Unit 5

PART – 1

Spread spectrum techniques

Spread spectrum communications

- In spread spectrum communication, channel bandwidth and transmitted power are sacrificed for the sake of secure communication.
- The primary advantage of spread spectrum communication is its ability to reject interference.
- An un-intentional interference is the one in which another user tries to transmit simultaneously through the same channel.
- In intentional interference the hostile transmitter attempts to jam the transmission.

Spread spectrum

- Spread spectrum is a means of transmission in which the data sequence occupies a bandwidth in excess of minimum bandwidth necessary to send it.

- The spectrum spreading is accomplished before the transmission through use of code that is independent of data sequence.

- The same code is used in the receiver to despread the received signal so that the original sequence may be recovered.

Types of spread spectrum

- Direct-sequence spread spectrum
  - Two stages of modulation used.
  - First the incoming data sequence is used to modulate a wideband code.
  - The code transforms narrow band data sequence into noiselike wideband signal.
  - The wideband signal undergoes second modulation using PSK technique.

- Frequency hop spread spectrum
  - The spectrum of data modulated carrier is widened by changing carrier frequency in pseudo-random manner.

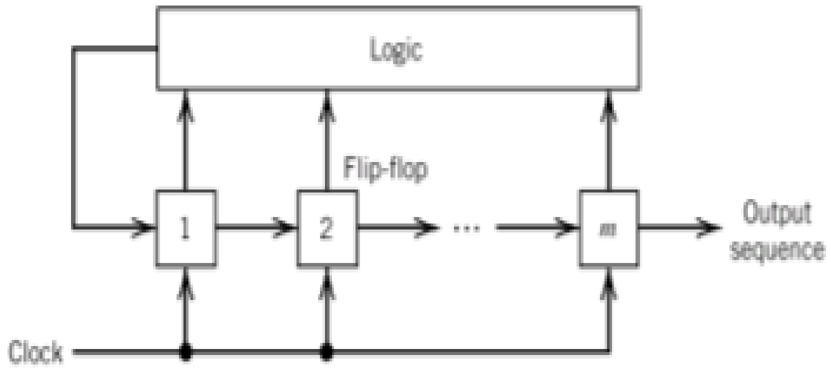
- Both spread spectrum techniques require noise-like spreading code called pseudo random sequence

Pseudo noise sequences

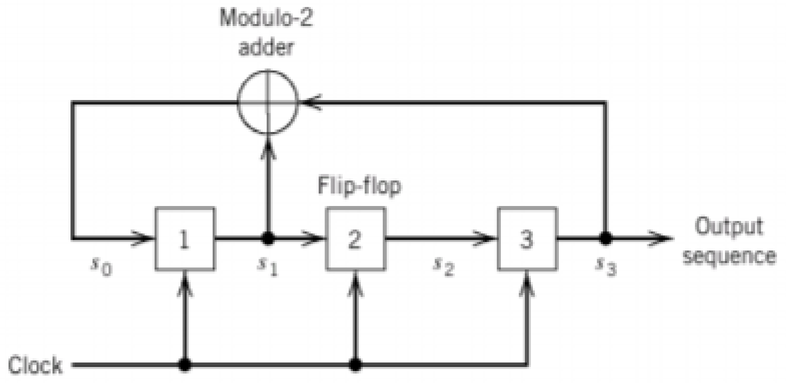
- A (digital) code sequence that mimics the (second-order) statistical behavior of a white noise.

- A pseudo-noise sequence is generated by using several shift-registers and a feedback through combinational logic.

- Feedback shift register becomes “linear” if the feedback logic consists entirely of modulo-2 adders.



PN Sequence generator



Linear feedback shift register

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- A PN sequence generated by a (possibly non-linear) feedback shift register must eventually become periodic with period at most 2^m, where m is the number of shift registers.

- A PN sequence generated by a linear feedback shift register must eventually become periodic with period at most $2^m - 1$, where m is the number of shift registers.

- A PN sequence whose period reaches its maximum value is named the maximum-length sequence or simply m-sequence.

- A maximum-length sequence generated from a linear shift register satisfies three properties
  - *Balance property: The number of 1s is one more than that of 0s.*
  - *Run property: (total number of runs = 2^m-1) i.e., ½ of the runs is of length 1, ¼ of the runs is of length 2…..and so on.*
  - *The correlation property: The autocorrelation sequence of a maximum-length sequence is periodic.*

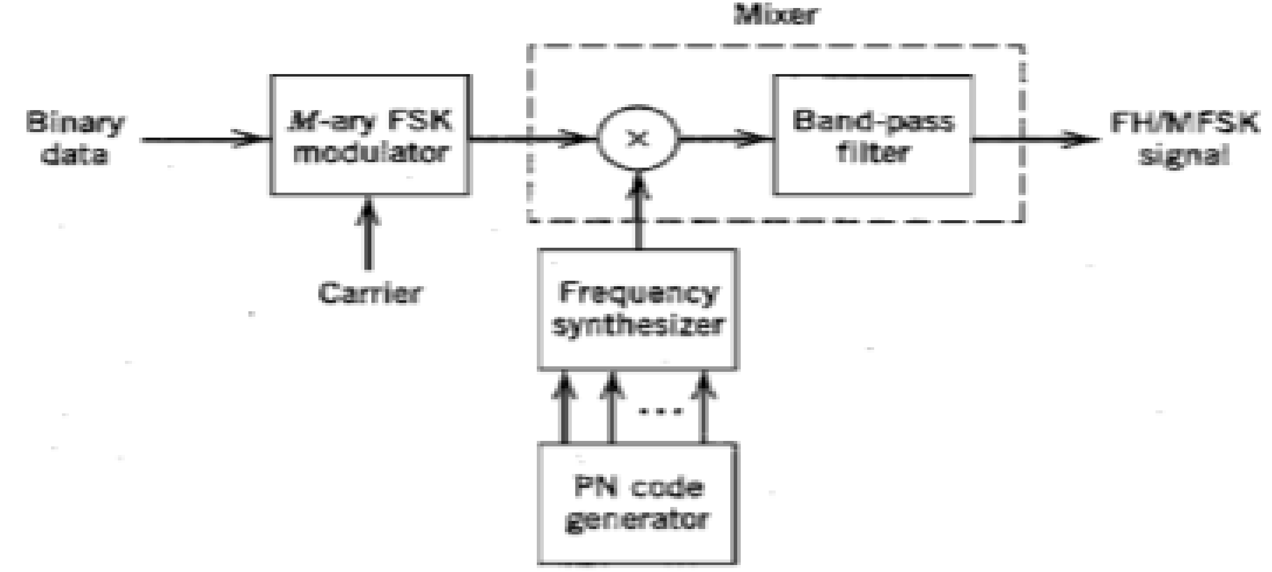
Frequency hop spread spectrum

- System with larger processing gain can combat effect of jammers.
- However processing gain is a function of PN sequence period.
- PN sequence with narrow chip duration provides larger processing gains.
- Physical devices are not capable of generating narrow chips which imposes limits on attainable processing gains.
- Also processing gain so attained is not large enough to overcome jammers.
- Alternate method is to force jammers to cover wide spectrum by randomly hopping data modulated carrier from one frequency to next.

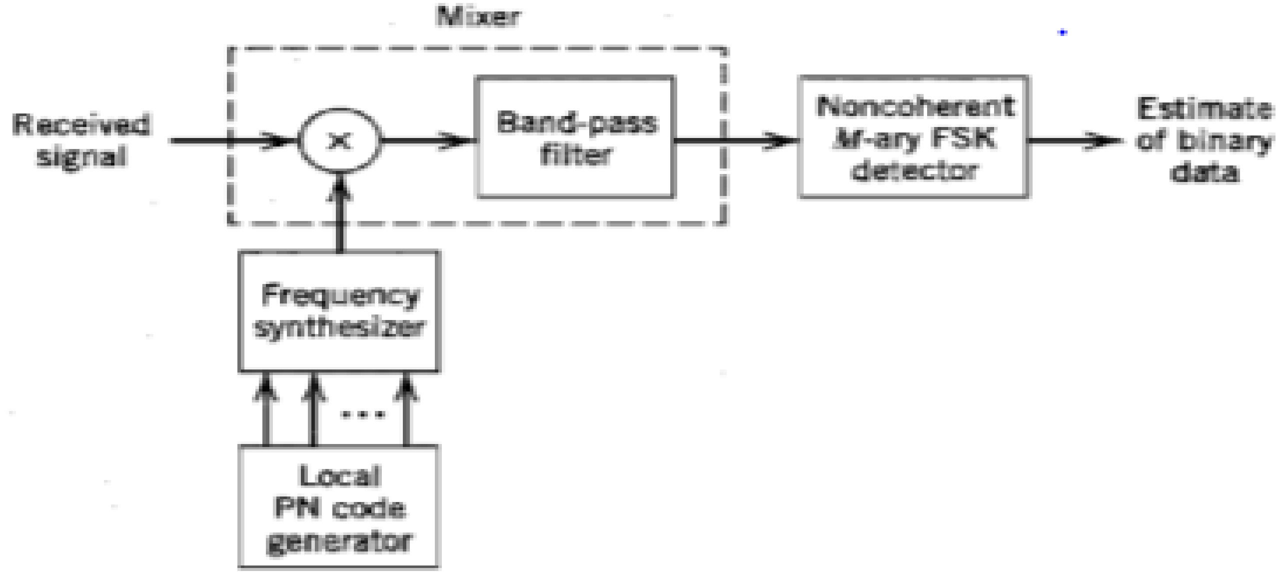
- The spectrum is spread pseudo randomly i.e., random frequency hops.

- Commonly used modulation format for frequency hopped systems is M-Ary frequency shift keying.

- TYPES:
    - Slow frequency hopping – Symbol rate(R_S) is equal to integer multiple (R_n)
    - Fast frequency hopping – Hop rate(R_h) is equal to integer multiple (R_s)



(a)



(b)

a)Transmitter b)Receiver (common for both)

Slow frequency hopping

- FSK is performed followed by mixing. Incoming binary data is applied to FSK modulator. The resulting modulated wave and output is applied to mixer consisting of multiplier followed by BPF.

- Filter is designed to select only sum frequency component.

- K- bit PN sequence drives synthesizer and enables carrier frequency to hop over 2^k distinct values.

- For 2^k frequency hops, FH/MFSK occupies larger bandwidth which is much larger than that achievable by DSSS.

- Inability to maintain phase coherence suggests use of non coherent detection for FHSS.

- Reverse process happens at demodulator side.

- In FHSS, individual FH/MFSK tone is referred to as chip.

- Chip rate is defined by $R_c = \max(R_h, R_s)$ where R_h is hop rate and R_s is symbol rate.

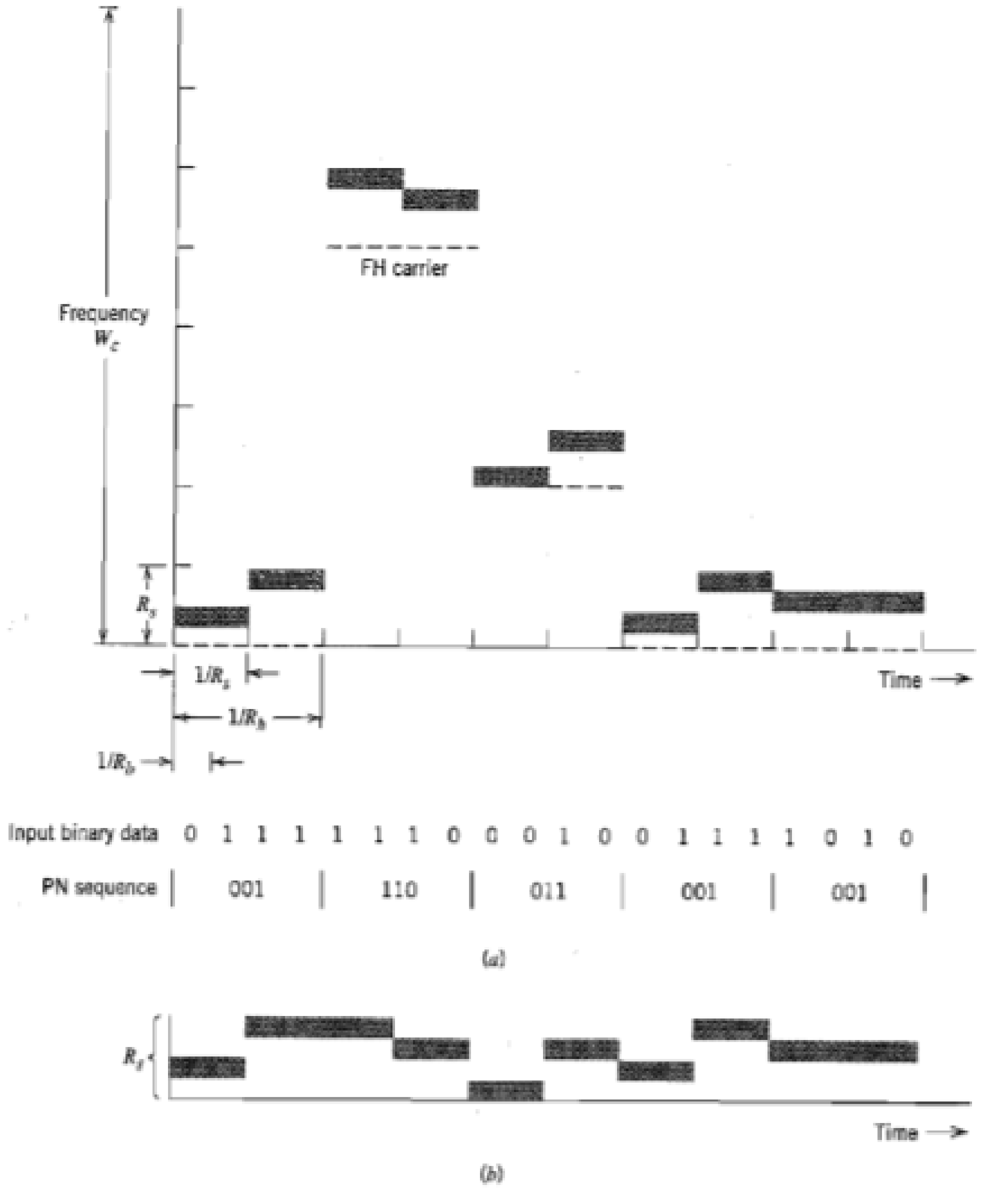
- The bit rate R_b, R_s, R_c and R_h are related by $R_c = R_s = \frac{R_b}{K} \geq Rh$ where $k = \log_2 M$.

- MFSK tones are separated in frequency by integer multiple of $R_c = R_s$ ensuring orthogonality.

- If jammer spreads its average power J over the entire frequency hopped spectrum with bandwidth W_c and power spectral density $N_o/2$ where $N_0 = J/W_c$.

- Symbol energy to noise spectral density ratio is $E/N_0 = (P/J)/(W_c/R_s)$.

- Processing gain is defined by $PG = W_C/R_S = 2^k$ and $PG(\text{in dB}) = 10\log_{10} 2^k = 3K$ where k is length of PN sequence.

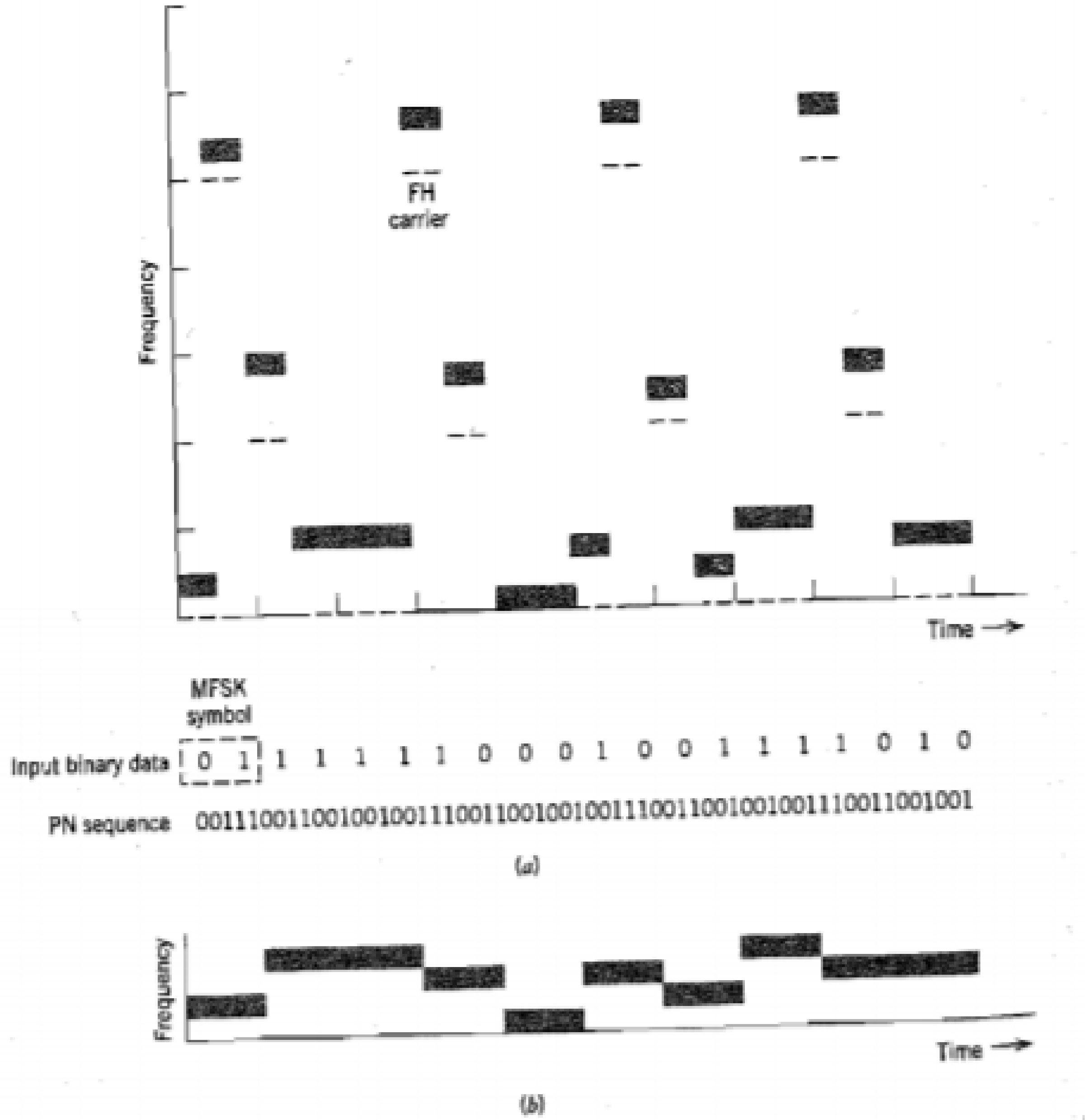


Number of bits per MFSK symbol	$K = 2$
Number of MFSK tones	$M = 2^K = 4$
Length of PN segment per hop	$k = 3$
Total number of frequency hops	$2^k = 8$

Slow frequency hopping a) Frequency variation for one complete period of PN sequence b) Variation of de-hopped frequency with time

Fast frequency hopping

- Fast FH/MFSK system has multiple hops per M-Ary symbol.
- To overcome jammer, the transmitted signal must be hopped to new carrier frequency before the jammer could interfere.
- Non coherent detection is used which is slightly different from slow FH/MFSK.
- 2 procedures are considered
  - For each FH/MFSK symbol, separate decisions are made on k frequency hop chips received and majority vote is used to estimate the symbol.
  - For each FH/MFSK symbol, likelihood functions are computed and largest one is selected.
- Receiver based on second procedure is optimum as it minimizes probability of symbol error.



Fast frequency hopping a)Variation of transmitter frequency with time b) Variation of de-hopped frequency with time

Number of bits per MFSK symbol	$K = 2$
Number of MFSK tones	$M = 2^K = 4$
Length of PN segment per hop	$k = 3$
Total number of frequency hops	$2^k = 8$

Direct sequence spread spectrum

- Spread spectrum modulation provides protection against externally generated jamming signals.

- It may be broadband noise or multitone waveform that disrupts communications.

- To protect information bearing signal from jamming signal it is made to occupy a bandwidth far in excess of minimum bandwidth required.

- This makes transmitted signal appear like noise and can be considered as camouflaging the information bearing signal.

- Modulation can be used to widen the bandwidth.

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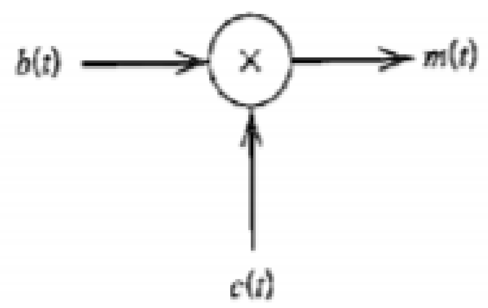
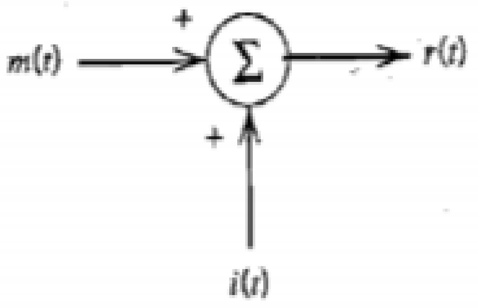


Transmitter



Channel

- b_k-binary data sequence, c_k-pseudo noise sequence, b(t) and c(t) is polar NRZ representation.

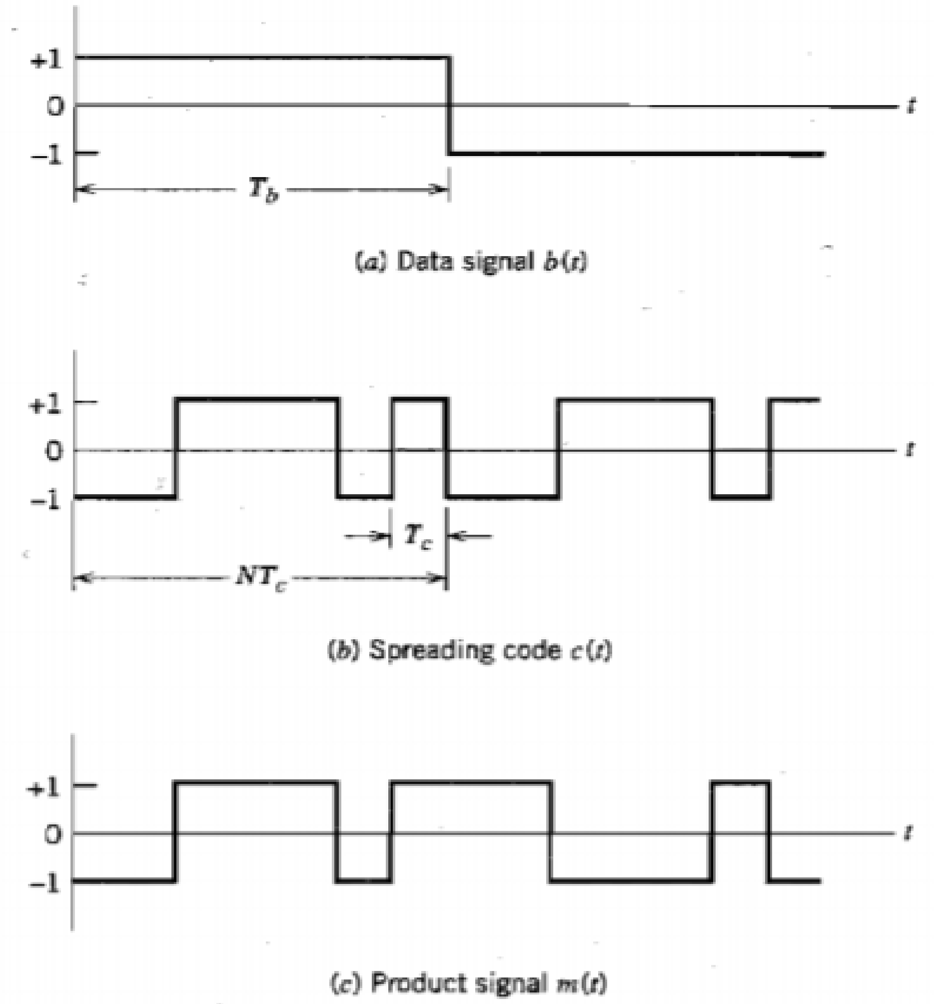
- b(t) and c(t) is applied to product modulator or multiplier.

- b(t) is narrowband and c(t) is wideband. Their product m(t) will have spectrum same as wideband PN signal.

- PN sequence acts as spreading code.

- By multiplying b(t) with c(t), the information bit is chopped and are called as chips.

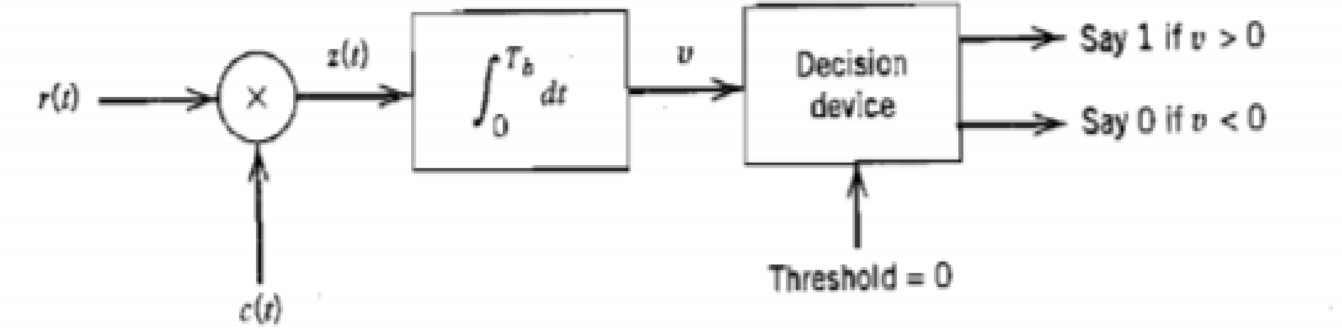
- Transmitted signal m(t)=c(t).b(t)



- The received signal r(t) consists of transmitted signal m(t) and additive interference denoted as i(t).

  r(t)=m(t)+i(t)

  r(t)=c(t).b(t)+i(t)



Receiver

- r(t) is applied to demodulator that consists of multiplier followed by integrator and decision device

- c(t) is exact replica of that used in the transmitter to provide synchronization.

- Multiplier output is given by

  Z(t)=c(t).r(t)

  $Z(t)=c^2(t).b(t)+c(t).i(t)$

- PN signal c(t) alternates between +1 and -1 and it becomes +1 when it is squared.

  $C^2(t)=1 \quad \forall t$

- Z(t) becomes Z(t)=b(t)+c(t).i(t)

- b(t) is produced at receiver. In addition there is interference term i(t) multiplied by c(t). c(t) spreads i(t).

- b(t) is narrowband. c(t).i(t) is wideband.

- By applying multiplier output to LPF, b(t) is recovered and c(t).i(t) is filtered out.

- LPF action is performed by integrator that carries out integration over $0 \leq t \leq T_b$ providing V
  - If V>0, binary 1 is sent
  - If V<0, binary 0 is sent
  - If V=0, random guess is made in favor of 1 or 0.

Points to note:

- Longer the period of spreading code, closer will be the transmitted signal to be truly random and harder it is to detect.

- But transmission bandwidth is increased. Also system becomes complex and processing delay will be more.

- TO HAVE A SECURE TRANSMISSION, THESE ARE NOT UNREASONABLE COSTS TO PAY

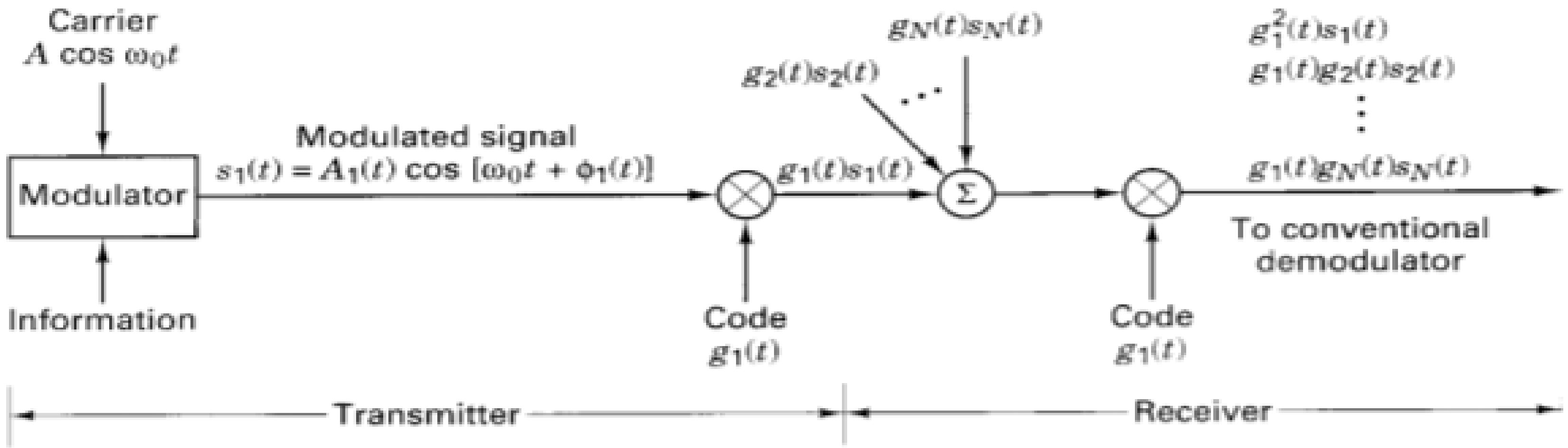
Code division multiple access of DSSS

- Each N user group is given its own code.

- The user codes are approximately orthogonal, so that the cross correlation of two different codes is near zero.

- The main advantage of CDMA system is that all the participants can share the full spectrum of the resource asynchronously.

$$\int_0^T g_i(t) g_j(t) dt = \begin{cases} 1 \text{ for } i = j \\ 0 \text{ for } i \neq j \end{cases}$$



- The modulator modulates the carrier and its output belong to the user from group1.

- The modulated signal is multiplied by the spreading signal g1(t) belonging to group 1 and resulting signal is transmitted over the channel.

- Simultaneously users from group2 through N multiply their signals by their own code.

- Codes are restricted from unauthorized access.

- The signal present at the receiver is the linear combination of emanation from each of the user.

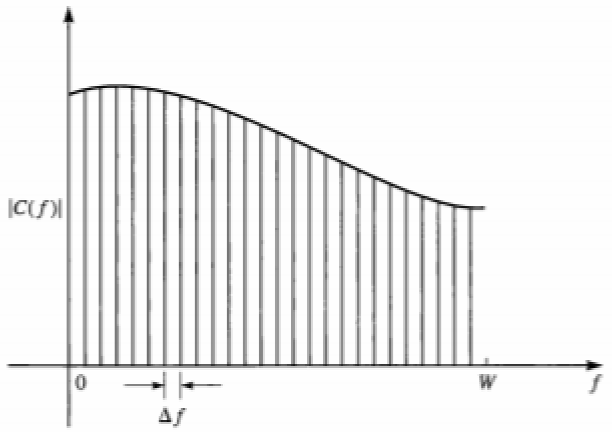
- Signal is narrow band when compared with the code and hence the product will have approximately the bandwidth of the code in CDMA.

- Code should be orthogonal to each other.

- At the receiver perfectly generated code yields original signal back. But practically codes are not orthogonal. Therefore performance degradation occurs which limits the number of simultaneous users.

OFDM communication

- OFDM transmits information on multiple carriers contained within the allocated channel bandwidth.
- The primary motivation for transmitting the data on multiple carriers is to reduce ISI and eliminate performance degradation.
- Multicarrier modulation divides the available channel bandwidth into subbands of narrow bandwidth $\Delta f = W/N$.
- It yields transmission rates close to channel capacity.
- The signal in each sub band may be independently coded and modulated at synchronous symbol rate of $1/\Delta f$.
- If Δf is small, the channel frequency response is constant across each subband. So ISI will be negligible.



Subdivision of the channel bandwidth W into narrowband sub channels of equal width Δf.

- With each sub band (or sub channel), we associate a sinusoidal carrier signal of the form

$$s_k(t) = \cos 2\pi f_k t, \qquad k = 0, 1, \ldots, N-1$$

- where f_k is the mid frequency in the k^{th} sub channel. By selecting the symbol rate 1/T in each of the sub channels to be equal to the frequency separation Δf of the adjacent subcarriers, the subcarriers are orthogonal over the symbol interval T, independent of the relative phase relationship between subcarriers. That is,

$$\int_0^T \cos(2\pi f_k t + \phi_k)\cos(2\pi f_j t + \phi_j)\, dt = 0$$

- where $f_k - f_j = n/T, \; n = 1, 2, \ldots, N-1,$ independent of the values of the phases φk and φj

- OFDM is a special type of multicarrier modulation in which the subcarriers of the corresponding sub channels are mutually orthogonal.

- Multicarrier modulation (OFDM) is widely used in both wire line and radio channels. For example, OFDM has been adopted as a standard for digital audio broadcast applications and wireless local area networks based on the IEEE 802.11 standard.

- A particular suitable application of OFDM is in digital transmission over copper wire subscriber loops.

- OFDM with optimum power distribution provides the potential for a higher transmission rate.