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REFLECTARRAY ANTENNA FOR X-BAND APPLICATION USING MATLAB AND CST SOFTWARE

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Master's Thesis

Supervisor

Asst. Prof. Dr. Mesut ÇEVIK

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Basma Abdullah Ghafil SULTANI

Signature

DEDICATION

This thesis paper is dedicated to my great wife and my doting parents, without whom I would not have been able to finish this project. They never fail to serve as a wellspring of creativity for me. In addition, I'd want to express my gratitude to my kind siblings for the assistance they provided with my thesis.

ABSTRACT

REFLECTARRAY ANTENNA FOR X-BAND APPLICATION USING MATLAB AND CST SOFTWARE

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A reflect array was created using CST simulations and the MATLAB computer language. In applications needing high gain and efficiency, reflect arrays are gradually replacing parabolic reflectors. Massive reflect arrays take a long time and a lot of effort to build. A feed antenna is required to excite a planar or conformal array of components in order to build a reflect array antenna. They are the most expensive for large antennas that demand a lot of electrical power, while being the most practical and cost-effective option. The "X band" has a variety of frequencies that may be found in the microwave radio region of the electromagnetic spectrum. The X band is a frequency range in communication engineering that ranges from 8 to 12 GHz. Following an intensive study of all pertinent data, the MATLAB code will be thoroughly examined. The data from the CST program will be utilized to build the antenna. The CST construction of a reflect array antenna is simplified by MATLAB code that generates an antenna pattern. A gain of 60 dBi is possible using a reflect array feed antenna and a horn as the feed antenna. This configuration yields a gain of sixty dBi.

Keywords: Horn antenna, Feed antenna, MATLAB, Reflectarray antenna, X-band.

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ABBREVIATIONS

CST	:	Computer Simulation Technology
CP	:	Circularly Polarized
RHCP	:	Right-Hand Circularly Polarized
LHCP	:	Left-Hand Circularly Polarized
D	:	Diameter

LIST OF SYMBOLS

mm : Millimetre

λ : Wavelength

ω : Angular frequency

1. INTRODUCTION

Reflectarrays are gaining popularity as a viable alternative to parabolic reflectors in applications requiring high gain and efficiency, such as telecommunications. Putting together a huge reflectarray is time-consuming and requires a lot of effort. In antenna design, planar or conformal arrays of components are used to generate an active reflectarray antenna [1] [2][3], which is a type of active reflectarray antenna. Consequently, when lighted by the feed antenna, each element is constructed in such a way that it incorporates an appropriate amount of reflected phase into its design. Once phase distributions are synthesized throughout the aperture, reflectarrays can create a collimated or shaped beam in any desired direction. Reflectarray components (also known as phasing elements) are critical in the study and design of these devices because they allow for the generation of reflected light. In order to create a reflectarray, there are two stages: first, the individual components are designed, and then the entire system design is completed. The design of the elements will be described in this chapter, and the design of the system will be discussed in the next chapters. Following the introduction to the fundamentals of phase distribution design on a reflectarray aperture, we will proceed to more complex elements. Following that, we'll go over a number of different methods for altering the phase of reflectarray members. Depending on how the different components are designed, electromagnetic waves are disseminated in specific phases. This course will cover the numerical and analytical analysis of reflectarray phasing elements, as well as examples of reflectarray phasing elements to show the concepts. The frequency behavior of reflectarray elements, the consequences of oblique stimulation, and the origins of phase inaccuracy in reflectarray elements are all topics that will be explored in detail.

The reflectarray antenna concept, which makes use of short-ended waveguide segments of variable length, was first devised in the early 1960s [4]. The feed antenna provided illumination to waveguides that had been reduced in length. Because of this, the reradiated signals were able to form a collimated beam that was aimed in the general direction of the planned far field. This early reflectarray antenna had a lot of potential, but the bulky and heavy waveguide structure was a major hindrance to its implementation.

Almost from the beginning, the reflectarray antenna has served as a catalyst for the creation of new and novel applications. When using spatial feed, it is necessary to compensate for phase delay by using elements of the reflectarray that reflect the electromagnetic wave with a given phase delay, as described above. When it comes to achieving phase shift of the components, a variety of ways are employed to do this, including variable size elements, phase delay lines, and element rotation. Infinite arrays are used to calibrate the relationship between element phase and element change [5]. Because of the large number of elements involved in a reflectarray antenna, fullwave simulation of the complete antenna is still a difficult task. However, different theoretical models for analyzing reflectarrays, such as the theory formulation and the aperture analysis technique, have been established, and they show good agreement with the measured data. The spectral transform has an additional benefit in that it allows for faster calculation of an antenna's radiation parameters, which is beneficial for synthesis design difficulties that involve iterative processes.

It is possible to achieve broadband and multiband performance from microwave frequencies up to THz using single and multilayer reflectarrays. This design has evolved greatly over the years, and various practical concepts have been put into action as a result of these developments. When developing reflectarray antennas, the most difficult challenge is to increase the bandwidth of the antenna. The fundamental disadvantage of printed resonator-type devices is that they have this constraint. It has been explored whether multilayer designs [6], [7], real-time delay lines [8], and sub-wavelength elements [9] have the potential to enhance bandwidth by more than 20 percent.

Given the fact that each array member can be controlled independently of the others, multi-beam performance can be accomplished with a single or several feed sources. Additionally, the design of contoured beam reflectarrays is a tough field to master [10]. Using a phase-only synthesis technique, it is possible to obtain the appropriate element phase shift from any given mask. Multiple feed, multiple beam contoured beam systems have been shown; nonetheless, their performance is marginally inferior to that of parabolic reflectors, which is not surprising. Another advantage of reflectarrays is that the antenna may scan the primary beam at significant angles off broadside, which is not possible with other types of antennas. In order to perform beam scanning, every component of a beam-scanning reflectarray is equipped with a low-loss phase shifter [11]. It will be difficult to further develop these antennas, despite the fact that various types of these beam-scanning reflectarrays have previously been verified and that a switch board is required to regulate the main beam direction.

1.1 PROBLEM STATEMENT

In the early 1960s, short-ended waveguide components of varying lengths were used to demonstrate the use of reflectarray antennas [12], which were thereafter widely adopted. It was decided to use shorter waveguide lengths such that when the feed antenna was illuminated, the phase of reradiated signals generated a collimated beam in the appropriate far-field direction. Despite this, the enormous and heavy waveguide design of this early reflectarray antenna was a significant negative, even though the concept appeared to be intriguing. Results from the experiments are displayed in Figure 1.1, which also depicts a waveguide reflectarray model based on these results. Because of its numerous applications, the reflectarray antenna has sparked a great deal of fresh research and the development of cutting-edge new applications. This is accomplished through the use of an infinite array [13] to calibrate the element phase versus element change relationships. Because of the enormous number of components involved, full-wave simulation of the entire reflectarray antenna is still a tough task to do.

It is advised that CST and MATLAB be used in order to model reflectarray antennas.

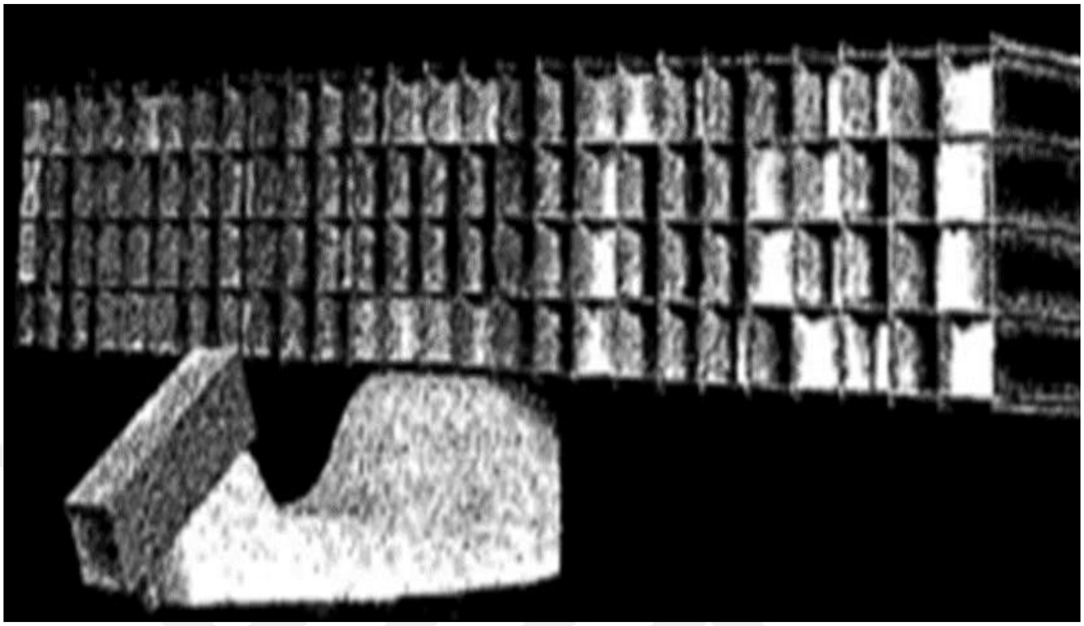

Figure 1.1: The first waveguide-based reflectarray antenna.

1.2 BACKGROUND

Until Guglielmo Marconi proved it in 1901, long-distance wireless communication was thought to be impossible. Long-distance communication has progressed to the point where individuals may now connect wirelessly throughout the Solar System and even further afield than previously possible. A significant number of antennas are required for long-distance communication in order to establish a wireless link between the transmitter and receiver. However, while they are one of the most viable and cost-effective options available for electrically large antennas, they are also one of the most expensive options available. With the discovery of electromagnetic waves by Maxwell, a new era in the history of communication with these antennas began [15], despite the fact that reflectors were initially designed as optical devices. In 1887, a cylindrical parabolic antenna fed by a dipole was used to demonstrate wireless communication for the first time in the world. A non-optical reflector antenna was employed in a reflector antenna for the first time, marking a significant advancement in the field. It is because of these advantages that reflectors have become the most extensively utilized high-gain antenna in a wide range of applications, including radio astronomy and remote sensing, as well as radar. Arrays of smaller antennas can also be utilized to attain the desired gain of a large antenna by combining a number of different ways [16]. The world's first antenna array was constructed more than a century ago [17]. The directivity of a single monopole can be enhanced, as established by Brown [18], by employing two vertical antennas that are half a wavelength apart and supplied out of phase. Over the course of several decades, he and a host of other notable scientists, including Marconi, Braun, and Adcock, investigated the special characteristics of antenna arrays [19]. Not that antenna array engineering didn't have an impact on the development of semiconductor technology and printed circuit board technology in the years following. This was especially true during World War II. The microstrip patch antenna, which was first developed by Deschamps in 1953 and later made practical by Munson in 1972 [19], is an excellent example of this. As a result of this research, a paradigm change occurred in the field of array engineering. For a long time, it was believed that a microstrip antenna array would have a significant impact on the development of phased array technology.

High-gain antennas are now competing with reflector and array systems for big aperture jobs in a wide range of systems, and they are becoming increasingly popular. Because of their low-profile and low-mass characteristics, these antennas are gaining more and more attention from the antenna and electromagnetic communities. A reflectarray antenna is the name given to this particular type of antenna. Because it is a hybrid design that encompasses many of the advantages of both regular reflector and printed array antennas, it is feasible that the reflectarray antenna will surpass both of these types of antennas in the future. Because of the curved surface of the parabolic reflector, it is difficult to construct and needs the use of expensive bespoke melds in many circumstances. It is also more difficult to fabricate at higher microwave frequencies than at lower ones. The disadvantages of antenna arrays, in addition to their advantages in terms of flexibility of design and a wide range of radiation performance, include the energy loss and design complexity associated with their feeding networks, as well as the high cost of T/R modules in active phased arrays. To put it another way, the reflectarray is quickly becoming a favored alternative to both classic technologies because of its ability to offset the flaws of both high-gain antennas while maintaining their benefits.

In addition to having a flat reflecting surface comprised of hundreds of components on its aperture, reflectarray antennas also include an illuminating feed antenna that is attached to them. Figure 1.2 is an illustration of this. Remember that the aperture of the feed antenna is spatially illuminated, and the elements are designed to reflect the incoming field with precise phase shifts in order for collimation to occur in the proper direction and form. When it comes to phase synthesis and beam collimation, antenna arrays and reflector antennas are essentially equivalent to this antenna; however, the functioning mechanism is different.

Figure 1.2: An antenna with an offset-fed reflect array.

1.3 METHODOLOGY

After a thorough review of all relevant material on the subject, the code for Matlab will be studied in detail. CST software will be used to develop and test the antenna, and this data will be incorporated in the design.

In this presentation, a summary of the findings and analyses will be provided.

1.4 OUTLINE

This thesis will be organized as follow:

a. Introduction: This chapter represented an overview of the main objectives of the research, statement of problems, aims and objectives of the study.

b. Literature review: This chapter presented a background about antennas, reflect-array antenna.

c. Methodology: This chapter 3 investigates the design on MATLAB and CST in addition to similar works and suggestions.

d. Results and analysis: Results will be shown and analyse in this chapter.

e. Conclusion: This chapter summarized the problems

2. LITERATURE REVIEW

A feed antenna is used to excite an array of components in a planar or conformal shape, resulting in the generation of a reflectarray antenna. A popular reflectarray antenna model is seen in Figure 2.1. Whenever the feed antenna lights an element, it introduces a little amount of reflected phase into the signal stream. Finally, by synthesizing the phase distribution over the reflectarray apertures, it is possible to generate a collimated or shaped beam of light. In the design and analysis of the system, the reflectarray elements (also known as phasing elements) are essential components.

The element design and the system design are the first two stages in the design of a reflectarray. The element design and the system design are the final two processes. It is intended that this chapter concentrate on the design of individual pieces, with later chapters concentrating on the design of the complete system. It will be investigated in this chapter how phase distribution changes with respect to the reflectarray aperture. The next section will discuss the many approaches for fine-tuning reflectarray elements. Alternatively, how each piece is constructed such that electromagnetic waves disperse in the desired phase is important to understand. Several examples of reflectarray phasing elements, as well as numerical and analytical approaches for their investigation, will be offered in this thesis. The phase error and frequency behavior of reflectarray elements, as well as the repercussions of oblique stimulation, will be explored in detail.

2.1 REFLECTARRAY APERTURE PHASE-SHIFT DISTRIBUTION

When the phase distribution on the aperture of a standard planar antenna array is evenly distributed, it is feasible to get a collimated beam in the broadside direction of the antenna. It is necessary to provide the components [4] and [5] a progressive phase distribution in order to guide the beam in a specific direction. Reflectarrays operate on a similar core working idea, but the placement of the feed antenna must be taken into consideration as well [6]. Figure 2.1 depicts how the feed antenna is positioned with respect to the reflectarray coordinate system in relation to the reflectarray coordinate system. Most reflectarrays may be represented by a plane wave that excites the elements at a certain incident angle, which is the case for the incidence electromagnetic field on each individual reflectarray element. The phase centre of the feed antenna creates electromagnetic fields that radiate outward in the form of a spherical wave pattern.

The reflectarray aperture undergoes a phase shift that is proportional to the distance travelled by the electromagnetic fields, depending on the distance reached by the electromagnetic fields. As a result, in order to create a collimated beam, the phasing components of the reflectarray must be adjusted to compensate for the phase shift. Figure 2.2 depicts a geometrical depiction of the reflectarray system, with the feed phase centre and the reflectarray coordinate system both clearly defined in the feed phase.

If the feed phase centre is located sufficiently far away from the reflectarray element, the reflection phase of the reflectarray element should be able to compensate for the SPD without being affected.

Instead of a single element, the reflectarray, in contrast to the parabolic reflector, is composed of a set number of components (typically organized in a Cartesian grid) rather than a single component Consequently, the reflectarray aperture phase distribution is pixelated in the most basic sense. It is assumed that each element has a constant phase across its own opening, as illustrated in the grid configuration for a Ka-band reflectarray antenna shown in Figure 2.3 for the purpose of this calculation.

The circular aperture of the reflectarray is 190 mm in diameter at 32 GHz, which is approximately 20 wavelengths in length. Because of the 4.7 mm element spacing, the array has a lattice size of 4.7 4.7 mm2 (4.7 4.7 mm2). There are a total of 1184 entries in this array in total.

When the feed phase centre is 170 mm away from the aperture, as shown in Figure 2.4(a), the effect is that there is a spatial phase delay on the aperture, which is depicted by the dashed line in Figure 2.2. Due to the fact that the array is meant to have a broadside beam, as indicated in Figure 2.4, there is no requirement for a progressive phase (b). Figs. 2.4(c) and (d) depict the phase distribution on the reflect array aperture in addition to the continuous phase distribution, respectively. It is possible to view almost three complete phase cycles (0 to 2) when the phase progresses outward from the array's centre when the array is configured this way.

There are a number of disadvantages to the cantered feed design, including feed obstruction, which will be described more in the next section. Figure 2.5 illustrates the phase distributions of an offset setup with an off-broadside beam using the same aperture settings as in the previous example. According to the coordinate system depicted in Figure 2.2, the feed antenna phase centre is located in the XZ plane with an offset angle of 30°, giving it the appearance of being 85 millimetres high and 47.22 millimetres wide. In order to focus the beam at (o = 30°, o = 0°), the array is configured with the feed pointing to the geometric centre of the aperture and the feed pointing to the geometric centre of the aperture.

Following from this research, it is clear from the data presented here that reflect array components must be capable of complete phase modification. It follows that the reflection phase of the components must be increased from 0 to 2.

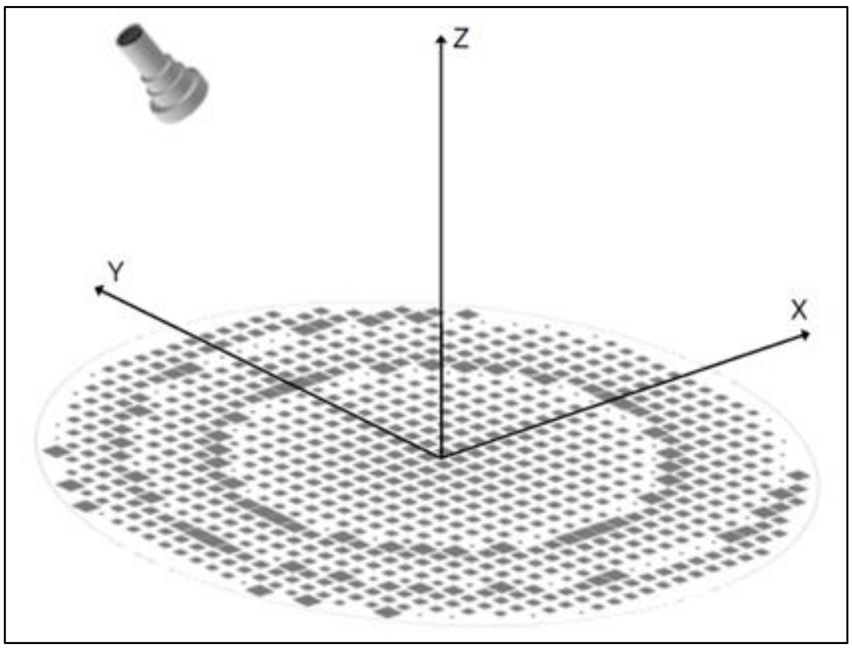

Figure 2.1: Antenna planar reflect array typical geometry.

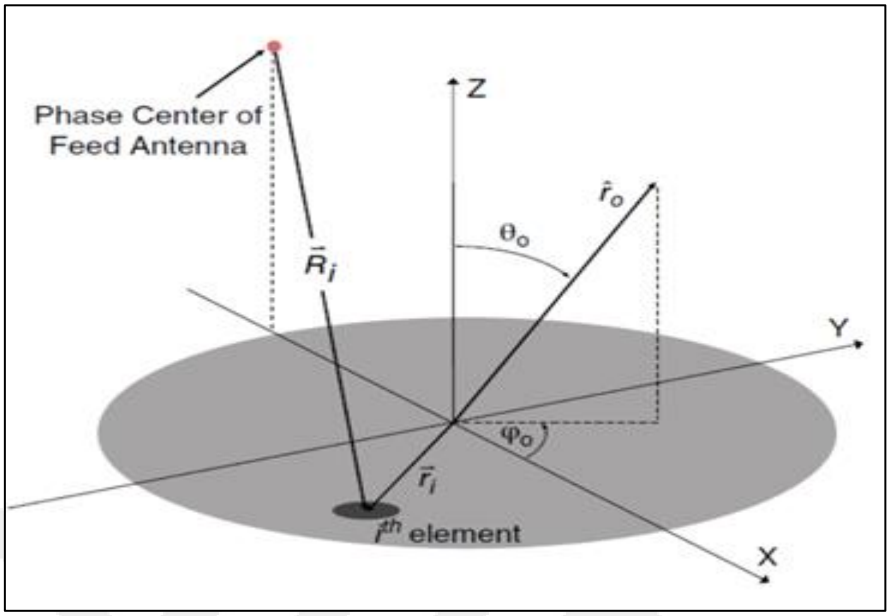

Figure 2.2: Planar reflectarray antenna typical geometrical characteristics.

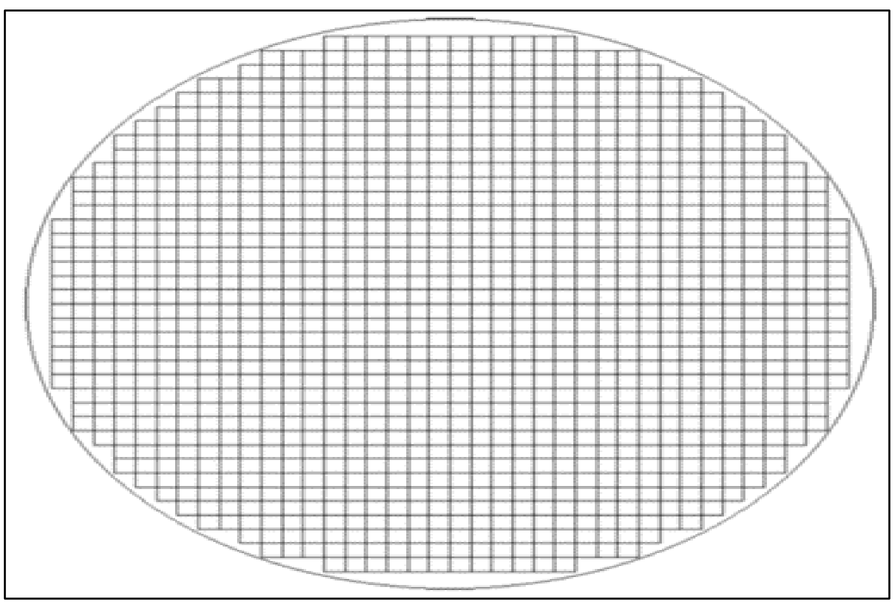

Figure 2.3: Antenna reflect array unit-cell grid configuration with circular aperture.

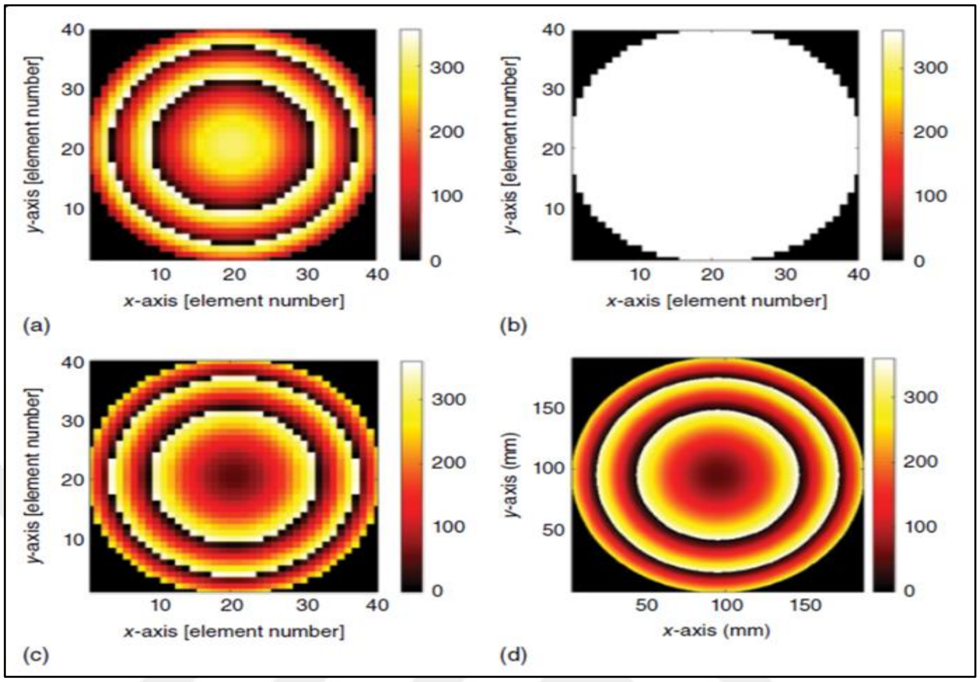

Figure 2.4: (a) Spatial delay, (b) Progressive phase, (c) Phase distribution on the reflectarray antenna, and (d) Phase distribution on the continuous aperture are the phases on the aperture with a centered feed and broadside beam.

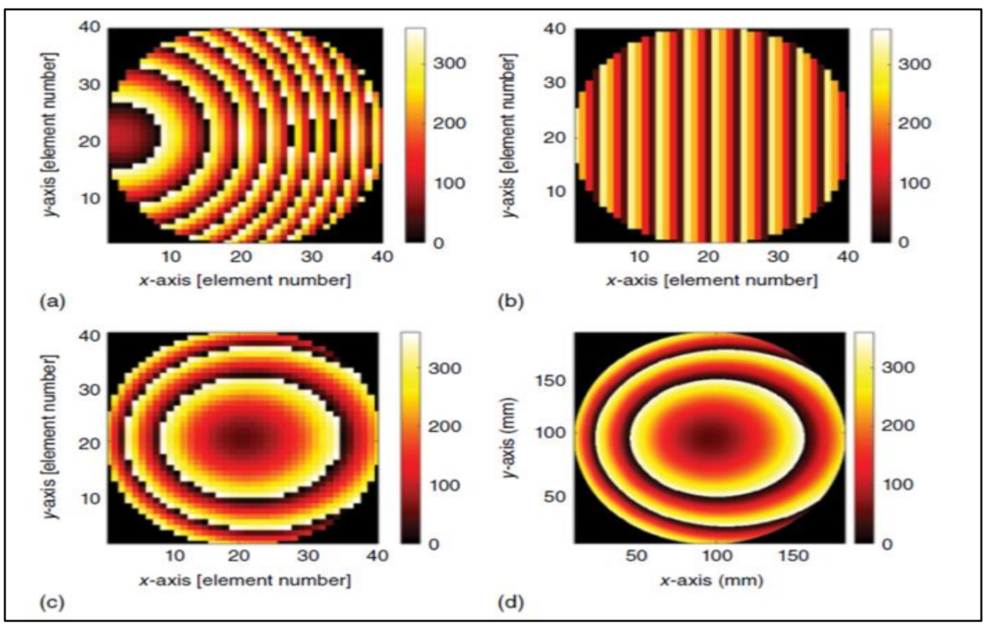

Figure 2.5: The phase distributions on the reflect array antenna, continuous aperture, and phase distributions with an offset feed and an off-broadside beam on the aperture.

2.2 REFLECTARRAY ELEMENTS PHASE TUNING APPROACHES

Establishing a phase tuning strategy for a reflectarray antenna that provides for the necessary phase tuning range is a critical stage in the design and construction of the antenna. It is required to select a phase tuning method in order to determine the radiation parameters of the antenna being studied.

There are a variety of ways available for fine-tuning the phase of reflectarray components, each of which has its own advantages.

a. Elements that rotate in opposite directions.

b. Various sized things are present.

c. In the elements, there are phase/time/delay lines.

To phase shift the incident wave before it is finally re-radiated in the first group, a delay-line microwave network is utilized. Berry [1] was the first to adopt this technology in 1963, when he introduced the world's first reflectarray antenna, which had components that were short-circuited waveguides. The technique is referred to as the guided-wave technique. The scattering field phase of the second set of elements, known as the variable size elements, may be changed by modifying the element's dimensions, such as the patch length, in the scattering field phase. As a last option, circularly polarized (CP) designs make use of the unique spinning wave vectors that are only achievable with CP designs to achieve phase correction, which is otherwise impossible.

2.2.1 Rotational Elements of Varying Degrees

The element rotation approach is a highly advanced phase tuning technique that can only be utilized in CP designs. It is not applicable to any other designs. Based on the rotational orientation of a circularly polarized (CP) antenna element around its origin (°), the radiated phase is either advanced or delayed by the same amount in this manner. These patch elements with associated phase delay lines were the first to employ this technology in reflectarrays, as demonstrated by the work of [20].

The phase shift of the reflected wave is a linear function of the rotation angle of the patches as they were rotated about their origin. If it is possible to create a direct link between rotation angle and phase, it may be possible to achieve phase adjustment of reflectarray components using this approach. Figure 2.6 shows a schematic representation of the unit cell being influenced by a right-hand circularly polarized (RHCP) wave travelling in the –z direction.

By virtue of the change in propagation direction, the reflected wave will be converted in the usual way to become a left-hand circularly polarized (LHCP) wave. Reflectarrays with dual-linear components (such as square patches) and reflector antennas are both instances of reflectarrays exhibiting this phenomenon. When an element produces a 180° phase difference between the two orthogonal components of a reflected field, reflectarrays, on the other hand, can retain their polarization and maintain their polarization.

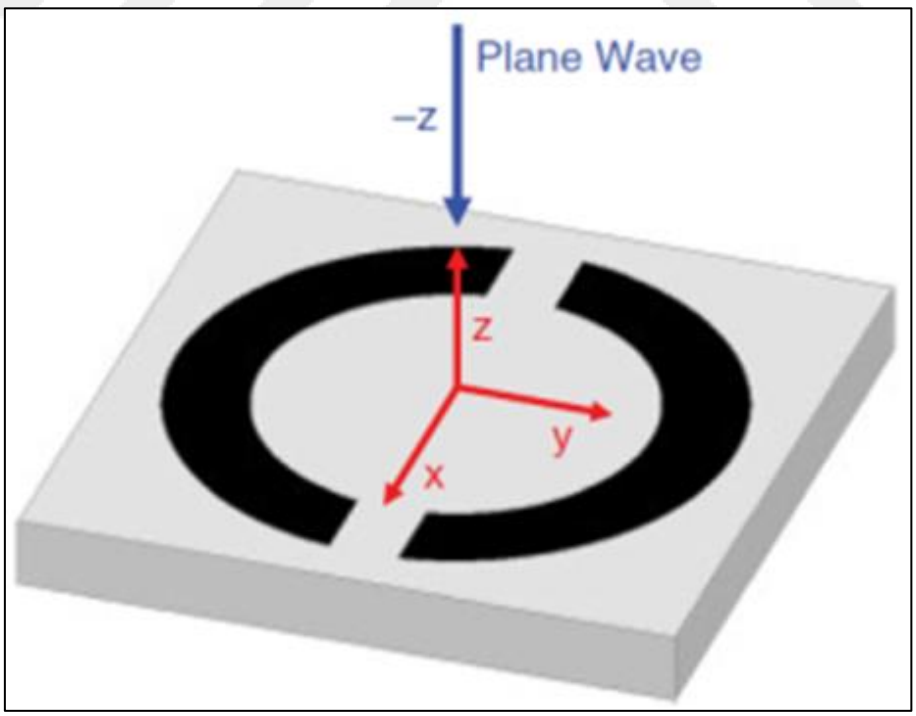

Figure 2.6: Schematic diagram of a Plane Wave element in a CP reflect array.

2.2.2 Variable Sizes Elements

The physical size of the element is changed in this manner in order to change its phase. Changing the length of a resonant element might potentially affect the resonance frequency of the antenna, which would in turn alter the phase of the emitted signal at a certain frequency. It is possible to employ a variation in the reflected phase of the resonant components as a starting point for the operational notion of the variable-size approach. Cross dipoles were first used in [21] for printed cross dipoles, and rectangular patches were first used in [22] for printed rectangular patches. However, despite the fact that square or circular patch geometries are the most popular, the variable element size technique provides the most variety of element geometries possible.

Printing antennas display a wide range of phase shift in the reflected wave due to the large quality factor and high resonant frequency of the reflected wave. It's possible to obtain 360 degrees of phase rotation from a single resonance, if you're lucky. In practice, though, you'll obtain less than that due of factors like as patch spacing and substrate thickness, among others. It is necessary for most reflectarray designs to have a phase tuning range of more than 300 degrees, which may be done with a substrate thickness of less than one tenth of a wavelength. Figure 2.7 displays a schematic representation of this type of element in more detail.

Because of the high-Q resonant nature of the printed antennas and the thin substrate on which they are printed, the phase variation obtained using this technology is exceedingly nonlinear. Near resonance, phase changes occur fast, but at the extremes, phase changes occur considerably more slowly. Although the S-shaped curve is the most generally used form for curves, the shape can vary based on the design scheme of the different parts in the design. The S-curve characteristic of a reflectarray element is illustrated in Figure 2.8.

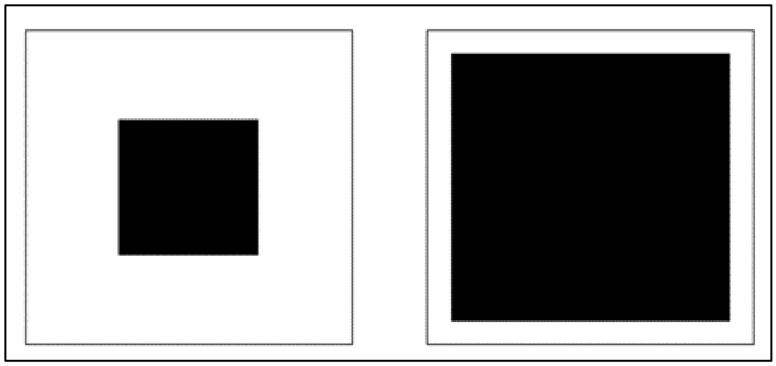

Figure 2.7: Sketches in various sizes components of varied sizes in a reflectarray square patch.

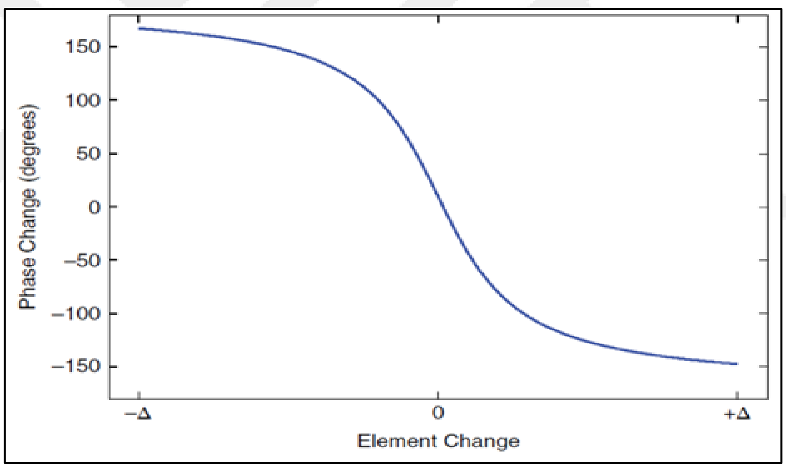

Figure 2.8: A typical S-curve for reflect array components of various sizes.

2.2.3 Lines of Delay in Phase or Time

This device (often a patch) receives an unguided electromagnetic wave from the feed antenna, which is directed to its destination by a transmission line (typically an ultra-thin microstrip wire) [23]– [24]. The transmission line can be terminated in either an open or a short circuit configuration. When a signal is reflected back from the transmission line termination, the element reradiates the signal back to the source. In Figure 2.9, you can see a simplified schematic depiction of this type of component. Although it is theoretically feasible to obtain a completely linear phase response from these types of components, in fact, specular reflections off the ground plane, stub resonance, and dissipative losses in transmission lines will all have an impact on the response obtained. This technique necessitates that the patch dimensions be chosen in such a way that they resonate at the frequency of the incident wave, similar to how the patch dimensions are chosen in normal microwave antennas. For appropriate guided wave propagation to occur, it is necessary that the line (stub) be properly matched to the patch. When there is a mismatch between the patch and the line, the signal will be reflected before it has a chance to go through the line properly. This is of enormous importance to me. In this case, the reflected wave will have two components, and the reflection phase will no longer be proportional to twice the length of the line in this case. One other key aspect to mention is that the patch and delay line should be constructed when the reflectarray antenna is positioned in the array environment, rather than as an isolated element, in order to account for the mutual coupling that exists between the array elements themselves.

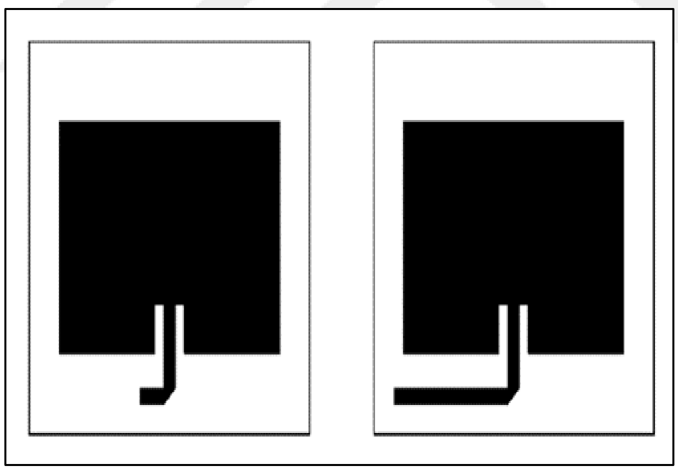

Figure 2.9: Two alternative lengths of phase/time delay lines are coupled to the reflect array patch components in the schematic representations.

2.3 ELEMENT ANALYSIS METHODS

Mutual coupling, the electromagnetic interaction between the elements of an antenna array, is something that must be taken into consideration while undertaking analysis and design of the array's components in most cases. In arrays, when the element spacing is small in relation to the wavelength, the effect of mutual coupling is substantial and must be taken into account. Large antenna arrays, such as reflectarrays, may have hundreds of elements, making analysis in the context of the entire array model problematic.

An array with a large number of equally spaced members behaves in the same way regardless of which element is being referenced. Due to the fact that there are no edges or other variations in the arrangement of the elements in an infinite array [2], every element behaves exactly the same way. Accordingly, an infinite array may represent practically all of the important characteristics of a very large regular array, which has long been recognized as the perfect basis for the production of elements in extremely large finite arrays of a single type. It is important to note that the infinite array approach assumes that all surrounding components are comparable, i.e., that the analyzed structure is periodic in nature. Reflectarrays, on the other hand, are composed of elements that are not similar to one another and have a quasi-periodic structure. However, in the vast majority of cases, this periodic approximation is adequate to represent the features of the reflectarray components.

2.4 SYSTEM DESIGN AND APERTURE OPTIMIZATION

The design of the phasing elements and the design of the system configuration are often the first two steps in the design of a reflectarray antenna. However, there are exceptions to this rule. Our last discussion covered phasing aspects; now we'll look at how the reflectarray system configuration is accomplished.

The majority of systems are built with a certain gain need in mind from the beginning. A reflectarray antenna's gain is calculated in the same way as the gain of classic reflector antennas [1], [2], and is proportional to the size of the electrical aperture. The gain of a reflectarray antenna is calculated as the product of aperture efficiency and maximum aperture directivity and is proportional to the size of the electrical aperture. It is possible to predict the size of the reflectarray antenna aperture that will be required to achieve the desired gain by doing an aperture efficiency study. In addition, the system should be constructed to have the best potential aperture efficiency to maximize its effectiveness. Aperture efficiency analysis may be used to enhance the features of a system, such as the feed specs, the f/D ratio, and the shape of the aperture. Consequently, an in-depth examination of aperture efficiency is essential for the system's development.

Aside from the efficiency of the aperture, other design considerations include feed blockage and edge taper. It is possible to lessen feed blockage by offsetting the feed antenna; however, this can result in decreased aperture efficiency and increased cross-polarization as a result. By maintaining the edge taper as little as feasible, it is possible to avoid significant diffractions at the reflectarray edge. It is as a result of this that some sacrifices in the system's design are required in order to attain overall optimal performance.

The placement and radiation characteristics of the feed antenna are two of the most essential considerations in the design of reflectarray antenna systems, yet they are often overlooked. It is necessary to have a clear description of the radiation pattern and position of the feed antenna in order to determine the efficiency of the reflectarray antenna and other system features.

Without losing sight of the generality of the situation, consider the geometrical layout of the reflectarray system, as represented in Figure 2.10. The reflectarray aperture is located on the XY-plane, and the focal point of the aperture is located at the centre of the coordinate system. The reflectarray aperture is composed of a rectangular aperture and a rectangular reflectarray. ' Using the geometric centre of the aperture as a reference, we oriented the feed antenna such that it pointed in the same direction as the geometric centre. Once the geometry of the system has been defined, it should be possible to compute the efficiency of the feed antenna using a closed-form mathematical method.

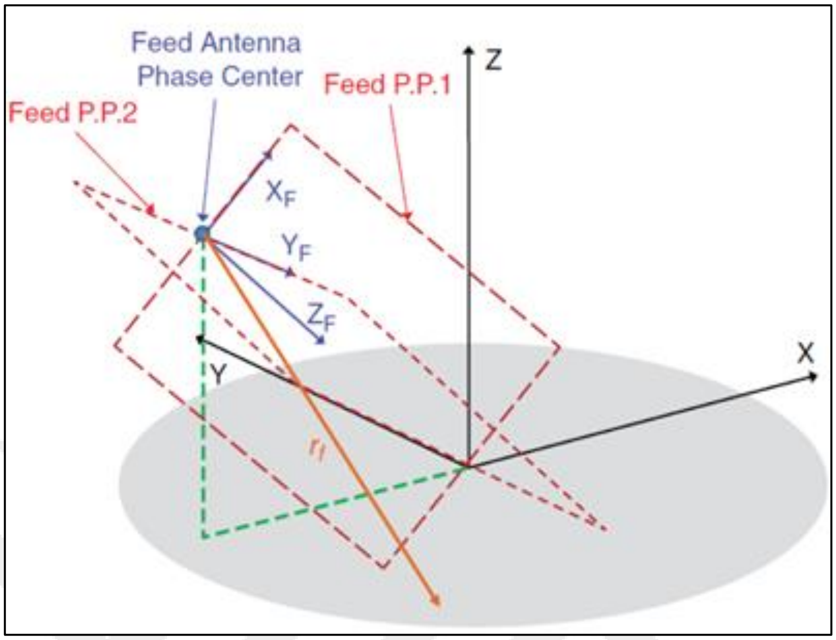

Figure 2.10: The reflectarray and feed system's coordinate system.

2.5 EFFECTS OF APERTURE SHAPE ON EFFICIENCY

The feed pattern for a reflectarray must be matched to the reflectarray in order to achieve optimal efficiency [3]. The shape of the reflectarray aperture, the radiation pattern of the antenna, and the position of the feed all play significant roles in optimizing the aperture efficiency of the reflectarray system. The goal of this part [3] is to compare the efficiency of different popular reflectarray aperture configurations with a balanced feed and a rotationally symmetric pattern as the primary feed antenna.

In a front-fed reflectarray configuration, the feed antenna is situated at a distance of 18 inches from the centre of the aperture. There are three different types of apertures explored in this paper, with the power pattern of the feed (the value of q) adjusted to optimize the reflectarray' s efficiency at each of the three types of apertures tested. For the first example, we will utilize a reflectarray with a rectangular aperture of 20 by 30 inches in size. The connection between aperture efficiency and q is seen in Figure 2.11(a), with a maximum efficiency of 4.5 being achieved. Efficiencies of overflow and illumination are calculated in this section. When these two elements are combined, we obtain an aperture efficiency of 69.76 percent as a consequence of the calculation. The normalized amplitude distribution of this q value on the aperture is seen in Figure 2.11 (right) (b).

A poor aperture efficiency for this shape of aperture is achieved even with an ideal feed pattern because the broadest side of the reflectarray aperture is not fully illuminated. According to general principles, an antenna feed that provides two orthogonal beamwidth patterns according to the x/y ratio of an aperture can significantly improve the efficiency of a reflectarray system in certain situations. Reflectarrays with a non-symmetrical main beam will be broader on the smaller aperture side than symmetric arrays because of the non-symmetrical main beam.

Examine a square reflectarray with a side length of 20 for the same system setup as previously discussed. The relationship between aperture efficiency and q is seen in Figure 2.12. (a). In this circumstance, the best value of q is 6.5, which results in an aperture efficiency of 75.35 percent, which is the highest possible. As can be seen in Figure 2.12(b), the normalized amplitude distribution on the aperture for this value of q results in a substantially greater lighting of the aperture, which ultimately results in a higher aperture efficiency as a result of the increased lighting. Despite this, the corners of the square are still dimly lighted, which is a significant drawback. It is hard to match the square aperture geometry to the symmetric feed pattern because of the spherical wave front of the symmetric feed pattern.

As seen in the prior two cases, the form of the aperture has a substantial influence on the efficiency of a reflectarray system. The aperture should have a shape that is proportionate to the radiation pattern that is supplied into the device in order to achieve optimal performance. Therefore, a circular aperture is well suited for providing a balanced feed pattern in the feed stream. This is validated by comparing a reflectarray antenna with a circular aperture of 20 microns to the identical system under investigation. According to this scenario, the best q value for this aperture is 8.5, resulting in an aperture efficiency of 78.12 percent.

On the right, you can see the link between the efficiency of the aperture and the parameter q, as well as the normalized amplitude distribution throughout the aperture when the parameter q is set to its ideal value. Using an amplitude taper that has amplitude that is rotationally symmetric (see Figure 2.13 (b)), it is possible to generate an appealing reflectarray radiation pattern. For front-fed symmetric reflectarrays, the most effective aperture shape is a circle. Despite this, the asymmetry of the system results in an amplitude taper, which reduces the effectiveness of offset configurations as a result. Depending on how great the offset angle is, an elliptical aperture form may be preferred; nevertheless, for reflectarrays, a circular aperture shape will give the most efficiency.

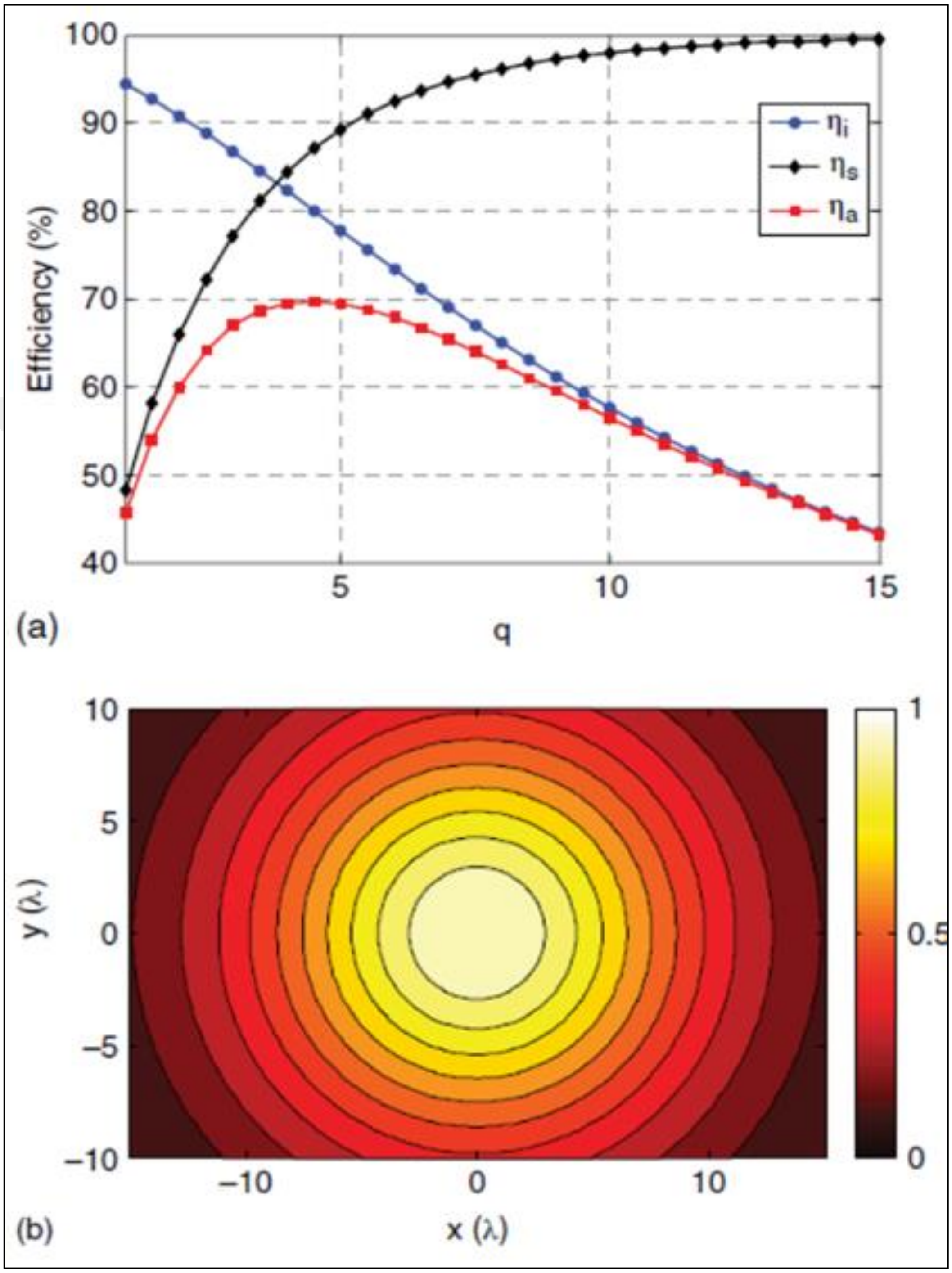

Figure 2.11: The effectiveness of the reflectarray' s rectangular aperture is plotted as a function of the square root of q.

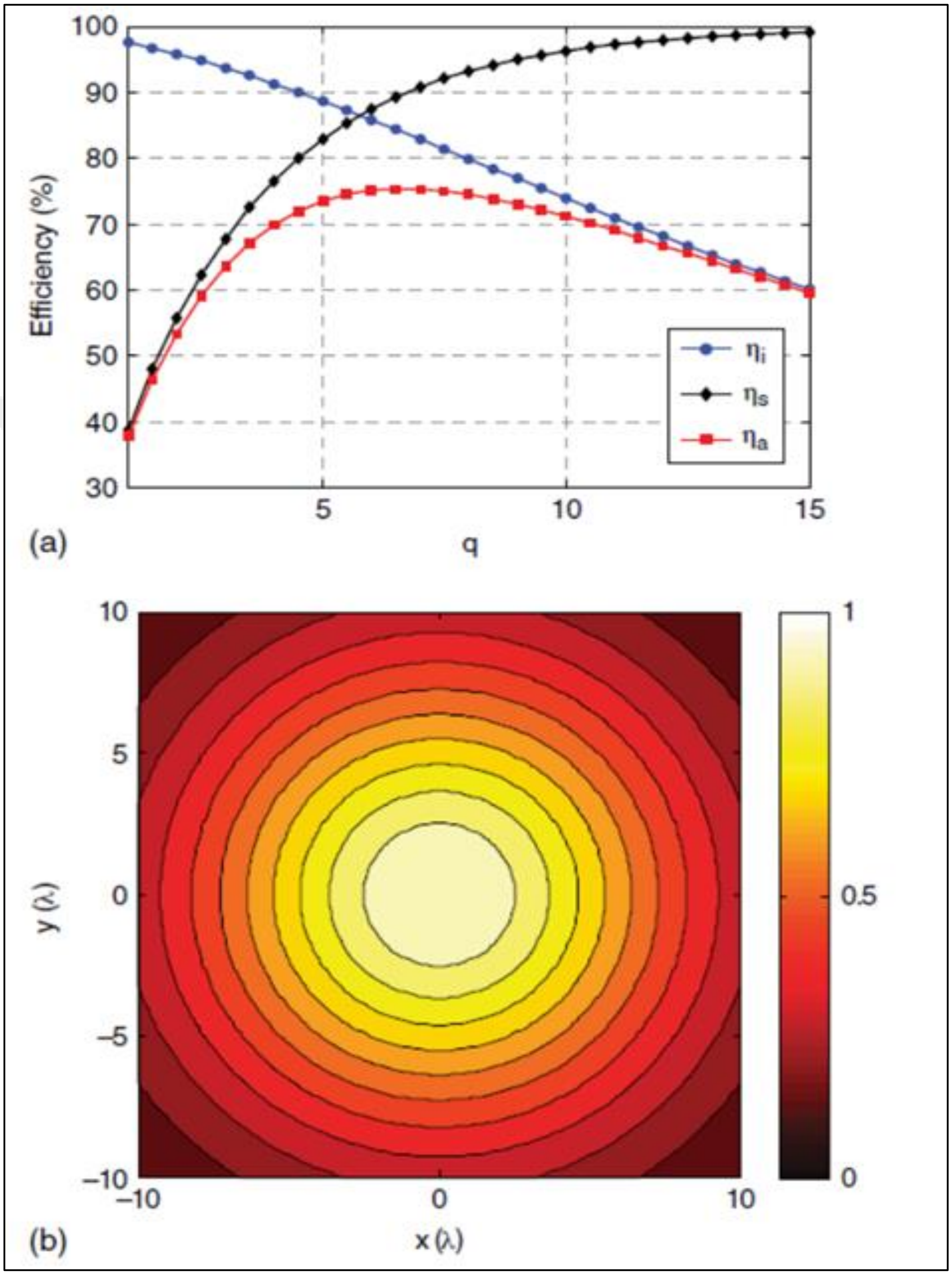

Figure 2.12: The efficiency of a reflectarray' s square aperture changes with the square of the aperture's amplitude.

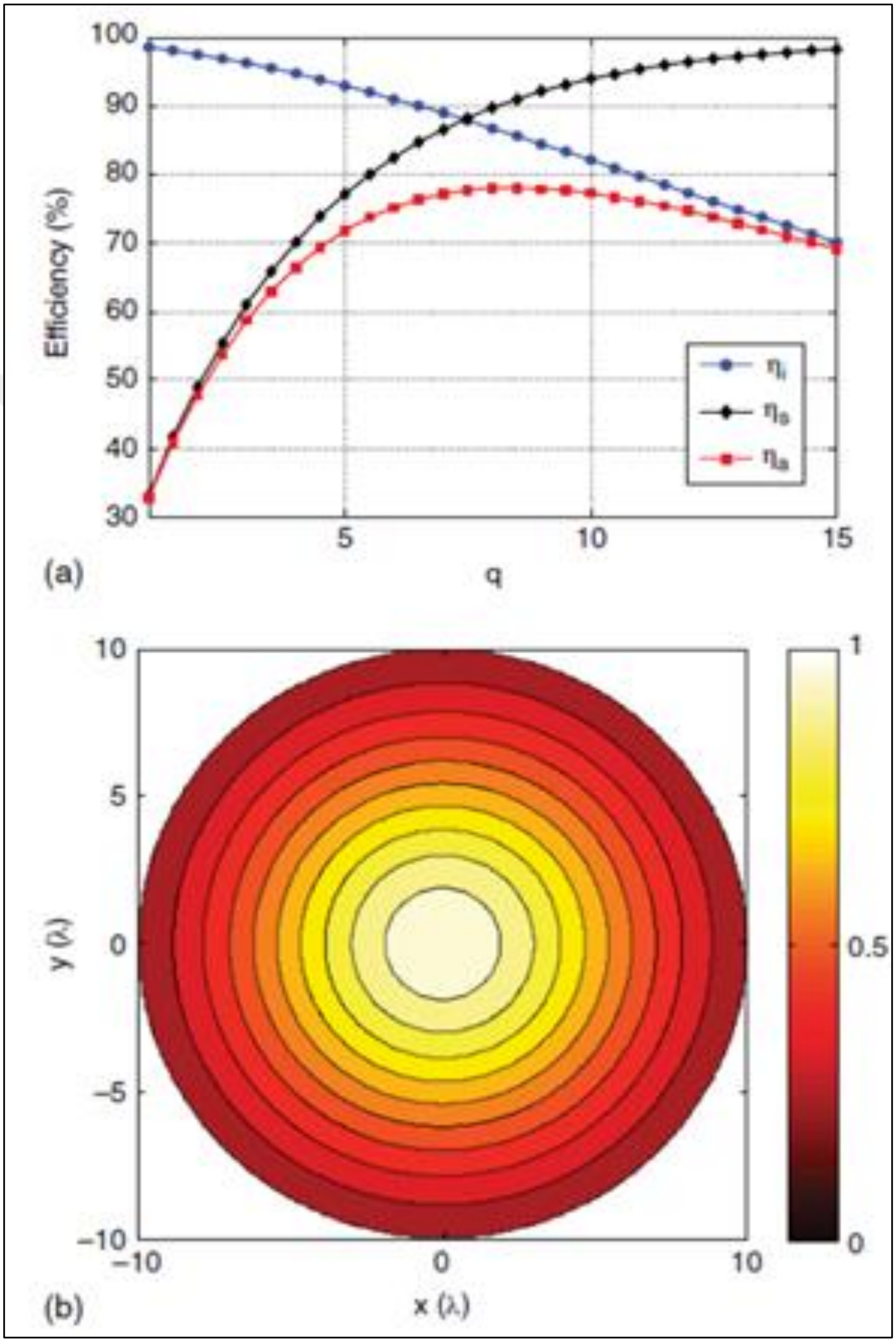

Figure 2.13: The reflectarray has a circular aperture, and its aperture efficiency.

2.6 EFFECTS OF FEED LOCATION ON EFFICIENCY

The feed location has already been determined during the previous aperture study phase. When it comes to practical reflectarray systems, the feed placement is a critical system design component to consider. The feed radiation pattern model, denoted by the letter q, and the feed distance from the reflectarray aperture are the two design parameters for this configuration (z). Figure 2.14 depicts the relationship between these two factors and aperture efficiency (a). By altering the feed position, it is possible to optimize the effectiveness of the aperture for a range of feed patterns.

Generally speaking, higher feed locations and more efficient apertures are related with higher q factor values. As a result of the large spread of the feed, it is impossible to attain a high aperture efficiency when using feed patterns with small q values. As an alternative, while large qs feed patterns are capable of achieving high aperture efficiency, they are typically not considered a good choice because feed antennas typically have a large physical volume (resulting in high aperture blockage) and also reduce the relative gain improvement obtained by the reflector system. The range of 6–8 for q is typically regarded as a good starting point for most people.

Figure 2.14 depicts the feed efficiency as a function of the feed's position for the same system (b). Observe that the efficacy of illumination improves as the distance between the feed and the aperture increases, but the spillover efficiency decreases as the distance between the feed and the aperture increases. A nominal value of 16.3 is therefore determined to be the optimal placement for this design, resulting in an aperture efficiency of 77.34 percent for this design.

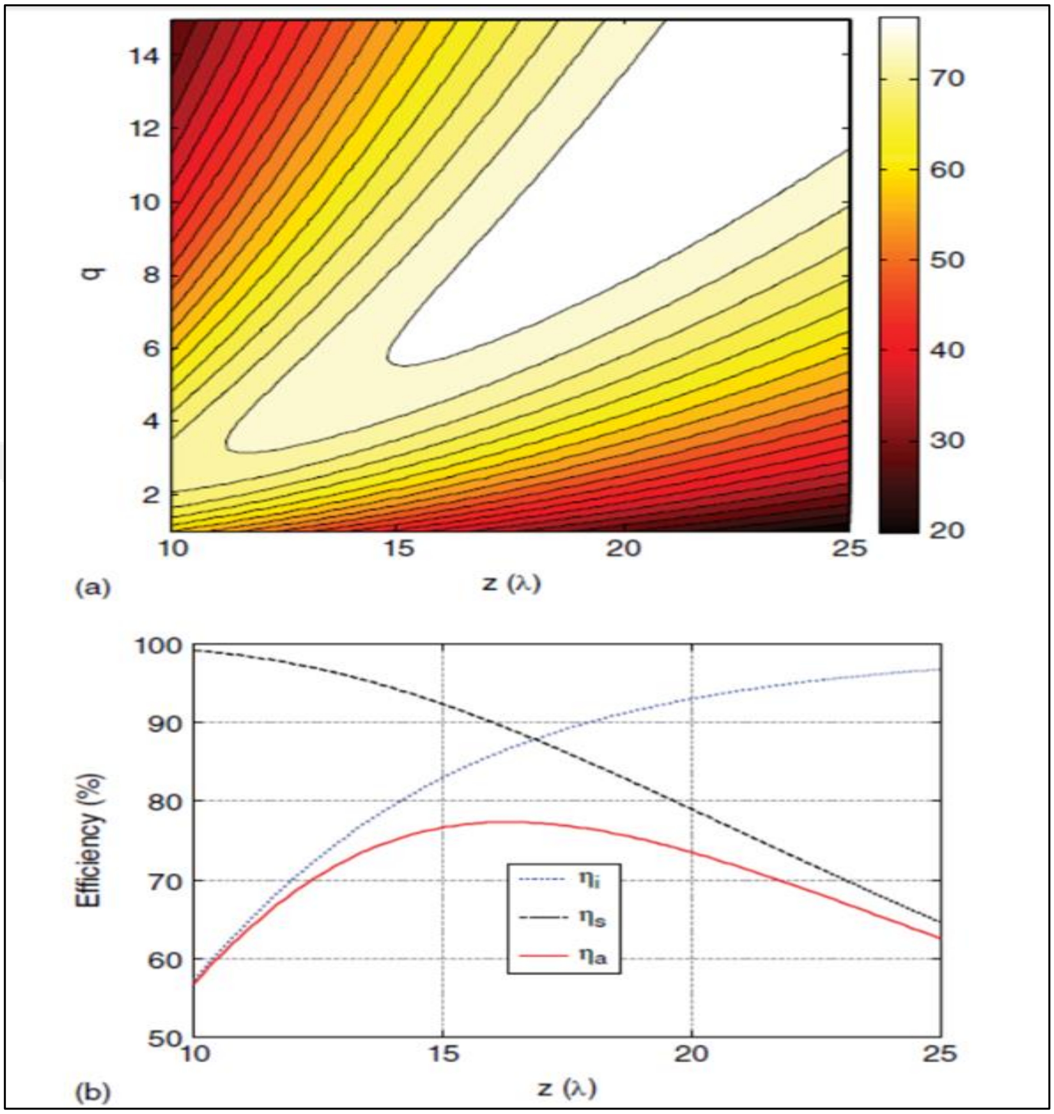

Figure 2.14: Efficiency of a front-fed symmetric reflectarray reflectarray in a reflectarray: feed position and q, (b) feed position and (a) efficiency as a function of (q = 6.5).

2.7 APERTURE BLOCKAGE AND OFFSET SYSTEMS

As shown graphically in Figure 2.15, the feed antenna (as well as the support structure) tends to block some radiation in reflectors and reflectarrays. This is depicted schematically in Figure 2.15 (a) as an example of aperture blocking. In general, the amount of aperture blockage is dictated by the relationship between the blockage diameter (D0) and the reflectarray diameter

(D). The blockage diameter does not correspond to the physical diameter of the feed antenna, but rather to an effective projection of the physical volume of the feed antenna. The principal implications of aperture blockage are an increase in sidelobe level and a drop in antenna gain, both of which become worse as the aperture blockage ratio increases. Reflectarrays, like reflectors, have a blockage ratio of less than 0.2; however, when working with reflectarrays with smaller aperture sizes, this becomes more problematic [25].

Alternatively, the feed antenna might be offset, as shown schematically in Figure 2.15 (b), in order to alleviate aperture blockage difficulties. A common reason why the offset system is preferred over the symmetric case for modestly large reflectarrays with nominal gains of 30dB or less is because the offset system is more akin to the symmetric situation. As a result of the smaller focal length-to-diameter ratio of offset systems, they have a higher cross polarization level [3], which is beneficial.

In part because of a reduced projected aperture effect, the gain of the offset system is lower for a given physical aperture diameter (D). The ability of the offset system to reduce feed blockage, on the other hand, is a significant advantage.

The efficiency of the offset system's aperture will now be investigated. The offset angle is commonly used to decrease feed blockage in offset designs since feed blockage is an issue in offset designs. It is possible to design the feed pattern in such a way that when it is utilized it points to the geometrical center of the aperture by using $q = 6.5$ and an offset angle of 20°. Figure 2.16 (a) depicts the aperture efficiency as a function of the feed distance to the reflectarray aperture, and it is obvious that the efficiency factors follow a general pattern that is similar to that seen in the symmetric situation. By positioning the feed at a distance of 15.2 meters from the reflectarray aperture, it is possible to obtain an aperture efficiency of 75.69 percent. Achieving an offset system efficiency comparable to that of the symmetric case (77.34 percent) may be accomplished with the additional benefit of a low feed blockage while still achieving an aperture efficiency comparable to that of the symmetric case.

The offset angle is extremely important in this situation and should not be neglected. Figure 2.16 (b) depicts the effectiveness of the aperture as a function of feed position and offset angle for the same feed pattern as in the previous figure. As can be shown, even at offset angles as small as 20°, a high aperture efficiency may be achieved; however, as the offset angle increases, the system's efficiency begins to deteriorate. In the case of reflectarrays, a considerable feed offset angle results in components being stimulated at extremely oblique angles, which further degrades the performance of the system. Because of this, it is recommended that the offset angle be minimized. The feed antenna was previously aimed towards the geometric center of the reflectarray aperture in prior research. However, even though this is the greatest option for symmetrical designs, when employing offset systems, the ideal feed beam aiming direction does not coincide with the array's geometric center. In order to explore this, we'll utilize the same offset reflectarray configuration as before, but with the feed positioned at a height of 15.2 from the aperture and offset by 20° instead of the usual 15°. Figure 2.10 shows how the feed may be shifted along the x-axis to change the direction of the beam aiming. Figure 2.17 depicts the position of the feed's beam aiming location (X0) as a function of the effectiveness of the aperture. Optimal beam point for feed in offset systems is positioned slightly below the geometrical center of the aperture, which is advantageous in some applications. According to this example, the value is 0.6, and the system will have an aperture efficiency of 76.1 percent with this configuration. When the feed is pointed at the geometric center of the reflectarray, as seen in Figure 2.18 (a) and (b), the amplitude distribution of the reflectarray produces the required results. When the optimal parameters (offset angle, feed location, and beam pointing direction) are applied, the efficiency of the offset reflectarray is just 1 percent lower than that of the symmetric case.

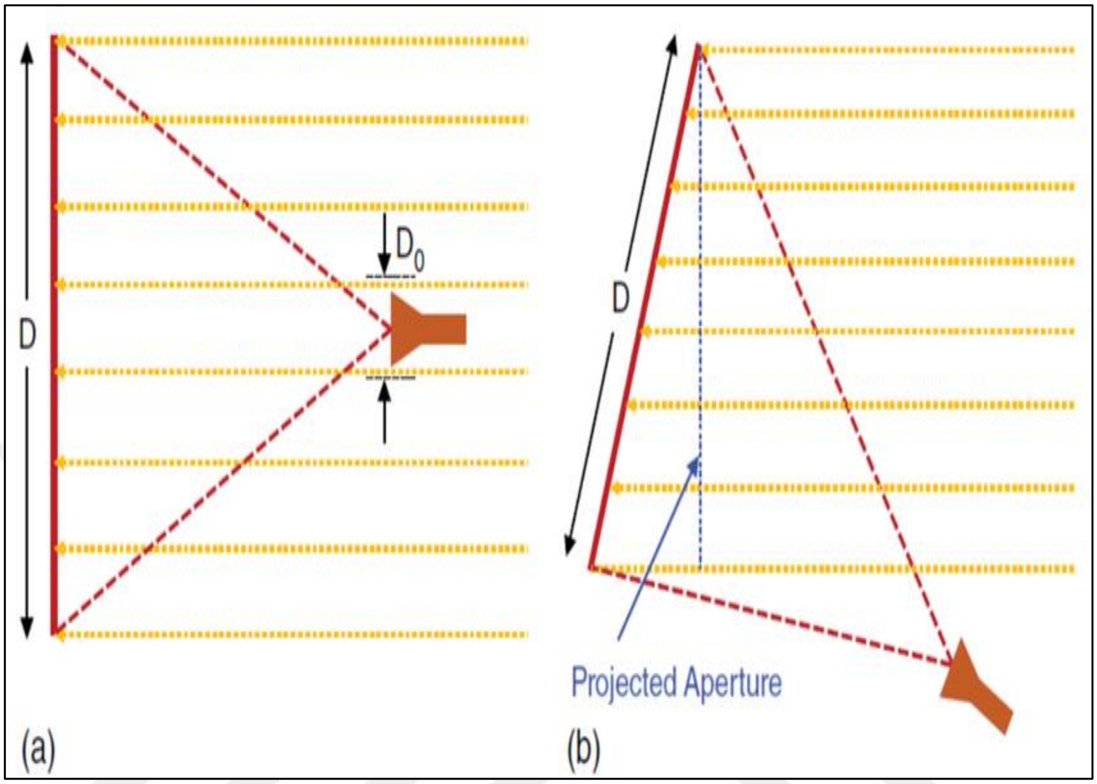

Figure 2.15: In front-fed reflectarray systems, the problem of aperture blockage symmetric (a) and (b) offset.

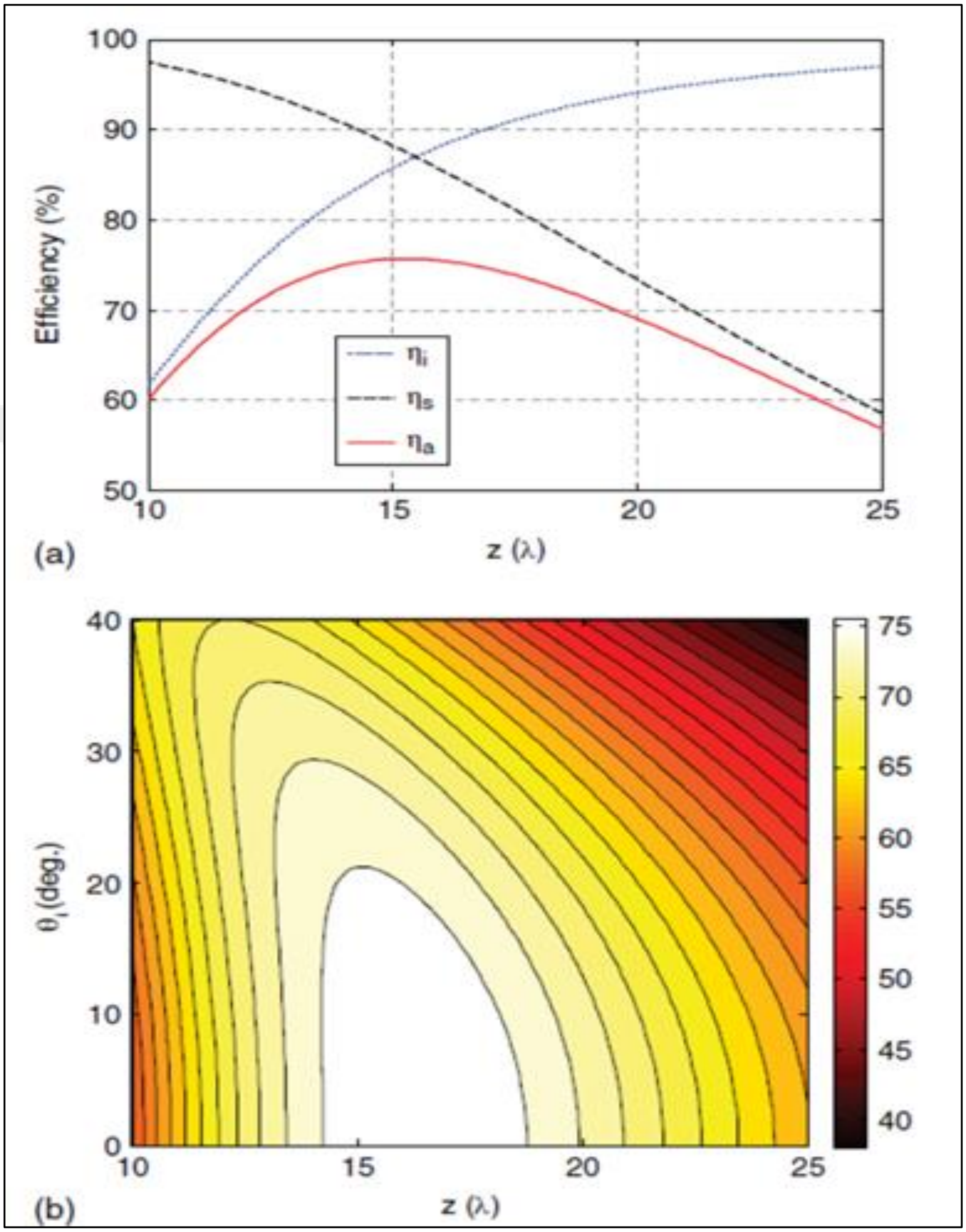

Figure 2.16: For an offset reflectarray with q = 6.5, efficiency is for offset = 20°, the efficiency of the feed position is shown in Figure 1. Figure 1: Efficiency of feed position and offset.

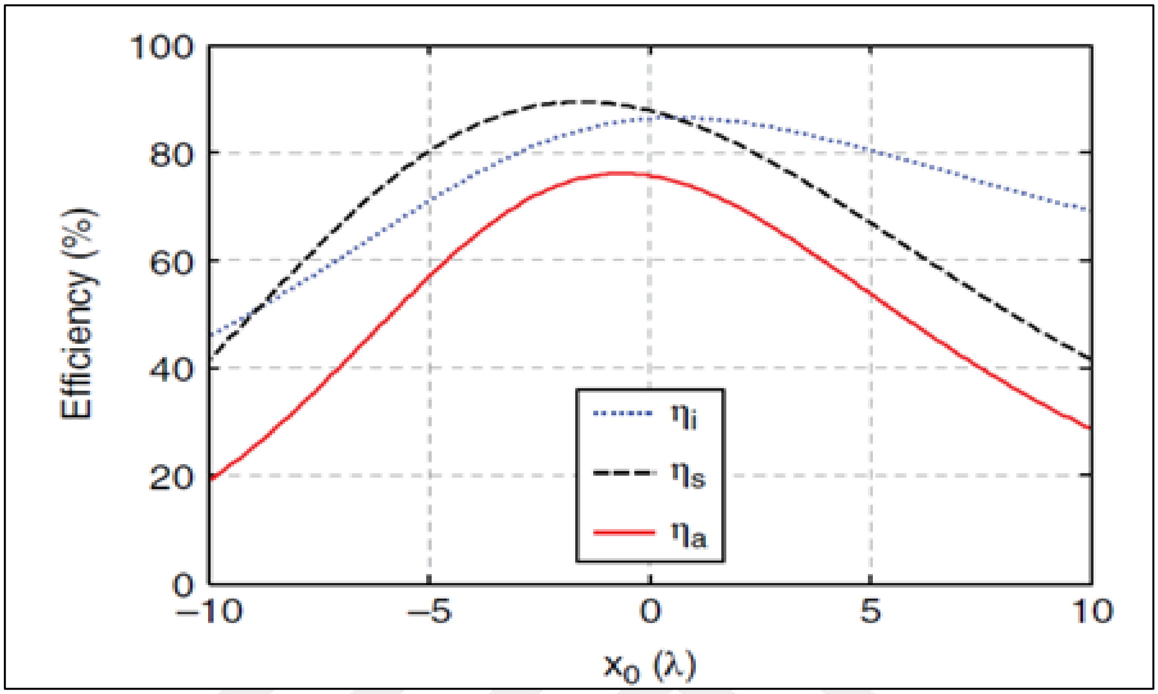

Figure 2.17: An offset reflectarray' s efficiency as a function of the aperture's feed beam pointing.

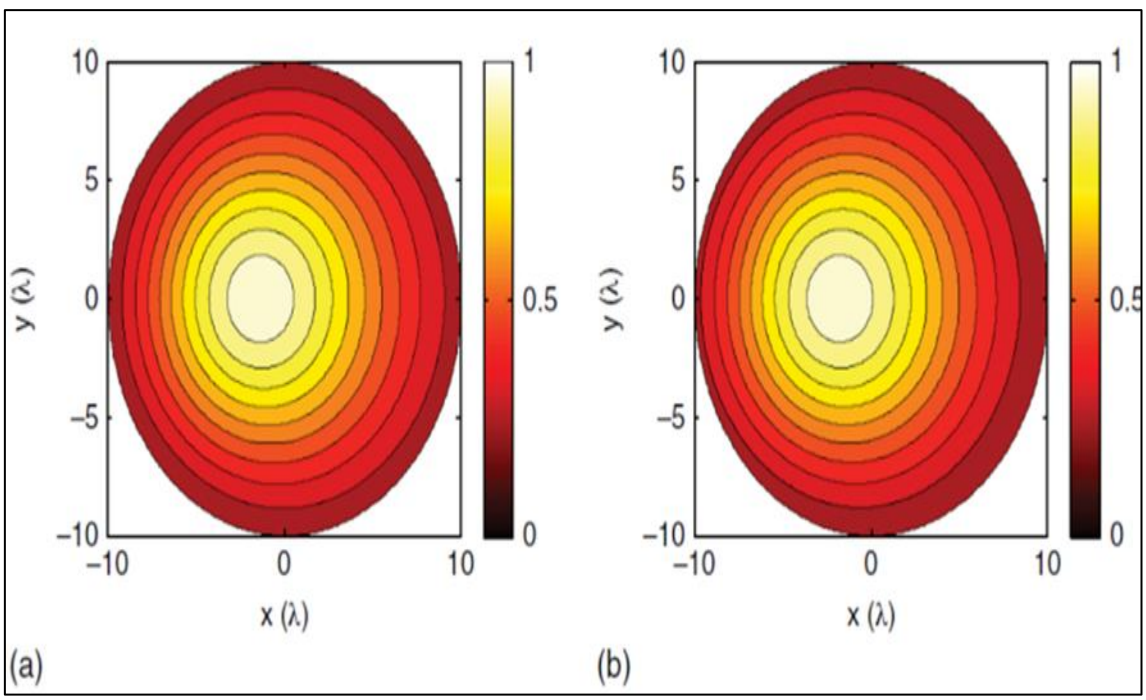

Figure 2.18: The reflectarray aperture amplitude distribution Feed points to the geometric center (a), feed pointers to the optimal position (b).

2.8 BANDWIDTH OF REFLECTARRAY ANTENNAS

Reflectarray antennas have an appearance that is similar to that of ordinary reflector antennas, but their performance in terms of system bandwidth [26–29] differs significantly.

Because a reflector antenna is nearly frequency independent, or has an infinite bandwidth, the primary feed antenna is responsible for restricting the bandwidth of a reflector antenna, which has an almost limitless bandwidth. Its bandwidth is governed by the physical nature of its phasing elements, as well as the flatness of its aperture in compared to the rest of the instrument. The bandwidth of reflectarray antennas is restricted by phase errors introduced as a function of frequency, which are generated by both of these factors together.

In microstrip reflectarrays, the element alone often provides just a few percent of the total bandwidth of the reflectarray system, which is rather low. The bandwidth of a reflectarray antenna can be enhanced by as much as 20 percent by including methods such as thick substrates, multilayer patches, and multi-resonant components into the design. Reflectarray elements are normally chosen to fulfil the required phase at the design frequency, regardless of whether phasing components are used in the overall design. The required phase in the array will change as the frequency fluctuates, and the phase of each reflectarray member will change in response to this change in need. It is possible for phase errors to be introduced into the array if these two phase shifts do not match each other, which is commonly the situation. A drop in the antenna's gain, pattern deterioration, and eventually bandwidth limits are all possible consequences of this.

It is important to note that the phase difference between the components in a reflectarray design is vital for creating the desired radiation pattern; hence, rather than the reflection phase of an individual element, the phase difference between reflectarray elements is significant here. It is impossible to create reflectarray phase elements without taking into consideration the relative phase requirements of each and every other reflectarray component. However, for certain relative phase requirements, it is possible to examine the frequency behaviour of the reflectarray members and determine whether or not a phase error has occurred.

Because of a phase difference that is not in agreement with the anticipated frequency behaviour, the reflectarray gain is lowered and the reflectarray bandwidth is constricted. A phase error term is defined as follows in order to measure the impact of this phase error term.

One term in this equation indicates the frequency behaviour of each element, while another term represents the spatial phase delay between the two terms in the equation. It is represented by this equation as the total of the angular misalignment of a collection of components with regard to a specific phase requirement.

$$PhaseError(f) = \{\varphi_2(f) - \varphi_1(f)\} - k \cdot (R_2 - R_1). \qquad (2.1)$$

Because the lesser the phase error, the greater the bandwidth of the reflectarray, it is a good tool for comparing different element designs. Reflectarray elements with quantized phase will have a phase error at the center frequency (f0), although this phase error is often small when compared to the other defects in the system. Quantized phase of reflectarray elements.

3. METHODOLOGY

3.1 INTRODUCTION

In this chapter, a detailed methodology of the working steps is presented. This study was aiming to design a reflectarray antenna using MATLAB tools and CST software for simulation at 8 to 12 GHz frequency range for X-band applications. This is not easy as it seems. The design should match the frequencies of the reflectarray antenna with the source of the signal which will be a horn antenna.

3.2 DESIGN THE REFLECTARRAY ANTENNA USING MATLAB GUI

In figure 3.1, the GUI of reflectarray design tool is presented. First field is corresponding to the radius of the antenna which is chosen to be 200 mm. The second field serve to specify the frequency. In this study, the frequency will be 10 GHz. The Coordinates of the phase centre could be calibrated under X, Y and Z label. In this case, Z will be 170. The beam direction factors, elevation and azimuth, will be zero in this trail. By click “Get Element data”, data.txt file will be chosen which is presented in table 3.1. The unit element dimension is chosen to be 4.7. and the phase reference is zero degree. Preview button shows an imaginary picture of the antenna before contracting in CST. By clicking “Construct in CST”, an automatic file in CST will be created and the modeller start to draw the square patches in the reflectarray pattern (Figure 3.2, 3.3, 3.4, 3.5). The Code use the CST-MATLAB-API Library to run both software.

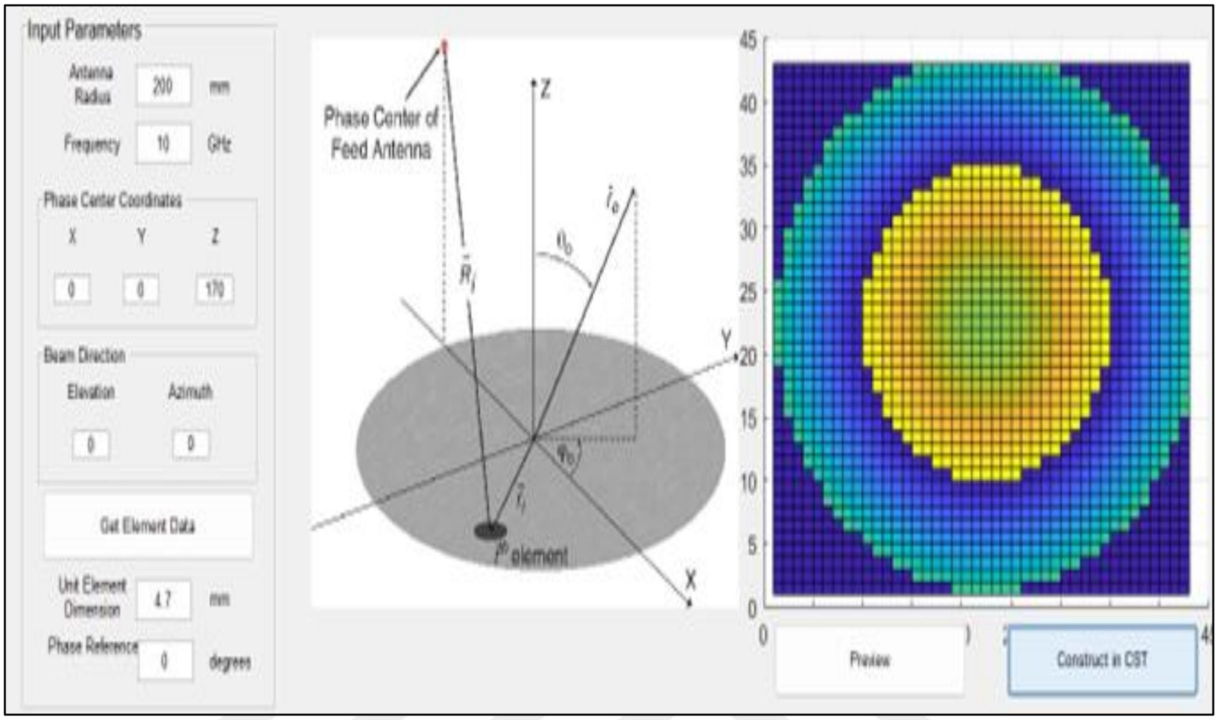

Figure 3.1: Reflectarray design tool.

Table 3.1: Data.

140	0.2
130	1.5
0	2.5
-150	3.5
-175	4.5

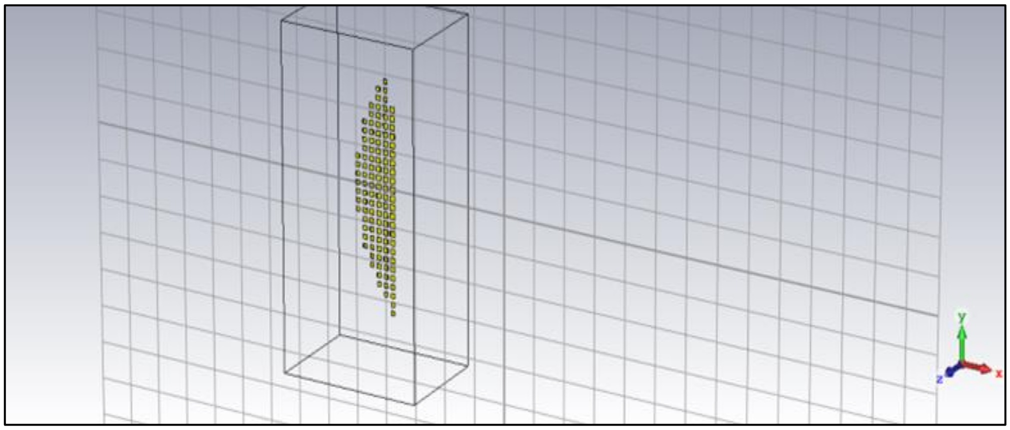

Figure 3.2: Constructing antenna in CST 1.

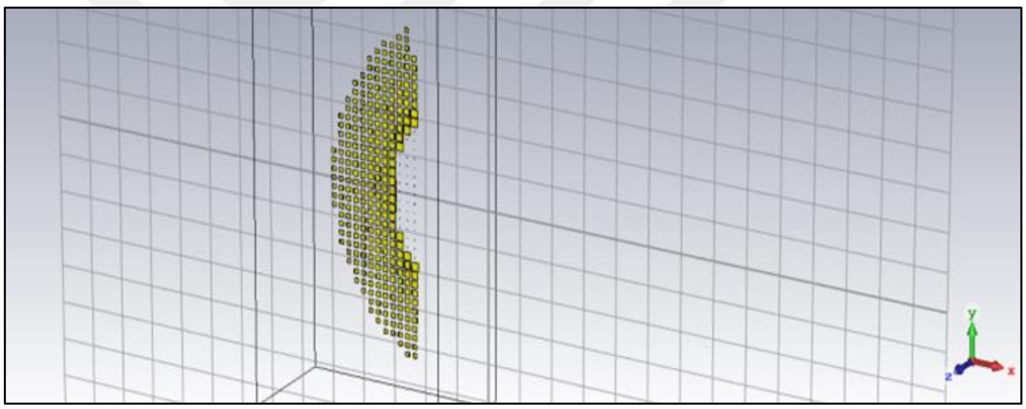

Figure 3.3: Constructing antenna in CST 2.

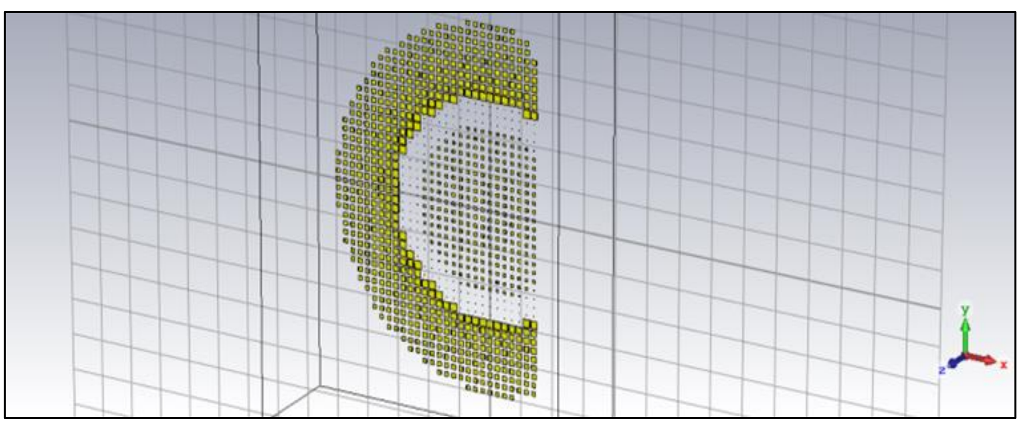

Figure 3.4: Constructing antenna in CST 3.

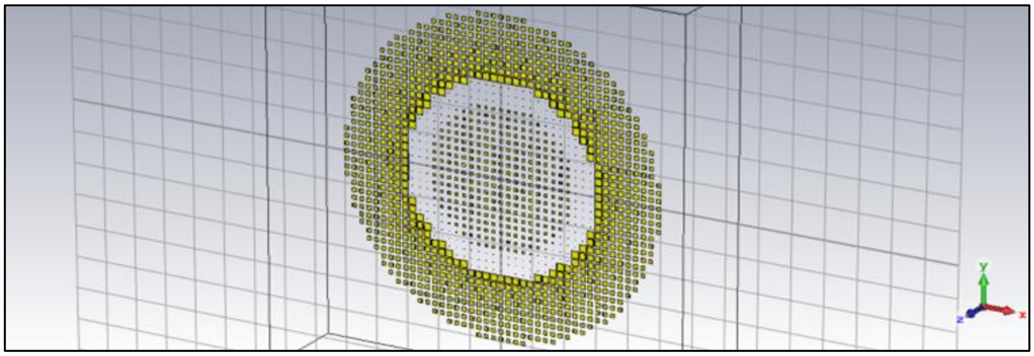

Figure 3.5: Constructing antenna in CST 4.

3.3 DESIGN THE REFLECTARRAY ANTENNA IN CST

After getting the square patches of the antenna constructed in CST, the design needs to have a substrate core. Aluminium with epsilon equal one is chosen to be the materiel of the substrate. A thickness of 1 mm is used. The radius of the circular shaped substrate is equal to 55 mm (Figure 3.6).

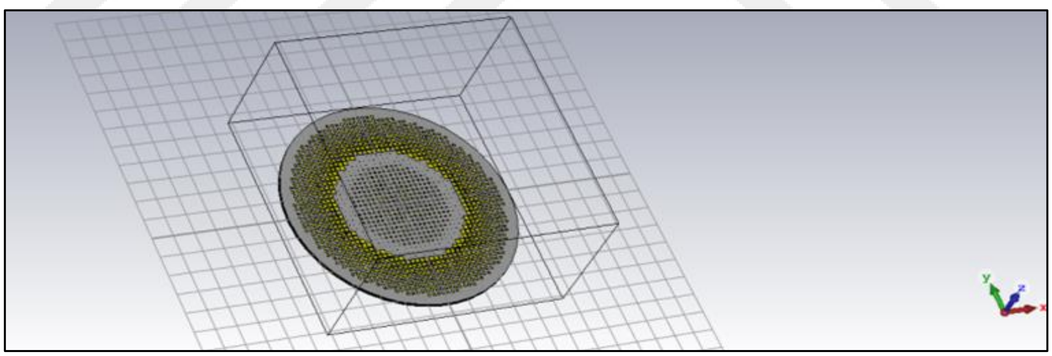

Figure 3.6: Reflectarray with Substrate.

For ground, a circular shaped cupper layer is used with a thickness of 0.1 mm (Figure 3.7).

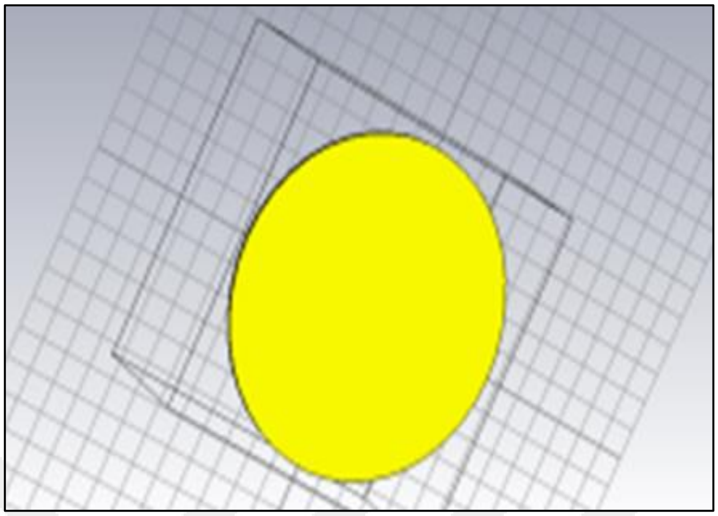

Figure 3.7: Ground layer.

3.4 DESIGN OF HORN ANTENNA IN CST

A design of horn antenna with waveguide is proposed to produce the signal where the reflectarray antenna will reflect.

The flaring metal waveguide, often known as the "horn" of the antenna, is where the radiation is focused, and it is on one side of the waveguide. Horns are frequently used as antennas in the ultra-high-frequency (UHF) and microwave bands, which operate at frequencies that are higher than 300 MHz. The major purpose of these antennas is to supply power to a parabolic antenna, serve as a reference point for determining the gain of a broader array, and act as a directing antenna for various pieces of equipment such as radar guns and microwave radiometers. Some of its characteristics include easy fabrication and tuning, moderate directivity, wide bandwidth, and low standing wave ratio (SWR).

Jagadish Chandra Bose, a Bengali Indian radio physicist, is credited with building the very first horn antenna as part of his ground-breaking work with microwaves.

Because they lack resonant sections, horn antennas have the distinct advantage of being able to function throughout a broad frequency range and bandwidth. This is because of their absence of resonant components. Although horn antennas typically have a practical bandwidth ratio of 10:1, it is feasible to get ratios of up to 20:1 in some cases (Such as enabling it to function at frequencies ranging from 1 GHz to 20 GHz). As a result of the input impedance slowly shifting throughout such a broad frequency range, it is feasible to achieve a low voltage standing wave ratio (VSWR). Horn antennas can achieve a gain of up to 25 dBi, with a figure between 10 and 20 dBi being more typical.

Multiple flare angles and expansion curves (elliptic, hyperbolic, and so on) are possible in the horns in both the E-field and H-field directions, which enables a diverse array of beam profiles to be created.

The pyramidal horn (a, on the right) is a type of horn antenna in which the horn itself is shaped like a pyramid with four sides and a rectangular cross section.

They are a common type of radio transmitter that make use of rectangular waveguides to send out radio waves that are linearly polarized.

A pyramidal horn known as a sectoral horn has only one pair of its sides flared while the other pair of sides are parallel. The result of having sides that flare outward is a beam that is fan-shaped because it is narrow in one direction but wide in another. This configuration is used rather commonly in wide search radar antenna feed horns.

The E-plane horn is a sectional horn that is flared in the direction of the electric field that is present in the waveguide (b).

A sectoral horn with a flared end in the direction of the waveguide's magnetic or H-field (H-plane horn, c).

Instead of referring to the actual shape of the horn, the word "conical" is being used here to describe the shape of the horn. They can be used in waveguides that have a cylindrical shape.

The term "exponential horn" refers to a curved horn in which the distance between the sides of the horn increases as the length increases. They are sometimes referred to as scalar horns and can have a cross section that is either pyramidal or conical. The frequency range of expansive horns is quite broad, and they have very few internal reflections. Additionally, their impedance and other characteristics are practically constant. One of their many applications is the creation of high-performance feed horns that can be used in communication satellite antennas and radio telescopes.

In a type of horn known as a corrugated horn, the interior of the horn is covered on the transverse plane by parallel slots or grooves that are relatively narrow in contrast to a wavelength. Because of its wider bandwidth, smaller sidelobes, and reduced cross-polarization, corrugated horns are frequently used as the feed horns for satellite dishes and radio telescopes.

A conical horn that can function in either of two modes (The Potter horn) This horn can be used in place of the corrugated horn, which suffers from significant loss and is difficult to manufacture at sub-mm wavelengths.

This straightforward dual-mode horn gives the impression of being a pyramidal horn with a square output aperture; however, in reality, it is a diagonal horn. This is not the case, despite the fact that the square output aperture seems as though it is rotated 45 degrees relative to the waveguide. In order to put these horns to use, you will need to split them in half and tune them to lower frequencies.

Horn of the Rhinoceros: A horn that is either triangular or octagonal in shape and has ridges or fins that run along its length. Because of the fins, the bandwidth of the antenna has been enhanced, and the cut-off frequency has been lowered.

A horn that contains multiple smaller horns called sub-horns, which are separated from the main horn by metal partitions called septum's.

A horn that has a relatively small hole and emits a plane wave; the length of the horn is sufficient to keep phase inaccuracy to within a few hundredths of a wavelength. Because the aperture efficiency is at 1.0, the resulting gain is the highest attainable, yet the beamwidth is as narrow as it can be. The only thing that can limit the gain is the diffraction that occurs at the aperture. They are utilized in radio telescope feed horns in addition to other high-resolution antennas.

In this study, a canonical shaped horn antenna is used (Figure 3.8). The design is dedicated to radiating in the range of frequency 8-12 GHz. It is consisted by 3 main solid objects:

a. The cone

b. The waveguide rectangle part 1

c. The waveguide rectangle part 2

The Cone had 150 mm as aperture diameter. The length of cone is 295mm.

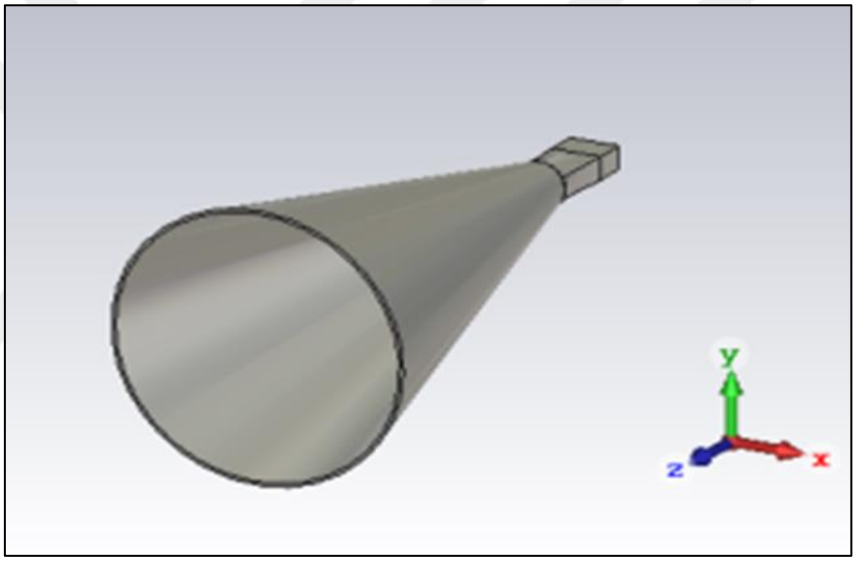

Figure 3.8: Horn antenna.

3.5 COMBINE THE REFLECTARRAY ANTENNA WITH THE HORN ANTENNA FOR SIMULATION

To simulate and test the design, saving model as 3D models is very important by exporting them as .sav files.

Both models are added to the domain where the reflectarray antenna is placed at (x, y, z) equal to (0,0,0). The horn antenna is scaled to 0.1 and placed at 70 mm away from the reflectarray antenna. Figures 3.9, 3.10, 3.11 shows the complete design.

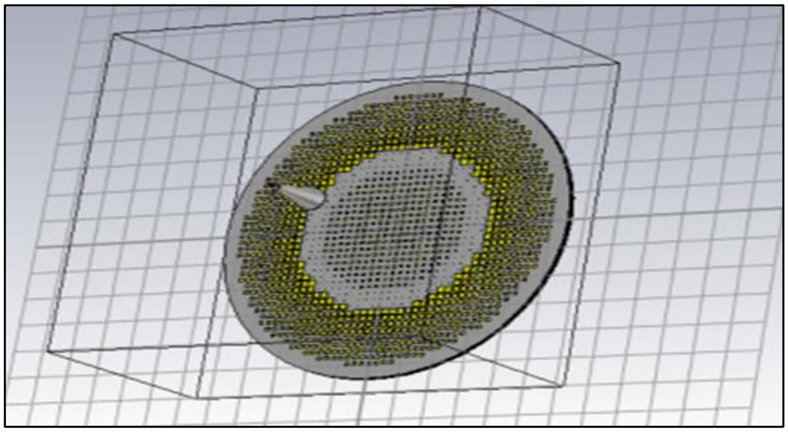

Figure 3.9: Right side of the design.

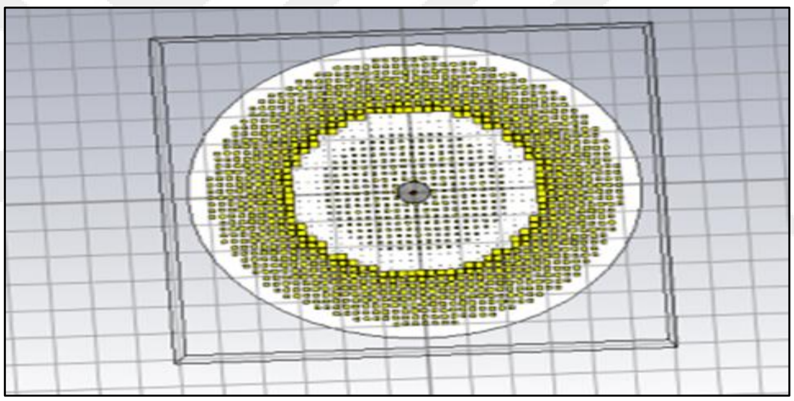

Figure 3.10: Top side of the design.

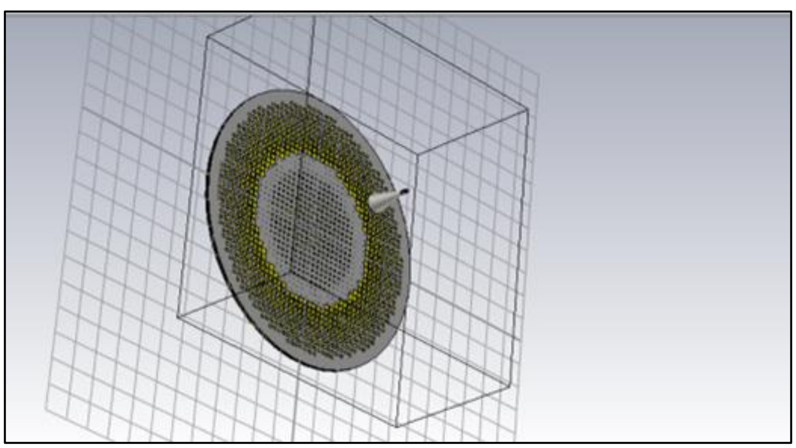

Figure 3.11: Left side of the design.

4. SIMULATION AND RESULTS

4.1 MATLAB AND CST LIBRARY

MATLAB® is a platform for programming that was developed expressly for the use of engineers and scientists in order to facilitate the evaluation and design of the systems and technologies that will bring about a revolution in our world. The MATLAB language, which serves as the platform's fundamental building block, offers the most intuitive means of expressing computational mathematics.

CST-MATLAB-API: Version 3 of the GNU General Public License, or (at your option) any later version, applies to this software, which means that you are free to redistribute and change it as you see fit as long as you adhere to the rules of the License. This license may be found here.

4.2 CST SOFTWARE

Engineers who want to design, evaluate, and optimize electromagnetic (EM) components and systems may do so with the help of the high-performance 3D EM analysis software that is CST Studio Suite®.

One user interface serves as the home for all of the electromagnetic field solvers that are included in CST Studio Suite. It is possible to develop hybrid simulations by combining several simulators. This enables engineers to investigate complicated systems that are comprised of numerous components in a straightforward manner. Through the use of co-design, the SIMULIA EM simulation may be incorporated into the design process and be used to drive development early on.

EM analysis commonly deals with issues such as electromagnetic compatibility and interference (EMC/EMI), exposure of the human body to electromagnetic fields, electro-mechanical effects in motors and generators, and thermal effects in high-power devices. Other common EM analysis problems include exposure of the human body to electromagnetic fields.

CST Studio Suite is used by a number of the most successful technology and engineering companies in the world. This technology has a number of benefits, some of which include a reduction in development times as well as expenses. Simulation opens the door to the possibility of virtual prototyping. In order to enhance the performance of the device, any compliance issues may be identified and sidestepped at the earliest feasible stage of the design phase, and the number of necessary physical prototypes can be reduced. Both of these steps can take place simultaneously.

4.3 HORN ANTENNA RESULTS

4.3.1 1D Results

Figure 4.1 shows that the antenna had high gain for frequencies between 8 and 12 GHz. S11 peak was at 8.3 and 8.5 GHz. For 10 GHz, S11 was -25 Db.

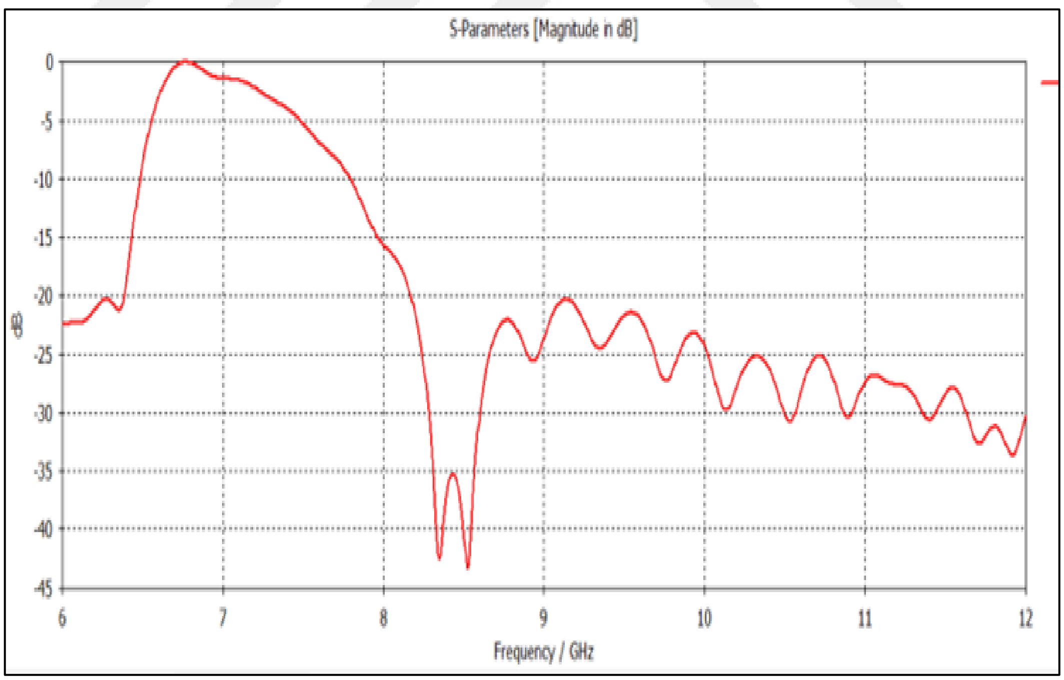

Figure 4.1: S11 Results.

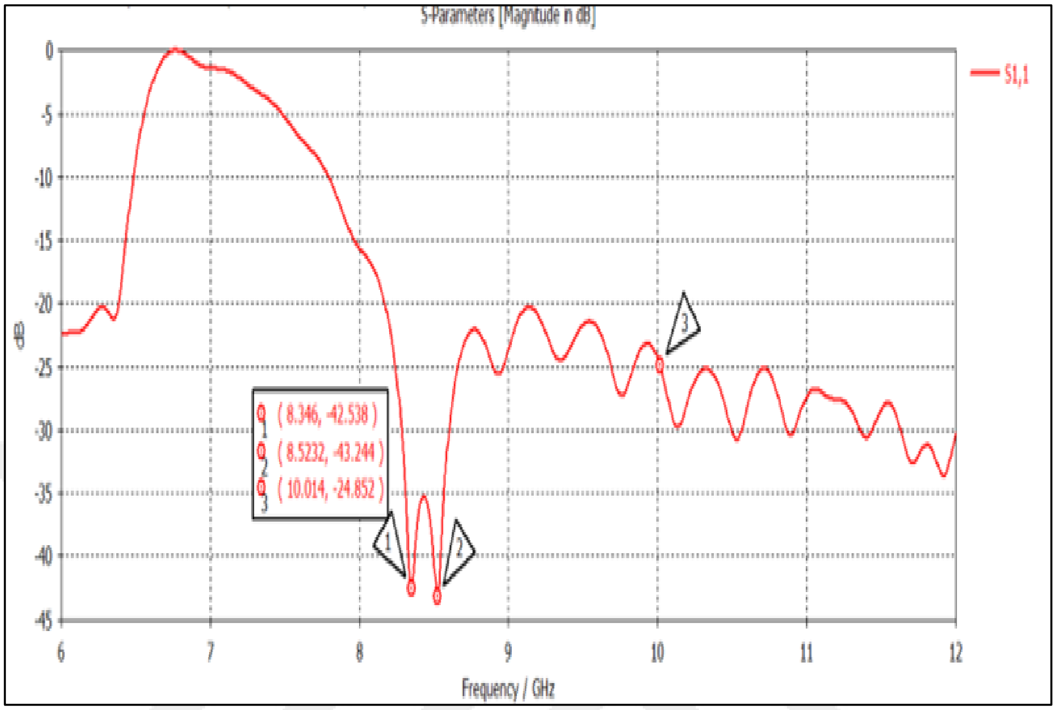

Figure 4.2: S11 Results with Markers.

4.3.2 Farfield Results

For 10.2 GHz, farfield results will be discussed. Figure 4.3 represents the polar results of the horn antenna. Farfield 3D gain result is shown in figure 4.4, the gain is equal to 22.55 dBi.

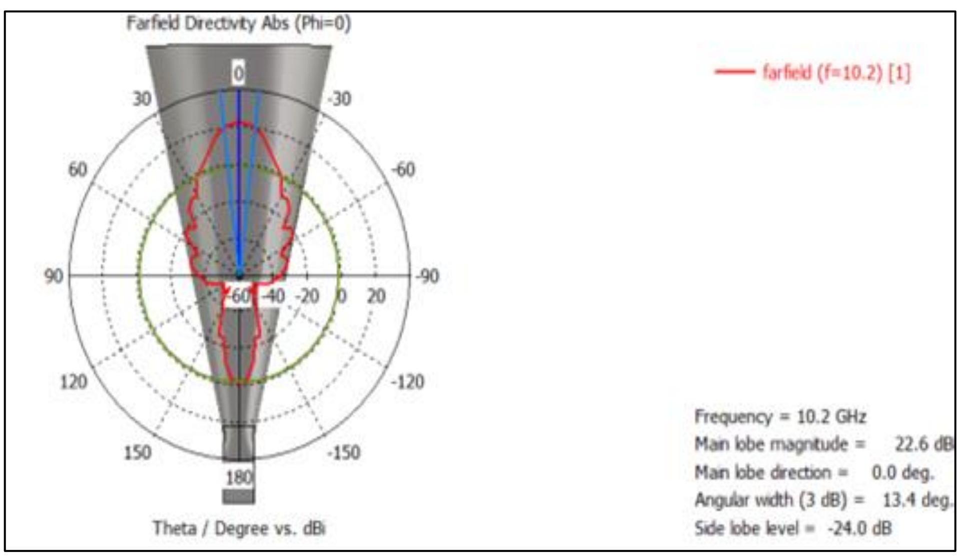

Figure 4.3: Polar Results.

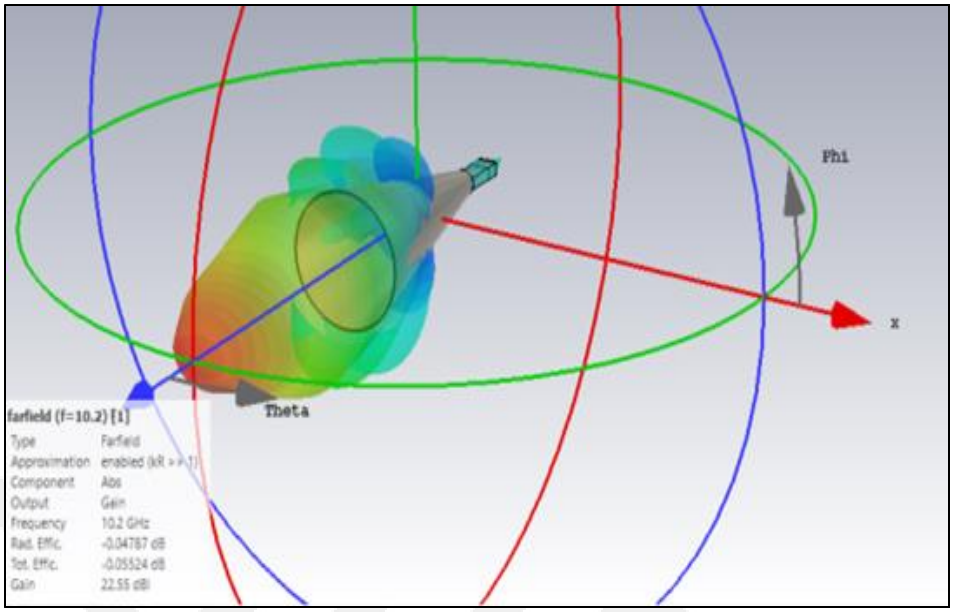

Figure 4.4: Gain Results.

4.4 REFLECTARRAY RESULTS

The simulation of the antenna in presence of the horn antenna previously mentioned shows a S11 result equal to -60 dB at 10 GHz.

VSWR results is fitting requirements at 10 GHz as shown in figure 4.5.

In figure 4.6, the 3D results of gain at 10 GHz are presented. The Reflectarray antenna work properly with a gain of 3.2 dBi.

In addition, figure 4.7 shows the 3D results of gain at 12 GHz where it achieves 60 dBi.

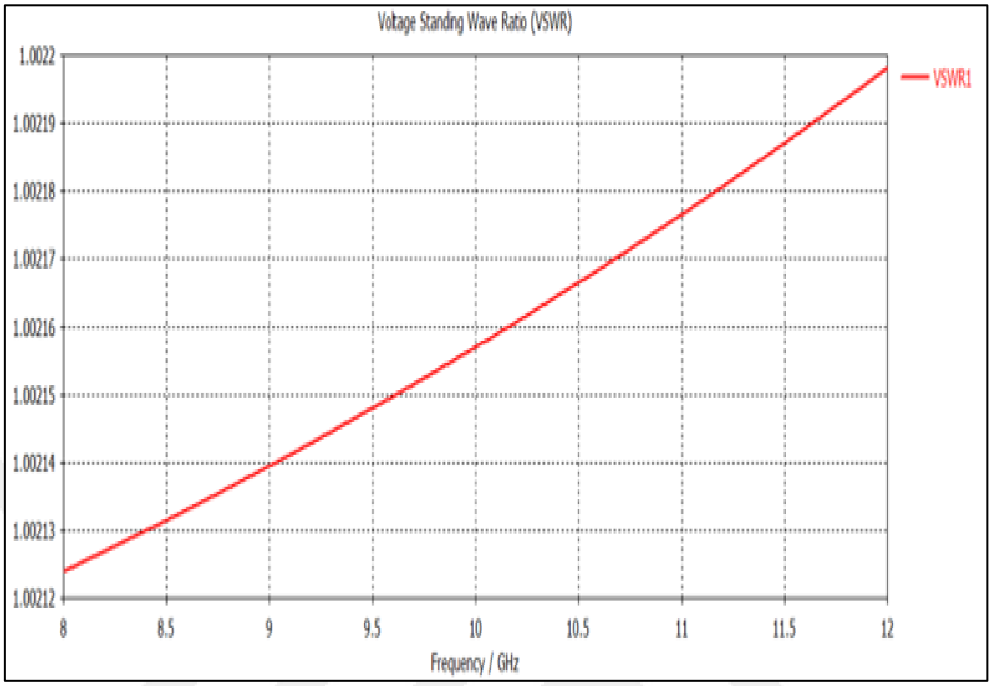

Figure 4.5: VSWR Results.

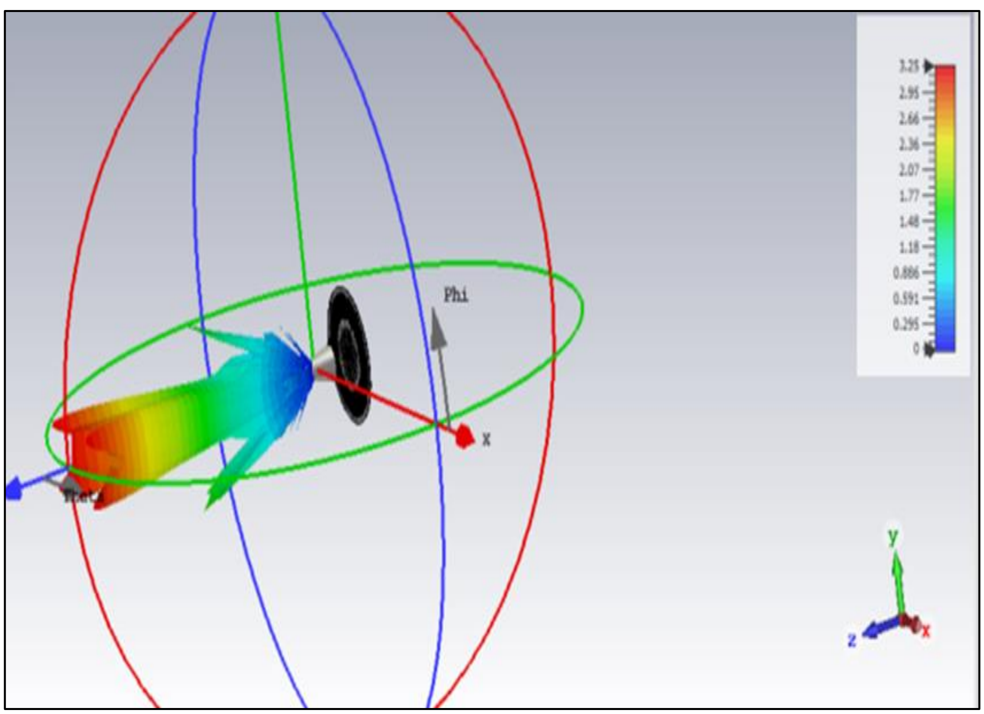

Figure 4.6: Gain 3D results at 10 GHz.

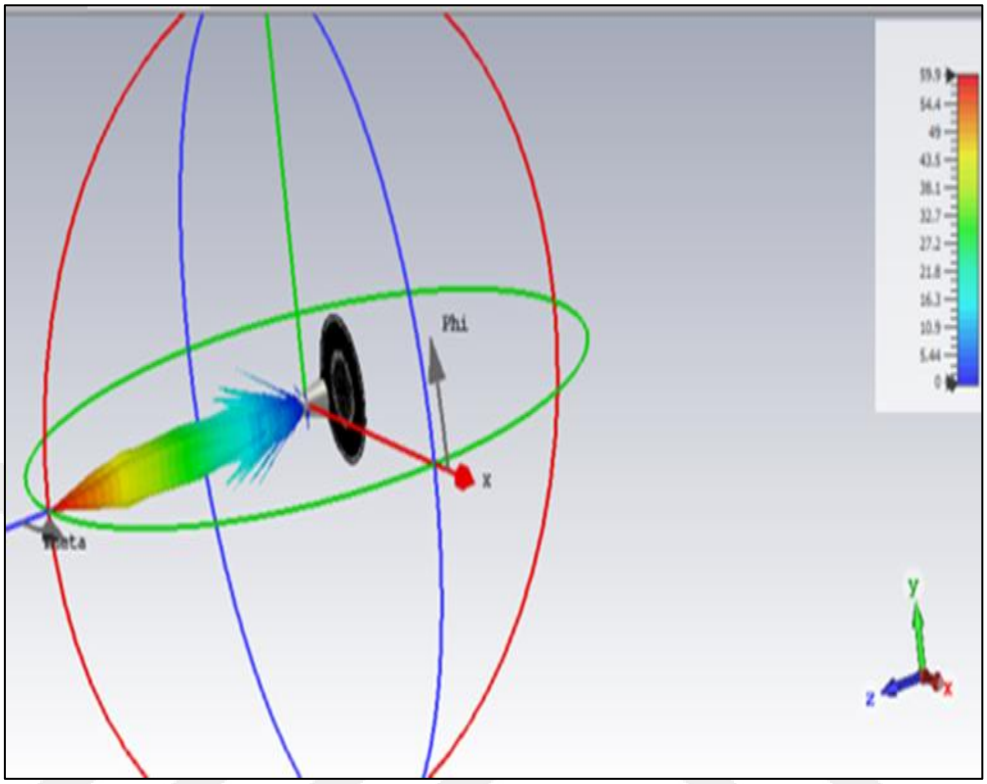

Figure 4.7: 3D Gain results at 12 GHz.

5. CONCLUSION

5.1 CONCLUSION

In this work, a reflectarray design using MATLAB and CST simulation was proposed.

In applications that need high gain and efficiency, reflectarrays are becoming an increasingly preferred substitute for parabolic reflectors. Putting up a huge reflectarray requires a significant amount of time and effort. Feed antennas are used to excite a planar or conformal array of components, which is necessary in order to generate a reflectarray antenna.

Because of recent developments in long-distance communication, it is now possible for individuals to communicate wirelessly not just throughout the Solar System but also to locations that were previously inconceivable. A vast number of antennas are required for wireless transmission of data across great distances, both between the transmitter and the receiver. However, while being the option that is both the most practicable and the most cost-effective, they are also the most expensive options for electrically large antennas.

The "X band" is a range of frequencies that may be found in the portion of the electromagnetic spectrum that is devoted to microwave radio. In the realm of communication engineering, one example of a frequency range is the X band, which ranges from around 7.0 to 11.2 GHz.

After conducting an exhaustive investigation into any and all pertinent data, the Matlab code will be scrutinized in great detail. When the antenna is being designed, data from the CST program will be included into it.

A series of antennas arranged in a pattern is generated by some MATLAB code in order to facilitate the construction of a reflectarray antenna in CST.

A gain of sixty dBi is attainable by combining a horn antenna with a reflectarray antenna as the feed antenna. This configuration results in a gain of sixty dBi.

5.2 FUTURE WORK

As future work, placing the feed antenna in a better place to get higher efficiency and gain is part of the plan. In addition, instead of the square patch used as unit cell for the reflectarray antenna, a 3 layers antenna could be used as unit cell could a good addition.

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