Spread spectrum is a technique whereby an already modulated signal is modulated second time in a such a way as to generate an expanded bandwidth wideband signal that does not significantly interfere with other signals and in other words spread spectrum techniques involve spreading the basband signal over a wider bandwidth so interception and jamming of the signal will become more difficult. The spread spectrum technique was developed initially for intelligence and military requirements.

Apart from military uses, the combination of spread spectrum and Code Division Multiple Access (CDMA) is becoming more and more attractive for commercial applications. We know that frequencies are a scarce resources around the world. Spread spectrum now allows an overlay of new transmission technology at same frequency at which current narrow band systems are already operating. The spread spectrum technique can be used to transmit either analog or digital data, using an analog signal.

After a brief overview of spread spectrum concept, we look at spread spectrum principles, spread spectrum Code Division Multiple ACCESS (CDMA), generation and characteristics of spreading sequence, merits and demerits of spread spectrum and then applications of spread spectrum communication.

4.1 THE CONCEPT OF SPREAD SPECTRUM

As the name implies, spread spectrum techniques involve spreading the signal bandwidth B over the complete available bandwidth $B.W_{tot}$ as shown in the figure 4.1. In other words the narrow band signal converted in wideband signal.

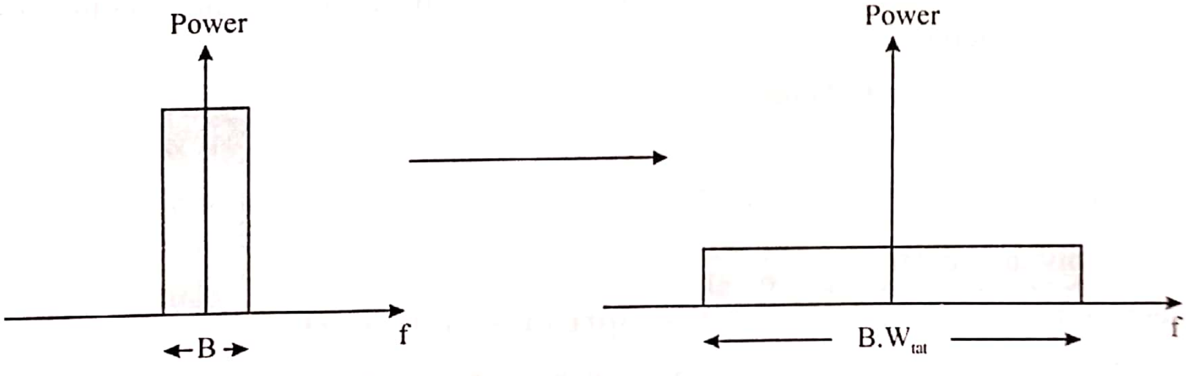

Fig. 4.1 Spreading the signal Bandwidth

As shown in figure 4.1 that sender spreads the narrowband signal into a broadband signal. The energy needed to transmit the signal, i.e., the area shown in the diagram, is the same, but it is now spreadover a larger frequency range. Thus the power level of the signal can be much lower than that of the original narrowband signal. Thatswhy power level of the user signal can even be as low as background noise. So it is difficult to distinguish the user signal from the noise and thus hard to detect it. We have already know that bandwidth expansion is achieved by a second modulation technique, it means that is independent of the information message. For this reason the expansion does not combat additive white Gaussion Noise (AWGN).

4.2 PRINCIPLES OF SPREAD SPECTRUM

The basic concept shown in figure 4.1 and the general model of spread spectrum digital communication shown in figure 4.2. In general model input is fed into a channel encoder that produces an analog signal with a relatively narrow bandwidth around some center frequency. This signal is further modulated using spreading sequence. This second modulation process increases the bandwidth (spreading) of the signal to be transmitted. This spreading signal transmitted through communication channel and at receiving end, the same spreading sequence is used to demodulate the spread spectrum signal. Finally the signal fed into a channel decoder to recover the input signal data.

Fig. 4.2 General Model of Spread Spectrum Digital Communication

The Basic idea of spread spectrum is to take energy of signal in Bandwidth B and spread it over the total available wider bandwidth (B, W_{ss}). To accomplish spread spectrum modulation, following four principles are available:

(i) Direct Sequence Pseudo Noise (PN)

(ii) Frequency Hopping (FH)

(iii) Time Hopping (TH)

(iv) Hybrid Spread Spectrum

4.2.1 Direct Sequence Pseudo Noise (PN) Spread Spectrum (DSSS)

A direct sequence spread spectrum (DSSS) signal is one in which the amplitude of an already modulated signal is spreading to the wider bandwidth using a spreading code (sequence). The spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used. Therefore, a 8-bit spreading code spreads the signal across a frequency band that is 8 times greater than 1-bit spreading code.

One technique with direct sequence spread spectrum is to combine the digital signal stream with the spreading sequence (code) bit stream using exclusive-OR (XOR). We know the rules of XOR as follows:

$$0 \oplus 0 = 0, \quad 0 \oplus 1 = 1, \quad 1 \oplus 0 = 1 \quad \& \quad 1 \oplus 1 = 0$$

We can understand the Direct sequence spread spectrum using example shown in figure 4.3. Let us assume, in this example the spreading code bit stream is clocked at 4 times the information rate. The input data stream performs XOR operation with locally generated PN bit stream and then transmitted through communication channel. Now at receiver the received signal again performs XOR operation with locally generated PN bit stream which is identical to transmitter PN bit stream. That XOR operation gives output signal which is same as input signal.

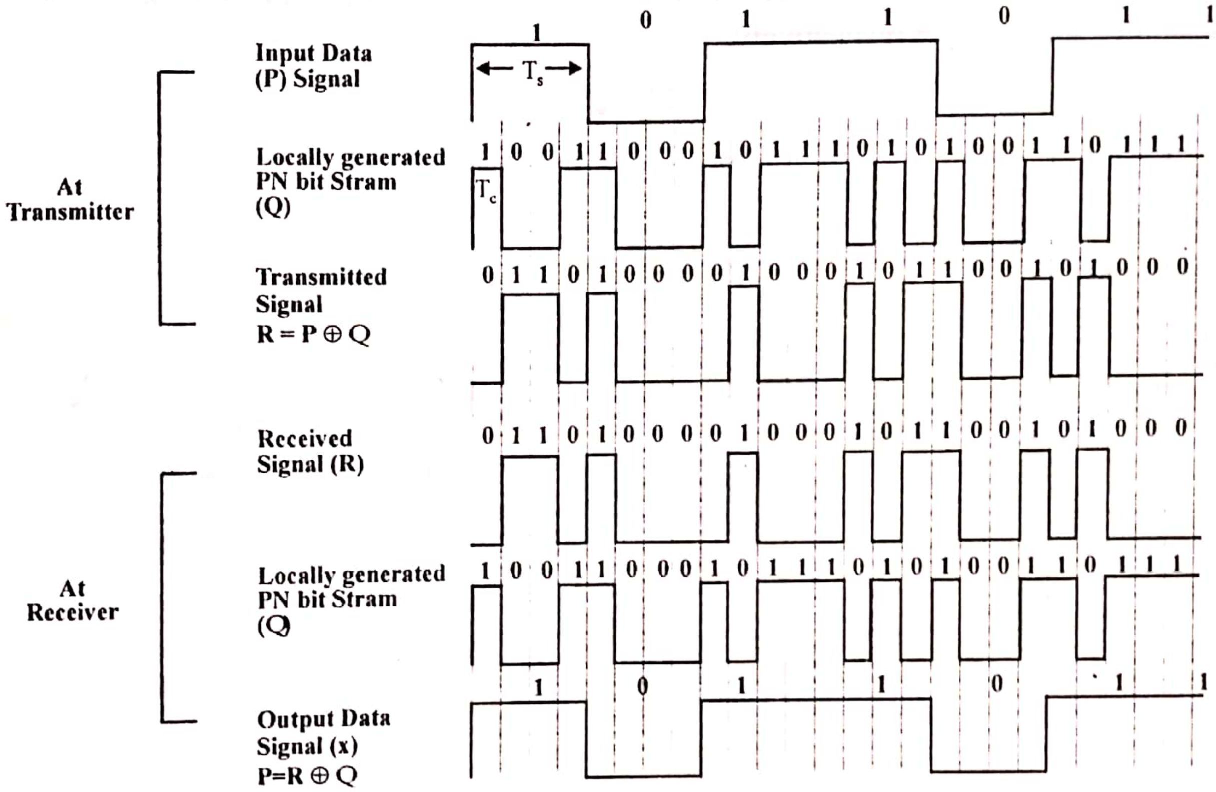

Fig. 4.3 Example of Direct Sequence Spread Spectrum

DSSS using BPSK

Let us assume that Binary Phase Shift Keying (BPSK) technique is used for modulation. In BPSK, rather than represent binary data with 1 and 0, it is more convenient to use +1 and -1 to represent the two binary digits. In that case, a BPSK signal can be represented as follows

$$S_d(t) = p\, d(t) \cos(2\pi f_c t) \quad \text{......(4.1)}$$

where

p = amplitude of signal $\qquad$ f_c = carrier frequency

d(t) = discrete function that takes +1 value for bit 1 and takes -1 value for bit 0.

For DSSS signal, the input signal $S_d(t)$ multiplied by the Q(t), which is the PN sequence taking an values of +1 and -1, then transmitted signal is

$$S(t) = S_d(t) \times Q(t)$$

$$S(t) = p\, d(t)\, Q(t) \cos(2\pi f_c t) \quad \text{......(4.2)}$$

At receiver, the received signal is multiplied again by Q(t). But we know that Q(t) * Q(t) = 1 and therefore the original signal is recovered.

$$S(t) * Q(t) = p\ d(t)\ Q(t) \cos(2\pi f_c t) * Q(t)$$

$$S_d(t) = p\ d(t) \cos(2\pi f_c t)$$

The transmitter and received for BPSK direct spread spectrum are shown in figure 4.4. For other types of modulation (i.e. PSK, DPSK, QPSK etc), we can change the modulator and demodulator of the transmitter and receiver respectively.

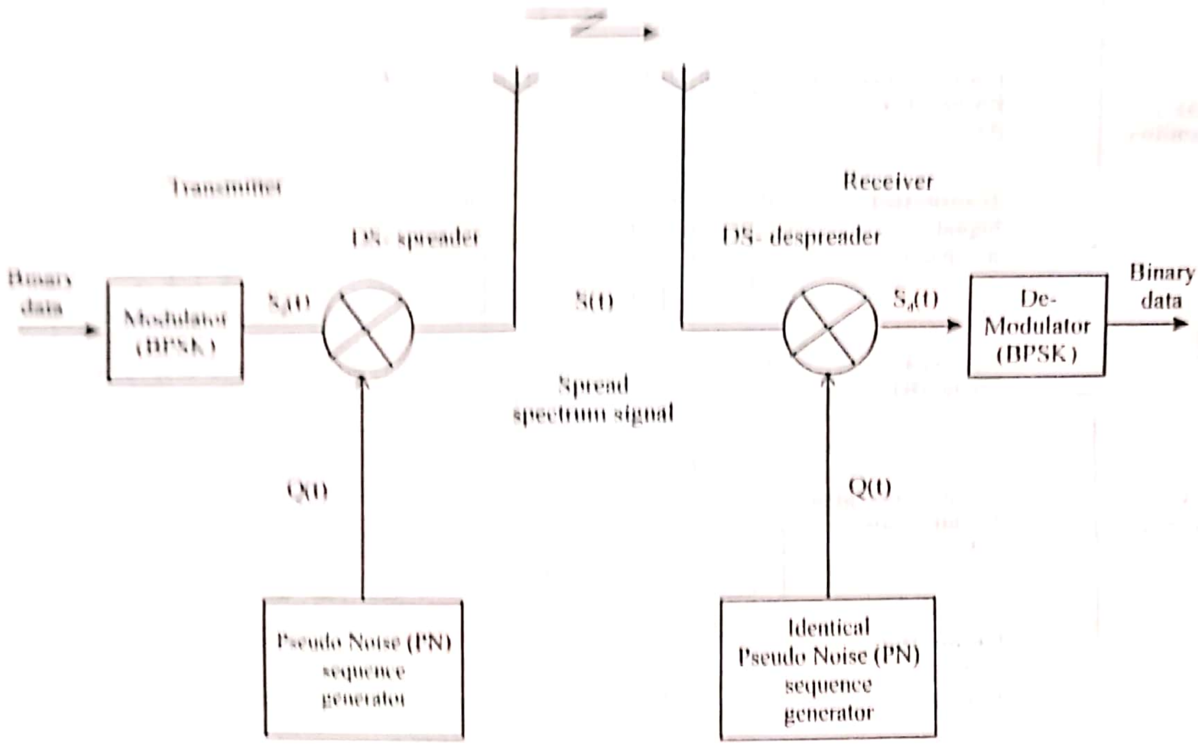

Fig. 4.4 BPSK Direct sequence spread spectrum (DSSS) Communication system

DSSS Performance

The spreading the waveform in DSSS is shown in the figure 4.5. Let us assume a bit width is T_s, then data rate is $1/T_s$. The spectrum of the signal is about $2/T_s$. Similarly, the spectrum of the PN signal is $2/T_c$. Let us assume a simple jamming signal at the center frequency of DSSS system, which is given by

$$S_j(t) = \sqrt{2S_j}\ \cos(2\pi f_c t) \qquad \text{...... (4.3)}$$

then the received signal is

$$S_r(t) = S(t) + S_j(t) + n(t) \qquad \text{......(4.4)}$$

where $s(t)$ – transmitted signal
$s_j(t)$ – jamming signal
s_j – jamming signal power
$n(t)$ – Additive white noise

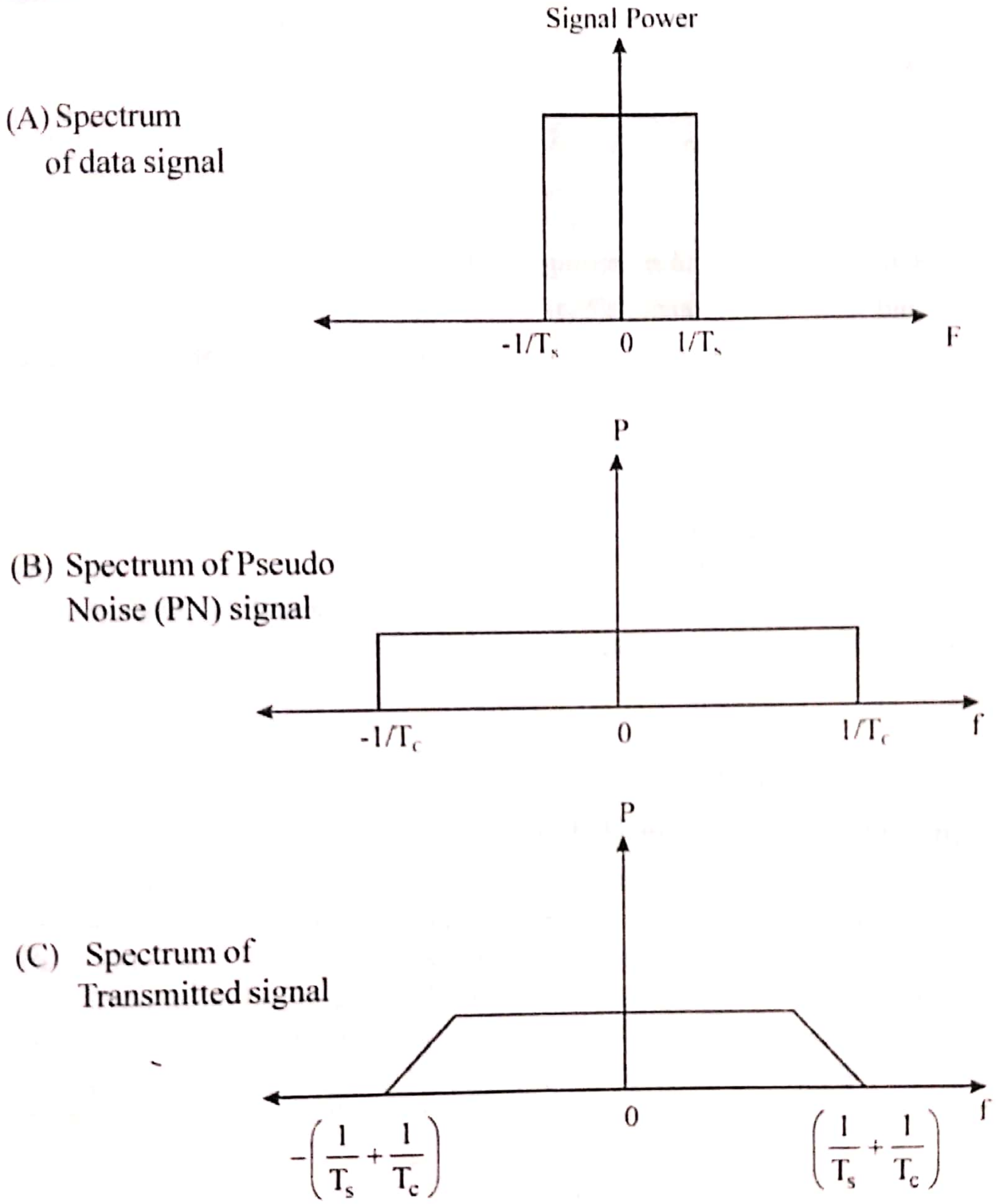

Fig. 4.5 Spectrum of DSSS signal

At the receiver, $S_r(t)$ multiplied by the Q(t), so the signal component due to jamming signal is

$$R_j(t) = \sqrt{2S_j}\ Q(t)\cos(2\pi f_c t) \qquad \text{......(4.5)}$$

Thus the carrier power S_j is spread over a bandwidth of $2/T_c$, but at receiver, a bandpass filter matched to the BPSK data with bandwidth of $2/T_s$. So the most of the jamming power is filtered. Approximately, we can say that the jamming power passed by the filter is

$$S_{j,eff} = S_j \times \frac{2/T_s}{2/T_c} = \frac{S_j}{(T_s/T_c)} \qquad \text{......(4.6)}$$

The jamming power has been reduced by a factor T_s / T_c because of spread spectrum. The factor T_s/T_c is known as processing gain of the system.

$$G_p = \frac{T_s}{T_c} = \frac{f_c}{f_s} = \frac{BW_{ss}}{BW_s} \qquad ......(4.7)$$

where G_p = Processing Gain

BW_{ss} = Bandwidth of spread spectrum signal

BW_s = Band width of modulated signal

In other wards, processing gain is ratio of the output to input signal to noise (S/N) ratio or signal to interference (S/I) ratio

$$G_p = \frac{(S/N)_0}{(S/N)_I} \qquad ......(4.8)$$

where $(S/N)_0$ = output signal to noise ratio

$(S/N)_I$ = input signal to noise ratio

The jamming margin or power S_j, takes into account the practical required $(S/N)_0$ and allows for a system implementation loss (L_{sys}). Then jamming power is defined by

$$S_J = G_P - \left[L_{sys} + \left(\frac{S}{N} \right)_0 \right] \qquad ......($$

where L_{sys} = system implementation loss

4.2.2 Frequency Hopping Spread Spectrum (FHSS)

In frequency hopping, the carrier frequency of the modulated information signal is not constant but changes periodically. During time interval T, the carrier frequency remains the same, but after each time interval the carrier hops to another frequency. The hopping pattern is decided by the spreading code. Figure 4.6 shows the basic concept of frequency hopping spread spectrum (FHSS). The spacing between carrier frequencies and hence the width of each channel usually corresponds to the bandwidth of the input signal. The sequence of channels used is dictated by a spreading code. Both transmitter and receiver use the same code to tune into a sequence of channels in synchronization.

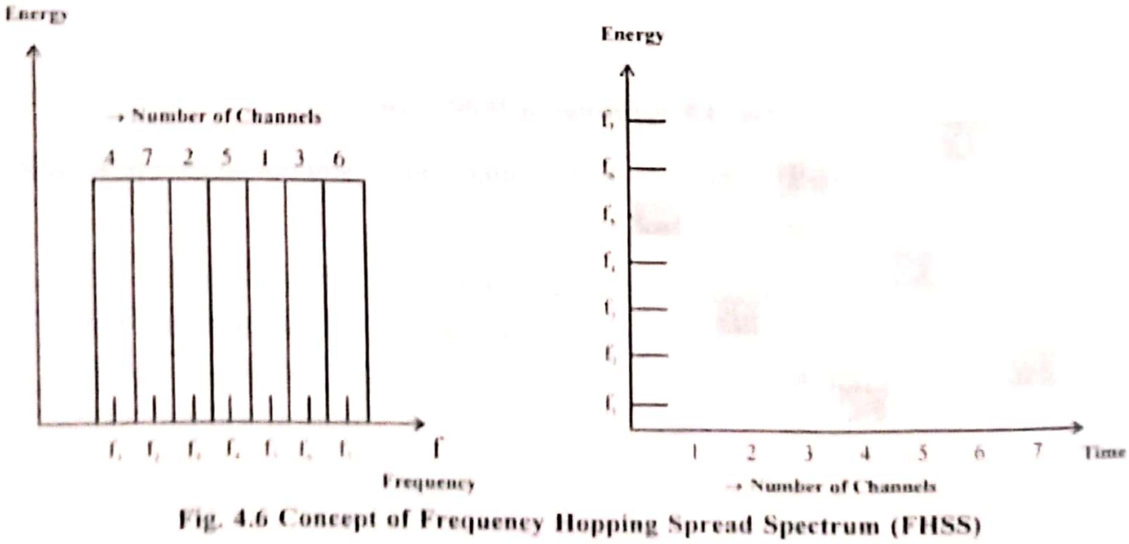

Fig. 4.6 Concept of Frequency Hopping Spread Spectrum (FHSS)

The frequency hopped signal shown in figure 4.6 looks like a noise signal thatswhy detection of this signal is very difficult and FHSS mostly used by military applications. The typical block diagram for a frequency hopping spread spectrum shown in figure 4.7. At transmitter, binary data are fed into a modulator using some digital-to-analog encoding scheme such as frequency shift keying (FSK) or binary phase shift keying (BPSK). Pseudonoise (PN) bit stream generator produces sequence for frequencies table; this is the spreading code. One of the 2^k carrier frequency specifies by a each K bits of the PN generator and selected a new carrier frequency. This frequency is then modulated by the signal produced from initial modulator to produce a new signal of same shape and new selected centered frequency. At receiver the spread spectrum signal is demodulated using the same sequence of PN derived frequencies and then demodulated to generate the output data.

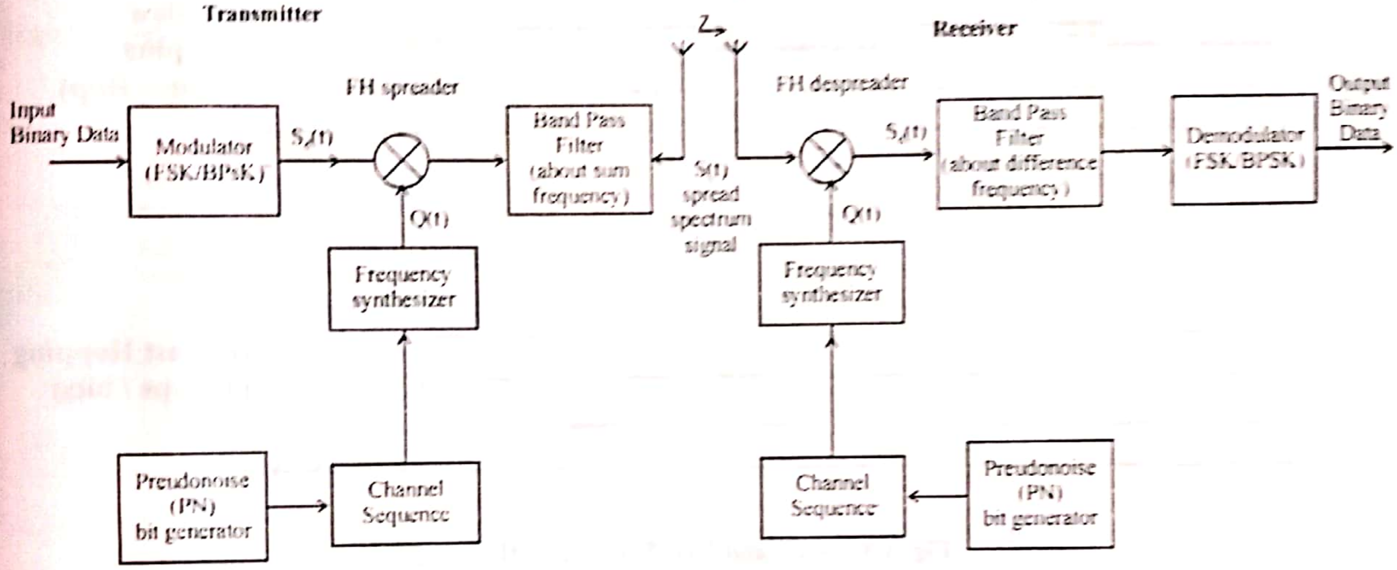

Fig. 4.7 Frequency - Hopping Spread Spectrum (FHSS) System

(a) Slow and Fast Frequency Hopping

In the frequency hopping when transmitter uses one center frequency for several bit durations then hopping is knows as slow frequency hopping. The figure 4.8(b) shows the slow hopping (4 bits/hops). Slow frequency hopping systems are typically cheaper and have relaxed tolerance, but they are not as immune to narrowband interference as fast hopping system.

In the frequency hopping when transmitter changes the several center frequency during one bit duration, then hopping is known as fast frequency hopping. The figure 4.8 (c) shows the fast hopping (4 frequency - hop/bit). Fast hopping system are more complex to implement because the transmitter and receiver have to stay synchronized with in smaller tolerance but they are much better immune to narrowband interference. An example of fast frequency hopping spread spectrum (FFHSS) system is Bluetooth. Bluetooth performs 1600 hops per second and uses 79 hop carriers equally spaced within 1MHz in the 2.4 GHz ISM band.

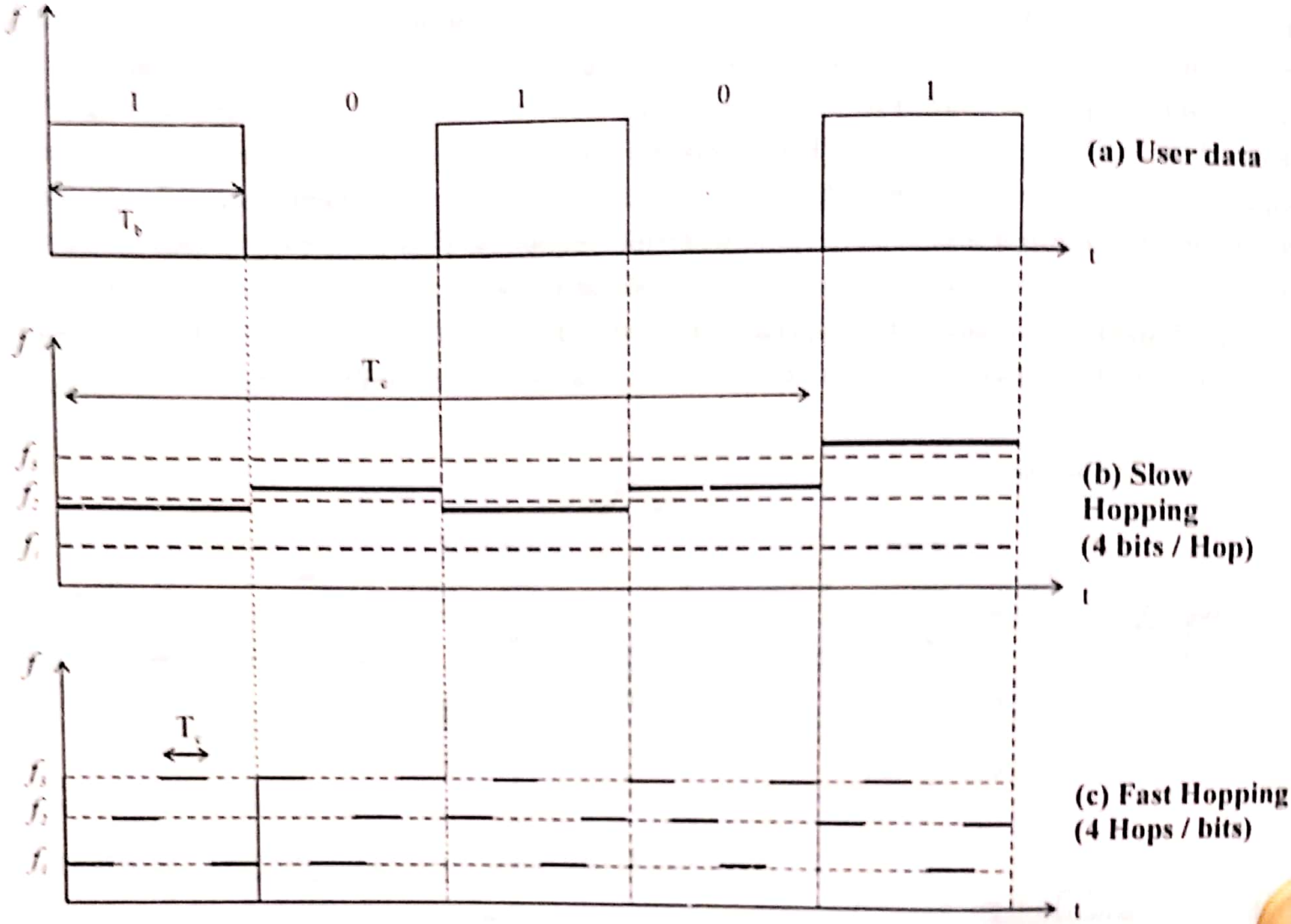

Fig. 4.8 : Slow and Fast Frequency Hopping

(b) FHSS Performance

A large number of frequencies are used in FHSS, thatswhy bandwidth of spread spectrum signal ($B.W_{ss}$) is much larger than bandwidth of modulated signal ($B.W_s$). One Major advantage of this system is that a large value of 2^k frequencies result offer high resistance to jamming. For FHSS, the jammer must jam all 2^k frequencies. With a fixed power, this reduces the jamming power in any one frequency band to $S_j / 2^k$. Then processing gain is

$$G_p = 2^k = \frac{B.W_{ss}}{B.W_s} \qquad \text{......(4.10)}$$

In comparison to DSSS, spreading is simpler using FHSS, systems. FHSS system uses only one portion of the total bandwidth at any time while DSSS system always uses the total bandwidth available. DSSS systems offer more resistance to fading and multipath effects.

4.2.3 Time Hopping Spread Spectrum (THSS)

In time hopping spread spectrum, the data signal is transmitted in rapid bursts at time intervals determined by the spreading code assigned to the user. In time hopping channels are established via time slots with in a given time frame. The basic time hopping transmitter and receiver shown in figure 4.9. The burst transmission is employed within the slot by a PN sequence code. The data bits within a frame are stored for transmission at high speed during the burst. The time slot selector selects the desired portion of the frame and then demodulation is performed. The time hopping and frequency hopping are analogous systems in time domain and frequency domain. The implementation of THSS is simpler than that of FHSS. A combination of three basic spread spectrum modulation techniques may be appropriate for different applications.

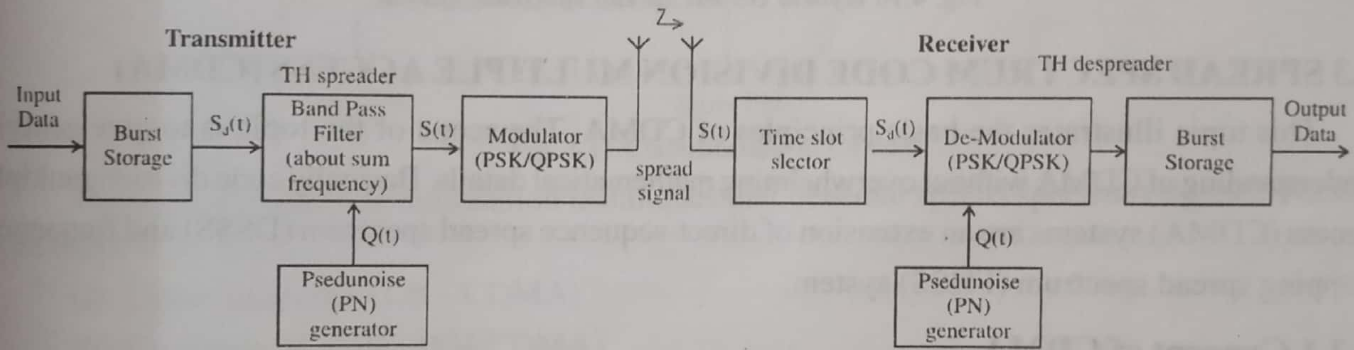

Fig. 4.9 Time Hopping Spread Spectrum (THSS) System

4.2.4 Hybrid Spread Spectrum (HSS)

The hybrid spread spectrum systems employ a combination of two or more of the above mentioned spread spectrum techniques. By combining the basic spread spectrum modulation techniques, we have four possible hybrid systems : DS/FH, DS/TH, FH/TH and DS/FH/TH.

The idea of the hybrid system is to combine the specific advantages of each of the modulation techniques. If we take, for example, the combined DS/FH system, we have the advantage of the anti-multipath property of the DS system combined with the favorable near-far operation of the FH system. Of course, the disadvantage lies in the increased complexity of the transmitter and receiver. For illustration purpose, we give a block diagram of a combined DS/FH hybrid spread spectrum in figure 4.10.

The data signal is first spread using DS code signal. The spread signal is then modulated on a carrier whose frequency hops according to another PN code sequence. A code clock ensures a fixed relation between codes.

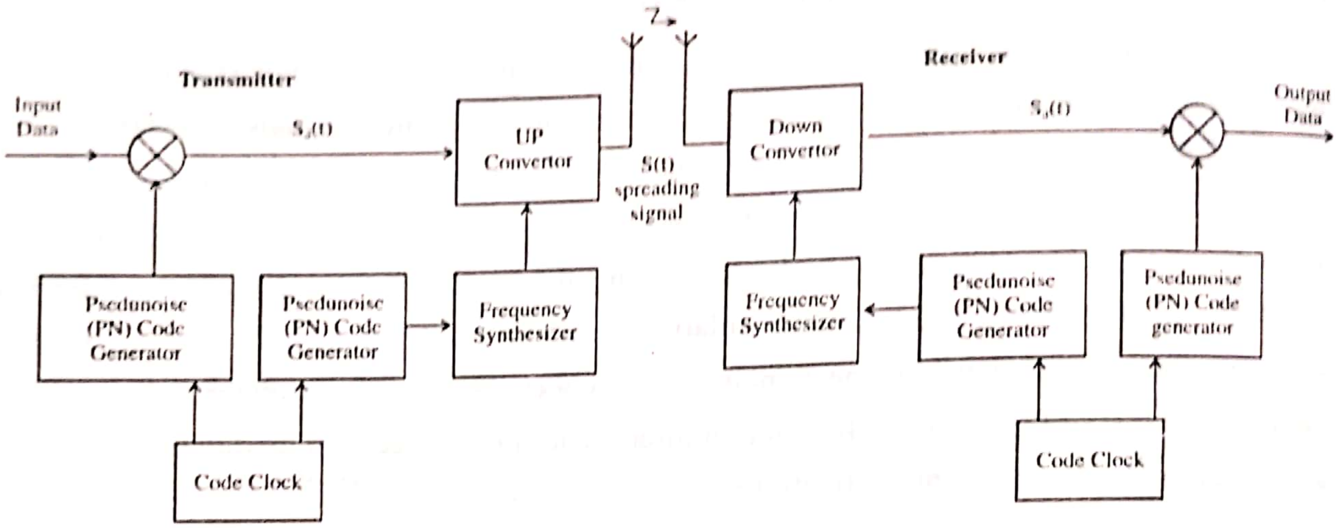

Fig. 4.10 Hybrid DS-FH spread spectrum system

4.3 SPREAD SPECTRUM CODE DIVISION MULTIPLE ACCESS (CDMA)

This topic illustrates the basic principles of CDMA. The scope of the topic is to give generic understanding of CDMA without overwhelming mathematical details. Basically code division multiple access (CDMA) systems are an extension of direct-sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS) system.

4.3.1 Concept of CDMA

In CDMA each user is assigned a unique code sequence (spreading code), it uses to encode its information bearing signal. The receiver, knowing the code sequence of the user, decodes a received signal after reception and recovers the original data. This is possible since the cross-correlations between the code of desired user and the codes of the other users are small. Since the bandwidth of the code signal is chosen to be much larger than the bandwidth of the information bearing signal, the encoding process spreads the spectrum of the signal and is therefore also known as spread spectrum modulation. The resulting signal is also called a spread spectrum signal and CDMA is often denoted as Spread Spectrum Multiple Access (SSMA).

A spread spectrum modulation technique must fulfill two criteria.

(i) The transmission bandwidth must be much larger than the information bandwidth.

(ii) The resulting radio-frequency bandwidth is determined by a function other than the information being sent (so the bandwidth is statistically independent of the information signals). This excludes modulation techniques like frequency modulation (FM) and phase modulation (PM). The general classification of CDMA is given in figure 4.11.

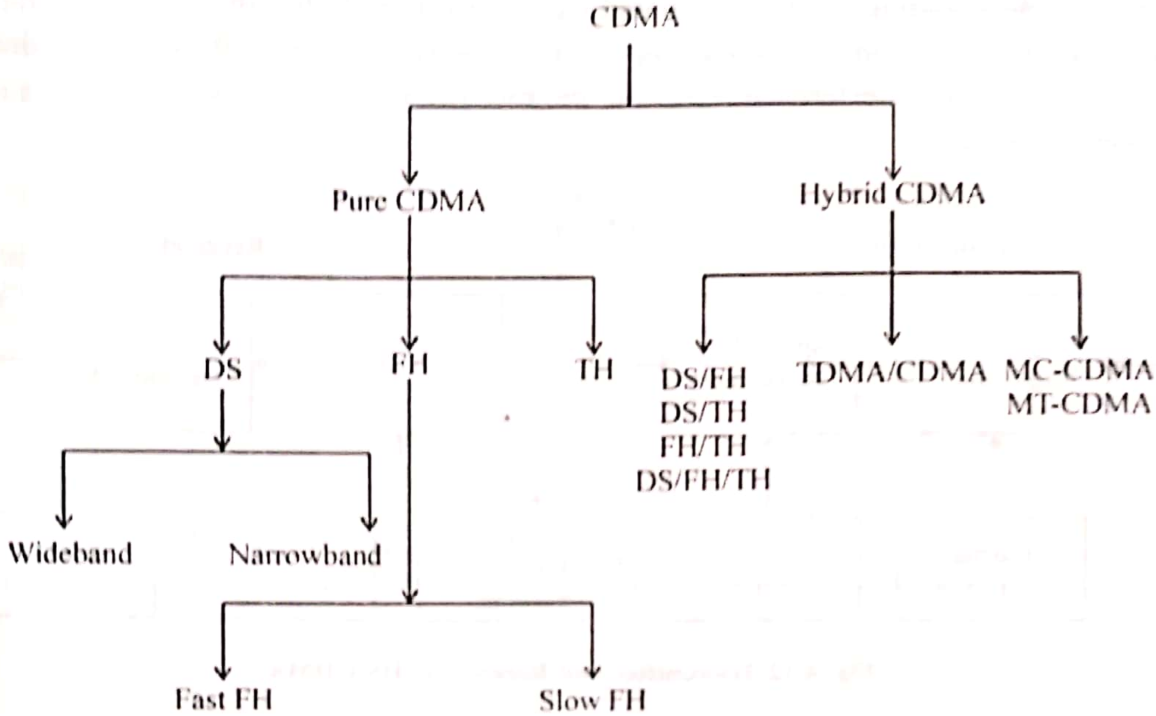

Fig. 4.11 Classification of CDMA

There are a number of modulation techniques that generate spread spectrum signals. These are as follows :

(i) Direct sequence (DS - CDMA)

(ii) Frequency Hopping (FH-CDMA)

(iii) Time Hopping (TH - CDMA)

(iv) Hybrid - CDMA

4.3.2 Direct Sequence CDMA (DS-CDMA)

In DS-CDMA the modulated information bearing signal (the data signal) in directly modulated by a digital, discrete time, discrete valued code signal. The data signal can be either an analog signal or a digital signal. In case of a digital signal, the data modulation is often omitted and the data signal is directly multiplied by the code signal and the resulting signal modulates the wideband carrier. It is from this direct multiplication that the direct sequence CDMA gets its name. In figure 4.12 a block diagram of DS-CDMA transmitter and receiver is given. The binary data signal modulates a RF carrier. The modulated carrier is then modulated by the code signal. This code signal consists of a number of code bits called "Chips". To obtain the desired spreading of the signal, the chip rate of the code signal must be much higher than the chip rate of the information signal. For the spreading modulation various modulation techniques (i.e., PSK, BPSK, DPSK, QPSK, MSK, GMSK, etc) are employed.

After transmission of the signal, the receiver despreads the spread spectrum signal using a locally generated identical code generator which must be synchronized with transmitter code generator. This synchronization must be accomplished at the beginning of the reception and maintained until the whole signal has been received. The code synchronization/tracking block performs this operation. After despreading, a data modulated signal results and after demodulation, the original data signal can be recovered. The most important properties of DS-CDMA are multiple access capability, the multipath interference rejection, the narrowband interference rejection and secure/ private communication.

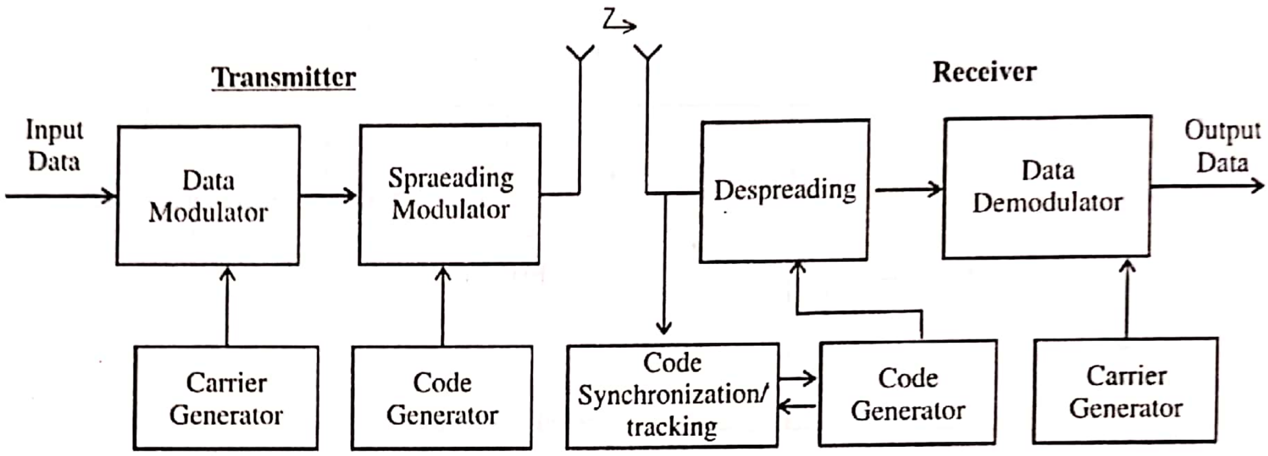

Fig. 4.12 Transmitter and Receiver of DS-CDMA

Apart from the above mentioned properties, DS-CDMA has number of other specific properties that we can divide into advantageous (+) and disadvantageous (–) behavior.

(+) The generation of the coded signal is easy. It can be performed by a simple multiplication.

(+) Coherent demodulation of the DS signal is possible.

(+) No synchronization among the user is necessary.

(–) It is difficult to acquire and maintain the synchronization between code generators of transmitter and receiver. Synchronization has to be kept within a fraction of the chip time.

(–) The power received from users close to the base station is much higher than that received from users further away and this effect is known as **near-far effect**. This will create interference. This near-far effect can be solved by applying a power control algorithm so that all users are received by the base station with the same average power.

4.3.3 Frequency Hopping CDMA (FH-CDMA)

In frequency hopping CDMA the carrier frequency of the modulated information signal is not constant but changes periodically. During time intervals, the carrier frequency remains the same, but after each time interval the carrier hops to another frequency. The hopping pattern is decided by the spreading code. The direct sequence (DS) system occupies the whole frequency band when it transmits, but the location of this part differs in time.

The block diagram for an FH-CDMA system is given in figure 4.13. The data signal is baseband modulated signal. Using a fast frequency synthesizer that is controlled by the code signal, the carrier frequency is converted up to the transmission frequency. The inverse process takes place at receiver. Using a locally generated code sequence, the received signal is converted down to the baseband.

The data is recovered after demodulation. The synchronization or tracking circuit ensures that the hopping of the locally generated carrier synchronizes to the hopping pattern of the received carrier so that correct despreading of the signal is possible.

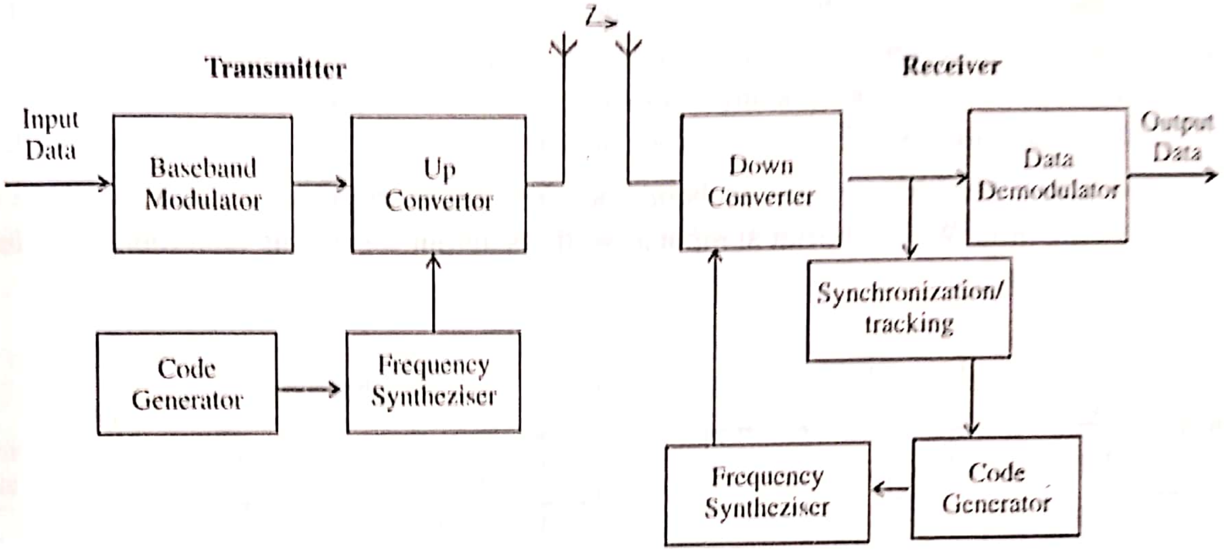

Fig. 4.13 FH-CDMA Transmitter and Receiver

Within frequency hopping CDMA, a distinction is made that is based on the hopping rate of the carrier. If the hopping rate is greater than the symbol rate, the modulation is considered to be fast frequency hopping (FFH). In this case the carrier frequency changes a number of times during the transmission of one symbol, so that one bit is transmitted in different frequencies. If the hopping rate is smaller than the symbol rate, one speaks of slow frequency hopping (SFH). In this case multiple symbols are transmitted at the same frequency. We can make the frequency changes smooth by decreasing the transmitted power before a frequency hop and increasing it again when the hopping frequency has changed. FH-CDMA provides properties of multipath interference rejection, narrowband interference rejection and multiple access capability.

Apart from the above mentioned properties, the FH-CDMA has number of other specific properties that we can divide into advantageous (+) and disadvantageous (–) behavior.

(+) Synchronization is much easier with FH-CDMA than with DS-CDMA. Thus, an FH-CDMA system allows a larger synchronizations error.

(+) Because of the larger possible bandwidth a FH system can employ, it offers a higher possible reduction of narrowband interference than a DS system.

(+) The probability of multiple users transmitting in the same frequency band at the same time is small.

(+) The near-far effect will be reduced in FH-CDMA

(–) A high sophisticated frequency synthesizer is necessary.

(–) Coherent demodulation is difficult because of the problems in maintaining phase relationship during hopping.

4.4 CHARACTERISTICS AND GENERATION OF SPREADING SEQUENCE

The spreading sequence is a sequence of binary digits shared by transmitter and receiver. The spreading codes are chosen so that the resulting signal in noiselike, therefore there should be an approximately equal number of ones and zeros in the spreading code and few or non repeated patterns. The high degree of redundancy provided by the spreading operation, then despreading operation is able to cope with the interference of other signals in the same bandwidth. The spreading sequence generally divided in two categories, first pseudonoise (PN) sequences and second orthogonal codes. PN sequences are the most common ones used in FHSS, DSSS and THSS. In DS-CDMA systems, both PN and orthogonal codes have been used. We describe both in briefs.

4.4.1 PN (Pseudonoise) Sequence

An ideal spreading sequence would be a random sequence of binary ones and zeros. The predictable way is required to generate the same bit stream at transmitter and receiver and yet retain the desirable properties of a random bit stream. This requirement is fullfil by a PN generator. PN sequences are generated by an algorithm using some initial value called the seed. If you do not know the algorithm and seed, it is impossible to predict the correct PN sequence. The major task of the PN sequences used in wireless communication and personal communications. To meet these task, the PN sequence need following properties:

PN sequence properties

(i) **Randomness :** A PN generator will produce a periodic sequence that eventually repeats but that appears to be random.

(ii) **Unpredictability :** Without knowing the algorithm and the seed, PN sequence should be unpredictable.

(iii) **Uniform distribution :** The distribution of numbers in the PN sequence should be uniform. If we use binary number system then numbers of ones and numbers of zeros should be equal.

(iv) **Independence :** No one value in the sequence can be inferred from the other values of PN sequence.

(v) **Correlation Property :** The PN sequences should have follow the properties of cross-correlation and auto-correlation functions. The correlation property obtained when the codes are compared bit by bit for every discrete shift of time.

Correlation Value	Interpretation
1	The two sequences match exactly.
0	There is no relation between sequences.
-1	The two sequences are opposite to each other.

The best known, best described PN sequences are maximal length sequences (m-sequences). They are suitable for spread spectrum systems and were widely used in military applications. Because of the cross - correlation demands, Gold sequences and kasami-sequences are more interesting for cellular or wireless communications including CDMA systems.

$$f_r = f_t \pm \frac{f_t v}{c} \qquad ......(4.13)$$

where

v = Relative velocity between transmitter and receiver in m/sec

c = speed of light, 3×10^8 m/sec

The positive (+) sign is applicable when transmitter and receiver are approaching each other and the negative (-) sign applied when transmitter and receiver moving away from each other . This is the nonrelativistic equation. For very large velocities, the relativistic equation is used, which is

$$f_r = f_t\sqrt{\frac{c-v}{c+v}} \qquad ......(4.14)$$

4.6 MERITS AND DEMERITS OF SPREAD SPECTRUM

Because of the coding and the resulting enlarged bandwidth, spread spectrum signals have number of properties that differ from the properties of narrowband signals. The most interesting from the communication system point of view are discussed below.

MERITS :–

(i) Multiple Access Capability : If multiple users transmit a spread spectrum signal at the same time, the receiver will still be able to distinguish between the users provided each user has a unique code that has a sufficiently low cross-correlation with the other codes.

(ii) Protection against multipath Interference : In a radio channel there is not just on path between the transmitter and receiver. Due to propagation techniques, a signal will be received from a number of different paths. The signal of the different path are all copies of the same transmitted signal but with different amplitudes phases, delays and arrival angles. Adding these signals at the receiver will be constructive at some of the frequencies and destructive at others. In time domain, this results in a dispersed signal. Spread spectrum modulation can combat this multipath interference.

(iii) Privacy : The transmitted signal can be only despread and the data recovered if the code is known to the receiver.

(iv) Interference Rejection : Cross - correlating the code signal with the narrowband signal will spread the power of the narrowband signal, thereby reducing the interfering power in the information bandwidth.

(v) Anti-jamming capability : This is more or less the same as interference rejection and privacy except the interference is now will fully inflicted on the system. Due to this property, spread spectrum modulation is attractive for military applications.

(vi) Low Probability of interception (LPI) : Because of its low power density, the spread spectrum signal is difficult to detect and intercept by a hostile listener.

DEMERITS :–

(i) High Bandwidth requirement : Due to spreading the baseband signal, system require more bandwidth. This will result more costly the system.

(ii) Near-far problem : In direct sequence spread spectrum the signals closer to the receiver are received with less power signals further away. Given the lack of complete orthogonality, the transmission from the more remote user may be more difficult to recover.

4.7 APPLICATIONS OF SPREAD-SPECTRUM SYSTEM

Now-a-days spread spectrum is more popular for a commercial applications. The applications of spread spectrum are as follows:

(i) Military application : Due to privacy and ant-jamming capability of spread spectrum, it is used for military communications.

(ii) CDMA communication : Spread spectrum techniques used in CDMA communication. In India, Reliance using the spread spectrum CDMA technique for mobile communication.

(ii) Wireless Local Area Network (WLAN) : The spread spectrum techniques used in local area networks (LAN).

(iv) High - resolution Ranging : Another application of DS spread spectrum is for ranging. Ranging means find the distance of intended target from the ground based transmitter.