Performance Analysis of Spread Spectrum Techniques

Astha Singh[1]
Faculty Electronics Engg. Dept.
Dr. Ambedkar Institute Of Technology For Handicapped
Kanpur (UP), India
engineerastha@gmail.com

Abstract

In this paper we had analyzed the spread spectrum techniques in a broader sense, in context of their performance. Spread spectrum is an increasingly important form of encoding for wireless communications. It can be used to transmit either analog or digital data, using an analog signal. The basic idea of spread spectrum is to modulate the signal so as to increase significantly the bandwidth (spread the spectrum) of the signal to be transmitted. It was initially developed for military and intelligence requirements. The use of spread spectrum makes jamming and interception more difficult and provides improved reception.

Keywords: SS, DSSS, FHSS, BPSK, SFH, FFH.

1. INTRODUCTION

Spread spectrum technology has blossomed from a military technology into one of the fundamental building blocks in current and next-generation wireless systems. From cellular to cordless to wireless LAN (WLAN) systems, spectrum is a vital component in the system design process.

Since spread-spectrum is such an integral ingredient, it's vital for designers to have an understanding of how this technology.
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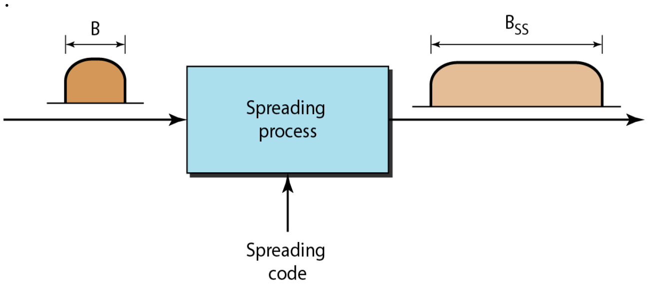

Fig 1: Spreading Process

Spread spectrum [1] is more precise: an RF communications system in which the baseband signal bandwidth is intentionally spread over a larger bandwidth by injecting a higher frequency signal. As a direct consequence, energy used in transmitting the signal is spread over a wider bandwidth, and appears as noise. The ratio (in dB) between the spread baseband and the original signal is called processing gain [2]. Typical spread-spectrum processing gains run from 10dB to 60dB.
To apply a spread-spectrum technique, simply inject the corresponding spread-spectrum code somewhere in the transmitting chain before the antenna (receiver). (That injection is called the spreading operation.) The effect is to diffuse the information in a larger bandwidth. Conversely, you can remove the spread-spectrum code (called a despreading operation) at a point in the receive chain before data retrieval. A despreading operation reconstitutes the information into its original bandwidth. Obviously, the same code must be known in advance at both ends of the transmission channel. (In some circumstances, the code should be known only by those two parties.)

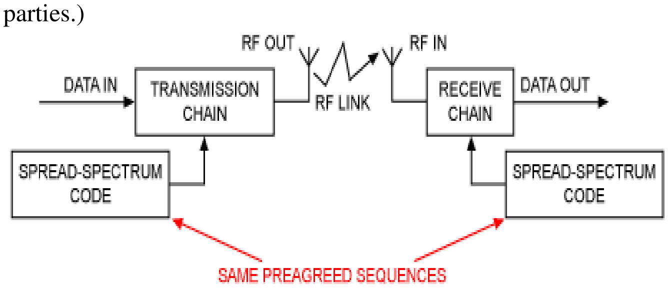

Fig2: Spread-spectrum communication system.

Spread-spectrum transmitters use similar transmit power levels to narrowband transmitters. Because spread-spectrum signals are so wide, they transmit at a much lower spectral power density, measured in watts per hertz, than narrow band transmitters. This lower transmitted power density characteristic gives spread-spectrum signals a big plus. Spread-spectrum and narrowband signals can occupy the same band, with little or no interference. This capability is the main reason for all the interest in spread spectrum today.

The use of special pseudo noise (PN) codes in spread-spectrum communications makes signals appear wide band and noise-like. It is this very characteristic that makes spread-spectrum signals possess a low LPI. Spread-spectrum signals are hard to detect on narrow band equipment because the signal's energy is spread over a bandwidth of maybe 100 times the information bandwidth **(Figure 2)**.

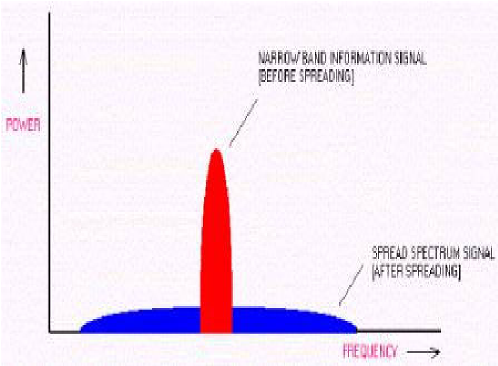

Fig 2: In a spread-spectrum system, signals are spread across a wide bandwidth, making them difficult to intercept, demodulate, and intercept

The spread of energy over a wide band, or lower spectral power density, also makes spread-spectrum signals less likely to interfere with narrowband communications. Narrowband communications, conversely, cause little to no interference to spread spectrum systems because the correlation receiver effectively integrates over a very wide bandwidth to recover a spread spectrum signal. The correlator then "spreads" out a narrowband interferer over the receiver's total detection bandwidth.

Since the total integrated signal density or signal-to-noise ratio (SNR) at the correlator's input determines whether there will be interference or not. All spread spectrum systems have a threshold or tolerance level of interference beyond which useful communication ceases. This tolerance or threshold is related to the spread-spectrum processing gain, which is essentially the ratio of the RF bandwidth to the information bandwidth.

Spread spectrum uses wideband, noise-like signals that are hard to detect, intercept, or demodulate. Additionally, spread-spectrum signals are harder to jam (interfere with) than narrow band signals. These low probability of intercept (LPI) and anti-jam (AJ) features are why the military has used spread spectrum for so many years. Spread-spectrum signals are intentionally made to be a much wider band than the information they are carrying to make them more noise-like.

1.1 Bandwidth Effects of the Spreading Operation

Spread-spectrum modulation is applied on top of a conventional modulation such as BPSK[3] or direct conversion. One can demonstrate that all other signals not receiving the spread-spectrum code will remain as they are, that is, unspread.

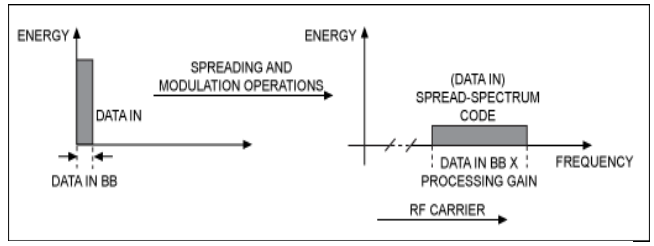

Fig 3: Spreading operation spreads the signal energy over a wider frequency bandwidth.

1.2 Bandwidth Effects of the Despreading Operation

Similarly, despreading can be seen in Figure4.

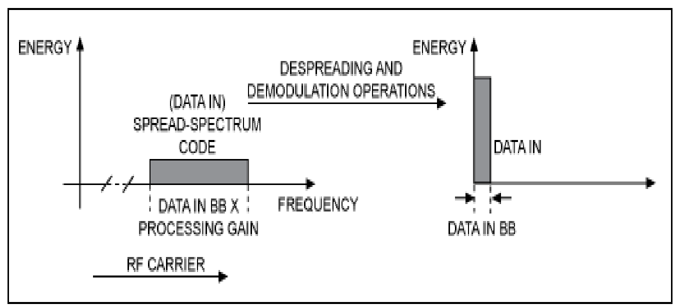

Fig 4. The despreading operation recovers the original signal.

Here a spread-spectrum demodulation has been made on top of the normal demodulation operations. One can also demonstrate that signals such as an interferer or jammer added during the transmission will be spread during the despreading operation!

1.3 Waste of Bandwidth Due to Spreading Is Offset by Multiple Users

Spreading results directly in the use of a wider frequency band by a factor that corresponds exactly to the "processing gain". Therefore spreading does not spare the limited frequency resource. That overuse is well compensated, however, by the possibility that many users will share the enlarged frequency band (**Figure 5**).

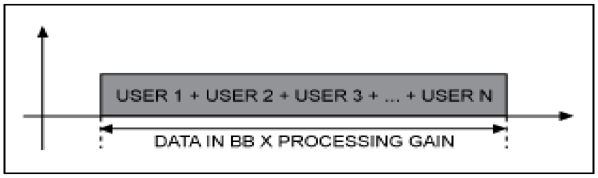

Fig 5. The same frequency band can be shared by multiple users with spread-spectrum techniques.

Spread Spectrum is a wideband technology. In contrast to regular narrowband technology, the spread spectrum process is a wideband technology. W- CDMA and UMTS, for example, are wideband technologies that require a relatively large frequency bandwidth, compared to narrowband radio.

1.4 Spread Spectrum Techniques:

1. **Direct Sequence Spread Spectrum**

DSSS significantly improves protection against interfering (or jamming) signals, especially narrowband and makes the signal less noticeable. It also provides security of transmission if the code is not known to the public. These reasons make DSSS very popular by the military. In fact, DSSS was first used in the 1940s by the military.

DSSS can also be used as a multiple access technique, whereby several different pseudo random spreading codes are being used simultaneously. This multiple access technique is better known as Direct Sequence CDMA.

DSSS is e.g. used in IEEE 802.11b and Zigbee.

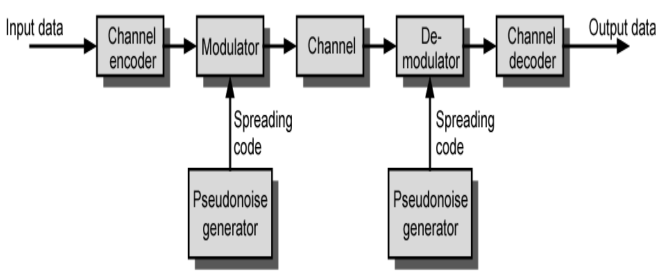

Fig 6: Block diagram for Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum (DSSS) [4] is spread spectrum technique where by the original data signal is multiplied with a pseudo random noise spreading code. This spreading code has a higher chip rate (this is bitrate of the code) which results in a wideband time continuous scrambled signal.

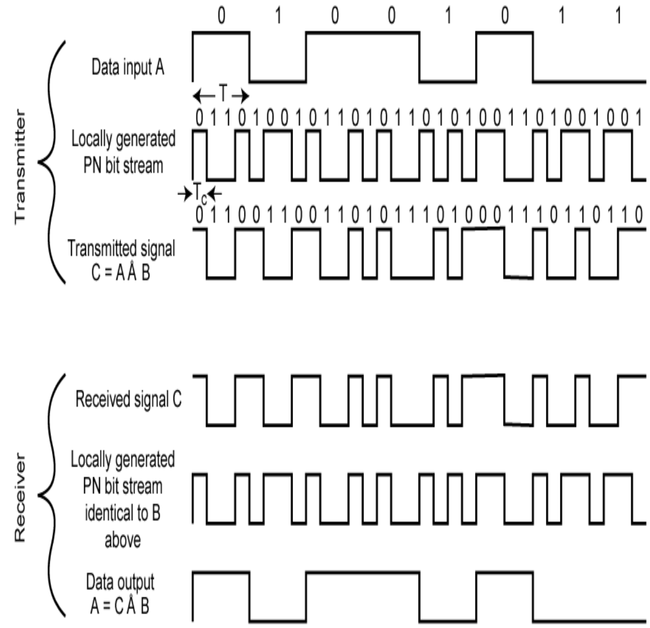

Fig 7: Example of Direct Sequence Spread Spectrum

information bit of one inverts the spreading code bits in the combination, while information bit of zero causes the spreading code bits to be transmitted without inversion. The combination bit stream has the death rate of the original spreading code sequence, so it has a wider bandwidth than the information stream. In this example, the spreading code bit stream is clocked t four times the information rate.

1.4.1 DSSS using BPSK

Rather than represent binary data with 1 and 0, it is more convenient for our purpose to use + I and - 1 to represent the two binary digits. In that case, a BPSK signal can be represented as:

Where,A= amplified of signal

F_c=carrier frequency

d(t)=the discrete function that takes on the value +1 for one bit time if bit in the stream bit is 1 and -1 for the one bit time if the corresponding bit in the bit stream 0.

To produce the DSS signal, we multiply the proceeding by C(t),which is the PN sequence taking on values of +1 and -1:

$$\mathbf{S(t)=Ad(t)c(t)cos(2\pi f_c t)}$$

At the receiver the incoming signal is multiplied again by c(t) but c(t)×c(t)=1 and therefore original signal is recovered:

$$\mathbf{S(t)c(t)=Ad(t)\ c(t)\ c(t)\ cos(2\pi f_c t)=S_d(t)}$$

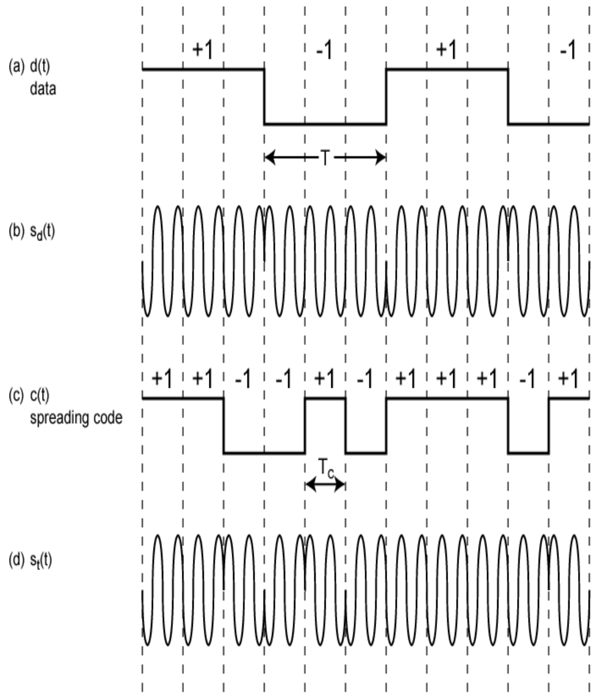

Fig 8: Waveform of Direct Sequence Spread Spectrum Using BPSK Example

1.5 Frequency hopping system

Frequency-hopping spread spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using pseudorandom sequence known to both transmitter and receiver. It is utilized as a multiple access method in the frequency-hopping code division multiple access (FH-CDMA) scheme.

Types of frequency hopping are:

(I) Slow frequency hopping

(2) Fast frequency hopping

1.5.1 Slow-frequency hopping- In slow frequency hoping the symbol rate R5 of the MFSK signal is an integer multiple of the hop rate R. That means several symbols are transmitted corresponding to each frequency hopping. Therefore each frequency hopping several symbols i.e. frequency hopping takes place slowly.

1.5.2 Fast frequency hopping- In the fast frequency hopping the hop rate R is an integer multiple of the MFSK symbol rate R. That means during the transmission of one symbol, the carrier frequency will hop several times. Therefore each symbol transmission several frequencies hops. Thus- the frequency hopping takes place at a fast rate.

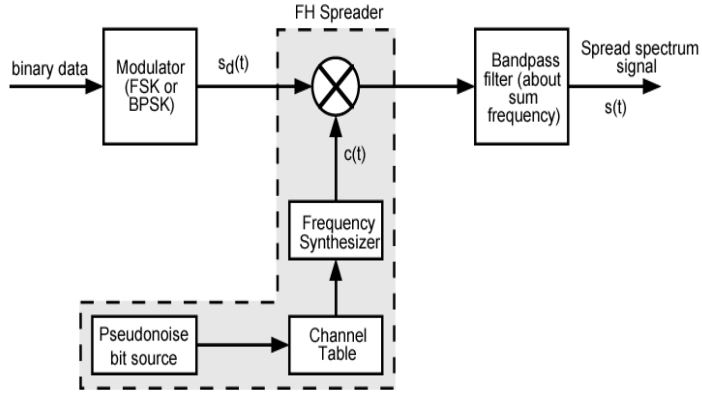

Fig 9.1: Frequency Hopping Spread Spectrum System (Transmitter)

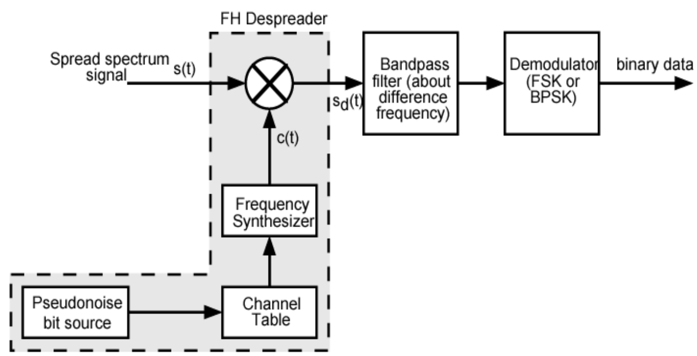

Fig 9.2: Frequency Hopping Spread Spectrum System (Receiver)

Fig.9.1 & 9.2 shows the Block diagram of frequency hopping system. For transmission, binary data are fed into a modulator using some digital - to analog encoding scheme, such as frequency shift keying (FSK) or binary phase shift keying (BPSK). A PN source serves as an index into a table of frequencies each K bit on PN source specifies one of the 2k carrier frequencies.

At each successive interval a new carrier frequency is selected. This frequency is then modulated by the signal produced from the initial modulator to produce a new signal with the same shape. On reception, the spread spectrum signal is demodulated using the same sequence of PN-derived frequencies and then demodulated to produce the output data.

1.6 Advantages of Spread Spectrum

Spread-spectrum systems provide some clear advantages to designers. As a recap, here are nine benefits that designers can expect when using a spread-spectrum-based wireless system.

1.6.1. Reduced crosstalk interference: In spread-spectrum systems, crosstalk interference is greatly attenuated due to the processing gain of the spread spectrum system as described earlier. The effect of the suppressed crosstalk interference can be essentially removed with digital processing where noise below certain threshold results in negligible bit errors. These negligible bit errors will have little effect on voice transmissions.

1.6.2. Better voice quality/data integrity and less static noise*:* Due to the processing gain and digital processing nature of spread spectrum technology, a spread-spectrum-based system is more immune to interference and noise. This greatly reduces consumer electronic device-induced static noise that is commonly experienced by conventional analog wireless system users.

1.6.3. Lowered susceptibility to multipath fading: Because of its inherent frequency diversity properties (thanks to wide spectrum spread), a spread spectrum system is much less susceptible to multipath fading.

1.6.4. Inherent security: In a spread spectrum system, a PN sequence is used to either modulate the signal in the time domain (direct sequence systems) or select the carrier frequency (frequency hopping systems). Due to the pseudo-random nature of the PN sequence, the signal in the air has been "randomized". Only the receiver having the exact same pseudo-random sequence and synchronous timing can de-spread and retrieve the original signal. Consequently, a spread spectrum system provides signal security that is not available to conventional analog wireless systems.

1.6.5. Co-existence: A spread spectrum system is less susceptible to interference than other non-spread spectrum systems. In addition, with the proper designing of pseudo-random sequences, multiple spread spectrum systems can co-exist without creating severe interference to other systems. This further increases the system capacity for spread spectrum systems or devices.

1.6.6. Longer operating distances: A spread spectrum device operated in the ISM band is allowed to have higher transmit power due to its non-interfering nature. Because of the higher transmit power, the operating distance of such a device can be significantly longer than that of a traditional analog wireless communication device.

1.6.7. Hard to detect: Spread-spectrum signals are much wider than conventional narrowband transmission (of the order of 20 to 254 times the bandwidth of narrowband transmissions). Since the communication band is spread, it can be transmitted at a low power without being detrimentally by background noise. This is because when de-spreading takes place, the noise at one frequency is rejected, leaving the desired signal.

1.6.8. Hard to intercept or demodulate: The very foundation of the spreading technique is the code use to spread the signal. Without knowing the code it is impossible to decipher the transmission. Also, because the codes are so long (and quick) simply viewing the code would still be next to impossible to solve the code, hence interception is very hard.

1.6.9. Harder to jam: The most important feature of spread spectrum is its ability to reject interference. At first glance, it may be considered that spread spectrum would be most effected by interference. However, any signal is spread in the bandwidth, and after it passes through the correlator, the bandwidth signal is equal to its original bandwidth, plus the bandwidth of the local interference. An interference signal with 2 MHz bandwidth being input into a direct-sequence receiver whose signal is 10 MHz wide gives an output from the correlator of 12 MHz. The wider the interference bandwidth, the wider the output signals. Thus the wider the input signal, the less its effect on the system because the power density of the signal after processing is lower, and less power falls in the band pass filter.

1.7 Conclusions

DSSS provides 11 Mbps capacity links, but it is a sensitive technology (collocation, multipath, near/far, Bluetooth). The most limiting factor, multipath, may be minimized by using the technology for short distances or in point to point applications. **FHSS[5]** provides only 3 Mbps capacity links, but it is a very robust technology, with excellent behavior in harsh environment characterized by large areas of coverage, multiple collocated cells, noises, multipath, Bluetooth presence, etc. The technology allows easy cellular point- to-multipoint deployment, providing excellent reliability.

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