Module - 5

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Spread spectrum modulation

Spread spectrum modulation is a signalling technique used for transmitting a signal to provide a secure communication.

The main advantage of spread spectrum communication technique is to prevent interference. The signals modulated with these techniques are hard to interfere and never allowed to crack signals with no official access.

Definition of spread spectrum modulation.

* "The modulated signal occupies a much more bandwidth than the minimum required bandwidth"
* The spectrum spreading at the transmitter and despreading at the receiver is obtained by special code [chipping code] which is independent of data [message signal]

Advantages of spread spectrum

1) Cross talk elimination
2) Better output with data integrity
3) Reduced effect of multipath fading
4) Better security
5) Reduction in noise
6) CO - existence with other systems
7) Longer operative distances.
8) Hard to detect

9> Not easy to demodulate | decode

10> Difficult to jam the signals.

Classification of spread spectrum systems.

Spread spectrum modulation techniques are classified as

1> Direct sequence spread spectrum [DSSS]

2> Frequency hopped spread spectrum [FHSS]

Direct sequence spread spectrum [DSSS]

The direct sequence spread spectrum uses two stages of modulation. In the first stage, each and every bit of the incoming data is multiplied by a secret code signal [PN signal]. This transforms the narrow band incoming signal into a wideband signal i.e the spectrum of the signal is spreaded.

In the second stage the wideband signal is modulated using Phase shift keying [PSK]

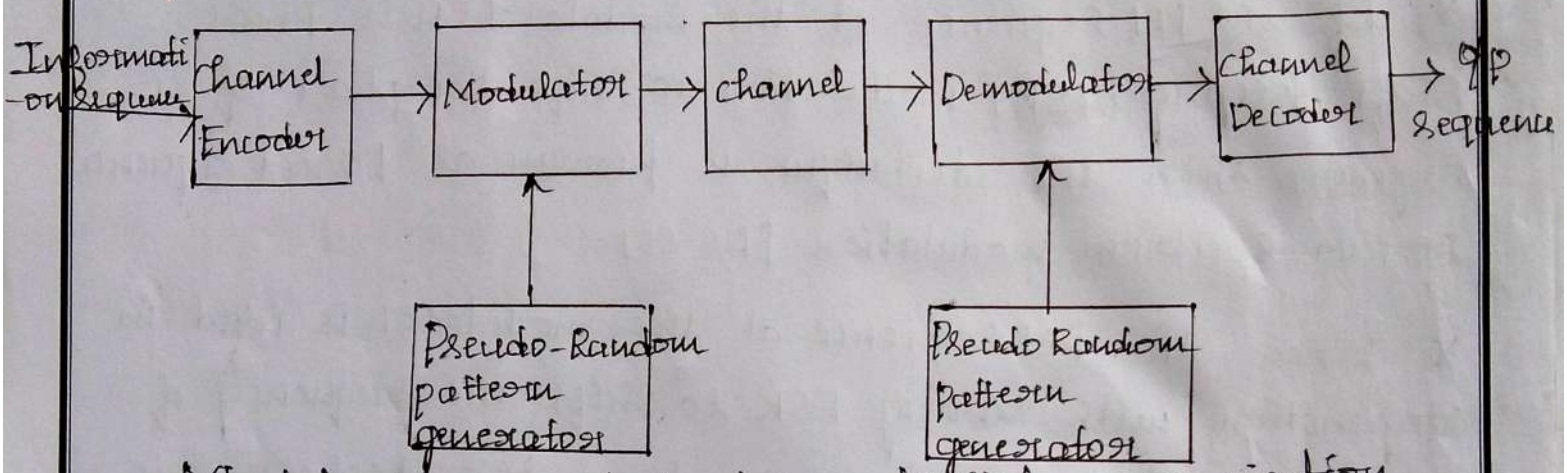
Frequency hopped spread spectrum.

In the frequency hopped spread spectrum the users are allowed to change the frequencies of usage, from one to another in a specified time interval. Hence the name frequency hopping.

The spectrum of the data modulated carrier is widened by changing the carrier frequency in pseudo random manner

For both direct sequence and frequency hopped spread spectrum modulation techniques, a noise like spreading code called Pseudo-noise [PN] sequence is used.

Model of spread spectrum digital communication system.



Model of spread spectrum digital communication system.

* The channel encoder encodes the binary information sequence
* The channel encoded sequence is then given to the modulator. The modulator gets pseudonoise [PN] sequence from the pseudo-random pattern generator.
* The PN sequence spreads the transmitted signal randomly over the wide frequency band. The signal at the output of the modulator is the spread spectrum modulated signal. This signal is transmitted over the channel.
* At the receiver, the demodulator recovers the encoded signal back from the spread spectrum signal

using the same PN sequence which was used at the transmitting end.

* Hence the pseudorandom pattern generators at the transmitter and receiver side operate in synchronisation with each other.

* The channel decoder decodes the binary information sequence back.

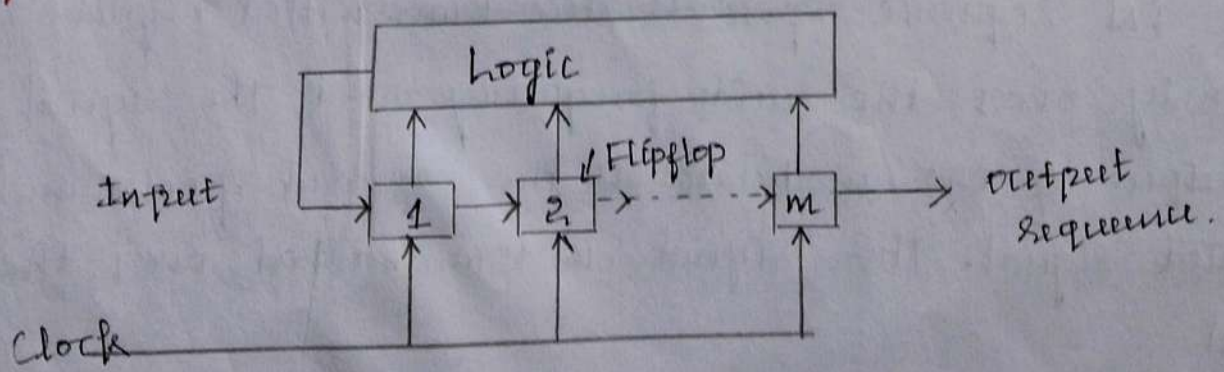
* If the PN sequence at the modulator uses phase shift keying [PSK] modulation to shift the phase of a signal, then this technique is known as Direct sequence spread spectrum modulation [DS-SS]

* When the PN sequence at the modulator is used in conjunction with M-ary FSK to shift the frequency of a signal pseudo randomly, then this technique is known as frequency hopped spread spectrum modulation [FH SS]

PN [pseudonoise sequence]

A pseudo-noise [PN] sequence is defined as a coded sequence of 1s and 0s with certain autocorrelation properties.

Generation of pseudo-noise [PN] sequence



Feedback shift register to generate PN sequence

* A pseudo noise [pseudo-random] sequence is a noise like high frequency signal

* The PN sequence is generated by a feedback shift register and the combinational logic

* The feedback shift register consists of m flip-flops. The data of one flipflop is shifted to the next flipflop whenever the clock pulse is applied. At the same time the output of flipflop is given to the logic circuit.

* Depending upon the outputs of flipflops, the output of combinational circuit decided. The combination logic circuit output is given as input for the first flipflop of the shift register.

* The PN sequence generated at the output of the last flipflop in the shift register

* The generated PN sequence is periodic and it repeats after 2^m digits. This is because the m-stage shift register have 2^m states, hence the output sequence repeats after 2^m bits.

* The combinational logic circuit used is a mod-2 adder [XOR].

* If the shift registers enters a zero state [Eg: 000], it is not possible to come out of this state [i.e $0 \oplus 0 = 0$] and output sequence generated will be only zeros.

* To prevent this problem, the zero state is not allowed. Therefore the total number of states in m-stage

feedback shift register is reduced from 2^m to 2^{m-1}.
The PN sequence generated have a period of $2^m - 1$ bits.

Maximum length sequences:

The pseudonoise [PN] sequence generated by a linear feedback shift register has the length $2^m - 1$, then the sequence is known as maximum length [ML] sequence.

Properties of maximum length sequences [ML]

1) Balance property: In each period of a maximum length sequence, the number of 1's is always greater by one number than the number of 0's. This property is called balance property.

For an ML-sequence generated by m-state shift register with linear feedback

i) Period $= 2^m - 1$ bits.

ii) Number of 1's $= 2^{m-1}$.

iii) Number of 0's $= 2^{m-1} - 1$.

2) Run property:

A Run is defined as a sequence of single type of binary [1s or 0s] digits.

* The appearance of an alternate digit in a sequence starts a new run.
* The length of the run is the number of digits in the run.
* Among the runs of 1s and 0's in each period of ML sequence, it is observed that one-half (1/2) the runs of each type [0s or 1s) are length 1.

one-fourth [Y_4] are of length 2, one-eighth are of length of 3 and so on.

* For a ML sequence generated by a m-stage linear feedback shift register,

The total number of runs $= \frac{L+1}{2}$ Where $L = 2^m - 1$

3. Autocorrelation property:

Let $\{C_0, C_1, C_2, \ldots C_{L-1}\}$ be a ML-sequence of period $L = 2^m - 1$, generated by a m-stage linear feedback register. The normalised circular autocorrelation function [ACR] of the sequence is given by

$$R(\tau) = \frac{1}{L} \sum_{i=0}^{L-1} C_i \, C_{(i \oplus \tau)_{mod-L}} \qquad \tau = 0, 1, 2, \ldots L-1.$$

Where τ is the shift.

* If The symbols 1 and 0 are represented by +1 volt and −1 volt respectively.

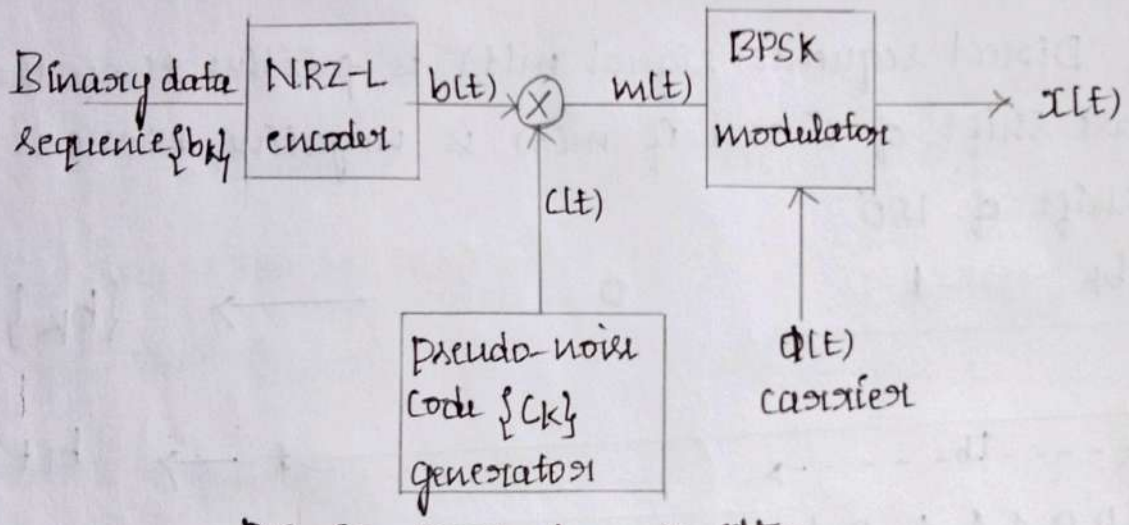
Autocorrelation function is defined as

$$R(\tau) = \begin{cases} 1 & \text{for } \tau = kL \quad k = 0, 1, 2 \ldots \\ -\frac{1}{L} & \text{for } \tau \neq kL \quad k = 0, 1, 2 \ldots \end{cases}$$

Direct sequence spread-spectrum system with BPSK [OR] DS-SS BPSK.

Consider the transmission of binary information sequence modulated by binary phase shift keying [BPSK] The information rate is R bits/sec, channel bandwidth is B_c Hz, where $B_c >> R$. At the modulator, the bandwidth of the information signal is expanded to $W = B_c$ Hz by using pseudo-noise [PN] sequence.

Generation of DS-SS signal [OR] DS-SS BPSK trasmitter.



DS-SS BPSK transmitter.

* Let the data sequence be represented $\{b_k\}$. This data sequence is converted to polar NRZ waveform $b(t)$.

i.e when $b_k = 1$, $b(t) = +1$

when $b_k = 0$, $b(t) = -1$

* Let $\{C_k\}$ denote the PN sequence and $c(t)$ denotes the polar NRZ signal generated by C_k.

i.e when $C_k = 1$, $c(t) = +1$

when $C_k = 0$, $c(t) = -1$

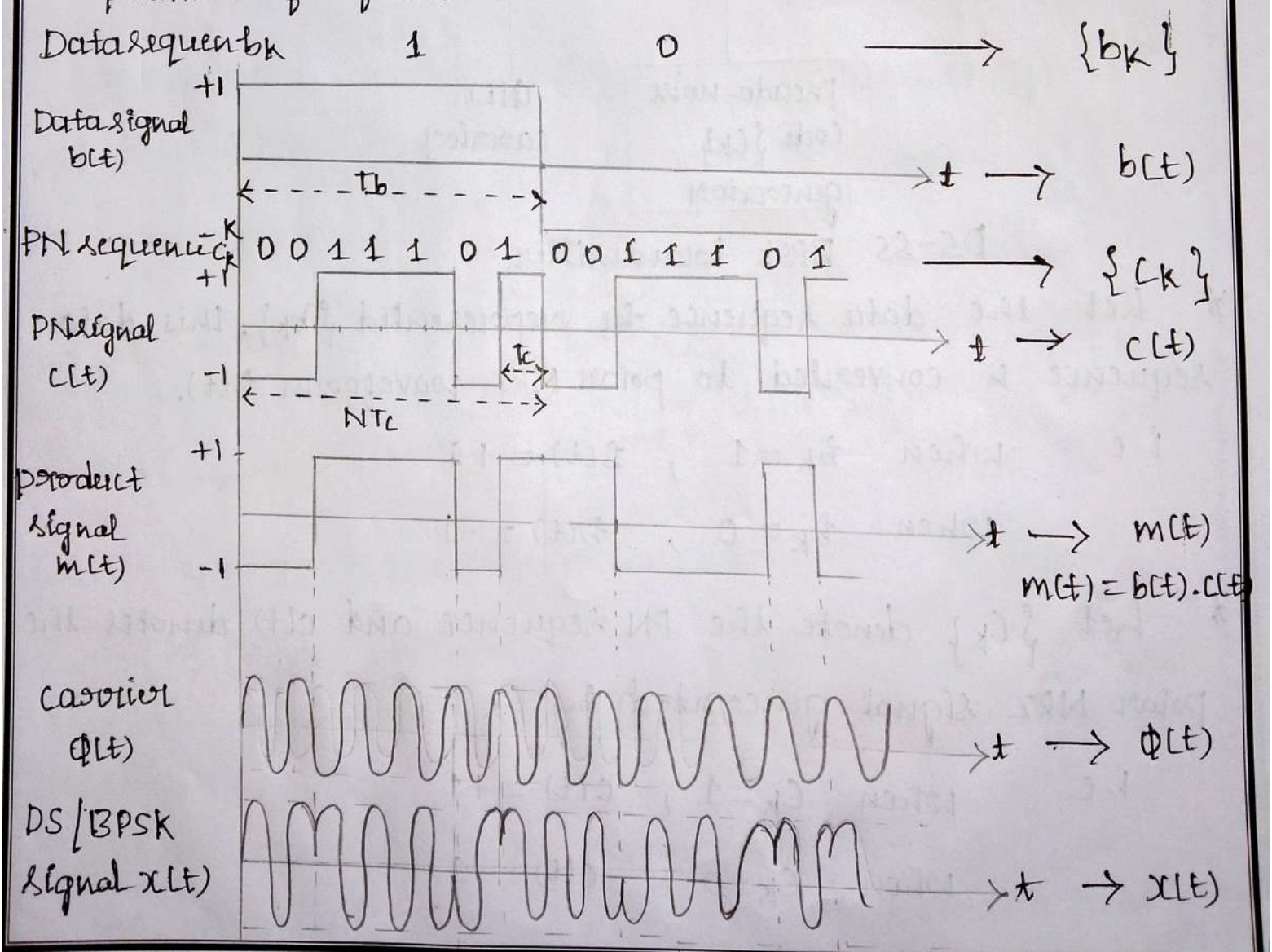
* The multiplier multiplies two signals $b(t)$ & $c(t)$ outputs direct sequence spread spectrum signal $m(t)$.
* This signal is given as modulating signal to BPSK transmitter.
* The Direct sequence BPSK signal is generated at the output $[x(t)]$.
* Let $\phi(t)$ be the carrier

$$\phi(t) = \sqrt{2/T}\ \sin 2\pi f_c t.$$

* then transmitted signal $x(t)$ is

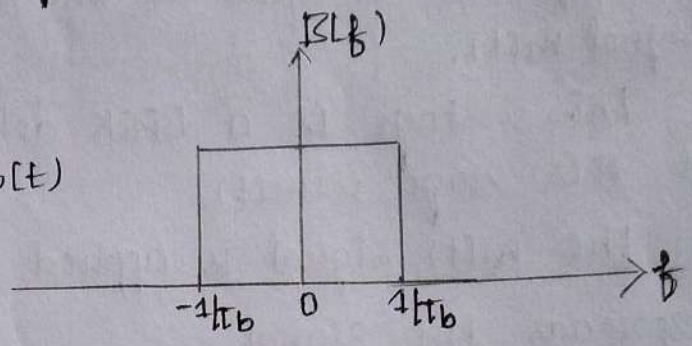
$$\boxed{x(t) = \sqrt{2/T}.\ m(t).\sin 2\pi f_c t.}$$ where $m(t) = b(t).c(t)$

* When Direct sequence signal $m(t)$ is positive then there is a phase shift of 0° and if $m(t)$ is negative, there is a phase shift of 180°

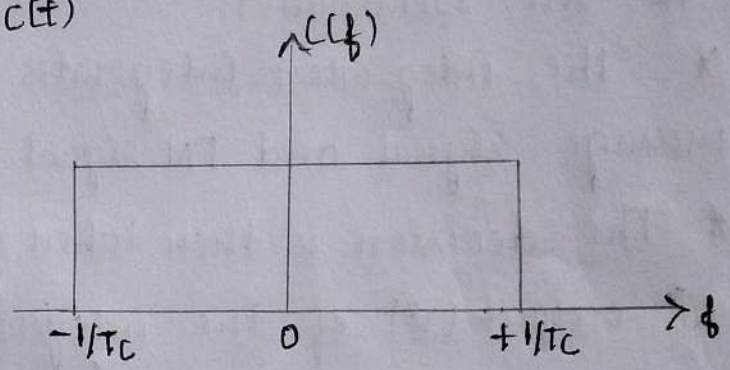


Spectrum spreading using simple rectangular spectra.

(a) Spectrum of data signal b(t)

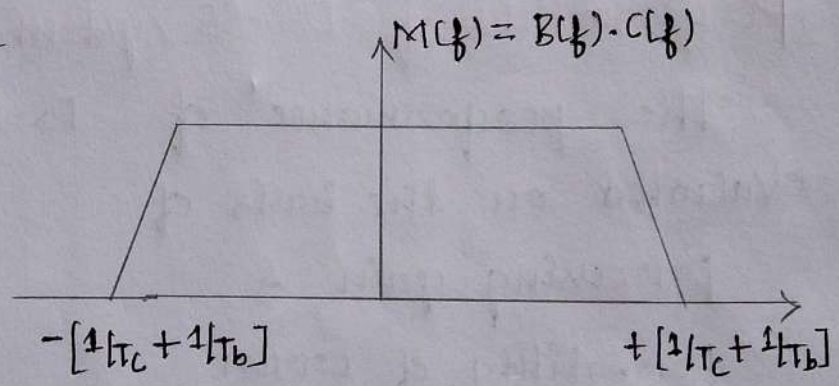


(b) Spectrum of PN carrier signal c(t)



(c) convolution of spectra of b(t) & c(t)

$m(t) = b(t) * c(t)$



Convolution of the spectra of data signal with PN code signal.

Direct sequence spread spectrum BPSK receiver OR DS-SS BPSK Receiver

* Fig shows the block diagram of DS-SS BPSK receiver
* there are two stages of demodulation

i) The received signal y(t) is multiplied with locally generated coherent carrier.

* The multiplied signal is passed through LPF. The Bandwidth of LPF is equal to the bandwidth of modulating signal m(t).
* This stage is a BPSK detector. The signal obtained at this stage is m(t).

ii) The m(t) signal is applied to second demodulator which despreads the signal

* The local PN signal is exact replica of that used at the transmitter.
* The integrator integrates the product of detected message signal and PN signal over one bit period Tb.
* The decision is then taken depending on the polarity of output (V) of the integrator.

Performance of DS-SS system

The performance of DS-SS system can be evaluated on the basis of

processing gain &

Probability of error.

▷ **Processing gain [PG]:** Processing gain is defined as the ratio of the bandwidth of spreaded message signal to the bandwidth of the unspreaded message signal.

$$PG = \frac{\text{BW of spread signal}}{\text{BW of unspreaded signal}}$$

Bandwidth of unspreaded msg signal, $R_b = \frac{1}{T_b}$.

Bandwidth of spreaded msg signal, $W_c = \frac{1}{T_c}$

Then $$PG = \frac{1/T_c}{1/T_b}$$

$T_b \rightarrow$ bit period

$$PG = \frac{T_b}{T_c} \longrightarrow (1)$$

$T_c \rightarrow$ chip period

we know that one bit period T_b of message signal is equal to 'N' bits periods of PN code signal.

i.e $$T_b = NT_c \longrightarrow (2)$$

By substituting eqn (2) in eqn (1)

$$PG = \frac{NT_c}{T_c}$$

$$PG = N$$

2) Probability of error

The probability of error for DS-BPSK system is

$$P_e = \frac{1}{2} \operatorname{erfc}\left(\sqrt{E_b/JT_c}\right) \longrightarrow (1)$$

Where $J \rightarrow$ average interference noise power.

W.K.T for coherent PSK.

$$P_e = \frac{1}{2} \operatorname{erfc}\left(\sqrt{E_b/N_0}\right) \longrightarrow (2)$$

In DS - BPSK, the Interference may be treated as wideband noise power density $N_0/2$ defined as.

From eq^n (1) and (2).

$$\frac{N_0}{2} = \frac{JT_c}{2}$$

$$N_0 = JT_c$$

* The bit energy $E_b = PT_b$

Where $P \rightarrow$ average signal power.

* The bit energy to noise density ratio is defined as

$$\frac{E_b}{N_0} = \frac{PT_b}{JT_c}$$

$$\frac{E_b}{N_0} = \frac{T_b}{T_c} \cdot \frac{P}{J}$$

$$\frac{E_b}{N_0} = PG \cdot \frac{P}{J}$$

$$\boxed{\frac{J}{P} = \frac{PG}{E_b/N_0}}$$

The ratio of J/P is termed as Jamming margin

$$(\text{Jamming margin})_{dB} = 10 \log_{10}\left(\frac{PG}{E_b/N_0}\right)$$

$$= 10\log_{10}(PG) - 10\log_{10}(E_b/N_0)_{min}$$

$$\begin{bmatrix}\text{Jamming} \\ \text{margin}\end{bmatrix}_{dB} = (PG)_{dB} - 10\log_{10}(E_b/N_0)_{min}$$

Effect of despreading on a Narrowband Interference

If the data sequence $b(t)$ is narrowband & PN sequence $c(t)$ is wideband.

Transmitted signal / spreaded signal $m(t) = c(t) \cdot b(t)$

Received signal $y(t) = m(t) + i(t)$

$$y(t) = c(t) \cdot b(t) + i(t).$$

where $i(t) \rightarrow$ interference signal.

* The received signal is demodulated by using a locally generated PN sequence ($c(t)$).

Demodulated signal is

$$z(t) = c(t) \cdot y(t) = c(t) [c(t) \cdot b(t) + i(t)]$$

$$z(t) = b(t) c^2(t) + i(t) \cdot c(t).$$

* As $c(t)$ alternates between -1 & $+1$, when it is squared $c^2(t) = 1$ for all t.

$$z(t) = \underbrace{b(t)}_{\text{Narrow band signal}} + \underbrace{c(t)\, i(t)}_{\rightarrow \text{ spreading code affects only } i(t)}$$

* The term $i(t) \cdot c(t)$ results in wideband interference with power spectral density $I_0 = P_I / W$
* The desired signal $b(t)$ is demodulated by passing $z(t)$ through matched filter that has a bandwidth R.
* The total power in the interference at the output of demodulator is

$$I_0 R = \frac{P_I}{W} \cdot R = \frac{P_I}{W/R} = \frac{P_I}{T_b/T_c} = \frac{P_I}{L_c}$$

* The power in the interfering signal is reduced by an amount equal to the bandwidth expansion factor W/R.

* The Reduction in the interference power is the basic reason for using spread-spectrum signals to transmit digital information over interfering channels.

Frequency hop spread spectrum [FH-SS]

The spread spectrum in which the carrier hops randomly from one frequency to another is called frequency hop spread spectrum technique. The modulation used is MFSK [M-ary FSK]

The FH-SS are of two types.

1) Slow FH-SS
2) Fast FH-SS.

In Slow FH-SS, the symbol rate 'R_s' of the MFSK signal is an integer multiple of the hop rate 'R_h'

i.e Several symbols are transmitted in each frequency hop.

hop rate $R_h < R_s$

In Fast FH-SS, the hop rate R_h is an integer multiple of the MFSK symbol rate 'R_s'. i.e carrier frequency will change or hop several times during the transmission of one symbol. $R_h > R_s$

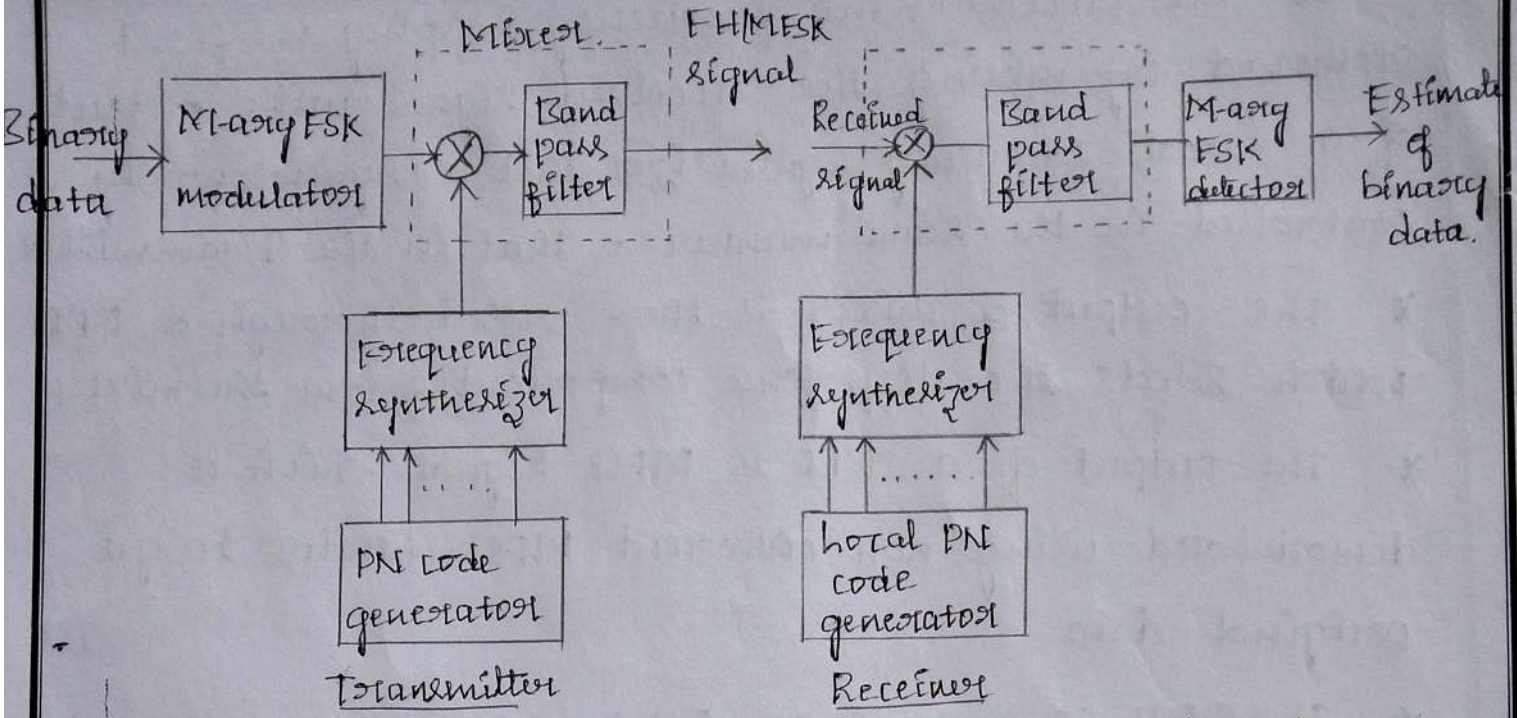


Fig shows the block diagram of a FH/MFSK transmitter and receiver

* the FH/MFSK transmitter involves frequency shift keying followed by mixer.
* the incoming data is applied to M-ary FSK system. The resulting modulated wave & output from a digital frequency synthesizer are then applied to a mixer that consists of a multiplier followed by a filter.
* The BPF is designed to select sum frequency component resulting from multiplication process.
* PN sequence will drive the frequency synthesizer, which enables carrier frequency over 2^k distinct values.
* on single hop, bandwidth of the transmitted signal is same as that resulting from the use of conventional MFSK format.
* For complete range of 2^k frequency hops, FH/MFSK signal occupies a much larger bandwidth.
* The Non coherent MFSK detector is used.

* At the receiver, the frequency hopping is first removed by mixing the received signal with output of a local frequency synthesizer that is synchronously controlled in the same manner as that in the transmitter.
* The output of mixer is then passed through a BPF which selects the difference component from the mixer.
* The output of a BPF is MFSK signal which is demodulated using non-coherent MFSK detector to get original data.
* In FH SS system, an FH tone of shortest duration is called 'chip'

The chip rate R_c,

$$\underline{R_c = \max(R_h, R_s)}$$

$R_h \rightarrow$ hop rate

$R_s \rightarrow$ Symbol rate

* For slow FH-SS system

$$R_c = R_s$$

$$\therefore R_c = R_s = \frac{R_b}{K} \geq R_h \qquad \text{where } K = \log_2 M$$

* For Fast FH-SS system

$$R_c = R_h$$

* Processing gain

$$PG = \frac{\text{BW of spreaded signal}}{\text{BW of unspreaded signal}} = \frac{\text{BW of FH-signal}}{\text{BW of Baseband signal}}$$

Let f_s be the symbol frequency. Wkt. there are 2^K frequency hops generated from K-bits of PN sequence.

$\therefore$ BW of the FH-signal is $2^k f_s$

BW of the unspreaded signal is f_s

$$P_{vj} = \frac{2^k f_s}{f_s}$$

$$\boxed{P_{vj} = 2^k}$$

Applications of Direct sequence spread spectrum [DS-SS] systems.

1) Low detectability signal transmission.

OR

Low probability Intercept.

For this application, the signal spectral density is intensionally kept small with respect to channel noise and receiver noise so that the presence of the signal is not detected easily.

Consider the average received signal power at the intended receiver is P_{av} and the noise power is N_{av}. Then the signal is transmitted at low power levels such that $\frac{P_{av}}{N_{av}} << 1$. Hence the receivers which are in the vicinity of the intended receiver cannot detect the presence of the signal.

The intended receiver recovers the message signal with the help of processing gain and coding gain. Other receivers who doesnot know the PN sequence hence they can not receive the information signal with the help of processing gain and coding gain. This is called as the signal has low probability of being intercepted. [LPI]

2) Code-division multiple Access with DS-SS [CDMA]

Many users transmit their signals on the same channel bandwidth. Each transmitter and receiver pair has a distinct PN sequence. Thus signals of particular transmitter are received by its intended receiver only. Even if many users are transmitting at the same time the signals from other users appear as additive interference which are rejected by the spread decoder. The level of interference depends on the number of users transmitting at a time.

The main advantage of CDMA is that the number of users sharing a same channel can be increased or decreased very easily.

Large number of users can transmit on the same channel if their messages are for short periods of time.

3) Wireless LAN

Spread spectrum signals have been used in the IEEE wireless LAN standards 802.11 and 802.11b which operate in the 2.4GHz frequency band.

The available channel bandwidth is subdivided into 14 overlapping 22MHz channels, although not all channels are used in all countries.

In the 802.11 standard, an 11-chip Barker sequence is modulated and transmitted at a rate of 11MHz. The 11 chip Barker sequence is {1, -1, 1, 1, -1, 1, 1, 1, -1, -1, 1}

The Barker sequence is modulated either with BPSK or QPSK. When BPSK is used with 11 chips per bit a data rate of 1 Mbps is achieved. When QPSK is used with 11-chips per symbol [2-bits] - a data rate of 2Mbps is achieved.

In the 802.11b standard 11 KHz chip rate is maintained but the Barker sequence is replaced by a set of 8-chip waveform sequences called complementary code shift keying [CCK]. The use of CCK modulation results in a data rate of 1Mbps.

CDMA system based on IS-95

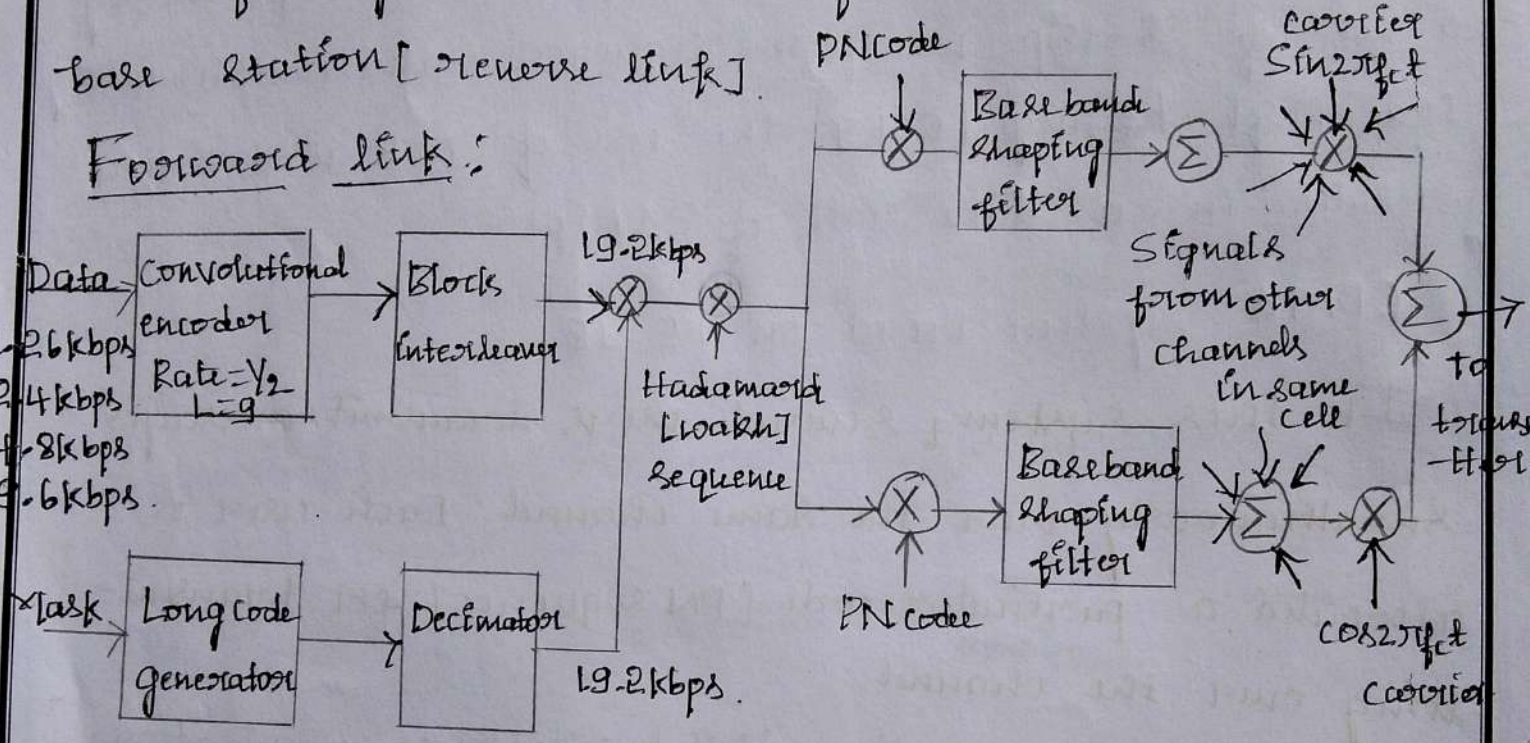
In this system, several users transmit messages simultaneously over the same channel. Each user is allocated a particular code [PN sequence] for transmitting over the common channel.

* CDMA (1st generation digital cellular communication system) was developed by Qualcomm, and it has been standardized and designated as IS-95 [Interim-standard] by Telecommunication Industry Association [TIA] for use in the 800MHz and 1800 MHz frequency bands.
* CDMA system based IS-95 is widely used in North America and some eastern countries.
* A major advantage of CDMA is that a large number of users can be accomodated, if each user transmits messages for a short period of time.

* Advantage of CDMA over other multiple access methods [TDMA & FDMA] is that the entire frequency band is available at each base station.

* The nominal bandwidth used for transmission from a base station to the mobile receivers [forward link] is 1.25 MHz. A separate channel (1.25 MHz bandwidth) is used for signal transmission from mobile receiver to base station [reverse link].

Forward link:



* The data from the speech coder is encoded by a rate 1/2, constraint length L=9, convolutional code. The speech coder generates data at the variable rates of 9.6 kbps, 4.8 kbps, 2.4 kbps & 1.2 kbps.

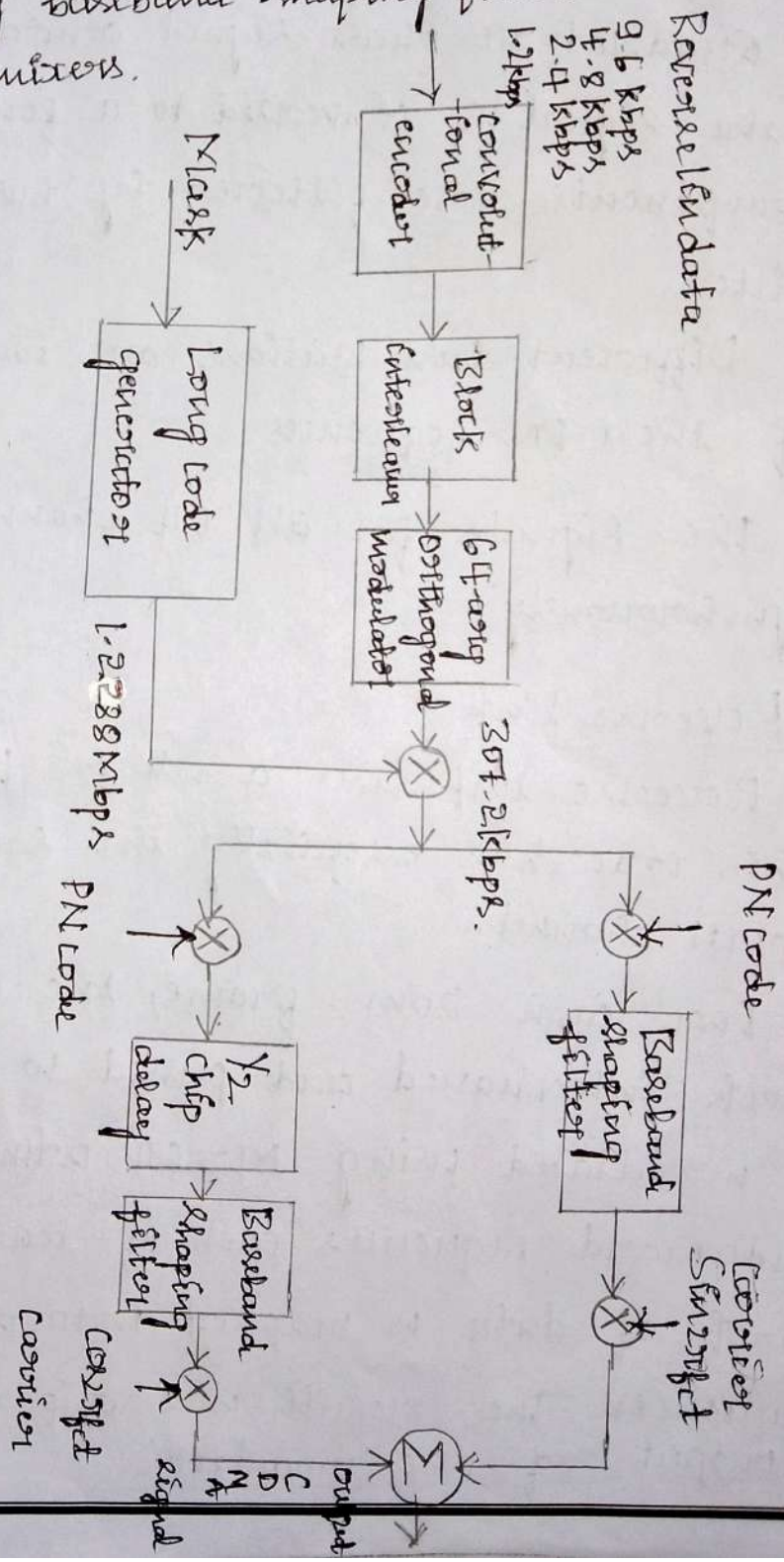
* The encoded bit for each frame are passed through a block interleaver, which overcomes the effect of burst errors that may occur in transmission through the channel.

* The data bits from the block interleaver are scrambled by multiplication with the output of a long code generator running at chip rate of 1.2288×10^6 chips/sec, but whose output is decimated by a factor of 64 to 19.2 k chip/sec.

* Each channel user is assigned Hadamard [walsh] sequence of length 64.
* Each user, using the assigned Hadamard sequence, multiplies the data sequence by the assigned Hadamard sequence. Thus each encoded data bit is multiplies the Hadamard sequence of length 64
* The resulting binary sequence is spread by multiplication with two PN sequences of length $N = 2^{15}$, this creates inphase & Quadrature phase signal components. Thus the binary data signal is converted to a four-phase and both I & Q components are filtered by baseband spectral shaping filter.
* Different base stations are identified by different offset of these PN sequences.
* The signals for all 64 channels are transmitted synchronously.

Reverse link

* Reverse link uses a rate 1/3, K=9 convolution coder. This code has essentially the same coding gain in an AWGN channel.
* For each 20ms frame, the 576 encoded bits are block interleaved and passed to the modulator. The data is modulated using M=64 orthogonal signal set of Hadamard sequences each of length 64. Thus a 6-bit block of data is mapped into one of the 64 Hadamard sequences. The result is a chip rate of 307.2 kbps at the output of the modulator.

* To reduce interference to other users, the time positions of the transmitted code symbol repetitions are randomised. Randomised signal is spreaded by the output of long code generator. Hence there are only four PN chips for every bit of the Hadamard sequence for the modulation.

* The resulting binary sequence create I & Q signal [QPSK] that are filtered by baseband shaping filter and then passed to Quadrature mixers.