Implementation of 2x2 MIMO-OFDM System using Universal Software Radio Peripherals

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Abstract: **The 2x1 and 2x2 Multiple Input Multiple Output (MIMO) systems with Orthogonal Space-Time Block Code (OSTBC) are implemented using Universal Software Radio Peripherals (USRPs) and LabVIEW. Bit Error Rate (BER) is estimated and compared for both systems using different M-ary Quadrature Amplitude Modulation (QAM) i.e. 4 QAM, 16 QAM, 64 QAM. The BER is reduced for a 2x2 MIMO than a 2x1. To improve spectral efficiency, Orthogonal Frequency Division Multiplexing (OFDM) is combined with MIMO configuration, known as MIMO-OFDM. 2x2 MIMO-OFDM with OSTBC is implemented with M-ary QAM and N IFFT (32, 64, 128 IFFT). Among these, better BER performance is observed for 2x2 MIMO with 64-IFFT. The MIMO-OFDM is used in Worldwide Interoperability for Microwave Access (WiMAX) which is the standard of IEEE 802.16.**

Index Terms: **Multiple Input and Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Bit Error Rate (BER), Universal Software Radio Peripheral (USRP)**

I. INTRODUCTION

In wireless communications systems, the current technology demands reliability and high data rates with improved spectral efficiency and Quality of Service (QoS) with various users at the same time. Improved spectral efficiency can be offered by Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) offers high data rates with spatial multiplexing and reliability with spatial diversity gain [1-2]. The reduced Bit Error Rate (BER) is obtained by diversity gain which provides several copies of transmitted signals at the receiver. Spatial multiplexing is also a MIMO technology that transmits different data streams over multiple antennas simultaneously without an increase in bandwidth results in high data rates. A decade ago, extensive research on MIMO has been started. In the 1990s, the Alamouti scheme was proposed in the literature [3] with simple transmit diversity scheme for two transmit antenna systems and the spatial multiplexing scheme was first proposed in literature [4]. The principle behind the spatial multiplexing scheme is as follows: the transmission of high data rate of bit sequence is de-multiplexed into a low data rate of M subsequences, is modulated and transmitted over different transmit antennas simultaneously using the same frequency band. The interference cancellation algorithm is used to separate transmitted sequences at the receiver [5].

The combined technology of MIMO with OFDM gained more attention due to high data rates with spectral efficiency. OFDM is a popular technology used in wireless communications systems because of multi-carrier transmission in which a wide bandwidth is split into parallel 'n' sub-bands with sub-carriers i.e. each subcarrier experiences a narrow band. The advantage of OFDM is immunity to multipath fading and Inter Symbol Interference (ISI). ISI occurs when modulated symbol time is less than the delay-spread results in a non-deductible error floor which reduces the performance of the system significantly. To overcome ISI, equalization [6] is carried out on the receiver side. Various detection algorithms are available at the receiver side for the frequency flat fading that is categorized by different trade-offs between performance and complexity. To reduce the complexity, a linear receiver is a better choice.

This paper focuses to achieve better BER performance with *2x1* and *2x2* MIMO systems. In this paper, a *2x2* MIMO-OFDM system is implemented with the help of Universal Software Radio Peripherals (USRPs) and LabVIEW. BER performance is compared by increasing the FFT size of OFDM and with different M-QAM modulations. LabVIEW is a graphical programming language that provides inbuilt blocks like Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) which are used to sample the real-time signals [7]. National Instruments (NI) USRPs are the Software Defined Radios (SDRs), which is a range of programmable Field Programmable Gate Array (FPGA) based Tx/Rx SDR made by Ettus research. With high speed and resolution ADCs and DACs, these high-quality devices take a modular approach and allow us to use a selection of a transmitter, a receiver, and transceiver. Radio Frequency (RF) daughter boards that are optimized to work at various frequencies [8].

The rest of the paper is organized as follows: Section II introduces an implementation of a simple MIMO system. The implementation of a *2x2* MIMO-OFDM system is presented in detail in section III. Section IV discusses the results and discussions. Section V deals with the conclusion of the paper.

II. IMPLEMENTATION OF THE MIMO SYSTEM

MIMO communications system developed in the year 1990s and they became an integral part of the present wire

or wireless communications systems. Multipath propagation is the advantage in MIMO, various paths are formed due to bounces of vehicles, buildings and other obstacles and reach the receiver in different directions and at different times, this increases the receiver signal capturing power [9].

The transmitted sequence bits are modulated using M-ary Quadrature Amplitude Modulation (M-QAM), two parallel streams and in that first stream transmit through Tx1 antenna and other is through Tx2 antenna using Alamouti Space Time Block Code encoding scheme. Orthogonal Space-Time Block Code (OSTBC) is a superior kind of Space-Time Block Code (STBC) in which each column in the matrix of this code is orthogonal to individuals. Full diversity is achieved over the coherent channel at low computational cost using STBC. The STBC encoding and decoding procedure for a *2x1* MIMO is clearly shown in Fig 1, where p1, p2, p3, p4 are transmitting symbols, the same pair of symbols p1 and p2 transmitted through two different antennas twice over two symbol periods [10]. The transmitted symbols at the physical antenna have a little variation at each symbol timing. At the symbol time t1 direct symbols p1 and p2 are transmitted and at the symbol time t2 modified symbols p2*and p1* are transmitted as shown in Table I. Where p1* and p2* are conjugate of p1 and p2 respectively. h1 and h2 are channel coefficients represented with noise and fading. If there is no fading, interference, and noise present in the channel, the receiver decodes the transmitted data successfully without complicated transmission but in real-time, it is not possible. y1 and y2 are the signals at the receiver antennas 1 and 2 respectively [11]. The receiver does not process the data at each symbol. It waits till it receives two received symbols and combined them to decode and separate the symbols p1 and p2 with the help of weight vectors. The decoding procedure is as follows:

TABLE I.
SYMBOL TRANSMISSION AT THE TRANSMITTER SIDE

Antenna's	Time slot 1	Time slot 2
1	p_1	$-p_2^*$
2	p_2	p_1^*

The received signal is represented as
$$\breve{y} = H\bar{p} + \bar{n} \tag{1}$$
Where Y is the signal received at the receiver, H is the channel matrix, p is the symbols transmitted at the transmitter and n is the noise.
The received signal at two-time slots is given by:
$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = [h_1 \quad h_2] \begin{bmatrix} p_1 & -p_2^* \\ p_2 & p_1^* \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{2}$$
Received signal at time t1 is given by:
$$[y_1] = [h_1 \quad h_2] \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} + [n_1] \tag{3}$$
Received signal at time t2 is given by:
$$[y_2] = [h_1 \quad h_2] \begin{bmatrix} -p_2^* \\ p_1^* \end{bmatrix} + [n_2] \tag{4}$$
Where
    y1 and y2 are the received signals at different time

P1* is the conjugate of p1 symbol
P2* is the conjugate of p2 symbol
n1 and n2 are noise

Simplifying the equation (4) to obtain y_2^*
$$y_2^* = [h_2^* \quad -h_1^*] \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} + n_2^* \tag{5}$$
Combining the equations (3) and (5) to get the orthogonal channel matrix as:
$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{6}$$
c1 and c2 are the first and second columns of the channel matrix. c_1^H represents transpose conjugate of c1. When multiplying c_1^H with c2, if the result is zero then c1 is orthogonal to c2. This is called an orthogonal channel matrix and is represented as:
$$c_1^H c_2 = [h_1^* \quad h_2] \begin{bmatrix} h_2 \\ -h_1^* \end{bmatrix} = 0 \tag{7}$$
To retrieve the transmitted symbols, weight vectors are used that are denoted as *W1* and *W2*
$$w_1 = \frac{c_1}{\|c_1\|} = \frac{1}{\|h\|} \begin{bmatrix} h_1 \\ h_2^* \end{bmatrix} \tag{8}$$
$$w_2 = \frac{c_2}{\|c_1\|} = \frac{1}{\|h\|} \begin{bmatrix} h_2 \\ -h_1^* \end{bmatrix} \tag{9}$$
Equation (8) multiplied with the equation (5) to retrieve p1 symbol as:
$$w_1^H \bar{y} = \frac{1}{\|h\|} [h_1^* \quad h_2] \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$
$$+ \overline{w_1}^H \overline{n_1} \tag{10}$$
$$= \frac{1}{\|h\|} [(h_1^* h_1 + h_2 h_2^*) \quad (h_1^* h_2 - h_1^* h_2)] \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$
$$+ \widetilde{n_1} \tag{11}$$
$$= \frac{1}{\|h\|} p_1 + \widetilde{n_1} \tag{12}$$
Equation (9) multiplied with the equation (5) to retrieve the p2 symbol as:
$$w_2^H \bar{y} = \frac{1}{\|h\|} [h_2^* \quad -h_1] \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$
$$+ \overline{w_1}^H \overline{n_1} \tag{13}$$
$$= \frac{1}{\|h\|} (h_1^* h_2 - h_1^* h_2) (h_1^* h_1 + h_2 h_2^*) \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$
$$+ \widetilde{n_2} \tag{14}$$
$$= \|h\| p_2 + \widetilde{n_2} \tag{15}$$
For a *2x2* MIMO, the same process is used to retrieve the transmitted symbols using the OSTBC code, but complexity is increased due to an increase in one more antenna at the receiver [12], [13].

III. IMPLEMENTATION OF 2 X 2 MIMO OFDM SYSTEM

MIMO-OFDM system setup consists of 4-USRP's, 2 for transmitting and the other 2 for receiving signals. LabVIEW is a software in which block diagram is constructed with the inbuilt blocks of communication tools. To interface LabVIEW with USRP's Gigabit Ethernet router is used.
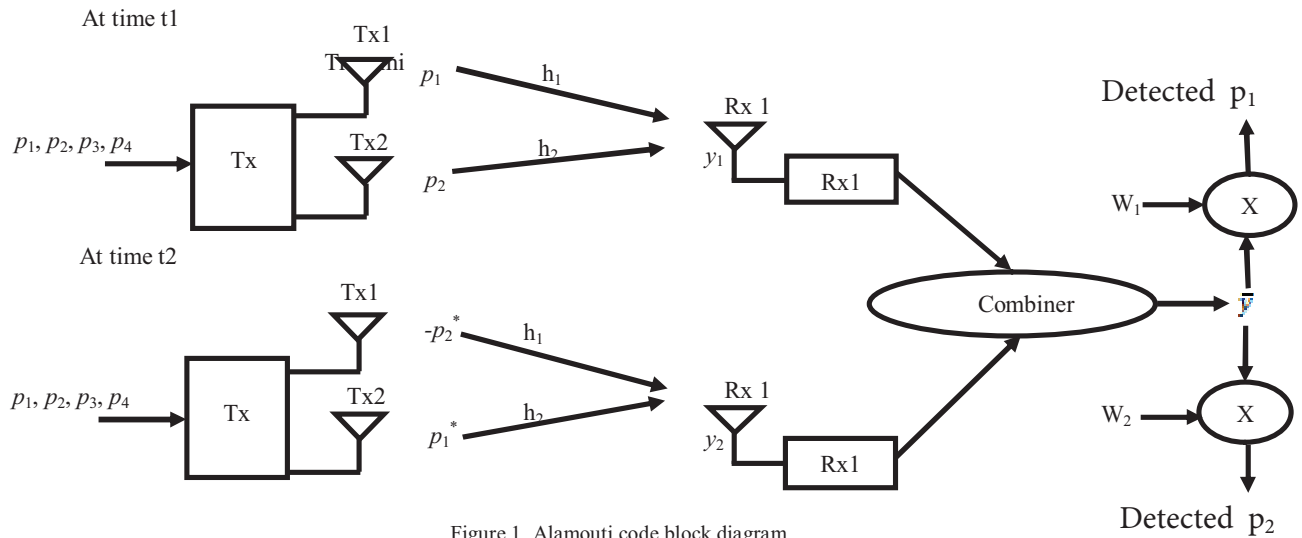
Figure 1. Alamouti code block diagram

Figure 2. Experimental *2x2* MIMO setup

In MIMO system, the data is transmitted from two transmitters at the same time. For that, an octa-clock is used for synchronization between the transmitter and receiver. The physical connection between the devices is shown in Fig. 2. The signal is transmitted with a bandwidth of 30 MHz and a frequency of 2.4 GHz. In *2x2* MIMO-OFDM system implementation, the PN sequence is used to generate a random sequence as a message signal. The generated bits are modulated using M-QAM (4, 16, 64 QAM) and modulated symbols are feed to the MIMO encoding block that results in transmitted signals in two channels, for each channel OFDM technique is applied as shown in Fig. 3In OFDM, the wideband of serial data is converted into narrowband of N parallel data. Each narrowband is modulated with N subcarriers. Before the serial to parallel conversion of data, a training sequence (length 11 frank sequence) 0 is added for the channel estimation. The modulated subcarriers are passed through IFFT and the resultant OFDM signal is represented as follows:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, e^{\frac{j2\pi kn}{N}}, 0 \le n \le N$$

The pulse shaping filter is used to reduce the bandwidth usage by clipping the edges and fit the signal into a transmitting channel.

The data is transmitted and received with the help of ADC in USRP. A maximum likelihood estimator is used for channel estimation. Schimidi cox algorithm is used for symbols timing recovery. The demodulation is used to recover the transmitted signal.

Fig. 4 shows the receiver of MIMO-OFDM in which a pulse shaping filter is used to receive the signal below the threshold level. The symbols in a signal get synchronized in symbol synchronization and the channel is estimated such that each channel constellation plot is obtained. To retrieve the Signal, the demodulated process is done.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

In LabVIEW front panel the results of 2x1 MIMO, 2x2 MIMO and 2x2 MIMO-OFDM are shown in figures 5-7. By using M-QAM modulation techniques, incoming bits are demodulated and an approximate constellation plot for two transmitting channels at the receiver is obtained. BER is calculated for the received signal and shown in Table II. The BER is estimated for 2x1 and 2x2 MIMO system with different M-ary QAM modulations and is given in Table II. From Table II, the *2x2* MIMO system BER is less. In the *2x2* MIMO system, 2 receivers receive the transmitted signals obtained from multiple paths and retrieve their respective transmitted signals. In a *2x1* MIMO system, a single receiver can receive both the transmitted signals. The signals obtained at different delays cause interference, this results in high BER.
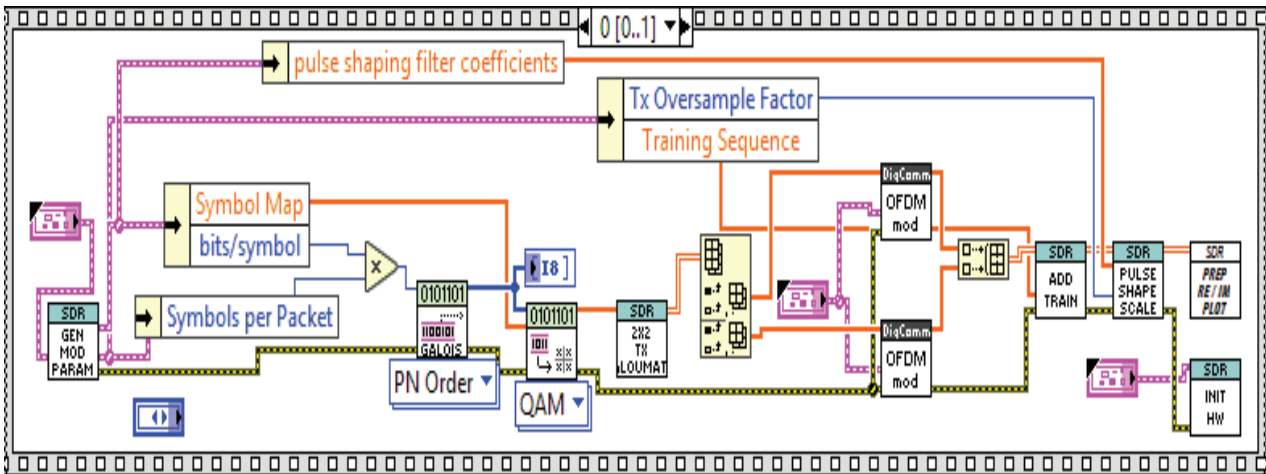
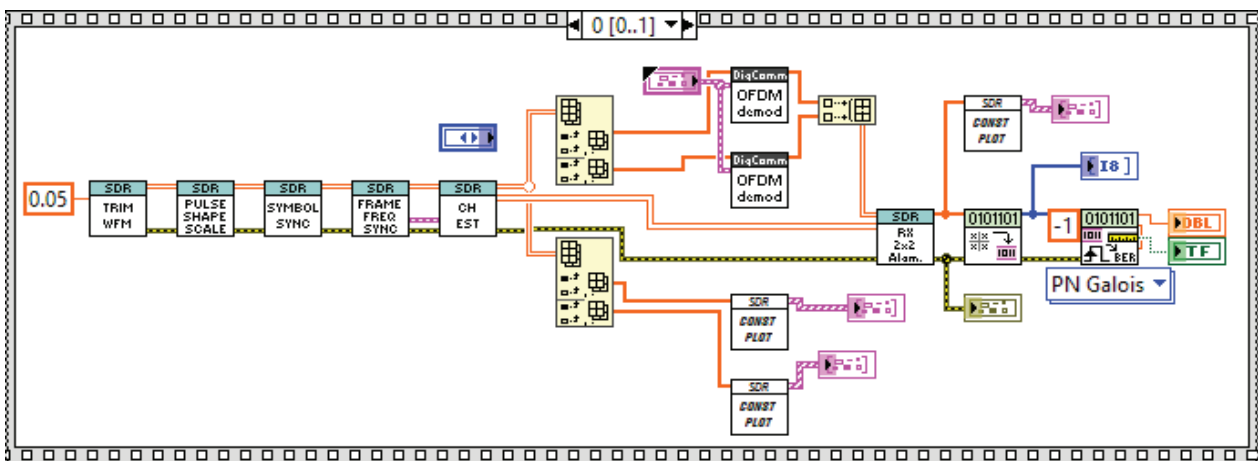Figure 3. Implementation of *2x2* MIMO-OFDM transmitter

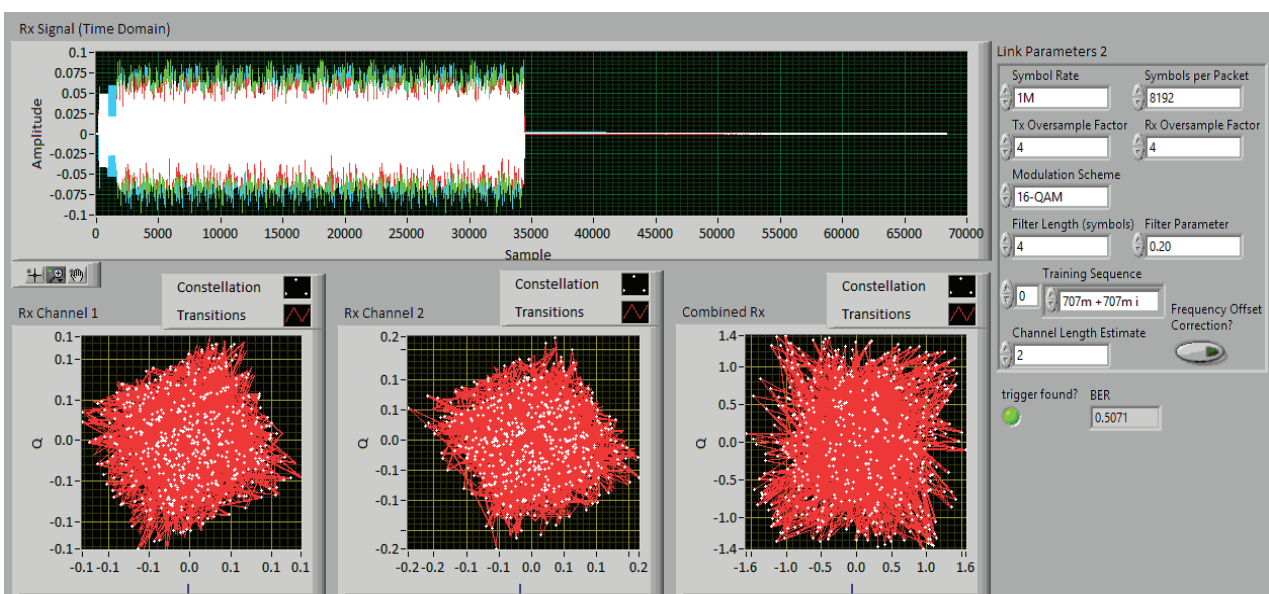Figure 4. Implementation of *2x2* MIMO-OFDM receiver
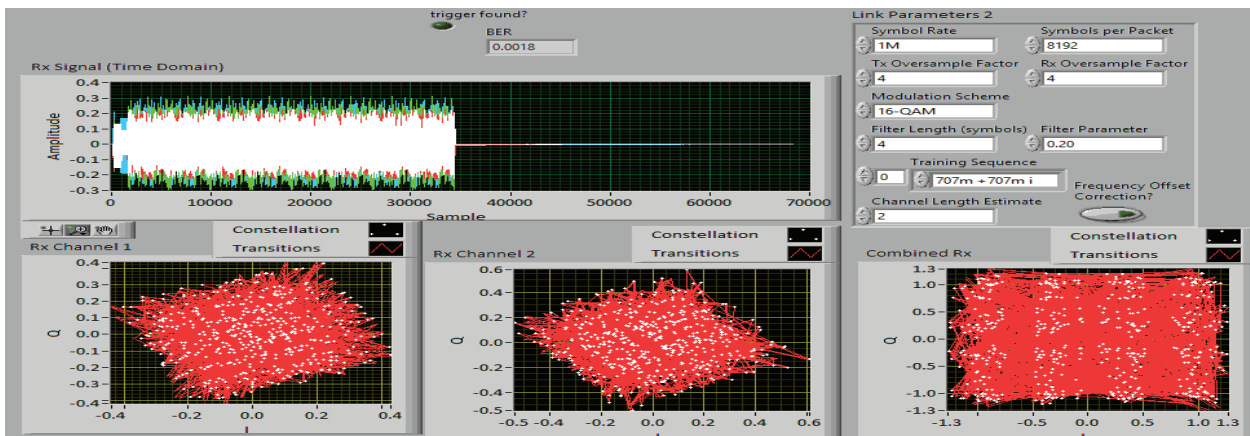

Figure 5. Front panel of 2X1 MIMO system

Figure 6. Front panel of *2x2* MIMO system

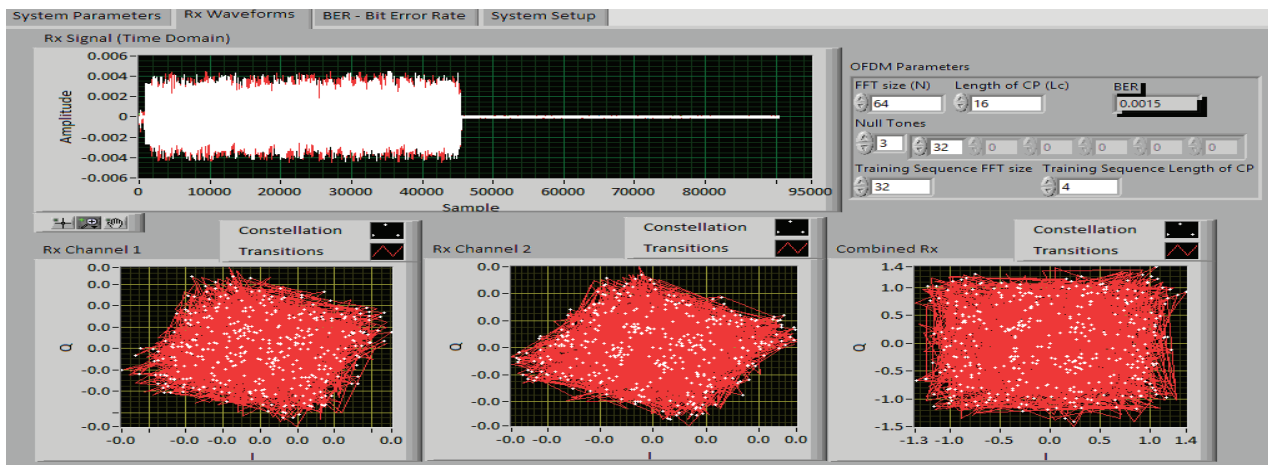Figure 7. Front panel of *2x2 MIMO*-OFDM system

TABLE II.
COMPARISON OF BER PERFORMANCE OF *2x1 AND 2x2*

QAM	BER	
	2x1	2x2
4	0.0160	0.0000
16	0.5071	0.0018
64	0.9010	0.0701

TABLE III.
COMPARISON OF BER PERFORMANCE AT DIFFERENT IFFT SIZES

2 X 2 MIMO-OFDM			
QAM	BER with different IFFT		
	32	64	128
4	0.0002	0.0000	0.0008
16	0.0039	0.0015	0.0028
64	0.0593	0.0456	0.0818

In order to increase spectral efficiency, the OFDM system is combined with the MIMO system to obtain better BER performance such that channel estimation of 2x2 MIMO-OFDM system constellation is shown in Fig. 7 and resultant information about M-QAM with BER Performance is shown in Table III.

From Table III, BER for 64 IFFT is reduced, when compared to 128 IFFT because with increasing the number of IFFTs the Peak to Average Power Ratio (PAPR) gets increases. PAPR is calculated as the average peak of signal to maximum power. As increasing M-ary QAM modulation, the constellation points increase, and this causes interference between symbols and reduces the BER performance.

V. CONCLUSIONS

This paper includes the implementation of MIMO systems and their advantages. The main advantage of MIMO is high data rates and OFDM is high spectral efficiency. To capture this advantage, MIMO is combined with OFDM and MIMO-OFDM is implemented in LabVIEW using USRP. The BER of the MIMO-OFDM system is estimated as 0.0456. With increase in the FFT size, BER also increases due to the increase in PAPR of the OFDM signal. *2x2* system is used in many applications includes IEEE 802.11n, IEEE 802.11a/g WLAN, Digital

Video Broad Casting - Terrestrial 2nd Generation (DVB-T2), 3rd Generation Partnership Project (3GPP). It is also used in WiMAX which is the standard of IEEE 802.16, 5G and upcoming 6G technologies.

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