DEPARTMENT
OF
ELECTRONICS & COMMUNICATION ENGINEERING

Digital Communication System

(Theory Notes)

Autonomous Course

Module – 5 SPREAD SPECTRUM MODULATION
Pseudo noise sequences, notion of spread spectrum, direct sequence spread spectrum, Frequency Hop Spread Spectrum, Applications

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SPREAD SPECTRUM MODULATION

Introduction:

Initially developed for military applications during II world war, that was less sensitive to intentional interference or jamming by third parties. Spread spectrum technology has blossomed into one of the fundamental building blocks in current and next-generation wireless systems

Problem of radio transmission

Narrow band can be wiped out due to interference

To disrupt the communication, the adversary needs to do two things,

(a) to detect that a transmission is taking place and

(b) to transmit a jamming signal which is designed to confuse the receiver.

Solution

A spread spectrum system is therefore designed to make these tasks as difficult as possible.

Firstly, the transmitted signal should be difficult to detect by an adversary/jammer, i.e., the signal should have a low probability of intercept (LPI).

Secondly, the signal should be difficult to disturb with a jamming signal, i.e., the transmitted signal should possess an anti-jamming (AJ) property

Remedy

spread the narrow band signal into a broad band to protect against interference

In a digital communication system the primary resources are **Bandwidth** and **Power.** The study of digital communication system deals with efficient utilization of these two resources, but there are situations where it is necessary to sacrifice their efficient utilization in order to meet certain other design objectives. For example to provide a form of secure communication (i.e. the transmitted signal is not easily detected or recognized by unwanted listeners) the bandwidth of the transmitted signal is increased in excess of the minimum bandwidth necessary to transmit it. This requirement is catered by a technique known as **"Spread Spectrum Modulation".** The primary advantage of a Spread – Spectrum communication system is its ability to reject '**Interference**' whether it be the unintentional or the intentional interference.

The definition of Spread – Spectrum modulation may be stated in two parts.

1. Spread Spectrum is a mean of transmission in which the data sequence occupies a BW (Bandwidth) in excess of the minimum BW necessary to transmit it.

2. The Spectrum Spreading is accomplished before transmission through the use of a code that is independent of the data sequence. The Same code is used in the receiver to despread the received signal so that the original data sequence may be recovered.

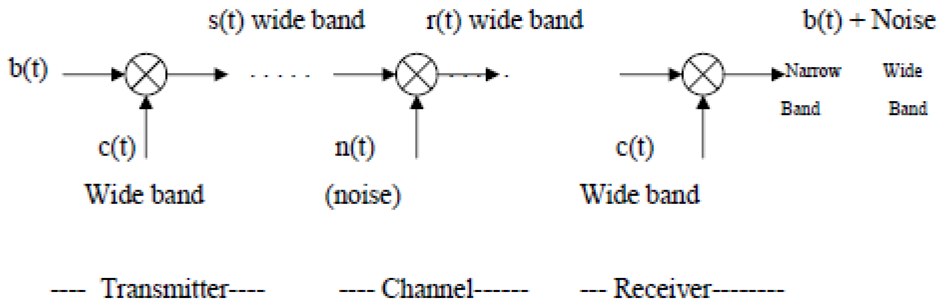


Fig: 1 spread spectrum technique.

b(t) = Data Sequence to be transmitted (Narrow Band)

c(t) = Wide Band code

s(t) = c(t) * b(t) – (wide Band)

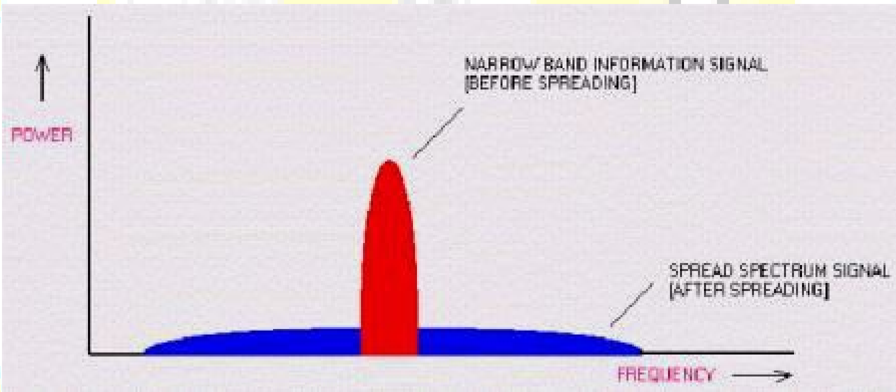


Fig: Spectrum of signal before & after spreading

5.1 PSEUDO NOISE SEQUENCES

Generation of PN sequence:

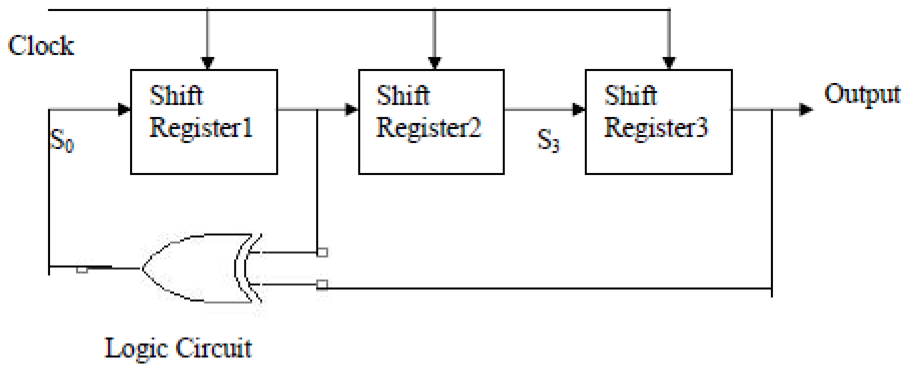
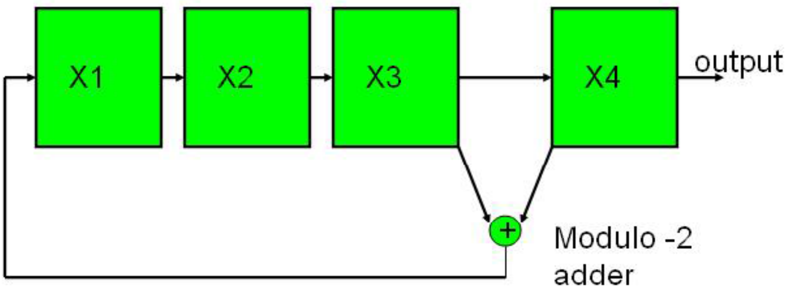


Fig 2: Maximum-length sequence generator for n=3

A feedback shift register is said to be Linear when the feedback logic consists of entirely mod-2-address (Ex-or gates). In such a case, the zero state is not permitted. The period of a PN sequence produced by a linear feedback shift register with 'n' flip flops cannot exceed 2^n-1. When the period is exactly 2^n-1, the PN sequence is called a '**maximum length sequence**' or '**m-sequence**'.

Example1: Consider the linear feedback shift register as shown in fig 2 involve three flip-flops. The input s_0 is equal to the mod-2 sum of S_1 and S_3. If the initial state of the shift register is 100. Then the succession of states will be as follows. 100,110,011,011,101,010,001,100 . . . . . .

The output sequence (output S_3) is therefore. 00111010 . . . . . . Which repeats itself with period 2^3-1 = 7 (n=3) Maximal length codes are commonly used PN codes. In binary shift register, the maximum length sequence is $\mathbf{N = 2^m - 1}$ chips, where **m** is the number of stages of flip-flops in the shift register.



Linear Feedback Shift Register with modulo two adder

At each clock pulse

- Contents of register shifts one bit right.
- Contents of required stages are modulo 2 added and fed back to input.

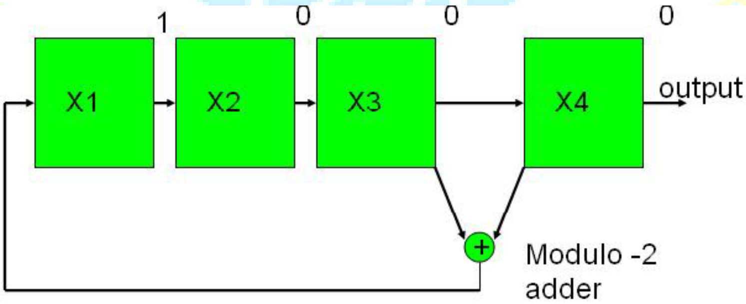


Fig: Initial stages of Shift registers **1000**

Let initial status of shift register be 1000

1	0	0	0
0	1	0	0
0	0	1	0
1	0	0	1
1	1	0	0
0	1	1	0
1	0	1	1
0	1	0	1
1	0	1	0
1	1	0	1
1	1	1	0
1	1	1	1
0	1	1	1
0	0	1	1
0	0	0	1
1	0	0	0

- We can see for shift Register of length m=4. At each clock the change in state of flip-flop is shown.
- Feed back function is modulo two of X_3 and X_4.
- After 15 clock pulses the sequence repeats.

Output sequence is 0 0 0 1 0 0 1 1 0 1 0 1 1 1 1

Properties of PN Sequence

Randomness of PN sequence is tested by following properties

1. Balance property
2. Run length property
3. Autocorrelation property

1. Balance property

In each Period of the sequence , number of binary ones differ from binary zeros by at most one digit .

Consider output of shift register 0 0 0 1 0 0 1 1 0 1 0 1 1 1 1

Seven zeros and eight ones -meets balance condition.

2. Run length property

Among the runs of ones and zeros in each period, it is desirable that about one half the runs of each type are of length 1, one- fourth are of length 2 and one-eighth are of length 3 and so-on.

Consider output of shift register

Number of runs =8

0 0 0 1 0 0 1 1 0 1 0 1 1 1 1

3 1 2 2 1 1 1 4

3. Auto correlation property

Auto correlation function of a maximal length sequence is periodic and binary valued. Autocorrelation sequence of binary sequence in polar format is given by

$$R_c(k) = \frac{1}{N}\sum_{n=1}^{N} c_n c_{n-k}$$

Where **N** is length or period of the sequence and **k** is the lag of the autocorrelation

$$R_c(k) = \begin{cases} 1 & \text{if} \quad k = lN \\ -\dfrac{1}{N} & k \neq lN \end{cases}$$

Where **l** is any integer.

$$R_c(k) = \frac{1}{N}$$

we can also state Autocorrelation function as

{ No. of agreements – No. of disagreements in comparison of one full period }

Consider output of shift register for l=1

0 0 0 1 0 0 1 1 0 1 0 1 1 1 1

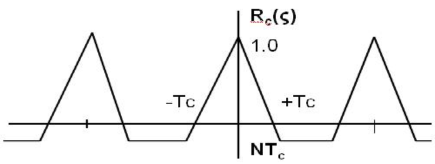
1 0 0 0 1 0 0 1 1 0 1 0 1 1 1

d a a d d a d a d a d d a a a

$$R_c(k) = \frac{1}{15}(7-8)$$

$$R_c(k) = -\frac{1}{15}$$

Yields PN autocorrelation as



PN autocorrelation function.

Range of PN Sequence Lengths

Length 0f Shift Register, m	PN Sequence Length,
7	127
8	255
9	511
10	1023
11	2047
12	4095
13	8191
17	131071
19	524287

Q) A 3-stage shift register with a linear feedback generates the sequence 0 1 0 1 1 1 0 0 1 0 1 1 1 0

a) Determine the period of the given infinite sequence

b) Verify the three properties of PN sequence for the given sequence.

Soln (a) $m = 3 \Rightarrow N = 2^m - 1 = 2^3 - 1 = 7$

0 1 0 1 1 1 0 | 0 1 0 1 1 1 0

$\therefore C(n) = 0\,1\,0\,1\,1\,1\,0$

(b) (i) Balance property # 1's = # 0's + 1

1's = 4

0's = 3

Balance property is satisfied

(ii) Run property:

$\underset{1}{0}\ \underset{2}{1}\ \underset{3}{0}\ \underset{4}{\underbrace{1\,1\,1}}\ \underset{5}{0}$

$\# \text{ runs} = \frac{N+1}{2} = \frac{7+1}{2} = 4$, should be there

But from above sequence; the property is not satisfied. to satisfy let's shift the sequence

$\underset{1}{\underbrace{0\ 0}}\ \underset{2}{1}\ \underset{3}{0}\ \underset{4}{\underbrace{1\,1\,1}}$

$n=1 \Rightarrow \frac{1}{2^1} \times 4 = 2$, 2 runs of length "1"

$n=2 \Rightarrow \frac{1}{2^2} \times 4 = 1$, 1 run of length "2"

3

$4 - 3 = 1 \Rightarrow$ 1 run of length "3"

Run property also satisfied.

(iii) Auto co-relation

0 0 1 0 1 1 1

mapping ↓

1 1 -1 1 -1 -1 -1

$$R(d) = \frac{1}{N}\sum_{n=1}^{N} C(n)\,C(n-d)$$

$$R(0) = \frac{1}{7}\sum_{n=1}^{7} c^2(n) = \frac{7}{7} = 1$$

$$R(1) = \frac{1}{7}\sum_{n=1}^{7} c(n)\,C(n-1) = -\frac{1}{7}$$

1 1 -1 1 -1 -1 -1

-1 1 1 -1 1 -1 -1

-1 1 -1 -1 +1 +1 +1

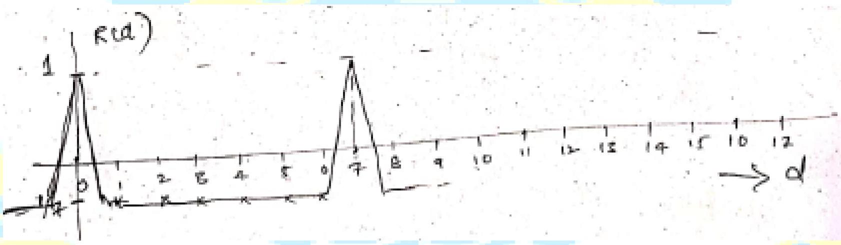
$$R(2) = \frac{1}{7}\sum_{n=1}^{7} C(n)\,C(n-2) = -\frac{1}{7}$$

1 1 -1 1 -1 -1 -1

-1 -1 1 1 -1 1 -1

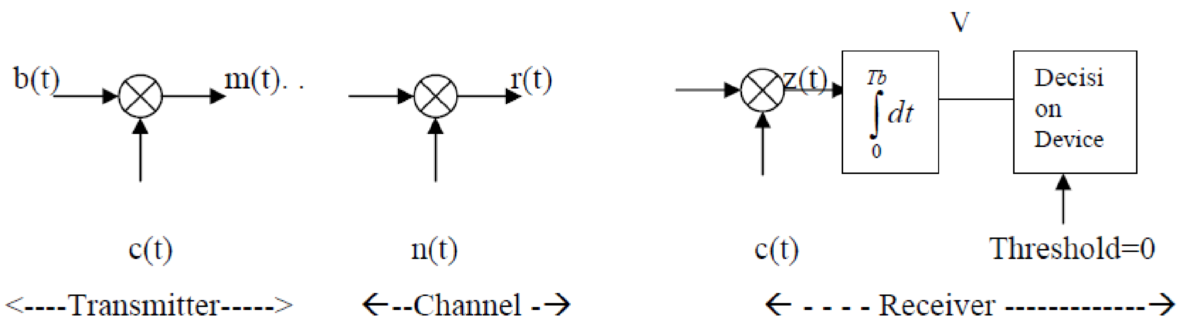
-1 + + + + + +

Illy $R(2) = R(3) = \cdots = R(6) = -\frac{1}{7}$



5.2 NOTION OF SPREAD SPECTRUM

An important attribute of Spread Spectrum modulation is that it can provide protection against externally generated interfacing signals with finite power. Protection against jamming (interfacing) waveforms is provided by purposely making the information – bearing signal occupy a BW far in excess of the minimum BW necessary to transmit it. This has the effect of making the transmitted signal a noise like appearance so as to blend into the background. Therefore Spread Spectrum is a method of 'camouflaging' the information – bearing signal.



Let $\{b_k\}$ denotes a binary data sequence. $\{c_k\}$ denotes a PN sequence.

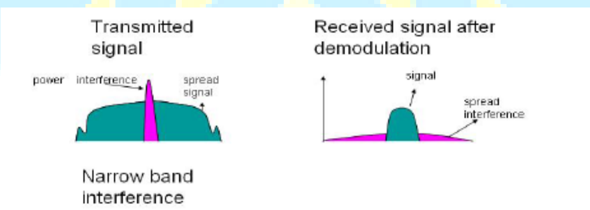
b(t) and c(t) denotes their NRZ polar representation respectively.

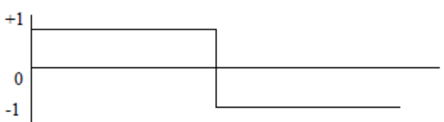
The desired modulation is achieved by applying the data signal b(t) and PN signal c(t) to a product modulator or multiplier. If the message signal b(t) is narrowband and the PN sequence signal c(t) is wide band, the product signal m(t) is also wide band. The PN sequence performs the role of a '**Spreading Code**". For base band transmission, the product signal m(t) represents the transmitted signal. Therefore m(t) = c(t).b(t)

The received signal r(t) consists of the transmitted signal m(t) plus an additive interference noise n(t), Hence

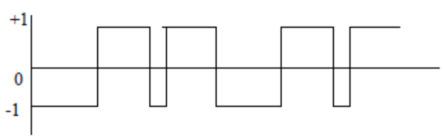
r(t) = m(t) + n(t)

= c(t).b(t) + n(t)

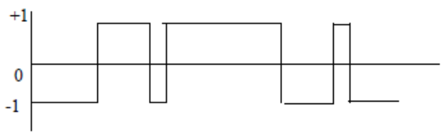




a) Data Signal b(t)



b)Spreading Code c(t)



c)Product signal or base band transmitted signal m(t)

To recover the original message signal b(t), the received signal r(t) is applied to a demodulator that consists of a multiplier followed by an integrator and a decision device. The multiplier is supplied with a locally generated PN sequence that is exact replica of that used in the transmitter. The multiplier output is given by

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

$= [b(t) * c(t) + n(t)]\ c(t)$

$= c^2(t).b(t) + c(t).n(t)$

The data signal b(t) is multiplied twice by the PN signal c(t), where as unwanted signal n(t) is multiplied only once. But $c^2(t)= 1$, hence the above equation reduces to

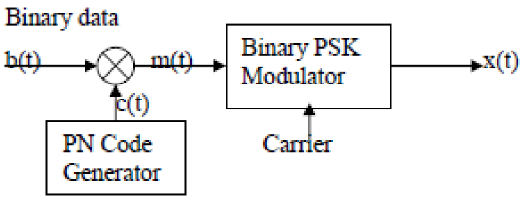
$Z(t) = b(t) + c(t).n(t)$

Now the data component b(t) is narrowband, where as the spurious component c(t)n(t) is wide band. Hence by applying the multiplier output to a base band (low pass) filter most of the power in the spurious component c(t)n(t) is filtered out. Thus the effect of the interference n(t) is thus significantly reduced at the receiver output. The integration is carried out for the bit interval $0 \leq t \leq T_b$ to provide the sample value V. Finally, a decision is made by the receiver.

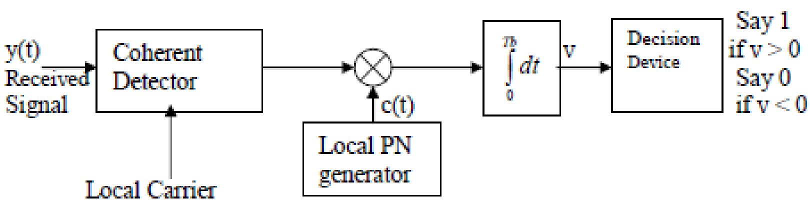
If V > Threshold Value '0', say binary symbol '1'

If V < Threshold Value '0', say binary symbol '0'

5.3 DIRECT – SEQUENCE SPREAD SPECTRUM WITH COHERENT BINARY PHASE SHIFT KEYING



a) Transmitter



b) Receiver

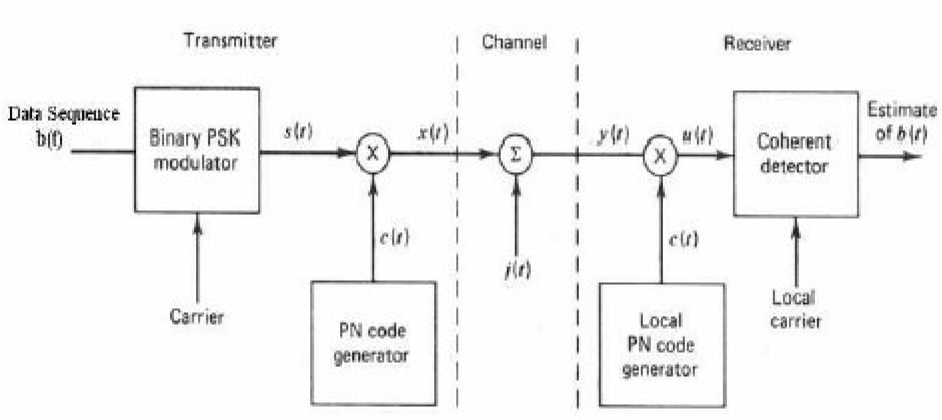


Fig: model of direct – sequence spread binary PSK system(alternative form)

To provide band pass transmission, the base band data sequence is multiplied by a Carrier by means of shift keying. Normally binary phase shift keying (PSK) is used because of its advantages. The transmitter first converts the incoming binary data sequence $\{b_k\}$ into an NRZ waveform b(t), which is followed by two stages of modulation. The first stage consists of a multiplier with data signal b(t) and the PN signal c(t) as inputs. The output of multiplier is m(t) is a wideband signal. Thus a narrow – band data sequence is transformed into a noise like wide band signal. The second stage consists of a binary Phase Shift Keying (PSK) modulator, which converts base band signal m(t) into band pass signal x(t). The transmitted signal x(t) is thus a direct – sequence spread binary PSK signal. The phase modulation θ(t) of x(t) has one of the two values '0' and 'π' (180_o) depending upon the polarity of the message signal b(t) and PN signal c(t) at time t.

Polarity of PN & Polarity of PN signal both +, + or - - Phase '0'

Polarity of PN & Polarity of PN signal both +, - or - + Phase 'π'

		Polarity of data sequence b(t)	
		+	-
Polarity of PN sequence C(t)	+	0	π
	-	π	0

The receiver consists of two stages of demodulation.

In the first stage the received signal y(t) and a locally generated carrier are applied to a coherent detector (a product modulator followed by a low pass filter), Which converts band pass signal into base band signal.

The second stage of demodulation performs Spectrum dispreading by multiplying the output of low-pass filter by a locally generated replica of the PN signal c(t), followed by integration over a bit interval T_b and finally a decision device is used to get binary sequence.

Signal Space Dimensionality and Processing Gain

- Fundamental issue in SS systems is how much protection spreading can provide against interference.
- SS technique distribute low dimensional signal into large dimensional signal space (hide the signal).
- Jammer has only one option; to jam the entire space with fixed total power or to jam portion of signal space with large power.

Consider set of orthonormal basis functions;

$$\varphi_k(t) = \begin{cases} \sqrt{\frac{2}{T_c}}\cos(2\pi f_c t) & kT_c \le t \le (k+1)T_c \\ 0 & \text{otherwise} \end{cases}$$

$$\tilde{\varphi}_k(t) = \begin{cases} \sqrt{\frac{2}{T_c}}\sin(2\pi f_c t) & kT_c \le t \le (k+1)T_c \\ 0 & \text{otherwise} \end{cases} \qquad k = 0, 1, \ldots\ldots\ldots\ldots, N-1$$

where

T_c is chip duration,

N is number of chips per bit.

Transmitted signal x(t) for the interval of an information bit is

$$\begin{aligned} x(t) &= c(t)\, s(t) \\ &= \pm\sqrt{\frac{2E_b}{T_b}}\, c(t) \cos(2\pi f_c t) \\ &= \pm\sqrt{\frac{E_b}{N}} \sum_{k=0}^{N-1} c_k \varphi_k(t) \qquad 0 \le t \le T_b \end{aligned}$$

where, E_b is signal energy per bit.

PN Code sequence { c_0, c_1, ……c_{N-1}} with c_k= + 1 Transmitted signal x(t) is therefore N dimensional and requires N orthonormal functions to represent it. j(t) represent interfering signal (jammer). As said jammer tries to places all its available energy in exactly same N dimension signal space. But jammer has no knowledge of signal phase. Hence tries to place equal energy in two phase coordinates that is cosine and sine.

As per that jammer can be represented as

$$j(t) = \sum_{k=0}^{N-1} j_k \varphi_k(t) + \sum_{k=0}^{N-1} \tilde{j}_k \tilde{\varphi}_k(t) \qquad 0 \le t \le T_b$$

where

$$j_k = \int_0^{T_b} j(t)\varphi_k(t)\,dt \qquad k = 0,1,\ldots\ldots\ldots\ldots N-1$$

$$\tilde{j}_k = \int_0^{T_b} j(t)\tilde{\varphi}_k(t)\,dt \qquad k = 0,1,\ldots\ldots\ldots\ldots N-1$$

Thus j(t) is 2N dimensional, twice the dimension as that of x(t).

Average interference power of j(t)

$$J = \frac{1}{T_b}\int_0^{T_b} j^2(t)\,dt$$

$$= \frac{1}{T_b}\sum_{k=0}^{N-1} j_k^2 + \frac{1}{T_b}\sum_{k=0}^{N-1} \tilde{j}_k^2$$

as jammer places equal energy in two phase coordinates , hence

$$\sum_{k=0}^{N-1} j_k^2 = \sum_{k=0}^{N-1} \tilde{j}_k^2$$

$$J = \frac{2}{T_b}\sum_{k=0}^{N-1} j_k^2$$

To evaluate system performance we calculate SNR at input and output of **DS/BPSK** receiver. The coherent receiver input is u(t) =s(t) + c(t)j(t) and using this u(t), output at coherent receiver

$$v = \sqrt{\frac{2}{T_b}}\int_0^{T_b} u(t)\cos(2\pi f_c t)\,dt$$

$$= v_s + v_{cj}$$

Where V_s is despread component of BPSK and V_{cj} of spread interference.

$$v_s = \sqrt{\frac{2}{T_b}}\int_0^{T_b} s(t)\cos(2\pi f_c t)\,dt$$

$$v_{cj} = \sqrt{\frac{2}{T_b}}\int_0^{T_b} c(t)\,j(t)\cos(2\pi f_c t)\,dt$$

Consider despread BPSK signal s(t)

$$s(t) = \pm\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \qquad 0 \le t \le T_b$$

Where + sign is for symbol 1

- sign is for symbol 0.

If carrier frequency is integer multiple of 1 / T_b, we have

$$v_s = \pm\sqrt{E_b}$$

Consider spread interference component v_{cj}

here c(t) is considered in sequence form { $c_0, c_1, \ldots\ldots c_{N-1}$ }

$$v_{cj} = \sqrt{\frac{T_c}{T_b}}\sum_{k=0}^{N-1} c_k \int_0^{T_b} j(t)\varphi_k(t)dt$$
$$= \sqrt{\frac{T_c}{T_b}}\sum_{k=0}^{N-1} c_k j_k$$

With C_k treated as independent identical random variables with both symbols having equal probabilities

$$P(C_k = 1) = P(C_k = -1) = \frac{1}{2}$$

Expected value of Random variable v_{cj} is zero, for fixed **k** we have

$$E[C_k j_k | j_k] = j_k P(C_k = 1) - j_k P(C_k = -1)$$
$$= \frac{1}{2} j_k - \frac{1}{2} j_k$$
$$= 0$$

and Variance

$$Var[V_{cj}|j] = \frac{1}{N}\sum_{k=0}^{N-1} j_k^2 \quad = \frac{JT_c}{2}$$

Spread factor $N = T_b/T_c$

Output signal to noise ratio is

$$(SNR)_0 = \frac{2E_b}{JT_c}$$

The average signal power at receiver input is E_b/T_b hence input SNR

$$(SNR)_I = \frac{E_b/T_b}{J}$$

$$(SNR)_0 = \frac{2T_b}{T_c}(SNR)_I$$

Expressing SNR in decibels

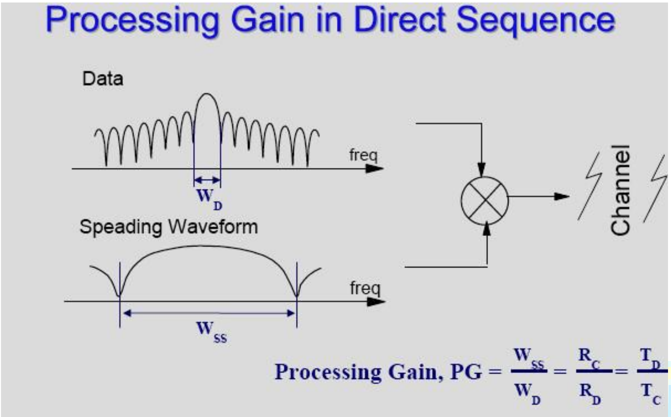
$$10\log_{10}(SNR)_0 = 10\log_{10}(SNR)_I + 3 + 10\log_{10}(PG), dB$$

where $$PG = \frac{T_b}{T_c}$$

3db term on right side accounts for gain in SNR due to coherent detection.

Last term accounts for gain in SNR by use of spread spectrum.

PG is called Processing Gain



Bit rate of binary data entering the transmitter input is

$$R_b = \frac{1}{T_b}$$

The bandwidth of PN sequence c(t) , of main lobe is W_c

$$W_c = \frac{1}{T_c}$$

$$PG = \frac{W_c}{R_b}$$

Probability of error

To calculate probability of error, we consider output component **v** of coherent detector as sample value of random variable **V**

$$V = \pm\sqrt{E_b} + V_{cj}$$

E_b is signal energy per bit and V_{cj} is noise component

Decision rule is, if detector output exceeds a threshold of zero volts; received bit is symbol 1 else decision is favored for zero.

- Average probability of error P_e is nothing but conditional probability which depends on random variable V_{cj}. As a result receiver makes decision in favor of symbol 1 when symbol 0 transmitted and vice versa
- Random variable Vcj is sum of N such random variables. Hence for Large N it can assume Gaussian distribution .
- As mean and variance has already been discussed, zero mean and variance **$JT_c/2$**

Probability of error can be calculated from simple formula for DS/BPSK system

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

Antijam Characteristics

Consider error probability of BPSK

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

Comparing both probabilities;

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

Since bit energy $E_b = PT_b$, P= average signal power.

We can express bit energy to noise density ratio as

$$\frac{E_b}{N_0} = \left(\frac{T_b}{T_c}\right)\left(\frac{P}{J}\right)$$

or

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

The ratio **J/P** is termed jamming margin. Jamming Margin is expressed in decibels as

$$(\text{jamming margin})_{dB} = (\text{Processing gain})_{dB} - 10\log_{10}\left(\frac{Eb}{N_0}\right)_{min}$$

Where E_b/N_0 is minimum bit energy to noise ratio needed to support a prescribed average probability of error.

Example1

A pseudo random sequence is generated using a feedback shift register of length m=4. The chip rate is 10^7 chips per second. Find the following

a) PN sequence length

b) Chip duration of PN sequence

c) PN sequence period

Solution

a) Length of PN sequence $N = 2^m - 1$

$= 2^4 - 1 = 15$

b) Chip duration T_c = 1/chip rate =1/107 = 0.1µsec

c) PN sequence period $T = NT_c$

= 15 x 0.1µsec = 1.5µsec

Example2

A direct sequence spread binary phase shift keying system uses a feedback shift register of length 19 for the generation of PN sequence. Calculate the processing gain of the system.

Solution

Given length of shift register = m = 19
Therefore length of PN sequence $N = 2^m - 1$
$= 2^{19} - 1$

Processing gain $PG = T_b/T_c = N$
in db $= 10\log_{10}N = 10\log_{10}(2^{19})$
$= 57$db

Example3

A Spread spectrum communication system has the following parameters. Information bit duration Tb = 1.024 msecs and PN chip duration of 1µsecs. The average probability of error of system is not to exceed 10-5. calculate a) Length of shift register b) Processing gain c) jamming margin

Solution

Processing gain PG =N= Tb/Tc =1024 corresponding length of shift register m = 10
In case of coherent BPSK For Probability of error 10^{-5}.
[Referring to error function table]
$E_b/N_0 = 10.8$
Therefore jamming margin

$$(\text{jamming margin})_{dB} = (\text{Processing gain})_{dB} - 10\log_{10}\left(\frac{Eb}{N_0}\right)_{min}$$

$$(\text{jamming margin})_{dB} = 10\log_{10}PG_{dB} - 10\log_{10}\left(\frac{Eb}{N_0}\right)_{min}$$

$$= 10\log_{10} 1024 - 10\log_{10} 10.8$$

$$= 30.10 - 10.33$$
$$= 19.8 \text{ db}$$

5.4 FREQUENCY HOP SPREAD SPECTRUM

In a frequency – hop Spread – Spectrum technique, the spectrum of data modulated carrier is widened by changing the carrier frequency in a pseudo – random manner. The type of spread – spectrum in which the carrier hops randomly form one frequency to another is called **Frequency – Hop (FH) Spread Spectrum.** Since frequency hopping does not covers the entire spread spectrum instantaneously. We are led to consider the rate at which the hop occurs. Depending upon this we have two types of frequency hop.

1. Slow frequency hopping:- In which the symbol rate R_s of the MFSK signal is an integer multiple of the hop rate R_h. That is several symbols are transmitted on each frequency hop.

2. Fast – Frequency hopping:- In which the hop rate R_h is an integral multiple of the MFSK symbol rate R_s. That is the carrier frequency will hoop several times during the transmission of one symbol. A common modulation format for frequency hopping system is that of M- ary frequency – shift – keying (MFSK).

<u>Slow frequency hopping:-</u>

Fig.a) Shows the block diagram of an FH / MFSK transmitter, which involves frequency modulation followed by mixing.

The incoming binary data are applied to an M-ary FSK modulator. The resulting modulated wave and the output from a digital frequency synthesizer are then applied to a mixer that consists of a multiplier followed by a band – pass filter. The filter is designed to select the sum frequency component resulting from the multiplication process as the transmitted signal. A 'k' bit segments of a PN sequence drive the frequency synthesizer, which enables the carrier frequency to hop over 2_n distinct values. Since frequency synthesizers are unable to maintain phase coherence over successive hops, most frequency hops spread spectrum communication system use non coherent M-ary modulation system.

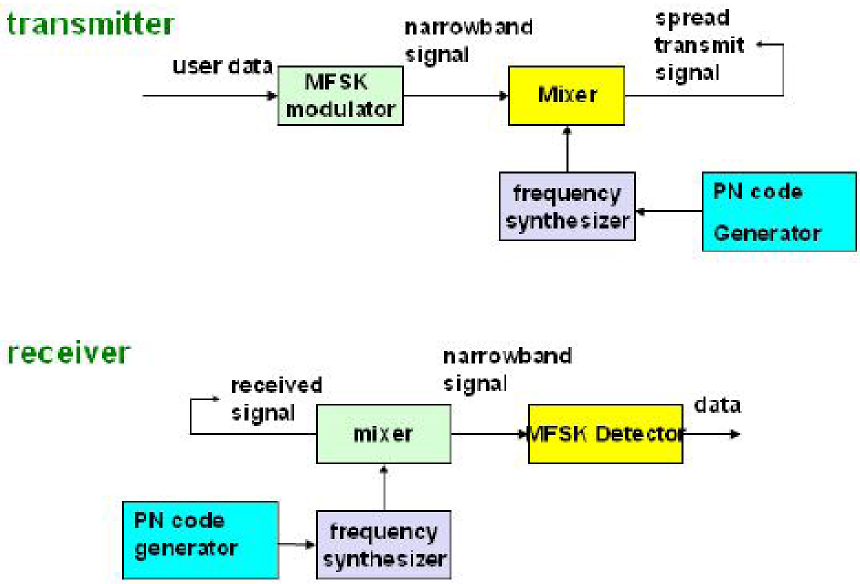


Fig a :- Frequency hop spread M-ary Frequency – shift – keying

In the receiver the frequency hoping is first removed by mixing the received signal with the output of a local frequency synthesizer that is synchronized with the transmitter. The resulting output is then band pass filtered and subsequently processed by a non-coherent M ary FSK demodulator. To implement this M-ary detector, a bank of M non coherent matched filters, each of which is matched to one of the MFSK tones is used. By selecting the largest filtered output, the original transmitted signal is estimated. An individual FH / MFSK tone of shortest duration is referred as a chip. The chip rate R_c for an FH / MFSK system is defined by $R_c = Max(R_h, R_s)$

Where R_h is the hop rate and R_s is Symbol Rate.

In a slow rate, frequency hopping multiple symbols are transmitted per hop. Hence each symbol of a slow FH / MFSK signal is a chip. The bit rate R_b of the incoming binary data. The symbol rate R_s of the MFSK signal, the chip rate R_c and the hop rate R_n are related by

$R_c = R_s = R_b / k \geq R_h$

where $k = \log_2 M$

Fast frequency hopping:-

A fast FH / MFSK system differs from a slow FH / MFSK system in that there are multiple hops per m-ary symbol. Hence in a fast FH / MFSK system each hop is a chip.

Fast Frequency Hopping	Slow Frequency Hopping
Several frequency hops Per modulation	Several modulation symbols per hop
Shortest uninterrupted waveform in the system is that of hop	Shortest uninterrupted waveform in the system is that of data symbol
Chip duration =hop duration	Chip duration=bit duration.

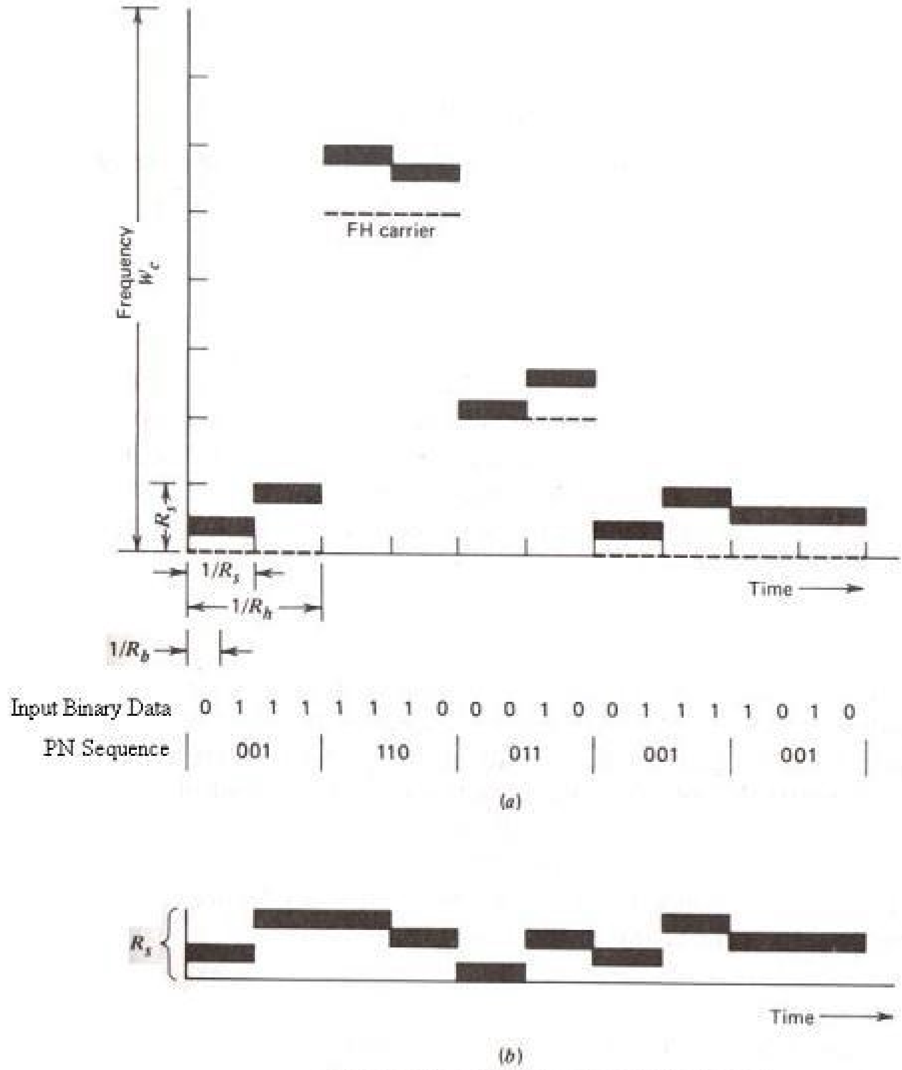
Fig. illustrates the variation of the frequency of a slow FH/MFSK signal with time for one complete period of the PN sequence. The period of the PN sequence is $2^4-1 = 15$. The FH/MFSK signal has the following parameters:

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 $2^k = 8$



Illustrating slow-frequency hopping.

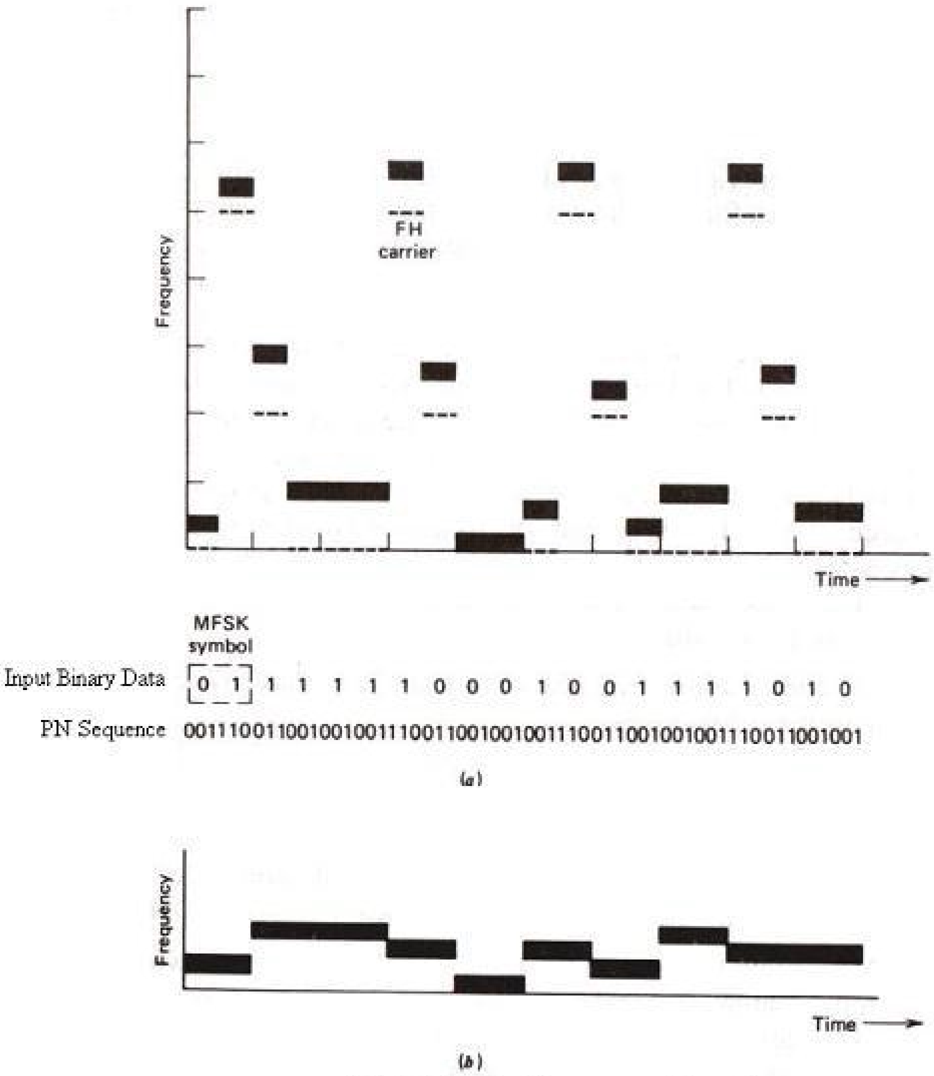
Fig. illustrates the variation of the transmitted frequency of a fast FH/MFSK signal with time. The signal has the following parameters:

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 $2^k = 8$



Illustrating fast-frequency hopping.

DP9.9. A PN sequence is generated using 4-stage linear feedback shift register as shown in Figure DP9.9(a), with initial conditon $(C_3C_2C_1C_0) = (1000)$. This sequence is used in a slow FH/MFSK system. The FH/MFSK signal has the following parameters.

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 $2^k = 8$

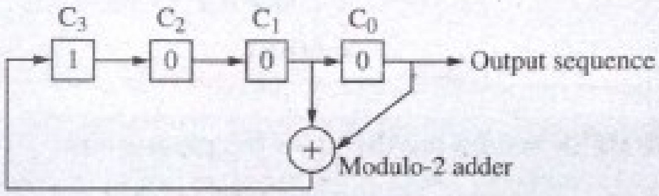


Figure DP9.9(a)

Determine the following:

a) Period of the PN sequence.
b) PN sequence for one periodic length.
c) Illustrate the variation of the frequency of FH/MFSK signal for one complete period of the PN sequence. Assume that the carrier hops to a new frequency after transmitting two MFSK symbols or four information bits. Assume binary data sequence to be 100011010001111111001.
d) Sketch the variation of dehopped frequency with time.

Solution:

a) The period of the PN sequence is $2^4 - 1 = 15$.
b) For the initial condition shown, the PN sequence is obtained by writing all the successive states of the shift register (SR), for one period. Table DP9.2 gives the successive states, the fed back bit and the output bit.
ii) The PN sequence of one periodic length is 000100110101111. The carrier is hopped to a new frequency after transmitting two MFSK symbols or four information bits. Number of bits per MFSK symbol $K = 2$. There are hence four MFSK frequencies corresponding to dibits 00, 01, 10 and 11. Length of PN segment per hop $k = 3$.

Table DP9.2

States of SR				Fed back bit	Output bit
C_3	C_2	C_1	C_0	$C_3 = C_1 \oplus C_0$	C_0
1	0	0	0	0	0
0	1	0	0	0	0
0	0	1	0	1	0
1	0	0	1	1	1
1	1	0	0	0	0
0	1	1	0	1	0
1	0	1	1	0	1
0	1	0	1	1	1
1	0	1	0	1	0
1	1	0	1	1	1
1	1	1	0	1	0
1	1	1	1	0	1
0	1	1	1	0	1
0	0	1	1	0	1
0	0	0	1	1	1
1	0	0	0	Repeats	Repeats

Hence, there are $2^3 = 8$ hopping frequencies corresponding to each block of 3 PN sequence bits.

Let the hopping carrier frequencies corresponding to each block of 3 bits be selected as shown in Table DP9.3.

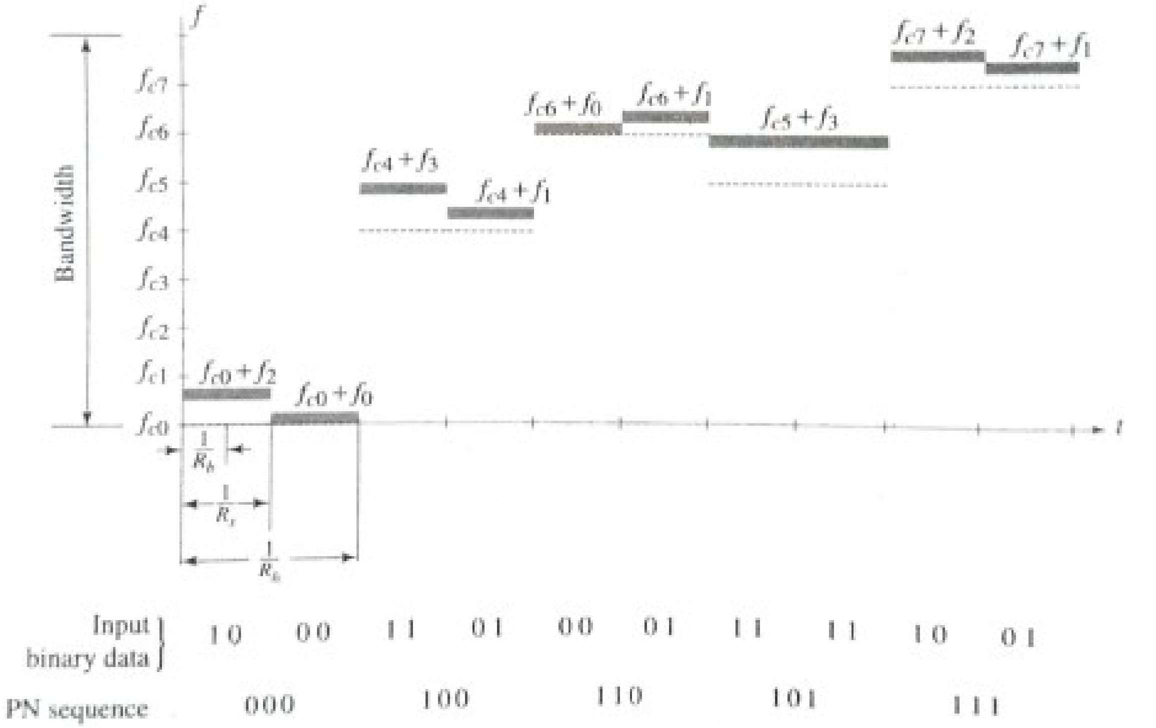
Table DP9.3

PN sequence segment	Hopping carrier frequency in Hz
000	f_{c0}
001	f_{c1}
010	f_{c2}
011	f_{c3}
100	f_{c4}
101	f_{c5}
110	f_{c6}
111	f_{c7}

The 4, MFSK tones be as shown in Table DP9.4.

Table DP9.4

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



Transmitted frequencies versus time for the given binary data and PN sequence.

Figure DP9.9(c) Dehopped frequencies.

DP9.10. In a fast FH/MFSK system, the signal has the following parameters:
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, $2^3 = 8$
Number of hops per MFSK symbol = 2
Period of PN sequence: $L = 15$.

i) Determine the relation between bit rate and chip rate.
ii) Sketch the variation of frequency of the transmitted signal with time. Assume binary data sequence to be 01101100 and one period of PN sequence is 111100010011010.
iii) Sketch the dehopped MFSK signal.

Solution:

i) In a fast FH/MFSK, there are multiple hops per MFSK symbol. Hence in a fast FH/MFSK system, each hop is a chip. In this example there are 2 bits/MFSK symbol and 2 hops/MFSK symbol. Hence bit rate R_b = hop rate R_h = chip rate R_c.

ii) Let the MFSK tones be denoted by f_0, f_1, f_2 and f_3 corresponding to MFSK symbols 00, 01, 10, 11, respectively.

Let the hopping carrier frequencies be denoted by: $f_{c0}, f_{c1}, f_{c2}, f_{c3}, f_{c4}, f_{c5}, f_{c6}$ and f_{c7} which correspond to the PN sequence segments 000, 001, 010, 011, 100, 101, 110, and 111, respectively.

During a hopping interval, if carrier frequency is f_{cj} and MFSK tone is f_i, then the transmitted frequency is $f_{cj} + f_i$.

The transmitted frequency and dehopped MFSK signal are shown in Figure DP9.10(a) and (b) respectively.

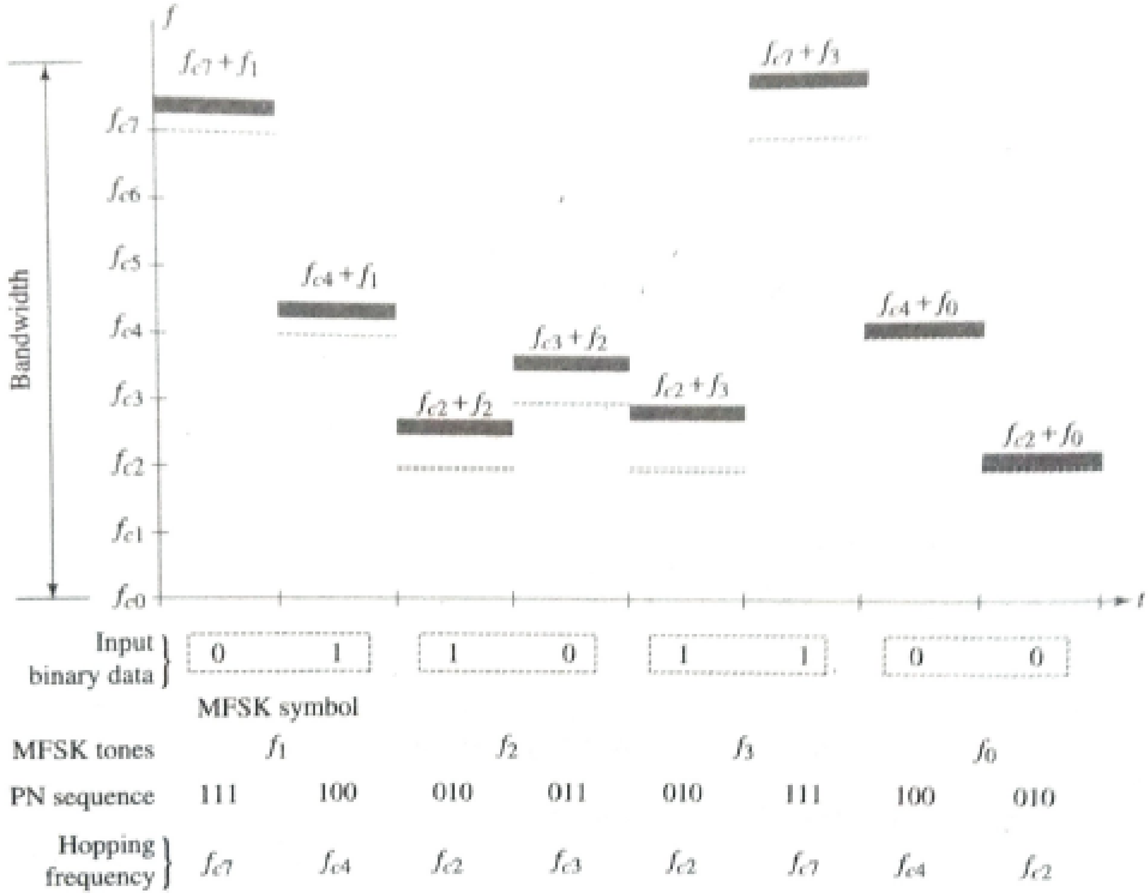


Figure DP9.10(a)

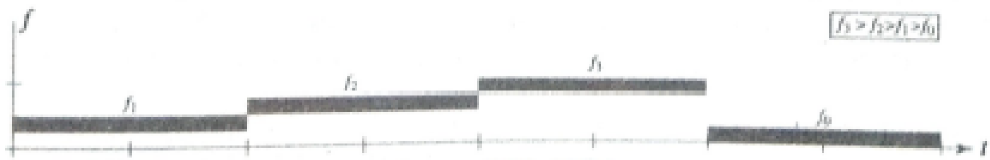


Figure DP9.10(b)

Comparsion Between Slow Frequency Hopping and Fast Frequency Hopping

Sl. No	Parameter	Slow frequency Hopping	Fast frequency Hopping
1	*Definition*	Multiple Symbols are transmitted in one hop.	Multiple hops are taken to transmit one symbol
2	*Chip Rate*	Symbol rate = chip rate	Hop rate = Chip Rate
3	R_h *and* R_s	$R_h < R_s$	$R_h > R_s$
4	*Carrier Frequencies*	One or more symbols are transmitted over same carrier frequency	One symbol is transmitter over multiple carriers in different hops.
5	*Jammer Interference*	This signal can be detected by jammer if carrier frequency in one hop is known	This signal is difficult to detect since one symbol is transmitted on multiple carrier frequencies.

FHSS	DSSS / CDMA
Multiple frequencies are used	Single frequency is used
Hard to find the user's frequency at any instant of time	User frequency, once allotted is always the same
Frequency reuse is allowed	Frequency reuse is not allowed
Sender need not wait	Sender has to wait if the spectrum is busy
Power strength of the signal is high	Power strength of the signal is low
Stronger and penetrates through the obstacles	It is weaker compared to FHSS
It is never affected by interference	It can be affected by interference
It is cheaper	It is expensive
This is the commonly used technique	This technique is not frequently used

Comprasion Between Direct Sequence Spread Spectrum and Fast Hopping Spread Spectrum

Sl. No	Parameter	DS - SS	FH -SS
1	*Definition*	PN Sequence of large Bandwidth is multiplied with Narrowband data signal	Data bits are transmitted in different frequency slots which are changed by PN Sequence.
2	*Spectrum of Signal*	Data Sequence is spread over entire B.W of spread spectrum signal	Data Sequence is spread over small frequency slots of spread spectrum signal
3	*Chip rate*	$R_c = 1/T_c$	$R_c = \max(R_h, R_s)$
4	*modulator*	BPSK	M-ary FSK
5	*Effect Of Distance*	System is distance relative	Less distance effect
6	*Acquisition time*	Long	Short

5.5 APPLICATIONS

Probably the single most important application of spread-spectrum techniques is that of protection against jammers. Two types of applications of spread-spectrum techniques, namely, code-division multiple access, and multipath suppression.

- **Code Division Multiple Access**

The two most common multiple access techniques for satellite communications are frequency-division multiple access (FDMA) and time-division multiple access (TDMA). In FDMA, all users access the satellite channel by transmitting simultaneously but using dis Joint frequency bands. In TDMA, all users occupy the same RF bandwidth of the satellite channel, but they transmit sequentially in time. When, however, all users are permitted to transmit simultaneously and also occupy the same RF bandwidth of the satellite channel, and then some other method must be provided for separating the individual signals at the receiver. Code-division multiple access (CDMA) is the method that makes it possible to perform this separation. To accomplish CDMA, spread spectrum is always used.

In particular, each user is assigned a code of its own, which performs the direct-sequence or frequency-hop spread-spectrum modulation. The design of the codes has to cater for two provisions:

1. Each code is approximately orthogonal (i.e., has low cross-correlation) with all the other codes.
2. The CDMA system operates asynchronously, which means that the transition times of a user's data symbols do not have to coincide with those of the other users.

The second requirement complicates the design of good codes for CDMA.

The use of CDMA offers- three attractive features over TDMA:

1. CDMA does not require an external synchronization network, which is an essential feature of TDMA.
2. CDMA offers a gradual degradation in performance as the number of users is increased. It is therefore relatively easy to add new users to the system.
3. CDMA offers an external interference rejection capability (e.g., multipath rejection or resistance to deliberate jamming).

- **Multipath Suppression**

In many radio channels, the transmitted signal reaches the receiver input via more than one path. For example, in a mobile communication environment, the transmitted signal is reflected of a variety of scatterers such as buildings, trees, and moving vehicles. Thus, in addition to the direct path from the transmitter to the receiver, there are several other indirect paths (arising from the presence of the scatterers) that contribute to the composition of the received signal.

Naturally, the contributions from these indirect paths exhibit different signal attenuations and time delays relative to that from the direct path. Indeed, they may interfere with the contribution from the direct path either constructively or destructively at the receiver input. The interference caused by these paths is called multipath interference or simply multipath. The variation in received signal amplitude due to this interference is called fading, as the al amplitude tends to fade away when destructive interference occurs between the contributions from the direct and indirect paths. The description of multi path fading is also complicated by whether the mobile receiving unit and nearby scatterers are all standing still, whether the mobile receiving unit is standing still but some of the scatterers are moving, or whether the mobile receiving unit is moving as well as some (or all) of the scatterers.

In a slow-fading channel, we may combat the effects of multipath by applying spread spectrum. Specifically, in a direct-sequence spread-spectrum system, we find that if the reflected signals at the receiver input are delayed (compared with the direct-path signal) by more than one chip duration of the PN code, then the reflected signals are treated by the matched filter or correlator of the receiver in the same way as any other uncorrelated input signal. Indeed, the higher the chip rate of the PN code, the smaller will the degradation due to multipath be.

In a frequency-hop spread-spectrum system, improvement in system performance in the presence of multipath is again possible, but through a mechanism different from that in a direct-sequence spread-spectrum system. In particular, the effect of multipath is diminished, provided that the carrier frequency of the transmitted signal hops fast enough relative to the differential time delay between the desired signal from the direct path and the undesired signals from the indirect paths. Under this condition, all (or most) of the multipath energy will (on the average) fall in frequency slots that are orthogonal to the slot occupied currently by the desired signal, and degradation due to multipath is thereby minimized.