# Performance Measurement, Analysis, and Optimization of Communication System Implemented using SDR Technology

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***Abstract*— Acronym SDR stands for Software-defined radio. An SDR is a digital programmable platform which has the ability to realize the structure of the system with high mobility, and flexibility. Though SDR technology is known from past 20-30 years, it gained more popularity nowadays as a result of advancement in DSPs architecture. The goal of this technology is to prototype any communication system with the help of reconfigurable hardware. With the help of SDR, a PC will turn into a powerful prototyping tool for a wireless communication system. One such approach has been discussed in this paper. This paper includes design process of FM transceivers for real-time signal transmission as well as OFDM systems for text transmission and the parameters observed during performance measurement.**

***Keywords*— *SDR; Re-configurability; USRP; Lab VIEW;DSP***

## I. INTRODUCTION

Wireless communication systems are dynamic in nature, means nobody can say with confidence what forms it will take in future. Using hardware devices to implement communication standards, in this case, will be expensive. Because we cannot predict what will be included in the new standards. In such case, the system designed for previous standard will become obsolete. Again deploying communication system with the new standard will consume more time and it is expensive too. In this scenario, a system where the user can switch between different standards just by configuring the parameter forms the key solution. One such flexibility is provided by SDR technology. The basic concept of SDR is that radio can be totally configured or defined by the software so that a common hardware platform can be used for different standards and the software used to change the configuration of the radio for the function required at a given time. This will allows one to upgrade the system to newly arrived standards. The flexibility goes even further. Designers are free to pick and choose among the software modules they created for earlier SDRs and use them in designing later products. This code reusability creates an open platform for both the evolutionary development of wireless systems and their rapid prototyping. Even hardware design becomes simpler because SDR relieves many complicated analog circuits by performing their functions in software.

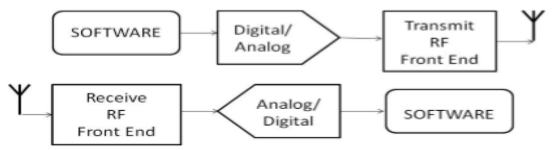


Fig. 1. A typical SDR transmitter and receiver block

(LabVIEW) Laboratory Virtual Instrument Engineering Workbench software from the national instrument with efficient tool boxes facilitates the design of communication systems with a high-level user interface. This is a graphical design tool which follows the data-flow programming. Universal Software Radio Peripherals (USRP) which acts as an RF front end is reconfigurable in nature, used for RF communication.

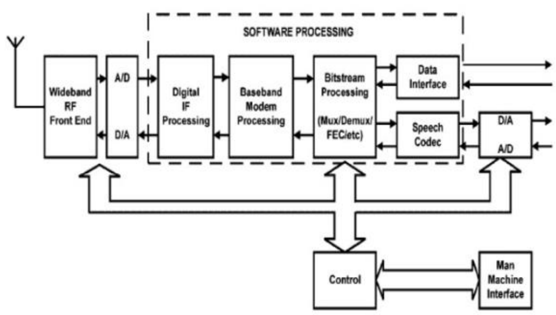


Fig. 2. Block diagram of SDR receiver

The first step in transforming the analog operations which are performed in hardware into SDR system is to make much of the circuitry in digital. In early days, the core part i.e, baseband processing is implemented in software. Gradually this process has been evolved to implement incoming RF signal into digital form as close to the antenna as possible to process it digitally on a programmable device and then to convert it back into analog form as close as possible to the transmitting device. From this, we can say that Analog to digital converters (ADCs) and Digital to Analog converts (DACs) plays a major role in SDR system.

USRP is a hardware which can be configured using software. This mainly consists of two parts. One is RF front end which will perform RF communication function and another is ADC and DAC blocks to provide a connection between host computer and hardware. (Refer Table (1) for device specifications)

## II. USRP 2901

TABLE I. USRP DEVICE SPECIFICATIONS

| S.L no | Parameters | USRP 2901 |
|---|---|---|
| 1 | Interface to the host computer | USB 2.0 |
| 2 | Frequency Range | 70MHz to 2GHz |
| 3 | Instantaneous bandwidth | 56MHz |
| 4 | Maximum output power | 20dBm |
| 5 | Maximum input power | -15dBm |
| 6 | Transmitter gain | 89.75 dB |
| 7 | Receiver gain | 76dB |
| 8 | Full-duplex | Yes |
| 9 | ADCs and DACs | 12 bits |

## III. DESIGN STEPS FOR WIRELESS PROTOTYPING

Prototyping work places a significant demand on hardware integration with technical computing software. It involves four steps which are discusses below

### A. System simulation

The initial step of the workflow executes all algorithms on desktop in a convenient and interactive fashion. Desktop execution makes it easier to explore algorithm alternatives, identify execution errors and tune the parameters.

### B. RF integration

This step configures RF I/O so that the desktop simulation receives and transmits data using the target hardware.

### C. Incremental deployment

The third step generates code for elements of the design, replacing desktop simulation with streaming execution on target hardware**.** This step places high importance on automatic code generation and data transfer between desktop and target hardware.

### D. System validation

The final step executes the design on the target hardware and validates it for correctness relative to simulation results obtained.

## IV. IMPLEMENTATION OF FM TRANSCEIVERS

In the design of FM radio, Frequency modulation technique plays a major role in combating interference effect compared to other analog modulation technique as it has large signal to noise ratio. Hence it is used for the transmission of an audio signal.

If m (t) is the message signal and x (t) = Ac Cos (2πft) then modulated signal is given by

S (t) = Ac Cos (ϴ) (1)

Where,

$$\Theta(t) = 2\pi f_c t + \frac{\Delta f}{f_m} \sin 2\pi f_m t$$

One of the important parameter to be considered here is frequency deviation termed as $\Delta f$

$$\beta = \frac{\Delta f}{f_m} \quad (2)$$

The modulation index affects the modulated sinusoid. Larger the modulation index, greater the instantaneous frequency will be from the carrier. This is illustrated in the graph below

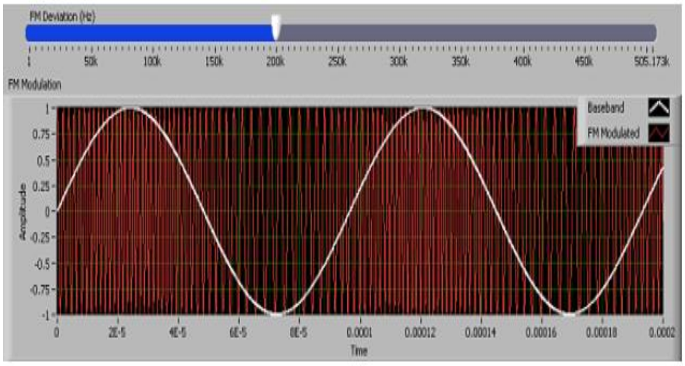


Fig. 3. signal with $\Delta f$= 200 MHz

Carson's rule for bandwidth calculation is given by

$$B_T = 2(\Delta f + f_m) \quad (3)$$

Equation (1),(2) and (3) represents the important parameter that we are using in the design.

Frequency deviation parameter has a great impact on the transmission bandwidth of the system which is illustrated with the help of Figure (4a) and (4b).

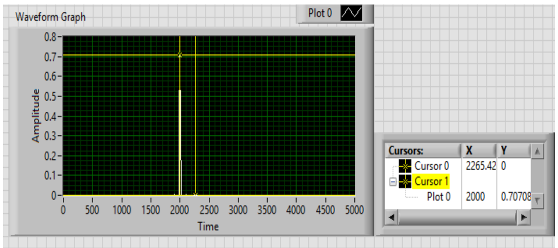


Fig. 4. $\Delta f$=1

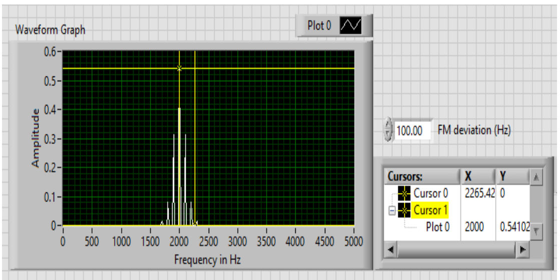


Fig. 5. $\Delta f$ =100

Design set up for FM radio using SDR is shown in Fig (5) where programming is done in PC and USRP is interfaced with PC using the USB cable. The necessary parameters are configured from PC which will be followed by USRP. Here we are transmitting an audio file as well as real time speech signal which can be received using USRP as well as mobile phones which are as depicted in Fig (5) and (6).

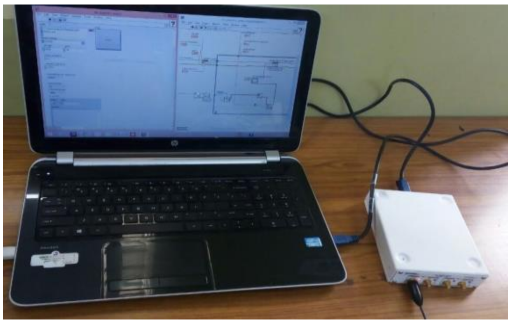

Fig. 6. FM transceiver design set up

Fig. 7. signal reception through mobile tuning

## V. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

Transmitting the data with higher data rate is one of the major requirements of any wireless communication system. Since free air is the channel for transmission the chances of fading is high. That too signals at higher data rate undergoes fading effect as they are having the bandwidth greater than the coherence bandwidth of the channel. To combat this fading effect high data rate signals are divided into multiple carriers of less data rate with each carrier being placed orthogonal to another to reduce interference. This property of orthogonality increases spectral efficiency which is illustrated in Fig (7). As the signals are orthogonal to each other overlapping of the signals can be achieved which leads to the efficient use of spectrum available. Because of all these advantages, OFDM has been adopted by several wireless standards such as IEEE 802.11a, 802.16, Hiper LAN.

### *A. Challenges in OFDM*

The major challenge in OFDM scheme is the removal of the inter-symbol interference (ISI) effect. ISI is due to the distortion in a signal in which one symbol interferes with the subsequent symbol. This will degrade the performance of the system. Guard interval insertion method is an effective method to reduce this effect. This includes zero padding as well as cyclic prefix addition to ensure symbol recovery. Fig 8 shows an example of how to add guard bits into the data stream. Achieving orthogonality between carriers is one major challenge. It is achieved by placing the subcarrier at a frequency which is an integral multiple of the fundamental frequency. If orthogonality is disturbed it leads to inter-carrier interference.

At the receiver side, there are two major challenges. One is symbol recovery and carrier frequency offset. Since we are transmitting our data in a multipath channel, we will receive symbols from multiple paths at different intervals of time. This arrival time difference is called delay spread. If this is more it will lead to distortion in a symbol. Another challenge is carrier frequency offset removal. This will occur if transmitter local oscillator frequency does not match with the receiver frequency. This will leads to the loss of orthogonality between carriers.

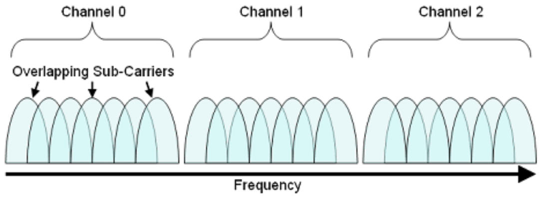


Fig. 8. illustrates how OFDM scheme is spectrally efficient compared to other schemes.

### *B. Modulation technique*

Quadrature phase shift keying (QPSK) is used as a modulation technique in OFDM. It involves digital information transmission by adjusting phase and amplitude of a signal. This technique uses group of bits (symbol) to represent carrier and hence it is spectrally efficient. Fig (12) and (13) shows the constellation diagram at transmitter and receiver side respectively. This plot will be used to recognize the interference type and distortion in a signal.

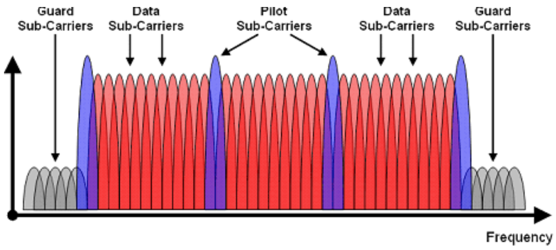


Fig. 9. An example showing how data stream looks at transmitting end.

## VI. RESULTS AND DISCUSSIONS

### *A. Bit error rate*

BER is defined as the ratio of the total number of bits in error to the total number of bits transmitted. In other words, it is the rate at which the error occurs during the transmission.

$$\text{Bit error rate} = \frac{\text{Number of bits get corrupted}}{\textit{total number of bits transmitted}}$$

BER value is very small in a case when the signal to noise ratio is high. It is always necessary to check the performance of the system as we cannot compromise on quality. BER is one parameter used to check the end-to-end performance of the system.


Fig. 10. BER value measured from OFDM system.

*B. Distance covered by the antenna*

This parameter will tell about the distance up to which a transmitter can cover or we can also define it as the distance between transmitter and receiver. This can be calculated by Friis equation given by

$$\frac{Pr}{pt} = GtGr\left(\frac{\lambda}{4\Pi d}\right)2$$

Where Pr= receiver power

Pt= Transmitter power

$G_t$= Transmitter gain

$G_r$= Receiver gain

$\boldsymbol{\lambda}$ = wavelength

d= Distance between transmitter and receiver.

With the obtained device specifications, coverage area is calculated as 21-26m.

## VII. CHANNEL NOISE AND INTER-SYMBOL INTERFERENCE

Eye patterns or eye diagram is the tool used to evaluate how the signals are affected by channel impairments. From the eye diagram, we can know whether the signals are poorly synchronized or noisy. We can know this by observing whether an open eye pattern is fully open or closed. Open eye pattern corresponds to minimal distortion whereas closed eye corresponds to a noisy signal. Fig (10) and (11) illustrates eye diagram for QPSK technique with different SNR values.

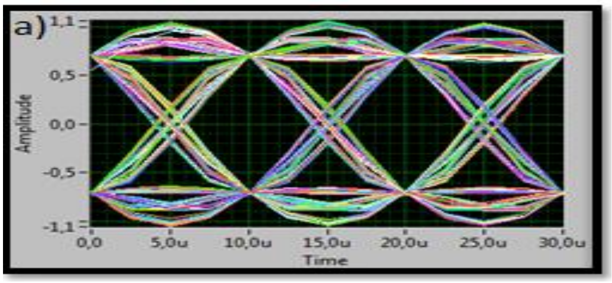


Fig. 11. Eye diagram for QPSK with SNR = 40 dB

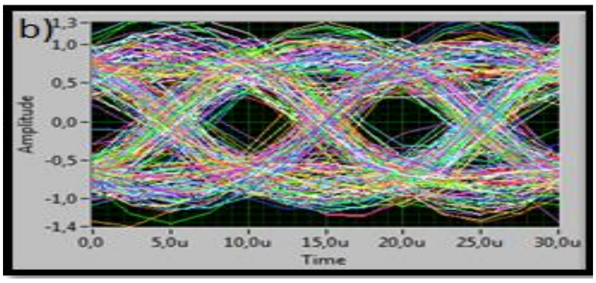


Fig. 12. Eye diagram for QPSK with SNR = 10 dB

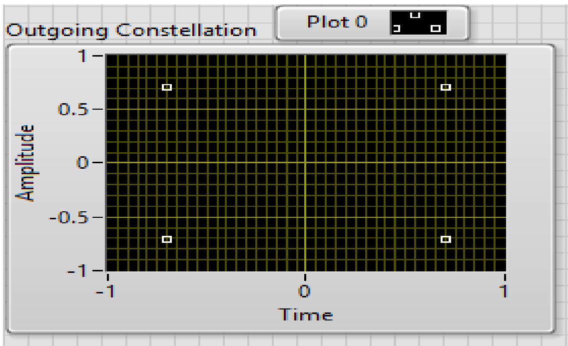


Fig. 13. Constellation diagram of QPSK at transmitter

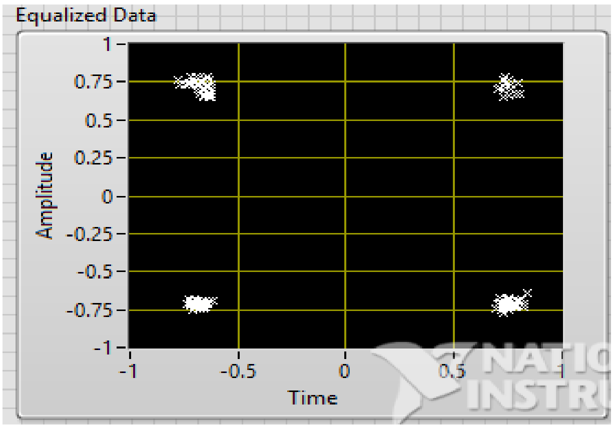


Fig. 14. Constellation diagram of QPSK at receiver

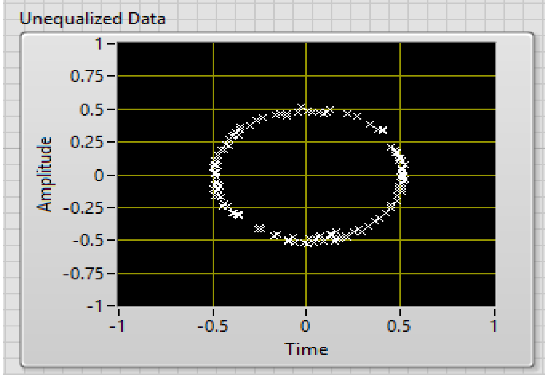


Fig. 15. Constellation diagram of QPSK before equalization

Fig (15) demonstrates a plot of BER versus SNR for different modulation techniques. This plot helps us in choosing modulation technique that is best suited for OFDM system. Fig (16) demonstrates a plot of power spectral density for FM system.

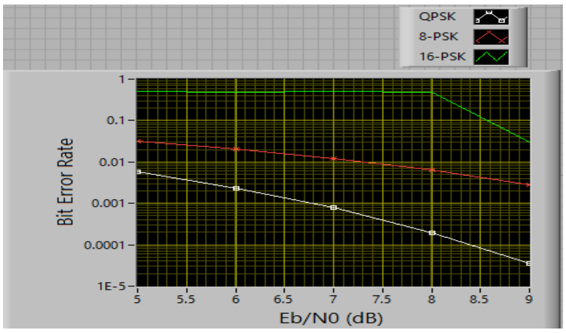


Fig. 16. Demonstrates plot of SNR versus BER.

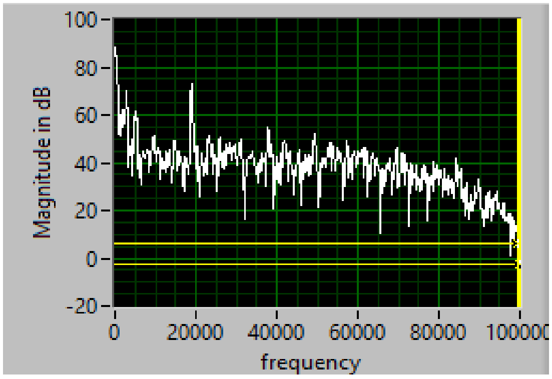


Fig. 17. Plot of spectral density estimate by frequency

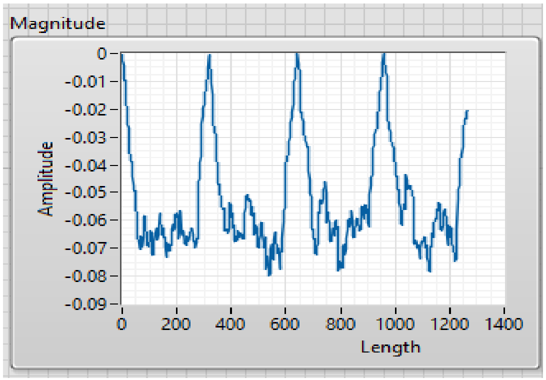


Fig. 18. Magnitude plot of an OFDM system

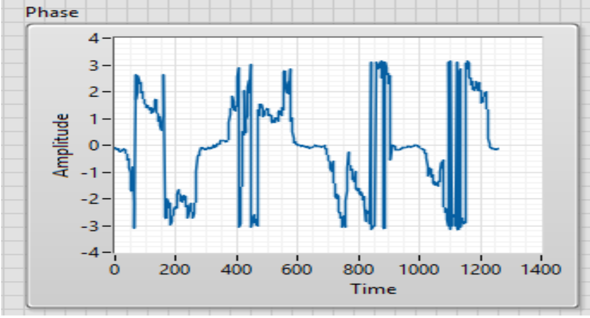


Fig. 19. Phase plot of an OFDM system

## VIII. CONCLUSION AND FUTURE SCOPE

SDR technology revolutionized the way we are looking at the communication systems. We can prototype any communication system if we have powerful technical software coupled with a reconfigurable hardware and measure the performance of different parameters for the betterment of knowledge.

Improvisation can be done on OFDM system to transmit and receive image and video signals from one point to another point. FM systems can be improved further to make the system which is capable of fetching the data from any corner of world and transmit it over a particular region.

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