Spread Spectrum Communication Tutorial with an Example in CDMA (June 2008)

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***Abstract*—This is a tutorial of the benefit spread spectrum techniques has over other modulation schemes. Direct Sequencing Spread Spectrum will be used to demonstrate, robustness to noise, and robustness to jamming. Also an example in CDMA will be used to demonstrate multiple access.**

***Index Terms*—Pseudonoise coded communication, Code division multiaccess,**

I. Introduction

SPREAD spectrum techniques transmits information over a wide range of frequencies. The bandwidth required is much greater then the bandwidth of the signal being modulated. This “spreading” is accomplished by modulating the signal twice. Once with a carrier and then modulating the result with a Pseudorandom sequence. The spreading of the spectrum has some great benefits like resistance to jamming, resistance to interception, resistance to fading, and multiple access capabilities (e.g. CDMA). This tutorial report will focus on Direct Sequencing Spread Spectrum (DSSS) systems and demonstrate some of the benefits of spreading the spectrum. Later there will be an example of Code Division Multiple Access (CDMA).

II. Direct Sequencing Spread Spectrum

A. Overview

This method of spreading the spectrum, directly modulates the signal that is already modulated using a wideband spreading waveform. Pseudorandom noise is often used to spread the spectrum. This is what is used in this tutorial.

The expression for BPSK is

$$\theta(t) = A \cdot p(t)\cos(\omega_c t) \qquad (1)$$

where p(t) is a binary switching function with possible states of ±1.

The equation for spreading the spectrum is

$$x(t) = A \cdot PN(t)\, p(t)\cos(\omega_c t) \qquad (2)$$

where PN(t) is the pseudorandom sequence used for spreading the spectrum.

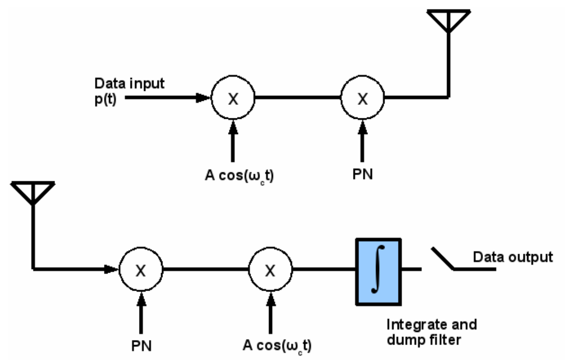

Fig. 1. DS-BPSK spread spectrum modulation and demodulation.

B. Modulation

The modulation and demodulation of the input signal is quite simple to understand and implement. Fig 1. shows the modulation process. First the input signal p(t) is modulated with a carrier. For the purpose of this tutorial the amplitude A equals one. It is then modulated again with a wideband signal (PN). This second modulation is what spreads the spectrum. The signal is then transmitted. Fig. 2. shows the input signal after the binary switching function, the pseudorandom sequence PN, the product of p(t) and PN, and the modulated signal. Fig. 3. shows the spectrum of each, notice that the spectrum of PN is very wide compared to the input signal.

C. Demodulation

Demodulation first multiplies the received signal by PN. It needs to be the same PN for correct demodulation. Next it is multiplied by the carrier and then goes through an integrator and dump filter. Even with noise in the spectrum the process of integrating and dumping filter will decide if the bit is ±1. At some point the noise will cause interfere with the signal. But DSSS can handle high signal to noise levels.

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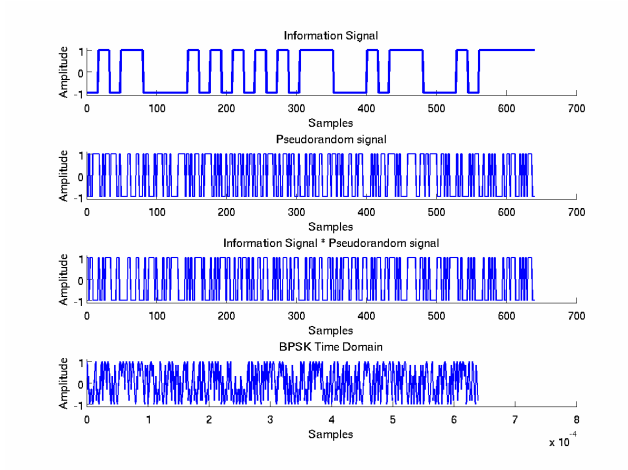

Fig. 2. Top: Input signal p(t) Center Top: Pseudorandom (PN) signal Center Bottom: p(t)*PN Bottom: Modulated Signal
x(t) = p(t)*PN*cos(ω_Ct)

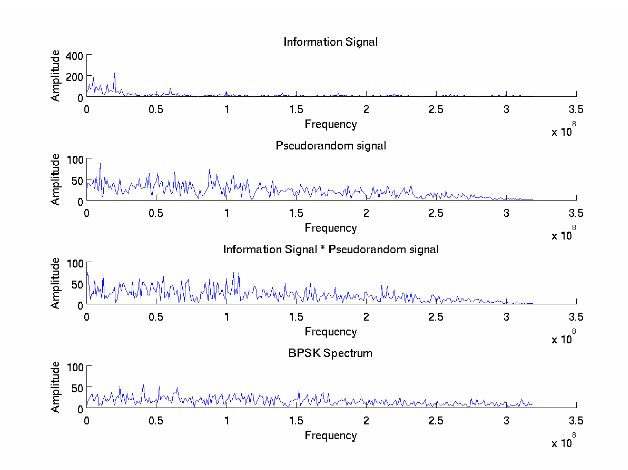

Fig. 3. Spectrum of the Input Signal p(t), Pseudorandom Signal (PN), p(t)*PN, and the modulated signal.

D. Robustness to noise

One of the advantages of spreading the spectrum is it's ability to be demodulated even when the signal to noise ratio is small. In this case a s/n ratio of one was attained with not bit errors.

Fig. 4. shows the transmitted signal with no noise and with noise. Fig.5. shows the noise level at the same level as the DSSS signal. This signal was demodulated with zero bit errors. As the noise increased above the level of the signal the original information started to have bit errors. Fig. 6. shows the noise level at 1.1 time the signal.

Other modulation schemes are more susceptible to noise. For example DSB-LC or AM is very sensitive to noise. Fig. 7. has two plots one with the modulated AM signal with no noise and the other with noise. After demodulation the signal looks distorted. (Fig. 8.).

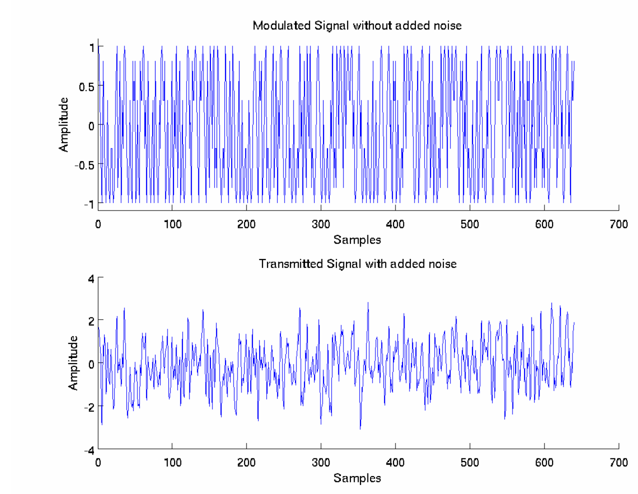

Fig. 4. Top: Modulated Signal with no noise add. Bottom: Modulated signal with noise added. Noise level is 1.0 of the input signal.

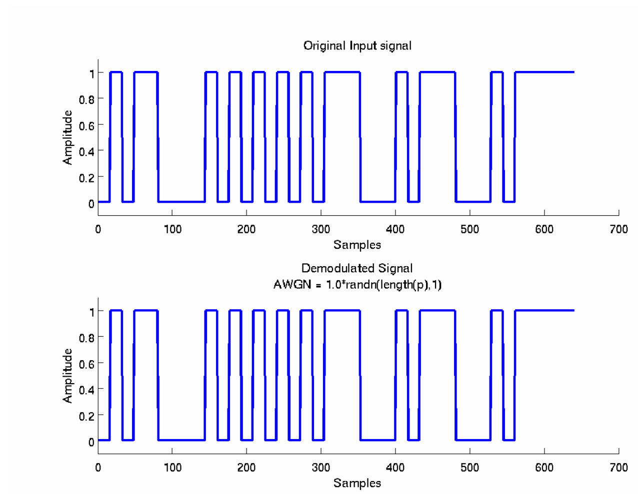

Fig. 5. Original signal and demodulated signal. Zero bit errors with noise level at 1.0.

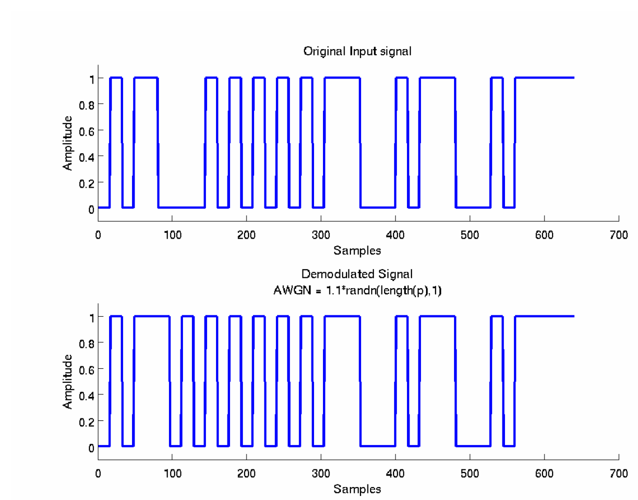

Fig. 6. Noise level at 1.1 time the signal level. Notice bit errors in the Demodulated signal.

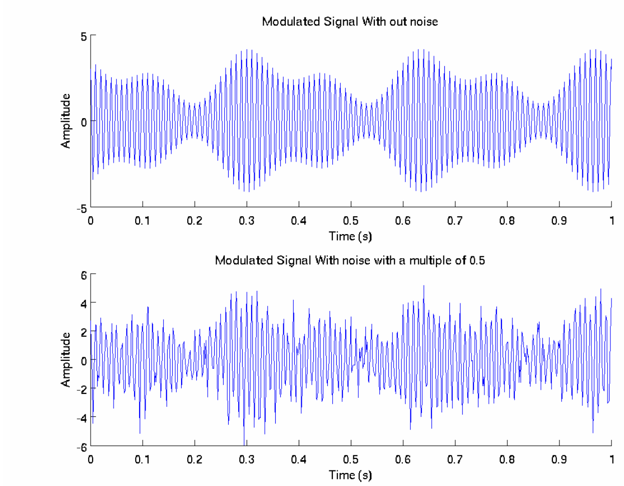

Fig. 7. Top: DSB-LC without noise. Bottom: DSB-LC with AWGN.

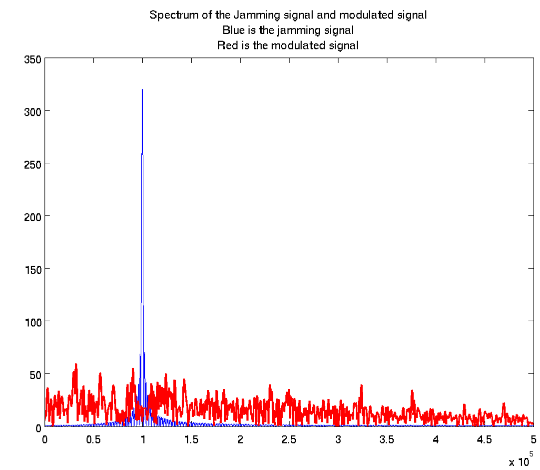

Fig. 9. Spread spectrum signal and a jamming signal.

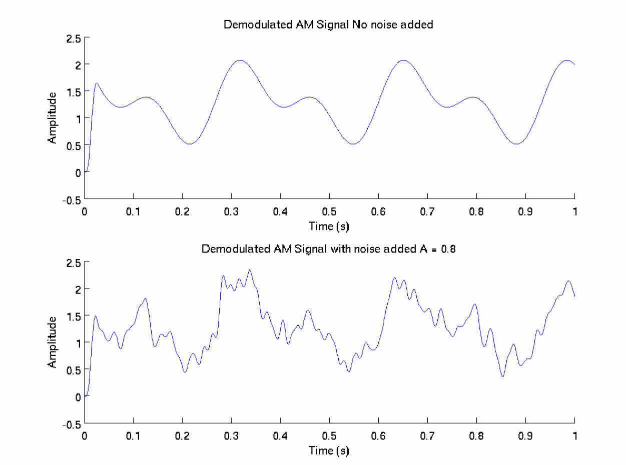

Fig. 8. Top DSB-LC Demodulated signal without noise. Bottom: Demodulated Signal with noise

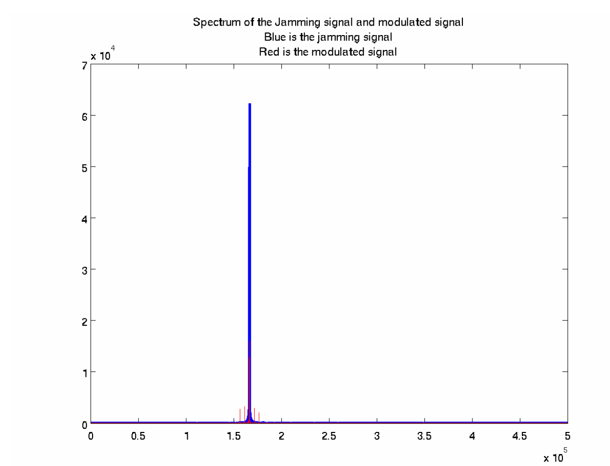

Fig.10. DSB-LC Spectrum, blue spike is the jamming signal.

E. Resistance to Hostile Jamming

Spreading the spectrum also makes it hard for others to jam the transmitted signal. This section will demonstrate the robustness of spreading the spectrum when the signal is trying to be jammed. Jamming spread spectrum signals is very hard because there isn't a signal frequency that the signal is being transmitted over. Fig. 9. Other modulation schemes like DSB-LC are easy to jam because the signal is modulated with a fixed frequency. Fig. 10.

III. Code Division Multiple Access

Having multiple users in the same spectrum is accomplished by each user having different Pseudorandom sequences or “codes”. To demonstrate CDMA two input signals where created, each have a separate pseudo random sequence. Fig. 11 shows the spectrum of both signals. Both these signals where demodulated by multiplying the entire transmitted signal by it's own pseudorandom number. Fig.12. Fig.13. Notice that in Fig. 13 there is one bit error. As more signals where added to the spectrum more bit errors occurred.

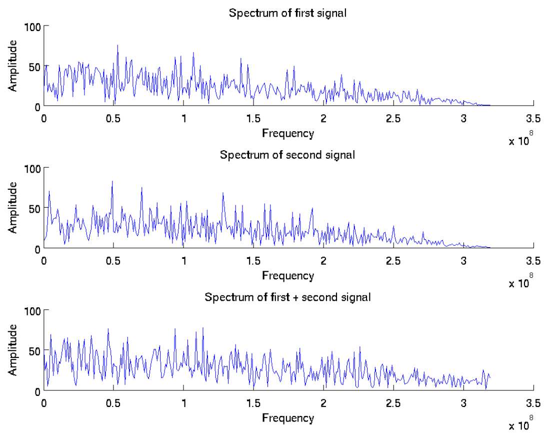

Fig. 11. Spread spectrum of two input signals times two different Pseudorandom numbers and there summations.

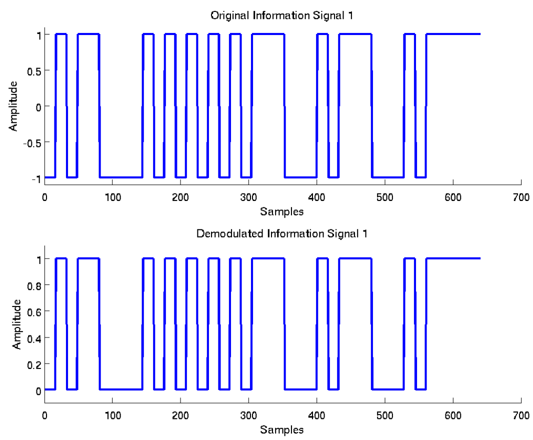

Fig. 12. Demodulation of CDMA.

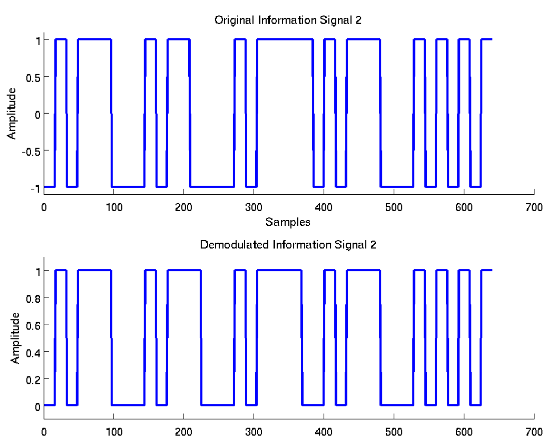

Fig. 13. Demodulation of CDMA Signal 2.

IV. Conclusion

Spreading the spectrum has some major benefits. This tutorial gave a brief overview of it's resistance to noise, resistance to jamming, and how it could be used for multiply access. DSSS was use to demonstrate these concepts.

References

[1] F. C. Stremler, “Introduction to Communication Systems” 3nd ed. Addison-Wesley Publishing Company, Inc. , 1992, pp. 627-634.

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