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BINARY PHASE SHIFT KEYING (BPSK) SIMULATION USING MATLAB

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ABSTRACT

In this paper the analysis for Bit error ratio (BER) with BPSK modulation scheme in Additive White Gaussian Noise (AWGN) channel is performed. The bit error probability curve is simulated using Matlab. The complete BPSK system is implemented in Matlab/Simulink environment. The behavior of the system is simulated and the results obtained are presented.

Keywords: AWGN, BER, BPSK, matlab, simulation, simulink.

1. INTRODUCTION

It is well known that in recent years the transition from analogue to digital systems has become increasingly important in all areas of communications. In summary, each digital communication system includes a set of information source, modulator, communication channel, demodulator, and pulse generator. Moreover, the quality of information transmission largely depends on the processes of modulation and demodulation of the signals. Depending on which parameters of the carrier analog signal will affect the modulation signal (digital array of logic 0 and logic 1), there are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying PSK) digital modulation formats, each of which is characterized by its peculiarities [1, 2, 3].

With the largest single application, the three types of digital modulation are the phase modulation variants. With the largest application in comparison between the three types of digital modulation are the different variations of digital phase modulation [2]. In the simplest version of PSK modulation the phase of the carrier signal switches between two values (0° and 180°) to transmit the two logic levels 0 and 1 of the digital stream [1, 3]. The modulation with two values of the carrier signal is known as Binary Phase Shift Keying - BPSK, the main advantage of which is the high level of resistance against errors in the transmission of the signal through the communication channel.

Bit Error Rate (BER) analysis, as well as the realization of a structural model for the study of BPSK modulated / demodulated signals, is essential task as it is a basis for exploring PSK systems with higher level modulation formats and complexity. The main objective of the present work is the theoretical analysis and simulation with Matlab of BER probability for BPSK modulation format and realization of Simulink model for simulation study of BPSK based communication system.

2. ANALYSIS AND SIMULATION OF BER PROBABILITY FOR BPSK MODULATION FORMAT

Basic indicators for the quality of information transmitted in digital communication systems are the probability of a bit error Pb, as well as the probability of a signal symbol error Ps (Symbol Error Rate - SER). These two parameters are closely interconnected, but in practice, the probability of a bit error is actually used, i.e. Pb, which is the subject of analysis in this paper.

BER probability for BPSK modulation format was obtained in two ways-analytically and through simulation, as for the simulation the Matlab tools were used [5]. To estimate this probability at a given Signal-to-Noise Ratio (SNR) value, the following dependence can be used:

$$P_b = \frac{N_b}{N}, \tag{1}$$

where **Nb** is the number of error bits, and **N** is the total number of transmitted bits.

The calculated BER probability value represents only one estimated point of the actual value. A statistically significant result can be obtained with a sufficiently large number of registered error bits at the output of the demodulator. It is considered to be sufficient Nb ≥ 100 [3].

In digital communication systems, the signal to noise ratio is generally defined as the ratio of the bit energy Eb to the noise power spectral density N0, i.e. Eb / N0. Furthermore:

$$E_b = PT_b, \tag{2}$$

where **P** is the signal power, and **Tb** is the time for transmission of one bit;

$$N_0 = P_n / W, \tag{3}$$

where **Pn** is the noise power, and **W** is the frequency bandwidth.

The definition of the SNR is a prerequisite for the analysis of the BER probability to be performed with respect to Eb/N0, i.e. to determine the dependence $P_b = f(E_b / N_0)$. To determine this functional dependence, the block diagram on Figure-1 is used.

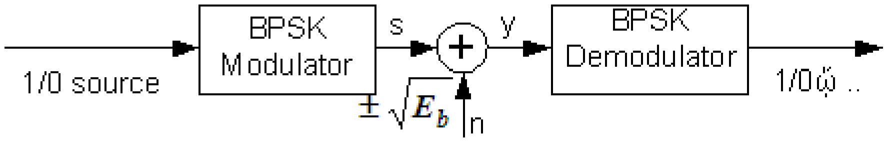

Figure-1. Summary block diagram of a system with BPSK modulator - demodulator.

The phase-modulated signal s is represented by two constant amplitudes $\pm\sqrt{E_b}$, which define the two logical levels 0 and 1, i.e. $s_0 = -\sqrt{E_b}$ (corresponds to logical 0 - bit 0) and $s_1 = +\sqrt{E_b}$ (corresponds to logical 1 - bit 1).

There is an additive white Gaussian noise in the communication channel (Additive White Gaussian Noise - AWGN) n, which is added to the modulated signal s. The noise is described by the Gaussian probability density function [2]

$$p(n) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{n^2}{2\sigma^2}\right), \tag{4}$$

where $\sigma^2 = N_0 / 2$ is the dispersion of noise n.

In the theoretical analysis, the input signal of the demodulator is represented by the equation

$$y = s_i + n, \tag{5}$$

where i = 0 or 1.

Signal y is a random signal with a probability distribution function for both cases, respectively:

- when a transmitted signal s_0 corresponding to a logical **0**

$$p(y|s_0) = \frac{1}{\sqrt{\pi N_0}} \exp\left[\frac{-\left(y + \sqrt{E_b}\right)^2}{N_0}\right], \tag{6}$$

- when a transmitted signal s_1 corresponding to a logical 1

$$p(y|s_1) = \frac{1}{\sqrt{\pi N_0}} \exp\left[\frac{-\left(y - \sqrt{E_b}\right)^2}{N_0}\right]. \tag{7}$$

Let the probability of transmitting logic 0 and logic 1 being the same, i.e.

$$p(s_0) = p(s_1) = 1/2 \tag{8}$$

In addition, let the threshold, to which a digital stream is formed at the output of the demodulator, is 0. In this case, the condition $y > 0$ corresponds to the transmitted logic 1, ($y > 0 \rightarrow s_1$), and $y \leq 0$ - to the transmitted logic **0** ($y \leq 0 \rightarrow s_0$).

Taking this threshold into account, the BER probability for a transmitted signal s_1 is obtained:

$$p_e(s_1) = \frac{1}{\sqrt{\pi N_0}} \int_{-\infty}^{0} \left[\exp\left(\frac{-\left(y - \sqrt{E_b}\right)^2}{N_0}\right)\right] dy = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{E_b}{N_0}}}^{\infty} \left[\exp\left(-x^2\right)\right] dx = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{9}$$

where $\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_{x}^{\infty} \exp\left(-x^2\right) dx$, and $x = \sqrt{\frac{E_b}{N_0}}$ is the so-called complementary error function [5].

BER probability for a transmitted signal s_0 is obtained:

$$p_e(s_0) = \frac{1}{\sqrt{\pi N_0}} \int_{0}^{\infty} \left[\exp\left(\frac{-\left(y + \sqrt{E_b}\right)^2}{N_0}\right)\right] dy = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{E_b}{N_0}}}^{\infty} \exp\left(-x^2\right) dx. \tag{10}$$

The total BER probability for BPSK modulation format is therefore:

$$P_b = p(s_1)p_e(s_1) + p(s_0)p_e(s_0). \tag{11}$$

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After substitution the probabilities in eq. (11) with their corresponding Equations (8), (9) and (10), the final functional dependence $P_b = f(E_b / N_0)$ is obtained:

$$P_b = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right). \tag{12}$$

The BER probability thus obtained is calculated for different values of the ratio. At the same time, simulation of the BER probability for the same E_b / N_0 values was performed by appropriate Matlab functions [5]. The theoretical and simulation-derived characteristics are shown in the general coordinate system of Figure-2.

It is evident, that the theoretical and simulated characteristics coincide almost completely, with a slight difference for the Signal-to-Noise ratio $E_b / N_0 > 9\text{dB}$. The square mean error between both BER probability characteristics is $\text{EPS\%} = 0{,}02819\%$, which is a prerequisite for the correctness of both the theoretical analysis and the simulation approach The results also confirm the thesis that with increasing the SNR, the BER decreases, where the rate at which the probability decreases in the particular case increases after $E_b / N_0 > 4\text{dB}$. For the simulated characteristic the value of $P_b = 10^{-5}$, which is often used as a reference value, is achieved at $E_b / N_0 = 9{,}27\text{dB}$, while for 8-PSK modulation format, for example, the value is reached at $E_b / N_0 = 12{,}32\text{dB}$.

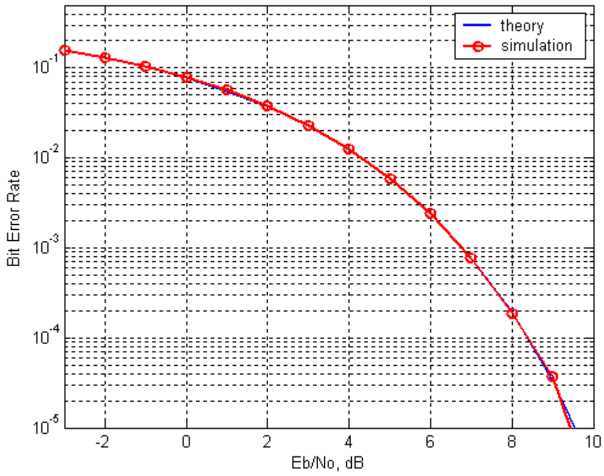

Figure-2. BER probability characteristic.

3. SIMULINK SIMULATION MODEL OF BPSK BASED SYSTEM

In order to simulate the process of digital phase modulation / demodulation in Simulink graphical environment, a structural model is synthesized - Figure-3.

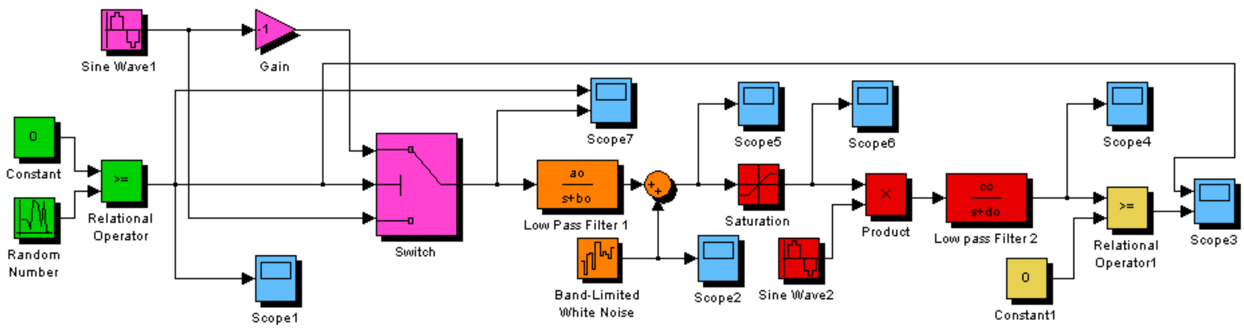

Figure-3. Simulink simulation model of BPSK based communication system.

The model is realized with the following functional blocks:

- **Binary signal source**

The source is synthesized by a Random number generator, a constant-generating block (**Constant**) and a comparison bloc (Relational Operator). The random number generator generates binary signals with a normal (Gaussian) distribution law. In the Relational Operator block, they are compared to a constant value (0) generated by the Constant block. If the value of the random signal is greater than 0, a signal corresponding to logic 1 is generated at the output of this block and otherwise - a signal corresponding to logic 0.

- **Modulator**

The modulator consists of a sinusoidal signal generator (Sine Wave1), which sets the carrier signal; a line amplifier (Gain) for signal de-phasing and a switch with two information and one control input. The switch is used as the phase switch of the carrier signal, and the switching is controlled by the middle input signal, whose amplitude is compared with the sensitivity threshold level set for the key.

- **Transmission channel**

The communication channel consists of a low-pass filter (Low Pass Filter1); band noise limited white noise generator (Band - Limited White Noise) and summator (Sum). There are two ways to model the filter -

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either by defining the transfer function of the filter by means of the polynomial coefficients in the numerator and the function denominator, or by selecting a method for approximating the amplitude-frequency response of the filter. For a more accurate simulation, it is necessary that the correlation noise time, which is the noise source parameter, should meet the condition:

$$t_c = \frac{1}{100} \frac{2\pi}{f_{max}}, \tag{13}$$

where f_{max} is the maximum channel frequency in **rad/sec**.

Using the summator, the noise is added to the filtered modulated signal.

- **Demodulator**

The demodulator model is implemented with a double-sided amplitude limiter (Saturation), a sinusoidal signal source (Sine Wave2), multiplier (Product) and a low-pass filter (Low Pass Filter2). The Saturation block limits from both sides the amplitude of the input signal to the input, as a result of which the superposed noise is removed. The received signal is proceeded at one of the inputs of the phase detector (multiplier), at the other input is proceeded the comparison voltage generated by a sinusoidal signal source (its frequency must be the same as that of the carrier signal). The demodulated signal is obtained after the low pass filter.

- **Pulse former**

Formation of pulses by which the signal is recovered at the output of the BPSK system, is simulated with the comparison bloc (Relational Operator1) and the Constant1 block, which sets a constant value used as a threshold value. The demodulated signal is compared to the threshold value (in this case 0) and depending on their ratio, a signal corresponding to 1 or 0 is generated at the output of the former.

To evaluate the model (Figure-3) simulations were performed, the results of which illustrate the essence of BPSK modulation - demodulation process.

In Figure-4 is shown the generated modulation binary signal.

The resulting phase modulated signal (Figure-5) is a sinusoidal signal with a constant frequency and amplitude and with a varying phase dependent on the modulation signal

It is evident that the phase of the carrier sinusoidal signal is switched between the two values **0° и 180°** in order to transmit the two levels of the modulation signal. In other words, the signal obtained by the simulation corresponds entirely to the BPSK modulated signal theory.

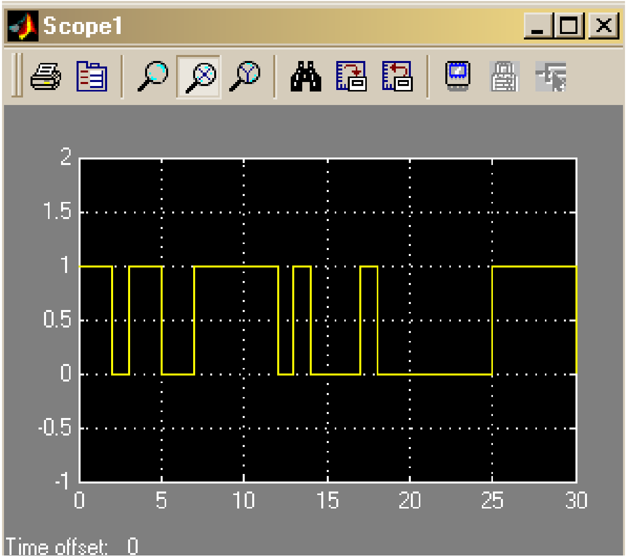

Figure-4. Binary modulation signal.

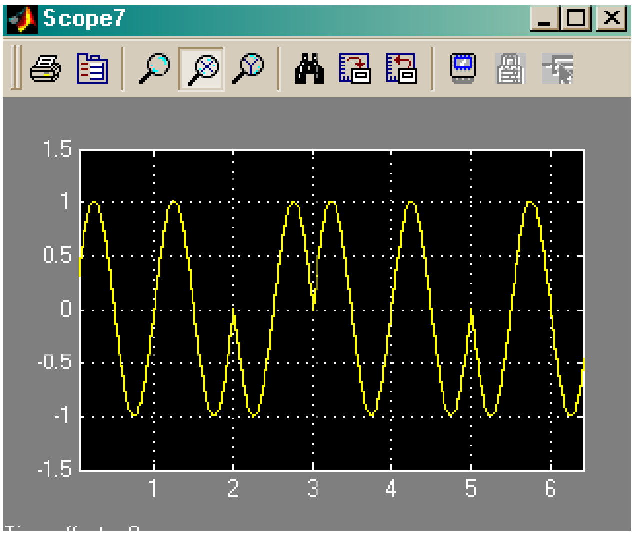

Figure-5. Phase modulated signal.

The demodulated signal is shown in Figure-6. The form of this signal is correct and suitable for processing with the impulse generator. The restored digital output sequence is illustrated in Figure-7.

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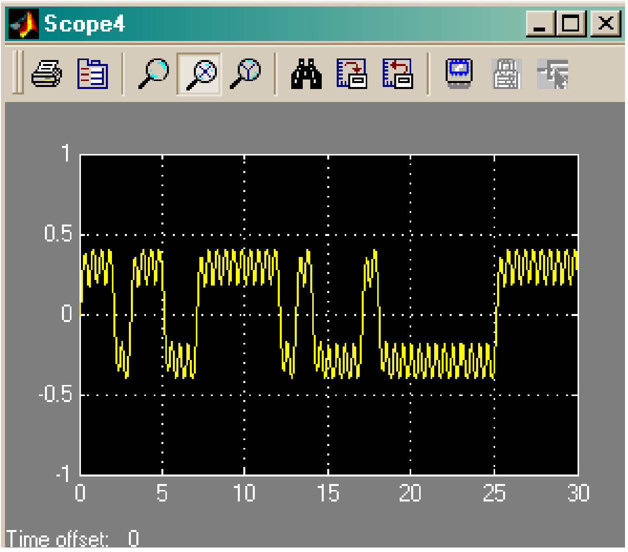

Figure-6. Demodulated signal

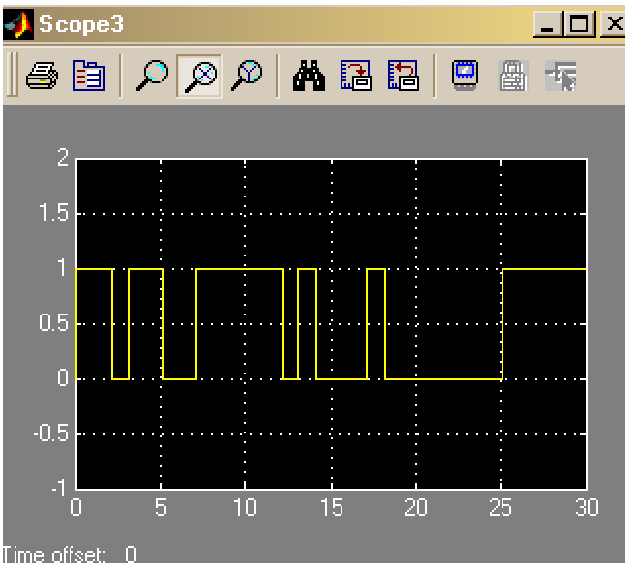

Figure-7. Recovered modulation signal.

The comparative analysis of the two signals - recovered (Figure-7) and the modulation signal (Figure-4) shows that they coincide almost entirely. There is only a minor delay of the recovered signal, which is quite natural.

The presented results are obtained at channel noise power of 2mW. Simulations have also been carried out at higher noise levels, the results of which show that the model takes proper account of the impact of the noise. With higher power noises the phase change and the amplitude of the received signal is increasing. In addition, there is a change in the recovered digital stream as compared to the input, with additional bits appearing at power above 150mW.

4. CONCLUSIONS

The results obtained for BPSK modulation format are obvious proof of the adequacy of the theoretical and simulation models. They are an objective prerequisite for selecting an optimal set of Matlab functions, block parameters in the structural Simulink model, and simulation conditions that ensure high quality modulation. The theoretical analysis and BER probability simulation for BPSK modulation format, as well as the proposed Simulink model of BPSK based communication system, can be successfully used for the study and evaluation of more complex digital phase modulation variants. For this purpose, only a minor modification is necessary to take into account the number of values that the phase of the carrier signal can take.

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