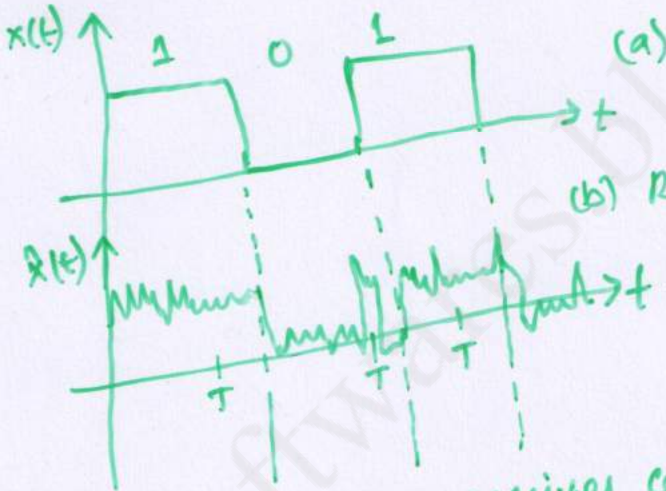
Baseband Transmission and Optimal Reception of Digital Signal. ⓪

→ In baseband transmission, the data is transmitted without modulation.

→ During the transmission of data over the channel, it is corrupted by noise.

→ Hence at the receiver, the noisy signal is received. Therefore correct detection of the transmitted signal is difficult.



(a) Signal transmitted at the T_x

(b) Received noisy signal at the R_x

Effect of noise at the receiver can make wrong decision.

→ The received signal $\hat{x}(t)$ is a noisy signal at the receiver.

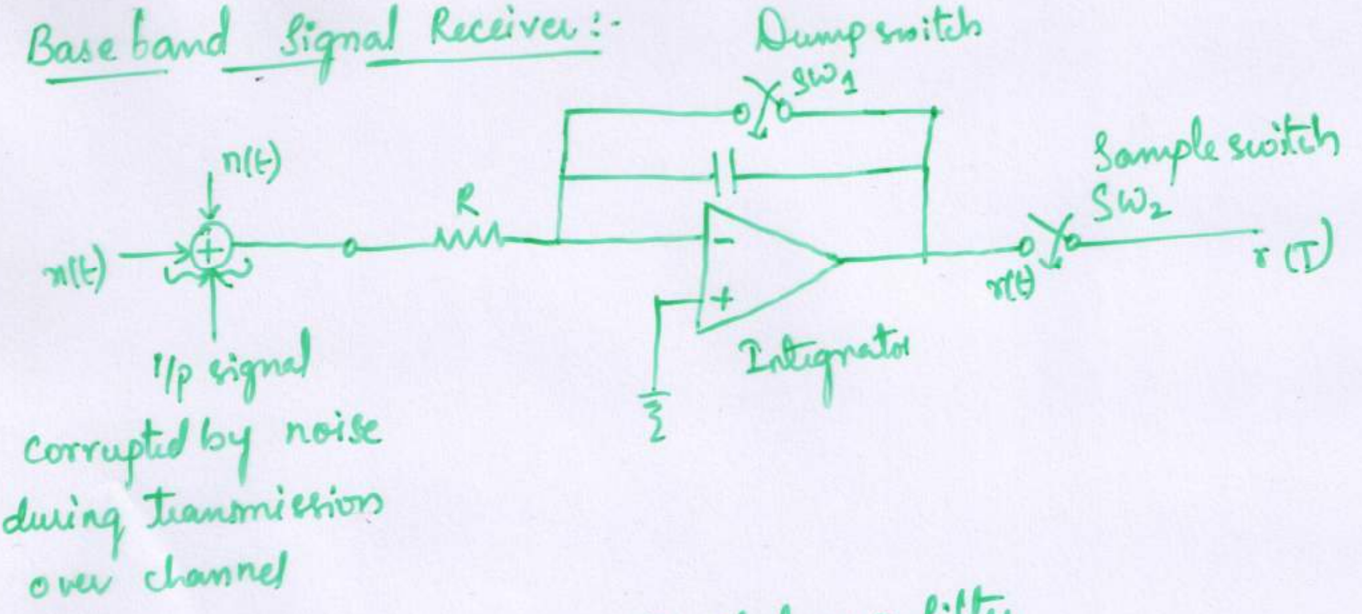
→ Let us consider that the detector checks $\hat{x}(t)$ at 'T' during every bit interval.

→ From the above figure, the decision in first interval will be correct i.e symbol '1'.

→ But in second interval, the decision will be '1' but it is wrong. At the time when detector checks $\hat{x}(t)$ [i.e at $t = T$], noise pulse is detected and decision is taken in favour of '1'. But actual symbol '0' is transmitted.

→ Thus errors are introduced because of noise.

Baseband Signal Receiver:-



Integrate & dump filter

→ It is a basic detector for the detection of digital signals.

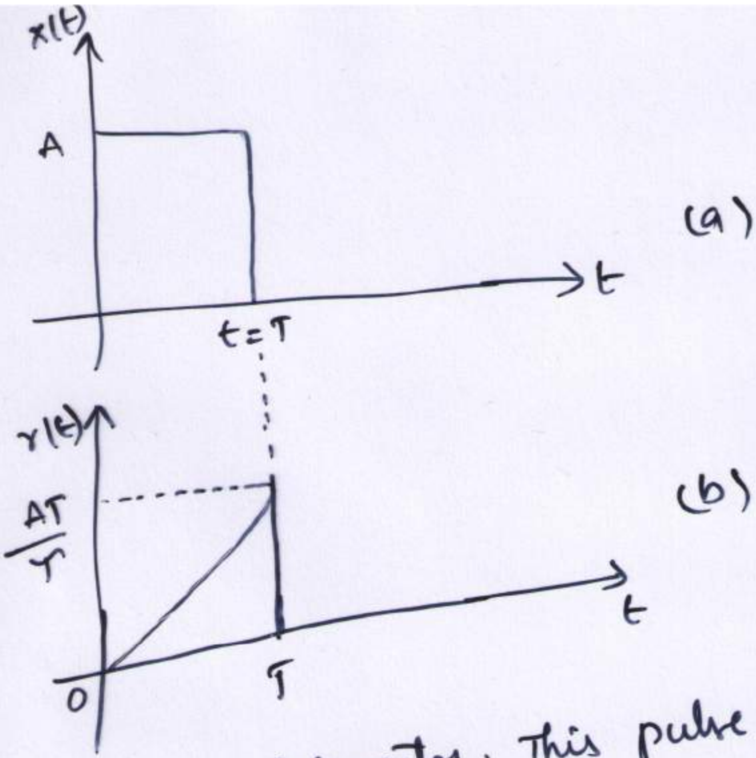
→ The digital signal x(t) is corrupted by white noise n(t) during transmission over the channel.

→ Such noisy signal {x(t) + n(t)} is given to the input of Integrate and dump filter.

→ The capacitor is discharged fully at the beginning of the bit interval. This is achieved by temporarily closing the switch SW_1 at the beginning of the bit interval.

→ The integrator then integrates noisy input signal over one bit period. This integrated signal is shown as r(t) in the figure below.

→ For the square pulse input, the output of the integrator will be a triangular pulse.



(a) Input pulse to the integrator. This pulse represents binary '1'. The width of pulse is 'T'.

(b) O/P of integrator. The initial O/P is zero. At $t=T$, O/P of integrator is $r(t) = AT$.

→ At the end of bit period i.e $t=T$, the value of $r(t)$ reaches to its maximum amplitude. Therefore the value of $r(t)$ is sampled at the end of bit period.

→ Depending upon the value of $r(T)$, the decision is taken. The dump switch SW1 is then closed momentarily to discharge the capacitor to receive next bit.

→ Thus Integrator integrates independent of the value of previous bit. This shows that the detection in integrate and dump filter is unaffected by values of previous bits.

→ the o/p of integrator will decrease after $t > T$.

Signal to Noise Ratio of the integrator & Dumpfilter

→ O/P of integrator can be

$$r(t) = \frac{1}{RC}\int_0^T [x(t) + n(t)]\,dt.$$

→ Here the integration is performed over one bit period i.e from 0 to T.

→ the above equation is written as.

$$r(t) = \frac{1}{RC}\int_0^T x(t)\,dt + \frac{1}{RC}\int_0^T n(t)\,dt$$

$$= x_0(t) + n_0(t)$$

→ Here $x_0(t)$ is the o/p signal voltage & $n_0(t)$ is the o/p noise.

→ consider o/p signal voltage, $x_0(t) = \frac{1}{RC}\int_0^T x(t)\,dt.$

→ Since the value of $x(t) = A$ from 0 to T, the above equation is written as,

$$x_0(t) = \frac{1}{RC}\int_0^T A\,dt = \frac{A}{RC}\int_0^T 1.dt$$

$$= \frac{A}{RC}\left[t\right]_0^T = \frac{AT}{RC}.$$

→ Let the time constant $RC = \tau$. Then above equation becomes,

$$x_0(t) = \frac{AT}{\tau}$$

→ Normalized signal power in standard 1Ω resistance will be,

$$\text{o/p signal power} = \frac{x_0^2(t)}{1\Omega} = \frac{A^2T^2}{\tau^2}$$

Calculation of Noise power:

→ A network which performs integration operation has the transfer function of $\frac{1}{j\omega RC}$

→ A delay of $t = T$ in time domain is equivalent to $e^{-j\omega t}$ in frequency domain.

→ Thus the network performing integration over the period of T can be represented by the following transfer function.

$$H(f) = \frac{1 - e^{-j\omega T}}{j\omega RC}$$

Since $\omega = 2\pi f$ & $RC = \tau$ then,

$$H(f) = \frac{1 - e^{j2\pi f T}}{j2\pi f \tau}$$

$$= \frac{1 - \left[\cos(2\pi f T) - j\sin(2\pi f T)\right]}{j2\pi f \tau}$$

By rearranging above equation,

$$H(f) = \frac{\sin(2\pi fT)}{2\pi f T} - j\,\frac{1-\cos(2\pi fT)}{2\pi f T}$$

→ The magnitude of this transfer function will be,

$$|H(f)|^2 = \frac{\sin^2(2\pi fT) + 1 - 2\cos(2\pi fT) + \cos^2(2\pi fT)}{(2\pi f T)^2}$$

→ $\therefore \quad |H(f)|^2 = \frac{\sin^2(\pi f T)}{(\pi f T)^2}$ — (1)

→ The average power of o/p noise signal $n_0(t)$ is obtained by Integrating its power density spectrum i.e,

$$\text{Power}, P = \int_{-\infty}^{\infty} S(f)\,df \quad \text{By definition}$$

→ In standard 1Ω resistance, the noise power will be

$$\frac{\overline{n_0^2(t)}}{1\Omega} = \overline{n_0^2(t)}$$

→ Here ~~mean~~ mean square value of noise is taken since it is random signal i.e,

$$\text{Noise power}, \overline{n_0^2(t)} = \int_{-\infty}^{\infty} S_{no}(f)\,df \longrightarrow (2)$$

→ The i/p & o/p power spectral densities are related as,

$$S_{no}(f) = |H(f)|^2 S_{ni}(f) \longrightarrow (3)$$

→ Here $H(f)$ is transfer function of filter,

$S_{no}(f)$ is psd of o/p noise

$S_{ni}(f)$ " " " i/p "

→ The power spectral density of white noise (i/p noise) is $S_{ni}(f) = \frac{N_0}{2}$ —— (4)

→ Put this value in above eqn (3)

$$S_{no}(f) = |H(f)|^2 \cdot \frac{N_0}{2}$$

→ Put this value in Eqn (2) we get

$$\overline{n_0^2(t)} = \int_{-\infty}^{\infty} |H(f)|^2 \cdot \frac{N_0}{2}\, df$$

→ Put eqn (1) in above eqn.

$$\overline{n_0^2(t)} = \int_{-\infty}^{\infty} \frac{\sin^2(\pi f T)}{(\pi f \tau)^2} \cdot \frac{N_0}{2}\, df$$

$$= \frac{N_0}{2} \int_{-\infty}^{\infty} \frac{\sin^2(\pi f T)}{(\pi f \tau)^2}\, df. \quad \text{—— (5)}$$

→ Put $\pi f \tau = x$

$\therefore\ dx = \pi \tau\, df$. (or) $df = \frac{1}{\pi \tau} dx$.

Here $f = \frac{x}{\pi \tau}$

$\pi f T = \frac{x T}{\tau}$

→ With these substitutions in Eqn (5) becomes,

$$\overline{n_0^2(t)} = \frac{N_0}{2}\int_{-\infty}^{\infty} \frac{\sin^2\left(\frac{xT}{\gamma}\right)}{x^2} \cdot \frac{1}{\pi\gamma}\, dx.$$

→ ~~Reassing~~ Rearranging the above Eqn.

$$\overline{n_0^2(t)} = \frac{N_0}{2}\int_{-\infty}^{\infty} \frac{\sin^2\left(\frac{xT}{\gamma}\right)}{\left(\frac{xT}{\gamma}\right)^2} \cdot \left(\frac{T}{\gamma}\right)^2 \cdot \frac{1}{\pi\gamma}\, dx.$$

$$= \frac{N_0}{2} \cdot \frac{T^2}{\pi\gamma^3}\int_{-\infty}^{\infty} \frac{\sin^2\left(\frac{xT}{\gamma}\right)}{\left(\frac{xT}{\gamma}\right)^2} \cdot dx$$

→ Let $\frac{xT}{\gamma} = u \Rightarrow dx = \frac{\gamma}{T}\, du.$

→ Now above Eqn becomes,

$$\overline{n_0^2(t)} = \frac{N_0}{2} \cdot \frac{T^2}{\pi\gamma^3}\int_{-\infty}^{\infty} \frac{\sin^2 u}{u^2} \cdot \frac{\gamma}{T}\, du.$$

$$= \frac{N_0 T}{2\pi\gamma^2}\int_{-\infty}^{\infty}\left(\frac{\sin u}{u}\right)^2 du.$$

→ Since the function $\frac{\sin u}{u}$ is squared, above eqn is written as,

$$\overline{n_0^2(t)} = \frac{N_0 T}{2\pi\gamma^2} \cdot 2\int_{0}^{\infty}\left(\frac{\sin u}{u}\right)^2 du$$

$$= \frac{N_0 T}{2\pi\gamma^2} \cdot 2 \cdot \frac{\pi}{2}$$

$$\boxed{\overline{n_0^2(t)} = \frac{N_0 T}{2\gamma^2}} \longrightarrow (6)$$

Calculation of Signal to noise ratio:-

Signal to noise ratio, $\rho = \frac{\text{Signal power}}{\text{Noise power}}$

$$\rho = \frac{A^2T^2/\gamma^2}{N_0T/2\gamma^2}$$

$$\rho = \frac{2A^2T}{N_0} \text{ (or) } \frac{A^2T}{N_0/2}$$

→ Signal to Noise ratio of Integrate & Dump receiver

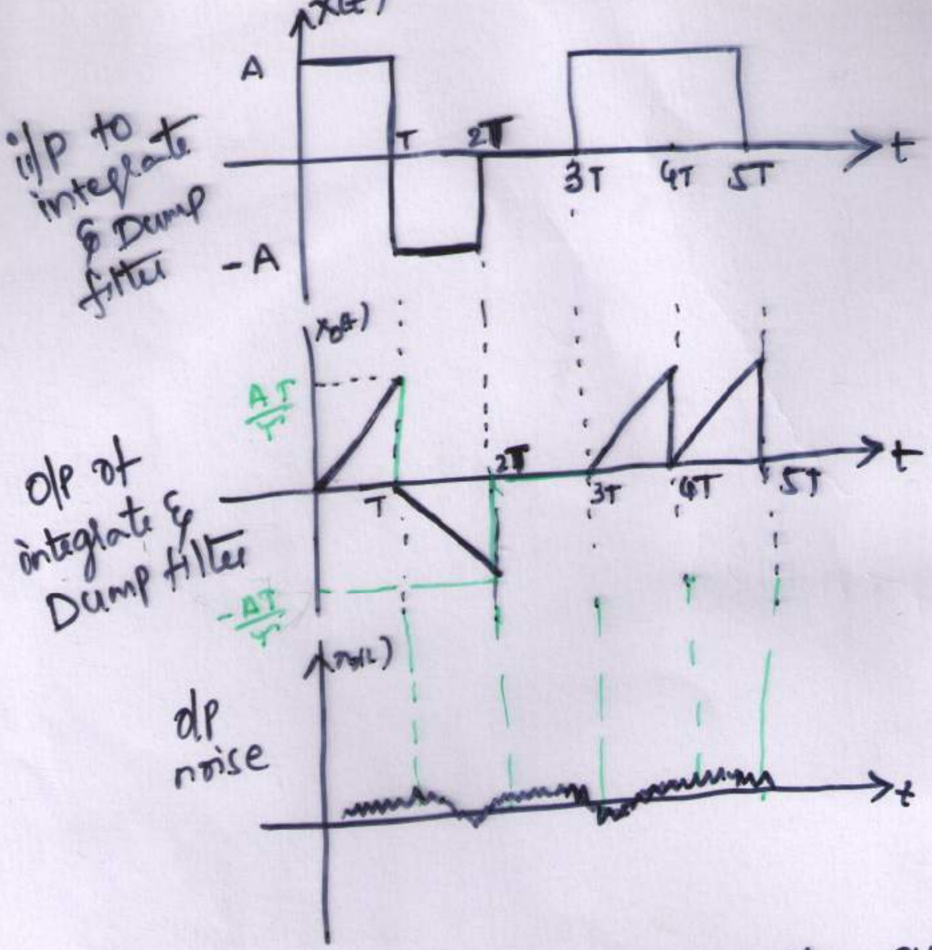
$$\boxed{\rho = \frac{A^2T}{N_0/2}}$$

→ This signal to noise ratio is called figure of Merit.

Comments:

→ Signal to noise ratio improves in proportion to Sampling period 'T'. It also increases as signal amplitude 'A' is more.

→ Since, noise has gaussian distribution and zero mean value at any time, the O/p of integrator also increases by very small amount at the end of bit Interval.



It is observed that the output signal voltage reaches to the value of $\pm \frac{AT}{\tau}$ at the sampling instant. This is the maximum signal voltage. But the noise voltage $n_o(t)$ doesnot increase in same proportion. This is due to the fact that the noise has zero average value and Gaussian distribution.

Optimum Receiver:-

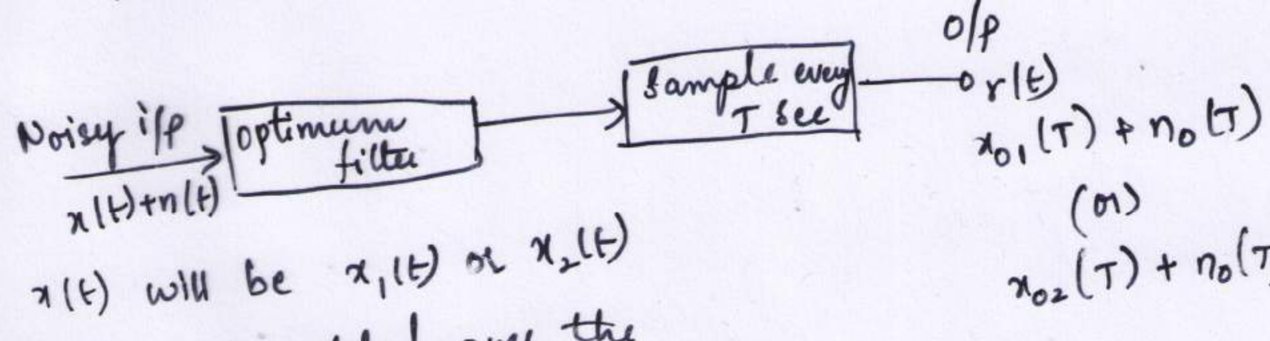
Definition:- A generalized filter for receiving binary coded signals is called optimum filter.

Decision boundary:-

- Assume that the received signal is a binary waveform
- Let the polar NRZ signal is used to represent binary 1s & 0s. i.e, for binary '1' ; $x_1(t) = +A$ for one bit period T.

& for binary '0' ; $x_2(t) = -A$; for one bit period 'T'.

- Thus the i/p signal $x(t)$ will be either $x_1(t)$ or $x_2(t)$ depending upon the polarity of NRZ signal.



$x(t)$ will be $x_1(t)$ or $x_2(t)$

Noise $n(t)$ added over the channel has psd of $S_{ni}(f)$

A receiver for binary coded signal

→ Input to the receiver $= x(t) + n(t)$

→ o/p from the receiver $= x_{01}(T) + n_0(T)$ (or) $x_{02}(T) + n_0(T)$

→ In the absence of noise $n(t)$, o/p of receiver will be,

$$r(T) = x_{01}(T) \quad \text{if} \quad x(t) = x_1(t)$$

$$r(T) = x_{02}(T) \quad \text{if} \quad x(t) = x_2(t)$$

→ In the absence of noise, decisions are taken clearly.

→ If noise is present then, select $x_1(t)$ if $r(T)$ is closer to $x_{01}(T)$ than $x_{02}(T)$ and select $x_2(t)$ if $r(T)$ is closer to $x_{02}(T)$ than $x_{01}(T)$. Therefore the decision boundary will be midway between $x_{01}(T)$ and $x_{02}(T)$.

→ It is given as,

$$\text{Decision boundary} = \frac{x_{01}(T) + x_{02}(T)}{2}$$

Matched filter:-

→ when the noise is white gaussian noise, then the optimum filter is called matched filter.

→ for the white gaussian noise the power spectral density is given as, $S_{ni}(f) = \frac{N_0}{2}$

Impulse Response of Matched filter:

→ The transfer function of optimum filter is given by

$$H(f) = K \cdot \frac{X^*(f)}{S_{ni}(f)} \cdot e^{-j2\pi ft}$$

→ In the above equation if we put $S_{ni}(f) = \frac{N_0}{2}$ i.e psd of white noise, then $H(f)$ will become transfer function of matched filter i.e.,

Transfer function of matched filter, $H(f) = K \cdot \frac{X^*(f)}{N_0/2} e^{-j2\pi ft}$

i.e $$\boxed{H(f) = \frac{2k}{N_0} X^*(f) \cdot e^{-j2\pi fT}}$$

→ By property of fourier transform we know,

$$X^*(f) = X(-f)$$

→ with this property we write,

$$H(f) = \frac{2k}{N_0} X(-f) e^{-j2\pi fT}$$

→ The impulse response of a matched filter is obtained by taking inverse fourier transform of above equation

$$h(t) = IFT\{H(f)\}$$

$$= IFT\left\{\frac{2k}{N_0} X(-f) \cdot e^{-j2\pi fT}\right\}$$

→ The inverse fourier transform of $X(-f)$ is $x(-t)$ and $e^{-j2\pi fT}$ represents time shift of T seconds.

i.e $FT\{x(-t)\} = X(-f)$

and $FT\{x(T-t)\} = X(-f) \cdot e^{-j2\pi fT}$

→ Here FT means fourier transform.

→ ∴ we can write $h(t) = \frac{2k}{N_0} x(T-t)$.

→ Since we have considered $x(t) = x_1(t) - x_2(t)$ the above equation will be,

→ Impulse response of matched filter : $h(t) = \frac{2k}{N_0}\{x_1(T-t) - x_2(T-t)\}$

UNIT – V

Spread Spectrum Modulation

Spread Spectrum

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - Spreading code or spreading sequence
  - Generated by pseudo noise, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted.
- On receiving end, digit sequence is used to demodulate the spread spectrum signal.
- Signal is fed into a channel decoder to recover data.

Spread Spectrum

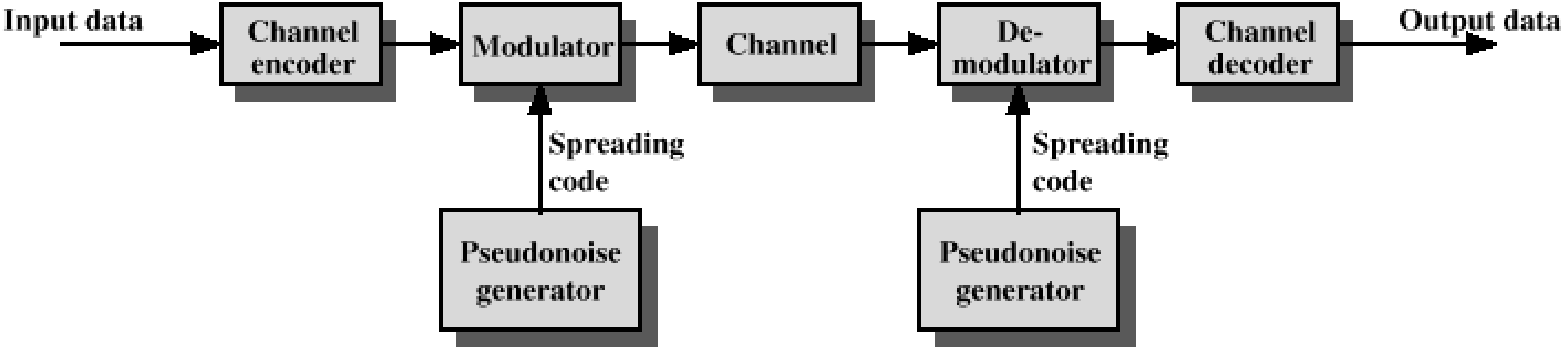


Figure 7.1 General Model of Spread Spectrum Digital Communication System

PN (Pseudo Noise or Pseudo Random)Sequences

- PN generator produces periodic sequence that appears to be random.
- Shift register consists of '*m*' flip-flops(FF), data from one FF shifts to next whenever clock pulse is applied.
- The PN sequence is generated at the output of last FF.

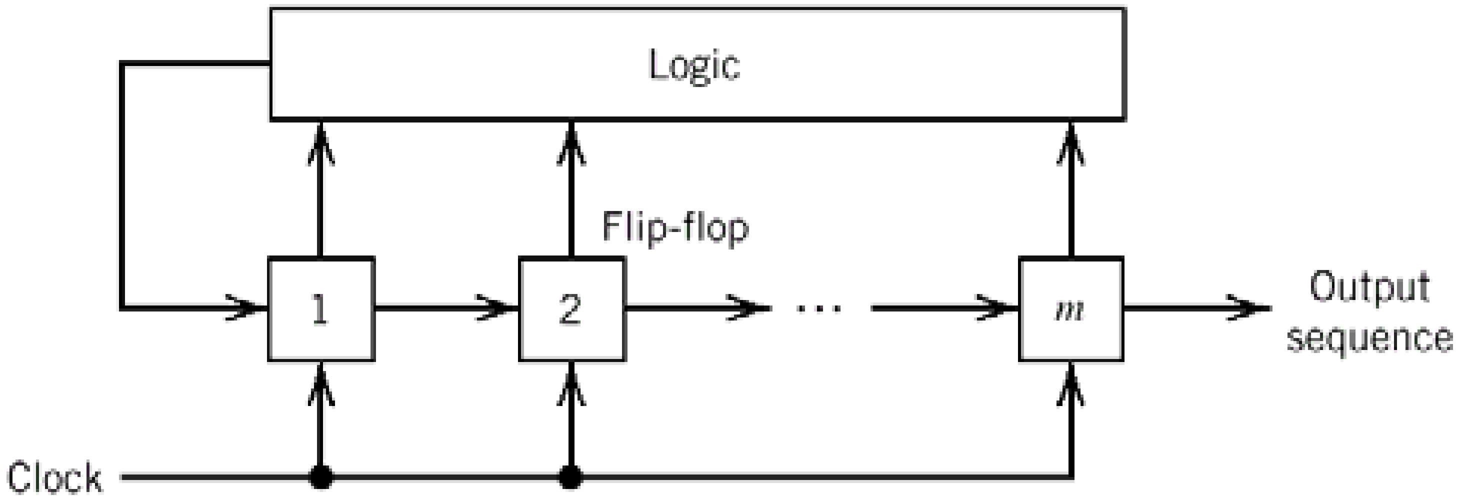
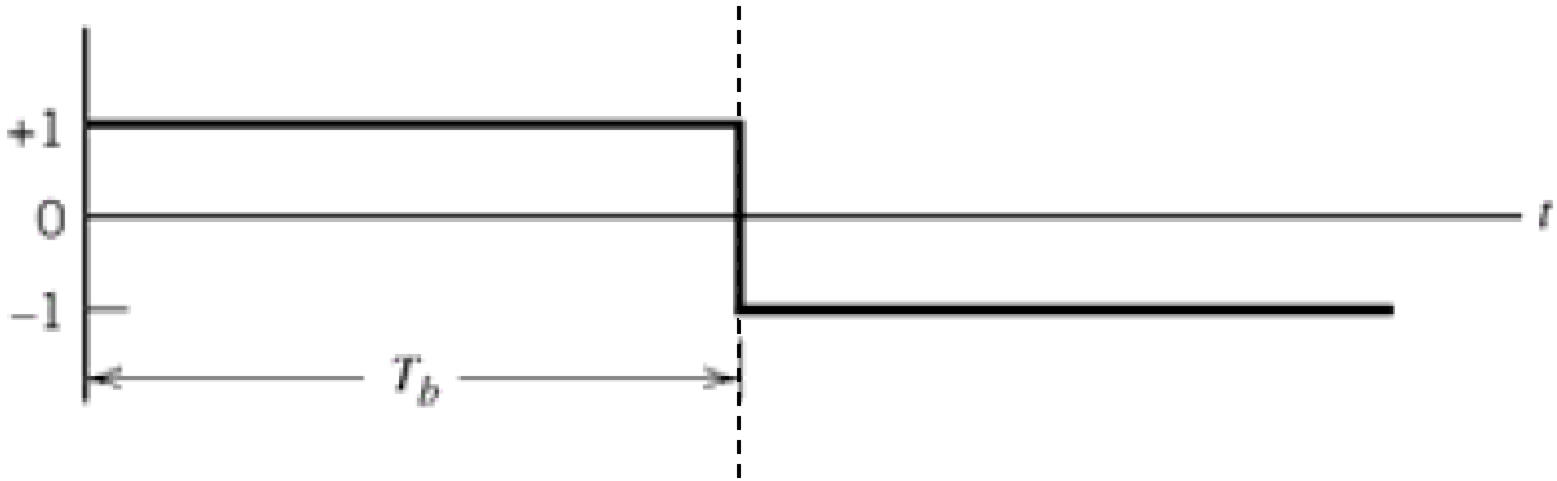


Figure: Feedback shift register to generate pseudo-noise sequences

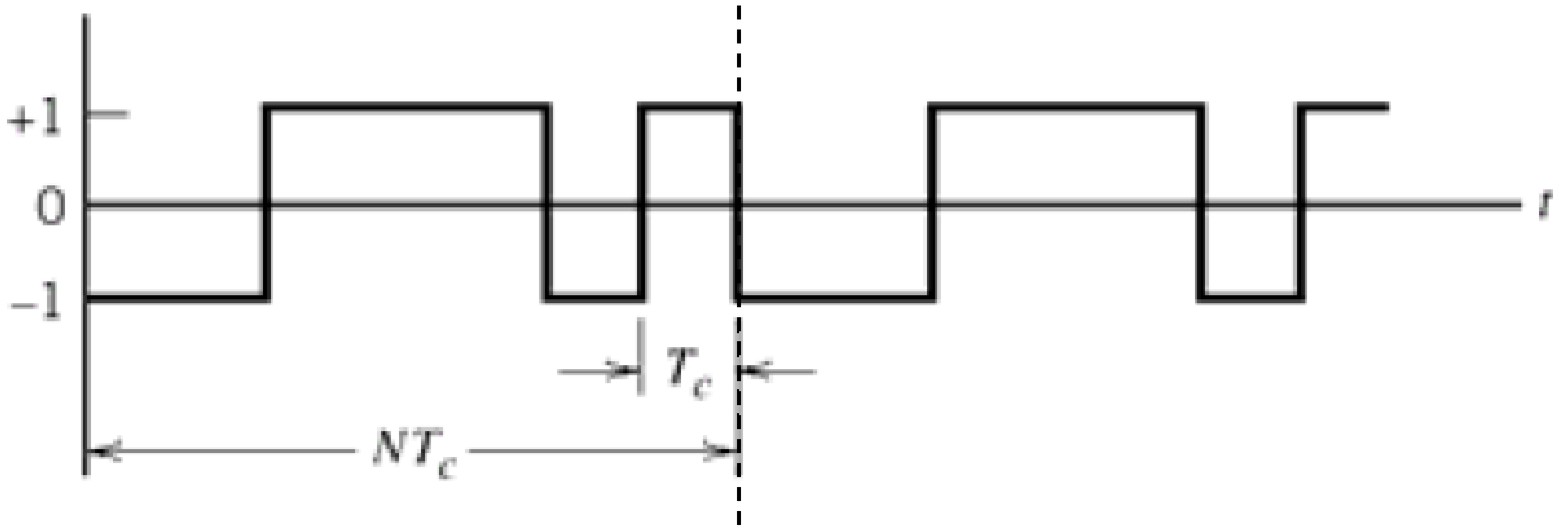
- Length (N)of PN sequence is 2^m-1, where *m* is the number of flip-flops.

$$N = 2^m - 1$$

- PN sequence is also known as maximum length sequence.
- Duration of each bit in PN sequence is known as chip (T_c).
- Period of PN sequence, $T_b = NT_c$
- R_c is the chip rate (chips per second), $R_c = 1/T_c$



(a) Data signal $b(t)$

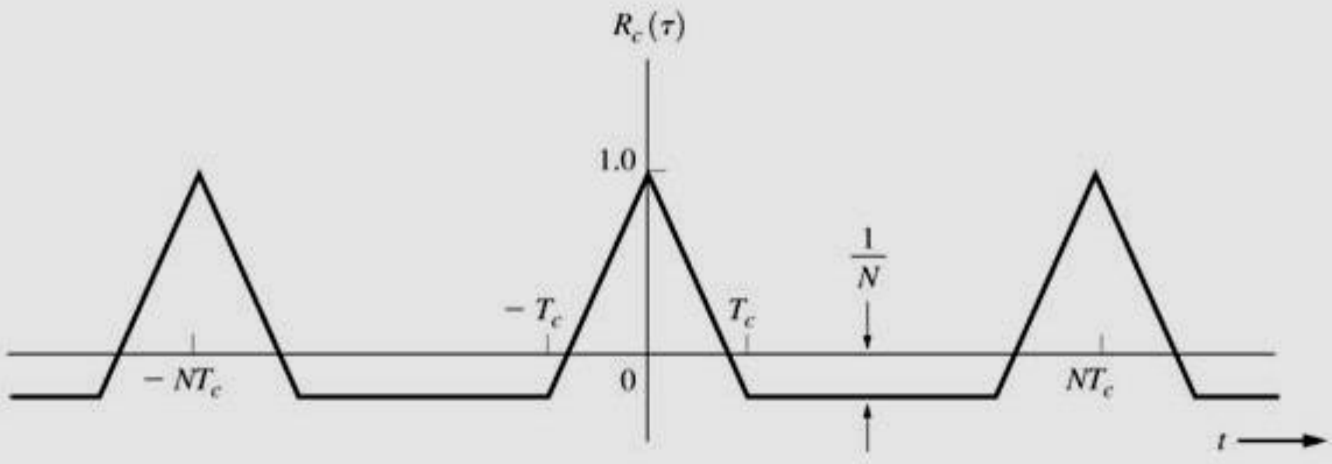


(b) PN sequence c(t)

Properties of PN Sequences

1. Balance Property: No. of 1's is always one more than no. of 0's in each period of a PN sequence.
2. Run Property: Run means subsequence of identical symbols i.e., 1's or 0's.
   - ½ of the runs of length 1
   - ¼ of the runs of length 2
   - 1/8 of the runs of length 3 ……
3. Correlation Property: The autocorrelation function of PN sequence is periodic and binary valued.

Autocorrelation of PN sequence ($R_c(\tau)$)



(a) Autocorrelation Function

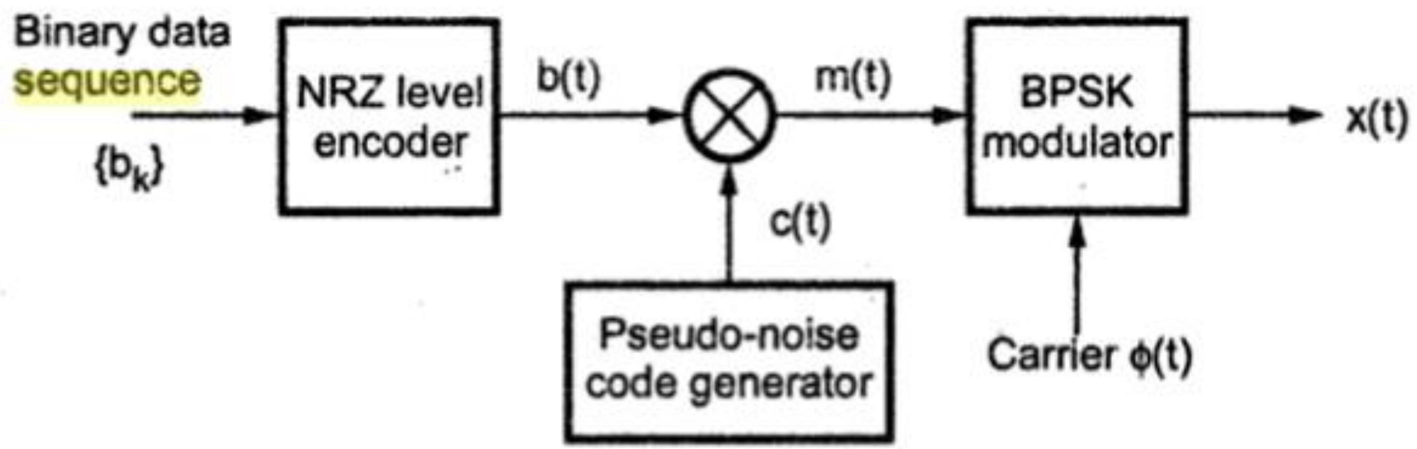
$$
\begin{aligned}
R_c(\tau) &= \frac{1}{T_b}\int_{-T_b/2}^{T_b/2} c(t)c(t-\tau)dt \\
&= \begin{cases} 1-\frac{N+1}{NT_c}|\tau|, & |\tau| \leq T_c \\ -\frac{1}{N}, & \text{the remainder of the period} \end{cases}
\end{aligned}
$$

Shift register stages, m	Feedback taps
2	(2,1)
3	(3,1)
4	(4,1)
5	(5,2); (5,4,3,2); (5,4,2,1)
6	(6,1); (6,5,2,1); (6,5,3,2)
…	…
…	…

Table: Feedback taps for shift registers up to 6 stages

Direct Sequence Spread Spectrum (DS-SS)with Coherent BPSK

- DS-SS BPSK Transmitter:



- Binary data b_k is given to NRZ level encoder to obtain bipolar NRZ sequence, b(t).
- Pseudo noise sequence generator generates PN sequence c(t) and is multiplied with b(t) to produce direct sequence spread signal m(t).
- BPSK modulator modulates m(t) with the carrier signal φ(t) and generates output signal x(t).

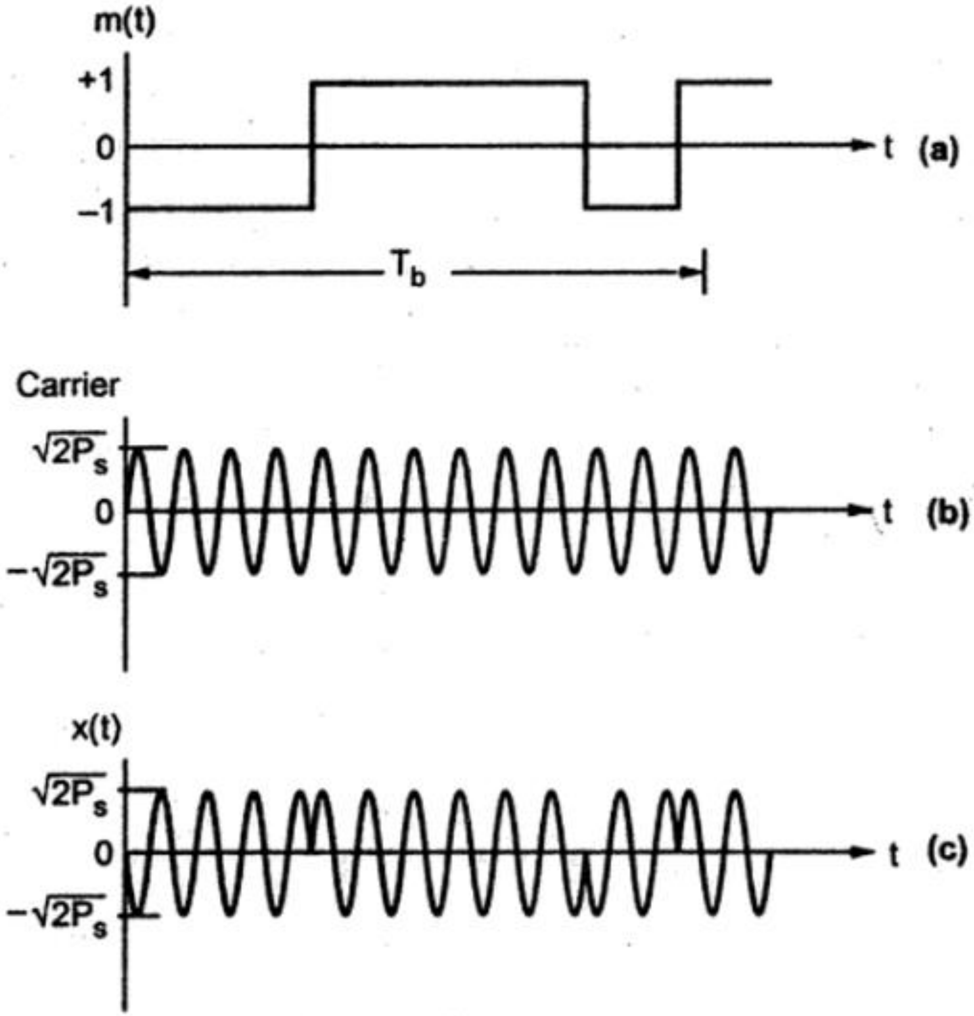


Fig. 4.4.5 Waveforms of DS/BPSK system
(a) Message signal m(t) (b) Carrier (c) Transmitted signal x(t)

$$\phi(t) = \sqrt{2P_s}\sin(2\pi f_c t)$$

the transmitted signal is

$$x(t) = \sqrt{2P_s}\, m(t)\sin(2\pi f_c t)$$

Direct Sequence Spread Spectrum (DS-SS)with Coherent BPSK

- DS-SS BPSK Receiver:

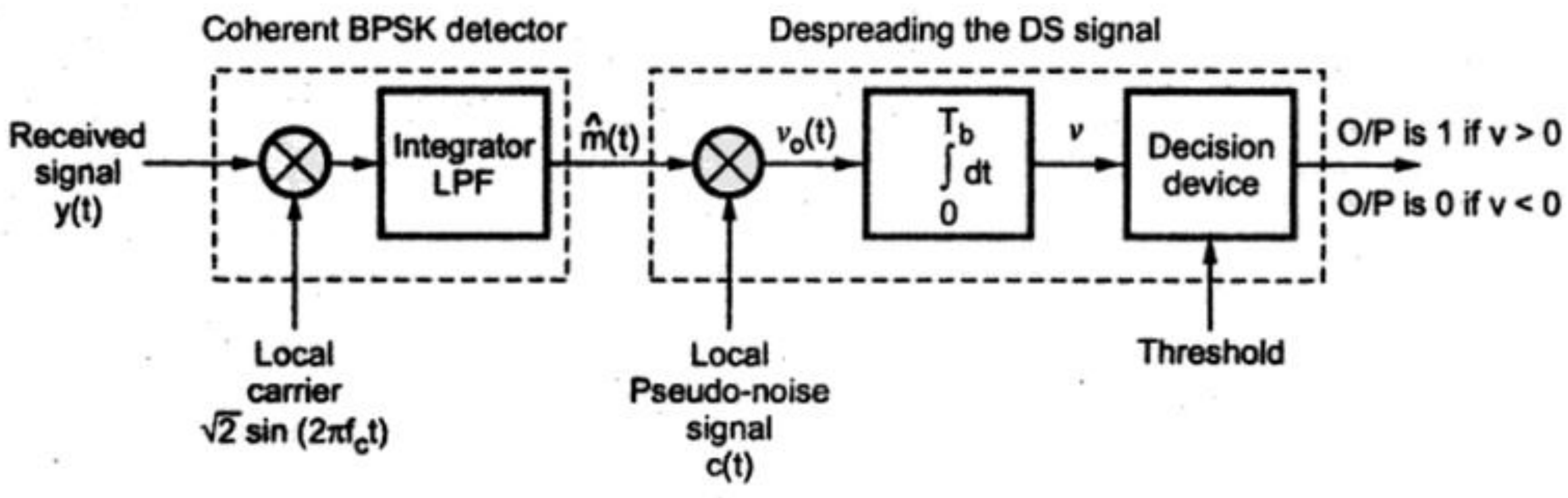


Fig. 4.4.6 Block diagram of DS/BPSK receiver or decoder

- DS-SS BPSK Receiver:
- Received signal y(t) is multiplied with the carrier signal and the product signal is then passed through a LPF to produce $m^{\wedge}(t)$. (The bandwidth of LPF is equal to that of m(t)).
- This signal is applied to the second demodulator which despreads the signal.
- The integrator integrates the product of the detected message signal and pseudo noise signal over one bit period, T_b.
- The decision is then taken depending up on the polarity of output (v) of the integrator.

Performance of Direct Sequence Spread Spectrum system

1. Processing Gain (PG): PG is defined as the ratio the bandwidth of spread message signal to the bandwidth of unspreaded data signal.

$$Processing\ Gain\ (PG) = \frac{BW\ (Spreaded\ Signal)}{BW\ (Unspreaded\ Signal)}$$

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

$$As,\ T_b = NT_c$$

$$PG = N$$

2. Probability of error of DS/BPSK System:

$$For\ BPSK,\ \ P_e = \frac{1}{2} erfc\sqrt{\frac{E_b}{N_0}},$$

$where\ \frac{N_0}{2}\ is\ noise\ spectral\ density\ and\ E_b\ is\ the\ bit\ energy$

$$\frac{N_0}{2} = \frac{JT_c}{2},where\ J\ is\ the\ interference\ power$$

$$Therefore,\ \ P_e = \frac{1}{2} erfc\sqrt{\frac{E_b}{JT_c}}$$

3. Jamming Margin:

$$\frac{E_b}{N_0} = \frac{P_s T_b}{N_0}$$

$$= \frac{P_s T_b}{J T_c}$$

$$Therefore, Jamming\ margin, \frac{J}{P_s} = \frac{T_b / T_c}{E_b / N_0}$$

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

$$\left(\frac{J}{P_s}\right)_{dB} = 10 log_{10}(PG) - 10 log_{10}\left(\frac{E_b}{N_0}\right)$$

Ranging using DS-SS

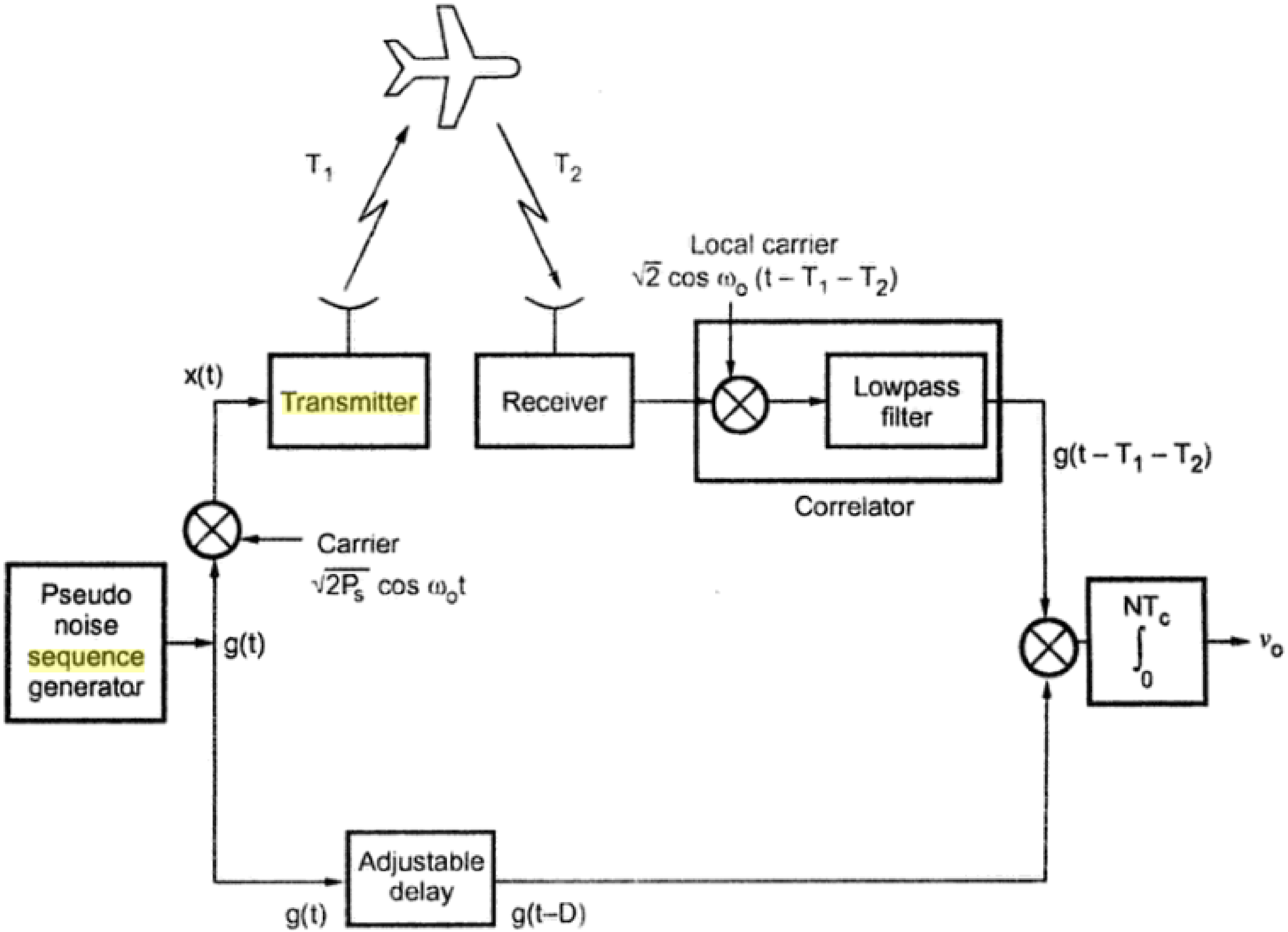


Fig. Ranging using DS-SS

Ranging using DS-SS

The pseudo-noise sequence generator generates the pseudo noise signal g(t). It modulates the carrier $\sqrt{2P_s}\cos\omega_o t$. Hence we get,

$$x(t) = \sqrt{2P_s}\,g(t)\cos\omega_o t$$

This signal is transmitted towards the spacecraft. The reflected signal from the spacecraft is,

$$y(t) = \alpha\, x(t - T_1 - T_2)$$

Here α is the attenuation of the signal, T_1 is the transmit time and T_2 is the receive time.

The signal reaches to the receiver after time $T_1 + T_2$.

$$y(t) = \alpha\sqrt{2P_s}\,g(t - T_1 - T_2)\cos(\omega_o t + \theta)$$

The output of integrator is given as,

$$v_o = R(D)$$

$$= \int_0^{NT_c} g(t - T_1 - T_2)\,g(t - D)\,dt$$

Here R(D) indicates correlation. N is the length of PN sequence.

The signal travels at velocity of light, i.e. $c = 3\times10^8$ m/sec. Hence,

$$\text{D in meters} = c\times D$$

And the range of the spacecraft is,

$$d = \frac{c\times D}{2}$$

$$= \frac{3\times10^8 \times D}{2}$$

$$= 1.5D\times10^8 \text{ meters.}$$

$$\text{or} \quad d = 150D\times10^3 km$$

The value of D can vary by one chip duration. Hence distance of the target will be,

$$d = 150(D\pm T_c)\times10^3 km$$

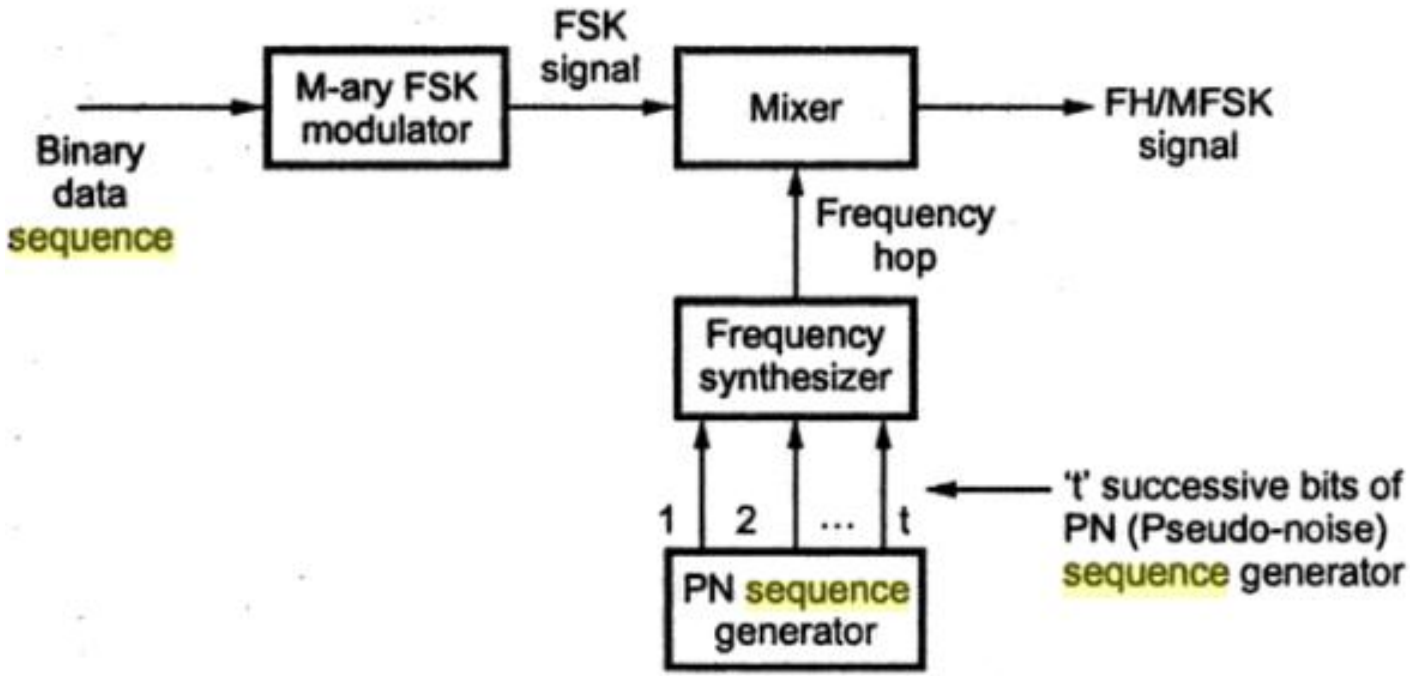
Frequency Hop Spread Spectrum (FH-SS)

- Frequency hopping means to transmit the data bits in different frequency slots.
- The total bandwidth of the output signal is equal to the sum of all these frequency slots or hops.
- Hop rate (R_h): The rate of change of frequency hops.
- Symbol rate (R_s): the rate at which k-bit symbols of data input sequence are generated.
- Types of frequency hopping:
  - Slow Frequency hopping
  - Fast Frequency hopping

Slow Frequency Hopping

- When several symbols of data are transmitted in one frequency hop, then it is called slow frequency hopping.
- One frequency hop = Several symbols are transmitted
- $R_h < R_s$
- M-ary FSK is used along with frequency hop spread spectrum.
- 'k' successive bits of input sequence represent $2^k = M$ symbols.
- Those M distinct symbols are transmitted with the help of M-ary FSK modulation.

Transmitter of FH/MFSK System



Transmitter of FH/MFSK System

- The input binary sequence is applied to the M-ary FSK modulator. The modulator output is the particular frequency (out of M frequencies) depending upon the input symbol.
- The output of FSK modulator is then applied to the mixer. The other i/p to mixer is particular frequency from frequency synthesizer.
- The o/p of mixer is the sum frequency component of FSK signal and frequency hop, known as FH/MFSK signal.
- The i/ps of frequency synthesizer are controlled by PN sequence generator.
- The ‘t’ successive bits of PN sequence generator control the frequency hops generated by the synthesizer.
- Since the bits of PN sequence generator change randomly, the frequency hops generated also change randomly.

Receiver of FH/MFSK System

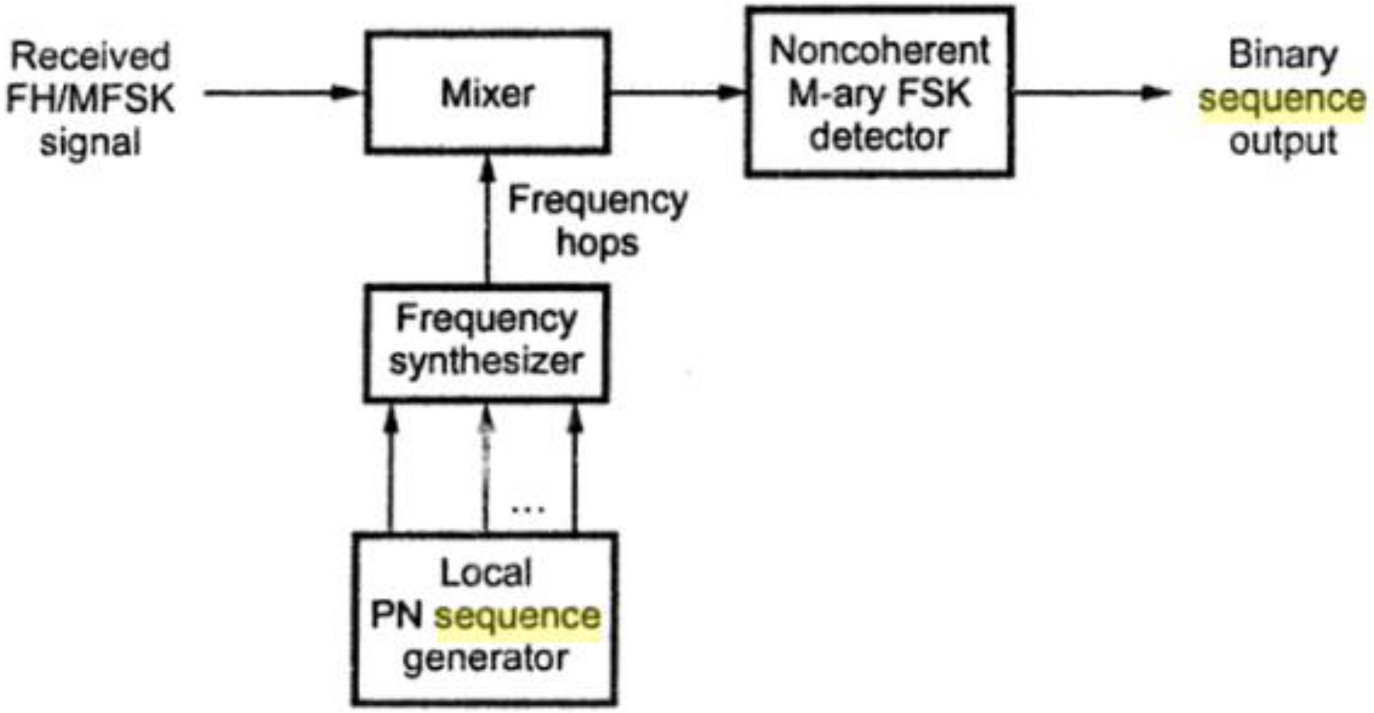


Fig. Block diagram of receiver of frequency hop spread spectrum

Receiver of FH/MFSK System

- The received FH/MFSK signal is applied to the mixer along with the synthesizer output.
- The sum and difference frequencies are generated by the mixer. Only difference frequencies are allowed to pass the mixer, which are exactly M-ary FSK signals.
- These signals are given to the non-coherent M-ary FSK detector which detects the symbols transmitted.

Example of slow frequency hopping

1. In the fig., 3 bits of PN sequence are used to select a hop i.e., there are $2^3 = 8$ hops over complete bandwidth.
2. Two bits of i/p data represent one symbol. Here, two symbols are transmitted on one frequency hop.
3. There will be total M=22=4 symbols. Thus in a single hop, there are 4 different frequencies that correspond to 4 different symbols.
4. In fig., two symbols can occupy any two frequencies in one hop out of four.
5. The symbol 01 has FSK frequency of f_2. and because of frequency hopping this frequency is increased to f_H+f_2.
6. Symbol 11 has frequency of f_H+f_4. The hop frequency f_H is controlled by bits of PN sequence.

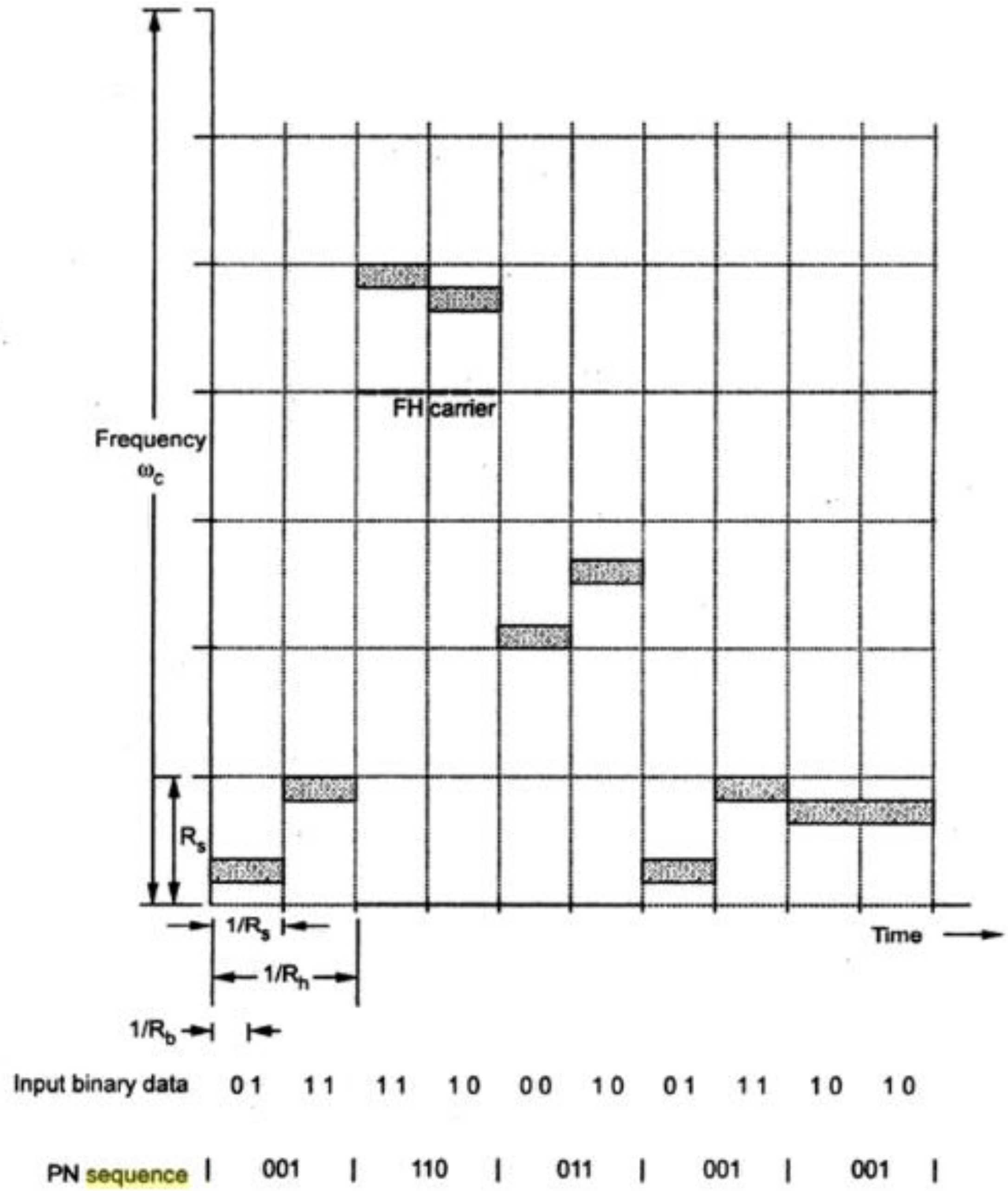


Fig. 4.5.3 Slow frequency hopping

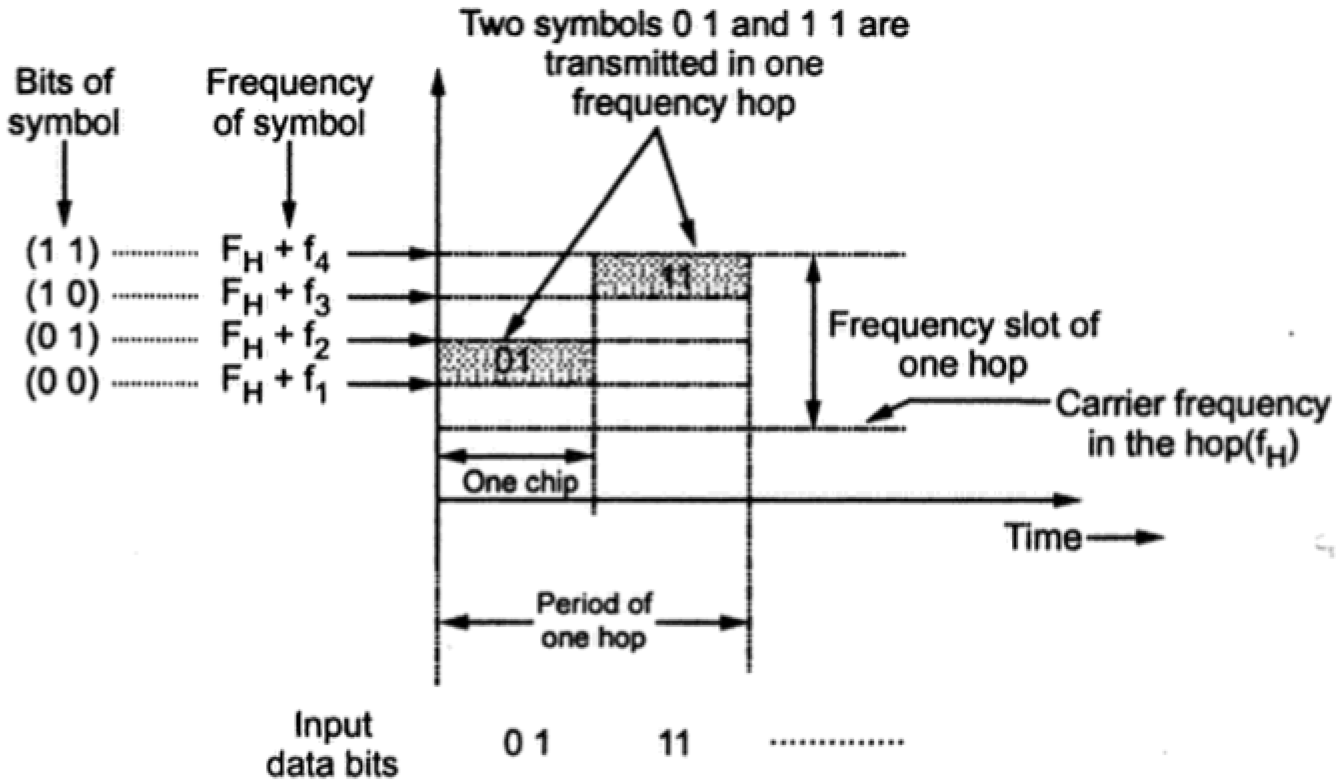


Fig. 4.5.4 Illustration of slow hopping

Fast Frequency Hopping

- When several frequency hops are used to transmit one symbol, then it is called fast frequency hopping.
- Several frequency hops = One symbol transmitted
- $R_h > R_s$
- Advantage of fast frequency hopping is that, before the jammer tries to complete reception of one symbol, carrier frequency changes.

Example of Fast Frequency Hopping

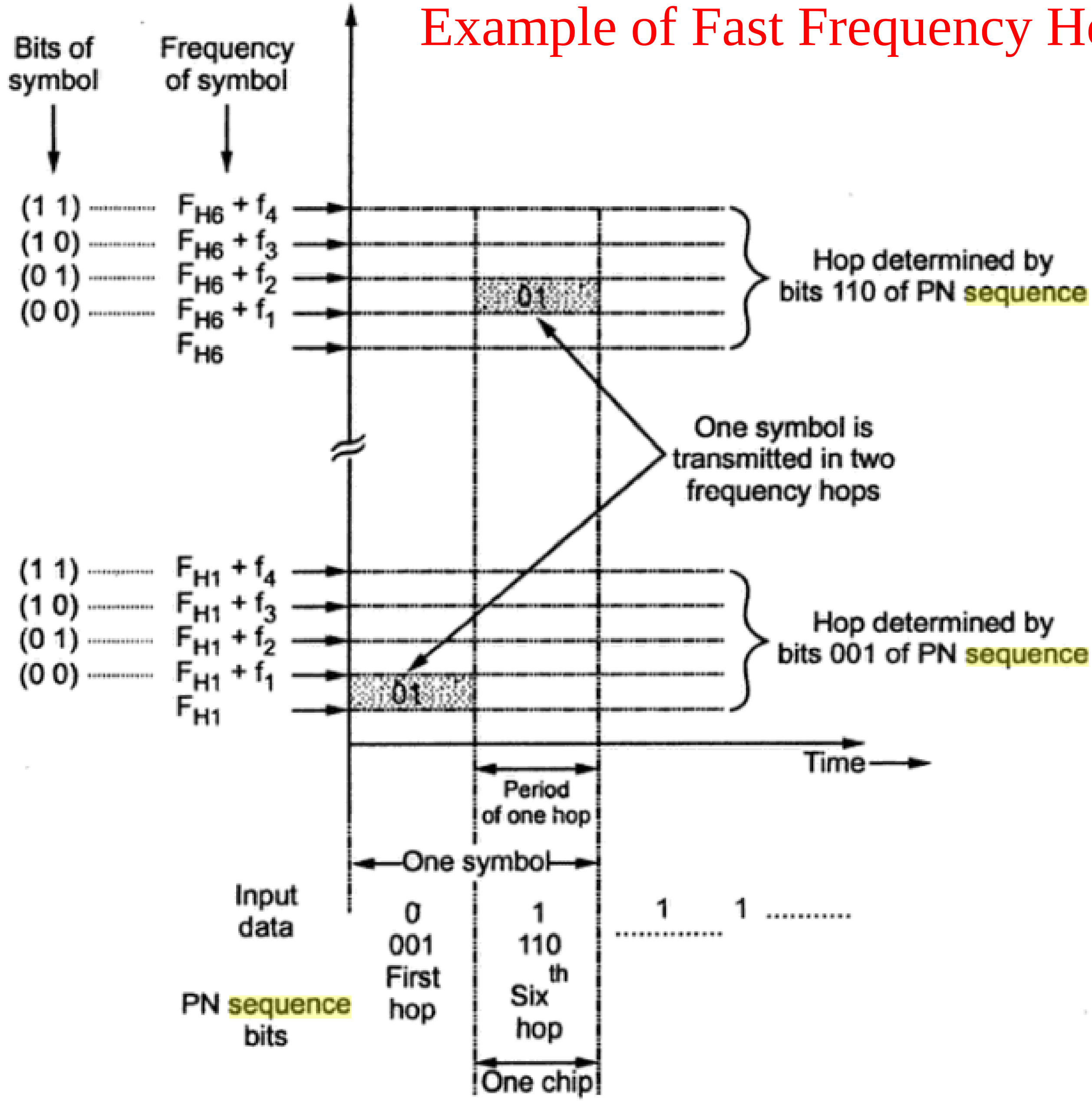


Fig. 4.5.6 Illustration of fast hopping

Example of Fast Frequency Hopping

1. The first two bits 01 of i/p binary data form one symbol (since bits per symbol are two).
2. Two hops are used to transmit one symbol.
3. As shown in figure, the frequency of FSK signal for symbol 01 is f_2. this symbol is transmitted in first hop ($f_{H1}+f_2$) and also in other hop ($f_{H6}+f_2$).

Comparison of slow and fast frequency hopping

Sr. No.	Parameter	Slow frequency hopping	Fast frequency hopping
1.	Definition	Multiple symbols are transmitted in one frequency hop.	Multiple hops are taken to transmit one symbol.
2	Chip rate	Symbol rate is equal to chip rate.	Hop rate is equal to chip rate.
3	R_h and R_s	Hop rate is lower than symbol rate.	Hop rate is higher than symbol rate.
4	Carrier frequencies	One or more symbols are transmitted over the same carrier frequency.	One symbol is transmitted 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.

Table 4.5.1 Comparison of FH-SS methods

Synchronization in spread spectrum systems

1. Spread spectrum systems are essentially synchronous. The pseudo noise sequences generated at the receiver and transmitter must be the same and locked to each other.
2. The synchronization of the spread spectrum systems can be considered in two parts: Acquisition and tracking.
3. Acquisition means initial synchronization of the spread spectrum signal.
4. Tracking starts after acquisition is complete. Acquisition is also called as coarse synchronization and tracking is called as fine synchronization.

Acquisition of DS Signal using Serial Search

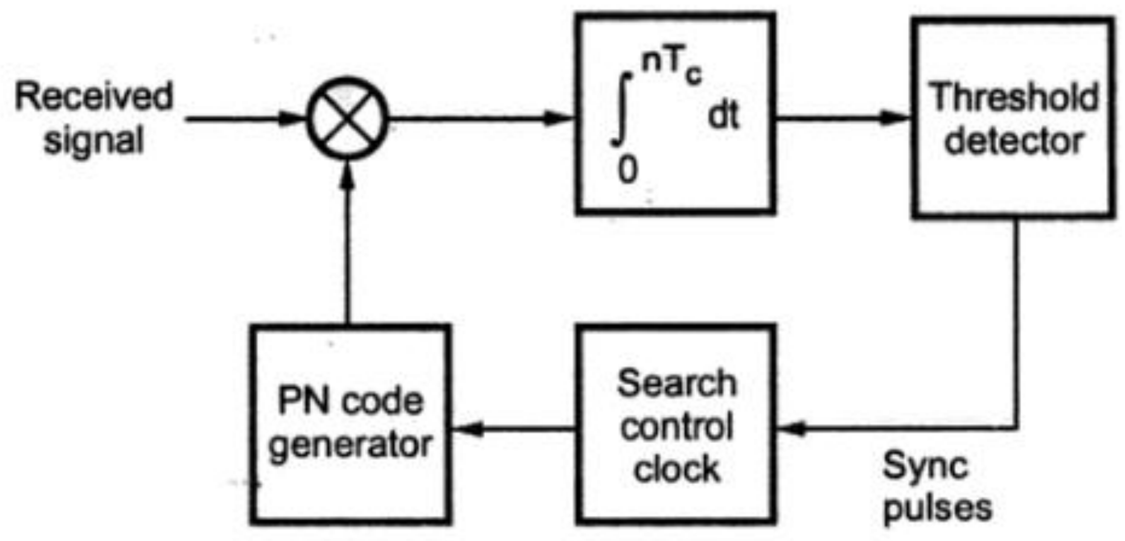


Fig. 4.6.1 A sliding correlator for the acquisition of DS signals

- It is based on the serial search concept.
- The received signal is correlated with the generated PN sequence over the time interval NTc.
- The o/p of correlator is compared with a threshold.

- If it exceeds the threshold, then the required signal is obtained.
- If it does not exceed, the PN generator o/p is advanced by half chip duration and correlation is performed.
- The o/p of correlator is again compared with the threshold and the procedure is repeated.

Acquisition of DS Signal using Serial Search

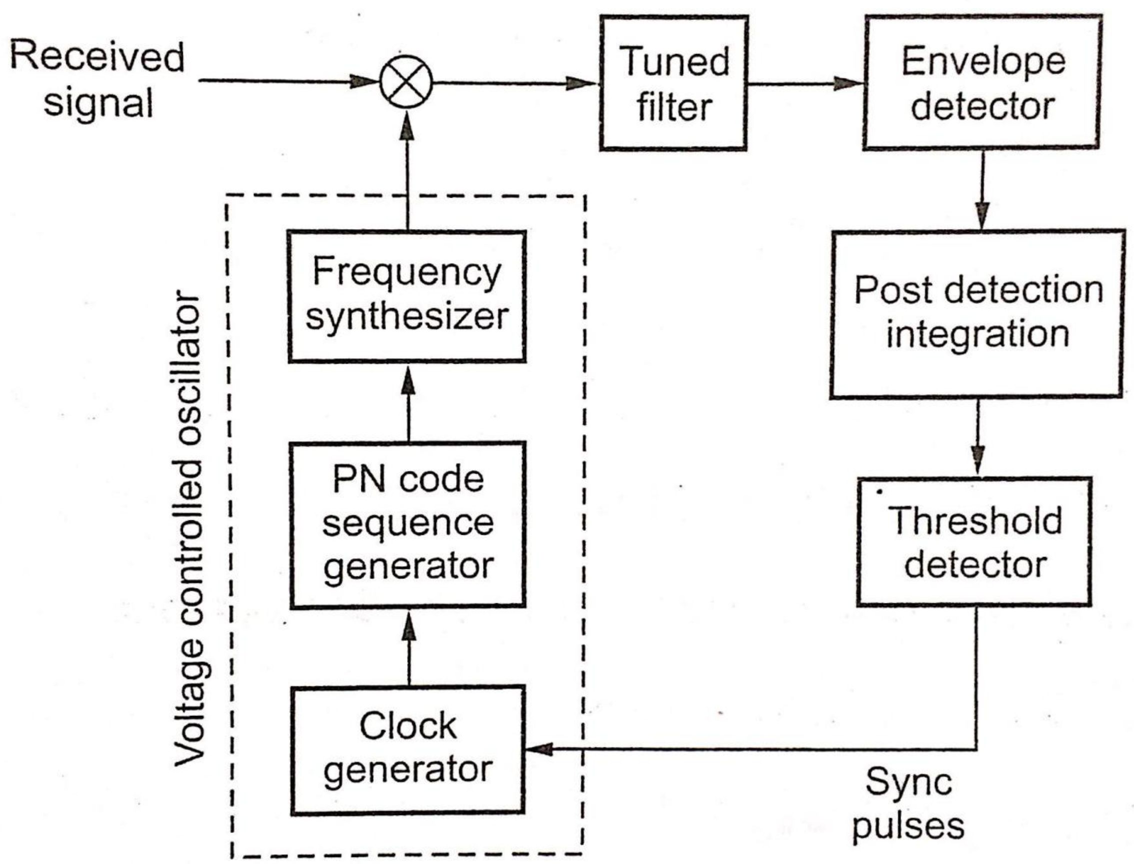


Fig. 8.7.2 Acquisition of FH signals

- The VCO consists of frequency synthesizer, PN generator and clock generator.
- The tuned filter passes only the intermediate frequency f_0.
- The envelope detector generates the output which is compared with the threshold voltage.
- When the i/p frequency and frequency of VCO are same, the o/p of threshold detector is high and the clock generator starts running continuously.
- Then the signal is said to have acquired and the tracking starts.

Comparison of Spread Spectrum Methods

Advantages of direct sequence symbols :

1. This system has best noise and antijam performance.
2. Unrecognized receivers find it most difficult to detect direct sequence signals.
3. It has best discrimination against multipath signals.

Disadvantages of direct sequence systems :

1. It requires wideband channel with small phase distortion.
2. It has long acquisition time.
3. The pseudo-noise generator should generate sequence at high rates.
4. This system is distance relative.

Comparison of Spread Spectrum Methods

Advantages of frequency hopping system :

1. These systems bandwidth (spreads) are very large.
2. They can be programmed to avoid some portions of the spectrum.
3. They have relatively short acquisition time.
4. The distance effect is less.

Disadvantages of frequency hopping systems :

1. Those systems need complex frequency synthesizers.
2. They are not useful for range and range-rate measurement.
3. They need error correction.

Sr. No.	Parameter	Direct sequence spread spectrum	Frequency hop spread spectrum
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 bandwidth of spread spectrum signal.	Data sequence is spread over small frequency slots of the spread spectrum signal.
3	Chip rate R_c	Chip rate is fixed. It is the rate at which bits of PN sequence occur. $R_c = \frac{1}{T_c}$	Chip rate is maximum of hop rate or symbol rate. $R_c = \max(R_h, R_s)$
4	Modulation technique	Normally uses BPSK modulation.	Normally uses M-ary FSK modulation.
5	Processing gain	$PG = \frac{T_b}{T_c} = N$	$PG = 2^t$, here t is the bits in PN sequence.
6	Probability of error	$P_e = \frac{1}{2} erfc\sqrt{\frac{E_b}{JT_c}}$	$P_e = \frac{1}{2} e^{-\gamma_b R_c / 2}$ Here $\gamma_b = \frac{E_b}{J_0}$
7	Effect of distance	This system is distance relative.	Effect of distance is less in this system.
8	Acquisition time	Acquisition time is long.	Acquisition time is short.

Table 4.7.1 : Comparison of direct sequence and frequency hopping spread spectrum

Applications of Spread Spectrum Modulation

1. Anti-jamming for military applications
2. Low probability of intercept
3. Mobile communications
4. Secured communications
5. Distance measurements
6. Selective calling
7. CDMA communication