INVESTIGATIONS ON FREQUENCY BEAM SCANNING MICROSTRIP (BSMS) ANTENNA STRUCTURES

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF MIDDLE EAST TECHNICAL UNIVERSITY

BY

BURHAN DÜNDAR

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ELECTRICAL AND ELECTRONICS ENGINEERING

AUGUST 2009

INVESTIGATIONS ON FREQUENCY BEAM SCANNING MICROSTRIP (BSMS) ANTENNA STRUCTURES

Submitted by **BURHAN DÜNDAR** in partial fulfillment of the requirements for the degree of **Master of Science in Electrical and Electronics Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan ÖZGEN ________________
Dean, Graduate School of Natural and Applied Sciences

Prof. Dr. İsmet ERKMEN ________________
Head of Department, Electrical and Electronics Engineering

Prof. Dr. M. Tuncay BİRAND ________________
Supervisor, Electrical and Electronics Engineering

Examining Committee Members:

Prof. Dr. Altunkan HIZAL ________________
Electrical and Electronics Engineering Dept., METU

Prof. Dr. M. Tuncay BİRAND ________________
Electrical and Electronics Engineering Dept., METU

Assoc. Prof. Dr. Şimşek DEMİR ________________
Electrical and Electronics Engineering Dept., METU

Assist. Prof. Dr. Lale ALATAN ________________
Electrical and Electronics Engineering Dept., METU

Dr. Orhan ŞENGÜL ________________
Chief Researcher, TÜBİTAK-UZAY

Date: 20.08.2009

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Burhan DÜNDAR

Signature:

ABSTRACT

INVESTIGATIONS ON FREQUENCY BEAM SCANNING MICROSTRIP (BSMS) ANTENNA STRUCTURES

DÜNDAR, Burhan
M. S., Department of Electrical and Electronics Engineering
Supervisor : Prof. Dr. M. Tuncay BİRAND

August 2009, 65 pages

Beam scanning Microstrip (BSMS) antenna is designed to work at center frequency of 10 GHz for using in the scanning applications of 9 GHz to 11 GHz band. The design parameters are defined and by using an Electromagnetic Simulation software program, the parameters are optimized. A Beam Scanning Microstrip Antenna is produced as a prototype and the measurement's results are compared with theoretical results. In conclusion, the values of deviation between theoretical and experimental results are discussed.

Keywords: Traveling wave Microstrip Antenna, Patch Antenna, Antenna Pattern

ÖZ

FREKANS DEMET TARAMALI MİKROŞERİT (BSMS) ANTEN YAPILARI ÜZERİNE İNCELEMELER

DÜNDAR, Burhan
Yüksek Lisans, Elektrik ve Elektronik Mühendisliği Bölümü
Tez Yöneticisi : Prof. Dr. M. Tuncay BİRAND

Ağustos 2009, 65 sayfa

Bu tezde, 10 GHz merkez frekansında 9GHz ile 11GHz arasında tarama uygulamalarında kullanılmak üzere bir Frekans Demet taramalı Mikroşerit Anten tasarımı gerçekleştirilmiştir. Tasarım parametreleri tanımlanmış ve bu parametrelerin alabileceği en uygun değerler Simülasyon programı kullanılarak optimize edilmiştir. Prototip olarak bir anten üretilerek teorik sonuçlarla pratik sonuçlar karşılaştırılmıştır. Sonuç olarak da deneysel sonuçlardaki sapma değerleri değerlendirilmektedir.

Anahtar Kelimeler: Kayan Dalga Mikrostrip Antenleri, Yama Anten, Anten Paterni

To ŞÜKRAN

ACKNOWLEDGEMENTS

I would like to express my gratitude to Prof. Dr. M. Tuncay BİRAND for his precious supervision, helpful guidance and frank interest throughout all the phases of this study. This thesis bears valuable importance to me for the fact that I had found the chance to work with him.

I would also like to acknowledge Prof. Dr. Altunkan HIZAL and my friend Sancay KIRIK for their very constructive suggestions and supports during the thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Phased array antennas have been and will continue to be a crucially important component in the development of future wireless systems with applications in communications, radar, and satellite technologies.

In spite of the significant developments in the design of modern phased array antennas, there continue to be significant and growing needs for developing high performance systems that are also low cost and with beam steering capabilities. Two-dimensional (2D) beam scanning antennas are required in high data rate wireless communication and radar/sensor systems of the next generation to exploit information in the dimension of space.

Beam scanning in two-dimension can be realized by a 2D array of antenna elements each of which is fed by a power dividing network with highly controlled phase shifters.

In general, the antenna systems tend to be complicated, lossy and costly when the number of elements becomes large. The usage of a single antenna on the system for various applications reduces the system size and cost.

The objective of this thesis is to design a low cost, “easy to implement” beam scanning antenna which can be used in communications, DF and /or radar systems applications.

Investigations leading to the design methodology included:

- Using appropriate simulation software
- Comparison of simulation results with those obtained using basic array theory
- Verification via experimental investigations

The simulation software was used to simulate antenna parameters such as return loss and radiation pattern.

A proximity coupled and traveling wave type of “Beam Scanning Microstrip Antenna” was found out to be a good choice as it has the advantages of low profile, low cost, robust construction and ease of fabrication.

The simulation tool used is the ENSEMBLE 8.0 software which is proved to be appropriate for the design considerations of BSMS Antenna.

CHAPTER 2

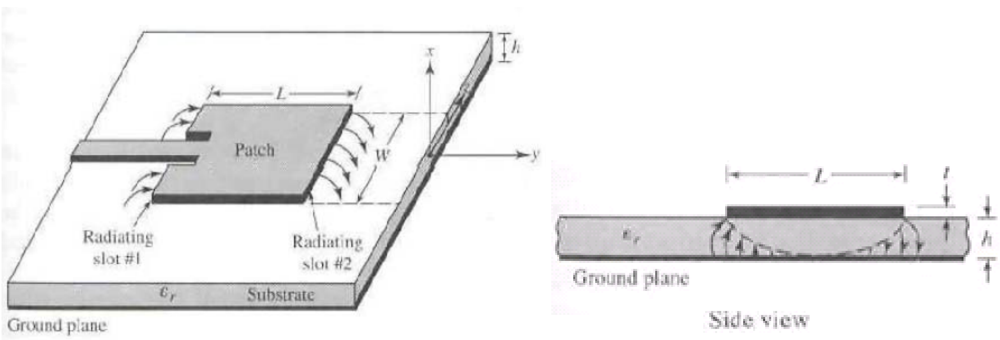
MICROSTRIP ANTENNAS

Microstrip antennas are one of the most common forms of printed antennas. They are constructed using simple fabrication techniques. These antennas are low profile antennas. In the last two decades, microstrip antennas became very popular and vast amount of investigations were carried out since 1970's. Now, they are being widely used in many telecommunications, radar, DF etc. applications. MSAs are manufactured using printed-circuit technology; therefore mass production can be done at a low cost. [1, 5]

In this chapter the basic properties of microstrip antennas will be explained and the advantages they offer will be discussed..

2.1 Microstrip Patch Antennas

Microstrip patch antenna structure consists of a very thin metallic strip on a dielectric substrate which is on the ground plane (Figure-1). Radiation can be mostly ascribed to the fringing fields at the open circuited edges of the patch. The resonant frequency of the antenna can be determined from the geometrical shape and the size of the patch. [7]



<u>Figure 1. Microstrip Patch Antenna</u>

2.2 Microstrip Slot Antennas.

Microstrip slot antennas are different from patch antennas but generally they look like same. As seen on the Figure-2, for slot antennas there is a ground plane with slots on it and a feeder line below this ground plane. As a result, bidirectional radiation (different from microstrip patch antenna) occurs. But we can change this bidirectionality by using a reflector on one side. For example, a ground plane under feeder line can be used [7].

(a) **(b)**

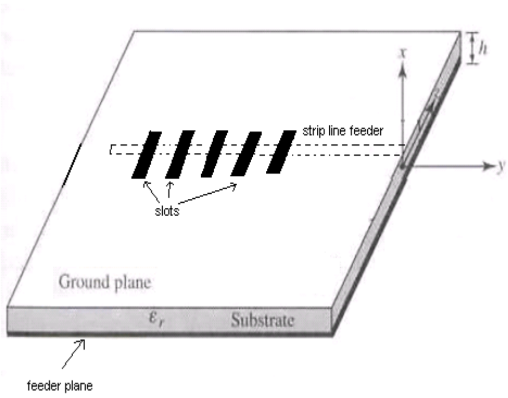


Figure 2. Two Different Types of Slot Antenna Models

(a) microstrip slot antenna

(b) waveguide slot antenna.

There are several feeding techniques for microstrip antennas. Those techniques will be discussed in detail in chapter 3.

2.3 Advantages and Disadvanteges of Microstrip Antennas

Microstrip antennas have several advantages compared to the conventional antennas and therefore they are used in many applications over a frequency range from approximately 100MHz to about 50GHz and even higher.

The main advantages are:

1) Microstrip antennas often are lightweight, low volume; thin profile structures

2) Microstrip antennas have low fabrication cost and are appropriate for mass production.

3) Linear and Circularly polarized structures can be realized using pretty simple feeding techniques

4) Dual frequency and/or dual polarized antenna structures can be realized.

5) Feed lines and matching networks can be fabricated on the same substrate.

6) Microstrip antennas can be easily integrated with microwave modular designs; such as modulators, phase shifters, amplifiers, switches etc. [6].

However, microstrip antennas also have some disadvantages, including:

1) Microstrip patch antennas radiate most of the energy into only a half space.

2) Microstrip antennas are lossy and therefore have somewhat lower gain.

3) Resonant type of microstrip antennas have narrow bandwidth.

4) The isolation between the feed and the radiating elements is so poor for Microstrip antennas.

5) Resonant type of microstrip antennas has relatively poor endfire radiation performance

On the other hand some disadvantages can be fixed by using some special techniques as listed below:

1) By using arraying techniques, dynamic beam shaping and beam steering can be possible although these antennas radiate only in one half plane[10].

2) Measuring the impact of coupling between the elements is possible by carefully designing an array, and ways can be found to minimize coupling effect, and give greater isolation between array elements.

3) For increasing the bandwidth there are some special techniques, but generally these methods increase the return loss and spurious radiations.

4) A technique called"High Impedance Ground Plane" or a Photonic bandgap substrate can be used for minimization of the excitation of surface waves [13].

CHAPTER 3

FEEDING METHODS

One of the important aspects of a microstrip patch antennas is the variety of feeding techniques applicable to them. A good impedance matching condition between the line and patch without any additional matching element depends heavily on the feeding technique that is used. There are several feeding structures of microstrip patch antenna. But, for the design of the **B**eam **S**canning **M**icrostrip **A**nttena (BSMS), the choice of the best feeding technique is crucial. Therefore, to this end,, several different excitation techniques will be examined. Then the advantages, disadvantages, and parameters that effect the feeding mechanism and matching characteristics will be investigated.

First, some crucial points and terminology for designing a feeding structure of microstrip antenna will be described. Then the main feeding methods and patch array feeding networks will be discussed by considering their properties as it is touched on the first paragraph. Finally in the conclusion part the kind of feeding structure that is chosen for the BSMS antenna and also the reasons for the choice will be explained in detail.

As it is well known, it is very diffucult, if not impossible to obtain a perfect match in the designs. One can only make it better. Furthermore there are reflection losses, surface wave losses and spurious radiations that neeed to be accounted for. Due to those unwanted events, the sidelobe levels, cross polarizations and return losses increase; as a result the design can not be sufficiently efficient. Thus, design criteria for feeding structures must be examined together with the other factors affecting the antenna performance [12]

3.1 Design Criteria

1. Good matching

For BSMS antenna, the signal comes from the source or goes to any electronic equipment and generally these coming signals or going signals have the impedance of either 50ohm or 75ohm. So the impedance of the transition point must coincide with these values. Also the discontinuities at the feed line disrupt the matching. As matching decreases, more reflection losses, surface wave losses and spurious radiations occur. As a result sidelobes and cross polarizations occur and that reduces the polarization characteristics of the antenna.

2. Spurious radiation

This kind of radiation is occur because of the discontinuities of the designed patch. If the techniques which are explained in detail at the following chapter used, these unwanted radiations can be eliminated.

3. Dielectric substrate thickness and permittivity

For radiating patch, antenna should have a thicker substrate and lower permittivity, so that the radiation occurs more efficiently and higher frequency bandwidth can be achieved. But for feed line, substrate must be thinner and with higher permittivity. This makes the line better for efficiency requirements. But at this time, one must be careful about the dielectric loss tangent coefficient, because very high permittivity increases this value and as a result more losses occur [1].

3.2 Microstrip Patch Antenna Feeding Methods

A patch antenna can be excited mainly by the following 3 techniques. These techniques are investigated more precisely for choosing the best one for our design. All have some advantages and disadvantages. They will be discussed and compared between each other to decide on the best one for our usage of microstrip antenna design.

1. Microstrip Line Feed.

2. Coaxial Feed/Probe Feed.
    a) Coaxial Buried Line Feed.
    b) Coaxial Panel Launch Line Feed.

3. Coupling Feeds.
    a) Coplanar Coupling Microstrip Feed.
    b) Proximity Coupled Microstrip Feed.
    c) Aperture coupled Microstrip Feed.
    d) Dielectric waveguide Coupled Feed.

3.2.1 Microstrip Line Feed

This feeding method is the most basic method that everyone can easily think about, because the patch is on a substrate and there must be a signal way that brings the signal (Figure-3). But this feed line must be matched to the patch. There are some methods for achieving this. For example using an inset technique and the arrangement of this inset position can help for matching. Additionally for the feeding of a perfect rectangular patch placing a cut on the contacting point is very useful technique for matching the feed line.

However placing the feed line and the radiation mechanism on the same substrate brings some problems. Because they have different jobs to do, one is for feeding and the other is for radiation. All the parameters must be arranged for best radiation mechanism and for transmitting the signal to the patch as efficient as possible but the conditions of the effective parameters coincide with each other.

For example, the substrate thickness must be as low as possible for feeding line to reduce the unwanted losses, but on other hand substrate thickness must be higher for higher bandwidth and better radiation. Also thicker substrates increases surface waves, spurious feed radiation and higher order mode generation. Because of these problems microstrip line feeding technique is not preferred for critical antenna applications [1].

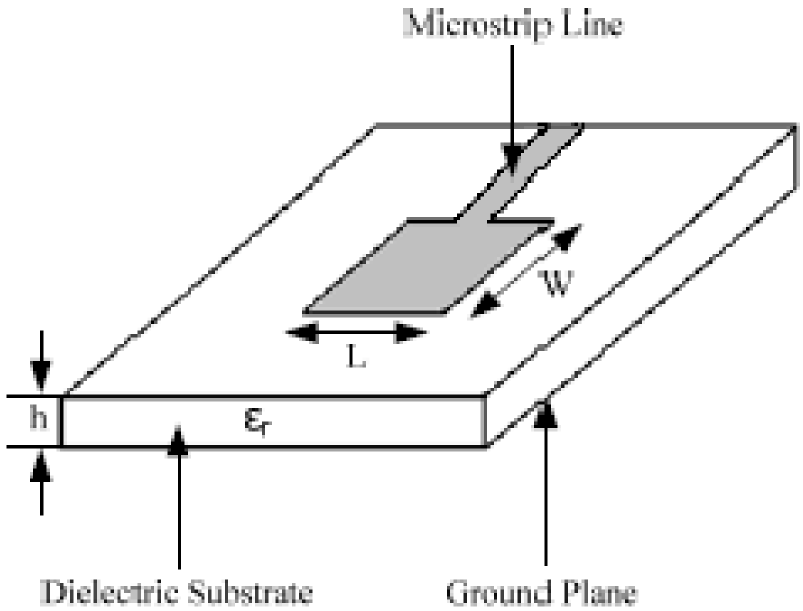


Figure 3. Microstrip Line Feed[14]

3.2.2 Coaxial Feed\Probe Feed

In this feeding technique the signal is needed to transfer from\to coaxial line. The junction of the signal between coax and microstrip line must be carefully arranged for being sure about the matching problems. There are two kinds of coaxial feed\probe feed techniques.

These are 1-Buried coaxial line feed and 2-Panel launch coax line feed.

3.2.2.1 Coaxial Buried Line Feed

As seen on the Figure–4 below, in this feeding method coaxial connector is plugged to the patch at the most appropriate position. This position is important for impedance matching of the coaxial probe and microstrip patch antenna and the polarization characteristic can be determined by the position of this coaxial probe and the patch connection. The inner conductor of the coaxial connector is connected to the radiation patch by extending across the dielectric substrate. On the other hand the outer conductor is connected to the ground plane. This feeding method has some disadvantages because of the connection of non planar and different mediums. Careful handling must be required to design such an antenna for avoiding mismatches and intrinsic radiations[6].

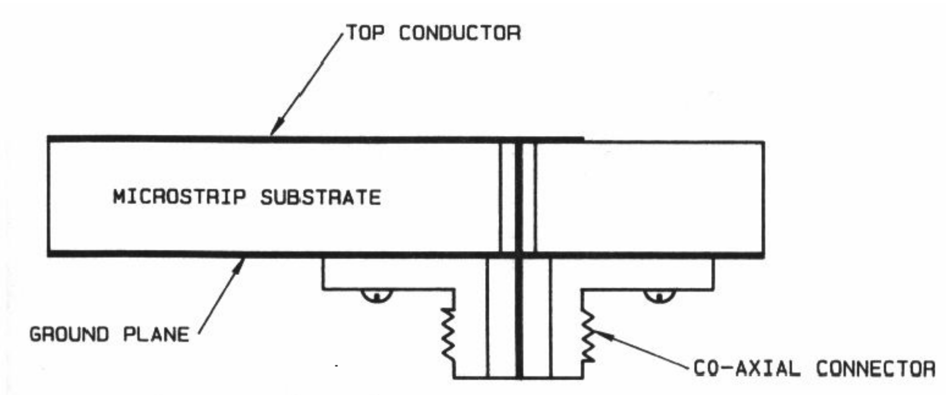


Figure 4. Buried Coaxial Line Feed [12]

Beside this, for patch antennas with thick substrate there are some problems; Intrinsic radiation, higher order mode radiation and more inductive input impedance start to occur. The third one can be easily solved by using a capacitive element but other problems can not be solved easily [1].

On the other hand this feeding method is favorable because, the feed line is behind the radiating patch and this prevents the unwanted radiations that affect the total radiation characteristic of the antenna.

3.2.2.2 Panel Launch Coaxial Line Feed

This feeding technique is the opposing technique of the buried coaxial line feed because of capacitive input impedance. The inner conductor is connected to the microstrip line and the outer conductor of the feed is connected to the ground plane (Figure-5). This connection is used for edge feeding of microstrip antenna. The connector is placed to the one of the appropriate edge of the antenna substrate. The connection must require very careful handling because the connection of the inner conductor of the coaxial line feed and the microstrip line require a pure soldering. At the same time the ground plane connection with the outer conductor of the connector is also very important to get a good matching. There exists a lot of connector types for coaxial-to-microstrip launch (Figure-6). Therefore for a beter design one must choose the most appropriate connector solution for the application. Frequency is the very crucial criteria for the selection.

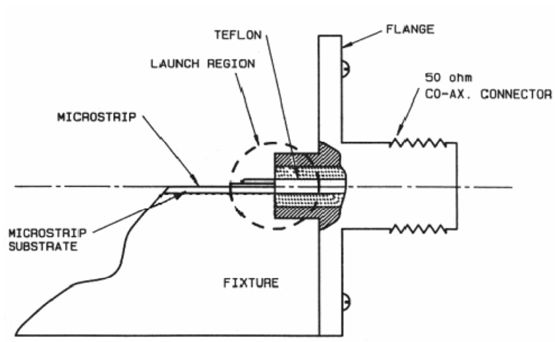


Figure 5. Panel Launch Coax Line Feed[12]

Figure6. A 50 Ohm Coax Line Connector

The capacitive effect of panel launch coaxial line feed comes from the fringing fields over the launch region. This effect can be eliminated by using some techniques but they require special processes. But basically using inductive notches (Figure-7) in front of the connection point of the microstrip line is the most applicable technique to eliminate the capacitive effect.

Because of the fringing fields over the launch region, Panel Launch Coaxial Line Feed has capacitive input impedance resulting in distortion of the matching and antenna pattern characteristics. The VSWR properties of the coaxial-to-microstrip launcher could be improved by using this technique[12].

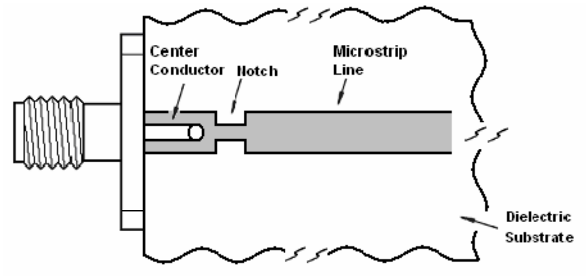


Figure 7. Notch for Inductive Effect[12].

3.2.3 Coupling Feeds

Feeding line is not connected to the radiating element so as a result the unwanted radiations and matching problems does not occur.

3.2.3.1 Coplanar Coupling Microstrip Feed.

The feeding line and the radiating patch are at the same plane. They are located on a dielectric substrate which is above the ground plane (Figure-8). The feeding line extends over the substrate and do not touch the radiating patch. We can feed number of patch elements for array at the same time by using this feeding technique. However, because of being on the same dielectric layer this feeding method have the same drawbacks of microstrip line feed.

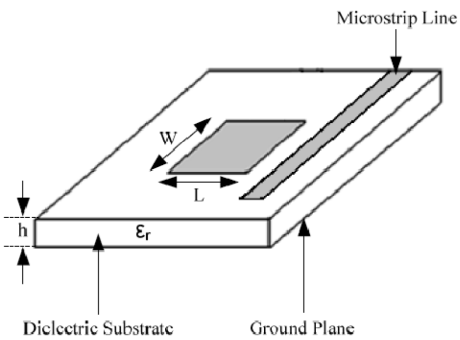


Figure 8.Coplanar coupling Feed[1]

3.2.3.2 Proximity Coupled Microstrip Feed.

This feeding method is the enhanced coupling technique related to coplanar coupling feed method. The feed line and the radiating element are located at different substrates (Figure-9). As a result the parameters of the substrates could be selected independently. Thin substrate for feed line and thick substrate for radiating patch could be chosen. Additionally a substrate with higher permittivity for feed line and a substrate with lower permittivity for better radiation of radiating element could be used. This technique also increases the bandwidth of the radiating signal approximately up to 15% [11]. But on the other hand, there exist some difficulties. For example the fabrication of this antenna is difficult and it requires very good handling because two substrates must be attached to each other with minimum blankness. The ground plane is common for two substrates, and it is the bottom plane of the antenna. The radiating patch is the top plane and the feed line stays at the middle as a result this creates some matching problems. The optimization of the length of the feeding line and radiating patch can be used for solving the matching problems. [4,11]

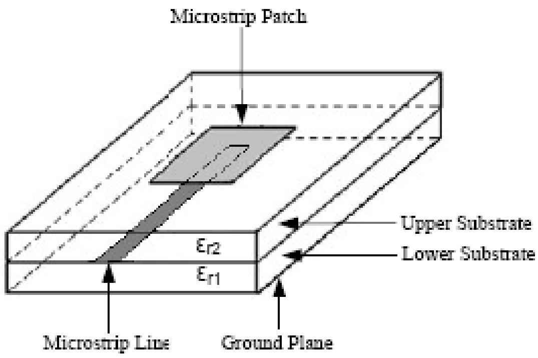


Figure 9. Proximity Coupled Microstrip Feed[7]

3.2.3.3 Aperture Coupling Feed

Aperture Coupling Feed is advancement to proximity coupling. The feeding line and radiation patch are separated by a ground plane which makes them not to affect each other (Figure-10). The ground plane embarrasses the spurious radiation from feed line, and it increases the quality of radiation purity. Additionally it has the same advantages as Proximity Coupled Microstrip Feed. But this advancement requires more careful handling. The size and the position of the aperture must be arranged very carefully and the alignment must be done perfectly. Because these requirement effect to the matching and the excess reactance of the antenna. For instance the excess reactance is affected by the aperture length.

For a good design first of all the apertures on the ground plane must be placed at the center of the patch to obtain maximum coupling and lower cross polarization. Moreover the shape and size of the aperture must be arranged carefully for handling the matching of the antenna[6].

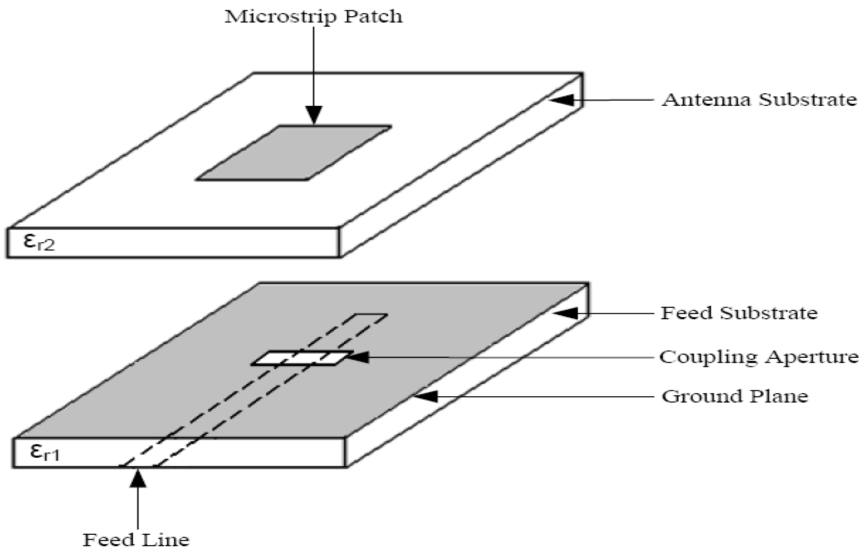


Figure 10. Aperture Coupled Microstrip Feed[12]

3.2.3.4. Dielectric Waveguide Coupling Feed

It is an alternative feeding technique that resembles Coplanar Microstrip Coupling Feed (Figure–11). Moreover this feeding is more efficient than Microstrip Coupling because of low-loss property of dielectric. But besides its efficiency this feeding technique is rather difficult to design. The interception of coaxial line with the dielectric wave guide is another difficulty and problem source for designers. As design criteria of dielectric waveguide coupling feed, the wave guide must be aligned as the distance between the patch is in reducing order. Also designer must be careful about the spurious radiation originated from dielectric wave guide coupling.

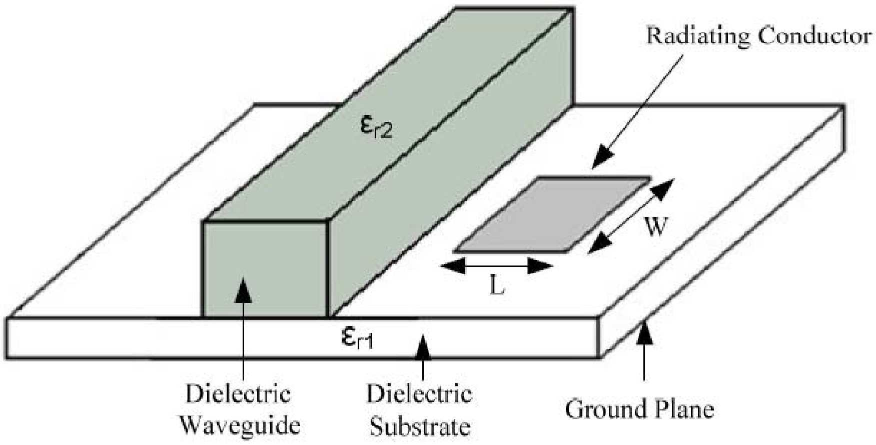


Figure 11. Dielectric Waveguide Coupling Feed[12]

3.3 Microstrip Patch Array Feeding Networks

Arrays are one of the most popular concepts for microstrip antennas. In several antenna applications single element is not sufficient, for example synthesizing a required pattern cannot be achieved with a single element. In addition, the applications that need beam scanning could be realized perfectly by only array networks. Moreover, increasing the directivity and performing various other functions that would be difficult for only one element can be done by using arrays.

The array elements can be fed by two ways. First one is The Series Feed Network, and the second one is the Parallel Feed Network.

3.3.1 The Series Feed Network

This model feed network based on a continuous transmission line which feeds all of the patch elements separately (Figure-12). By using this technique, there is no need to use lots of power dividers for feeding the radiating elements. But as a result of feeding from same source, the radiating patch elements can be feed sequentially. Therefore, this makes the excitation coefficient of each patch gets different value and the elements coming after for the feed line get less power from the feed. So to pass over this problem some design techniques must be used.

This feeding technique can be used for linear and planar arrays. Different polarizations can be achieved by using this feeding technique. In addition, for design criteria the distance between the elements of array must be multiples of half-guided wavelength for avoiding phase shift of the feeding signal to the radiating patch element. As our design concept where beam direction is needed to change this feeding method is one of the best choice. Because, when the frequency changed, the guided wavelength of the signal changes, so the patches are excited with different phase valued signal and that causes the beam steering.

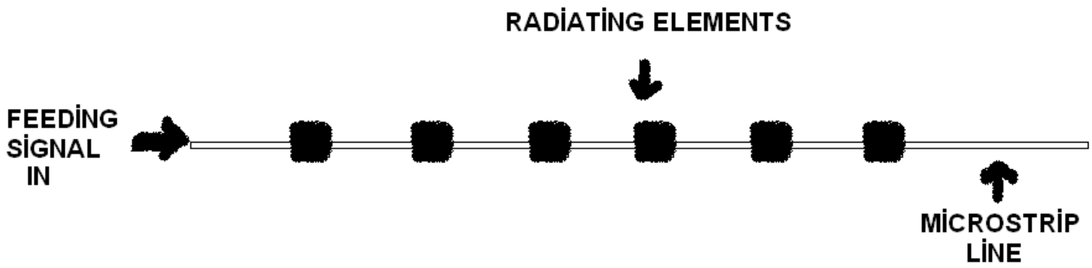


Figure 12. Series Feed

3.3.2 Parallel Feed Network

There are several parallel feed alternatives exist. For parallel feeding method each radiating element is individually excited. In addition the power is divided into the number of elements. As a result all the elements get equal power for radiation. Moreover each patch is coupled with same phase valued signal. Consequently this technique makes the antenna beam to radiate in broadside direction with frequency independency. However this feeding technique is not so simple. First of all, all the lines must be equal in length, then there must be several power dividers used to distribute the power to each patch equally. But using a lot of power dividers increases the losses gradually, so these antenna types become more inefficient than the others.
In Figure-13 a paralel feed network example can be seen.

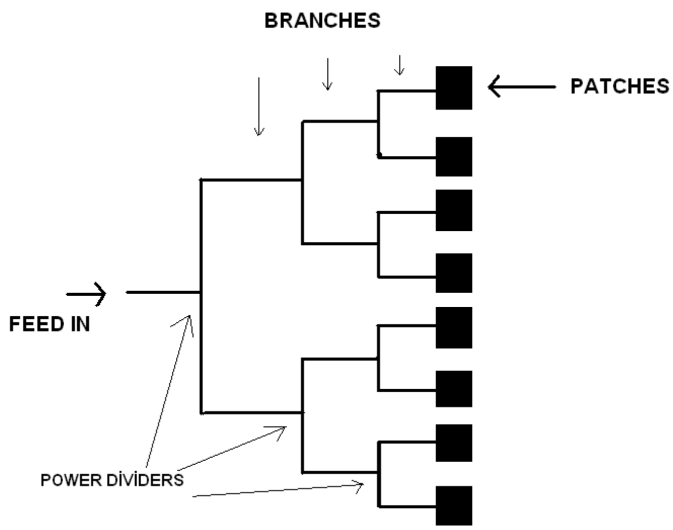


Figure 13. Parallel Feed

Beside the parallel and series feed networks there exists the hybrid feeding solutions. It is the combination of the series and parallel feed networks and an example of hybrid feed network can be seen on Figure- 14;

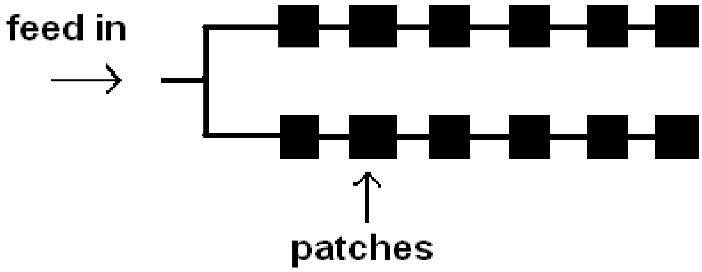


Figure 14. Hybrid Feed

3.4 Determination of the Suitable Feeding Technique

First of all, in our design it is needed to make an antenna suitable for beam scanning applications. As it is investigated that the feeding methods in this section that, series feed array is appropriate solution for the objective of designing a beam scanning antenna. In addition after comparing the advantages and disadvantages of connection of signal feed with microstrip line, Panel Launch Coaxial Line Feed is decided to use in our design.

However, as it is indicated before there are several series feeding techniques but it is decided to use serial coupling feeding array in BSMS antenna. Proximity Coupling tecnique is chosen, because this tecnique has a great effect on increasing the bandwidth up to about %15 and also this feeding technique has several advantages for phase exitation of phase elements[11].

In addition for the connector choice one must be careful about mismatches and reflection losses. Connectors are differentiated between each other for being appropriate for different frequencies. As a result it is decided to use a panel launcher for 10GHz in the design of BSMS Antenna as a feeding connector.

CHAPTER 4

TRAVELING WAVE ANTENNAS

Traveling wave antennas are the structures designed for radiating the beam in any direction between back fire and end fire of the antenna. A traveling wave antenna is terminated by a resistance that matches its characteristic impedance, so no standing wave is present. As a result of the lack of standing wave means that the length of the traveling wave antenna is not depend on the signal frequency that will be received or transmitted.

In addition, if the traveling wave microstrip antenna is investigated; it can be seen that the end of microstrip line is terminated by a resistive match. This is required as it is mentioned before; for avoiding standing waves on the antenna. If there is standing wave on the antenna, the radiation is totally to the direction of broadside, so for radiation in any direction between back fire and end fire, a good resistive match at the end of the antenna structure is needed.

Moreover it is investigated that any TEM structure can support the radiation of traveling-wave. As a result microstrip patch type radiators are chosen for acting as a traveling wave antenna for beam scanning applications [9].

4.1 Radiation Mechanism

In traveling wave antenna both guided wave and radiated wave are transported together. The guided waves traveling along the guiding structure excite the radiating elements, and then radiation occurs. As it is known from previous chapter the radiation element and feeding elements have different properties and required different valued characteristic parameters. But for traveling-wave antenna designer must coinside these two contradicted elements together.

The traveling waves are represented by a complex propagation constant;

$$\Psi = \beta - j\alpha.$$

The real part of the complex propagation constant ‘β’ gives the phase information of the guided signal, on the other hand the imaginary part ‘α’ is comes from excitation of elements responsible from radiation[9].
The theoretical equations for traveling wave antennas will be explained in more detail in the next sections.

4.2 Radiation Pattern

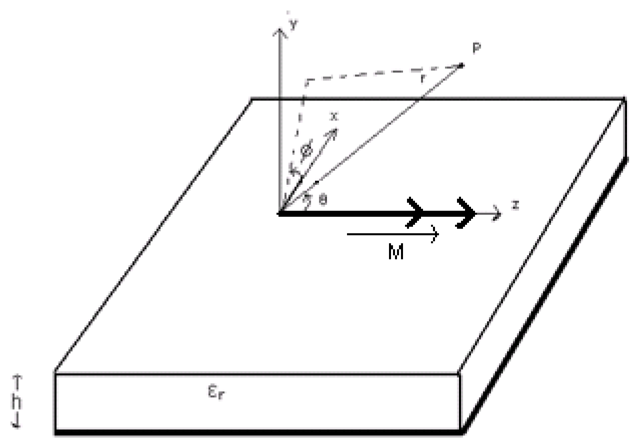


Figure 15. Traveling–wave Antenna

By using vector electric potential method, the far-field radiation pattern of a traveling-wave antenna represented by a magnetic current density M as shown in Figure-15. For a magnetic current line source, the vector electric potential at far-zone can be written as;

$$F = \frac{\in}{4\pi} * \frac{e^{-jk_0 r}}{r} * \int_0^L M(z) e^{jk_0 cos\theta_z} \, dz$$

, where M(z) = $\hat{z} M_0 e^{-j\gamma z}$ and M_0 is the magnetic current at z = 0.

The vector potential can be written as;

$$F_z = -j \frac{\in M_o}{4\pi} * \frac{e^{-jk_0 r}}{r} * \frac{e^{jL(k_0 cos\theta - \gamma)} - 1}{(k_0 cos\theta - \gamma)}$$

and far field components of the magnetic field can be obtained as;

$H\Phi = 0,$

$H\theta = jwFzsin\theta,$

$E\Phi = -\eta H_\theta$,

$$= - \frac{k_o V}{2\pi} * \frac{e^{-jk_0 r}}{r} * \frac{e^{jL(k_0 cos\theta - \gamma)} - 1}{(k_0 cos\theta - \gamma)} * \sin\theta.$$

$E\theta = 0,$

4.3 Beam Direction:

Beam direction of the traveling wave antenna is given by the below formula [9]. To obtain this formula the derivative of R(θ) with respect to θ is taken and equated to zero to find the angle where maximum radiation occurs.

$\theta_m = \cos^{-1}(\beta / k0)$ when $\alpha = 0,$

And for arbitrary Ψ values the angle can be calculated by the following formula:

$$\theta_m = \cos^{-1}\left[\frac{\left(k_0{}^2+\beta^2+\alpha^2\right)-\left[\left(k_0{}^2+\beta^2+\alpha^2\right)^2-4k_0\beta^2\right)\right]^{1/2}}{2k_0\beta}\right]$$

4.4 Efficiency:

η, efficiency of the antenna is basically given by the derivation of Radiated Power/Input Power.

$$\eta\% = \frac{P_r}{P_0}\,x\,100.$$

$$P_0 = P_r + P_L + P_T$$

P_0 is the power fed to the antenna.

P_r is the power radiated per unit length,

P_L is the power dissipated due to ohmic and dielectric losses.

P_T is the power absorbed in a matched load. [9].

CHAPTER 5

BSMS ANTENNA DESIGN

<u>In this chapter the design methodology for the BSMS antenna structure will be discussed.</u>

The design starts with the choice of the individual elements of the BSMS array. Then, the parameters affecting the realization of the desired radiation pattern must be taken into consideration. . Finally, the feeding technique suitable for the BSMA structure must be decided..

There is need to compare different design alternatives for the beam scanning application because as it is was mentioned before, there are several design alternatives for microstrip antennas. Radiating slot antennas or radiating patch antennas can be used as a BSMS antenna. So initially, a traveling wave aperture coupled slot array is designed using the simulation program ENSEMBLE 8.0.

5.1 Slot Array BSMS Antenna Model:

As seen on the Figure-16, the slot array antenna can be basically designed with a dielectric substrate above a microstrip line and a top layer of ground with radiating slots. This model has bidirectional radiation pattern different from microstrip patch antennas. However it can be resembled to microstrip patch ones by using a ground reflector under the microstrip feeder line. Two slot array antennas are designed for comparing the radiation properties between each other and patch array ones.

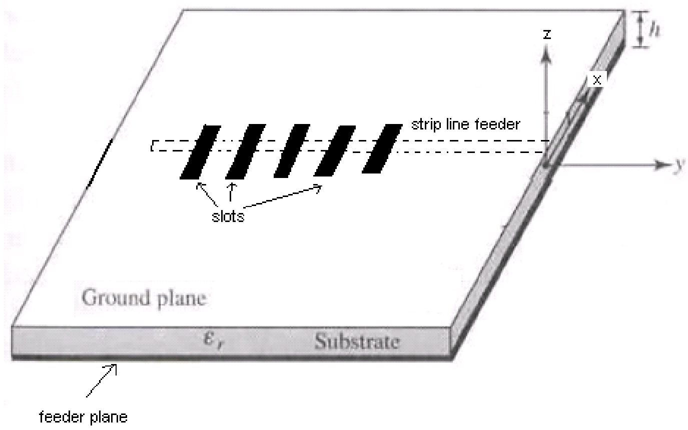


Figure 16. Aperture Coupled Slot Array Antenna

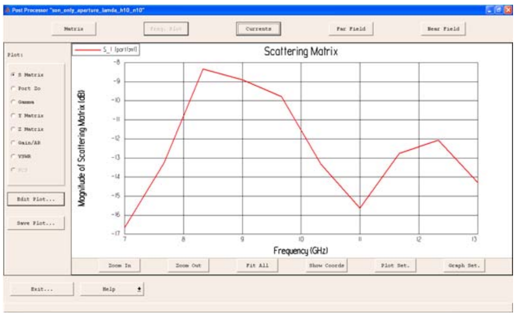
5.1.1 Comparison of Radiation Patterns:

The only difference for the constructed slot array antenna designs is the number of elements. We have a design of slot array with 10 elements and a design of 5 elements.

After designing the models with the simulation program ENSEMBLE 8.0, the simulation results of radiation patterns are taken as seen on Appendix B**.**

The Gain of the antenna array with 10 elements is higher compared to with 5 element one and also the beam width is narrower for 10-elements antenna array.

(a) S_{11} for N=10 model **(b) S_{11} for N=5 model.**



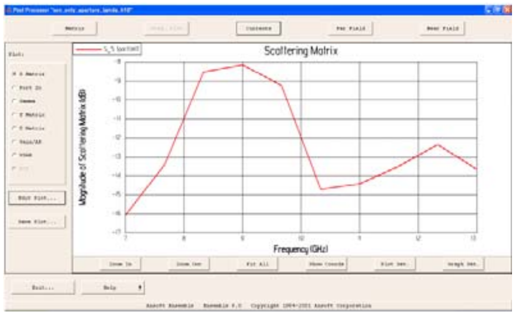


Figure 17. S_{11} values for (a) N=5 model. (b) N=10 model.

As it is seen from Figure-17, S_{11} parameter is approximately same for each design. Secondly the port characteristic impedance is simulated as 50 ohm as seen on the Figure-18.

This is done by calculating appropriate line width for microstrip line by using the equations seen on Appendix A.

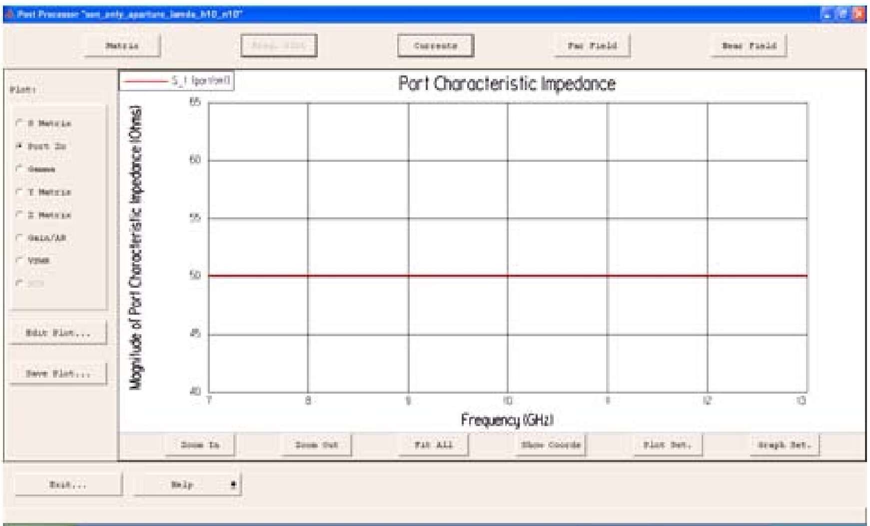


Figure 18. Port Characteristic Impedance of Slot Array Antenna

As a result, after simulating the designs and investigating the antenna parameters, it is seen that aperture coupled slot array has less gain values and the S_{11} parameter is not appropriate for a design of BSMS antenna. So it is decided to construct a Microstrip Patch Array for the beam scanning application.

5.2 Microstrip Patch Array Antenna Design

As it is indicated before microstrip patch antennas are unidirectional antennas. In order to make a beam scanning antenna with efficient antenna parameters array approach must be used for this patch antenna design.

5.2.1 Single Element Design

Because of determining the operating frequency, bandwidth and the physical shape of the overall structure, the single element of radiating patches of the array structure is the most important step of the design. The dimensions of each patch element are independent of overall structure.

The criterias for designing a single radiating element are:

- Appropriate dielectric substrate.
- Appropriate radiating patch geometry.

The design material is chosen as RO-4003. This material is stronger and durable to environmental effects. It is widely used in electronic word. Moreover its loss tangent at 10 GHz is small and as a criterion of ‘high loss tangent increases dielectric loss and therefore reduces antenna efficiency’, this is better for our design.

It has the dielectric properties as seen on the Table-1 below:

TABLE-1 Characteristics of RO4003 Material.[10]

ROPERTY	*RO4003*	*UNITS*
Dielectric Constant @ 10 GHz	*3.38 ± 0.05*	_
Thermal Coefficient of ε_r @0 to 100^{0}C	*+ 40*	*ppm/^{0}C*
Dissipation Factor @ 10 GHz	*0.0027*	_
Glass Transition (Tg)	*>280*	*^{0}C*

RO4003 is a material, which is processable by a large number of designers. Because;

- It has lower processing and assembly costs.
- It can be fabricated like FR4.
- It is ideal for applications with higher operating frequency requirements.
- It is ideal for multilayered and mixed dielectric constructions.
- It is ideal for applications sensitive to temperature change.
- It is ideal for designing patch antennas.

After selecting the dielectric material, selection of the geometrical shape of the radiating patch element comes. Rectangular, circular and dipole patch elements are most widely used structures as patch radiators. After comparing the design simplicity, fabrication and for better analysis and results rectangular patch type is selected for the design of BSMS Antenna.

Lastly, shaping of the structure is handled and as a result we make our selection as it is written below;

A ticker substrate is a good choice for better radiation. Because it will increase the radiated power and reduces the conductor loss. Moreover the substance becomes mechanically strong and the impedance bandwidth improves. However there are some disadvantages besides these advantages. For instance the weight increases, surface wave loss increases and lastly dielectric loss also increases with increasing the substrate thickness.[1,4]

Element Length and Width.

The element length affects the resonant frequency and radiation pattern of the antenna. While the patch width has lesser effect on resonant frequency and radiation pattern, it affects the input resistance, bandwidth and radiation efficiency.

The most suitable choice for width and length of a rectangular patch is formulated as [7]:

$$1 < W/L < 2.$$

The relationship between resonant frequency and the length is given by:

$L = \frac{c}{2f_r\sqrt{\varepsilon_{re}}} - 2\Delta L$, where ε_{re}, is the effective dielectric constant which is defined as:

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + \frac{10}{u}\right)^{-ab} \quad \text{where, } u = \frac{W}{L}$$

$$a = 1 + \frac{1}{49} ln\left\{\frac{u^4+(\frac{u}{52})^2}{u^4+0.432}\right\} + \frac{1}{18,7} ln\left\{1 + (\frac{u}{18.1})^3\right\}.$$

$$b = 0.564\left(\frac{\varepsilon_r-0.9}{\varepsilon_r+0.3}\right)^{0.053}$$

ΔL is the fringe factor and can be written as [1]:

$$\Delta L = 0.412h\frac{(\varepsilon_{re}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{re}-0.258)(\frac{W}{h}+0.813)}, \quad \text{where,} \quad (W/h \geq 1).$$

Because of the design considerations; it is decided to work at center frequency of 10GHz. An antenna which steers the beam direction around this frequency is tried to design. For example, from 9GHz to 11GHz the beam angle can be changed to θ_1 to θ_2 which is the angle between normal of array axis and propagation vector r.

$$f_0 = 10\ GHz,$$

ε_r= 3.38, for the dielectric substrate RO4003 (table-1).

The total thickness of the substrate for the antenna is:

$$h = h_1 + h_2 \; = \; 2.05mm.$$

$$W \; = \; \frac{c}{2f_r}\left(\frac{\varepsilon_r+1}{2}\right)^{-1/2}.$$

By using the above equation it is found that $W = 9{,}136$ and for simplicity it is taken as $W = 9mm.$

Then,

$\mathcal{E}_{re}$= 3.3.

$\Delta L = \; 0.71mm.$

As a result by making the calculations, it is found that:

$L = \; 6.9mm$ for 10 GHz.

Now, there is a radiating rectangular patch with length=6.9mm and width=9mm.

Selection of Feeding Method

As it is indicated before, there are several feeding structures for a microstrip patch antenna. After making an interpretation for a better design, it is decided to choose proximity coupled feeding technique for the design of BSMS Antenna. Because this technique is crucial for the array approach and also by using this method, the operating bandwidth increases up to 15-20% [11].

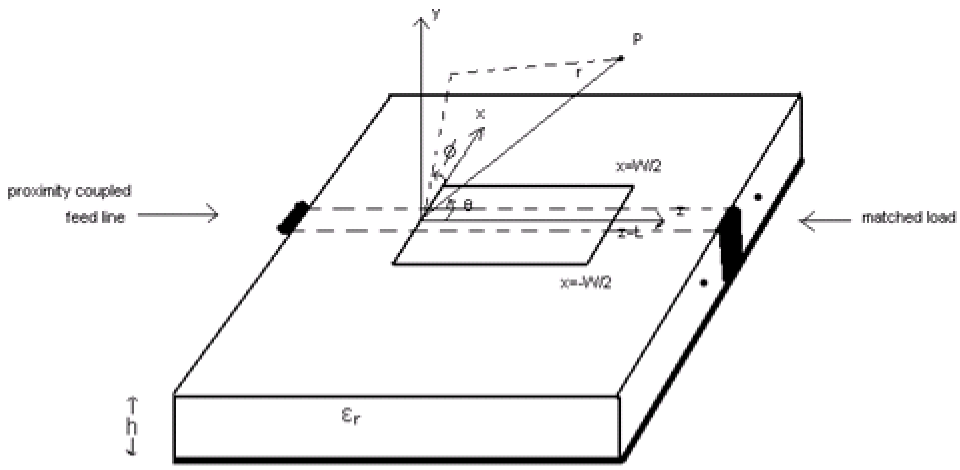


Figure 19. A Proximity Coupled Patch Antenna with Match Load.

A single rectangular patch with proximity coupling feeder is represented on the Figure 19. The difference of this design from other ordinary patch antennas is its matced load at the end of feeder line. By matching the feeder line, the goal of steering the beam from back fire to end fire is achieved.

The configuration is also drawn by using Ensemble Simulation Program (Figure-20) as:

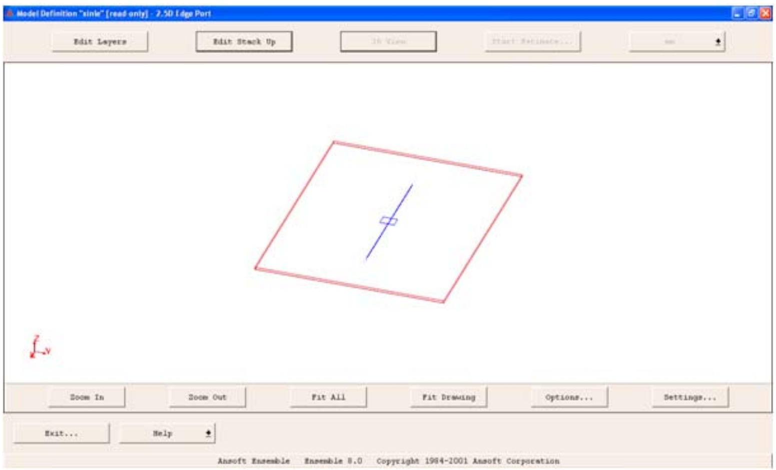


Figure 20. A Single Patch Antenna's Top View

The rectangular patch is located at the center point which is the origin of xy plane. The length is located between y= -4 and y= +4,

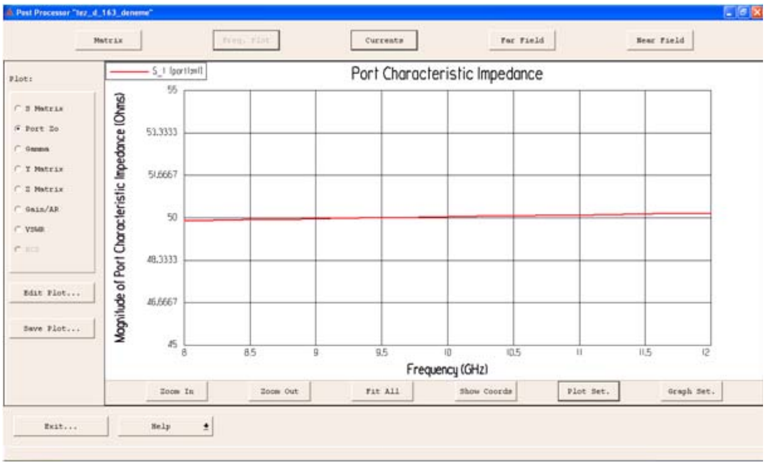


Figure 21. Port Char. İmpedance of Single Patch Antenna

First, the microstrip line is not terminated by a 50 ohm resistance it is leaved as an open circuit then the radiation field of E at center frequency of 10 GHz becomes as seen on Figure 22 below. The radiation pattern of the antenna can not be changed by changing the frequency. The shape of the beam is always same for different frequencies from 9-11 GHz.

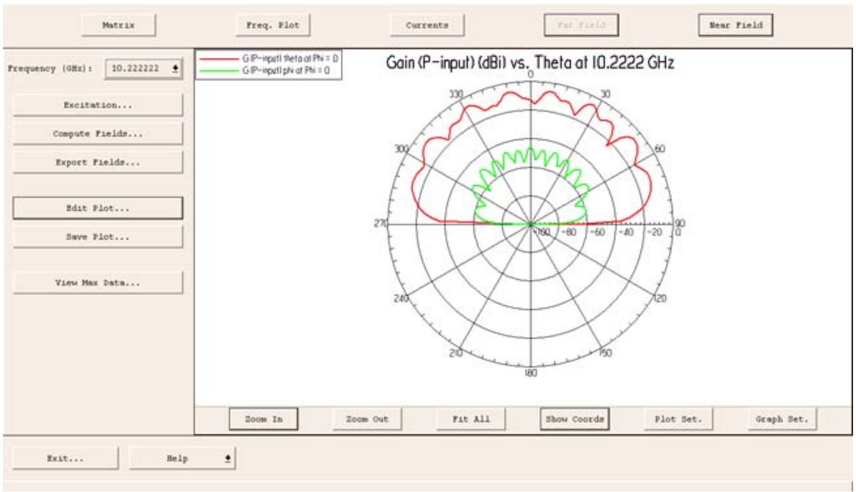
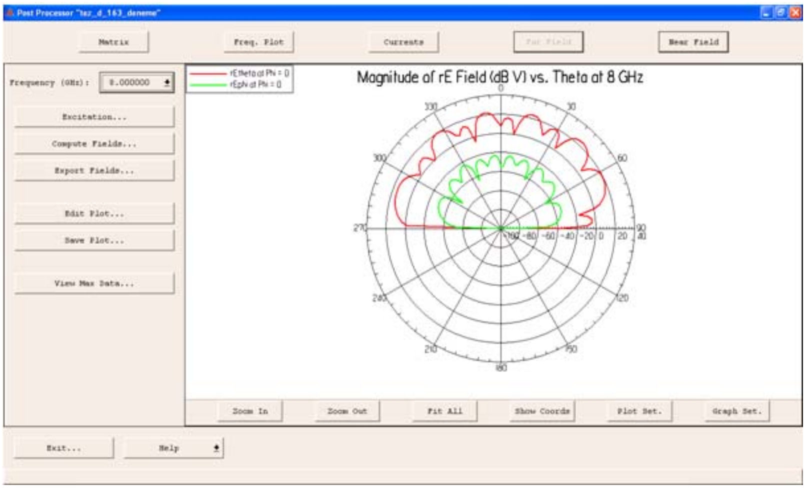


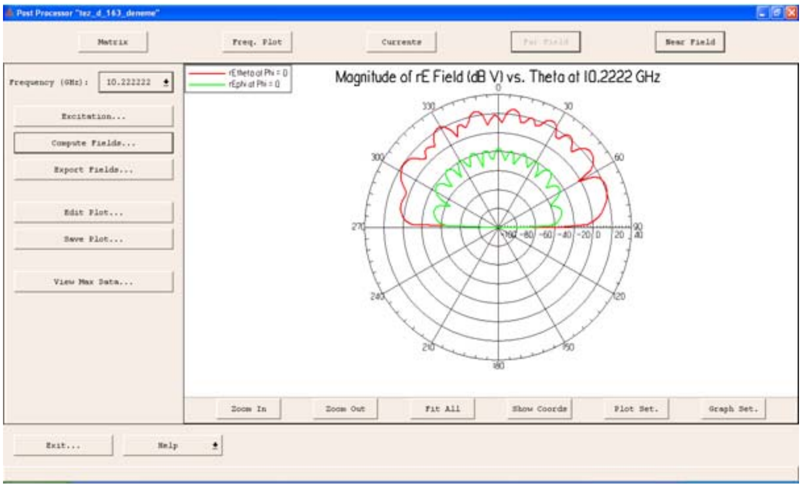
Figure 22. Beam Shape of Single Patch Antenna(open circuited feed line) at 10 GHz.

On the other hand, when the line is terminated; it is seen that the beam pattern is changed with changing the frequency of our input signal. But as it is seen on the following page, it is not as obvious as it is expected. So the array approach is used for a better design of beam scanning antenna.

(a)8GHz



(b)10.22GHz



(c)11.11GHz

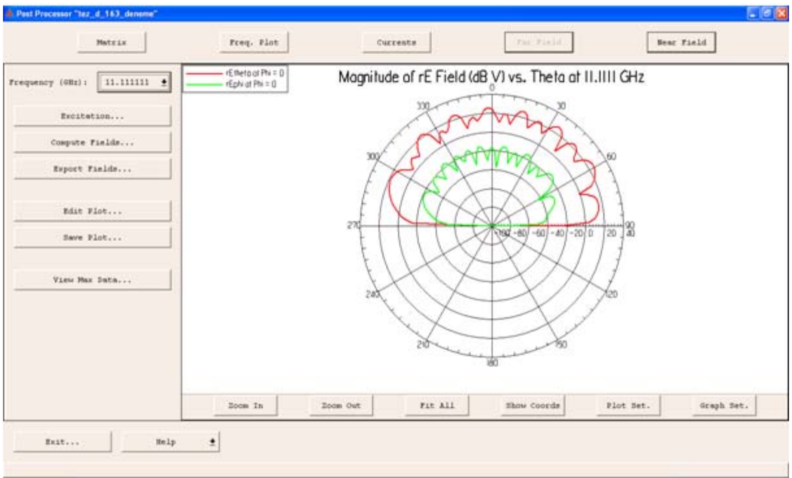


Figure 23. Beam Shape of Single Patch Antenna (with matched load feed line) at 8-11GHz

As it is seen from simulation graphs, the characteristic impedance of feed line is nearly 50 ohm in the frequency band of 9 - 11GHz range (Figure- 21).

The radiation pattern of E-field is directed to the broadside direction (Figure 23), there are several lobes at the broadside direction. But it can be said that approximately the beam is toward to the broad-side and steering of the beam is expected but because of spreading of beam to the all semi-sphere it can not be achieved. For solving this problem the array theory is used which will be shown at the following section.

Traveling wave antenna is represented by a complex propagation constant;

$$\Psi = \beta - j\alpha.$$

By using the ENSEMBLE simulation program the complex propagation constant is found approximately totally imaginary.

$$\Psi = \beta - j\alpha = 0.6 - 380j \quad \text{at 10GHz}$$

This means that the input signal is totally radiated and/or terminated. Losses are smaller compared to radiated/terminated one. This is because of taking the matching loss as negligible as it is explained before.

5.2.2 Array Design:

This problem of separated beams and several lobes is solved by using array technique of multi radiation elements, which means that the single element structure is changed to N element structure.

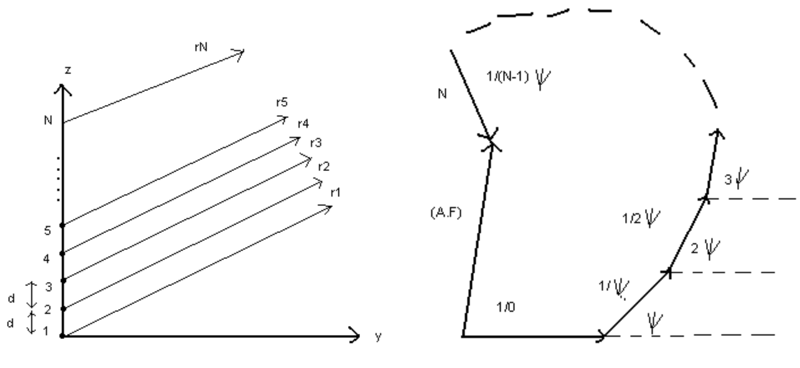
Generally, the single element radiation pattern is relatively wide. But for long distance communication it is needed to have very directive antennas. And this can be achieved by two ways. One is increasing the size of the element dimensions and the other choice is forming a multi element antenna configuration, called an ARRAY.

There are 5 important design criteria for an array these are

- The overall array geometry.(linear, circular, rectangular,spherical etc.)
- The amplitude excitation of the individual elements.

- The phase excitation of the individual elements.
- The relative displacement between the elements.
- The relative pattern of the individual elements. [3].

As a result for the configuration of a n-element linear array as seen on Figure-24 below;



(a) **(b)**

Figure 24. Array Theory

(a) N-element Linear Array

(b) N-phasors

The array factor is given by approximately as:

$$AF = \sum_{n=1}^{N} e^{j(n-1)\gamma}$$

Where $\gamma = kd\, cos\theta + \beta$.

Since the total array factor is a summation of exponentials (Figure-24), it can be represented by the vector sum of N phasors seen on the figure above.

Consequently after some approximations and taking some special circumstances [2,3], the final expression of array factor of equally distanced and equally phased with equal elements of any array becomes as:

$$AF = \left[\frac{sin(\frac{N}{2}\gamma)}{sin(\frac{1}{2}\gamma)}\right].$$

For the design of BSMS Antenna, linear array configuration is used. The elements are located in xy-plane and center element of the array located at the origin. The N is taken as 11, one element at the origin and five elements at positive side of y axis and the remaining are at negative side of y axis.

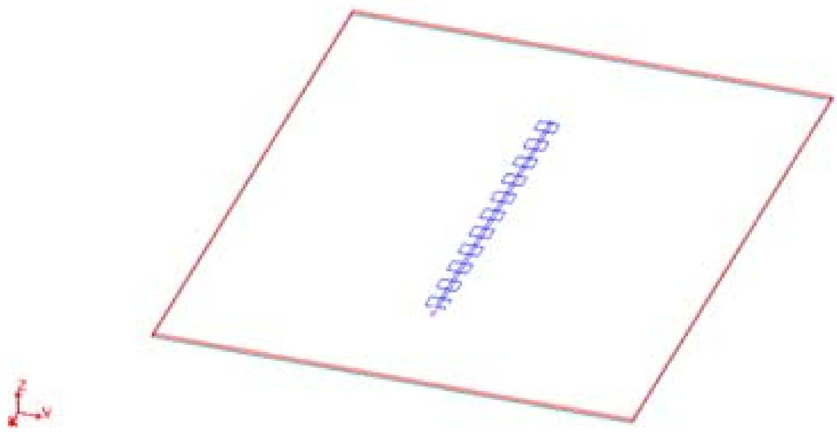


Figure 25.Top View of BSMS Antenna.

As it is seen on Figure-25, there are 11 radiating elements located at the upper side of structure. On the other hand, the 50ohm microstrip feeding line is located below the radiating patches and there is a coupling effect between them. And also at the bottom there is a ground plane which prevents backlobe radiation and also which is an obligation for a microstrip patch antenna configuration for better radiation.

The structure can be modeled as seen on Figure-26 below:

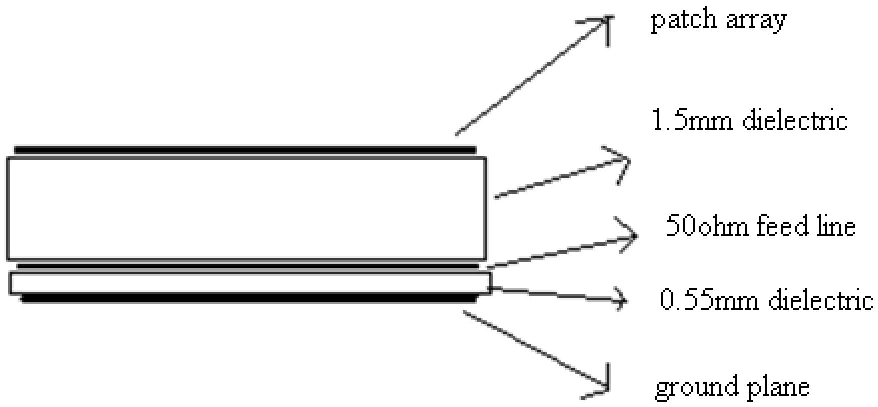


Figure 26. Side View of Simulated Antenna.

The radiating array has the properties of:

- Number of elements = 11
- Distance between adjacent elements = 16.3mm (which is equal to the guided wave length.)
- Each element is a rectangular patch with a length of 6.9mm and 9mm width.
- All the elements are equal in size.
- The total length of the array is 169.9mm.
- The ground plane length is 200mm and width is 140mm in size.
- The 50 ohm line has 1.08mm width and 190mm length.

The dielectric material used for this structure is RO4003. Which has the dielectric constant of 3.38 around 10GHz.

The distance between elements is chosen as one wavelength of guided signal because of eliminating the spurious gating lobes and increasing the gain this value is chosen. Moreover, crucially selecting the distance as a one wavelength provides phase orientation of signal for feeding the elements.[4]

<u>The 50 ohm feed line has a width of 1.08mm and length of 190mm.</u> the length is not important but the width is very crucial for determining the impedance of the line. The expression of calculating the impedance of microstrip line is shown in Appendix A. Also the dielectric constant of material and the thickness are important factors.The feed line is excited by a coaxial feed connected from left side edge by an appropriate probe connector. On the other hand the line is terminated from other edge by a 50 ohm resistance (which is the most important obligation for traveling wave structure).

After construction of the structure, the analysis point comes, it is expected to design an array of rectangular microstrip patches. So as a result the radiation pattern is mostly determined by array factor combination.

The structure is a 11 equal sized and equal distanced linear rectangular array. As a result, one must first look at the radiation pattern of one element

and then take the effect of array factor, for finding the overall radiation pattern of the structure. [2]
The expression for far field power pattern is:

$$F(\theta,\Phi) \; = \; |\, f(\theta,\Phi)|^2 \, . \, |\, f_e(\theta,\Phi)|^2$$

In which $f(\theta,\Phi)$ is for the array factor and $f_e(\theta,\Phi)$ for the element pattern.
It is easy to estimate the radiation pattern of one element because, that is a rectangular patch antenna with definite width and definite length. It can be basically said that the radiation pattern of one element is overall broadside direction of patch. It is broad type in the half sphere above the rectangular patch. Because of the ground plane, no radiations occur at the half sphere of the back region.

As a result the overall radiation pattern can be determined by only the array factor expression. The effect of the radiation pattern of one element is identity in all direction of θ above the patch.
In the design of BSMS Antenna, all elements is considered to excite with identical amplitudes but each succeeding element has a β progressive phase lead current excitation relative to the preceding one.

An array of identical elements all of identical magnitude and each with a progressive phase is referred to as a uniform array. The array factor can be obtained by considering the elements to be point sources. If the actual elements are not isotropic sources, the total field can be formed by multiplying the array factor of isotropic souces by the field of a single element. This method can only be applied to identical elements and it is called pattern multiplication rule [2,3].

The array factor for this structure is:

$$AF = \sum_{n=1}^{N} e^{j(n-1)\gamma}$$

where, $\gamma = kdcos\theta + \beta$

this expression can be expressed in more compact form as:

$$AF = [\frac{sin\,(\frac{N}{2}\gamma)}{sin\,(\frac{1}{2}\gamma)}],$$

The max value of this expression is N so the normalized form of the above expression can be written as:

$$(AF)n = \frac{1}{N}\,[\frac{sin\,(\frac{N}{2}\gamma)}{sin\,(\frac{1}{2}\gamma)}],$$

The expression of array factor, for equal size, equally distanced and equally excited elements is:

$$|\,f(\theta,\Phi)| = (\,\frac{1}{N}).|\frac{sin(\frac{N\gamma}{2})}{sin(\frac{\gamma}{2})}|,$$

And, after making some approximation as assuming uniform element excitation coefficient amplitudes as the perturbation per radiating element is fairly small and a linear phase taper which depends on the unperturbed propagation constant. The expression of the array power pattern is reduces to:

$$|\,f(\theta,\Phi)|^2 = (\,\frac{1}{N})^2.|\frac{sin(\frac{N\gamma}{2})}{sin(\frac{\gamma}{2})}|^2,$$

In which θ is the angle measured from z-axis. N is the number of radiating elements.

and $\gamma = k_0dcos\theta - k_zd$.

where

$k_0 = \frac{2\pi}{\lambda 0}$, where k_0 is the free space propagation constant.

$k_z = \frac{2\pi}{\lambda g}$, where k_z is the propagation constant of microstrip line.

$\lambda_g = \frac{\lambda 0}{\sqrt{\varepsilon_{re}}}$, where λ_g is the wavelength at the microstrip line.

ε_{re} ,is the effective dielectric constant.

As discussed before it is calculated as:

ε_{re} = 3,3 for this design. So,

$\lambda_g = \frac{\lambda 0}{\sqrt{\varepsilon_{re}}}$ = 16.3mm. ,for 10GHz.

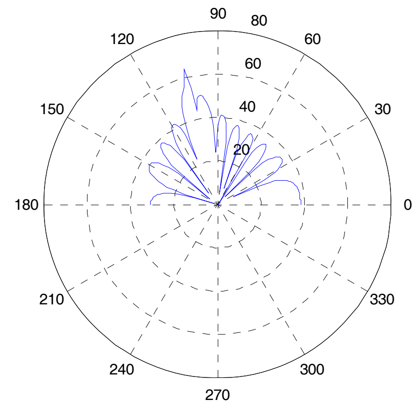
The aim is designing a beam scanning\steering antenna around 10 GHz so one must take the distance between each element as λ_g of 10GHz.

After determining the distance between each elemet and knowing the single elements radiation pattern. There remains only the array effect for the antenna's radiation pattern calculation.

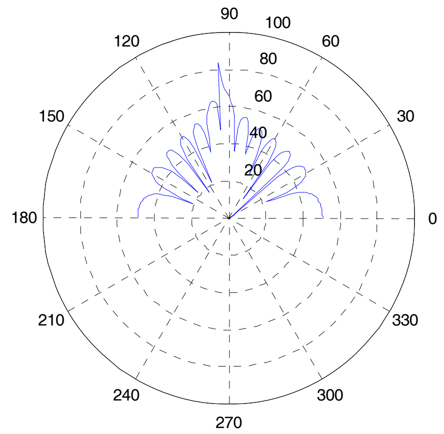
It is forecasted that every single element has same radiation pattern of broadside directed semispherical beam so for the array beam pattern the main determiner for the beam pattern is the Array Factor. So by taking the array factor equation as it is said before from MATLAB calculation program the beam pattern estimation can be done.

The MATLAB codes for determining the radiation pattern in the θ-plane are given in Appendix B and the MATLAB beam pattern simulations can be seen on Figure-27 at the following page.

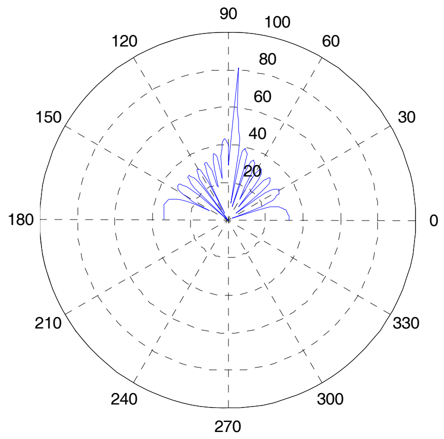
(a) 9GHz.



(b) 10GHz.



(c) 11GHz.



<u>Figure 27. MATLAB Simulation of Array Factor in Polar Coordinates</u>

After theoretical explanation of the design, there also have simulation graphs of radiation pattern of the antenna which are done by using ENSEMBLE 8.0 simulation program.

Table-2 Pattern Scanning with Frequency Changing.

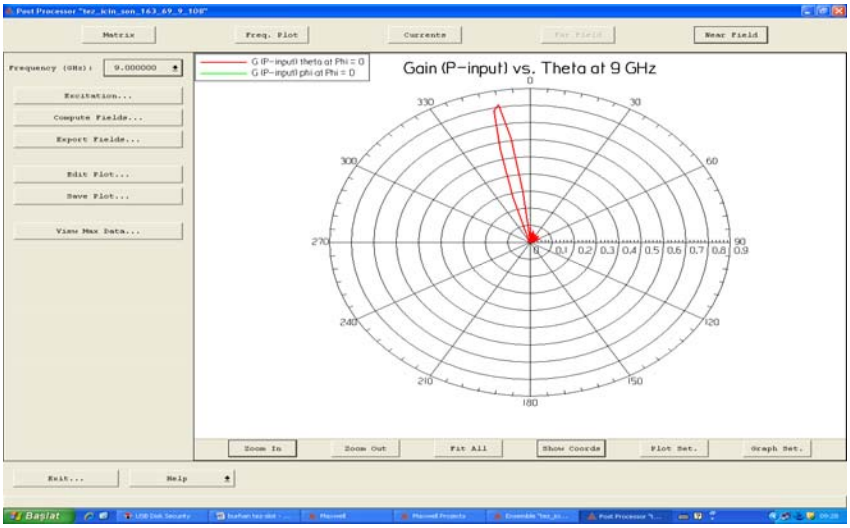
FREQUENCY	THETA	GAİN
9.22 GHz	352^0	1.234 dBi
9.44 GHz	354^0	3.29 dBi
9.66 GHz	356^0	4.61 dBi
9.88 GHz	360^0	5.49 dBi
10.11 GHz	2^0	5.98 dBi
10.33 GHz	4^0	4.86 dBi
10.77 GHz	6^0	1.6 dBi
11 GHz	8^0	0.6 dBi

At the Table-2 it can be seen that the maximum gain of the antenna is at center frequency of 10 GHz. And the gain of antenna decreases step by step when the cursor goes further from center frequency.

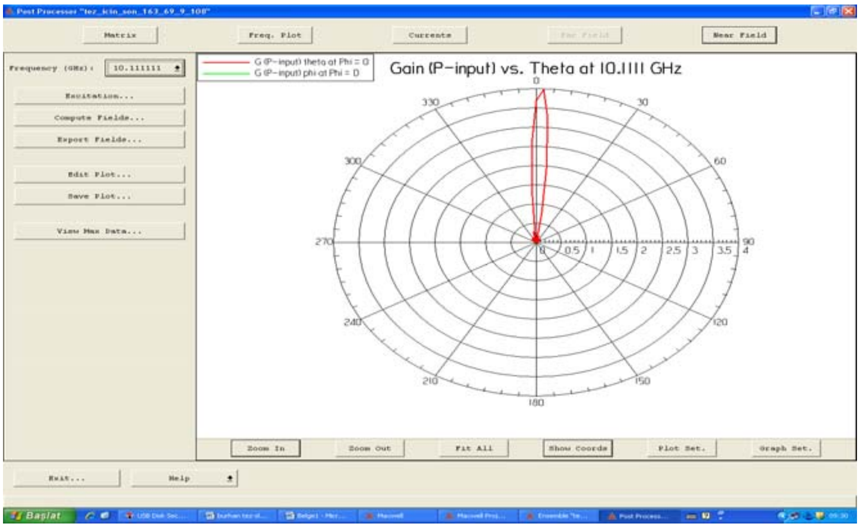
5.2.3 Simulation Results of BSMS Antenna

The Simulation results of E-Field Beam Pattern drown by ENSEMBLE 8.0 Program can be seen from Figure-28 at the following page:

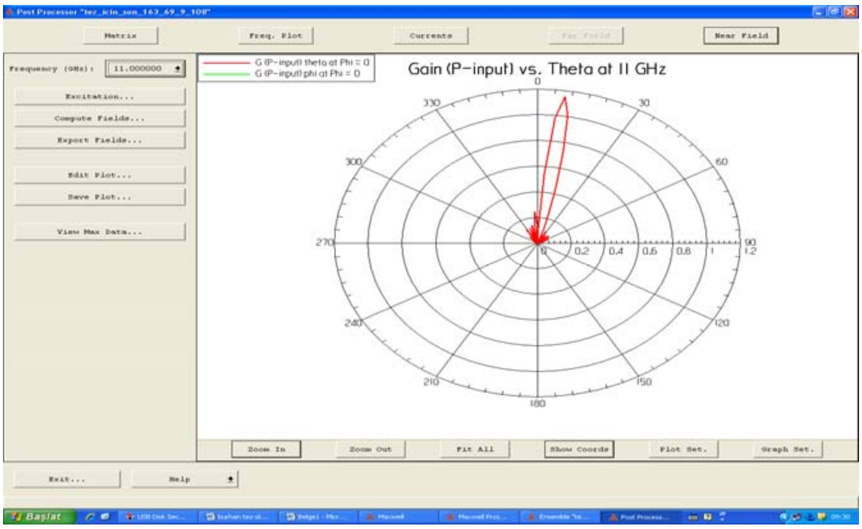
9GHz



10GHz



11GHz



<u>Figure 28. ENSEMBLE Sim. Results of Designed BSMS Antenna</u>

Consequently, the conformity between the MATLAB simulation and ENSEMBLE simulation results can be seen easily from the figures..

For matlab simulation only the array factor is taken and it is considered that the radiation of a single element has no directivity to any direction. It is considered as it radiates to the broadside direction with equal amplitude to the all hemisphere. As a result it is considered that the radiation equation of a single element as 1 and the radiation equation of the array approximately equated to the array factor as it is explained in detail above.

Table-3 S_{11} Values for Different Frequency Values

FREQUENCY	MAGNITUDE OF S_{11} in dB
9 GHz	-33.8 dB
9.5 GHz	-27.46 dB
10 GHz	-13.6 dB
10.5 GHz	-26.8 dB
11 GHz	-35.03 dB

As it is seen from Table 2 and 3 there is no any crucial reflection at the operating band of 9-11 GHz. The beam is steered from 352^0 to 8^0 efficiently.

Table-4 Magnitude of VSWR for different frequencies.

FREQUENCY	MAGNITUDE OF VSWR
9 GHz	1.29
9.5 GHz	1.46
10 GHz	1.44
10.5 GHz	1.19
11 GHz	1.22

Table 4 is prepared with the ENSEMBLE 8.0 simulation program, and it is seen that the VSWR values are also appropriate for the designing approach.

CHAPTER 6

VERIFICATION OF THE THEORETICAL DESIGN MODEL

A prototipe of BSMS antenna is produced and measurements of antenna characteristics are done by using special equipments in our department’s lab. As seen on the below photos antenna measurements are done in un-echoic chamber. Our prototype is consists of two layers. First layer is feeding layer and it is made of a dielectric substrate of Rogers RO4003 between ground plane and a microstrip feeding line. Second layer is also a dielectric substrate of Rogers RO4003 dielectric material with radiating patches over it. The dielectric constant of Rogers RO4003 dielectric substrate is ε_r =3,38 [10].

6.1 BSMS Antenna Production

The figure of our structure is as seen below;

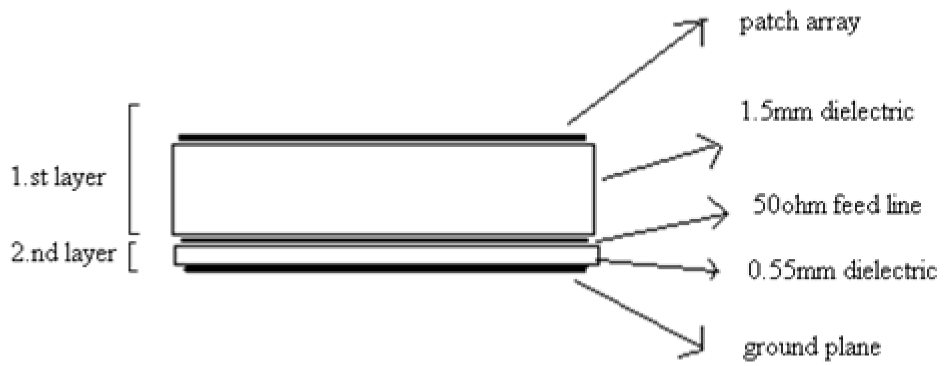


Figure 29.Side View Model of BSMS Antenna

We use only Rogers RO4003 dielectric substrate but they have different thicknesses (Figure-29). As we stated before in Chapter3 for radiation layer thicker substrate is more suitable because of needing wider bandwidth and better radiation. So we use the thickest one in our lab. It is 1,5mm and we have limited source. After that for feeding layer we need a thinner substrate for efficient feeding (from chapter3). Therefore we use our thinnest one of 0.55mm dielectric substrate of Rogers RO4003.

Then we come to the point of plotting and scraping off the microstrip line and radiating patch array. We use LPKF machine which is a special macine for printed circuits and printed antenna designs. We use 20x14 cm substrates for feeding layer and radiation layer which is appropriate for our design considerations. After plotting the microstrip line and patch array by using Proteous Drawing Program, we scraped off the microstrip line and patch array by using LPKF machine. After producing our layers we come to the operation of aligning and integrating of the layers. First we take off the copper cladding of 1.5mm Rogers RO4003 dielectric substrate. Because it is a two-layered substrate and we need one-layered one. For 0.55mm dielectric substrate we do not make anything because we use its coppered layer as the ground plane for our antenna. It is 20x14 cm in size and it is enough for being a ground plane for a 10 GHz microstrip antenna. Because it needs 3 or 4 times bigger than freespace wavelength sized ground plane and it is approximately 12x12 cm in size for our application.

For aligning and integrating the substrates we use a drilling machine and screws. We use 20 screws for integrating the layers (Figure-30). We use so many screws because of a better integration of the layers. The coupling between the microstrip line and patch array is the crucial point of our design so we need to make the aligning and integration perfect. As seen on the below photos we try to make aligning and integration of layers as well as possible.

Figure 30. BSMS Antenna

6.2. Measurements of the Antenna Parameters

As a result, the goal is achieved and the BSMS Antenna is designed as seen on the photos. After that we need to prepare our test equipments in eneqoic chamber as seen on the below figures.

Figure 31. BSMS Antenna Measurement Set-up

There is a signal amplifier below the antenna (Figure-31). It amplifies the signal coming from the antenna about 36.5 dB.

There is a horn antenna at the broadside of the antenna axis (Figure 32). The test equipment is rounding with respect to its axis and as a result the beam pattern of the antenna can be measured. The test area, test equipments and the results seen from the computer can be seen from the following figures.

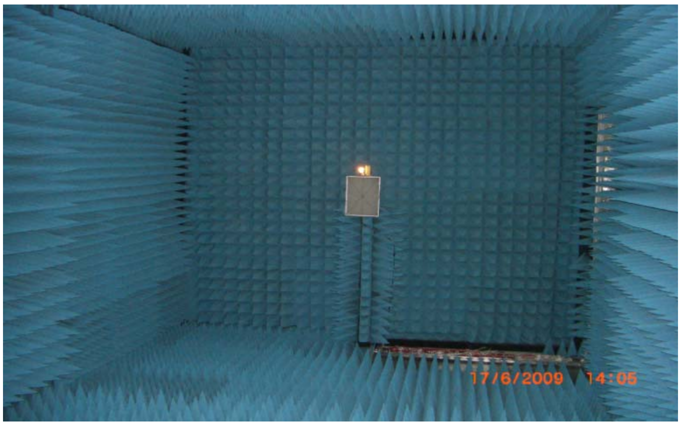


Figure 32. Antenna Test Area.(Anechoic chamber)

The anechoic chamber is a room for testing the antenna parameters. The inside of the anechoic chamber is covered with radiation absorbent material (RAM) as seen on the figure 32. The RAM is a material designed and shaped for absorbing the incident RF radiation as effectively as possible.

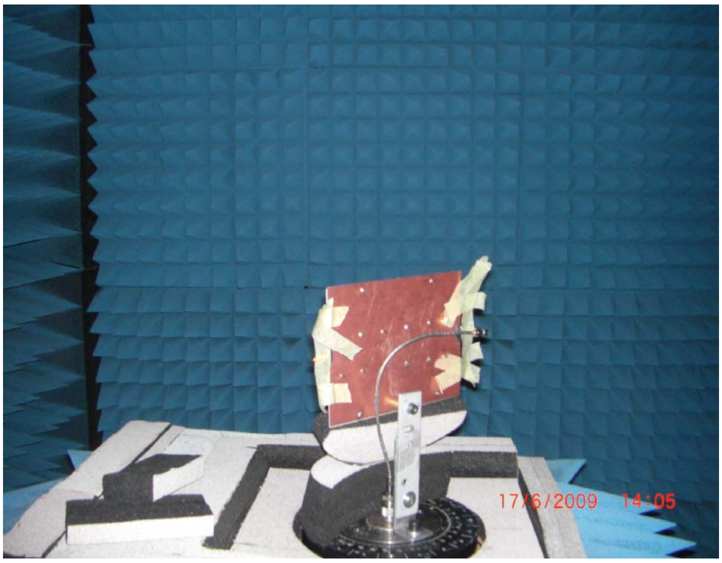


Figure 33. Antenna Rotation Mechanism

Antenna rotation Mechanism: It rotates the antenna 360^0 at the horizontal plane as seen on the figure 33 and 36. For aligning the receiver antenna and transmitter antenna we put our antenna axis 19cm above the top surface of rotation mechanism. We put absorbers around our antenna for having better test results as seen on the photos.

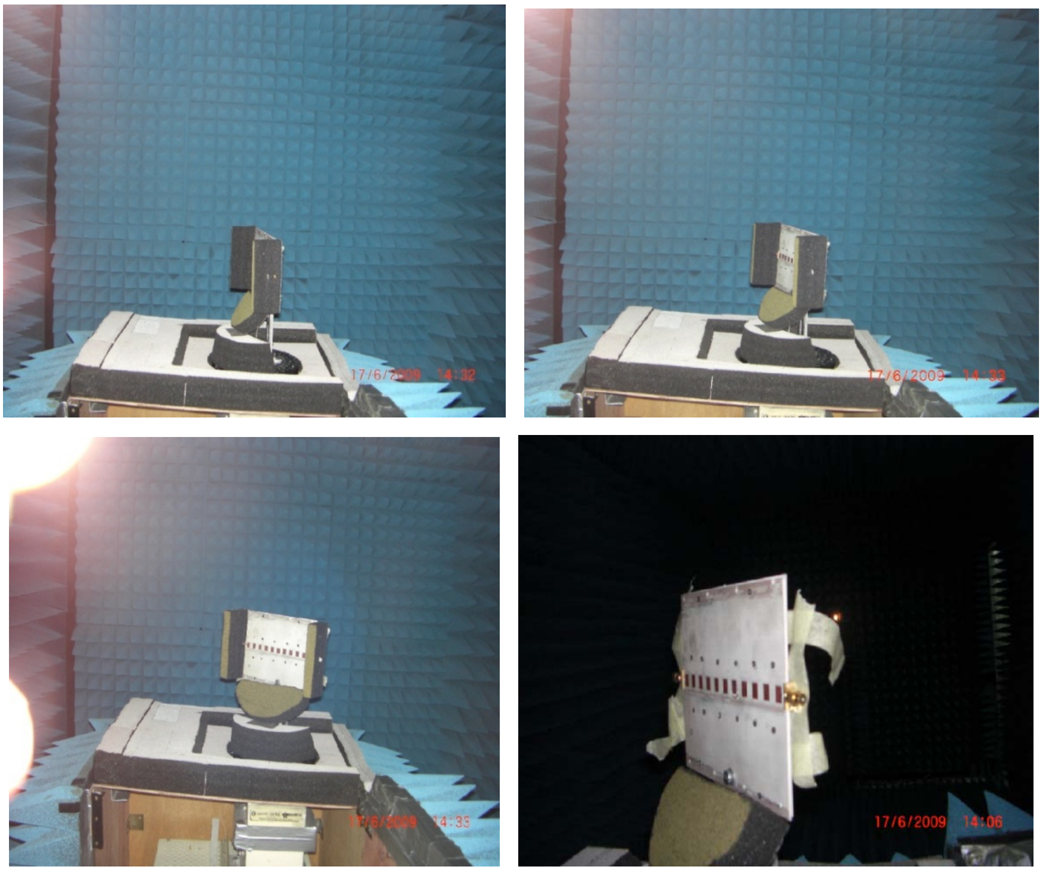


Figure 34. Antenna Photos in Test Environment

Measuring the beam pattern

The experiments are done in the anechoic chamber. The experiment tools are connected to each other for taking the results of the antenna parameters. Practically the photos of beam pattern results are taken from the anechoic chamber's computer monitor as seen on the Figure-35 at the following page.

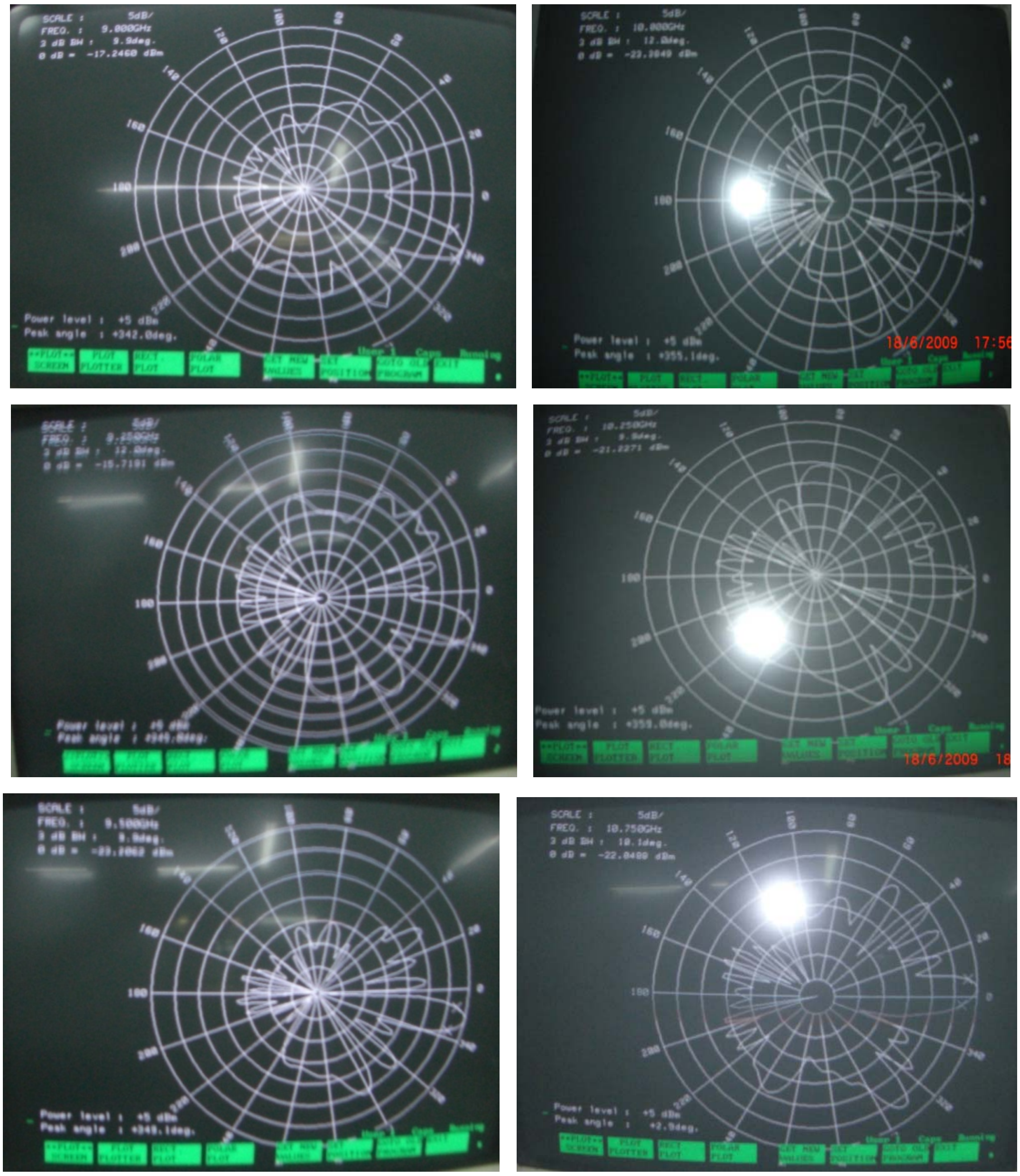


Figure 35. Photos of beam patterns(0^0 is broadside direction.)

And then, it is seen from the Figure-35 that, the main beam of the antenna is steered from 340^0 to 5^0. The power levels and the beamwidth of the main beam and the side lobes are not perfect but they are compatible with the simulation results. The more detailed figures with the gain and beamwidth values of the above beam patterns can be seen on Appendix B.

The Reflection Coefficient (S_{11})

By using the network analyzer in the lab, the S_{11} values for different frequencies are measured. The figure of frequency vs S_{11}, S_{12} = S_{21}, S_{22} values can be seen on the Figure-36 below.

<u>Figure 36. S_{11} S_{12} S_{22} values of the BSMS Antenna</u>

The reflection coefficient of S_{11} is somewhat below the -10dB level. There are some peak values between 9 - 10 GHz band but this can be corrected by squeezing the plates more tightly. The measurement scale is chosen for 8-12 GHz band and it is seen that generally our S_{11} value is below -10dB. This is because of terminating the microstrip line by 50 ohm resistance. This termination requires for beam scanning/steering application and that also makes a light coupling between radiation elements and the microstrip line. This property is needed for an unpertubed signal traveling and excitation of array elements [2].

As a result much of the signal is terminated on the matched 50 ohm load. This can also be seen from the results of S_{12} values of the antenna for which the $S_{12} = S_{21}$ because the BSMS Antenna is a symmetrical antenna.
The measured S_{11} values can be seen on Table-5 below;

Table-5 Measured S_{11} values of BSMS Antenna

FREQUENCY	MAGNITUDE OF S_{11} in dBi
9 GHz	-10.28 dB
9.5 GHz	-14.3 dB
10 GHz	-19.6 dB
10.5 GHz	-16.8 dB
11 GHz	-10.23 dB

The Transmitted or Terminated Power (S_{12})

As it is mentioned before the BSMS Antenna requires unperturbed signal excitation for making the beam scanning event accurately. Additionally, this unperturbation requires smaller excitation of radiating elements which is done by using the matching load. Therefore the S_{12}=S_{21} value is measured so high, as seen on the table-6 and the Figure-36.

Table-6 Measured S_{12} values of BSMS Antenna

FREQUENCY	MAGNITUDE OF S_{12} in dBi
9 GHz	-5.2 dB
9.5 GHz	-2.8 dB
10 GHz	-3.3 dB
10.5 GHz	-5.01 dB
11 GHz	-3.23 dB

Polarization

The polarization of the antenna can be determined easily because basically there is a one feed point and a 50 ohm termination on the other side. But, although we have this configuration we prepare our polarization test environment manually. By rotating the receiver antenna around its own x-y plane and measuring the power levels of received signal Table-7 is formed. We can estimate the polarization of the antenna from the table as seen below.

Table-7 Power Levels of Receiver antenna

Theta Angles	Normalized Power Values at Broadside Angle
0^0	0.21 dB
15^0	1.89 dB
30^0	3.03 dB
45^0	5.42 dB
60^0	8.51 dB
75^0	12.06 dB
90^0	20.30 dB

The antenna's power is maximum at 0^0 angle and the antenna accepts very small power at 90^0. The cross polarization is acceptably small for this antenna. As a result, one can say that the antenna is linearly polarized.

Gain

For calculating the gain of our antenna, we get three different measurements such as [14]:

- Antenna 1 is transmitter – BSMS antenna is receiver
- Antenna 1 is transmitter – Antenna 2 is receiver
- BSMS antenna is transmitter – Antenna 2 is receiver

From these measurements, we can write the following expressions:

$$P_1 = P_{in} + G_1 + G_2 + \left(\frac{\lambda}{4\pi R}\right)^2_{db}$$

$$P_2 = P_{in} + G_1 + G_3 + \left(\frac{\lambda}{4\pi R}\right)^2_{db}$$

$$P_3 = P_{in} + G_2 + G_3 + \left(\frac{\lambda}{4\pi R}\right)^2_{db}$$

And as a result we get:

$$2G_2 = P_1 + P_3 - P_2 - \left(\frac{\lambda}{4\pi R}\right)^2_{db}$$

After considering the cable losses as -5 dB on both sides and Amplifier as 36,5 dB, we get the Gain expression as:

$$2G_2 = P_1 + P_3 - P_2 - \left(\frac{\lambda}{4\pi R}\right)^2_{dB} + Loss_{cable}(Tx)_{dB} + Loss_{cable}(Rx)_{dB} - (Amplifier)_{dB}$$

where

- P_1 is the first measured received power in dB
- P_2 is the second measured received power in dB
- P_3 is the third measured received power in dB
- P_{in} is the input power in dBm
- G_1 is the antenna-1 gain in dBi
- G_2 is the BSMS antenna gain in dBi
- G_3 is the antenna-2 gain in dBi [14]

Our input power is 8 dBm, and the distance between transmitter antenna and receiver antenna is nearly 5 m long so the free space attenuation expression is [14];

$\left(\frac{\lambda}{4\pi R}\right)^2_{dB}$ which equals to -63.89 dB,

Then the gain is calculated as:

$2G_2$ = -14.21 – 36.85 + 21.31 + 63.89 + 5 + 5 – 36.5 = 9.64 → G_2 = 2.82 dBi

The measured gain is not same as the simulation result which is nearly 5dBi. The measured gain in this setup is not accurate. The setup is not perfectly calibrated and the losses used in the equations are not the actual values. However, one can say that the BSMS antenna gain is about 4 - 5 dbi which is expected from the simulation results.

6.3. Comparison of Theoretical and Measured Results

The results are similar to the simulation results but not identical. There exist several side lobes and these side lobes are more powerful than the simulated one's radiation pattern side lobes. Moreover the main lobe has lower power and the main beams beamwidth is smaller compared to the simulation results. However it has been shown that by making similar designs with better and appropriate materials and tools, better scanning antennas for different frequencies can be designed.

CHAPTER 7

CONCLUSION

In this thesis, the electrical properties of several types of “Beam Scanning Microstrip Antennas (BSMSA)” are examined using simulation tools and basic array theory.

The aim is to develop a full understanding of the factors affecting the beam direction and the gain; hence based on this experience, to implement the design a compact traveling wave type of scanning/steering antenna.

Microstrip antennas are chosen because they offer the advantages of realizing low profile, low weight, low cost and “easy to implement” designs.

Traveling wave antenna structures offer, ‘if desired’ the possibility of steering the beam by changing the frequency of operation.

Proximity coupled type of traveling-wave antenna designs are realized and the frequency steering capabilities are studied using both analytical methods and simulation techniques.

Experimental investigations regarding the performance of the constructed model are carried out.

REFERENCES

[1] Ramesh Garg, Prakash Bhartia, Inder Bahl, Apisak Ittipiboon, *Microstrip Antenna Design Handbook*, Artech House, Boston-London, 2001.

[2] M. Tuncay Birand, *A Novel Frequency Scanning Millimeter Wave Array*, METU Journal of Pure and Applied Sciences Vol. 16, No.1, pp. 111-134.

[3] C. A. Balanis, *Antenna Theory Analysis and Design Second Edition,* John Wiley & Sons, United States of America, 1997

[4] J-F. Zürcher, F. E. Gardiol, *Broadband Patch Antennas*, Artech House, Inc., Norwood, MA, 1995.

[5] G. Kumar and K. P. Ray, *Broadband Microstrip Antennas*, Artech House,United States of America, 2003.

[6] J. R. James and P. S. Hall, *Handbook of Microstrip Antennas*, Peter Peregrinus, London, UK, 1989

[7] I. J. Bahland and P. Bhartia, *Microstrip Antennas*, Artech House, Dedham, MA, 1980.

[8] "Microstrip line Design"
www.emtalk.com/designer_tut_1.htm
Last accessed at July 2009

[9] Traveling Wave Antennas by Carton H.Walter,1965 by McGraw-Hill, Inc.

[10] "RO4003 datasheet"
www.pcbtech.ru/pages/downloads/33.
Last accessed at July 2009

[11] D.M. Pozar and B. Kaufmann, "Increasing the Bandwidth of a Microstrip Antenna by Proximity Coupling," *Electronic Letters*,Vol.23,No.8,1987,pp.368-369

[12] E. Akgün, Millimeter Wave Microstrip Launchers and Antenna Arrays, METU, 2006

[13] Microstrip and Printed Antenna Design, Second Edition Randy Bancroft 300 pages SciTech Publishing, Copyright 2009

[14] M.S. Kırık, Design, Analaysis, and Implementation of Circular Disk-Annular Ring (CDAR) Antenna, METU, 2007.

APPENDİX A

Microstrip transmission line can be fabricated by forming a copper conductor line over a dielectric substrate with a appropriate width (W). The most important parameter of such a transmission line is its characteristic impedance. The connection of this line with other circuit elements is done by considering its characteristic impedance. Generally the impedance is chosen as 50 ohm for signal network or electronic designs. This characteristic impedance can be evaluated by below formula and it is seen that the width of the line determines the characteristic impedance mostly [12].

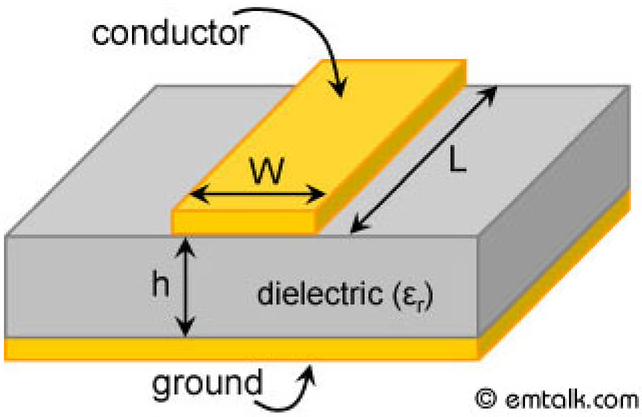


Figure A1. Microstrip Line [8]

$$W_e = W + 0.398T\left(1 + ln\left(\frac{4\pi W}{T}\right)\right), \qquad \frac{W}{H} \leq \frac{1}{2\pi}$$

$$W_e = W + 0.398T\left(1 + ln\left(\frac{2H}{T}\right)\right), \qquad \frac{W}{H} > \frac{1}{2\pi}$$

$$C_a = \frac{2\pi\varepsilon_r}{ln\left(\frac{8H}{W_e} + \frac{W_e}{4H}\right)}, \qquad \frac{W_e}{H} \leq 1$$

$$C_a = \varepsilon_r \left[\frac{W_e}{H} + 1.393 + 0.667\ ln\left(\frac{W_e}{H} + 1.444\right)\right], \qquad \frac{W_e}{H} > 1$$

$$\varepsilon_{e,lf} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + \frac{12H}{W_e}\right)^{-1/2} + F(\varepsilon_r\ , H) - 0.217(\varepsilon_r - 1)\frac{T}{\sqrt{W_e H}}\ ,$$

$$F(\varepsilon_r\ , H) = 0.02(\varepsilon_r - 1)\left(1 - \frac{W_e}{H}\right)^2, \qquad \frac{W_e}{H} \leq 1$$

$$F(\varepsilon_r\ , H) = 0, \qquad \frac{W_e}{H} > 1$$

$$\varepsilon_{e,lf} = \frac{\varepsilon_r - \varepsilon_{e,lf}}{1+\left(\frac{f}{fa}\right)^m}\ ,$$

$$Zc = \sqrt{\frac{\varepsilon_0 \mu_0}{\varepsilon_e}}\ \frac{1}{C_a}\ ,$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_e}}\ ,$$

$$f_a = \frac{f_b}{0.75 + (0.75 - 0.332\varepsilon_r{}^{-1.73})\frac{W_e}{H}}\ ,$$

$$f_b = \frac{47746}{H\sqrt{\varepsilon_r - \varepsilon_{e,lf}}}\, tan^{-1}\left(\varepsilon_r \sqrt{\frac{\varepsilon_{e,lf} - 1}{\varepsilon_r - \varepsilon_{e,lf}}}\right)\ ,$$

$$m = m_0 m_c \leq 2.32 \ ,$$

$$m_0 = 1 + \frac{1}{1+\sqrt{\frac{W_e}{H}}} + 0.32\left(1 + \sqrt{\frac{W_e}{H}}\right)^{-3},$$

$$m_c = \ 1 + \frac{1.4}{1+\frac{W_e}{H}}\left(0.15 + 0.235e^{-0.45\frac{f}{fa}}\right)^{-3}, \qquad \frac{W_e}{H} \leq 0.7$$

$$m_c = 1 \ , \qquad \frac{W_e}{H} \leq 0.7$$

$$\varepsilon_{e,hf} = \frac{\varepsilon_r - \varepsilon_{e,lf}}{1+\left(\frac{f}{fa}\right)^m} \ ,$$

APPENDIX B

MATLAB CALCULATIONS

The MATLAB codes for drawing the radiation pattern of the antenna array of 11 elements with equally sized, equally distanced and equally excited is given below.

Figures drown in dBi scale are done by using the below codes.

```
clear
clc
clf
f=8;
G=0:1:180;
theta=0:pi/180:pi;
for i=1:1:181
    G(i)=-
10*log10(abs(0.008*(sin(1.87*f*cos(theta(i))-
2.04*f)/sin(0.21*f*cos(theta(i))-0.3*f))^2));
end
G=G-max(G);
polar(theta+pi,G)
%plot(theta/pi*180,G)
```

Comparison of Slot Array Antenna's Radiation Patterns:

The only difference for the constructed slot array antenna designs is the number of elements. Left side we have the design of #10 elements and right side we have #5.

N=10 N=5

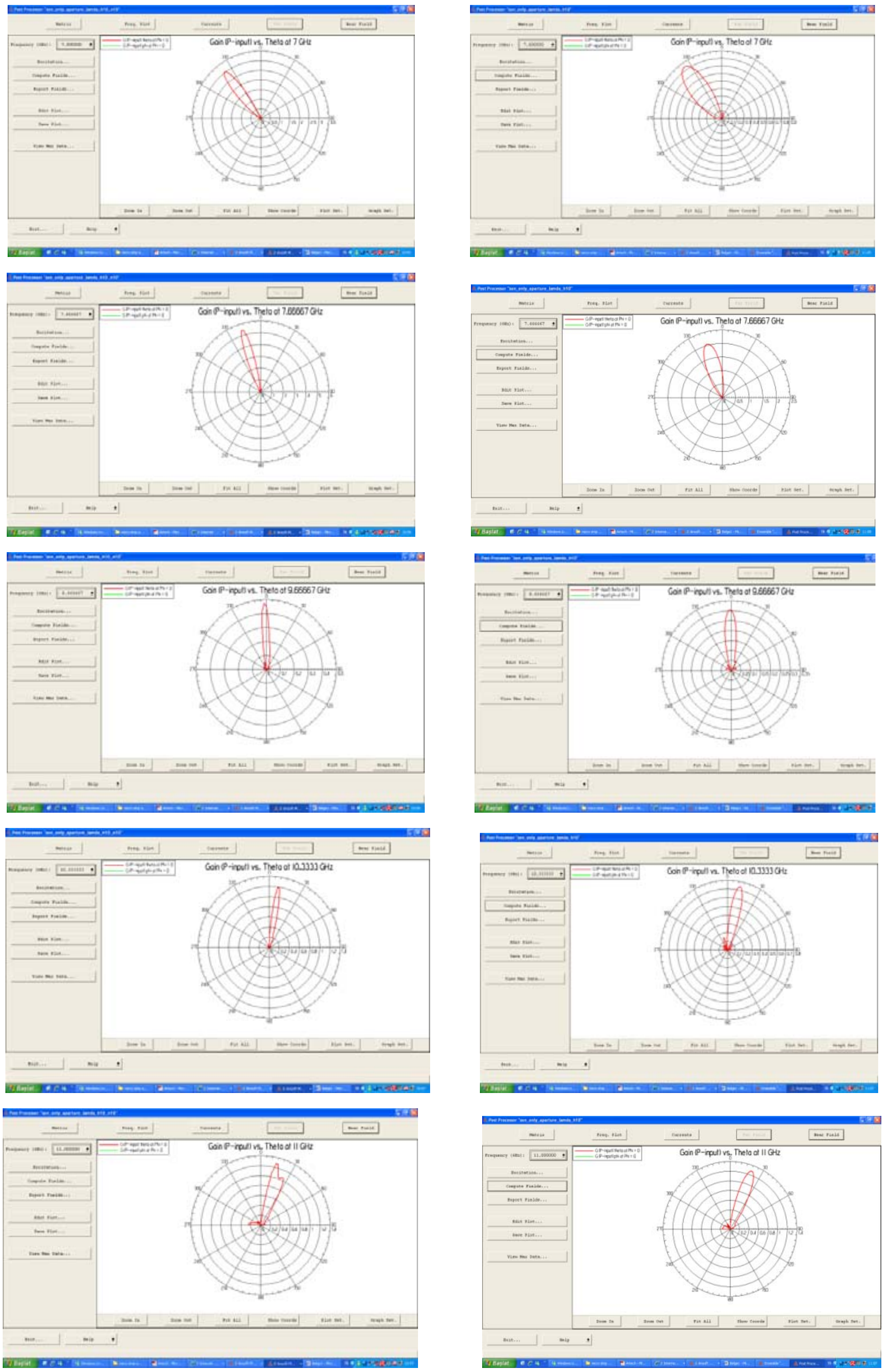
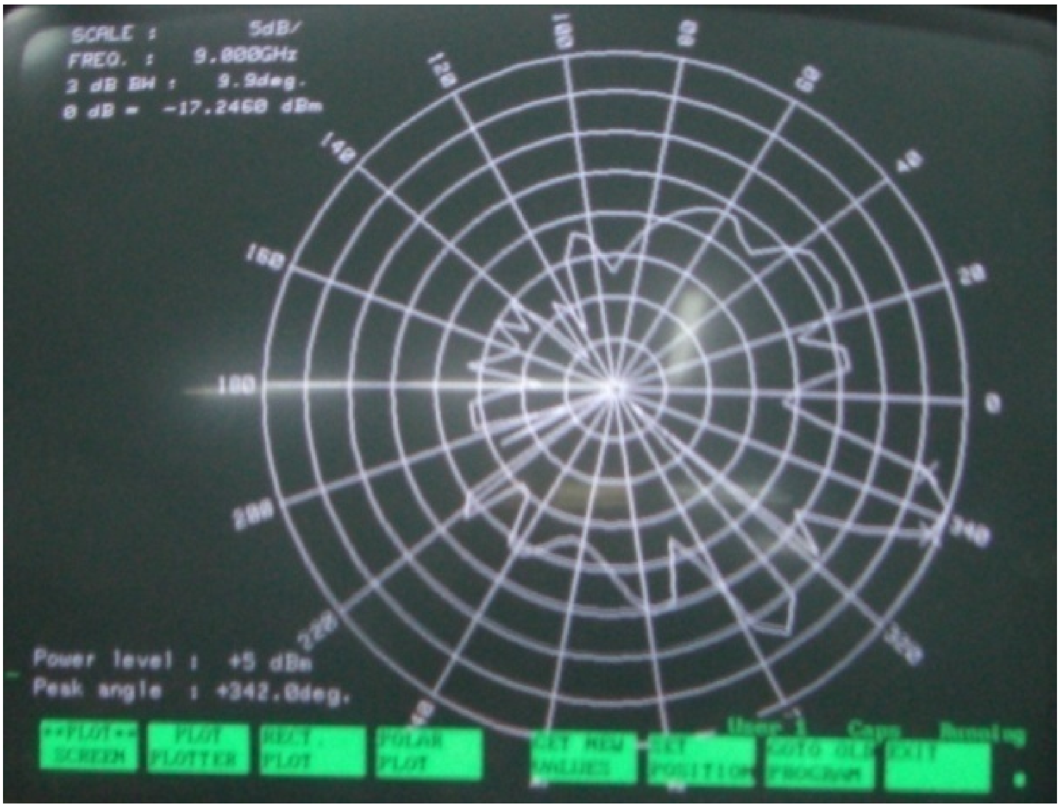


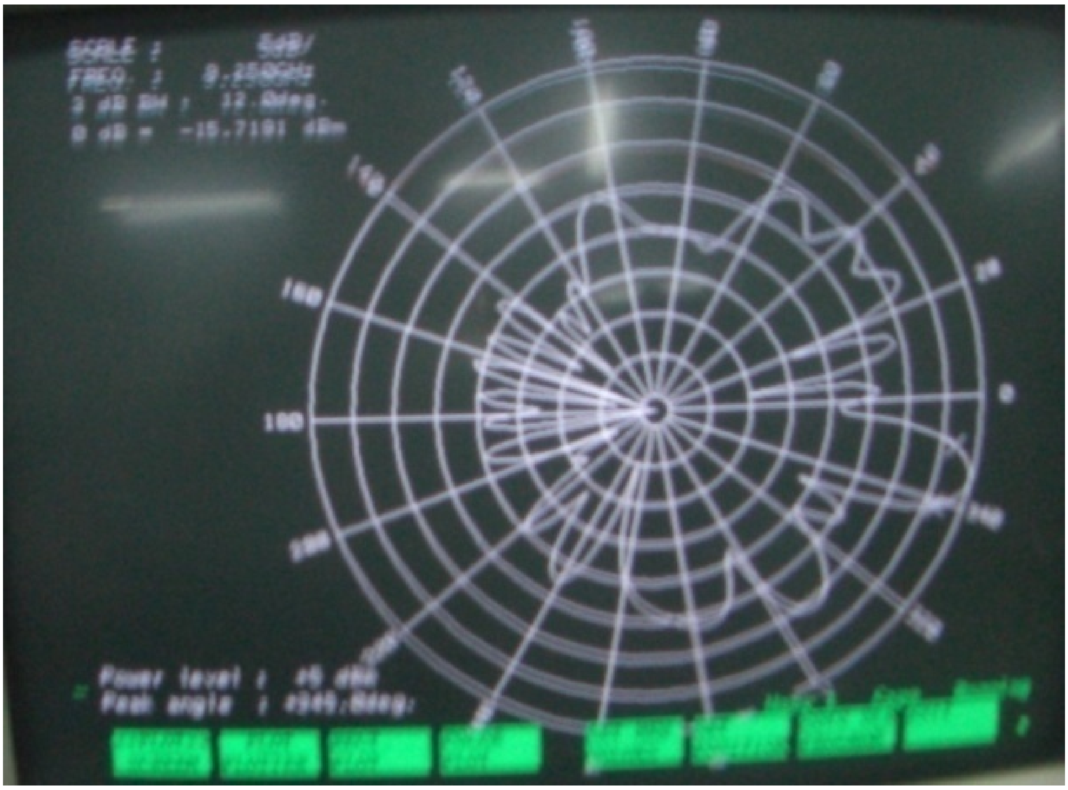
Figure B1. Slot array antenna beam pattern comparison

Photos of beam patterns (0^0 is broadside direction.)

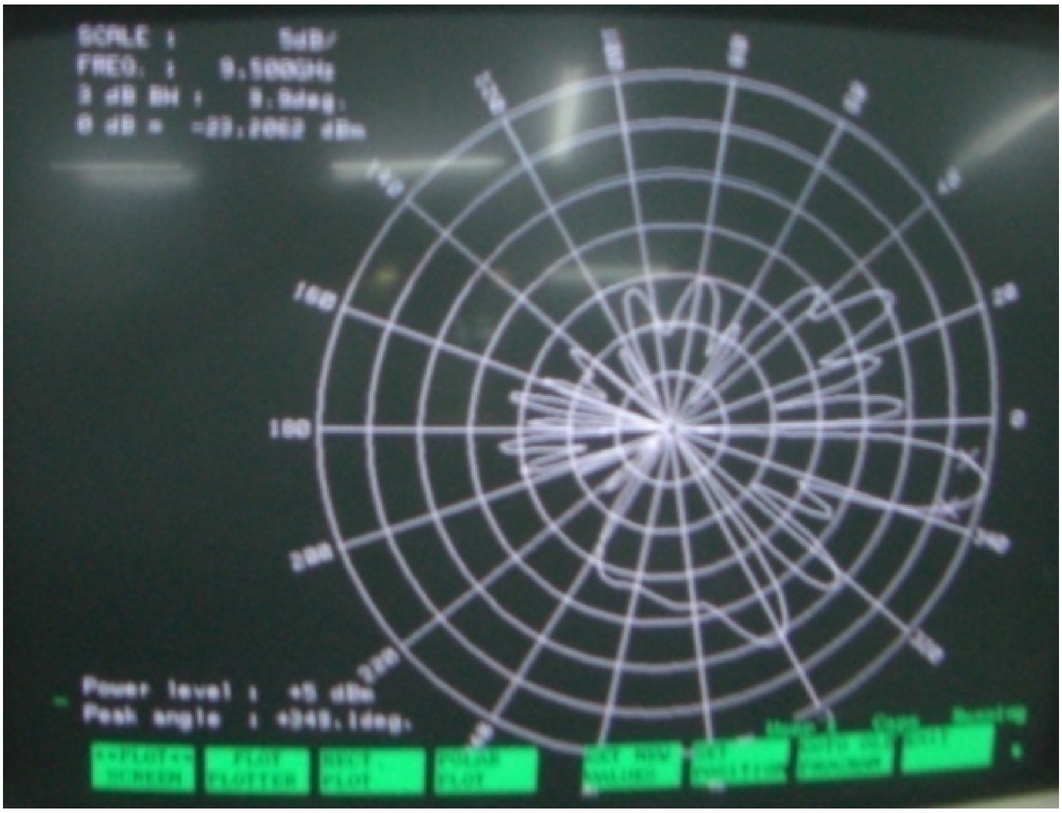
(a)



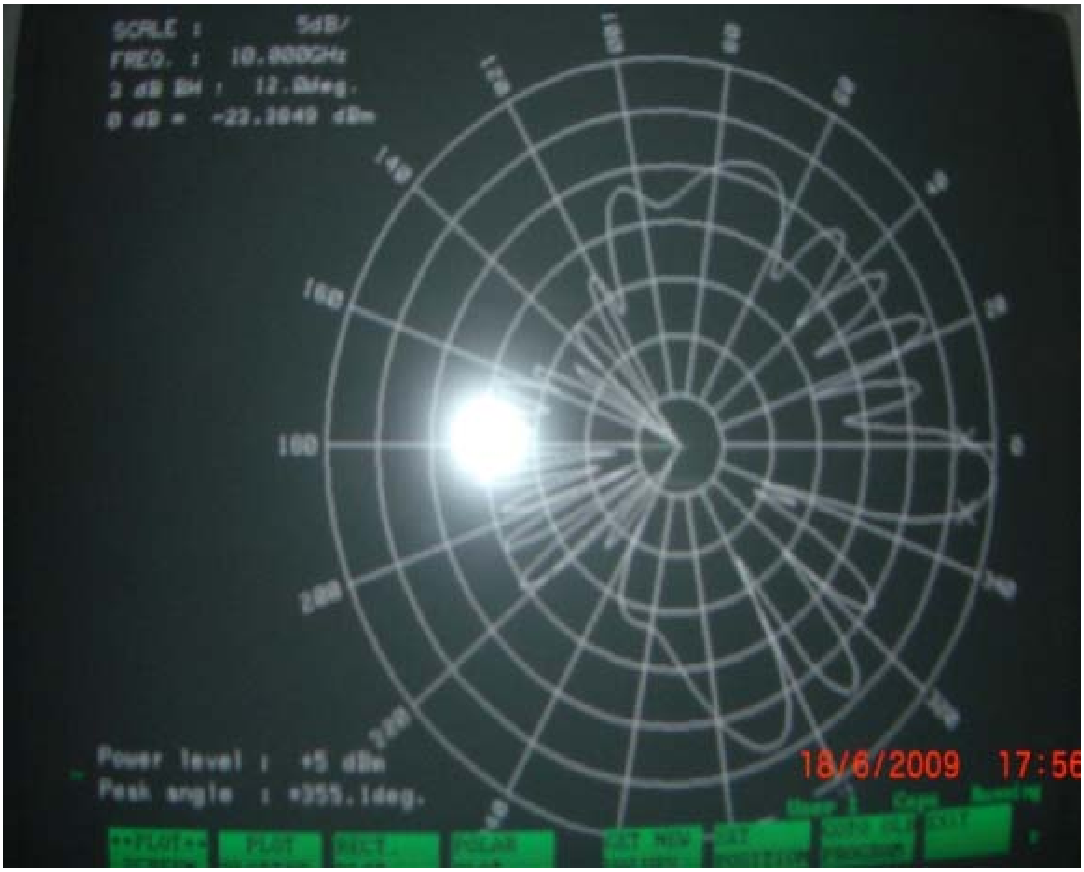
(b)



(c)

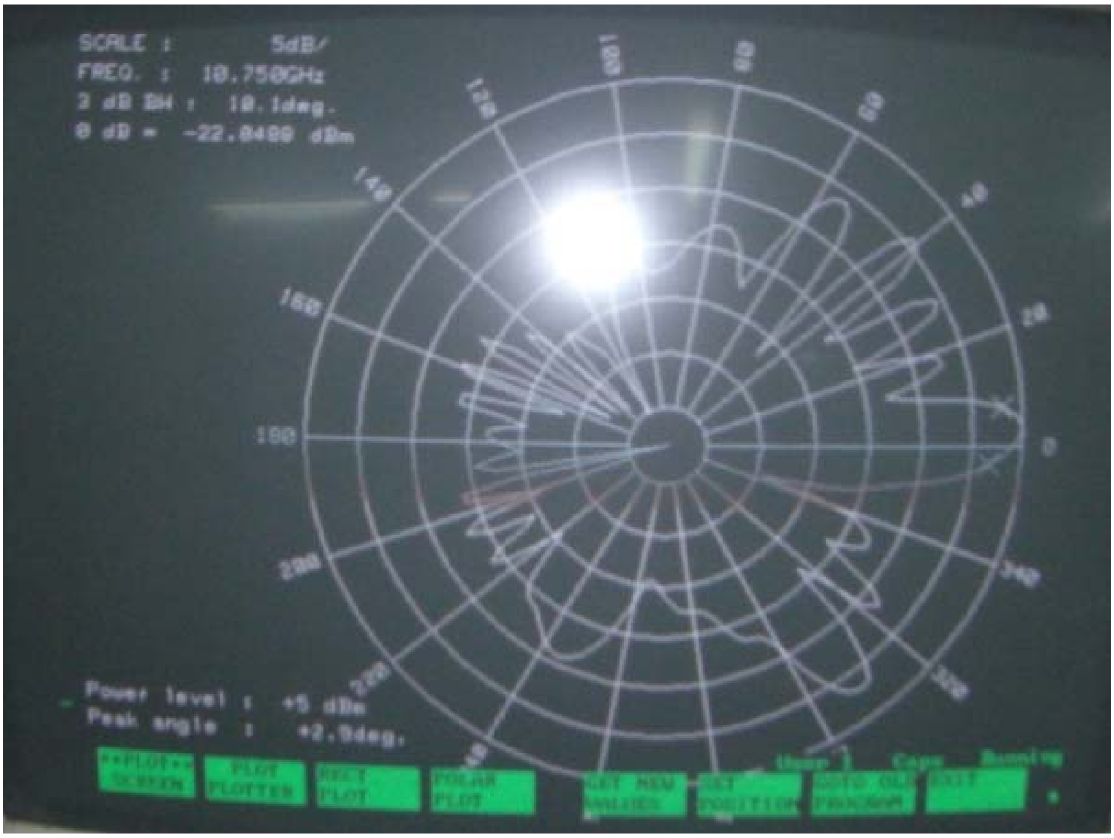

SCALE : 5dB/
FREQ. : 9.500GHz
0 dB = -23.2062 dBm
Power level : +5 dBm
Peak angle : +349.1deg.

(d)


SCALE : 5dB/
FREQ. : 10.000GHz
3 dB BW : 12.0deg.
Power level : +5 dBm
Peak angle : +355.1deg.
18/6/2009 17:56

(e)

(f)



<u>Figure B2. Detailed Photos of Beam Patterns of BSMS Antenna</u>