. As shown in the Fig. 4.4.5, the center of CSC is at 18.045 MHz from pilot frequency. The pilot frequency is 70 MHz IF. There are total 800 RF channels of 45 kHz each. SPADE has all the advantages of SCPC over FDM/FM system. That is reduced transponder power consumption, reduced cost of earth stations etc.

4.4.4 FDMA Downlink Analysis

- Consider the situation where each carrier of the FDMA system occupies a bandwidth B and has a downlink power denoted by $[EIRP]_D$.

$$\left[\frac{C}{N}\right]_D = [EIRP]_D + \left[\frac{G}{T}\right]_D - [LOSSES]_D - [K] - [B]$$

Example 4.4.1 *Calculate the $[C/N]_D$ for $[EIRP]_D$ = 27, $[G/T]_D$ = 30, $[LOSSES]_D$ = 196, $[k]$ = − 228.6 and $[B]_{TR}$ = 75.56.*

Solution :

Given : $[EIRP]_D$ = 27 dB

$\qquad [G/T]_D$ = 30 dB/k

$\qquad [LOSSES]_D$ = 196 dB

$\qquad [k]$ = − 228.6

$\qquad [B]_{TR}$ = 75.56 dBHz

$$\left[\frac{C}{N}\right]_D = [EIRP_S]+\left[\frac{G}{T}\right]_D -[LOSSES]_D -[K]-[B_{TR}]$$

$$= 27 + 30 - 196 + 228.6 - 75.56$$

$$= \textbf{14.04 dB} \qquad\qquad\qquad …\textbf{Ans.}$$

4.4.5 Advantages and Disadvantages of FDMA

Advantages of FDMA

1. Using well established technology.

2. No need for network timing.

3. No restriction regarding the type of baseband or the type of modulation.

Disadvantages of FDMA

1. Inter-modulation noise in the transponder leads to interference with other links-satellite capacity reduction.

2. Lack of flexibility in channel allocation.

3. Requires up-link power control to maintain quality.

4. Weak carrier tend to be suppressed.

4.5 Time Division Multiple Access (TDMA)

- TDMA is a method of time-division multiplexing of digitally modulated carriers. In TDMA, each station transmits digitally modulated carriers during a preassigned time slots, making use of the entire transmission channel during its transmission. The stations are synchronized such that only one carrier is present on the channel at any given time. Thus avoiding collisions of stations. Sufficient guard bands are also provided to ensure collision avoidance. Each station spends most of the time accumulating packets and preparing them for transmission in a burst during the assigned time slot. The average bit rate of each channel is same because time slot available is same for each station. Fig. 4.5.1 shows how TDMA stations use a fixed portion of time slot in the frequency band.
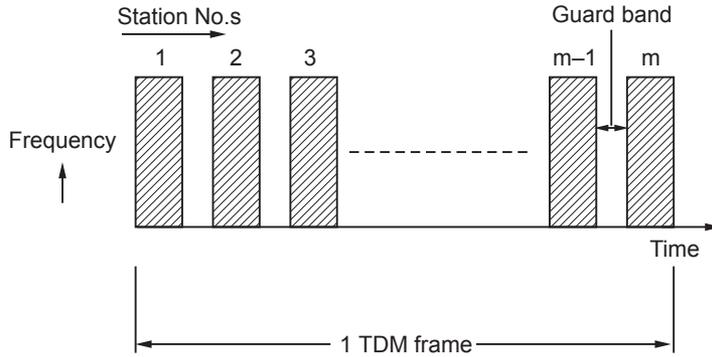
Fig. 4.5.1 TDMA

- The earth stations access the transponder as shown in Fig. 4.5.2.
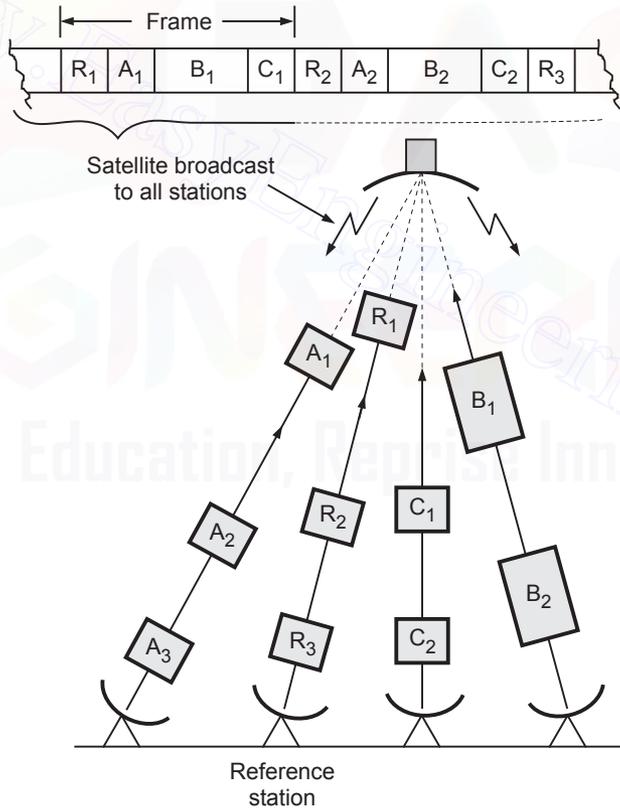

**Fig. 4.5.2 Time division multiple access (TDMA)**

- At any time, the power amplifier in the transponder amplifies only one carrier signal. Hence intermodulation is absent. TDMA is mainly suitable for transmission of digitally modulated signals.

- TDMA needs accurate synchronization of the earth stations, whereas in FDMA it is not required. Therefore TDMA is very complex compared to FDMA.

4.5.1 Capacity and Efficiency of TDMA

- Time allocated for data transmission

$$T_d = \left(T_{frame} - \sum_i \left(T_p + T_g \right) \right) \approx T_{frame} - N \left(T_p + T_g \right)$$
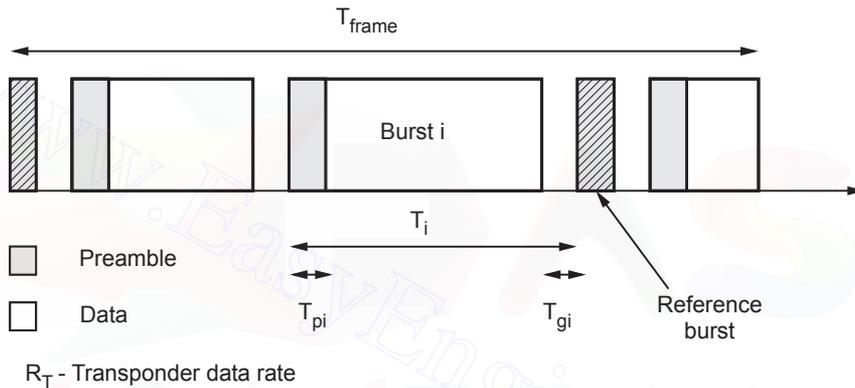
- Total available rate for user traffic

$$R_u = \frac{T_d}{T_{frame}} R_T$$

- Rate for the ith user

$$R_{ui} = \frac{T_i - \left(T_{pi} + T_{gi} \right)}{T_{frame}} R_T = \frac{T_i - T_p - T_g}{T_{frame}} R_T$$

- Multiple earth station sharing transponder
- TDMA efficiency

$$\eta = \frac{T_d}{T_{frame}} \times 100 \ [\%]$$

4.5.2 TDMA Frame Structure

- In TDMA, a preamble or reference burst is transmitted at the beginning of every TDMA frame. The reference burst is normally transmitted by one of the earth stations to designate it as master station. Fig. 4.5.3 shows the typical TDMA reference burst.
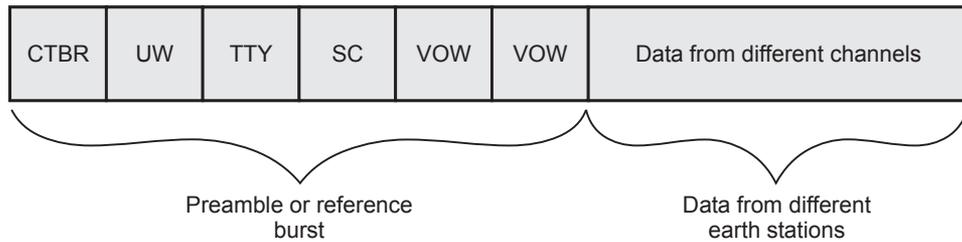
Fig. 4.5.3 TDMA frame showing reference burst

- The segments CTBR and UW contains -

i) Carrier recovery waveform   ii) Bit clock synchronization

iii) Unique word   iv) Station identifier

CTBR (Carrier and Bit Timing Recovery)

- It enables the receiving earth station to recover remainder of the burst. CTBR contains the sequence of predetermined signals. These signals are used for synchronization of the bit clock.

Unique Word (UW)

- Length of the unique word is 20 to 48 bits. The unique word serves following purposes :

   i) Unique word acts as station identifier

   ii) It provides Start of Frame (SOF)

   iii) It acts as burst marker

   iv) It acts as a carrier phase ambiguity detector.

- For each earth station there is separate unique word. The unique word can be detected from TDMA frame with the help of unique word correlator. If there are large number of stations, then single unique word is used. The stations are then identified by separate station identifier word.

Teletype Link (TTY)

- These are 16 bits in each burst. They are used to identify the teletype link between the earth stations.

Service Channel (SC)

- These are 16 bits. They are used for management of the TDMA system alongwith TTY and VOW.

Voice Order Wire (VOW)

- This field is 64 bits. These are two fields of VOW. They are used in digital voice links between the earth stations.

- The remaining part of the TDMA frame consists of data from various channels.

4.5.3 TDMA Synchronization

- TDMA system is about several different synchronization problems. Successful operation of TDMA system depends on network wide synchronization.

- With demodulate Burst PSK carrier, it must recover carrier and bit timing in starting part's inversion recovery of every frame. So, the usual TDMA demodulator uses rapid circuit to recover carrier and timing signal.

- Every Burst signal should be timed. This kind of synchronization can prevent frames which from all earth stations to be overlapped in satellite repeater, which is called frame synchronization.

- Satellite perturbations -- > ± 0.1° in longitude, 2-3° in inclination. This leads to uncertainty of ± 75 km in range (equivalent to uncertainty of 500 μsec in time). Therefore a a guard time of 500 μsec is necessary to avoid adjacent burst collision.

- To minimize guard bands, synchronization must be used.

- Frame synchronization can make every pulse enter satellite repeater with respect to reference pulse keeping the prescribed timing difference.

- Several methods of frame synchronization are :
  1. Synchronization of global beam : Every transmitting station acquires the timing error by checking the received signal sequence.

  2. Synchronization of feedback : After having checked the timing error, the receiving station or reference station sends the frame position error information to sending station by means of control channel.

  3. Synchronization of open loop : Confirming transmitting timing by computing or measuring the distance from every station to satellite.
- Two types of TDMA synchronization can be used :
  1. Open loop.

  2. Closed loop.

Open Loop :
- Each earth station maintains an accurate clock, independent of other earth stations. Open loop synchronization is easy to implement. Guard band in the order of 100 μsec is achieved.

Closed Loop :
- These synchronizations require that every station can receive the sent frame.

- Synchronization is achieved through continuous adjustment of the burst position (in time), based on real time measurements. Received burst is compared with desired T_a, and a correction $(T_a - T_m)$ is applied to the initial estimate in the next transmission.
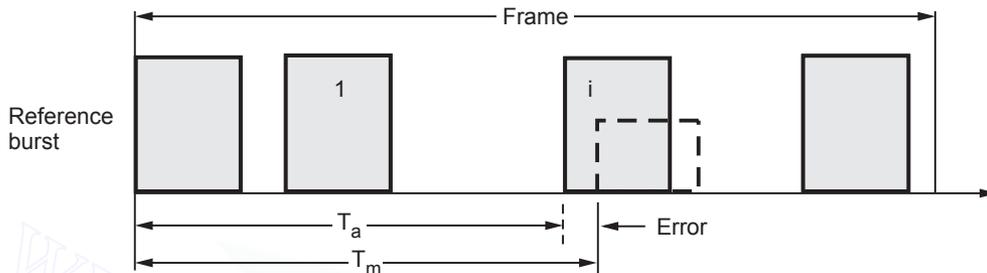

Fig. 4.5.4 TDMA synchronization

- In another synchronization scheme, a reference station is used that observes the burst time slots and provides feed back to each station to apply the necessary correction.

4.5.4 Synchronization Stages

1. Carrier recovery - required for coherent demodulation

2. Bit synchronization - required for matched filter operation

3. Burst synchronization - required for decoding of individual earth stations

4. Frame synchronization - required for proper operation of TDMA
- Synchronization data is embedded in the burst preamble
  a) CBTR (Carrier and Bit recovery) and

  b) UW (Unique Word)

4.5.5 Unique Word Decoding

- Unique word is modulated sequence of noise like autocorrelation properties.
- Two approaches of UW :
    1. Station identified - different unique word

    2. Station identified - unique word + signaling
- Unique word determines the beginning of the frame at the receive side.
- It is important that unique word has
    1. High probability of detection

    2. Low probability of false alarm
- If unique word is not detected then earth station misses the entire frame.
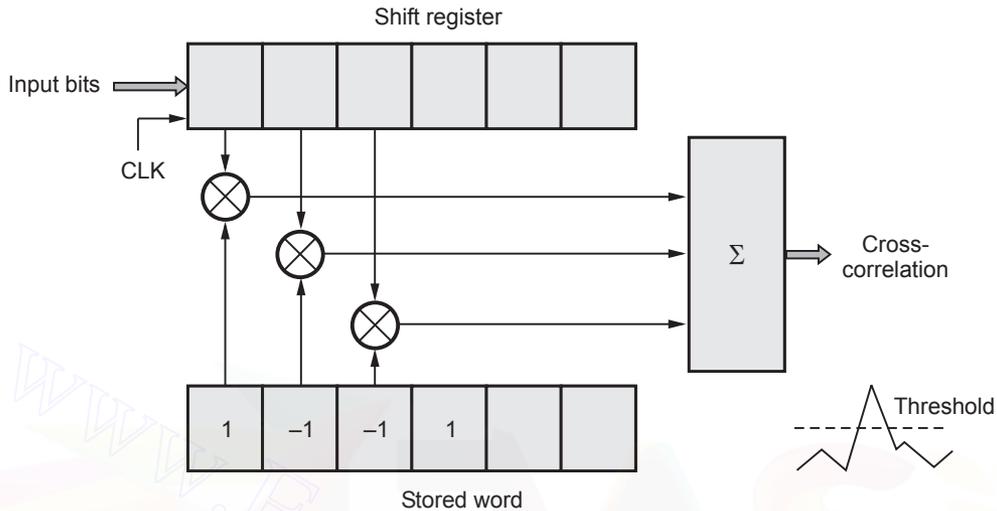
- Fig. 4.5.5 shows unique word correlator.

Fig. 4.5.5 Detection of UW sequence

4.5.6   Transmit Power in TDMA Networks

- Earth station access entire transponder bandwidth.
- Noise bandwidth is large in TDMA networks.
- To maintain S/N ratio large signal power is required.
- TDMA networks are suitable for systems with large data throughput.
- Not suitable for small earth stations - high power difficult to achieve.

4.5.7   Advantages of TDMA

1. At a given time only one carrier is present on the channel hence intermodulation distortion is eliminated.

2. TDMA transmission is separated in time domain. Processing of signal in time domain is easier.

3. TDMA is most efficient method of transmission because of efficient use of transmission resources.

4. TDMA can accomodate a wider range of bit rates by allowing a station to be allocated several slots. Thus TDMA is more flexible than FDMA.

5. No intermodulation products (if the full transponder is occupied).

6. Saturated transponder operation possible.

7. With a flexible Burst Time Plan it will optimize capacity per connection.

4.5.8 Disadvantages of TDMA

1. Precise synchronization between stations is required. Transmission of every station must occur during exact time slot.

2. Bit and frame timings must be maintained by TDMA.

3. Requires network-wide timing synchronization.

4. Analog signals must be converted to digital.

5. Interface with analog terrestrial plants is expensive.

Example 4.5.1 *Four stations share transponder in TDMA, each using 125 μs frames.*

Transponder bandwidth = 36 MHz

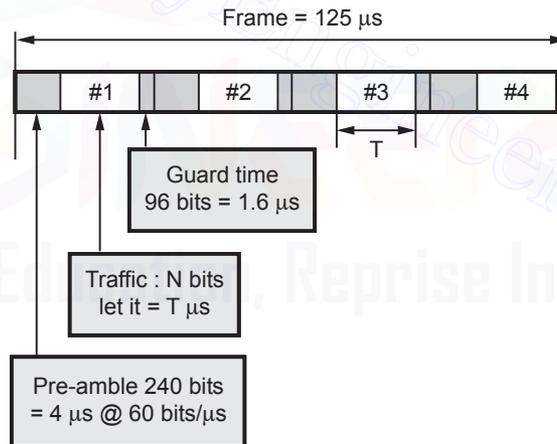*Bit rate (QPSK) 60 Mbps = 60 bits/μs*

Preamble = 240 bits

Guard time = 1.6 μs

Calculate : - (a) Transponder capacity in terms of 64 kbps speech channels?

- (b) How many channels can each earth station transmit?

Solution :

There are four earth stations transmitting within the 125 μs frame, so

$$125 = (4 \times 4 \text{ μs}) + (4 \times 1.6 \text{ μs}) + (4 \times T \text{ μs})$$

Or $T = (125 - 16 - 6.4)/4 = 25.65$ μs is the period of data transmission for each earth station per frame.

60 Mbit/s = 60 bits/μs, thus 25.65 μs => N = 1539 bits per earth station per frame.

1 frame is sent every 125 μs, i.e., 8000 frames are sent per second.

Voice channels : 8000 words per second, 8 bits per word.

$$1539 \text{ bits}/(8 \text{ bits/word}) = 192 \text{ words/frame/earth station}$$

$$= 192 \text{ voice channels/earth station}$$

a) Transponder capacity : $4 \times 192 = 768$ voice channels

b) Number of channels each earth station transmit: 192 voice channels (users per frame)

4.5.9 Satellite-Switched TDMA (SS-TDMA)

- A satellite-switched TDMA system is an efficient TDMA system with multiple spot beam operation for the uplink and downlink transmissions. The interconnection between the uplink and downlink beams is performed by a high-speed switch matrix located at the heart of the satellite.

- An SS-TDMA scheme provides a full interconnection of TDMA signals among various coverage regions by means of interconnecting the corresponding uplink and downlink beams at a switching time.

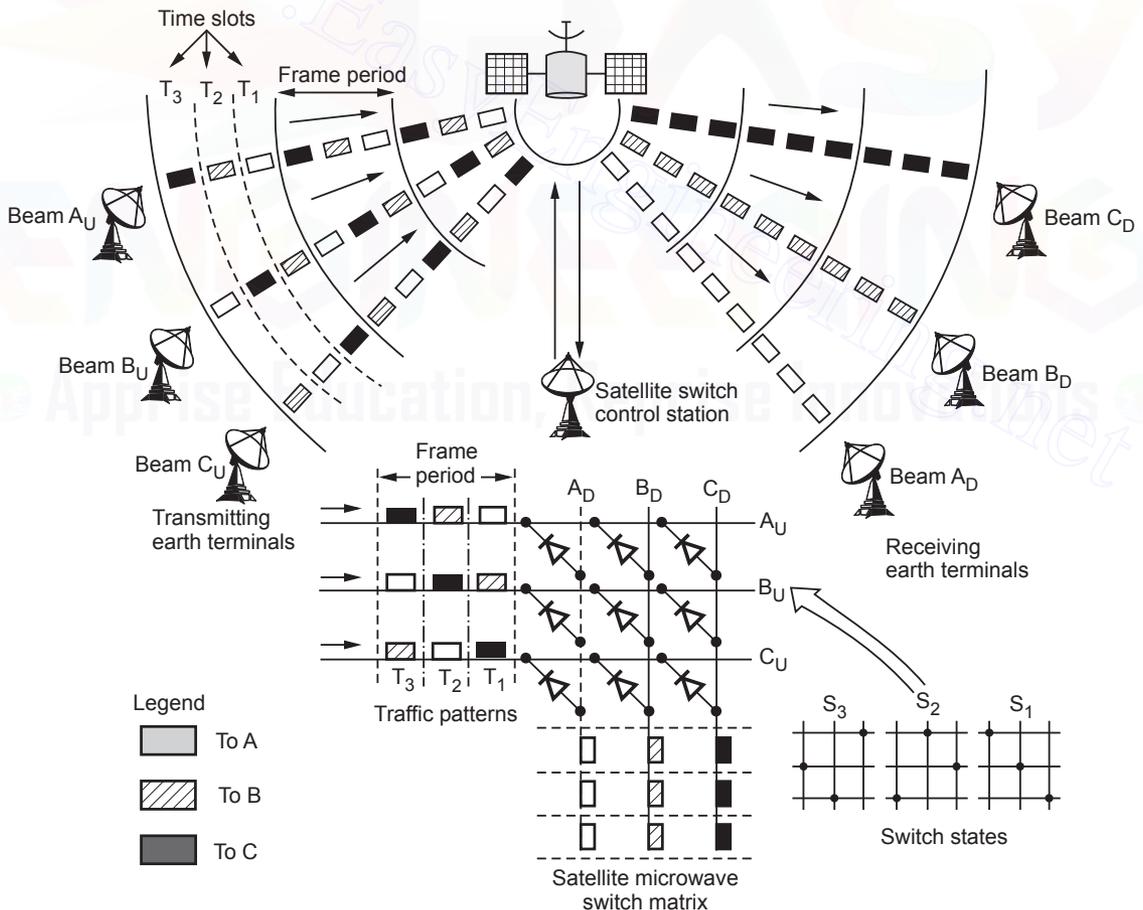- Fig. 4.5.6 shows a three-beam (beams A, B and C) example of a SS-TDMA system.

Fig. 4.5.6 Satellite Switched TDMA (SS/TDMA)

- The switch matrix is configured in a crossbar design in which only a single row is connected to a single column at a time. In this figure, three different traffic patterns during time slot intervals T1, T2 and T3, with three different switch states s1, s2 and s3 are also shown.

- The switching sequence is programmed via a ground control so that states can be changed from time to time.

- The advantages of SS-TDMA systems over TDMA systems are :
  1) The possibility of frequency re-use by spot-beam spatial discrimination, i.e. the same frequency band can be spatially re-used many times. Hence, a considerable increase in satellite capacity can be made.

  2) The use of a narrow antenna beam which provides a high gain for the coverage region. Hence, a power saving can be obtained in both the uplink and downlink.

- An SS-TDMA scheme has been planned for INTELSAT VI.

4.6 Code Division Multiple Access (CDMA)

- Code Division Multiple Access (CDMA) is also called as spread spectrum communication. The term "spread spectrum" refers to the expansion of signal bandwidth, by several orders of magnitude in some cases, which occurs when a key is attached to the communication channel.

- In CDMA, the transmitted signals are not discriminated by their frequency assignment (as in FDMA), nor by their time slot assignment (as in TDMA), but by a characteristic code which is superposed on the information signal. This feature has allowed CDMA to gain attention in commercial satellite communication.

- CDMA was adopted in cellular mobile telephone as an interference-tolerant communication technology that increases capacity above analog systems.

- All concerned earth stations simultaneously share the same bandwidth and recognize the signals by various processes such as code identification.

- The two most common CDMA techniques are :
  1. Direct Sequence Spread Spectrum (DSSS), also called pseudo-noise (PN) modulation, which is the dominant technique.

  2. Frequency Hopping Spread Spectrum (FHSS)

- Spread Spectrum signals use fast codes that run many times the information bandwidth or data rate. These special "Spreading" codes are called "Pseudo Random" or "Pseudo Noise" codes. They are called "Pseudo" because they are not real Gaussian noise.

4.6.1 Functions of CDMA Receiver

- A typical CDMA receiver must carry out the following functions in order to acquire the signal, maintain synchronization, and reliably recover the data :
  1. Synchronization with the incoming code through the technique of correlation detection;
  2. De-spreading of the carrier;
  3. Tracking the spreading signal to maintain synchronization;
  4. Demodulation of the basic data stream;
  5. Timing and bit detection;
  6. Forward error correction to reduce the effective error rate;
- The first three functions are needed to extract the signal from the clutter of noise and other signals.
- The processes of demodulation, bit timing and detection, and FEC are standard for a digital receiver, regardless of the multiple access method.

4.6.2 Features of Spread Spectrum

- Following features of spread spectrum technology (whether DSSS or FHSS) :
  1. Simplified multiple access : No requirement for coordination among users.
  2. Selective addressing capability if each station has a unique chip code sequence-provides authentication : Alternatively, a common code may still perform the CDMA function adequately since the probability of stations happening to be in synch is approximately 1/n.
  3. Relative security from eavesdroppers : The low spread power and relatively fast direct sequence modulation by the pseudorandom code make detection difficult.
  4. Interference rejection : The spread-spectrum receiver treats the other DSSS signals as thermal noise and suppresses narrowband interference.

4.6.3 Advantages of Spread Spectrum System

1. Low power spectral density.
2. Privacy due to unknown random codes.
3. Random access possibilities.
4. Good anti-jam performance.
5. Reduced crosstalk interference.
6. Better voice quality/data integrity and less static noise.

7. Lowered susceptibility to multipath fading: Applying spread spectrum implies the reduction of multi-path effects.

8. Inherent security.

9. Co-existence.

10. Synchronization between stations in the system is not required (unlike TDMA, where synchronization is a critical feature of the system). This means that a station can access the system at any time.

11. Longer operating distances.

12. Hard to detect.

13. Hard to intercept or demodulate.

4.6.4 Direct Sequence Spread Spectrum : (DS/SS)

- In SS system the signal spreading code is the so-called pseudo-noise (PN) sequence, which is generally periodic and consists of periodic coded sequence correlation properties.

- These signals are pseudorandom as they appear to be unpredictable to an outsider, though they can be generated by deterministic means by the person for whom they are intended.

- The polar signal c(t) representing this binary sequence is the pseudo-random carrier that is used to multiply the message signal m(t).

- Signal c(t) is a pseudorandom signal as it appears to be unpredictable though it can be generated by deterministic means (hence pseudorandom).
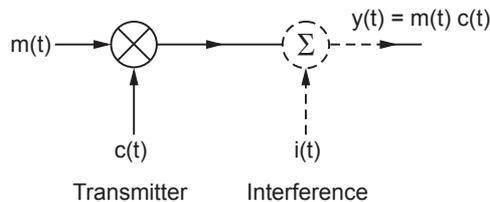 Fig. 4.6.1 shows the generator of DS/SS signal.

Fig. 4.6.1 DS/SS generator

- The bit rate of c(t) is much higher than the bit rate of m(t).
  The basic pulse in c(t) is known as *chip* and the bit rate of c(t) is known as *chip rate* (R_c).

chip rate $R_c = \dfrac{1}{T_c}$

Where T_c is chip width.

- The auto correlation function $\psi_c(t)$ of c(t) is very narrow.
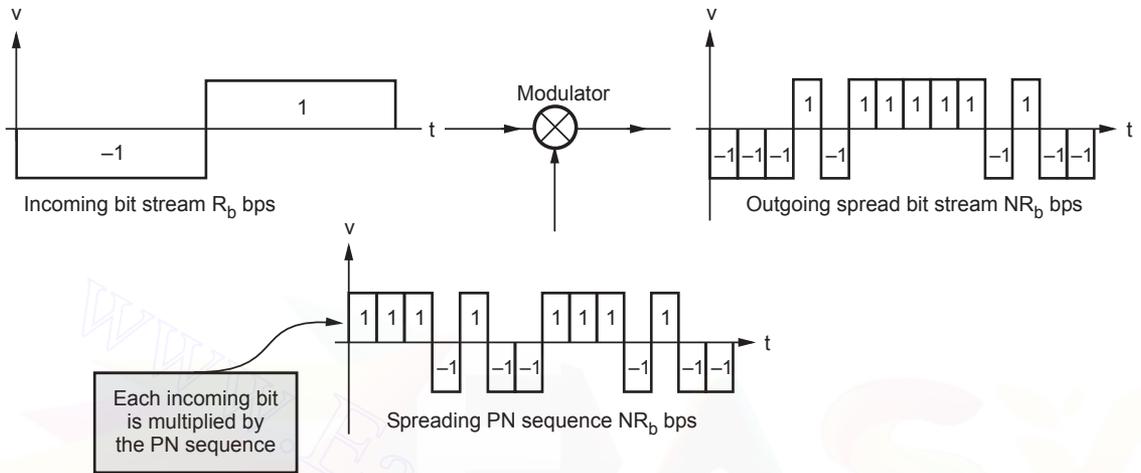
Fig. 4.6.2 shows the signals at the SS generator.

Fig. 4.6.2 Principle of Direct Sequence Spread Spectrum

1) Detection

- At the receiver for detection a synchronous pseudorandom sequence c(t) similar to transmitter is used.

- The received DS/SS signal y(t) is multiplied by c(t) to recover desired signal m(t).

$$\because \quad y(t)\, c(t) = m(t)\, c^2(t)$$
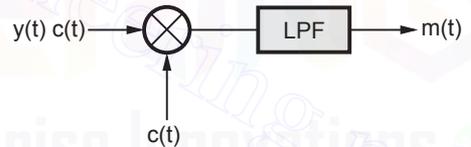
$$= m(t) \qquad \because c^2(t) = 1$$

Fig. 4.6.3 shows DS/SS receiver.

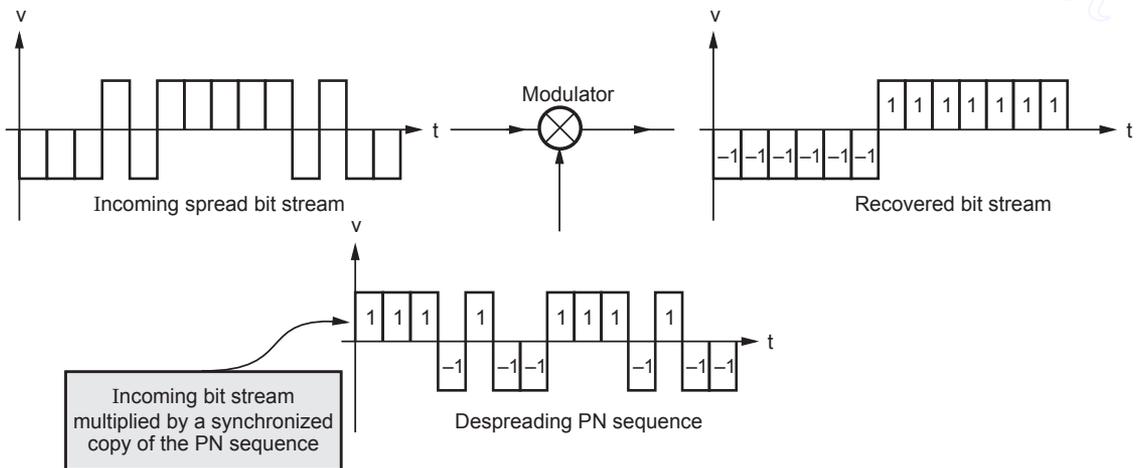**Fig. 4.6.3 DS/SS receiver**

Fig. 4.6.4 De-spreading signal

- A LPF is basically an integrator. The receiver performs the correlation incoming signal m(t) c(t) and locally generated c(t).

2) Signal Spectra

- Chip rate = R_c bits/sec and message symbol rate = R_b bits/sec.

The processing gain is given as

$$N = \frac{R_c}{R_b}$$

or

$$N = \frac{T_b}{T_c}$$

where T_c is chip width.

- The power spectral density (PSD) is given by

$$S_m(\omega) = T_b \sin c^2\left(\frac{\omega T_b}{2}\right) \qquad \text{For input signal (A)}$$

$$S_y(\omega) = T_c \sin c^2\left(\frac{\omega T_c}{2}\right) \qquad \text{For output signal (B)}$$

- The PSD of input signal m(t) and output signal of DS/SS y(t) is shown in the Fig. 4.6.5. Since the PSD bandwidth is directly proportional to bit rate, the PSD of y(t) is N times wider than PSD of m(t).
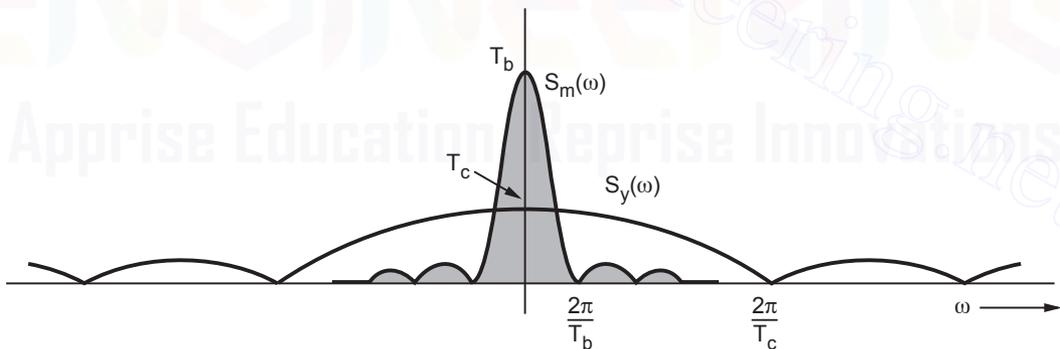

Fig. 4.6.5 PSDs of the input and the output signals of a DS/SS system

- The power of input and output equations are same. This indicates that PSD of y(t) is weaker than that of m(t) by a factor N (processing gain). In other words the spreading process reduces the PSD of a signal by factor N.

4.6.4.1 Approximate Pattern of DS/SS Signal

- Let the bit width of information signal is T, therefore data rate is $\frac{1}{T}$. The spectrum of signal, depending on encoding technique is approximately $\frac{1}{2\,T}$. Fig. 4.6.6 shows spread spectrum achieved by direct sequence technique.

- The spectrum of PN signal is $\frac{2}{T_c}$. The resulting spectrum spreading is shown in Fig. 4.6.6 (c).

Signal energy

$\frac{-1}{T}$ 0 $\frac{1}{T}$

(a) Spectrum of data signal

$\frac{-1}{T_c}$ 0 $\frac{1}{T_c}$

(b) Spectrum of pseudonoise signal

$-\left(\frac{1}{T}+\frac{1}{T_c}\right)$ 0 $\frac{1}{T}+\frac{1}{T_c}$
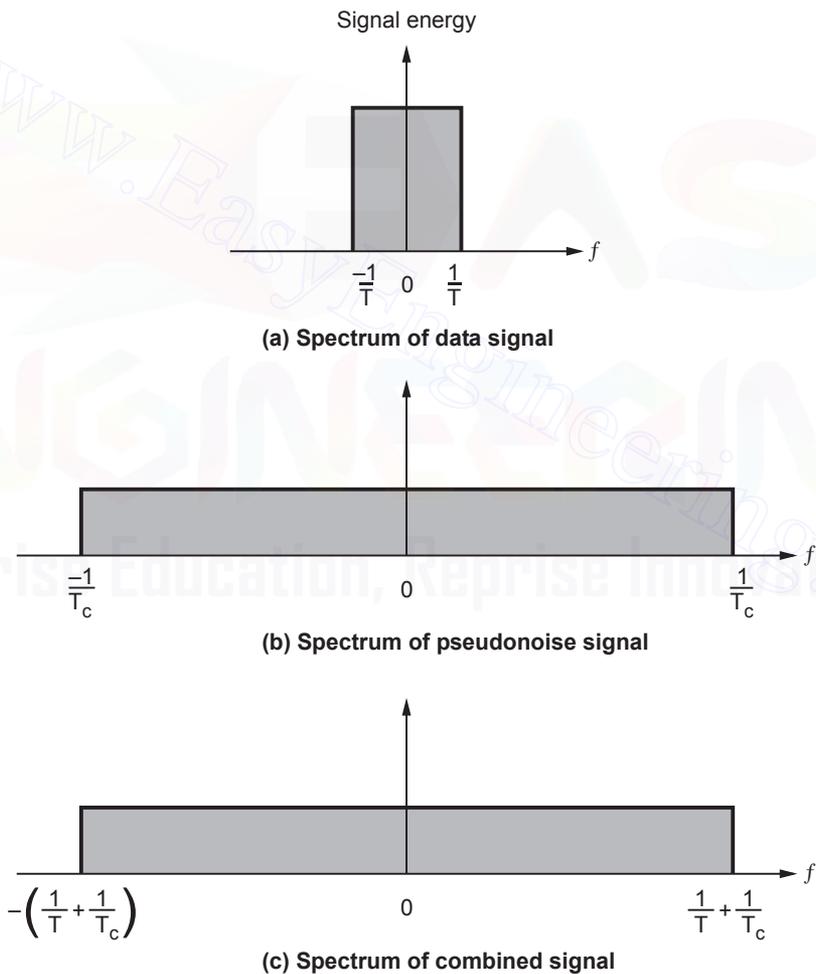
(c) Spectrum of combined signal

Fig. 4.6.6 Approximate spectrum of direct sequence spread spectrum signal

4.6.4.2 **Features of DS/SS**

1. Secure communication :

In DS/SS, the signal can be detected at the receiver if the pseudorandom code used at transmitter is known. This prevents unauthorized access of signal.

2. Hiding of signal :

The DS/SS signal spectrum is spread over a wide band, the signal PSD is very small. Hence it is easy to hide the signal within the noise floor.

3. Jamming resistance :

The DS/SS signal spectrum power is distributed over a wide band, hence these signals are difficult to jam. Because of spectral spreading PSD of jamming signal (interference) decreases by factor N.

While PSD of signal m(t) becomes stronger because of despreading.

4. Multiple access (several users on same band) :

Several users can utilize the same band with better signal to noise ratio.

5. Advantages of CDMA :

The DS/SS supports greater capacity of communication channels. Several users can occupy irrespective of separation distance between them. Since each user has a unique spreading codes. This features allows Code Division Multiple Access (CDMA).

6. Resistance to multipath fading :

The signal received due to reflection is a delayed version of original DS/SS signal (interfering signal). Because DS/SS signal has a unique feature of low auto co-relation with its delayed version i.e. interfering signal will not be despread by c(t). Alternatively this minimizes the effect of multipath signals (multipath immunity).

7. Near-far problem :

The DS/SS suffers from the near-far problem. The near-far problem occurs because of unequal received power by the user.

When an unwanted signal strength is more because of its proximity of its transmitter to the receiver and the desired signal strength is weak. In such situation the desired signal may be suppressed. This problem can be eliminated by making all the codes orthogonal but it is difficult to make large number of codes orthogonal.

4.6.4.3 **Advantages of DS/SS**

1. DS/SS system has best noise and antijam performance.

2. Unidentified receivers find it most difficult to detect direct sequence signals.

3. DS/SS has best discrimination against multipath signals.

4.6.4.4 **Disadvantages of DS/SS**

1. DS/SS requires wideband channel with small phase distortion.

2. DS/SS has longer acquisition time.

3. The pseudo noise generator should generate sequence at high rates.

4.7 **Part A : Short Answered Questions [2 Marks Each]**

Q.1 **Explain Frequency Division Multiple Access (FDMA).**

Ans. : Frequency Division Multiple Access (FDMA) -

- A large number of geographically separated users share a common communication medium to transmit information to a receiver. There must be a coordinated effort to share the resource. FDMA is one such method.

- FDMA divide the bandwidth of the communication medium into N non-overlapping frequency slots and assign a slot to each user upon request.

Q.2 **Explain TDMA in satellite communication.**

Ans. : Time Division Multiple Access (TDMA) -

- 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.

Q.3 **Define SCPC. What is a thin route service ? State feature of Intelsat SCPC system.**

Ans. : SCPC

- SCPC stands for Single Channel Per Carrier.

- In SCPC, a thin route circuit, a transponder channel (36 MHz) may be occupied by a number of single carriers, each associated with its own voice circuit.

Thin Route Service

- SCPC systems are widely used on lightly loaded routes, this type of service being referred to as a thin route service.

Features of SCPC

- The system is that each channel is voice activated. This means that on a two way telephone conversation only one carriers is operative at any one time.

4.8 Multiple Choice Questions

Q.1   **The limitations of FDMA-satellite access are _____ .**

| a | if the traffic in the downlink is much heavier than that in the uplink, then FDMA is relatively inefficient. |

| b | compared with TDMA, FDMA has less flexibility in reassigning channels. |

| c | carrier frequency assignments are hardware controlled |

| d | all of the above |

Q.2   **Frequency modulation is used in satellite communication because _____ .**

| a | small bandwidth and negligible noise |

| b | large bandwidth and severe noise |

| c | maximum bandwidth and minimum noise |

| d | high modulation index |

Q.3   **Satellite cross-link referred to as ____ .**

| a | Earth-to-satellite link | b | Satellite-to-earth link |

| c | Satellite-to-satellite link | d | None of these |

Q.4   **_____ is used by Earth station.**

| a | Despun antenna | b | Helical antenna |

| c | Toroidal antenna | d | Cassegrain antenna |

Answer Keys for Multiple Choice Questions

Q.1	d	Q.2	b	Q.3	c	Q.4	d

❑❑❑