UNIT II

SPREAD SPECTRUM SYSTEMS

Spread Spectrum System Model – Direct Sequence SS Systems – Classification of Direct Sequence Spread Spectrum Systems – Pulse Jammer – Partial Band Jammer – Multitone Jammer – Modulation and Demodulation of DSSS – Performance of DSSS in noise and jammer

2.1 INTRODUCTION

- Conventional wireless communication consist of a transmitter, transmitting information at a frequency which remains constant with time, as constant as technology permits, thus the bandwidth is kept within certain limits
- With conditions such as these it leaves the transmitted signal very susceptible to interception and interference. In order to circumvent such disastrous outcomes that could arise from such vulnerabilities, the theory of spread spectrum was introduced.
- Spread spectrum involves the deliberate variations in frequency of the transmitted signal over a comparatively large segment of the electromagnetic spectrum. This variation is done in accordance with a specific, complicated mathematical function. This frequency-versus-time function must be 'known' by both sender and receiver to ensure synchronization.
- Spread Spectrum uses wide band, noise-like signals. Because Spread Spectrum signals are noise-like, they are hard to detect. Spread Spectrum signals are also hard to Intercept or demodulate.
- Further, Spread Spectrum signals are harder to jam (interfere with) than narrowband signal because Spread Spectrum signals are so wide, they transmit at a much lower spectral power density, measured in Watts per Hertz, than narrowband transmitters
- For a signal transmitted in such a manner to be incepted, a receiver must be tuned to frequencies that vary precisely according to this frequency-versus-time function, and must also have knowledge of the starting point at which the function begins.
- It is imperative for the spread spectrum function be kept very confidential and out of the hands of unauthorized persons

2.2 SPREAD SPECTRUM TECHNOLOGIES

There are two main types of spread spectrum techniques that are employed. These are Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS).

Direct Sequence Spread Spectrum

- Direct Sequence Spread Spectrum also known as Direct Sequence Code Division Multiple Access (DS-CDMA) entails the division of the stream of information into small pieces, each of which is allocated to a frequency channel across the spectrum

- A data signal at the point of transmission is combined with a higher data-rate bit sequence, also known as the 'chipping code', which divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and enables the original data to be recovered if data bits are damaged during transmission.

- For a more practical example of the techniques employed by DSSS, consider a direct sequence spread spectrum radio. A DSSS radio works by mixing a Pseudorandom Noise (PN) sequence with the data. This mixing is done either by generating a wideband signal which, in turn, is used to modulate the Radio Frequency (RF) carrier, or by modulating the carrier source with the data and then spreading the signal prior to transmission. On the receiving end, the incoming Direct Sequence (DS) signal is reconstructed by generating local replica of the transmitter's PN code, and synchronizing the signal with this local PN sequence.

- By removing the effects of the spreading sequence through the second time modulation of the incoming signal by the local PN sequence, the spread signal collapses into a data-modulated carrier. Using correlation techniques the identity of a signal that has been spread with a particular PN sequence can be discovered.

Frequency Hopping Spread Spectrum

- Frequency Hopping Spread Spectrum (FHSS) also known as Frequency Hopping Code Division Multiple Access (FH-CDMA) involves a signal being transmitted across a frequency band that is much wider than the minimum bandwidth required by the information signal

- The transmitter 'spreads' the signal originally in the narrowband, across a number of frequency band channels on a wider electromagnetic spectrum.

- In a FHSS system, a transmitter 'hops' between available frequencies according to a spreading algorithm. The transmitter operates in synchronization with the receiver, which remains tuned to the same center frequency as the transmitter.

- The transmitter is therefore capable of hopping its frequency over a given bandwidth several times a second, transmitting on one frequency for a certain period of time known as the 'dwell time', then hopping to another frequency in the same spreading bandwidth and transmitting again.

- Ideally each frequency should be occupied with equal probability and the probability of hopping from one channel to any other channel should also be equal.

2.3 CLASSIFICATION OF DIRECT SEQUENCE SPREAD SPECTRUM SYSTEMS

- In DSSS, the data signal is directly spread by means of a wide spread code sequence. The main idea is to spread the spectrum of the modulated (modulation that can be baseband or digital) data signal a second time by the use of a wideband spreading signal.
- The wideband spreading signal is selected in such a way as to make demodulation possible only by the intended receiver and to make demodulation by an unintended receiver impossible.
- Direct sequence contrasts with the other spread spectrum process, in which a broad slice of the bandwidth spectrum is divided into many possible broadcast frequencies.
- In general, frequency-hopping devices use less power and are cheaper, but the performance of DS-CDMA systems is usually better and more reliable.

- DSSS systems can be classified into:
  - Baseband DSSS
  - Modulated DSSS

- The baseband DSSS system applies the direct sequence spread spectrum technique directly to the baseband digital data

- Similarly, the modulated DSSS applies the spread spectrum technique to the data that is already modulated by some digital modulation technique. Different types of modulation are used before the DSSS technique is applied. Most common are BPSK and QPSK modulation.

2.4 BASEBAND DSSS SYSTEM

The baseband direct sequence spread spectrum system spreads the baseband digital signal using the wide-bandwidth spreading-code signal. The spreading is done to the baseband signal directly without any digital modulation. The technique and hence the system is called as baseband DSSS. The block diagram of a baseband DSSS system is shown in Figure 2.1.

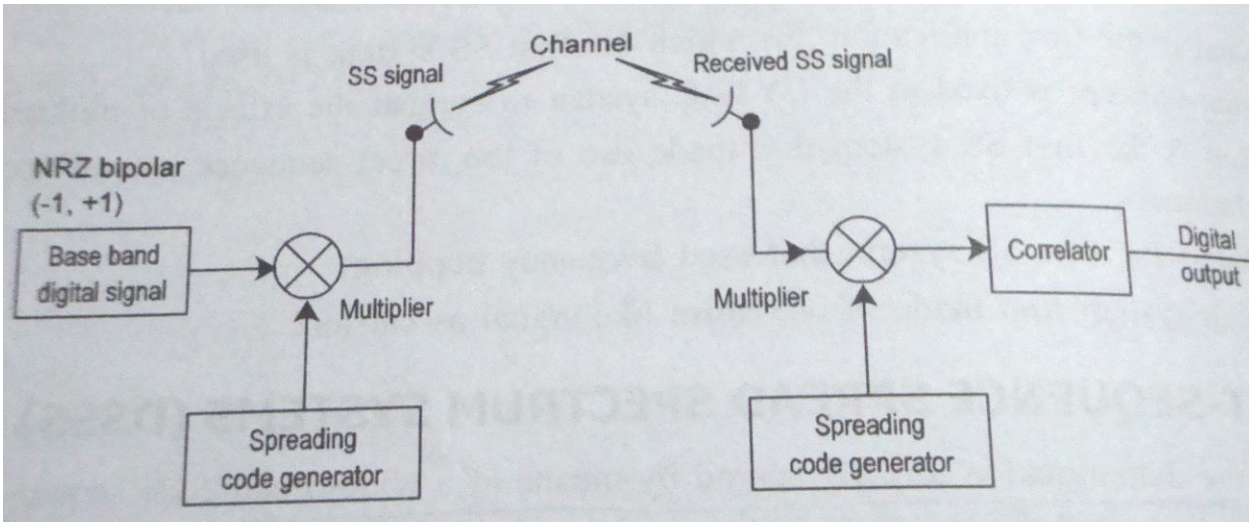
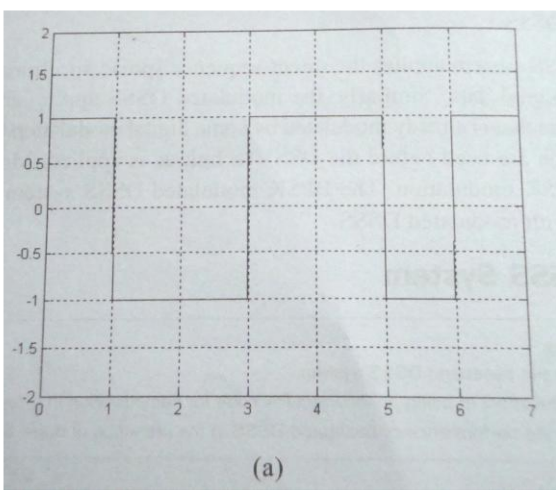


Figure 2.1 Block diagram of Baseband DSSS System

The original data signal which is of low bandwidth is multiplied with the wide-bandwidth direct sequence spreading code. This operation widens the bandwidth of the data signal. Figure 2.2 a) shows the original digital signal (NRZ bipolar +1, -1) and the spectrum of the signal is shown in Figure 2.2 b). A sample digital bit pattern of 1010011 is used as the baseband digital signal. The digital signal bandwidth is very narrow and the spectrum is wrapped-around FFT of the digital signal. The spectrum shows that the signal is centered on zero frequency with a very narrow bandwidth extending over a few frequency bins (approximately 100).



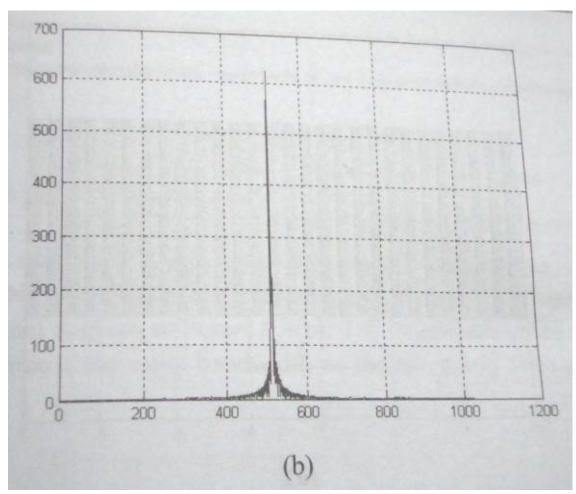


Figure 2.2 a) Digital Signal b) Spectrum of Digital signal

A high frequency PN code signal with process gain 60 is shown in Figure 2.3 a) and its spectrum is shown in Figure 2.3 b). The spectrum of the PN code is also centered on the zero frequency, but is of very wide bandwidth compared to the digital signal. Also, the power spectral density of the PN code is less than that of the digital signal. This accounts for the low density and low probability of detection.

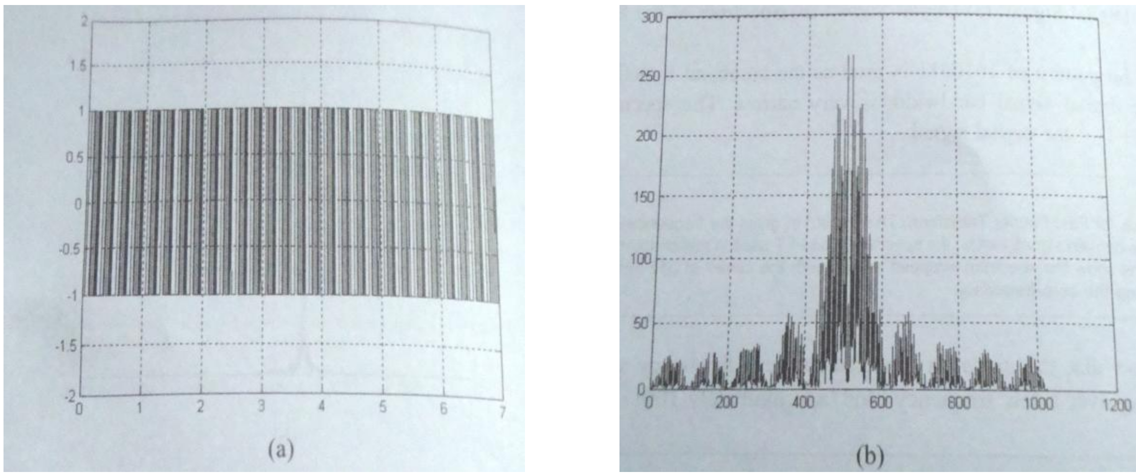


Figure 2.3 a) PN code b) Spectrum of PN code

The resulting spread spectrum signal obtained as a result of multiplying the high chip-rate PN code with the low-bit rate digital signal is shown in Figure 2.4 a) and the spectrum of the resulting spread spectrum signal is shown in Figure 2.4 b). The bandwidth of the signal has widened and has occupied almost the same bandwidth as the PN spreading code.

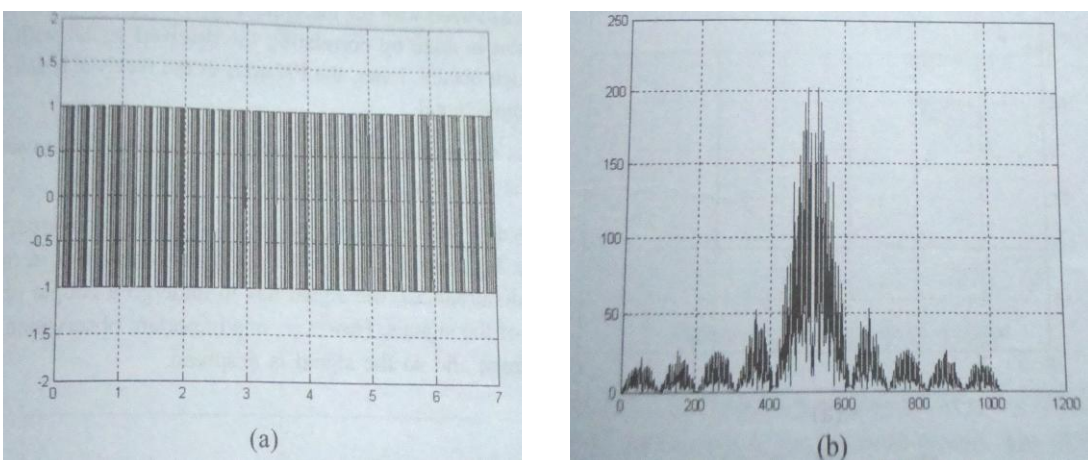


Figure 2.4 a) Spread Spectrum Signal b) Spectrum

Despreading at the baseband DSSS receiver system is done by remultiplying the received signal with the same PN code used at the transmitter. The chip rate is to be kept the same. Also, the despreading has to be perfectly synchronized, as the PN codes have very good autocorrelation properties. The despread signal using the same PN code used at the transmitter, however this being the ideal case, the output is same as the digital signal is shown in Figure 2.5 a) and the spectrum of the despread signal is shown in Figure 2.5 b). But in the presence of noise and other channel disturbances, the signal has to undergo a couple of other processes for optimum detection of the signals. However, one observation is that the spectrum of the signal is narrow and so the signal is despread. The other two mandatory processes are correlation and decision.

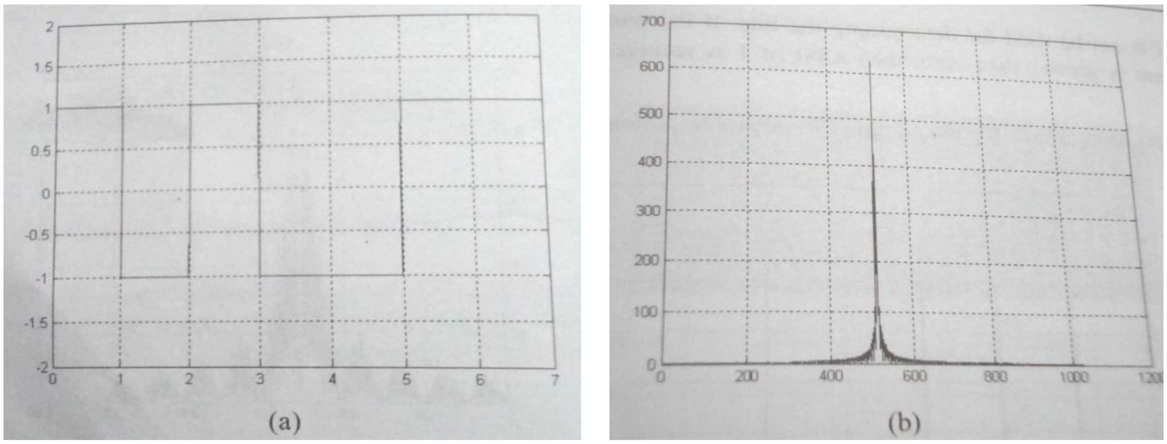


Figure 2.5 a) DeSpread Spectrum Signal b) Spectrum

The correlation-receiver output for the despread signal. The pulse-shaping signal used for multiplication prior to integration is a rectangular pulse with one-bit duration. The correlator output shown in the Figure 2.6 is sampled at every decision-time instant and is sent to the decision circuit. The decision circuit contains a threshold detector that compares the sampled correlator output with a reference value. A reference value of 0 can be used for determining the bits. If the correlator output at the decision-time instant is greater than zero, then a bit is received, else a bit of 0 is received.

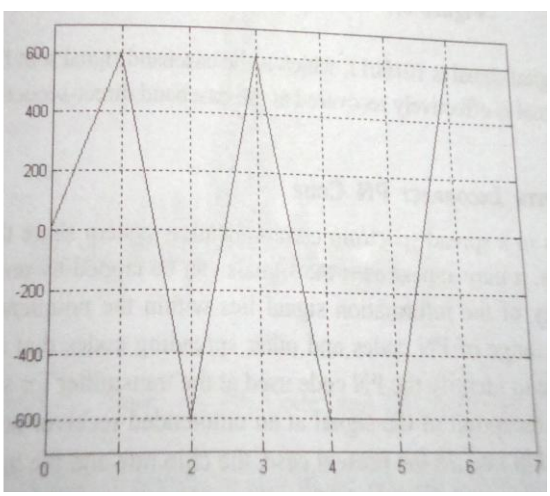


Figure 2.6 Correlator Output

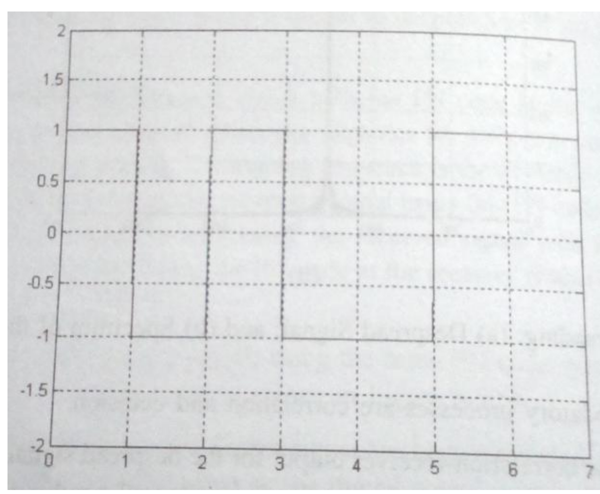


Figure 2.7 Final Recovered Digital Signal

The output of the decision circuit for the sample bit pattern is shown in Figure 2.7. The recovered digital signal is 1010011, which is the baseband signal sent from the transmitter. Therefore, the signal is effectively recovered at the baseband direct-sequence spread spectrum receiver system.

DEMODULATION WITH INCORRECT PN CODE

All the users in a spread spectrum communication system share the same bandwidth for communication and hence it may appear as if the signals can be tapped by unintended users. The privacy and secrecy of the information signal lies within the uniqueness of PN code used. With a range of PN codes and other spreading codes that can be generated, it is not possible to identify the PN code at the transmitter for spreading. Hence the reception of the signal at the unintended receiver on using different PN codes with similar chip rate can be investigated. An incorrect PN code that is used by an unintended user to despread and detects the signal is shown in Figure 2.8 a) and its spectrum is shown in Figure 2.8 b). The spectrum of the PN code is similar to that of the original PN code used for spreading at the transmitter.

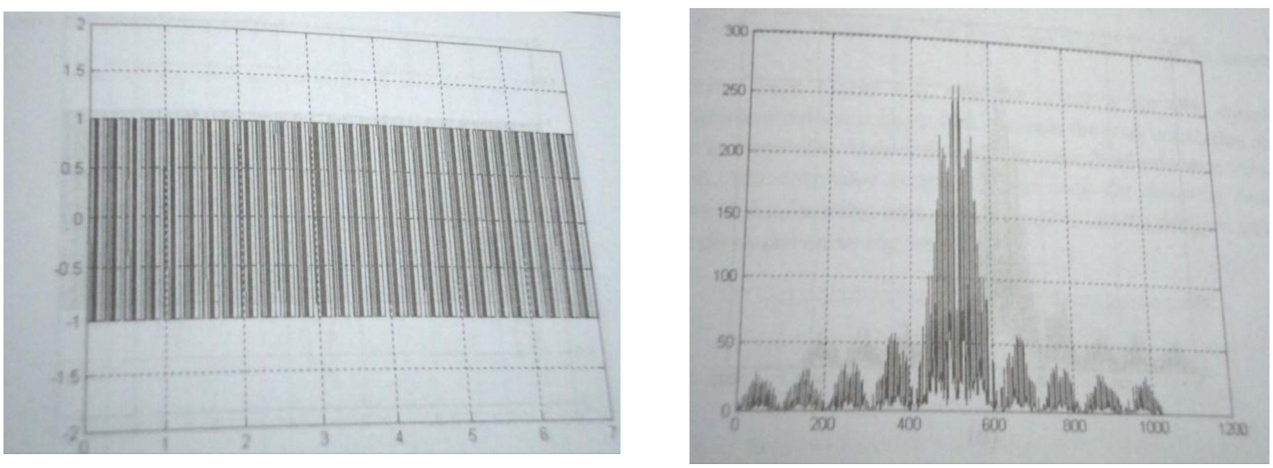


Figure 2.8 a) Incorrect PN code b) Spectrum of the PN code

The despread signal and its spectrum are shown in Figure 2.9 a) and 2.9 b) respectively. From the spectrum it is observed that the recovered signal is not effectively despread, as the frequency of the despread signal appears to be high. The spectrum of the despread signal also extends along a wide bandwidth and it is seen that the despreading is not effective with a PN code different from the one used at the transmitter.

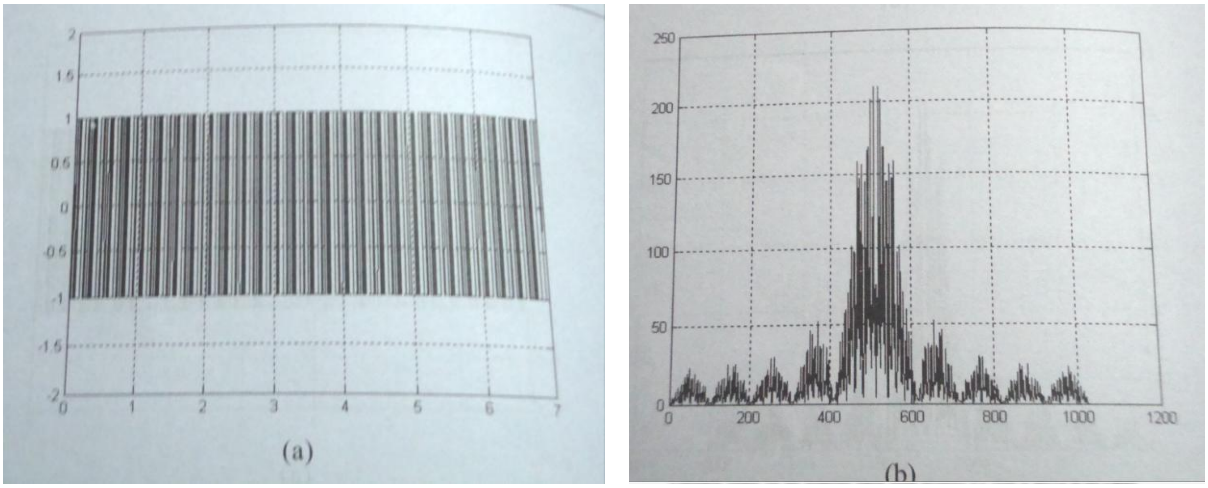


Figure 2.9 a) Despread Signal b) Spectrum of Despread signal

Correlator output for the despread signal using incorrect PN code is shown in the Figure 2.10. The peak correlation magnitude obtained is about 100, whereas the peak correlation obtained using incorrect PN code is about 600. Since the threshold reference value in the decision circuit is zero, this correlator output may be used for detecting data bits. When the correlation output at the decision-time instants is given to the decision circuit, the output of the decision circuit is shown in the Figure 2.11.

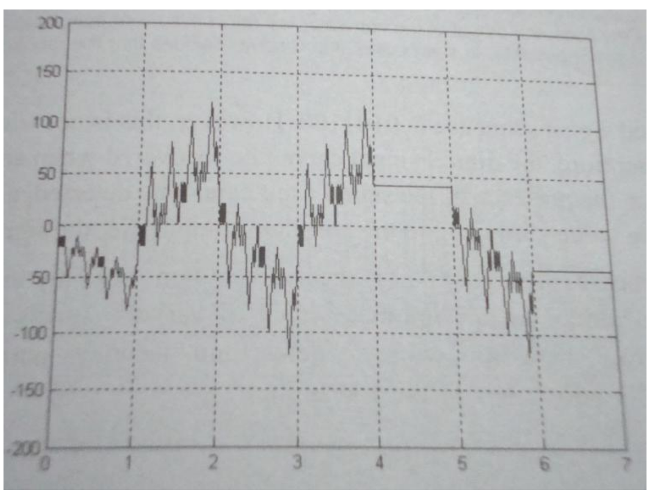


Figure 2.10 Correlator Output

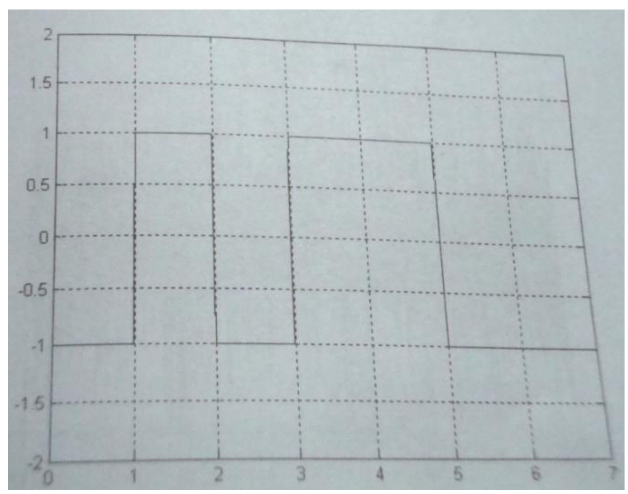


Figure 2.11 Decoded Signal using Incorrect PN code

The decoded digital sequence signal sequence is 0101100 and this is transmitted by the transmitter. Hence the digital signal cannot be recovered when an incorrect PN code is employed. The presence of the signal itself cannot be detected, as the signal detector has a high reference value compared to the corrector output. So, the signal goes undetected. The signal that is received contains not only the signal transmitted by this single transmitter, but a combined signal of various signals from similar DSSS transmitters. Hence it is impossible to detect and decode a particular DSSS signal without the exact PN code used in the transmitter.

PERFORMANCE IN NOISE

The performance of the baseband DSSS technique is analyzed in the presence of noise. The AWGN channel model is used for analysis. Figure 2.12 shows the AWGN noise added by the channel to the transmitted spread spectrum signal. The amplitude of the noise signal is comparable to the magnitude of the spread spectrum signal.

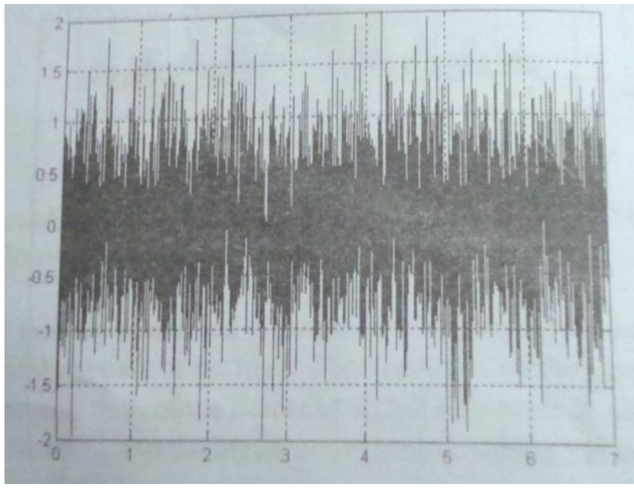


Figure 2.12 AWGN Noised added by the channel

The spread spectrum signal that is received at the baseband DSSS receiver system corrupted with noise is shown in Figure 2.13 a) and its corresponding spectrum is shown in Figure 2.13 b). When compared to the original spread spectrum signal, this signal appears to be corrupted beyond recognition. The spectrum of the signal, even though it occupies the same bandwidth, seems to be distorted uniformly by noise, as shown by the spikes at the top of the spectrum envelope. AWGN affects all the frequency components alike and as the noise bandwidth is infinite and uniform, the spectrum shape and width remain the same.

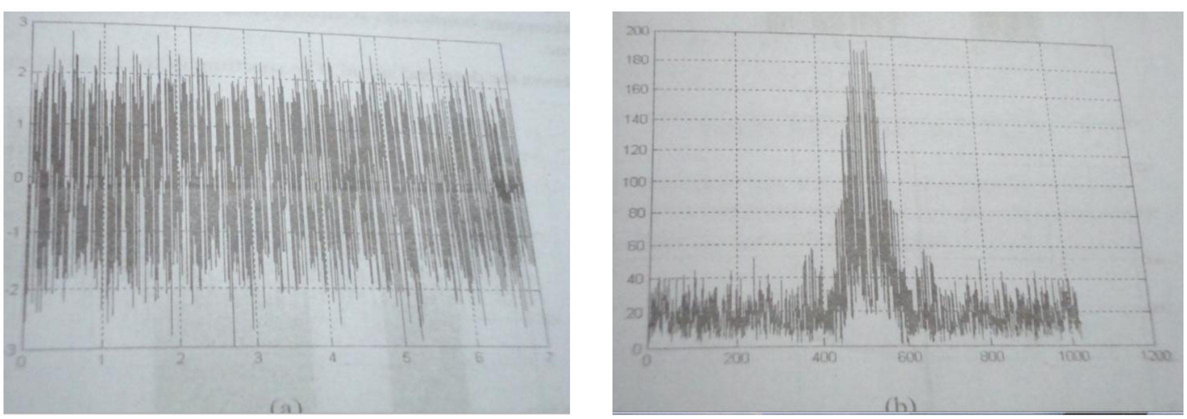
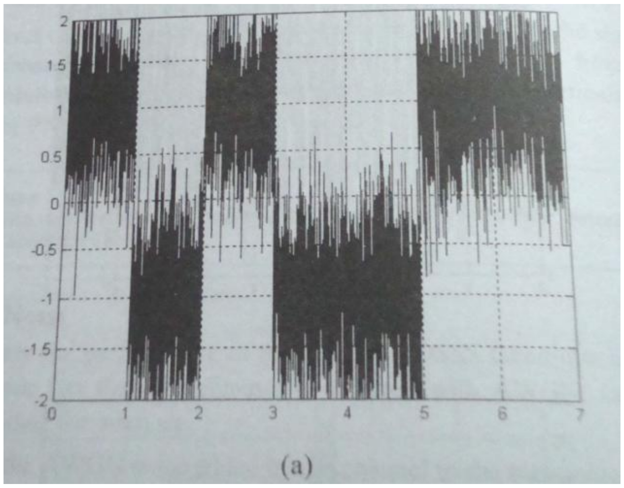


Figure 2.13 a) Noise corrupted received Spread spectrum signal b) Spectrum

The despread signal, though corrupt with heavy noise, seems to have strong low-frequency component. The wideband AWGN noise is simply superimposed on this low-frequency data signal. The despread signal and its spectrum is shown in the Figure 2.14 a) and 2.14 b) respectively. There is a single dominant peak centered on the zero frequency with uniform noise all along the bandwidth. The low-frequency data signal can either be recovered by efficient low-pass filtering or by use of the more common correlation receiver.



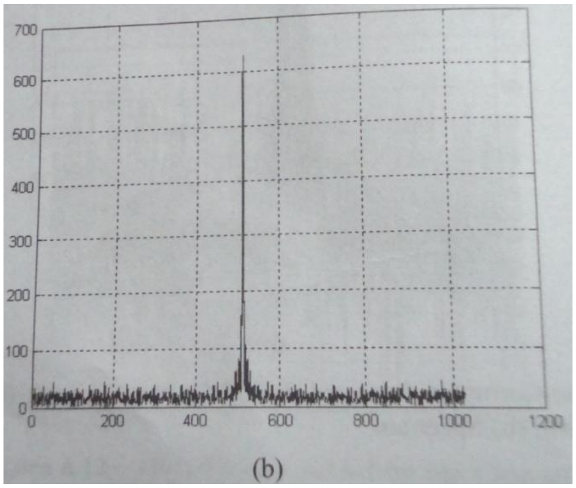


Figure 2.14 a) Despread signal b) Spectrum

Even though the despread signal appears to be noisy, the correlator receiver output shown in Figure 2.15 is similar to the noise free case. The correlator output at the decision-time instants is unambiguous. Figure 2.16 shows the final decoded digital signal. The recovered digital pattern is 1010011, which is the transmitted sequence and hence the DSSS technique fares well in the AWGN channels.

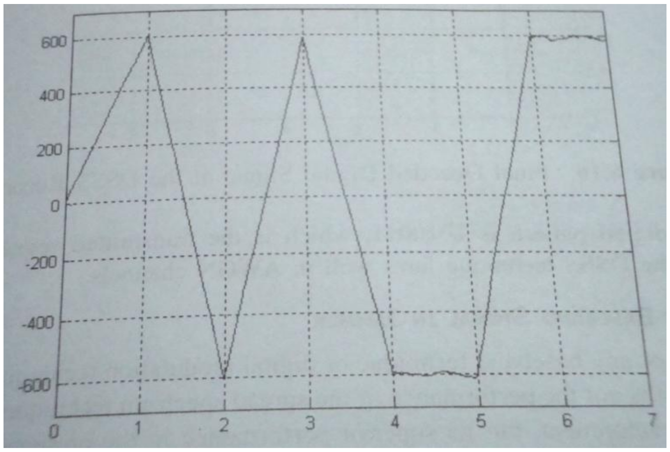


Figure 2.15 Correlator Output

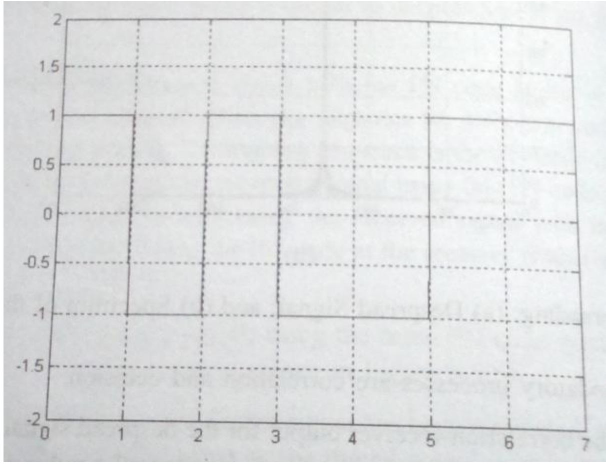


Figure 2.16 Final Recovered Digital Signal

PERFORMANCE OF BASEBAND SIGNAL IN JAMMER

The performance of any baseband technique or digital modulation technique quiet satisfactory in AWGN noise. The pulsed jammer signal that has rectangular pulses with the same duration as the data signal and the spectrum of the jammer signal in comparison with the original baseband digital signal is shown in Figure 2.17 a) and 2.17 b) respectively. The jammer spectrum has exactly matched with the digital signal spectrum.

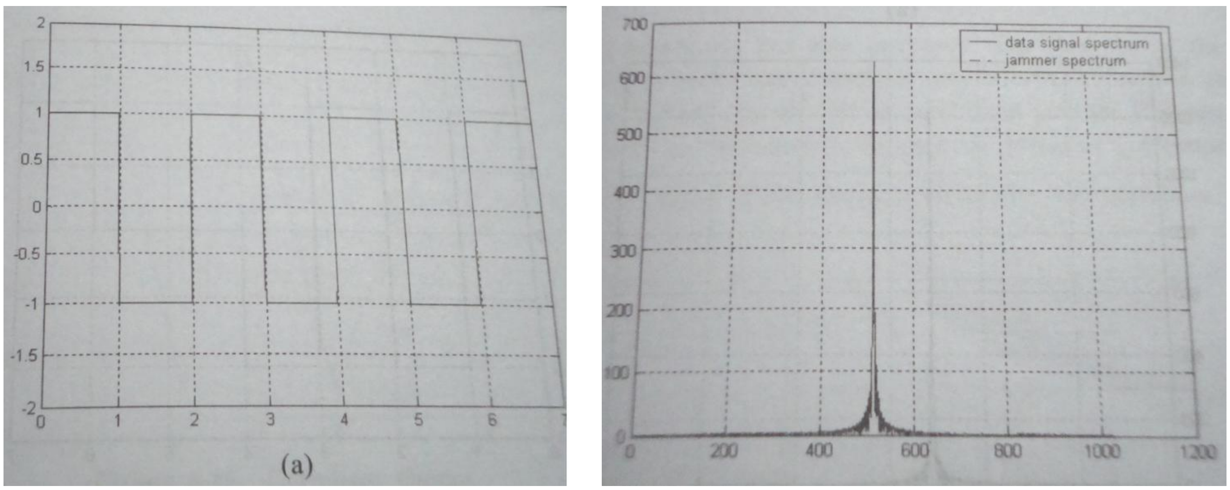


Figure 2.17 a) Jammer signal b) Spectrum

The baseband signal as altered by the jammer on the channel. The signal that is received at the baseband receiver system is shown in the Figure 2.18 a) and its spectrum is shown in Figure 2.18 b). The spectrum of the signal has not altered but has increased in its magnitude.

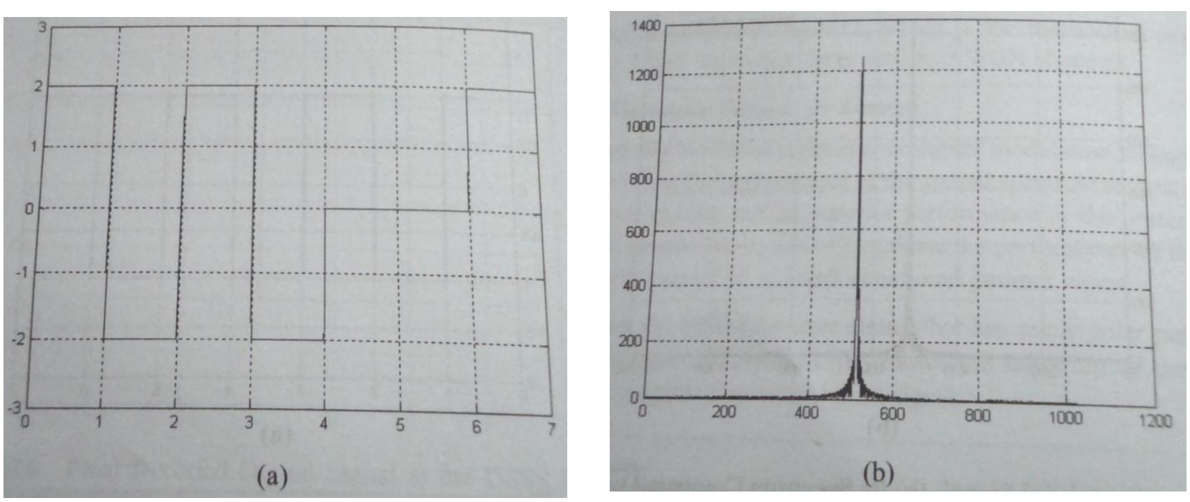


Figure 2.18 a) Received signal at the receiver b) Spectrum

The correlator peak magnitude has also increased. The increase in the spectral-power magnitude and the output of the peak correlator may inform the receiver about the jammed signal. The correlator output for the received signal with jamming is shown in Figure 2.19. However the jammer can also be an intelligent jammer that can vary the signal amplitude so that there is no increase in the spectral power or correlator output. The output of the decision circuit for the correlator output is shown in Figure 2.20.

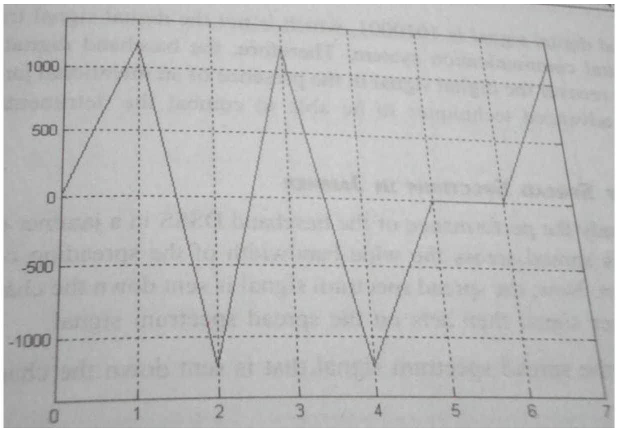


Figure 2.19 Correlator Output

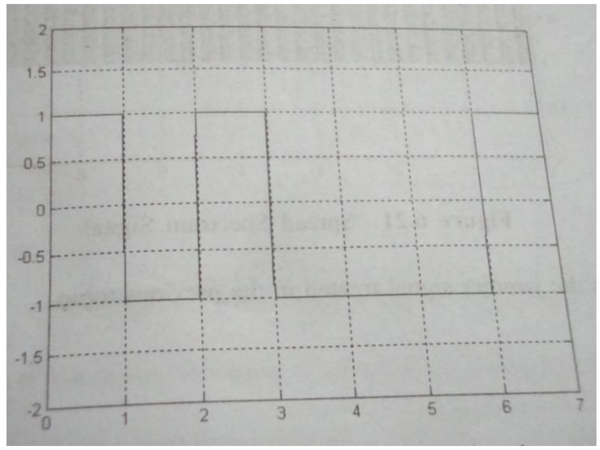


Figure 2.20 Decoded Digital Signal

The recovered digital signal is 1010001, which is not the digital signal transmitted by the baseband digital communication system. Therefore, the baseband digital communication system cannot recover the digital system in the presence of an intentional jammer signal. The system needs advanced techniques to be able to combat the detrimental effects of the jammer.

PERFORMANCE OF SPREAD SPECTRUM IN JAMMER

The baseband signal is spread across the wide bandwidth of the spreading code. The spread spectrum signal is sent down the channel by the DSSS system. The jammer signal then acts on the spread spectrum signal. The spread spectrum signal that is sent down the channel by the DSSS system is shown in Figure 2.21 and the Jammer signal is shown in Figure 2.22.

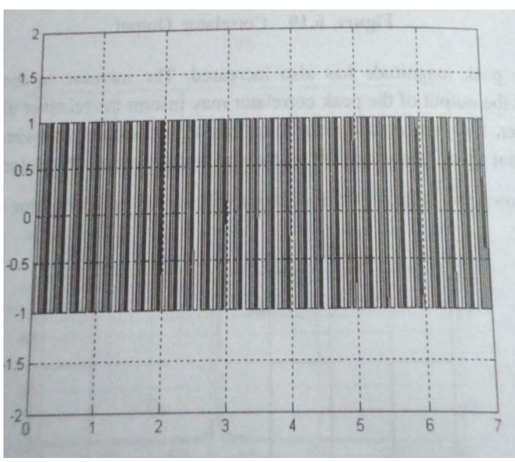


Figure 2.21 Spread Spectrum Signal

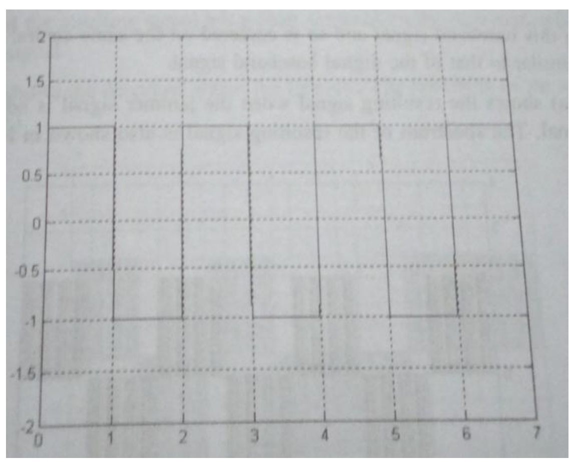


Figure 2.22 Jammer signal

The jammer signal is of narrow bandwidth compared to the spread spectrum signal because the jammer has knowledge of the baseband signal spectrum. The jammer is aimed at distorting this baseband signal and so is centered on the same central frequency with a bandwidth similar to that of the digital baseband signal. The comparison of the spectrum of jammer signal with the spread spectrum signal is shown in Figure 2.23.

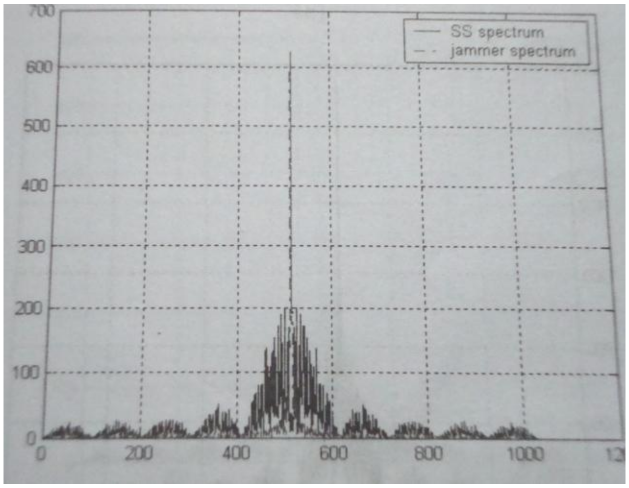


Figure 2.23 Comparison of Spectrum of Jammer signal and Spread Spectrum Signal

The resulting signal when the jammer signal is added the spread spectrum signal is shown in Figure 2.24 a) and its spectrum is shown in Figure 2.24 b). The spectrum of the resulting signal has a peak centered on the zero axis, which is the axis of the jammer signal.

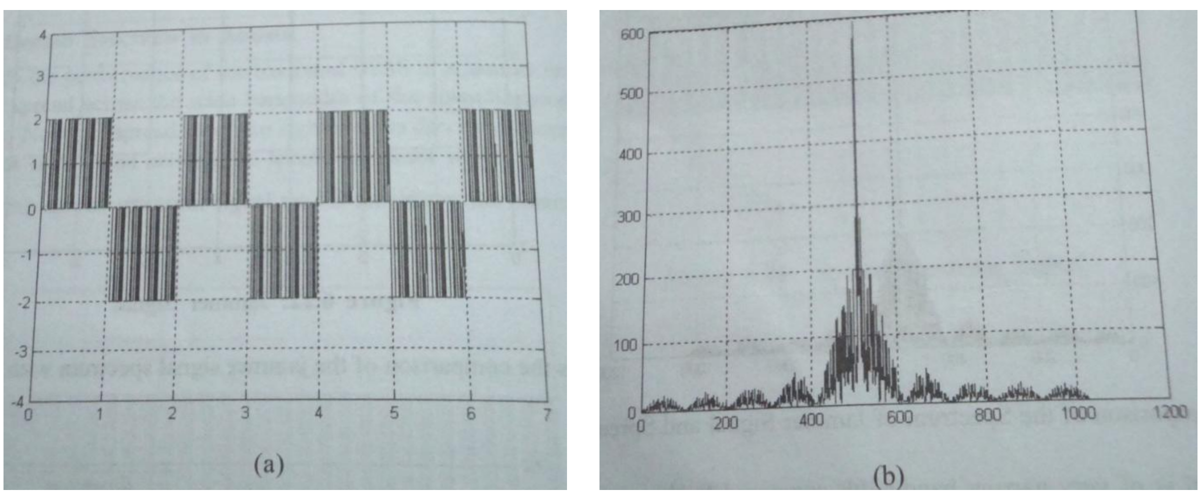


Figure 2.24 a) Compared signal b) Spectrum of the Compared signal

The despread signal received at the receiver and its spectrum is shown in Figure 2.25 a) and b) respectively. The spectrum of the despread is not similar to the original signal spectrum; but is spread across the wide bandwidth.

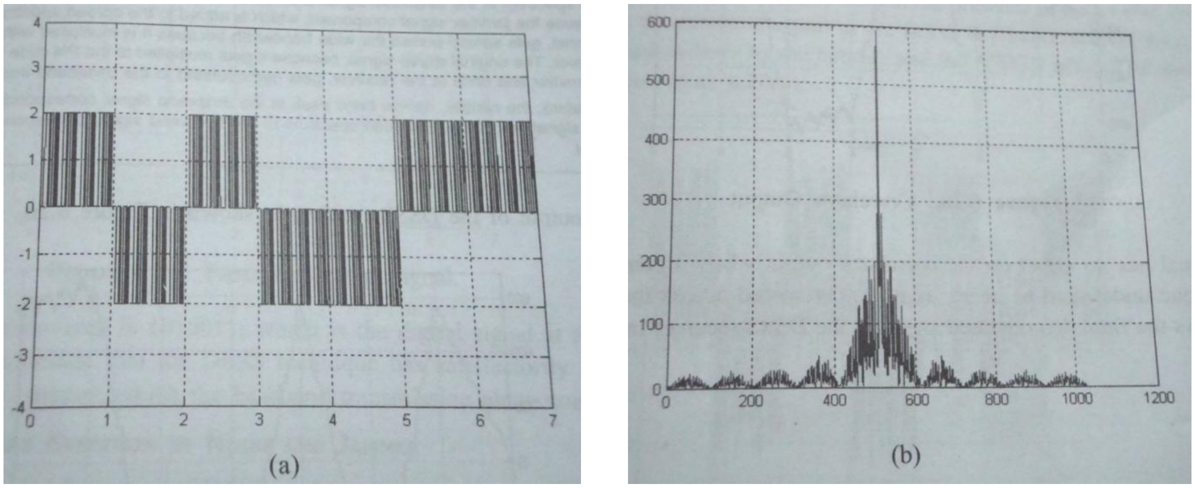


Figure 2.25 a) Despread signal b) Spectrum of the Despread signal

The correlator output of the DSSS receiver is shown in the Figure 2.26. The jammer has no effect on the correlator output when it comes to the detection of bits. It has gone undetected as noise, as it is now spread across the whole bandwidth. Figure 2.27 shows the final demodulated signal at the DSSS receiver in the presence of the jammer.

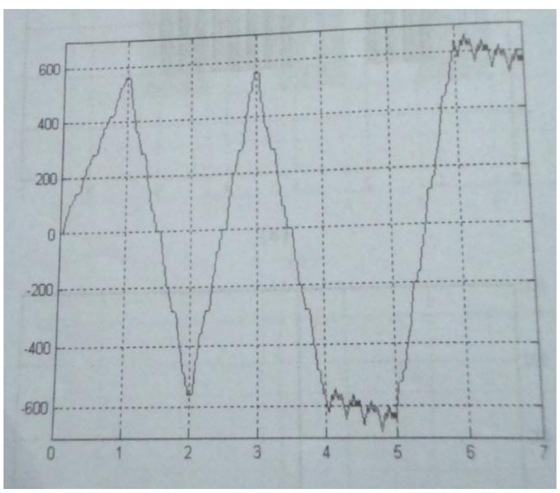


Figure 2.26 Correlator Output

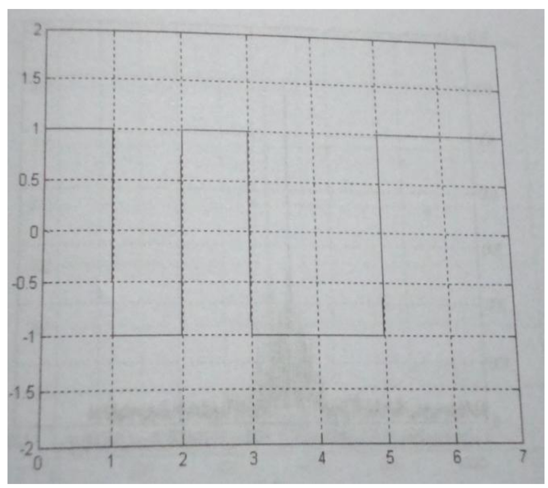


Figure 2.27 Final Digital Signal Output

The digital sequence recovered is 1010011, which is the digital signal at the transmitter. Therefore, the DSSS technique has satisfactorily eliminated the negative effects of the jammer which the baseband transmission alone could not handle.

PERFORMANCE OF SPREAD SPECTRUM IN NOISE AND JAMMER

The received signal at the DSSS baseband receiver when the spread spectrum signal is acted on both by the jammer and the AWGN noise is shown in Figure 2.28 a) and its spectrum is shown in Figure 2.28 b). The combined signal has been corrupted by both the jammer signal and the noise. The spectrum of the combined signal, therefore, shows a central peak corresponding to the jammer component, a wide spread spectrum corresponding to the spread spectrum signal and noise along the whole spectrum corresponding to the AWGN.

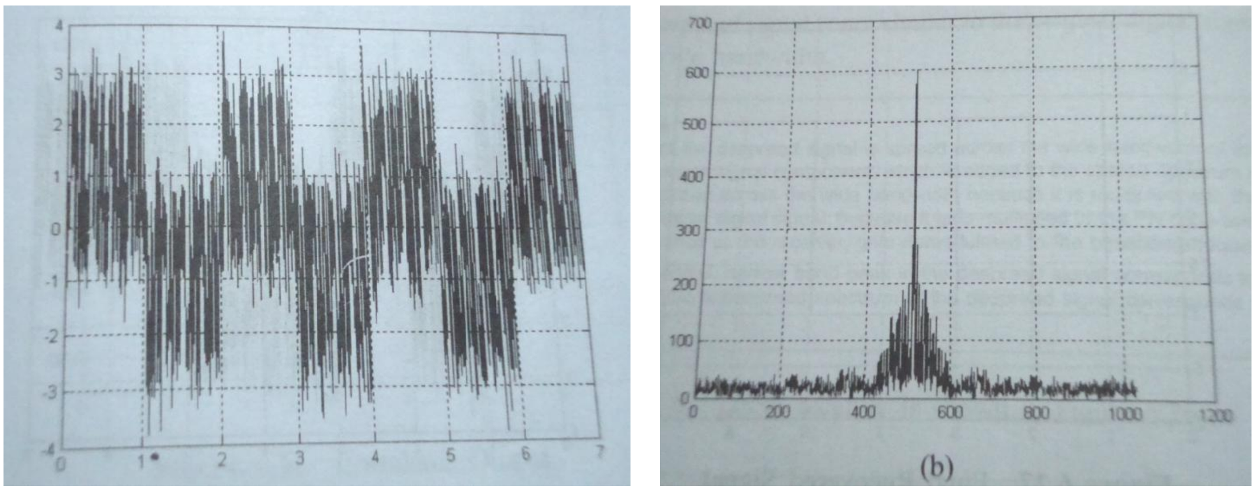


Figure 2.28 a) SS signal acted on by both Noise and Jammer b) Spectrum of the signal

The result of despreading this combined signal at the receiver and its spectrum is shown in Figure 2.29 a) and b) respectively. The spectrum of the despread signal has the central peak that corresponds to the original digital signal component, the wide spread spectrum corresponds to the jammer signal and the noise component.

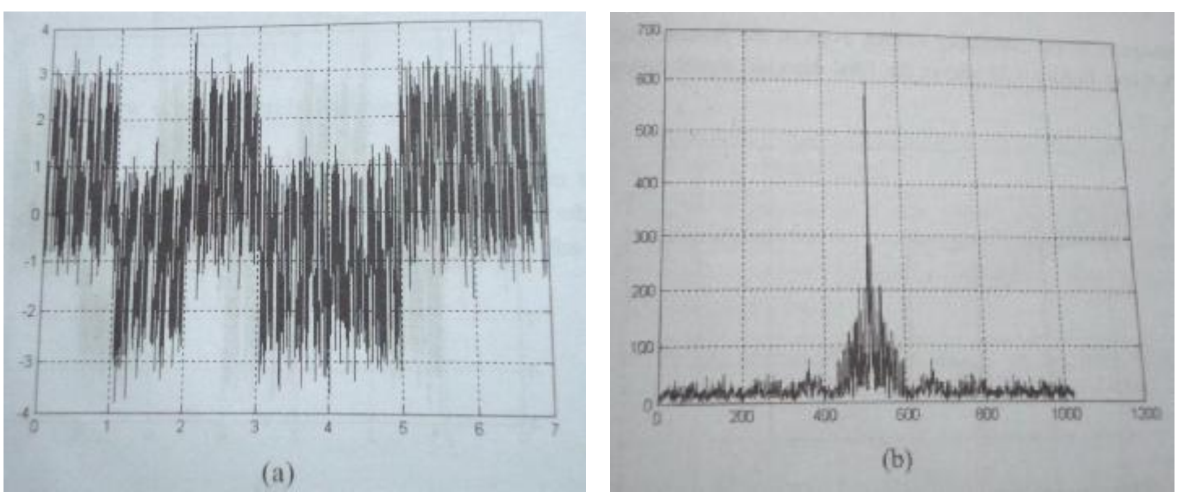


Figure 2.29 a) Despreading the Combined signal b) Spectrum of the signal

There is no ambiguity in the correlator output for the despread signal even in the presence of the jammer signal and the AWGN signal. This is shown in figure 2.30 and the final detected signal output from the decision is shown in figure 2.31.

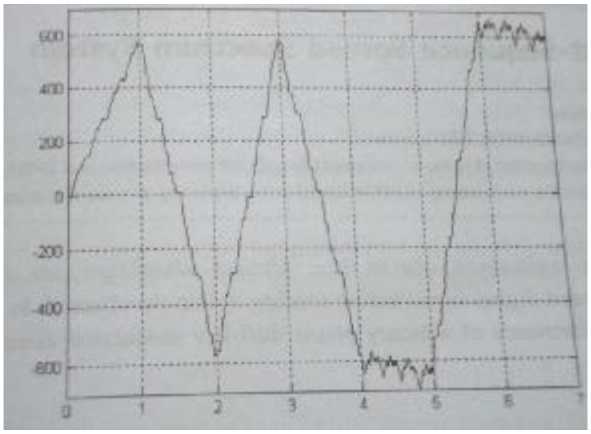


Figure 2.30 Correlator Output

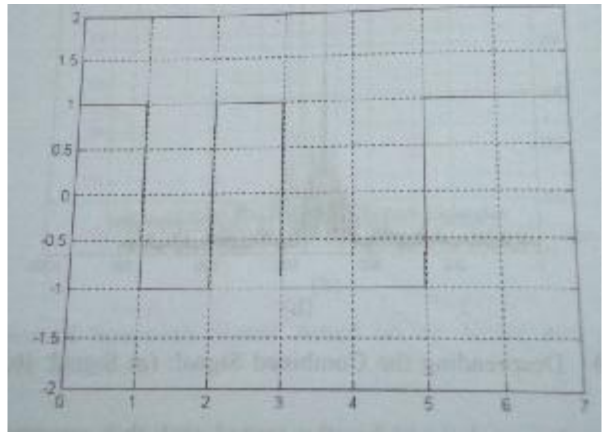


Figure 2.31 Final Digital Signal Output

The digital signal is perfectly recovered at the receiver end even in the presence of noise and jammer signal by the application of direct sequence spread spectrum technique to the baseband digital signal.

2.5 MODULATED DIRECT SEQUENCE SPREAD SPECTRUM SYSTEM

Digital modulation techniques, due to their inherent advantages, are often employed to modulate the baseband digital signal before sending it onto the channel. The performance of modulated DSSS is analyzed with Binary Phase Shift Keying (BPSK) modulation technique. The general block diagram of modulated DSSS system is shown in Figure 2.32.

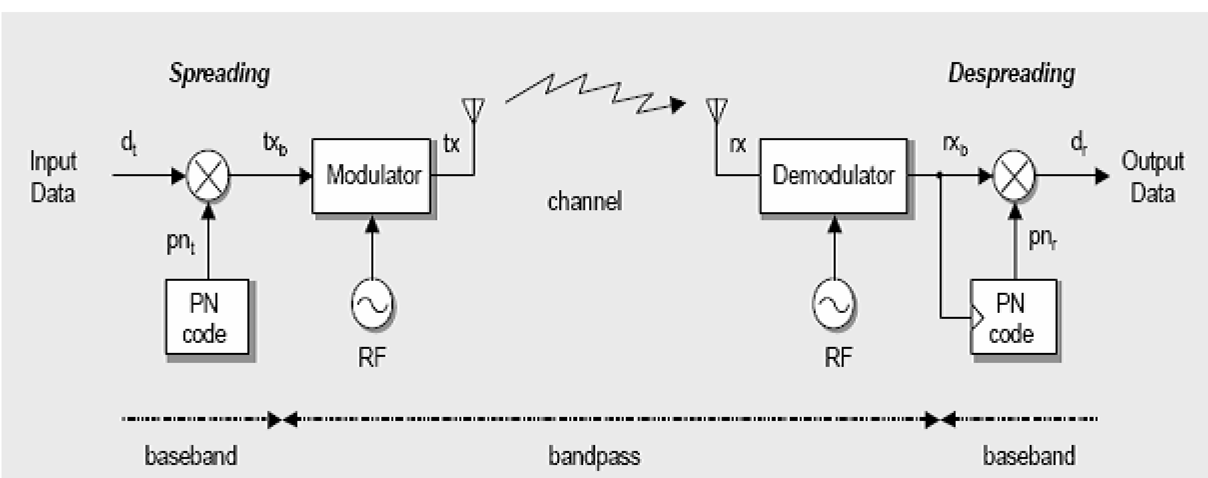


Figure 2.32 Block Diagram of Direct Sequence Spread Spectrum system

There are two versions of BPSK DSSS system:

- In the first type, the digital signal is first BPSK modulated using the BPSK carrier. The modulated signal is then spread across the wide bandwidth by means of the spreading code. At the receiver end, the signal is first despread by multiplication with the spreading code and then it is BPSK modulated.

- In second type, the digital system is first spread using the spreading code, just as in the baseband DSSS system. The resulting signal is then BPSK modulated using the BPSK carrier. At the receiver, the signal is first BPSK demodulated and then it is despread using the spreading code.

2.6 BPSK MODULATE DSSS SYSTEM (I type)

BPSK modulated DSSS of first type is shown in Figure 2.33. First the digital signal is BPSK modulated and is then multiplied with the spreading code to obtain the BPSK DSSS signal. This signal is then sent down the channel. At the receiver signal is despread by multiplication with the spreading code. It is then demodulated using the correlator receiver and the same reference carrier.

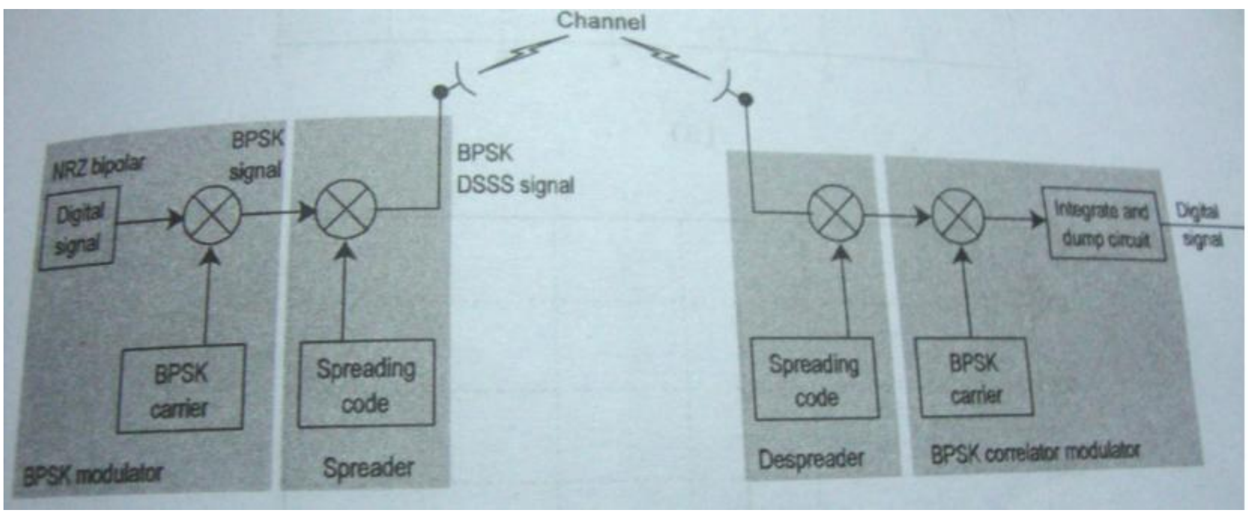


Figure 2.33 Block Diagram of BPSK Direct Sequence Spread Spectrum system

The original digital signal sequence is 1011001, which is BPSK DSSS modulated. The signal and its spectrum are shown in Figure 2.34 a) and b). The spectrum of the digital signal is narrow and is centered on the zero frequency. BPSK carrier signal and its spectrum are shown in Figure 2.35 a) and b) respectively.

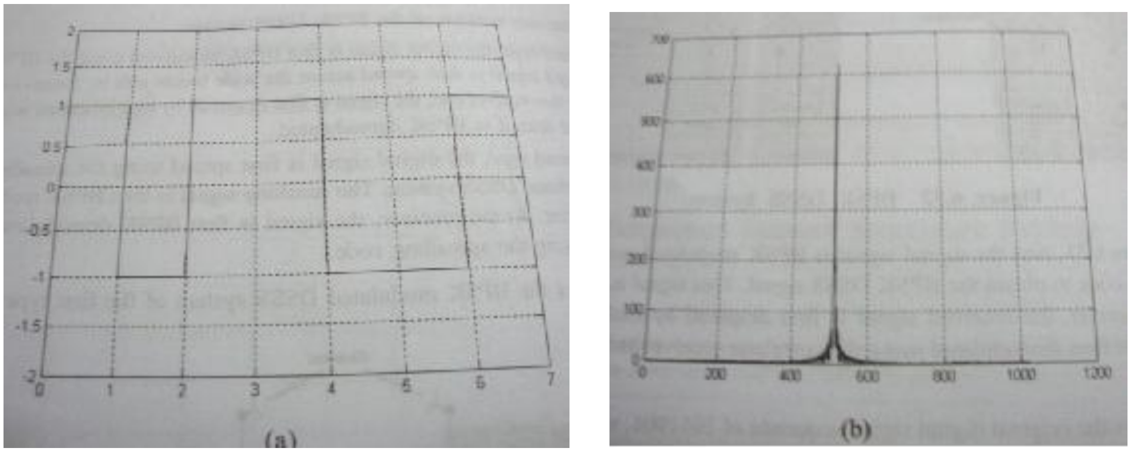


Figure 2.34 a) Digital Signal b) Spectrum of Digital signal

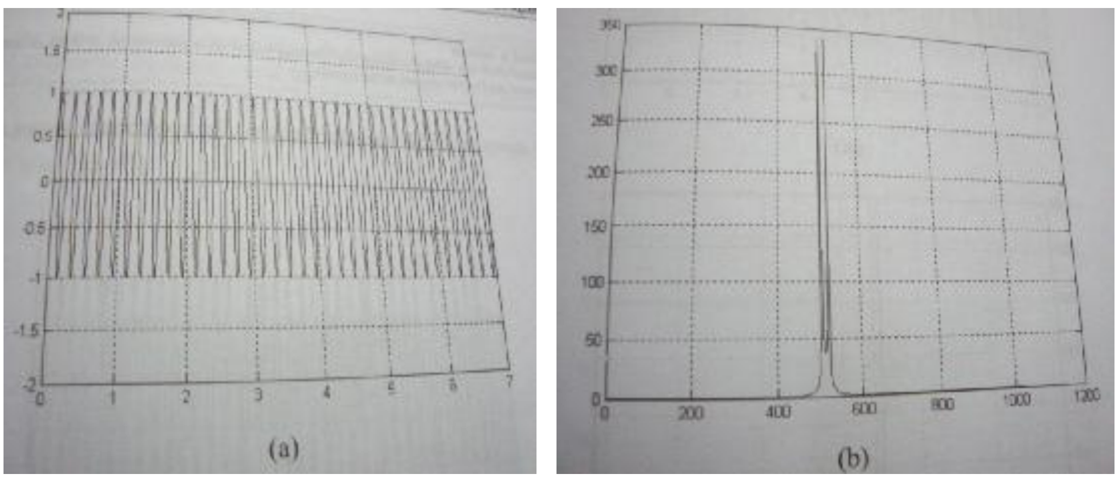


Figure 2.35 a) BPSK Carrier Signal b) Spectrum

The BPSK carrier is high frequency compared to the digital signal. The spectrum of the BPSK carrier has two peaks that are mirror image of each other about the zero frequency. The spectrum shows two plain peaks without any side bands of noise, as the carrier contained just a single frequency. The spectrum of the digital power does not have a single frequency but a combination of various frequencies.

BPSK modulated signal is shown in Figure 2.36 a) and its spectrum is shown Figure 2.36 b). The phase reversal is clearly observed at the bit transitions. The digital signal used is NRZ bipolar; the signal is simply multiplied with the BPSK carrier to obtain the BPSK modulated signal. The digital signal has to pass through a level generator that will generate the (+1, -1) levels corresponding to bits 1 and 0.

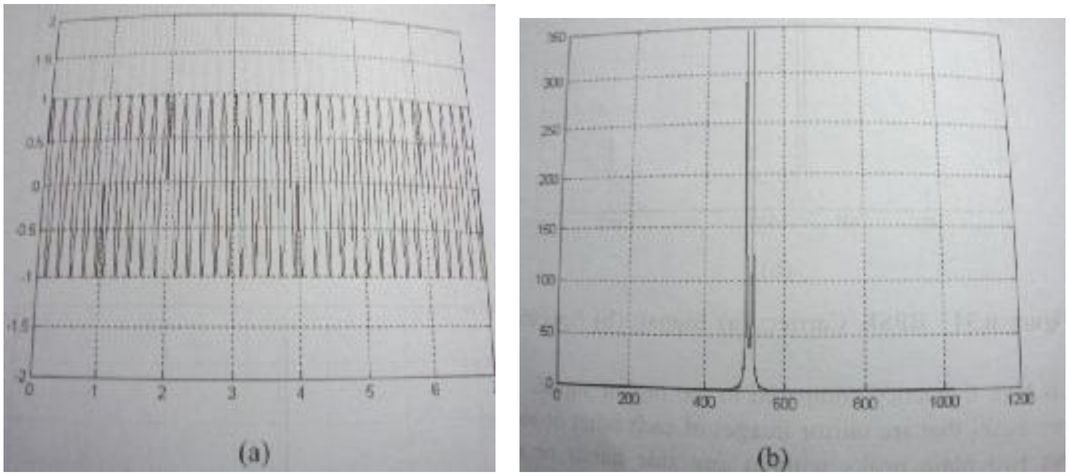


Figure 2.36 a) BPSK Modulated Signal b) Spectrum

PN code used for spreading and its spectrum is shown in Figure 2.37 a) and b) respectively. The PN code is of high bit rate and its spectrum is very wide compared to the baseband signal and the BPSK carrier.

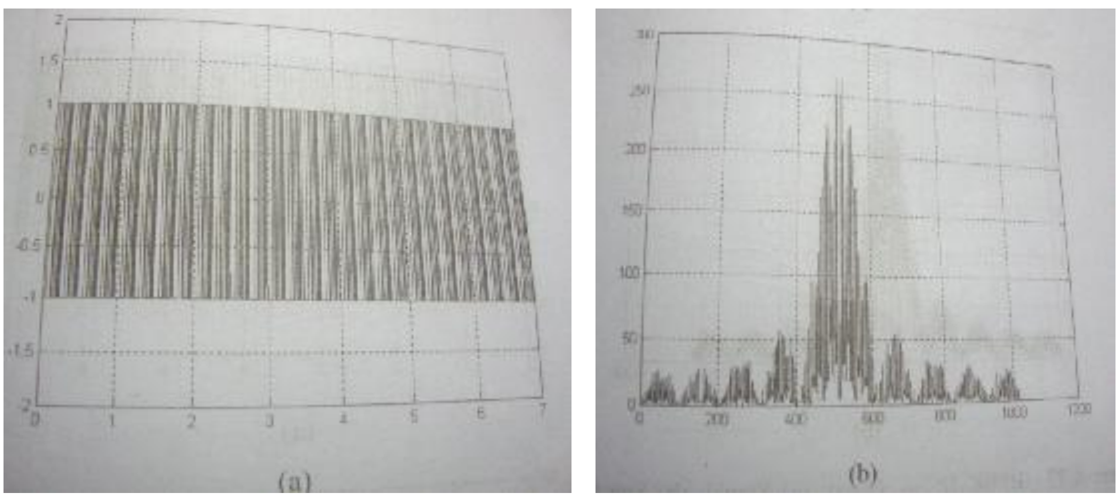


Figure 2.37 a) PN code b) Spectrum of PN code

The BPSK DSSS signal after the BPSK signal has been spread with the spreading code. This is shown in Figure 2.38 a) and its spectrum is shown in Figure 2.38 b). The signal spectrum is spread across a wide bandwidth. The BPSK components are also visible in the spectrum as two low-frequency peaks. This BPSK DSSS signal is then sent into the channel.

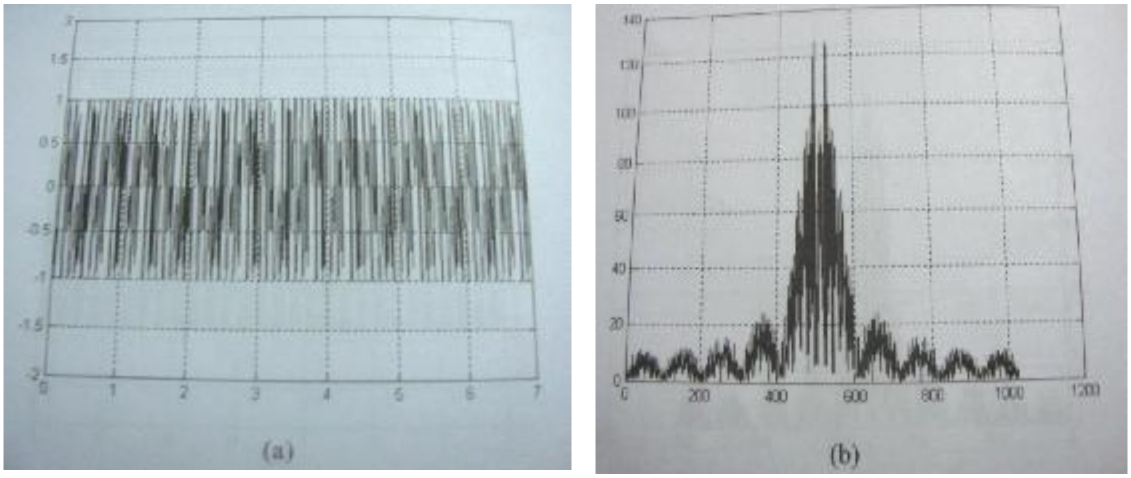


Figure 2.38 a) BPSK DSSS Signal b) Spectrum

At the receiving end the received signal is first despread with the same PN code used at the transmitting end. Figure 2.39 a) and b) shows the despread signal and its spectrum. The despread signal is the BPSK modulated signal. The spectrum of the signal is also the same as that of the BPSK signal generated at the transmitter end. This BPSK signal is demodulated to obtain the original digital signal sequence.

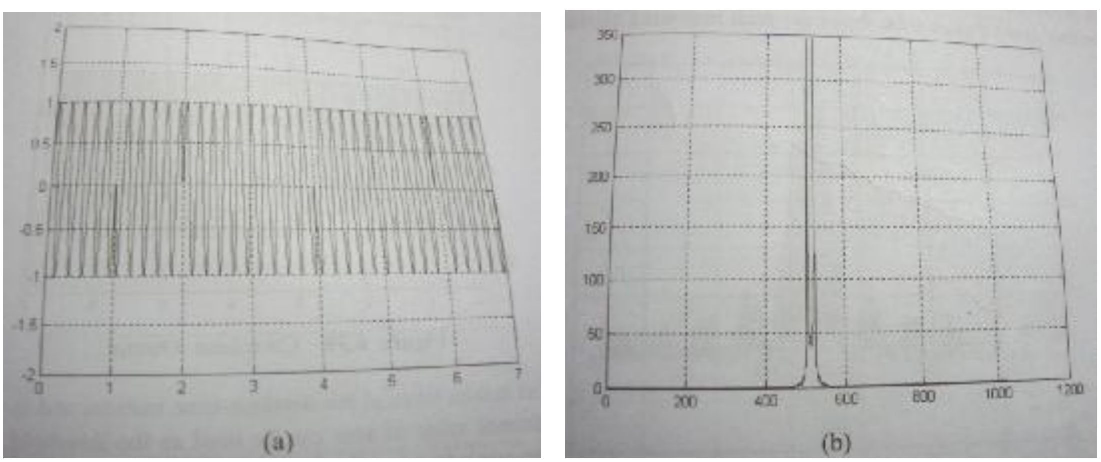
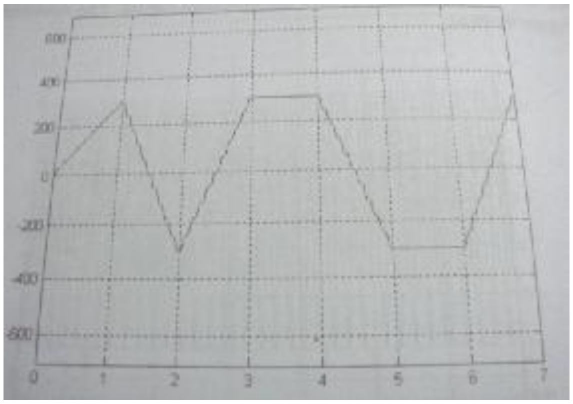


Figure 2.39 a) Despread Signal b) Spectrum

The correlator output of the BPSK demodulator is shown in figure 2.40 and the final recovered digital signal sequence is shown in Figure 2.41. The correlator output is then taken at the decision-time instants and is sent to the decision circuit, where a reference value of zero can be used as threshold value for detection.



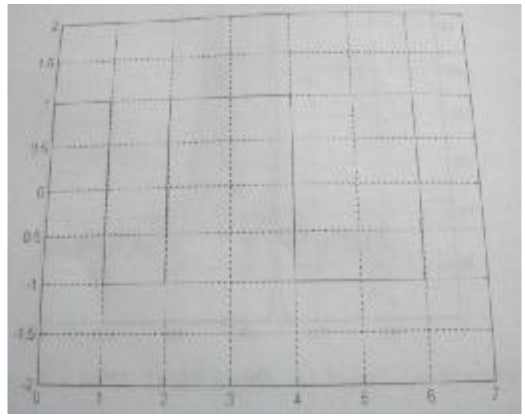


Figure 2.40 Correlator Output **Figure 2.41 Final Digital Signal Output**

DEMODULATION OF BPSK DSSS USING INCORRECT PN CODE

The unintended listener may not have the exact information about the chip rate of the PN code used or the spectrum of the PN code. To provide the best possible interception, the listener has this information and so is able to a PN code with the same chip rate and spectrum. However, the code generated is different from the one used at the transmitter. The incorrect PN code and the corresponding spectrum of the code is shown in figure 2.42 a) and b) respectively.

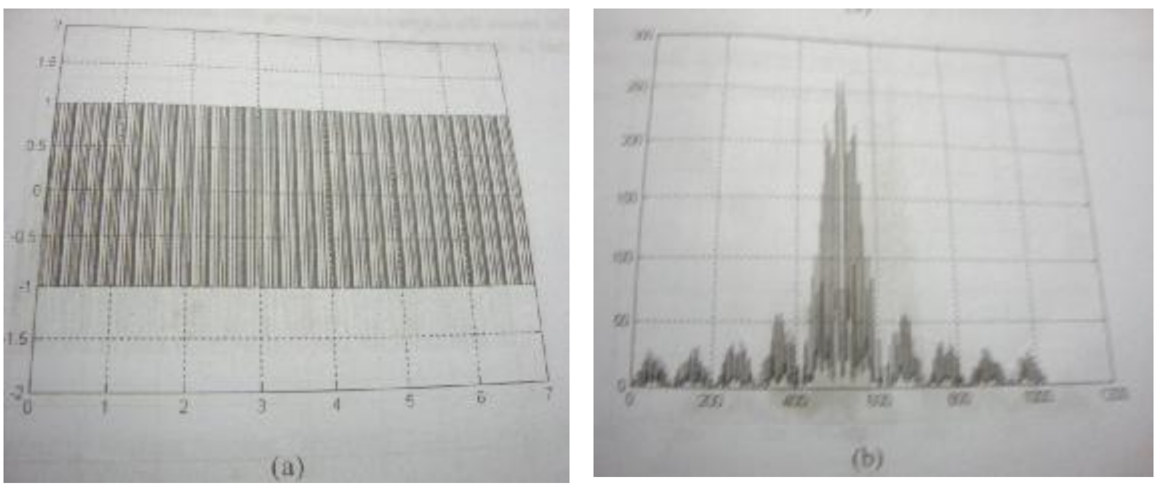


Figure 2.42 a) Incorrect PN code b) Spectrum of the PN code

The despread signal using this incorrect PN code and the spectrum of the despread signal is shown in figure 2.43 a) and b). The bit rate of the despread signal and its spectrum that the signal is not despread correctly. The despread signal should have a spectrum that is narrow like that of the original digital signal. But the spectrum is almost as wide as that of PN code.

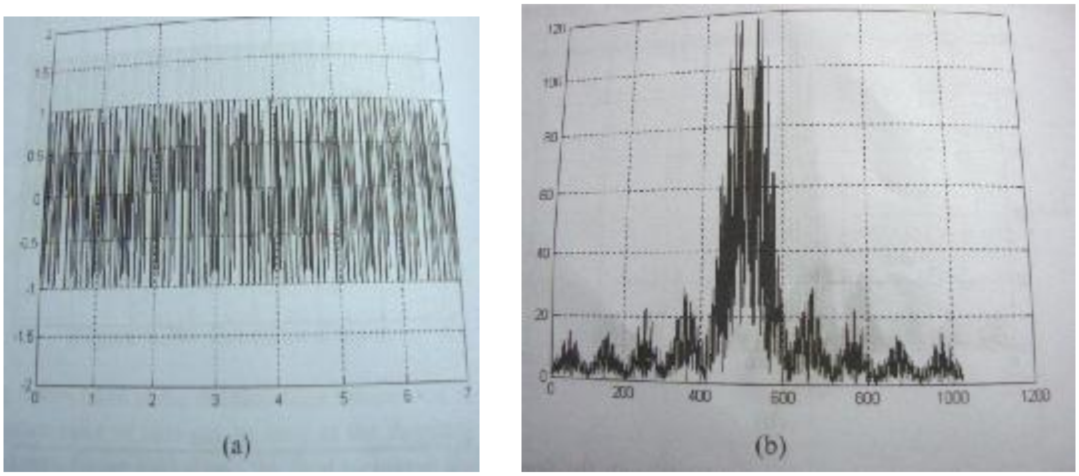


Figure 2.43 a) Despread Signal Using Incorrect PN code b) Spectrum

The peak value of the correlator output is very less compared to the actual correlator output, when the received signal is despread using the correct PN code. This is observed from the Figure 2.44 and Figure 2.45 shows the final recovered digital signal using the incorrect PN code.

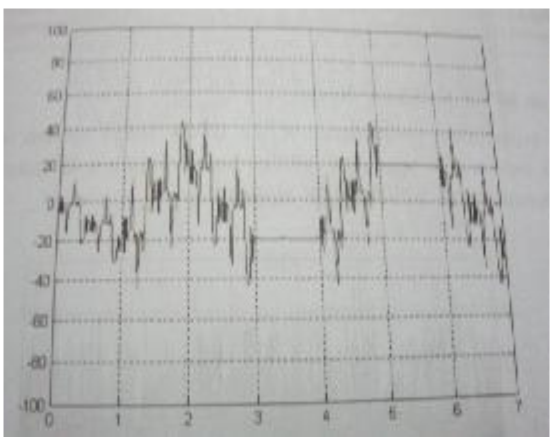


Figure 2.44 Correlator Output

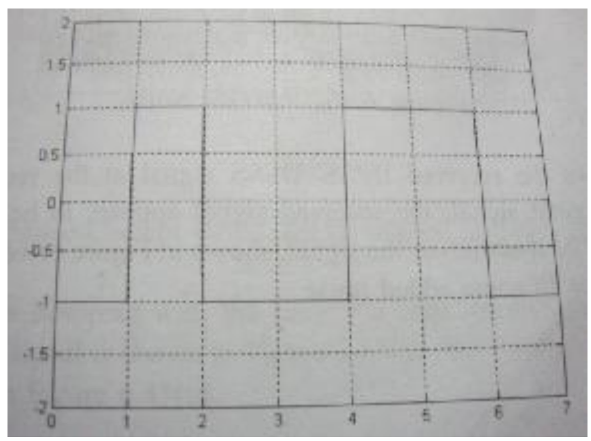


Figure 2.45 Final Digital Signal Output

The final recovered digital signal is 0100110, which is not the original digital sequence sent from the transmitter. Therefore, with an incorrect PN code, it is impossible to demodulate and decode the original information signal in the BPSK DSSS system.

PERFORMANCE OF BPSK DSSS IN NOISE

The performance of the BPSK DSSS system is analyzed in the presence of noise, which is the AWGN. The noise that is added by the channel to the BPSK DSSS signal is shown in Figure 2.46.

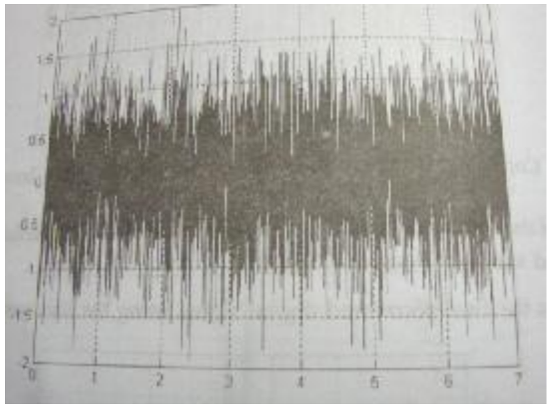
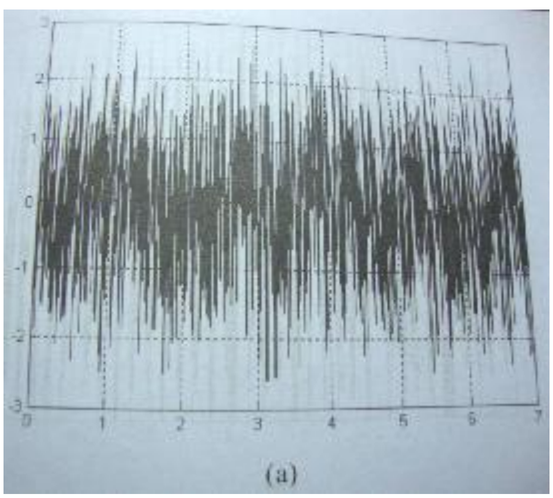


Figure 2.46 AWGN Noise

The received BPSK DSSS signal at the receiver system is shown in figure 2.47 a) and its spectrum is shown in Figure b). When compared to the original signal, the received signal appears to be completely distorted beyond recognition. The spectrum occupies the same bandwidth, with some added noise. The received signal is despread with the same PN code used at the transmitter end and the resulting despread signal and its corresponding spectrum is shown in Figure 2.48 a) and b) respectively.



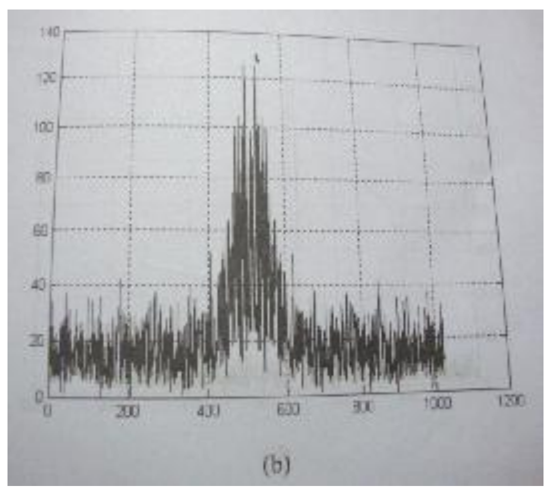


Figure 2.47 a) Noise corrupt BPSK –DSSS Signal b) Spectrum

The despread signal appears to be completely noisy. By looking at the signal, there is no way to recognize the phase-reversal positions. The spectrum of the despread signal shows the two low-frequency peaks that correspond to the BPSK signal. The noise that is spread cross whole bandwidth is due to the AWGN noise. The noise has almost negligible effect when it comes to recovering the digital signal. The correlator output for this despread signal is shown in Figure a) and the final recovered digital signal. The recovered digital signal is the same as the one that is transmitted. The BPSK system performed satisfactorily in the presence of AWGN noise.

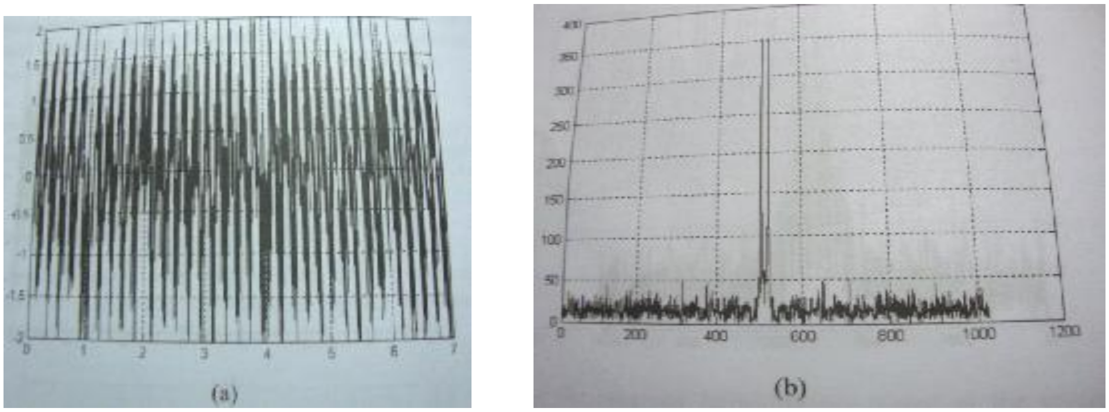
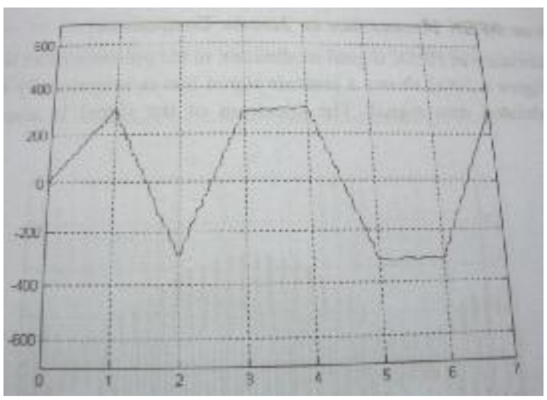


Figure 2.47 a) Despread Signal b) Spectrum



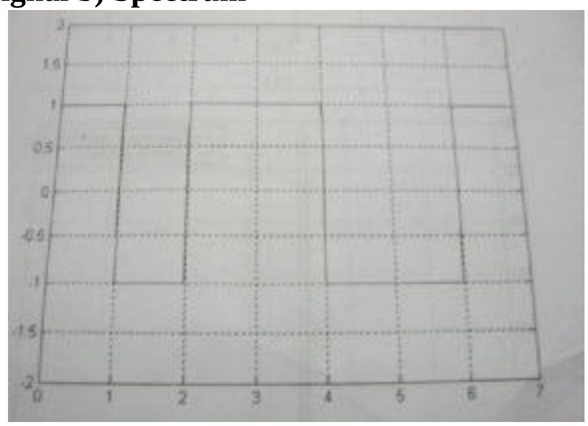


Figure 2.48 Correlator Output **Figure 2.49 Final Digital Signal Output**

PERFORMANCE OF BPSK MODULATION IN JAMMER ENVIRONMENT

The performance of a BPSK digital modulation in the presence of an intentional jammer is evaluated. Figure 2.50 a) shows a jammer signal that is intentionally developed to alter the BPSK modulated signal and its spectrum is shown in Figure 2.50 b). From the comparison of the jammer-signal spectrum and the BPSK signal, it is found that the jammer signal is exactly in the same frequency band as the BPSK signal.

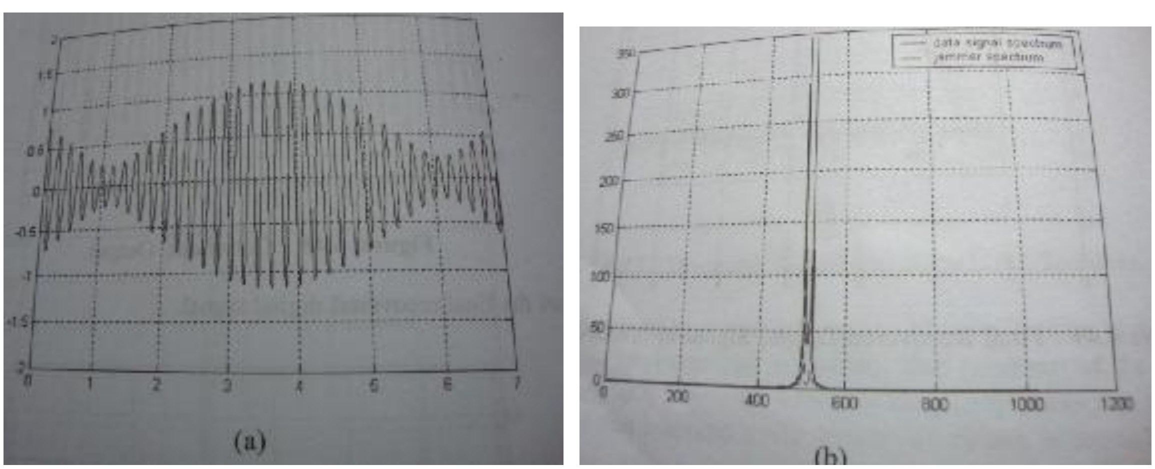


Figure 2.50 a) Jammer signal b) Spectrum

The resulting signal after the addition of the jammer signal is shown in Figure 2.51 a) and the signal's spectrum is shown in Figure 2.51 b). This signal is received at the BPSK receiver. The spectrum of the signal did not change in either its location or its magnitude. Hence the receiver will not be aware of the jammer and will treat the received signal as the actual signal sent by the transmitter station.

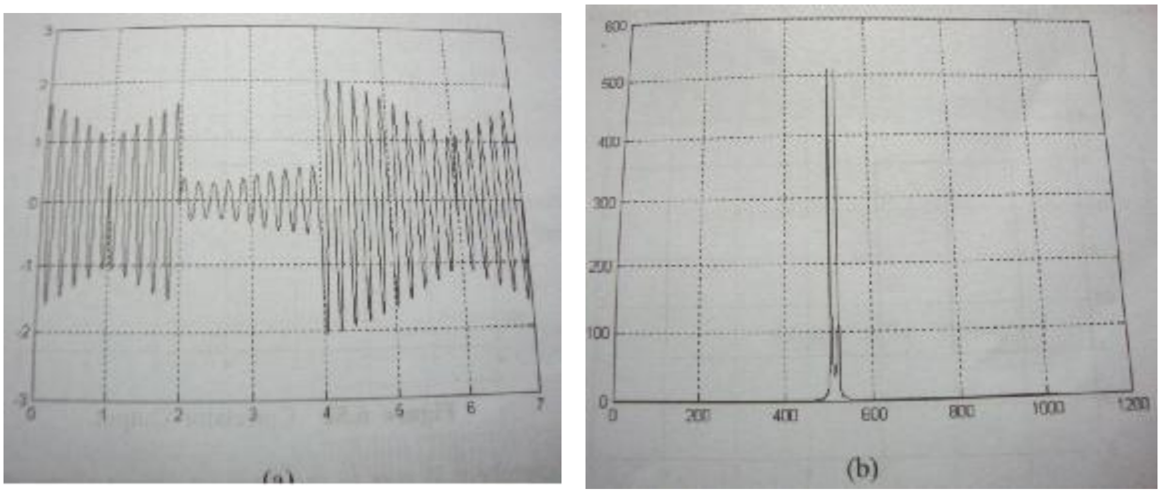
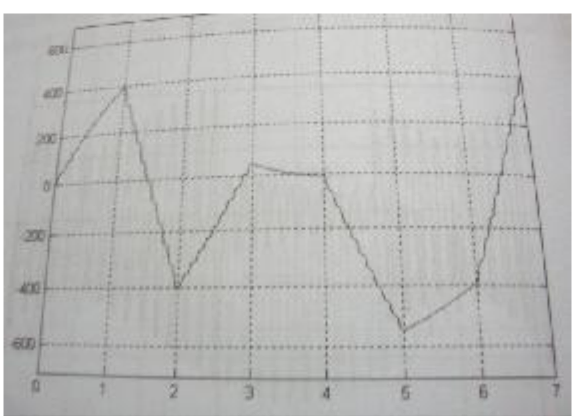


Figure 2.51 a) BPSK Signal after Jamming b) Spectrum

The correlator output for this received signal is shown in Figure 2.52 and the final demodulated output is shown in Figure 2.53. The output of the correlator is, sent to the decision-sampling instant. The demodulated output, when a zero reference is used as the threshold value. The final demodulated digital sequence is 1010001, which is different from the original signal modulated at the BPSK transmitter end. Hence BPSK modulation cannot effectively remove the effects of the jammer signal.



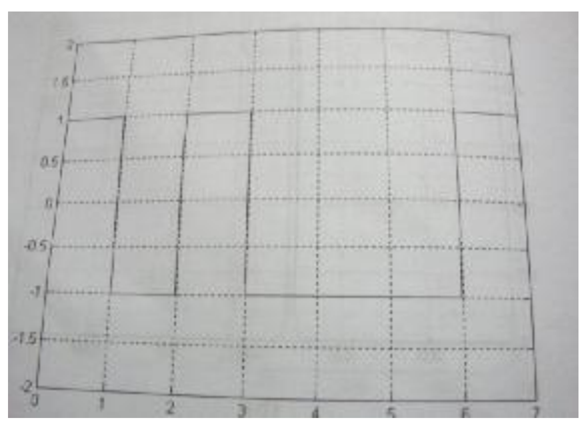


Figure 2.52 Correlator Output **Figure 2.53 Final Digital Signal Output**

PERFORMANCE OF BPSK DSSS IN JAMMER

In BPSK DSSS system, the signal that is sent down the channel is the BPSK signal, which is spread across a wide bandwidth. The jammer signal gets included to this wideband BPSK DSSS signal. The spread spectrum signal sent along the channel is shown in figure 2.53 a) and comparison of the jammer signal spectrum with the BPSK DSSS signal spectrum is shown in Figure 2.53 b). The spectrum of the jammer is very narrow compared to the spectrum of the spread spectrum signal because the jammer has information only about the frequency spectrum of the BPSK carrier signal.

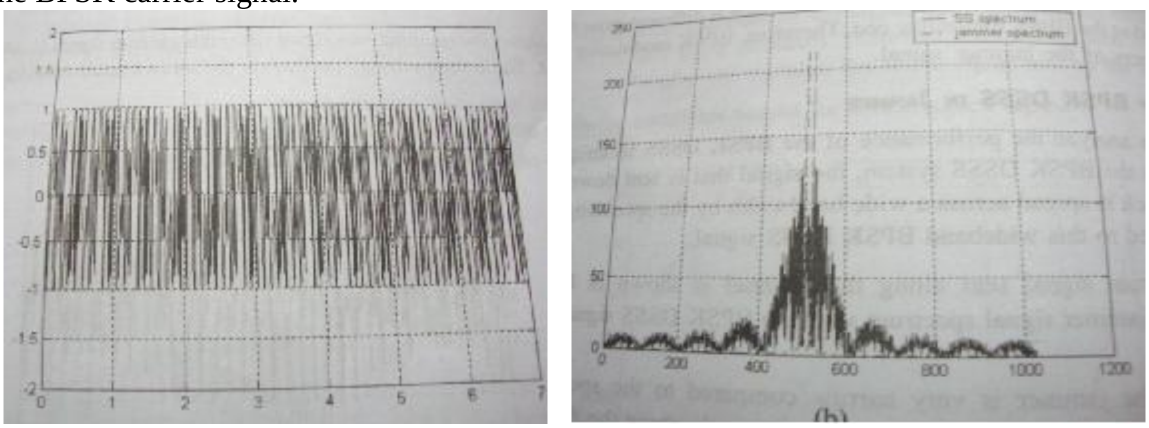


Figure 2.53 a) Spread Spectrum Signal   b) Signal with Jammer Spectrum

The resulting sum signal when this jammer signal is added to the spread spectrum and its corresponding spectrum is shown in Figure 2.54 a) and b) respectively. The addition of the jammer signal has changed the constant-amplitude envelope of the spread spectrum signal. However the spectrum of the resulting signal is unchanged except for a couple of peaks in the low-frequency region corresponding to the low-frequency jammer signal.

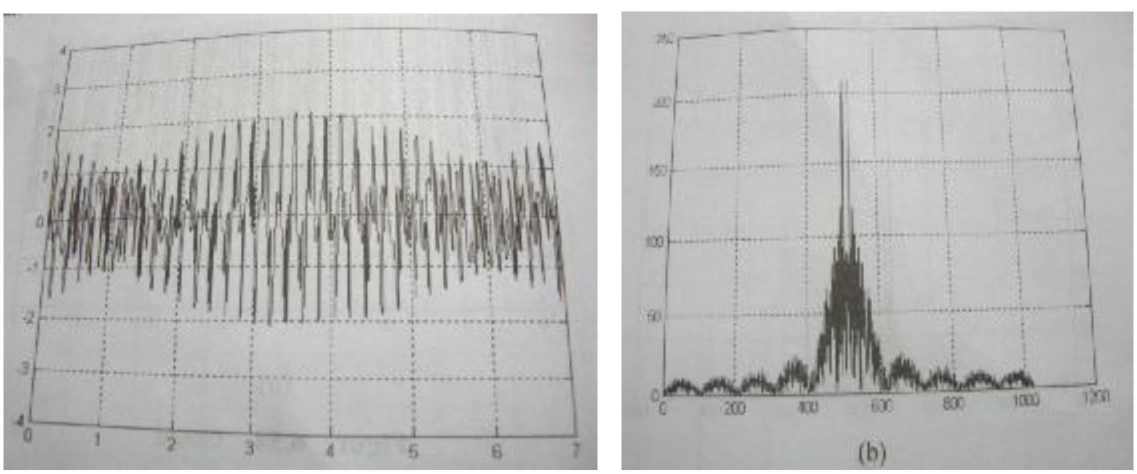


Figure 2.54 a) Sum Signal   b) Spectrum of Sum Signal

Figure 2.55 a) shows the despread signal that is obtained when this spread spectrum signal altered by the jammer signal is despread at the BPSK DSSS receiver system using the same PN code as at the transmitter. The spectrum is shown in figure 2.55 b).The phase reversal information is not quite obvious in the despread signal. The spectrum of the despread signal though narrow is not completely the same as the original BPSK modulated signal.

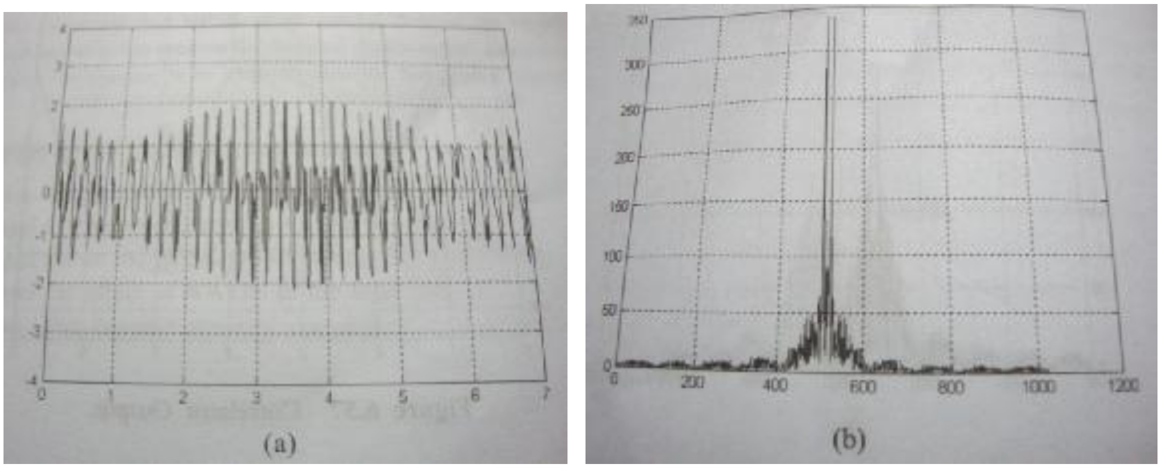
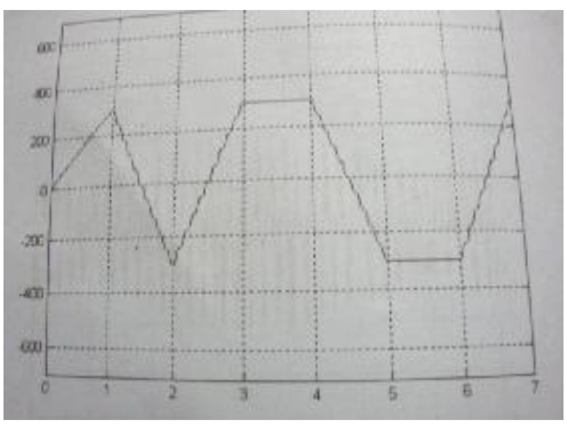


Figure 2.55 a) Despread Signal b) Spectrum

The correlator output of the BPSK demodulator is shown in Figure 2.56 a) and the final demodulated digital signal at the BPSK DSSS receiver system is shown in Figure 2.56 b). Even though the despread signal appears to be distorted, the jammer signal has negligible effect on the correlator output of the BPSK demodulator, when the DSSS technique is used in conjunction with the BPSK modulation.



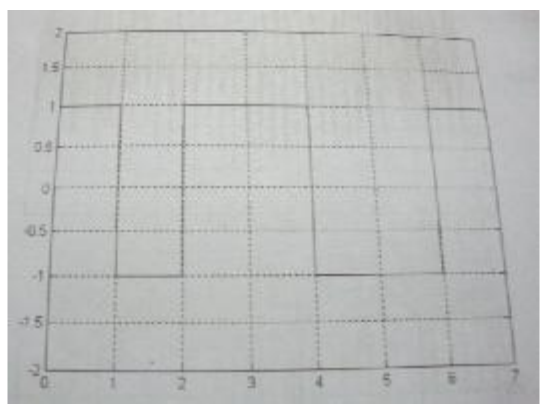


Figure 2.56 Correlator Output **Figure 2.57 Final Digital Signal Output**

The digital sequence recovered is 1011001, which is the digital signal that is modulated at the transmitter end. The BPSK alone cannot remove the negative effects of the jammer signal and has failed to recover the original digital signal. However, when BPSK is coupled with DSSS technique, it is able to recover the digital signal perfectly.

PERFORMANCE OF BPSK DSSS IN NOISE AND JAMMER

Figure 2.58 a) shows the resulting signal when both noise and jammer signal act on the BPSK DSSS signal. The spectrum of the signal shown in Figure 2.58 b) shows the effect of AWGN in the form of noise spread along the whole width of the spectrum. The jammer spectral component is identified by the two low-frequency peaks.

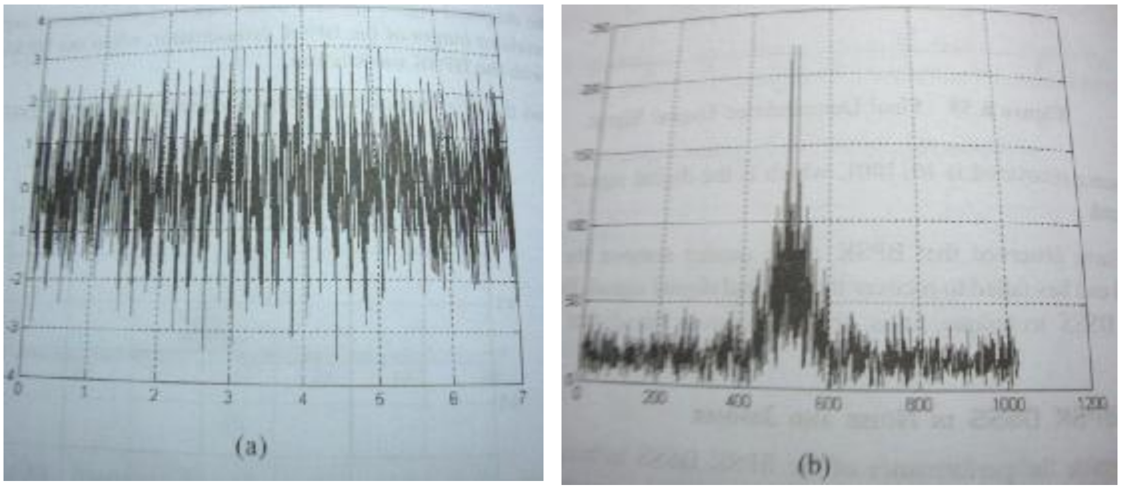


Figure 2.58 a) Combined Signal of Spread Spectrum, Noise and Jammer b) Spectrum

The combined signal received at the BPSK DSSS receiver. The signal is then despread using the PN code. The spectrum of the despread signal has two low-frequency components. These correspond to the original digital signal that is despread by multiplication with the PN code. However, the spectrum appears to be noisier than when only AWGN is present. This is because the jammer that is added in the channel now gets spread across the whole bandwidth of the PN code. The resulting despread signal is shown in figure 2.59 a) and the spectrum of the despread signal is shown in Figure 2.59 b).

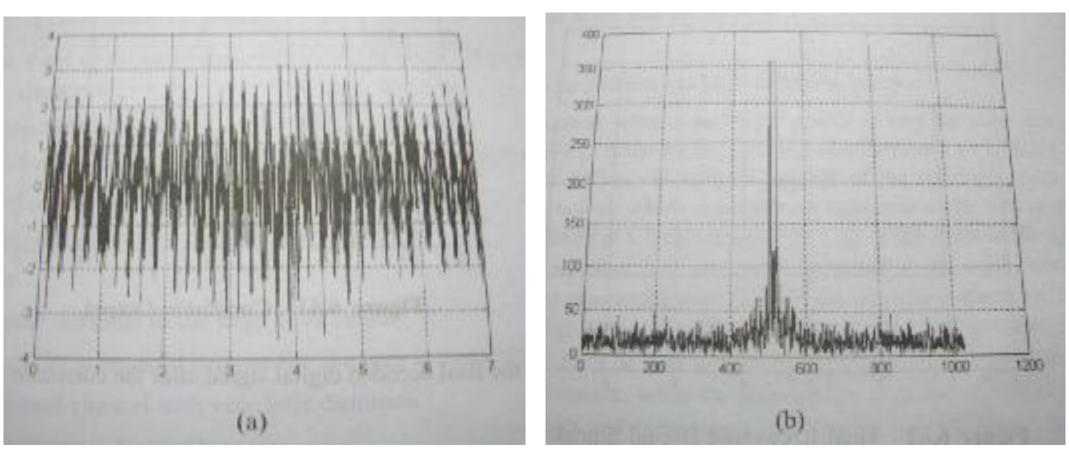


Figure 2.59 a) Despread Signal b) Spectrum

The correlator output seems to be without any obvious distortion that could cause error or ambiguity in detecting the digital signal. The correlator output for this despread signal is shown in Figure 2.60 and the final decoded digital signal after the correlator output is given to the decision circuit. This is shown in figure 2.61 and the digital sequence recovered is 1011001, which is the same as the actual digital signal modulated at the transmitted end. The BPSK DSSS system performed well even in the presence of noise and a jammer signal.

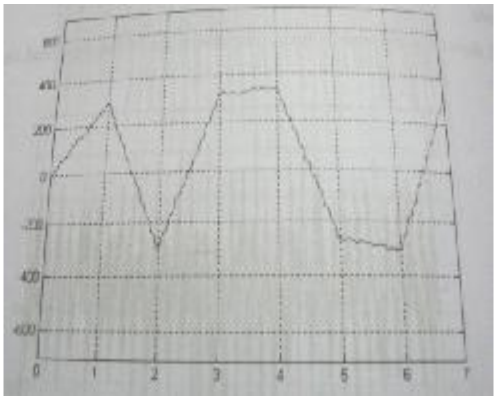


Figure 2.60 Correlator Output

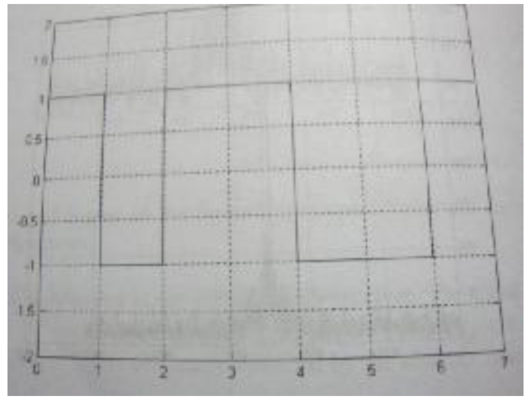


Figure 2.61 Final Digital Signal Output

2.7 BPSK MODULATE DSSS SYSTEM (II type)

The second method of BPSK DSSS is also the digital system is first spread using the spreading code, just as in the baseband DSSS system. The resulting signal is then BPSK modulated using the BPSK carrier. At the receiver, the signal is first BPSK demodulated and then it is despread using the spreading code.

BPSK DS- SS TRANSMITTER

- The information signal undergoes primary modulation by PSK, FSK or other narrow band modulation; but the most widely modulation scheme is BPSK (Binary Phase Shift Keying) and secondary modulation with spread spectrum modulation
- Spread spectra are obtained by multiplying the primary modulated signal and the square wave, called the PN sequence. In Direct Sequence-Spread Spectrum the baseband waveform is XOR by the PN sequence in order to spread the signal. After spreading, the signal is modulated and transmitted
- The equation 2.1 that represents this DS-SS signal and the block diagram of the BPSK DSSS Transmitter is shown in Figure 2.62 a)

$$x(t) = \sqrt{(2\, E_s/T_s)}\, [b(t) \otimes c(t)] \cos(2\pi f_c t + \theta) \qquad (2.1)$$

where

$b(t)$ is the data sequence
T_s is duration of data symbol
$c(t)$ is the PN spreading sequence
f_c is the carrier frequency
θ is the carrier phase angle at t=0

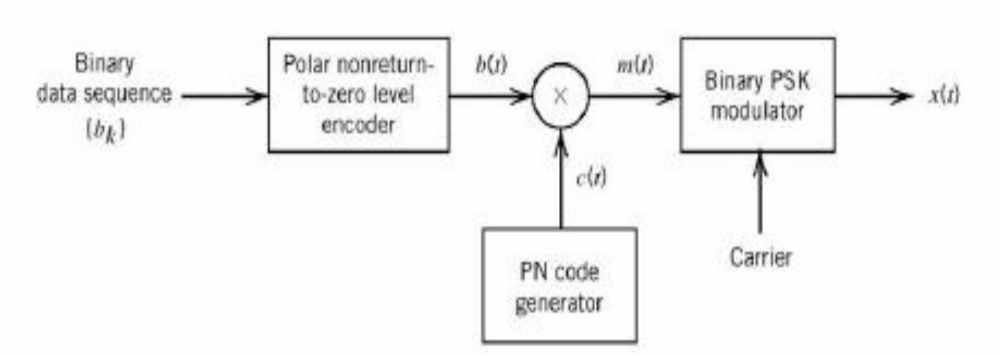


Figure 2.62 a) Block Diagram of DS- SS Transmitter

The block diagram of the BPSK DSSS Transmitter is shown in Figure 2.62 b). The demodulator, de-modulates the modulated (PSK) signal first, low Pass Filter the signal, and then de-spread the filtered signal, to obtain the original message.

The process is described by the following equation 2.2,

$$y(t) = [\ x(t) * \cos(2\ \pi\ fc\ t + \theta\ )\ ] \otimes c(t) \qquad 2.2$$

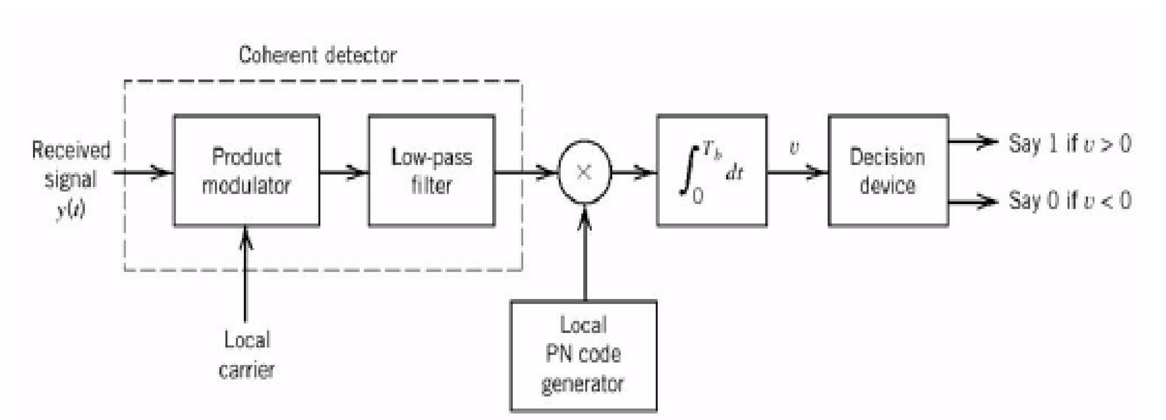


Figure 2.62 b) Block Diagram of DS- SS Receiver

It is clear that the spreading waveform is controlled by a Pseudo-Noise (PN) sequence, which is a binary random sequence. This PN is then multiplied with the original baseband signal, which has a lower frequency, which yields a spread waveform that has noise-like properties. In the receiver, the opposite happens, when the pass-band signal is first demodulated, and then de-spread using the same PN waveform. An important factor here is the synchronization between the two generated sequences.

If despreading is applied to the received diffuse wave, it returns to the PSK or FSK modulated wave resulting from primary modulation. Then, as with narrowband demodulation, if the despread wave and local signal are multiplied, and appropriate low pass processing is applied, the information signal is obtained. Despreading involves multiplying the same PN code as that used at the transmitting end for the receiving wave. At this time, it's necessary to synchronize the receiving wave and PN code. The interference component power that falls into the demodulation frequency band is reduced.

There are two processing methods on the receiving side, demodulation of the information signal after despreading, and obtaining a positive and negative PN code by multiplying the local signal by the receiving wave and despreading using correlation detection. With the former there is process gain but the problem of synchronization remains. With the latter, the spectrum density of the receiving wave itself is low and regeneration of the local carrier for performing synchronous detection is a problem.

The occurrence of errors is calculated using a stochastic process, so ultimately, using a spread spectrum results in fewer errors and this is why spread spectrum communication is resistant to interference.

2.8 ADVANTAGES AND LIMITATIONS OF DSSS SYSTEMS

The advantages include:

- Best noise Performance
- Very low probability of interception and therefore most difficult to detect
- Best anti-jam performance
- Best possible discrimination in multi-path environments

The limitations are:

- Long acquisition time due to large code length
- Fast code generator is required because the chip rate is much higher than the data rate
- Requires wideband channel with very little distortion
- Susceptible to the near-far problem

Far-Near Problem

Consider the situation, when a particular mobile is very far away from the mobile base-station. Since the mobile is very far from the base-station, the effective power of the received signal is very low. Consider another mobile, which is positioned right next to the first mobile. The power of the signal from the second mobile is very high compared to the weak power signal of the first mobile. Since two signals are positioned very close in the frequency spectrum, it is possible that the high powered signal may completely overpower the low powered signal. As a result, the first mobile will not be able to receive the signal from the mobile station. The problem repeats at the base-station, when the base-station is trying to receive a low powered signal from a far-off mobile and at the same time another mobile, which is in close proximity to the base-station sends out a high powered signal that is close in spectrum to the weak signal frequency. This causes the signal to be garbled and causes distortion. This situation is commonly referred as near-far problem in wireless communication.

2.9 JAMMING CONSIDERATIONS

The Jamming Game

- The goal of a jammer are to deny reliable communications to his adversary and to accomplish this at minimum cost
- The goals of the communicator is to develop a jam-resistant communication system under the following assumptions:
    - Complete invulnerability is not possible
    - The jammer has a prior knowledge of most system parameters, frequency bands, timings, traffic
    - The jammer has no prior knowledge of PN spreading or hopping codes
- Protection against jamming waveforms is provided purposely making the information-beating signal occupy a bandwidth far in excess of minimum Bandwidth necessary to transmit it
- This has the effect of making the transmitted signal assume noise like appearance so as to blend into background
- The transmitted signal is thus enabled to propagate through the channel undetected by anyone who may be listening
- Spread spectrum is a method of "camouflaging" the information-bearing signal

Tools of the Anti-Jam Communicator

- The usual design goal for an anti-jam (AJ) communication system is to force a jammer to expend its resources over
    - a wide-frequency band
    - for a maximum time
    - from a diversity of sites
- The most prevalent design options are
    - Frequency diversity – by the use of DSSS and FHSS techniques
    - Time diversity – by the use of time hopping
    - Spatial discrimination – by the use of a narrow beam antenna, which forces a jammer to enter the receiver via an antenna sidelobe and hence, suffer a 20 to 25 dB disadvantage
    - Combination of the previous three options

2.10 CLASSIFICATION OF JAMMERS

- Broad band noise Jamming
- Partial-band noise Jamming
- Multi-tone Jamming
- Pulse Jamming
- Repeat-back Jamming
- BLADES systems

Pulse Jammer

A pulse noise jammer is one that transmits pulses of band-limited white Gaussian noise with a total average power of J. The effect of the jammer is more if it is successful in modelling its central frequency and bandwidth to be identical with the communication channel.

The probability of bit error is given by

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

Where,

$Q(x) = 0.5*\mathrm{erfc}(x/\sqrt{2})$

E_b - Energy per bit

N_0 - Receiver front end thermal noise

While transmitting the noise pulse within the receiver bandwidth, the noise jammer will cause the receiver front-end thermal noise power spectral density to increase.

$$N_0' = N_0 + (N_j/\rho)$$

Where,

N_0' - New thermal noise power spectral density of the receiver

N_j - Jammer power spectral density

ρ - duty factor

The jammer power spectral density N_J is related to the total average noise power of the jammer by the following relation:

$$N_J = J/BW$$

Where BW –bandwidth of the transmitted signal

The new increased average probability of error is

$$\overline{P_b} = (1-\rho)Q\left(\sqrt{\frac{2E_b}{N_0}}\right) + \rho\, Q\left(\sqrt{\frac{2E_b}{N_0 + N_j/\rho}}\right)$$

Compared to noise introduced by jammer, the thermal noise of RADAR, the first term in the above equation is negligible. The probability of bit error is given by

$$\overline{P_b} = \rho\, Q\left(\sqrt{\frac{2E_b\rho}{N_j}}\right)$$

Using the Q function and maximizing the resultant error probability with respect to ρ, the maximum value of the duty factor is

$$\rho = N_j / 2E_b$$

The corresponding error probability is

$$\overline{P}_{b,\max} \approx \frac{1}{\sqrt{2\pi e}} \frac{1}{2 E_b / N_j}$$

As a result, the maximized new error probability is proportional to N_J, the jammer noise power spectral density.

Partial Band Jammer

The partial-band noise jammer, which consists of noise whose total power, is evenly spread over some frequency band that is a subset of the total spread bandwidth. Owing to the smaller bandwidth, the partial-band noise jammer is easier to generate than the barrage noise jammer. A PBNJ where the jammer transmits noise over a fraction of the total spread spectrum signal band spreads noise of total power J evenly over some frequency range of bandwidth W_j, which is a subset of the total spread bandwidth W_{ss}.

The fraction ρ is defined as the ratio

$$\rho = \frac{w_j}{w_{ss}}$$

where r is (0, 1) which is the fraction of the total spread spectrum band that has noise of power spectral density

$$\frac{J}{W_J} = \frac{J}{W_{SS}} \cdot \frac{W_{ss}}{W_J} = N_J / \rho$$

$$N_J = N_J / \rho$$

A Gaussian noise jammer is chosen to restrict its total power J to a fraction r of the full SS bandwidth W_{ss}. A corresponding degraded SNR level

$$\frac{E_b}{N_t} = \frac{\rho\, E_b}{N_t}$$

It is assumed that the jammer hops the jammed band over W_{ss}, relative to the FH dwell time $1/R_h$, but often enough to deny the FH system the opportunity to detect that it is being jammed in a specific portion of W_{ss} and take remedial action.

Multitone Jammer

In tone jamming (TM), one or more jammer tones are strategically placed in the spectrum where they are placed and their number affects the jamming performance. Two types of tone jamming are

- Single-tone jamming (STJ) places a single tone where it is needed
- Multiple-tone jamming (MTJ) which distributes the jammer power among several tones

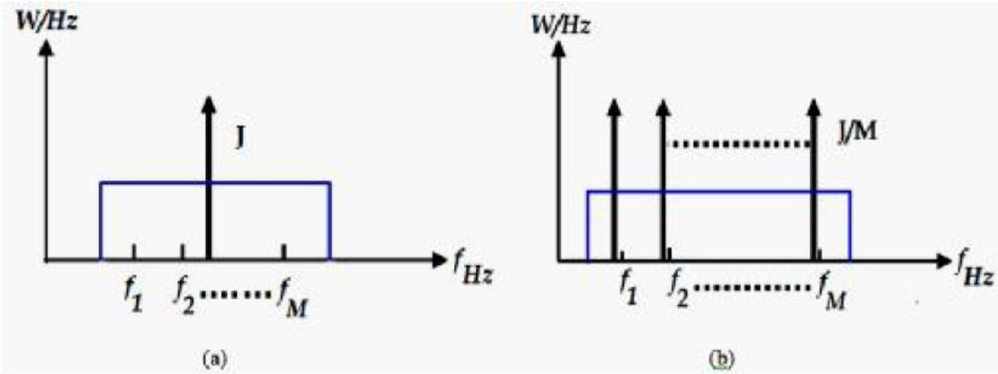


Figure 2.63 Power spectral density of (a) STJ and (b) MTJ

Single-tone jamming (STJ)

A jamming signal transmitted at a single frequency was shown in Figure 2.63. Thus, the jamming signal is a continuous wave tone placed at a single frequency. STJ is also called spot jamming. A continuous wave tone centered at the carrier frequency is well known to be a good jamming signal against a direct sequence system. The STJ can be expressed as:

$$J(t) = A \cos(2\pi f_0 t + \theta)$$

Where:

A is the amplitude

f_0 is frequency of STJ and

θ is the initial phase which is uniform distribution between $(0, 2\pi)$.

Multiple-tone jamming (MTJ)

The multitone jammer, which is the tone equivalent of the partial-band noise jammer. A jamming signal transmitted at multi tones, randomly placed, or placed at specific frequencies. Tone-jamming is impulse signal having high power. So, MTJ means there are some impulse signals in certain frequency of whole bandwidth. Because total power of jamming signal is limited, the more the number of tone jamming signals is increasing, the more power of each tone jamming signal is lower.

For MTJ using N_T equal power tones each tone-jamming signal can be expressed as:

$$j(t) = \sqrt{\frac{2P_J}{N_T}} \sum_{j=1}^{N_T} \cos(2\pi f_j t)$$

Where P_J and N_T are total jamming power and the number of multi tone jamming respectively. P_J is divided into same power equally depending on the number of multi tone jamming and f_j is jamming frequency. All phases are assumed to be independent and uniformly distributed over $(0, 2\pi)$.