A REPORT

ON

Beamforming Test Setup using Simulink

BY

Names of Student	ID	Discipline
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Abstract:

The objective of the project is to create a Simulink model to check the Digital Beamforming implementation which is achieved by a phased array model with a beamformer finally connected to the Ethernet Module.

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1. INTRODUCTION

The world has seen a rise in the need for increased data rates to meet the necessities of the people. Recently, demand for technologies to identify a specific target has also been immensely increased for military purposes. In order to achieve this, we have to maximize the signal-to-noise ratio as much as possible so as to reduce the interference of noise. Beamforming is one of the most important techniques employed for the same.

Traditionally, a single antenna produces a wireless signal that radiates in all directions provided there are no obstructions. However, to focus the signal in a specific direction there should be a mechanism that transfers the intended data. This forms the basis of Beamforming, where there are multiple antennas located at the transmitter end, and specifically in the phased array model all the radiating elements constructively interfere to produce main lobes and sidelobes. The main lobe transfers the energy to the desired locations and wherever it destructively interferes forms sidelobes.

The project is developed using Simulink, where an OFDM signal is transmitted (of MHz range) and is digitally upconverted to a higher frequency range (of GHz). In the later part, the digitally upconverted signal is passed through a phased array model with the beamformer created in Simulink and then transferred through a noise channel which is finally passed through the Ethernet Module to be checked at the receiver end. To check the signal strength at the receiver end it is connected via Ethernet Module
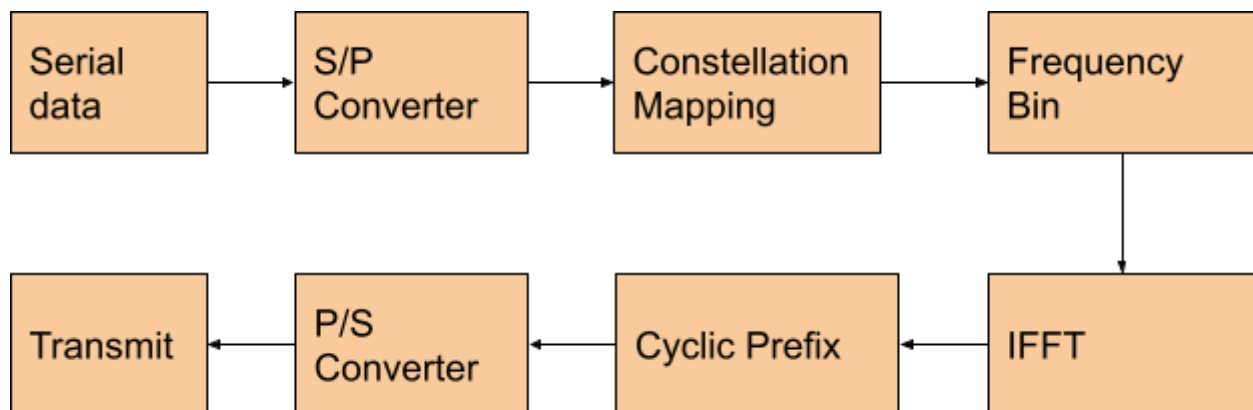
2. WORKFLOW

2.1.Block Diagram:
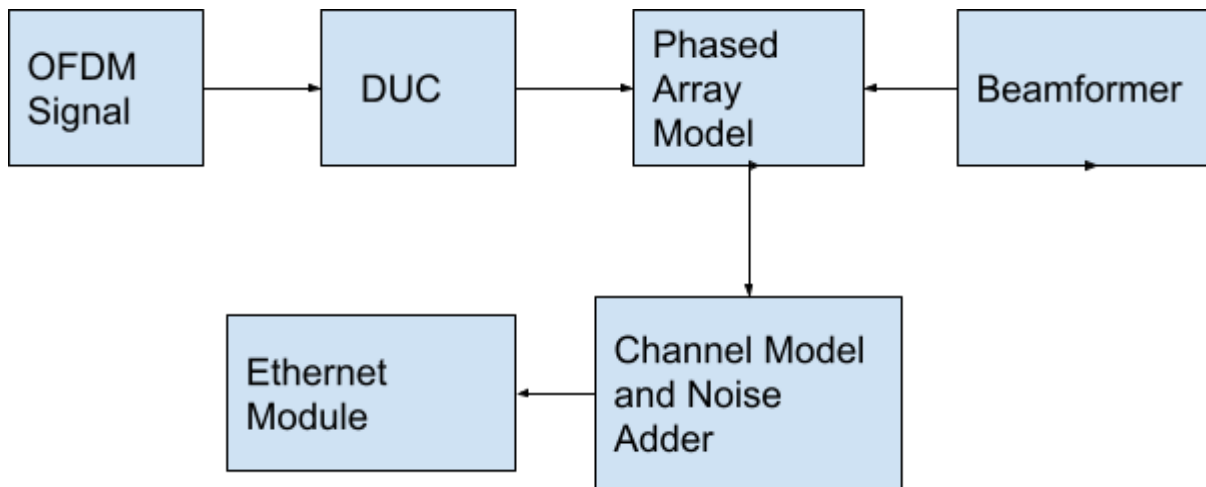
3. MODELLING

3.1.OFDM:

BLOCK DIAGRAM OF OFDM:

Transmission of an OFDM Signal is the first step to be performed in the project. The principle of OFDM is employed for large bandwidth signals which when transmitted using a single carrier wide-band frequency experience distortion/may change the data initially intended to be transmitted.

For Ex: If the transmitted signal is having a bandwidth of 20MHz then the symbol time is 0.05μs and the delay spread is around 2-3μs. Since the symbol

time is less than the delay spread it leads to intersymbol interference.

So, to avoid the ISI, the large bandwidth signals are divided into many narrowband signals which remove the ISI, the symbol time of the channel now becomes more than the delay spread. So, a system with multiple subbands and subcarriers form Multicarrier Modulation.

Ex: Let the transmitted signal of bandwidth 20MHz be divided into 1000 subcarriers where each subcarrier has a frequency of 20kHz, the symbol time becomes 100μs which is greater than the delay spread.

Equations and Steps of the transmission of the MCM Signal:

$Sk(t) = Xk * e^{j2\pi kf}$ ->is the equation for the kth Subcarrier of center frequency f.

The net transmitted MCM Signal is $S(t) = \sum Sk(t)$

To recover the Xk, take the inverse Fourier transform.

After IFFT Processing, to avoid the past symbols having an influence on the current symbols, Cyclic Prefix should be added. Generally, the length of Cyclic Prefix is 1/4th of the length of subcarriers.

3.2.DUC:

The transmitted signal is then digitally upconverted to a higher frequency for transmission purposes. This is widely employed in 5G, LTE where signals with higher frequencies are of more significance.

3.3.PHASED ARRAY BEAMFORMER MODEL:

Phased array beamformers find its application in the modern wireless communications for improved performance of the system. As mentioned, unlike the traditional mechanically steered antennas, these are electrically steered and hence have higher reliability.

The DUC produces an output which has a phase of theta and from the beamformer, at each instant another phase of phi gets added to theta via phase shifter for each antenna element present in the uniform rectangular array. The steering can be checked with the help of a polar plot.

The phase shift beamformer considers the antenna to be in the rectangular array fashion in the project.

Block Diagram:
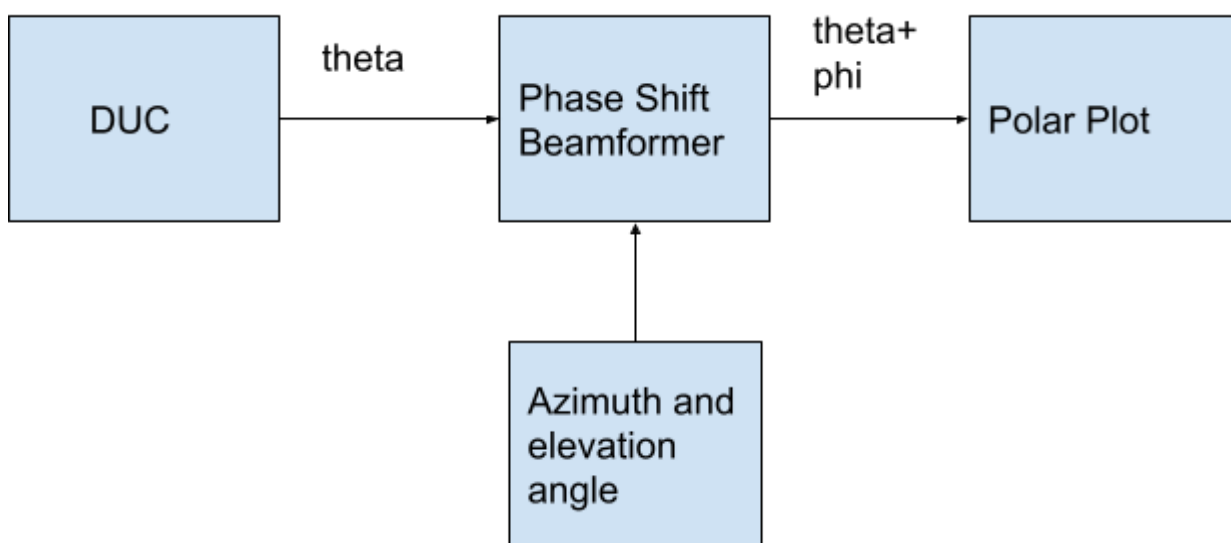
4. SIMULATION STEPS AND RESULTS:

Steps for Generating OFDM Signal and Upconversion:

The data is generated using any random source generator. The received is mapped accordingly as per the constellation of the modulation schemes that we want to perform. In the project, the source is a Bernoulli binary generator and the bits are mapped as per the QPSK modulation scheme, where two bits are transmitted together.

Later, the transmitted bits are converted from serial to parallel, the buffer is used and the Inverse Fast Fourier Transform is computed with the help of the inbuilt IFFT block. For the addition of Cyclic Prefix, Multiport Selector in Simulink is used so as to append the last bits to the original data. The parallel data is unbuffered and analyzed using a spectrum analyzer which later sent to the next block (i.e DUC)

The OFDM signal is upconverted to a higher frequency for transmission purposes with the aid of Digital-Up Converter Block in Simulink

Simulation Steps:
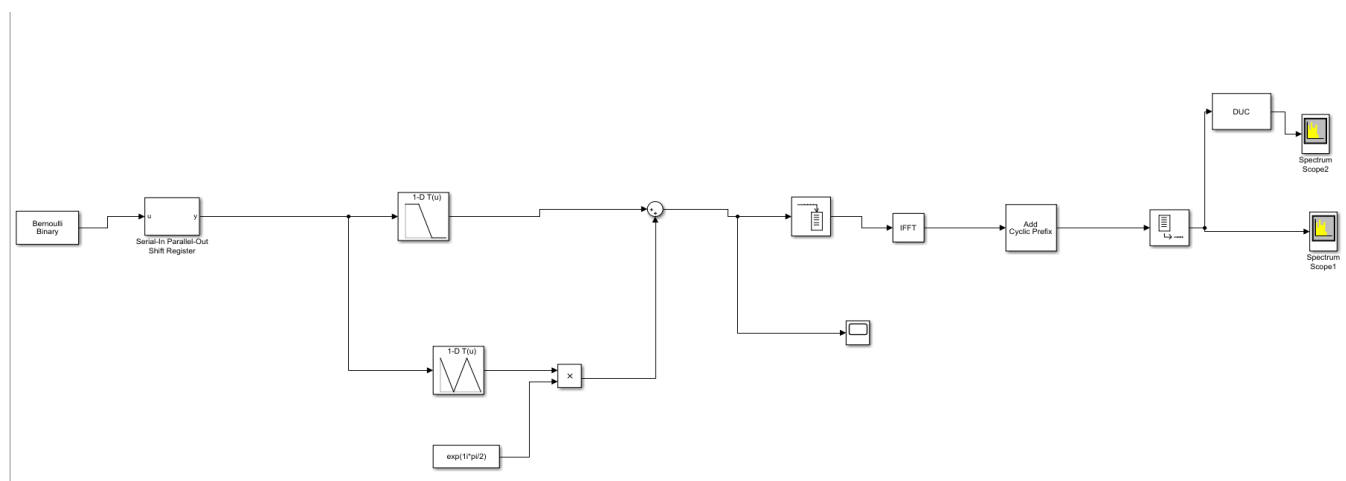
Arrange the Simulink as mentioned in the above picture

Parameters and Blocks:

The Bernoulli binary generator takes the Sample per frame as 64 with the initial seed of 61(the data keeps repeating itself after 61-time units) with the sample time as 0.05exp(-6) because the assumed bandwidth of as signal is 20MHz.

In the Serial-In Parallel Out Shift Register, the number of samples is considered to be 2 because 2 bits are transferred in QPSK modulation.

The lookup table maps the bits as per the constellation of QPSK i.e, 00->1+j,01->1-j,10->-1+j,11->-1-j since the lookup table only takes real values as input and convert it to a complex value, multiplying with "j" is necessary.

The buffer size per channel is considered as 16 (so that the serial data is converted into 4 subchannels).

The IFFT is performed by taking 64 points and it is then unbuffered to get back the original serial data.

Finally, the DUC Parameters are updated as per the requirements.

Simulation Results:

Let the input sequence be

Since the modulation is QPSK, the corresponding constellation is

00->1+j; 11-(-1-j)

01->1-j;10-(-1+j) if there is an offset of π/4.

The input bandwidth is 20MHz.
If the number of subcarriers is 64 then the symbol time for each channel becomes 312.5KHz. Now the corresponding symbol duration of each subcarrier is 3.2μs, where the cyclic prefix duration is 1/4th of the symbol duration that is 0.8μs.
The total symbol duration is 4μs. The total number of samples hence becomes 80.

The OFDM signal is generated by QPSK Modulation with a length of 64 and is buffered into 4 parallel streams and it is centered at a frequency of approximately 20 MHz since the sample time in the Bernoulli Binary generator is 0.05exp(-6).

The OFDM signal after passing through the IFFT Block and Cyclic Prefix with a central frequency of approximately 20MHz matches with our initial condition of the addition of a cyclic prefix to the original signal
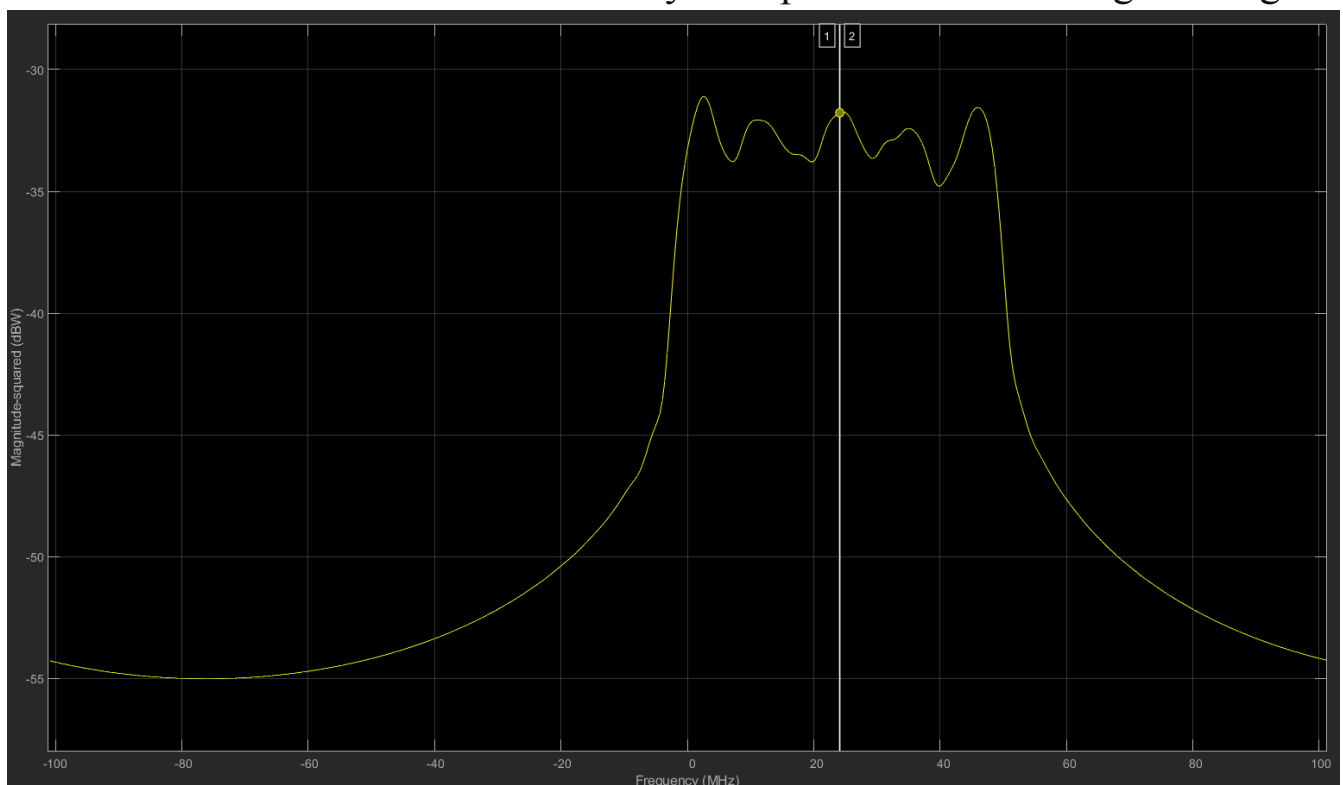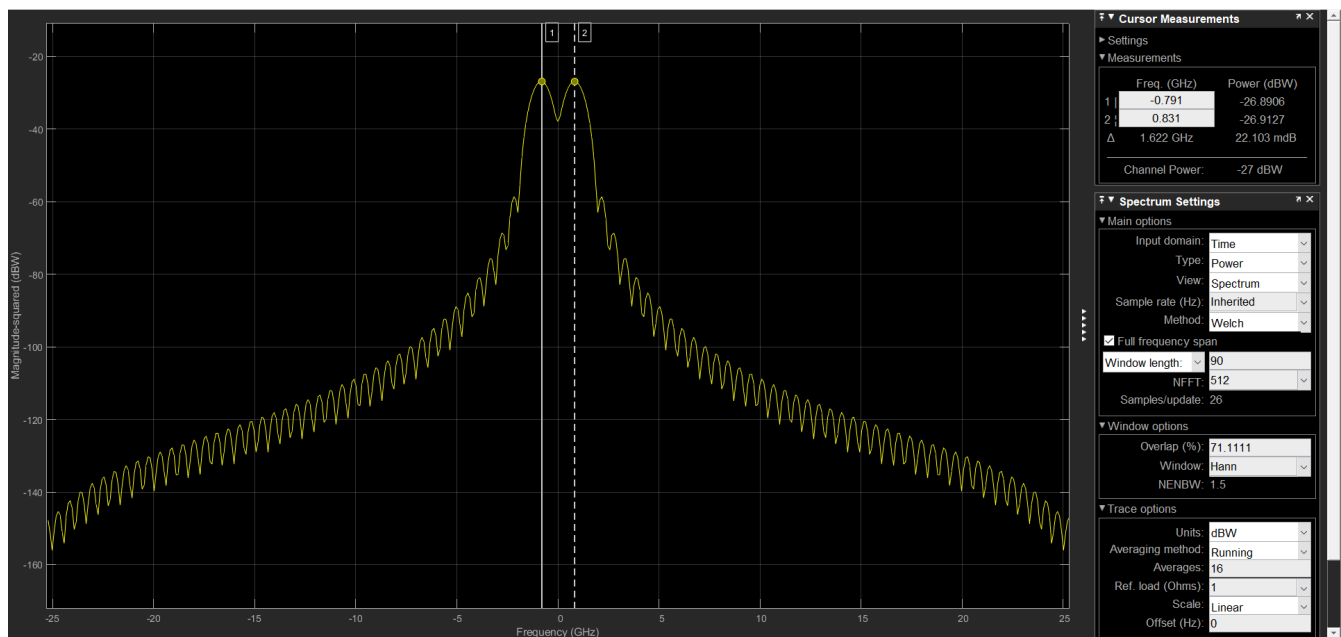
After passing through the Digital UpConverter, with the center frequency being set to 800MHz, the signal transforms as follows:
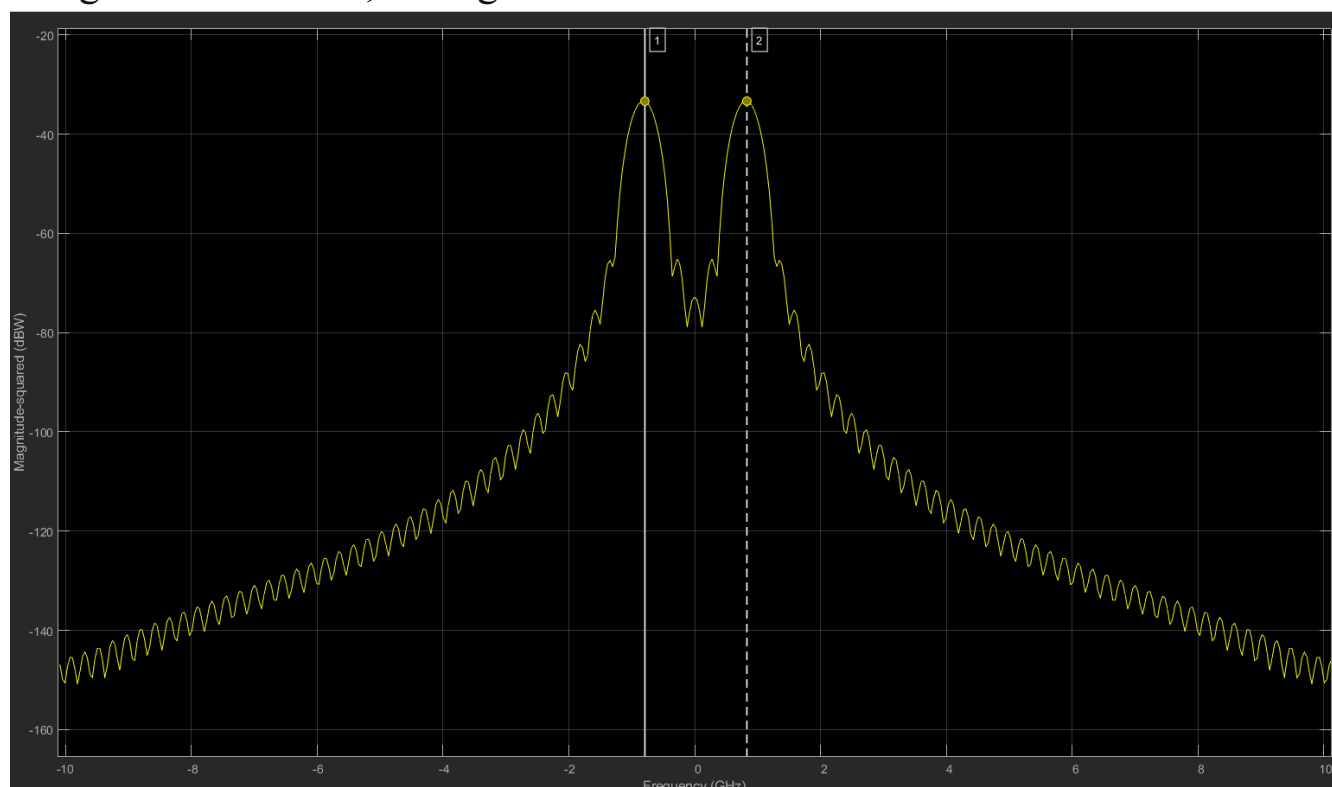
Similarly, if the input signal has a bandwidth of 50MHz, the corresponding OFDM Signal looks like
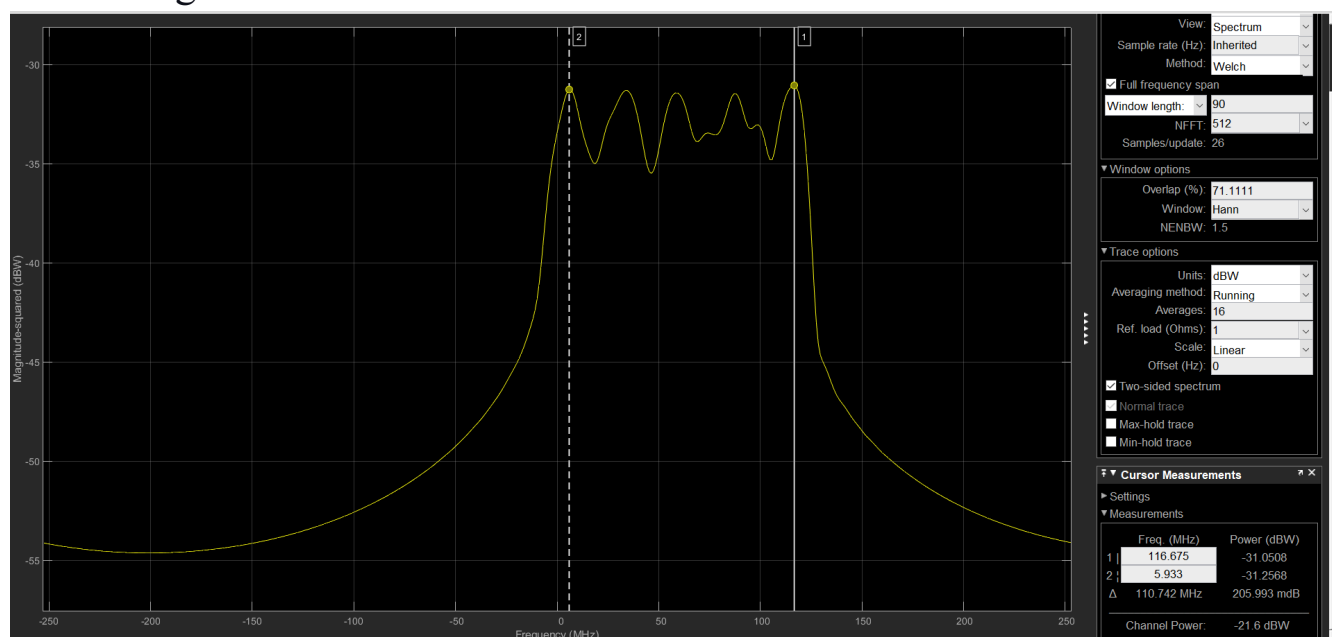

The DUC signal with a center frequency of 800 MHz looks like,

Phase shift beamformer:

The obtained DUC signal is replicated four times so as to get the matrix in 4 dimensions for the uniform rectangular array. The azimuth and elevation angle are also taken as inputs in the number of beamforming directions that we specify and the beamformer performs delay and sum where the delay is approximated using time domain and all other necessary inputs like operating frequency etc are provided as per the user convenience. The simulation time is set for 10^{-6} seconds.

The resulting output is a matrix, each column representing the samples in that beamforming direction. On careful analysis, the peak value recorded by each steering angle is different from another, proving the existence of phase shift between the array elements.
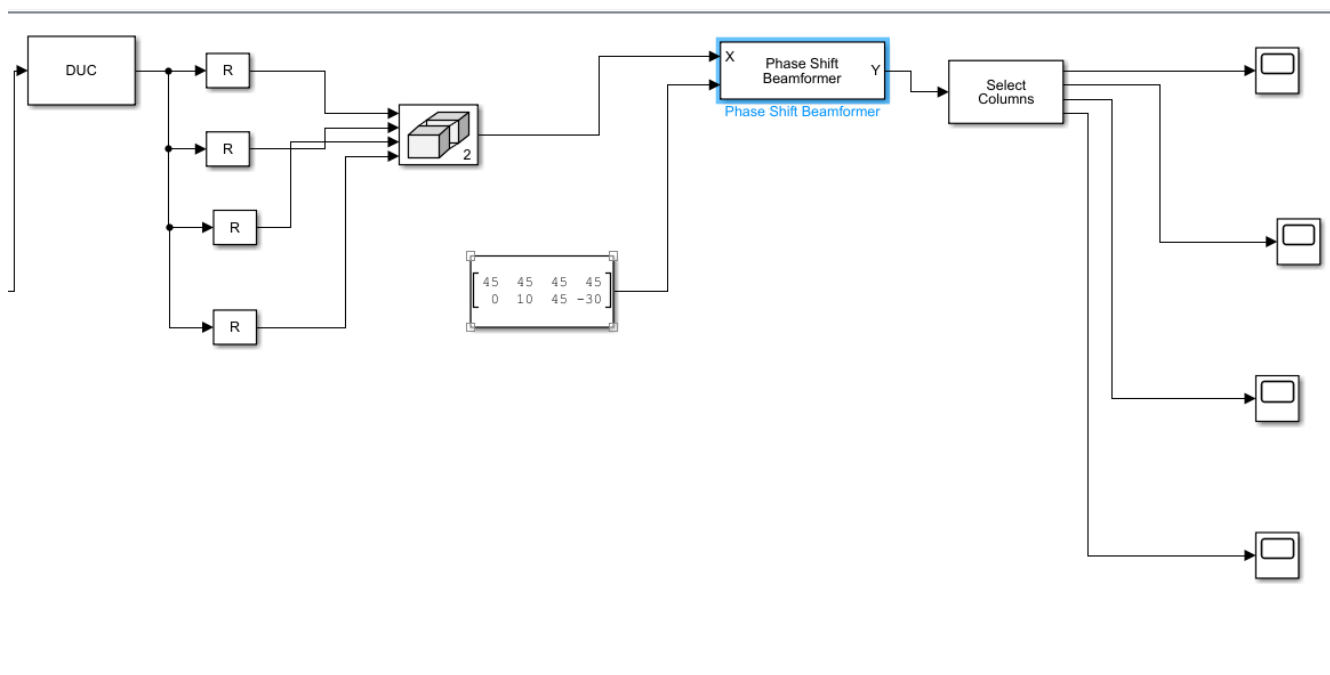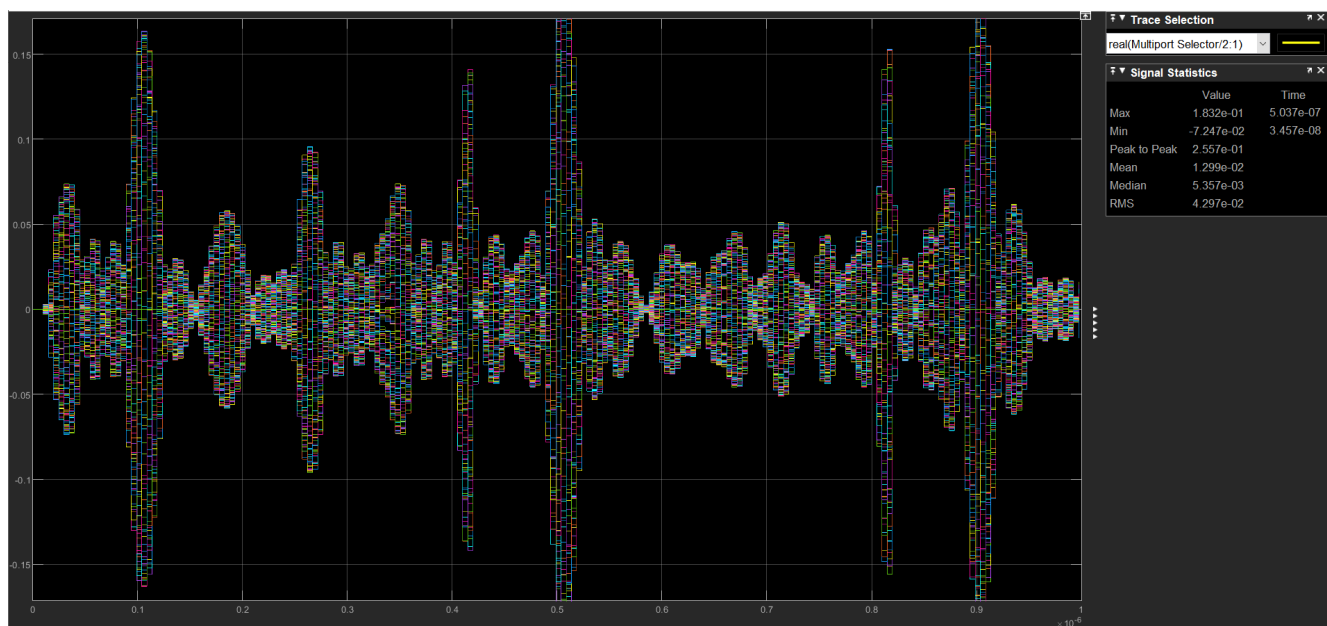
To view the results produced by different angles, use the multiport selector where the columns are chosen to independently represent the data from each angle.
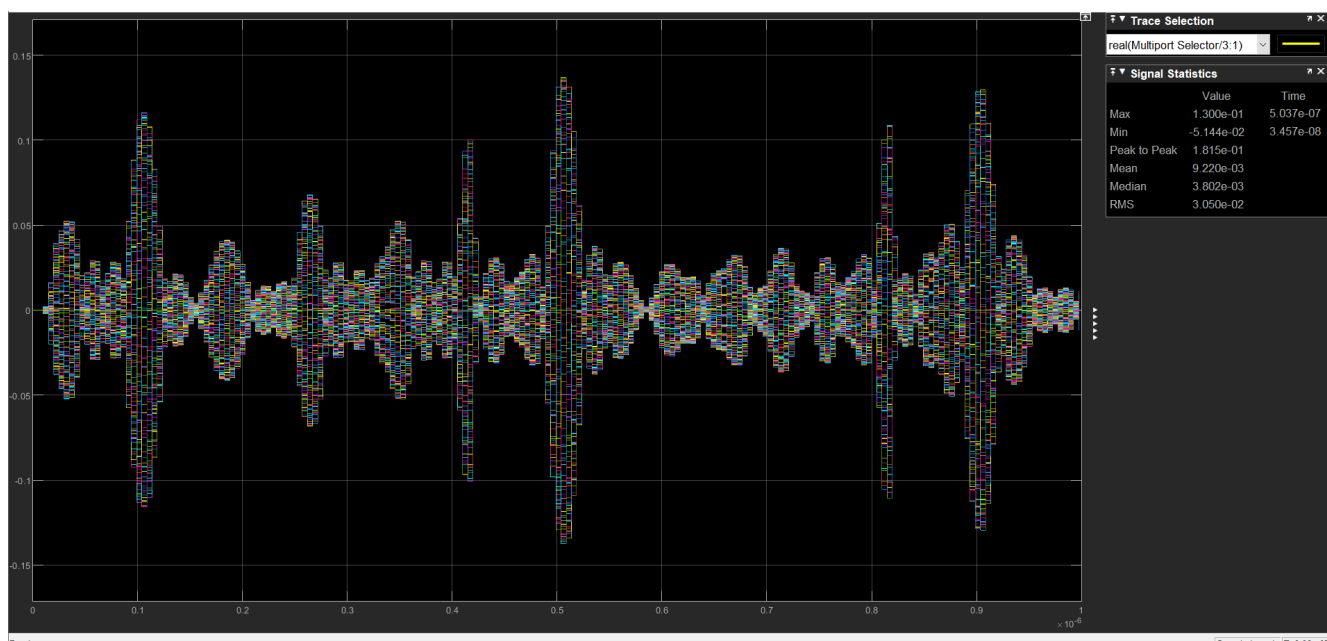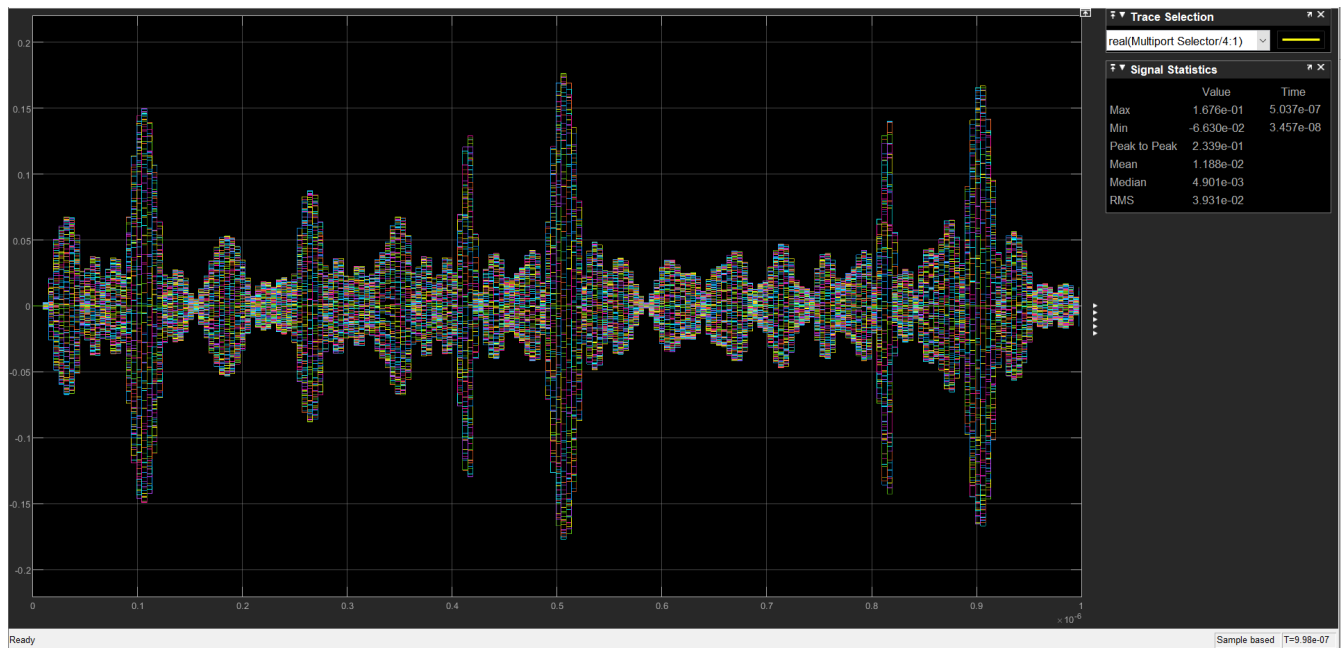
For 0 degrees, the obtained graph is:
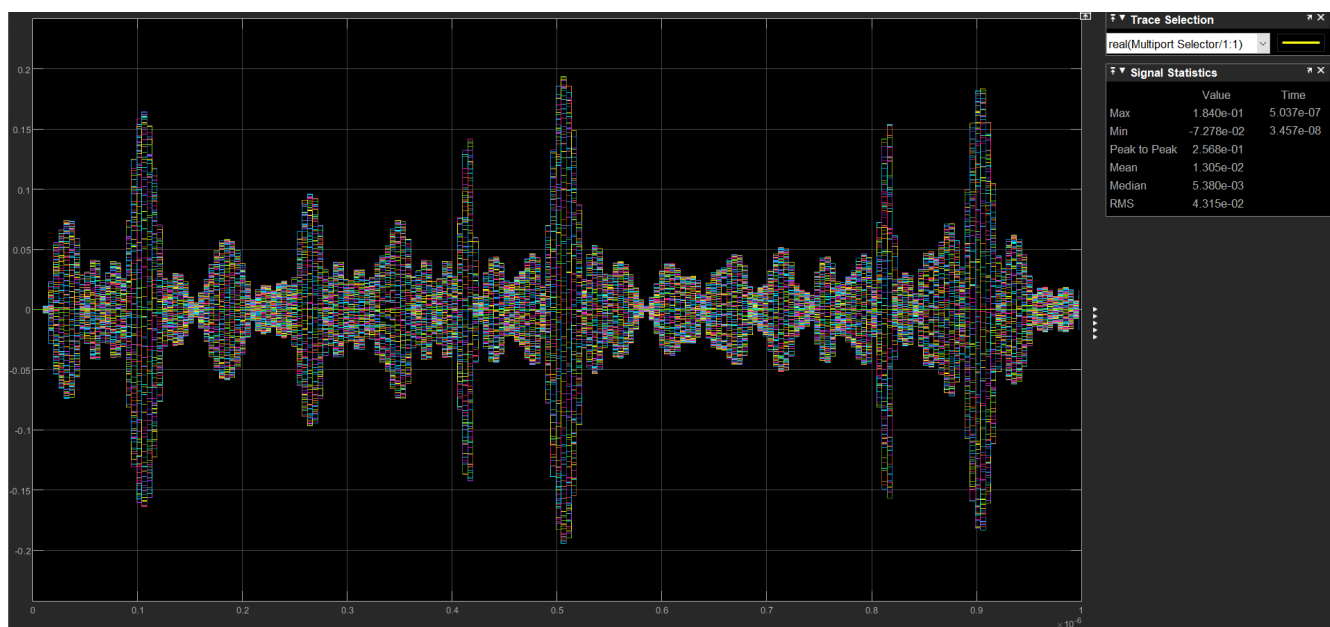
For 10 degrees, the obtained graph is:

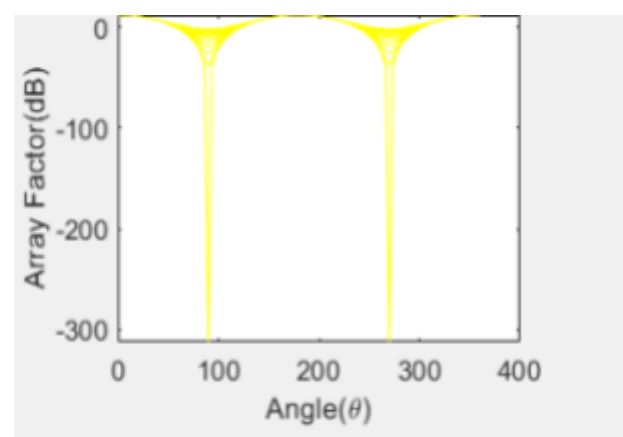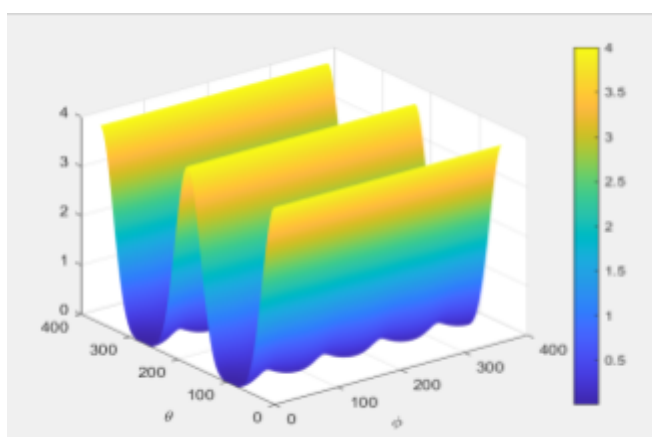For 45 degrees the obtained graph is:

For -30 degrees, the obtained graph is:

Verification and generating Array Factor for Uniform Rectangular Array:

Matlab Code is written to check the array factor of a Uniform Rectangular Array for different steering angles. The following relation between theta and phi are obtained for 0 degrees

5. WORKING OF THE ETHERNET MODULE

To test the analysis of the beamforming model created, analysis should be done at the receiver end too. Before going to that step, since this project aims to build a 5G testbed(transmitter) noise channel could be included. To establish the communication between transmitter and the receiver, an Ethernet module is necessary(wireshark could also be used).

Testing of the TCP/IP Communication between the two computers/sessions using Matlab:

To understand the data transmission between two computers, a small code which generates the sum of the numbers till the given input is read onto server using client Matlab session.

Firstly, the Matlab programs corresponding to Server and Client are written separately. To start with the procedure the following steps are to be followed:

1)Get the IP address of the host by using the following code

```
[~,hostname] = system('hostname');
hostname = string(strtrim(hostname));
address = resolvehost(hostname,"address");
```

2)After getting the address, copy it to both server and client sessions. Assign the same random port number to both of the sessions. The server waits until it receives the connection from the client's end.
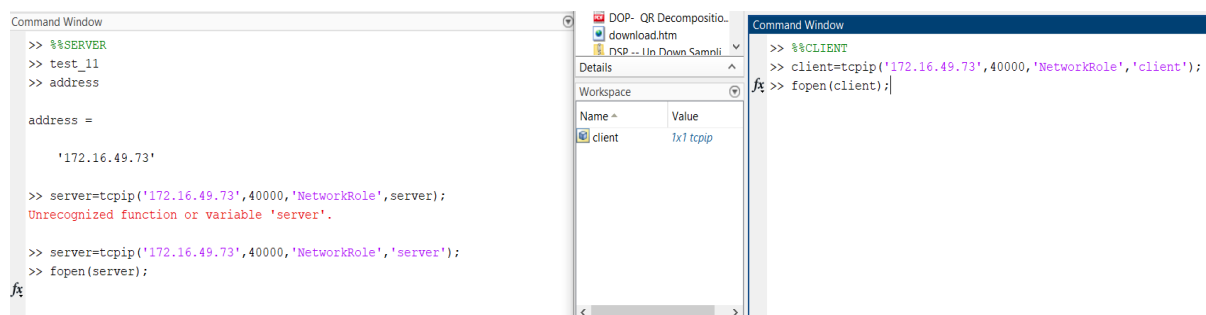
3) Once the connection is established, the data is written onto the client and then it is read back to the server using special commands like fread,fwrite.

The following snippet shows the data transmission of the sum of N numbers

Client:

```
>> k=0;
N=input('');
for i=1:N
    k=k+i;
end
fwrite(client,k);
10
>> k

k =

    55

fx >>
```

Server:

```
>> data=fread(server,10);
Warning: The specified amount of data was not returned within the Timeout
period.
'tcpip' unable to read all requested data. For more information on
possible reasons, see TCPIP Read Warnings.
>> data

data =

    55
```

In a similar way, the beamformed output is sent from clients to be tested at the server side with the server being an FPGA board.

6. FURTHER EXPLORATIONS

Working of the Ethernet module between two target computers via Simulink:

We can transfer data between two computers using Simulink and the following aims to explain the same.

One of them acts as the transmitter and the other acts as the receiver and both of them need to have an ethernet card for the application. With the simulink being set up, in the transmitter, set the Ethernet Configuration block and its configuration parameters present(Driver, PCI Bus, PCI Slot) send the data in bytes to the configuration block at the transmitter, and also set the MAC address of the destination correctly, the Ethernet transmit block sends the packet over the network.

The receiver is also similar to the transmitter, where the data is received at Ethernet receive block which feeds to Extract Ethernet Packet Block, the data once received is unpacked using Byte unpacking block. The scope is used to view the received signal/data. Later both models are built and downloaded onto the target computer.

7. CONCLUSION

The project begins with understanding the important concepts like Beamforming, applications of Beamforming, and different optimization techniques and algorithms(QR-Decomposition) used to achieve it. Later, for designing the same an OFDM signal transmission is chosen which requires the knowledge of Single Carrier Transmission, Multi-Carrier Transmission, and Cyclic Prefix. Finally, the data is upconverted to a certain frequency and its utilization for the phased array model forms the crux of the project.

8. REFERENCES

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