SMART ANTENNA

A project report
submitted in partial fulfillment of the
requirements for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

by

Ms Lakkoju Sri Sai Swathi B141362
Ms Tangellamudi Maheswari B141740
Ms Thalla Aruna B141902

Under the guidance of

Mr. A Ch MadhusudanaRao M.Tech(IIT Madras),

Rajiv Gandhi University of Knowledge Technologies
Basar - 504107

Batch 2020

Dedicated to

Telecommunications

CERTIFICATE

This is to certify that the thesis entitled Smart Antenna being submitted to the Rajiv Gandhi University of Knowledge Technologies, by Ms Lakkoju Sri Sai Swathi(IDNo.B141362) Ms Tangellamudi Maheswari (IDNo.B141740) Ms Thalla Aruna (IDNo.B141902) in partial fulfillment for the award of Bachelor of Technology in Electronics and Communication Engineering is a bonafide work carried out by them under our supervision and guidance. The matter embodied in this thesis has not been submitted to any other University for the award of any degree or diploma. This thesis, in our opinion, is worthy consideration for the award of the degree of Bachelor of Technology in accordance with the regulations of the institute.

Mr.A.Ch.Madhusudanarao,
Supervisor,
Asst. Professor in ECE,
Rajiv Gandhi University
of Knowledge Technologies,
Basar.

Date:
Place:

Mr. A.Dheeraj,
Head of the Department
Asst. Professor in ECE
Rajiv Gandhi University
of Knowledge Technologies,
Basar.

Date:
Place:

CERTIFICATE OF EXAMINATION

This is to certify that I have examined the thesis entitled Smart Antenna submitted by Ms Lakkoju Sri Sai Swathi (IDNo.B141362) Ms Tangellamudi Maheswari (IDNo.B141740) Ms Thalla Aruna (IDNo.B141902) and hereby accord my approval of it as a study carried out and presented in a manner required for its acceptance in partial fulfillment for the award of the graduate degree for which it has been submitted. This approval does not necessarily endorse or accept every statement made, opinion expressed or conclusion drawn as recorded in the thesis. It only signifies the acceptance of the thesis for the purpose for which it has been submitted.

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Date:

Place: Basar

DECLARATION

I hereby declare that the work embodied in this thesis has been carried out by me under the supervision of **Mr. A Ch Madhusudana Rao M.Tech(IIT Madras)** in the department of Electronics and Communication Engineering, Rajiv Gandhi University of Knowledge Technologies, Basar and has not been submitted to any other University. Information derived from the published and unpublished work of others has been acknowledged and a list of references is given.

Place: Basar	Lakkoju Sri Sai Swathi(B141362)
Date:	Thalla Aruna(B141902)
	Tangellamudi Maheswari(B141740)

ABSTRACT

Smart antenna refers to a digital wireless communication antenna system that enables effortless performance of communication systems by efficiently managing the signals that are received through each antenna. These are also known as multiple antennas or adaptive antennas (MIMO) and are extensively being used to identify the direction of the arriving signal at the transmitter and receiver or both.Smart antennas has been on the rise as they are known to enhance the signal range, reducing fading of signals, suppressing interfering signals, and thus improving the capacity of the wireless communication system. A smart antenna is a multi-element antenna in which the signals that are received at each antenna element are combined and managed intelligently in order to improve the performance of the wireless system. These antennas are capable of increasing the signal range, suppressing interfering signals, combating signal fading and as a consequence increasing the capacity of a wireless system. The smart antennas include signal processing capability that can perform tasks such as analysis of the direction of arrival of a signal and then the smart antenna can adapt the antenna itself using beam-forming techniques to achieve better reception, or transmission. In addition to this, the overall antenna will use some form of adaptive antenna array scheme to enable the antenna to perform is beam formation and signal direction detection.

ACKNOWLEDGEMENTS

Perseverance,inspiration and motivation have played a great role in the success of any venture.It would be incomplete to submit this report without acknowledging the people behind this endeavour and without whose support I wouldnt have able to acheive this. It gives immense pleasure to express my gratitude to everyone who shared with me their precious time and effort during the project. A mammoth job like this calls for both intelligence nourishment and encoragement.I would like to thank Mr. A.Ch.Madhusudanarao, Asst.Professor in the Department of Electronics and Communication Engineering for giving me oppurtunity to work on such a fabulous project. I would like to convey my sincere gratitude towards our project coordinator Mr.V S S K R Naganjaneyulu G M.E(IISc), Asst. professor in the Department of Electronics and Communication Engineering ,for guiding and motivating me to collect fair,accurate,reliable and unbiased information. I would like to thank Mr.Agshare Dheeraj, Head of the Department of Electronics and Communication Engineering,for his valuable help and guidance. I would be failing my duty if I do not express my sincere gratitude towards my honorable vice chancellor of RGUKT,Basar Dr. A. Ashok, I.A.S.,for providing all the requirements to finish this project. At last I extend my thanks to all my freinds who have given me reliable and valuable information to complete this project.

Thank you all

Lakkoju Sri Sai Swathi(B141362)
Thalla Aruna(B141902)
Tangellamudi Maheswari(B141740)

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ABBREVIATIONS

Abbreviations	Description
ML	Machine Learning
DNN	Deep Neural Network
LSTM	Long Short-Term Memory
RNN	Recurrent Neural Network
MIMO	Multiple Input Multiple Output

CHAPTER 1

Introduction

Smart antennas are antenna arrays with smart signal processing algorithms used to identify spatial signal signatures such as the direction of arrival of the signal, and use them to calculate beamforming vectors which are used to track and locate the antenna beam on the mobile/target. Two of the main types of smart antennas include switched beam smart antennas and adaptive array smart antennas. Switched beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point in time, based upon the requirements of the system. Adaptive arrays allow the antenna to steer the beam to any direction of interest while simultaneously nulling interfering signals.Beamdirection can be estimated using the so-called direction-of-arrival (DOA) estimation methods.To traject the mobile user before hand to direct the beam, a Deep learning method based on long-term and short-term memory (LSTM) architecture is used to get an accurate path and based on this, the end-to-end convolution LSTM network is designed and trained to predict the time walker trajectory.

1.1 Literature Survey On topic

1.1.1 Why this project

Smart Antenna are comprised of a number of individual antennas and associated signal processors which provide the smart portion. Smart antennas can use either, or both, for the signal transmission and the signal reception. The major advantage is to use a smart antenna to reduce the overall system power, reduction in communication interference, and increase in system capacity and improve in power efficiency. Smart Antenna at the receiver provides reduction of signal loss in multipath fading, which means more overall robust signal quality independent of the variations of the transmitted signal due to the physical environment and other electromagnetic interferences. For mobile applications, there are fewer dropped calls, reduced areas of low-signal / no-signal or dead zones better reception, reduction of bit error rate, reduction in handoffs and higher data rates. What we have learned over the past year is that the millimeter wave signal is much more resilient than anyone expected.With lead researchers suggesting that mobile data traffic will rise at a clip of 53for the foreseeable future, this higher-band spectrum will be essential to accommodating this uptick while still ensuring speeds up to (and even in excess of) one gigabit per second. One of the unique challenges of deploying millimeter wave spectrum is extending the distance the signal can travel. That is especially true in dense urban environments, where buildings and trees can disrupt signals. However, our field trials have shown that millimeter wave spectrum actually performs better than anyone could have anticipated in a real-world environment. To that end, Verizons 5G network will be based on higher frequencies more specifically the 28 and 39GHZ, known commonly as millimeter wave spectrum. These frequencies can carry massive amounts of data at very high speeds and with very little latency, or lag. That makes them ideal for accommodating a massive increase in data demands from mobile-first users, connected homes, AR/VR devices, cloud gaming systems, self-driving vehicles, IoT sensors and other cloud- connected devices. In the global race to 5G, Verizons investment in millimeter wave technology can provide consumers and enterprises with more computing power than ever before.

1.1.2 Previous Work

The first smart antennas were developed for military communications and intelligence gathering. The growth of cellular telephone in the 1980s attracted interest in commercial applications. The upgrade to digital radio technology in the mobile phone, indoor wireless network, and satellite broadcasting industries created new opportunities for smart antennas in the 1990s, culminating in the development of the MIMO (multiple-input multiple-output) technology used in 4G wireless networks. Smart antenna technology can overcome these capacity limits as well as improve signal quality and let mobile telephones operate on less power. Smart antenna are also known as adaptive array antennas, MIMO or multiple antennas.Smart antenna techniques, such as multiple-input multiple-output (MIMO) systems, can extend the capabilities of 3G and 4G systems to provide customers with increased data throughput for mobile high-speed data applications.So we tried to work for 5G antenna which can boost the data.In a conventional wi-fi communication system, a method called single input single output [SISO] is used, that is one antenna will be connected to the source and another one will be connected to the destination. When the signals arrive late at the destination, they may arrive faded, cut-out and also with common communication problems like picket fencing.So we go to Smart antenna.The mobiles or targets at which the signals are to be sent are first sought out and then a radiation pattern of the antenna array is created by adding the signal phases. At the same time the mobiles which will not need the signal will be out of pattern. 4G LTE technology currently uses lower frequency spectrum, generally below 1 gigahertz (GHz), to deliver data at great speed. The velocities achieved over 4G LTE have dramatically changed the ways we communicate, consume media, manage our lives and even hail a ride. However, as technology evolves, so do our expectations for how we will harness and use it. As society becomes increasingly digital-reliant, the demands created by tomorrows even more data-intensive applications whether virtual reality or real-time design programs will require a fundamental reimagining of how data flows.

1.2 Our approach to Smart Antenna

Firstly,In order to make an adaptive or smart antenna the primary step is beam forming.This beam should have a frequency ranging from 29GHZ-39GHZ which helps us to form a pencil beam.So that the desired user can only access the beam without any interferes or interferences. The antenna having millimeter wave frequency can be made using CST studio. Secondly,the beam formed need to be allocated to the desired user.So in order to allocate the beam,We need to know the path of the user which can be predicted using LSTMs(Long short term memory networks)

1.3 Prerequisites

1.3.1 Anaconda Navigator

Anaconda is a scientific Python distribution. It has no IDE of its own. The default IDE bundled with Anaconda is Spyder which is just another Python package that can be installed even without Anaconda.

Anaconda bundles a whole bunch of Python packages that are commonly used by people using Python for scientific computing and/or data science. It provides a single download and an install program/script that installs all the packages in one go. Alternatively, one can install Python first and then individually install all the required packages using pip. Additionally, it provides its own package manager (conda) and package repository. But it allows installation of packages from PyPI using pip if the package is not in Anaconda repositories,in addition to being a package manager, is also a virtual environment manager allowing you to install independent development environments and switch from one to the other.

1.3.2 What applications can I access using Navigator?

The following applications are available by default in Navigator:

JupyterLab

Jupyter Notebook

Spyder

VSCode

Glueviz

Orange 3 App

RStudio

1.4 CST STUDIO SUITE

CST STUDIO SUITE is a software package which can simulate and solve all electromagnetic problems from Low frequency to Microwave and optic as well as thermal and some mechanical problems.It is a high-performance 3D EM analysis software package for designing, analyzing and optimizing electromagnetic (EM) components and systems.Common subjects of EM analysis include the performance and efficiency of antennas and filters, electromagnetic compatibility and interference (EMC/EMI), exposure of the human body to EM fields, electro-mechanical effects in motors and generators, and thermal effects in high-power devices.

1.4.1 Steps to work with CST to simulate Antenna

step 1:create project

step 2:Choose MW,RF,Optical

step 3:Choose Antennas

step 4:Select Planar(Patch,slot,etc)

step 5:Choose Time domain

step 6:Select the units

step 7:Select the frequency range and monitors farfield at resonant frequency or any frequency need to monitor

step 8:click finish

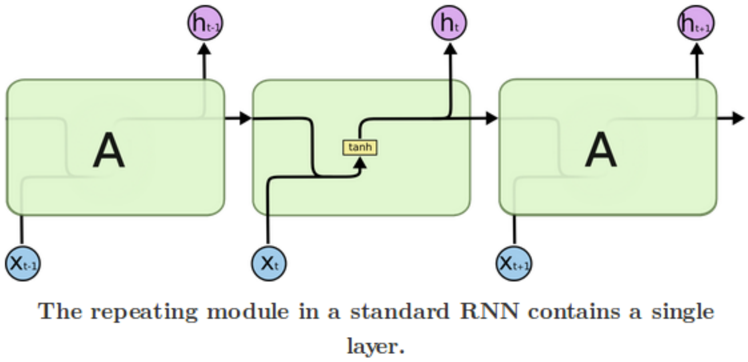


FIGURE 1.1: LSTM Networks with single layer

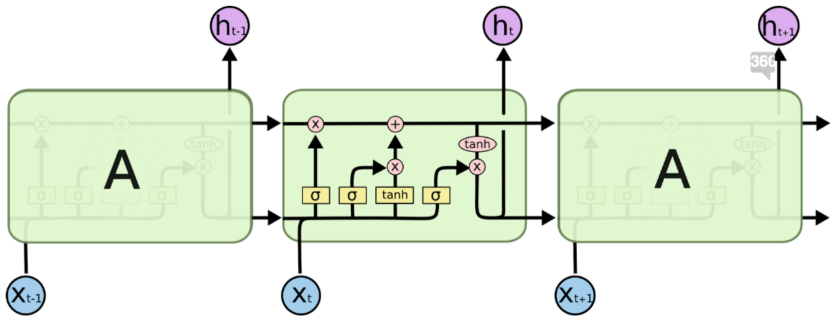


FIGURE 1.2: LSTM Networks with multiple layers

1.5 Deep Learning Based LSTM

LSTM networks: Long Short Term Memory networks usually called LSTMs are a special kind of RNN, capable of learning long-term dependencies. They were introduced by Hochreiter and Schmidhuber(1997),and were refined and popularized by many people in following work.They work tremendously well on a large variety of problems, and are now widely used. LSTMs are explicitly designed to avoid the long-term dependency problem. Remembering information for long periods of time is practically their default behavior, not something they struggle to learn! All recurrent neural networks have the form of a chain of repeating modules of neural network. In standard RNNs, this repeating module will have a very simple structure, such as a single tanh layer.

LSTMs also have this chain like structure, but the repeating module has a different structure. Instead of having a single neural network layer, there are four, interacting in a very special way.

An interesting feature of LSTM cells is the presence of an internal state which serves as the cells memory, denoted by mt.Based on a new input xt, its previous state mt1 and previous output ht1, the cell performs different operations using so-called gates. [8]

CHAPTER 2

Antenna Design and Simulation

2.1 Beamforming

It is the method used to create the radiation pattern of the antenna array by adding constructively the phases of the signals in the direction of the targets/mobiles desired, and nullifying the pattern of the targets/mobiles that are undesired/interfering targets. This can be done with a simple FIR tappeddelay line filter. The weights of the FIR filter may also be changed adaptively, and used to provide optimal beam forming, in the sense that it reduces the MMSE between the desired and actual beam pattern formed. Typical algorithms are the steepest descent, and LMS algorithms. There is an ever-increasing demand on mobile wireless operators to provide voice and high-speed data services. At the same time, these operators want to support more users per base station to reduce overall network costs and make the services affordable to subscribers. As a result, wireless systems that enable higher data rates and higher capacities are a pressing need[1].

Types of Smart Antenna

Two of the main types of smart antennas include switched beam smart antennas and adaptive array smart antennas.

Switched Beam:

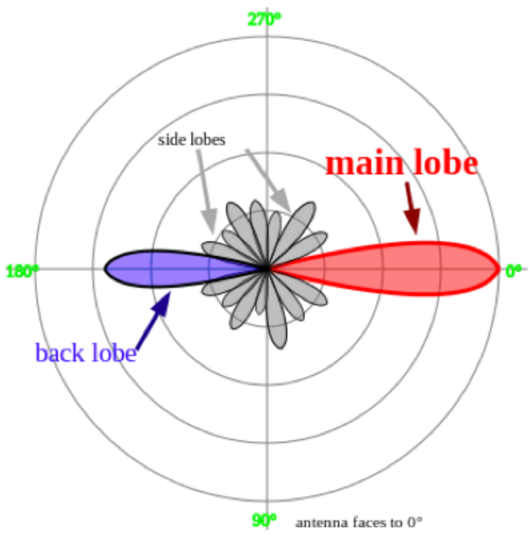


FIGURE 2.1: Antenna Beam Pattern

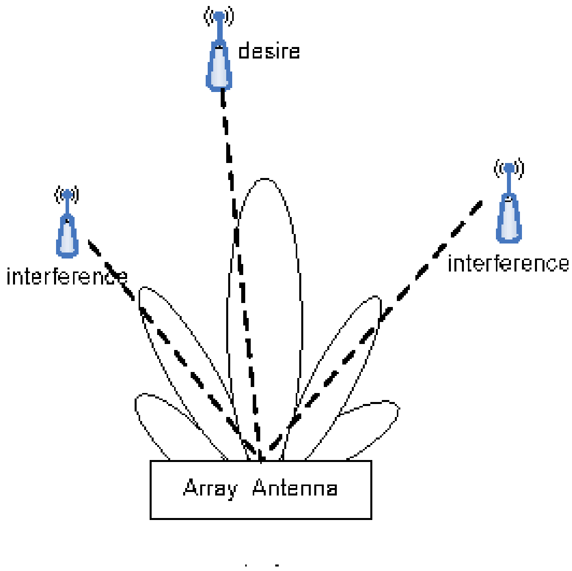


FIGURE 2.2: Switched Beam Antenna Pattern

Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams and switch from one beam to another as the mobile moves throughout the sector. Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element, switched beam systems combine the outputs of multiple antennas in such a way as to form finely directional beams with more spatial selectivity than can be achieved with conventional, single-element approaches [7].

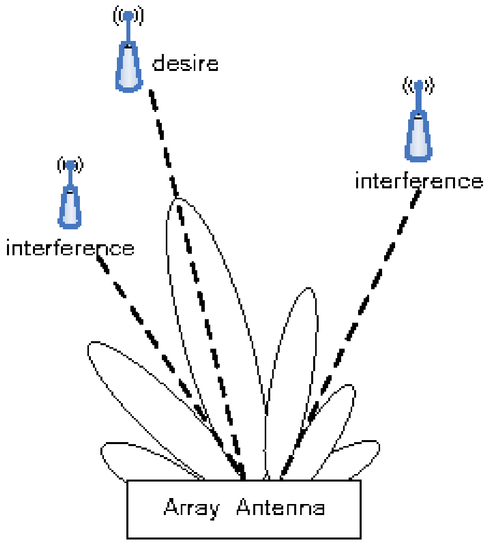


Figure 2.3: Adaptive Beam Antenna Pattern

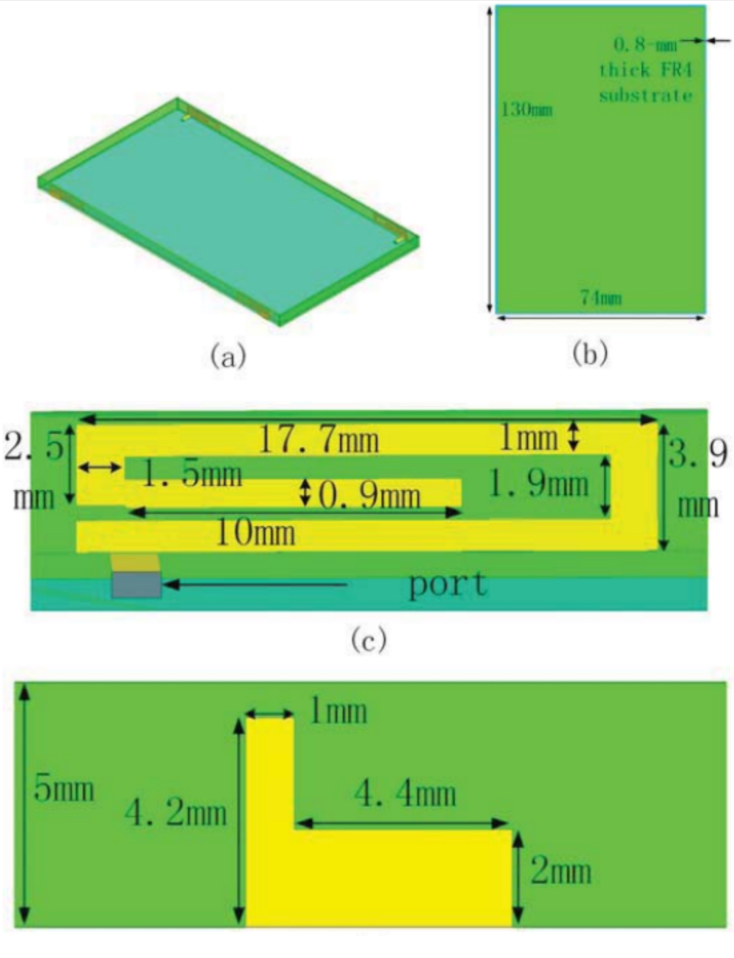
Adaptive Beam:

Adaptive antenna technology represents the most advanced smart antenna approach as on date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception. Both systems attempt to increase gain according to the location of the user, however, only the adaptive system provides optimal gain while simultaneously identifying, tracking and minimizing interfering signals[4].

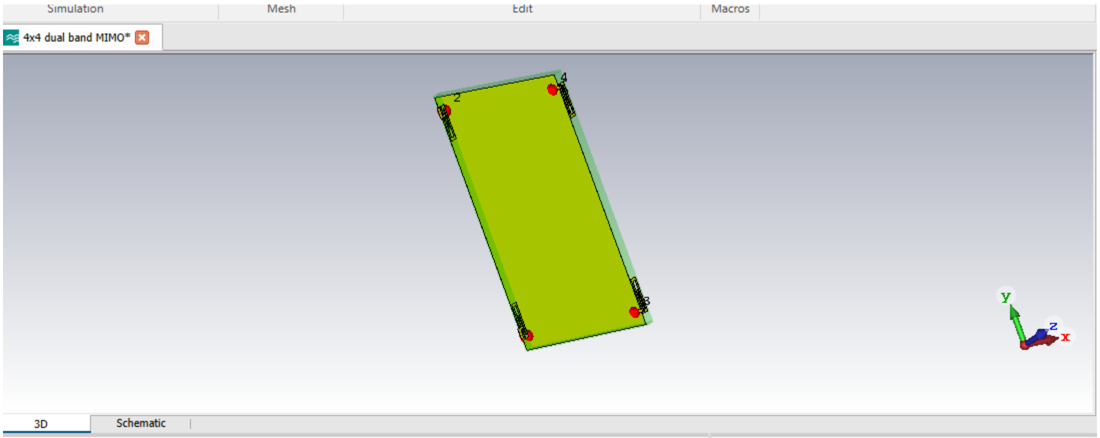
2.2 Design of a Dual-band MIMO Antenna

dual-band MIMO antenna which consist of four elements is proposed. The proposed antenna not only canoperating in the dual frequency band of 3300-3600 MHz and 4800-5000 MHz. but also a 12 dB of isolation is obtained. The structure and dimensions of the proposed antenna array is shown in Fig.1. As is seen, the antenna system consisting of four bent lines.The radiation part of the antenna can be divided into two parts: front radiation part is a bending line monopole, feed part as shown in Fig.1(c) below ; the back of the radiation part is a L-shaped short-circuit stub. The monopole adopts the bent line structure, and the coupling capacitance generated by the L-shaped branch behind helps to match the impedance of the low frequency band so that the low frequency can cover the frequency band of 3.5GHz better, the front feeder belt and monopole lengths resonate around 4900MHz and the coupling capacitors created by the back L-shaped branches and the front bend line contribute to high- frequency impedance matching[9].

Based on the reference Design of a Dual-band MIMO Antenna for 5G smartphone Application by Weijun zhang,Zibin Weng,Lei Wang [9] . This antenna consists of 4 antennas,it operating at 3300-3600 MHz and 4800-5000 MHz.

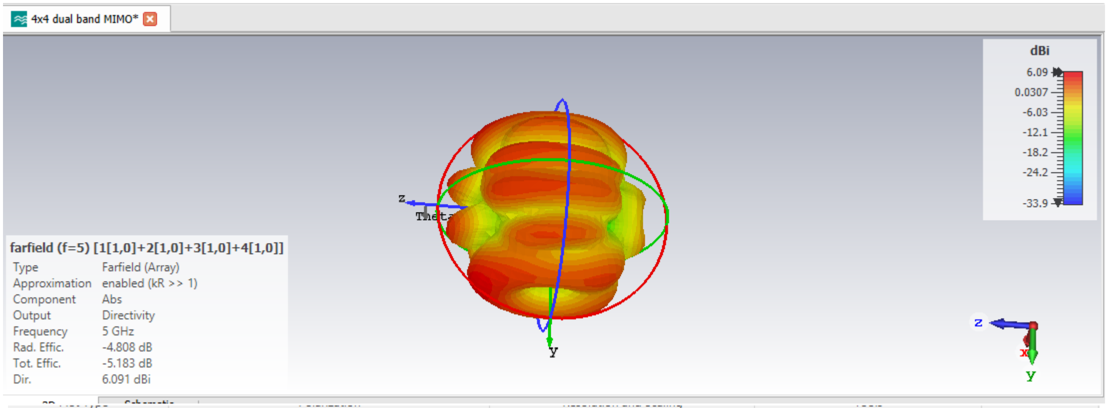


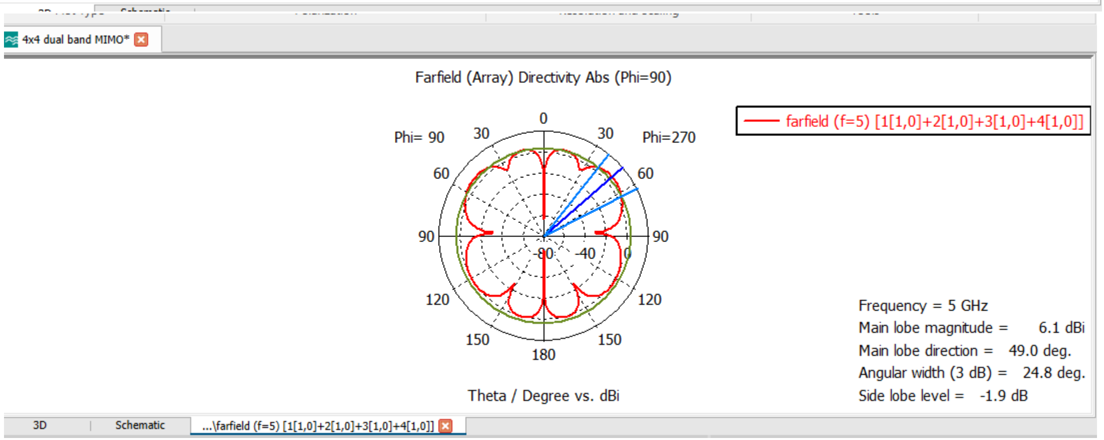
The proposed antenna array structure (a) Antenna 3D model. (b) Antenna model top view.(c) Antenna model main view.(d) Antenna element rear view.

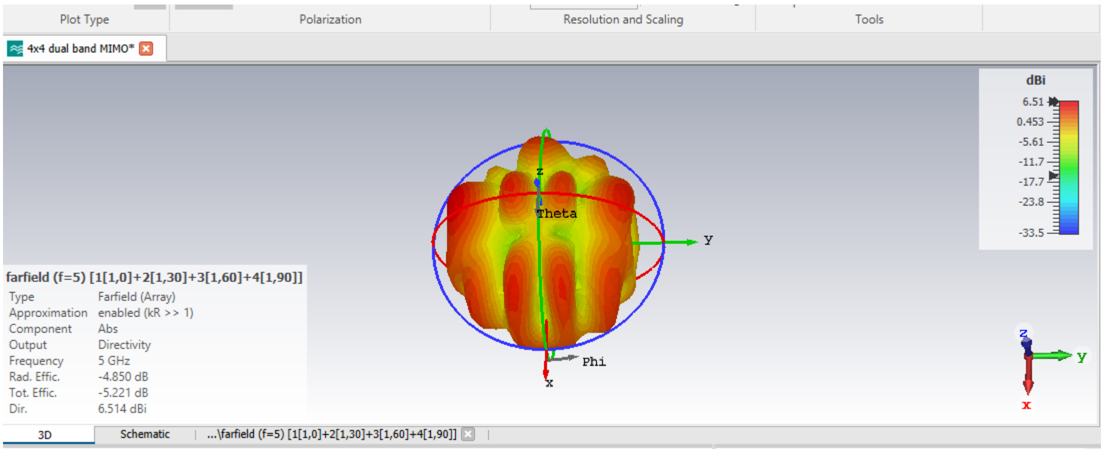


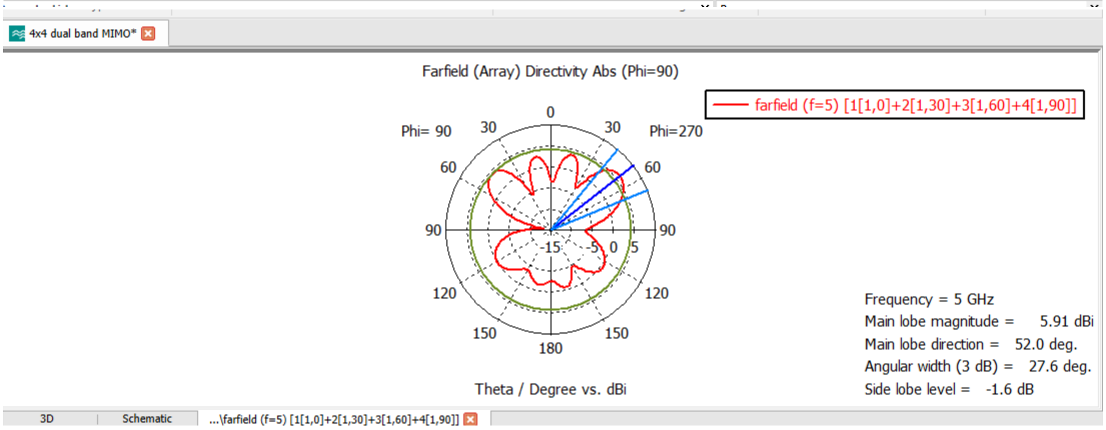
3D view of Desired Antenna

Simulation Results

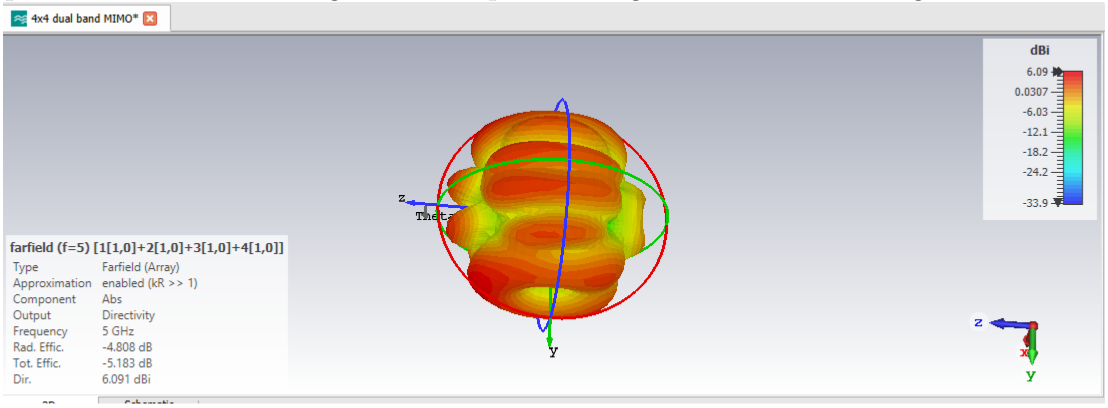




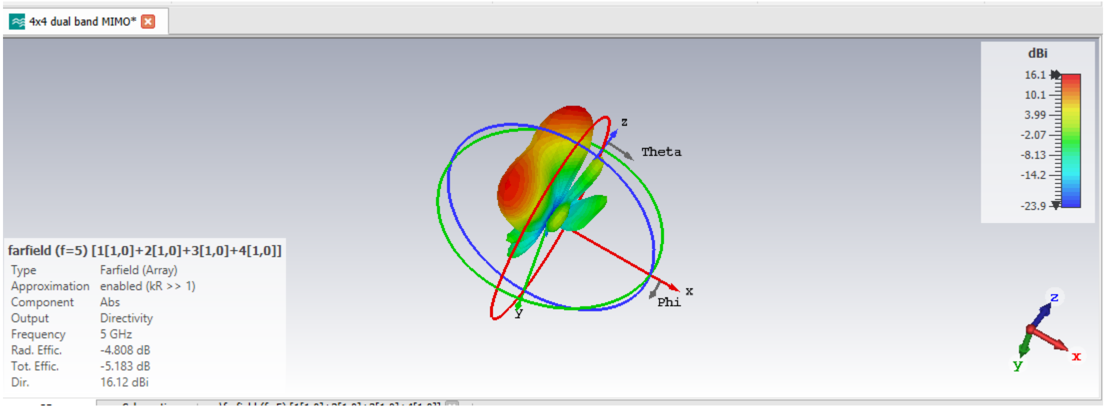




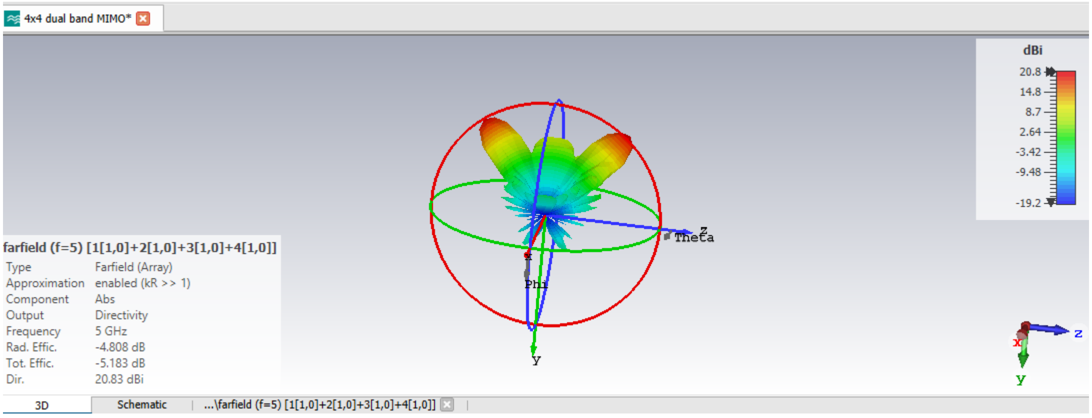
The above are the results taken at 5ghz frequency but at different magnitudes and phases. Since there is magnitude and phase change we can obtain change in direction.



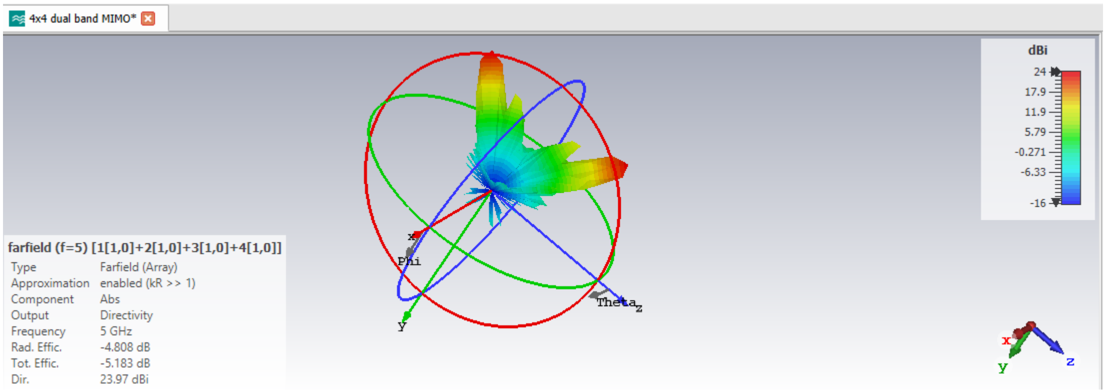
1a) 5ghz antenna 1 element



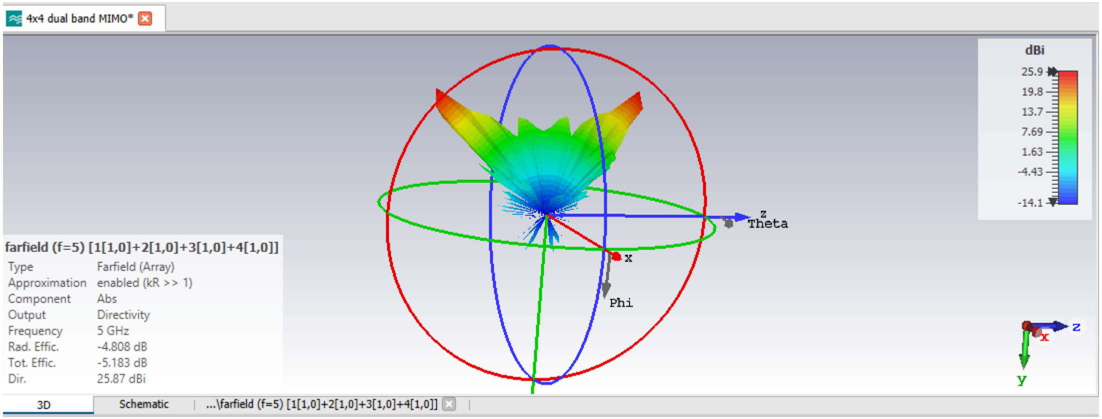
1b) 10x10 Array antenna



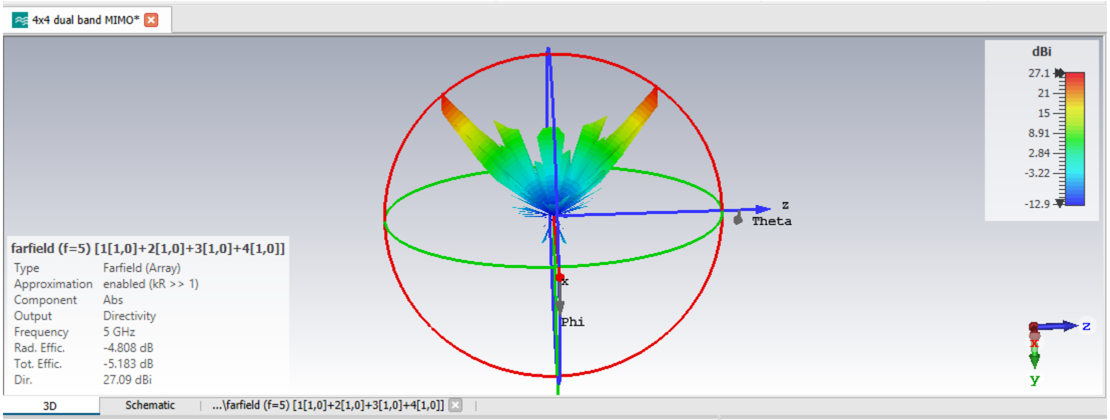
1c) 20x20 Array antenna



1d) 30x30 Array antenna



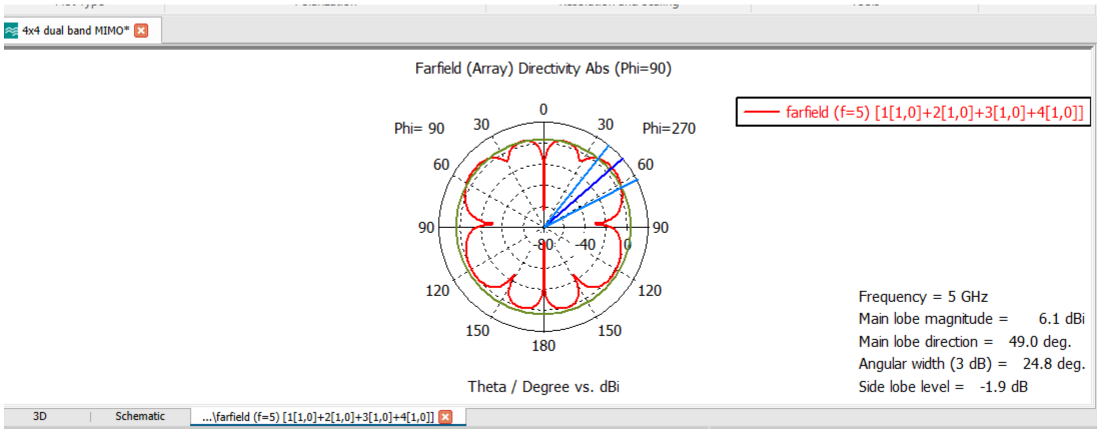
1e)40x40 Array antenna



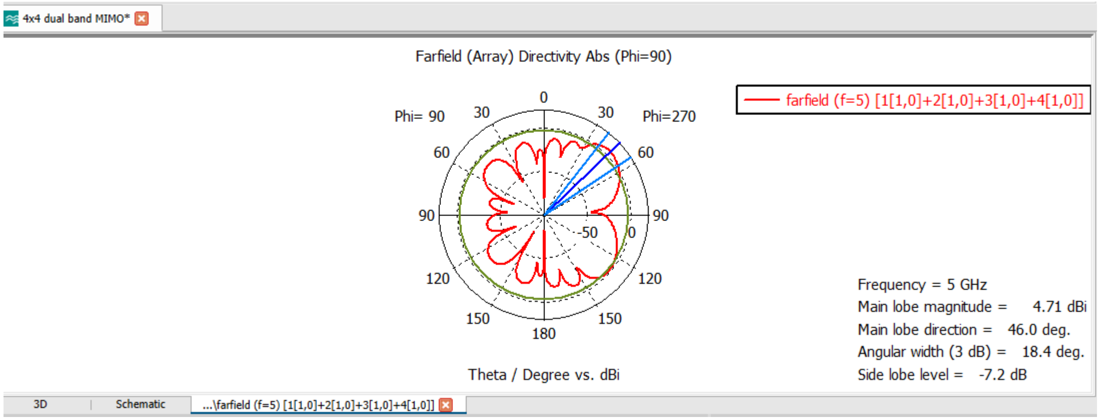
1f)50x50 Array antenna

The above figures 1a to 1f are the simulation results for 1x1 array to 50x50 array antenna respectively. From the above results it is evident that if we go on increasing number of antennas placed in array we can obtain Narrow beam.To decide whether we are getting narrow beam or wide beam we need 3dB bandwidths.

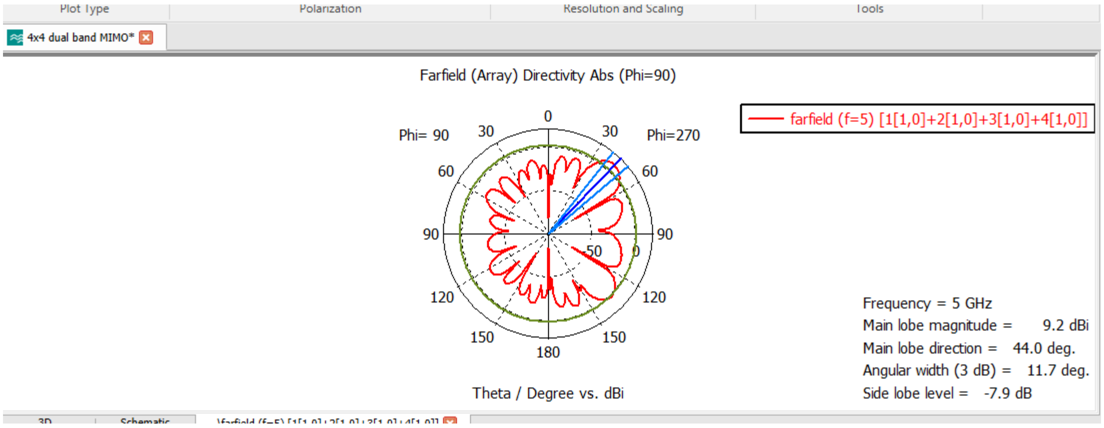
In order to find out 3dB beamwidth we require the Polar plots for the above.



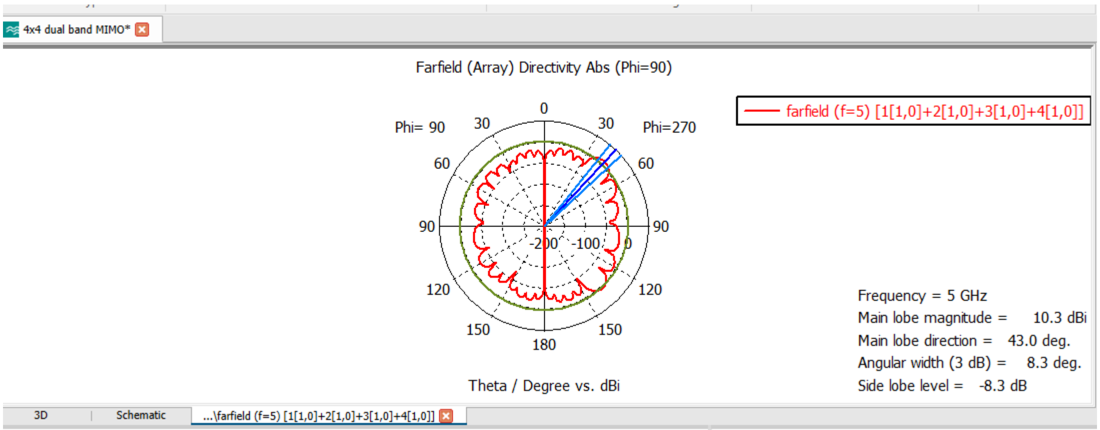
(2a) Polar Plot for 10x10 antenna



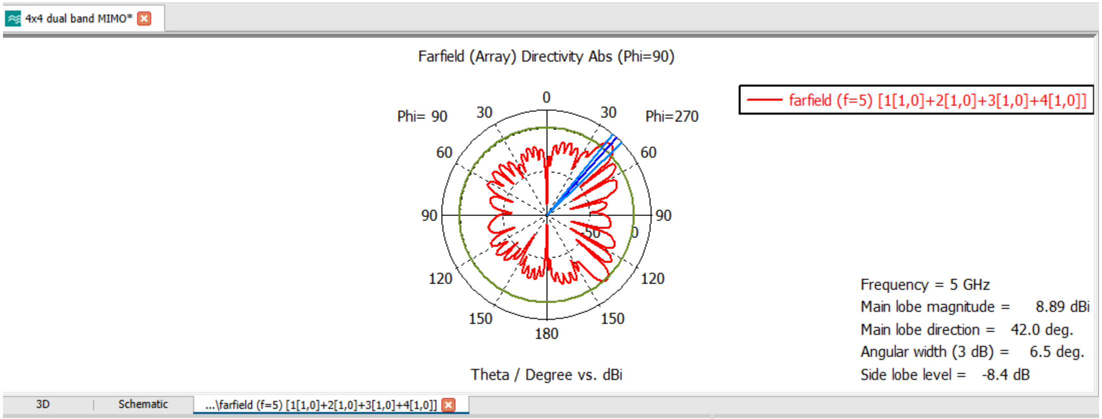
(2b) Polar Plot for 10x10 antenna



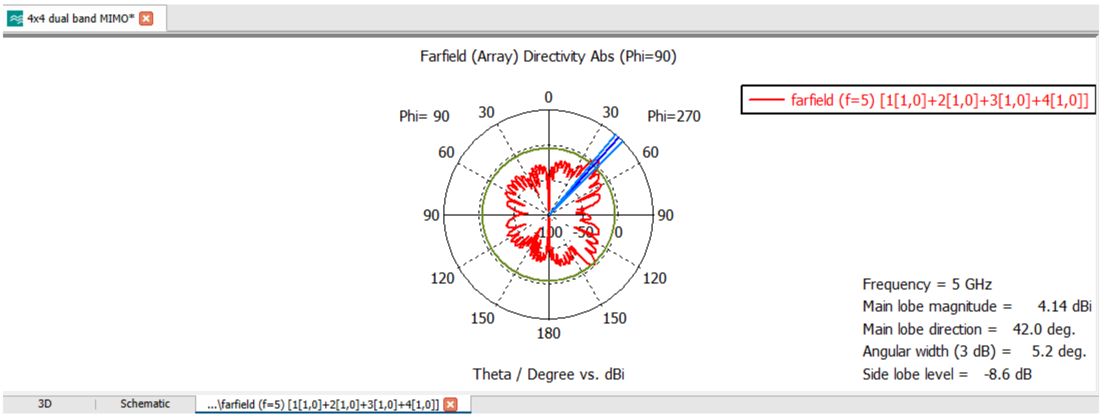
(2c) Polar Plot for 20x20 antenna



(2d) Polar Plot for 30x30 antenna



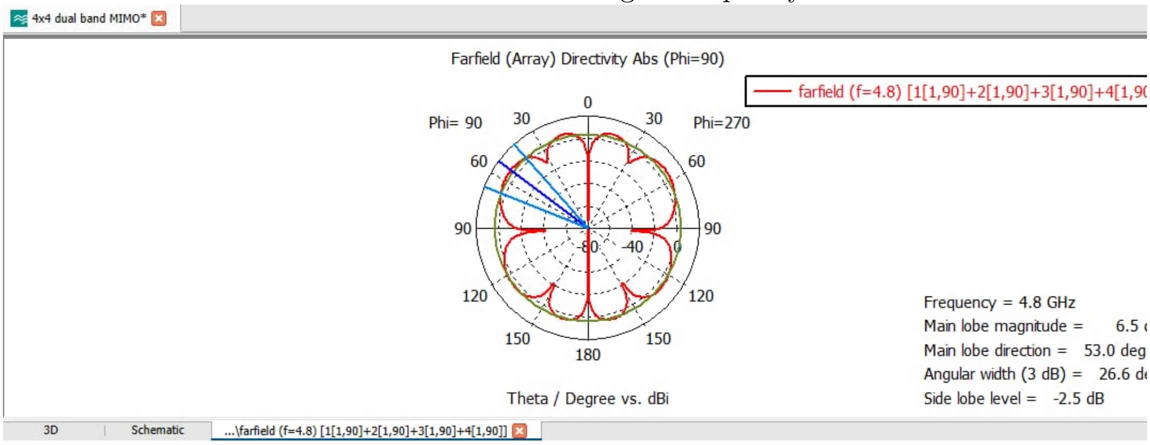
(2e) Polar Plot for 40x40 antenna



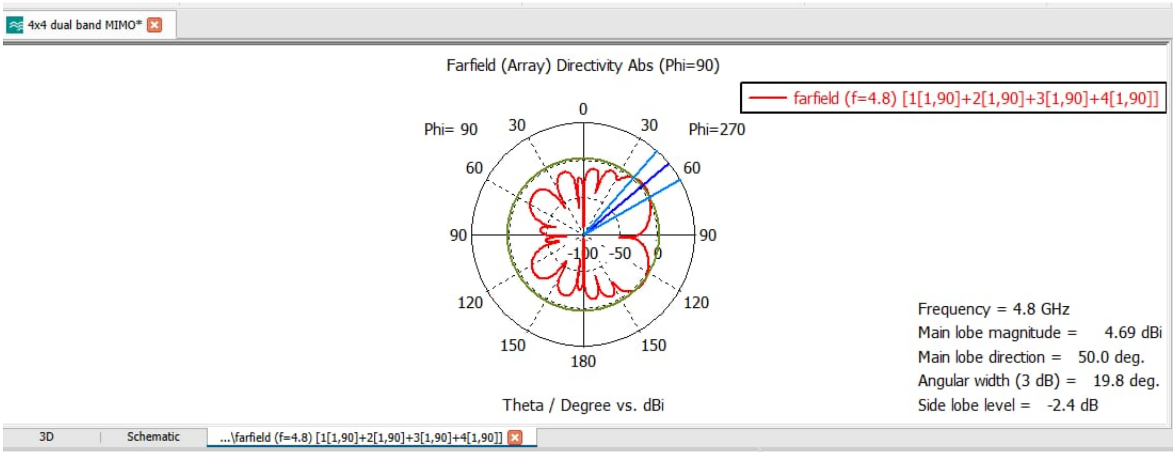
(2f) Polar Plot for 50x50 antenna

Figure no.	Main Lobe to Side lobe ratio	3dB Beamwidth(degrees)
2a	-3.21	24.8
2b	-0.66	18.4
2c	-1.16	11.7
2d	-1.24	8.3
2e	-1.05	6.5
2f	-0.48	5.2

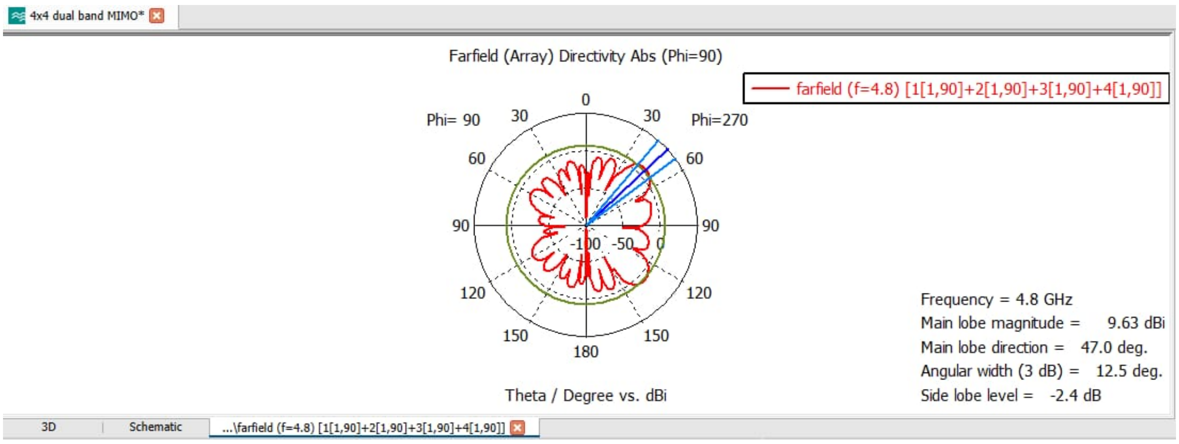
POLAR PLOTS AT 4.8ghz Frequency



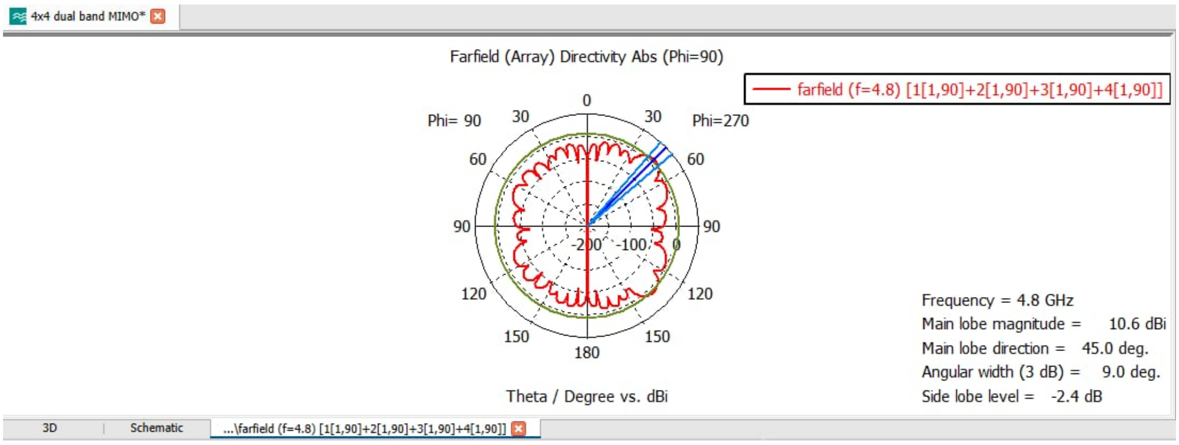
(3a) 4.8Ghz 1 element Antenna



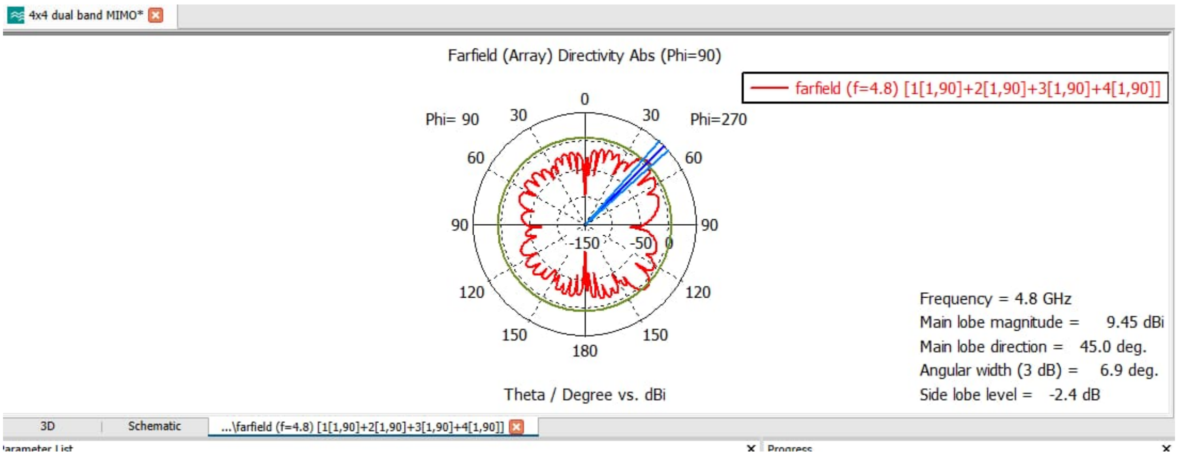
(3b)10x10 Array Antenna



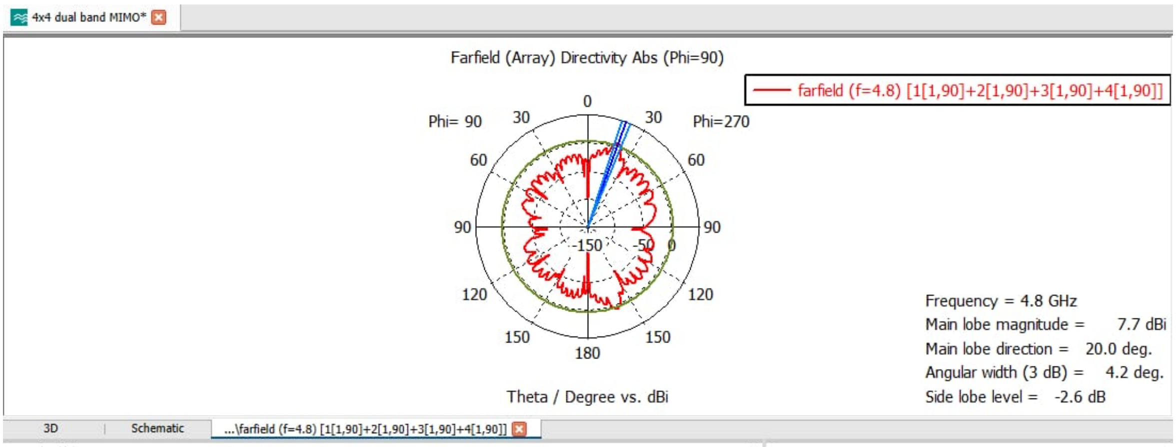
(3c)20x20 Array Antenna



(3d)30x30 Array Antenna



(3e)40x40 Array Antenna



(3f)50x50 Array Antenna

Figure no.	Main Lobe to Side lobe ratio	3dB Beamwidth(degrees)
3a	-2.6	26.6

3b	-1.95	19.8
3c	-4.01	12.5
3d	-4.41	9.0
3e	-3.93	6.9
3f	-2.96	4.2

As the number of antennas are increasing 3db beamwidth is decreasing. Since 3db beamwidth is very small it comes under Narrow beam. By adjusting phases and magnitudes of antennas we can get high main lobe to sidelobe magnitude .

Frequency(GHz)	Mainlobe Magnitude(dB)	Direction(deg)	Weights and Phase
4.9	6.4	54	[1,0]+[2,0]+[4,0]+[8,0]
4.9	6.04	56	[1,0]+[2,30]+[4,60]+[8,90]
4.9	5.84	54	[2,0]+[2,30]+[2,60]+[2,90]
4.9	6.48	52	[2,15]+[2,30]+[2,45]+[2,60]
4.9	6.37	55	[4,15]+[8,30]+[16,45]+[32,60]
4.9	6.04	56	[4,30]+[8,60]+[16,90]+[32,120]
4.9	6.66	51	[1,90]+[1,90]+[1,90]+[1,90]

Frequency(GHz)	Main to sidelobe ratio	3dB Angular width(deg)
4.9	3.04	28
4.9	2.62	30.5
4.9	4.86	29.5
4.9	7.2	26.8
4.9	3.03	28.7
4.9	2.62	30.5
4.9	8.32	25.9

Table:Simulation results of 4.9Ghz frequency

Frequency(GHz)	Mainlobe Magnitude(dB)	Direction(deg)	Weights and Phase
5	5.6	52	[1,0]+[2,0]+[4,0]+[8,0]
5	5.7	54	[1,0]+[2,30]+[4,60]+[8,90]

5	5.9	52	[2,0]+[2,30]+[2,60]+[2,90]
5	6.3	51	[2,15]+[2,30]+[2,45]+[2,60]
5	5.9	53	[4,15]+[8,30]+[16,45]+[32,60]
5	5.8	54	[4,30]+[8,60]+[16,90]+[32,120]
5	6.1	49	[1,90]+[1,90]+[1,90]+[1,90]

Frequency(GHz)	Main to sidelobe ratio	3dB Angular width(deg)
5	9.40	8.4
5	8.83	8.7
5	6.77	8.0
5	12.47	7.1
5	8.48	8.3
5	8.83	8.7
5	6.43	6.8

Table:Simulation results of 5Ghz frequency

From the above two tables we can see that the direction of main lobe changes as the weights and phases are varied.And also 3dB angular width decreases from 4.9GHz to 5Ghz.

Mainlobe magnitude(dB)	3dB Angular width(deg)
19.69	6.2
18.85	5.4
13.5	5.1
8.16	4
17.4	5.3
18.8	5.4

Table:Array of 20X20 Antenna results

Mainlobe magnitude(dB)	3dB Angular width(deg)
29.8	3.8

29	4.3
29.8	3.8

Table:Array of 30X30 Antenna results

Results of the above two tables depict that, as we increase antenna arrays narrow beam is achieved which is vital for Smart Antenna.

CHAPTER 3

LSTM Networks

As we have already done beam-forming through CST studio.The next stage of allocation of beam is made possible through finding the trajectory of the vehicle/desired user.So now our main concern is to find the trajectory of the vehicle.

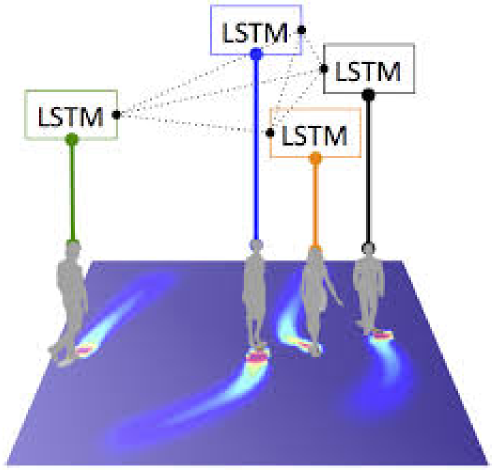
3.1 Methodology to find Trajectory

Inputs: x-y coordinates of sequential steps of a person/vehicle.

Output: x-y coordinate of the next step of this person/vehicle.

Methods: LSTM, KNN with linear regression.

All the data is fed/uploaded through the jupyter notebook.When you open a new Jupyter notebook, you'll notice that it contains a cell. Cells are how notebooks are structured and are the areas where you write your code. To run a piece of code, click on the cell to select it, then press SHIFT+ENTER or press the play button in the toolbar above. This model compares performances of different methods on predicting x-y coordinates based on sequential time steps.We are interested in predicting the future trajectory of people based on their past positions.We propose an LSTM model which can learn general human movement and predict their future trajectories[3]. This is in contrast to traditional approaches which use hand-crafted functions such as Social forces. We demonstrate the performance of our method on several public datasets. Our model outperforms state of the art methods on some of these datasets.



In particular, We introduce a Social pooling layer which allows the LSTMs of spatially proximal sequences to share their hidden states with each other. This architecture, which we refer to as the Social-LSTM, can automatically learn typical interactions that take place among trajectories which coincide in time[2].Finally, we demonstrate that our Social-LSTM is capable of predicting trajectories of pedestrians much more accurately than state of the art methods on two publicly available datasets: ETH[6], and UCY[5]. We assume that each scene is first preprocessed to obtain the spatial coordinates of the all people at different time instants.At any time-instant,the ith person in the scene is represented by his/her xy-coordinates(Xit ,Yit). We observe the positions of all the people from time 1 to Tobs , and predict their positions for time instantsTobs+1 to Tpred . This task can also be viewed as a sequence generation problem, where the input sequence corresponds to the observed positions of a person and we are interested in generating an output sequence denoting his/her future positions at different time instants.

The above figure shows we use a separate LSTM network for each trajectory in a scene. The LSTMs are then connected to each other through a Social pooling (S-pooling)layer. Unlike the traditional LSTM, this pooling layer allows spatially proximal LSTMs to share information with each other.The bottom row shows the S-pooling for one person in the scene. The hidden states of all LSTMs within a certain radius are pooled together and used as an input at the next time-step.

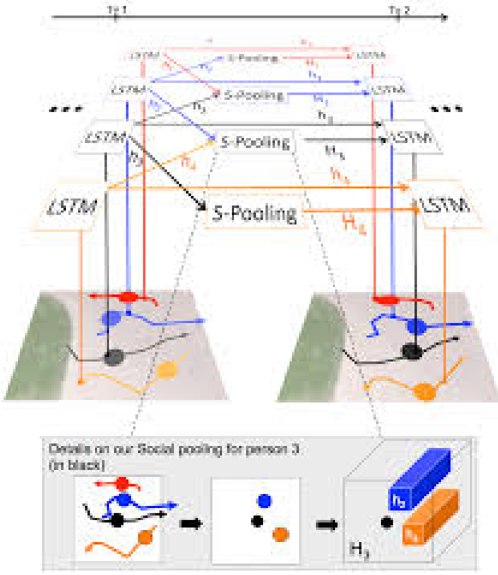
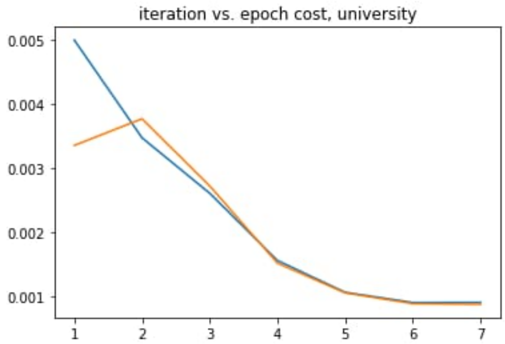


FIGURE 3.1: LSTM network for each trajectory

3.2 Training and Testing Result

```
('number i: ', 465, 'iteration: ', 1524, 'cost: ', array([0.02144858]))
('number i: ', 466, 'iteration: ', 1672, 'cost: ', array([0.01886506]))
('number i: ', 467, 'iteration: ', 1808, 'cost: ', array([0.01830542]))
('number i: ', 468, 'iteration: ', 1812, 'cost: ', array([0.01816398]))
('number i: ', 469, 'iteration: ', 1794, 'cost: ', array([0.01797719]))
('number i: ', 470, 'iteration: ', 1789, 'cost: ', array([0.01796732]))
('number i: ', 471, 'iteration: ', 1411, 'cost: ', array([0.02219168]))
('number i: ', 472, 'iteration: ', 1396, 'cost: ', array([0.02221413]))
('number i: ', 473, 'iteration: ', 1389, 'cost: ', array([0.02227078]))
('number i: ', 474, 'iteration: ', 1406, 'cost: ', array([0.02240618]))
('number i: ', 475, 'iteration: ', 1440, 'cost: ', array([0.02201221]))
('number i: ', 476, 'iteration: ', 1554, 'cost: ', array([0.01871184]))
('number i: ', 477, 'iteration: ', 1745, 'cost: ', array([0.01740353]))
('number i: ', 478, 'iteration: ', 1796, 'cost: ', array([0.01759543]))
('number i: ', 479, 'iteration: ', 1785, 'cost: ', array([0.01769305]))
('number i: ', 480, 'iteration: ', 1776, 'cost: ', array([0.01769562]))
('number i: ', 481, 'iteration: ', 1378, 'cost: ', array([0.02211546]))
('number i: ', 482, 'iteration: ', 1423, 'cost: ', array([0.02219775]))
('average cost: ', array([0.01994767]))
```

```
('Train iteration', 1, 'train loss:', 0.005003572981028507)
('Train iteration', 1, 'dev loss:', 0.003355906632107993)
('Train iteration', 2, 'train loss:', 0.003474856972590916)
('Train iteration', 2, 'dev loss:', 0.003772919299080967)
('Train iteration', 3, 'train loss:', 0.0026066928785035593)
('Train iteration', 3, 'dev loss:', 0.002721314764736841)
('Train iteration', 4, 'train loss:', 0.001554645492514181)
('Train iteration', 4, 'dev loss:', 0.0015126501113021126)
('Train iteration', 5, 'train loss:', 0.001056791873027881)
('Train iteration', 5, 'dev loss:', 0.0010472695643935974)
('Train iteration', 6, 'train loss:', 0.0008963728983265657)
('Train iteration', 6, 'dev loss:', 0.0008785741791749995)
('Train iteration', 7, 'train loss:', 0.0008986188855487854)
('Train iteration', 7, 'dev loss:', 0.0008699880961406355)
```




```
('Test loss:', 0.0005968359269900248)
```

CHAPTER 4

Conclusion

Smart antenna arrays use Multiple Input Multiple Output (MIMO) at both the source (transmitter) and the destination (receiver) to improve signal quality. This is in contrast to non-array systems in which a single antenna (and signal path) is used at the source and the destination. The market for smart antennas is nothing new as they provide efficient coverage for 2G, 3G, and LTE. However, 5G smart antennas will be necessary to provide mobility support for many new and enhanced apps and services such as virtual reality, self-driving cars, connected vehicles, and Voice over 5G (Vo5G).

Massive MIMO Beamforming is the state-of-the-art technology creating 5G signals which enables a greatly expanded network capacity. This technology will substantially increase the peak data rate and throughput per user, reaching a connection speed of up to 10Gbps. With a large antenna array at a base station, this technology can simultaneously support a huge number of users. Moreover, the technology can provide a better signal-to-interference-plus-noise ratio (SINR) and spectral efficiency, as well as mitigate inter-cell interference by sending a focused signal stream to a specific user instead of a transmission of a broadcast signal. Massive MIMO Beamforming supports both 4G and 5G networks, which provides flexibility for operators to upgrade their networks and services to 5G.The use of millimetre-wave techniques at 60 GHz offers many advantages for short-range systems compared to radio methods at lower frequencies. The main advantages of this frequency band are, on the one hand, the large (license-free) bandwidth which permits high data rates and in the short wavelength on the other which leads to small antenna dimensions even with multi-antenna systems.

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