Spread Spectrum Modem for Voice and Data Transmission

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***Abstract*— This paper describes the design of a direct sequence spread spectrum (DSSS) modem for voice and data transmission using SYSTEMVIEW and MATLAB. The advantage of DSSS voice and data transmission includes the immunity from interference signals and anti-jamming effect. The paper represents a mathematical model for DSSS modem and based on this model, simulation is carried out by MATLAB and SYSTEMVIEW software. The obtained results were satisfactory within reasonable limit.**

***Index Terms*— spread spectrum modem, mathematical modeling, BER (bit error rate), SNR (signal to noise ratio), voice and data transmission, simulation.**

I. INTRODUCTION

Spread spectrum communication techniques have been widely accepted in mobile and wireless communications. They have very beneficial and tempting features, like Antijam, security and multiple accesses. The purpose of this paper is to describe the features of spread spectrum systems. Spread Spectrum is a technique which is used as a way to reduce the power density of radio transmission shown in Fig. 1. Spread Spectrum waveforms can also be used to primarily improve performance in the area of interference tolerance [1, 7]. This is done by spreading the signal over a wide band of frequencies. The signal is usually spread to at least 10 times the information rate or much higher. Under some conditions, the reduction of power density allows for greater spectrum sharing opportunities in comparison with using the traditional access. Traditional access consists of the method of frequency-division multiple access (FDMA) or even time-division multiple access (TDMA). The receiving system must dispread the spectrum signal just the opposite from how it was originally spread and in exact synchronization. This gives an added advantage of jamming and immunity from frequency-selective fading. Some modern cellular and other systems use a form of spread spectrum called code-division multiple access (CDMA) [10]. The circuit design will be divided into three phases. The first phase consists of the transmitter. The purpose of the transmitter is to generate the direct sequence spread spectrum method and modulation. The second phase consists of the receiver. The receiver is responsible for the demodulation and correlation of the received data. The third phase is the design, which will be based on direct sequence design. This is where the information signal is modulated by the signal that is spread and then the resulting wideband signal is transmitted. Upon reception, the wideband signal is demodulated using a synchronized copy of the code signal and the information is recovered shown in Fig. 2 [6, 8]. So it is indeed to study of a direct sequence spread spectrum (DSSS) modem for many different uses and advantages to spread spectrum waveforms.

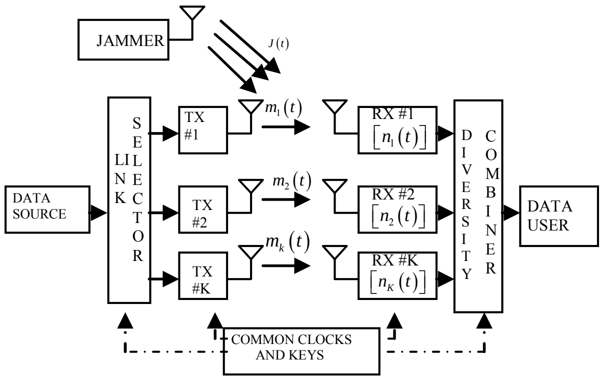

Figure 1. Spread Spectrum Systems

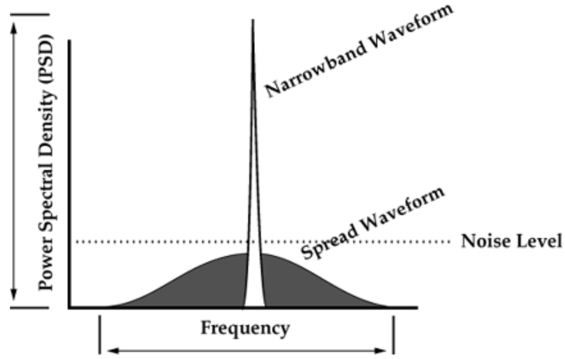

Figure 2. Recovery of Coded Signal and Information from demodulated signal

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II. IMPLEMENTATION

Efforts have been given to construct a simple spread spectrum modem and the design of this system are completed in three steps. The first step consists of simulating the transceiver based on direct-sequence spread spectrum (DSSS). The second step involves the determination of probability of error. The final step deals with the power source which is needed to drive the circuit. A 12V DC wall adapter and a laptop battery will satisfy the power need for the device.

A. Transmitter

The functional block diagram of a DS transmitter is shown in Fig. 3.

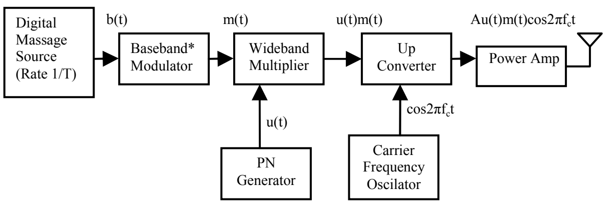

Figure 3. Functional block diagram of a direct sequence transmitter

Most of the time, the bit stream, *m(t)* is multiplied directly by the PN chip sequence. Direct Sequence is preferred since PN generated chip sequence directly multiplies the bit stream. The bit stream, *m(t),* and chip stream, *u(t)* are clocked together so that the number of chips in a bit interval is an integer. The purpose of the direct multiplication of the bit stream by the chip stream is to spread the spectrum of the bit stream [6, 7]. For Binary Shift Keying (BPSK) DSSS, the transmitted signal is of the form

$$s(t) = \sqrt{2P_s}\ m(t)u(t)\cos(2\pi f_c + \theta) \text{ ------(1)}$$

where P_s is the signal power, m(t) is a + and – bit sequence with bit duration T_c, u(t) is the spreading code sequence, which is a + and – binary sequence with chip duration T_c, and f_c is the carrier frequency. The carrier phase is assumed to be uniformly distributed in [0, 2π). Assuming independence between m(t) and u(t) and each being a random binary sequences, the power spectrum of s(t) can be written as

$$S_s(f) = \frac{P_sT_c}{2}\{\text{sinc}^2[T_c(f - f_c)] + \text{sinc}^2[T_c(f + f_c)]\} \text{ -----(2)}$$

B. Receiver

A simplified functional block diagram of a direct sequence receiver is shown in Fig. 4. The function shown within the dashed rectangle is known as correlator. The correlator may be implemented as an active correlator or as a matched filter or convolver. In all implementations, proper synchronization is required to within a fraction of the chip duration [4, 8].

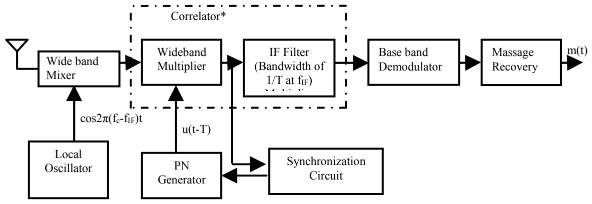

Figure 4. Simplified functional block diagram of direct sequence receiver

The received signal (neglecting propagation delays) is of the form

$$r(t) = s(t) + n(t) + \sqrt{2P_j}\cos[2\pi(f_c + \Delta f) + \phi] \text{ -------(3)}$$

where n(t) is additive white Gaussian noise (AWGN) of spectral density $N_0/2$, P_j is the jammer power, Δf is the jammer frequency offset from the carrier, and ϕ is independent and uniformly distributed in [0,2π). The received signal power spectrum is of the form

$$S_r(f) = \frac{P_sT_c}{2}\{\text{sinc}^2[T_c(f - f_c)] + \text{sinc}^2[T_c(f + f_c)]\} + \frac{N_o}{2} + \frac{P_j}{2}\{\delta(f - f_c - \Delta f) + \delta(f + f_c + \Delta f)\}\text{---(4)}$$

The mainlobe bandwidth of the received signal component is $\frac{2}{T_c}$ embedded in a flat noise spectrum along with a single spectral line component from the jammer. Following despreading with an identical spreading code sequence, we have

$$z(t) = \sqrt{2P_s}\ m(t)\cos(2\pi f_ct + \theta) + n(t)u(t) + \sqrt{2P_j}\ u(t)\cos[2\pi(f_c + \Delta f) + \phi)] \text{ -----(5)}$$

The corresponding despread signal power spectrum is

$$S_z(f)=(\frac{P_sT_b}{2})\{\text{sinc}^2[T_b(f-f_c)] + \text{sinc}^2[T_b(f+f_c)]\} + \frac{N_o}{2} + \frac{P_j}{2}\{\text{sinc}^2[T_c(f-f_c-\Delta f)] + \text{sinc}^2[T_c(f + f_c + \Delta f)]\} \text{ ------------(6)}$$

The despread received signal consists of a data spectrum with a mainlobe bandwidth of $\frac{2}{T_b}$, a flat noise spectrum of height $\frac{N_o}{2}$ along with a spread jammer component with a mainlobe of bandwidth of $\frac{2}{T_c}$.

To minimize the probability of error, assume that where each bit starts and begins and also assume that the receiver is synchronized to transmitter. The proposed receiver structure is referred to as an integrate-and-dump detector. The probability that when a single bit is received an error can be calculated as follows:

Received signal for bit i:

$$y(t) = s(t) + n(t) \text{ ------------------------------(7)}$$
$$= A + n(t),\ (i-1)T \le t \le iT \ \text{(1 sent) ---7(a)}$$
$$= -A + n(t),\ (i-1)T \le t \le iT \ \text{(0 sent) ---7(b)}$$

Output of sampler:

$$V_i = \int_{(i-1)T}^{iT} y(t)dt = \int_{(i-1)T}^{iT} [s(t)+n(t)]dt \text{ ----(8)}$$
$$= AT + N, \quad \text{1 sent -------------8(a)}$$
$$= -AT + N, \text{ 0 sent -------------8(b)}$$

where $N = \int_{(i-1)T}^{iT} n(t)dt$,

N is a random variable.

Since n(t) is a white Gaussian noise and integration is a summation, then the summation of Gaussian random variables is also a Gaussian Random Variable.

Therefore, the pdf of N is $f_N(\gamma) = \dfrac{e^{\frac{-\gamma^2}{NoT}}}{\sqrt{NoT\pi}}$ --(9)

There can be two cases in which errors are likely to happen:

Case 1: send a 1, receive a 0

P(error | 1sent)=P(AT + N < 0) = P(N < -AT) -----(10)

Case 2: send a 0, receive a 1

P(error | 0sent)=P(-AT + N < 0) = P(N > AT) ------(11)

To find the probability of error, P_E

$$P(\text{error} \mid 0 \text{ sent}) = \int_{AT}^{\infty} f_N(\gamma)d\gamma = \int_{AT}^{\infty} \frac{e^{\frac{-\gamma^2}{NoT}}}{\sqrt{NoT\pi}}$$
$$= Q\left(\sqrt{\tfrac{2A^2T}{No}}\right) \text{ ------------(12)}$$

P(error | 1 sent) = 1 - P(error | 0 sent)

The total probability of error (from total probability theorem) is given by

$$P_E = P(\text{error} \mid 1 \text{ sent})\, P(1 \text{ sent}) + P(\text{error} \mid 0 \text{ sent})\, P(0 \text{ sent})$$
$$= Q\left(\sqrt{\tfrac{2A^2T}{No}}\right) [P(1 \text{ sent}) + P(0 \text{ sent})]$$
$$= Q\left(\sqrt{\tfrac{2A^2T}{No}}\right) \text{ -----------------------------------(13)}$$

The energy transmitted for each bit:

$$E_b = \int_T s^2(t)dt = A^2T \text{ ----(14)}$$

The signal-to-noise ratio (SNR) is $SNR = \dfrac{E_b}{N_o}$

Therefore, $P_E = Q(\sqrt{2SNR})$ --------------(15)

C. Direct Sequence

Direct-sequence spread spectrum (DSSS) is a modulation technique that spreads the transmitted signal bandwidth so that it is much greater than the inherent bandwidth of the modulating signal shown in Fig. 5. To accomplish the desired BER of $1E^{-6}$, the specified SNR is exceeded at the input to the detector; the bit error probability for QPSK signaling with optimal detection will be determined by calculations. The noise energy will be determined by the product of Boltzmann's constant, $1.38*10^{E-23}$ and temperature of the system in degrees Kelvin, assumed to be 298. The bandwidth for our system will be determined by simulation using the parameter calculated for N_o and E_b. DSSS modulation employed to provide resistance to intentional jamming by another source and to provide a range-measuring capability [2, 3].

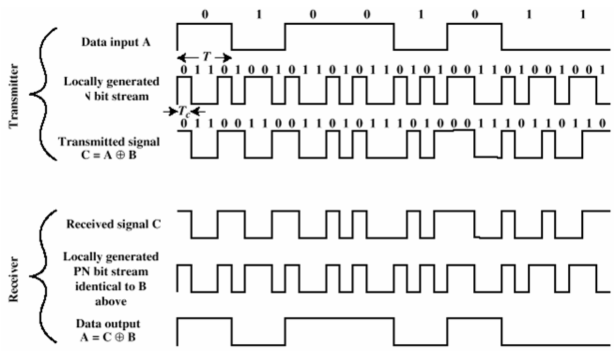

Figure 5. Direct Sequence Spreaded Spectrum

III. PERFORMANCE ANALYSIS

The objective is to design of a wireless modem system that will allow the modems to transfer data between two terminals. The traditional 1200-baud and 9600-baud packet links are not able to provide adequate speed for today's web-based applications. Spread spectrum modems can offer data rates that are higher than even the fastest conventional modems, without the need to be connected to a phone line. A DSSS system spreads the base band data by directly multiplying the base band data pulses with a pseudo-noise sequence that is produced by a pseudo-noise code generator [7, 9].

One of the most important advantages of spread spectrum is being able to work in the environment of intentional interference (jamming) or even non-intentional interference. It also has the ability to eliminate the effect of multipath interference. Spread spectrum communication offers a security against unwanted observers or users. While conventional communication systems other than wide-band frequency modulation have a multiplicity factor near unity, spread spectrum systems typically have multiplicity factors in the thousands. Therefore, a well-designed spread spectrum system forces a jammer to guess which signaling format is being used, and reduces his power of interference. Also, with permitted transmitter power levels of 1 Watt, wireless modems can have a range of tens of kilometers [4, 5].

IV. SIMULATION RESULTS

A. Transmitter

The signal in Fig. 6 shows the spreaded DSSS output of the transmitter.

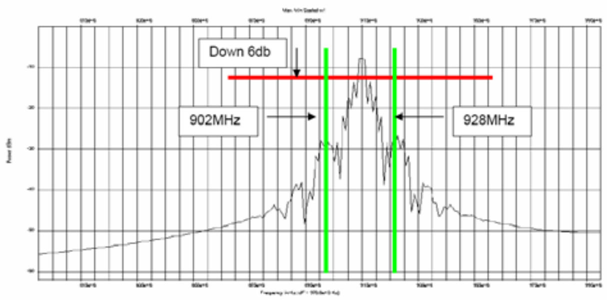

Figure 6. Transmitter output of Spreaded DSSS.

The signal was spreaded over a 26MHz bandwidth, which meets the requirements of FCC standards of 902-928 MHz DSSS. 6dB down from the peak shows the frequency operation of 2MHz, which is our data rate. This 6dB down also adheres to part 15 of FCC regulations.

B. Attenuation

For 900 MHz, the attenuation is –96 dBm for the first mile and increases by –6 dBm each time the distance doubles. Table 1 shows the ranges of transmission and their corresponding received power and Fig. 7 shows the results of power received vs distance.

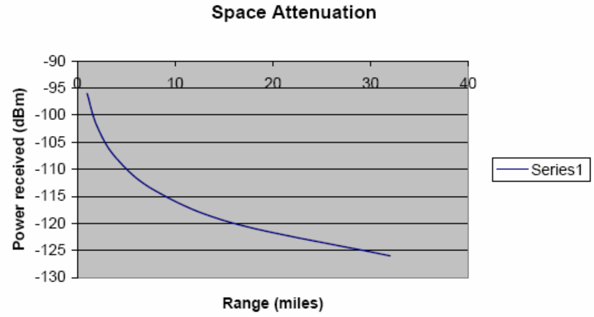

Figure 7. Power received vs Distance

TABLE I.
ATTENUATION AT DIFFERENT DISTANCE

Range (mile)	Power received
1	-96 dBm
2	-102dBm
4	-108 dBm
8	-114 dBm
16	-120 dBm
32	-126 dBm

C. Calculation of P_E

Let us consider, each bit of transmitted signal as a rectangular pulse of width T. Without loss of generality, assume that this pulse is centered about t = 0 (if not, we have merely a phase shift which will not affect the calculation of bandwidth). The probability of error for a single bit using the proposed integrate-and-dump receiver is

$$P_E = Q(\sqrt{2SNR})$$

$$= Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \text{-------------------}(16)$$

$$= Q\left(\sqrt{\frac{2(10^{-6})}{6.66x10^{-8}}}\right)$$

$$= Q \times 5.48$$

As expected, increasing SNR decreases the probability of error. Most systems on the market with a BER 10^{-6} have a SNR of 15dB. From the graph in Fig. 8, the results show that for a desired BER of 10^{-6} and obtained a SNR of 11dB. This results satisfies the specifications of most standard spread spectrum modems.

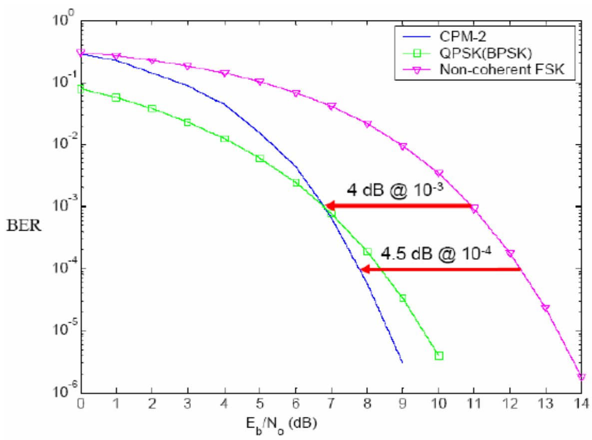

Figure 8: Increasing SNR decreases the probability of error (BER).

D. Receiver

The dispread signal at receiver is shown in Fig. 9. The maximum recieved Bit Error Rate is 10^{-6}. Only one error out of 4.295 billion errors will remain undetected. Therefore, the recieved end-to-end bit error rate is 2.32E-14%.

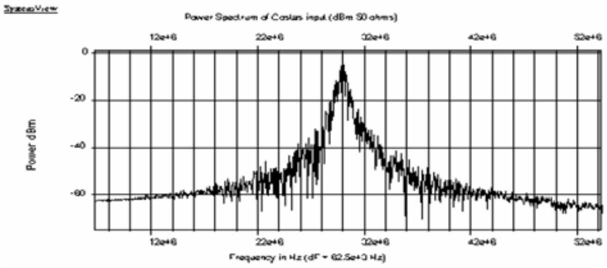

Figure 9: Despread Signal at Receiver

V. DISCUSSION

The obtained result is satisfactory with in a reasonable limit. The aim was to achieve 3-miles distance of transmission, maximum desired Bit Error Rate is 10^{-6} and frequency of operation at the frequency range of 902 to 928 MHz DSSS. The bit error rate achieved by determining the noise energy E_o and the SNR, for a given energy per transmitted bit E_b [2, 8]. The system have a raw data throughput of 128 Kbps. In order to boost the data throughput, the system need to have compression. Therefore, the data link between the device and the PC must be greater than the wireless link. The main problems that are faced is the sensitivity of the components and also to transmitting at 900 MHz band using discrete components. The most difficult part of this design is the synchronization of the transmitter and receiver, in terms of transmit and receive switching. By improving this area, it would enable the demodulator to lock the PLL very quick and the transmit and receive would happen at the same time.

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