ELP 725 Wireless Communication Laboratory

Experiment 4

“OFDM implementation using SDR”

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1. INTRODUCTION.

Orthogonal frequency-division multiplexing (OFDM) is a bandwidth-efficient signalling scheme for wideband digital communications. The main difference between frequency division multiplexing (FDM) and OFDM is that in OFDM, the spectrum of the individual carriers mutually overlap. Nevertheless, the OFDM carriers exhibit orthogonality on a symbol interval if they are spaced in frequency exactly at the reciprocal of the symbol interval, which can be accomplished by utilizing the discrete Fourier transform (DFT). With the development of modern digital signal processing technology, OFDM has become practical to implement and has been proposed as an efficient modulation scheme for applications ranging from modems, digital audio broadcast, to next-generation high-speed wireless data communications.
In this experiment, we will be designing an OFDM transmitter and receiver module on SDR, vary the FFT size and cyclic prefix study there effect.

2. OBJECTIVES.

(a) Design the OFDM transmitter and receiver module on SDR.

(b) Vary the FFT size and observe its effect on
   - (i) Peak-to-Average Power Ratio (PAPR)
   - (ii) Frequency selectivity of the channel

(c) Study the effect of cyclic prefix and zero-padded cyclic prefix on inter-symbol interference mitigation.

3. EQUIPMENT USED.

(a) Two SDRs, Laptop, antennas

(b) Laptop for programming the SDR

4. EXPERIMENTAL SETUP.

(a) Open the GNU radio on the laptop
(b) Design an OFDM transmitter and receiver
(c) Set the parameters for SDRs and then connect the Laptop with the SDR.
(d) Check various parameters eg varying the FFT size and the effect of cyclic prefix.

5. OBJECTIVES.

(a) Requirement 1: Designing an OFDM transmitter and Reciever

(i) The OFDM transmitter and receiver are enclosed in the same grc file. Using vector source of range 0 to 50 , we pass it through the Stream to Tagged Stream block, which converts a regular stream into a tagged stream. It adds length tags in regular intervals. Next, we add Throttle block to ensure that the average rate does not exceed the specified rate.

(ii) We then pass it through the OFDM Transmitter block. Next, we use Channel Model, which is a basic channel model simulator that can be used to help evaluate, design and test various signals, waveforms and algorithms. Then we pass the signal through the OFDM Receiver block.

(iii)We add a Tag Debug block to print out any received tag. To calculate peak-to-average power ratio of the received signal (PAPR), we use different blocks- Max, Moving Average, Divide, Log10.

(iv) Various GUI Time Sinks, GUI Frequency Sinks and GUI Number Sinks were used at various steps to get information for each step.

(v)For the hardware implementation, we connect our device (laptop) with the SDR Hardware devices using Ethernet Cable and a switch to connect both transmitter and receiver.

(vi)To each of the SDR hardware device (both transmitter and receiver), we add an antenna after placing the antennas on their tripod stands.

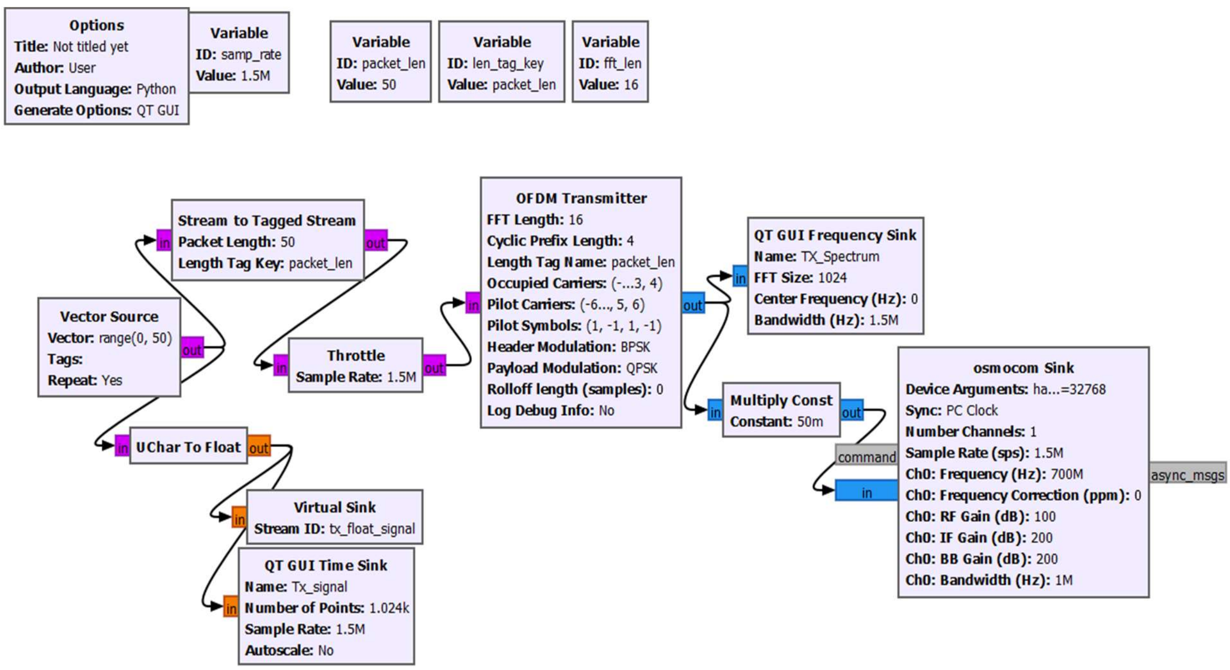

Figure1: OFDM Transmitter-SDR
FOR 16FFT

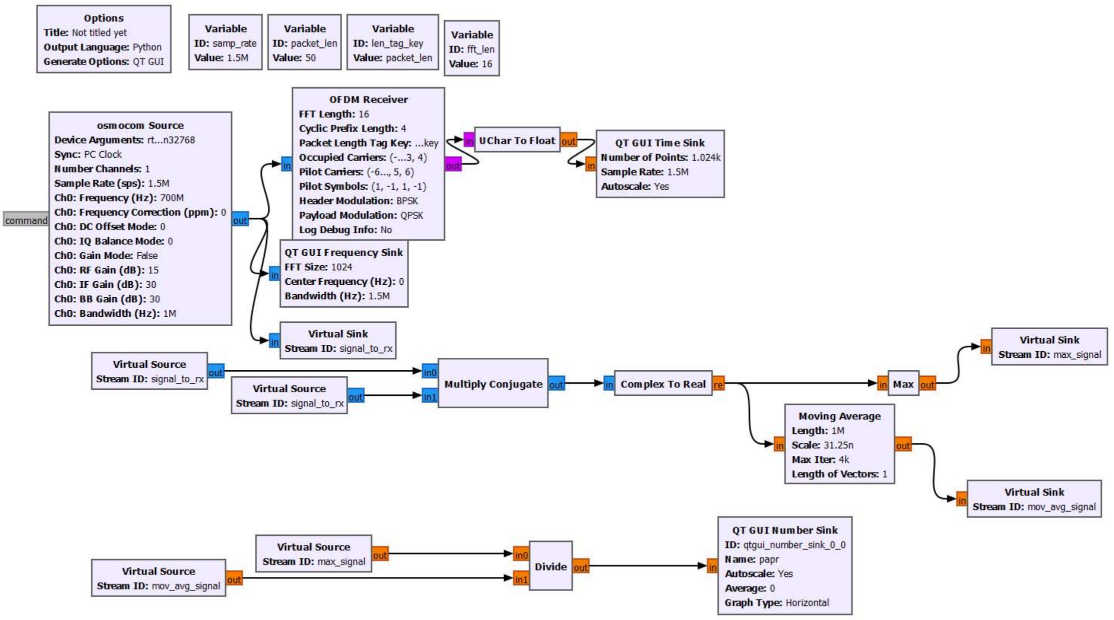

Figure 2: OFDM Receiver – SDR FOR 16FFT

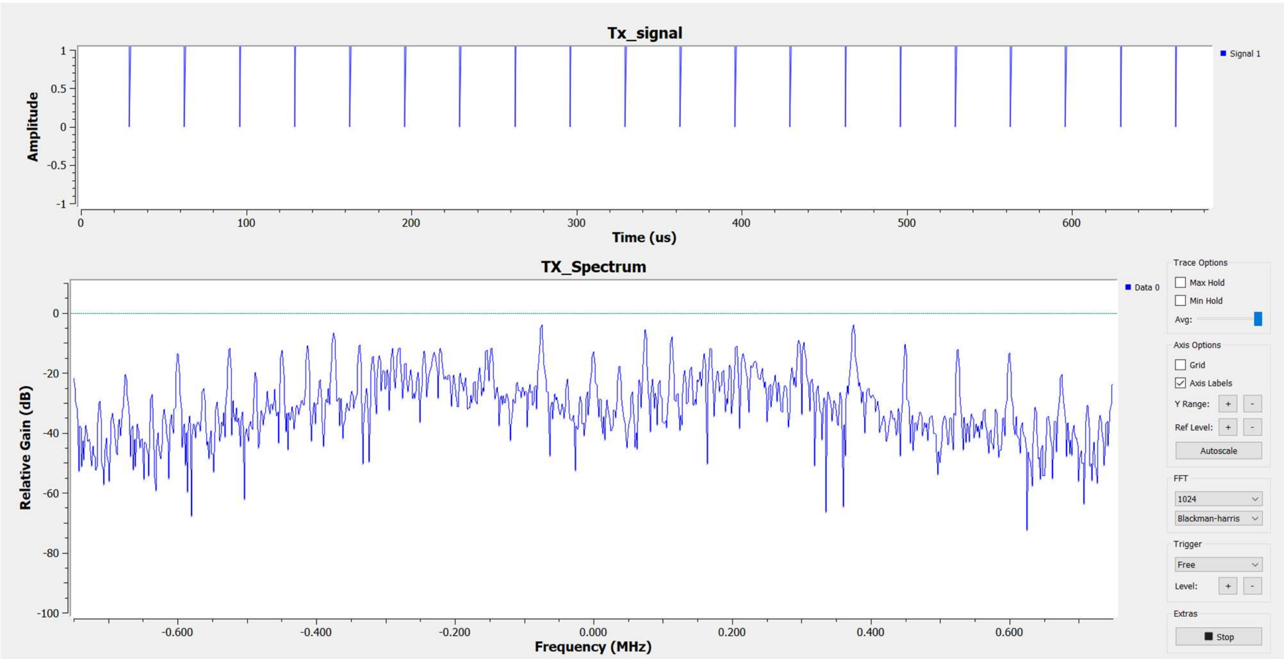

Figure 3: OFDM TX SIGNAL-SDR FOR 16 FFT

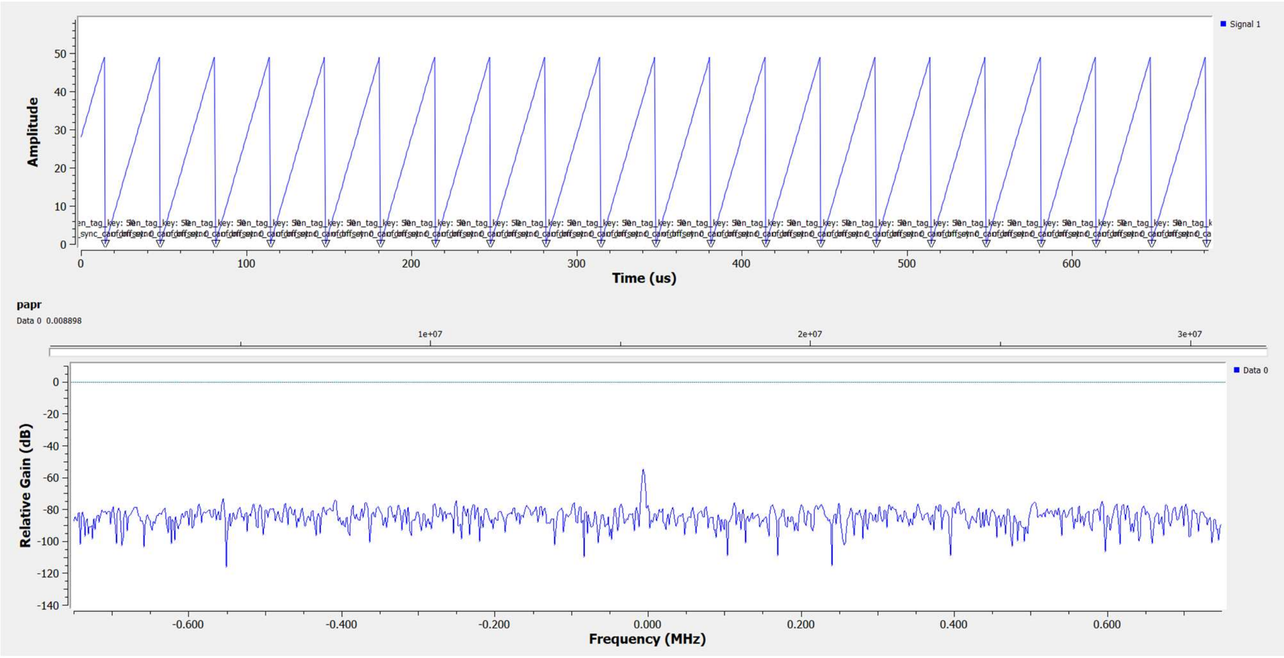

Figure 4: OFDM RX SIGNAL-SDR

FOR 16FFT

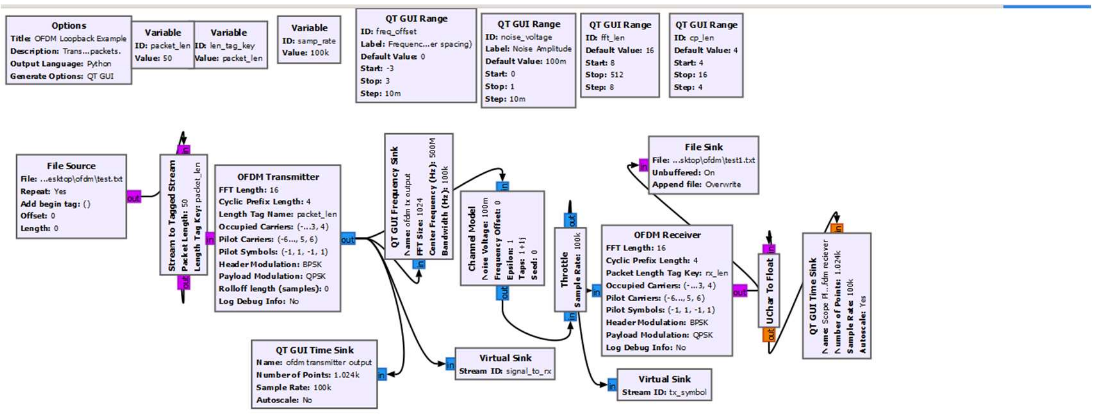

FIGURE 5: OFDM Simulation on GNURADIO

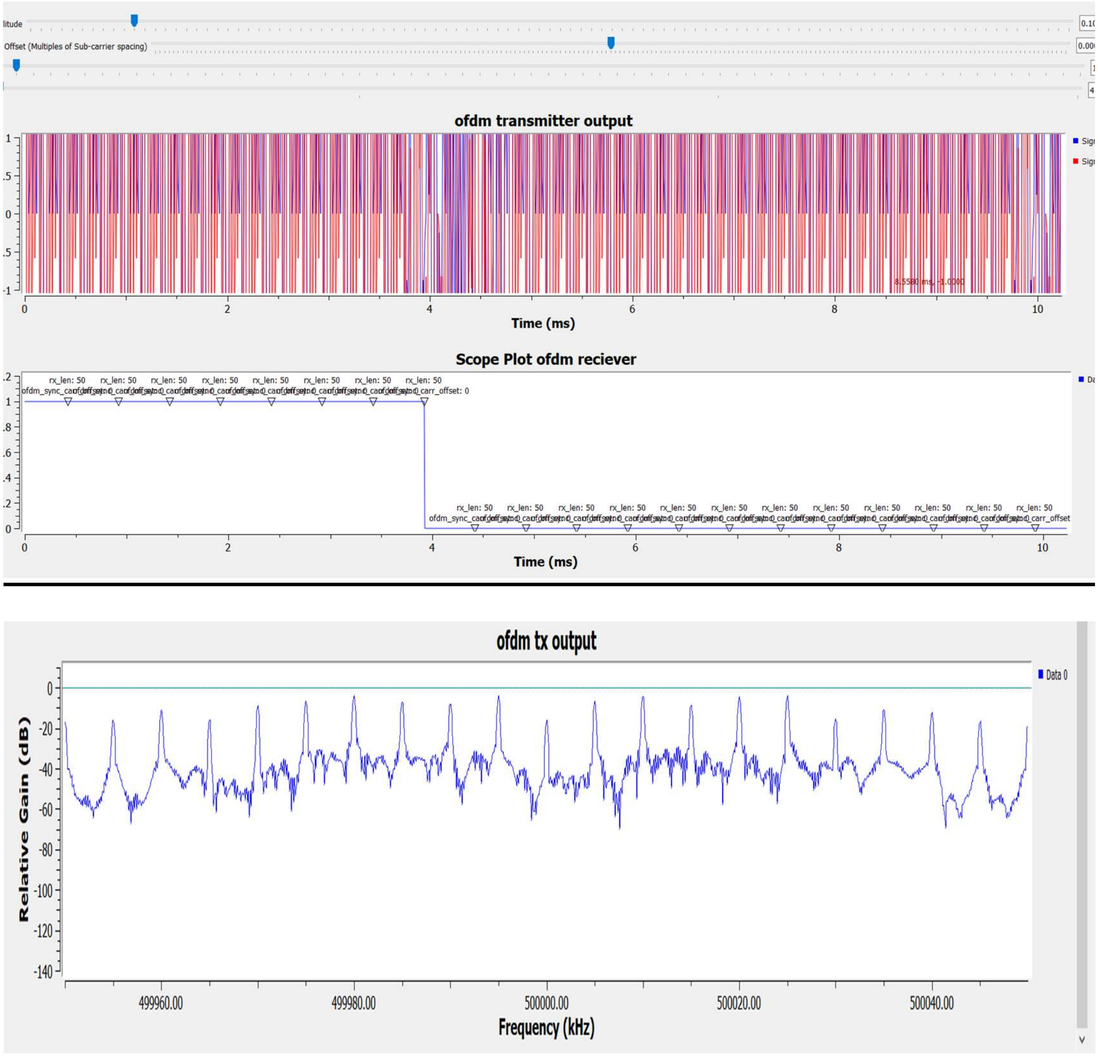

FIGURE 6: OFDM Simulation RESULTS ON GNURADIO FOR 64FFT

(b) <u>Requirement 2: Vary FFT Size and observe its effect on I. PAPR</u>

(i) <u>Observations.</u>

(aa) The PAPR in OFDM is equal to the number of sub-carriers. This implies that as the number of sub-carriers or the FFT Size increases, the PAPR increases.

(ab) This means that the swing of the carrier increases which in turn makes the Power Amplifier deviate from its Linear characteristics and operate in the Non-Linear region.

(ab) However, on the other side, increasing the FFT size means increasing the number of sub-carriers which makes the individual signal Bandwidth lesser than the Bandwidth of the frequency selective channel. Hence the channel starts behaving more and more flat or the channel displays flat fading characteristics.

(ac) It was also observed that , as we increase the FFT size, the frequency selectivity of the channel decreases

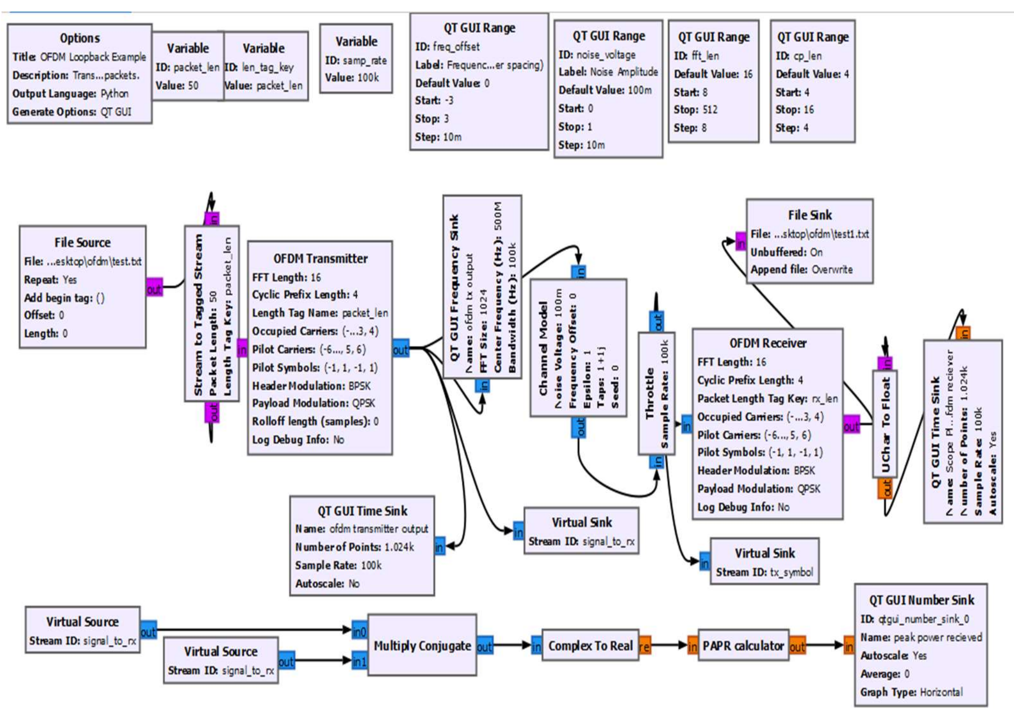

FIGURE 7: PAPR CALCULATION ON GNU RADIO

PAPR RESULT ON GNU RADIO

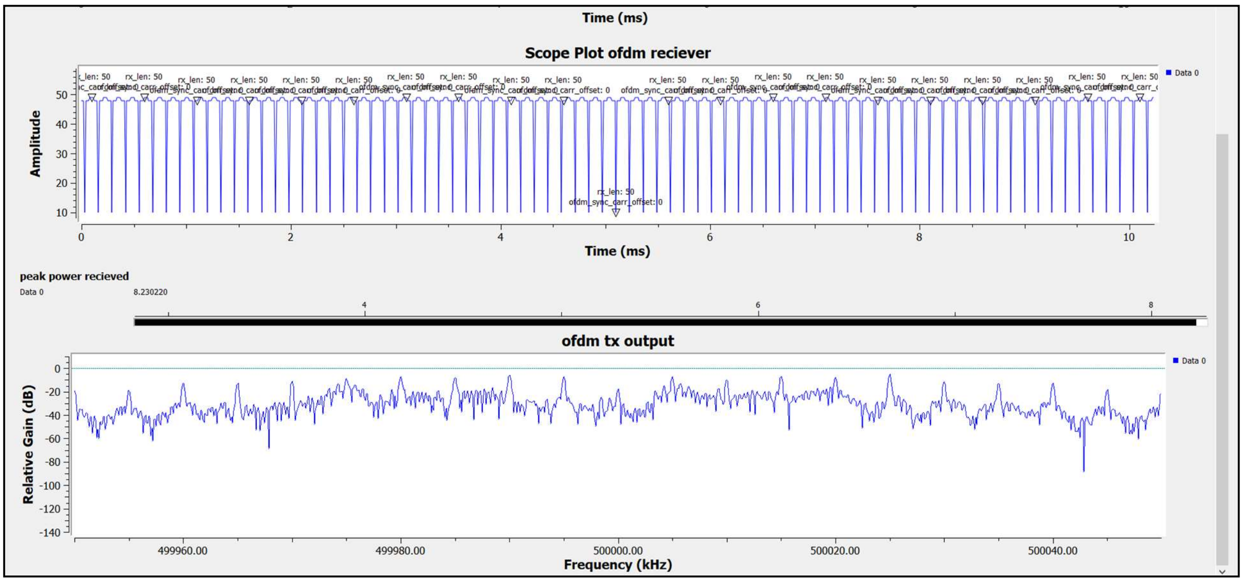

FIGURE 8: PAPR= 8.23 for FFT size= 16

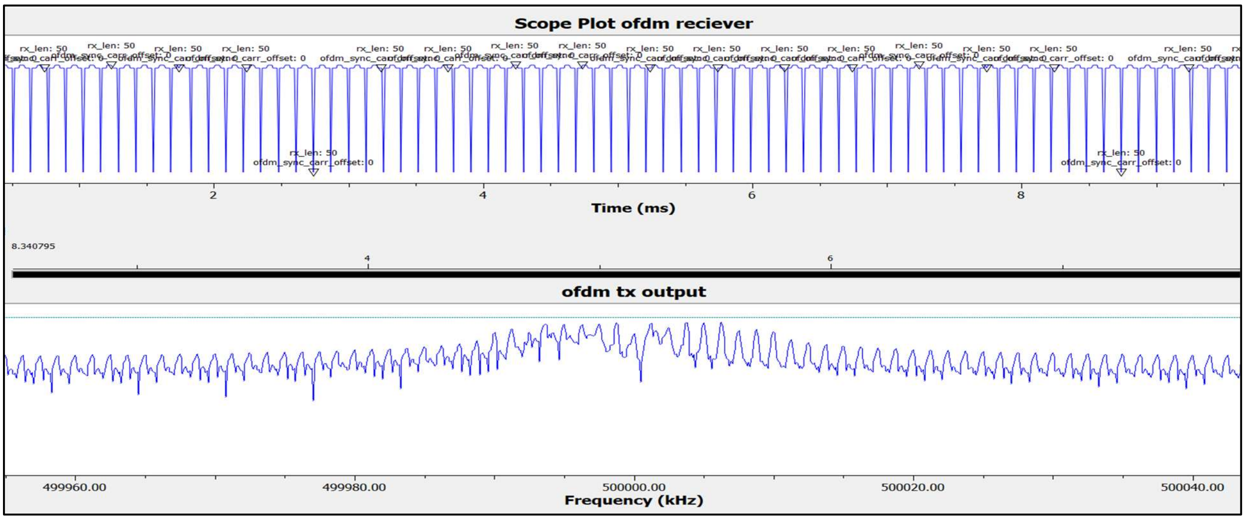

FIGURE 9: PAPR= 8.34 for FFT size= 64

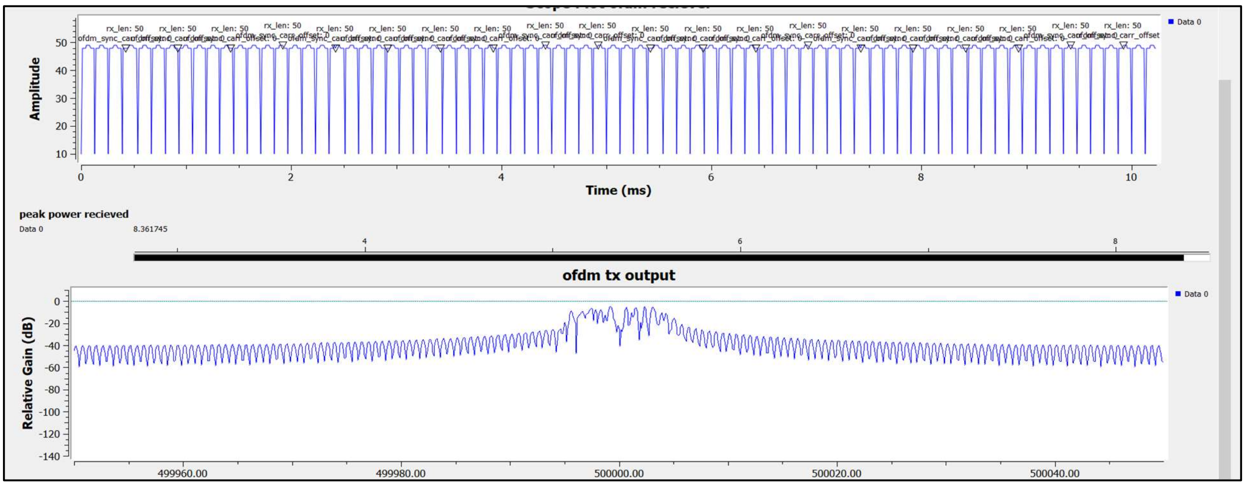

FIGURE 10: PAPR= 8.36 for FFT size= 128

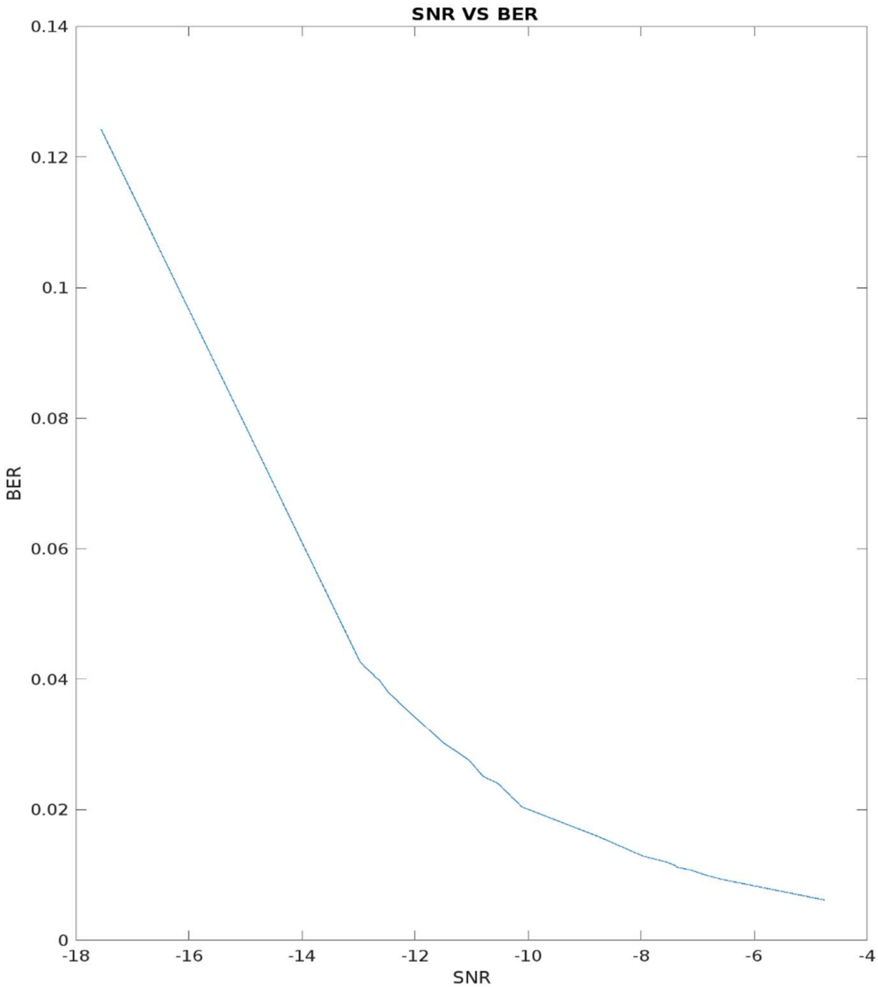

FIGURE 11: FFT size= 64 SNR Vs BER

ii. Frequency selectivity of the channel.

(aa) Gnu Radio simulation for 16 and 64 FFT was done for the frequency selective channel model.

(ab) The no of taps in the frequency selective channel model were changed and the results were observed.

(ac) The results along with the GNU flow graph is as shown under.

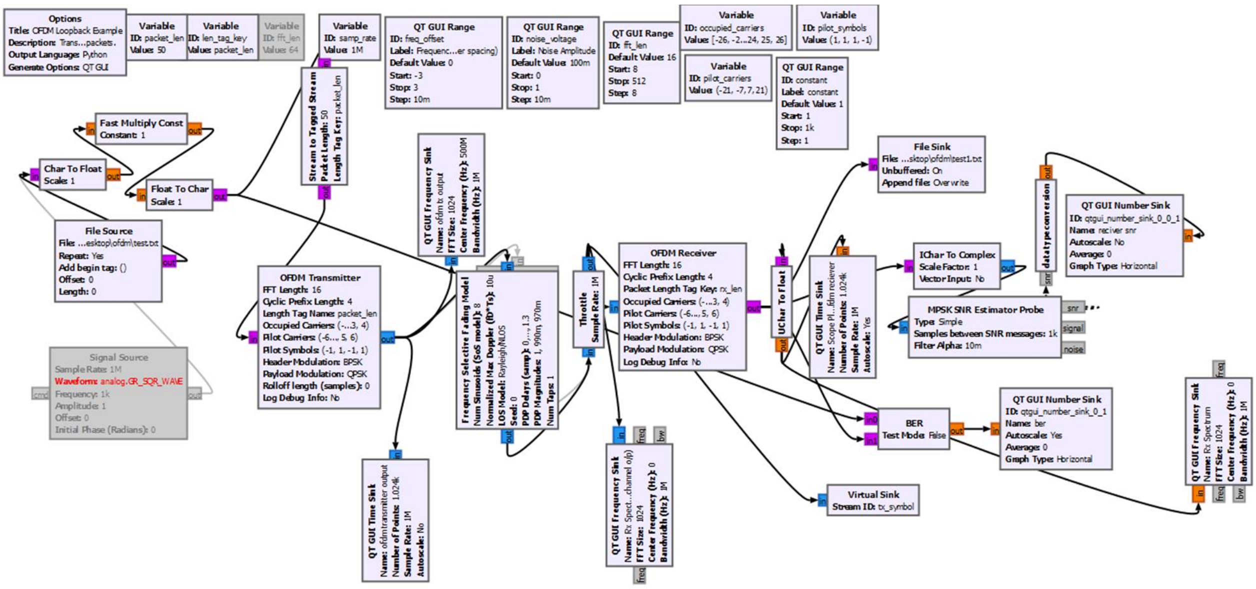

FIGURE 12: FFT size= 16 Frequency Selectivity gnuradio flow graph

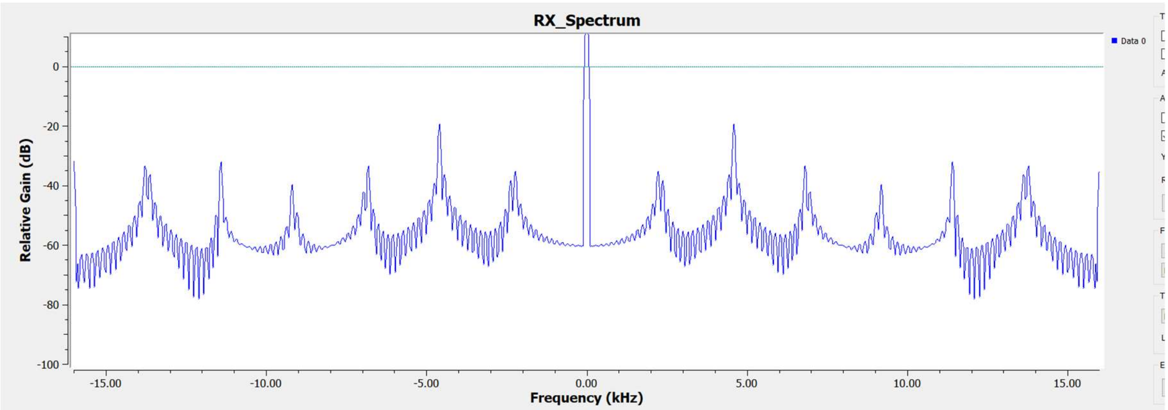

FIGURE 13: FFT size= 16 Channel Taps=1

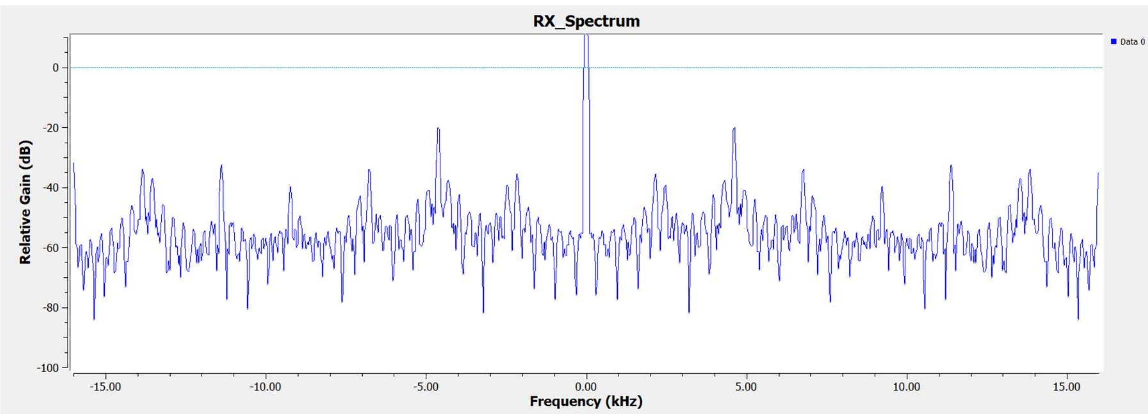

FIGURE 14: FFT size= 16 Channel Taps=4

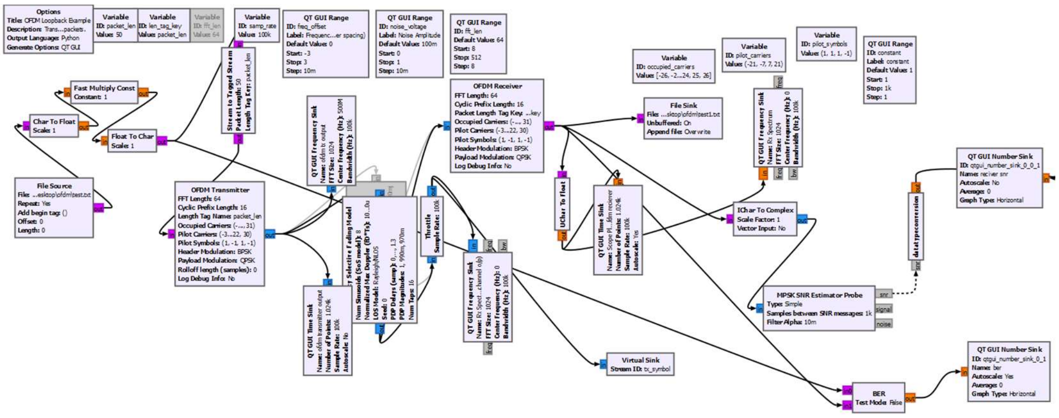

FIGURE 15: FFT size =64 GNU radio frequency selectivity

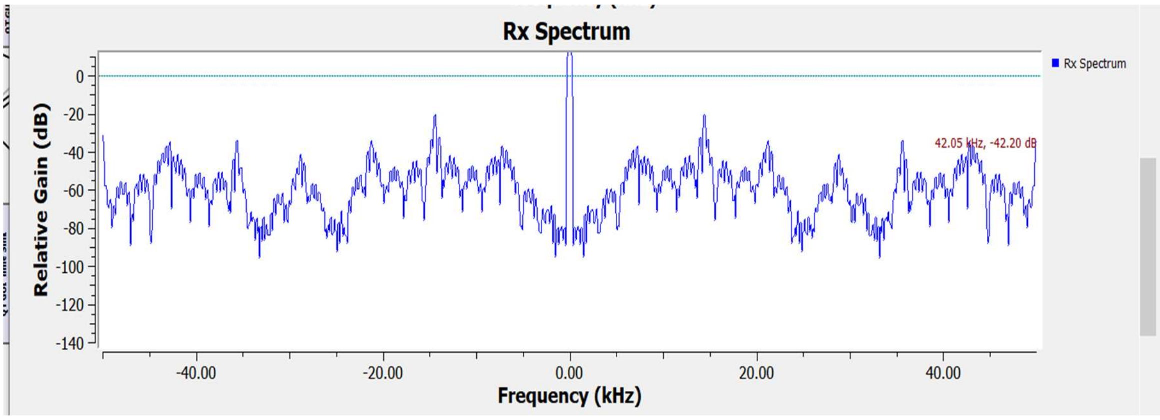

FIGURE 16: FFT size= 64 channel taps =1

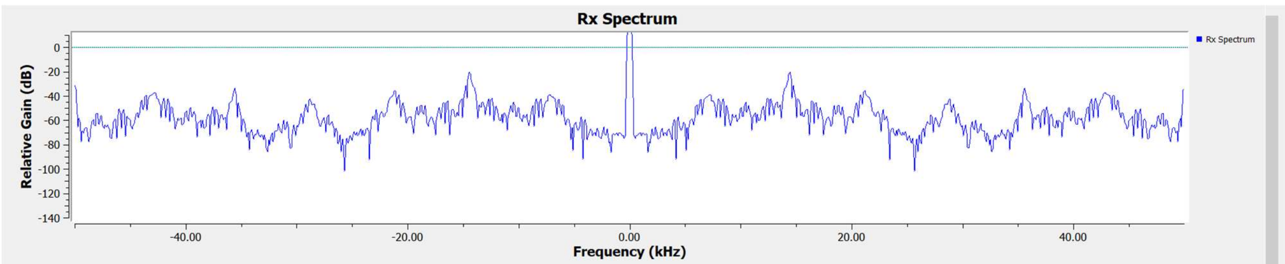

FIGURE 17: FFT size= 64 channel taps =16

(c) Requirement 3: Effect of Cyclic prefix (CP) and Zero Padding (ZP) on ISI:

(i) A guard time, usually in the form of CP or ZP, is inserted between OFDM symbols to eliminate the ISI. Transmission of symbol with cyclic prefix or zero padding reduces the ISI and Bit Error Rate (BER). AWGN channel has only one path between the transmitter and the receiver and only a constant attenuation and noise is considered. Therefore, no multipath effect is considered. The BER performance in an AWGN channel is same regardless of the length of CP and ZP because there is no multipath delay in the AWGN channel.

(ii) Rayleigh fading channel has multipath between transmitter and receiver. Multipath distortion can also cause inter-symbol interference (ISI) where adjacent symbols overlap with each other. This is prevented in OFDM by the insertion of a cyclic prefix or zero padding between successive OFDM symbols. As cyclic prefix duration increases the ISI decreases for Rayleigh fading channel. The effect of ISI on the BER performance becomes significant in the multipath Rayleigh fading channel as the length of CP & ZP decreases, which eventually leads to an error.

(iii) The main idea of using Cyclic prefix in OFDM systems is because of 2 reasons:

(aa) To eliminate ISI from previous symbol.

(ab) To model linear convolution as circular convolution.

(iii) If an OFDM symbol is Zero padded instead of cyclic prefix, ISI due to adjacent symbol still gets eliminated, but it cannot be modeled using circular convolution. Circular convolution converts frequency selective multipath channel into flat fading channel. Circular convolution simplifies channel estimation and equalization which can be done easily in Frequency domain.

(v) ZP guarantees the recovery of the symbol but ZP needs more power as compared to CP because of the introduction of certain non-linearity distortion.

Cyclic Prefix Observation

For FFT size = 16

Cyclic Prefix Size	No. of Taps in Channel	BER
4	5	0.99
4	4	0
2	3	0.5
2	2	0

For FFT size = 32

Cyclic Prefix Size	No. of Taps in Channel	BER
8	10	0.65
8	8	0
6	8	0.45

6	5	0

As the number of taps increases in the channel, ISI increases for the same FFT and Cyclic Prefix size but in increasing FFT size, ISI decrease.

6. CONCLUSIONS.

(a) OFDM transmitter and Receiver modules were successfully implemented using both GNU Radio and SDRs.

(b) FFT size was varied, and it was observed that the PAPR increases as we increase the FFT size . We observed peak-to-average ratio (PAPR) with different FFT; as the FFT size increasing the FFT size, the PAPR value increases, but it never crosses the FFT size The same could be simulated using GNU radio.

(c) Moreover, as we increase the FFT size, the frequency selectivity of the channel decreases.

(d) Cyclic Prefix and zero padding both can be used for reducing ISI, however cyclic prefix transforms linear convolution to circular convolution which makes the channel flat fading.

(e)As the number of taps increases in the channel, ISI increases for the same FFT and Cyclic Prefix size but in increasing FFT size, ISI decrease.

7. References.

1. Andrea Goldsmith, “Wireless communications”.
2. https://www.wikipedia.org
3. https://nptel.ac.in/courses/117104118, Principles Of Signal Estimation For MIMO/ OFDM Wireless Communication by Prof. Aditya K.Jagannatham

Python code for PAPR calculation

```
import statistics as stat

import numpy as np

from gnuradio import gr

class blk(gr.sync_block):  # other base classes are basic_block, decim_block, interp_block

    """Embedded Python Block example - a simple multiply const"""


    def __init__(self):  # only default arguments here

        """arguments to this function show up as parameters in GRC"""

        gr.sync_block.__init__(

            self,

            name='PAPR calculator',   # will show up in GRC

            in_sig=[np.float32],

            out_sig=[np.float32]

        )

        # if an attribute with the same name as a parameter is found,

        # a callback is registered (properties work, too).

        self.num=0

        self.den = 0

        self.papr = 0


    def work(self, input_items, output_items):

        """example: multiply with constant"""

        self.den=stat.mean(input_items[0])

        self.num=max(input_items[0])

        self.papr=self.num/self.den
```

output_items[0][:]=self.papr

return len(output_items[0])

Matlab code to find BER

```
tx1 = fopen("txexp2.txt",'rb');
rx1 = fopen("rxexp2.txt",'rb');
tx = fread(tx1,Inf,"char");
rx = fread(rx1,Inf,"char");
tx2=tx(1:size(rx));
ber = sum(tx2(:)~= rx(:))/numel(tx2(:));
```

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