**DETAIL ANALYSIS OF OFDM SYSTEMS**

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**ABSTRACT*:* The project aims to give a detailed analysis of the Orthogonal Frequency Division Multiplexing System. OFDM systems uses an advanced multiple carriers concept to modulate the information from the source to the destination. OFDM is a 4th Generation technology developed and it enables a faster transfer of data and secure encryption of the data. The project simulates a developed code in MATLAB to demonstrate various features of the OFDM system and thereby concluding the advantages of the system. It also discusses the integration of the OFDM-MIMO systems and simulates a simple code for the particular system.**

**Keywords: OFDM, Orthogonality, 4G Subcarriers, MIMO, MATLAB.**

1. Introduction

Due to the tremendous development of communications over the past 3 decades, there is always a certain shift in technology perspective whenever a new decade starts. Various generations of technology starting from analog switching have since been replaced by digital switching techniques. Likewise, many technological changes have occurred whenever a different generation comes into picture.

The 1st generation (1G) technology used the basic analog switching techniques and used Frequency Division Multiple Access Scheme (FDMA) as slotting technique. Though it was fruitful for the foundation, various problems emerged like it could not support enough users. Then the 2nd Generation (2G) technology used Time Division Multiple Access (TDMA) slotting technique and used digital switching techniques. But, it also suffered from various shortcomings like it can be easily jammed and band was not efficiently utilized. The 3rd Generation (3G) technology gave more importance to the data traffic apart from voice traffic and introduced the concept of mobility for the user. It used Code Division Multiple Access (CDMA) which used the same band to support large number of users. The 4th Generation (4g) technology used Orthogonal Frequency Division Multiplexing (OFDM) technique and introduced the concept of global mobility. OFDM along with Long Term Evolution (LTE) provided a pivotal shift from voice-centric traffic to data-centric traffic. The upcoming 5th Generation (5G) technology will use internet of things and big-data concept and support data for a large number of users.

Earlier technologies used single carrier baseband system. When Frequency division Multiplexing (FDM) scheme came into picture, using of multi-carriers to transmit information started. But, all of the technologies suffered from two different problems: Inter-Carrier Interference (ICI) and Inter-Symbol Interference (ISI).

OFDM uses the concept of digital multi-carrier modulation scheme to solve ICI as well as ISI.it employs large number of low data rate multi-carriers to invariably develop a high data rate communication system. Due to the low-data rate carriers, it will have large symbol periods, which will eliminate the problem of ISI. All the carriers are orthogonal to each other which will diminish the ICI.

1. OFDM Basics and Background

OFDM is a digital communication technique, which primarily rests on the fact that all the information are represented as bits. The data are generated by taking symbols from the spectrum using various modulation schemes like DPSK, BPSK, QAM, MSK, QPSK, and converting the data into time-domain through Inverse Fourier Transform (IFFT) or Inverse Discrete Fourier Transform (IDFT). The reason of using IFFT over IDFT is the fast computation are possible in IFFT and secondly, it is very cost effective method.

Now, after the FFT algorithm is implemented, the signal is encoded as a parallel sideband multiple carriers so that it occupies the complete frequency band for the efficient use of band and high spectral efficiency. During the modulation of the signals, the signals is interpreted as frames and all the symbols are divided into frames. The reason is each data being encoded as frame will help synchronizing with the receiver. Now, here comes a problem of ISI, to nearly eliminate that problem, use of cyclic prefix is preferred. The cyclic prefix concept is a signal extension is added to each symbol. An exact copy form the rear is added to the front end of the symbol which ranges optimally around 25%. This will allow the demodulator to buffer within the period so that it will

get the signal correctly even if the signal’s uncertainty might come into picture.

1. Concept of Orthogonality

The main concept of the whole system is based on maintaining the orthogonality of the system. If the integration of product of the two signals over a period of time is comes out to be zero, then the signals are said to be orthogonal. The sub-carrier frequencies are chosen such that the sub-carriers are orthogonal to each other. This means that cross-talk between the corresponding sub-carriers are eliminated meaning no guard bands are required. This will generally simplify the design as no additional hardware like sub-channel filters for each sub-channel will not be required.

The orthogonality condition will be satisfied through a variety of conditions. One condition is the sub-carrier spacing will be given by

Where δf= sub-carrier spacing

K= any positive integer

T=receiver window size.

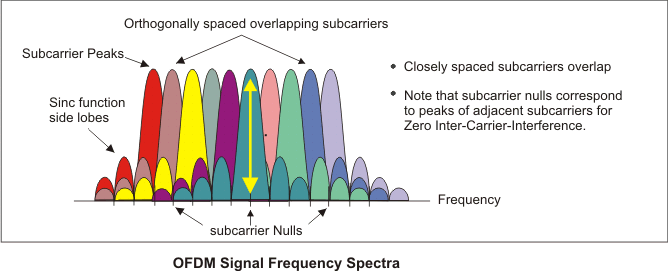
Orthogonality provides the OFDM with a spectral efficiency. The complete frequency band can be utilized given the frequency rate will be near the Nyquist Rate and OFDM spectrum also has minimum electromagnetic interference. 

Fig.2- OFDM SIGNAL SPECTRUM

1. OFDM Transmission

The Core of the transmitter of OFDM is the modulator and the FFT generation of the signals. The orthogonality allows for efficient and effective modulator and demodulator with the FFT and Inverse FFT technique on the receiver and sender side respectively. Although the theoretical and beneficial aspects of OFDM were known since the 1970s, OFDM is popular for wideband communications today by way of low-cost digital signal processing components that can efficiently calculate the FFT. The time to compute the inverse-FFT or FFT transform has to take less than the time for each symbol.

There might be a case when number of transmitting bits might be less than the number of sub-carriers. So, to convert from serial to parallel, the modulator pads zeros to the end of data to fit with the number of sub-carriers.



Fig.3.- OFDM Transmitter Simulation

The first task to consider is that the OFDM spectrum is centered on f c; i.e., subcarrier 1 is 7.61 2 MHz to the left of the carrier and subcarrier 1,705 is 7.61 2 MHz to the right. One simple way to achieve the centering is to use a 2N-IFFT [2] and T/2 as the elementary period. As we can see in Table 1, the OFDM symbol duration, TU, is specified considering a 2,048-IFFT (N=2,048); therefore, we shall use a 5 4,096-IFFT. The next task to consider is the appropriate simulation period. T is defined as the elementary period for a baseband signal, but since we are simulating a passband signal, we have to relate it to a time-period, 1/Rs, that considers at least twice the carrier frequency.



Fig.4. Time Response of Signal Carriers.



Fig.5- Frequency Response of Carrier Signals

In Figure 2 and Figure 3, we can observe the result of this operation and that the signal carriers uses T/2 as its time period. We can also notice that carriers is the discrete time baseband signal. We could use this signal in baseband discrete-time domain simulations, but we must recall that the main OFDM drawbacks occur in the continuous time domain; therefore, we must provide a simulation tool for the latter. The first step to produce a continuous-time signal is to apply a transmit filter, g(t), to the complex signal carriers



Fig.6. Time Response of the Output Signal

The output of this transmit filter is shown in Figure 4 in the time-domain and in Figure 5 in the frequency-domain. The frequency response of Figure 5 is periodic as required of the frequency response of a discrete-time system. The proposed reconstruction is through Digital to Analog Filter. It is a Butterworth filter of order 13 and cut-off frequency of approximately 1/T.. The first thing to notice is the delay of approximately 2x10-7 produced by the filtering process. Aside of this delay, the filtering performs as expected since we are left with only the baseband spectrum. We must recall that subcarriers 853 to 1,705 are located at the right of 0 Hz, and subcarriers 1 to 852 are to the left of 4 fc Hz.



Fig.7. Frequency Response of the Output Signal

Finally, the time response using a direct simulation of (2.1.4) is shown in Figure 2.14, and the frequency responses of the direct simulation and 2N-IFFT implementation are shown in Figure 2.15. The direct simulation requires a considerable time (about 10 minutes in a Sun Ultra 5, 333 MHz); therefore, a practical application must use the IFFT/FFT approach.



Fig.8.- Frequency Response of the Direct Simulation.



Fig.9. –Frequency Response of Direct Simulation

1. OFDM Reception

The design of an OFDM receiver is open. So, as the receiver design is open, most of the research is done in this field so that synergy is maintained between the transmission and receiver design. The receiver picks up the signal, which is then quadrature-mixed down to baseband using cosine and sine waves at the carrier frequency. This also creates signals centered on\scriptstyle 2 f_c, so low-pass filters are used to reject these. The baseband signals are then sampled and digitized using analog-to-digital converters (ADCs), and a forward FFT is used to convert back to the frequency domain. This returns \scriptstyle N parallel streams, each of which is converted to a binary stream using an appropriate symbol detector. These streams are then re-combined into a serial stream, which is an estimate of the original binary stream at the transmitter.



Fig.10- OFDM Reception Simulation

OFDM is very sensitive to timing and frequency offsets. Even in this ideal simulation environment, we have to consider the delay produced by the filtering

operation. For our simulation, the delay produced by the reconstruction and demodulation filters is about td=64/Rs. This delay is enough to impede the reception, and it is the cause of the slight differences we can see between the transmitted and received signals. With the delay taken care of, the rest of the reception process is straightforward. 

Fig.11- Time Response of the Received Signal.



Fig.12.-Frequency Response of Received Signal

Fig.13-Frequency Response of the Signal After Fast Fourier Transform (FFT)

Fig.14-Time Domain Response of the Signal of the Information Signal.

1. OFDM Advantages

* Higher spectral efficiency
* Negligent Inter-Symbol Interference (ISI).
* It is very robust when multipath propagation systems comes into picture.
* Immune to co-channel interference.
* Less sensitivity to synchronization effects.
* Effective and efficient implementation due to Fast Fourier Transform (FFT).
* No sub-channel filters are required.

1. OFDM Disadvantages

* It is sensitive to the Doppler shift.
* Due to the presence of cyclic prefix, there will be time consumed for signal decoding and efficiency is lost.
* It has poor power efficiency due to the High Peak-to-Average-Power ratio (PAPR) which requires linear circuits.

1. APPLICATIONS OF OFDM

OFDM is the basis of 4G technology and 5G technologies being developed will be based on OFDM and MIMO, which is explained in the later stages of the paper. Applications of OFDM are as follows:

* The wireless LAN (WLAN) interfaces standards like IEEE 802.11a, e, g.
* Various Digital Radio systems like DAB/EUREKA 147.
* In Terrestrial Digital Systems and terrestrial mobile systems.
* The Ultra-Wideband (UWB) IEEE 802.15.3a
* The Mobile Wi-MAX standard IEEE 802.16e and Mobile Broadband Wireless Access (MBWA).

1. OFDM-MIMO Design and Integration

Multiple Input Multiple Output (MIMO) in OFDM is a popular interface transmission method for 4G and 5G technology.it combines both the MIMO as well as the OFDM technology. MIMO which incorporates the fact of transmitting different signals over the multiple antennas combines with OFDM to provide high-data rates and reliable communication link. MIMO actually in broad sense signifies not only multiple transmission nd receiver antennas, but it also signifies transmitting multiple signals simultaneously to maximize the spectral efficiency.Gregory Raleigh was the first to use MIMO in OFDM technology. He proved his hypothesis in a theoretical paper he published by advocating the use of multiple antennas with multiple carriers. After which, he again published additional research over the design, techniques of synchronization, performance of system under different conditions. Then again, the MIMO technique is experimentally being used in OFDM for the development of 5G technologies.

MIMO-OFDM is the foundation for most advanced wireless local area network network standards because it achieves the greatest spectral efficiency and, therefore, delivers the highest capacity and data throughput. MIMO-OFDM is a particularly powerful combination because MIMO does not attempt to mitigate multipath propagation and OFDM avoids the need for signal equalization. MIMO-OFDM can achieve very high spectral efficiency even when the transmitter does not possess channel state information (CSI). When the transmitter does possess CSI (which can be obtained through the use of training sequences), it is possible to approach the theoretical channel capacity. CSI may be used, for example, to allocate different size signal constellations to the individual subcarriers, making optimal use of the communications channel at any given moment of time.More recent MIMO-OFDM developments include multi-user MIMO (MU-MIMO), higher order MIMO implementations (greater number of spatial streams), and research concerning “massive MIMO” and “Cooperative MIMO” for inclusion in coming 5G standards.MU-MIMO is part of the IEEE 802.11ac standard, the first Wi-Fi standard to offer speeds in the gigabit per second range. MU-MIMO enables an access point (AP) to transmit to up to four client devices simultaneously. This eliminates contention delays, but requires frequent channel measurements to properly direct the signals. Each user may employ up to four of the available eight spatial streams. For example, an AP with eight antennas can talk to two client devices with four antennas, providing four spatial streams to each. Alternatively, the same AP can talk to four client devices with two antennas each, providing two spatial streams to each. Multi-user MIMO beamforming even benefits single spatial stream devices. Prior to MU-MIMO beamforming, an access point communicating with multiple client devices could only transmit to one at a time. With MU-MIMO beamforming, the access point can transmit to up to four single stream devices at the same time on the same channel.

Fig.15-Output of the MATLAB Code for OFDM-MIMO Integration.

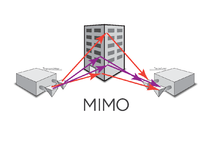
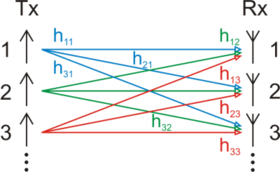
 

Fig.16-MIMO Idea-Multipath Propagation

1. MATLAB CODE:

*OFDM TRANSMITTER*

%DVB-T 2K Transmission

%The available bandwidth is 8 MHz

%2K is intended for mobile services

clear all;

close all;

%DVB-T Parameters

Tu=224e-6; %useful OFDM symbol period

T=Tu/2048; %baseband elementary period

G=0; %choice of 1/4, 1/8, 1/16, and 1/32

delta=G\*Tu; %guard band duration

Ts=delta+Tu; %total OFDM symbol period

Kmax=1705; %number of subcarriers

Kmin=0;

FS=4096; %IFFT/FFT length

q=10; %carrier period to elementary period ratio

fc=q\*1/T; %carrier frequency

Rs=4\*fc; %simulation period

t=0:1/Rs:Tu;

%Data generator (A)

M=Kmax+1;

rand('state',0);

a=-1+2\*round(rand (M,1)).'+i\*(-1+2\*round (rand (M,1))).';

A=length (a);

info=zeros(FS,1);

info (1:(A/2)) = [ a(1:(A/2)).']; %Zero padding

info ((FS-((A/2)-1)):FS) = [ a(((A/2)+1):A).'];

%Subcarriers generation (B)

carriers=FS.\*ifft(info,FS);

tt=0:T/2:Tu;

figure(1);

subplot(211);

stem(tt(1:20),real(carriers(1:20)));

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subplot(212);

stem(tt(1:20),imag(carriers(1:20)));

figure(2);

f=(2/T)\*(1:(FS))/(FS);

subplot(211);

plot(f,abs(fft(carriers,FS))/FS);

subplot(212);

pwelch(carriers,[],[],[],2/T);

% D/A simulation

L = length(carriers);

chips = [ carriers.';zeros((2\*q)-1,L)];

p=1/Rs:1/Rs:T/2;

g=ones(length(p),1); %pulse shape

figure(3);

stem(p,g);

dummy=conv(g,chips(:));

u=[dummy(1:length(t))]; % (C)

figure(4);

subplot(211);

plot(t(1:400),real(u(1:400)));

subplot(212);

plot(t(1:400),imag(u(1:400)));

figure(5);

ff=(Rs)\*(1:(q\*FS))/(q\*FS);

subplot(211);

plot(ff,abs(fft(u,q\*FS))/FS);

subplot(212);

pwelch(u,[],[],[],Rs);

[b,a] = butter(13,1/20); %reconstruction filter

[H,F] = freqz(b,a,FS,Rs);

figure(6);

plot(F,20\*log10(abs(H)));

uoft = filter(b,a,u); %baseband signal (D)

figure(7);

subplot(211);

plot(t(80:480),real(uoft(80:480)));

subplot(212);

plot(t(80:480),imag(uoft(80:480)));

figure(8);

subplot(211);

plot(ff,abs(fft(uoft,q\*FS))/FS);

subplot(212);

pwelch(uoft,[],[],[],Rs);

%Upconverter

s\_tilde=(uoft.').\*exp(1i\*2\*pi\*fc\*t);

s=real(s\_tilde); %passband signal (E)

figure(9);

plot(t(80:480),s(80:480));

figure(10);

subplot(211);

13

%plot(ff,abs(fft(((real(uoft).').\*cos(2\*pi\*fc\*t)),q\*FS))/FS);

%plot(ff,abs(fft(((imag(uoft).').\*sin(2\*pi\*fc\*t)),q\*FS))/FS);

plot(ff,abs(fft(s,q\*FS))/FS);

subplot(212);

%pwelch(((real(uoft).').\*cos(2\*pi\*fc\*t)),[],[],[],Rs);

%pwelch(((imag(uoft).').\*sin(2\*pi\*fc\*t)),[],[],[],Rs);

pwelch(s,[],[],[],Rs);

*OFDM RECEIVER*

%DVB-T 2K Reception

clear all;

close all;

Tu=224e-6; %useful OFDM symbol period

T=Tu/2048; %baseband elementary period

G=0; %choice of 1/4, 1/8, 1/16, and 1/32

delta=G\*Tu; %guard band duration

Ts=delta+Tu; %total OFDM symbol period

Kmax=1705; %number of subcarriers

Kmin=0;

FS=4096; %IFFT/FFT length

q=10; %carrier period to elementary period ratio

fc=q\*1/T; %carrier frequency

Rs=4\*fc; %simulation period

t=0:1/Rs:Tu;

tt=0:T/2:Tu;

%Data generator

sM = 2;

[x,y] = meshgrid((-sM+1):2:(sM-1),(-sM+1):2:(sM-1));

alphabet = x(:) + 1i\*y(:);

N=Kmax+1;

rand('state',0);

a=-1+2\*round(rand(N,1)).'+i\*(-1+2\*round(rand(N,1))).';

A=length(a);

info=zeros(FS,1);

info(1:(A/2)) = [ a(1:(A/2)).'];

info((FS-((A/2)-1)):FS) = [ a(((A/2)+1):A).'];

carriers=FS.\*ifft(info,FS);

%Upconverter

L = length(carriers);

chips = [ carriers.';zeros((2\*q)-1,L)];

p=1/Rs:1/Rs:T/2;

g=ones(length(p),1);

dummy=conv(g,chips(:));

u=[dummy; zeros(46,1)];

[b,aa] = butter(13,1/20);

uoft = filter(b,aa,u);

delay=64; %Reconstruction filter delay

s\_tilde=(uoft(delay+(1:length(t))).').\*exp(1i\*2\*pi\*fc\*t);

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s=real(s\_tilde);

%OFDM RECEPTION

%Downconversion

r\_tilde=exp(-1i\*2\*pi\*fc\*t).\*s; %(F)

figure(1);

subplot(211);

plot(t,real(r\_tilde));

axis([0e-7 12e-7 -60 60]);

grid on;

figure(1);

subplot(212);

plot(t,imag(r\_tilde));

axis([0e-7 12e-7 -100 150]);

grid on;

figure(2);

ff=(Rs)\*(1:(q\*FS))/(q\*FS);

subplot(211);

plot(ff,abs(fft(r\_tilde,q\*FS))/FS);

grid on;

figure(2);

subplot(212);

pwelch(r\_tilde,[],[],[],Rs);

%Carrier suppression

[B,AA] = butter(3,1/2);

r\_info=2\*filter(B,AA,r\_tilde); %Baseband signal continuous-time (G)

figure(3);

subplot(211);

plot(t,real(r\_info));

axis([0 12e-7 -60 60]);

grid on;

figure(3);

subplot(212);

plot(t,imag(r\_info));

axis([0 12e-7 -100 150]);

grid on;

figure(4);

f=(2/T)\*(1:(FS))/(FS);

subplot(211);

plot(ff,abs(fft(r\_info,q\*FS))/FS);

grid on;

subplot(212);

pwelch(r\_info,[],[],[],Rs);

%Sampling

r\_data=real(r\_info(1:(2\*q):length(t)))... %Baseband signal, discretetime

+1i\*imag(r\_info(1:(2\*q):length(t))); % (H)

figure(5);

subplot(211);

stem(tt(1:20),(real(r\_data(1:20))));

axis([0 12e-7 -60 60]);

grid on;

15

figure(5);

subplot(212);

stem(tt(1:20),(imag(r\_data(1:20))));

axis([0 12e-7 -100 150]);

grid on;

figure(6);

f=(2/T)\*(1:(FS))/(FS);

subplot(211);

plot(f,abs(fft(r\_data,FS))/FS);

grid on;

subplot(212);

pwelch(r\_data,[],[],[],2/T);

%FFT

info\_2N=(1/FS).\*fft(r\_data,FS); % (I)

info\_h=[info\_2N(1:A/2) info\_2N((FS-((A/2)-1)):FS)];

%Slicing

for k=1:N,

a\_hat(k)=alphabet((info\_h(k)-alphabet)==min(info\_h(k)-alphabet)); %(J)

end;

figure(7)

plot(info\_h((1:A)),'.k');

title('info-h Received Constellation')

axis square;

axis equal;

figure(8)

plot(a\_hat((1:A)),'or');

title('a\_hat 4-QAM')

axis square;

axis equal;

grid on;

axis([-1.5 1.5 -1.5 1.5]);

OFDM-MIMO DESIGN BASIC PROGRAM

QMod = comm.QPSKModulator;

hQDemod = comm.QPSKDemodulator;

hOFDMMod = comm.OFDMModulator('FFTLength',128,'PilotInputPort',true,...

'PilotCarrierIndices',cat(3,[12; 40; 54; 76; 90; 118],...

[13; 39; 55; 75; 91; 117]),'InsertDCNull',true,...

'NumTransmitAntennas',2);

hOFDMDemod = comm.OFDMDemodulator(hOFDMMod);

hOFDMDemod.NumReceiveAntennas = 2;

showResourceMapping(hOFDMMod);

hAWGN = comm.AWGNChannel(...

'NoiseMethod', 'Signal to noise ratio (Es/No)', ...

'EsNo', 30);

modDim = info(hOFDMMod);

% Number of OFDM frames to transmit

nFrames = 100;

% Generate data for each (subcarrier, symbol, tx antenna) triplet

rng('default') % Initialize random number generator to default seed

dataInputDim = [nFrames 1 1] .\* modDim.DataInputSize;

data = randi([0 3], dataInputDim);

modData = step(hQMod, data(:));

modData = reshape(modData, dataInputDim);

%Create an ErrorRate System object to collect error statistics.

hError = comm.ErrorRate;

%Simulate the OFDM system over 100 frames assuming a flat, 2\*2, Rayleigh fading channel. Remove the effects of multipath fading using a simple, least squares solution, and demodulate the OFDM waveform and QPSK data. Generate error statistics by comparing the original data with the demodulated data.

for k = 1:nFrames

% Find row indices for kth OFDM frame

indData = (k-1)\*modDim.DataInputSize(1)+1:k\*modDim.DataInputSize(1);

% Generate random OFDM pilot symbols

pilotData = complex(rand(modDim.PilotInputSize), ...

rand(modDim.PilotInputSize));

% Modulate QPSK symbols using OFDM

dataOFDM = step(hOFDMMod, modData(indData,:,:), pilotData);

% Create flat, i.i.d., Rayleigh fading channel

chGain = complex(randn(2,2),randn(2,2))/sqrt(2); % Random 2x2 channel

% Pass the OFDM signal through Rayleigh and AWGN channels

receivedSignal = step(hAWGN, dataOFDM \* chGain);

% Apply least squares solution to remove fading channel effects

rxSigMF = chGain.' \ receivedSignal.';

% Demodulate the OFDM data

receivedOFDMData = step(hOFDMDemod, rxSigMF.');

% Demodulate the QPSK data

receivedData = step(hQDemod, receivedOFDMData(:));

% Compute error statistics

dataTmp = data(indData,:,:);

errors = step(hError, dataTmp(:), receivedData);

end

fprintf('\nSymbol error rate = %d from %d errors in %d symbols\n',errors);

1. REFERENCES

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1. THINGS I LEARNT FRROM THIS PROJECT
2. Introduction of OFDM- technologies
3. OFDM-Transmission and Reception
4. OFDM with MIMO integration.
5. YOUTUBE LINK

[1] Description of the Project-

[**https://youtu.be/\_ZOPqSUzn6s**](https://youtu.be/_ZOPqSUzn6s)

[2] Output of the project-Output graphs-

[**https://youtu.be/w906p0DUOd8**](https://youtu.be/w906p0DUOd8)