Module - 5

Principles of spread spectrum

In any communication system, two important factors that are considered while designing are transmitter power & bandwidth.

→ Channel coding allows us to reduce the transmitter power by increasing the transmitted signal B.W.
→ Let 'R' denote the information rate at the i/p of Tx.
& 'W' denote the channel B.W.
→ The ratio W/R defines the BW expansion factor of channel coded transmitted signal, it is denoted by 'Be'.

→ By increasing Be, the power in the transmitted signal is reduced to achieve required performance.

→ For example, in multiple access communication, when two or more transmitter uses same channel to transmit information, the interference created will effect the performance of the system.

→ To overcome the degradation of performance caused by interference, the bandwidth of the transmitted signal is increase such that 'Be = W/R' is much greater than unity. This is one of the characteristic of spread spectrum signal.

→ The second characteristics is that the information signal at the modulator is spread in bandwidth by means of a code that is independent of the information signal.

→ It is desired to have the system with minimum transmission B.W. there are situations where the transmission B.W is purposefully high to a value much higher than baseband signal BW, such techniques are called spread spectrum modulation.

→ Main advantages of SSM are.

* It provides immunity against intential jamming of signals by other users.
* It provides immunity against interference from other channels.
* It also provides immunity against degradation of signal because of multipath fading.
* It provides asynchronous multiple access capability. Ex: CDMA.

→ The definition of spread spectrum may be stated in two parts:

* Spread spectrum is a means of transmissi[on] in which the data of interest occupies a BW in excess of the minimum BW necessary to send the data.
* The spectrum spreading is accomplished before transmission through the use of a code that is independent of the data sequ[ence]. the same code is used in the Rx[r] to despread the received signal so that the original i/p data is reconstructed.

→ Basically SSM is classified into two types based on code signal,

* Direct sequence spread spectrum
* Frequency hopping spread spectrum.

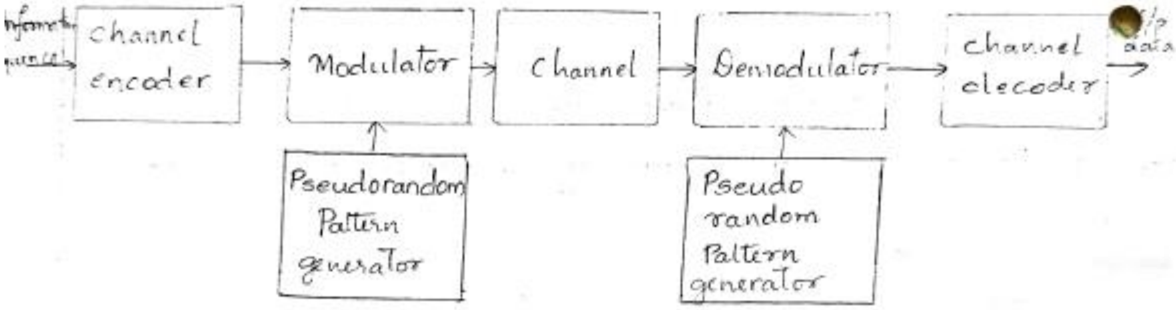
* Model of spread spectrum digital communication system:

→ The basic block diagram is as depicted in fig (a).

→ The basic elements of DCS are channel encoder, decoder, modulator & demodulator.

→ In addition, a spread spectrum s/m. employs two identical pseudorandom sequence generators, one is interfaced with the modulator at the transmitting end & other with the demodulator at the receiving end.

→ These two generators produce a pseudorandom (or) pseudonoise(PN)sequence, which is used to spread the transmitted signal at the modulator & to despread the received signal at the demodulator.



→ Time synchronisation of the PN sequence generated at the receiver with the PN sequence contained in the received signal is required to properly despread The received spread spectrum signal.

→ synchronization is established prior to the transmission of information, this is achieved by transmitting a fixed PN bit pattern.

→ In the data mode, the communication system usually tracks the timing of the incoming received signal & keeps the PN sequence generator in synchronism.

→ Interference is introduced in the transmission of the signal. & this interference is categorized as broadband (or) narrowband relative to the bandwidth of the information-bearing signal.

* Pseudo-noise sequence / Pseudo random sequence / Maximum length sequence :-

→ A PN sequence is a code sequence of 0's & 1's with certain autocorrelation property similar to those of white noise.

→ The sequence used in spread spectrum communicatio is periodic. i.e. the sequence of 1's & 0's repeats periodically with known period.

→ (1) A shift register of length 'm' consists of m-flipflops regulated by a single timing clock.

→ Pseudo random signals are not random in nature. It is a deterministic periodic signal which will be known only to the Tx^r & Rx^r.

→ It appears as random noise to unauthorized users, hence it is known as pseudonoise sequence (or) pseudo random binary sequence.

→ PN sequence is generated by using m-stage shift register having appropriate feedback signal, with period "$N = 2^m - 1$" bits, such sequence are called maximum length sequence.

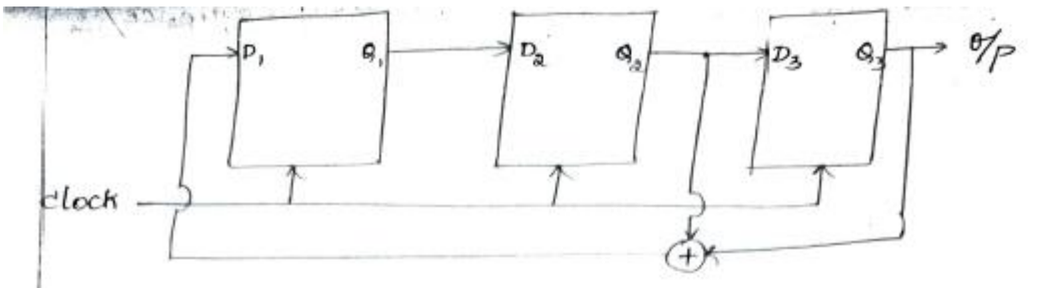
Where $m \rightarrow$ no of shift register

→ (2) At each clock pulse, the state of each flip-flop is shifted '1' bit right. In order to prevent the shift register being empty by 'm' clock pulse, feedback is provide.

→ (3) The feedback function is obtained by using modulo-2 adder. The i/p to modulo-2 adder are the output of various flipflop.

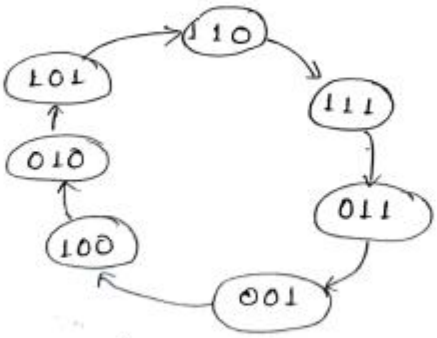
→ For example :-

Consider a 3-bit shift register with synchronous clocking which uses a linear feedback.



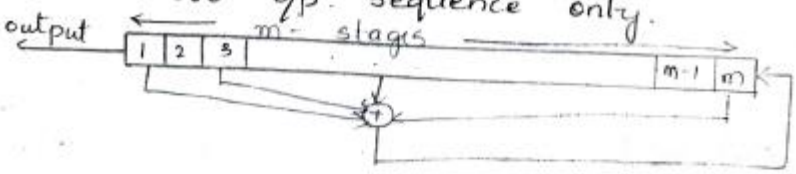
3-stage sequence generator

clock pulse	Present state	Next state
Initially	1 1 0	1 1 1
1	1 1 1	0 1 1
2	0 1 1	0 0 1
3	0 0 1	1 0 0
4	1 0 0	0 1 0
5	0 1 0	1 0 1
6	1 0 1	1 1 0
7	1 1 0	1 1 1



State diagram

'000' is not selected as initial status, because it results in "catastrophic cyclic code", i.e. it results in 000 o/p sequence only.



* **Properties of maximum length sequence :-**

→ Three basic properties of ML sequence are,

* Balance property
* Runlength property
* Correlation property

1. **Balance property :-**

Balance property states that, " In a periodic maximum length sequence the number of 1's is always one more than number of 0's.

ie. No. of 1's $= 2^{m-1}$

No. of 0's $= 2^{m-1} - 1$

Period, $N = 2^m - 1$

Ex: For a 3-stage shift register, $N = 2^3 - 1 = 7$

0 0 1 0 1 1

No of 0's, $2^{m-1} - 1 = 2^2 - 1 = 3$

No. of 1's, $2^{m-1} = 2^2 = 4$

2. **Runlength property :-**

Among the runs of 1's & 0's in each period of a ML-sequence, one half the runs are of length one, one-fourth are of length two, one eight are of length three & so on as long as these fractions represent meaningful no of runs.

→ For a ML- sequence generated by feedback shift register of length 'N', then the total number of runs is $\frac{N+1}{2}$

→ Ex: 0 0 1 0 1 1 , N = 7

Total no. of runs = $\frac{N+1}{2} = \frac{7+1}{2} = 4$

00, 1, 0, 111 = 4 runs

1 0 → two runs are of length one

00 → one run is of length two

111 → one run is of length three

3 Correlation property :-

→ The autocorrelation function of a ML-sequence is periodic & binary valued

→ Let binary symbols '0' & '1' represent -1 & +1 ∴ the autocorrelation sequence of a binary sequence $\{c_n\}$ is given by,

$$R_c(m) = \sum_{n=1}^{N} c_n c_{n+m} \quad ; \quad 0 \le m \le N-1$$

Where, N — period of the sequence

Since c_n is periodic with period N, the autocorrelation sequence R_c is also periodic with period N

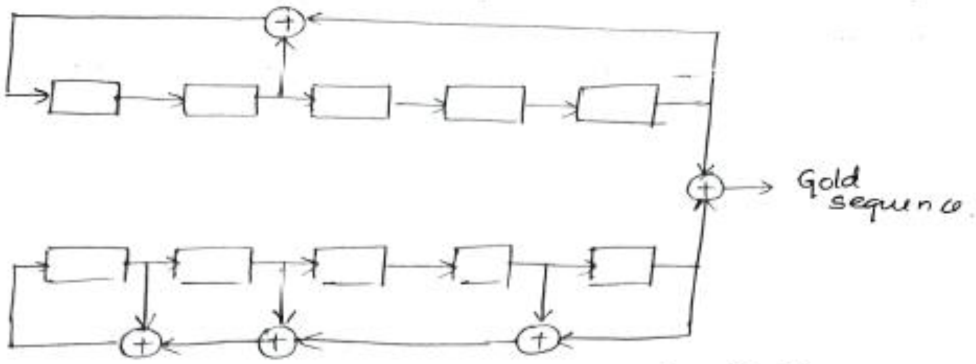
→ The ideal autocorrelation sequence is,

$$R_c(m) = \begin{cases} N & m = 0 \\ -1 & 1 \le m \le N-1 \end{cases}$$

→ Methods for generating PN sequences with better periodic cross correlation properties have been developed by Gold & Kasami.

→ Gold sequence is generated by taking a pair of specially selected m-sequences called preferred m-sequences & forming the modulo-2 sum of two sequences for each of N cyclicly shifted versions of one sequence relative to the other sequence.

→ N gold sequences are generated as illustrated in fig.



Generation of gold sequence of length 31

→ For 'm' odd, the maximum value of the cross correlation function b/w any pair of gold sequence is,

$R_{max} = \sqrt{2L}$

→ For 'm' even, $R_{max} = \sqrt{L}$

→ Kasami described a method of constructing PN sequence by decimating an m-sequence.

→ In this method, every $2^{m/2}+1$ bit of an m-bit sequence is selected

→ This method yields smaller set of PN sequence compared to gold sequence with maximum cross correlated value is $R_{max} = \sqrt{L}$

1. Verify all the properties & find the period of PN sequence 01011100101110 [3-stage shift register]

→ Soln. m = 3.

$\therefore N = 2^m - 1 = 2^3 - 1 = 7$

0101110 | 01 01110
(7 bits)

* Balance property :-

No. of 1's : $2^{m-1} = 2^2 = 4$

No. of 0's : $2^{m-1} - 1 = 2^2 - 1 = 3$.

* Runlength property :- Total No of runs, $\frac{N+1}{2} = 4$

No. of runs according to given sequence is 5, but it should be '4' ∴ In order to make it as 4 runs shift one bit right, ∴ we get

00, 1, 0, 111

∴ Total runs = 4

1, 0 → two runs are of length one

00 → one run is of length two

111 → one run is of length three.

* **Autocorrelation property:-**

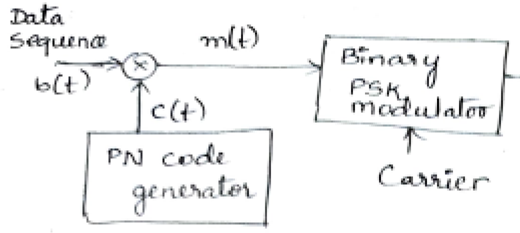
C_n	0	1	0	1	1	1	0	
p bits C_n	−1	+1	−1	+1	+1	+1	−1	
C_n	−1	+1	−1	+1	+1	+1	−1	
	1	1	1	1	1	1	1	= 7

C_n	−1	+1	−1	+1	+1	+1	−1	
C_{n-1}	−1	−1	+1	−1	+1	+1	+1	
	+1	−1	−1	−1	+1	+1	−1	= −1

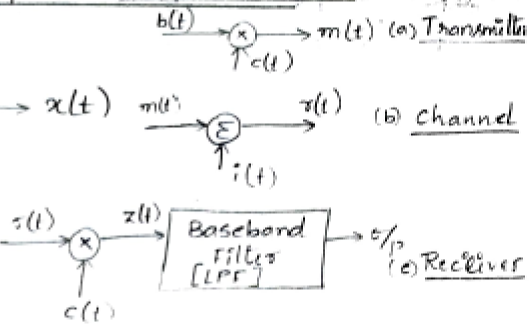
C_n	−1	+1	−1	+1	+1	+1	−1	
C_{n-2}	+1	−1	−1	+1	−1	+1	+1	
	−1	−1	+1	+1	−1	+1	−1	= −1

$$\therefore R_c(m) = \begin{cases} N = 7 & m = 0 \\ -1 & 1 \le m \le N-1 \end{cases}$$

* Direct Sequence Spread Spectrum:-



(a) Transmitter



At T_x: $m(t) = b(t) \cdot c(t)$

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

$r(t) = b(t)\, c(t) + i(t)$

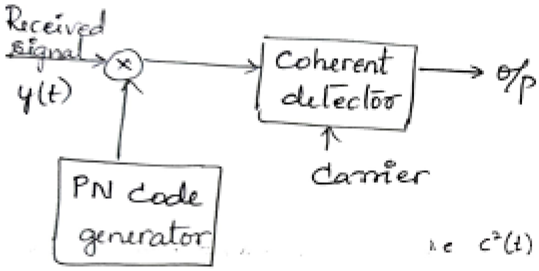
At R_x: $z(t) = r(t) \cdot c(t)$

$z(t) = \{b(t)c(t) + i(t)\}\, c(t)$

$\Rightarrow = c^2(t)\, b(t) + c(t)\, i(t)$

i.e. $c^2(t) = 1$ for all 't'

$z(t) = b(t) + c(t)\, i(t)$



(b) Receiver

→ consider the transmission of a binary information sequence by means of binary PSK.

→ The information rate is 'R' bits per second & the bit interval is $T_b = \frac{1}{R}$ seconds. The available 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 shifting the phase of the carrier pseudorandomly at a rate of 'W' times per second according to the pattern of the PN-generator.

→ DSSS technique can be used over bandpass channel by incorporating coherent BPSK into T_x & R_x.

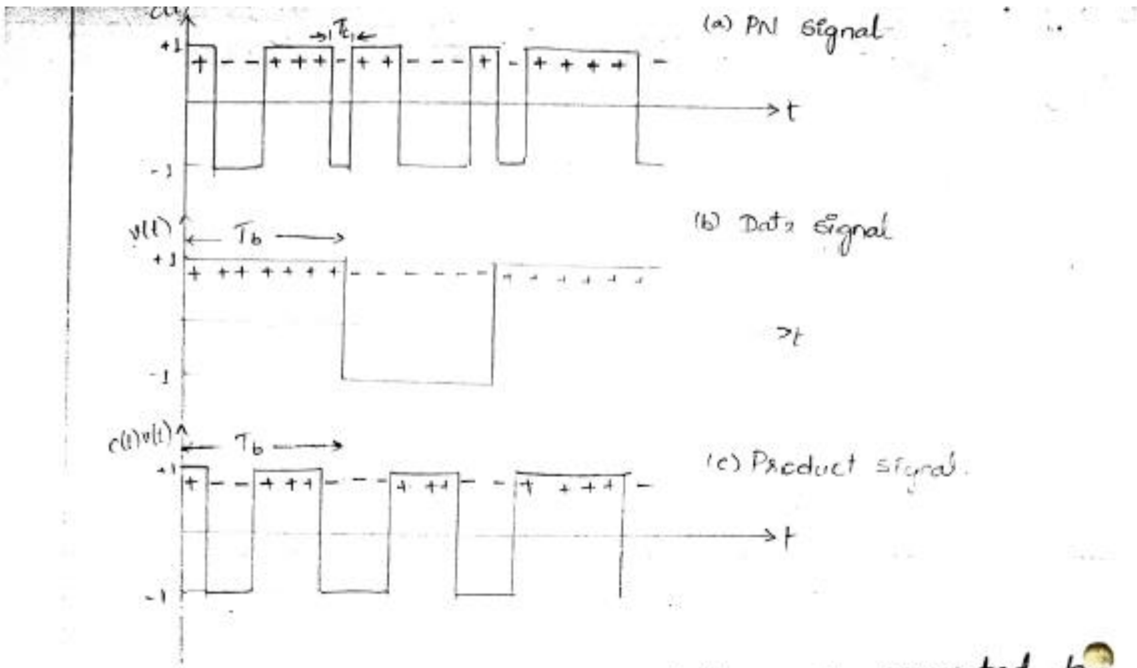
→ The basic method of accomplishing the spreading is shown in fig. (c).

→ The information signal $v(t)$ is,

$$v(t) = \sum_{n=-\infty}^{\infty} a_n g_T(t - nT_b) \rightarrow (1)$$

Where, $a_n = \pm 1$ $\quad -\infty < n < \infty$.

$g_T(t) \rightarrow$ rectangular pulse of duration 'T_b'.



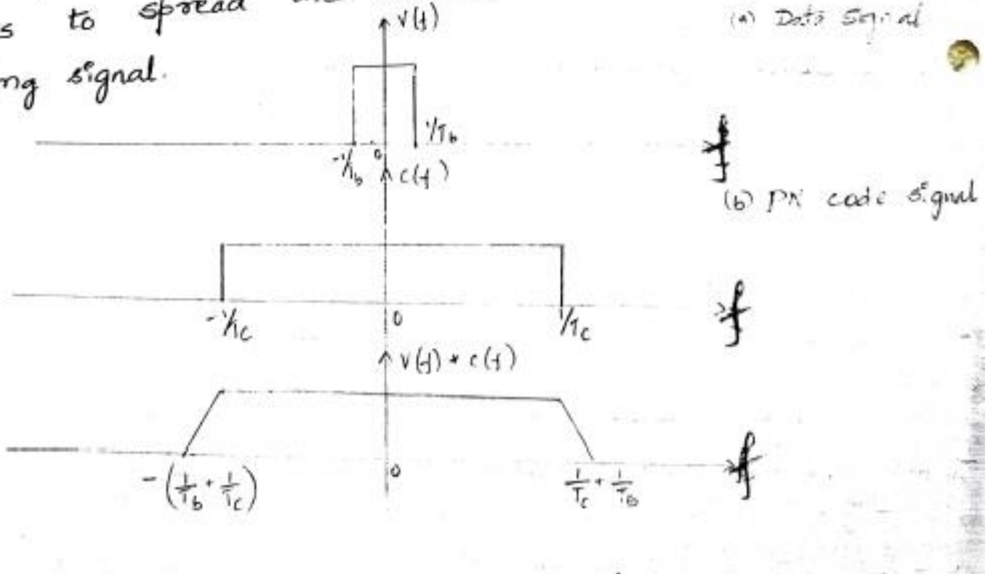
→ $v(t)$ is multiplied with the PN sequence generated by PN sequence generator. The PN sequence is expressed as,

$$c(t) = \sum_{n=-\infty}^{\infty} c_n \, p(t - nT_c) \longrightarrow (2)$$

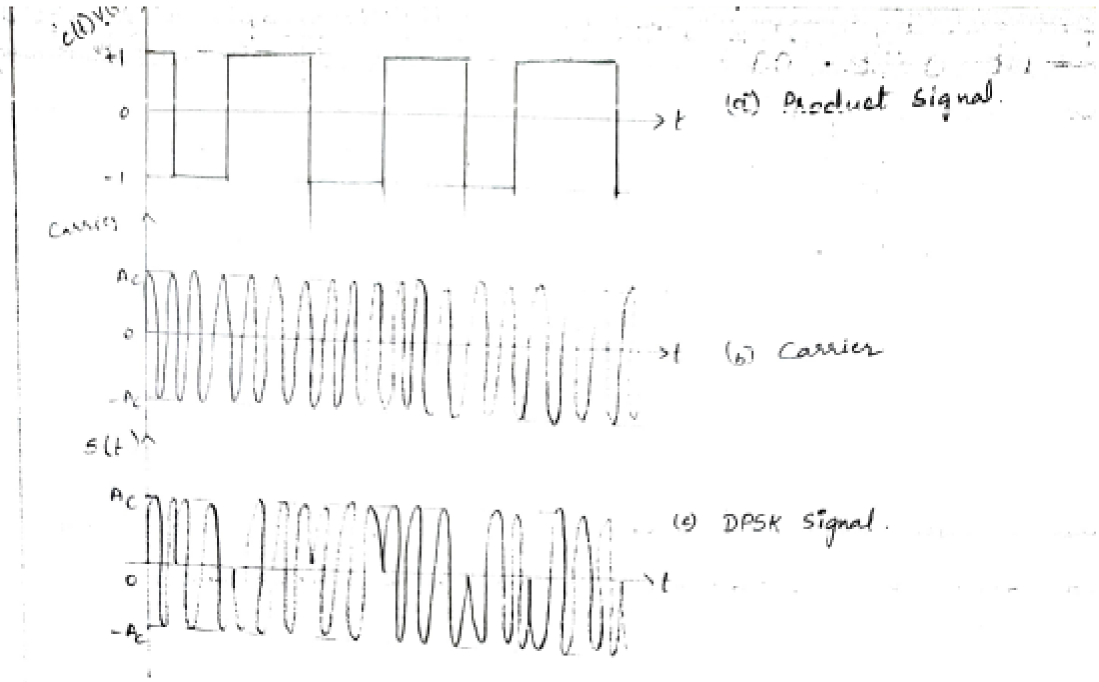
Where, $c_n \rightarrow$ binary PN sequence of ± 1

$p(t) \rightarrow$ rectangular pulse of duration T_c. It is called chip $[T_c]$

→ $v(t)$ & $c(t)$ is multiplied. This multiplication operation serves to spread the bandwidth of the information bearing signal.



Convolution of the spectra.



→ The product signal v(t)c(t) amplitude modulates the carrier & generates DSB-SC, $u(t) = A_c v(t) c(t) \cos 2\pi f_c t$.

Since, $v(t)\, c(t) = \pm 1$, ∀ 't', it follows that the carrier modulated signal can also be expressed as,

$$u(t) = A_c \cos\left[2\pi f_c t + \theta(t)\right].$$

Where, $\theta(t) = 0$, when $v(t)\, c(t) = 1$
& $\theta(t) = \pi$, when $v(t)\, c(t) = -1$

∴ the transmitted signal is BPSK signal.

→ The rectangular pulse p(t) is called chip, with duration 'T_c' called chip interval. The ratio of T_b and T_c is denoted by L_c.

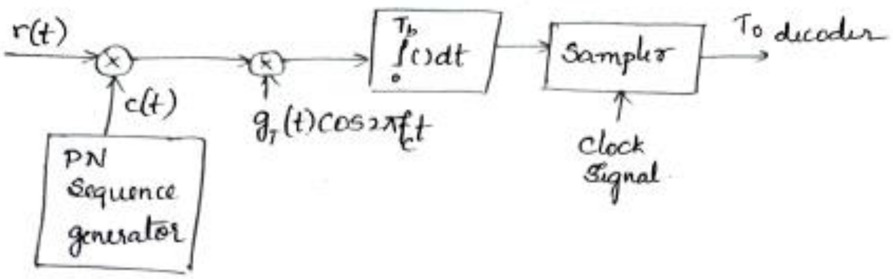
∴ $\boxed{L_c = \frac{T_b}{T_c}}$ where, L_c → no of chips of PN sequence per information bit.

→ 'L_c' also represents no of possible 180° phase transitions in the transmitted signal.

→ The block diagram of demodulation is shown in fig(i). The received signal is first multiplied by c(t), this is called despreading.

Effect of de-spreading:

∴ At receiver we have $A_c v(t) c^2(t) \cos 2\pi f_c t = A_c v(t) \cos 2\pi f_c t$



fig(1): Demodulation of DSSS signal

* DSSS System performance:-

The performance of DSSS is evaluated based on,

* processing gain
* Probability of error
* Jamming margin

* Processing gain:-

The ratio of bit interval to chip interval is called processing gain

* The total power in the interference at the o/p. of the demodulator is,

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

where, $I_0 = \frac{P_I}{W}$ Power spectral density of wideband interference.

and, $P_I = \frac{A_I^2}{2}$ is the average power of the interference.

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

* The ratio of bandwidth of spreaded message signal to the bit rate of unspreaded data signal.

$$P.G = \frac{\text{B.W. of spreaded signal}}{\text{Bit rate of unspreaded signal.}} = \frac{W_c}{R_b}$$

Where, BW of spreaded signal, $W_c = \frac{1}{T_c}$

Bit rate of unspreaded signal, $R_b = \frac{1}{T_b}$

$$\therefore P.G = \frac{W_c}{R_b} = \frac{1/T_c}{1/T_b} = \frac{T_b}{T_c} = L_c.$$

W.K.T, $T_b = NT_c$

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

* Probability of error :-

The probability of error of DSSS is given by,

$$P_e = Q\left[\sqrt{\frac{2E_b}{I_o}}\right] \rightarrow (*)$$

$$\begin{cases} Q(z) = \frac{1}{2}\,\mathrm{erfc}\,\sqrt{\frac{z}{\sqrt{2}}} \\ Q(z) = \int_z^{\infty} \frac{1}{\sqrt{2\pi}}\, e^{-\frac{y^2}{2}}\, dy. \end{cases}$$

Where, $I_o \rightarrow$ power spectral density of an equivalent breadband interference

Q. A DSSS signal is designed so that the power ratio P_R/P_N at the intended receiver is 10^{-2}. If the desired $E_b/N_o = 10$ for acceptable performance, determine the minimum value of the processing gain.

→ Soln:
$$\left(\frac{P_I}{P_S}\right)_{dB} = 20dB; \quad \frac{P_I}{P_S} = 100$$

$$(SNR)_D = 13dB = 20$$

$$\therefore L_c = \frac{1}{2}\left[\frac{P_I}{P_S}\right](SNR)_D = \frac{1}{2} \times 100 \times 20 = 1000.$$

* Interference margin :- Is a measure of immunity against Jamming.

Eqn. (*) can be expressed as,

$$\frac{E_b}{I_o} = \frac{P_S T_b}{P_I/W} = \frac{P_S/R_b}{P_I/W} = \frac{W/R_b}{P_I/P_S}$$

(or) $$10\log\left(\frac{E_b}{I_o}\right) = 10\log\left(\frac{W}{R_b}\right) - 10\log\left(\frac{P_I}{P_S}\right)$$

(or) $$10\log(P_I/P_S) = 10\log\left(\frac{W}{R_b}\right) - 10\log\left(\frac{E_b}{I_o}\right)$$

$$\left(\frac{P_I}{P_S}\right)_{dB} = \left(\frac{W}{R}\right)_{dB} - \left(\frac{E_b}{I_o}\right)_{dB}$$

The ratio $\left(\frac{P_I}{P_S}\right)_{dB}$ is called interference margin.

* **Frequency hopping spread spectrum :-**

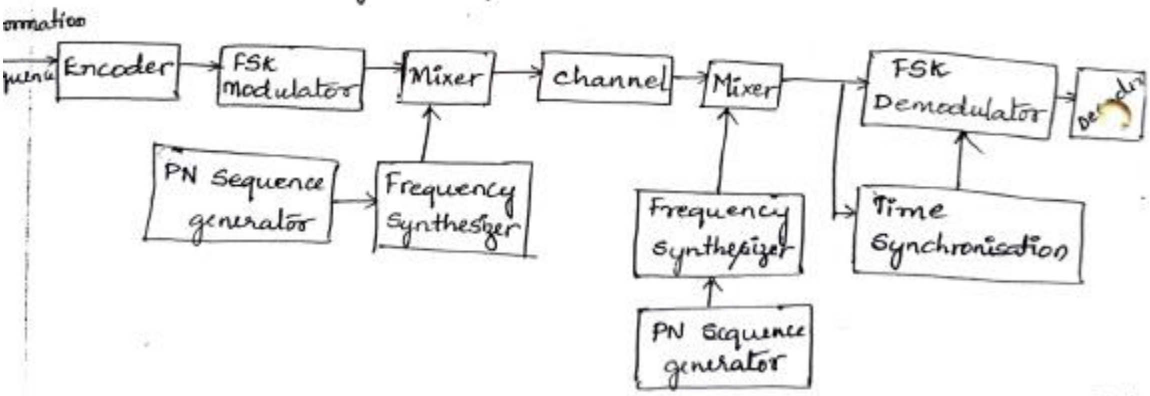
→ Frequency hopping spread spectrum is a type of spread spectrum in which the carrier hops from one frequency to another.

→ In FHSS, the available channel bandwidth 'W' is subdivided into a large number of non-overlapping frequency slots.

→ In any signaling interval, the transmitted signal occupies one (or) more of the available frequency slots.

→ The selection of the frequency slot in each signal interval is made pseudorandomly according to the o/p of PN generator.

→ The block diagram of FHSS is shown below,



→ The modulation used is either binary or M-ary FSK

→ If BFSK is used, the modulator selects one of two freqs. 'f_0' (or) 'f_1' corresponding to the transmission of a '0' (or) a '1'.

→ The resulting BFSK signal is translated in frequency by an amount determined by the o/p sequence freq. f_c that is synthesized by the frequency synthesizer.

→ This frequency is mixed with the o/p. of FSK modulator & the resultant signal is transmitted over the channel.

→ By taking 'm' bits from the PN generator, $2^m - 1$ possible carrier frequencies can be specified.

→ At the receiver, there is an identical PN sequence generator which is synchronized with the received signal & is used to control the o/p. of the frequency synthesizer.

Thus, the pseudorandom frequency translation introduced at the Txr. is removed at the Rxr.

→ The resultant signal is demodulated using FSK demodulator.

→ The frequency hopping rate, denoted as 'R_h' may be either equal to the symbol rate, lower than the symbol rate or higher than the symbol rate.

→ Based on frequency hopping rate, FHSS is classified into 2 types:

* Slow frequency hopping S.S: R_h is equal to or lower than symbol rate. $[R_h \leq R_s]$

* Fast frequency hopping S.S: R_h is higher than the symbol rate. $[R_h > R_s]$

→ FHSS signals can be used in CDMA where many users share a common bandwidth.

* **Slow frequency hopping:-**

Consider a slow frequency hopping system in which the hop rate $R_h = 1$ hop per bit.

→ Assume the interference on the channel is

→ ∴ The probability of error for the detection of noncoherently demodulated BFSK is,

$$P_e = \frac{1}{2} e^{-\rho_b/2}$$

where, $\rho_b = \frac{E_b}{I_0}$ is the SNR per bit.

(or) $$P_e = \frac{1}{2} e^{-\frac{E_b}{2I_0}}$$

But. $E_b = P_S T_b = \frac{P_S}{R_b}$ where, P_S → avg transmitted power

R_b → bit rate

& $I_0 = \frac{P_I}{W}$ P_I → avg. power of the broadband interference

W → channel bandwidth

SNR,

$$\therefore \rho_b = \frac{E_b}{I_0} = \frac{P_S \cdot W}{P_I \cdot R_b} = \frac{W/R_b}{P_I/P_S}$$

where, W/R_b → processing gain

P_I/P_S → Interference margin.

Ex: The FH/MFSK signal has the following parameters

No of bits per MFSK symbol, $K = 2$

No of MFSK tones, $M = 2^K = 2^2 = 4$

length of PN segment per hop, $m = 3$

Total no of freq. hops $= 2^m = 2^3 = 8$

Given data sequence is 01 11 11 10 00 10 01 11 10 10

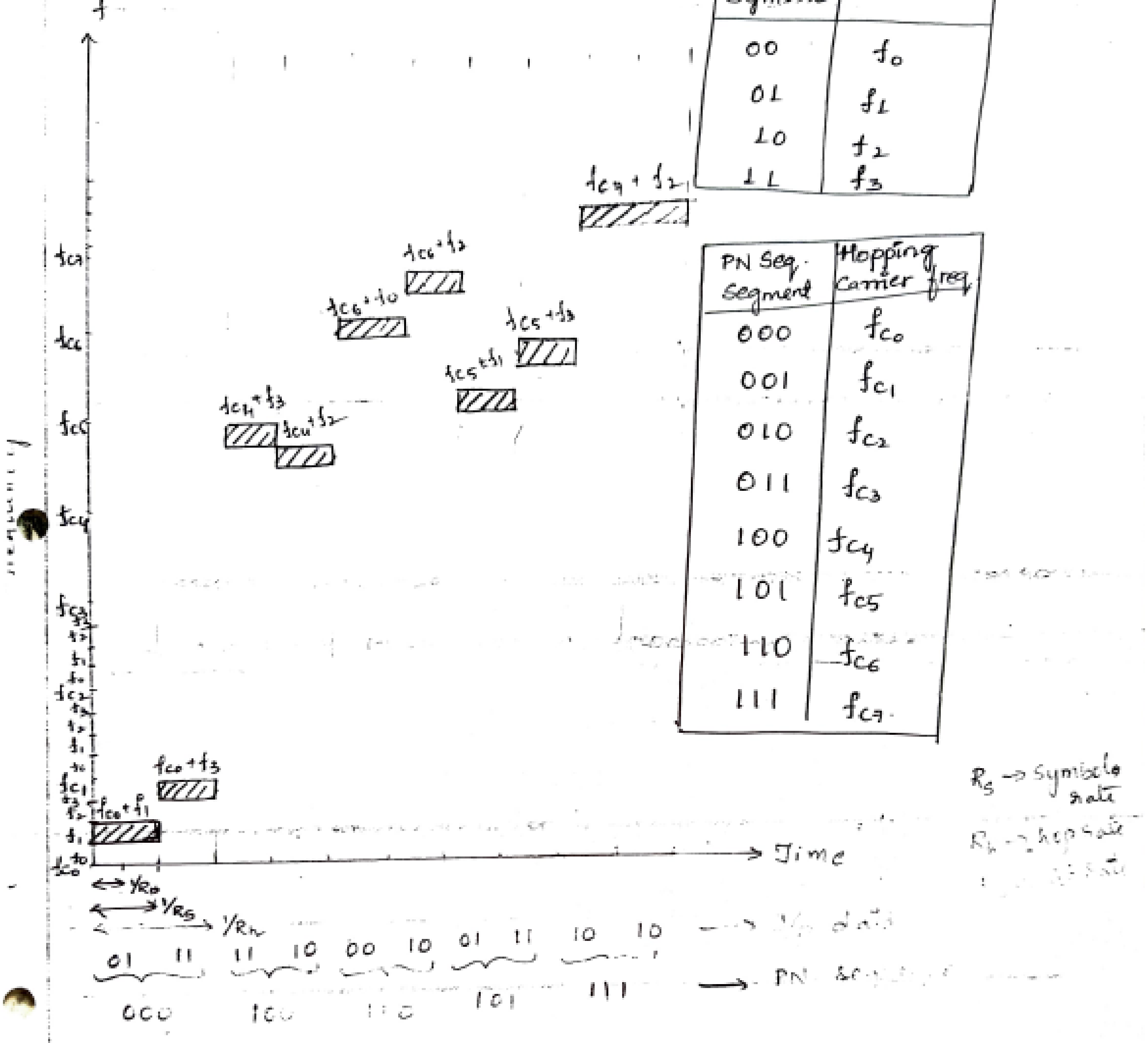
& PN sequence is 000 100 110 101 111 [4-stage shift register]

→ Soln: Period of PN sequence, $N = 2^4 - 1 = 15$

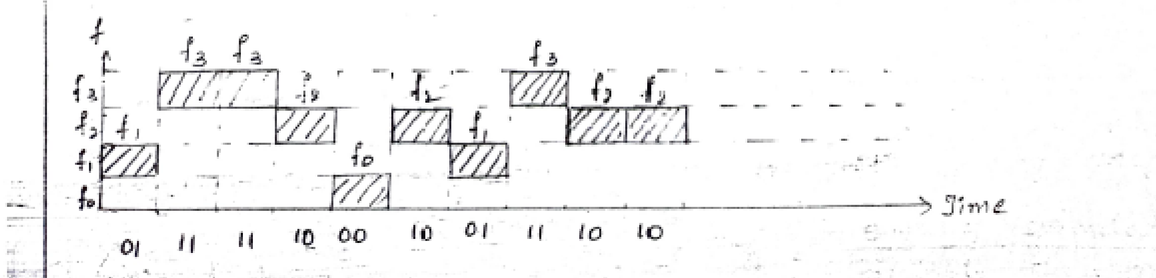
No of MFSK tones = 4

Bits of MFSK symbol	MFSK tone in Hz
00	f_0
01	f_1
10	f_2
11	f_3

PN Seq. Segment	Hopping Carrier freq
000	f_{c0}
001	f_{c1}
010	f_{c2}
011	f_{c3}
100	f_{c4}
101	f_{c5}
110	f_{c6}
111	f_{c7}



SLOW FREQUENCY HOPPING



DEHOPPING

Some Applications of DS Spread-Spectrum Signals

1. Low-detectability Signal Transmission:

- The aim is to hide the presence of the signal from receivers that are in the vicinity of the intended receiver.
- The signal is transmitted at very low power.

$$P_R/P_N \ll 1.$$

P_R Signal Power
P_N Noise Power

- The intended receiver can recover the weak information-bearing signal from the background noise using the processing gain and the coding gain.

2. Code Division Multiple Access:

- The type of digital communication in which each transmitter receiver user pair has its own distinct code for transmitting over a common channel bandwidth is called *code division multiple access (CDMA).*
- If there are N_u *simultaneous users, the* desired signal-to-noise interference power ratio at a given receiver is:

$$\frac{P_S}{P_N} = \frac{P_S}{(N_u - 1)P_S} = \frac{1}{N_u - 1}$$

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3. Communication Over Channels with Multipath:

- DS spread spectrum can generate a wideband signal for resolving multipath signal components.
- By separating the multipath components, we may also reduce the effects of fading.
- For example, in LOS communication systems where there is a direct path and a secondary propagation path resulting from signal reflecting from buildings and surrounding terrain, the demodulator at the receiver may synchronize to the direct-signal component and ignore the existence of the multipath component.

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4. Wireless LANs:

- DSSS is used in IEEE wireless LAN standards 802.11 and 802.11b, which operates in the 2.4GHz frequency band.
- In the 802.11 standard, an 11 chip Barker sequence is used.

$$\{1, -1, 1, 1, -1, 1, 1, 1, -1, -1, -1\}$$

- With a BPSK modulation a data rate of 1Mbps is achieved.
- With a QPSK modulation a data rate of 2Mbps is achieved.

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- In the second generation standard IEEE 802.11b, a data rate of 11Mbps is achieved.
- Complementary Code Keying (CCK), is used to encode data for 11Mbps.

Data rate	Code length	Modulation
1 Mbps	11 (Barker sequence)	BPSK
2 Mbps	11 (Barker sequence)	QPSK
5.5 Mbps	8 (CCK)	QPSK
11 Mbps	8 (CCK)	QPSK

CDMA based on IS-95

- With the help of CDMA it is possible to transmit many DS spread spectrum signals so that they can occupy same channel bandwidth. Each channel has its own PN sequence.
- CDMA is used widey for voice communication. It is standardized as IS-95. It uses the frequency band of 800 MHz TO 1900 MHz. CDMA has the advantage that the frequency reuse factor is 1.
- The bandwidth of 1.25 MHz is used for transmission from base station to mobile, on forward link. On separate channel, the bandwidth of 1.25 MHz is used on reverse link.
- The DS spread spectrum signals with CDMA are transmitted on forward and reverse link with the chip rate of 1.2288×10^6 chips/sec.

Forward Link (Base Station to Mobile Receiver)

Fig. 5.11.1 shows the block diagram of forward link.

- The speech encoder output is available at the rates of 9.6 kbps, 4.8 kbps, 2.4 kbps or 1.2 kbps. This data is encoded by convolutional encoder of rate 1/2 and constraint length of 9.
- The encoded data is then passed through a block interleaver. It overcomes the effects of burst errors. The output of interleaver is available at the rate of 19.2 kbps.
- The output of interleaver is scrambled by multiplication with long code. The long code generator has the chip rate of 1.2288 Mchips/sec. Its output is decimated to 19.2 kchips/sec.
- The Walsh sequence generator generates 64 bit long orthogonal Hadamard sequences. Each sequence is assigned to separate base station. There are 64 Hadamard sequences. Thus 64 channels are available for transmission.
- The Hadamard sequence multiplies with data sequences. Each encoded data bit is multiplied by the Hadamard sequence of length 64.
- The binary output sequence from multiplier is then multiplied with two PN sequences of length $N = 2^{15}$. It creates inphase and quadrature components.
- The I and Q components are passed through baseband shaping filters. The different base stations are identified by offsets of PN sequences.
- The I and Q DS spread signals are then modulated on two quadrature carriers and combined. This combined signal is then transmitted.
- The RAKE demodulator at the receiver is used to receive these signals. Viterbi soft devision decoder is used.

5.11.2 Reverse Link (Mobile to Base Station)

- Fig. 5.11.2 shows the block diagram of reverse link. The mobile transmitters are battery operated. Hence power efficient transmission is used.
- The speech encoder output is available at the rates of 9.6 kbps, 4.8 kbps, 2.4 kbps or 1.2 kbps. This data is encoded a convolutional encoder of rate 1/2 and constraint length of 9.
- Every 20 msec frame, 576 encoded bits are passed through block interleaver. Output of block interleaver is available at the rate of 28.8 kbps.
- The output of block interleaver is modulated with 64 orthogonal signal sets using Hadamard sequences each of length 64.
- The output of modulator has the bit rate of 307.2 kbps. The modulated signal is then randomized with the help of long code generator. It provides code at the rate of 1.2288 M chips/sec. Due to randomization, consecutive signal bursts and interference effects are reduced.
- The signal is then spread by two separate PN sequences over 'I' and 'Q' channels. The PN generators run at the rate of 1.2288 M chips/sec. Thus there are four PN chips for every bit of Hadamard sequence from modulator.
- The 'I' and 'Q' signals are then filtered by baseband spectral shaping filters. These signals then modulate two quadrature carriers. The modulated signals are finally added. This is nothing but offset QPSK.
- Computationally efficient Hadamard transform is used to reduce the computational complexity at demodulation. Viterbi decoder is then used to decode the signal.

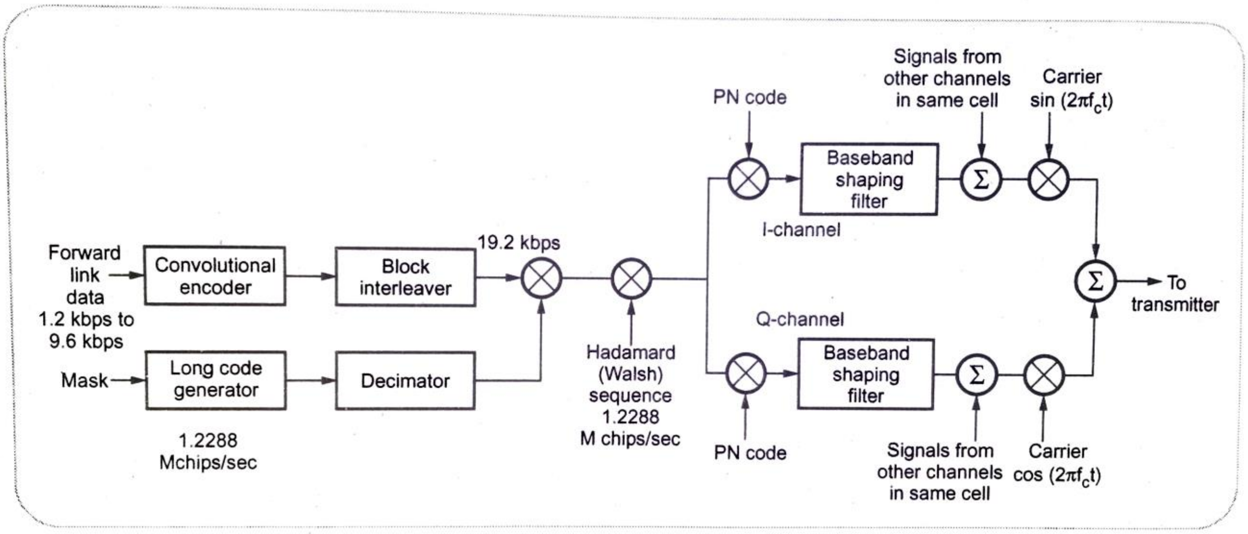

Fig. 5.11.1 Block diagram of forward link

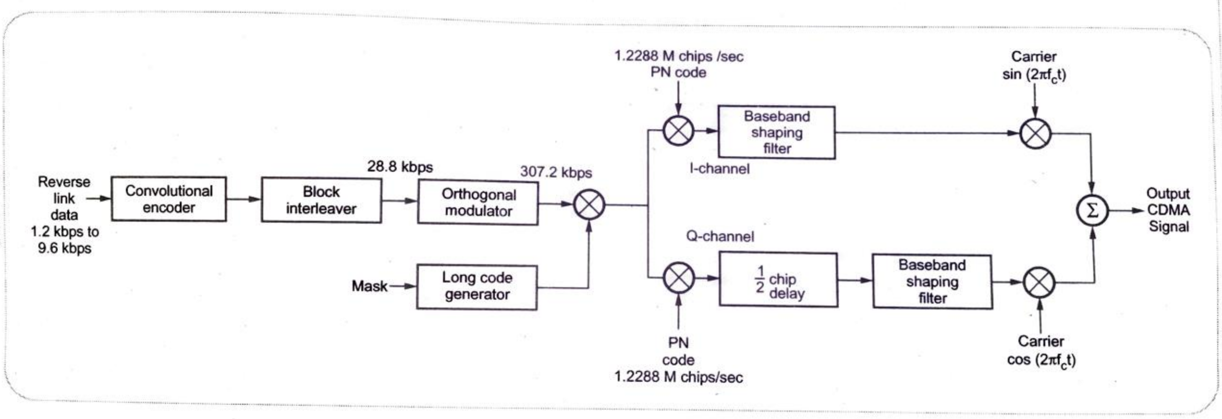

Fig. 5.11.2

Figure 5.11.2 Block Diagram of reverse link