EE400 SUMMER PRACTICE REPORT

MIDDLE EAST TECHNICAL UNIVERSITY

Department of Electrical and Electronics Engineering

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SP Date	: 18/07/2022 to 12/08/2022
SP Company Name	: Türksat Uydu Haberleşme Kablo TV ve İşletme AŞ
SP Company Division	: Uydu Programları Direktörlüğü/Satellite Programs Department
SP Company Location	: Gölbaşı, Ankara, Turkey

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1.Description of the Company

TÜRKSAT is a satellite communication company which provides services for TV, Internet, radio broadcast via its TÜRKSAT satellites. It is divided mainly by three parts: Satellite Services, Information Services for e-Government (E-devlet) and Cable Services. TÜRKSAT is the 144th largest company in Türkiye among the 500 largest companies of the country [1]. The revenue of the company in 2021 was approximately 1.8 billion TL [2]. The organizational structure of the company is given in Figure 1.

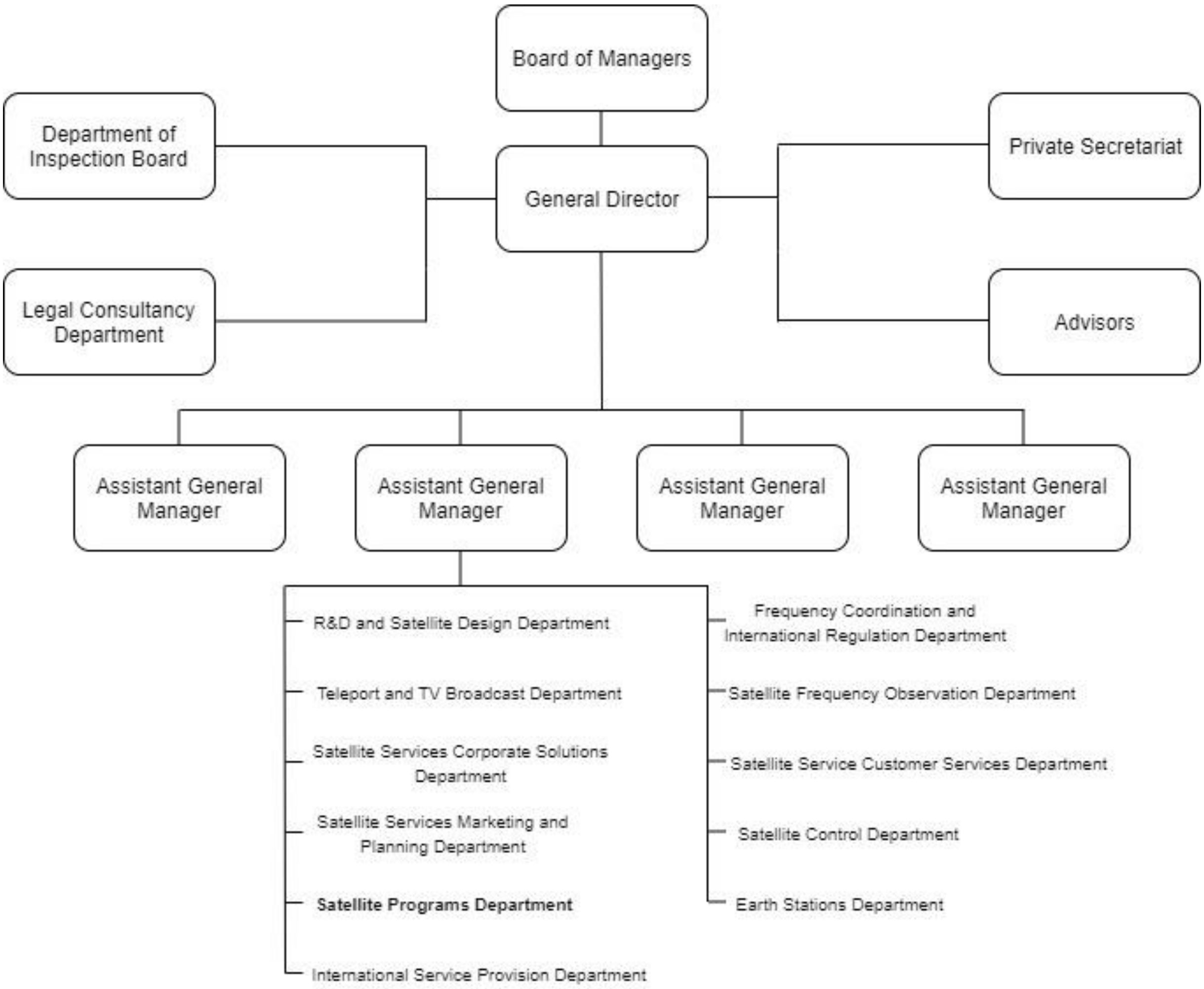


Figure 1: The organizational structure of TÜRKSAT

My division Satellite Programs Department can be seen in the second assistant general manager in the second column of the organizational structure on the left side, the second one from the bottom. The Director of Satellite Programs Department is M. Mehmet Nefes.

In TÜRKSAT, approximately 420 engineers work currently, a significant number of them is electrical-electronics engineer. In my division, Satellite Programs Department, there are approximately 25 engineers, and three fourth of these engineers are electrical-electronics engineer.

There are about 1100 workers in TÜRKSAT, and most of them are white-collar workers [2].

Due to privacy policy of the company, I could not write the exact numbers about the number of workers and engineers in this summer practice report.

2.A Brief History of the Company

In 1990, the communication satellite operator TÜRKSAT was established by the state in the name of TÜRKSAT National Communications Satellites (TÜRKSAT Milli Haberleşme Uyduları). The current TÜRKSAT company was founded officially in Ankara in 2004 [1]. There are 6 satellite projects of TÜRKSAT so far, and the first TÜRKSAT satellite 'TÜRKSAT 1A' was the first satellite project of the company; however, it exploded in the atmosphere due to the failure of the launcher in 1994. Then, in the same year, TÜRKSAT 1B was launched successfully, and it was in the service until 2006. TÜRKSAT 1C, 2A, 3A, 4A, 4B, 5A was launched in 1996, 2001, 2008, 2014, 2015, 2021, respectively. The newest satellite of the company, which is TÜRKSAT 5B, was launched in December 2021. Currently, TÜRKSAT runs large satellite communication projects as well as giving consultancy about this field.

3.Introduction

I chose TÜRKSAT for my summer practice because I am interested in antennas and microwaves field as well as telecommunication field, which is a field that I would like to pursue a career after graduation, and also, I am planning to take courses related to these field in my senior year. In addition, I thought that observing a team of engineers and being in a large state company could be fairly good experiences for my second summer practice after my first summer practice in a manufacturing factory last summer.

I have found my summer practice location by National Internship Program (Ulusal Staj Programı).

My summer practice lasted 20 workdays, which are 4 weeks, and although I was usually an observer in my summer practice location, I did my assignments successfully in the guidance of my supervisor EE engineer.

The first two weeks of my summer practice started with the introduction of my summer practice company, in my division. After the presentation, a supervisor EE engineer was assigned for me in my summer practice. Then, my supervisor gave documents and books that are needed before doing my assignments. My first assignment was to make research about Phased Array Antennas (PAAs) in Satellite Communication and to make a report and an informative presentation to my supervisor. PAAs and Satellite Communication were new topics for me, and I learned a lot during my research and questions to my supervisor because I am interested in these topics. I used MATLAB to observe the effects of the parameters in Phased Array Antennas and made simple simulations.

In the second week of my summer practice, two other summer practice students and I visited The Teleport and TV Broadcast Department for one day and Satellite R&D and Design Department (Uydu Araştırma Geliştirme ve Tasarım Direktörlüğü) for two days. During my visits, I learned about TV broadcast and the use of helium balloons in communication.

In the third week, I was given an assignment, which was a group work, about Digital Video Broadcasting – Satellite (DVB-S) in MATLAB. Before doing my assignment, I learned my preliminary knowledge of telecommunication systems.

In the last and fourth week, I continued my communication simulation assignment with the two other summer practice students[1]. In this week, the summer practice students in my department and Satellite R&D and Design Department visited Turkish Aerospace Industries (TAI) for one day to observe and learn about TÜRKSAT 6A satellite, which is the first communication satellite manufactured in our country. It was an informative and useful visit for me due to my interest in satellites.

[1] In Satellite Programs Department, the other summer practice students are Türker Erdem and Kadir Acar, both of whom are senior year EE students at Marmara University and Ege University, respectively. I informed them about the fact that I wrote their names in my summer practice report here.

4. Work Conducted at the SP Company

4.1 Preliminaries on Satellite Communication Systems

First of all, I studied the documents and a book[2] on satellite communication systems as well as observing the work done by a cross-functional team in the first week of my summer practice.

4.1.1 The Configuration of Satellite Communication Systems

There are three configuration of satellite communication systems: Space segment, control segment and ground segment. The summary of these three segments can be found visually in Figure 2.

Space segment:

The space segment in a satellite communication system is the parts that are in the space environment, which means one or more satellites orbiting around the earth in space.

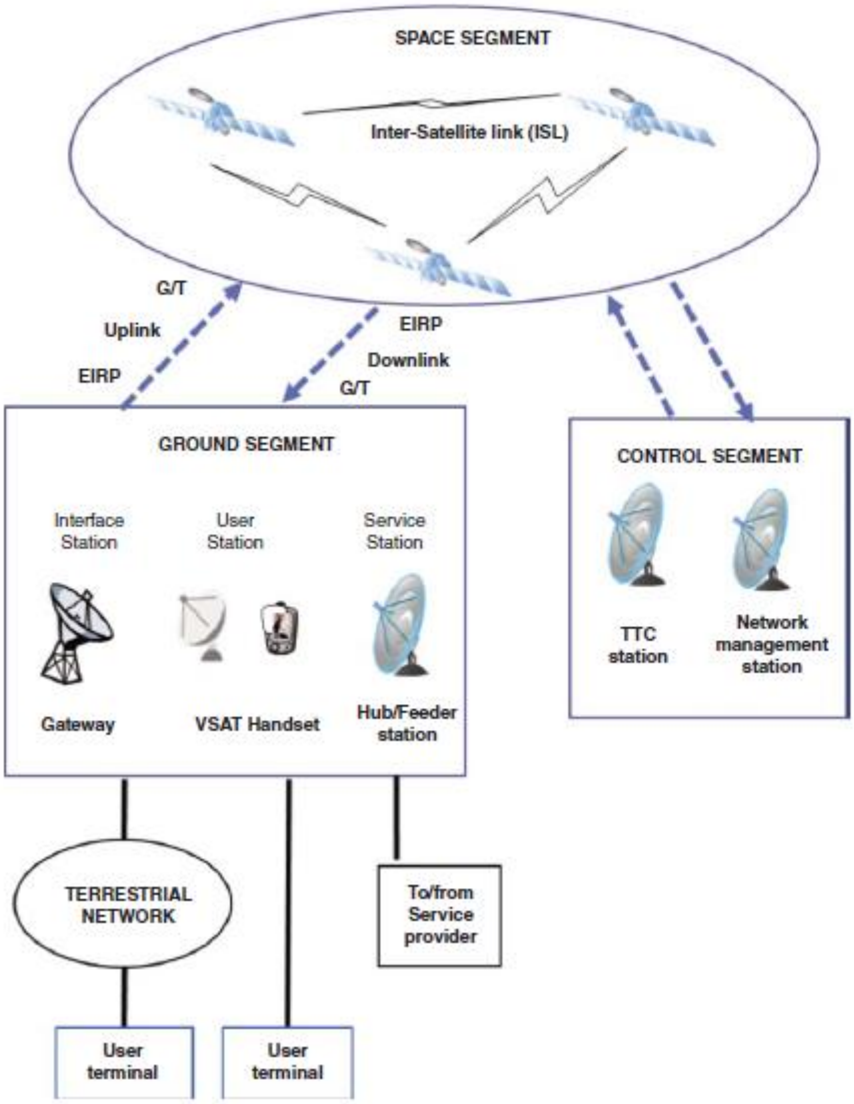


Figure 2: Configuration of Satellite Communication Systems [3, Ch. 1, p. 4]

[2] G. Maral, M. Bousquet, and Z. Sun, Satellite Communications Systems, 6th ed. Wiley, 2020.

Control Segment:

The control segment consists of the observing, monitoring, and controlling units for the satellites in space from the ground of the earth. There are large antennas for tracking, telemetry[3], and command (TTC) stations.

Ground Segment:

Ground segment is the gateways, service stations that connect to the users on earth through satellite communication. The antennas used in TURKSAT can be seen in Figure 3, which is example for the ground segment of the communication segment of the satellite communication systems.

Figure 3: The antennas in TURKSAT Gölbaşı campus [4]

4.1.2 Orbitals, Frequency Bands and GMAT Program

There are three types of orbits according to the distance from the earth surface: Low Earth Orbit (LEO), Middle Earth Orbit (MEO) and Geostationary Earth Orbit (GEO).

LEO: About 2000 km from the earth surface. The CubeSats are usually in this orbit.

MEO: Between 2000 and 35786 km from the earth surface.

GEO: The distance from the earth surface is 35786 km, where almost no gravitational force on the satellite. The communication satellites are in this orbit.

Frequency Bands:

-L band: 1.4 to 1.7 GHz	-X band: 7.0 to 8.0 GHz
-S band: 1.9 to 2.2 GHz	-Ku band: 10.0 to 14.0 GHz
-C band: 4.0 to 6.0 GHz	-Ku+ band: 15.0 to 18.0 GHz
-Ka band: 20.0 to 30.0 GHz	-Q & V bands: greater than 40.0 GHz

In satellite communication, the K bands is usually used.

Uplink and Downlink: Uplink means communication from earth to space, and downlink means communication from space to earth.

[3] *Telemetry* in satellite communication is collecting the data of measurements from the subsystems and instruments on the satellite regarding the condition of the satellite in space. The inverse of the telemetry can be called telecommand, collected data from the earth to the satellite.

FSS and BSS: Fixed and Broadcast Satellite Services. The difference between FSS and BSS is the frequency bands used for satellite communication.

GMAT Program: GMAT (General Mission Analysis Tool) is a program developed by NASA is used to make orbital simulations for the satellites. The GMAT program screen is shown in Figure 4 from my computer, which is a free-to-use program. For the orbital design of the satellites and predictions, this program is used. I was introduced the program interface briefly by an EE engineer, but I was not given any task to do on the program in the first week.

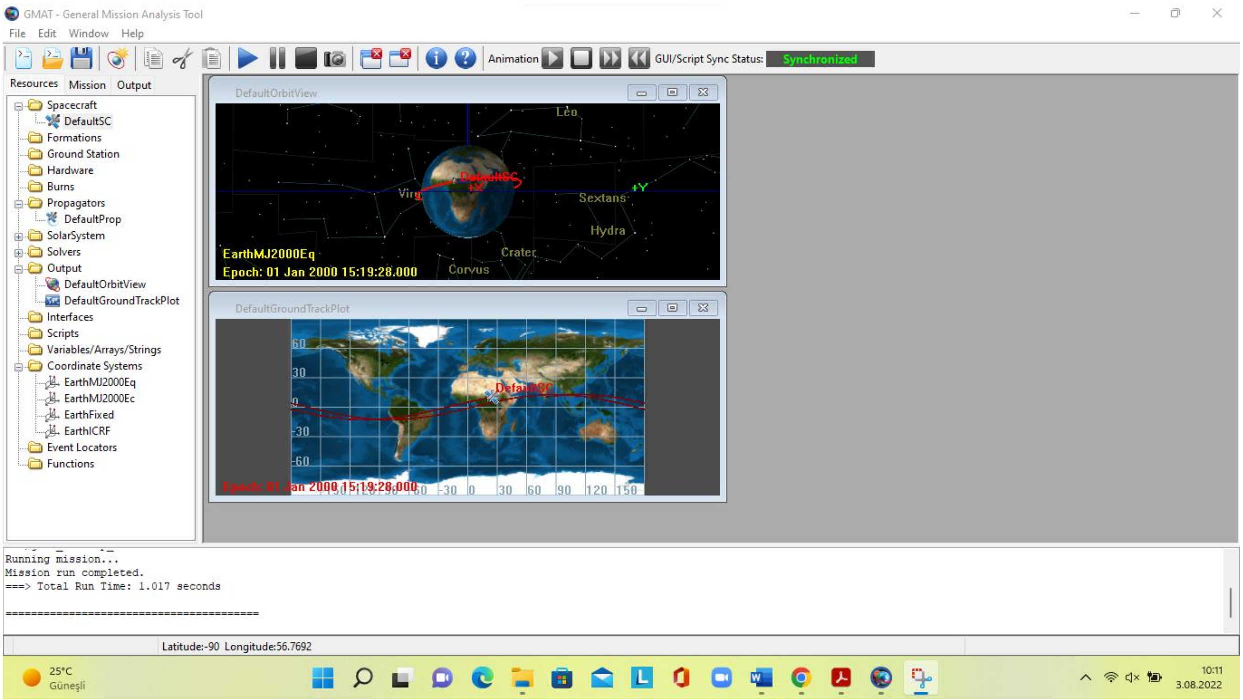


Figure 4: The interface of GMAT Program on my computer

Communication Satellite Missions: Communication satellite missions require a lot of project management and knowledge of the payloads. Its aim is 100 % success in the end, so a detailed teamwork is need, like in my division in my summer practice, which is Satellite Programs Department.

4.1.3 Visit to Satellite R&D and Design Department in TÜRKSAT

In the second week of my summer practice, two summer practice students and I visited R&D and Design Department for two days, and we were informed about the Helium Balloon mission experience as well as learning about that department. Helium balloons is also used for observation and communication in place of drones due to its advantages to them. My notes on Helium balloons are given in Appendix A.

4.1.4 Visit to Turkish Space Systems, Integration and Test Center at TAI

During my summer practice, other summer practice students and I, at total of 8 students, visited to Turkish Space Systems, Integration and Test Center at TAI (TUSAŞ - USET) to see the production and test processes of TÜRKSAT 6A satellite. The main area of this center can be seen in Figure 5. Testing and monitoring of the production of TÜRKSAT 6A satellite is one of the responsibilities of my department, Satellite Programs Department, in TÜRKSAT company because TÜRKSAT is customer of TAI for the production of the satellite.

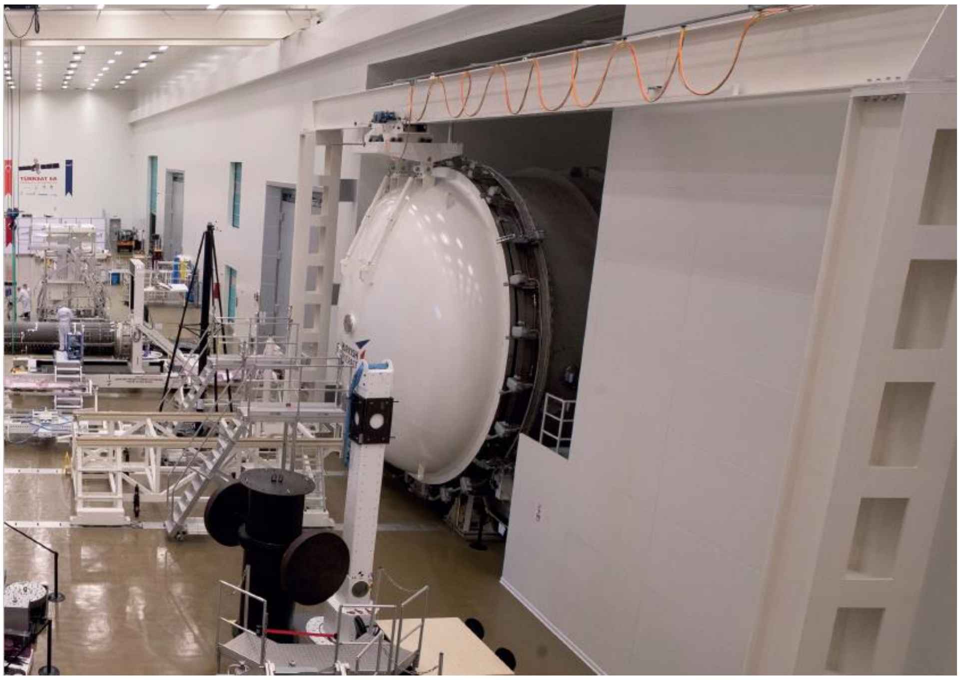


Figure 5: Turkish Space Systems, Integration and Test Center, which I visited, main area [5]

Anechoic room of test system:

We visited the anechoic chamber of test system and were given introduction to making electromagnetic wave and antenna tests there.

An anechoic, or an-echoic, or non-reflective, chamber is a closed room that prevents the reflections of electromagnetic waves in it. Also, it absorbs and prevents the electromagnetic waves coming from the outside of the room almost completely. The photograph of the EMI/EMC Test System Room at TAI can be found in Figure 6. The walls of this room are filled with a radiation absorbent material (RAM). The RAMs in the chamber had cone shapes, and this material is a lossy one to absorb the electromagnetic waves in the room. The height of these cones is one fourth of the wavelength of the electromagnetic wave tested in the room. Therefore, if the testes waves are high frequency ones, then the height of the cones is longer compared to the heights of the cones for testing lower frequencies of electromagnetic waves. This can be summarized as $h = \frac{\lambda}{4}$ where $\lambda = \frac{c}{f}$.

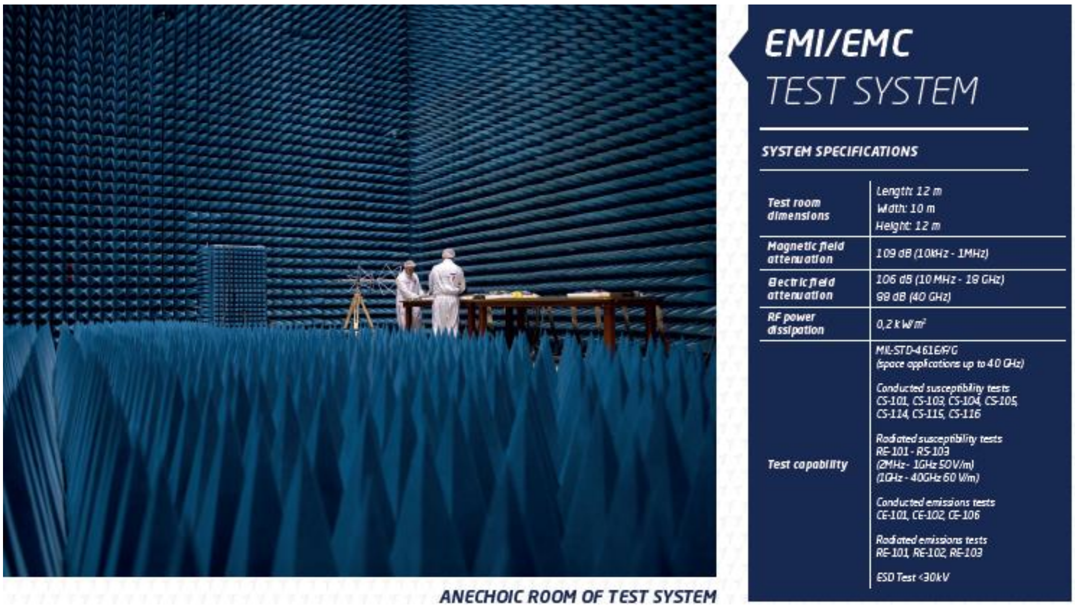


Figure 6: The anechoic chamber that I visited [5]

Also, there is another anechoic chamber where there are large metal reflectors as can be seen in Figure 7. This room simulates the communication between the satellite and earth stations. The metal reflectors make the electromagnetic waves into plane waves because we know that plane waves are an approximation of electromagnetic waves in long distances from the source of electromagnetic waves.

Figure 7: The chamber with reflectors in my visit [5]

In addition, we learnt that for an antenna, the Voltage Standing Wave Ratio (VSWR) value and the bandwidth is two important things that we want to adjust. VSWR should be below 3, and it is always greater than 1. If VSWR value of an antenna is close to 1, then that antenna is a good one because it reflects very low power back to the transmitting side. On the other hand, bandwidth is about in which frequency range we can use the antenna.

There are also other tests/test rooms in this test center: Vibration Test Center, Acoustic Test Center, Large and Medium Thermal Vacuum Test System. The whole test center is said to be 'Temiz Oda', or 'Clean Room' in English, which requires advanced cleanness physically and electromagnetically.

4.2 Flexible Payloads and Phased Array Antennas

I was given an assignment in the first week of my summer practice about making research about flexible payloads and phased array antennas, mostly focusing on the phased array antennas. Firstly, I read the documents that are given to me in the summer practice place, which are from the notes of Mathieu Dervin[4] from ENSEEIHT[5] in order to learn the preliminary knowledge of satellites and their communication systems. Due to privacy reasons of the company policy, I did not include these notes on my summer practice report. Secondly, I made literature research in the guidance of my summer practice supervisor and wrote a short report on the flexible payloads and phased array antennas.

In addition, I did make MATLAB simulation which includes the phased array antennas for different parameters.

4.2.1 Flexible Payloads

'Payload' in a spacecraft is the useful load that is carried for a specific purpose and the thing that is spent money in the mission. In recent commercial communication satellites, the payload consists of two parts: 'repeater' and 'antennas' [3, Ch. 9, p. 479]. 'Flexible payloads' are the payloads which is configurable in coverage, or the payloads having changeable properties such as frequency plan and routing, which is more desirable and efficient to the needs of a communication satellite mission [3, Ch. 9, p. 520]. Figure 8 show the general concept of flexible payload in satellite communication payload.

Beam coverage flexibility can be performed by using rotatable spot beam antenna, mechanically reconfigurable antenna, phased array antenna and beam hopping with a digital processor. The Rx and Tx antennas shown in Figure 8 represents this type of method used for the flexibility of the payload.

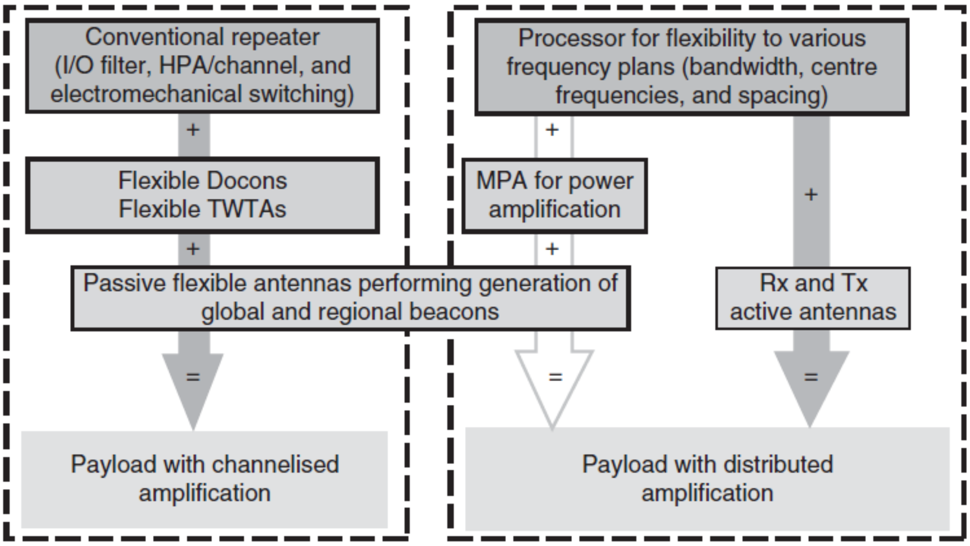


Figure 8: The concept of flexible communication system [3, Ch. 9, p. 520]

There are two parts of the flexible payloads: payloads with channelized amplification and payloads with distributed amplification.

[4] He is from Centre National d'Études Spatiales/National Centre for Space Studies, Toulouse, France.

[5] *L'École nationale supérieure d'électrotechnique, d'électronique, d'informatique, d'hydraulique et des télécommunications* is a French engineering school (Grande École) which offers education in Electrical Engineering, Electronics, Computer Science, Hydraulics and Telecommunications. The employees in my division, which is Satellite Programs Department, have taken a *know-how* education about satellite technology in France recently.

Frequency plan and channel-to-beam flexibility can be provided by analog and digital processors. RF power distribution flexibility can be done by using flexible Traveling Wave Tube Amplifiers (TWTAs) and Solid State Power Amplifiers (SSPAs) as well as multiport amplifiers [6, Ch. 10, p. 273]. By using these types of technologies, our aim is to meet the increasing demand for the flexible data traffic between the satellite space segment and ground segment such as mobile users and earth stations. Although these new technologies are now expensive, the overall cost of a communication satellite mission can be optimized and in the long run it may be more efficient due to its properties meeting the increasing demand and needs of the future data traffic in the world.

Then, I focused on the beam coverage flexible technology used in communication system of a satellite and describe the active antennas before mentioning about phased array antennas.

4.2.2 Active Antennas

The antennas with amplification are called active antennas, which means they have amplifier circuits including transistor. This type of antennas amplifies the electromagnetic wave received to the antenna or transmitted to the antenna. Currently, most of the space communication antennas are reflector passive antennas, which has no amplification. Therefore, the use of active antennas is limited use to certain applications that require on-board flexibility.

Radar antennas, telecommunication antennas for Low Earth Orbit (LEO), multiple beams generation for mobile users and scanned beams generation for Geostationary Orbit[6] (GEO) are some of the uses of active antennas in satellite communication systems.

In order to have higher flexibility in payloads, active antennas are needed for a couple of its advantages. Firstly, the active antennas have low power, solid-state amplifiers that enable good linearity. Secondly, with parallel connection of a large number of identical elements, the reliability about realizing a function. In other words, failure of one of these identical elements does not lead to a noticeable effect on the performance of the function [3, Ch. 9, p. 566]. Also, the current new technologies such as the fifth generation 5G standard for mobile telecommunication uses the active antennas in the communication satellites.

[6] The orbit that has an altitude of 35.786 km from the Earth surface. In GEO orbit, the satellites have almost no gravitational force on it, and it is easy to move and adjust a spacecraft there. Therefore, most communication satellites such as our TURKSAT 5B satellite are on the GEO orbit.

There are also disadvantages of active antennas. The ohmic losses due to the amplifier circuits and the limited efficiency of these amplifiers are two of the disadvantages [3, Ch. 9, p. 566]. Pre-amplifiers and power amplifiers in an active antenna system can be seen in Figure 9, which is from a communication satellite STENTOR. Figure 9 also shows us that an active antenna cannot be used as both transmitter and receiver by reciprocally due to the amplifier.

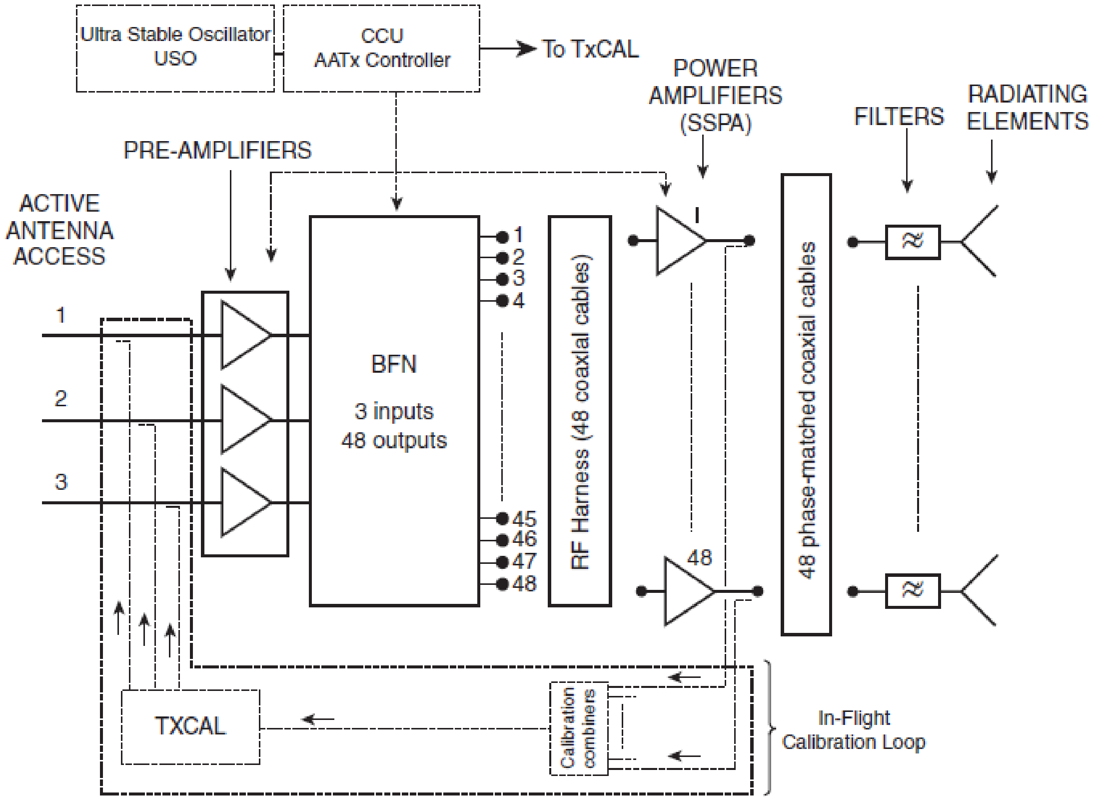


Figure 9: Active antenna used for transmitting in the STENTOR Satellite [3, Ch.9, p. 567]

The circuit technology used in active antennas is high frequency integrated circuits, especially MMIC[7]s [3, Ch. 9, p. 566].

4.2.3 Phased Array Antennas

The antennas used in communication satellites are usually three types: Horn, Phased Array and Parabolic Antennas. Phased array antennas have the advantage of changing its direction by the change of phase of the transmitted electromagnetic wave while it is in a constant movement in a satellite. In other words, it uses phase shifters on each element of the antenna array. Also, it can change the gain in one direction and can reduce the gain in a direction for decreasing the interference between the signals [3].

Despite the satisfying advantage of steering in a certain direction, the use of phased array antennas in radio frequency (RF) communication is few now because of the high cost of this technology [3, Ch. 8, p. 425].

[7] 'MMIC' stands for 'Monolithic Microwave Integrated Circuit', which is a circuit used at microwave frequencies and uses the GaAs semiconductor technology.

Array Characteristics and Geometry:

By using the word 'array' when we talk about phased array antennas, we deal with small cells which have a certain geometry. Figure 10 shows a linear array geometry for an array antenna.

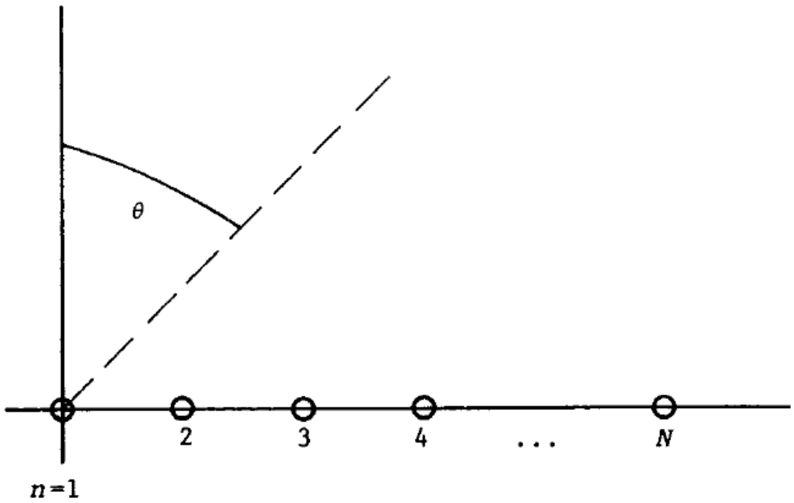


Figure 10: Linear array geometry: The pattern is on a line and the angle θ is the same for all of them [6, Ch. 3, p. 50].

Figure 11 shows an array lattice in the spherical system. The azimuth angle ϕ and elevation angle θ are the parameters used in the calculations of phased array antennas. The elements in a phased array antenna are represented by the small circles, which has a planar array geometry.

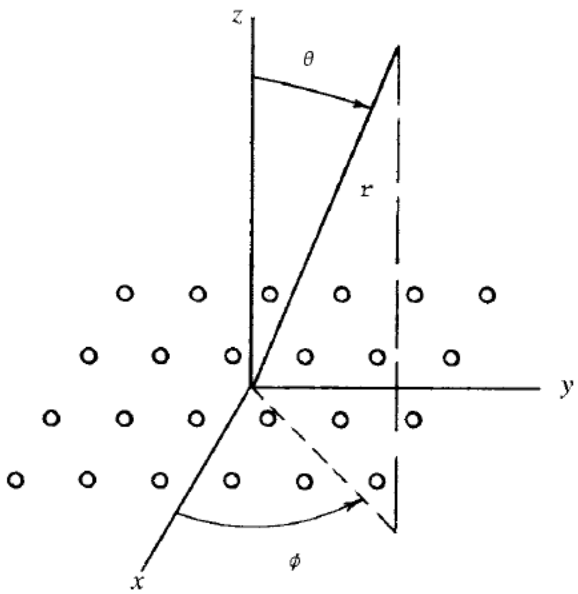


Figure 11: The planar array lattice and spherical system [6, Ch. 2, p. 17]

In Formula 1, θ_0 is between the 0° and 180°. β is used for the phase shifting operation to adjust the zenith angle. θ_0 is the zenith angle, and this formula shows the β mathematically to adjust the zenith angle.

$$\boxed{\psi = kd\cos\theta + \beta|_{\theta=\theta_0} = kd\cos\theta_0 + \beta = 0 \Rightarrow \beta = -kd\cos\theta_0}$$

Formula 1: Obtaining the phase excitation constant β [7, Ch. 6, p. 301]

Table 1 shows the comparison of some phased array modeling software capabilities. Since I have a MATLAB license from my university, I used MATLAB to simulate some array patterns and antenna.

Software	Phased Array Modeling	Platform Effects	Mutual Coupling	Antenna Modeling
MATLAB	Y	N	Y	N
STK	Y	N	N	N
GRASP	Y	Limited	N	Y
GRASP - MoM	Y	Y	Y	Y
HFSS - IE	Y	Y	Y	Y

Table 1: The comparison of some phased array modeling software capabilities, Y: Yes, N: No [8]

Simulation in System Toolkit (STK):

System Tool Kit (STK) program example is shown in Appendix B. A test scenario and radiation pattern in space in STK can be shown there.

Simulation in MATLAB:

Using MATLAB Antenna Toolbox and Phased Array System Toolbox, I made a few simulations with different parameters for phased array antennas. The auto-generated MATLAB code for this simulation is given in Appendix C. The array geometry that I used in the simulation is shown in Figure 12.

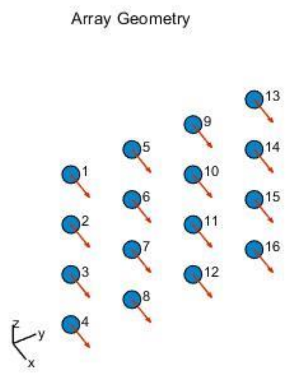
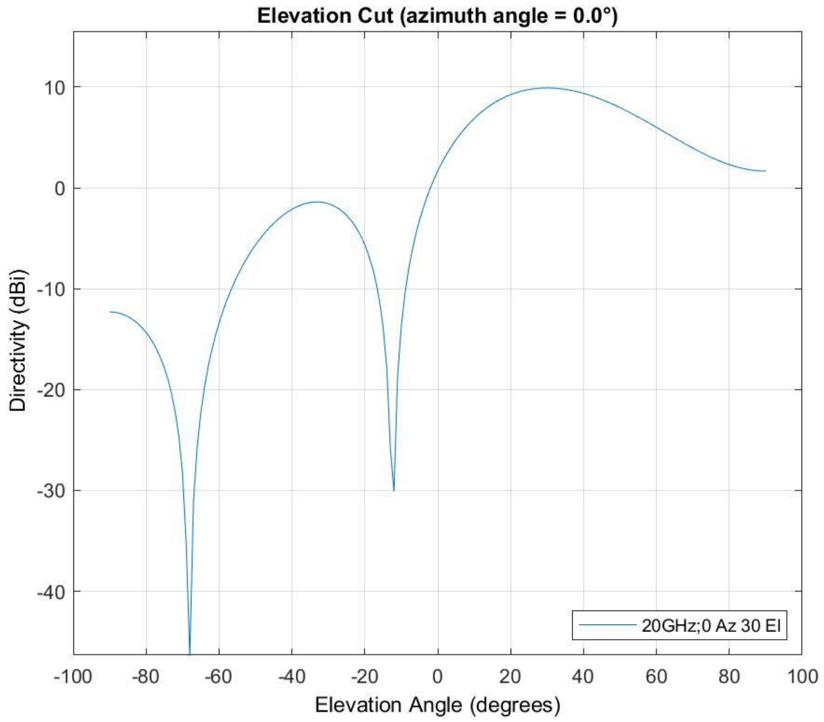


Figure 12: The array geometry that I used in MATLAB simulations, 4 by 4 phased array antenna model

Figures 13-18 show phased array antenna radiation patterns for different $\frac{d}{\lambda}$, which is the ratio of distance between the elements of the antenna and the wavelength of the electromagnetic wave when the elevation, or zenith, angle is equal to 30 degrees. The frequency of the electromagnetic wave is equal to $20\,GHz$. Since the LEO satellites that uses phased array antennas usually use Ka band frequencies, I chose a frequency in Ka band. The azimuth angle is 0 degrees in my all simulations for phased array antennas for the simplicity. In addition, we know that $\lambda = \frac{c}{f}$ where the f is the frequency. If we increase the $\frac{d}{\lambda}$ ratio in the antenna from 0.35 to 0.6, then we see that the distance between the peaks of the antenna radiation pattern decreases.

The number of elements used in a phased array antenna array depends on the frequency band. For a X-band phased array antenna, typically 26 elements are needed for the antenna [9].



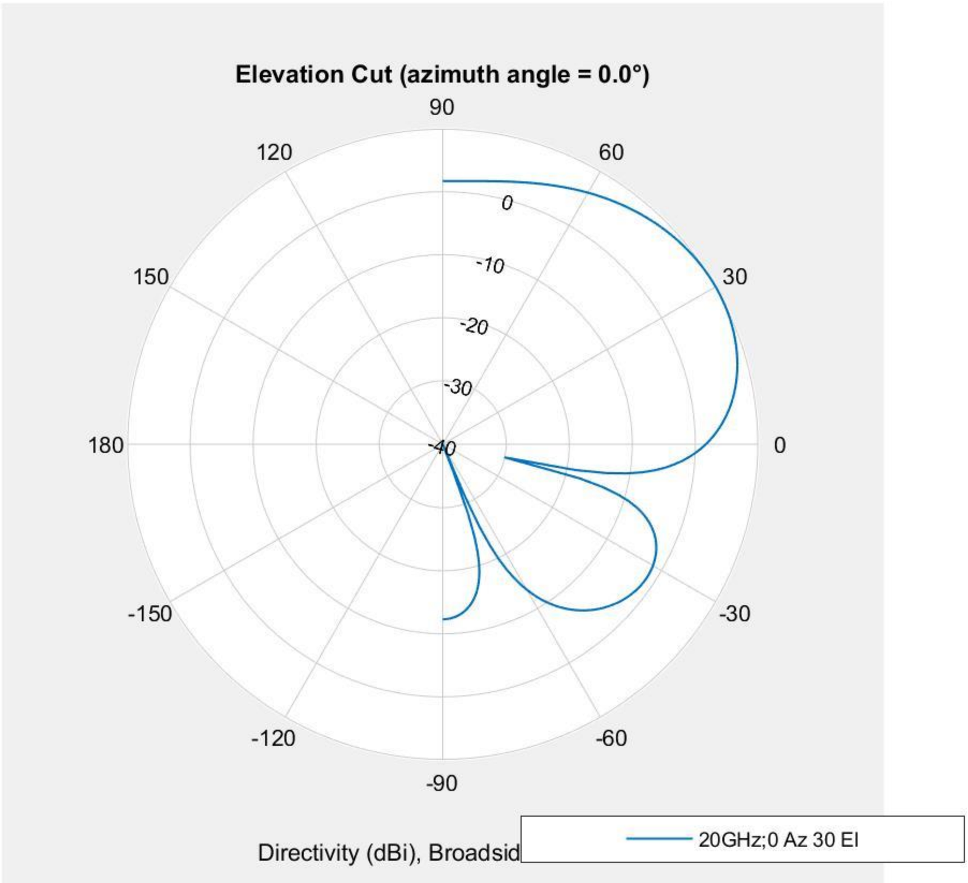
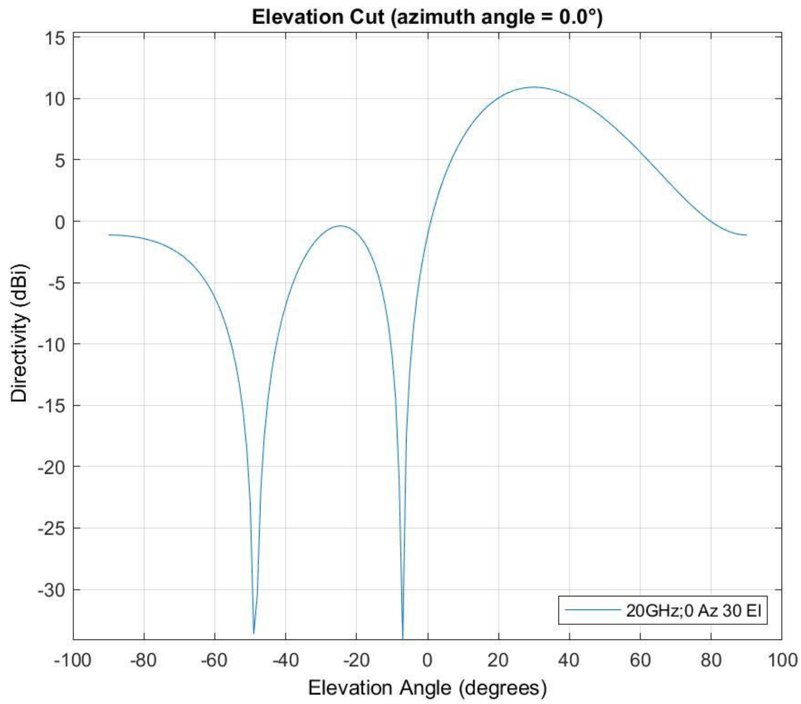


Figure 13: The radiation pattern for $d = 0.35\lambda$ when the elevation angle is 30°, rectangular and polar plots in MATLAB



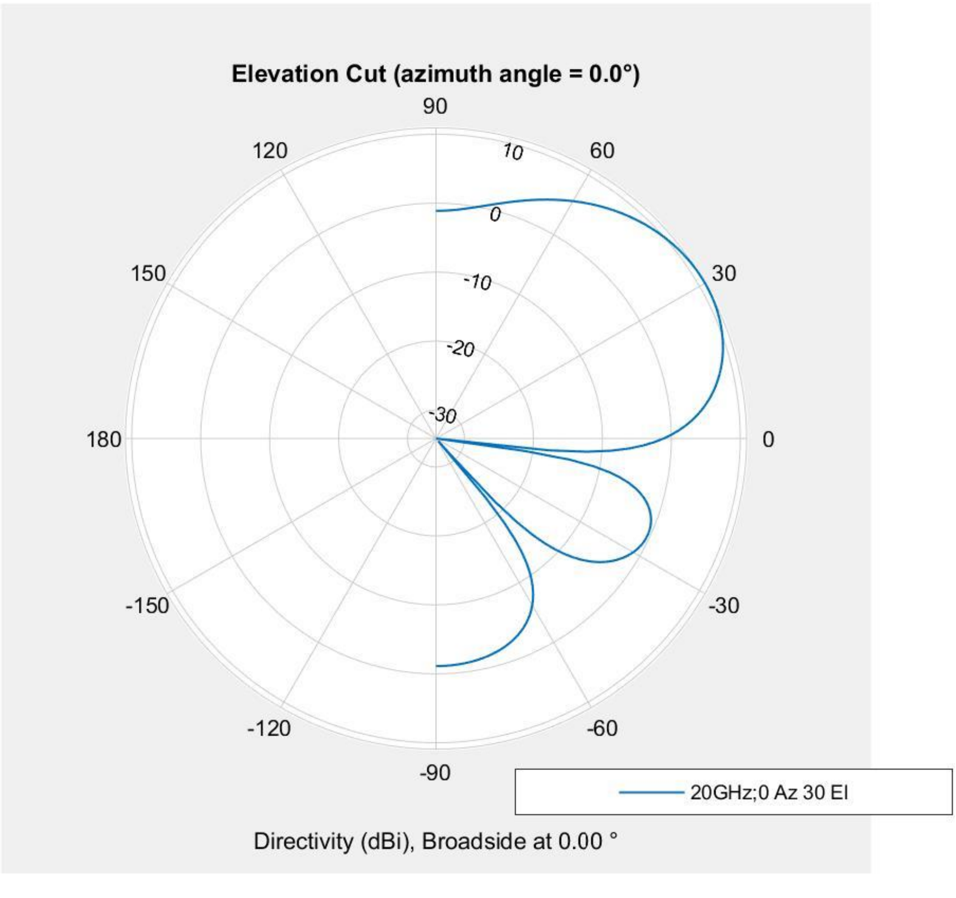
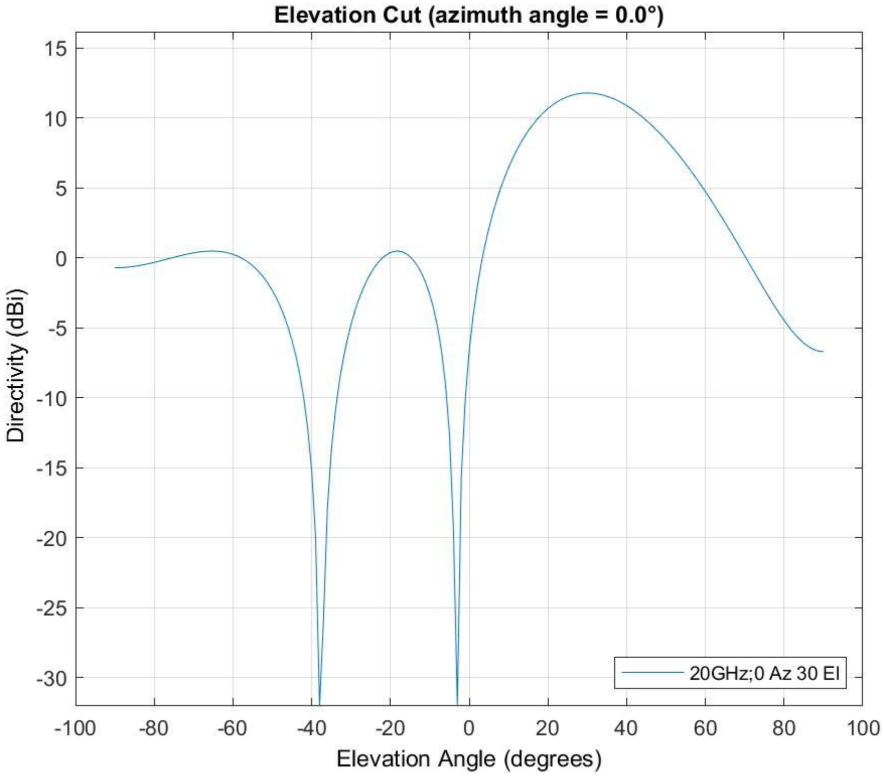


Figure 14: The radiation pattern for $d = 0.40\lambda$ when the elevation angle is $30°$, rectangular and polar plots in MATLAB



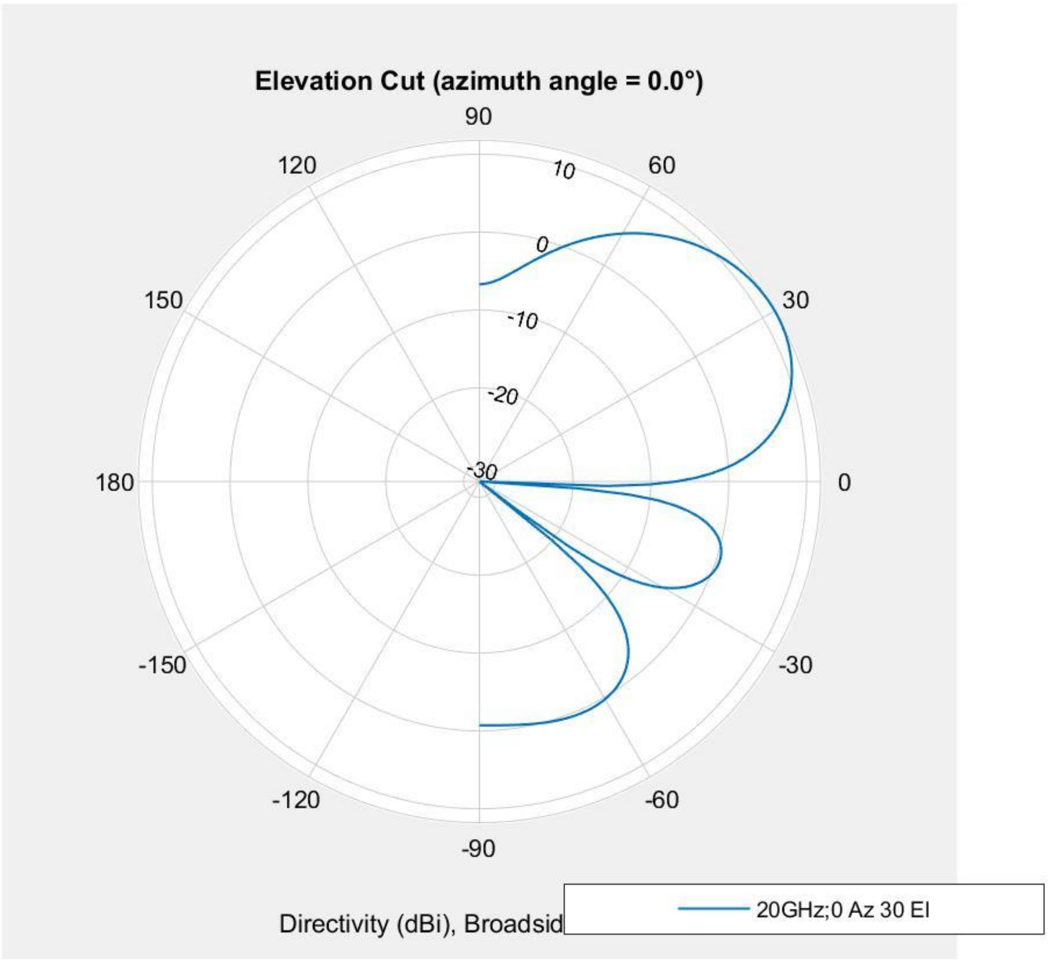
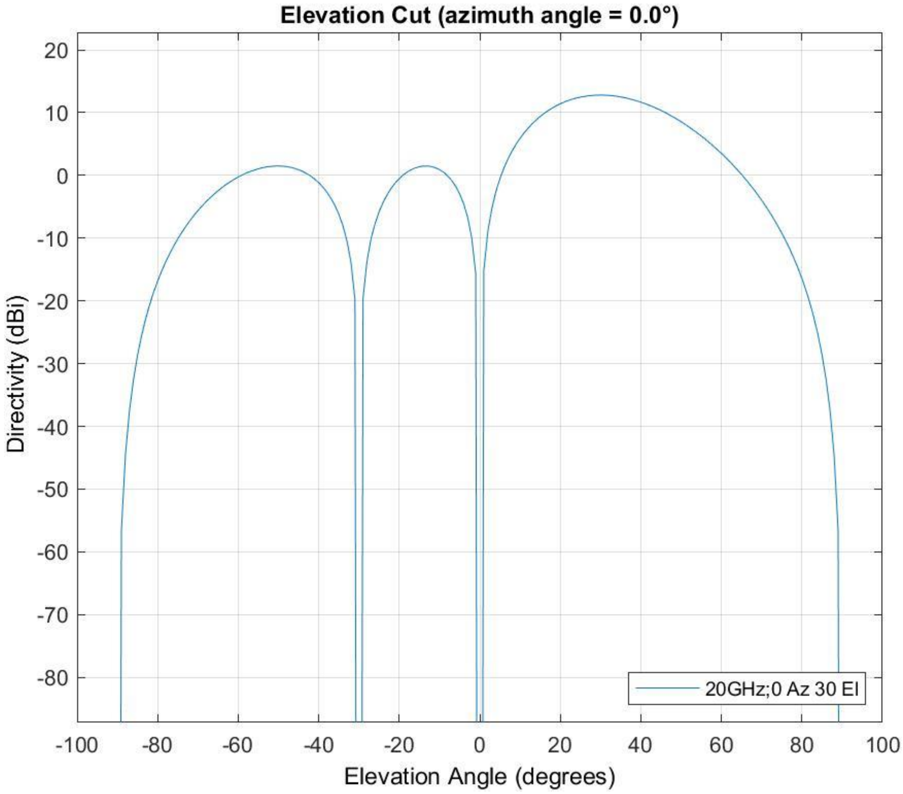


Figure 15: The radiation pattern for $d = 0.45\lambda$ when the elevation angle is $30°$, rectangular and polar plots in MATLAB



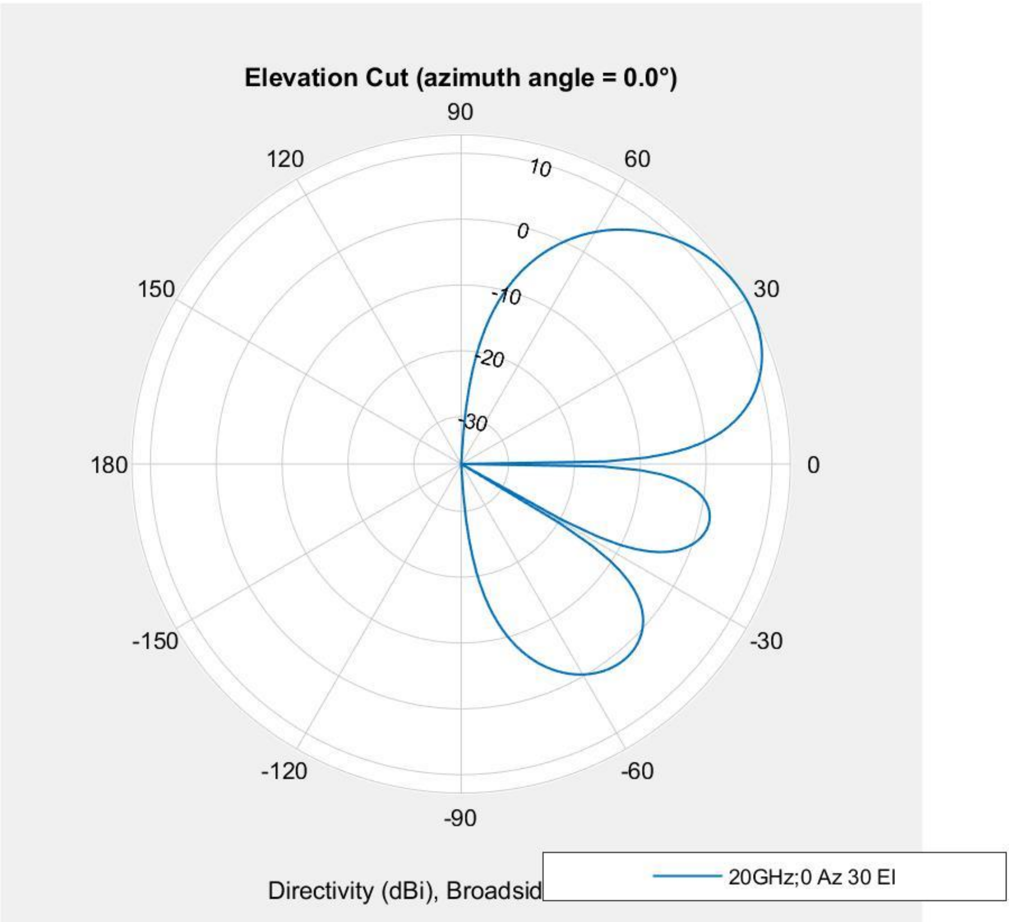


Figure 16: The radiation pattern for $d = 0.50\lambda$ when the elevation angle is $30°$, rectangular and polar plots in MATLAB

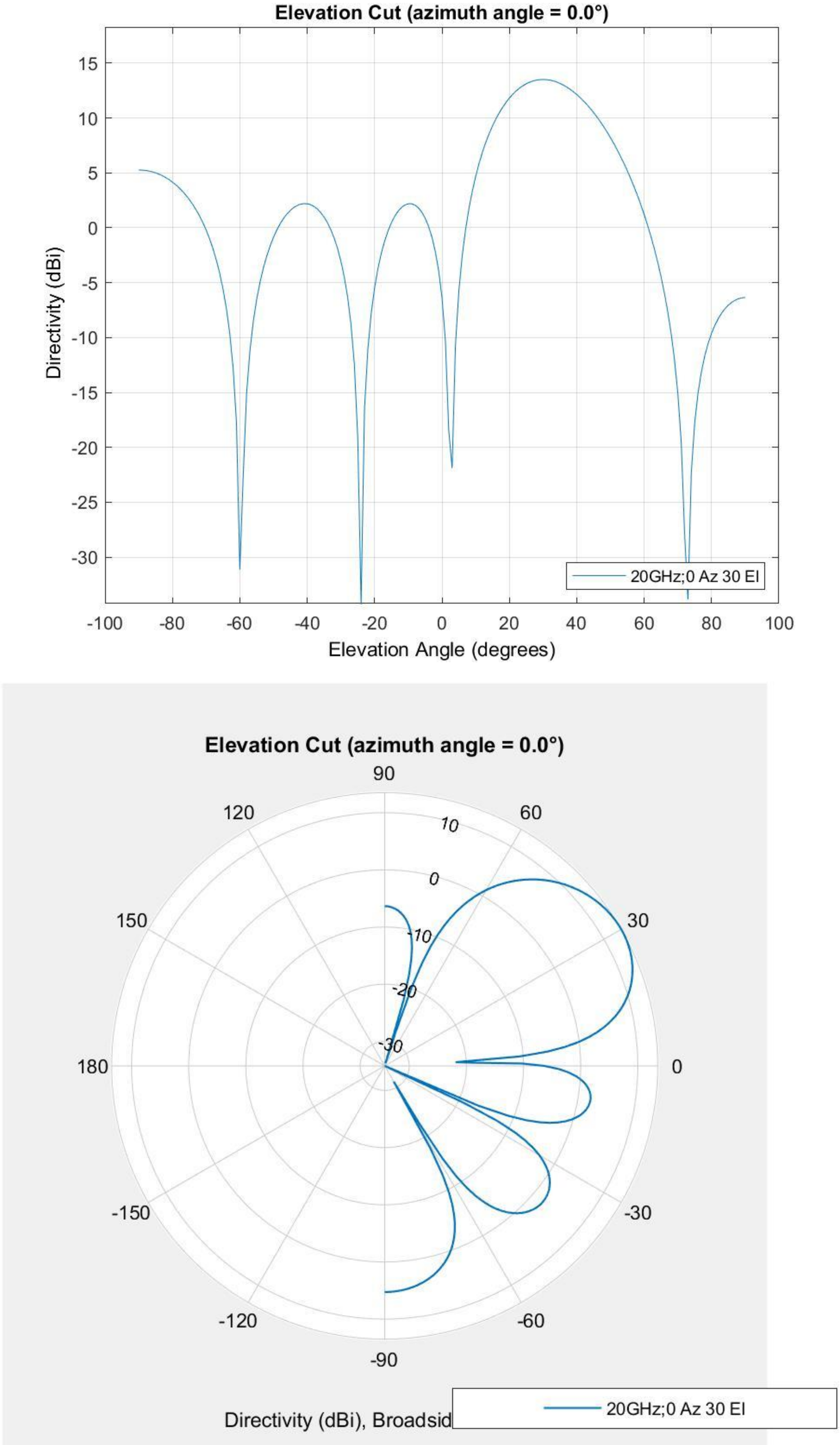
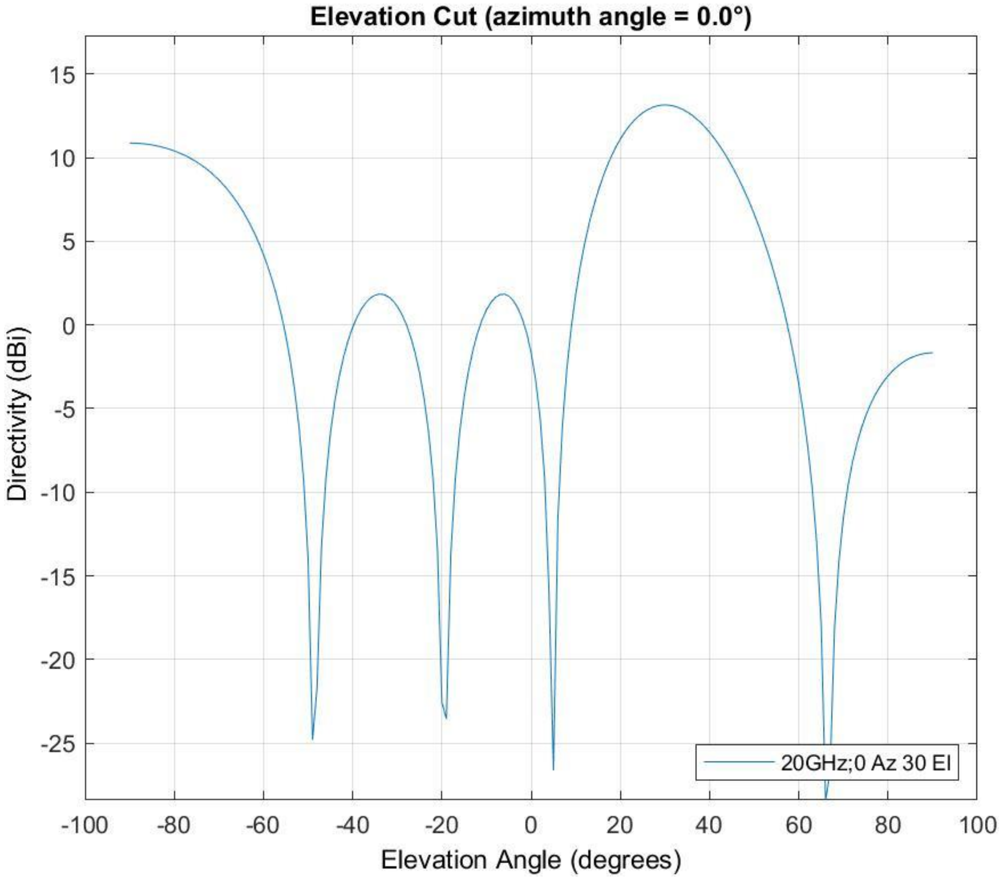


Figure 17: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is $30°$, rectangular and polar plots in MATLAB



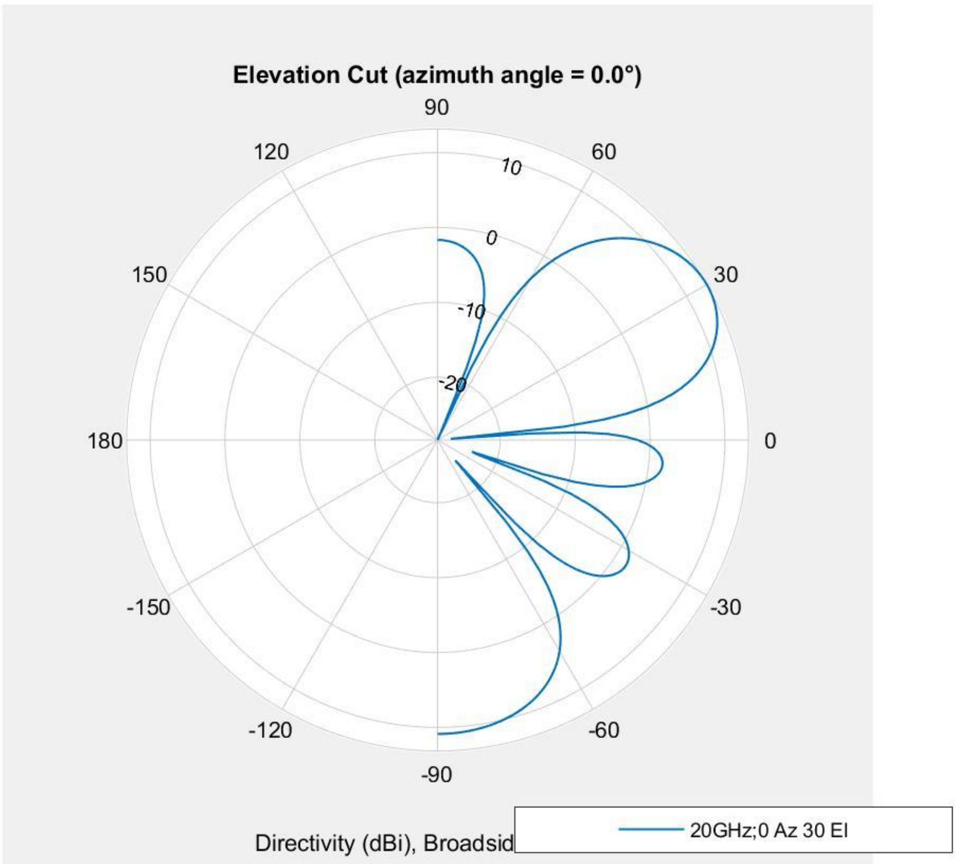
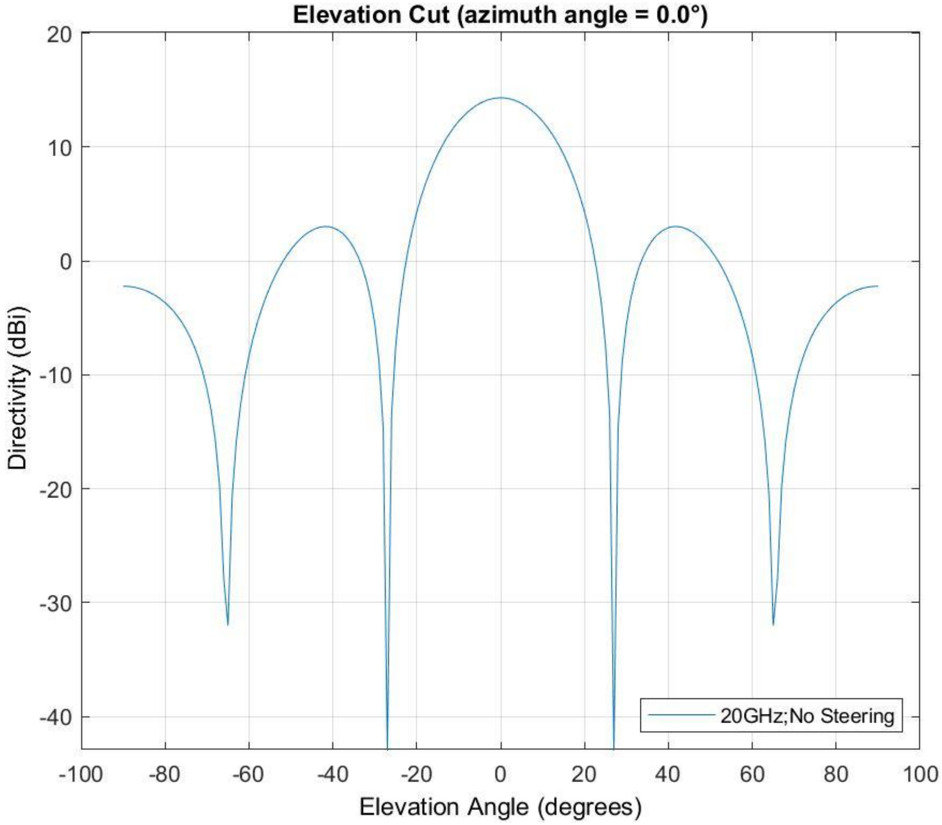


Figure 18: The radiation pattern for $d = 0.6\lambda$ when the elevation angle is 30°, rectangular and polar plots in MATLAB

Also, for different elevation angles, the radiation pattern in rectangular and polar forms is given in Figures 19-24. They have usually a peak point the corresponding elevation angle, but not every elevation angle is optimum.



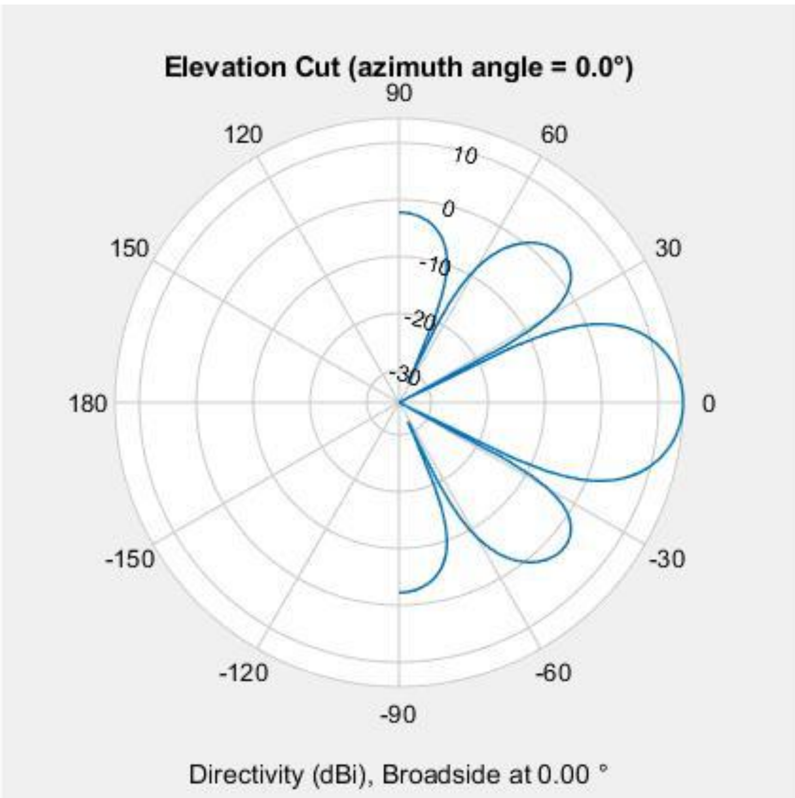
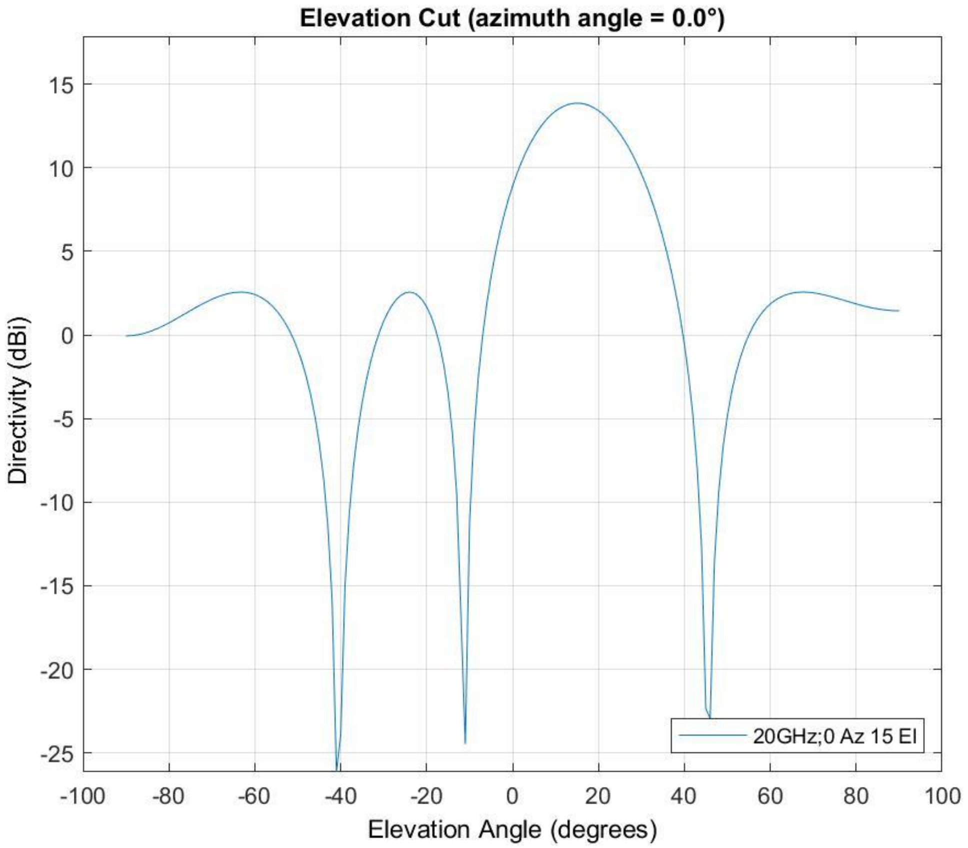


Figure 19: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is 0°, rectangular and polar plots in MATLAB



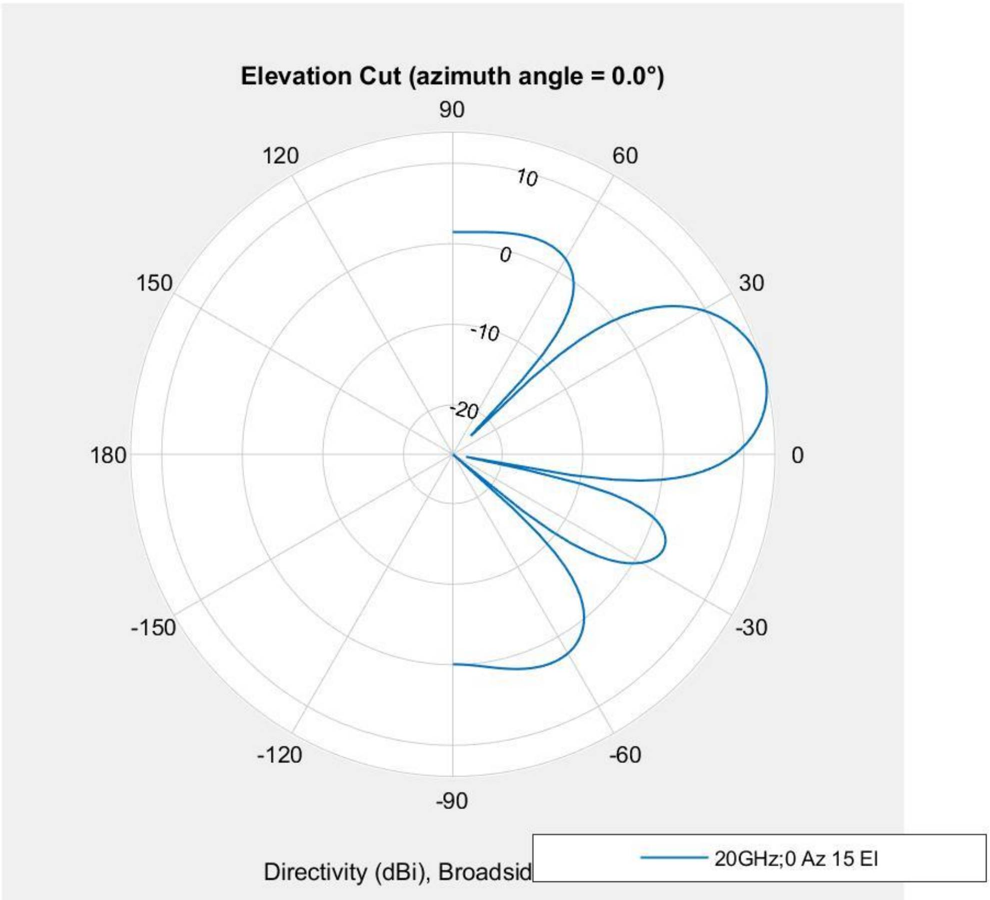
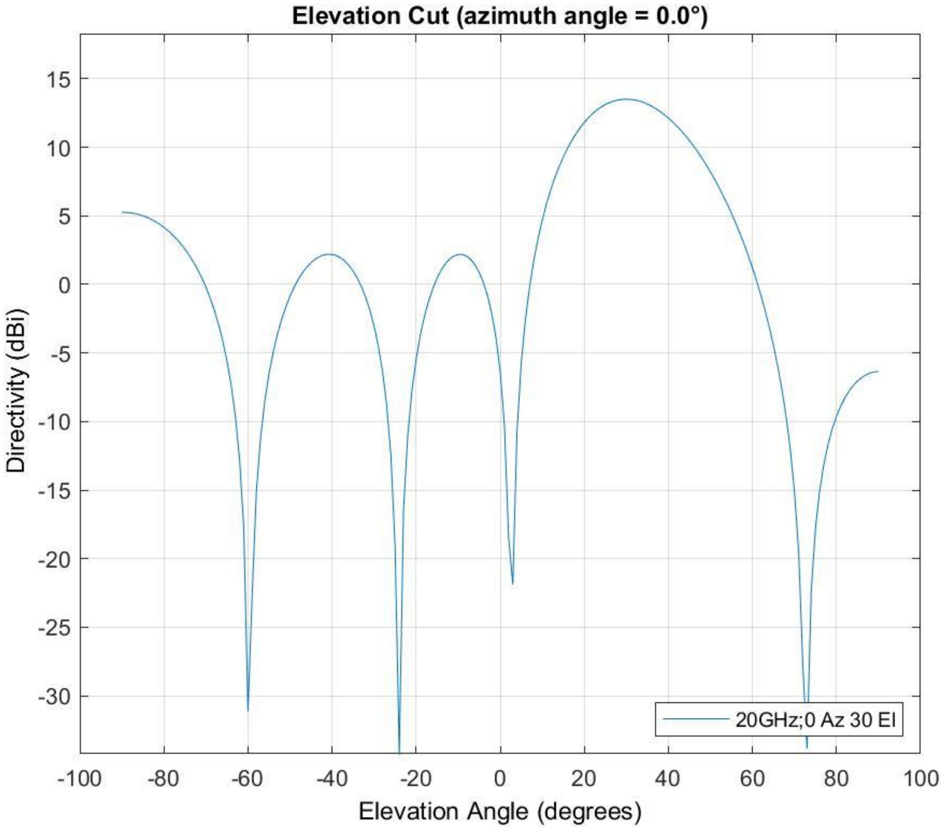


Figure 20: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is $15°$, rectangular and polar plots in MATLAB



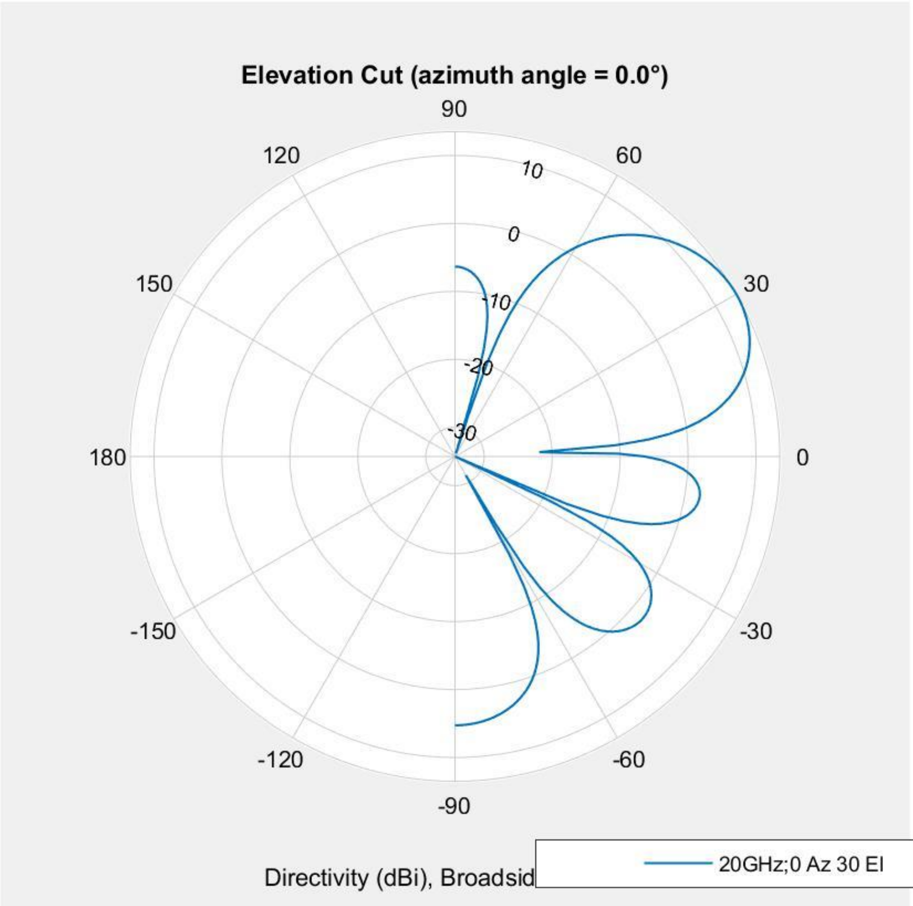


Figure 21: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is $30°$, rectangular and polar plots in MATLAB

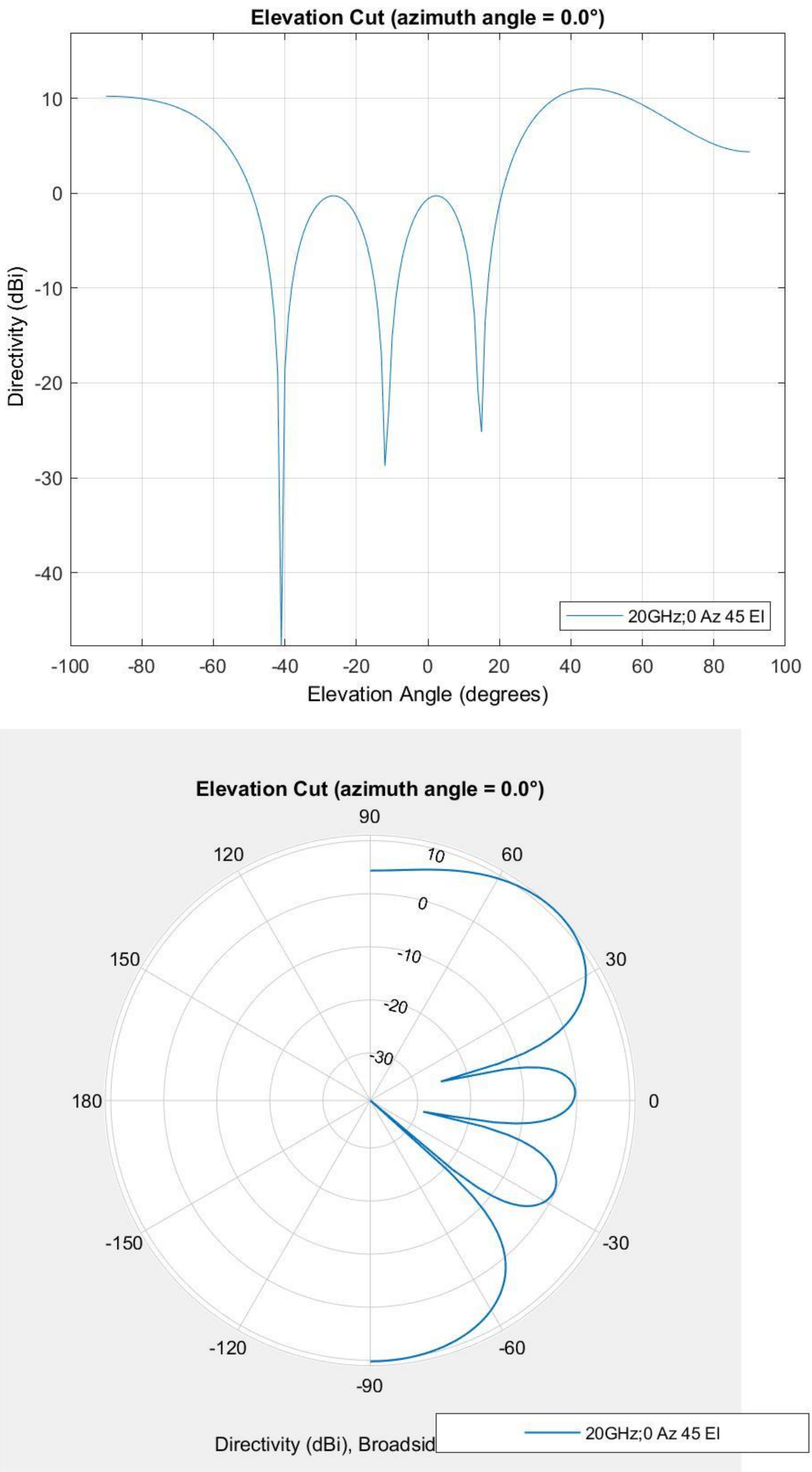
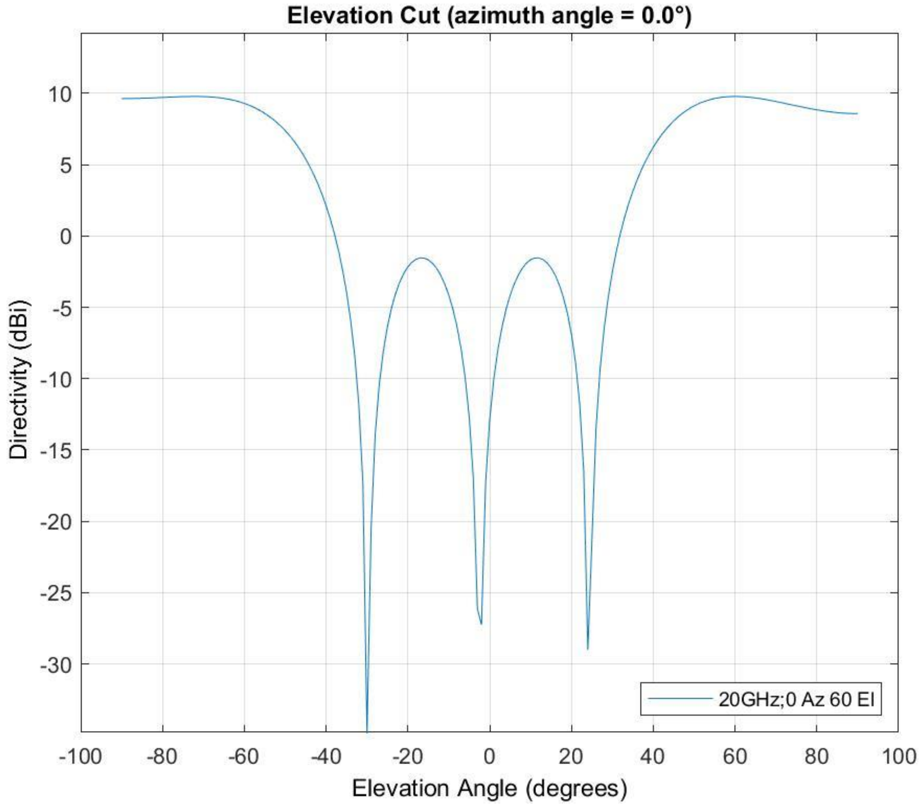


Figure 22: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is 45°, rectangular and polar plots in MATLAB



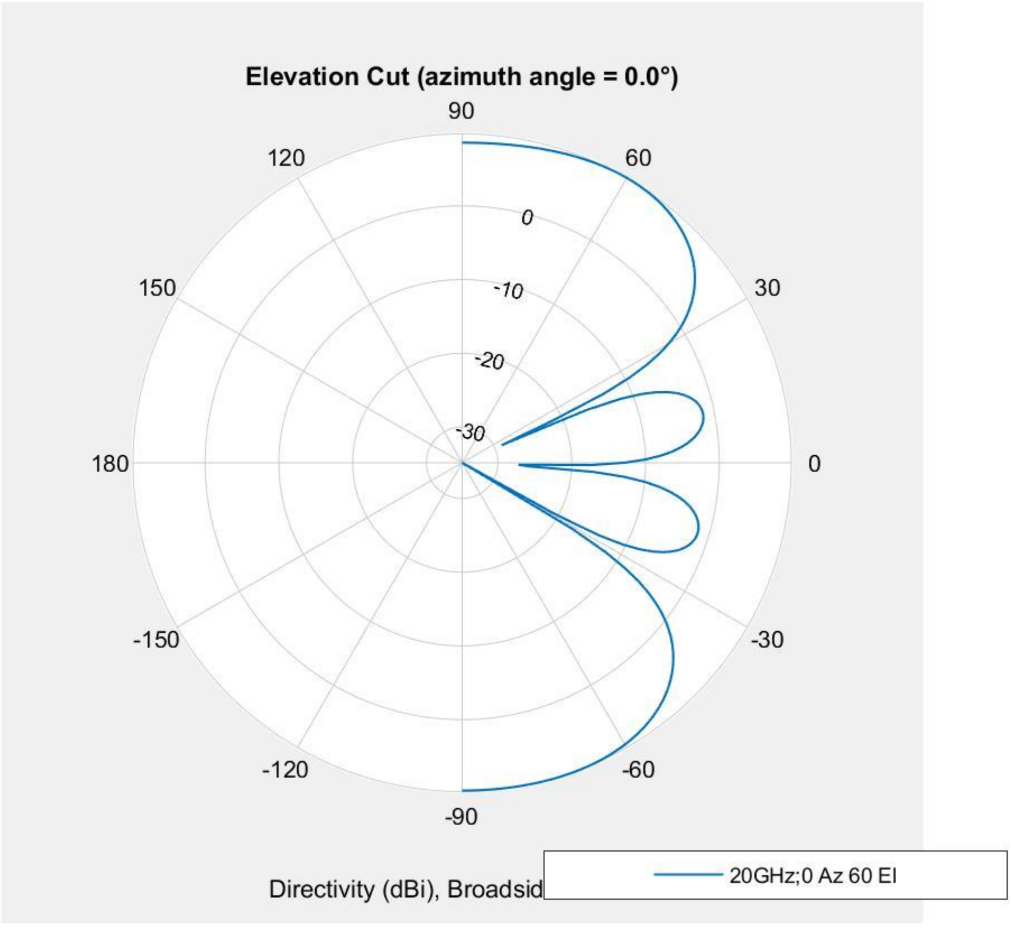
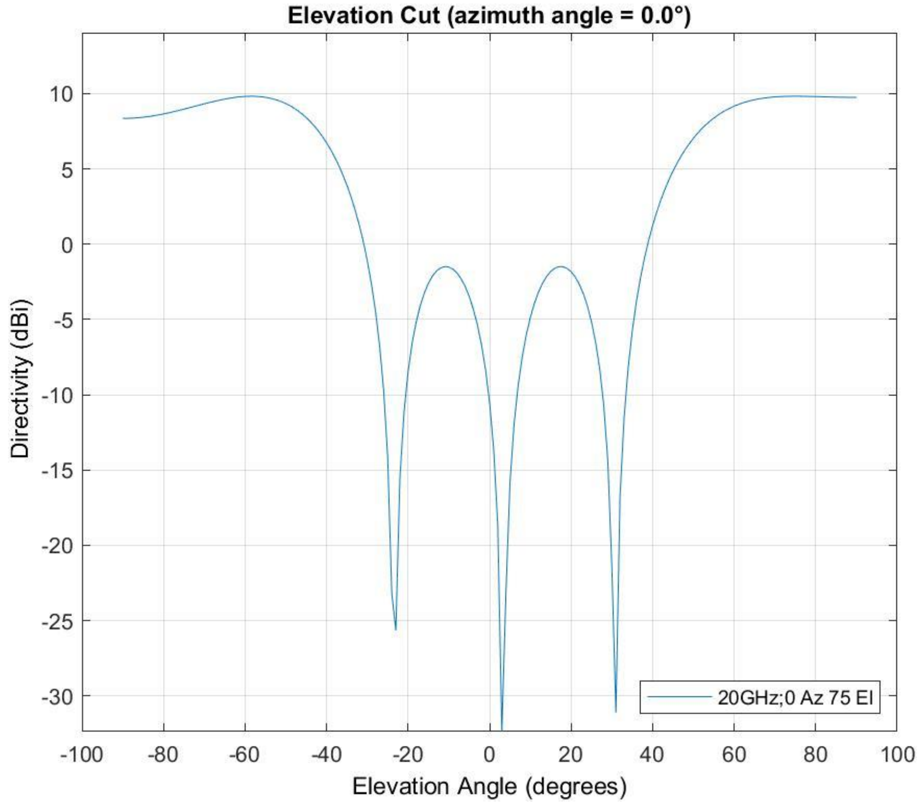


Figure 23: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is $60°$, rectangular and polar plots in MATLAB



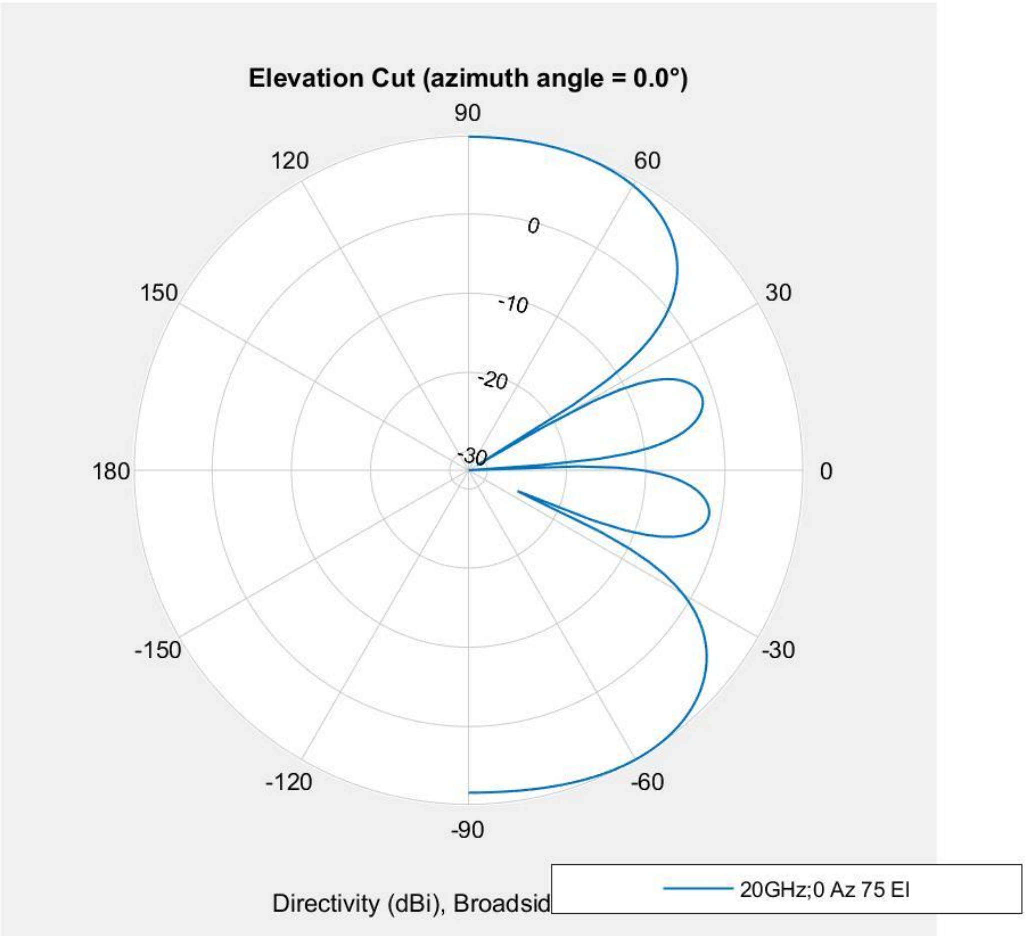


Figure 24: The radiation pattern for $d = 0.55\lambda$ when the elevation angle is $75°$, rectangular and polar plots in MATLAB

The 3D radiation pattern of the phased array antennas for different cases is given in Figure 25-26. Obviously, when the spacing is $d = 0.55\lambda$, the phased array antenna is functioning better.

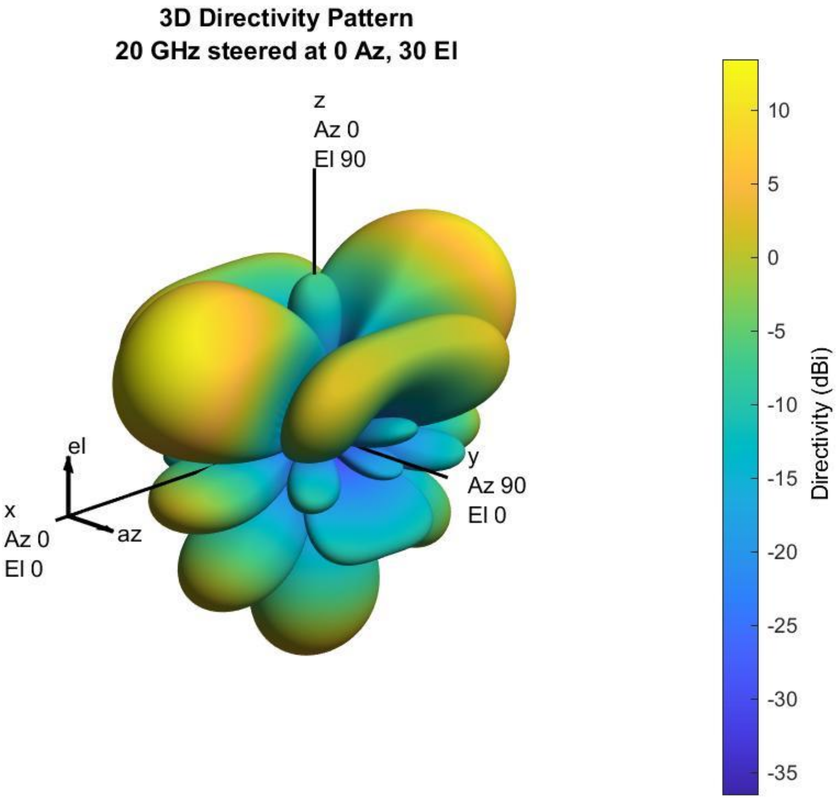


Figure 25: The directivity pattern of the array antenna in MATLAB, where the normal axis is x-axis, when the elevation angle is 30 degrees, and the spacing is $d = 0.55\lambda$

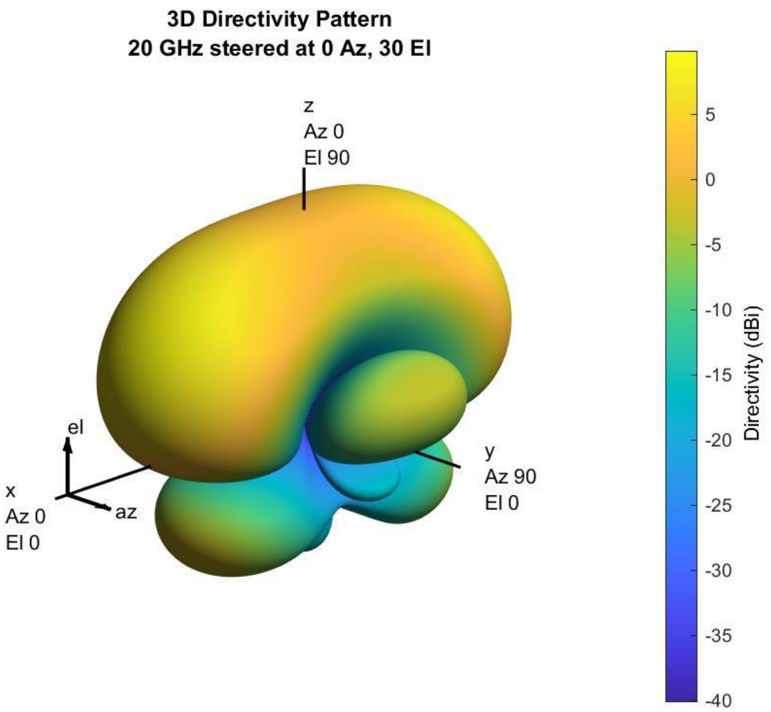


Figure 26: The directivity pattern of the array antenna in MATLAB, where the normal axis is x-axis, when the elevation angle is 30 degrees, and the spacing is $d = 0.35\lambda$

The 3D directivity patterns as well as the polar and rectangular plots for radiation pattern so far, we see that there should be an optimization operation to determine the optimum parameters for the purposed use of the phased array antenna. Thus, I concluded that optimization is an important part of phased array antenna design.

The use of phased array antennas in communication satellites commercially:

Iridium Satellite Constellation (First launch date: 1997):

Figure 27 shows a replica of an Iridium satellite.

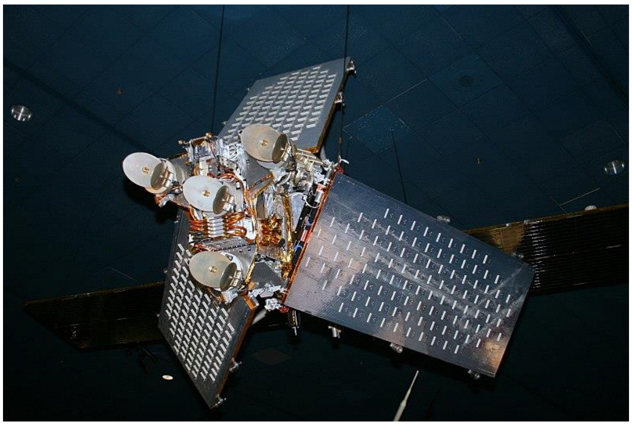


Figure 27: First generation of the Iridium Satellite (replica) [10]

In Figure 28, the phased array antenna which uses K band frequency can be seen. It is a relatively small satellite with a few dozens of them in space. It is used for satellite communication as well as providing Internet from the satellites, and their coverage is the entire earth surface. Aireon Payload shown in the Figure X is for controlling the air traffic.

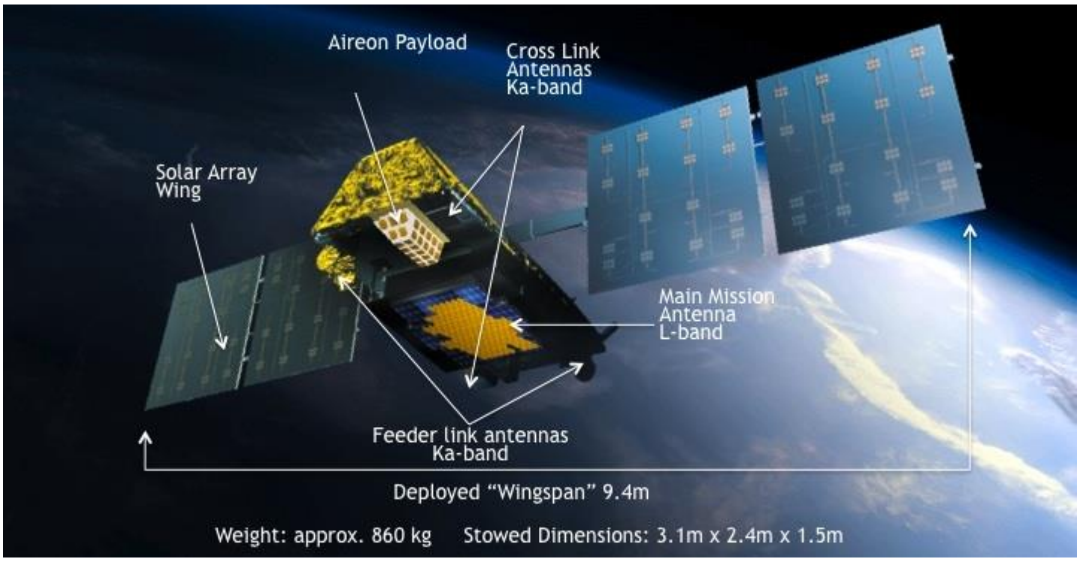


Figure 28: Iridium Next Satellite Properties [11]

STARLINK Satellites (First launch date: 2019):

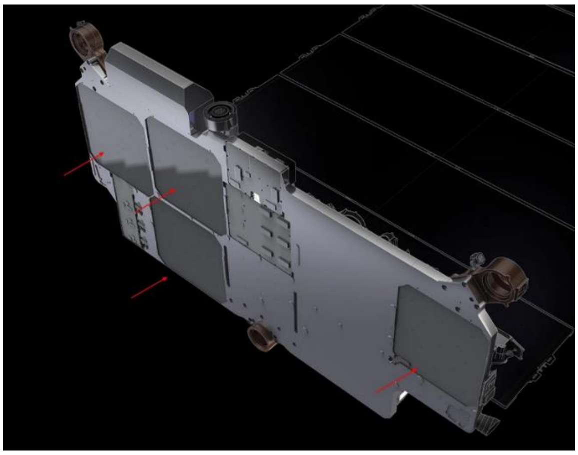


Figure 29: The Starlink satellites of SpaceX and its phased array antennas [12]

In Figure 29, the LEO orbit Starlink Satellite can be seen with its 4 phased array antennas for transmitting.

Amazon Project Kuiper (First launch date: 2022):

Similar to Starlink Satellites, Amazon Project Kuiper systems uses small satellites to provide Internet access from LEO orbit above the Earth, and these small satellites also use phased array antenna technology for the RF communication. The Amazon Project Kuiper phased array antenna photograph can be seen in Figure 30 with some of its properties.

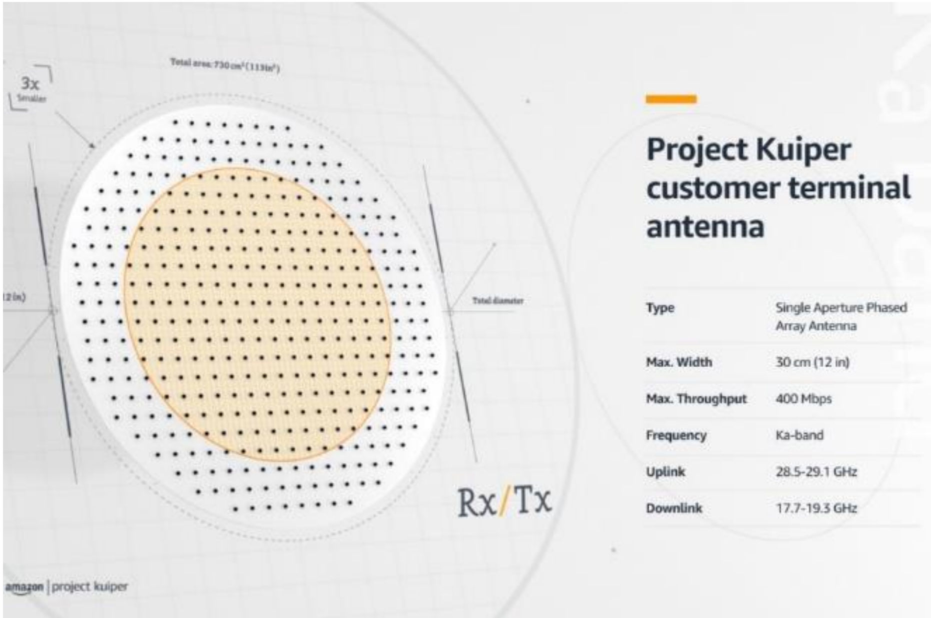


Figure 30: Amazon Project Kuiper satellites and earth stations using phased array antennas [13]

Such satellites will probably increase in the near future as the IoT for vehicles is used more, as there becomes a lot of air traffic, as the need for the flexibility of the payloads in satellites increases.

<u>Phased Array Antennas with and without Reflectors:</u>

Phased array antennas can be used with and without reflectors. A parabolic reflector is an example of this. These antennas provide from 5 to 10 degrees of electronic beam scanning [14].

Reflect arrays:

Reflect arrays use reflective elements that is illuminated by a feed. An example of reflect array structure is given in Figure 31.

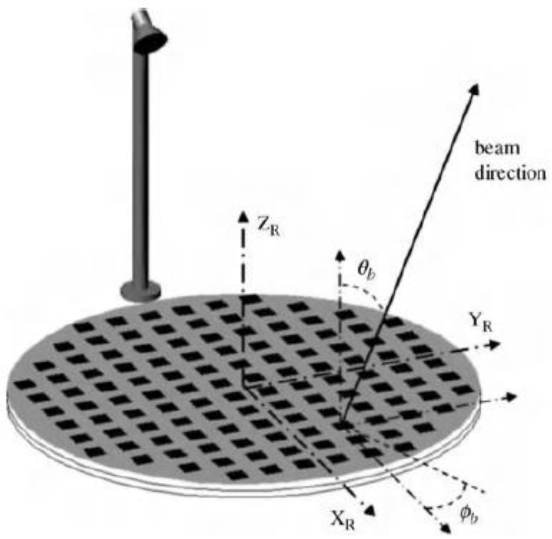


Figure 31: The printed reflect array structure [15]

4.3 DVB-S Communication Channel Layer Simulation Project

4.3.1 Preliminaries on Communication Systems and DVB-S

4.3.1.1 The TV Broadcast in TURKSAT

In the Teleport and TV Broadcast Department (Teleport ve TV Yayın Direktörlüğü), I attended the presentation and a small lecture on TV broadcast services. The block diagram in Figure 32 shows the summary of a TV broadcast from a TV channel office to the TV broadcast that we watch at home.

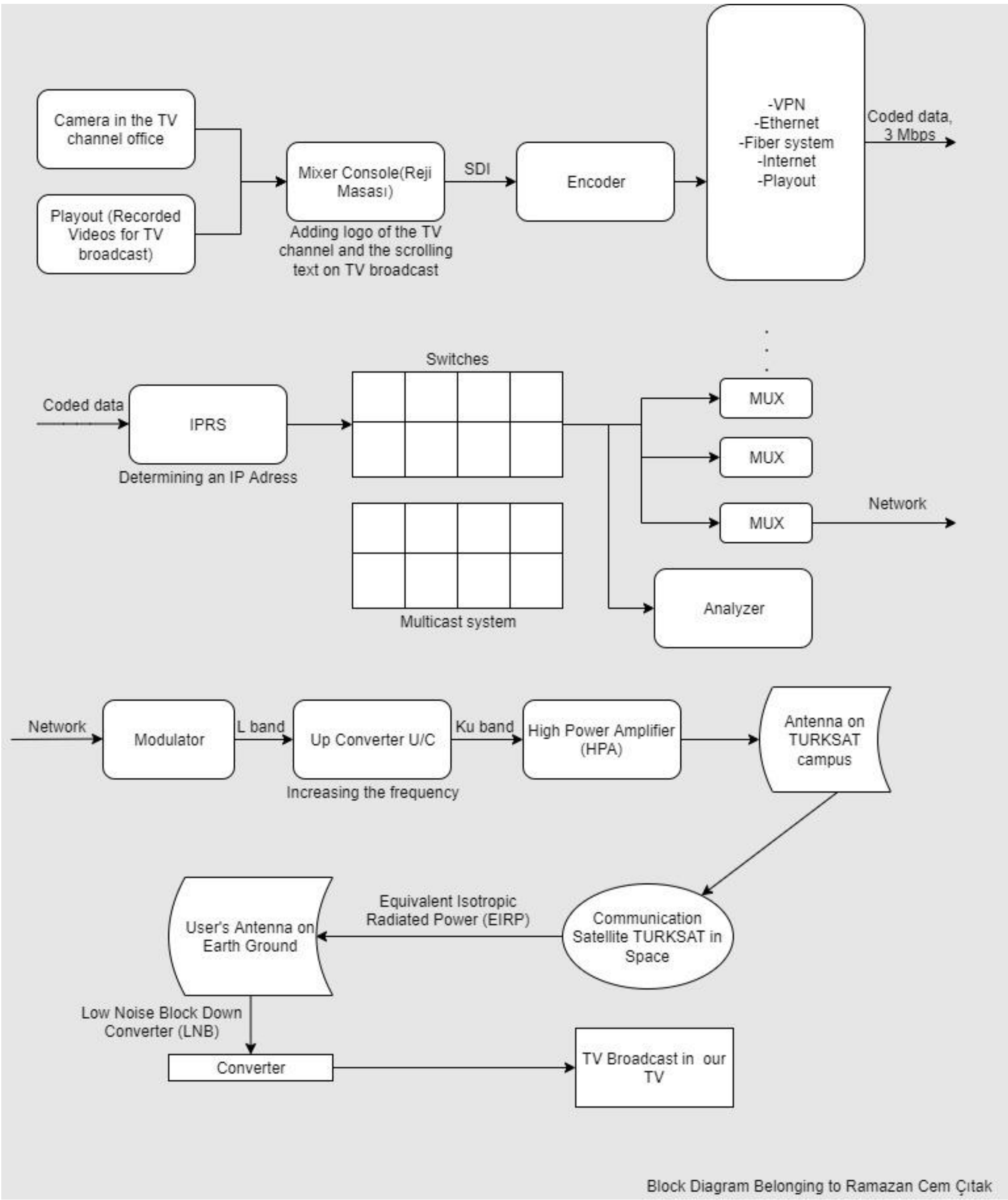


Figure 32: The block diagram based on my notes for the TV broadcast from a TV channel, from the Teleport and TV Broadcast Department visit in my summer practice

The Figure 33 shows a block diagram representing the structure of a transponder used in the communication satellite such as TURKSAT.

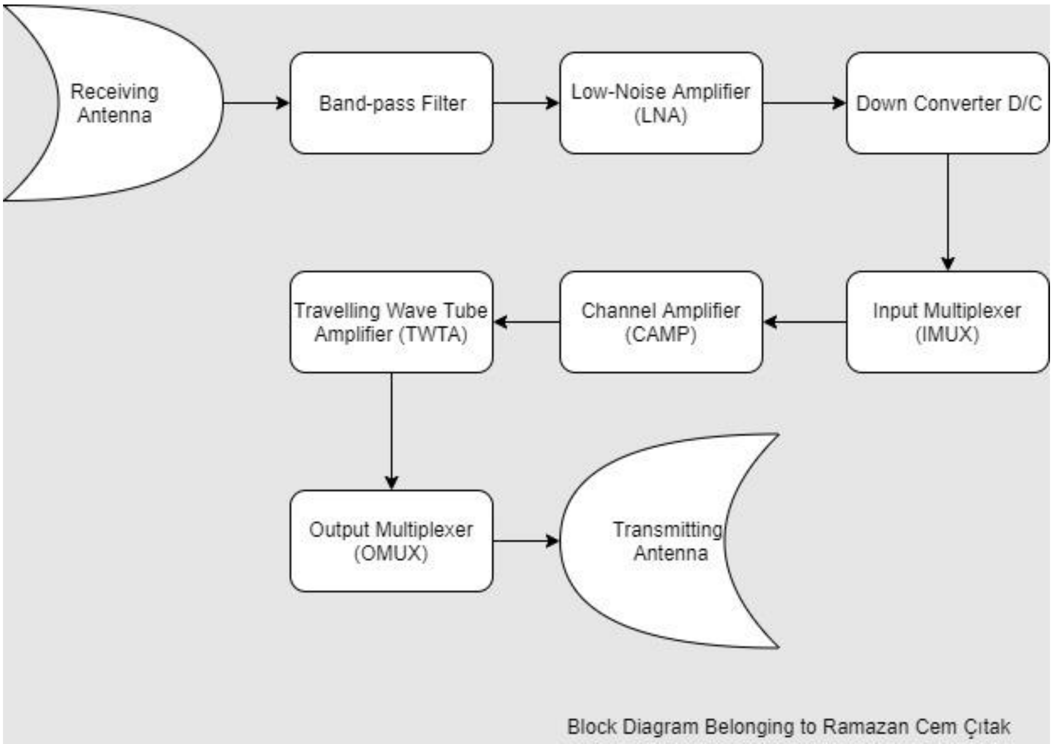


Figure 33: The structure of transponder used in a communication satellite,

from my notes during the Teleport and TV Broadcast Department visit in my summer practice

The transponder in a communication satellite takes a signal from its receiving antenna and amplifies it, and then it transmits the same signal. Transponders form a communication channel between these receiving and transmitting antennas and they are common payloads in the satellites and other spacecrafts.

Figure 34 shows the Teleport and TV Broadcast Department in TÜRKSAT.

Figure 34: The Teleport and TV Broadcast Department (Teleport ve TV Yayın Direktörlüğü) that I visited during my summer practice [4]

4.3.1.2 The Fundamentals on Communication Systems

Before starting the project, I studied the notes from the notes of Mathieu Dervin[8] and Chapter 1 from a book[9] about communication systems.

<u>*Mathematical models for communication channels:*</u>

There are a number of mathematical models for communication systems: The additive noise channel, the linear filter channel, and LTI filter channel. Since the project had only the additive noise channel, I focused on it during my summer practice.

Additive noise channel: It is the simplest model for a communication channel. The transmitted signal is added by a noise signal in this channel. The random noise can be a Gaussian distribution, which gives a 'Gaussian noise process' [16].

4.3.1.3 DVB-S and Project Preliminaries

<u>*DVB-S:*</u>

'DVB' stands for 'Digital Video Broadcasting', and 'DVB-S' means 'Digital Video Broadcasting-Satellite'. It was developed in 1991, which is a video broadcast standard. It is used to communicate using satellites.

<u>*QPSK:*</u>

It stands for 'Quadrature Phase Shift Keying'. It basically means four-state modulation in data transmission [3, Ch. 4, p. 141]. Basically, we use a sinusoid to carry our information signal.

Figure 35 shows the summary of QPSK method in a few steps: First, we take the NRZ signal, then symbol generator sends the data encoder. After that, the symbols can take one of four phase states.

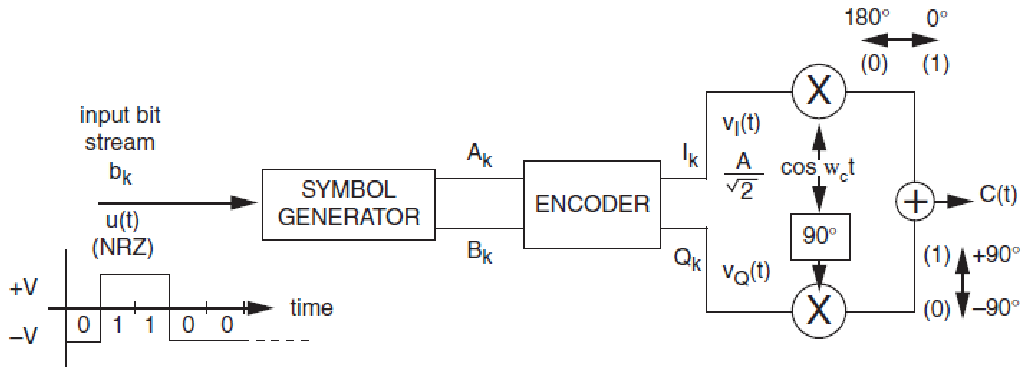


Figure 35: QPSK method [3, Ch. 4, p. 142]

<u>*NRZ:*</u>

NRZ stands for 'non-return to zero' in telecommunication systems. It represents binary information by using high and low voltage levels. For high voltage, this modulation technique uses a positive voltage, and for low voltage, it uses a negative voltage.

<u>*FEC:*</u>

It stands for 'Forward Error Correction'. FEC is a method used for controlling errors in the data transmitting processes when the channel has noise or unreliability [17].

[8] I mentioned about these notes in page 10 of this summer practice report before.

[9] J. G. Proakis, M. Salehi, *Fundamentals of Communication Systems*, 2nd ed. Pearson, 2014.

Constellation Diagram:

It is the representation of a modulated signal in the Cartesian coordinates. In MATLAB, `scatter.m` function is used to obtain this diagram. The constellation diagram for QPSK is given in Figure 36.

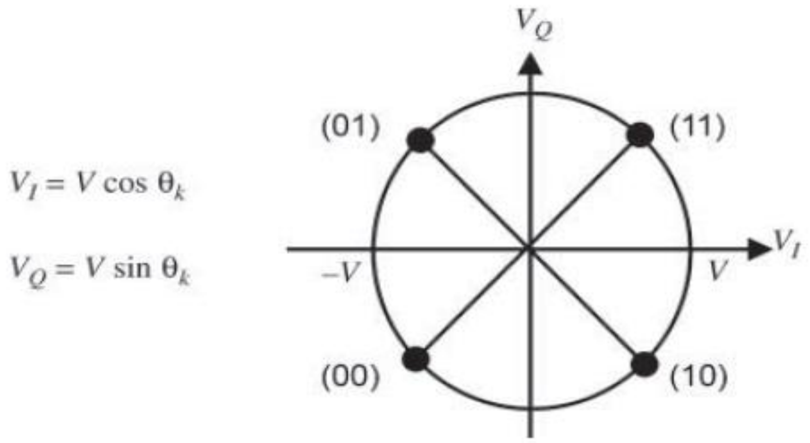


Figure 36: The constellation diagram for QPSK [3, Ch. 4, p. 142]

Eye Diagram:

Eye diagram shows the performance of a system in communication system operations [18]. Figure 37 shows an eye diagram example. In this Figure from a to d, the distance between the transmitting side and receiving side increases; as a result, the eye diagram loses its sharpness, which means the communication system performance decreases. Eye diagram in MATLAB can be obtained using `eyediagram.m` function.

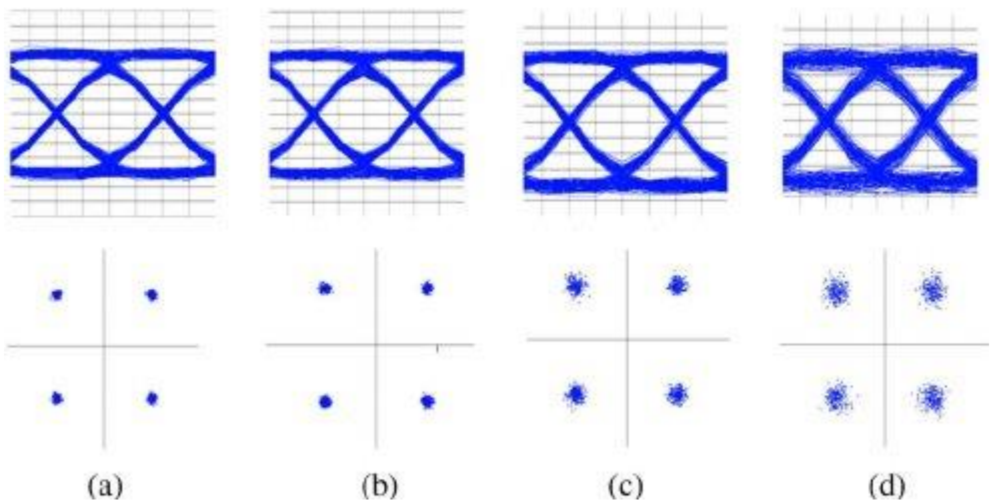


Figure 37: The eye diagram example for QPSK modulation [19]

4.3.2 Project Description

The thing that was asked to simulate from us was *the physical layer of DVB-S standard communication system*. This project is based on the notes[10] from the Satellite Program Department team from their know-how education in France. QPSK is used with FEC codes, and we add a white Gaussian noise.

[10] These notes belong to Marie-Laure Boucheret (ENSEEIHT) and Nathalie Thomas (University of Toulouse), and I was not allowed to share these notes in my summer practice report.

I did only the modulation part of the project due to my limited time during the summer practice. The other portions[11] were made by other summer practice students.

The portion that I made has two parts:

Part 1-Generate a random information with 0's and 1's

Part 2-Make baseband modulation with this random data:

-Do the mapping operation

-Do the oversampling process

-Do the shaping filter using a Finite Impulse Response Filter

-Final Goal: Obtaining a reasonable eye diagram after the filter operation for the information

4.3.3 Solution for My Part

Part 1:

I used `randi.m` function to generate the random 0's and 1's. The MATLAB code for this part is in Appendix C. The signal that we obtained can be seen in Figure 38. It has real and imaginary parts, both of them are produced randomly.

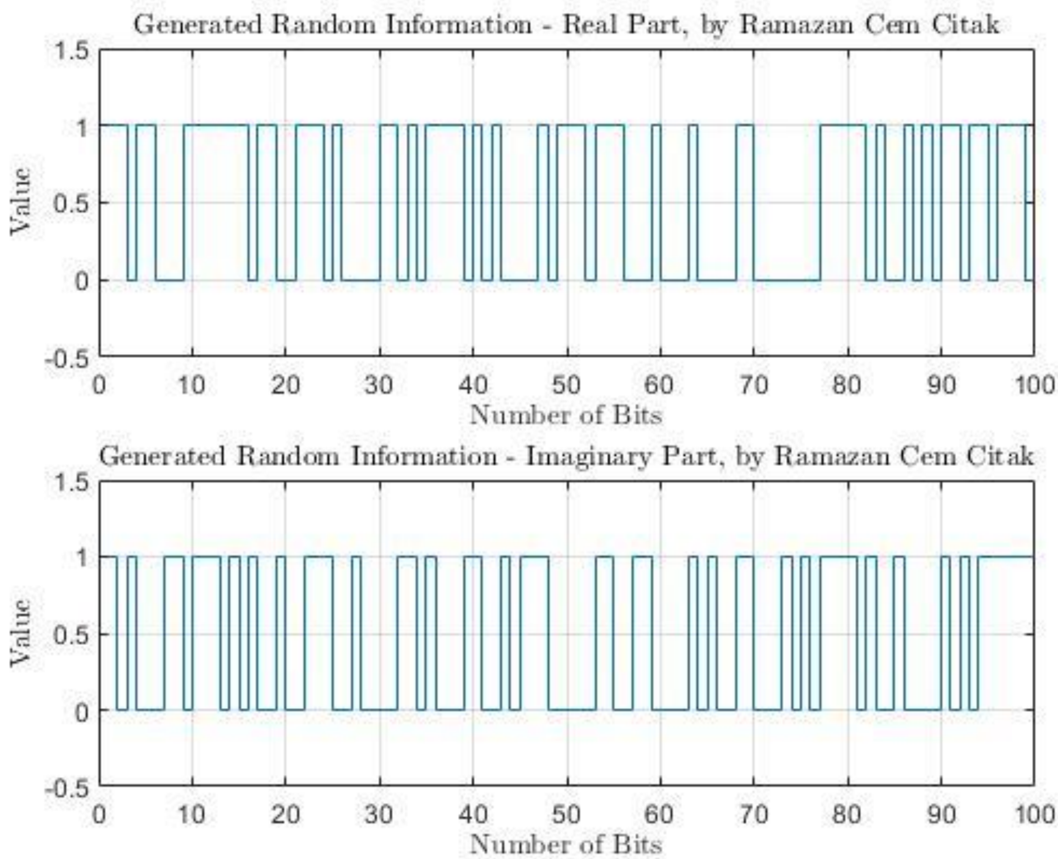


Figure 38: The generated random binary data graph obtained in MATLAB

[11] I did not see the end of the project because my summer practice time was over first among the other summer practice students.

Part 2:

The MATLAB code for this part is in Appendix D.

Upsampling operation: It is the process of sampling a signal at a sample rate that is higher than the Nyquist rate [14]. The upsampling operation gives the graph in Figure 39. There will be zeros between the random generated 1's and 0's in Part 1.

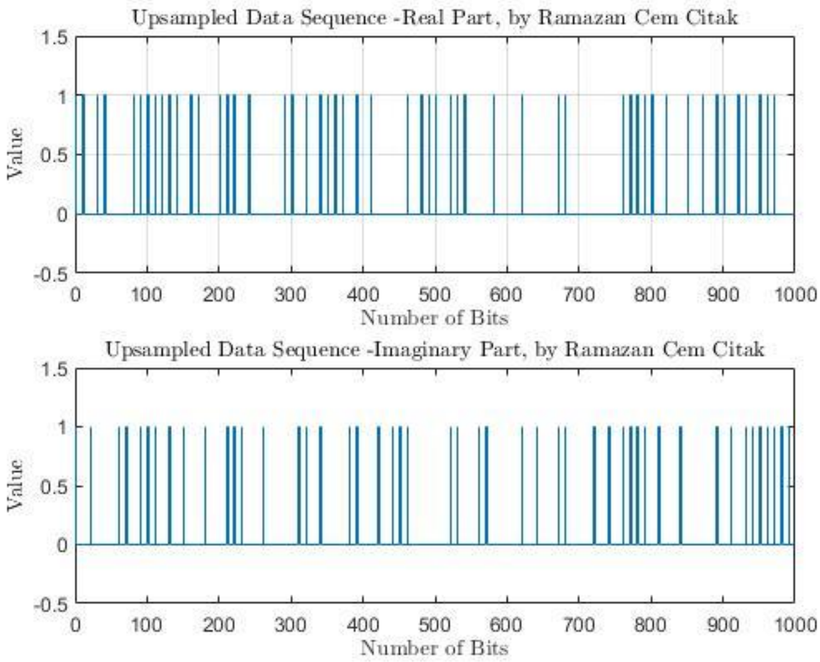


Figure 39: The upsampled data sequence obtained in MATLAB

Obtaining NRZ: The NRZ signal plot for real and imaginary parts is given in Figure 40. This is a mapping operation that matches the samples to +1 and -1.

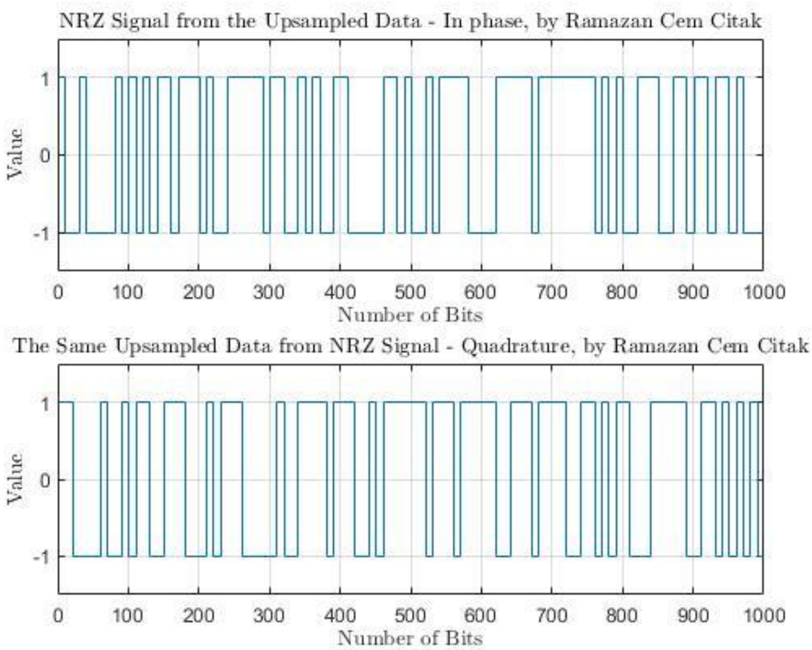


Figure 40: The NRZ Signal obtained from the Upsampled Data

The constellation diagram using the NRZ signal is given in Figure 41. The signal there is without any noise added.

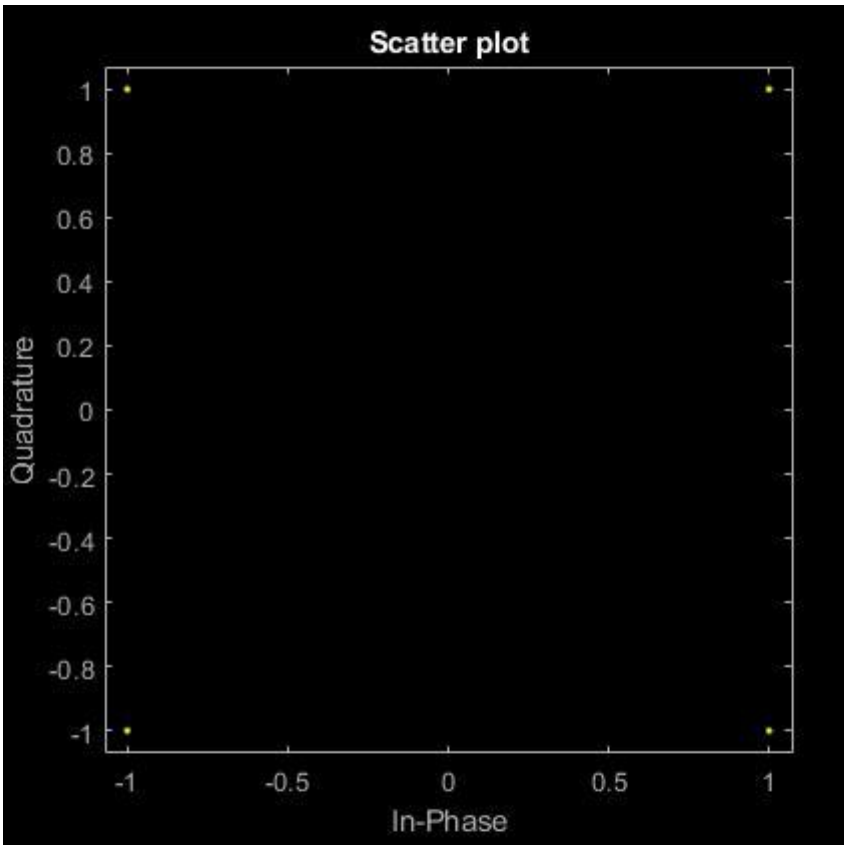


Figure 41: The constellation diagram using the NRZ signal

Obtaining Filter: The filter that I obtained in MATLAB is given in Figure 42. This filter is obtained very easily by using the `rcosdesign.m` and `fvtool.m` functions in MATLAB. This filter is the optimal filter to prevent the noise in our signal with noise.

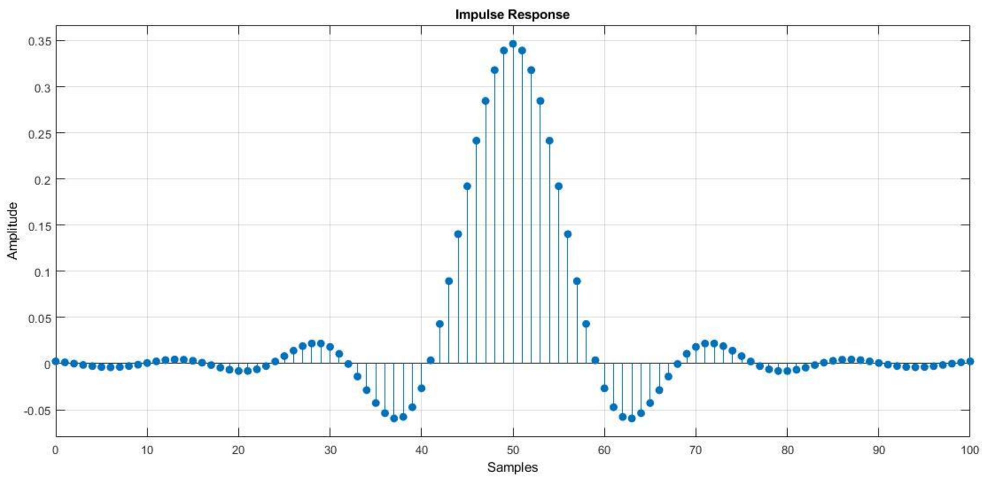


Figure 42: The Finite Impulse Response Filter

Generating a noise signal: The noise signal generated in MATLAB can be seen in Figure 43 and 44, in Cartesian plot and scatter plot, respectively.

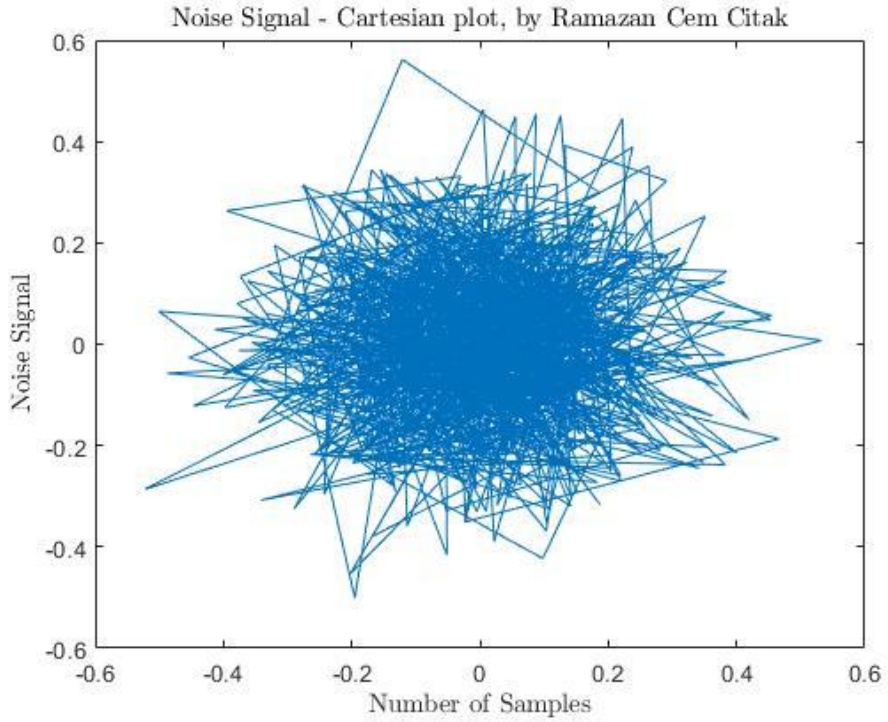


Figure 43: The noise signal in Cartesian plot

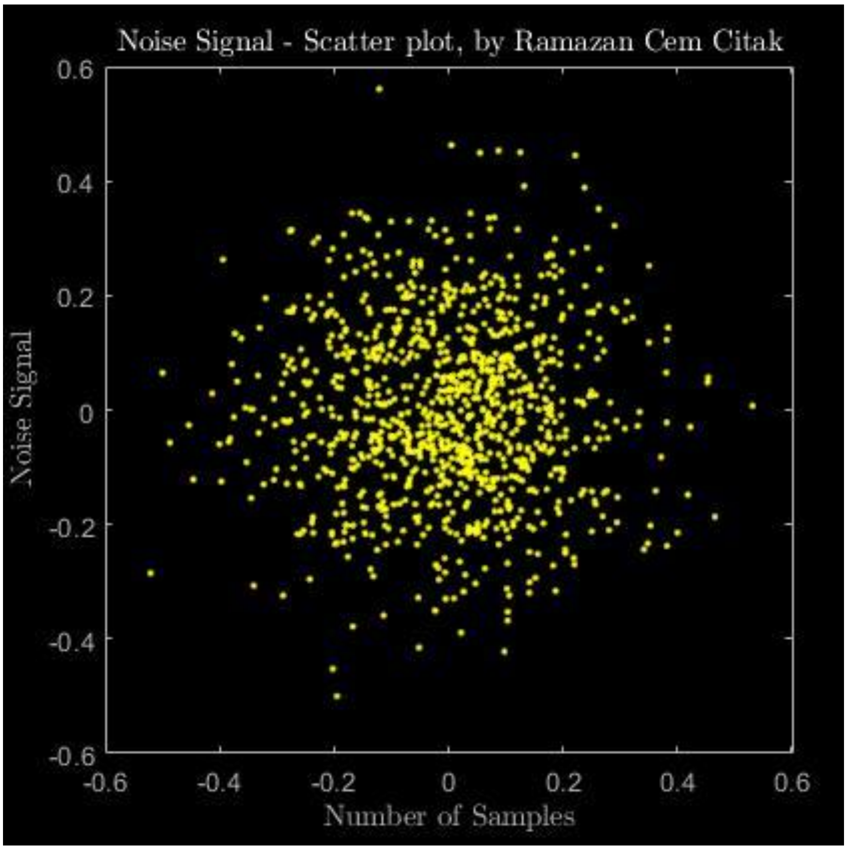


Figure 44: The noise signal, scatter plot

Obtaining eye diagram: The signal with noise is given in Figure 45. The eye diagram, which is my final work is shown in Figure 46. It is what I expected: A sinusoid-shaped in-phase and quadrature signals.

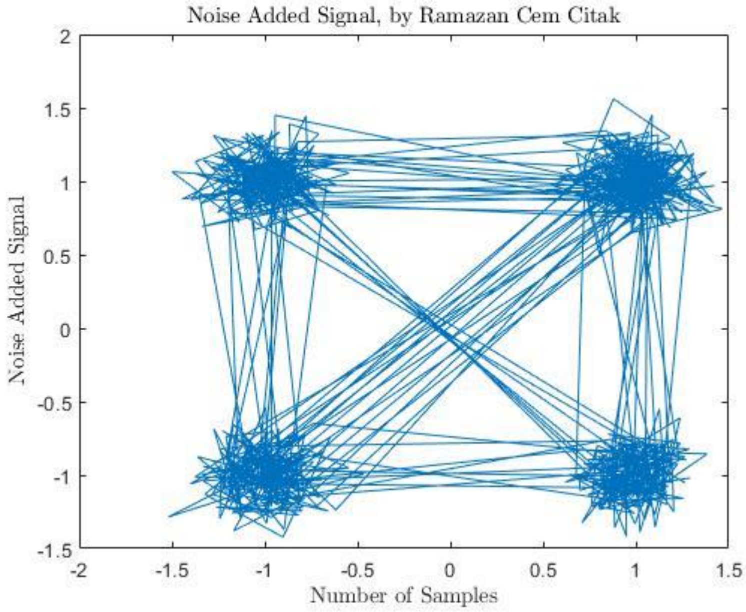


Figure 45: The signal with noise, Cartesian plot

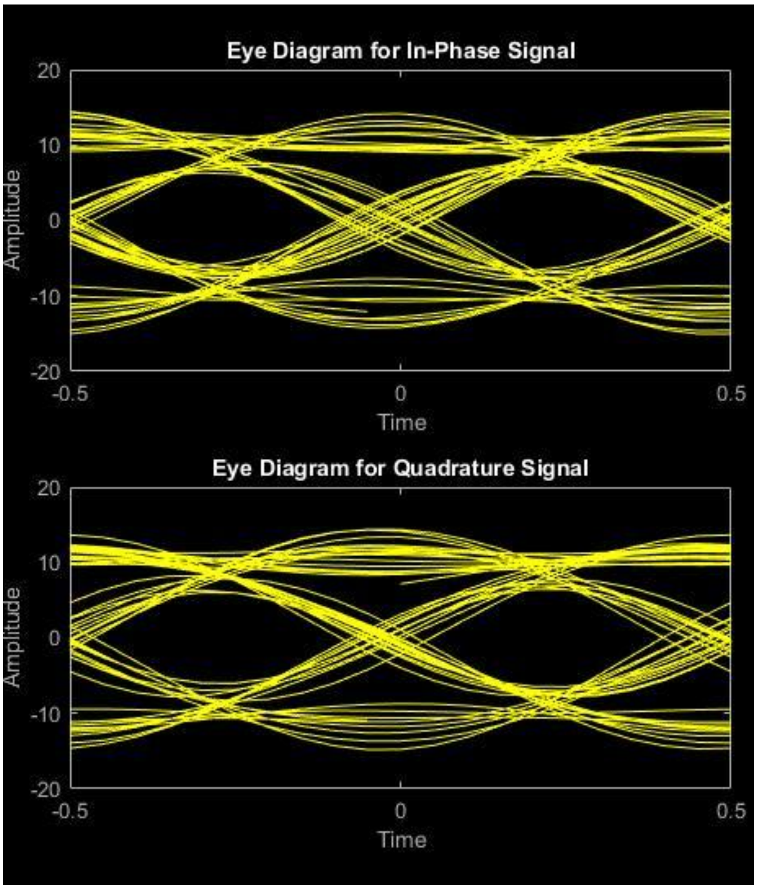


Figure 46: The eye diagram obtained from the signal with noise

Also, we can obtain the constellation diagram with noise in the end. It is given in Figure 47. The effect of the noise can be seen there.

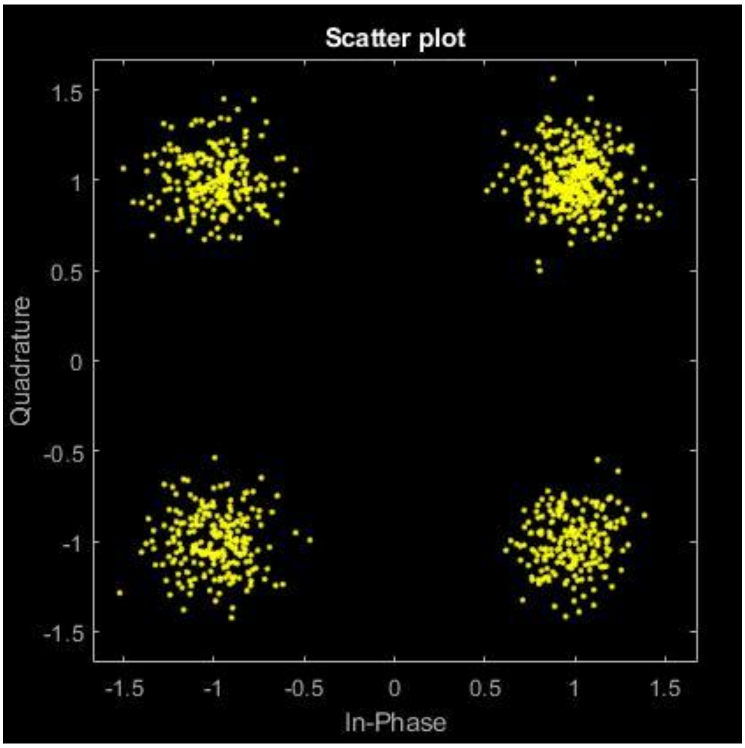


Figure 47: The constellation diagram of the noise added signal

After the modulation, we should do demodulation to obtain the binary information. The block diagram for a DVB-S layer simulation is shown in Figure 48.

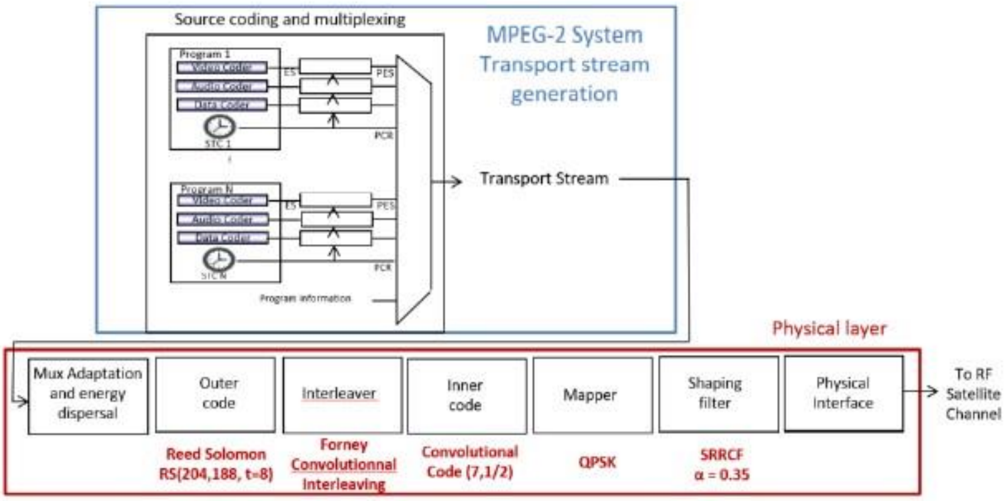


Figure 48: The DVB-S layer for the project diagram given by my supervisor

5.Conclusion

I completed my summer practice at Satellite Programs Department in TÜRKSAT. My summer practice had two main parts. Firstly, I made research and a presentation about Phased Array Antennas in satellite communication systems. While being prepared for this first assignment of my summer practice, I used mainly the knowledge of EE303 course. Secondly, I worked on a DVB-S project in MATLAB. This project was a group work, and I did a certain part of the project during my limited summer practice time. I mainly used my knowledge of EE301 and EE306 courses during this project, and I developed my MATLAB skills. During the four weeks of my summer practice, I acquired an introductory knowledge of radio frequency engineering focusing on a certain type of antennas as well as learning about telecommunication systems. In addition to these main parts of my summer practice in electrical engineering, I learned a lot about space environment, orbitals, and space missions.

Overall, although my work at the workplace was not used by the company and was not given a real work due to privacy reasons, I was monitored closely by my supervisor while doing my assignments at the workplace. It was easy to ask questions to the engineers there. Also, observing a dynamic team of engineers in TÜRKSAT was a good experience for my future work life. I understood how much important the presentation and communications skills at the workplace together with the technical skills are during my summer practice.

I recommend this summer practice place to those who are interested in radio frequency engineering and telecommunication in satellite systems. TÜRKSAT is a good place that you can see a governmental corporate company where an enthusiastic cross-functional team in Satellite Programs Department and a workplace that you can see the project management and engineering processes.

6.References

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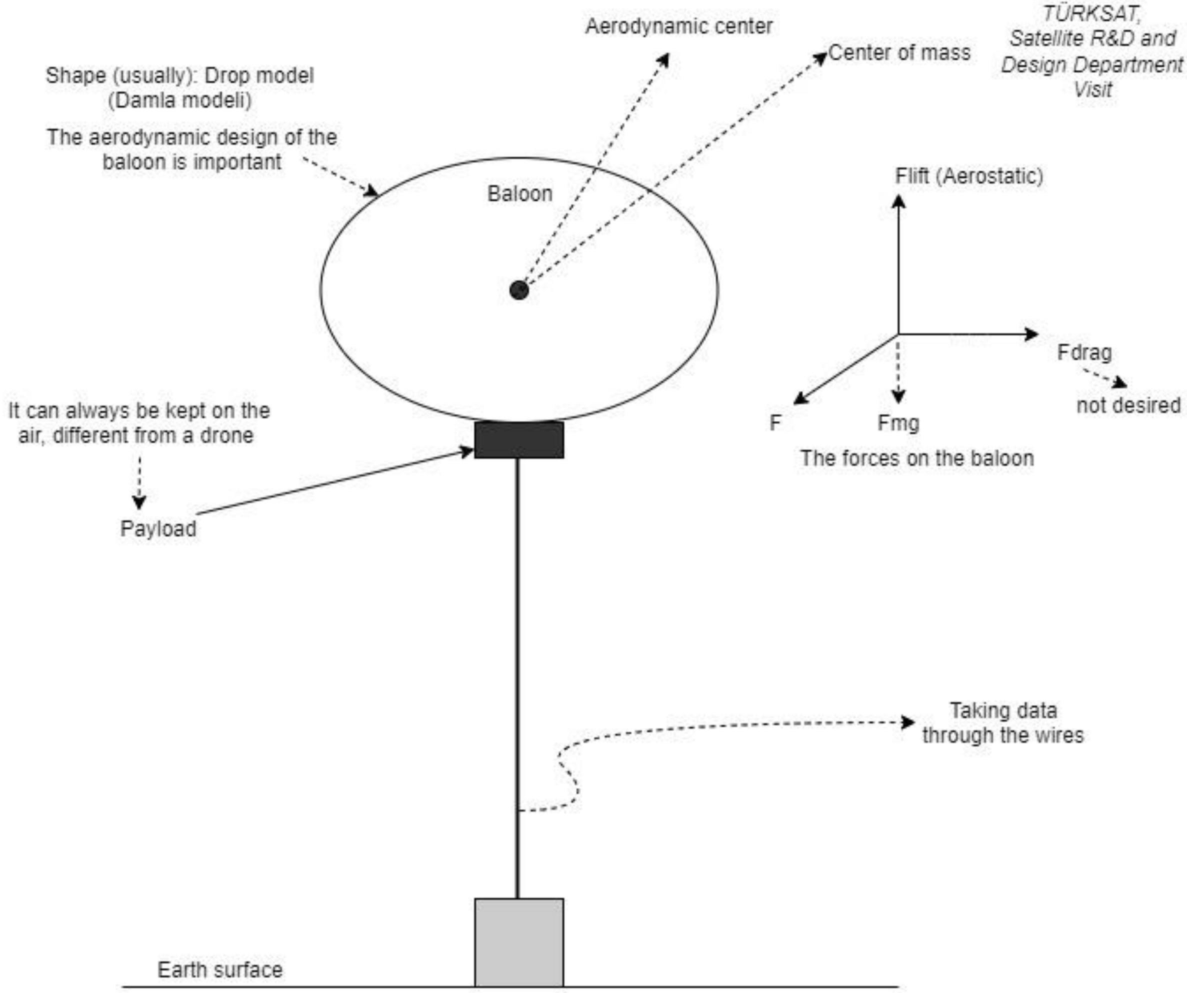
7.Appendices

Appendix A: Notes on Helium Balloons

Helium Balloons

July 29, 2022
Friday,
TÜRKSAT,
Satellite R&D and Design Department Visit



Properties:
-At 300 to 1500 meters of altitude
-<u>Remote sensing</u>: Camera, Radar, Lidar
-<u>Communication</u>: Base stations, Relay (coverage area)
-4-5 axes camera

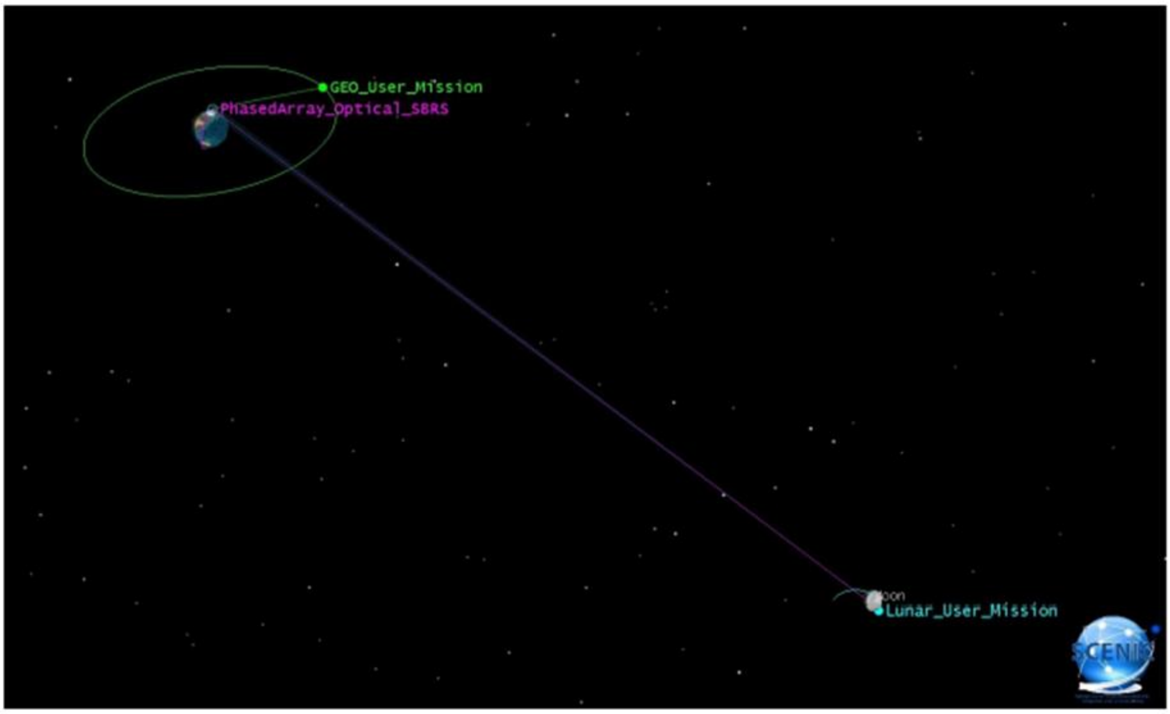
Desired properties:
1-Always being able to stand on the air
2-Always being able to be stable (depends on the aerodynamical design)
3-Sustainablity (about technicalrenovation, cost and user friendliness)

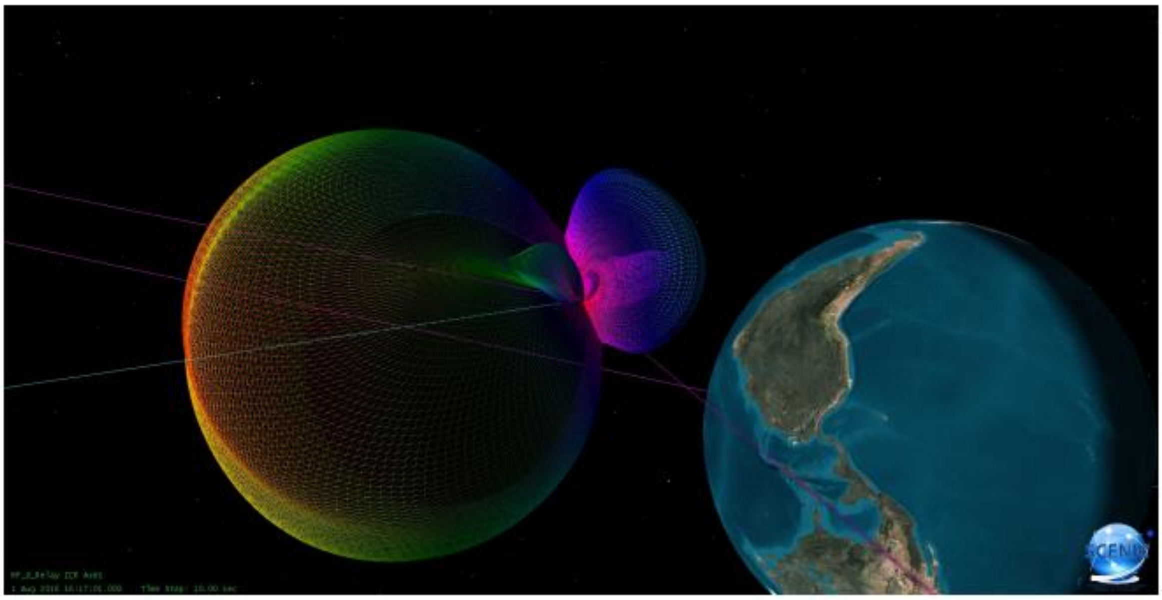
-Cost is about the payload of the system.

-In case of natural disasters
-To increase the capacity and coverage of the base stations
} It is a mobile, portable system through land vehicles

Notes belonging to Ramazan Cem Çıtak

Appendix B[12]: Screenshots from the System Toolkit (STK) Program for the Simulation of Phased Array Antennas





[12] N. Tchorowski, R. Murawski, R. Manning, and M. Fuentes, "Modeling and Simulation of Phased Array Antennas to Support Next-Generation Satellite Design". *American Institute of Aeronautics and Astronautics.* Oct. 18, 2016. Accessed July 25, 2022. [Online].

Appendix C: Phased Array Antenna Simulations in MATLAB Signal Analyzer App

```
% Subject: Simulation of a Phased Array Antenna - Auto-Generated Code
% Author: Modified by Ramazan Cem Çıtak
% Date: August 5, 2022
% APPENDIX C - EE400 Summer Practice Report

% MATLAB Code from Sensor Array Analyzer App

% Generated by MATLAB 9.11 and Phased Array System Toolbox 4.6

% Generated on 05-Aug-2022 10:49:16

% Create a uniform rectangular array
Array = phased.URA('Size',[4 4],...
'Lattice','Rectangular','ArrayNormal','x');
% The multiplication factor for lambda units to meter conversion
Array.ElementSpacing = [0.55 0.55]*0.015;
% Calculate Row taper
rwind = ones(1,4).';
% Calculate Column taper
cwind = ones(1,4).';
% Calculate taper
taper = rwind*cwind.';
Array.Taper = taper.';

% Create an isotropic antenna element
Elem = phased.IsotropicAntennaElement;
Elem.FrequencyRange = [0 20000000000];
Array.Element = Elem;

% Assign Frequencies and Propagation Speed
Frequency = 20000000000;
PropagationSpeed = 300000000;


% Create Figure

% Plot Array Geometry
figure;
viewArray(Array,'ShowNormal',true,...
  'ShowTaper',true,'ShowIndex','All',...
  'ShowLocalCoordinates',true,'ShowAnnotation',false,...
  'Orientation',[0;0;0]);

% Calculate Steering Weights

Freq3D = 20000000000;
% Find the weights
w = ones(getNumElements(Array), length(Frequency));

% Plot 3d graph
format = 'polar';
figure;
pattern(Array, Freq3D , 'PropagationSpeed', PropagationSpeed,...
 'Type','directivity', 'CoordinateSystem', format,'weights', w(:,1),...
  'ShowArray',false,'ShowLocalCoordinates',true,...
  'ShowColorbar',true,'Orientation',[0;0;0]);

% Find the weights
w = ones(getNumElements(Array), length(Frequency));
```

```
% Plot 2d elevation graph
format = 'rectangular';
cutAngle = 0;
figure;
pattern(Array, Frequency, cutAngle, -90:90, 'PropagationSpeed',
PropagationSpeed,...
 'Type', 'directivity', 'CoordinateSystem', format ,'weights', w);

% Find the weights
w = ones(getNumElements(Array), length(Frequency));
```

Appendix D: MATLAB Code for Generating Random Binary Data, The First Part of the Project

```
% Subject: Simulation of a DVB-S Communication Channel Project
% Author: Ramazan Cem Çıtak
% Date: August 3, 2022
% APPENDIX D - EE400 Summer Practice Report

% PART 1
% Generating a random information consisting of 0's and 1's for 100
elements
binary_info_real = randi([0 1], 1, 100);
binary_info_imag = randi([0 1], 1, 100);
binary_info = binary_info_real+j*binary_info_imag;

figure();
subplot(2,1,1);
stairs(binary_info_real);
title('Generated Random Information - Real Part, by Ramazan Cem Citak',
Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 100, -0.5, 1.5]);
grid on

subplot(2,1,2);
stairs(binary_info_imag);
title('Generated Random Information - Imaginary Part, by Ramazan Cem
Citak', Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 100, -0.5, 1.5]);
grid on
```

Appendix E: MATLAB Code for QPSK Modulation, The Second Part of the Project

```
% Subject: Simulation of a DVB-S Communication Channel Project
% Author: Ramazan Cem Çıtak
% Date: August 8, 2022
% APPENDIX E - EE400 Summer Practice Report

% PART 2
% Generating a random information consisting of 0's and 1's for 100
elements
binary_info_real = randi([0 1], 1, 100);
binary_info_imag = randi([0 1], 1, 100);
binary_info = binary_info_real+j*binary_info_imag;

figure();
```

```
subplot(2,1,1);
stairs(binary_info_real);
title('Generated Random Information - Real Part, by Ramazan Cem Citak',
Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 100, -0.5, 1.5]);
grid on

subplot(2,1,2);
stairs(binary_info_imag);
title('Generated Random Information - Imaginary Part, by Ramazan Cem
Citak', Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 100, -0.5, 1.5]);
grid on

% Upsampling operation
upsampled_data_real = upsample(binary_info_real, 10);
upsampled_data_imag = upsample(binary_info_imag, 10);
figure();
subplot(2,1,1);
stairs(upsampled_data_real);
title('Upsampled Data Sequence -Real Part, by Ramazan Cem Citak',
Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 1000, -0.5, 1.5]);
grid on
subplot(2,1,2);
stairs(upsampled_data_imag);
title('Upsampled Data Sequence -Imaginary Part, by Ramazan Cem Citak',
Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 1000, -0.5, 1.5]);

% Obtaining NRZ signal
encodednrzsig_real = nrz_encode(upsampled_data_real);
encodednrzsig_imag = nrz_encode(upsampled_data_imag);

decodednrzsig_real = nrz_decode(encodednrzsig_real);
decodednrzsig_imag = nrz_decode(encodednrzsig_imag);

complex_envelope = encodednrzsig_real+j.*encodednrzsig_imag;

figure();
subplot(2,1,1);
stairs(encodednrzsig_real);
title('NRZ Signal from the Upsampled Data - In phase, by Ramazan Cem
Citak', Interpreter="latex");
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 1000, -1.5, 1.5]);
grid on

subplot(2,1,2);
stairs(encodednrzsig_imag);
title('The Same Upsampled Data from NRZ Signal - Quadrature, by Ramazan Cem
Citak', Interpreter="latex");
```

```
xlabel('Number of Bits',Interpreter="latex");
ylabel('Value',Interpreter="latex");
axis([0, 1000, -1.5, 1.5]);
grid on

% Obtaing a constellation diagram for the transmitted signal
scatterplot(complex_envelope);

% Obtaining Finite Impulse Response Filter
h = rcosdesign(0.35,10,10); % Roll off 0.35 is given to me.
fvtool(h,'Analysis','impulse');

% Obtaining noise to signal
SNRdB = 10; % arbitrarily chosen SNR value in dB
SNR = 10.^(SNRdB./10); %SNR value
No = 1./SNR; % Variance
noise = (sqrt(No/2)*(randn(1,1000) + 1j*randn(1,1000)))/sqrt(2);

figure();
plot(noise)
xlabel('Number of Samples', Interpreter="latex");
ylabel('Noise Signal', Interpreter="latex");
title('Noise Signal - Cartesian plot, by Ramazan Cem Citak',
Interpreter="latex");

scatterplot(noise)
xlabel('Number of Samples', Interpreter="latex");
ylabel('Noise Signal', Interpreter="latex");
title('Noise Signal - Scatter plot, by Ramazan Cem Citak',
Interpreter="latex");

% Obtaining noise added signal
with_noise = complex_envelope + noise;
figure();
plot(with_noise);
xlabel('Number of Samples', Interpreter="latex");
ylabel('Noise Added Signal', Interpreter="latex");
title('Noise Added Signal, by Ramazan Cem Citak', Interpreter="latex");

% Filtering Operation to noise added signal
filtered_sig = filtfilt(h,1, with_noise);
eyediagram(filtered_sig,20);

% New constellation diagram
scatterplot(with_noise);


% Function used for decoding NRZ signal
function decoded = nrz_decode(encoded)
N = length(encoded);
decoded = zeros(1,N);

for i=1:N
    if i==1 % For the start of the array
        if encoded(i)==-1
            decoded(i)=0;
        else
            decoded(i)=1;
        end
    else % For the other elements
        if encoded(i)== encoded(i-1)
```

```
            decoded(i)=0;
        else
            decoded(i)=1;
        end
    end
end
end

% Function used for encoding NRZ signal
function encoded = nrz_encode(data)
N=length(data);
threshold=0.5; % It is 0.5 because of the average of 0 and 1
encoded = zeros(1,N);

for i=1:length(data)
    if data(i)>threshold
        binary_data(i)=1;
    else
        binary_data(i)=0;
    end
end

for i=1:N
    if i==1
        if binary_data(i)==0
            encoded(i)=0;
        else
            encoded(i)=1;
        end
    else
        if binary_data(i)==0
            encoded(i)=encoded(i-1);
        else
            encoded(i)=~encoded(i-1);
        end
    end
end
encoded = (2.*encoded)-1;
end
```