ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE

LOW-COST MICROSTRIP PATCH ARRAY ANTENNA FOR X BAND SATELLITE APPLICATIONS

M.Sc. THESIS

Muhittin Mert KUZER

Department of Communication Systems

Satellite Communication and Remote Sensing Programme

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

X BAND UYDU UYGULAMALARI İÇİN DÜŞÜK MALİYETLİ MİKROŞERİT YAMA ANTEN TASARIMI

YÜKSEK LİSANS TEZİ

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İletişim Sistemleri Anabilim Dalı

Uydu Haberleşmesi ve Uzaktan Algılama Programı

Tez Danışmanı: Prof. Dr. İbrahim AKDUMAN

ARALIK 2018

Muhittin Mert KUZER, a **M.Sc.** student of ITU Informatics Institute student ID **705151010**, successfully defended the **thesis/dissertation** entitled "**LOW-COST MICROSTRIP PATCH ARRAY ANTENNA FOR X BAND SATELLITE APPLICATIONS**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. İbrahim AKDUMAN** Istanbul Technical University	....
Jury Members :	**Assoc. Prof. Mehmet ÇAYÖREN** Istanbul Technical University	....
	Assist. Prof. Dr. Evrim TETİK Istanbul Aydin University	....

Date of Submission : 16 November 2018
Date of Defense : 14 December 2018

To my mother and father,

FOREWORD

This project had consumed huge amount of work, research and dedication. Still, implementation would not have been possible if I did not have the support of many individuals, especially Ahmet GUVENMAN who is the CEO of the Aktif Group Companies, and organizations in the IMES industrial estate. Therefore, I would like to extend my sincere gratitude to all of them.

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Nevertheless, I express my gratitude towards my family and fellow students for their kind co-operation and encouragement which have helped me in completion of this project.

December 2018

Muhittin Mert KUZER
(Electronic and Communication Engineer)

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ABBREVIATIONS

BUC	: Block Upconverter
CST	: Computer Simulation Technology
dB	: Decibel
dBi	: Decibel Isotropic
EAGLE	: Easily Applicable Graphical Layout Editor
FR-4	: Flame Retardant 4
GHz	: Giga Hertz
HAL	: Hot Air Levelling
ITU VLSI	: Istanbul Technical University Very Large Scale Integrated Circuit
LAN	: Local Access Network
LHC	: Left Hand Circular
LNB	: Low Noise Suppressor
PCB	: Printed Circuit Board
RHC	: Right Hand Circular
S11	: Reflection Coefficient
UWB	: Ultra Wide Band
VSAT	: Very Small Aperture Terminal

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LOW-COST MICROSTRIP PATCH ARRAY ANTENNA FOR X BAND SATELLITE APPLICATIONS

SUMMARY

In this thesis, the aim of the design a microstrip patch array antenna that operate between 7.25 GHz and 8.4 GHz frequencies for VSAT satellite communication so VSAT structure and array antenna structures which are used and designed in the literature are examined in detail. The bow tie antenna has been studied as the first design can produce broadband results. S11 parameter was expected to be at least -10 dB in the desired frequency range, but the result was observed as -7 dB. Therefore, this design was decided to be completely replaced. In order to obtain a better result in the desired frequency range S11 parameter, a new design has been obtained by applying the "proximity coupling" method which is used for this purpose in the literature. But this method is not allow us to reach the desired results. After these results, due to the complexity of bow tie antennas, it is decided to design a microstrip square patch antenna which is easier to design in the literature rather than this type of antenna. It was observed that the results were better than the previous designs in the S11 parameter values in the desired frequency range. In the antenna structures designed in the literature, the radiation patterns occur in the middle of the antenna. However, the main problem in this design is that the pattern of radiation is exposed in the upper right lobe and upper left lobes of the antenna. This design should be positioned vertical in the area used for realization and use. However, in order to increase the applicability of the design, horizontal positioning is of great importance so improvement of this design has been abandoned. In the final stage of the thesis study, microstrip square patch antenna which is the basic structure was designed with the addition of a proximity coupling system to operate in the desired frequency range. This latest design has a radiation pattern in the center of the antenna and operates in the desired frequency range in the X-band. The desired radiation pattern is reached at the desired frequencies so it has began study to increase the gain. In order to increase the gain, the array antenna design was replicated. Four, eight and sixteen patch array antenna designs were realized, respectively. The desired results were successfully reached by the simulation on CST software.

X BAND UYDU UYGULAMALARI İÇİN DÜŞÜK MALİYETLİ YAMA ANTEN TASARIMI

ÖZET

Uydu haberleşmesinde temel olarak kullanılan VSAT(Very Small Aperture Terminal) sistemleri ile yapılan çalışmalar, 1960'lardan günümüze kadar devam etmektedir. İlk geliştirilen VSAT uydu modelleri askeri alanlarda kullanılmaya başlanmış daha sonra yapılan geliştirmelerle sistem ticari amaç için kullanılmaya uygun hale getirilip bu yönde kullanılmaya başlanmıştır. VSAT uydu sistemleri üç temel bileşenden oluşmaktadır. Yer terminali, yeryüzü istasyonu ve uydu, bu bileşenlerin ana isimleridir.

VSAT haberleşme sistemlerinde bulunan, uydu ile yer istasyonlarının arasında haberleşmek için kullanılan anten modeli, genellikle yüksek kazanca sahip olduğundan ötürü parabolic reflektör anten olarak tercih edilir. Parabolik antenlerin VSAT uydu sistemlerinde kullanılmasının en önemli avantajı, haberleşmede kullanılan elektromanyetik dalgaları dar bir demetle hedefe yönlendirmek ya da sadece hedeften gelen dalgaların en düşük kayıpla alınmasını sağlamasıdır. Bu antenlerin en büyük dezavantajları ise kullanılan frekansa ve istenilen kazanca göre boyutlarının devasa büyüklüklere ulaşabilir olması, taşınabilir sistemlerinin de motorlu ve çok daha karmaşık yapıya sahip olmasından dolayı üretimlerinin çok yüksek maliyetlere ulaşıyor olmasıdır. Bu tezde geliştirilen antenin temel amacı ise, taşınabilirliği artırmak küçük boyutlu ve ince olmasını sağlamaktır.

VSAT uydu haberleşme sistemlerinde yaygın olarak L-band(Yükleme:1.6 GHz, İndirme:1.5 GHz), C-Band(Yükleme:5.925-6.425 GHz, İndirme:3.7-4.2 GHz), X-band(Yükleme:7.9-8.4 GHz, İndirme:7.25-7.75 GHz), Ku-band(Yükleme:14 GHz, İndirme:10.9-12.75 GHz), Ka band (Yükleme:26.5-40 GHz, İndirme:18-20 GHz) frekans bandları kullanılmaktadır. Temel olarak antenler verici, alıcı ve hem verici hem alıcı olarak üç farklı tasarıma sahiptir. Bu tezde tasarlanan antenin hem alıcı hem verici olarak çalışması amaçlanmıştır.

Bu tasarımda frekans bandı aralıkları X bandına uygun olarak seçilip, antenin askeri amaçla kullanımı hedef alınmıştır. Tez çalışmasında, hedeflerimiz doğrultusunda daha önceden tasarlanmış anten yapıları incelenmiş ve kullanılmış olan malzemeler araştırılmıştır. Amaçlarımızdan biri olan sistemin en ucuz olması fikri için mikrostrip yama anten tasarımı yapılması hedeflenmiş ve FR-4 dielektrik malzeme seçilmiştir.

Bu tezde geliştirilen antenin tüm analiz, tasarım ve optimizasyon çalışmaları CST Studio Suite programı kullanılarak gerçekleştirilmiştir. Analiz sonuçları, S11, giriş referans direnci, uzak alan simulasyonlarında kazanç ve yönelme parametreleri kullanılarak değerlendirilmiştir. Bu çalışma kapsamında hedeflenen X band frekans aralığı için S11 parametresinin düşme değerinin minimum -10 dB olması hedeflenmiştir.

Tez süresince dört adet birbirinden farklı tasarım üzerinde çalışılmıştır.

Birinci tasarımda, papyon(bow-tie) anten ismiyle bilinen yapının mikrostrip bir yapıda FR-4 dielektrik malzemesinin üzerine uygulanarak istenilen X-Band frekans bandını kapsamaya çalışılmıştır. Literatür taramalarından elde edilen bilgilerde, çift kutuplu(dipole) antenlerin, kutuplarındaki iletken yüzeylerinin genişletilmesiyle band genişliklerinin arttığı tespit edilmiş olup, bu geliştirme ile papyon anten tasarımının ortaya çıktığı bilinmektedir. Tasarım sonucunda antenin seçilmiş olan X Band 7.25 GHz ve 8.4 GHz frekans bandları aralığında olmadığı, sadece ortalama 7.36GHz ile 8.07GHz aralığında -10dB nin altına düşdüğü gözlemlenmiştir. Bunun sonucunda elde edilmiş olan en iyi tasarımın farklı boyutları ile bir hibrit dizi yapıya dönüştürülerek farklı frekanslarda da çalışabilir olması amaçlanmıştır. Bu tasarım sonuçlarıda beklediğimiz S11 sonucuna ulaşılamadığı ve antenin çok karmaşık bir yapıya dönüşmeye başladığı için, yeni bir tasarıma geçmek bu sorunun çözüm kaynağı olmuştur.

İkinci tasarımda, mikrostrip papyon yama anten tasarımını baştan alarak nasıl bu tasarımın band genişliğini nasıl daha arttırabiliriz sorusuna cevap aranmaya başlandı. Bu tasarımın iyileştirilebilmesi için besleme kısmına doğrudan dokunmalı bağlantı yerine yakınlık eşleşmesi(proximity coupling) özelliği kullanılarak tasarım yeniden düzenlendi. Bu tasarımın ulaştığı frekans aralığı 7.25GHz den 8.26GHz e kadar -10dB nin altına inerek bizi amacımıza yakınlaştırdı. Fakat antenin ışıma desenine baktığımız zaman, ışıma yönünün antenin arka tarafında da oluştuğu gözlemlendi. Bu istenmeyen bir durum olduğu için tasarımı tamamen değiştirme kararı alındı.

Üçüncü tasarım, literatür taraması sonucunda mikrostrip kare antenlerinde geniş bandlı olarak tasarlanabileceği ve ultra geniş band(UWB) destekleyen anten ile ilgili olan çalışmalarda bulunan tasarımların incelenmesiyle çalışılmaya başlandı. Çalışma sonucunda istenilen S11 parametresindeki X-band frekans aralığı, tasarlanan bu anten ile 7.25GHz üzerinde -14.5dB, 8.4GHz üzerinde -15dB olarak, -10dB nin altına düşmeyi başardı. Fakat -10dB nin altına düştüğü bölge 6.87GHz ten 9.33GHz e kadar olduğu için, bu tasarlanan antenin istenmeyen bölgelerde çalıştığını gösterdi. Sonuç olarak X-band üzerinde çalışıp, diğer sinyalleri almak istemezsek bir de filtre tasarımına ihtiyacımız olacağı anlaşıldı. Uzak alan simülasyonu sonucunda oluşan ışıma deseni antenin yüzeyinde oluşmayıp yan tarafından iki ayrı lob olarak oluştuğu görüldü. Bu durum antenin kazancını düşürdüğü gibi, anteni kullanabilmek için dik konuma getirmemiz gerekiyordu. Dik konuma getirilen anten, kazancı arttırmak için dizi haline dönüştürüldüğünde, çok yer kapladığından ürün haline gelecek olan bu antenin ince tasarım ve taşınabilir olmasının önüne geçiyordu. Bu sorunu göz önünde bulundurarak, tasarımımızın yeniden değiştirilmesi gerektiği kararlaştırıldı.

Dördüncü tasarım, en temel yapı olan mikrostrip kare yama anten tasarımı ele alınarak yeniden çalışılmaya başlandı. Bu yapının tercih edilmesinin ana sebebi, antenin çalışması sırasında oluşan ışıma deseni, yamadan yukarıya doğru lineer polarizasyonla oluşuyordu. Bu ince yapılı anten tasarımı için istenen bir durum olmasına rağmen, anten dar band olarak çalışıyordu. Daha önceki tasarımda uyguladığımız yakınlık eşleşmesi(proximity coupling) özelliğini bu tasarıma da uygulanmasına karar verildi. Bu çalışmalar ile oluşturulmuş olan tasarımın S11 simülasyon sonuçları tam 7.25 GHz üzerinde -10.7 dB, 8.4 GHz üzerinde -10.1 dB ye ulaşarak tam istenilen hedef tutturulmuş oldu. Antenin uzak alan simulasyonu sonucunda oluşan ışıma deseni lineer polarizasyonla oluşurken, bu yapıyı dairesel polarizasyona çevirmek için çalışma yapılmaya başlandı. Yama kısmında bulunan karenin, iki çapraz kenarından kesilen üçgen parçacıklar ve besleme noktasının geriye çekilmesiyle oluşan ışıma deseninin dairesel polarizasyon olarak ışıma yapmaya başladığı gözlemlenmiştir. Bu tasarımın sonucunda antenin, dünyanın yer yüzeyinden bir uydu ile haberleşme yapmasını beklediğimiz için, kazancın oldukça yüksek olması gerekiyordu. Bu tasarımda kazancı arttırabilmek için tasarlamış olduğumuz hücre yapıyı bir dizi formatına getirmeye karar verildi. Bununla birlikte en temel problem olan gücün nasıl bölüneceği sorunu ortaya çıktı. Literatürde yapılan araştırmalara göre Wilkinson Power Divider ve Corporate Feed Network isimli iki farklı metod bu sorun için çözümler sunuyordu. En başta belirlenen hedeflerden biri olan en ucuz anten olması gerektiğinden ötürü Wilkinson Power Divider metodundan vazgeçildi. Çünkü bu metod gerçeklenmesi sırasında ekstra direnç gibi pasif malzemelere ihtiyaç duyuyordu. Bu tez tasarımında tercih edilen corporate feed network çözümü, anten üzerine ilk olarak 4 lü yapıyı bir araya getirmek için uygulandı. Daha sonra bu çözümü 8 li yapı ve son olarakta 16 lı yapı takip etti. Array yapısında bulunan antenlerin artması kazancımızı arttırdı. Fakat, anteni üretip pratikte ölçümünü yaparak, teorik ve simülasyon sonuçlarıyla karşılaştırmamız gerektiğine karar verildi.

Üretimden sonra elde edilip pratikte ölçülen sonuçlar ile simülasyonda elde edilmiş olan değerlere yakın sonuçlara ulaşıldı. Oluşan sonuç değerleri üzerindeki farklar, üretimden kaynaklı olarak özellikle çift katlı pcblerin ön ve arka yüzeylerinde oluşan metal yoğunluğu farkı ve lehim kaplama yapılırken, yüksek ısıya maruz kalmasından dolayı oluşan eğrilmelerinden ötürü kaynaklandığı gözlemlenmiştir. Çünkü ölçüm sırasında PCB el yardımıyla düzeltildiğinde, sonuçların simulasyona yakın oluştuğu ölçülmüştür.

Bu tez için oluşturulan, ucuz ve taşınabilir olması hedeflenerek gerçekleştirilmiş mikrostrip yama anten tasarımı, hem teorik olarak, hem de pratik olarak birbirlerini karşılayan sonuçlar ortaya çıkarmış ve tez başarıyla sonuçlanmıştır.

1. INTRODUCTION

1.1 Purpose of Thesis

Recently, VSAT antennas are preferred due to their gain values are higher than other antennas. However, the weight and size of these structures are very high. Besides, many electronic devices are minimized and lightened for easy transportation especially satellite communication systems. When looking at VSAT satellite antennas, they are available in sizes of 1.2 meters and above and are designed with a curved reflector. The aim of this thesis is to design a microstrip patch antenna array which can be used for military purposes with the use of VSAT satellite antenna on X Band that should be portable, small size and low-cost.

1.2 Literature Review

VSAT represents wireless communications used in satellite and communication technologies in communication services [1]. VSAT networks provide value-added satellite-based services capable of supporting the Internet, LAN, voice/fax communications, video, security, and provide powerful, dependable private and public network communications solutions [2]. A low-cost microstrip patch antenna arrays for the wireless communication is presented in [3]. In this article, a 3 x 3 square patch array is designed with approximately 35° beamwidth and up to 60° electronic scanning capability. 4 Elements Rectangular Microstrip Patch Antenna with High Gain for 2.4 GHz Applications is presented in [4]. Designed a microstrip patch antenna to have wide band by increasing the substrate thickness, optimizing impedance matching, reducing the substrate effective permittivity. Characterize and compensate coupling effects in an array of antennas is presented in [5]. Designed individual antenna which including the active radiation pattern is measured. Active reflection coefficient of each antenna in the array is -45 dB, so the result is demonstrated perfect matched include coupling effects. A shared aperture Dual-Frequency Circularly polarized microstrip array antenna is peresented in [6]. This design includes 2x2 subarray of aperture coupled microstrip antenna radiators and the low and high band feed networks operating 4 and 6 GHz. Axial ratio was below 1.2 dB for all desired frequencies. The purpose of the study given in [6], is to use the designed antenna as a building block in full duplex wireless communication applications such as satellite internet (VSAT) and focal plane arrays for wireless connectors. Flat mobile VSAT antenna design for Ku/Ka band satellite communications with auto-beam steering capability is presented in [7]. Designed system include eight rows of microstrip subarrays, in the same time each subarray is composed of 64 element of patch. One of the most important advantages of this structure is that it is compact compared to the size of the parabolic dish. In addition, this structure has small air resistance and can be used in moving vehicles. A 2x16 microstrip antenna array for mobile antenna VSAT application at Ku band frequency is presented in [8]. The designed antenna works as a receiving antenna at a frequency of 12 GHz and a transmitter antenna at 14 GHz. The proposed antenna is the gain of 18.69 dB while the return loss value is 23 dB. The performance of a focal plane array operating in transmit mode at 30 GHz for use in future very small aperture terminals is presented in [9]. In this study, silicon transmitter integrated circuit (IC) is used to phase shifting upconverter. The experimental results are used to calculate the far-field pattern of the complete system. High gain substrate slotted microstrip path antenna design for X band satellite uplink applications is presented in [10]. It has 8.2 GHz rezonans frequency and -58.22 dB return loss. The proposed antenna can be used for indoor location or RFID tag applications. Novel high gain air gap directive antenna design for X-band satellite to earth downlink applications is presented in [11]. Power from the coaxial connector has fed the designed antenna thanks to the microstrip line. The designed antenna can be used for X band applications in satellite application.

2. VSAT ANTENNAS

VSAT's are two-way satellite base station. Generally, it has less than 3m parabolic reflector antenna structure. VSAT antennas do not have grounded telecommunications infrastructure. At the same time, these antennas can be vehicle mounted as fixed or portable. Therefore, it is the primary commercial telecommunications technology used in isolated zones. Moreover, VSAT satellite communication provides reliable internet communication even in remote locations.

VSAT systems can be analyzed in three parts, data transmission, data receiving and interactive [12]. As shown in Fig.1.1, while data transmission is the link to the satellite, data receiving is the link from the satellite irrespective of which side of the link you are, Teleport/Hub or VSAT remote site.

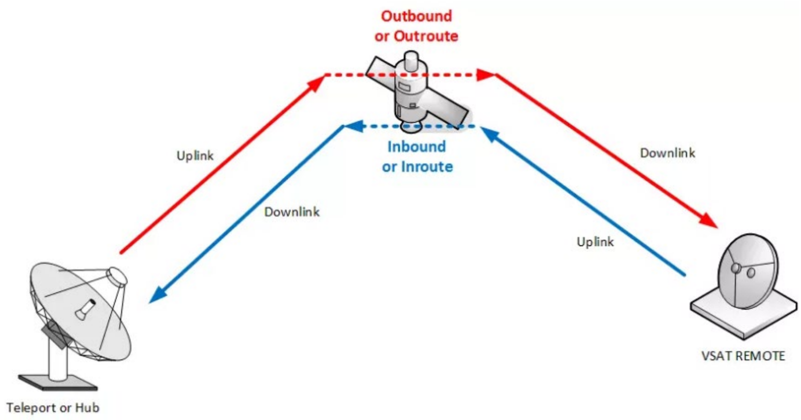

Figure 1.1 : VSAT link diagram [13]

The Outbound is from the teleport hub to the remote VSAT and the Inbound is the the remote VSAT to the teleport hub.

2.1 VSAT Network

Star topology is used in Vsat network. In this topology, the large antenna gain at the hub optimizes the use of the satellite space segment. the disadvantages of this topology used to increase the delay. On the other hand, mesh topology allows all terminals to communicate with each other directly [14].

2.2 VSAT Equipment

One of the VSAT equipment is an antenna. Their structure varies according to their size, power and mounting. Figure 2.1 shows an example of such structures.

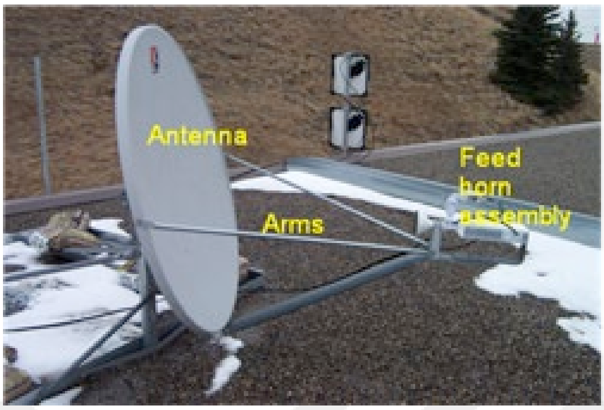

Figure 2.1 : Antenna for VSAT [14].

As shown in Figure 2.2, the VSAT antenna sends and receives signals over the feed horn assembly, LNB (low noise suppressor) and BUC (block upconverter).

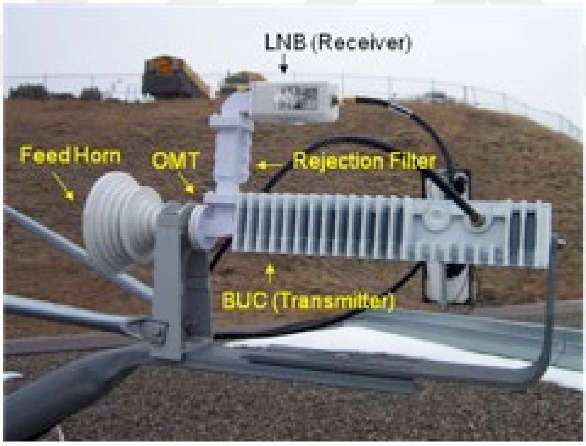

Figure 2.2 : Antenna equipment for VSAT [14].

The indoor equipment will consist of a satellite router along with other LAN equipment that may be required for your remote site as shown in Figure 2.3.

Figure 2.3 : Indoor equipment for VSAT [14].

2.3 Frequency Bands for VSAT

There are five different radio frequency bands for communication satellites and military satellites that determine link quality and coverage such as L band, C band, X band, Ku band, Ka band. L band is generally used for mobile satellite services. Figure 2.5 shows the frequencies used in VSAT applications.

The L-band signal is easy to process, and RF equipment fot this band is less costly than equipment used at other frequencies. The uplink value in the L band is 1.6 GHz while the downlink value is 1.5 GHz.

The C band is primarily used for voice and data communications as well as backhauling [16]. Larger antennas are preferred because the power for this frequency is weak. It is also not affected by adverse weather conditions thanks to its lower frequency range. The uplink value in the C band is 5.925- 6.425 GHz while the downlink value is 3.7-4.2 GHz.

The X band is generally used in military communication and Wideband Global SATCOM (WGS) systems. Low frequency range is less sensitive to weather conditions than Ku Band. The uplink value in the X band is 7.9- 8.4 GHz while the downlink value is 7.25 – 7.75 GHz. Antenna structures designed in this thesis study can be used for applications in X band frequencies.

The Ku band is preferred for consumer direct-to-home access, distance learning applications, retail and enterprise connectivity [16]. Since the frequency values of this band are high, the gain values are also high. Therefore, smaller antenna sizes are preferred at this frequency. The uplink value in the Ku band is 14 GHz while the downlink value is 10.9-12.75 GHz.

The Ka band is used for two-way consumer broadband and military networks. At this frequency, dishes of the antennas are in the range of about 60cm-1.2m. This is the frequency with the greatest transmission power. The uplink value in the Ka band is 26.5- 40 GHz while the downlink value is 18-20 GHz.

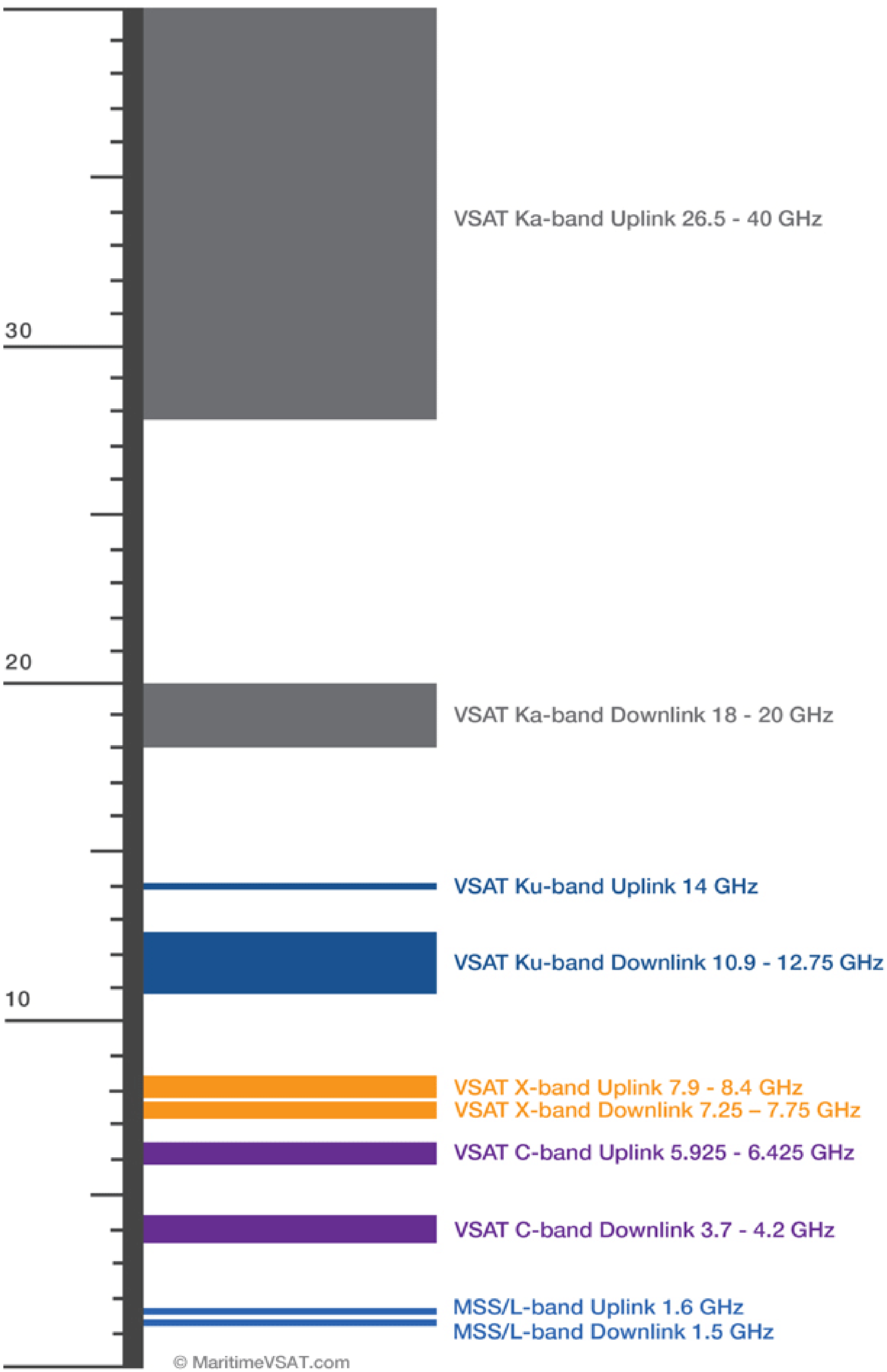

Figure 2.4 : Frequency Bands for VSAT [15].

2.4 VSAT Antenna Types

VSAT antennas can be fixed or portable. Such antennas can be mounted on vehicles and can also be used in the marine. Portable VSATs are commonly referred to as Flyaway Units. The quality and cost of VSAT will vary according to the specifications required.

Marine VSATs are gyroscopically stabilized so that no matter how the boat moves, the VSAT antenna “tracks” and maintains a precise aim to the desired satellite [17]. In marine VSAT antennas, the antenna is placed in a special fiberglass radome to prevent the antenna from being affected by wind or other environmental conditions. The use of marine VSAT antennas is shown in Figure 2.5.

Figure 2.5 : Marine VSATs [17].

Vehicle-mounted VSATs are usually designed to be compatible with each satellite network. Vehicle-mounted VSAT systems have a size from 0.75 meters to 1.2 meters. Voice, video and data communication are the most widely usage of this types antennas for emergency situations because it is fast to communicate in such antennas. The use of vehicle-mounted VSAT is shown in Figure 2.6.

Figure 2.6 : Vehicle-mounted VSATs.

2.5 VSAT Microstrip Patch Antennas

VSAT microstrip patch antenna is a sort of passive wave guiding structure, which includes a patch structure, ground structure and a dielectric substrate between these two constructions. The most common shapes of the microstrip patches are rectangular, circular and square due to their characteristics with low cross-polarization. In addition, these types of patches can analyse and fabrication easily.

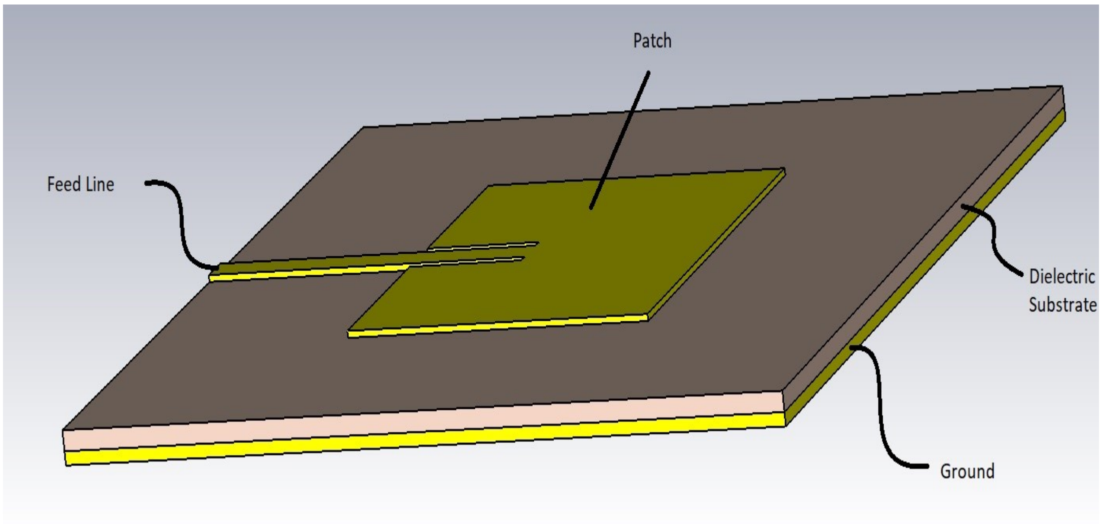

Figure 2.7 : Microstrip patch antenna.

2.5.1 VSAT antenna polarization

Polarization is the one of basic property of all antennas. There are three types of antenna polarization which are linear polarization, circular polarization and elliptical polarization. Linear polarization is describe as way of an electromagnetic wave that the electric vector at a fixed point in space remains pointing in a fixed direction, although varying in magnitude[18].

2.5.1.1 Linear polarization

Linear polarization is describe as way of an electromagnetic wave that the electric vector at a fixed point in space is pointing in a fixed direction. It means that, the electric-field vector or magnetic field vector at that point is always going throughout in the same straight line at every instant time.

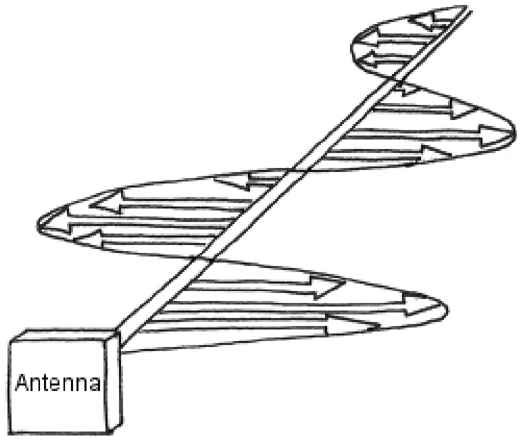

Figure 2.8 : Linear polarization.

2.5.1.2 Circular polarization

When the electric field or magnetic field vector in a time-harmonic wave follows a circle as a function of a time, this structure is called circularly polarized[19]. The circular polarization comprises a rotating polarization plane like a corkscrew model and performs a complete rotation along each wavelength. The circular polarized wave emits the energy in the horizontal and vertical plane as well as in each plane. There are two propagation directions that come with circular polarization: The Right-Hand-Circular (RHC) watches a clockwise pattern and the Left-Hand-Circular (LHC) follows a counter-clockwise pattern.

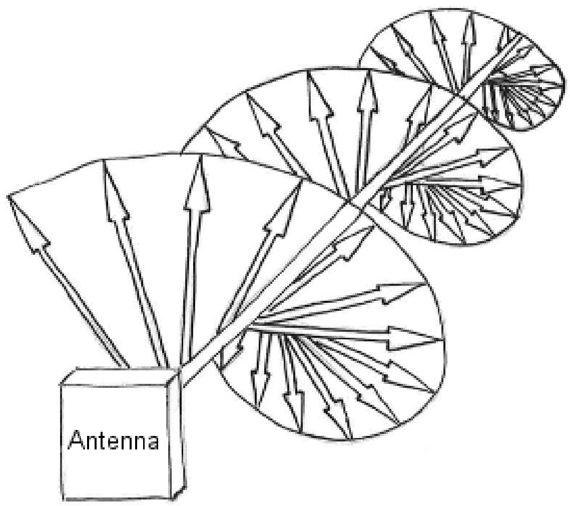

Figure 2.9 : Right hand circular polarization.

2.5.1.3 Elliptical polarization

When the field vector (electric or magnetic) follows an elliptical line in space, the time-harmonic wave is elliptically polarized. At various times, the field vector changes continuously over time to continue on an elliptical line. The field vector have to two perpendicular linear ingredients. These two ingredients can have the different or same magnitudes. If their magnitudes are different, their time-phases difference should not be multiples of 180° or 0°. Because, the result will be linearly polarized. If they have same magnitude, their phase difference should not be odd multiples of 90°. Because, the result will be circularly polarized. If the wave has polarized elliptically and its two components have the different magnitude but have odd multiples of phase difference with 90°, the polarization ellipse will not be bent but will align with the main axis of the field component.

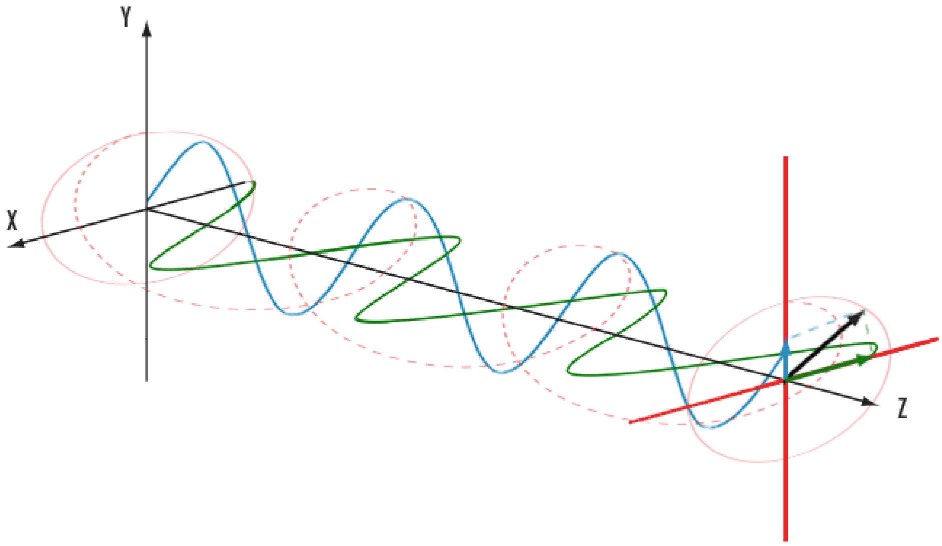

Figure 2.10 : Elliptical polarization.

2.5.2 Corparate feed network

A microstrip transmission line feed network may include any possible combination of transmission lines for a passive array microstrip construction such as, directional couplers, bends, line width transitions and T-junctions. In general, a microstrip transmission line has include a conductive structure printed on a dielectric substrate which has also ground plane. The areas associated with a microstrip line has two separate dielectric regions: one of the region between the strip conductive structure and ground plane, and the other region in the air with the strip conductive structure which name is calling as superstrate as shown in Figure 2.11.

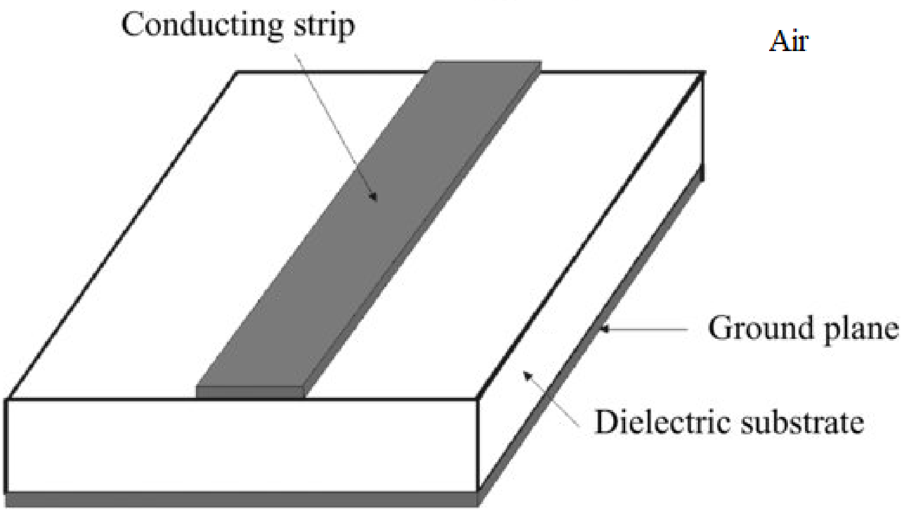

Figure 2.11 : Microstrip line layers.

The microstrip line has an important feature which can be formed as an impedance transformer.

2.5.2.1 Quarter wavelength impedance transformer

The quarter wavelength impedance transformer is an impedance matching techniques which uses simple transmission line theory, including properties of standing wave on a mismatched line [20].

The transmission line length is equal to a quarter of a wavelength($\lambda/4$). The transmission line's characteristic impedance that length is equal to $\lambda/4$, can be calculated with following formula (2.1).

$$Z_0 = \sqrt{Z_{in} Z_L} \tag{2.1}$$

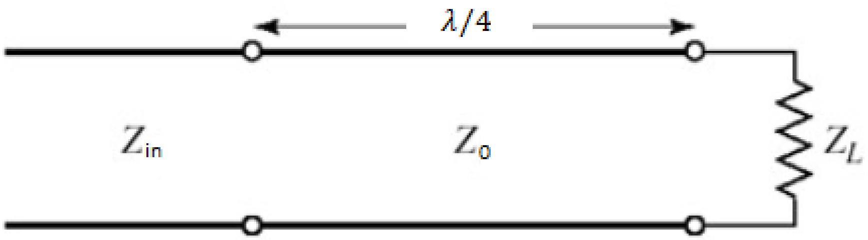

Figure 2.12 : Quarter wave impedance transformer.

2.5.3 Proximity coupling

The microstrip antenna include that a microstrip feed line with a grounded substrate. Another dielectric substrate with rectangular microstrip patch is placed on the upper surface. There is not any ground plane between these two dielectric laminate. So, the feed network which has the power is coupled to the patch as electromagnetically. In addition, these types of feed connection antennas are calling as electromagnetically coupled patch antenna.

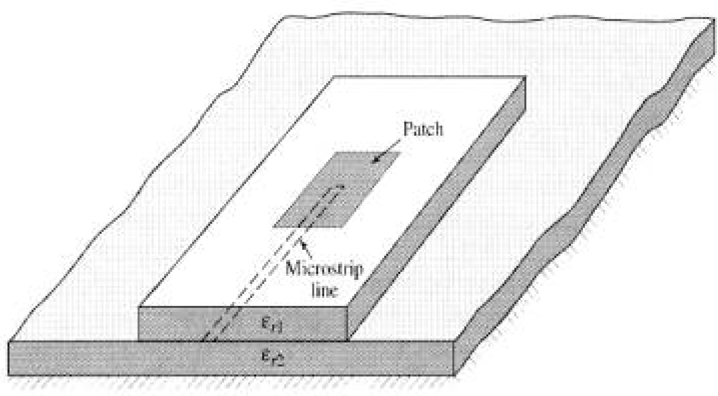

Figure 2.13 : Proximity coupling patch antenna.

An important feature of the proximity-coupled patch antenna is coupling mechanism which is capacitive in nature. This is the opposite of direct contact methods which are mainly inductive. The difference of these direct contact method connection and proximity coupled connection affects the available impedance bandwidth, because the direct contact connection of the edge and probe feed geometries limits the thickness of the useable material. Therefore, proximity coupled patch antennas have larger bandwidth than the direct connection feed antenna.

2.5.4 VSAT microstrip square patch antennas calculations

- Calculation of the Patch Width(W):

The width of the square patch microstrip antennas formula given equation (2.2).

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2.2}$$

- Calculation of the Effective Dielectric Constant(ε_{eff}):

The effective dielectric constant is calculating from the formula (2.3) below.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 10\frac{h}{W}\right]^{1/2} \tag{2.3}$$

- Calculation of the Effective Length (L_{eff}):

The effective length is calculating the equation (2.4) below.

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \tag{2.4}$$

- Calculation of the Length Extension (ΔL):

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{2.5}$$

- Calculate the actual patch length (L):

The actual patch length is calculating the formula (2.6) below.

$$L = L_{eff} - 2\Delta L \tag{2.6}$$

3. DESIGNS OF PLANAR VSAT ANTENNAS

The purpose of the thesis is design a microstrip patch array antenna which is working on X Band frequencies for VSAT satellite communication. The designed structure in this study is expected to catch S11 parameters minimum -10 dB frequenciy range from 7.25 GHz to 8.4 GHz.

According to literature studies, the bow-tie antenna was first our first choice. For the first design, the aim of study was catched the S11 results which covers from 7.25 GHz to 8.4 GHz. Unfortunately, the results were not as expected. S11 results only reached approximately -7 dB. However, this study was continued by multiplying this structure like an array. Because it was possible to reach this conclusion by bringing them together in different structures. It means that, same structure with different dimensions. Nevertheless, it was decided to change the work completely because we could not achieve the result we wanted with the array structure.

For the second design, it was decided to integrate the proximity coupling system to the bow-tie antenna. Feed system completely changed and connect on the center of bow-tie antenna. In this structure, the results could be reached with the results of -9.6 dB at 7.25 GHz and an average of -6 dB at 8.4 GHz. Therefore, the desired results could not be achieved with this structure.

The third study of this thesis, completely different, was intended to design the microstrip square patch antenna for wide band frequency. The S11 result was very successful, but it also radiated in unwanted areas. In addition, although the polarization of the antenna was desired at the top, the antenna was radiating from the side. This solution was abandoned due to the vertical positioning of the antennas would take up a lot of physical space.

In the final study of this thesis, our first aim was to restart with a simple design before thinking complex. The square microstrip patch antenna which is a basic structure, was designed with the addition of a proximity coupling system to operate in the desired frequency range. According to the simulation results of this antenna design, the antenna neither did not broadcast in unwanted areas nor did not operate at frequencies other than the X-band. Then it was decided to reproduce this antenna as an array and it appears that needed an extra work on how to divide the power which is our main problem. It was decided to use corporate feed to solve this problem. With the completion of the design, an array of 4x4 antenna was obtained for X-band frequencies. In this system, the input resistance is designed as 50 ohms. In addition, some improvements have been made to convert the polarization of the antenna into a circular polarization while working polarization is linear. In the final design of this thesis, the desired results were successfully reached by the simulation on CST software.

The four different structures are designed in this dissertation explained below, sequentially.

3.1 Design 1: BowTie Antenna for X band

Due to the increased demand for wide-band antennas, antenna researchers began working to increase the bandwidth of antennas. The first concept of the bowtie antenna was implemented with increasing the radius of the dipole antenna to increase the bandwidth [21], but this developing is not enough to find the all requirements for wide-band antennas. If the conductors are designed to not form of a biconical structure, this concept can be extended to further improve bandwidth. Therefore, the fixed wire diameter can be replaced by a seamlessly changing diameter with a constant angle of the conical surface which helps in obtaining a wider bandwidth [21].

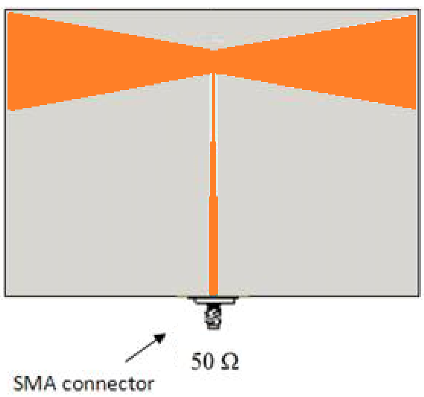

Figure 3.1 : Bow-tie patch microstrip antenna.

In this study, first step of bow-tie antenna design includes only one substract with patch and ground plane. In this study, we realized a different design by going out of normal design, using two bow-tie patches on top of each other in the same plane at a 90° angle. After the various of some experiments, the bow-tie antenna implementation was reached the final view with all dimensions on the figure 3.2 below.

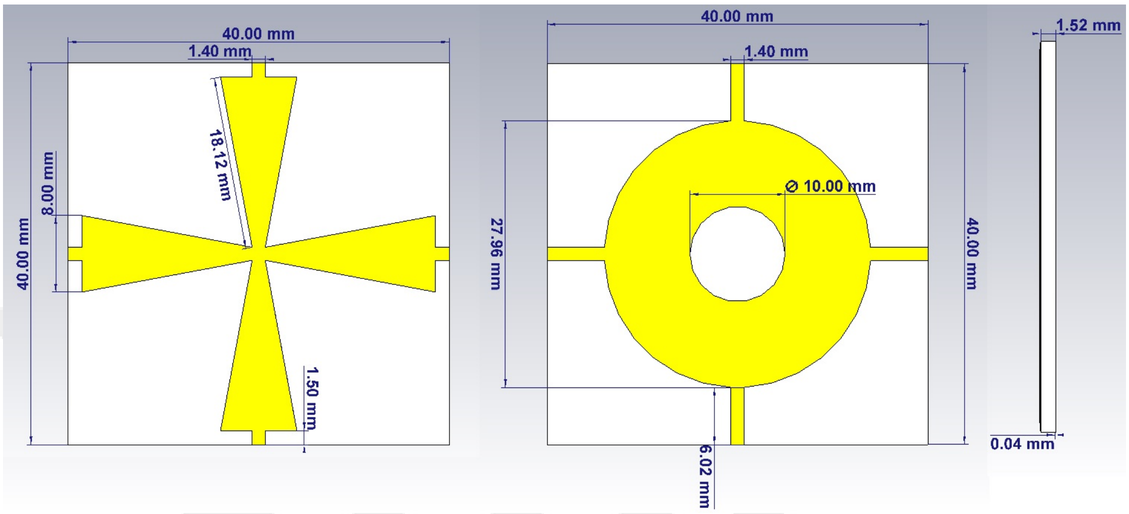

Figure 3.2 : Bow-tie microstrip antenna design with all dimensions.

The S11 result of this antenna on the Figure 3.3 below.

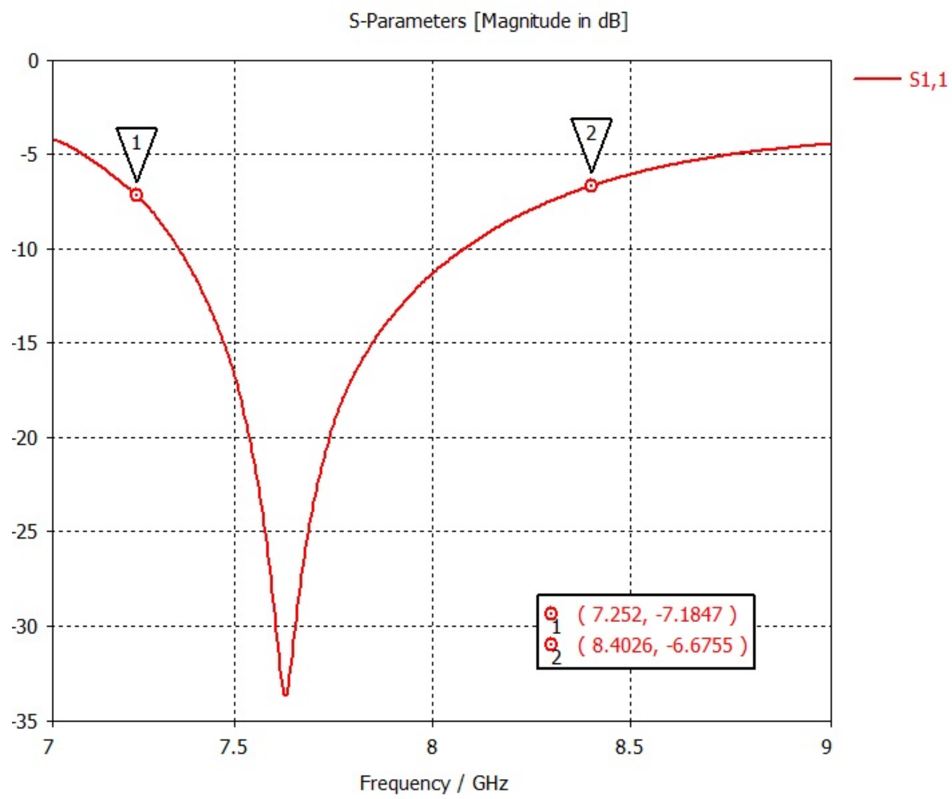

Figure 3.3 : Bow-tie microstrip antenna S11 result.

As shown in the Figure 3.3, the bow-tie antenna design did not work in the desired the frequency values. S11 results were reached approximately -7dB. However, this study was continued by creating an array structure with use that antenna. Because bringing them together in different structures were possible to reached right results. It means that, different dimensions of that structure create a hybrid array antenna which supports all needs. On the other hand, it was decided to change the work completely because we could not achieve the result that we wanted with the array structure.

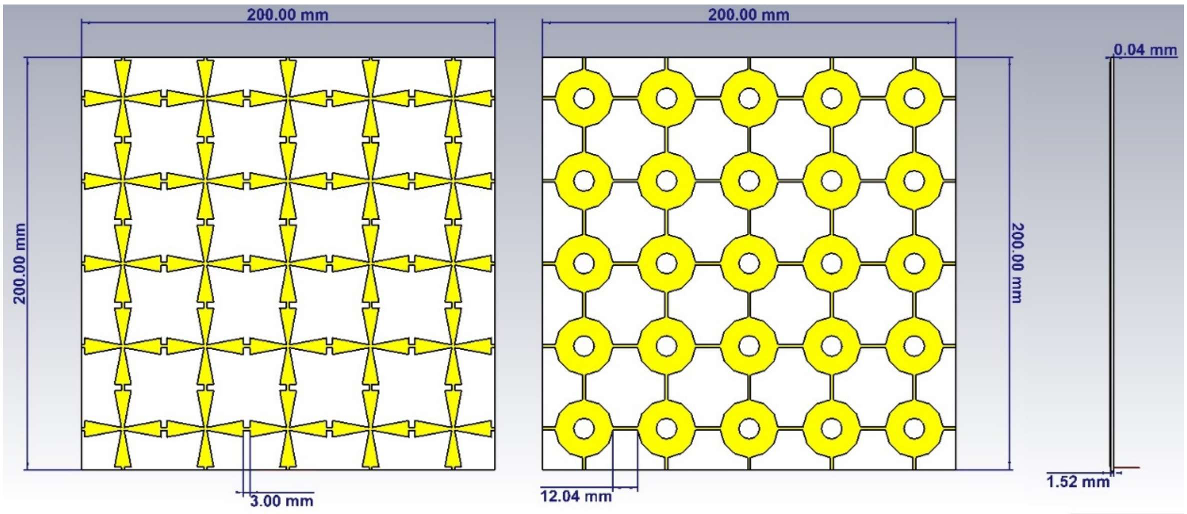

Figure 3.4 : Bow-tie array antenna.

Firstly, the bow-tie microstrip patch array antenna was designed as shown in Figure 3.4.

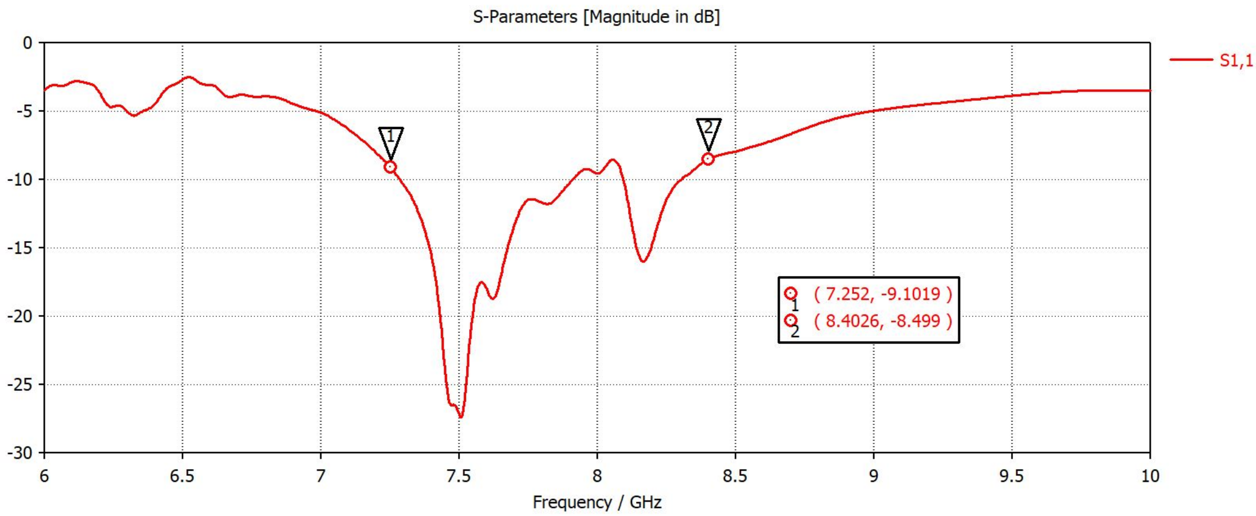

Figure 3.5 : Bow-tie array antenna S11 results.

The design steps were performed by the CST program. The S11 results of the design was as shown in Figure 3.5. The results of S11 obtained did not show the desired results. So, it was decided to make changes on the design.

The design steps were performed by the CST program. The S11 results of the design was as shown in Figure 3.5. The results of S11 obtained did not show the desired results. So, it was decided to make changes on the design.

3.2 Design 2: BowTie Antenna with Proximity Coupling for X-Band

The array structure of the antenna was changed and the patch structure design was created. The feeding process was performed by using the designed patch structure proximity coupling method as shown in Figure 3.6.

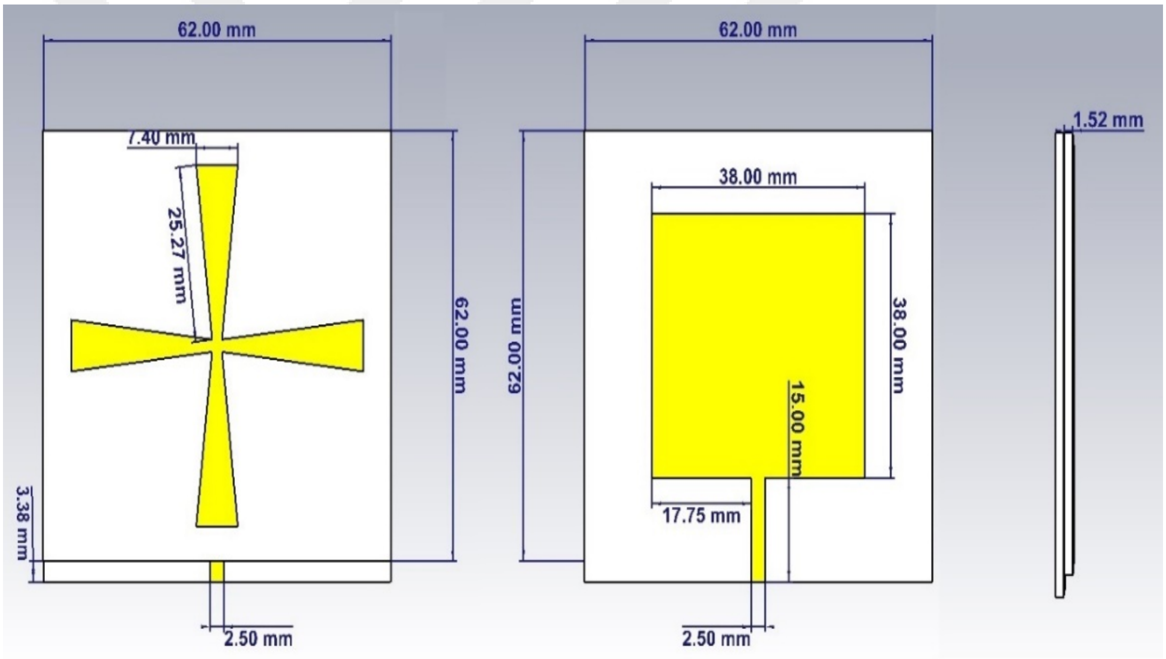

Figure 3.6 : Bow-tie array antenna with proximity coupling.

In order to prevent the radiation occurring in the back of the structure, the round structure previously designed in the ground structure was design as square. When the parameters of the S11 resulting from this change is evaluated as shown in Figure 3.7, this design is abandoned since the frequency band obtained does not contain the entire required frequency band.

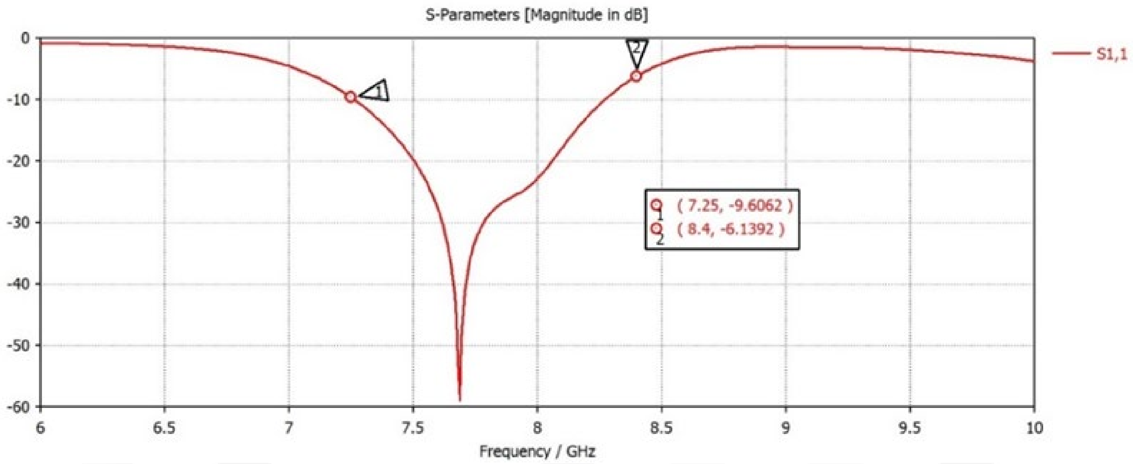

Figure 3.7 : S11 results for square ground structure.

3.3 Design 3: Wide-Band Microstrip Antenna

After the above mentioned design steps were made in order to solve problems, it was decided to abandon complex structures and to design simpler structures. After a large literature research, it was decided to add rectangular structures to the gap part on the microstript patch antenna as shown in Figure 3.8. Thus, the bandwidth of the designed structure has been increased.

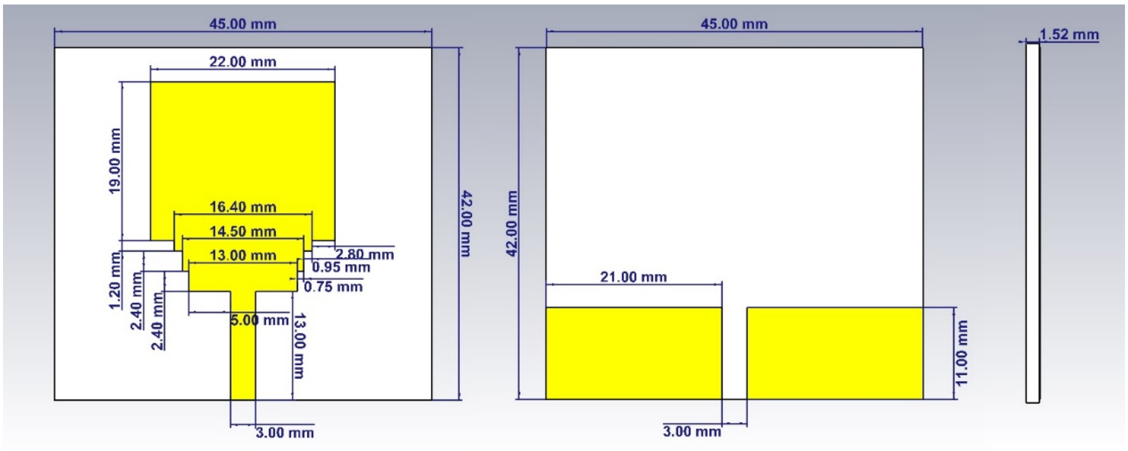

Figure 3.8 : Wide-band microstrip patch antenna.

S11 parameter was observed as -15 dB from 7.25 GHz to 8.4 GHz. The maximum value in this frequency range was -30 dB on the Figure 3.9 below.

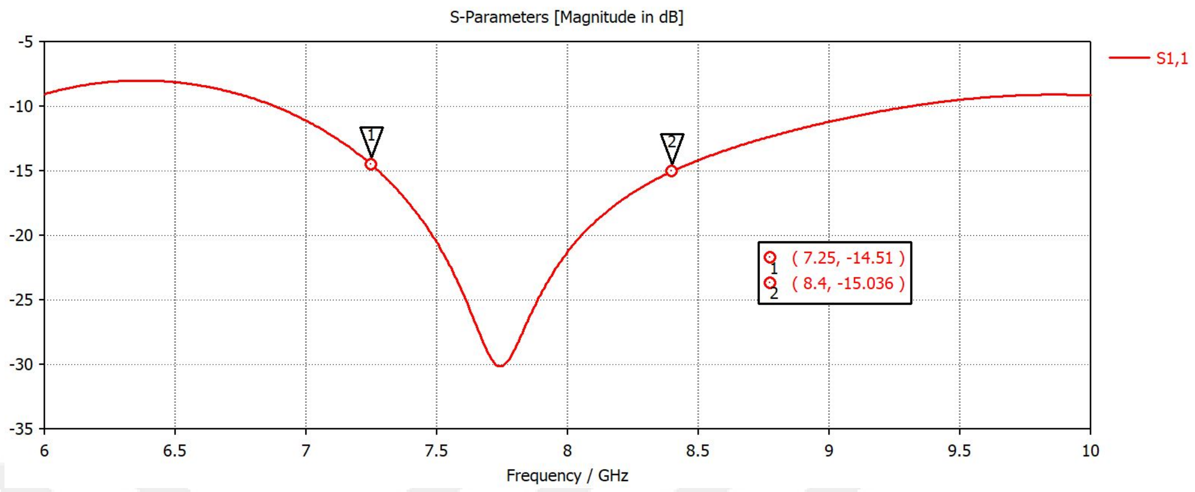

Figure 3.9 : S11 result of the wide-band microstrip patch antenna.

However, the problem with this design is that the antenna polarization occurs on the sides of the antenna on Figure 3.10.

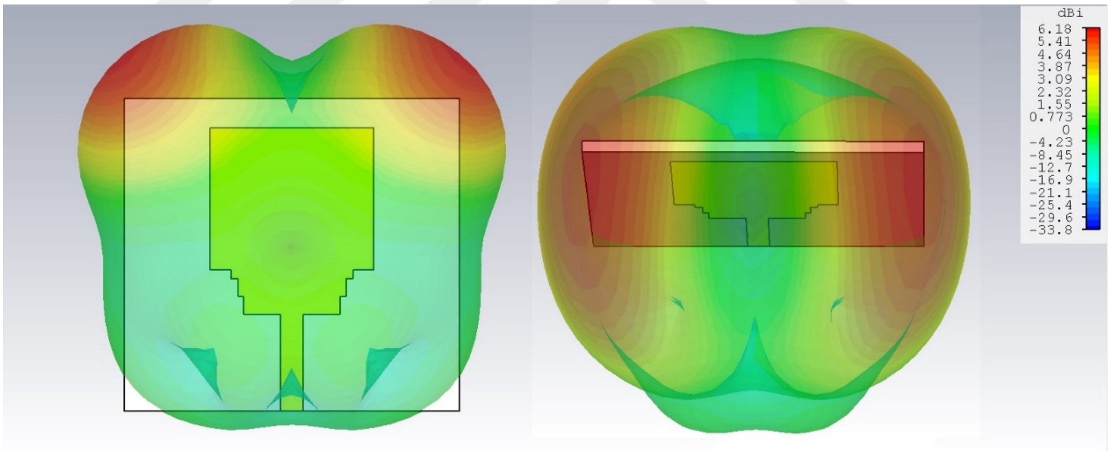

Figure 3.10 : Far-field result of the wide-band microstrip patch antenna.

The designed antenna must be positioned horizontally, not vertically to use it for locating less space to portable.

3.4 Design 4: Microstrip Square Patch Antenna with Proximity Coupling

The purpose of this antenna is to design the proximity coupling used to increase bandwidth, to have a slim design, to cover a small area and to produce in the cheapest way. It was decided to work on a new design to prevent polarization on the sides of antennas as mentioned chapter 3.3 because the purpose of these designs are to ensure the polarization of the antenna in the microstrip square patch structure. In order to provide the bandwidth in the desired frequency range, we used the method of proximity coupling which we previously used in design two. In order to convert linear polarization into circular polarization, the notches are equally opened from the two crossings edges as shown in Figure 3.11.

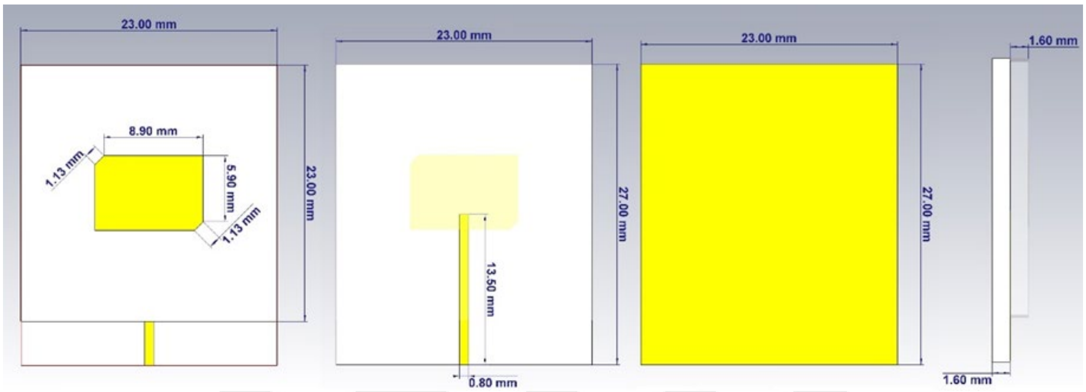

Figure 3.11 : Microstrip patch antenna dimensions with proximity coupling.

At the same time, the feed port on the proximity coupling is slightly down shifted due to obtain circular polarization. The results of the S11 parameters are given in Figure 3.12.

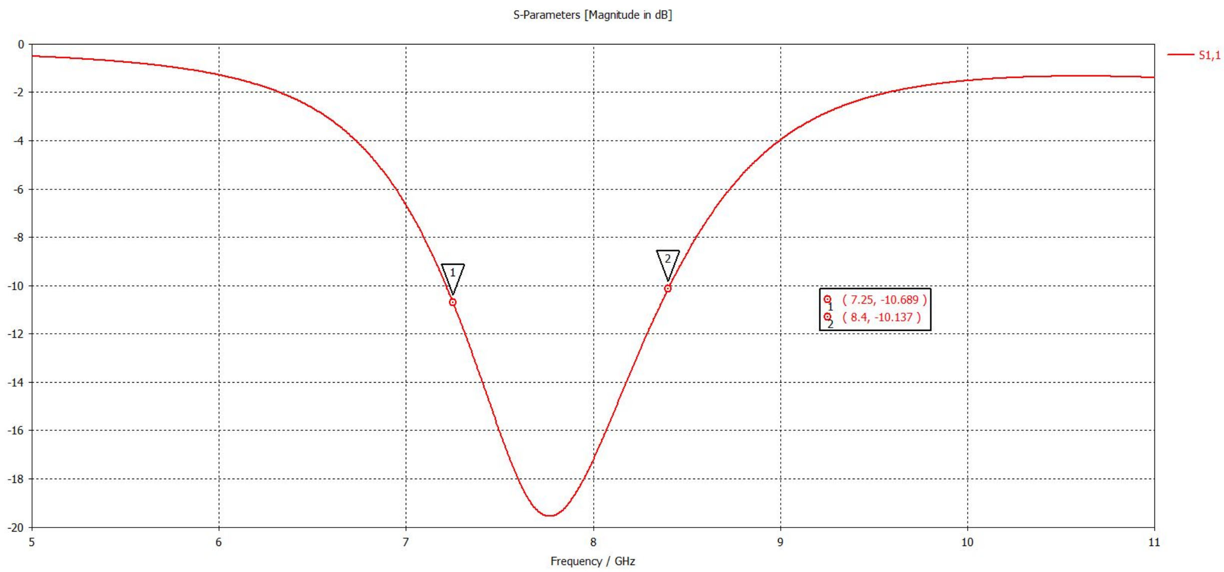

Figure 3.12 : S11 parameters for microstrip square patch antenna.

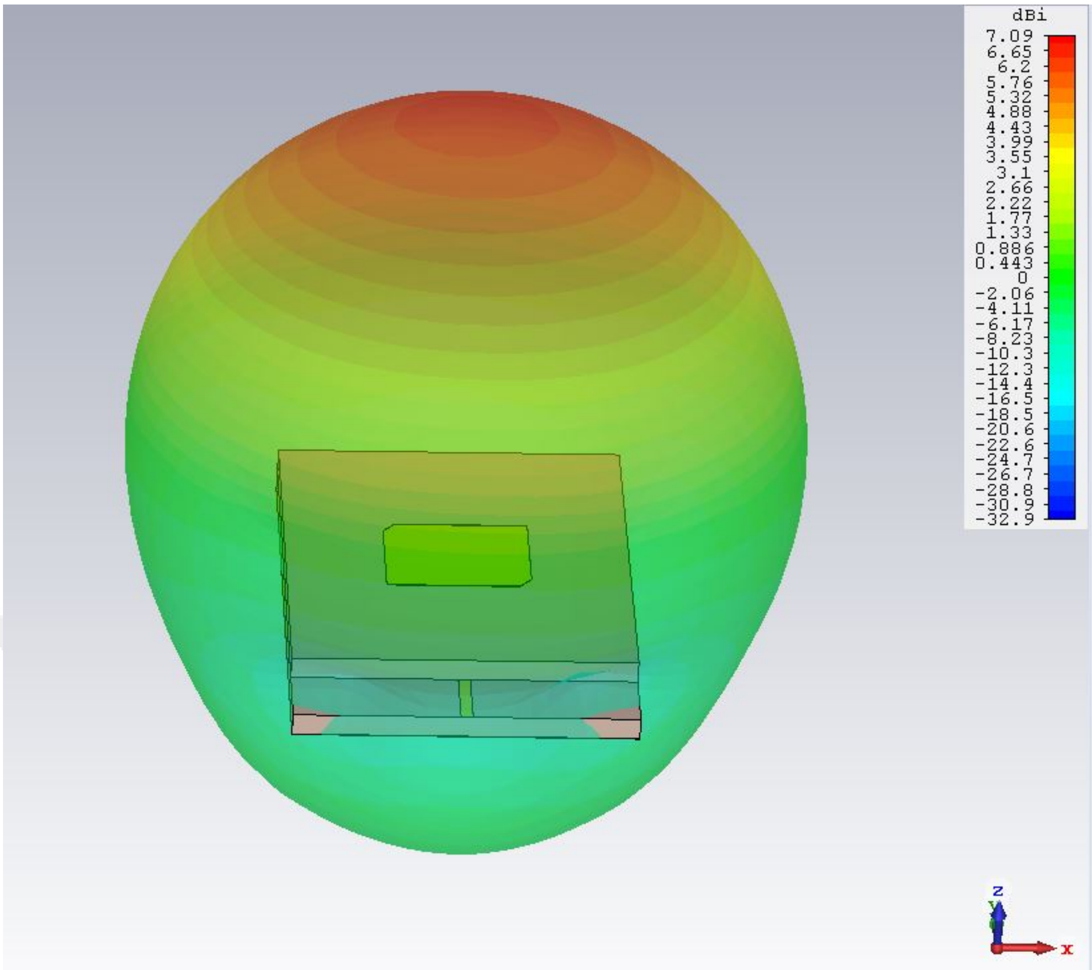

Figure 3.13 : Polarization for microstrip square patch antenna.

The polarization of the microstrip square patch antenna as shown in Figure 3.13.

3.4.1 Array antenna and corporate feed design

In the structure mentioned in detail Section 3.4, S11 parameter and polarization result have been observed to have good values but the gain is not the desired value. In this section, necessary studies have been carried out to increase the gain. The main problem in this study is how to divide power. Necessary research has been done in the literature on "Wilkinson power divider" and "corporate feed network". For wilkinson power divider designs, passive material is required to be able to impedance match between microstrip paths. The use of extra materials was avoided to avoid the high cost of the design. It was decided to use corporate feed network method instead of this method.

The designed array structure was increased as four , eight and sixteen patches and the final design was obtained.

After complete design of the first patch antenna, the corporate feed design was started with resistance values on the Figure 3.14 below.

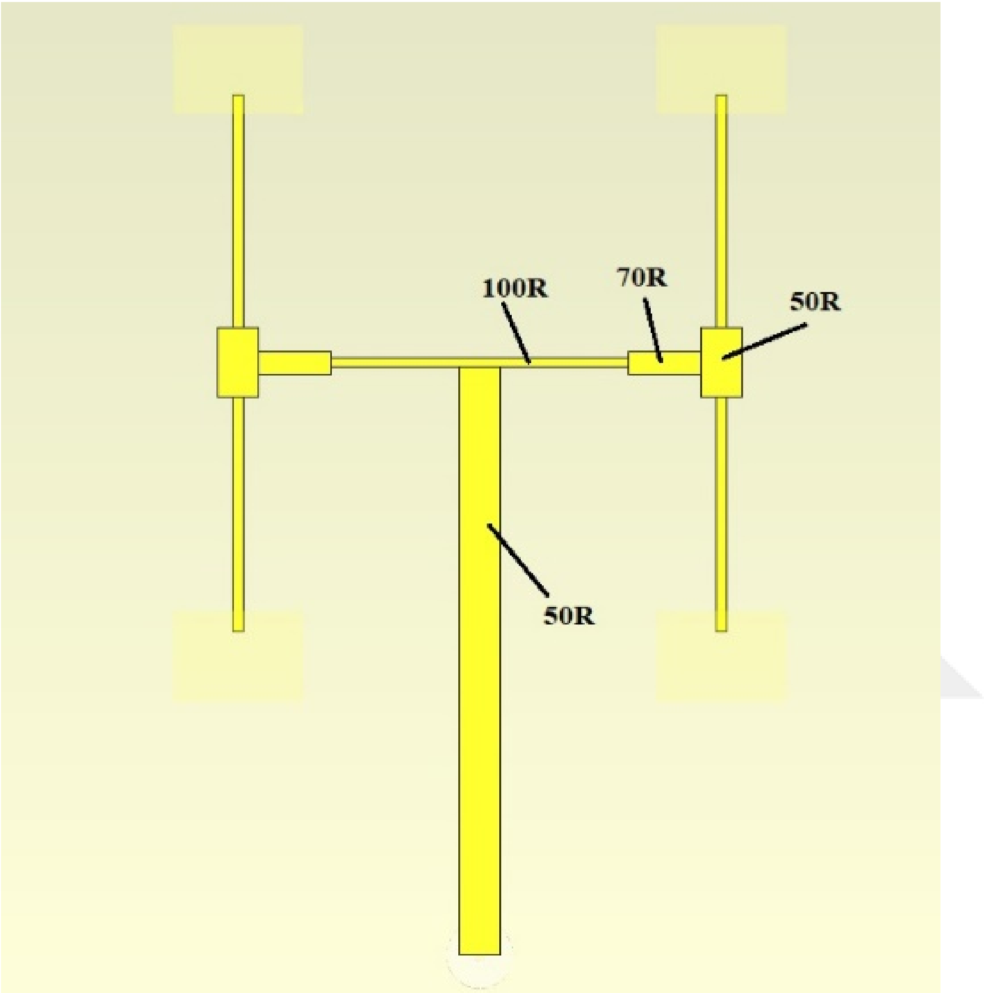

Figure 3.14 : Four patch corporate feed design resistance values.

After the success simulation, the construction of eight patch followed this process. The construction of eight patch corporate feed resistance values in shown Figure 3.15 below.

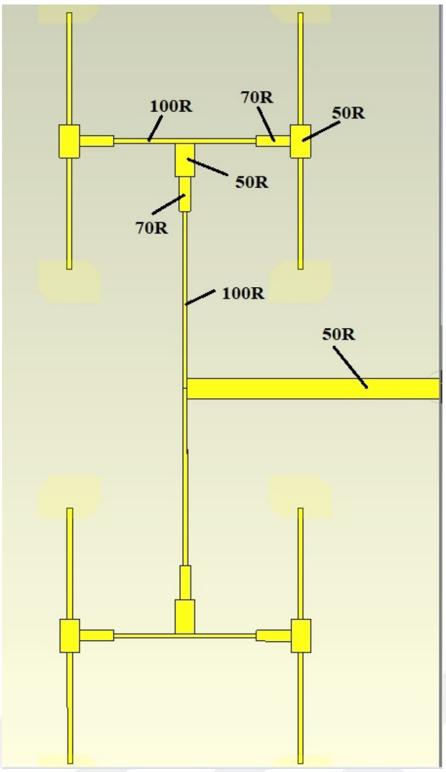

Figure 3.15 : Eight patch corporate feed resistance values.

The new sixteen patch corporate design was started after finished eight patch design and sixteen patch design resistance values in shown Figure 3.16.

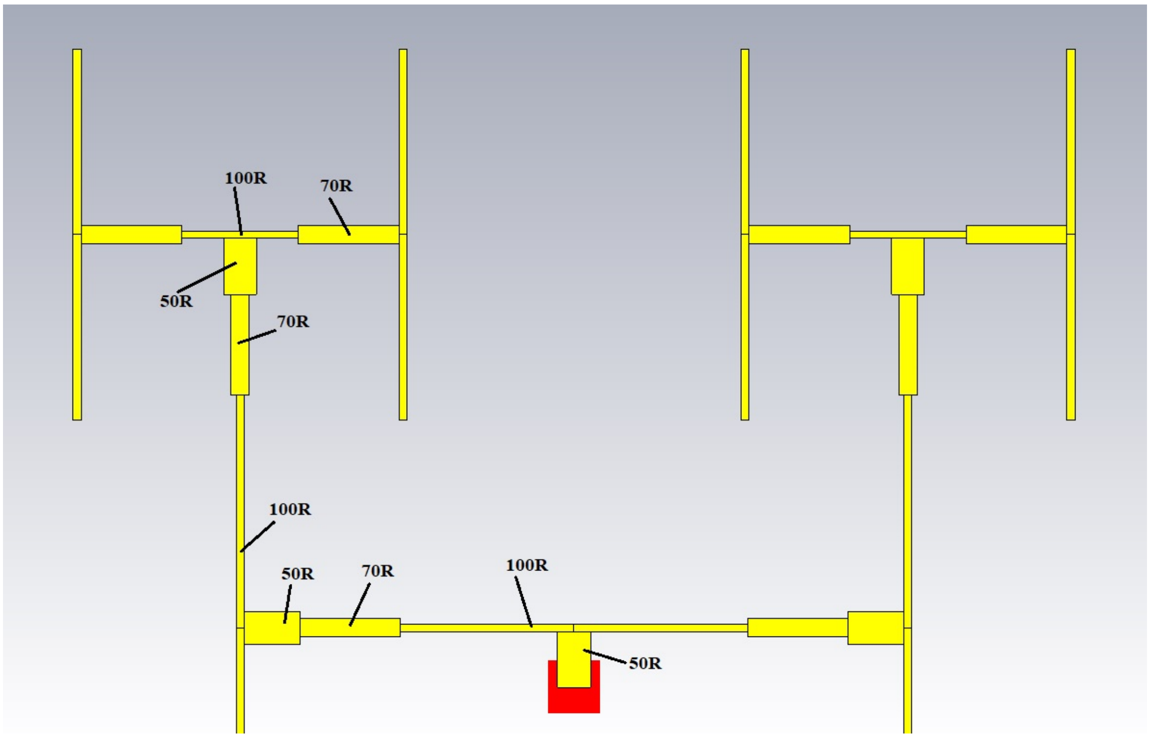

Figure 3.16 : Sixteen patch corporate feed resistance values.

After the success of the final simulation, the dimension values of the corporate feed were obtained as shown in Figure 3.17 below.

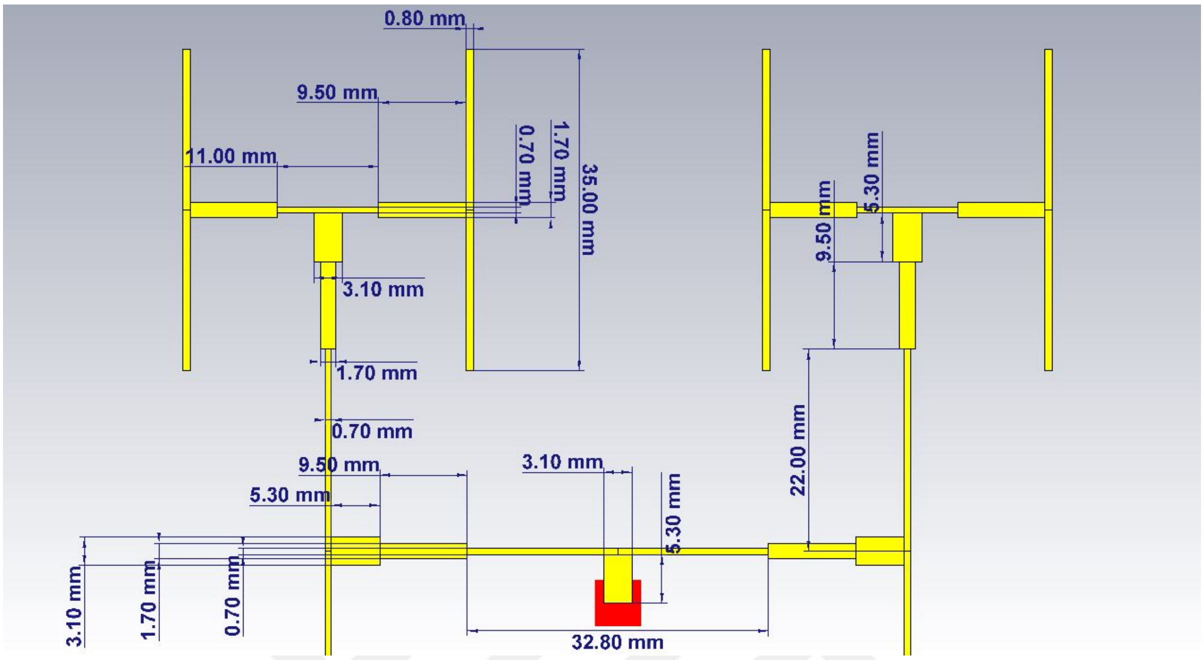

Figure 3.17 : Final design corporate feed dimensions.

Other regions were symmetric with these dimensions values. Owing to this design, we were able to increase the gain from 7 dBi to 16 dBi.

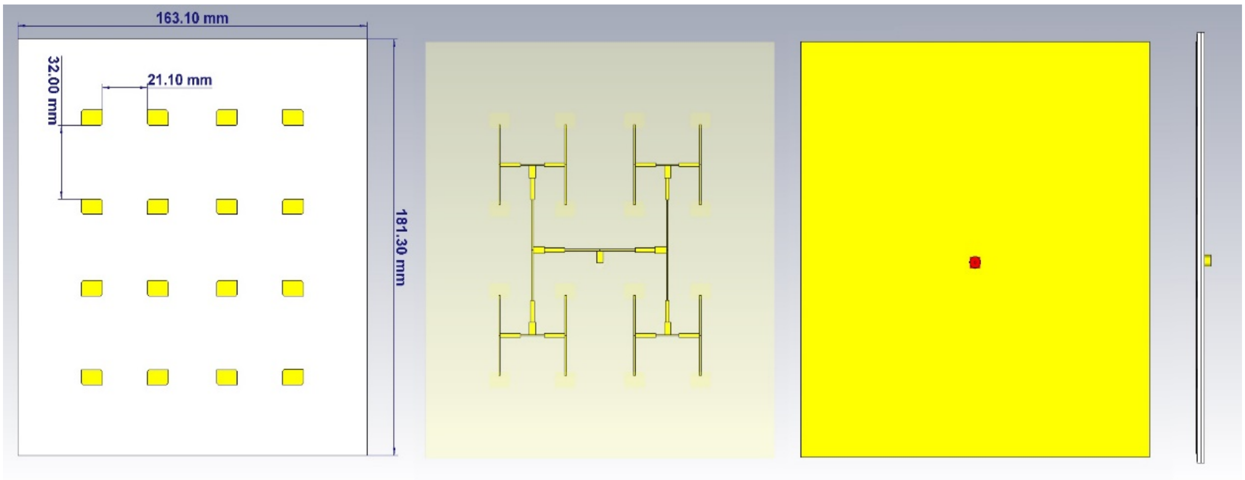

Figure 3.18 : Final design.

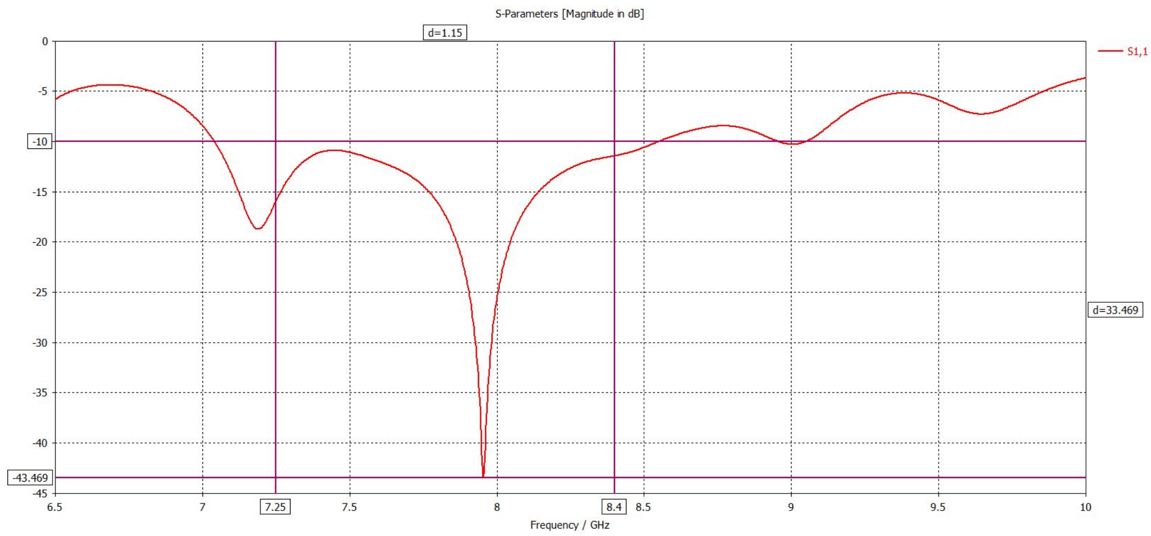

Figure 3.19 : S11 result for final design.

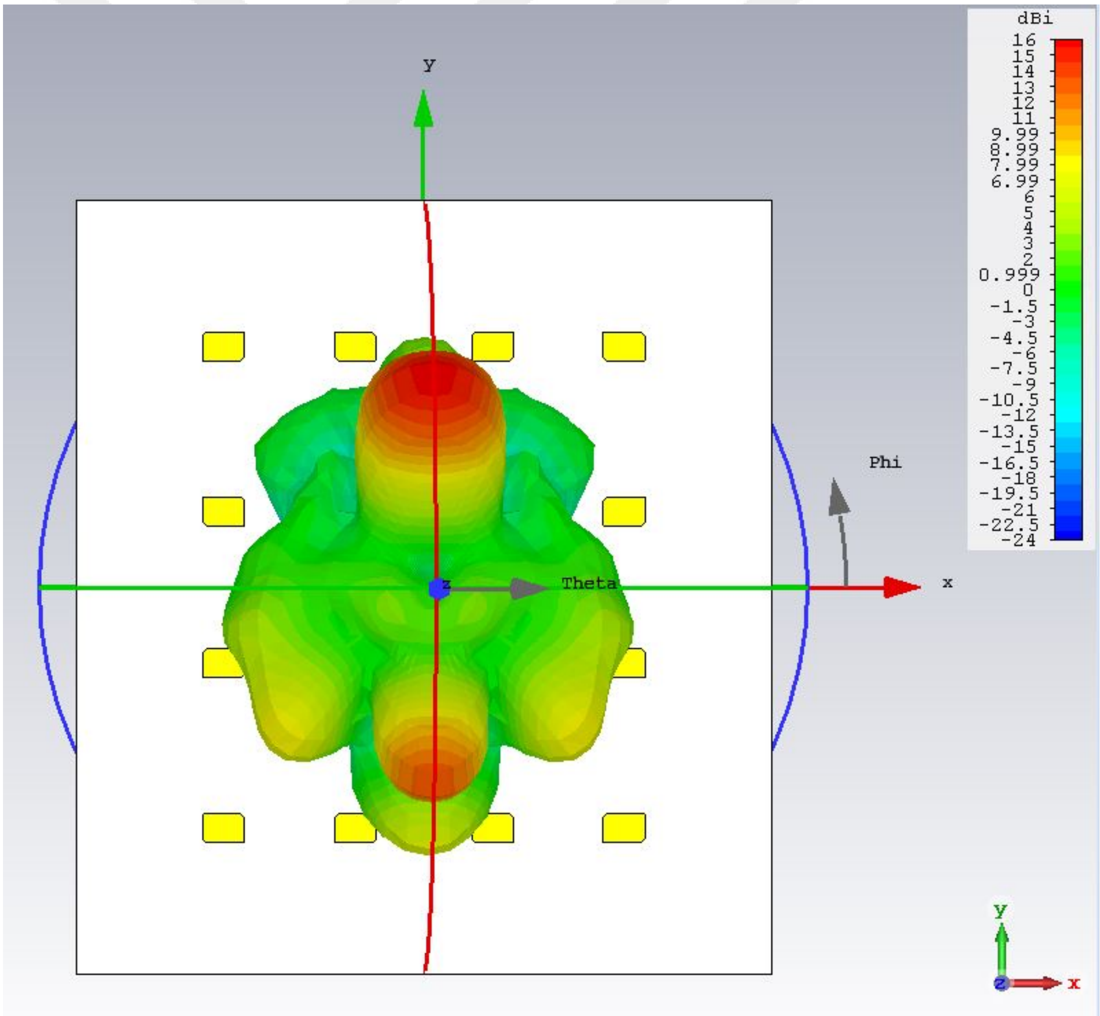

Figure 3.20 : Far field result for final design.

When the S11 parameter and polarization results were evaluated, it was observed that the antenna that was designed was operating in the desired frequency bands and that the radiation pattern occurred in the upper part of the antenna. When the cause of this problem is examined, it is understood that the first patch structure consists of proximiting coupling. It is observed that the shift in the radiation pattern is increased when the patch antenna is designed as an array. A less lossless dielectric layer such as Rogers could be used to solve this problem but in this study FR-4 was used to realize a low cost design. In this design production, plastic screws must be used to combine the two layers so crews were added to the design and simulation results were observed. The effect of the screw was observed to be low and manufacturing decision was made.

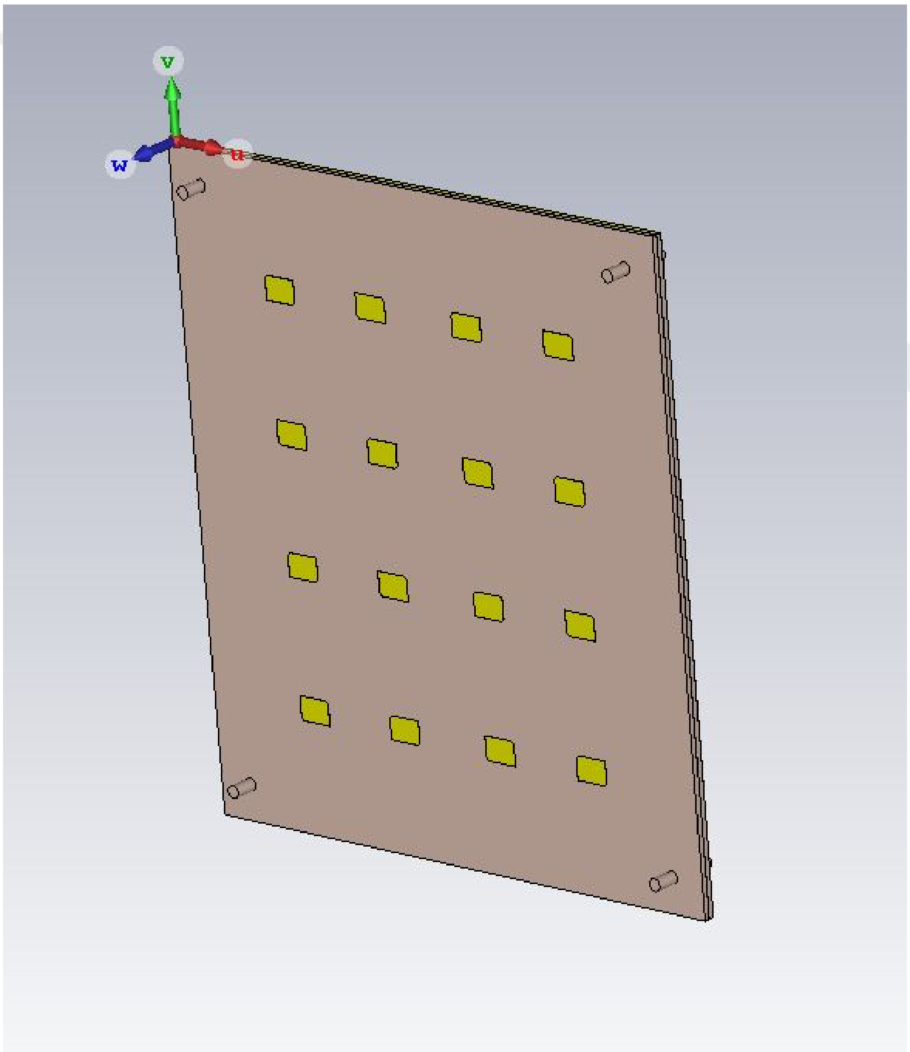

Figure 3.21 : Final array with screws.

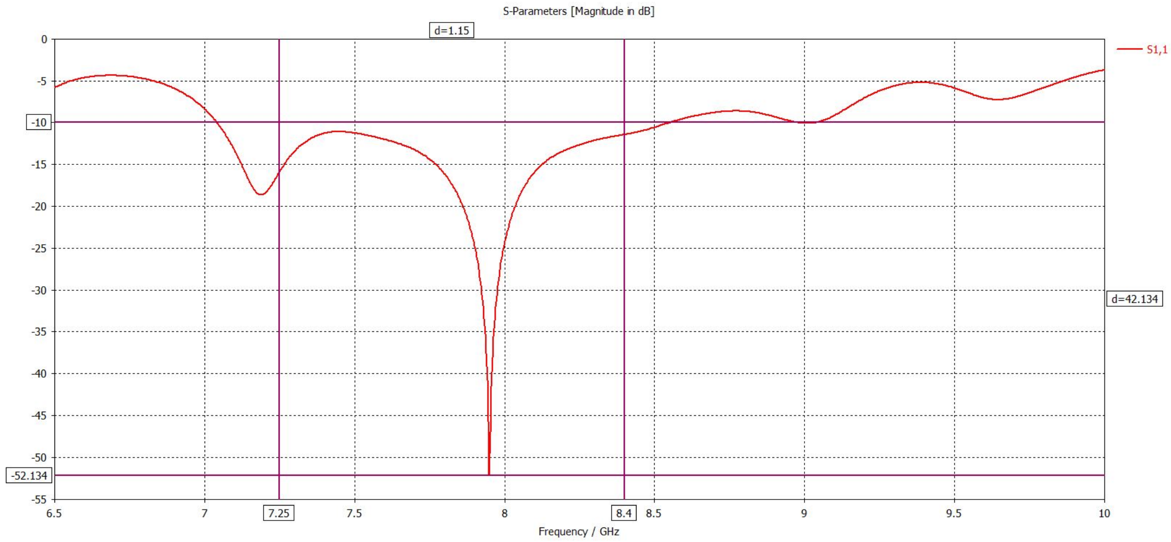

Figure 3.22 : S11 result of the array antenna with screws.

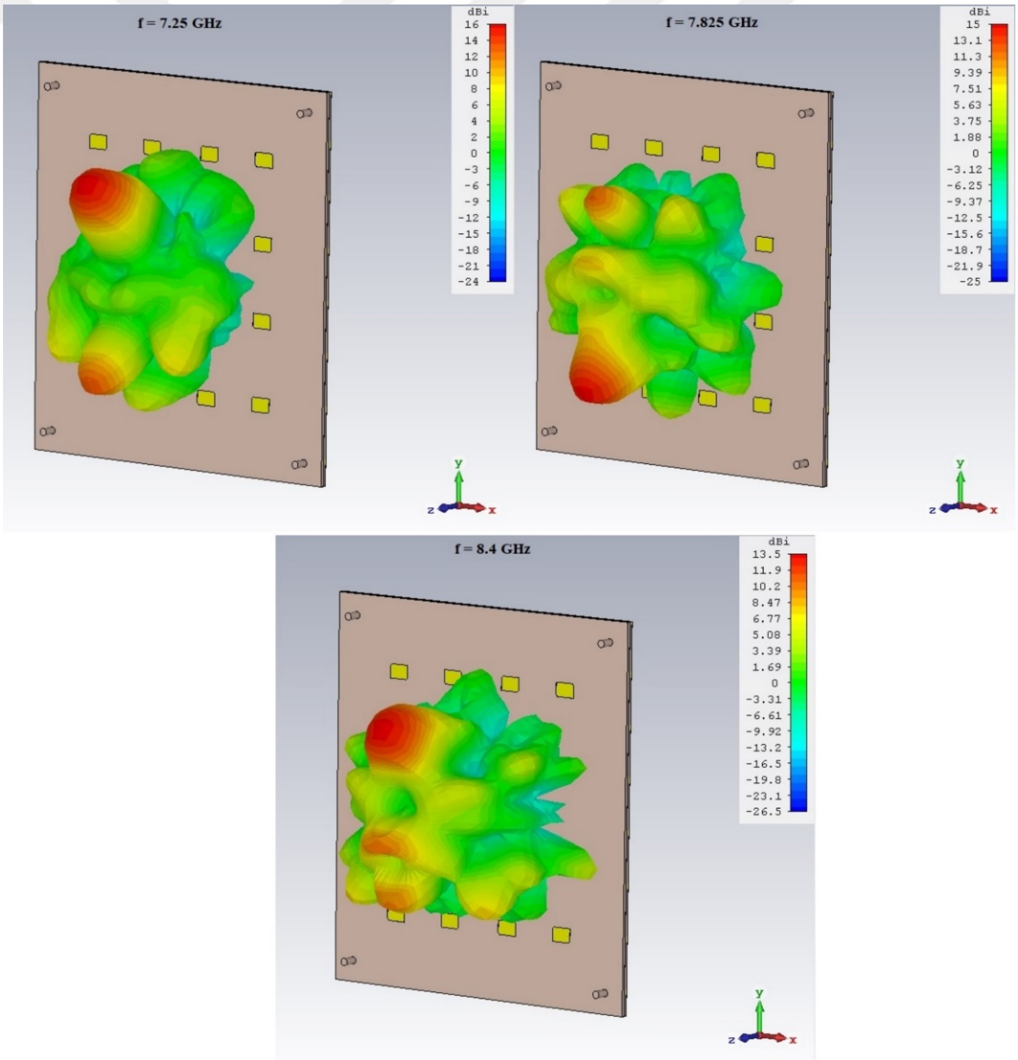

Figure 3.23 : Different frequencies output of the far field analysis.

4. MANUFACTURING AND MEASUREMENTS

The most important part of the production stage is to give the gerber file which the manufacturer can understand.

4.1 Gerber Output

In order to get the gerber file of the structure, each layer's .dxf extension files are extracted via the CST program. Then, .dxf extension files were opened using the EAGLE program. The accuracy of the dimensions of the structures in the .dxf extension files opened in this program was examined in detail. Two different gerber files were created for two different PCB production. In this design, the ground plane and the microstrip feed line together created a double-layer pcb, while the microstrip patch created a separate single-layer PCB.

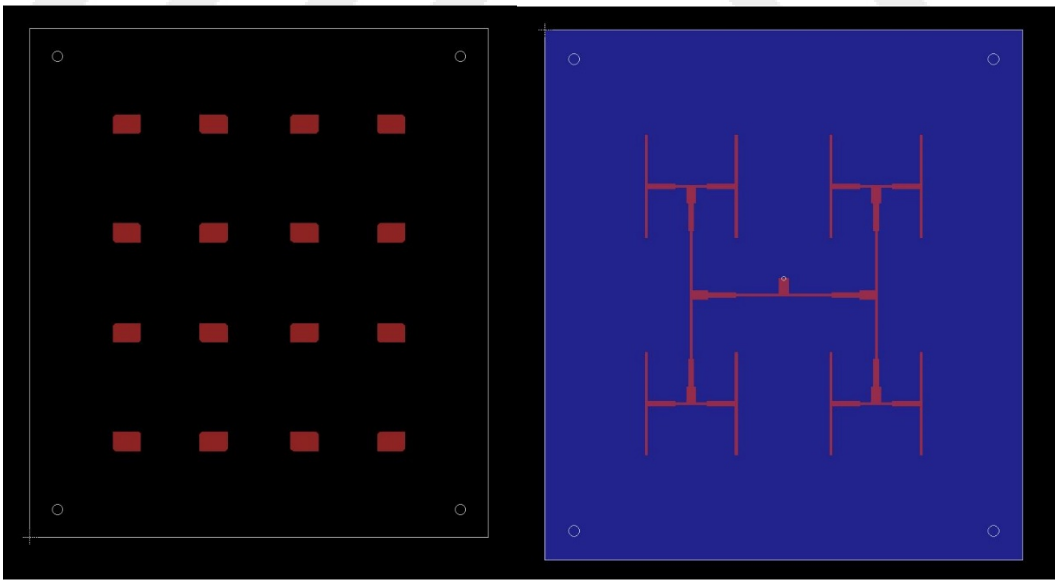

Figure 4.1 : EAGLE gerber output.

4.2 PCB Printing

After the necessary price research for the production of pcb's, printing was done in Guler PCB. Both two-layer and single-layer five-piece PCBs were produced with HAL coating. HAL coating was preferred to prevent the rapid rustiness of the produced pcb. Production completed PCBs are shown in Figure 4.2.

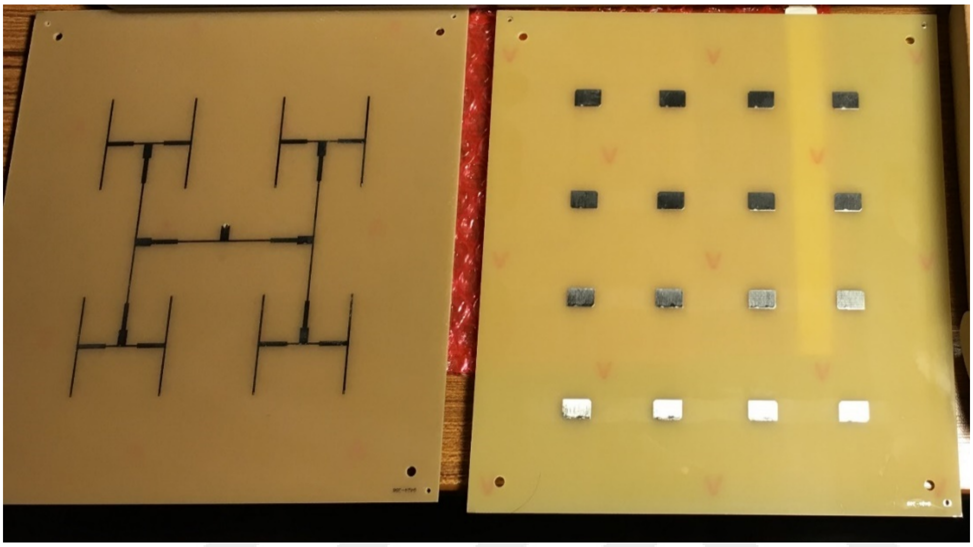

Figure 4.2 : Both single layer and double layer PCBs.

4.3 Soldering and Assembling

Connector with 50 ohm input, coded "L-KLS1-SMA001" from Ozdisan companies, are taken. The legs of this product are shortened and soldered without any problem as shown in Figure 4.3.

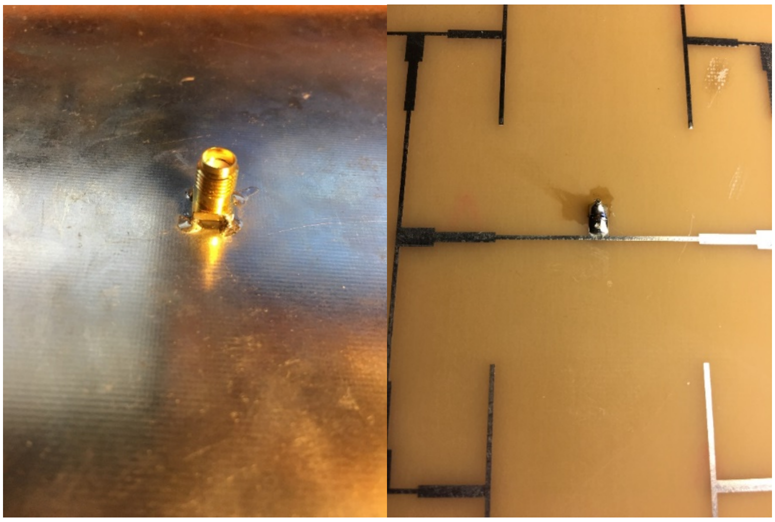

Figure 4.3 : Top and bottom view of soldering connector.

Errors resulting from soldering were corrected with rasp and the closest condition to the antenna was obtained.

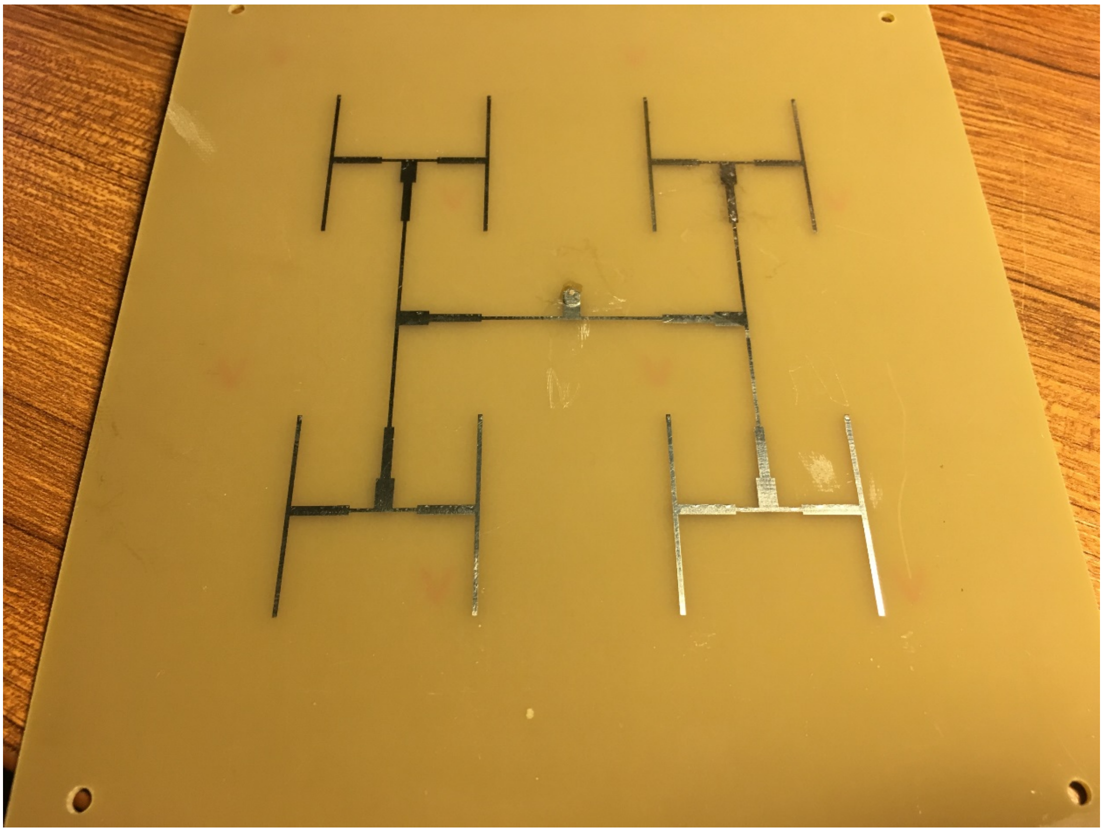

Figure 4.4 : View PCB after rasp.

Since the metric 3 plastic screws could not be found, the two layers were assembled together using the plastic handcuff.

Figure 4.5 : Antenna view after connection two sides with handcuffs.

4.4 Measurements

For the measurement, agient technologies N5230A 10MHz-40GHz PNA Series Network Analyzer in the ITU VLSI laboratory was used as shown in Figure 4.6.

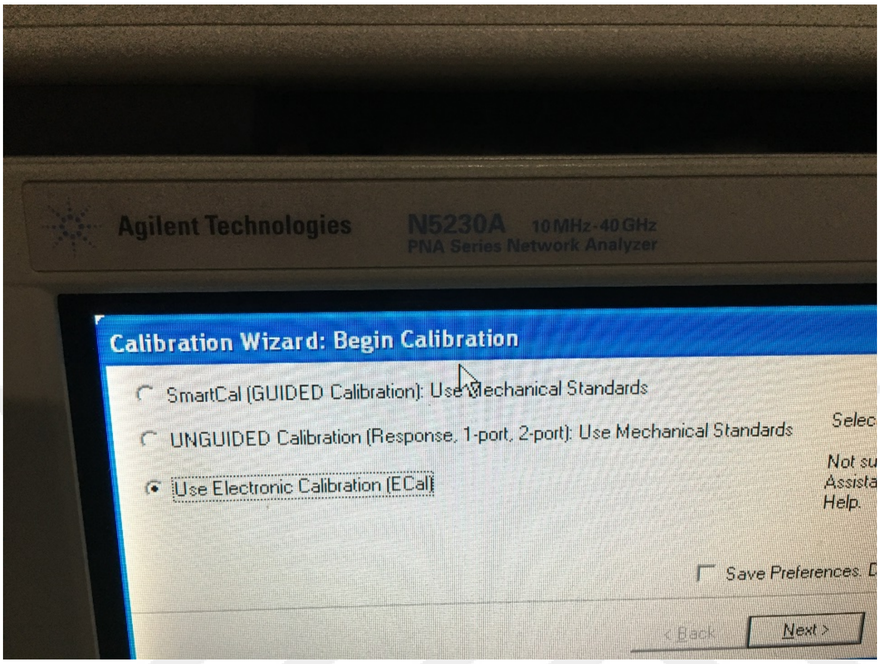

Figure 4.6 : Agilent N5230A network analyzer.

Agilent N4693-6001 electronic calibration module was used primarily for calibration.

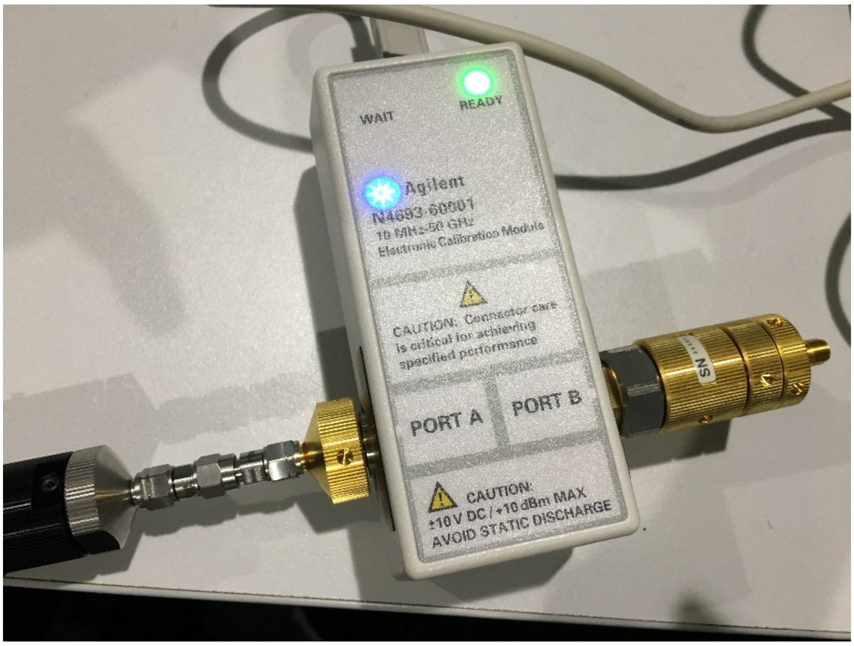

Figure 4.7 : Electronic calibration module.

The measurement system is as follows.

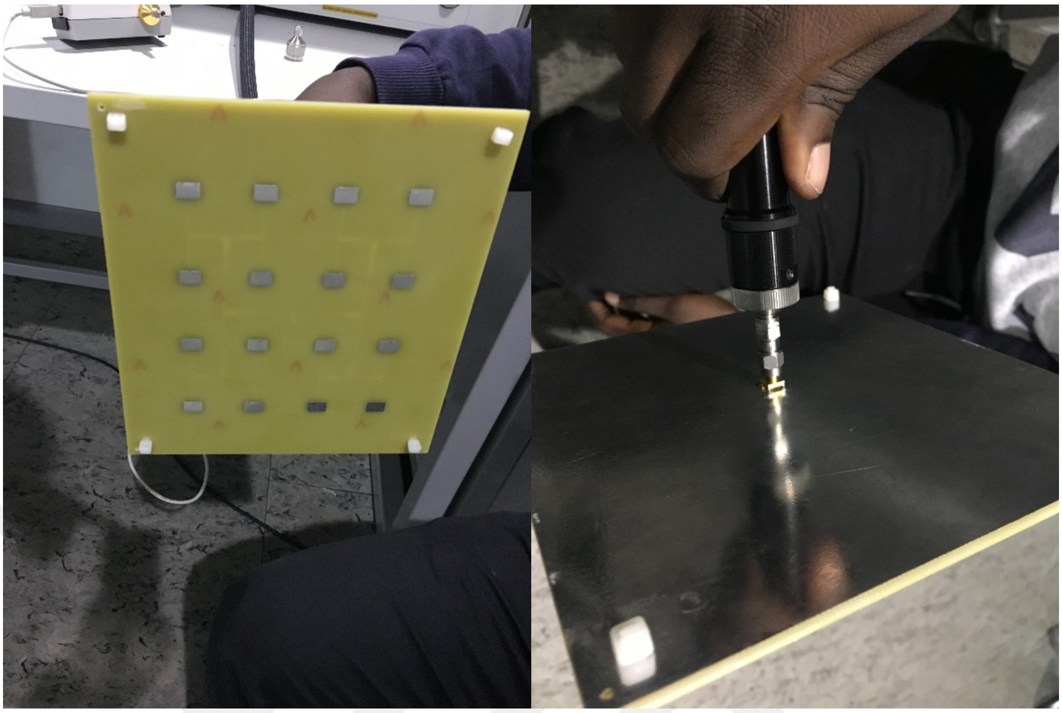

Figure 4.8 : The measurement system.

The results of this measurement system are shown in Figure 4.8.

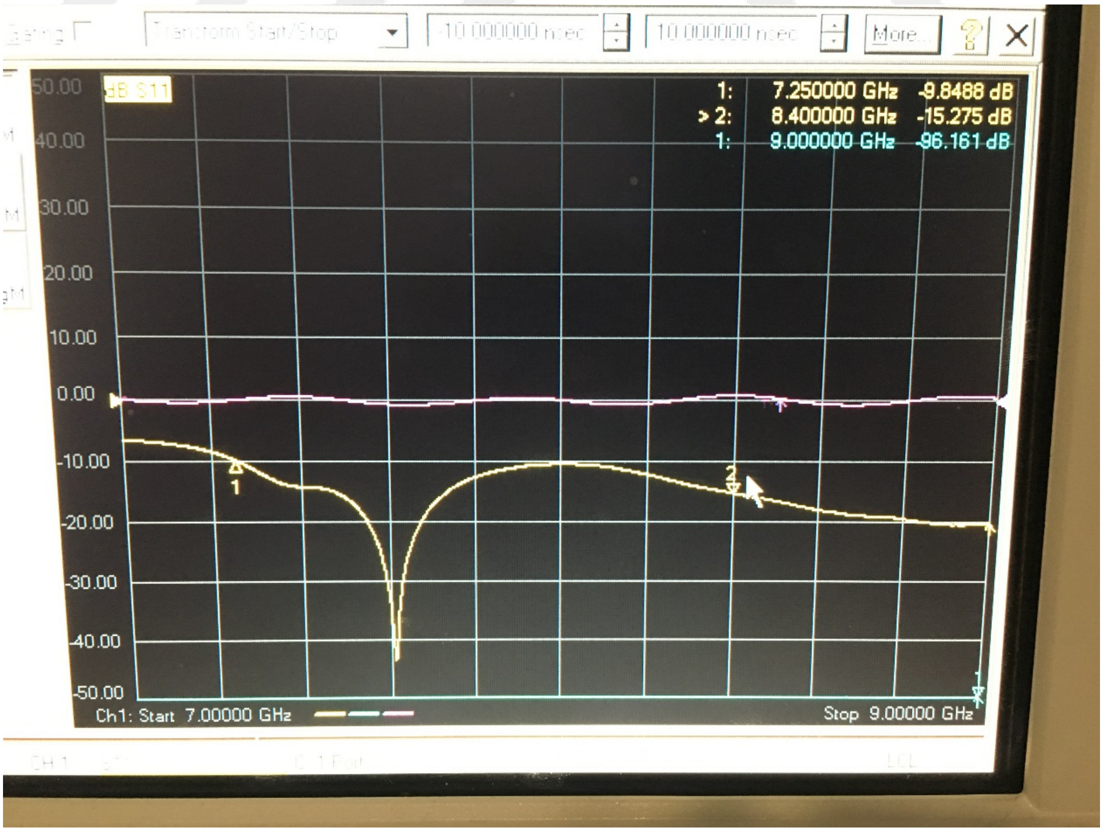

Figure 4.9 : Measurement result of the antenna.

5. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, low-cost microstrip patch antenna design has been done to decrease the cost and dimensions on this thesis and to increase the portability. The designed frequency was determined to be X-band in order to use on military purposes.

In general, parabolic reflector antenna is the most preferred antenna for satellite communication due to have high gain. The most important advantage of the use of parabolic antennas in VSAT satellite systems is to direct the electromagnetic waves used in the communication to the target with a narrow bundle or to ensure that the waves coming from the target are taken with the lowest loss. On the other hand, the metal reflector part used in such antennas makes them large, heavy and immovable.

The goal of this thesis is to design a portable and lightweight low-cost microstrip patch array antenna which operates on X-band frequency range that between 7.25GHz and 8.4GHz for military VSAT satellite communication. The process took a handful of researching to fully create a working theoretical antenna and adapt the theory into first simulation and next to a real antenna. Since the aim was to develop a low-cost microstrip patch antenna with such properties but also doesn't exceed a realistic budget the found sources could only act as a small reference and most of the work has been completed after multiple simulation trials and a lot of research.

The comparison of the measurement result and simulation result MatLab graph is given on the Figure 5.1. The simulation results and the measurement results appear to be close to each other on average. The measurement results appear to shift to low frequencies according to simulation results. This problem is though to be caused by the production stage. After the production, double layer pcb is a little bit bending which is causing the more metal density one side than the other. This situation becomes more apparent due to the heat applied in the soldering process. It is thought that can be other problem is cover the copper plane with HAL from the production process due to prevent from rustless by the time. The HAL coating creates unwanted particles on copper surface. When the production-related problems are ignored, the antenna still works successfully in the X-band frequency.

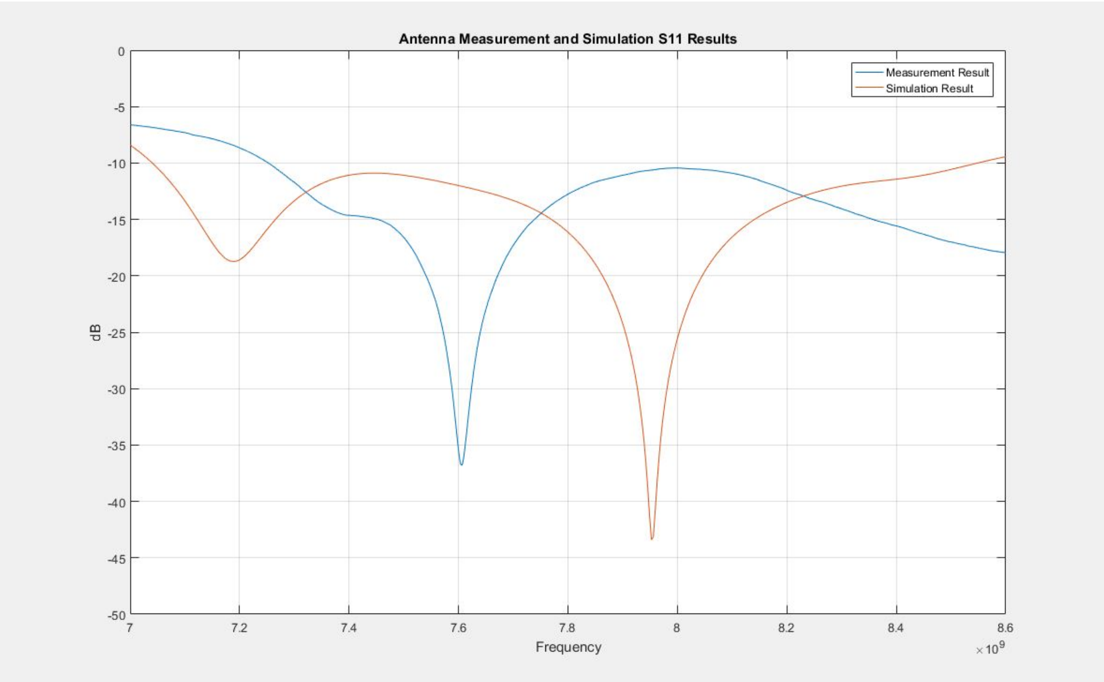

Figure 5.1 : Measurement and simulation S11 results.

The end of this thesis, I would recommend a future study that include direction of the electromagnetic beam routable with that array antenna system using phase shift method on corporate feed network.

As a result, low-cost microstrip patch array antenna has achieved what it was initially expected to perform and yielded results at the end of practical results. Hence it can be easily claimed that the project is a practical, very usable and improveable antenna ready to be used in simple tasks performed by people who communicate with the satellite at X-band frequency range.

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