Processing Gain for Direct Sequence Spread Spectrum Communication Systems and PRISM®

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Introduction

This application note addresses the concept of processing gain (PG) of Direct Sequence Spread Spectrum (DSSS) systems. The PRISM chipset is used to implement DSSS radio designs. The processing gain provides the unique properties to the DSSS waveform primarily in terms of interference tolerance. The PG of a DSSS system is centered around the utilization of random codes which are used in conjunction with the data. These random codes are referred as Pseudo Noise (PN) codes. The HSP3824 provides this coding capability for the PRISM.

Description

In a DSSS system random binary data with a bit rate of r_b bits per sec (bps) is multiplied (Exclusive Ored) by a pseudorandom binary waveform, which is at much higher rate and it provides the frequency spreading operation. This pseudorandom (PN) binary source outputs symbols called chips at a constant chip rate r_C chips per sec (cps).This is a random, noise like signal and hence the name PN signal. The chip rate is always higher than the bit rate, and the ratio of the chip rate to the bit rate is defined as the processing gain (PG) [3]. The PG is a true signal to jammer (interference) ratio at the receiver after the despreading operation (removal of PN).

The rate of the PN code is the one that defines the bandwidth of the transmitted spread waveform.

The receiver of a DSSS system must remove the spreading as the first step in the demodulation process.

During the despreading operation the receiver must generate a phase locked exact replica of the pseudorandom spreading waveform to match the transmitted signal. This is achieved by the code acquisition, and code tracking loops embedded in the HSP3824. The receiver PN sequence must be exactly in phase with the transmitted PN sequence, and this is achieved by correlation techniques.

DSSS Transceiver

A DSSS transmitter is shown in Figure 1. The data is denoted by d(t), the spreading signal is denoted by c(t), and the spread waveform q(t) is fed to the BPSK modulator operating at a carrier frequency f_C, and the transmitted signal is denoted by x(t).

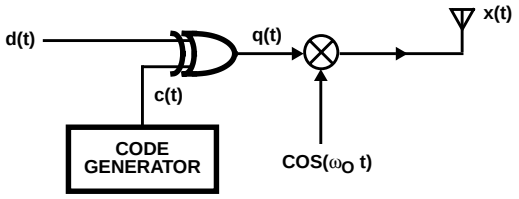

FIGURE 1. DSSS TRANSMITTER

A text book conceptual block diagram of a DSSS receiver is depicted in Figure 2. Note that PRISM is architected to perform the despreading function at baseband (HSP3824) rather than at RF as shown on Figure 2. This example is used for illustration of the concept and not to reflect the actual PRISM implementation.

The received signal for this text book example is the combination of the transmitted spread spectrum signal and a narrow band jammer $x_J(t)$. The locally generated despreading sequence is denoted by c'(t), and should be equal to c(t). The despread signal is then band pass filtered before data demodulation and d'(t) should be equal to d(t).

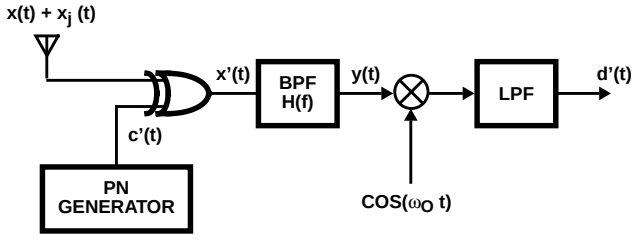

FIGURE 2. DSSS RECEIVER

PG Benefits

The primary benefit of processing gain is its contribution towards jamming resistance to the DSSS signal. The PN code spreads the transmitted signal in bandwidth and it makes it less susceptible to narrowband interference within the spread BW. The receiver of a DSSS system can be viewed as unspreading the intended signal and at the same time spreading the interfering waveform. This operation is best illustrated on Figure 3.

Figure 3 depicts the power spectral density (psd) functions of the signals at the receiver input, the despread signal, the bandpass filter power transfer function, and the band pass filter output. Figure 3 graphically describes the effect of the processing gain on a jammer. The jammer is narrow, and has a highly peaked psd, while the psd of the DSSS is wide and low. The despreading operation spreads the jammer power psd and lowers its peak, and the BPF output shows the effect on the signal to jammer ratio.

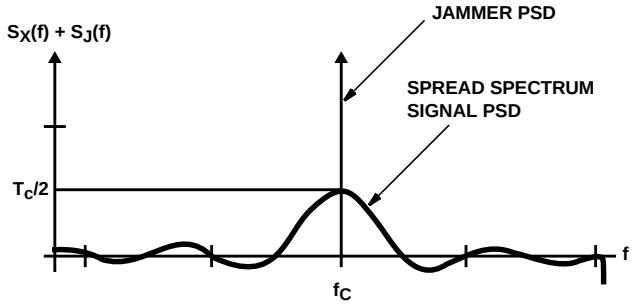

FIGURE 3A. PSD OF SPREAD SPECTRUM SIGNAL AND NARROWBAND JAMMER

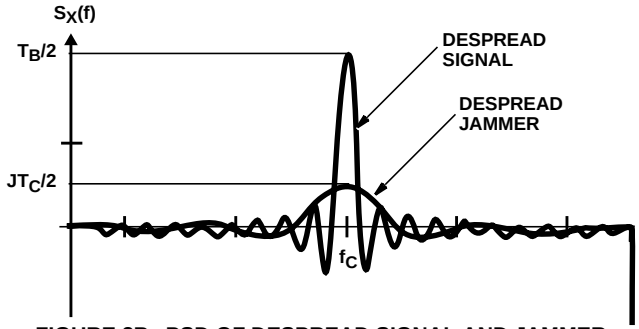

FIGURE 3B. PSD OF DESPREAD SIGNAL AND JAMMER

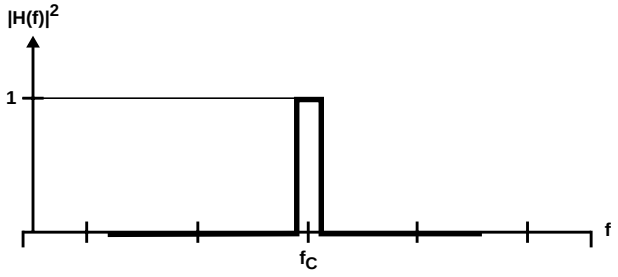

FIGURE 3C. POWER TRANSFER FUNCTION OF BPF

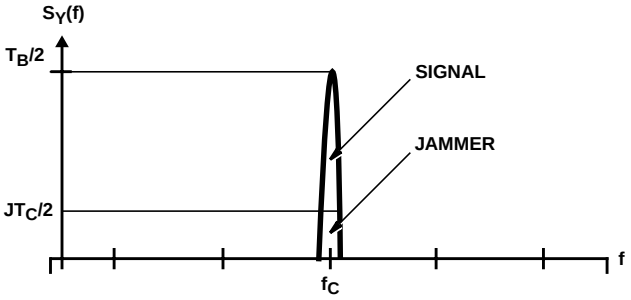

FIGURE 3D. PSD OF BPF OUTPUT

FIGURE 3. PROCESSING GAIN EFFECT ON NARROW BAND JAMMING

If for example, BPSK modulation is used and an Eb/No of lets say 14dB is required to achieve a certain BER performance, when this waveform is spread with a processing gain of 10dB then the receiver can still achieve its required performance with the signal having a 4dB power advantage over the interference. This is derived from the 14dB required minus the 10dB of PG.

The higher the processing gain of the DSSS waveform the more the resistance to interference of the DSSS signal.

The classical definition of processing gain is the 10 Log number $[r_C/r_B]$ in dB. By this definition a system that has a data rate of 1MBPS and a chip rate (rate of PN code) of 1MCPS will have a PG of 10.41dB. Using the PRISM chip set each data bit is x-ored with an 11 bit sequence for this particular example. The processing gain can be then viewed as the 10Log[11]dB where 11 is the length of the PN code. If a code with a length of 16 bits is to be used then the processing gain is equivalent to 10 Log[16] dB or 12.04dB.

To this end these PN signals must posses certain mathematical properties to be useful as part of a DSSS system. Primarily the PN codes that are useful must have very good autocorrelation and crosscorrelation properties as well as maintaining some randomness properties.

The DSSS receiver is utilizing a reference PN sequence which is a replica to the transmitted sequence and when it detects correlation between the reference and the incoming sequences it declares initial acquisition and it establishes initial symbol timing. Any partial correlations can result to false acquisitions and degradation to the receiver performance. This is why the PN code must have good correlation properties. Some of the PN code classes with such properties are described next.

This paper highlights the Barker codes, Willard codes and m-sequences with 7 and 15 chips per period which are implementable using the HSP3824.

PN Codes

PN codes with the mathematical properties required for implementation of a DSSS radio are:

Maximum Length Sequences

Maximum length sequences (m-sequences), are PN sequences that repeat every 2^n-1, where n is an integer, they are implemented by shift registers and Exclusive Or gates, they are governed by primitive polynomials, and possess good randomness properties including a two-valued autocorrelation function [4].

For example the 7 chip PN sequence is governed by the primitive polynomial generator

$$c_7(x) = 1 + x^2 + x^3$$

and the output chips are given by:
0 0 1 0 1 1 1 0 0 1 0 1 1 1 **0 0 1 0 1 1 1** 0 0 1 0 1 1 10...

Figure 4 depicts the d(t), c(t) with the above m-sequence, and with q(t) the x-or of d(t) and (ct).

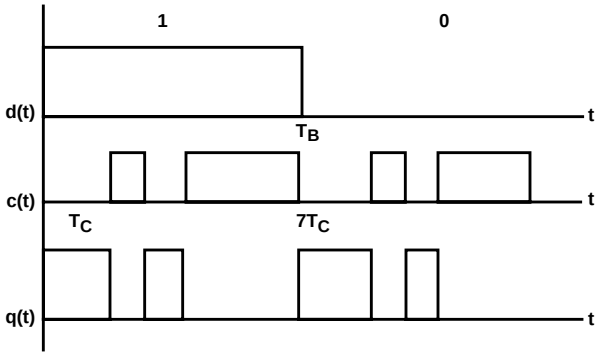

FIGURE 4. TIME DOMAIN SIGNALS WITH PG = 7

Figure 5 depicts the 7 chip sequence and its autocorrelation function. Note that the autocorrelation also repeats every 7 chips, or once per bit of the actual data if each of the data bits is spread by the entire sequence.

As another example, the 15 chip PN sequence is governed by the primitive polynomial generator

$$c_{15}(x) = 1 + x^3 + x^4$$

and the output chips are given by:

0 0 0 1 0 0 1 1 0 1 0 1 1 1 1 0 0 0 1 0 0 1 1 0 1 0 1 1 1 1
0 0 0 1 0 0 1 1 0 1 0 1 1 1 1...

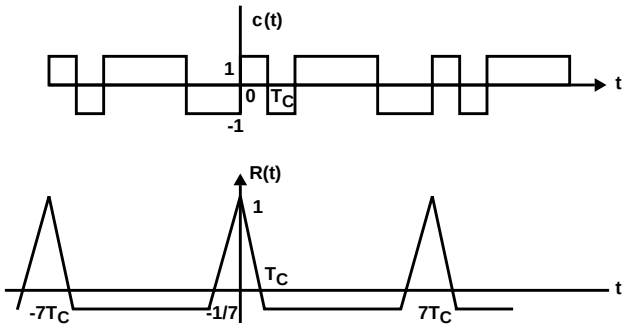

FIGURE 5. SEVEN CHIP M-SEQUENCE AND ITS AUTOCORRELATION FUNCTION

Barker Codes

Barker Codes are short unique codes that exhibit very good correlation properties. These short codes with N bits, with N=3 to 13, are very well suited for DSSS applications and can all be generated by the HSP3824. A list of Barker Codes is tabulated in Table 1.

Willard Codes

Willard Codes, found by computer simulation and optimization, and under certain conditions, offer better performance than Barker Codes. They can all be generated by the HSP3824, as was done for the Barker Codes. A list of Willard Codes is provided in Table 1.

The inverted or bit reversed versions of the codes listed on Table 1 can be used since they still maintain the desired autocorrelation properties.

TABLE 1. BARKER AND WILLARD CODES

N	BARKER SEQUENCES	WILLARD SEQUENCES
3	110	110
4	1110 or 1101	1100
5	11101	11010
7	1110010	1110100
11	11100010010	11101101000
13	1111100110101	1111100101000

Configuring the HSP3824 to Implement Various PN Codes

The HSP3824 is the baseband processor of the PRISM chipset and it generates the PN sequence. The device is programmable to any desirable sequence of up to 16 bits.

PN Generator Description

The spread function for the radio is the same sequence and is applied to every symbol as BPSK modulation. PN generation is performed by parallel loading the sequence from a configuration register (CR) within the HSP3824 and serially shifting it out to the modulator.

PN Generator Programmable Registers

A maximum of 16 bits can be programmed into the configuration register. Registers CR13 and CR14 contain the high and low bytes of the sequence for the transmitter. The corresponding registers for the receiver are CR20 & CR21. Bits 5 & 6 of CR3 set the sequence length in chips per bit. The sequence is transmitted MSB first. When fewer than 16 bits are in the sequence, the MSBs are truncated.

PN Correlator Description

The PN correlator is designed to handle BPSK spreading. Since the spreading is BPSK, the correlator is implemented with two real correlators, one for the I and one for the Q channel. It has programmable registers to hold the spreading sequence and the sequence length for both the receiver and the transmitter. This allows a full duplex link with different spreading parameters for each direction.

The correlators are time invariant matched filters otherwise known as parallel correlators.

References

[1] Madjid A. Belkerdid, Electrical and Computer Engineering Department, University of Central Florida, Orlando, FL 32816.

[2] R. L. Pickholtz, D. L. Schilling, and L. B. Milstein, “Theory of Spread-Spectrum Communications - A Tutorial”, IEEE Trans. Comm., vol COM-30, May 1982.

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[4] R. L. Peterson, R. E. Ziemer, and D. E. Borth, “Introduction to Spread Spectrum Communications”. Inglewood Cliffs, NJ: Prentice Hall, 1995.

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