# EE 451 – Communication Systems II

## The Performance of OFDM in DVB-T Systems

# Final Project Report

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**Objective: The main aim of this project is to generate an Orthogonal Frequency Division Multiplexing (OFDM) system and to perform performance analysis for DVB-T parameters.**


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# 1. INTRODUCTION

Orthogonal Frequency-Division Multiplexing (OFDM) is a digital multi-carrier modulation method which has become popular modulation technique for wireless communication systems. It is used in various wireless and telecommunication standards such as Wi-Fi 802.11ac, 4G and 5G cellular phone technologies, TV broadcasting, satellite and many others. OFDM is ideal for high data transmission and combating multipath fading in wireless communication. [1]

DVB-T (Digital Video Broadcast- Terrestrial) is an application of OFDM which is used in digital television broadcasting. In DVB-T, various modulation schemes such as QPSK, 16QAM, 64QAM can be used and it has two modes called 2k and 8k for the number of carriers [2]. By using numbers of carriers which are regularly spaced, data is transmitted. Each subcarrier is orthogonal to the other subcarriers which prevents interference and provides utilization of bandwidth efficiently. Since the subcarriers are orthogonal to each other, when each carrier is sent, other subcarriers are zero so that transmitted subcarrier can be seen in the output. Furthermore, each carrier transmitted small amount of the data which end up with low bit rate per carrier [3].

Other important advantages of OFDM are efficient use of available spectrum due to its closed-spaced overlapping subcarriers, it is more resistant to frequency selective fading because of dividing channel into multiple narrowband signals. However, having a high peak to average power ratio is an important drawback of the OFDM system. [4]

# 2. SYSTEM MODEL AND DESIGN

In this project, DVB-T parameters are used in OFDM implementation. For practical implementation, all parameters are given in Table 1 for different modes [5].

| Parameter | 2k Mode | 8k Mode |
|---|---|---|
| Modulation Schemes | 4, 8, 16QAM | 4, 8, 16QAM |
| Elementary period T | 7/64 µs | 7/64 µs |
| Number of carriers K | 1705 | 6817 |
| Duration $T_U$ | 224 µs | 896 µs |
| Carrier spacing $1/T_U$ | 4,464 Hz | 1,116 Hz |
| Spacing between carriers | 7.61 MHz | 7.61 MHz |
| Guard interval | 1/32, 1/16, 1/8, 1/4 | 1/32, 1/16, 1/8, 1/4 |
| Duration of guard interval | 56 µs, 28 µs, 14 µs, 7 µs | 224 µs, 112 µs, 56 µs, 28 µs |
| Symbol duration | 280 µs, 252 µs, 238 µs, 231 µs | 1120 µs, 1008 µs, 952 µs, 924 µs |

**TABLE 1: DVB-T Parameters for OFDM Implementation.**

## 1.1.Transmitter

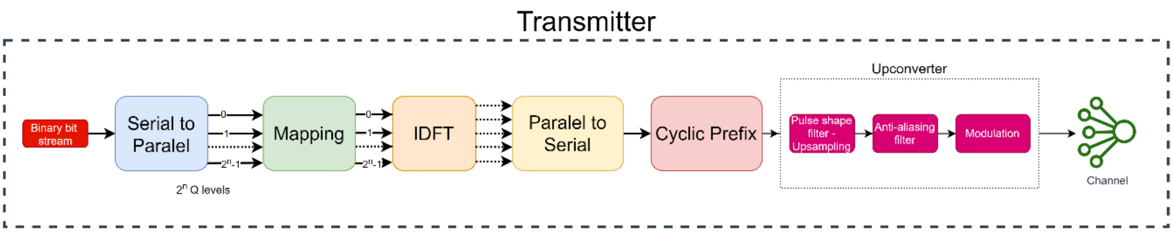


**Figure 1: Block Diagram of the Transmitter**

In the transmitter side, the implementations performed are in as the block diagram shown in Figure 1.

**Data:** The input of the system was determined as a uniform random bit stream.

**Serial to Parallel Converter:** During transmission, number of bits to be used are determined due to the chosen modulation scheme. The number of bits is log2 N for N constellation points. The data is paralleled according to number of bits and converted to decimal.

**Mapping:** The parallelized data is passed through M-ARRAY QAM modulation. Besides, in order to reconstruct the input pass through the Fourier transform, the size of the data has been adjusted to the size of the frequency sampling by applying zero padding.

**Inverse Discrete Fourier Transform (IDFT):** The main advantages of OFDM is using the spectrum efficiently. This is ensured by overlapping subcarriers with each other provided they are orthogonal. As shown in Figure 2, subcarriers at different frequencies are generated by multiplying each one with a different sinusoidal oscillator.

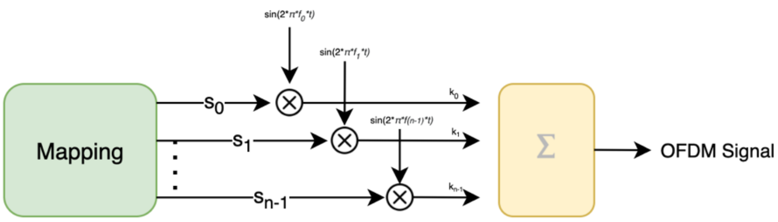


**Figure 2: Generating Orthogonal Subcarriers to Each Other**

The general expression of this step is given in Equation 1.

$$x(t) = \sum_{n=0}^{N-1} X_k e^{j\frac{2\pi k}{T}t}$$

Analog electronics implementation in above can be expressed as digital computation by using Inverse Discrete Fourier Transform [7]. All sinusoidal converters are eliminated with this method. The output of the IDFT gives parallel data in the time domain. In this project scope, the sampling frequency is selected as 2*N (N=2048 for 2k mode) to centre the OFDM spectrum [6].

**Parallel to Serial Converter:** In order to obtain a serial output as passed through the summation process in Figure 2, the outputs of the IDFT are serialized.

**Cyclic Prefix:** Cyclic Prefix is used to prevent intersymbol interference (ISI) caused by the previous symbol. The added guard interval minimizes the channel delay by prefixing a symbol with a repetition of the end. Therefore, the linear convolution of a frequency-selective multipath channel can be modelled as circular convolution [7]. The size of the cyclic prefix is obtained by taking a specified ratio of the length of the input.

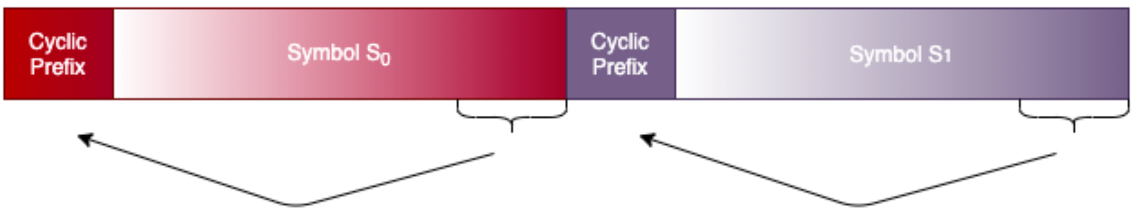


**Figure 3: Cyclic Prefix**

**Upconverter:** In communication, real signals can be sent through devices. However, signal processing is performed in the baseband and these signals are complex. Therefore, up conversion is applied to get a real-valued signal in the passband.

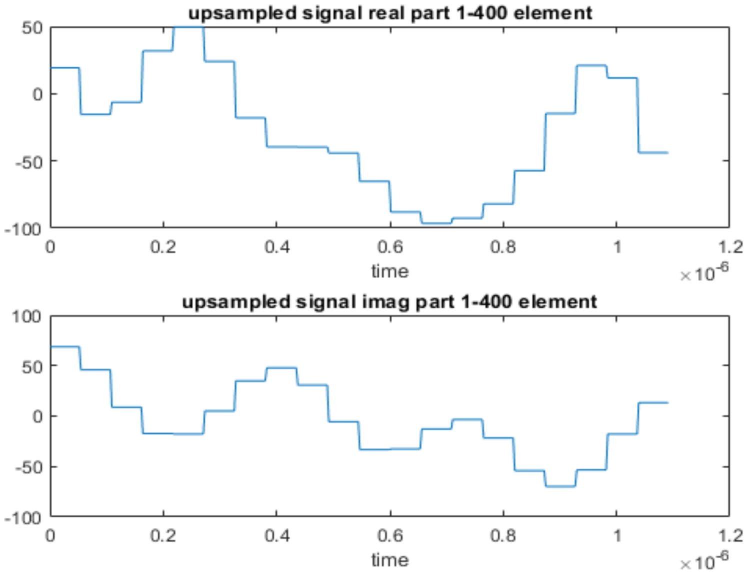


**Figure 4: Up sampled Signal with Window Filter**

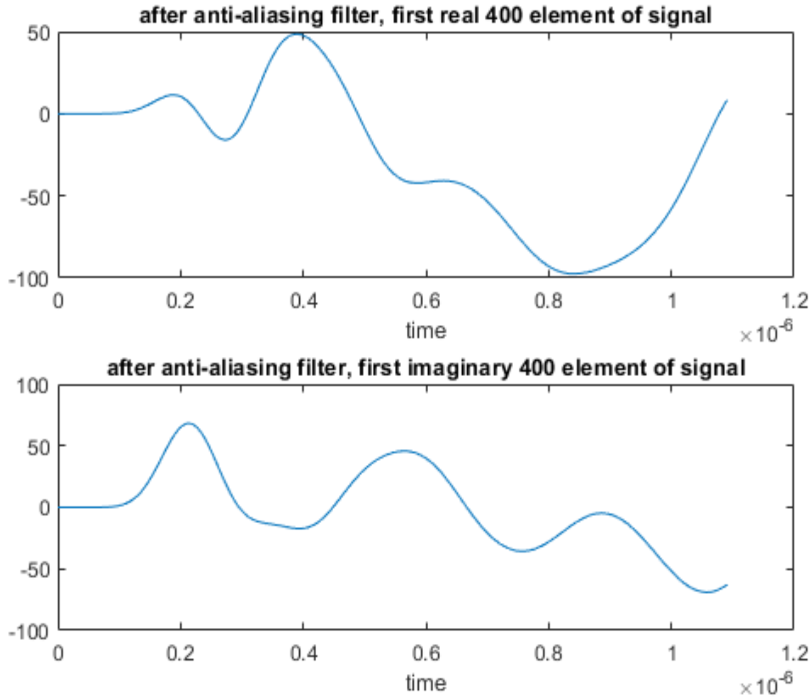


**Figure 5: After Anti-Aliasing Low-Pass Filter**

Firstly, a pulse shape filter is applied to the signal. These filter types are window, raised cosine, and Gaussian as given in Figure 6. In this step, up sampling is applied. After, the low pass filter is used to eliminate the anti-aliasing part of the signal. In the last step in the upconverter, the signal was transferred from the baseband to the passband by multiplying the filtered output with e(I*2*pi*fc*t). Thus, the real values of the generated signal are transmitted as given in Figure 7.

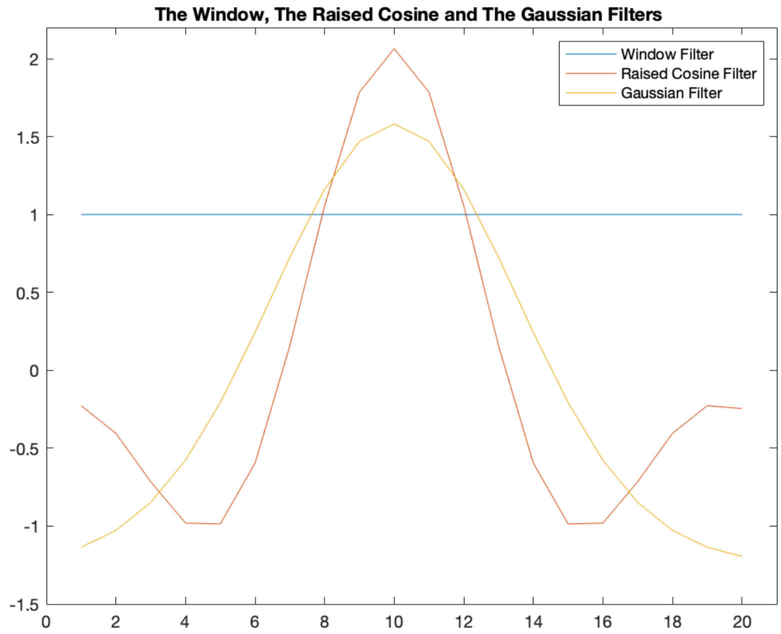


**Figure 6: The Used Filter Types**

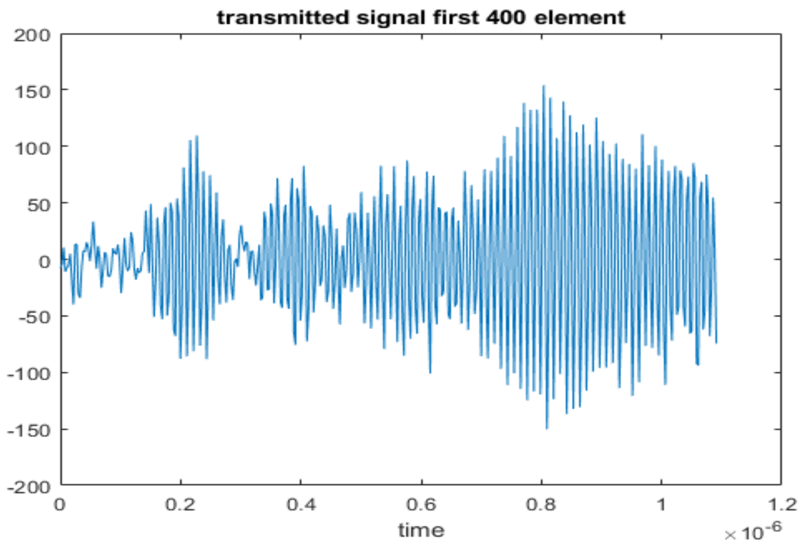


**Figure 7: Transmitted Signal**

## 1.2. Receiver

On the receiver side, the implementations performed are in as the block diagram shown in Figure 8.

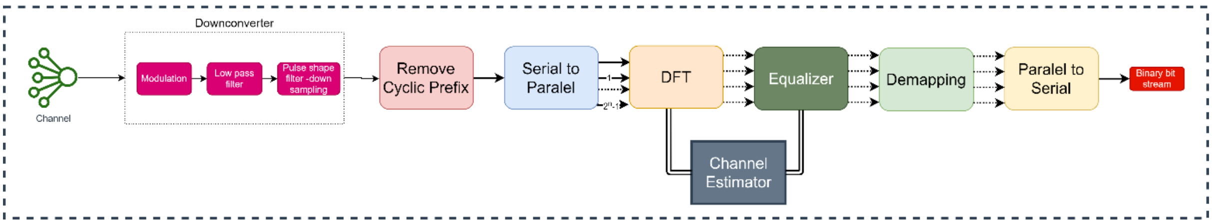


**Figure 8: Block Diagram of the Receiver**

**Downconverter:** In order to convert the received high-frequency signal to the low frequency as in the original, the signal is needed to down convert [8]. Firstly, the received signal that is around the carrier frequency is multiplied by e(-1*I*2*pi*fc*t) to shift the signal to baseband. Due to the frequency shifting property of the Fourier Transform, there will be 2 types of frequency components; one of them is centered at the sum of the frequencies of the two multiplied elements, the other is centered at the difference of the frequencies of the two multiplied elements . For the baseband representation of the original signal, a low pass filter designed to get the difference component as given in Figure 9.

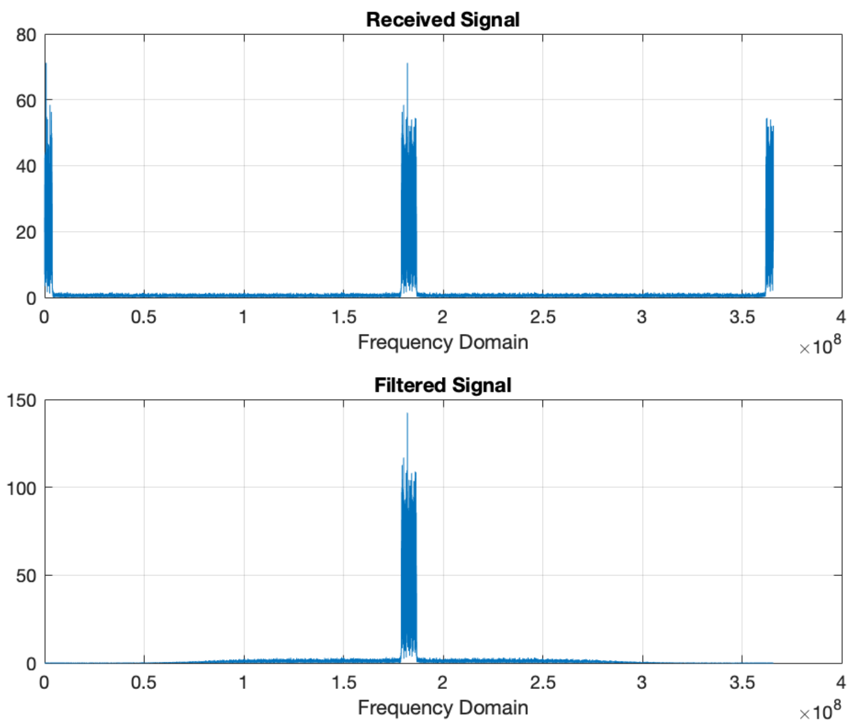


**Figure 9: Effect of the Low Pass Filter**

Then, the response of the pulse shape filter applied in the transmitter is applied to the signal obtained. After, the filtered signal is down sampled to provide the rate of the original signal. The down sample rate is equal to the up sample rate on the transmitter side. The real part of the first 20 elements of down-converted signal can be seen in Figure 10.

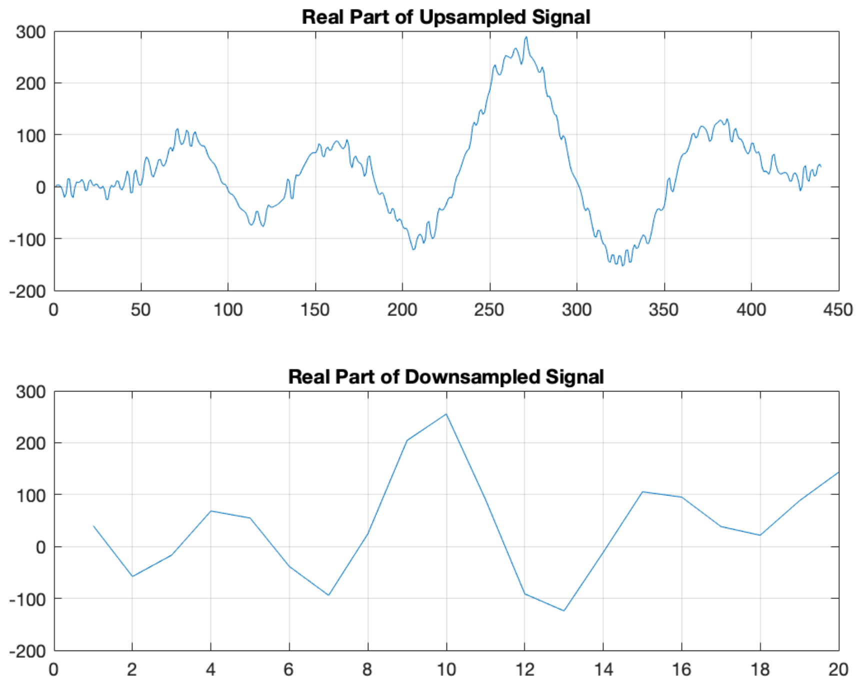


**Figure 10: Down sampled Signal**

**Remove Cyclic Prefix:** The added cyclic prefix to avoid intersymbol interference is removed at this step to get the original subcarriers.

**Serial to Parallel:** Serial subcarriers are converted into parallel.

**Discrete Fourier Transform (DFT):** N-point Discrete Fourier Transform is taken to obtain transmitted symbols. Applied zero padding in the signal to be processed in the time domain is removed at this stage.

**Channel Estimator:** An estimation of the channel characteristic is necessary to eliminate the effect of the channel. Pilot subcarriers at a certain position are used to estimate the behavior of the channel [9]. The change of these pilot subcarriers whose positions are known by the receiver and passing through the channel enables the channel characteristic to be determined.

**Equalizer:** In this step, the effect of the channel is removed by using the information got from the channel estimator.

**Demapping:** Quadrature Amplitude Modulation (QAM) signal is demodulated according to the order of M. Also, the resulting decimal signal is converted to binary.

**Parallel to Serial:** The binary signal obtained in parallel is converted into series.

**Binary Bit Stream:** It is expected that the binary bitstream obtained from the operations applied in the receiver will ideally be the same as that sent on the transmitter. In an environment where there is no channel, they are the same as shown in Figure 11.

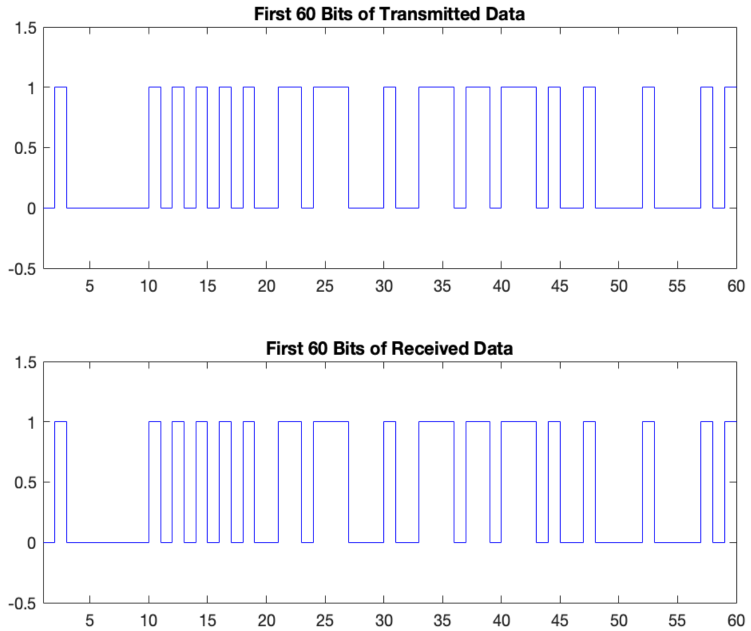


**Figure 11: Transmitted and received data without a channel**

## 1.3. Channel

Experiments were done on fading channel samples. Since OFDM is a wideband modulation technique, it must be simulated in fading and Additive White Gaussian Noise (AWGN) channels instead of flat channels. The simulations have been made in two different channels to be real and complex shown in Figure 12. An estimation of the channel characteristic is necessary to eliminate the effect of the frequency selective channel.

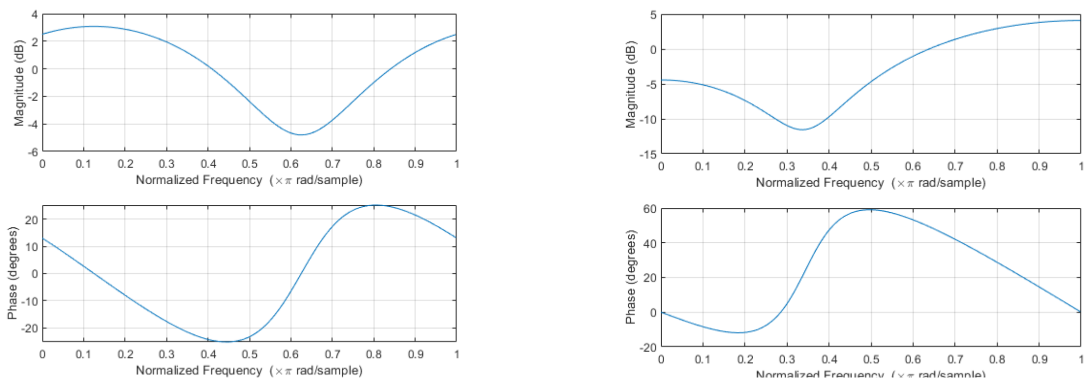


**Figure 12: Frequency Response of fading channels. Left hand side plot is frequency response of real fading channel, Right hand side plot is complex channel frequency response**

The method for the estimation is to insert reference subcarriers into the subcarriers. These pilot subcarriers at a certain position are known by the receiver side. The comparison between these carriers to which the channel effect is added and their original value expresses the characteristic of the channel. This dynamically obtained information about the channel is used to eliminate the effect of the channel. Changes in constellation points on the receiver side after channel estimation are as shown in Figure 13.

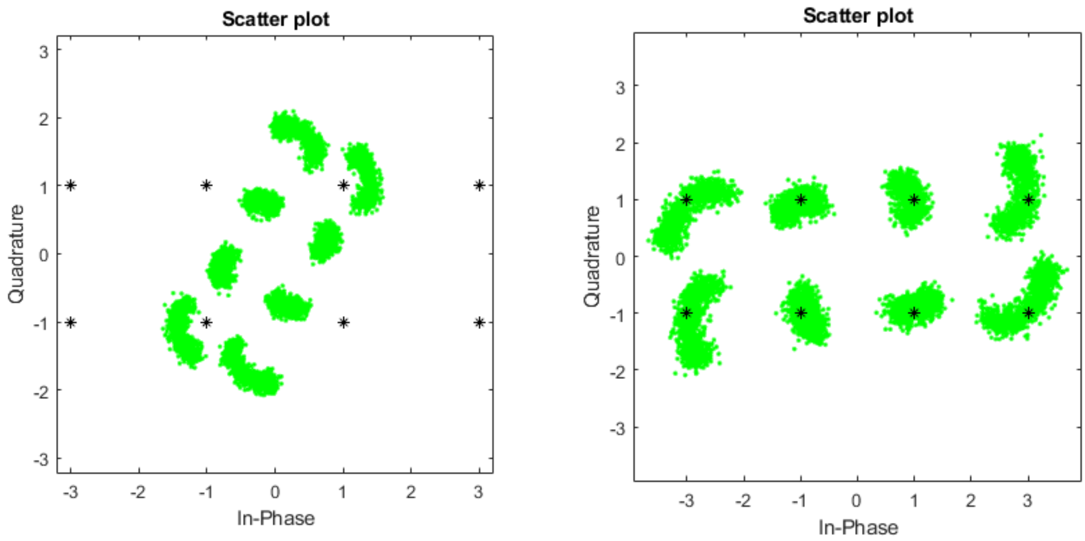


**Figure 13: Least square channel estimation with pilot carriers**

# 3. NUMERICAL RESULTS

This section includes the performance analysis of the designed OFDM system. While calculating the results, various experiment sets were created. Respectively, shaping filter comparison, M array QAM 2-4-8-16 level comparison and 2k mode 8k FFT sampling mode comparison were made. The experiments aimed to evaluate OFDM performance using DVB-t parameters.

Bit error rate and Symbol error rate were calculated as the metrics used in the results. Markov chains were calculated by running the experiments 1000 times in random stats for SER and BER values. AWGN was used during the experiments. SNR values were changed from 0 to 20 dB by increasing 2 dB.

In the first experiment, Window filter, raised cosine and Gaussian filter were used in 4QAM 2k mode and no guard interval. The purpose of this experiment is to observe the effect of 3 different shaping filters on the error probability. Figure 14 shows the characteristics of all 3 filters against the noise generated in the channel. Points not in the figure represent 0 errors in 1000 samples. It is possible to obtain approximate values of these points by increasing the size of the Markov Chain. As seen in the figure, the windows filter gives the best error probability value.  In the next set of experiments, window filter is preferred as shaping filter in order to have minimum contribution of shaping filter while calculating error probability.

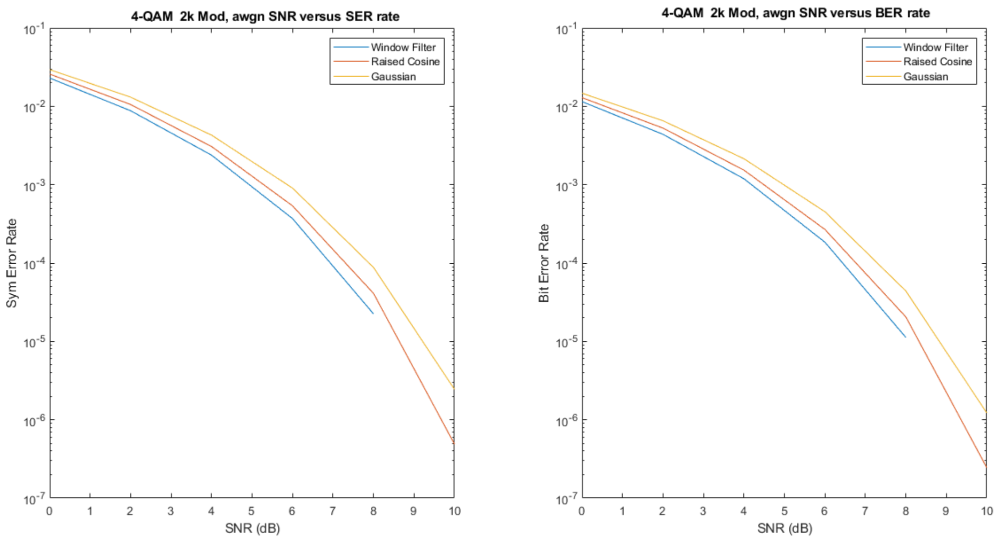


**Figure 14: SER and BER error of each shaping filter.**

In the second experiment, the differences of M values were compared. The parameters used during this experiment are no guard interval, 2k FFT mode and windows shaping filter. Figure 15 shows the results for this experiment. As expected, as the M level increases, the error rate increases, but the number of bits transmitted increases. These two parameters constitute a bit rate- error trade-off.

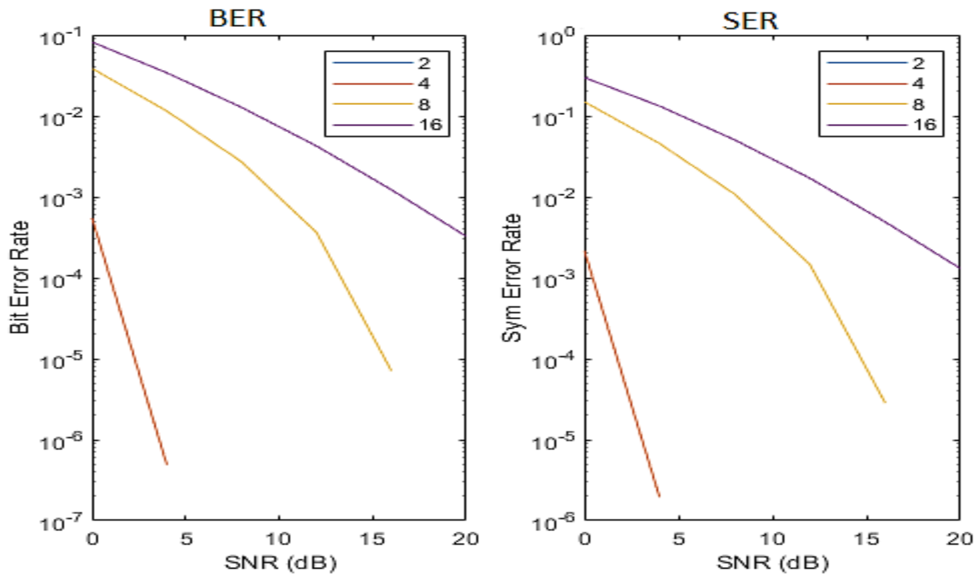


**Figure 16:BER and SER scores of different M levels. The curves that are not shown in the zero error.**

As a third experiment, 2k and 8k FFT mode will be compared. Although FFT size and symbol duration change in 2k and 8k mode, elementary period and total bandwidth do not change. In this way, more subcarriers can be sent using the same bandwidth and therefore the resulting bit rate is higher than in 2k mode. The results of the test show that 8k mode has lower BER and SER scores (Figure 16).

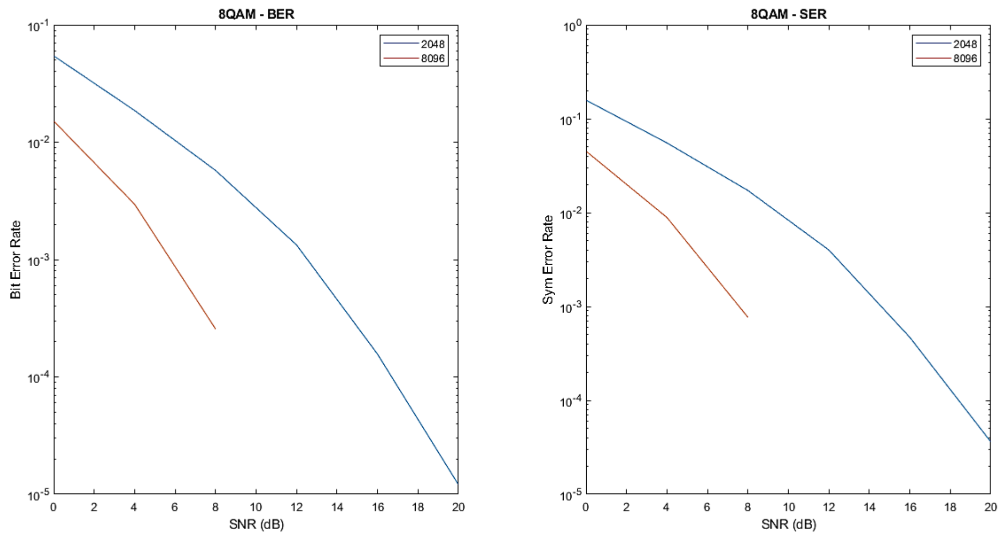


**Figure 15: BER and SER scores of FFT size comparison of DVB-t**

In the next experiment, the effects of two complex and real channels determined as arbitrary on BER and SER scores were examined. For the sake of simplicity, 2-tap fading channels are preferred. Channel estimation has been made to eliminate the effect of these channels. As seen in Figure 17, there are BER and SER scores depending on the characteristics of each channel. It is possible to see different results in channels with different characteristics. In the channel estimation part of experiment, it is possible to make better estimations by using adaptive equalizing or high number of pilot subcarriers in order to eliminate the effect of adaptive channels in real life conditions.

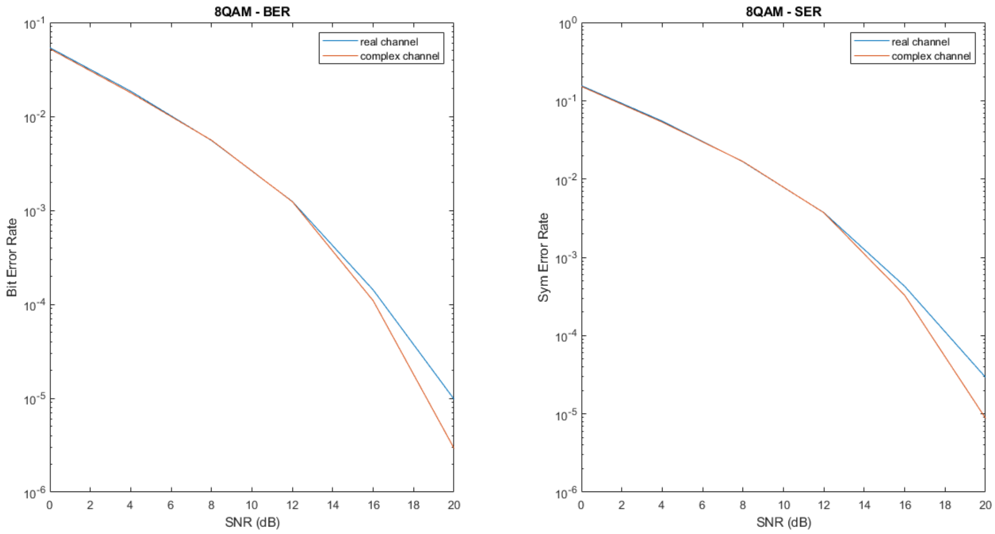


**Figure 18: BER and SER scores of real and complex channels.**

As the last experiment, the effect of cyclic prefix on error scores was investigated. These cyclic prefixes are taken as 0, 1/4, 1/8, 1/16 and 1/32 times the incoming signal. Based on the figure 18, it has been observed that using the cyclic prefix decreases the error probability scores. The best ratio is 1/32 in the figure. In this case, it can be said that convolution of Cyclic prefix added signal (i.e., cyclic convolution) is more effective than ordinary convolution.

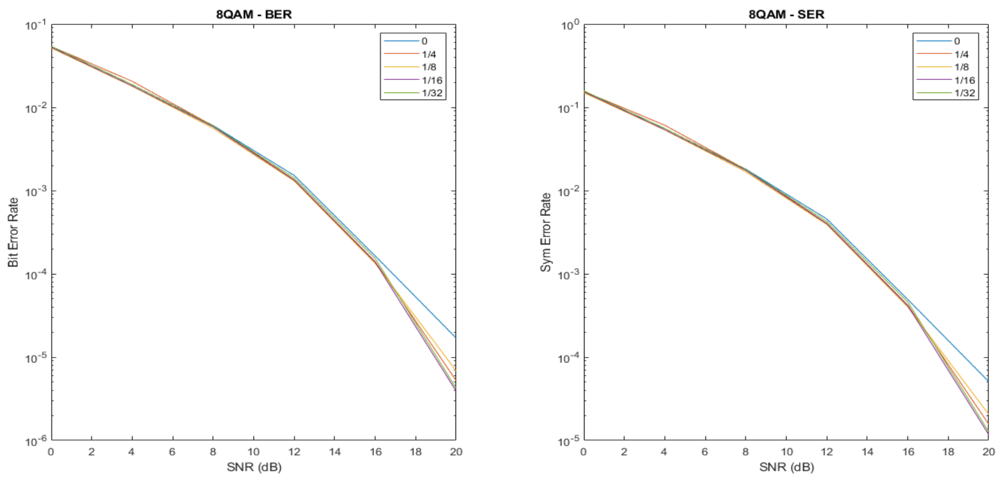


**Figure 17: SER and BER scores of different cyclic prefix rates**

# 4. CONCLUSION

In this paper, OFDM (Orthogonal frequency-division multiplexing) is proposed by using DVB-T (Digital Video Broadcast- Terrestrial) parameters. This work includes 2, 4, 8, and 16QAM modulation schemes and 2k and 8k mode parameters, cyclic prefix and channel response, performance analysis and simulations. Also, 3 different shaping filters are used which are window filter, raised cosine and gaussian filter. Random bit stream is employed as input of the system. Simulations are made in fading and Additive White Gaussian Noise (AWGN) channels and for both real and complex components.

As a result, transmitting signals combined closely and orthogonal to each other which results in signals acting independently and with no interference. It provides utilizing the bandwidth very efficiently and reliable data transport over different signal path conditions.

In future studies, the BER SER values can be examined by passing the signals through the Rayleigh and Rician channels. Channel estimation can be performed in variable channel scenarios in order to make simulations in real life conditions. In addition to the error rate, parameters such as quality can be examined by focusing on the bit rate. Performance scores of OFDM derivative modulation techniques such as OFDM in OFDMA can be compared. Modern techniques developed for digital video broadcasting can be examined.

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