Implementation of Baseband Binary Communications over a Distorted Channel

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Abstract

In this work the use of a nulling filter to remove/mitigate the effects of a sinusoidal jamming signal on a baseband digital communications waveform is implemented. The design of the jamming filter itself is the main focus of this work. The use of a nulling or notch filter in the context of a digital communication system might seem too advanced. Details of the digital communication system will be kept to a high level, yet allow some exposure to digital communication concepts. BEP performance using the semi-analytic simulation technique is shown. Results are shown with and without the IIR notch filter. The number of symbols used in the simulation is increased from 1000 to 100,000 to improve the statistical accuracy of the SA-BEP method. At PE = 10^{-6} we see a performance improvement of about 0.83 dB.

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I. Introduction

A block diagram of the baseband digital communication system is shown in Figure 1.

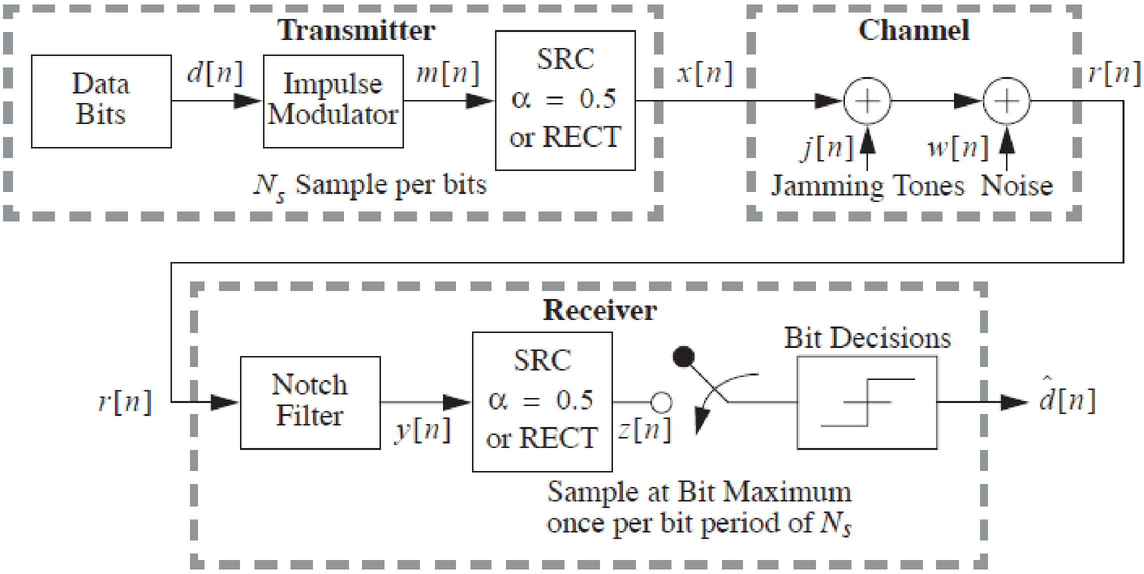

Figure 1: Baseband digital communication system block diagram.

The notch filter, which appears as the first block in the receiver is the focus of this investigation. To better understand the purpose of the notch/nulling filter in this context, a brief explanation of the entire communication system will be provided. As depicted in Figure 1 the transmitter is composed of three functions. The block labeled Data Bits produces a string of random data bits to represent a binary encoded message or data source. For the purposes of this transmitter the data bit levels are +-1 amplitude values as opposed to 0/1 values that are found in digital logic. The transmitted data bits are contained in the vector data. The Impulse Modulator block prepares the data bits for waveform encoding by stuffing zero sample values between the input signal d[n]. The waveform generation process assumes that a new transmitted bit is sent every Ns samples. With Ns samples per bit, Ns-1 zero samples are stuffed in between each +-1 data bit. The final transmitter block provides pulse shaping to produce the actual waveform that exits the transmitter. Two pulse shaping functions are considered in this work. The first is a simple rectangular pulse shape, which is a constant value over Ns sample values. The second pulse shape is a popular digital communications shaping function known as a square-root raised cosine (SRC) function.

II. Implementation

To apply the pulse shape all we do is filter the impulse train modulated signal, m[n], with an FIR filter whose impulse response is one of the two pulse types. The pulse shapes for Ns = 10 are shown in Figure 2.

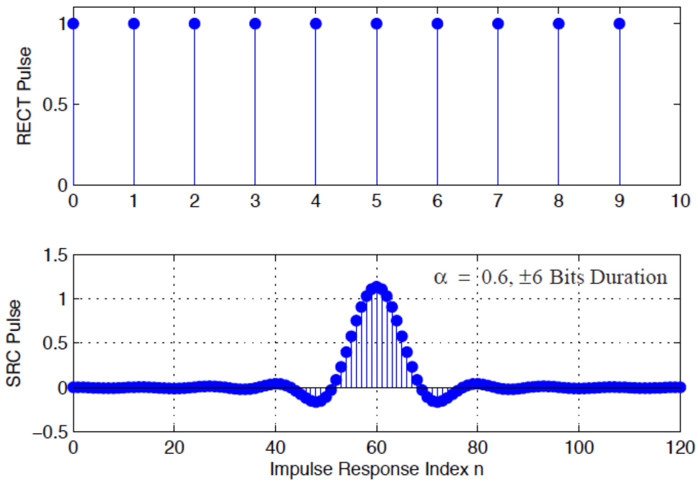

Figure 2: Pulse shapes with $N_s = 10$.

A sample of the transmitter output signal with RECT and SRC pulse shaping is shown in Figure 3.

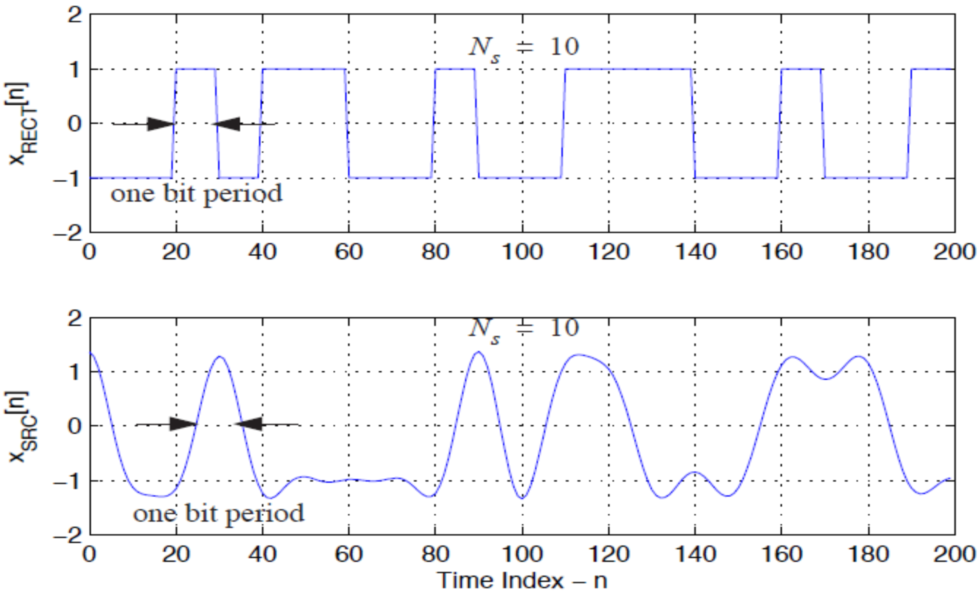

Figure 3: Transmitter output waveforms.

The channel adds two signals to the transmitter output x[n]. The first signal is a single sinusoid waveform of the form

$$j[n] = A_j \cos(2\pi f_j/(N_s R_b)n + \phi_j) \tag{1}$$

Note that the equivalent sampling rate in this simulation is fs = NsRb Hz. This signal constitutes a jamming or interference signal which is undesired. The amplitude of this signal is adjusted so that the level of the interference results in a particular signal power, Psignal, relative to the jammer power, Pjammer, known as the signal-to-interference ratio (SIR) and defined as

$$\mathrm{SIR_{dB}} = 10\log_{10}\left(\frac{P_{\mathrm{signal}}}{P_{\mathrm{jammer}}}\right). \tag{2}$$

The second signal that the channel adds to the transmitted signal is noise of a particular power level and constant frequency spectrum. The amplitude of this signal is adjusted so that the level of the noise results in a particular signal power relative to the noise power, Pnoise, known as the signal-to-noise ratio (SNR) and defined as

$$\mathrm{SNR_{dB}} = 10\log_{10}\left(\frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}}\right) = 10\log_{10}\left(\frac{E_b}{N_0}\right). \tag{3}$$

In a binary digital communication system, the SNR is equivalent to the ratio of Eb=N0, where Eb is the energy-per-bit and N0 is the noise power spectral density. The power spectral density (PSD) tells us how the power of a particular signal is distributed in frequency. The units of N0 is Watts of power per Hz of frequency bandwidth.

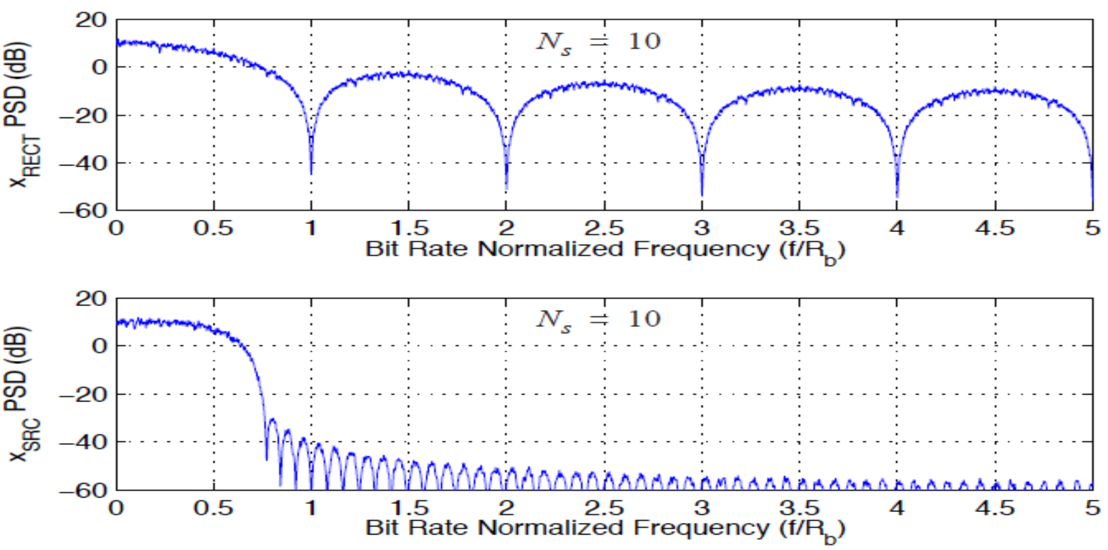

Figure 4: Transmitter output frequency spectrum.

The top subplot of Figure 5 shows the desired signal with just the jammer present. The lower subplot shows the combination of signal, jamming, and noise. With just the jamming signal present we see the flat area on the top of each data bit has been replaced with sinusoidal wiggles. When the noise is included the wiggles are now blended with random fluctuations due to the noise. If either the noise or the jamming levels increase, that is SNR and/or SIR decrease, it will become harder for the receiver to discern the original +-1 binary signal levels, and bit errors will result. The frequency domain allows up to see the impact of the distortions differently.

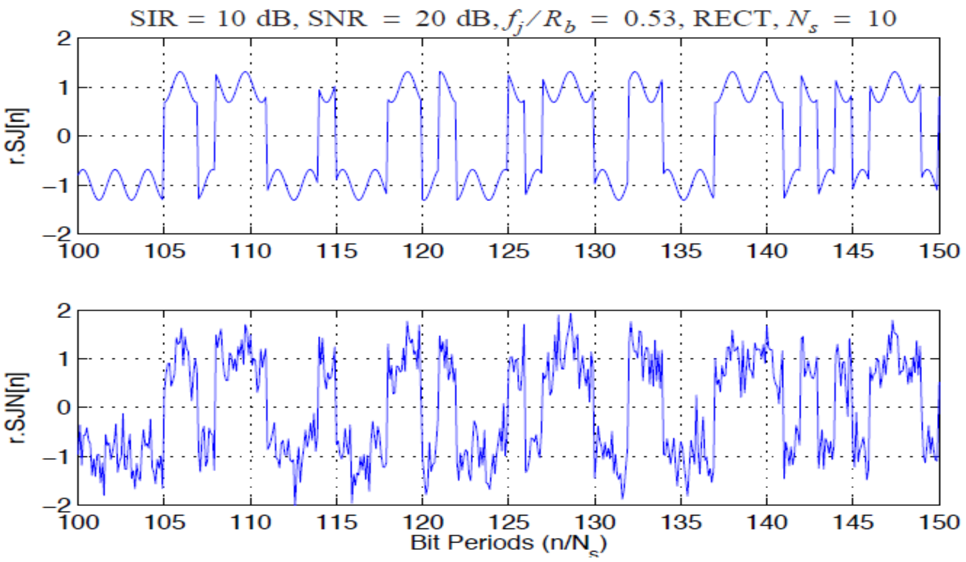

Figure 5: Channel outputs for the RECT pulse shape with signal + jamming (top) and signal + jamming + noise (bottom) for SIR = 10 dB and SNR = 20 dB.

Figure 6 shows the signal spectrum

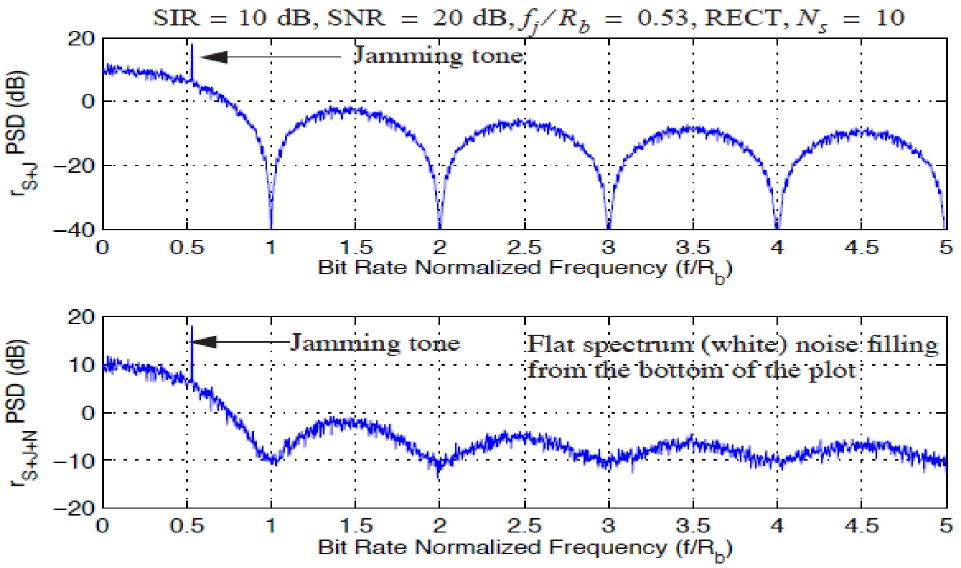

Figure 6: Channel outputs in the frequency domain for the RECT pulse shape with signal + jamming (top) and signal + jamming + noise (bottom) for SIR = 10 dB and SNR = 20 dB.

The three primary functions of the receiver are a notch or jammer nulling filter, a matched filter to remove noise and optimize the signal amplitude at the bit decision sampling instants, and a device to convert the once per bit sampled waveform back to a pure binary sequence (still +-1 amplitude levels).

The proposed notch filter for this project is a second-order IIR filter of the form

$$H_{\text{IIR-notch}}(z) = \frac{1 - 2\cos(\hat{\omega}_0)z^{-1} + z^{-2}}{1 - 2r\cos(\hat{\omega}_0)z^{-1} + r^2 z^{-2}}. \tag{4}$$

Note that this filter becomes an FIR nulling filter if we set r D 0, i.e.,

$$H_{\text{FIR-notch}}(z) = 1 - 2\cos(\hat{\omega}_0)z^{-1} + z^{-2}. \tag{5}$$

The design parameters for this filter are the notch filter center frequency, ω0, with respect to the ω axis, and the pole radius, 0 <=r < 1. The second block is the matched filter, which is matched in impulse response shape to the transmitting filter. For a receiver operating in just additive white noise, the matched filter serves to maximize the SNR at a particular sampling instant at the filter output. The main point being that this filter removes as much noise as possible, while retaining the maximum possible amplitude of the signal at the optimum sampling instant. The function of the matched filter is best understood by observing waveforms at the output of the matched filter. The eyeplot function slices the time-domain signal up into contiguous segments an integer number of bit times in duration. The segments are then overlap plotted on top of each other. If Ns=10 we might plot the eyeplot using a 20 sample window length, so we can see two bit signal transitions. The eyeplot shows all possible waveform transitions over the input signal vector. This way we can clearly see where the optimum sampling instant is as the switch in the receiver block diagram needs to know this. Secondly, we can view how open the eye is and immediately see how much distortion is present in the received signal.

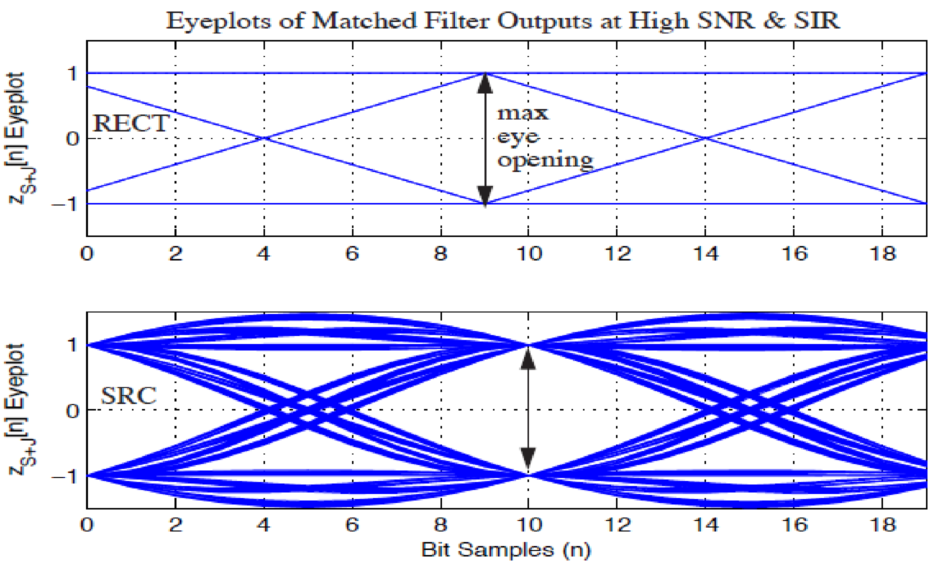

Figure 7: Eyeplots of the matched filter output under high SNR and SIR conditions; RECT (top), SRC (bottom).

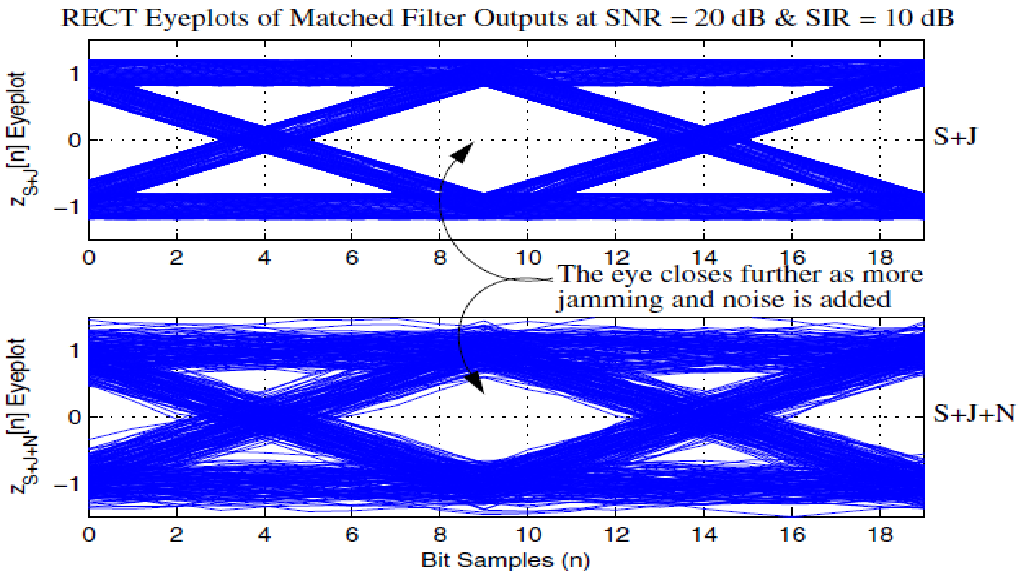

Figure 8: Eyeplots of the matched filter output with SNR = 20 dB and SIR = 10 dB; S+J for RECT (top), S+J+N for RECT (bottom).

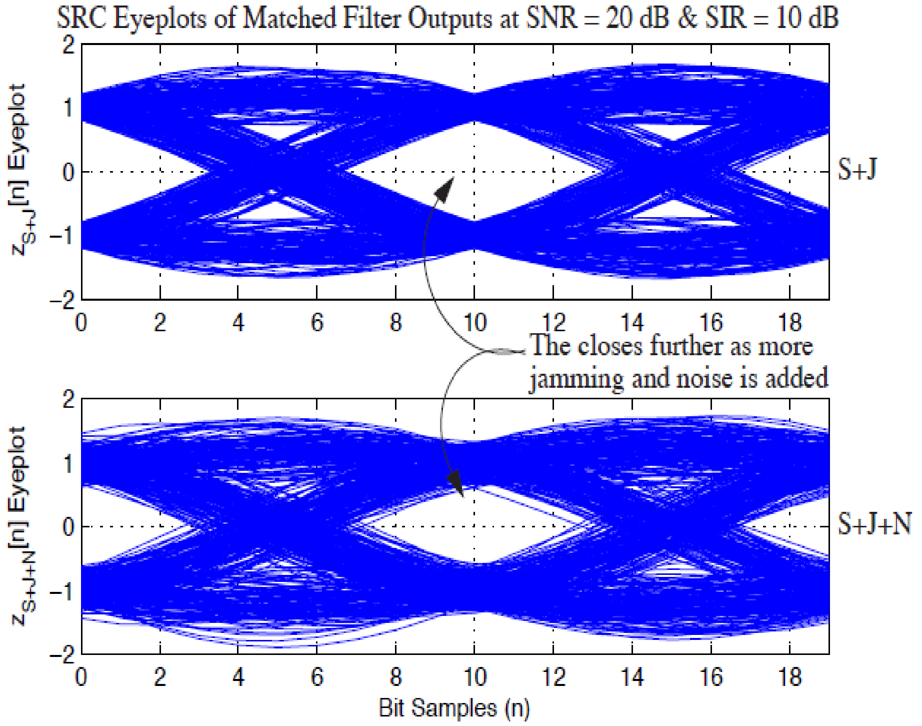

Figure 9: Eyeplots of the matched filter output with SNR = 20 dB and SIR = 10 dB; S+J for SRC (top), S+J+N for SRC (bottom).

III. Results

In Figure 10 the theoretical BEP performance for an additive noise channel is given. This result holds independent of the pulse shape. When jamming is present degraded performance is obtained. Consider the performance with SRC pulse shaping and SIR = 8 dB.

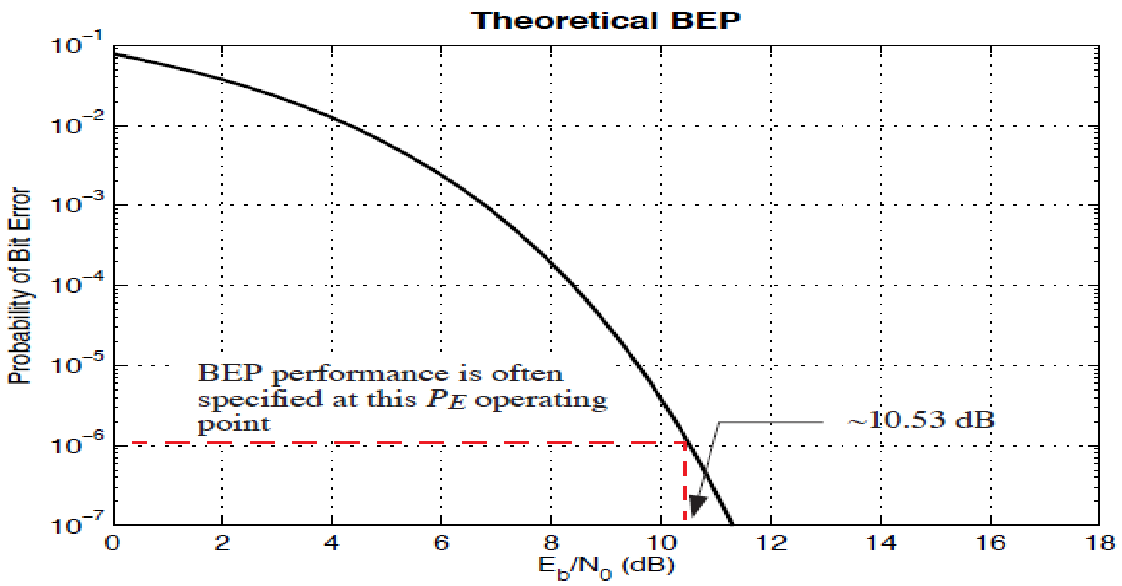

Figure 10: Theoretical BEP performance in additive white Gaussian noise only.

In Figure 11 experimental BEP performance using the semi-analytic simulation technique is shown. Results are shown with and without the IIR notch filter. The number of symbols used in the simulation is increased from 1000 to 100,000 to improve the statistical accuracy of the SA-BEP method. At PE = 10^{-6} we see a performance improvement of about 0.83 dB.

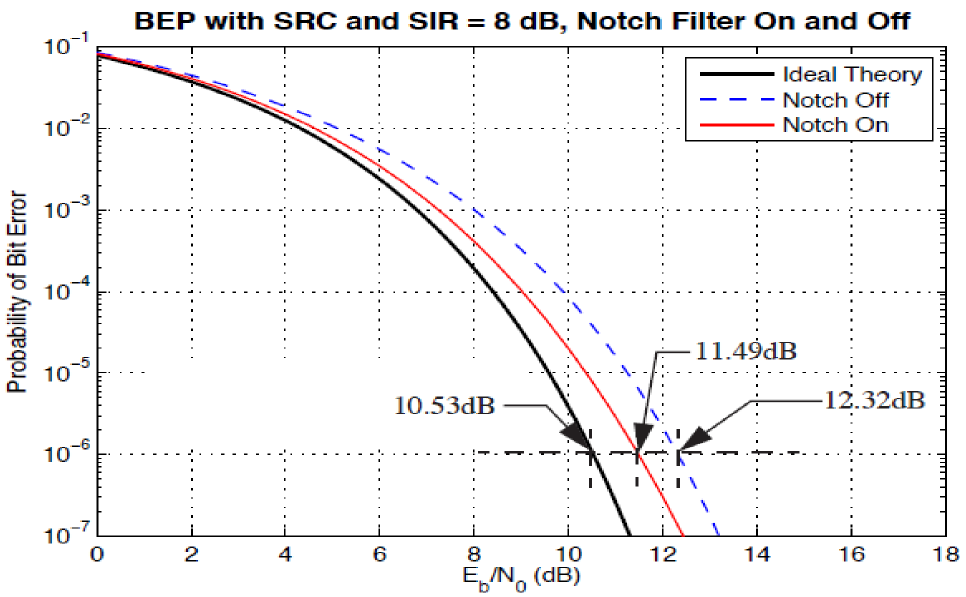

Figure 11: SA-BEP performance using the SRC pulse with and without a notch filter when SIR = 8 dB.

A plot of the power function versus sampling instant, denoted Sampling Index, is given in Figure 12.

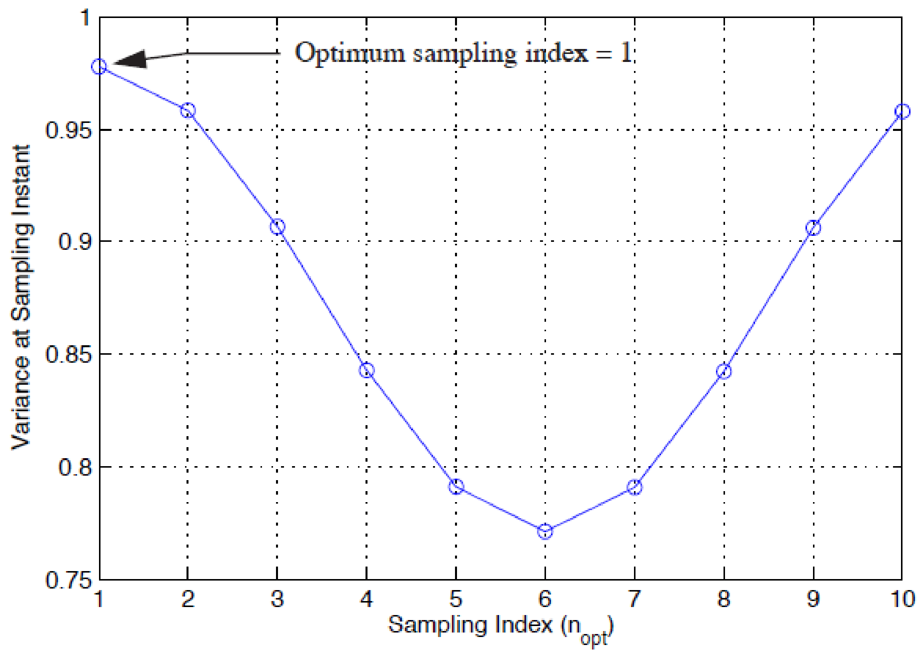

Figure 12: Plot of the sampling instant variance used to estimate the bit sample timing.

IV. Conclusion

The influence of channel SNR on system performance is analyzed by eye diagram and bit error rate (BER). It is shown that under the same condition, the larger the SNR is, the smaller the BER is, and the better the transmission quality. Analysis consistent. From the simulation results analysis and BER performance verification, bipolar digital baseband transmission system fully meet the design requirements. To control the effect of jamming tone and noise, notch filter is used at the receiving end.

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