Frequency Diversity MIMO- OFDM System using GNU Radio

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Abstract

In this work, a frequency-diversity scheme is used with an orthogonal-frequency-division-multiplexing (OFDM) system to improve bit-error-rate (BER) performance without increasing the signal bandwidth or decreasing the transmission rate. In this scheme, the same OFDM symbol is transmitted on multiple carrier frequencies, each with a different gain. The number of transmitted symbols is equal to the diversity order (N), and as a result, the transmission rate is reduced by a factor of N. This means that the system sacrifices some transmission rates to gain the benefits of diversity. To further improve the spectral efficiency of the transmitted signal, a multiple-input-multiple-output (MIMO) transmitter is used in spatial multiplexing mode. The number of antennas, known as the spatial multiplexing order, is equal to the diversity order. By employing multiple antennas, the system can transmit multiple independent data streams simultaneously, thereby increasing the overall data rate. The proposed system assumes operation in a frequency-selective channel, which means that the channel introduces different frequency-dependent effects on the transmitted signal. In the receiver, a maximal-ratio-combiner (MRC) is utilized to combine the received signals from the different carrier frequencies and antennas. The MRC combines the signals in a way that maximizes the signal-to-noise ratio (SNR) and improves the overall system performance. To evaluate the performance of the proposed system, the system is implemented using GNU Radio, a free and open-source software development toolkit for building software-defined radios.

Keywords: Frequency-diversity, Orthogonal-Frequency-Division-Multiplexing system (OFDM), Maximal ratio combiner (MRC), Multiple-Input-Multiple-Output system (MIMO), GNU Radio.

1. Introduction

The MIMO-OFDM system is popular due to its high transmission rate, robustness against multipath fading, and good spectral efficiency. It provides reliable communication and wide coverage. Accurate recovery of CSI and synchronization between the transmitter and receiver pose significant challenges in the MIMO-OFDM system. These aspects are crucial for optimal system performance. The MIMO system combines multiple transmitting and receiving antennas to improve the channel capacity of wireless communication that enhances the spectrum efficiency of the system. The OFDM system employs multi-carrier modulation, where data is transmitted at a lower rate on each subcarrier using orthogonal sub-channels. OFDM mitigates the effects of multipath by converting frequency-selective channels into flat channels. Signal diversity is used to receive different copies of transmitted symbols in the receiver. It can be achieved through time, frequency, and space diversity. Frequency diversity is a fundamental technique employed in MIMO-OFDM systems to enhance the performance and reliability of wireless communication [1]. By leveraging the inherent characteristics of the frequency domain, frequency diversity enables robust transmission in frequency-selective fading channels without sacrificing the system's spectral efficiency. In frequency diversity, the modulated symbol is sent on different carrier frequencies to save the transmission rate, but it also reduces the spectral efficiency of the received signal by increasing the transmission bandwidth [2]. In [3], the authors referred to the system performance, accuracy, reliability, and robustness concerning the BER performance and error resilience, therefore, it introduced the term Performance-Complexity Tradeoff. In the literature of wireless communications, there are two attributes of the wireless electromagnetic medium, namely the frequency spectrum and the power, as the two major resource categories. The energy-bandwidth efficiency tradeoff in MIMO multi-carrier wireless networks was studied and the effects of different numbers of antennas on the energy-bandwidth efficiency tradeoff were investigated in [4]. In [5] the authors explored the properties and the implications of the power versus bandwidth efficiency criteria. They showed the power and the bandwidth efficiencies as a function of the SNR recorded at the receiver. When the SNR is increased, the bandwidth is increased, and the power efficiency decreased. The authors have analyzed the performance of enhanced OFDM system on GNU radio and USRP1 [6]. In [7], the authors introduce the BER performance analysis of OFDM-MIMO system using GNU Radio. Simulation and Implementation of MIMO-OFDM System with STBC using GNU Radio and USRP are introduced in [8]. In [9], the author introduces a new method frequency diversity using diversity encoder and an OFDM modulator to achieve signal diversity in frequency selective fading channels. The authors used the diversity encoder in MIMO-OFDM system to enhance the bandwidth and power efficiency in [10].

This paper is organized as follows. Section two presented the material and methods. The diversity encoder is discussed in section three. The diversity system using GNU radio is discussed in section four. Section five represents the Results and Discussion, the simulation parameters that compare between two schemes and the specifications of the implemented system are represented. BER performance results of the simulated and implemented system are presented at different SNRs. Finally, the Conclusions are represented in the last section.

2. Material and Methods

In this work, the proposed frequency-diversity system is introduced to enhance signal transmission through frequency- selective slow fading channels that occur when the linear phase response of the wireless channel is narrower than the signal bandwidth. The same symbol is sent on different carrier frequencies with different gains. Every frequency slot that has the same gain, the symbol is sent. After the gain is changed, the same symbol is sent to granted diversity. At the mean that, the OFDM symbol is sent every coherent bandwidth. The symbol interleaving is used in that the depth is equal to the number of sub-channels that has the same gain, and the width is equal to N the diversity order. The diversity order (N) is equal to the number of transmitted symbols in the OFDM symbol. The transmission rate is decreased by N the diversity order. MIMO is used in spatial multiplexing mode. The number of antennas is equal to the used diversity order to compensate for the decrease of the rate by N. The spatial multiplexing MIMO transmission also increases the spectral efficiency of the transmitted OFDM signal.

In the proposed system, the Bandwidth is the same and may be increased by increasing the number of transmitted and received antennas. Power efficiency can be increased by increasing the diverse order of the system. When order diversity is increased, the BER is improved. The new spectral efficiency will be equal to:

$$\eta_{BW} = \frac{M_t \times M}{N.(M+\propto_{roll})} \tag{2.1}$$

Where M_t is the number transmitting antennas, M is the number of subcarriers in the OFDM symbol. The roll-off factor ($\propto_{roll}$) of the used shaping pulse (the shaping factor of the transmitting filter).

3. The frequency-diversity system using diversity encoder

The diversity encoder is proposed in the paper [9], the system proposed in one antenna in the transmitter and one antenna in the receiver. In [10], the diversity encoder is used in time diversity MIMO-OFDM. In this paper, we introduce the diversity encoder in MIMO to increase bandwidth efficiency.

In this system, the transmitted symbol rate does not decrease due to the signal diversity method used. Furthermore, the transmission bandwidth of the transmitted OFDM symbols does not change. In this system, M diversity encoders are used before the OFDM modulator to implement the proposed frequency-diversity mechanism. M is the number of subcarriers in the OFDM symbol. A diversity encoder is added in the path of the modulated symbols of each OFDM subcarrier. The diversity encoder maps the modulated symbols of each subcarrier to diversity symbols. Every mapping cycle, the diversity encoder buffers a set of N modulated symbols, and then it maps this set of buffered modulated symbols to a set of N diversity symbols. N represents the frequency-diversity gain in the proposed system. By changing the value of N, different diversity gains can be achieved. The diversity symbols will modulate the OFDM subcarriers instead of the modulated symbols. N×M diversity symbols are transmitted by M OFDM subcarriers through N OFDM symbol periods. The transmission period of the N OFDM symbols represents the diversity period of each modulated symbol in the proposed system. A MIMO transmitter that works in the spatial multiplexing mode, is added in the proposed system to increase the transmission rate of the OFDM symbols in the same transmission bandwidth.

The spectral efficiency of the frequency-diversity system using the diversity encoder after the OFDM modulator is shown in equation (3.2).

$$\eta_{Bw} = \frac{\mathrm{M}_t \times \mathrm{M}}{(\mathrm{M} + \alpha_{roll})} \tag{3.2}$$

The Unity Gain Combiner (UGC) is used to estimate modulated symbols. The diversity decoder combines the same modulated symbols from N diversity symbols that were transmitted in successive N OFDM symbols on the same subcarrier.

4. GNU-RADIO design

GNU Radio is an open-source software toolkit for SDR [11]. This toolkit provides numbers of radio components, rewritten in C++ or Python programming languages, which can communicate with each other using various data types. GNU Radio offers a graphical design environment, known as GNU Radio Companion (GRC). Python is an object-oriented scripting language that runs on Linux/windows, and it has great support for interfacing with C++ code. GNU Radio can work as a simulation environment, but it can also be used to create a real radio system using SDR platforms. A simulation of frequency diversity MIMO-OFDM system using GNU Radio is shown in Figure 1.

i. Transmitter

The transmitter side contains data generation, channel coding and OFDM modulation with frequency diversity.

1) Data generation

- Random source: Generates number of samples of random numbers of [min, max) meaning the max value won't be included. Repeat samples if specified. Useful for creating bytes of information for testing a modulator.
- Pack K bits: Converts a stream of bytes with 1 bit in the LSB to a byte with K relevant bits.
- QAM Mod block: it computes the QAM modulation. In this section, we shall use LAT combined with other methods to solve linear and nonlinear fractional differential equations.

2) Frequency diversity

- Stream to Tagged Stream: Converts a regular stream into a tagged stream.
- Stream to Streams: Converts a stream of items into N streams of N times less items.
- Stream to Vector: Convert a stream of items into a stream of vectors containing Num Items.
- Vector to Stream: Convert a stream of vectors into a stream of items.
- OFDM Mod: to perform the OFDM modulation in the transmitter.

ii. Channel modeling

- Channel model: A basic channel model simulator that can be used to help evaluate, design, and test various signals, waveforms, and algorithms. This model allows us to set the voltage of an AWGN noise source, a (normalized) frequency offset, a sample timing offset, and a seed () to randomize or make reproducible the AWGN noise source. It can be replaced with a FIR filter and AWG noise (Noise source).

iii. Receiver

- OFDM Demod: to perform the OFDM demodulation in the receiver.
- Stream to streams: use it to convert stream to two streams.
- Maximum_Ratio_Combining: this block isn't included in the gnu radio that includes multiple blocks:
  - RMS: Calculates RMS average power.
  - Float To Complex: Opposite Complex To Float. One or two floats in, complex out.
  - Multiply: Multiply across all input streams.
  - Add: Add samples across all input streams.
  - Divide: Divide across all input streams.
  - Null source: A source of zeros, used mainly for testing.
- QAM Demod: to perform the QAM demodulation in the receiver.
- Error rate: to compute the bit error rate (BER), it compares the received byte stream with the reference byte stream.

5. Results and Discussion

In this section, the system specifications and the simulation and implementation results of the proposed MIMO-OFDM system are represented. The proposed system is simulated using MATLAB m-file scripts. The BER in the simulated system is compared with the Eb/N0 at different diversity gains. The frequency diversity order in the simulated system uses N equal to 2,4,8 and 16. The frequency selective channel is the used model of the propagation channel. Figure (2) shows the simulation results of the average BER in the data received from the proposed receive which the frequency diversity is used. The simulation parameters are 16-QAM, No. of symbols=10000, the number of transmitted antennas (M_t) = 4, and the number of received antennas (M_r) = 4. Maximum Ratio Combiner (MRC) is used in the receiver.

Figure (3) shows the simulation results of the average BER in the received data when the diversity encoder is used. The simulation parameters are 16-QAM, the number of symbols=10000, the number of transmitted antennas (M_t) = 4, and the number of received antennas (M_r) = 4. The Unity Gain Combiner (UGC) is used in the receiver. The figure shows the BER performance is better than the order of the Walsh matrix (N-order).

As can be seen, the BER performance of the proposed system is improved when the order of diversity is increased. Without spatial multiplexing, When the diversity order is equal to 2, the bandwidth efficiency (η_{BW}) is ½ (reduced to half).

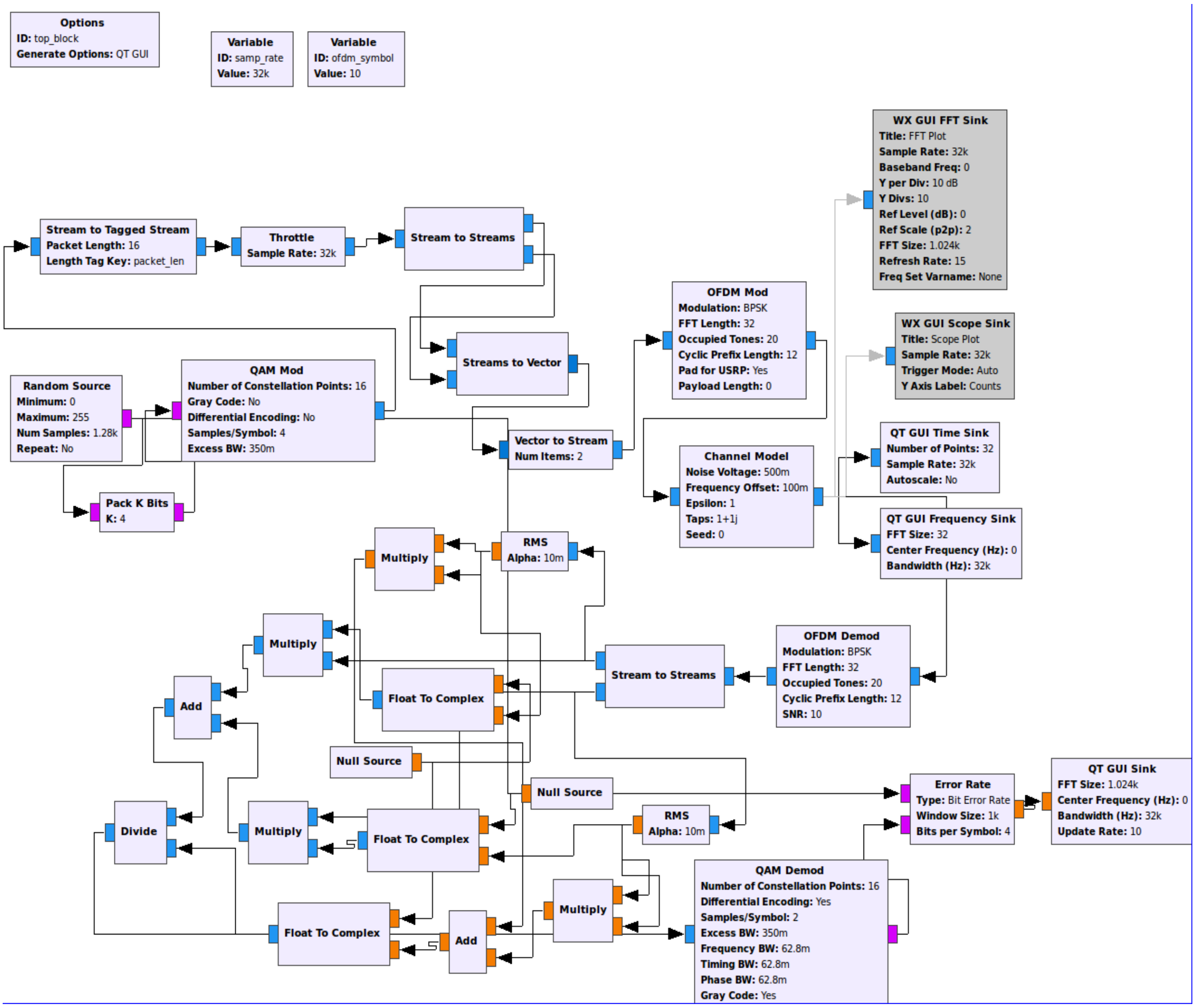

Fig. (1) The frequency diversity MIMO-OFDM system using GNU Radio.

When the diversity order is equal to 4, the bandwidth efficiency (η_{BW}) is 1/4 (reduced to quarter). When the diversity order is equal to 8, the bandwidth efficiency (η_{BW}) is 1/8 (reduced to quarter). That means, the bandwidth is reduced by the number of diversity orders (N). So, spatial multiplexing is used to improve bandwidth efficiency. When spatial multiplexing is equal to 4, the bandwidth efficiency is improved η_{BW} is equal to 2 at diversity order is equal to 2. When the diversity order is equal to 4, the bandwidth efficiency (η_{BW}) is 1. When the diversity order is equal to 8, the bandwidth efficiency (η_{BW}) is ½. So, the bandwidth efficiency can be improved by increasing the number of transmitting and receiving antennas (spatial multiplexing).

Table 1 shows the bandwidth efficiency and bit rate comparison in the proposed system and the diversity system uses diversity encoder. The number of sub carriers is M, and the number of Antenna is M_t.

In contrast, the proposed system is less than the diversity encoder in bandwidth efficiency, but its more efficient in BER. The required parameters for simulation/implementation purpose and their values are listed in table 2.

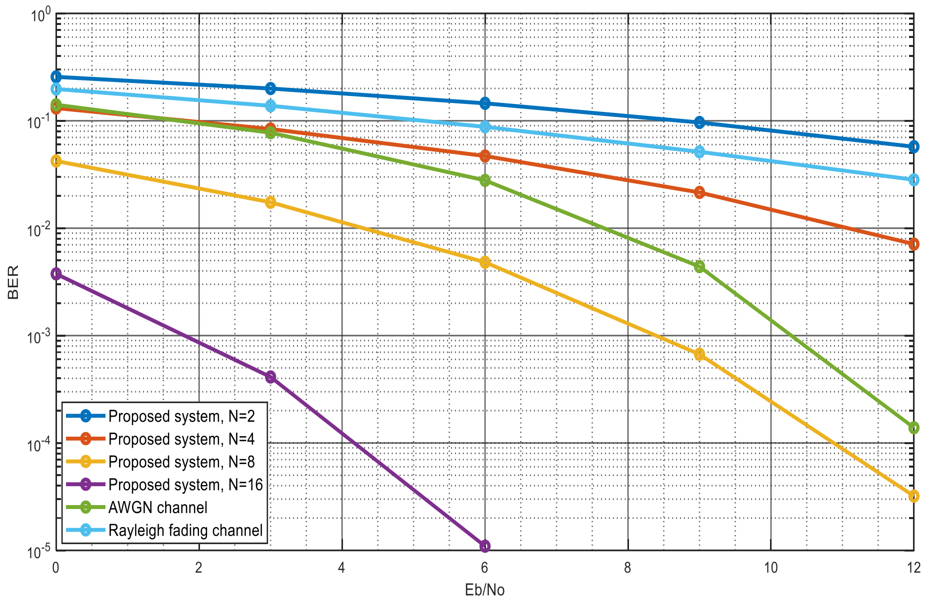

Fig. (2) The BER vs. Eb/N0 when diversity=2,4,8,16, AWGN channel and Rayleigh fading channel using the frequency diversity scheme.

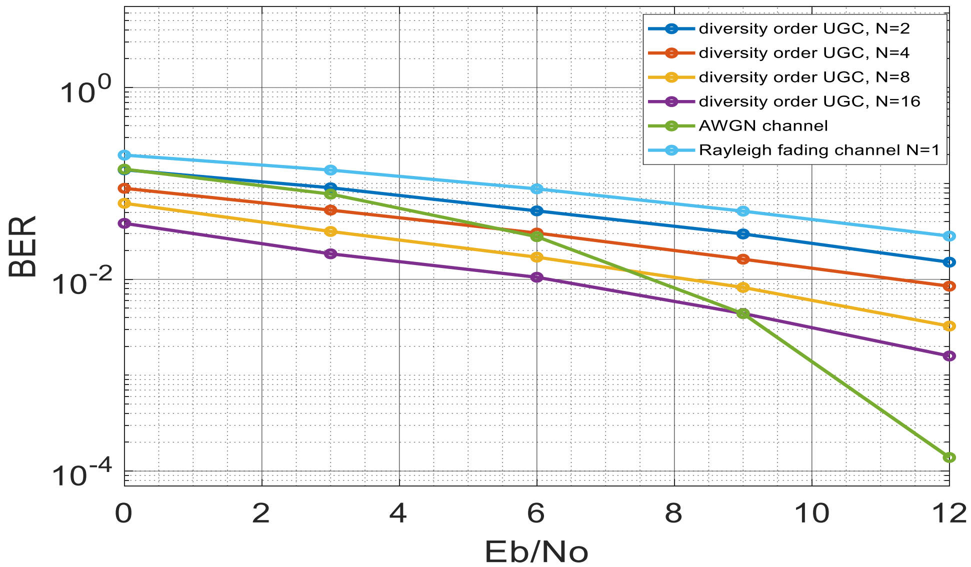

Fig. (3) The BER vs. Eb/N0 when diversity=2,4,8,16, AWGN channel and Rayleigh fading channel using the encoder-diversity scheme with Unity Gain combiner.

Table (1) The comparison between the proposed diversity system and the diversity encoder system

Diversity order	**Diversity Encoder**		**proposed frequency diversity**	
	Bit rate	**BW$_{eff}$**	**Bit rate**	**BW$_{eff}$**
2	$M_t \times M \times R_o$	$\frac{M_t \times M}{(M + \propto_{roll})}$	$M_t \times M \times \frac{R_o}{2}$	$\frac{M_t \times M}{2(M + \propto_{roll})}$
4	$M_t \times M \times R_o$	$\frac{M_t \times M}{(M + \propto_{roll})}$	$M_t \times M \times \frac{R_o}{4}$	$\frac{M_t \times M}{4(M + \propto_{roll})}$
8	$M_t \times M \times R_o$	$\frac{M_t \times M}{(M + \propto_{roll})}$	$M_t \times M \times \frac{R_o}{8}$	$\frac{M_t \times M}{8(M + \propto_{roll})}$

Table (2) Simulation parameters

parameters	values
FFT length	1024
Diversity order	2
$\mathbf{N_t}$	4
$\mathbf{N_r}$	4

The signal received is shown in time domain, its FFT plot and the BER calculation (fig. 4, 5, 6 respectively).

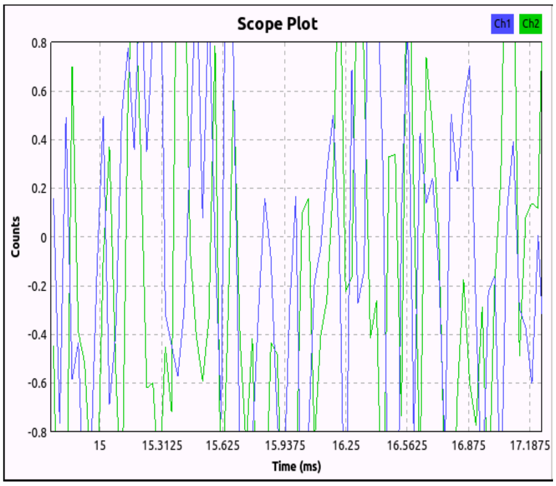

Fig. (4) Received time domain signal without noise.

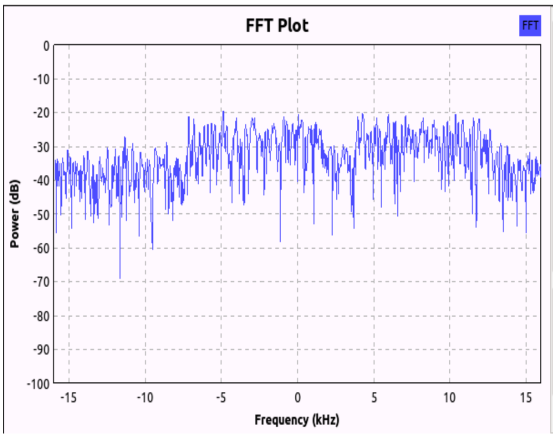

Fig. (5) FFT plot of the received signal.

Table 3 shows the BER (Bit Error Rate) values as a function of varying SNR for the MIMO-OFDM systems using 16- QAM modulation using the AWGN channel model.

Conclusion

The proposed MIMO-OFDM system achieves frequency diversity with order N without increasing the transmission bandwidth or reducing the rate of the transmitted symbols. The bandwidth efficiency of the proposed OFDM system with the proposed diversity method is the same as the bandwidth efficiency of the conventional OFDM system. When MIMO transmission in spatial multiplexing mode is added to the proposed OFDM system, the bandwidth efficiency increases by a factor equal to the number of transmitting antennas in the MIMO system. The results of GNU radio are the same as simulation results of MATLAB.

The next step of the research will be implementing MIMO- OFDM for different MIMO schemes using GNU Radio and USRP network series which has the flexibility of LO synchronization as MIMO cable is used.

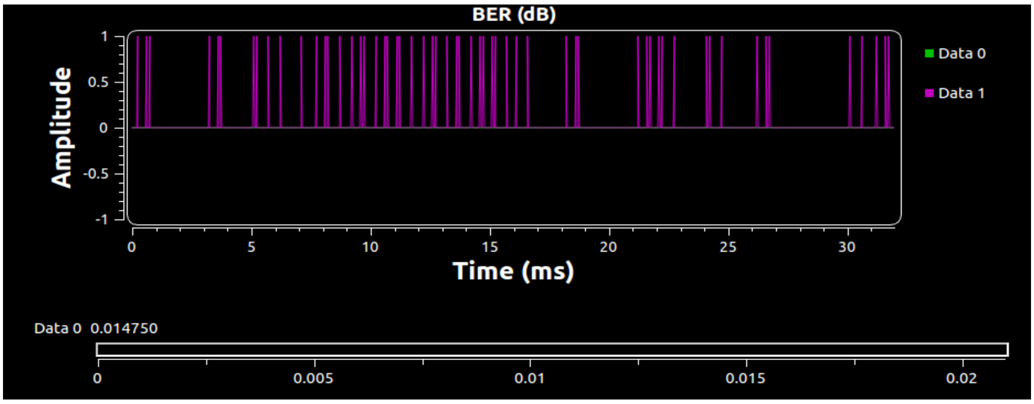

Fig. (6) *BER values generated.*

Table (3) BER for different SNR values.

SNR (dB)	0	3	6	9	12
BER	0.1410	0.0775	0.0279	0.0044	0.0001

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