Simulink and FPAA Implementation of FSK Signals

Bikram Choudhury and Aruna Tripathy

Abstract Fundamental to all wireless communication is modulation, the process in which the message data is transmitted on a high frequency radio carrier. Most of the wireless transmissions today are digital as it has more advantages than analog; the effect of distortion, noise, interference is minimized through the use of ingenious digital signal processing as compared to analog communication system. In this paper, we have considered binary frequency shift keying (BFSK) as the modulation technique to send data over a wireless channel. The corresponding demodulator is responsible for retrieving the transmitted data from the noisy, faded signal as impacted by the channel. The metric usually used to evaluate a digital modulation scheme is its average probability of bit error. We have evaluated the bit error rate (BER) of BFSK signals in both the additive white Gaussian noise (AWGN) and flat Rayleigh fading channels. The evaluation has been carried out in both MATLAB and SIMULINK platforms which are subsequently validated by the corresponding theoretical values. After the simulated, BER values are verified and matched with their corresponding theoretical values, hardware realizations have been attempted. The contribution of this paper is (a) the BER evaluation of BFSK through MATLAB simulation and SIMULINK platform, followed by theoretical validations in two different channels and (b) investigation of a hardware platform called Field Programmable Analog Array (FPAA) to build and test a BFSK modulator demodulator (MODEM). Test results show promising outcomes as to the suitability of such MODEM. Indeed data is retrieved at the expense of a small delay.

Keywords FSK · BER · AWGN · Rayleigh flat fading · SIMULINK · FPAA

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1 Introduction

Frequency Shift Keying (FSK) is a modulation scheme that is widely used in digital communication system due to the simple construction of both its modulator and demodulator (MODEM), the ease of generation of orthogonal carriers and simple envelope detection at the receiver. Here, the frequency of the carrier (which is usually a sinusoidal signal) is varied according to the amplitude of the message bearing or the baseband digital signal. For binary baseband signal, a higher carrier frequency (f_H) called mark frequency is produced for a binary '1', whereas for binary '0', a lower carrier frequency (f_L) called as space frequency is produced. Numerous efforts have been reported [1–10] that assess BFSK over different channels. The contribution of this paper is an attempt to assess the performance of a BFSK signal in both the additive white Gaussian noise (AWGN) as well as frequency flat Rayleigh fading channels using simulations carried out on MATLAB as well as SIMULINK. The simulated performances are validated with the corresponding theoretical values. The almost perfect match shown by the simulated results with their corresponding theoretical bounds motivated attempts to design a BFSK MODEM on a reconfigurable hardware platform. Hardware implementations of a number of analog functional blocks are reported on other platforms [11–17]. However, the suitability of an FPAA to construct and subsequently test it for information retrieval using BFSK is missing in literature. The novelty of this paper is one of the hardware implementation of a BFSK MODEM and to assess its suitability to detect data from the modulated waveform on a platform called Field Programmable Analog Array (FPAA) from Anadigm Designer 2. The MODEM shows promising results of information retrieval at the expense of a small delay. The necessary mathematical expressions used to evaluate a given MODEM are presented in Sect. 2. Section 3 discusses the system models developed in SIMULINK, followed by the FPAA implementation. Results are discussed in Sect. 4, followed by concluding remarks in Sect. 5.

2 Theoretical Bit Error Rate of BFSK in AWGN and Rayleigh Flat Fading Channels

A BFSK signal can be represented as

$$V_{fsk}(t) = V_c \cos\{2\pi [f_c + V_m(t)\Delta f]t\}, \quad 0 \le t \le T_b, \tag{1}$$

where $V_{fsk}(t)$ represents the binary FSK waveform, $V_m(t)$ is the digital message signal, Δf = frequency deviation from the carrier frequency, V_c = Peak analog carrier amplitude and T_b is the bit duration. So when $V_m(t) = +1$, we will get the frequency component as $f_c + \Delta f$ and $f_c - \Delta f$ when $V_m(t) = -1$. So in this sense, for binary '1', we are sending a higher carrier frequency (f_H) called as mark frequency, whereas for binary '0', lower carrier frequency (f_L) is called as space frequency.

We note from Eq. 1 that a multilevel base band signal changes the carrier frequency in multi steps instead of binary. The theoretical equation for probability of average BER in AWGN is,

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \tag{2}$$

E_b represents energy per bit while N_0 is the one-sided power spectral density of white noise in (2). The simulated values are compared with Eq. 2. For Rayleigh flat fading channels, the average BER is expressed as [4]

$$P_{e,\text{Rayleigh}} = \left[\frac{1}{2}(1-\mu)\right]^L \sum_{k=0}^{L-1} \binom{L-1+k}{k} \left[\frac{1}{2}(1+\mu)\right]^k \tag{3}$$

In our work,

$$L = 1,\ \mu = \sqrt{\frac{\overline{\gamma_c}}{1+\overline{\gamma_c}}} \tag{4}$$

Further,

$$\overline{\gamma_c} = \frac{E_b}{N_0} \tag{5}$$

The expressions are simplified to the following in our work as,

$$P_{e,\text{Rayleigh}} = \frac{1}{2}(1-\mu) \tag{6}$$

For AWGN channels, the theoretical average BER is evaluated by (2), whereas for Rayleigh flat fading channels, use is made of Eq. 6 in the subsequent sections.

3 Simulink Models and Validation of Results

In this section, the SIMULINK models for a BFSK MODEM in both AWGN and Rayleigh flat fading channels are presented. A comparison is also made between the simulated BER with the theoretical ones using Eq. 2. The SIMULINK model of BFSK in AWGN is presented in Fig. 1.

The BER of BFSK in AWGN as obtained in Fig. 1 has been compared with the theoretical one using Eq. 2 in Fig. 2 and both show a good match.

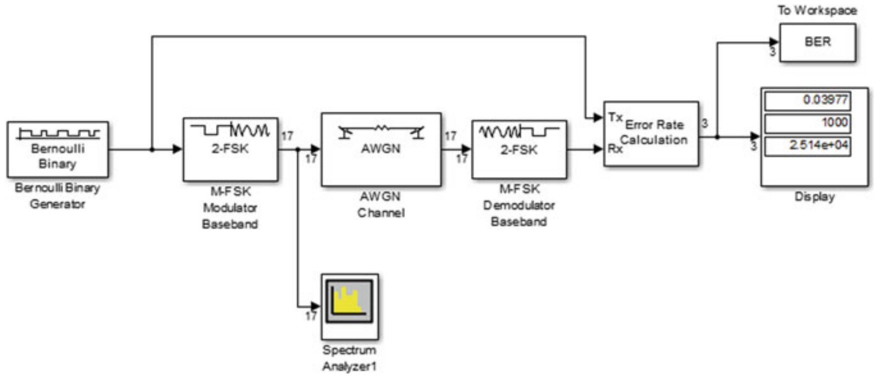

Fig. 1 BFSK SIMULINK Model in AWGN Channel

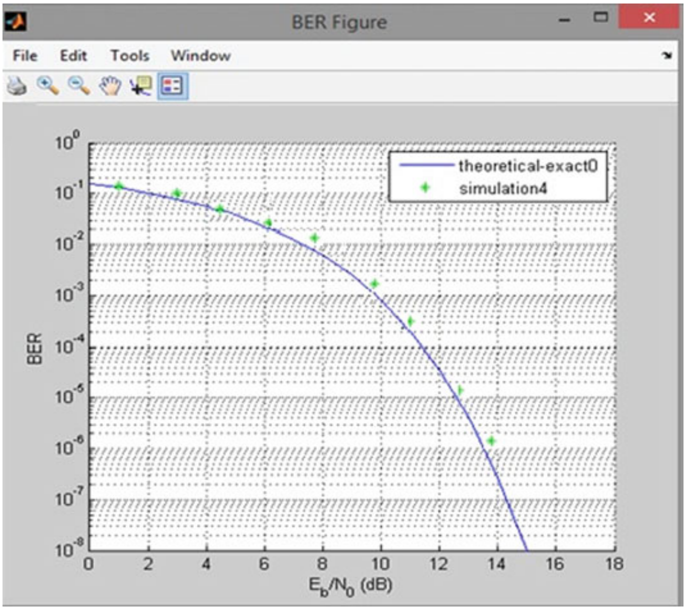

Fig. 2 BER curve of BFSK under AWGN Channel in SIMULINK Model

The model used to assess the BER of BFSK in flat Rayleigh fading is shown in Fig. 3. The Rayleigh fading block is used after the BFSK modulator block in order to determine the effect of Rayleigh fading effect in BFSK. The math function 1/u acts as a normalizing factor. The Spectrum Analyzer block accepts input signals with discrete sample times and displays frequency spectra of these signals. The Error Rate Calculation block compares input data from a transmitter with input data from a receiver and helps to obtain the BER curve.

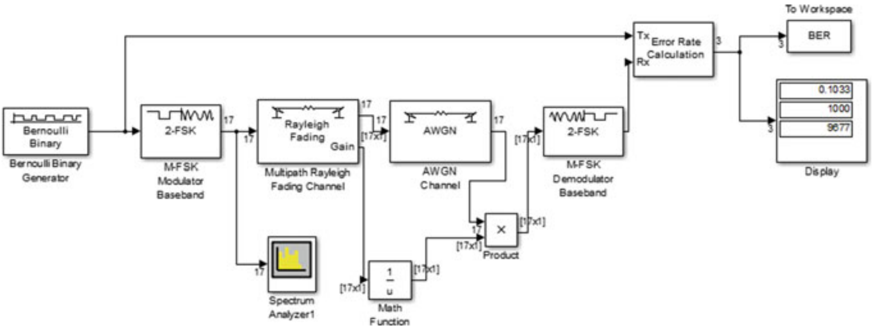

Fig. 3 BFSK SIMULINK model in Rayleigh fading

The BER of BFSK in flat Rayleigh fading as obtained in Fig. 3 has been compared with the theoretical one using Eq. 6 in Fig. 4 and both are in good agreement.

MATLAB 2014 version has been used to simulate the BFSK signal where binary data is taken as input. Two carrier signals $C_1(t)$and $C_2(t)$ are generated. According to two carriers, FSK signal is generated and demodulated.

The simulation for probability of bit error for BFSK over AWGN and Rayleigh Fading is done by using MATLAB 2014 and the parameters considered for this simulation are mentioned in Table 1.

Figure 5 shows the comparison of simulated BER curve which is simulated in MATLAB of BFSK in AWGN and Rayleigh fading channel. Here, SNR dB is taken from 0 to 12 dB. It is observed from this figure that the BER performance of BFSK

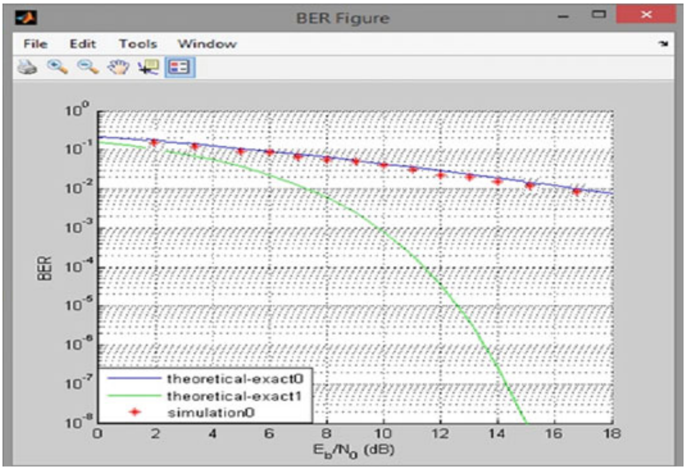

Fig. 4 BER curve of BFSK in Rayleigh fading in SIMULINK model compared with the corresponding AWGN curve

Table 1 Parameter table for simulation of bit error probability of BFSK over AWGN and Rayleigh fading

Modulation order (M)	2 (BFSK Coherent)
No. of Bits	1,000,000
Samples/bit	20
SNR	0:1:12 dB
Carrier frequencies	1 Hz, 2 Hz

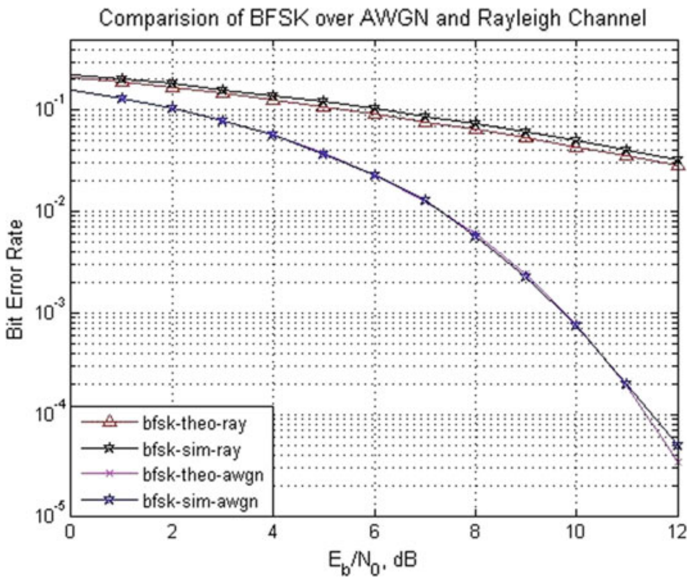

Fig. 5 Comparison of MATLAB Simulation of BER curves of BFSK in AWGN and Rayleigh fading channel

over AWGN is better than BER performance of BFSK over Rayleigh channel. This is for the sake of completeness.

From Figs. 2 and 3, the Spectrum analyzer is used after the BFSK modulator baseband block to obtain the Power spectral density of BFSK in Simulink model and to validate those results in MATLAB simulation, we have used FFT algorithm to obtain the Power Spectral Density in MATLAB 2014 version. The results for PSD of BFSK from SIMULINK and MATLAB simulation are mentioned in Figs. 6 and 7.

The PSD of BFSK signal is the superposition of PSD of two signals generated for 0 and 1. As we are computing PSD of BFSK, we observe two sharp peaks in Figs. 6 and 7. This is due to the two carrier frequencies used in BFSK. This is because of the orthogonal nature of the basic functions. From Figs. 7 and 8, two main lobes are generated exactly at the same distance from the center frequency. Two lobes from both the simulations correspond to the energy of the two symbols/frequencies.

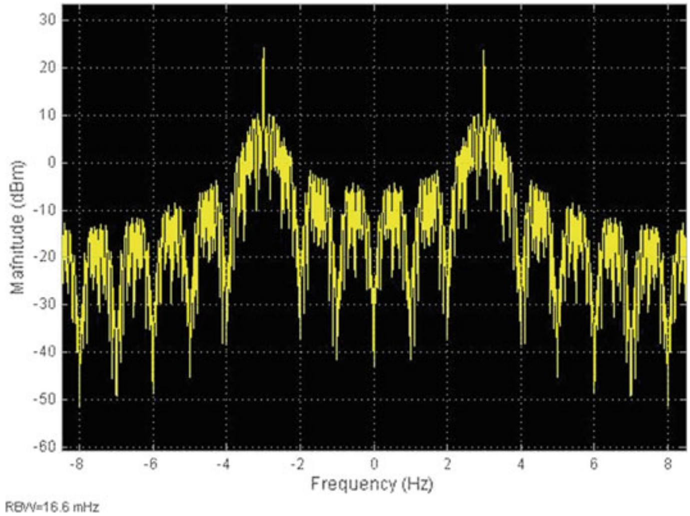

Fig.6 Simulated power spectral density of BFSK in SIMULINK Model

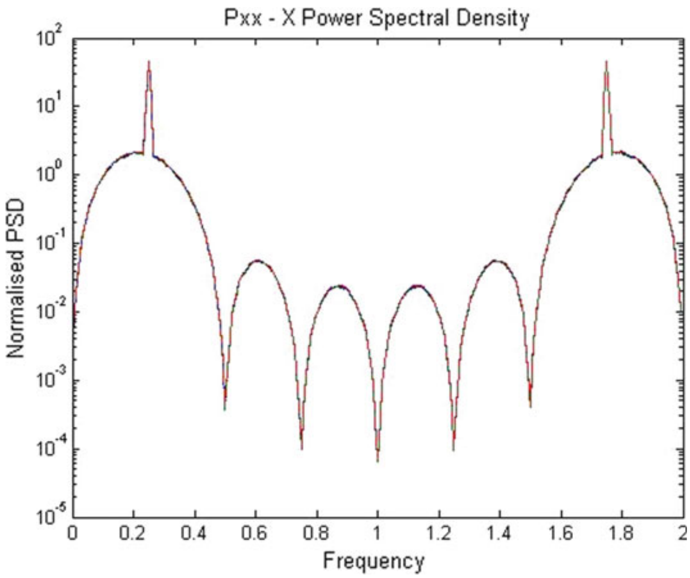

Fig.7 Simulated power spectral density of BFSK in MATLAB

The spike at center of each frequency lobe represents the carrier frequency of each symbol.

Next, we have shown one hardware implementation of a BFSK modem. Some of the readily available FPAA software sources are as follows: ANADIGM (CMOS

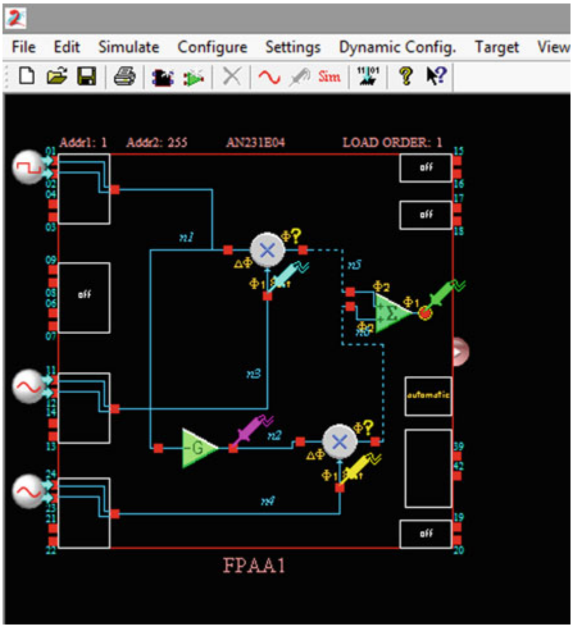

Fig. 8 Generation of BFSK Modulated signal using Anadigm Designer-2

Technology, 2 MHz BW), MOTOROLA (Discrete time Technology, 200 kHz BW), IMP Inc. (CMOS Technology, 125 kHz BW), FAST ANALOG SOLUTION (Bipolar Technology, 4 MHz BW), University of TORONTO (CMOS Technology, 100 kHz BW). But in this paper, the hardware realization has been carried out on ANADIGM-2 FPAA. FPAAs help in the algorithmic implementation of the analog circuit creation policies, provides a very convenient medium in which analog circuits and systems can be designed and implemented in a very short time frame. Anadigm Designer 2 software has designed all the functional codes and blocks as analog units and the programs that are inscribed in each block are suitable for analog modulation and demodulation scheme. However, some of the functional blocks like periodic wave generator, zero cross detector, etc., essential for a BFSK MODEM implementation are suitable and helpful in digital modulation schemes. Utilization has been made of these functional blocks to construct and test such a MODEM on this platform.

4 FPAA Implementation of BFSK Modulator

A hardware implementation of BFSK modulator has been carried out on a platform called ANADIGM DESIGNER 2. The message signal and two carrier signals are generated by the Signal Generator Controller and we set the frequency and amplitude of each signal used in this block. The message signal has 10 kHz frequency, and the 2 frequencies are 50 kHz and 20 kHz, respectively, and amplitude of 1 V. The

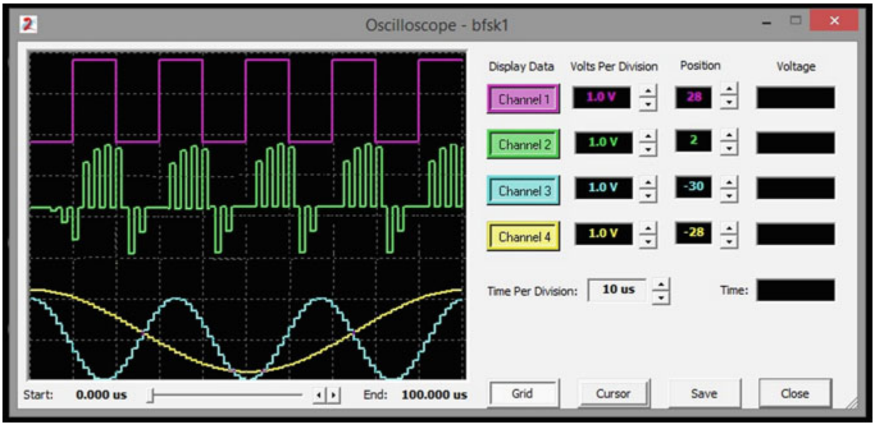

Fig. 9 Output of BFSK modulated signal

square wave message signal is passed through an inverter to produce 0 and 1 with equal probabilities. Then the message signal is multiplied with both the carriers with the help of two multipliers. Both multiplied signal passed to an adder to get the modulated signal. For the sum purpose, we have used the SumFilter. (It creates a full cycle summing stage with up to three inputs that includes a single pole low pass filter.) The inputs may be either inverting or non-inverting so that both sums and differences may be created in the transfer function. The modulator for BFSK signal in ANADIGM DESIGNER 2 is shown in Fig. 8, while its output is illustrated in Fig. 9.

From Fig. 9, we can observe that we are getting a high-frequency signal for + 1 of the binary wave and a low frequency signal for –1 of the binary wave. In this diagram, the purple color signal is the message signal, blue color signal indicates higher frequency signal, the yellow color signal is the lower frequency signal, and the green color signal indicates the modulated signal of BFSK technique. Next, we show one implementation of a BFSK demodulator using ANADIGM 2.

Figure 10 shows a realization of coherent demodulator. The modulated signal is multiplied with the same carriers as used in the modulator. Then these signals are passed through LPFs (Low pass filter) having cutoff frequency 25 kHz to get two output signals. Finally these signals are passed through a comparator to get the original message signal. The comparator will produce a digital output level of ±2 V, based on the chip reference voltages. The output of this FPAA design is described in Fig. 11.

The Purple line indicates the message signal and the blue line indicates the demodulated signal. In this case, we are getting a delay in demodulated signal as compared to the message signal. This is attributable to the fact that all the functional blocks in an FPAA are designed to process analog signals leading to inherent delays between connecting blocks produced by the various functional blocks that process the analog signals.

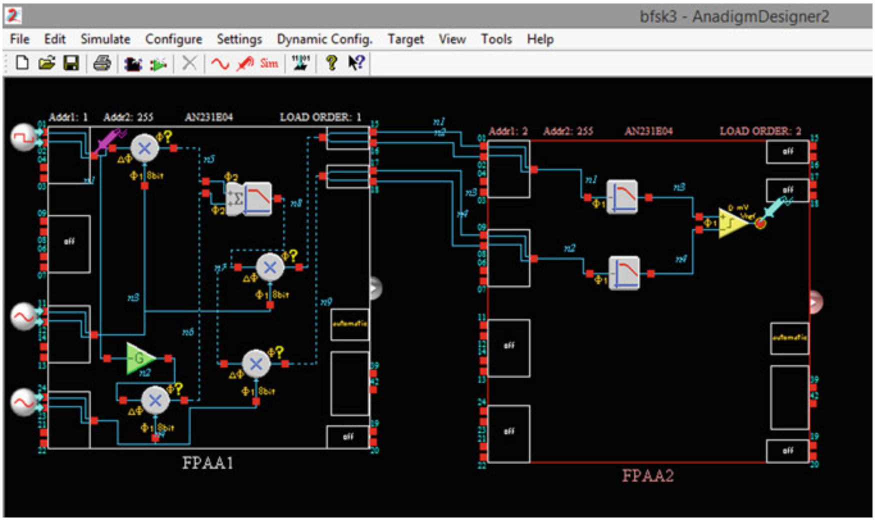

Fig. 10 BFSK demodulator on FPAA

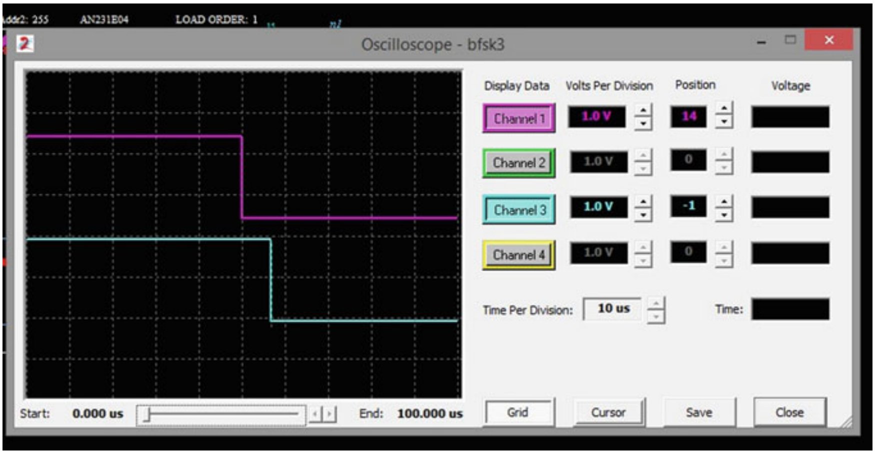

Fig. 11 Output of BFSK demodulated signal

5 Conclusion

The aim of this Simulink Model is to analyze the modulation/demodulation scheme BFSK using BER as a performance indicator. The BER characteristics as obtained through MATLAB simulation and SIMULINK models match their theoretical values both in the AWGN channel and Rayleigh fading for almost all the SNR values considered. The successful simulation of BFSK has motivated to construct and test a BFSK

MODEM. This has been carried out on a hardware platform called Anadigm Designer 2's FPAA. One of the possible implementations of a BFSK modem shown in this paper uses coherent detection in the absence of any real channel. During modulation process we are getting accurate outputs as desired but during demodulation process we observe some time shift at the outputs as Anadigm Designer 2 makes use of all analog signal processing blocks. Both the input signal and demodulated waveforms show a good match at the expense of a delay of about 15 μS.

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