# Design and Implementation of Software Defined Radio System for OFDM Communications

**Zaidoon Y. Hadi, Manal J. Al-Kindi**

Department of Electronic and Communications Engineering, Al-Nahrain University Baghdad,Iraq

Corresponding Author: Zaidoon Y. Hadi:

## Abstract

OFDM transceiver literature is a common course subject in most engineering colleges, where the need of the OFDM test bench becomes very important in most cases. In this paper a practical SDR for educational purposes based on the integration of MATLAB/SIMULINK and Raspberry PI 3 B+ platform, beside the supporting lab equipment. The design consists of two main stages, the OFDM simulation based on Simulink and downloading the simulation model to Raspberry PI hardware via the proper link between the PC and Raspberry PI. The desired test bench shows an easy and handy way to deal with in teaching the principle and behavior of OFDM communication systems. OFDM system performance specification input signal and output spectrum display facilities are incorporated along with the ability of study the effects of the parameters of different types of channels the received/equalized signal at the receiver.

*Keywords :* platform, devices, Simulink, Raspberry PI, systems, radio, defined, software, OFDM.

## I. Introduction

The new communication standard is going towards free moving user without base station or handset limitation [1, 2]. This can only be accomplished by the multi standard which is important in varying conditions. The most encouraging way to do this by utilizing the SDR. The last period of ten years witnessing a magnificent growth of configurable microchips specially made for signal processing, such as field programmable gate array (FPGAs) and digital signal processors (DSPs). These tools made the Software Defined Radio (SDR) theory a valid truth, so that currently the baseband part of a communication system can be executed by the software on such hardware. Latest telecommunications engineering needs a wide knowledge in the SDR area, including programming-languages, digital signal processing methods and hardware associated problems, that should be taught through their classes at the college. The designing of a communication technique with ongoing experimentation requires being flexible such that it supports up to date conclusions and testing different use cases. Currently, 5G transmission and reception blocks are being developed theoretically and explored by simulation, but there is an absence of applications that permit the proof of concepts and evaluation under actual channel environment, which worsen the signal status. Software defined radio (SDR) is an attractive approach for flexible modelling of communication system where the performance of the system depends on the software implemented in a configurable gadget: system on chip (SOC) field programmable gate array (FPGA), digital signal processor (DSP) or general purpose processor (GPP). Thus, the software update of the system is possible, through the operation time, by restore a firmware or adjusting the software. Thus, SDR opens the way for developing in both research and teaching; allow the composition and examining of digital communication system in a realistic way [3-5]. Many propositions have been introduced in the studies about the SDR field of study, like Lab-view (e.g. [6]) and MATLAB/Simulink (e.g. [7]). The above mentioned technologies needs very high knowledge and practice in SDR area for the engineers to know while there is no hands on practice in the college courses and if any It's only a short period of the course, the main reasons of this are the cost of such equipment and the difficulty to teach communications, digital signal processing and FPGA not to mention the hardware building and programming at the same lecture. The proposed solution presented by the broad manufacturing of the general purpose processors that are not costly compared to the other SDRs and the automatic generation of software depending on the design of the model. The GPP used in this case is RASPBERRY PI 3 B+, single board low cost. The main reason this device was adopted it is fully supported by Math-works, Simulink Support Package.
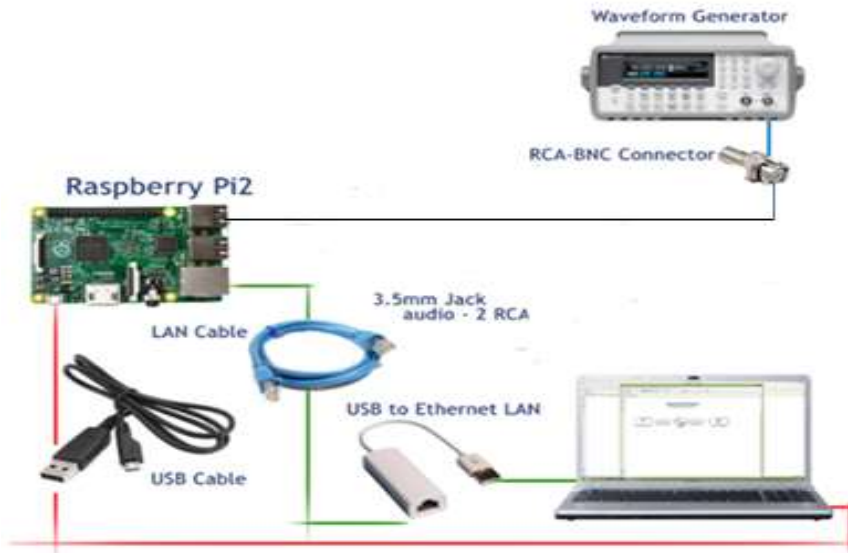
Figure 1 Workstation scheme

## II. SOFTWARE DEFINED RADIO

Based on Raspberry Pi 3 Model B+ (from now on just Rasperry Pi) and Simulink, this SDR experience will help to teach the modeling and the following equipment building of essential communication technology and SP design.
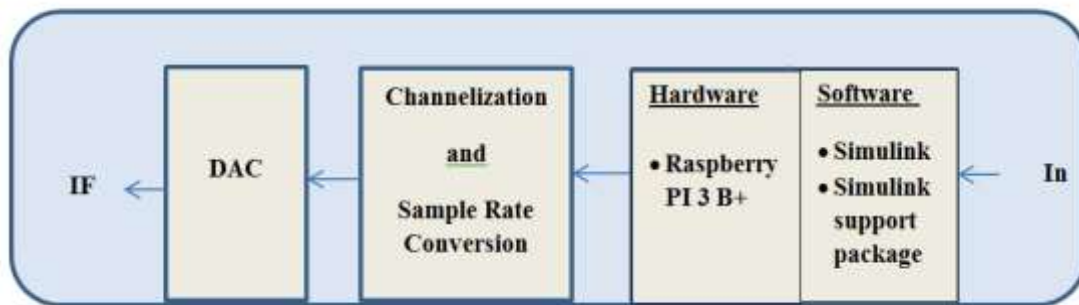


**Figure 2 Raspberry PI SDR BLOCK DIATGRAM**

### III.RASPBERRY PI 3 B+

The Raspberry Pi board [8] is, maybe, the most applicable illustration of equivalent devices: it is a well-known cheap single board computer advance by the Raspberry Pi with the aim of recommend the education of basic computer science. It is widely used as a server in home networks or as a media center and it is also adopted in many academic courses [9].

**Figure 3 Raspberry PI 3B+ 1.4 GHz Software Platform**

Raspberry PI in most of the time used to teach computer science and network. What is precisely related for the Signal Processing educational goal explained now, is that MatLab delivers a Support bundle, an add-on software element to be used by third-party kit, especially defining the link between the Raspberry Pi and Simulink/MathWorks [10]. It's the Signal Processing academic program that used for long several years to instruct the fundamentals of the SDRs at the University of Bologna [11].

## IV. Matlab –Simulink Program

To change evolution of aggregate technologies, band leader firms took on MBD by consistently using prototype all over the whole procedure [12-14].

- employ a computer simulated model to test your system early and often

- confirm your configuration in parallel with real models, Hardware-in-the-Loop testing, and rapid modelling

- Generate manufacturing-class C, C++ , CUDA, PLC, Verilog, and VHDL code and used right to the processor.

- preserve a digital strain with detectability completely demands, system building design, element design, code and experiments

- convert prototype to systems in order to do diagnostic preserving and fault examination.

## V. OFDM

In wireless communication system the multi carrier telecommunication technique, transfer more signals at the very instant through unconnected media at less data amount or sub carriers. In single carrier telecommunication technique transferring multiple signals across the same communication channel, will produce cross one and other, while in multi carrier technique because of sub carriers the signals do not cross. At the receiver starting with each sub carrier the transferred messages are regained [15].

Fading problem can be solved by dividing the original bandwidth by multiple small bandwidth SCs each of which is modulated separately and leads to simplify the equalizer used at the other end [16].

That is the modulating carriers of N parallel information stream are used as replacement of a single high data rate modified by a single carrier, the result of the dividing of the bandwidth into N limited bandwidth channels is having a flat fading effect. This will make the equalizers at the receiver much simpler if needed even through dispersive channel [17].

## VI. System model

The design of the model is made full transceiver having all parts needed and used three different outputs to simulate examine different scenarios and study the effects of the noise generated by the additive white noise channel and the multi path fading channel (Rician) of the full OFDM transceiver.

The OFDM simulation model is shown in figure 2, including three stages: the transmitter, the channel modelling, and the receiver. At the transmitter side, the OFDM modulator block is used to reform the QAM symbols generating from the data generator and QAM modular block. The channel consists of two serial blocks, where the transmitted OFDM symbols are filtered through Rician fading channel in the first block, and then the noise is added to the signal in the next block. The OFDM demodulator block is applied to the received signal at the first stage in the receiver side to obtain the received QAM symbols, which pass through the equalizer and QAM demodulator block.
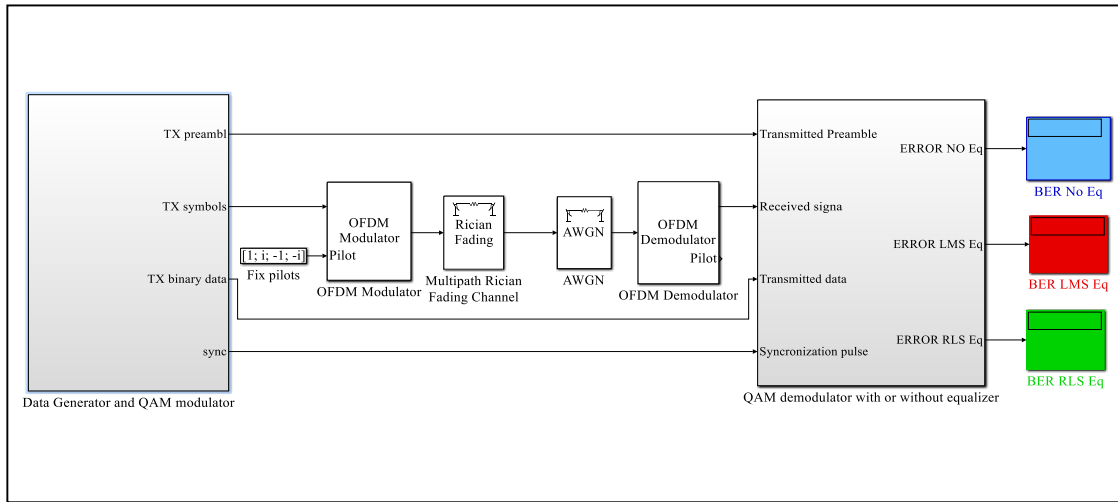


**Figure 4 Simulink OFDM Model**

Figure 4 shows the block diagram of data generator and QAM modulator at the transmitter, including random integer generator in the range [0 15] and QAM modulator blocks, in addition to the pulse generator block to synchronize the system.
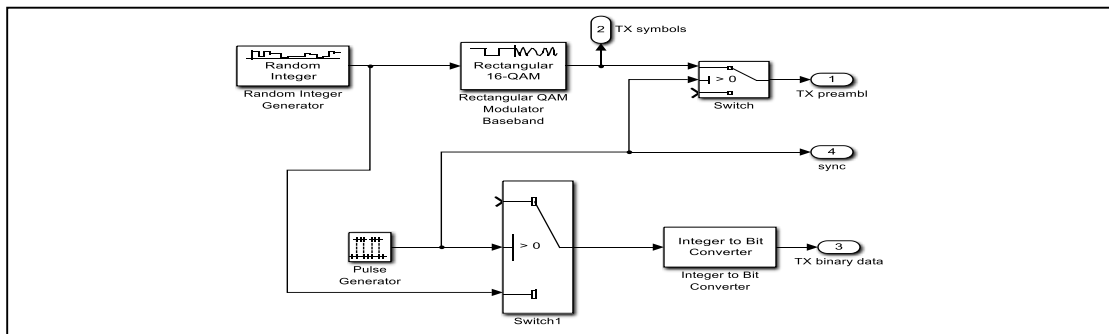


**Fig.5 Data Generation and QAM Modulation at the Transmitter**

The QAM demodulator with or without equalizer block at the receiver consists of three blocks as shown in figure 3. Each block includes QAM demodulator, integer to bit converter, and two error calculators blocks, one of them to display and the other workspace. The comparison process between transmitted and received information.
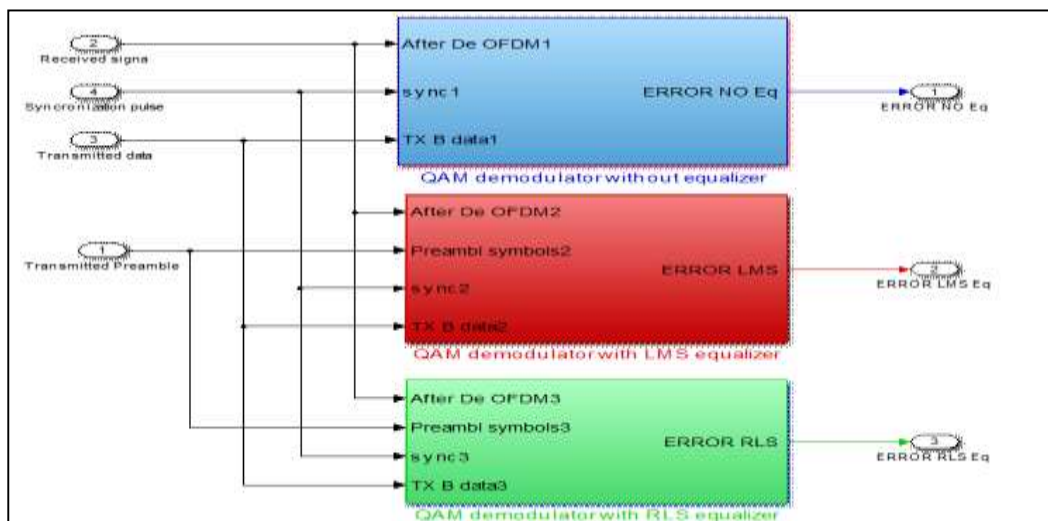


**Fig.6 OFDM demodulation in different equalization techniques**

**The simulation parameters**: we choose the below parameters for simplicity and it convenience with our Raspberry PI

1)  The length of **FFT** or **IFFT** is **64**, which is equal to the number of subcarriers in frequency domain.
2)  The type of digital modulation is **16_QAM,** so the number of bits per one subcarrier is log2(16)=**4bits**.
3)  **48** subcarriers are allocated to carry a stream of data bits.
4)  **11** subcarriers are assigned as guard bands in system.
5)  The pilots are transmitted on **4** subcarriers with index [12 26 40 54], and **one** subcarriers for DC null.
6)  The cyclic prefix is 64/4=16, so there is 64+16=**80** sample per each OFDM symbol.
7)  Sampling rate is 48000 sample/second

## VII.        Working steps

We installed the Simulink support package into the sd-card of the Raspberry PI and booted the device with the new software, so the Raspberry PI have complete library of the Simulink and connected to the PC by Ethernet, used the audio output from the Raspberry PI connected it to the spectrum the first part of the transceiver is connected to examine the output intermediate frequency generated from the Raspberry PI and compare it with frequency generated in simulation.
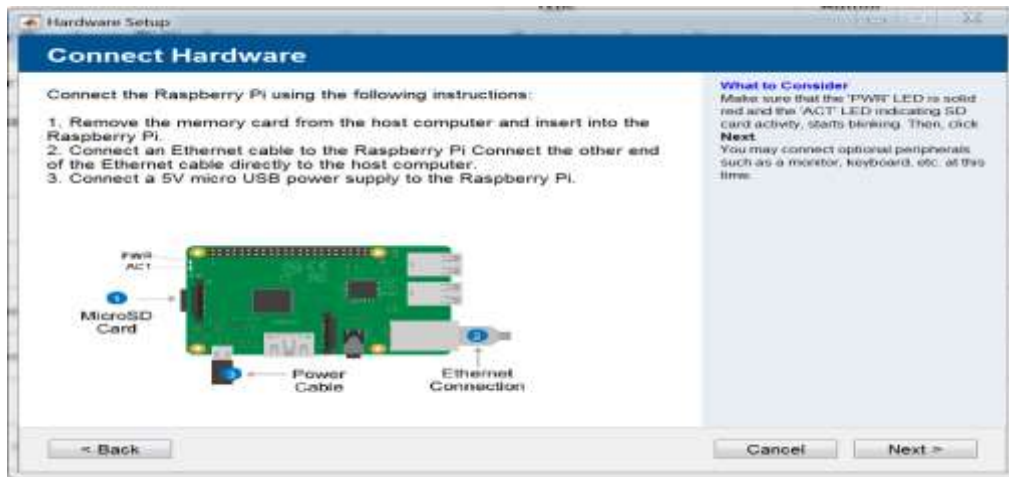


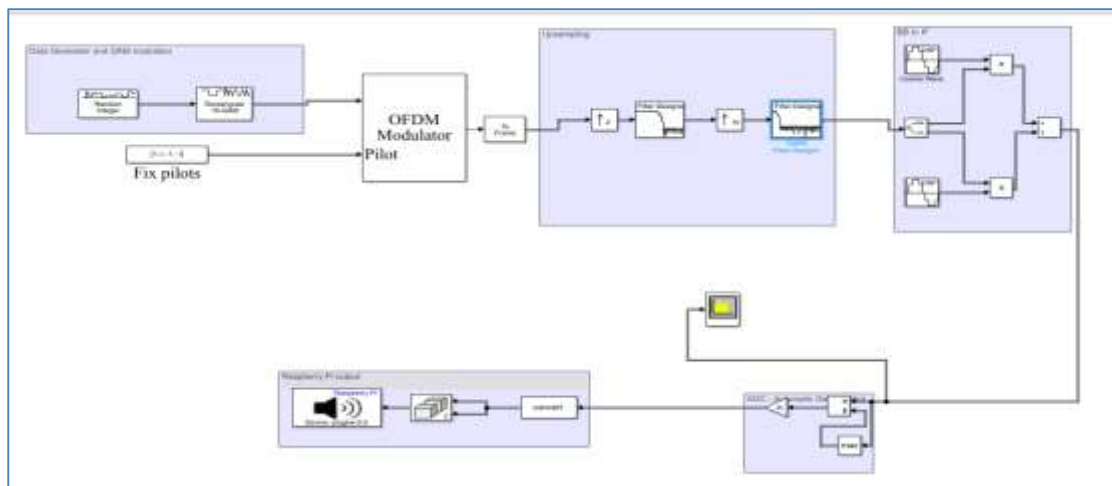**Fig.7 Installing the Support Package of the Raspberry PI 3 B+**



**Figure 8 OFDM transmitter part prepared to connect with Raspberry PI**

## VIII.        Results

The Simulink model use to build OFDM transceiver the equalizers used to keeps the information safe in the case of multi path fading, using two different equalizers LMS,RLS techniques.
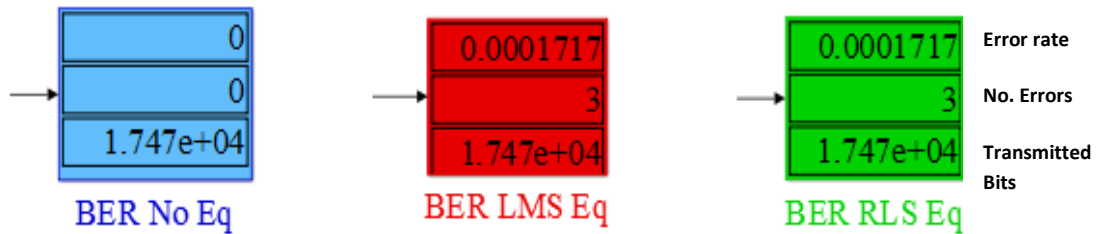
| | | Error rate |
| BER No Eq | BER LMS Eq | BER RLS Eq |

(labels: Error rate, No. Errors, Transmitted Bits)
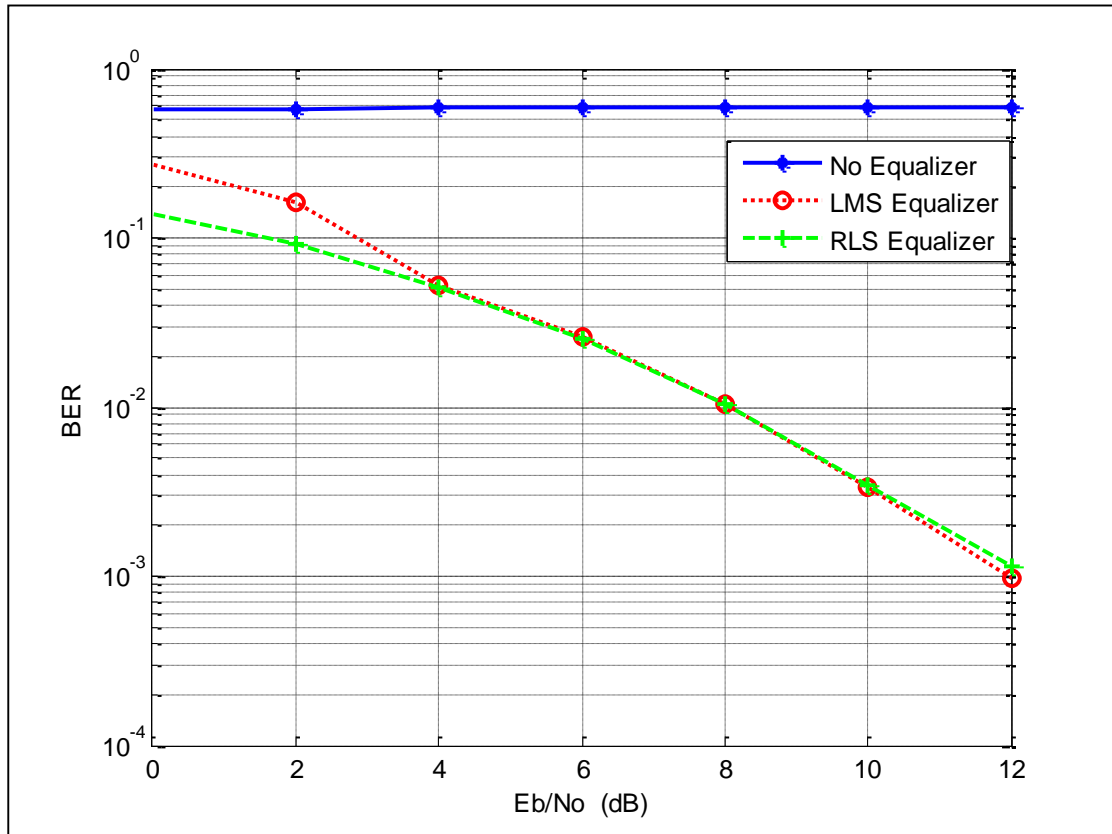
**Figure 9 BER after multipath fading**



**Figure 10: The BER versus Eb/No under multipath Rician fading channel with path delay vector $[0\ 10^{-6}]$ sec.**

In **Fig**.10 above the two equalizers' branches results in good BER, while the non-equalized branch has high loss result.

The output of the Raspberry PI IF frequency is the same as the simulated waveform which indicates that this SDR is platform is applicable not for the use of educational purposes only but also for further more applications if the limitations of the frequency carrier handled by some SDR-dungle which can elevate the frequency into several MHz.
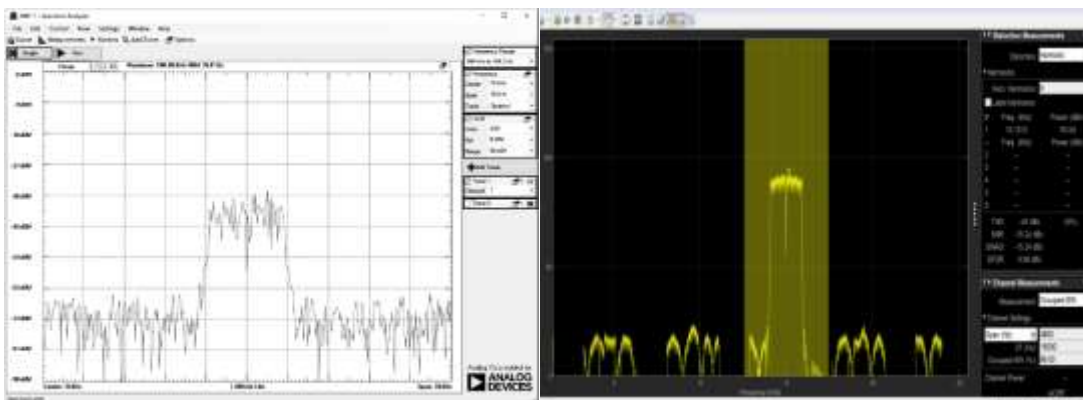


**Figure 11 Spectrum analyzer Figure**

## IX. Summary

In this paper we developed SDR using  GPP  Raspberry PI 3 B+ and simulation from MATLAB/SIMULINK producing both low cost and academically helpful for understanding DSP, communication model design ,FPGA aspects and hardware implementation, the simulation of OFDM system used to examine the effects of channels (Rician ,AWGN ), used two equalizers (LMS,RLS).

The Raspberry PI platform used as an SDR produced output signal and viewed by the spectrum analyzer and matched the signal from the simulation transmitter part. The frequency range can be elevated by many MHz using different types of smart antenna .

## REFRENCES

[1] A. Ghazi, S. Aljunid, S. Z. S. Idrus, A. Fareed, A. Al-dawoodi, Z. Hasan*, et al.*, "Hybrid Dy-NFIS & RLS equalization for ZCC code in optical-CDMA over multi-mode optical fiber," *Periodicals of Engineering and Natural Sciences,* vol. 9, pp. 253-276, 2021.

[2] A. Ghazi, S. Aljunid, A. Noori, S. Z. S. Idrus, C. Rashidi, and A. Al-Dawoodi, "Design & investigation of 10x10 gbit/s MDM over hybrid FSO link under different weather conditions and fiber to the home," *Bulletin of Electrical Engineering and Informatics,* vol. 8, pp. 121-126, 2019.

[3] D. T. Nguyen, F. Safaei, and P. J. Vial, "An experimental study of OFDM in software defined radio systems using GNU platform and USRP2 devices," in *2014 International Conference on Advanced Technologies for Communications (ATC 2014)*, 2014, pp. 657-662.

[4] S. A. A. Ghazi, S. Idrus, A. Fareed, L. Hamood, R. Endut, N. Ali*, et al.*, "Comparison of MD & ZCC one dimension code for optical-CDMA over multi-mode fiber based on Laguerre-Gaussian modes," *Journal of Engineering Science and Technology,* vol. 16, pp. 3588-3599, 2021.

[5] A. Amphawan, A. Ghazi, and A. Al-dawoodi, "Free-space optics mode-wavelength division multiplexing system using LG modes based on decision feedback equalization," in *EPJ Web of Conferences*, 2017, p. 01009.

[6] B. an Affordable, "8x8 MIMO Testbed with NI USRP," *National Instruments,* 2014.

[7] M. Braun, M. Muller, M. Fuhr, and F. K. Jondral, "A USRP-based testbed for OFDM-based radar and communication systems," in *Proceedings of 22nd Virginia Tech. Symposium on Wireless Communications*, 2012.

[8] R. P. website. Available: http://www.raspberrypi.org

[9] R. P. A. website. Available: http://www.raspberrypi.org/picademy

[10] R. P. S. f. M. website. Available: http://it.mathworks.com/hardware-support/raspberry-pi-simulink.html

[11] G. Pasolini, A. Bazzi, and F. Zabini, "A raspberry pi-based platform for signal processing education [sp education]," *IEEE Signal Processing Magazine,* vol. 34, pp. 151-158, 2017.

[12] S. i. f. M.-B. Design. Available: https://www.mathworks.com/products/simulink.html

[13] N. Fatima, "Image transmission over OFDM system using trigonometric transforms," in *2015 International Conference on Communication, Information & Computing Technology (ICCICT)*, 2015, pp. 1-6.

[14] Z. A. Jaffri, M. Tahir, and S. Rauf, "Evaluating the performance of OFDM transceiver for image transfer using 16PSK and 16QAM modulation schemes," *International Journal of Scientific Engineering and Technology,* vol. 3, pp. 222-226, 2014.

[15] K. Sharma, A. Mishra, and A. De, "Robust watermarked image transmission on OFDM wireless network," in *2012 25th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, 2012, pp. 1-6.

[16] S. Jain and S. Yadav, "Image Transmission Using 64-QAM Modulation Technique in Digital Communication System," *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET),* vol. 4, pp. 4400-4403, 2015.

[17] A. Goldberg and T. Radzik, "A heuristic improvement of the Bellman-Ford algorithm," STANFORD UNIV CA DEPT OF COMPUTER SCIENCE1993.