PN-Spread spectrum system behavior in a highly impulsive noise environment

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Contents: In the present work the behavior of a Pseudo Noise (PN)-Spread Spectrum system in the presence of a highly impulsive plus Gaussian noise environment is studied. In appraising the acquisition or tracking performance of a PN-spread spectrum system, it was noticed that the noise process when multiplied by the receiver's local PN-code is spectrally spread with a resultant decrease in the noise spectral density. This leads to a significant improvement of the system signal to noise ratio for a given Bit Error Rate (BER), demonstrating so that spread spectrum techniques can provide reliable communications even in such complex impulsive noise environments.

Das Verhalten eines PN-ausgebreiteten Spektrum-Systems in einem hoch impulsiv verrauschten Kanal


1 Introduction

Spread-Spectrum (SS) systems have been developed since about the mid-1950's. The initial applications have been to military antijamming tactical communications, to guidance systems, to experimental anti-multipath systems, and to other applications [1]. Under the general definition [2] that

"Spread Spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information; the band spread is accomplished by means of a code which is independent of the data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery".

standard modulation schemes such as FM and PCM which also spread the spectrum of an information signal do not qualify as spread spectrum.

The means by which the spectrum is spread is crucial. Several of the techniques are “direct-sequence” modulation in which a fast pseudorandomly generated sequence causes phase transitions in the carrier containing data; “frequency hopping”, in which the carrier is caused to shift frequency in a pseudorandom way; and “time hopping”, wherein bursts of signal are initiated at pseudorandom times. Hybrid combinations of these techniques are frequently used.

Although the current applications for spread spectrum continue to be primarily for military communications (antijamming, antiinterference, highresolution range etc.), there is a growing interest in the use of this technique for mobile radio networks (radio telephony, packet radio), timing and positioning systems, some specialized applications in satellites etc. While the use of spread spectrum naturally means that each transmission utilizes a large amount of spectrum, this may be compensated for by the interference reduction capability inherent in the use of spread-spectrum techniques, so that a considerable number of users might share the same spectral band. There are no easy answers to the question of whether spread spectrum is better or worse than conventional methods for such multiuser channels. However, the one issue that is clear is that spread spectrum affords an opportunity to give to a desired signal a power advantage over many types of interference, including multitone interference, Gaussian noise etc.

The behavior of the spectral characteristics of
transmitted SS signals, in Gaussian noise and/or multitone interference environments, has been extensively studied by various authors [2–4]. However, it is well known that disturbances occurring in communication channels may be of other forms as well; e.g. an additive mixture of Gaussian plus Impulsive noise [5]. Such noise process is characterized by short duration bursts with large amplitudes in comparison to the average power of the background Gaussian noise.

In the present paper, under the assumption that the two (Gaussian and Impulsive) noise processes are stationary uncorrelated and ergodic, the power spectrum of the PN-spread spectrum filtered noise mixture is extrapolated by its auto-correlation function. In addition this work was carried out considering that:

i) Maximal-length shift register sequences [4] are used as the spreading code pseudosequences,
ii) the arrivals of the incoming impulsive noise bursts follow a Poisson distribution law and
iii) the noise burst's amplitude probability density function (apdf) follows a random distribution law.

Finally it is shown that for a constant system Bit Error Rate (BER) performance the evaluated spread noise power spectrum causes a significant improvement to the Signal to Noise Ratio (SNR), which is mainly due to the reduction of the noise power spectrum density.

2 PN-spread and processing gain

A fundamental issue in spread spectrum is how this technique affords protection against interfering signals with finite power. Considering the simplified model of a coherent receiver shown in Figure 1, for the case of a noncoherent interferer, the input signal plus tone interference at the same frequency may be modeled as.

In Eq. (1) the desired signal has a power $P$ and the tone interferer has a power $P_y$. The data sequence $d(t)$, has symbol duration $T_s$ sec. The process $\Theta(t)$ is assumed to be of the form $\Omega t + \Theta_0$, where $\Theta_0$ is a uniform random variable. For the following discussion it will be assumed that the code tracking loop provides a perfect estimate of the receiver PN sequence and the carrier tracking loop provides a perfect estimate of the carrier signal, so that the input of the data demodulator due to the signal component is baseband data. For convenience it will be assumed that the data symbols are Non-Return-to Zero (NRZ) as shown in Fig. 2. Therefore the optimum data demodulator is considered to be an integrate-and-dump matched filter. Assuming that the $2\omega_0$ term is removed by the matched filter the signal into the input of the filter is given by

$$e_i(t) = \sqrt{P} d(t) + \sqrt{P_y} PN(t) \cos(\Theta(t))$$

If $0 < \Omega/2\pi \ll 1/T_s = R_c$, where $T_s$ in the pseudo-noise code symbol duration (chip time) [2], and assuming that the $PN(t)$ is a very long code with $T_s \ll T_c$ [3, 4], then the output signal voltage and the mean square interference power are

$$e_o = \sqrt{P} d(T_s)$$

$$\langle e_y - \bar{e}_y \rangle^2 = P_y T_s \left( \frac{1}{T_c} \right)$$

Equation (4) results from the fact that the two-sided spectra of a long PN-code is $P_yT_c$ near $f = 0$ [Hz] and the two-sided bandwidth of the averager (matched filter) is $1/T_s$ [4]. Therefore follows that the output $SNR$ is

$$SNR_0 = \frac{e_o^2}{\langle e_y - \bar{e}_y \rangle^2} = \frac{P_d(T_s)}{P_y} \left( \frac{R_c}{R_s} \right)$$

where $R_s = 1/T_s$ and $d(T_s)$ indicating the zero crossing of the information symbols. The effective reduction of the interference is thus $R_s/R_c$. Consequently $R_c/R_s$ is called the processing gain [4]. Hence higher PN code rates reduce the interference to a greater degree.

3 Channel considerations

In Fig. 3 is shown a simplified model of $PN$-spread spectrum noise receiving system, with $BPF$ indicating a Band Pass Filter. The noise $\bar{n}(t)$ at the receiver's input is modeled as an additive mixture of the two random processes, assumed statistically independent of one another because of the different mechanisms of generation, i.e.

$$\bar{n}(t) = \bar{n}_d(t) + \bar{n}_f(t)$$