Design and Analysis of 5G base station Series-Fed Patch Antenna

A thesis was submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering

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DECLARATION

This is to confirm that this thesis, named " **Design and Analysis of 5G base station Series-Fed Patch Antenna**," was done by the following students under my supervision. They have carried out this work in the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the electrical and electronic engineering Bachelor of Science degree.

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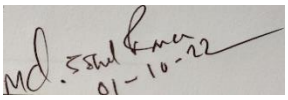

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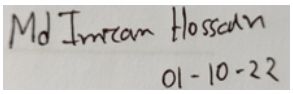

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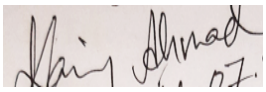

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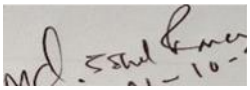

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We would like to express our boundless honor and respect to our thesis Supervisor Professor Mr. Md. Sohel Rana, Lecturer (Senior Scale), Department of Electronics and Electronic Engineering, Daffodil International University, for his encouragement and for permitting us to involve with an electronics-related thesis. We have done my view according to his direction.

We want to thank you in the most sincere way possible, Dr. Md. Rezwanul Ahsan, Professor, and Head, of the Department of Electrical & Electronic Engineering, Daffodil International University.

I thank all staff of my departments for their help during the working period. We must acknowledge with respect the constant support and patients of our parents.

Finally, we beg pardon for our unintentional errors and omission, if any.

ABSTRACT

Cellular services have experienced incredible growth and advancement in the last several years, including customers, data rates, services, and more. The first generation of mobile wireless communication was 1G. Subsequent generations included 2G, 3G, and 4G, with 5G and 6G still being researched. The study compares 4G and 5G wireless technologies in terms of speed, frequency band, switching design foundation, and forward error connection.

Poor coverage, poor interconnection, poor service quality, and a lack of flexibility are issues that may be resolved with the aid of 5G wireless technology. We discussed the variations among mobility communication eras in this essay.

The wireless scientific community is already preparing for 5G's replacement as the utilization of mobile radio broadcasting picks up speed throughout the world. The requirements of more excellent information, low-latency, and hyper-reliability applications are being met by 5G. The key features of the 6G network, along with the social, economic, and technological components, are then covered in a systematic order. Critical technologies are anticipated to assist the transition to 6G.

This paper's comparative analysis of those eras is our effort.

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Chapter-1

Organization

1.1 INTRODUCTION

Voice calls were just the primary point of contact from the first generation (1G) to the second generation (2G), and simple email was possible. However, beginning with the 3rd generation (3G), mobile devices can deliver data communications such as multimedia data such as pictures, audio, and video. Bangladesh Sector Power Grid Company Ltd. (PGCB) is the only company in Bangladesh, and Rural Electrification Board (REB), including Palli Bedyut Samity (PBS), is one of the largest distributors around this country.

Smartphones have gained popularity due to massive wireless communication up to 100 Mbps with Long Term Evolution (LTE), and many multimedia communication systems have developed. Mobile internet, the next generation of 4G technology, has already reached a maximum communication speed of as close to 1 Gbps. The fifth-generation (5G) mobile communication system is a more technologically advanced version of the fourth-generation (4G) system. With scientific features such as high speed, large capacity, low latency, and massive connectivity, 5G is expected to create better value as a primary fundamental processing system in the future industry in many ways, along with machine learning (AI) and the Internet-of-things (IoT), as well as other significant multimedia upgrading communication systems. As a result of

5G evolution and 6th generation (6G) innovation, the "3rd Wave" launched by 5G is expected to be a giant wave in 2030, boosting industry and society's upcoming technological evolution from the viewpoint of 5G and 6G evolution.

1.2 EVOLUTION

Due to the fast development of digital technology, mobile communication has become more popular recently. The 1G revolution succeeded with 2G, 3G, 4G, 5G, and then 6G.

1.3 GENERATION ONE (1G)

A first-generation technology, known as 1G, was created in the 1980s. It was based on a standard analog system. The first deployment of the 1G network was in Japan, so it quickly spread to the rest of the world. It was used for voice calls based on the Improved Mobile Telephone Technology.

Here below are some of the essential characteristics:

- 2.4 Kbps is the maximum speed available
- The voice quality is poor
- A small capacity
- The phone is quite large
- Analog-based system
- The number of calls dropped in frequency
- There is no security.

1.4 GENERATION TWO (2G)

The second generation, 2G, was launched in Finland in 1991. It is based on a digital system. Due to 2G networks, mobile phone networks were able to deliver services like Text messages, video messages, and MMS. The text messages are completely secured, but only the receiver can see and get them. Since 1G networks use analog radio waves, 2G networks use digital radio waves.

Both systems use digital signals to link the cell phone towers to the rest of the mobile system.

Here below are some of the essential characteristics:

- Data transmission rates of up to 64 kilobits per second (kbps) are possible
- Processing issues with video
- The digital signal is dropping
- Improves the quality and capacity of the product
- The system is digital.

1.5 GENERATION THREE (3G)

The 3rd generation system, known as 3G, was already launched in 2000. It's also based on the Global Telecommunication Union, part of the Global Mobile Telecommunication program. It uses both packet switching and loop changing methods. Smart broadcast TV, GPS, and video calls are just a few of the value-added services offered by 3G networks.

- Here below are some of the essential characteristics:
- Up to 2Mbps of download speed is available

- In video conferencing, there is a lot of clarity
- Large email messages get sent as well as received
- Allows for speedier contact
- Just eleven seconds to 1.5 minutes are needed to download a
- three-minute high-quality audio track.
- Video chat, GPS, smart TV, and more programs are provided.

Chapter-02

Evolution

2.1 GENERATION FOUR (4G)

The fourth generation of mobile networks, called 4G, was launched in 2010. Long Term Evolution (LTE) is a kind of 4G network. Additional services, such as Multimedia Magazines, allow users to view television shows and communicate data more quickly than in prior generations.

Here below are some of the essential characteristics:

- Speeds of up to 100 Mbps are possible.
- Video streaming is in high definition.
- Extremely safe
- Fast capacity and high speed
- Bits are cheap.

2.2 4G IMPLEMENTATION

- Television in three dimensions
- Streaming video
- Conferencing over video
- High-Speed Internet on a Mobile Device
- Services related to gaming.

2.3 4G'S DOWNFALLS

- It is necessary to engage in challenging combat.
- The usage of batteries has increased.
- Implementation is complex.

2.4 GENERATION FIVE (5G)

The fifth generation of wireless communication devices, which began in the late 2010s, is the most recent. High data rates, low latency, energy efficiency, cost savings, increased system capacity, and massive device connectivity are all goals of 5G performance. Global Wireless and the World Wide Web will be the primary focus of 5G. It is an unlimited wireless network.

Here below are some of the essential characteristics:

- Low-cost, high-speed Internet
- Fast capacity, high speed
- Data transfer is more rapid than in earlier generations
- More significant phone storage, more immediate calling, and a more
- unmistakable sound
- It's also able to communicate in real-time with a lag of less than a millisecond.
- Better functional and elegant.

2.5 4G VS. 5G. WHAT'S THE DIFFERENCE

Specifications	4G	5G
Starting from the beginning	2010	2015
Maximum speed	1Gbps	10Gbps
Efficiency in the Spectral Domain	30 b/s/Hz	120 b/s/Hz
Latency	10ms (radio)	<1ms (radio)
Frequency of Connections	1000/Km2	1000000/Km2
Data from Frequency Bands	2 to 8 GHz	3 to 300 GHz
Mobility	350Kmph	500Kmph

Chapter-03

5G Challenges

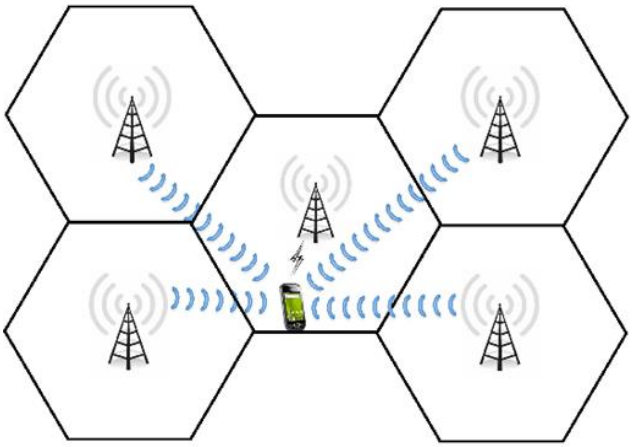
3.1 5G CHALLENGES

i. Technical challenges

- Intercellular Communication
- Controlling Medium Access Efficiently
- Controlling Traffic. Several Options.

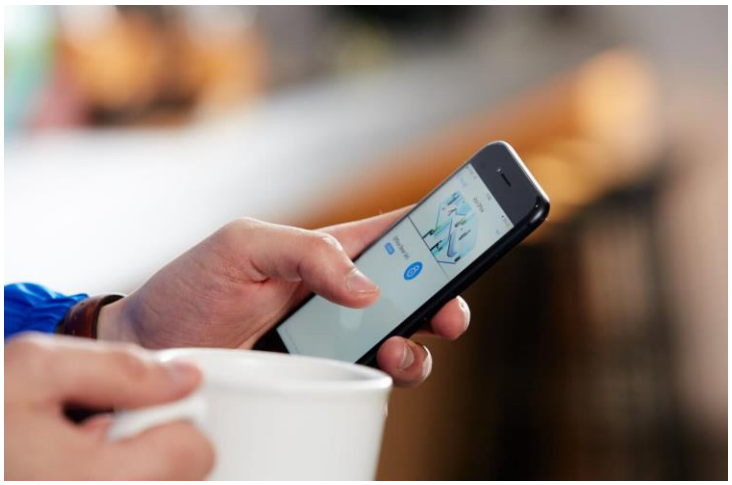
3.2 INTERCELLULAR COMMUNICATION

It is among the most pressing technological concerns. Conventional macro cells and contemporaneous tiny cells have different sizes, which causes interference.



3.2 CONTROLLING MEDIUM ACCESS EFFICIENTLY

When a device and intelligent access points and user terminals are necessary, user bandwidth will be limited, latency will be high, and the hotspot will be unable to deliver high throughput using cellular technology. To maximize the system, it must be thoroughly explored.



3.3 CONTROLLING TRAFFIC

In contrast to typical human-to-human traffic in wireless networks, many machine-to-machine devices in a cell may provide primary. System issues, resulting in overload and latency.

3.5 TYPICAL DIFFICULTIES

Typical difficulties

- Safety and Confidentiality
- Several Options
- Cyberlaw legislation.

3.6 SAFETY AND CONFIDENTIALITY

One of the most significant issues that 5G faces are ensuring personal data security. 5G will have to
Clarify the unknowns around security risks such as trust, privacy, and cybersecurity, which are on the rise worldwide.

3.7 SEVERAL OPTIONS

With existing radio signal services, 5G will significantly challenge providing services to diverse networks, technologies, and devices in various geographic locations.
So, the issue is to standardize wireless services that are dynamic, global, consumer, and data-rich to meet people's high expectations.

3.8 CYBERLAW LEGISLATION

With 5G's high speed and widespread availability, cybercrime and other forms of fraud may arise.

Chapter-04

Generation six (6G)

4.1. GENERATION SIX

Wireless mobile communication is cutting-edge technology in its sixth generation (6G).6G is also known as 5g Long-Term Extension. It is planned that 5G technology be integrated to provide worldwide coverage. 6G provides terabits per second while maintaining microsecond latency. When traveling long distances, it delivers high data rates and fast Internet speeds through wireless and mobile devices with data ranges up to 11Gbps. Multimedia video, high-speed Internet access, and Global mapping satellite networks are employed for resource monitoring and weather parameters. 6G will be based on an all-IP network and a real-world wireless environment.

4.2. 6G'S FEATURES

- Speeds of up to 10-11 Gbps are possible.
- Internet connectivity with high bandwidth
- Microsecond latency and unrestricted bandwidth are also available.
- Cities, towns, and villages with intelligent homes are all on the horizon.
- ATMs are accessible from the comfort of one's own home.

4.3 5G VS. 6G: WHAT'S THE DIFFERENCE

Specifications	5G	6G
Starting at the beginning	of 2015	From 5G forward
The speed of data	From 1 Gigabit per second to 20 Gigabits per second	One terabit per second
Bands of Frequency	Sub 6 GHz mm-wave for fixed access	Sub 6 GHz mm-wave for mobile access
Technology	4G+www	5G+Satellite
Latency	5 ms	< 1 ms
Experience of the user	Everywhere 50 Mbps 2D	Everywhere 10 Gbps 3D

4.4 6G REQUIREMENTS

REQUIREMENTS OF 6G

- **Resolving social issues**
- **Humans and objects can communicate.**
- **Expansion of the communication landscape**

- **Resolving social issues**

That globe is projected to grow into a place where every person, data, and thing can be accessed from anywhere in an ultra-real experience, with no limits on working hours or Time. This would significantly reduce social and cultural gaps between rural and urban regions, prevent urbanization and foster local development. It has the potential to reduce stress in 's careers.

- **Humans and objects can communicate**

Developed smartwatch features, such as XR (virtual reality, augmented reality, and mixed reality), high-quality photographs, and 3d objects surpassed 8K, and new five Sense communication systems, such as senses, will propagate, making communication systems between humans and humans and things ultra-real and rich. Massive data analysis, comprising high-definition photos and device management with ultra-low latency will be carried out by machines, necessitating high speed and low latency performance far beyond human capability.

- **Expansion of the communication landscape**

Technologies has become as common as the air we breathe and as necessary as power and water. It is just not essential for users to be informed of the communication settings or the communication service area. With the increase in the activity area of people and things, communication with the environment will be necessary everywhere.

Large walls, drones, flying vehicles, airplanes, and event space will be biological activity areas and communication areas will include not only the ground but also the sky and orbit.

Chapter-05

The vision of 6G

5.1 MANUFACTURING WITH INTELLIGENCE

The digital economy may become overloaded by deploying new technologies for agricultural development. By utilizing information technology, 6G will achieve intelligent production. Agriculture, for example, makes use of drones. Virtual reality and robotics will improve factory efficiency. 6G will feature more intelligent manufacturing thanks to new technology such as automated systems.

5.2 THE INTELLIGENT SOCIETY

In 2030, the universal coverage network will significantly increase public service coverage while bridging the digital gap between locations. Generally, a 6G network will improve social control and provide the groundwork for high society.

5.3 FLEXIBILITY IN THE NETWORK

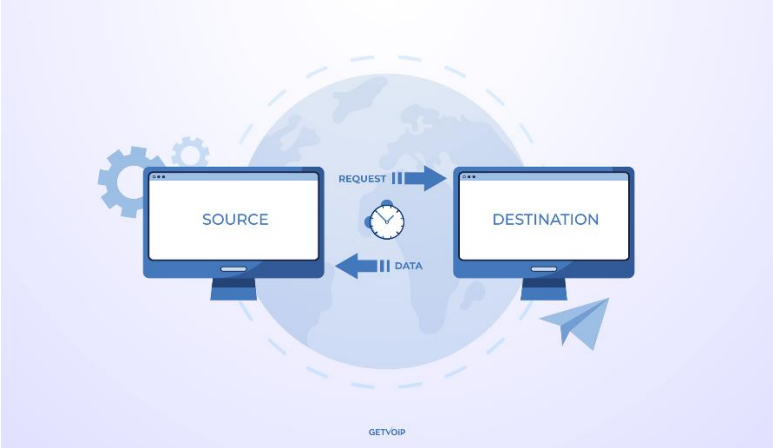
6G intends to boost network flexibility by saving electricity, deployment costs, advancement, and management. Systems for assuring active network installations will be essential in the future if a low-cost, secure, and high-capacity network is to be deployed.

For 6G use cases, the network system must be made more flexible, accessible, and dependable to control the increasing deployment possibilities. A core network (CN) and Radio Access Network (RAN) installations in the future will be less managed, with more shared platforms (RAN). Also, by merging RAN and CN functions, they are avoiding network function duplication.

5.4 HIGH LEVELS OF COVERAGE

The new radio access solutions should perform well in various ways to enable new services at reasonable prices.

For starters, faster data rates and lower latency are required. Also, to meet greater service demands, strong network access coverage is needed. To allow optimal quality and overall network deployments at a reasonable cost, 6G needs the development of new mesh networking technologies and more integrated access and backhaul networks.

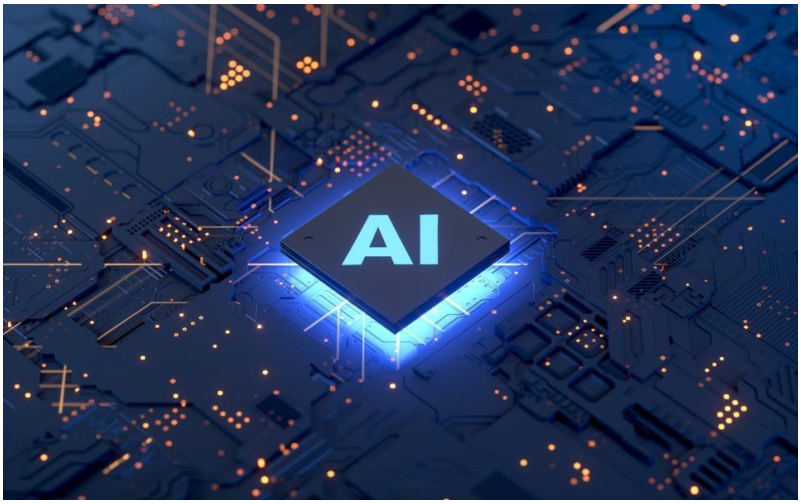


5.5 SYSTEMS THAT CAN BE TRUSTED

Building reliable systems requires the capability to resist, detect, react to, and recover from attacks and incidental confusion. The four essential building elements for trustworthy systems are

- Private computing solutions
- Secure identification and protocols
- Service availability.
- Security insurance and defense

AI should significantly affect future technological development and security in the four domains above.

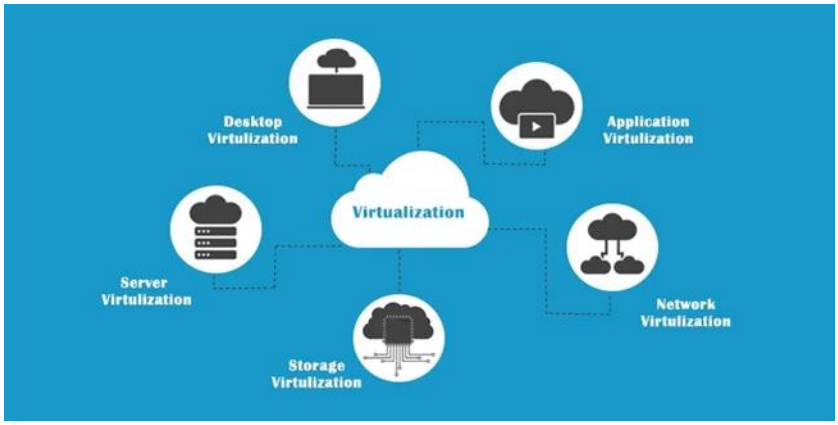


5.6 INTELLIGENT SENSOR DIVERSITY

Future services will need to be connected in all places and situations. 6G networks can handle billions of tiny Intelligent devices while providing reliable, always-on connections. High-speed machine-to-machine communication now offers data speeds of up to 100 kbps. However, their battery life may last up to 10 years in certain situations. The device's value is limited by battery replacement or charge. However, highly energy-efficient communication protocols must be devised since the quantity of energy harvested is usually relatively tiny.

5.7 COMPUTING OVER A NETWORK

6G will bring all physical devices into the computation. It will control biological systems. Service providers can improve application performance, reliability, and latencies by virtualizing computing and storage. Moreover, network computing will provide services and tools with connections for businesses and industries. New applications are developed to communicate with physical systems.



Chapter-06

Architectural vision and hardware for 6G networks

- The intelligent network that is linked
- AI and Machine Learning (ML) Merge
- Connectivity with complete coverage

6.1 THE INTELLIGENT NETWORK THAT IS LINKED

6G is a distributed type of deep that will connect the real and virtual worlds, bringing a new era of fast, secure, and intelligent networks. The edge of this sizeable deep net connects with the other neural edges or centers freely and smoothly. The communication between 6G supports the future intelligence of everything on network edges.

6.2 AI AND MACHINE LEARNING (ML) MERGE

AI and ML will be used in 6G wireless medium and network designs to improve system operation and management. As each 6G network combines processing, communication, and sensor systems, autonomous intelligence in the cloud gives way to segments that are expected to grow at the edges. A distributed machine learning architecture will be essential for society and businesses.

6G claims to be an intelligent, universal mobile communication technology that redefines terminals, cloud borders, and connections.

6.3 CONNECTIVITY WITH COMPLETE COVERAGE

Speeds comparable to optical fibers will be achieved with 6G. The density of 5G connections, millimeter-level imaging, centimeter-level localization, and end-to-end dependability rise tenfold with 6G. It allows future help and speeds sector industry digitalization and improvement.

Chapter-07

Project of 5G and 6G

7.1 BRAUNS PROJECT

Big industrial workloads, services, materials, and devices need new wireless communication technologies in the future. Unlocking these intelligent wireless networking solutions is required. New frequency resources and artificial intelligence (AI) solutions properly control online services. The project trying to bring learning algorithms into The Radio Light Network for Massive Links (6G BRAINS) will develop an AI-driven self-learning platform at various decision layers for future industrial uses of large-scale and variable needs, such as massive links over device-to-device communications.

7.2 E-HEALTH

Healthcare services are no longer limited to patients; they are now required to improve modern lifestyles. Medical assistance, insurance services, Intelligent Wearable Devices (IWD), online operations by doctors, care facility (H2H) services, pharmacy services,

and other healthcare applications are included. IWD is another one of those services, and it will effectively assist sufferers. These gadgets are connected via the Internet and send vital information about patients. In monitoring and testing labs, such data is collected and processed.

7.3 DRONES (AUTONOMOUS VEHICLES)

Between 5G and 6G, a critical element of wireless networks is the primary and growing usage of crewless aerial vehicles that will define the next generation of UAVs. Wireless communication has to be implemented. It must be reliable, secure, and cost-effective to support such a comprehensive Internet. UAVs are being deployed. In this situation, cellular networks are essential for UAVs to function as flying user devices.

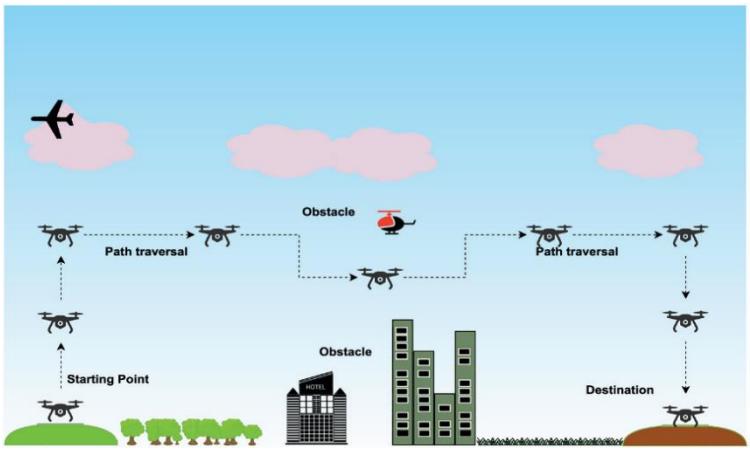
UAVs can connect to cellular networks via a variety of methods. However, there are various challenges to assuring stable UAV operations. This paper gives an overview of the significant design challenges and barriers to widespread commercial use of flying UAVs, as well as potential solutions.

7.4 MASSIVE MIMO

Through the deployment of multiple antennas of MIMO, ground BSs may perform dynamic 3D waves with reflectors to quality-measure UAVs in the sky and land users. Massive MIMO could be utilized in UAV systems to increase spectral efficiency and coverage.

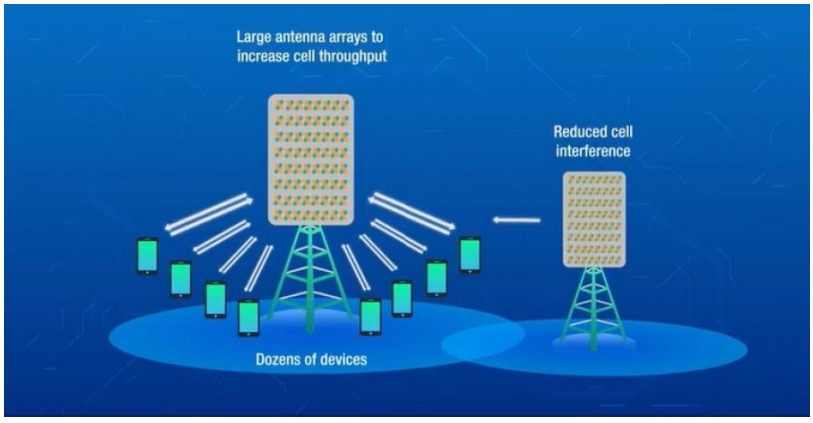
High data rate services could be provided via THz and millimeter-wave communications. In this paper, scientists developed a new dynamic curves framework for 6G massive MIMO wideband UAV channels. The impact of UAV-specific parameters such as the direction of motion, position, and rate on channel analytical aspects may be characterized using this model.

The hyperspace value, envelope crossover speed, based on signal energy, and decline duration are also calculated. The impact of UAV-related parameters on channel data sets is explored, which could aid the development of 6G massive MIMO wideband UAV control systems.



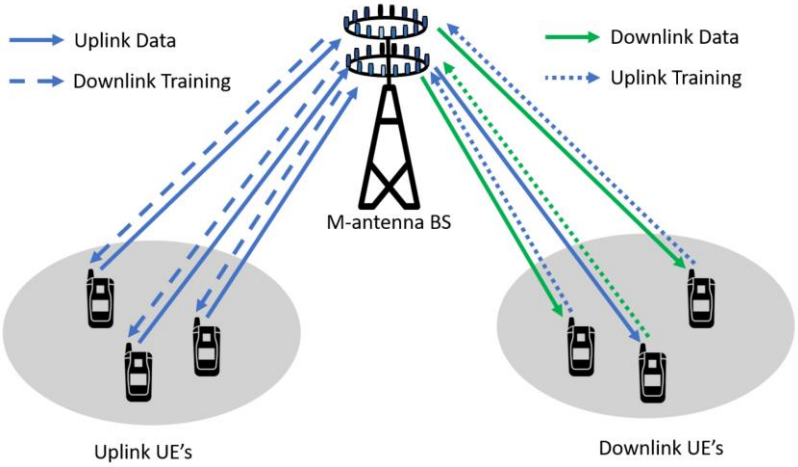
7.5 BEAMFORMING

The ability of the base station to adjust to the antenna's radiation pattern is known as beamforming. Beamforming lessens interference from neighboring users while also assisting the base station in determining the best route to take while sending data to the user. For networks beyond 5G, beamforming provides a number of benefits. Future networks may use wideband technology in a variety of ways, depending on the circumstances. Beamforming aids in enhancing data rates for millimeter waves and large MIMO systems, respectively, by increasing spectrum efficiency. In massive MIMO systems, the base station can provide data to the user from a variety of pathways, and beamforming in this case coordinates the packet flow and arrival rate to allow multiple users to contribute data at once.



7.6 TECHNOLOGY FOR FULL DUPLEX

Cellular signal intensity frequently doesn't occur at the same frequency bands to prevent conflict. Therefore, every multimodal system must use the time or frequency domain to divide the uplink and downlink channels to provide orthogonal, interference-free signals. According to the Figure, full-duplex refers to simultaneous transmitter and receiver across the same frequency range. Networks will use full-duplex signal delivery to increase network capacity, which is advantageous for higher layers. Full-duplex technologies have the drawback of causing more signal interference due to intrusive echo. There has been considerable research on the advantages of full-duplex equipment for systems.

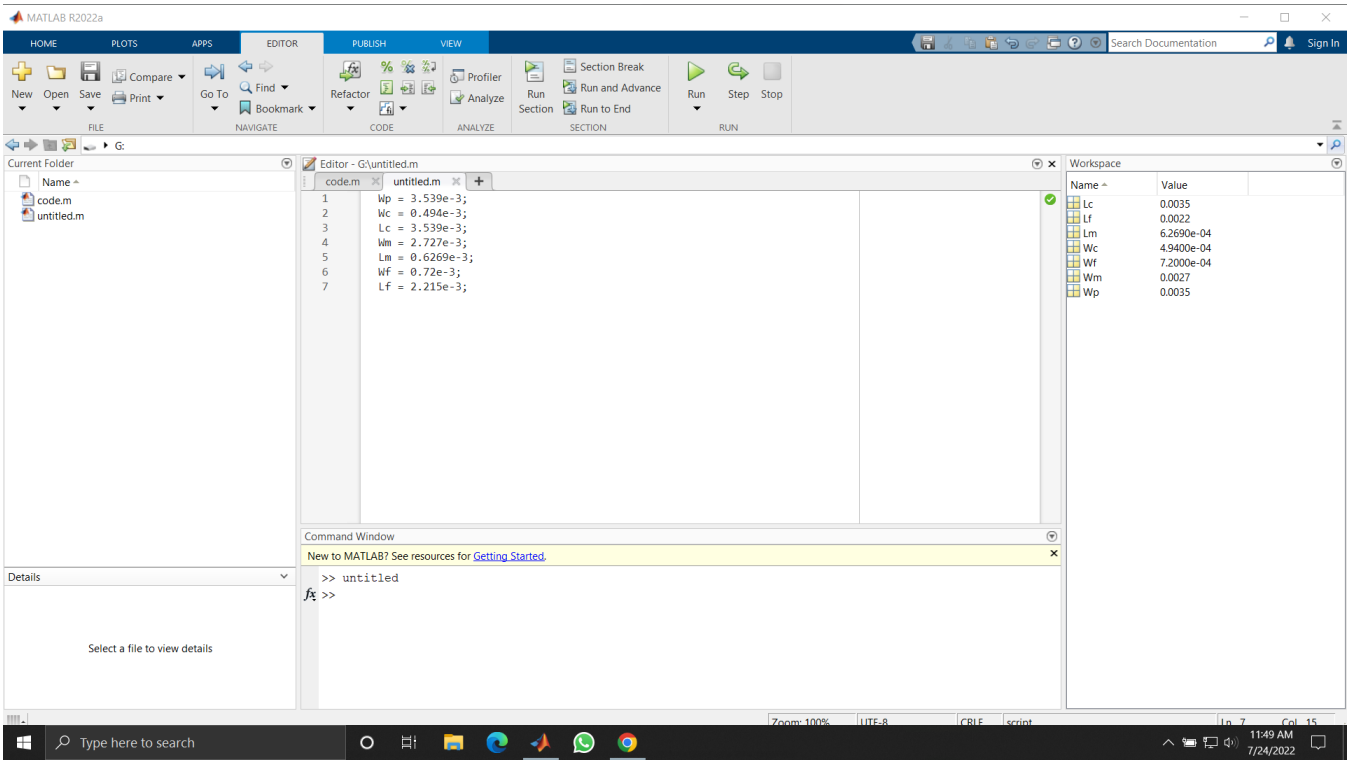


Chapter-08

5G Base Station Antenna Design Series-Fed Patch Antenna

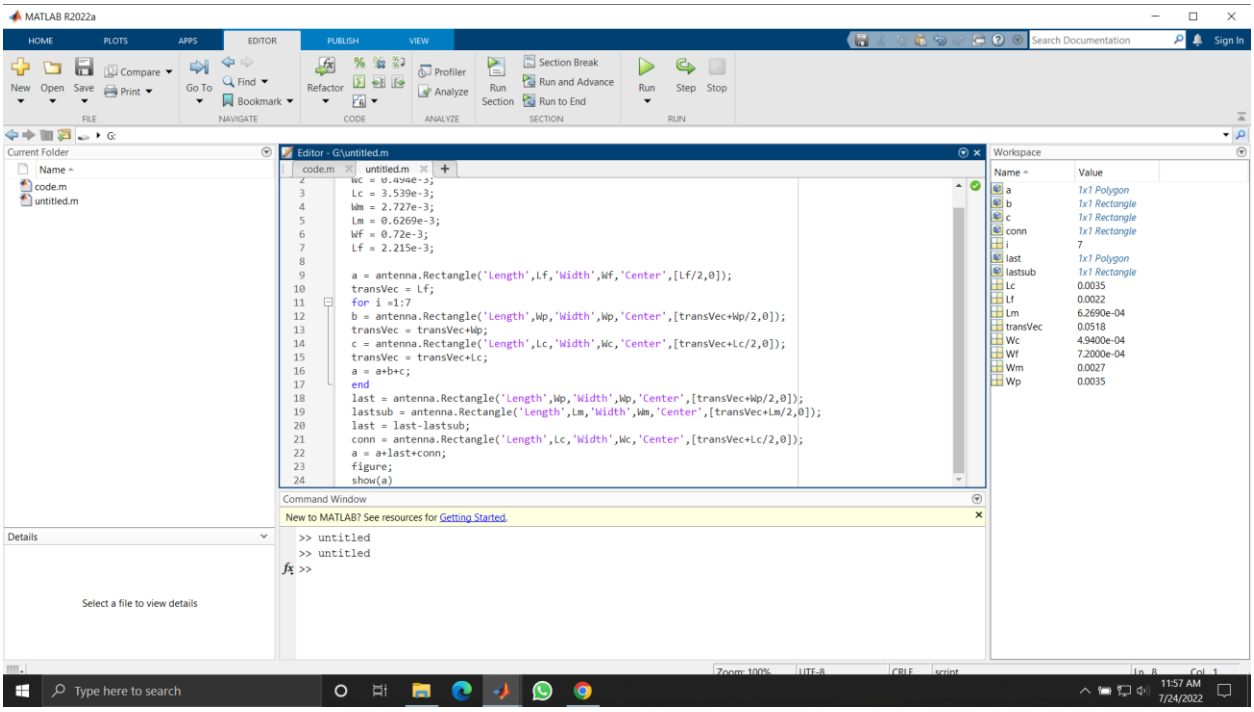
8.1 SET UP VARIABLES

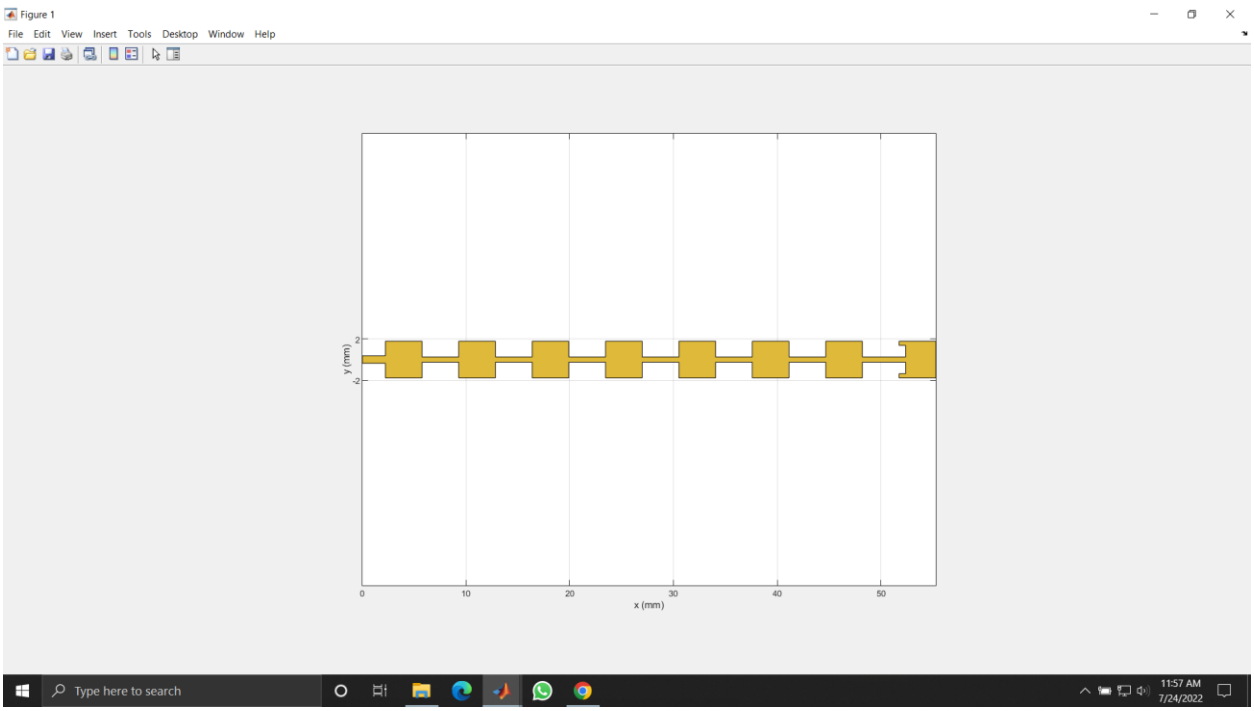
Make the variables, then give them values



8.2 GENERATE GEOMETRY

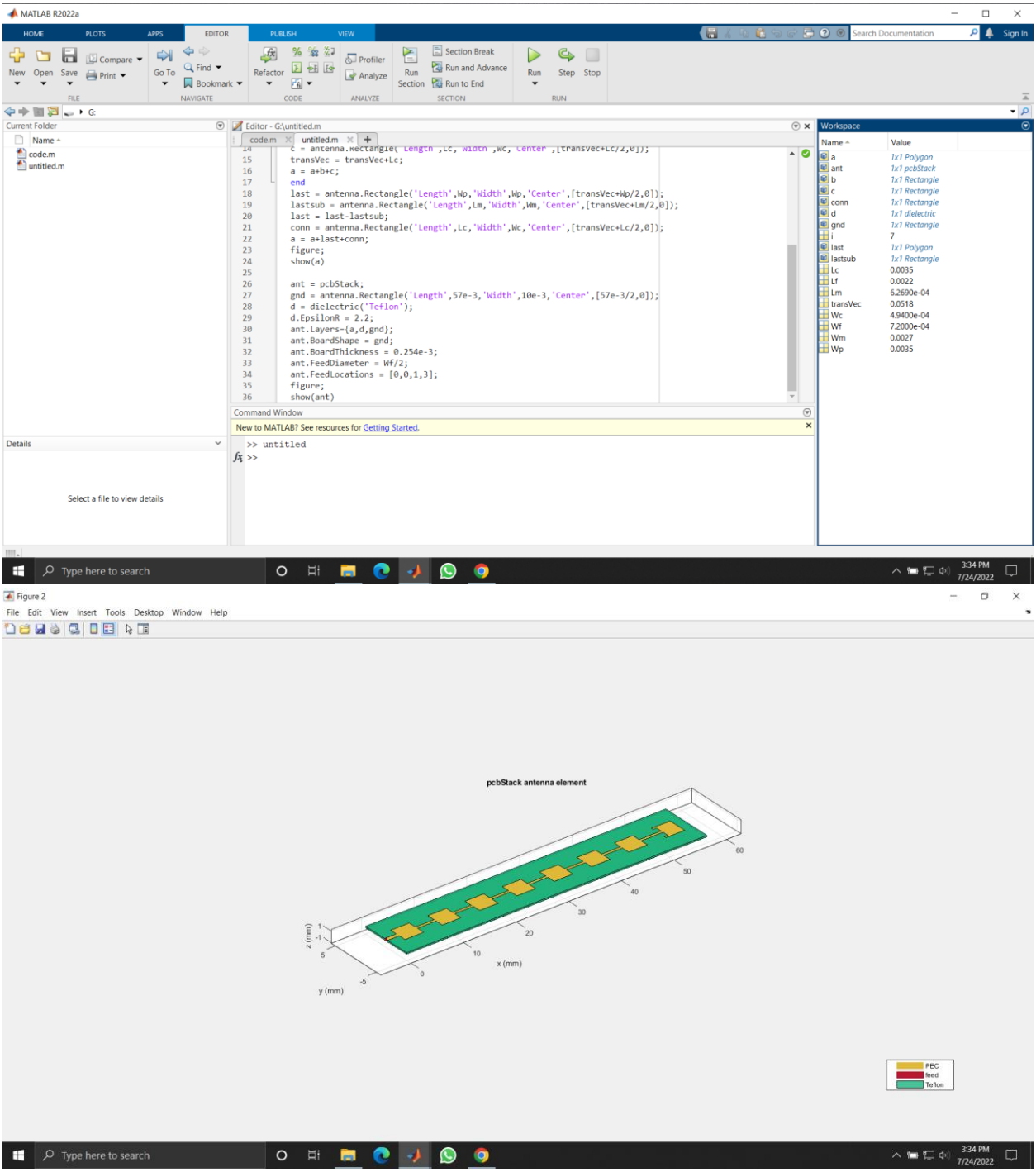
Utilize the antenna. In order to build the structure's many rectangles, use an object with a rectangle form. Utilize the display option to see the structure in detail.





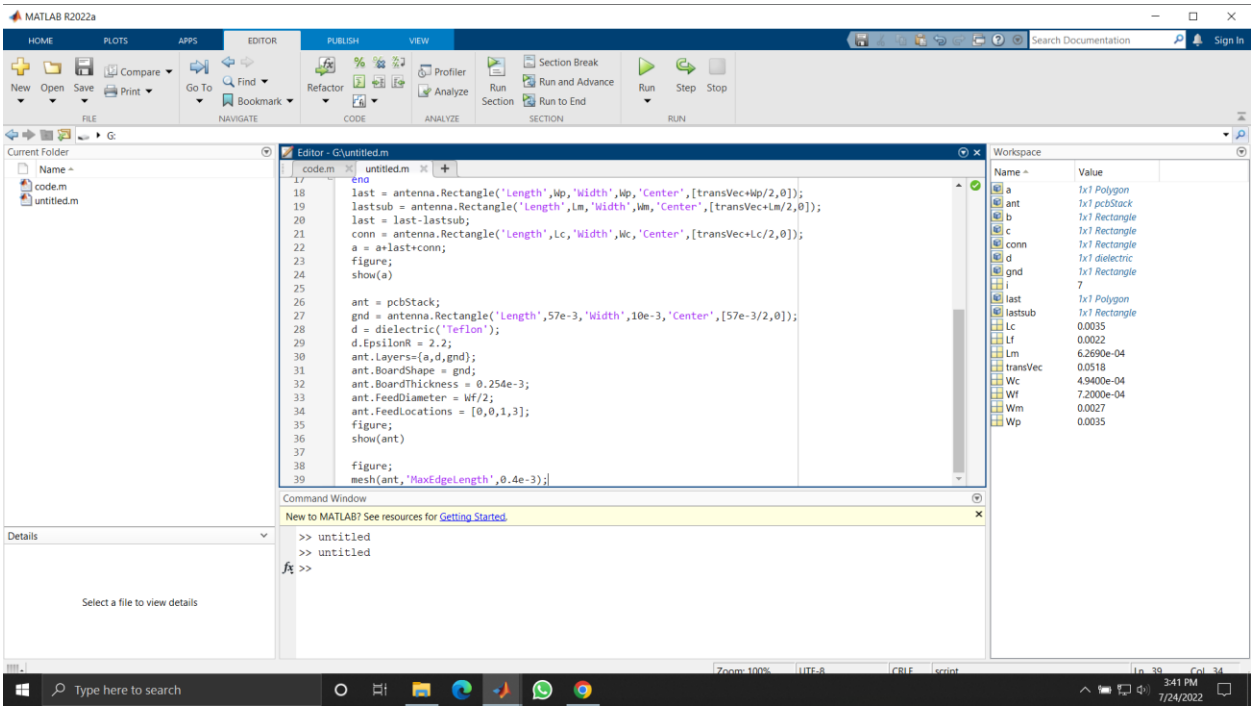
8.3 CREATE PCB BOARDS

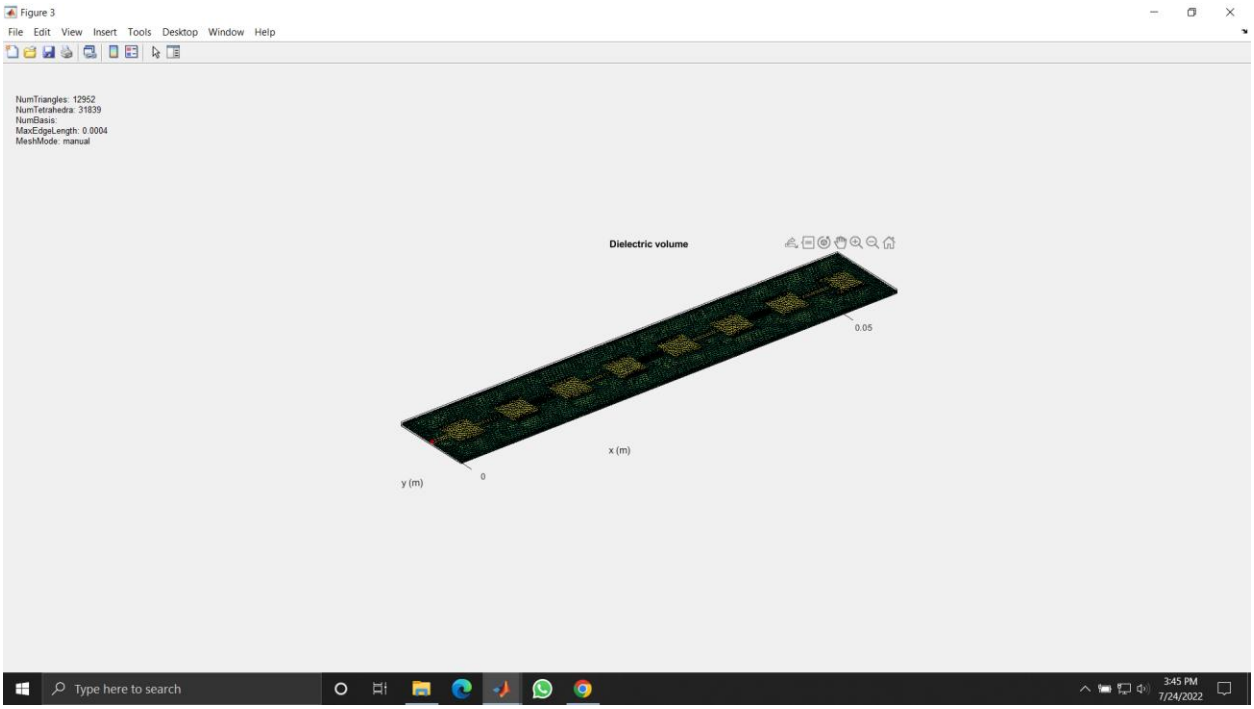
The PCB stack should be created using the PCB Stack object. Set the Board Form to be the same shape as the ground plane before creating the ground plane and the dielectric layers. Picture the PCB stack.



8.4 PERFORMANCE ANALYSIS OF ARRAYS

To make sure there are 30 triangles per wavelength, manually alter the mesh using the mesh tool and set the Max Edge Length value to 0.4 mm.

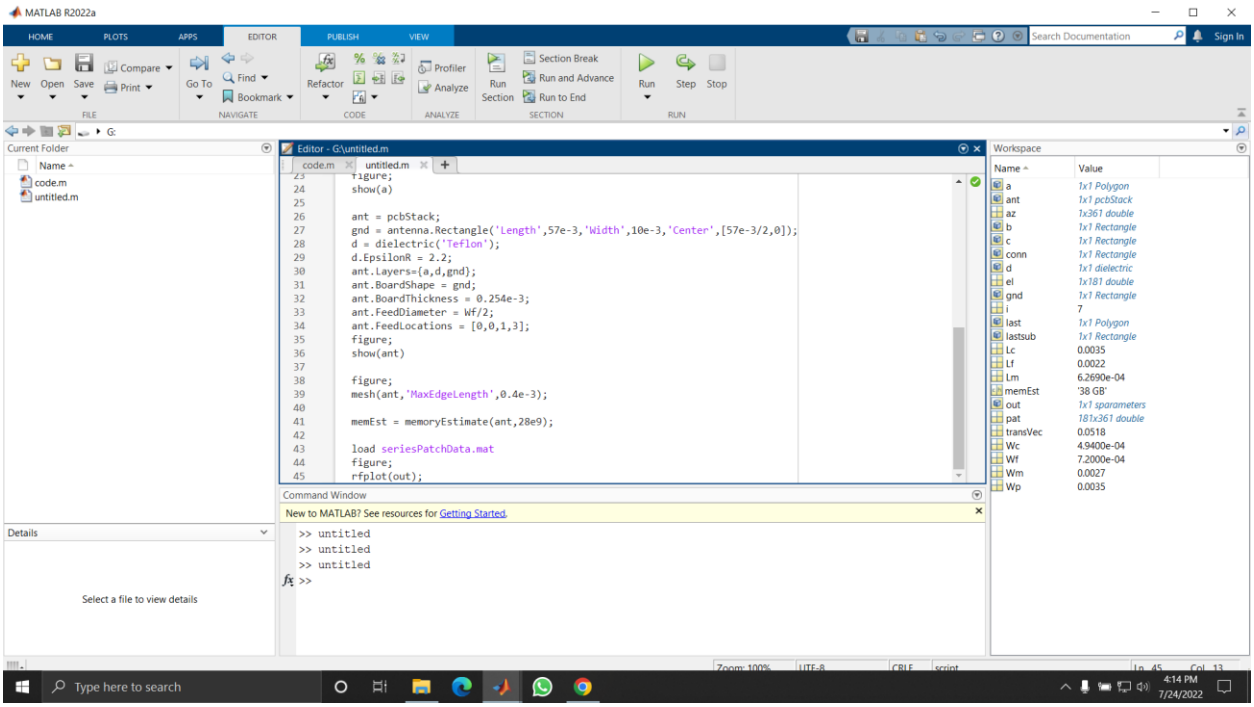


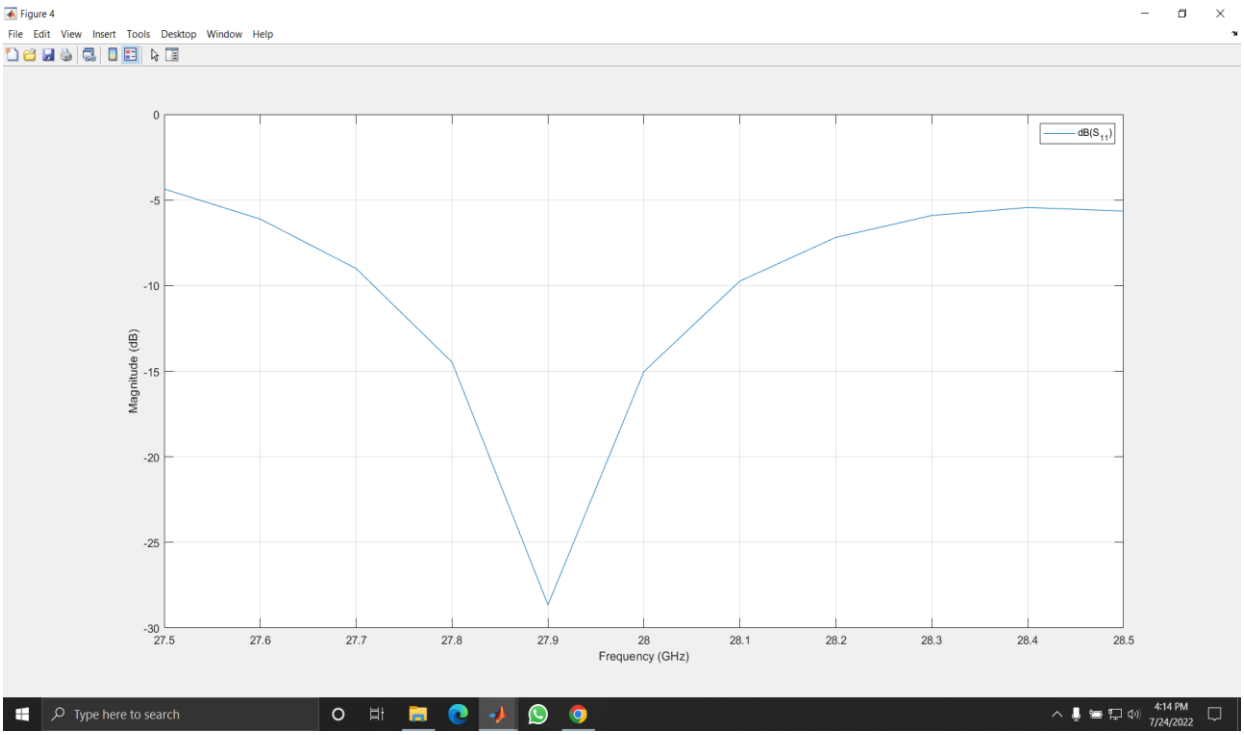


Calculate the amount of memory needed to solve the structure using the memory Estimate function.

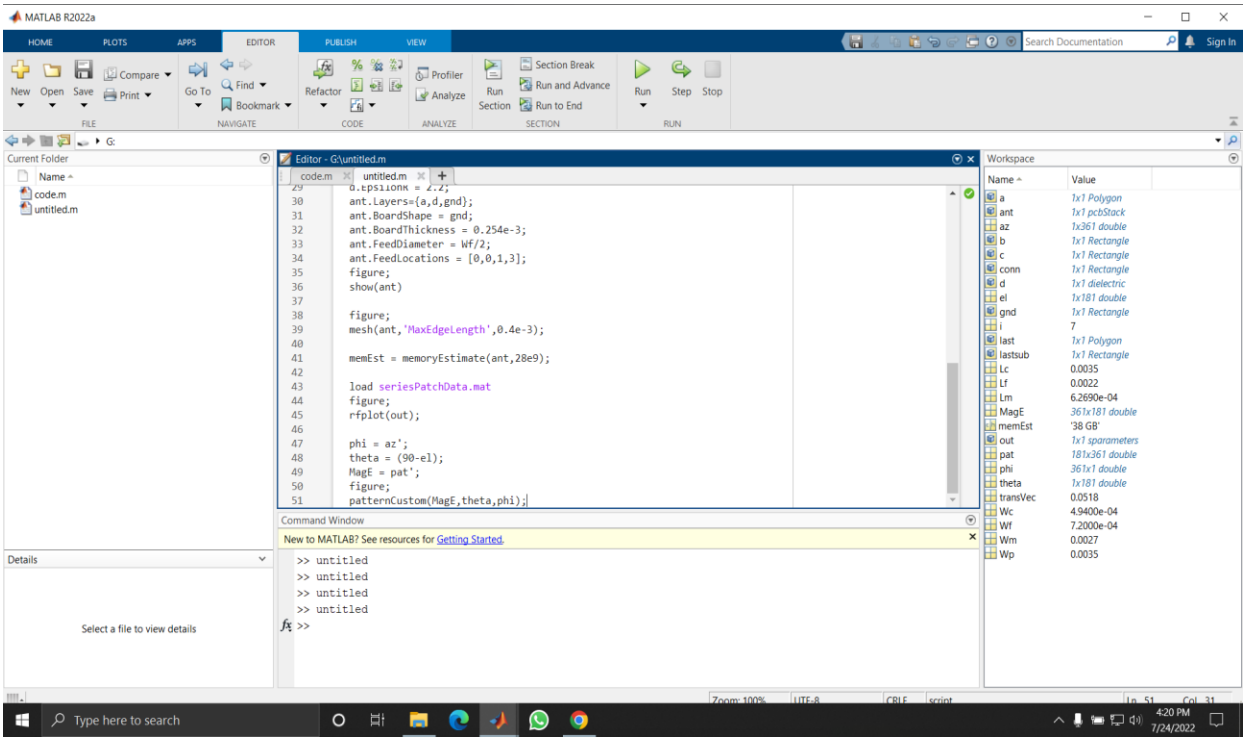
memEst = '38 GB'

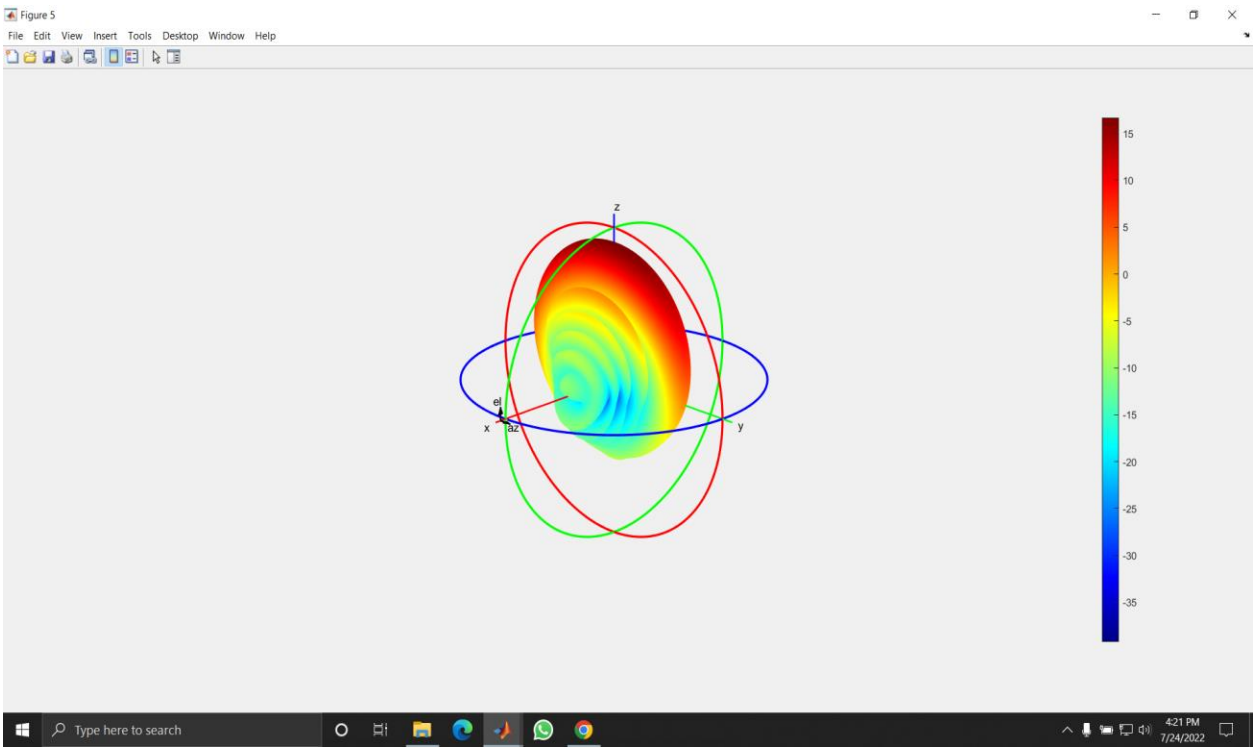
You will need additional time to compute the S-parameters and plot the antenna layout because of how much memory is required. The computations for the return loss and pattern data are included in a MAT file with this example. The Return Loss and Pattern Data Computations section contain the source code used to calculate the results. One frequency may be solved on a workstation with 64 GB of RAM and an Intel(R) Xeon(R) W-2133 CPU processor in around 50 minutes. Plot the return loss using the rf plot function after loading the MAT file.





To visualize the antenna's 2-D or 3-D radiation pattern, use the pattern Custom tool.

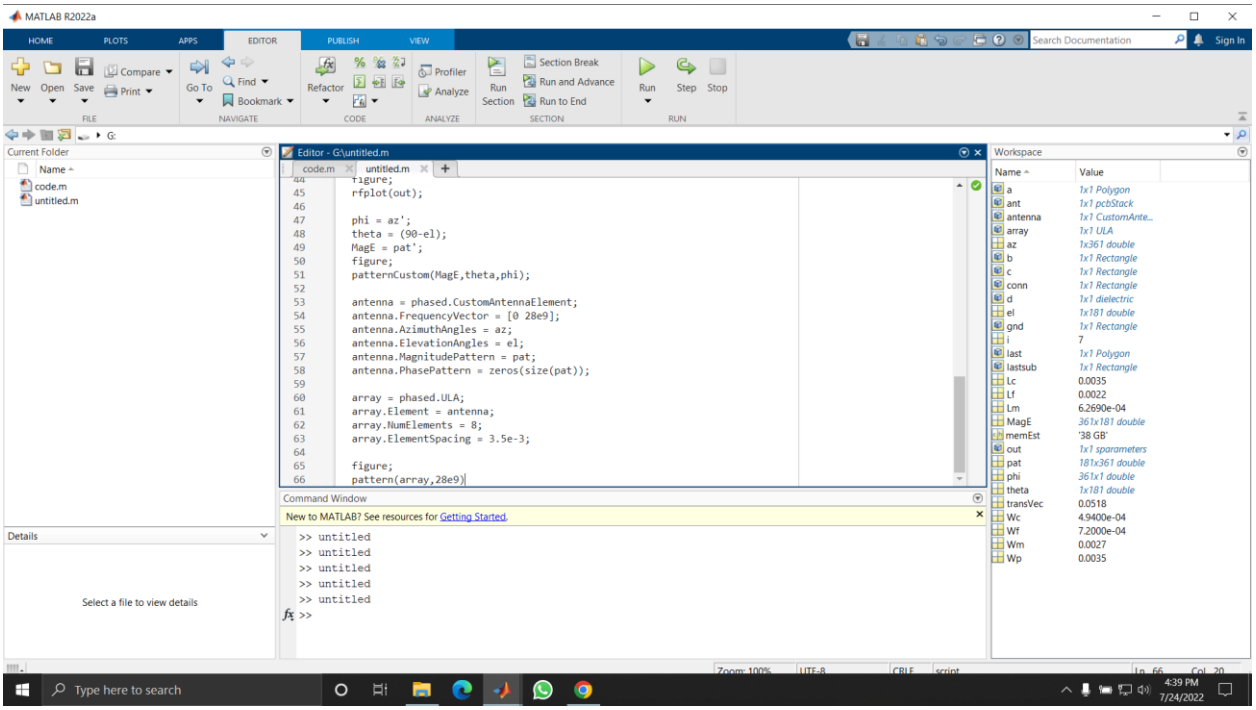


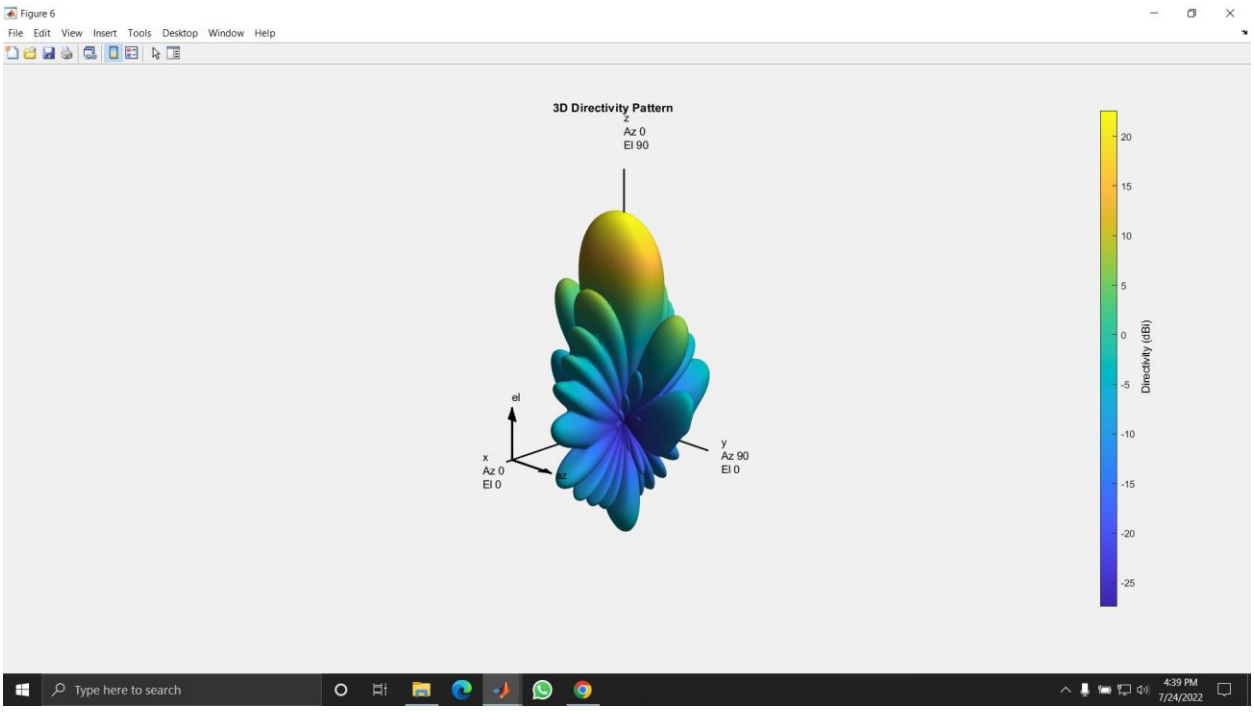


8.5 RADIATION PATTERN PLOTTING USING PATTERN MULTIPLICATION

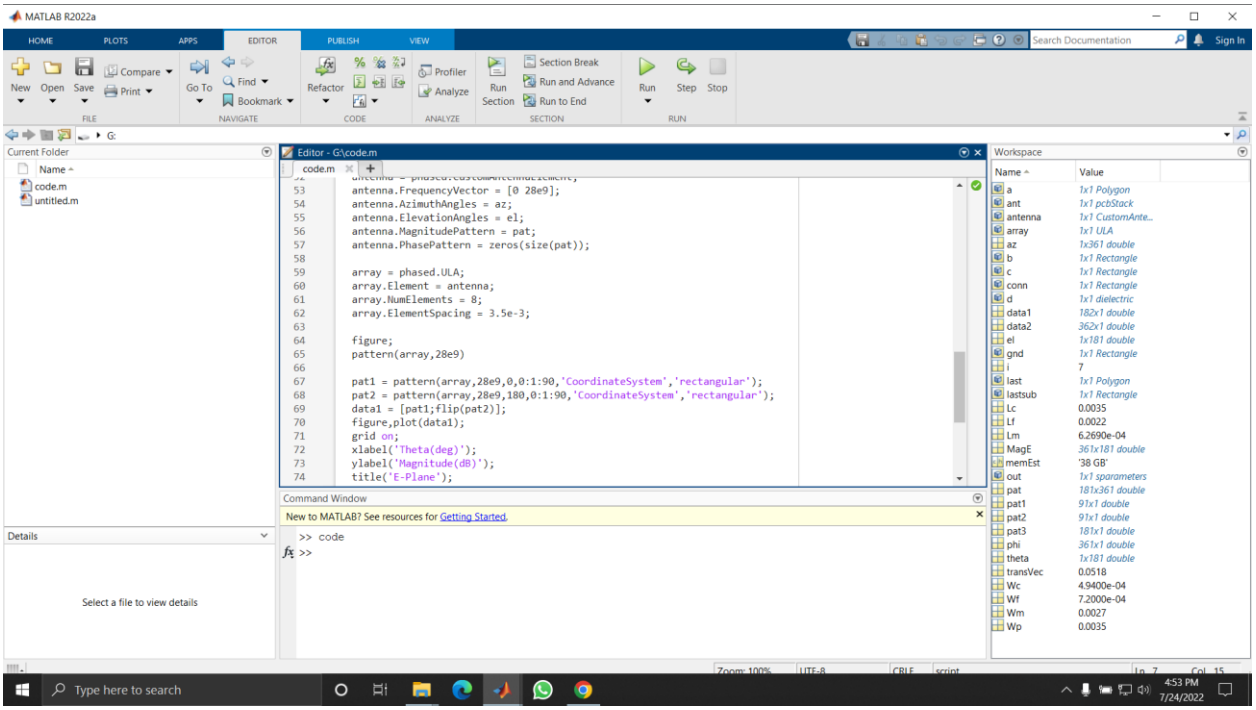
Instead of solving the complete structure using the MoM solver, use pattern multiplication to depict the 8-by-8 array's radiation pattern. Pattern multiplication requires a license for the Phased Array System Toolbox. The pattern data from the MAT file imported above may be used to construct the custom antenna element using the phased. Custom Antenna Element System object. Employ the phases. The 8 by 8 array was created using a ULA System object. Set the array element to be the custom element. Set the element spacing to 3.5 mm and the element count to 8.

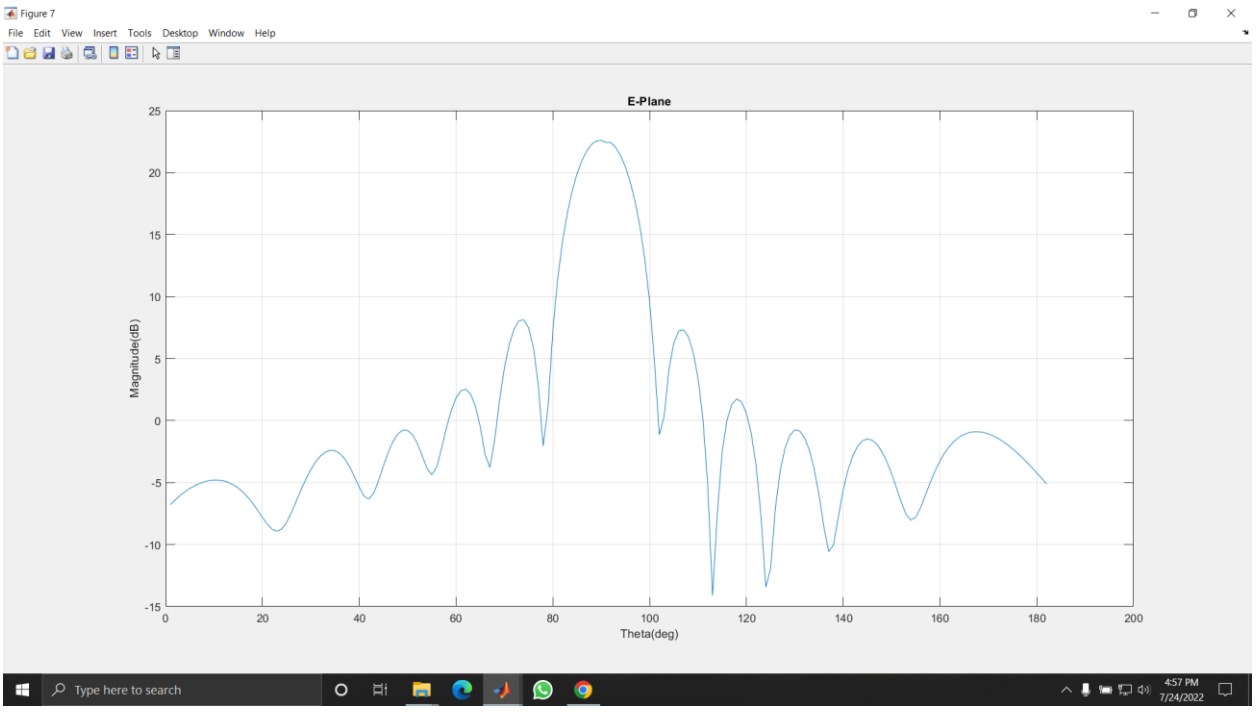
8.6 PLOT THE 3-D RADIATION PATTERN USING THE PATTERN FUNCTION



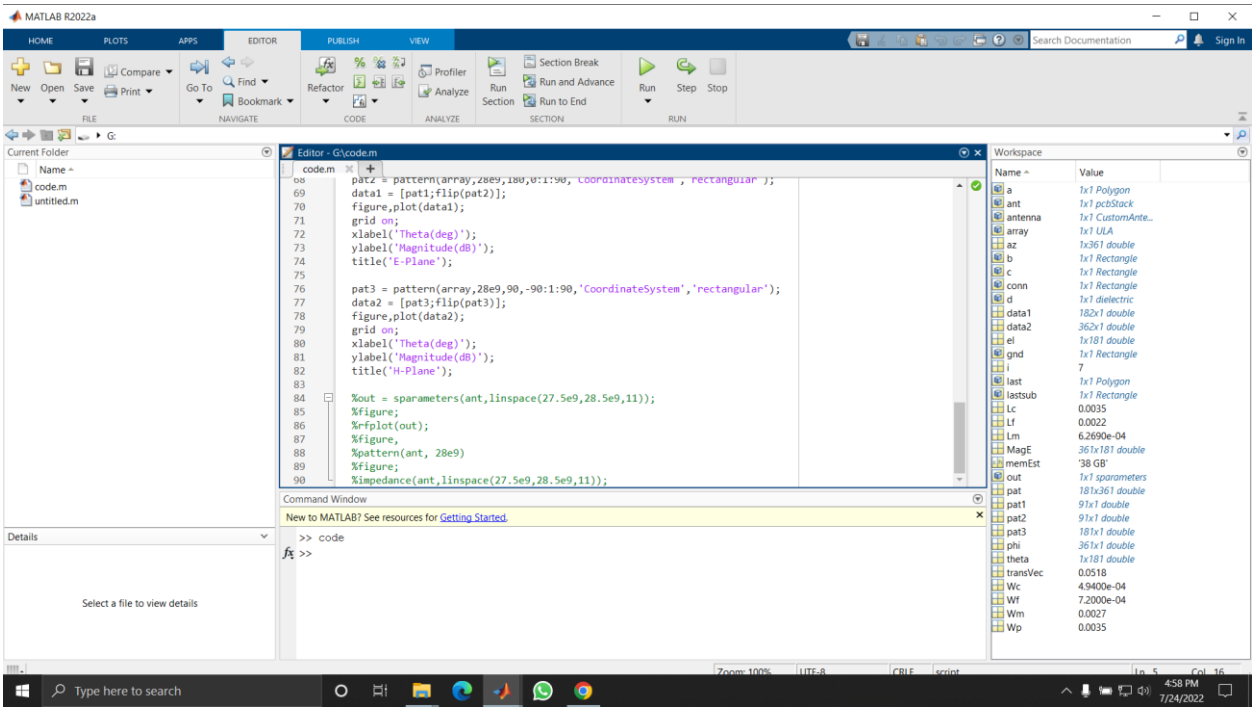


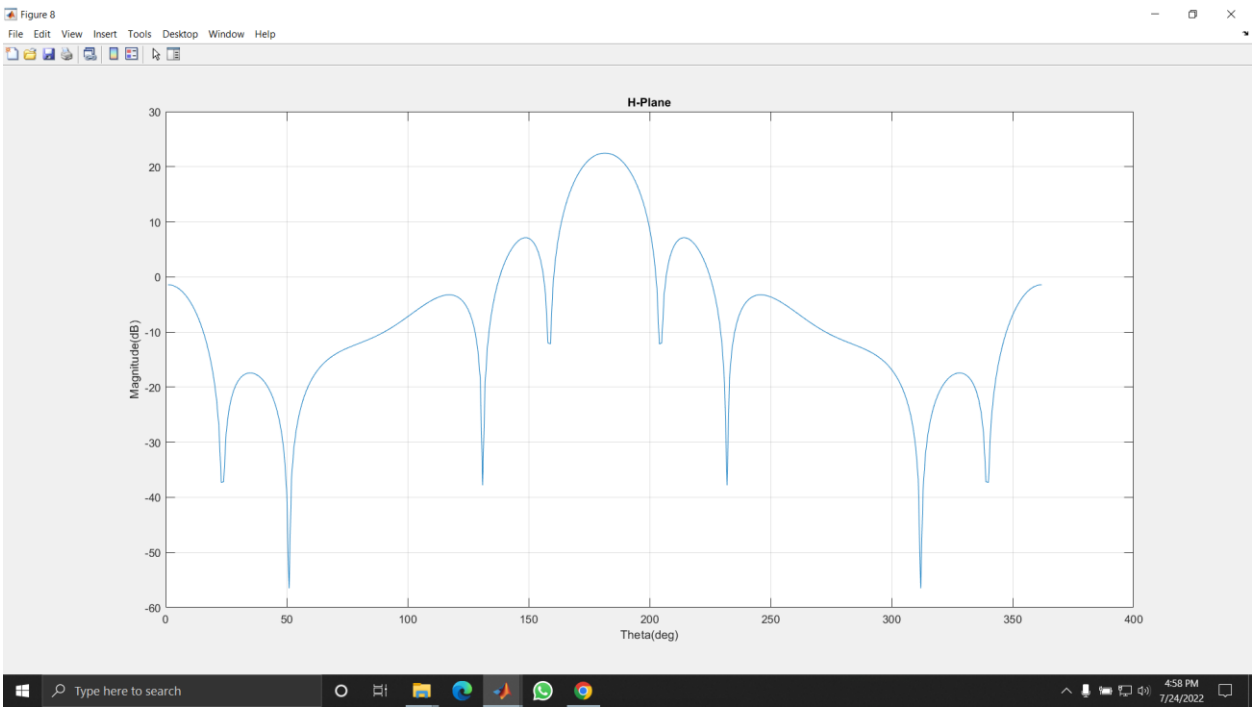
8.7 PLOT THE RADIATION PATTERN IN THE E-PLANE USING THE PATTERN FUNCTION





8.8 PLOT THE RADIATION PATTERN IN THE H-PLANE USING THE PATTERN FUNCTION





CONCLUSION

As new generations of wireless communication networks are created to meet future demands, old technologies are enhanced, and new features are introduced. Therefore, the constantly growing communication needs are too much for 5G technology to handle. Thus, to satisfy the communication technology requirements of this new era, it is crucial to plan to implement 5G networks. This page gives a systematic summary of the 6G wireless generation networks, covering the evolution of communication networks from 1G to 5G, research activities on 6G mobile networks, 6G network supporting technologies, and current state-of-the-art. Additionally, the study lists the essential requirements for the 6G upgrade: high coverage, network flexibility, cognitive network, network computing, and trustworthy systems.

REFERENCES

[1] Expanded 6G Vision, Use Cases, and Societal Values. [Online]. Available: https://hexa-x.eu/wp-content/uploads/2021/05/HexaX_D1.2.pdf

[2] IMT-2030 (6G) Promotion Group, 6G Vision and Candidate Technologies. [Online]. Available:http://www.caict.ac.cn/english/news/202106/P020210608349616163475.pdf

[3] Ms. Anju Uttam Gawas, "An overview on Evolution of Mobile Wireless Communication Networks: 1G-6G", (IJRITCC), Volume 3, Issue 5, May 2015.

[4] Abdullah Al Mamun, Sultan Anwar, Hassan Ali, "4G to 5G Mobile Communication Networks: Features Analysis, Comparison, and Proposed Architecture", IJCST Vol.7, Issue 2, April-June 2016.

[5] T. Murakami, R. Ohmiya, T. Nakahira, K. Ishihara, and T. Hayashi, "Proposal of virtual massive MIMO (VM-MIMO),"IEICE General Conference 2019, B-1-123, Mar. 2019.

[6] M. G. Kibria, K. Nguyen, G. P. Villardi, O. Zhao, K. Ishizu, and F. Kojima, "Big data analytics, machine learning, and 12 Wireless Communications and Mobile Computing artificial intelligence in next-generation wireless networks," IEEE Access, vol. 6, pp. 32328–32338, 2018.

[7] "EM Simulation of 28 GHz Series-Fed Patch Antenna Array for 5G [2019-02-01] Microwave Journal." Accessed January 21, 2022. https://www.microwavejournal.com/articles/31731-em-simulation-of-28-ghz-series-fed-patch-antenna-array-for-5g.

[8] Ishfaq, Muhammad Kamran, Tharek Abd Rahman, Yoshihide Yamada, and Kunio Sakakibara. "8×8 Phased Series Fed Patch Antenna Array at 28 GHz for 5G Mobile Base Station Antennas." In 2017 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), 160–62. Verona, Italy: IEEE, 2017.