# PSK Modulation/Demodulation and Performance Evaluation in FM Band Using USRP

Syed Muhammad Hashir
Department of Electrical-Electronics Engineering, Istanbul Medipol University, Istanbul, Turkey
Email: msyed@st.medipol.edu.tr

***Abstract*—Rapid changes in the wireless systems require reconfigurability. So, an efficient and highly configurable hardware is feasible for such kind of systems. Reconfigurability in fixed hardware systems increases complexity. Thus, it does not cater the problem of frequent changes. A Software Defined Radio (SDR) is a platform which is viable in terms of reconfigurability to implement different types of communication system requirements with same sort of software and hardware such as Lab View and USRP. This paper presents the USRP based communication system, which implements the PSK modulation and demodulation. This system transmits the PSK modulated signal in FM band to examine the channel. Further in the paper, Bandwidth and Bit Error Rate (BER) performance are compared for two different types of PSK modulations based on multiple pulse shaping techniques.**

***Index Terms*—FM band, USRP, Software Defined Radio, Modulation**

## I. Introduction

IN wireless communication, the diverse nature of communication channel is the primary problem. Several technologies, systems and algorithms have been developed to eliminate or at least mitigate the fundamental issues as much as possible while retaining the quality of communication. However the rapid change in the communication systems and methodologies demands hardware reconfigurability. Same systems with different specifications require changes. Amendments in Application-Specific Integrated Circuit (ASIC) based system consumes significant time and money. On the other hand, Field Programmable Gate Array (FPGA) based systems ensures hardware reconfigurability but occupy more chip size than ASIC systems [1]. This trade-off can be accepted in most of the communication applications. FPGA based systems in wireless communication are called Software Defined Radios (SDR). SDR are highly configurable and provides high performance almost identical to application specific systems [2].

In this paper I have used two Software Defined Radios to implement Phase shift keying (PSK) modulation and demodulation which transmit and receive a PSK modulated signal through a wireless channel in FM band. Effect of Modulation order and pulse shaping on Bit Error Rate (BER) and bandwidth is also studied by using this system.

The rest of the paper is organized as: Section II presents the overview of Software Define Radios, Section III explains the PSK modulation and pulse shaping filters in the literature, Section IV presents the PSK Modulation/Demodulation communication setup using USRPs, Section V discusses the results and comparisons of the communication system and last section concludes the whole paper.

## II. SDR Platform

Joseph Mitola introduced the concept of Software Defined Radio in [3]. In SDR, the blocks of transmitter, receiver and other radio components are designed in software such as modulators, filters and etc. It provides reconfigurability of TX/RX front end power, transmission frequency, Sampling rate and other technical specifications through software which are normally hard coded in application specific systems [4]. Further in this area, Matt ettus worked in parallel with SDR on the hardware side. Later, it was called Universal Software Radio Peripheral (USRP) [5]. These USRPs and other SDRs are controlled with multiple softwares in which most of the common among researchers are GNU Radio, Matlab and LabView [6] [7].

### *A. USRP*

Universal Software Radio Peripheral (USRP) is a hardware platform for the realization of SDR. This hardware platform is designed in such a way that it is suitable for most of the applications such as cognitive radio, networking, navigation and etc [8]. Ettus research designed it for most of the Radio Frequency applications i.e. for frequencies starting from few MHz to few GHz. USRP is normally a RF front end of radio receiver. It is designed to capture and digitize RF signals from antenna on the receiver side and convert digital samples into analog form and transmit it through antenna on transmitter side [5].

### *B. Lab View*

Laboratory Virtual Instrument Engineering Workbench (Lab View) is a programming tool in which user can program different logics by using graphical notations. It is different from other programming tools where user type in text to build logics or implement pseudo codes. In addition, Lab View has signal processing tool box which can be used for digital communication applications. This software also provides hardware compatibility and complete software control for USRPs. With the increase in interest of several researchers on USRPs, National instrument provided complete Modulation Toolkit for USRPs to implement communication systems for multiple applications [9].

## III. Background

### *A. Phase Shift Keying (PSK) Modulation scheme*

In PSK modulation, digital data bits are encoded in to analog form by changing the phase of the sinusoidal carrier wave. In this way, more than one bit can be assigned to the carrier wave. PSK modulation is defined by following equation:

$$Sm(t) = g(t)Cos(2\pi f_c t + \theta_m) \quad (1)$$

Where, $\theta$ is the phase shift and g(t) is the pulse shaping signal. The most common and primary type of PSK is the Binary Phase Shift Keying (BPSK). In BPSK, single bit is assigned to the carrier. When bit is 0 then the carrier phase shift is 0 degrees and when Bit is 1 the carrier phase shift is 180 degrees and it can be interchanged. In Quadrature Phase Shift Keying (QPSK), 2 bits are mapped on each carrier phase. So phases in QPSK are: 45, 135, 225 and 315 degrees as illustrated in [10]. Constellation of BPSK corresponds to one dimensional with N=1. Both of the message symbols (M=2) are spaced equally. QPSK is a two dimensional constellation with N=2 and M=4. QPSK is same as M-ary PSK modulation with M=4 possible carrier phases, which is described by following equation:

$$\theta_m = \left( \frac{2\pi(m-1)}{M} \right) \quad (2)$$

Where, m=1, 2.., M is the total M phases of the carrier signal. On the receiver side, a coherent reference signal is needed in order to demodulate a PSK modulated signal by carrier recovery, which calculates and removes the phase and frequency offsets from the received carrier waveform and match it with the local carrier signal of receiver generated by local oscillator. Timing recovery algorithms are used for symbol synchronization.

The bandwidth of the PSK modulated signal is related to the symbol rate which is defined by sampling rate and samples per symbol. Bandwidth of PSK modulated signal without applying any filtering or shaping of the pulse, is equal to the sampling rate with 1st lobe equal to two times of symbol rate. With applying pulse shaping techniques, the null to null bandwidth is approximately equal to two times of symbol rate. Parameters of the filter also plays an important role in defining the bandwidth. The comparison of bandwidths for my system is discussed in results section. Other detailed information about digital modulation can be found in [10], [11], [12]

### *B. Pulse shaping*

There are two significant requirements in the communication channel. First, to generate a band limited signal. Second one is to reduced the Inter Symbol Interference (ISI). These can be fulfill by using pulse shaping filter which shapes each symbol

During phase modulation, sharp transition between phases is a common problem. It results in adding high frequency components in the frequency spectrum of the signal and also creates interference for adjacent channels. Once the filter is applied, the sharp transitions in the phases and high frequency components in the spectrum are removed. The signal becomes band limited.

In long distance transmission, wireless signals are normally affected by multi-path reflections. Transmitted symbol can be delayed or interfere with next or previously sent symbol. If pulse shaping is applied ISI can be reduce while making signal band limited. Additionally a matched filter is required at the receiver to reduce ISI.

Match filter has equivalent importance than pulse shaping. Pulse shaping generates the symbol in such a way that the preceding and following symbols does not overlap with each other. In the same way match filter reduce multi-path reflections which causes interference between symbols at the receiver.

There are three famous pulse shaping filters available in the literature. Those are: Raised Cosine Filter, Root Raised Cosine Filter and Gaussian Filter [13][14].

Raised Cosine Filter minimize ISI by attenuation of the signal from the start and end of the symbol period. These are the positions where most of the interference are expected. It's Impulse response is defined as:

$$h_{RC}(n) = \frac{\pi}{4} sinc(\frac{\pi n}{R}). \left[ sinc(\frac{\pi}{2} - \alpha\frac{\pi n}{R}) + \frac{sin(\frac{\pi}{2} - \alpha\frac{\pi n}{R})}{\frac{\pi}{2} + \alpha\frac{\pi n}{R}} \right] \quad (3)$$

Where $\alpha$ is the roll off factor, which ranges between 0 and 1. It can be seen in the above equation that Sinc pulse is used to implement Raised cosine filter.

Root Raise Cosine Filter produces a unity gain in lower frequency band and complete gain at higher frequencies in the frequency response. This filter is the most common filter in the digital communication systems and it must be used in pairs. Transmitter applies pulse shaping of Root Raised Cosine and then Matched filtering of same shape is used by receiver. Impulse response can be defined mathematically as:

$$h_{SRC}(t) = \frac{\left[\frac{4\alpha}{\pi} cos(\frac{(1+\alpha)\pi n}{R})\right] + \left[(1-\alpha) sinc(\frac{(1-\alpha)\pi n}{R})\right]}{\sqrt{R}\left[1 - (\frac{4\alpha n}{R})^2\right]} \quad (4)$$

Where, R is the total number of samples per symbol.

Gaussian Filter is usually used in Minimum Shift Keying (MSK) and Frequency shift Keying (FSK) modulations. It is different from previous two filter in a way that it does not implement on zero crossing points. Impulse response of Gaussian Filter is:

$$h_G(t) = Q\left(\frac{2\pi\alpha}{\sqrt{ln2}}(n-0.5)\right) - Q\left(\frac{2\pi\alpha}{\sqrt{ln2}}(n+0.5)\right) \quad (5)$$

## IV. Experimental setup and Methodology

In the communication setup, I have used Ettus Research's B210 USRP and suitable antenna for both transmitter (Tx) and receiver (Rx). Selected center frequency was 86 MHz in FM band. A simple communication setup can be seen in Figure 1. A detailed version of the same setup is given in Figure 2 and 3.

The Tx and Rx USRPs are connected with the host computers. I used National Instrument's LabView software for our application with current and updated UHD drivers. On the Tx side, PN sequence of level 10 was generated. After that it is

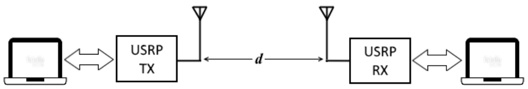


Figure 1: Communication Setup

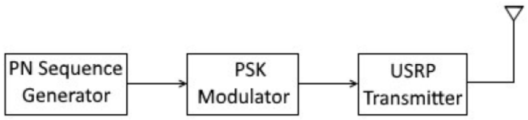


Figure 2: Transmitter Setup

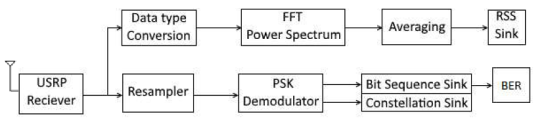


Figure 3: Receiver Setup

passed through a PSK modulator. There are two operations of this block a) It maps the input bit stream to a complex valued symbol sequence b) It performs pulse shaping filter operation. Finally in the last block it is passed through the RF front end in USRP, which up converts the modulated signal through analog operations and transmit it through antenna. Communication parameters can be seen in Table I.

Table I: Communication Setup Parameters

| | |
|---|---|
| Center frequency | 86 MHz |
| Tx power | -20.96 dBm |
| Antenna heights (Tx and Rx) | 1.5 m |
| Transmitted signal | PN sequence |
| Modulation | BPSK, QPSK |
| Sampling rate | 100 kHz |
| Samples per symbol | 4 |
| Symbol Rate | 25k |

On the Rx side in Figure 3, signal is picked through antenna and then down converted through RF front end in USRP. Now the block diagram is divided into two branches 1) Received Signal Strength (RSS) detection 2) PN sequence detection and Constellation plot.

In the first branch, re-sampler re-samples the acquired signal to multiple of expected symbol rate then signal passes through PSK demodulator, which has multiple operations here a) filter the received signal phase in order to reduce Inter symbol Interference (ISI) b) extraction of required symbols from oversampled signal c) Frequency offset correction d) Symbol detection and mapping of hard symbols to bit values per the transmitted symbol map. This block is also synchronized for certain symbol map. Finally we have the received bit sequence and recovered complex waveform for constellation plot. From the received bits, Bit Error rate is calculated in BER block.

In the second branch signal is converted in to Complex Double Waveform Data Type (CDB WDT) then fed to FFT power spectrum block which computes the FFT and forms the power spectrum of the time signal. Now the magnitude values are extracted from the signal and averaging block calculates the RSS by taking mean of 200 magnitude values from left and right of center frequency. This averaging is done in order to reduce the impact of frequency offset and instability in the values.

All of the blocks were implemented in Lab View with the help of Modulation toolkit. I compared the Bandwidth, BER and other parameters for different Sampling Rates and pulse shaping types in the Results and comparison section.

## V. Results

In the experiment, two types of PSK were chosen to compare bandwidth, Bit Error Rate (BER) and Inter symbol Interference (ISI) based on pulse shaping techniques (without pulse shaping in this section corresponds to rectangular pulse shaping)

### *A. BPSK*

In this experiment, sampling Rate is 100k and samples per symbol is 4 which makes symbol rate of 25k symbols/second. The signal was transmitted in the wireless channel. Figure 4 and 5 shows the transmitter and receiver constellation plot.

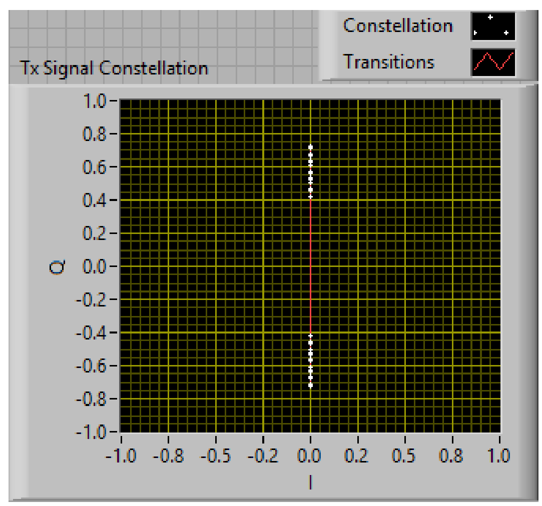


Figure 4: constellation at transmitter

It can be seen in Figure 4 and 5 that there are still little bit offset in the phases but the phase recovery implementation shows great results because at a glance both of the constellations look similar. The distance between transmitter and receiver was very small. Figure 6 and 7 shows the baseband Power Spectrum of the transmitted signal at the receiver USRP, without filter and with Root Raised Cosine filter respectively.

It can be seen in Figure 6 that total bandwidth is equal to the sampling rate which is 100k with half being on each side of zero point. The middle lobe is approximately equal to twice of symbol rate which is 25k. In Figure 7, Root Raised Cosine pulse shaping filter reduced the bandwidth and now there is only single lobe whose bandwidth is approximately equal to twice of symbol rate (little less than that because of filter roll of factor and length).

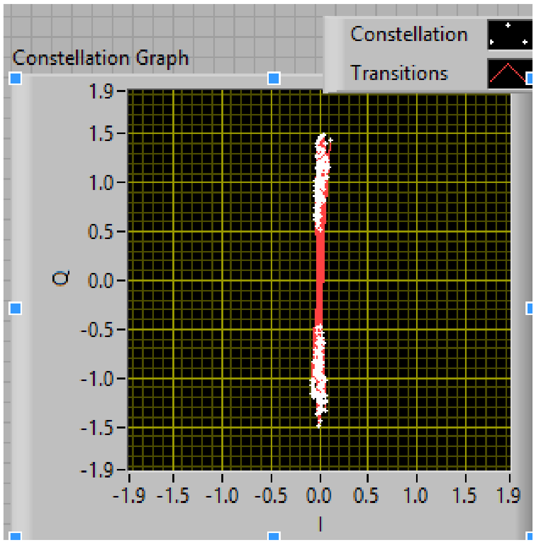

Figure 5: constellation at receiver

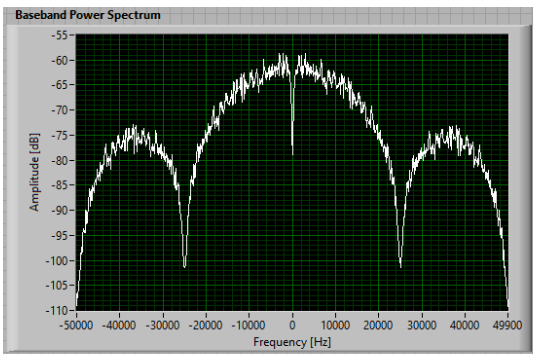

Figure 6: Baseband Power Spectrum with out filter (BPSK)

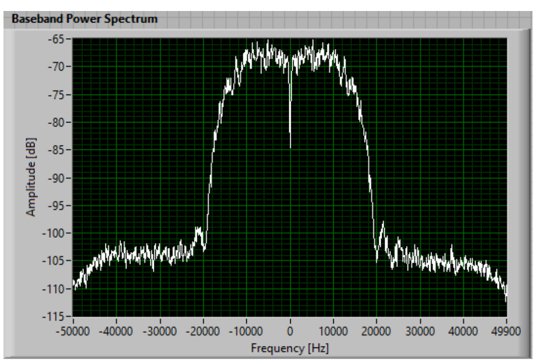

Figure 7: Baseband Power Spectrum with RRC filter (BPSK)

### *B. QPSK*

In this experiment, sampling rate, samples per symbol and symbol rate is same as BPSK. The modulation type was changed to QPSK from the front panel in the Lab View. Figure 8 and 9 shows the constellation plot of transmitted and received signal.

Figure 10 and 11 shows the baseband power spectrum of the QPSK transmitted signal at the receiver end. It can be seen from both of the figures that the bandwidth is same as BPSK and defined by symbol rate.

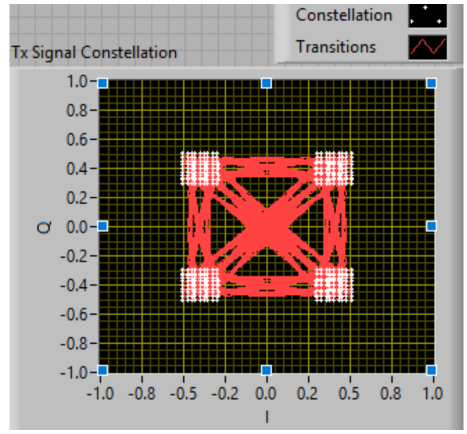

Figure 8: constellation at transmitter

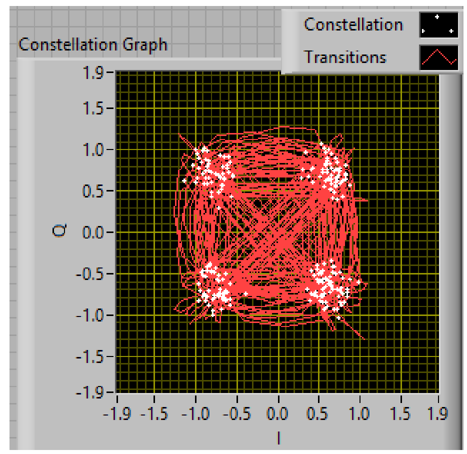

Figure 9: constellation at transmitter

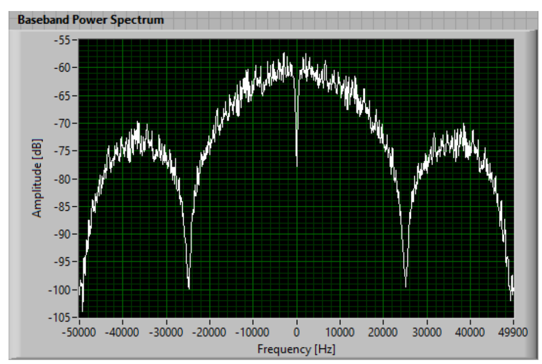

Figure 10: Baseband Power Spectrum with out filter (QPSK)

### *C. Eye diagram and BER*

Figure 12 shows the eye diagram of BPSK signal at the transmitter without any pulse shaping applied.

Figure 13 shows the eye diagram of transmitted BPSK signal at the receiver without any pulse shaping applied.

Figure 14 shows the eye diagram of BPSK signal at transmitter with Root Raised cosine pulse shaping is applied.

Figure 15 shows the eye diagram of transmitted BPSK signal at the receiver with Root Raise Cosine pulse shaping applied.

It can be seen from Figure 13, 14, 15 and 16 that Root

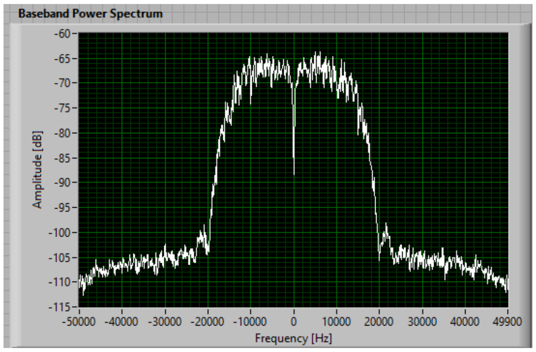

Figure 11: Baseband Power Spectrum with RRC filter (QPSK)

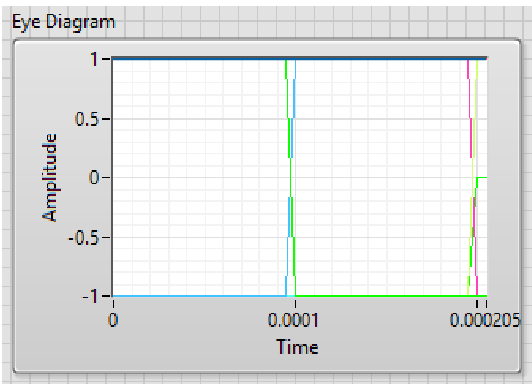

Figure 12: Eye Diagram at transmitter without pulse shaping (BPSK)

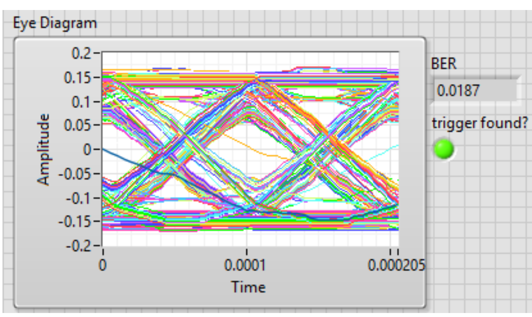

Figure 13: Eye Diagram and BER at receiver with out pulse shaping (BPSK)

Raise Cosine pulse shaping reduced the BER significantly.

Figure 16 shows the eye diagram of QPSK signal at transmitter without any pulse shaping is applied.

Figure 17 shows the eye diagram of transmitted QPSK signal at the receiver without any pulse shaping is applied.

Figure 18 shows the eye diagram of QPSK signal at transmitter with Root Raise Cosine pulse shaping is applied.

Figure 19 shows the eye diagram of transmitted QPSK signal at the receiver with Root Raised cosine pulse shaping is applied.

From figure 16-19. The results are approximately same as BPSK in terms of ISI and BER. QPSK and BPSK differs in bit rate. BPSK transmits 1 bit per symbol while QPSK transmits two bits per symbol. The symbol rate used in this experiment

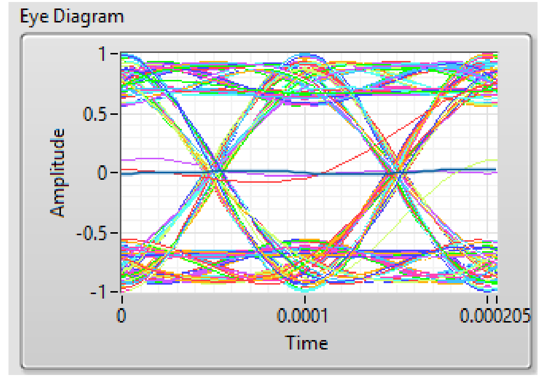

Figure 14: Eye Diagram at transmitter with RRC pulse shaping (BPSK)

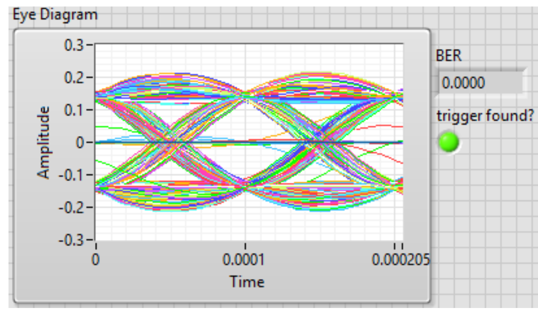

Figure 15: Eye Diagram and BER at receiver with RRC pulse shaping (BPSK)

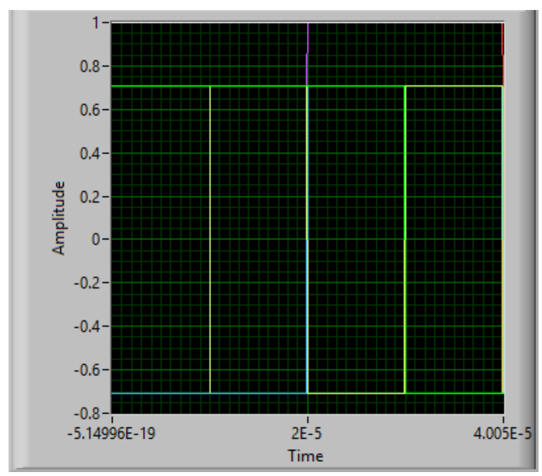

Figure 16: Eye Diagram at transmitter without pulse shaping (QPSK)

was 25k symbols per second. So the bit rate for BPSK is same as symbol rate and for QPSK it is twice of symbol rate.

## VI. Conclusion

In this paper, a most common Software Defined Radio (SDR) have been utilized to implement a PSK based communication system. It can be concluded that USRP and Lab View are reliable and efficient tools to implement a communication system like in this paper. While using the same hardware, software reconfigurability allows to implement different standards, protocols and modulation techniques in

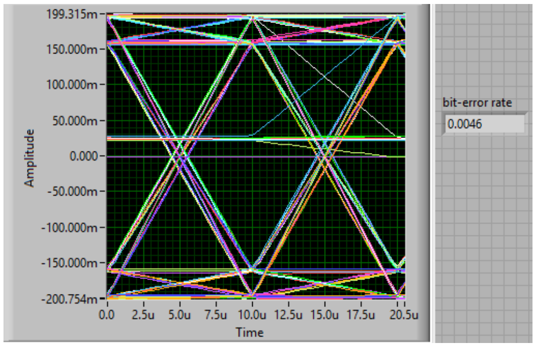

Figure 17: Eye Diagram at receiver without pulse shaping (QPSK)

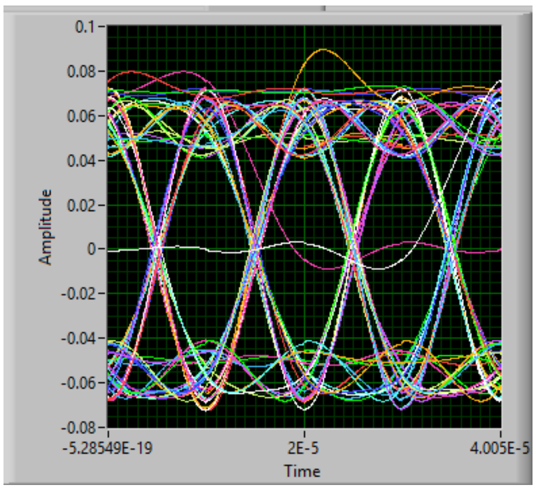

Figure 18: Eye Diagram at transmitter with RRC pulse shaping (QPSK)

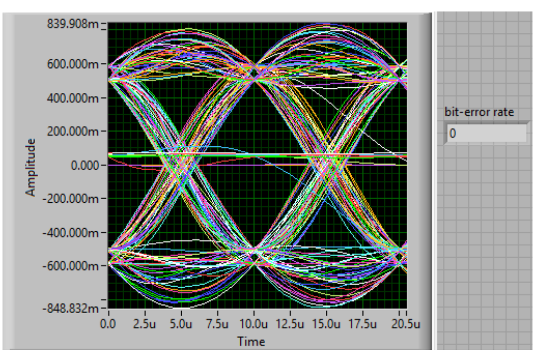

Figure 19: Eye Diagram at receiver with RRC pulse shaping (QPSK)

communication system. Further, the background knowledge of PSK modulation and pulse shaping techniques were discussed which follows with the implementation of PSK modulation based communication system.

Two different types of PSK modulation were compared. It was shown in the results that without using pulse shaping technique bandwidth of signal is equal to sampling rate with middle lobe is approximately equal to twice of sampling rate and causes interference among adjacent symbols. pulse shaping of the signal reduced signal bandwidth. It was equal to twice of symbol rate with very little inter symbol interference and improved BER performance

Bandwidth of BPSK and QPSK were identical to each other. They differ by data rate performance. QPSK achieved better data rate performance. Conclusively, this system can be extended to explore wireless channel modeling in the future.

## Acknowledgment

I would like to thank my teachers Dr. Mehmet Kemal Ozdemir and and Dr. Tuncer Baykas for their guidance and support throughout this project.

## References

[1] O. Šćekić, "Fpga comparative analysis," *university of Belgrade*, 2005.
[2] J. Mitola, "Software radios: Survey, critical evaluation and future directions," *IEEE Aerospace and Electronic Systems Magazine*, vol. 8, no. 4, pp. 25–36, 1993.
[3] M. Joseph, "The software radio architecture," *IEEE Communications magazine*, vol. 33, no. 5, pp. 26–38, 1995.
[4] S. Russell and P. Norvig, "Definitions of software defined radio (sdr) and cognitive radio system (crs)," *Artificial Intelligence: A Modern Approach (2nd ed.), Upper Saddle River, New Jersey: Prentice Hall, ISBN 0-13-790395-2*, 2003.
[5] M. Ettus and M. Braun, "The universal software radio peripheral (usrp) family of low-cost sdrd," *Opportunistic Spectrum Sharing and White Space Access: The Practical Reality*, pp. 3–23, 2015.
[6] "B. seeber, "spench.net." [online]. available: http://spench.net/."
[7] "A. csete, "amateur radio, space tech, and other nerd stuff." [online]. available: http://www.oz9aec.net/."
[8] "M. ettus, "universal software radio peripheral." [online]. available: http://www.ettus.com."
[9] G. W. Johnson, *LabVIEW graphical programming*. Tata McGraw-Hill Education, 1997.
[10] *S. Haykin, "Communication systems," IET, New York, 2001.*
[11] A. M. Wyglinski and D. Pu, *Digital communication systems engineering with software-defined radio*. Artech House, 2013.
[12] J. Salehi, "Digital communications," 2008.
[13] C. R. Johnson and W. A. Sethares, *Telecommunication breakdown: concepts of communication transmitted via software-defined radio*. Prentice Hall, 2004, vol. 1.
[14] T. S. Rappaport *et al.*, *Wireless communications: principles and practice*. prentice hall PTR New Jersey, 1996, vol. 2.