QUASI-YAGI MICROSTRIP LINEAR ANTENNA ARRAYS AT 10 GHz

by

Hayrettin Odabasi

B.S., Gebze Institute of Technology, 2005

ABSTRACT OF THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering in the Graduate School of Syracuse University

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Approved __________________
Prof. Ercument Arvas

Date__________________

ABSTRACT

Quasi-yagi microstrip antenna arrays were designed, simulated, built, and tested for 3, 5, and 9 elements at 10 GHz. 17 and 33 element arrays are also designed and simulated. The radiation patterns of these arrays are considered as approximations to a given desired radiation pattern. Antenna synthesis was done for this given desired radiation pattern to obtain the best excitation coefficients for the finite arrays. Based on this synthesis the antennas were designed, simulated and measured. The results are discussed based on array theory, simulation and measurement.

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ACKNOWLEDGEMENTS

I would like to state my sincere appreciation and gratitude to Professor Ercument Arvas and Professor William A Penn for their guidance, patience and support during this work. I am also grateful to Chih-Min Hsu and Serhend Arvas for their suggestions and helps during both in design and manufacturing process.

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Finally, I thank to my family for their patience and love.

1. INTRODUCTION

1.1 MOTIVATION

Antenna arrays are commonly used in many real world applications such as; radar, satellite communication, wireless communication, etc. Due to the deficient properties of the single antenna element for many applications, it becomes very important to design such a system that produces specific radiation characteristics. This can be done by combining several antennas that constitute so called “arrays”. An array can be classified as Linear, Planar and Circular depending on the spatial alignment of the array elements.

Since radar applications and wireless communications are developing very rapidly, the demand of specific radiation patterns for particular applications is increasing proportionally. This demand can be solved by using antenna arrays. Designing good working antennas in terms of bandwidth, return loss, and a desirable radiation pattern is becoming more important.

Antenna analysis is the process of the finding the radiation pattern for given excitation coefficients whereas antenna synthesis is the process of the finding the excitation coefficients for given radiation pattern. Many methods have been developed for antenna synthesis to obtain the proper excitation coefficients. Our design project consists of pattern synthesis, array design, fabrication, and measurement.

The single antenna element to be used in the array is another important issue. One has to pick the most efficient one to obtain best results. The quasi-yagi microstrip antenna is chosen for our project.

1.2 PROBLEM DEFINITION

The goal of this project is to design and built a quasi-yagi antenna arrays at 10 GHz. The arrays are designed, built and tested for odd numbers of elements 3, 5, and 9. The simulation results were obtained for 17 and 33 element arrays. This project mainly consists of; pattern synthesis, array design, quasi-yagi antenna design, fabrication, and measurement.

First a desirable radiation pattern had to be selected. In the intended application, ground reflections are very undesirable thus downward radiation toward the ground must be minimized. Backward lobes should also be minimized. As one can see more clearly from Figure 2 the only desirable region into which the antenna radiates is the first elevation quadrant of the whole space. Theoretically, of course, it is impossible to produce that radiation pattern exactly. In fact one would need an infinite number of elements to obtain such a pattern.

The first step of the antenna synthesis was to formalize a desirable radiation pattern. Pattern synthesis is the process of determining the excitation coefficients of the antenna array. MATLAB code was written to determine the coefficients of the array elements by using a Fourier series method. While the exact recovery of the ideal pattern requires infinite number of elements, we only treat the cases here of 3, 5, 9, 17, and 33 element arrays.

After determining the excitation coefficients of the array elements, it is necessary to design a feed network that delivers the proper amplitude and phase for each single element. Since we work with odd numbers one eventually will need a three-way power splitter for the center of the array. Two-way power splitters on the right and left side of the center element are used, and then combined with the central three-way splitter. The power division is done by changing the impedances of the branches of the transmission line which basically means changing the width of these branch transmission lines. Designing the feed network is the most difficult part of the array design because of the sensitivity of the properties to the design specifications. For instance, at 10 GHz the wavelength of the signal is 30 mm in free space and 12 mm in the substrate which has 10.2 permittivity and 25 mils thickness. So we are dealing with very small numbers.

We used a quasi-yagi single element which has quite desirable properties for our purpose. Our quasi-yagi antenna design is based on the procedure in the references: [7, 8]. Arrays are built on 25 mils Rogers 3010 substrate.

We fabricated and tested the arrays in Microwave Lab of Syracuse University. The simulation and the measurement results are agreed well.

2. ANTENNA ARRAY THEORY

In this section a small brief of array theory will be discussed.

2.1 ANTENNA ARRAYS

For many applications a single element antenna cannot be made to satisfy the desired antenna characteristics such as; directivity, gain, and radiation pattern. Several elements can be combined to overcome such difficulties, which generates the so called "array". By changing the number of elements, geometrical arrangement of the elements, and relative amplitudes and phases of the elements, one can control the radiation pattern of the array [1, 2].

2.2 PATTERN MULTIPLICATION

Kraus defines the pattern multiplication as "The field pattern of an array of nonisotropic but similar point sources is the product of the pattern of the individual source and the pattern of an array of isotropic point sources, having the same locations, relative amplitudes and phases as the nonisotropic point sources" [2].

This principle may be applied to arrays of any numbers of sources provided only that they are similar. Then the pattern multiplication can be written as follows;

$$E(\theta,\phi) = AF(\theta,\phi) \cdot EF(\theta,\phi) \tag{1}$$

where $AF(\theta,\phi)$ is the antenna array factor and $EF(\theta,\phi)$ is the element pattern.

2.3 LINEAR ARRAYS

For linear arrays the array factor can be written

$$AF(\theta,\phi) = \sum_n a_n \cdot e^{j\cdot(k\cdot d_n + \delta_n)} \tag{2}$$

where $k = \frac{2 \cdot \pi}{\lambda}$ is the wave number, λ is the wave length, d_n is the distance between the array elements, δ_n is the phase of the each array element, and $n = 0,1,2....N-1$ is the number of array element. Next, defining

$$\psi_n = k \cdot d_n \cdot \cos(\theta) + \delta_n \tag{3}$$

then AF becomes,

$$AF(\theta,\phi) = \sum_n a_n \cdot e^{j \cdot \psi_n} \ . \tag{4}$$

Now consider that the antennas are oriented along the z axis as fallows

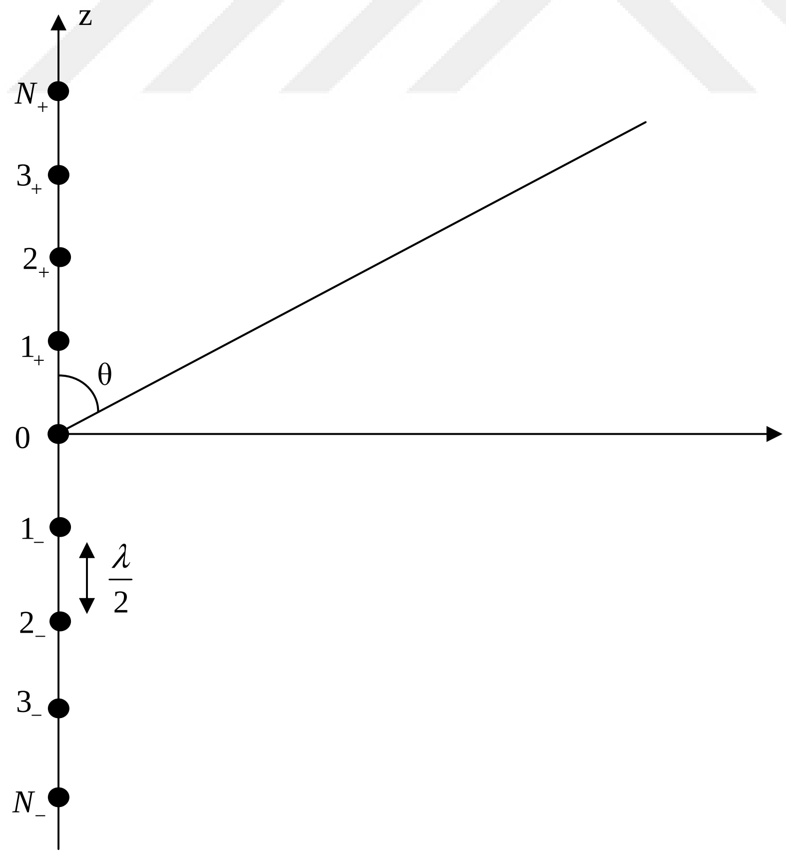


Figure 1 Array aligned towards the z direction

where the black circles are the single elements of the array, that are aligned symmetric to the x-axis. For a symmetric case the array factor for odd number of elements can be written

$$AF(\theta,\phi) = a_0 + \sum_n \left[a_n \cdot e^{-j\cdot(k\cdot d_n + \delta_n)} + a_{-n} \cdot e^{j\cdot(k\cdot d_n + \delta_n)} \right] \tag{5}$$

Here the excitation amplitude coefficients are symmetrical so that $a_n = a_{-n}$

$$AF(\theta,\phi) = a_0 + \sum_n a_n \left[e^{-j\cdot\psi_n} + e^{j\cdot\psi_n} \right]. \tag{6}$$

3. ANTENNA SYNTHESIS

Determining the coefficients of the array elements of the antenna array is basically named “antenna synthesis”. The process is the reverse of the antenna analysis. First we define our desired radiation pattern then we choose our single element antenna. The rest is just the application of the pattern multiplication. There are many methods to evaluate the coefficients for an array such as; Fourier series method [3], Schelkunoff’s method [4], Z Transform method [5], etc. Besides these mathematical methods there are also some other methods including so-called optimization methods such as; Particle swarm optimization, and Genetic algorithm [6] which are basically finding the optimum solution for given parameters.

In our study, The Fourier Series method has been used to determine the coefficients of the array elements. This method is based on the inverse discrete-space Fourier Transform of the array factor. Due to the form of our array factor, the array factor can be thought as an expansion of Fourier series. So if one wants to find the excitation coefficients of the array elements for a given desired radiation pattern, the corresponding inverse transform will be

$$a_n = \frac{1}{2\pi}\int_{-\pi}^{\pi} AF\left(\psi\right)\cdot e^{-j\cdot m\cdot\psi} d\psi \quad ; \; m = 0, \pm1, \pm2... \tag{7}$$

where AF is the desired array factor.

In general, the ideal desired array factor requires an infinite number of coefficients to be represented exactly but we may obtain pretty close results by using a relatively modest number of elements.

3.1 DETERMINATION OF THE DESIRED PATTERN

If we had an antenna which has a radiation pattern that is shown in Figure 2, it could be very useful in the specific airport application of this study. It is seen from Figure 2 that there is no radiation towards ground or in the backward direction. This then becomes our “ideal” desired radiation pattern.

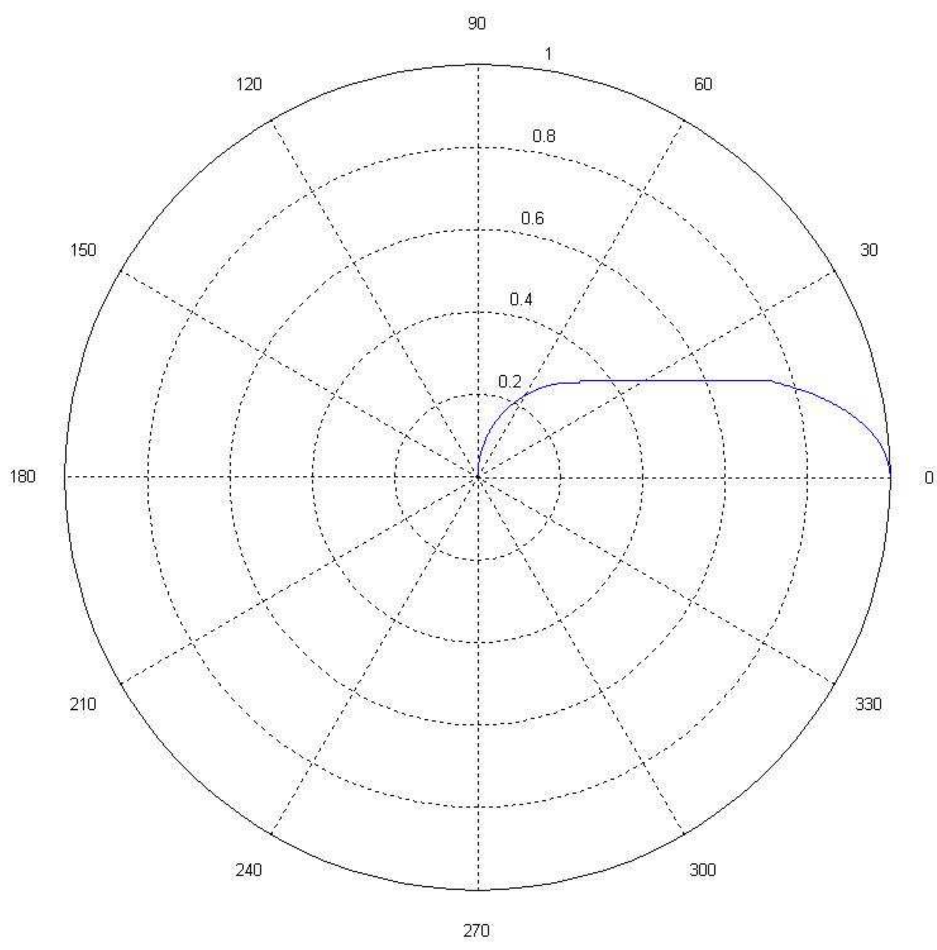


Figure 2 Ideal desired radiation pattern of the array

3.2 CALCULATION OF THE EXCITATION COEFFICIENTS

Using array theory we wrote a MATLAB code to determine the array coefficients by using Fourier series method. The code was written for an odd number of array elements, resulting in the array element number to be in the form of $2^n + 1$. So the results are for 3, 5, 9, 17, and 33 and so on. We wanted to build an array with 33 elements but unfortunately the resources and time constraints precluded that. Table 1 shows the amplitude, phase and the power values for each element for a total of 33 elements. Smaller number of elements for smaller arrays can be selected from this table same of values.

Table 1 Antenna Weights for 33 Element Array

Element #	Amplitude	Phase (Degree)	Power (dB)
1	0.0890	87.3847	-21.0081
2	0.1011	88.1552	-19.9009
3	0.1077	-89.7892	-19.3574
4	0.1130	88.2835	-18.9416
5	0.1292	85.2771	-17.7720
6	0.1526	86.8129	-16.3282
7	0.1714	89.8986	-15.3203
8	0.1930	-89.5846	-14.2876
9	0.2347	-87.6845	-12.5903
10	0.2836	-79.7056	-10.9460
11	0.3066	-69.6290	-10.2675

12	0.3035	-66.6077	-10.3574
13	0.3558	-73.0781	-8.9768
14	0.5292	-69.5180	-5.5271
15	0.7534	-51.8148	-2.4595
16	0.9324	-27.1921	-0.6080
17	1	0	0
18	0.9324	27.1921	-0.6080
19	0.7534	51.8148	-2.4595
20	0.5292	69.5180	-5.5271
21	0.3558	73.0781	-8.9768
22	0.3035	66.6077	-10.3574
23	0.3066	69.6290	-10.2675
24	0.2836	79.7056	-10.9460
25	0.2347	87.6845	-12.5903
26	0.1930	89.5846	-14.2876
27	0.1714	-89.8986	-15.3203
28	0.1526	-86.8129	-16.3282
29	0.1292	-85.2771	-17.7720
30	0.1130	-88.2835	-18.9416
31	0.1077	89.7892	-19.3574
32	0.1011	-88.1552	-19.9009
33	0.0890	-87.3847	-21.0081

4. ANTENNA ARRAY DESIGN

4.1 SINGLE QUASI-YAGI ANTENNA

Quasi-yagi *printed* antennas have reasonably wide bandwidth and desirable properties when they used in linear arrays [7, 8]. Figure 3 shows the layout of the quasi-yagi printed antenna element. The simulations are performed using ANSFOT HFSS [9]. The antenna was built on 25 mils thick Rogers 3010 substrate [10].

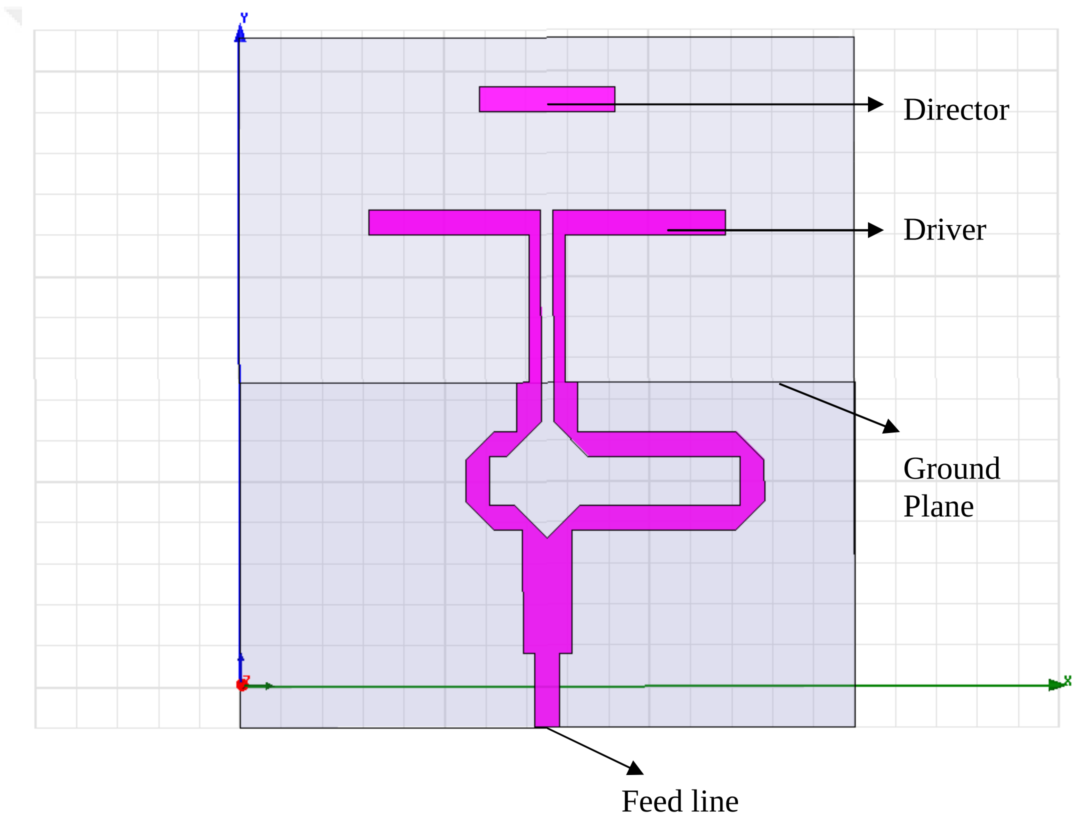


Figure 3 The layout of the single quasi-yagi printed antenna element

Figure 4 shows the return loss of the single quasi-yagi antenna which has 4GHz bandwidth below -10 dB and -30 dB return loss at 10 GHz. Figure 5 shows the radiation pattern of the single quasi-yagi element.

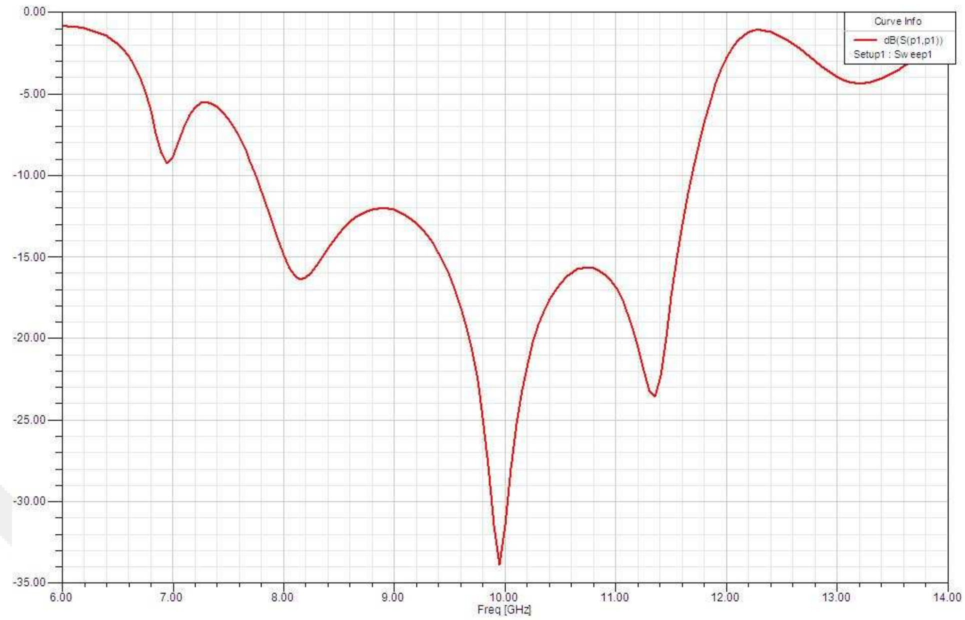


Figure 4 Return loss of the single quasi-yagi printed antenna element

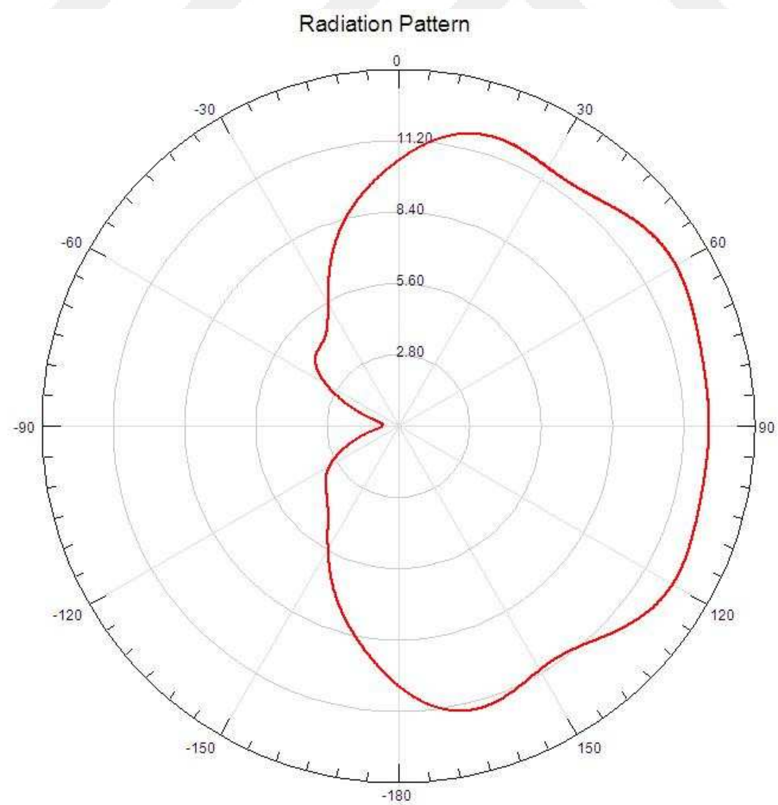


Figure 5 Radiation pattern of the single quasi-yagi print antenna element

4.2 FEED NETWORK DESIGN

All the simulations for feed network design are performed using ANSOFT DESIGNER [11].

4.2.1 3-ELEMENT ARRAY

We need to design a three way power splitter which provides the proper power division. The phases of the right and left elements also should be opposite sign (180^o phase different) which means the length of the transmission line of these lines should be correspondingly by one-half wavelength different. The proper power division was achieved with the following design. Figure 6 shows the layout of the feed network for a 3-element array.

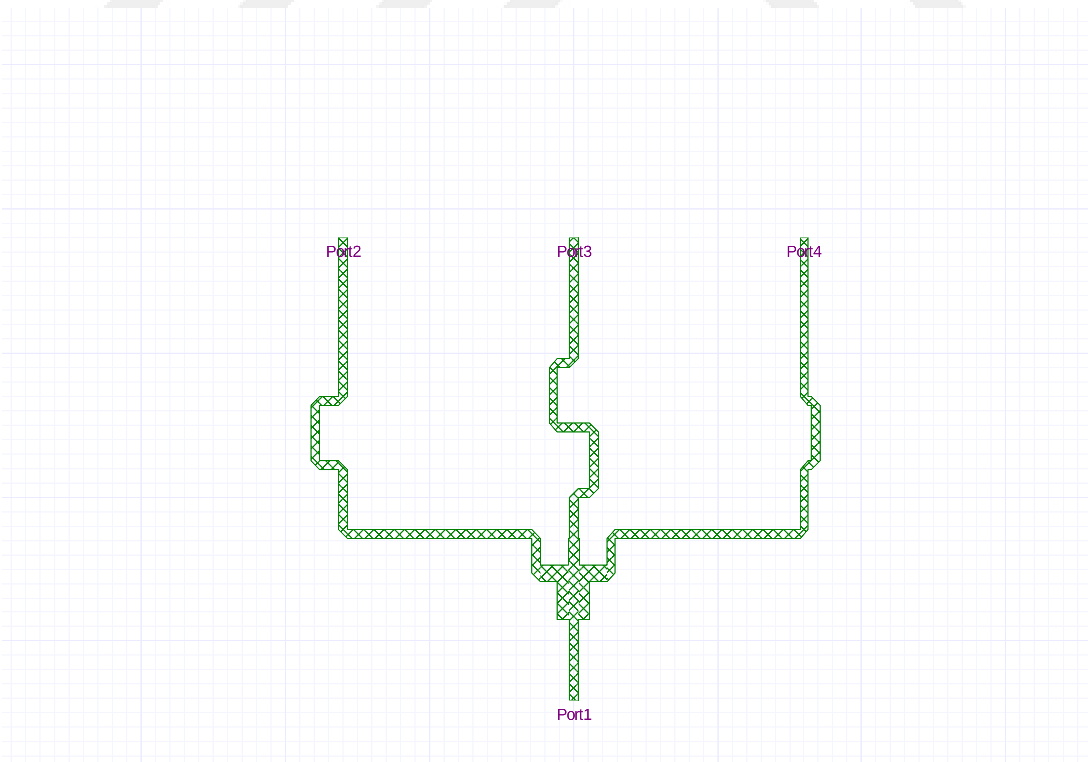


Figure 6 The layout of the feed network for 3-element array

Figure 7 shows the power values for each port and the return loss. 0.6 dB power ratio was achieved between the center element and the wings and the return loss is about -40 dB at 10 GHz.

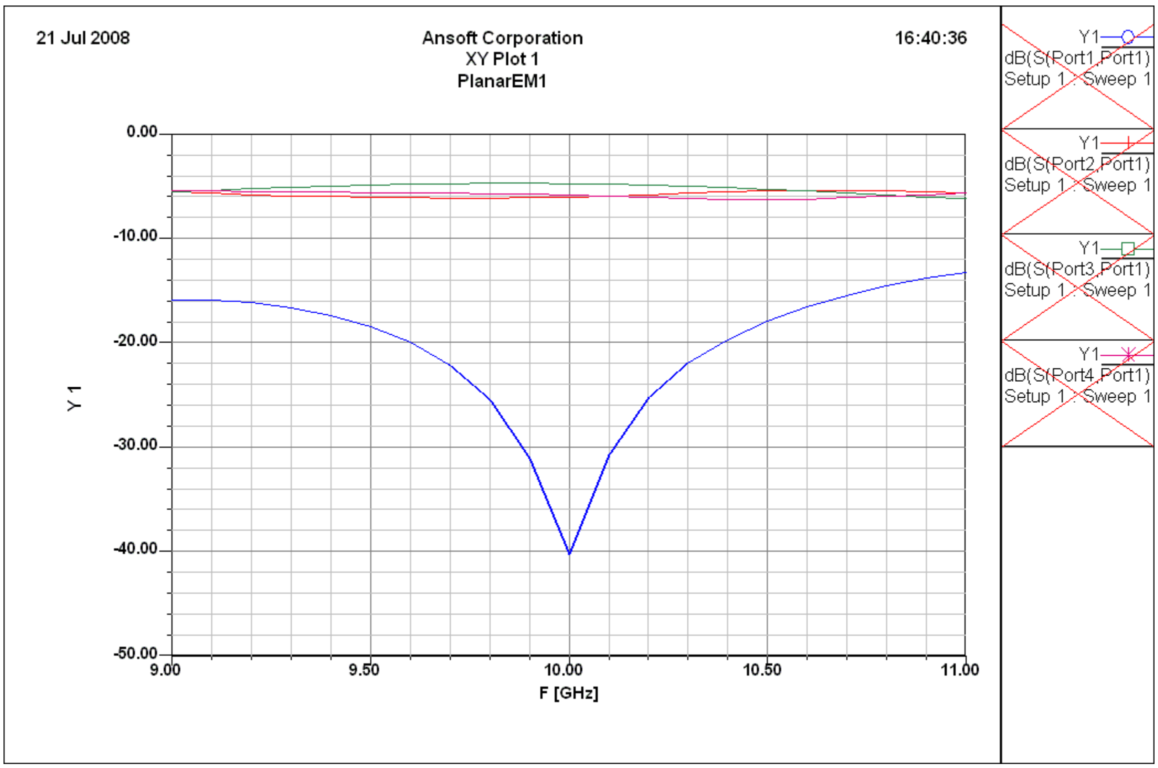


Figure 7 S parameters of the 3-element array

Figure 8 shows the phase values of the feed network for 3 elements. 27^{o} is achieved with $\pm 5^{o}$ error which not very big for 10 GHz design.

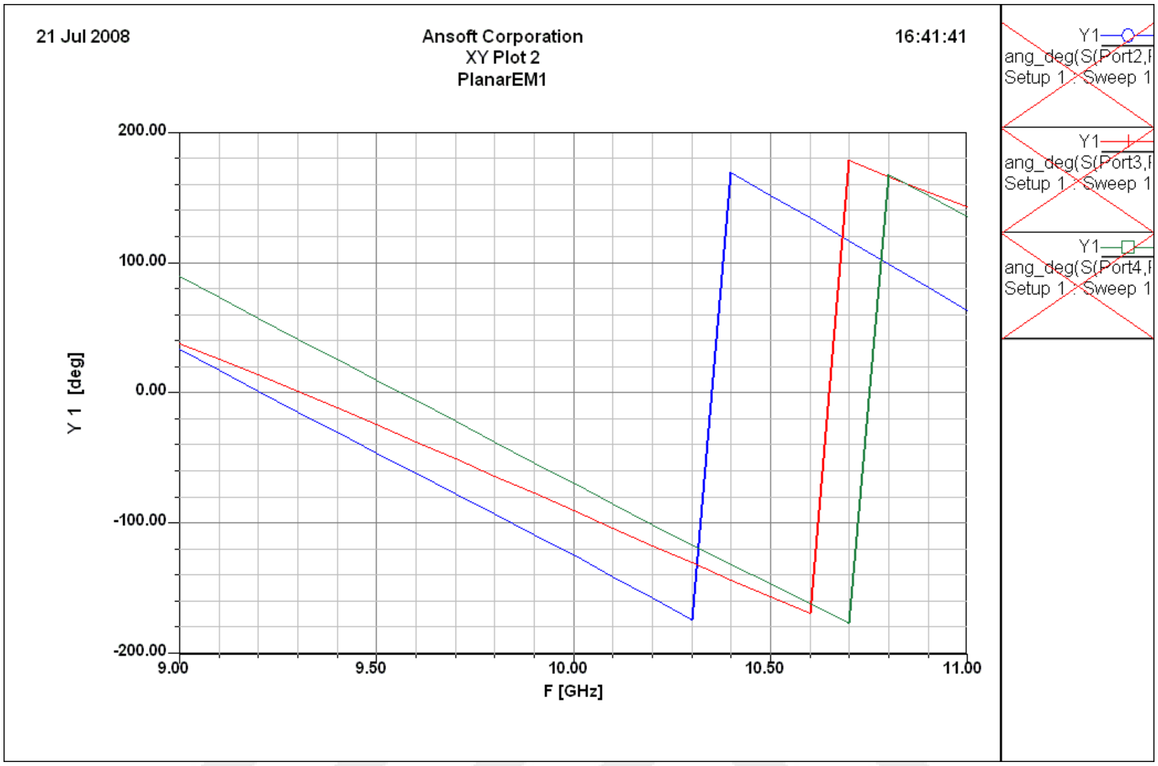


Figure 8 Phases values for 3-element array

4.2.1 5-ELEMENT ARRAY

Now we need to use two way splitters at the wings and combine this with the three-way power splitter. The power ratio is also changed for three-way power splitter because of the increased number of elements for each side.

Figure 9 shows the layout of the feed network for 5 elements. Figure 10 and 11 show the S parameters and phase values respectively.

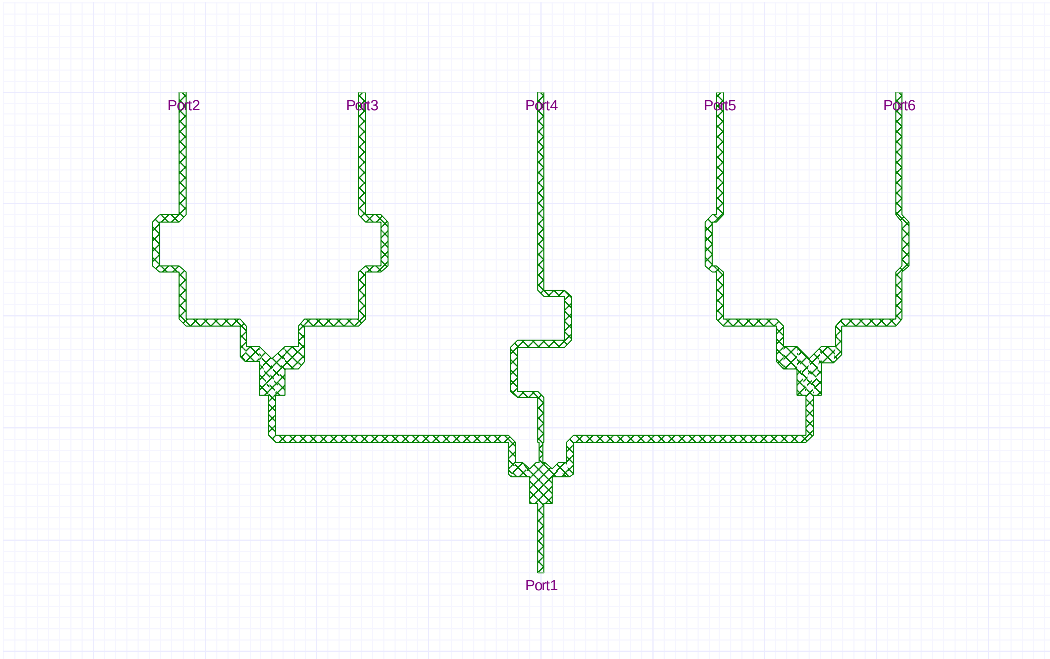


Figure 9 The layout of the feed network of 5-element array

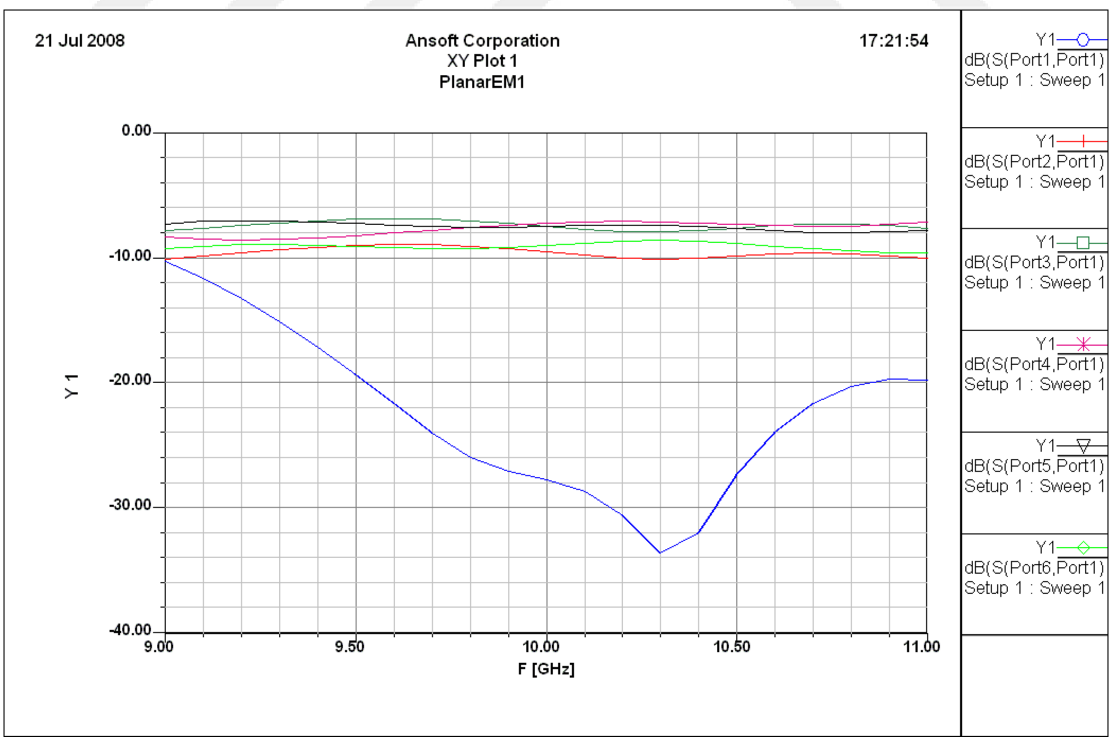


Figure 10 S parameters of the feed network of 5-element array

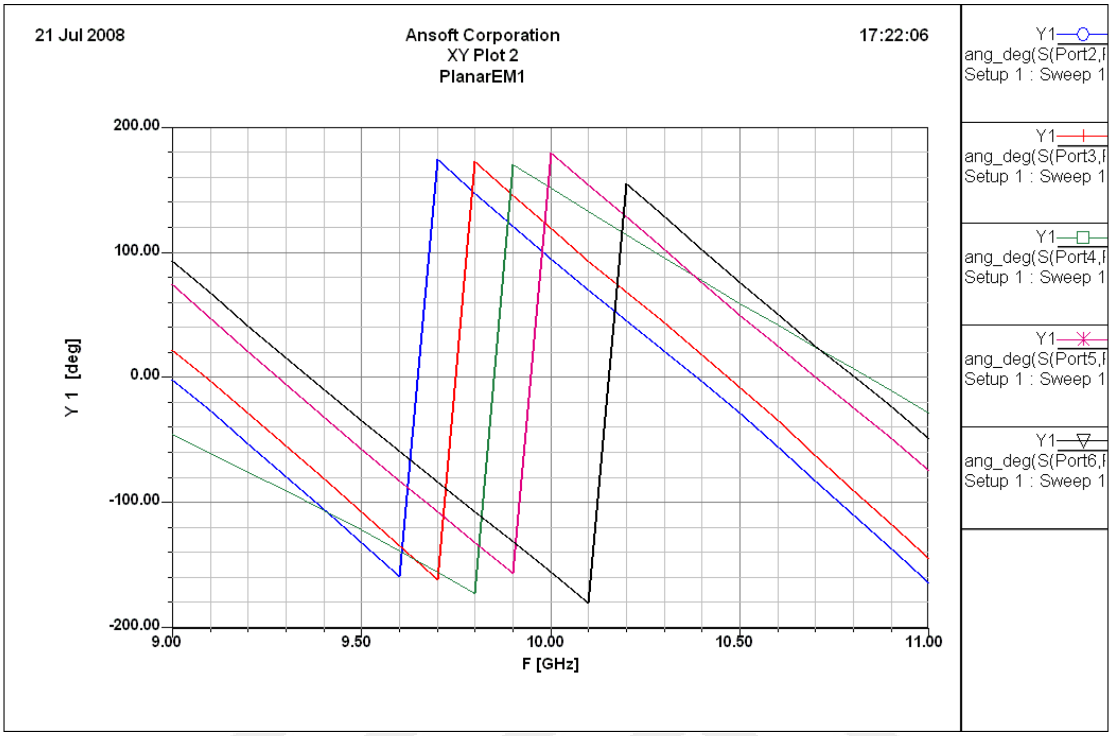


Figure 11 Phase values of the 5-elements array

4.2.1 9-ELEMENT ARRAY

The layout, S parameters and the phase values are shown in the following figures.

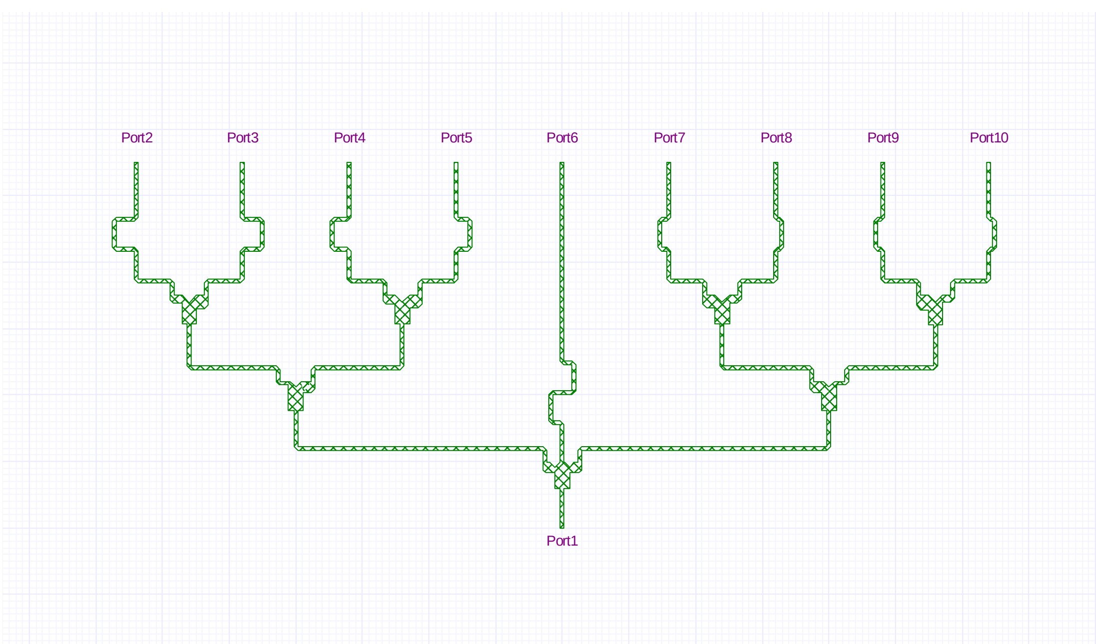


Figure 12 The layout of the feed network for 9-element array

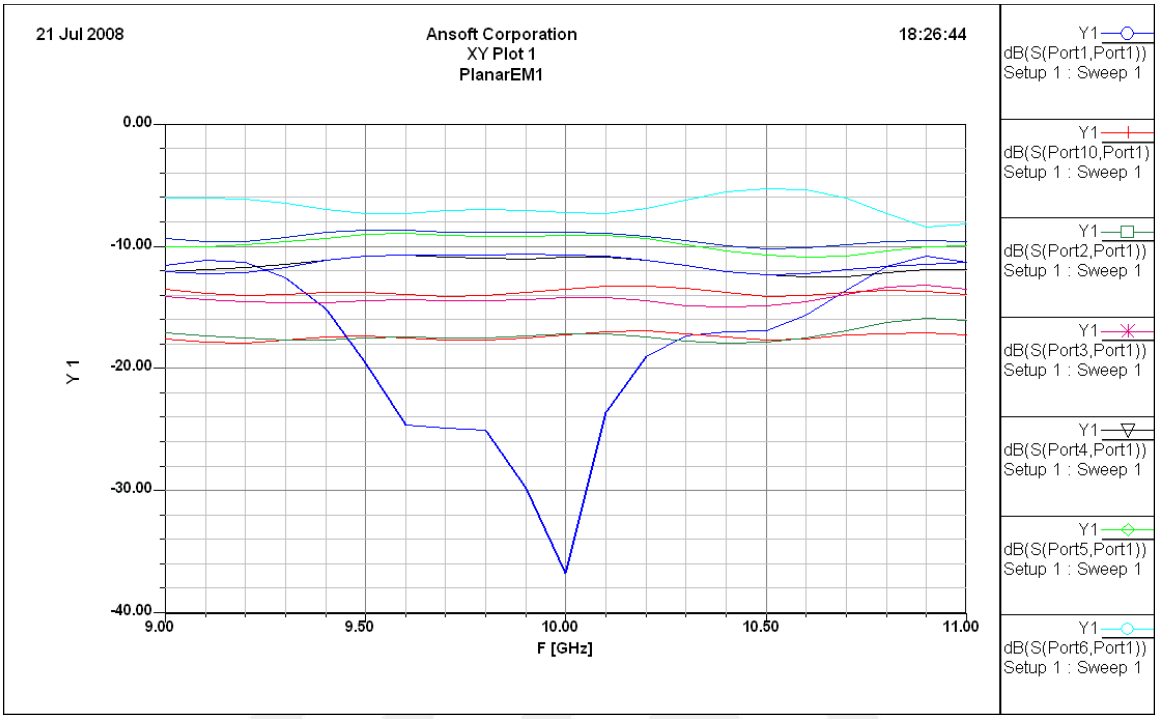


Figure 13 S parameters of the feed network for 9-element array

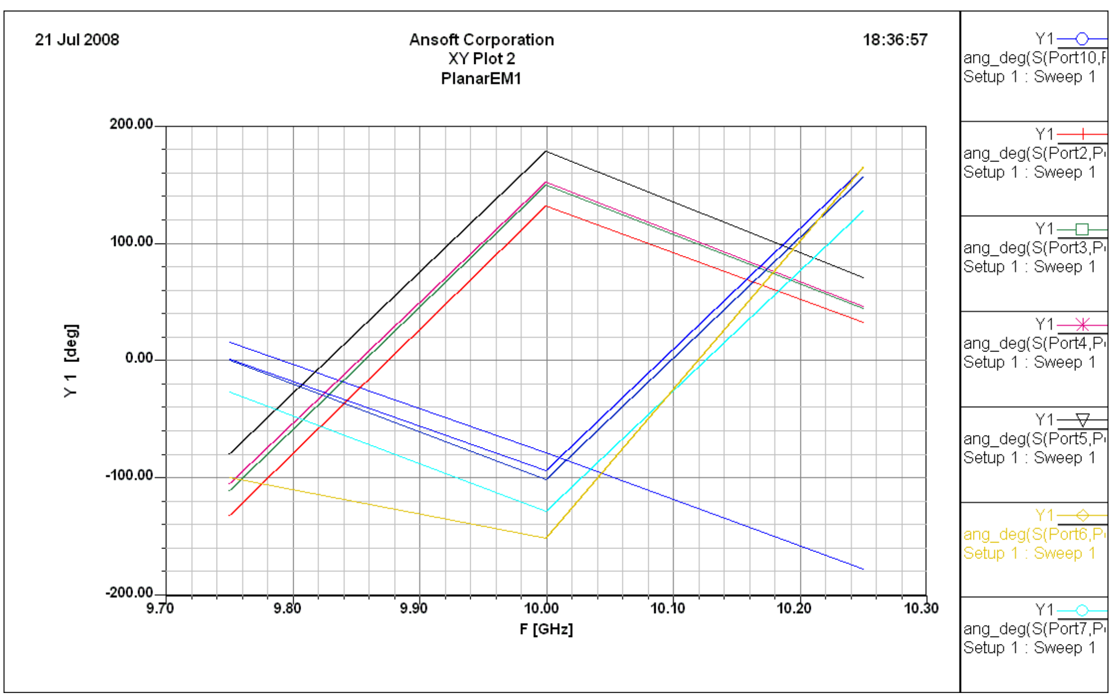


Figure 14 Phase values of the feed network for 9-element array

5. RESULTS AND DISCUSSION

In this chapter, the results of the array theory, simulation and measurement will be discussed. We first used array theory to find out the excitation coefficients and recalculate the radiation pattern by reducing the element number to 3, 5, 9,17, and 33. Then we simulate these arrays using ANSOFT HFSS software. Finally we built our arrays and measured the radiation patterns.

We have designed, simulated, built and measured for 3, 5 and 9 elements. Only design and simulation was done for 17 and 33 elements. The results agree well in terms of radiation patterns and return loss.

Increasing the number of elements in our array helps to get a better radiation pattern but it also makes the feed network design more difficult. We have done our tests for a maximum of 9 elements. The further intention is to try to build arrays using 17 and 33 elements.

Since the milling machine in the S.U RF / Microwave Lab is not very sensitive for our designs, the arrays that we built are not perfect but the results are still admissible.

5.1 3-ELEMENT ARRAY

Figure 15 and 16 show the layout and the actual picture of the 3-element array. This array is fed by the excitation coefficients and spaced according to the Table 2. The antennas are spaced by a half-wavelength and excited symmetrically. The phase values are also symmetric but with opposite sign. Figure 17 and 18 show the simulated and measured return losses respectively. Figure 19, 20 and 21 shows the radiation pattern of array theory, simulation and measurement respectively.

Table 2 Spacing and the excitation coefficients of 3-element array

	1	2	3
Space	$-\frac{\lambda}{2}$	0	$\frac{\lambda}{2}$
Amplitude	0.9324	1	0.9324
Phase	27.1921^{o}	0^{o}	-27.1921^{o}

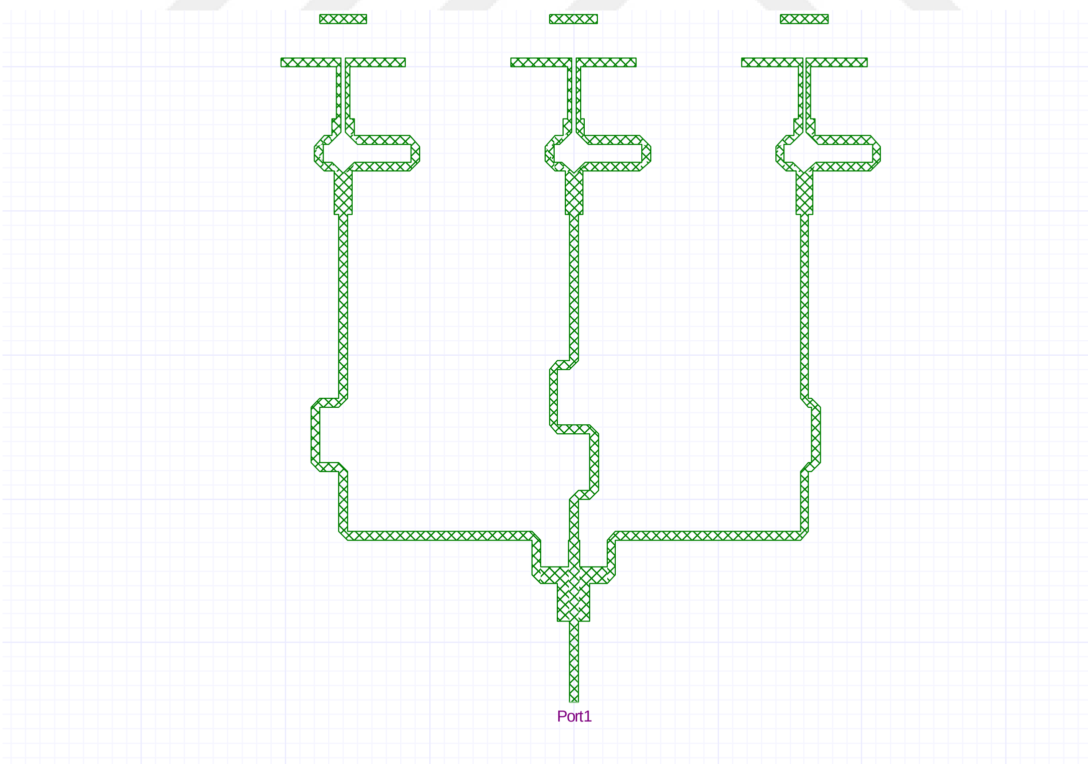


Figure 15 The layout of the 3-element array

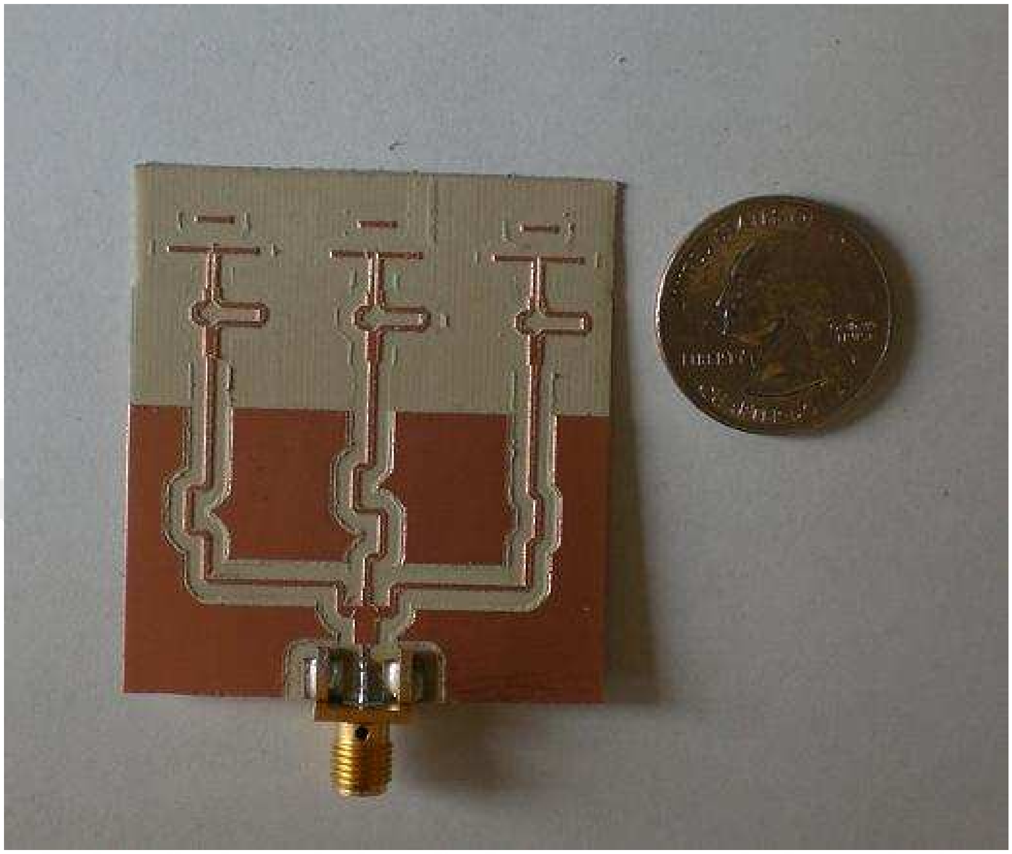


Figure 16 Actual array for 3-elements

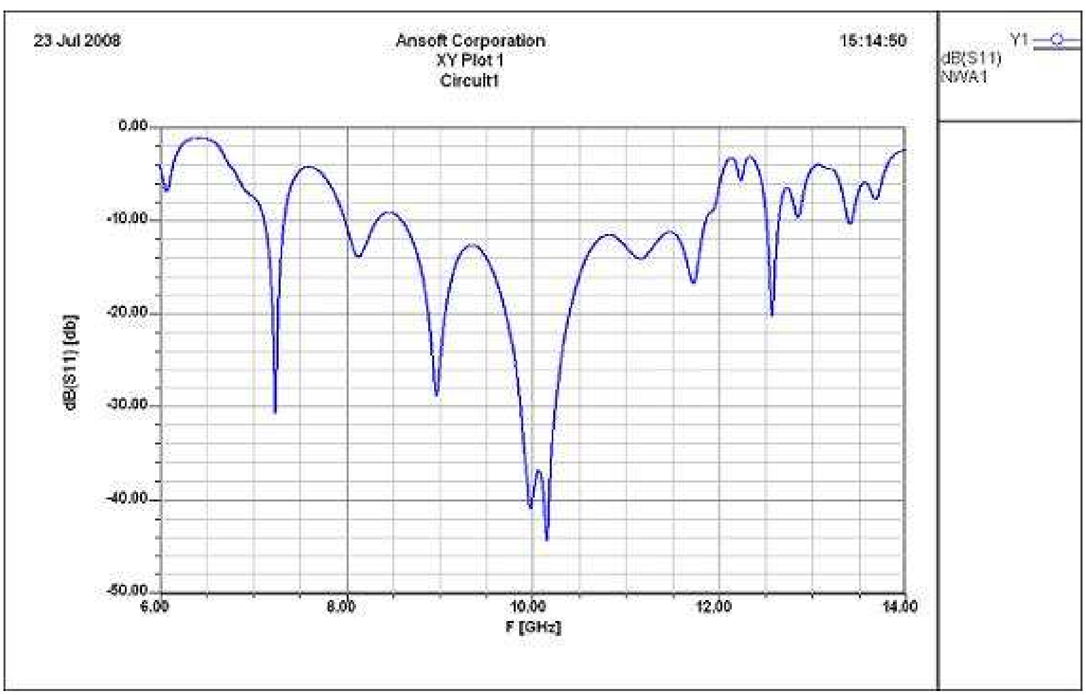


Figure 17 Simulated return loss for 3-element array

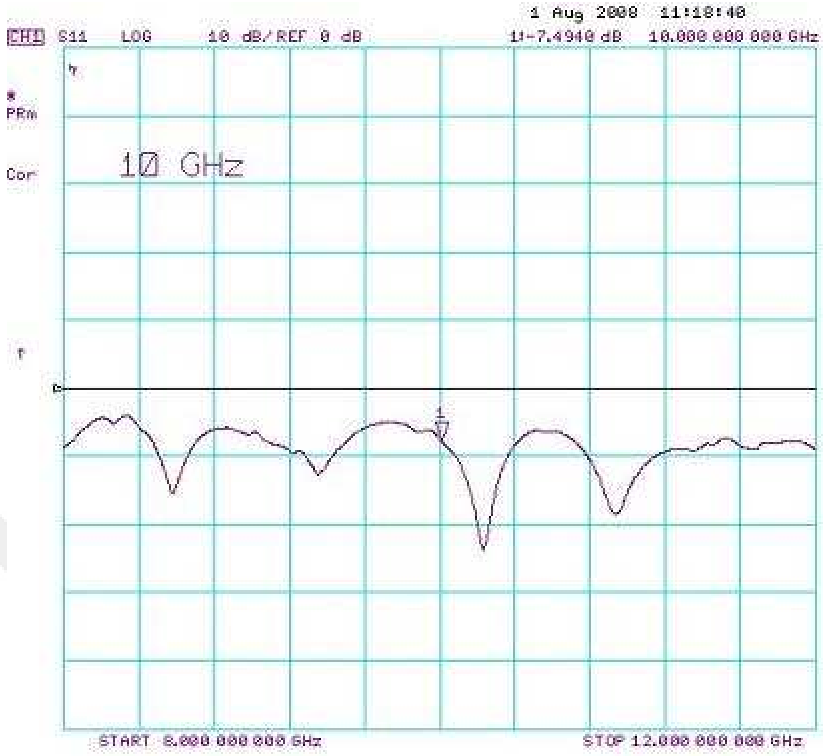


Figure 18 Measured return loss for 3-element array

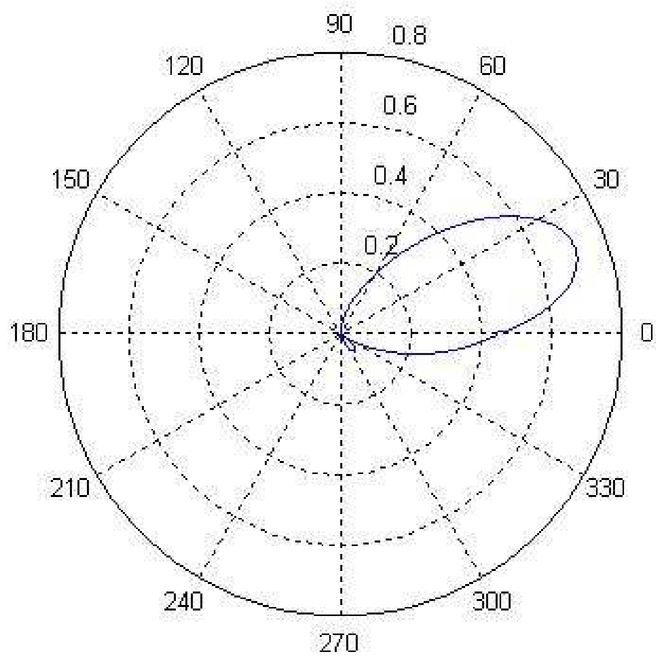


Figure 19 Radiation pattern for 3-element array of array theory

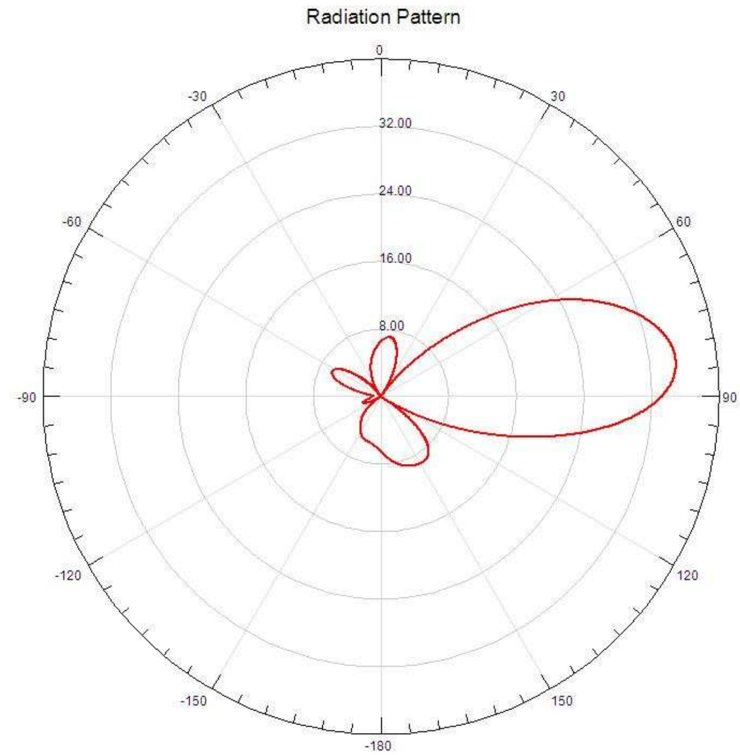
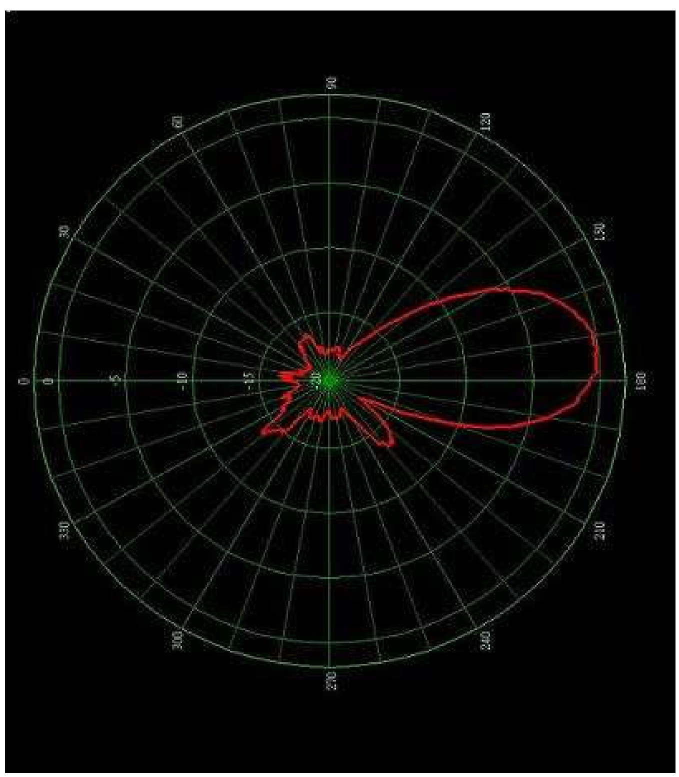


Figure 20 Simulated radiation pattern for 3-element array



F**igure 21** Measured radiation pattern for 3-element array

5.2 5-ELEMENT ARRAY

Again the results for a radiation pattern are displaced here according to the array theory, simulation and measurement results. Now for 5 elements we see that main beam of the radiation pattern is getting narrower as the number of elements is increased.

Table 3 Spacing and the excitation coefficients for 5-element array

	1	2	3	4	5
Space	$-\lambda$	$-\frac{\lambda}{2}$	0	$\frac{\lambda}{2}$	λ
Amplitude	0.7534	0.9324	1	0.9324	0.7534
Phase	51.8148^{o}	27.1921^{o}	0^{o}	-27.1921^{o}	-51.8148^{o}

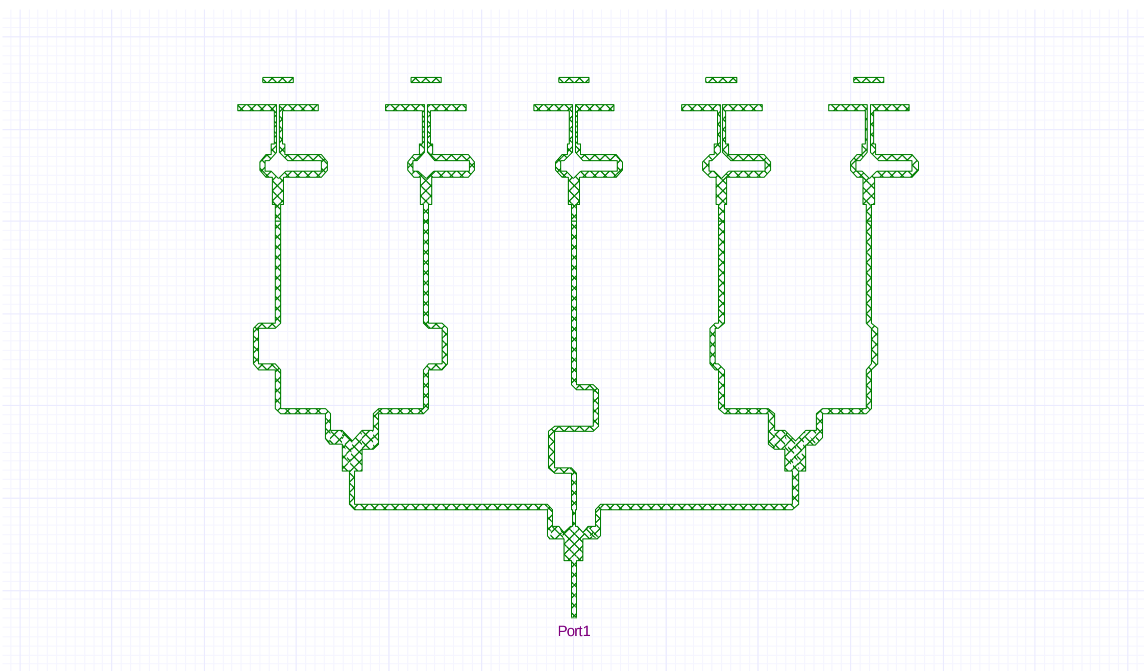


Figure 22 The layout of the 5-element array

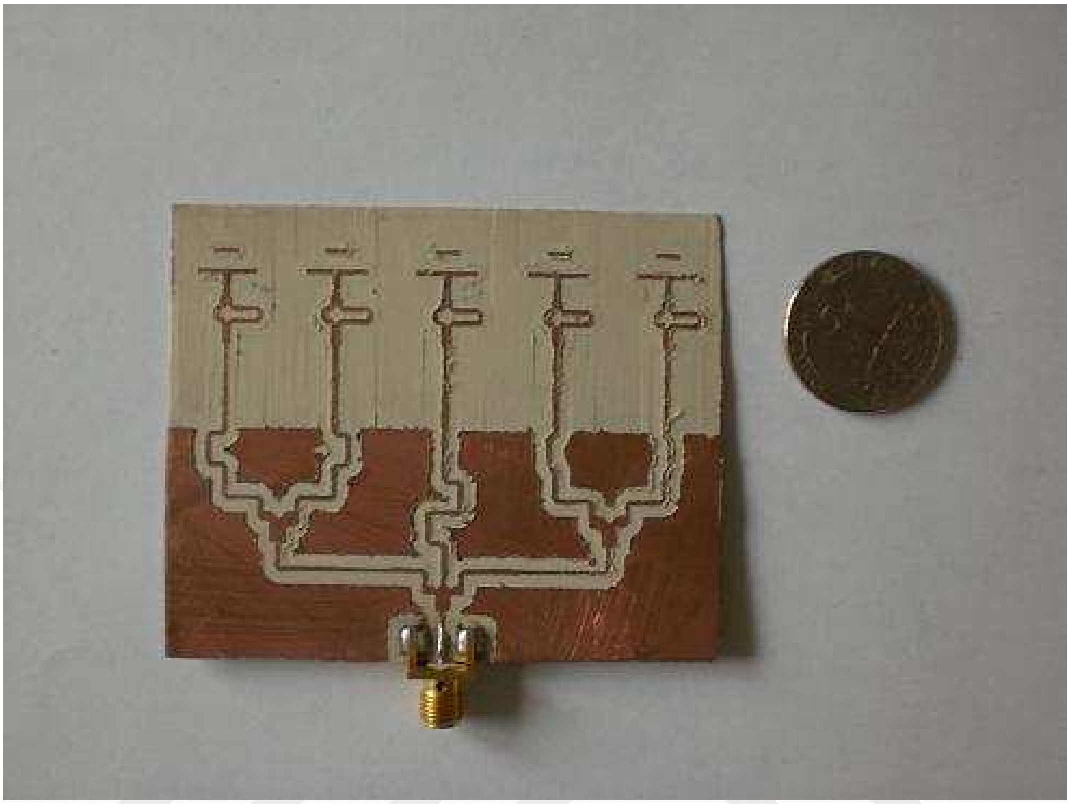


Figure 23 Actual 5-element array

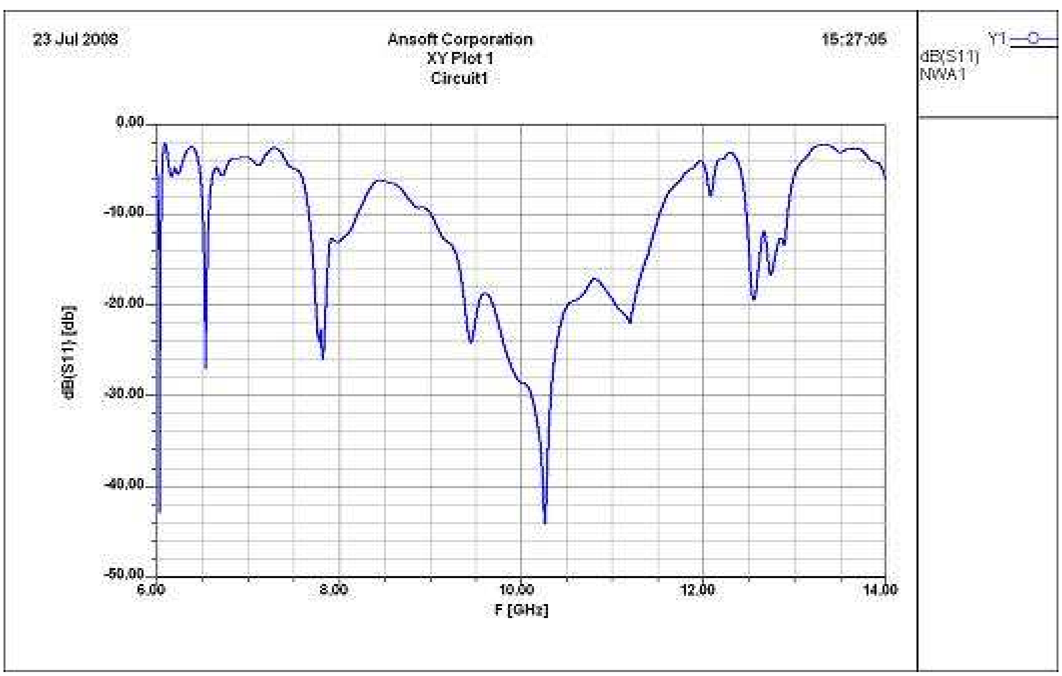


Figure 24 Simulated return loss for 5-element array

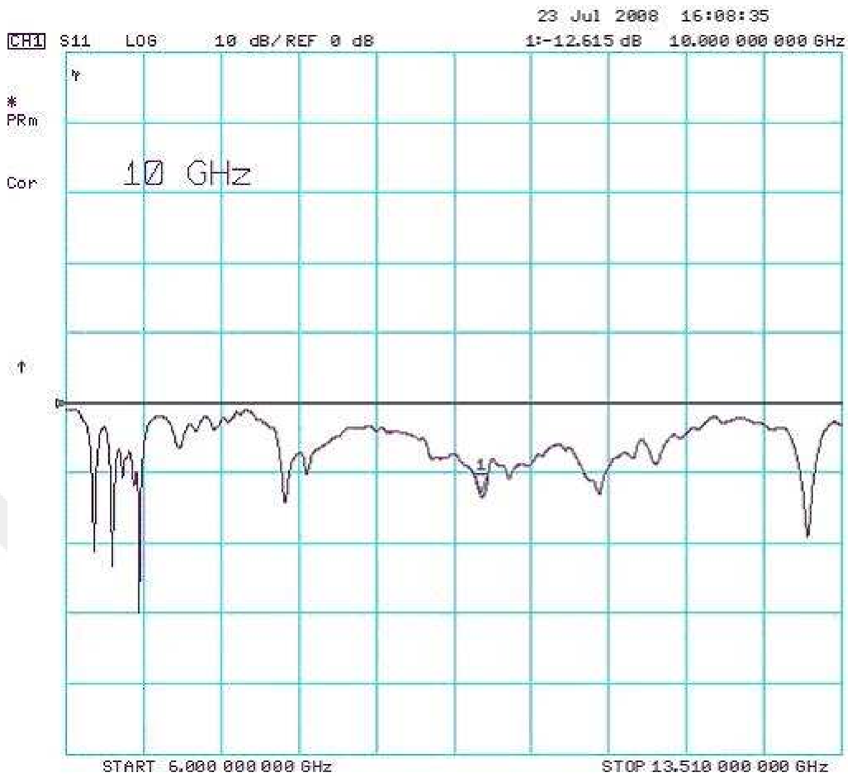


Figure 25 Measured return loss for 5-element array

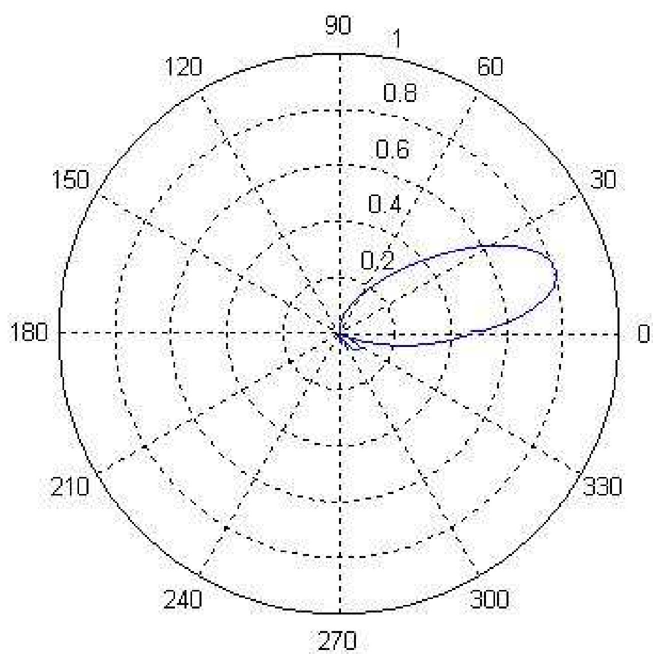


Figure 26 Radiation pattern for 5-element array of array theory

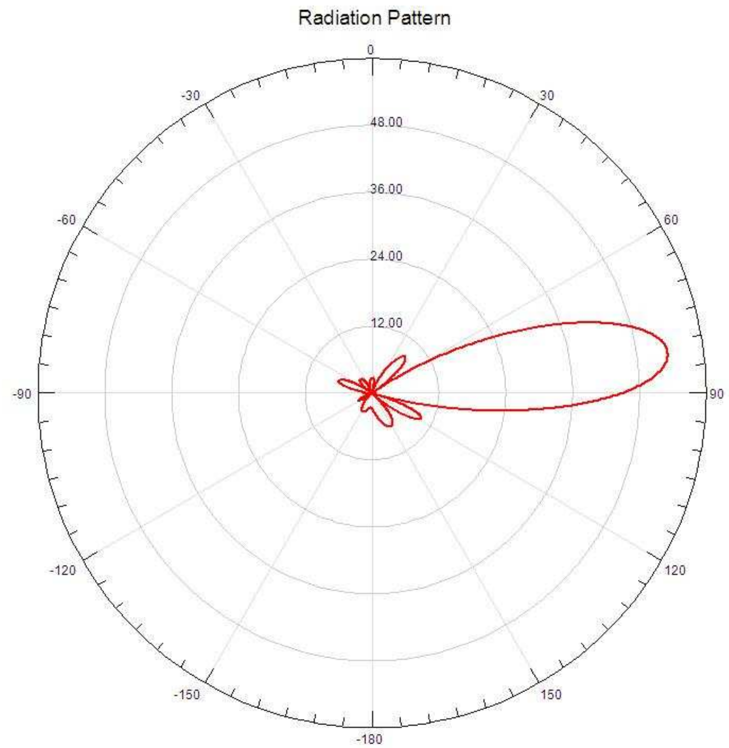


Figure 27 Simulated radiation pattern for 5-element array

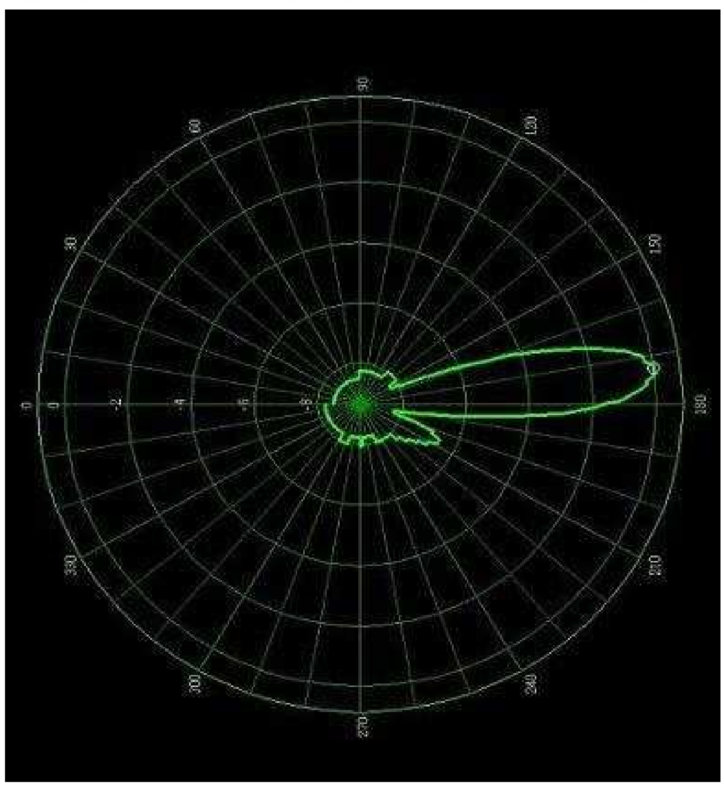


Figure 28 Measured radiation pattern for 5-element array

5.3 9-ELEMENT ARRAY

As expected the displayed results are best for a 9-element array. The following figures show the comparison of array theory, simulation and measurement. They all agree well.

Table 4 Spacing and excitation coefficients for 9-element array

	1	2	3	4	5	6	7	8	9
Space	-2λ	$-\frac{3\lambda}{2}$	$-\lambda$	$-\frac{\lambda}{2}$	0	$\frac{\lambda}{2}$	λ	$\frac{3\lambda}{2}$	2λ
Amplitude	0.35	0.52	0.75	0.93	1	0.93	0.75	0.52	0.35
Phase	73^o	69^o	51^o	27^o	0^o	-27^o	-51^o	-69^o	-73^o

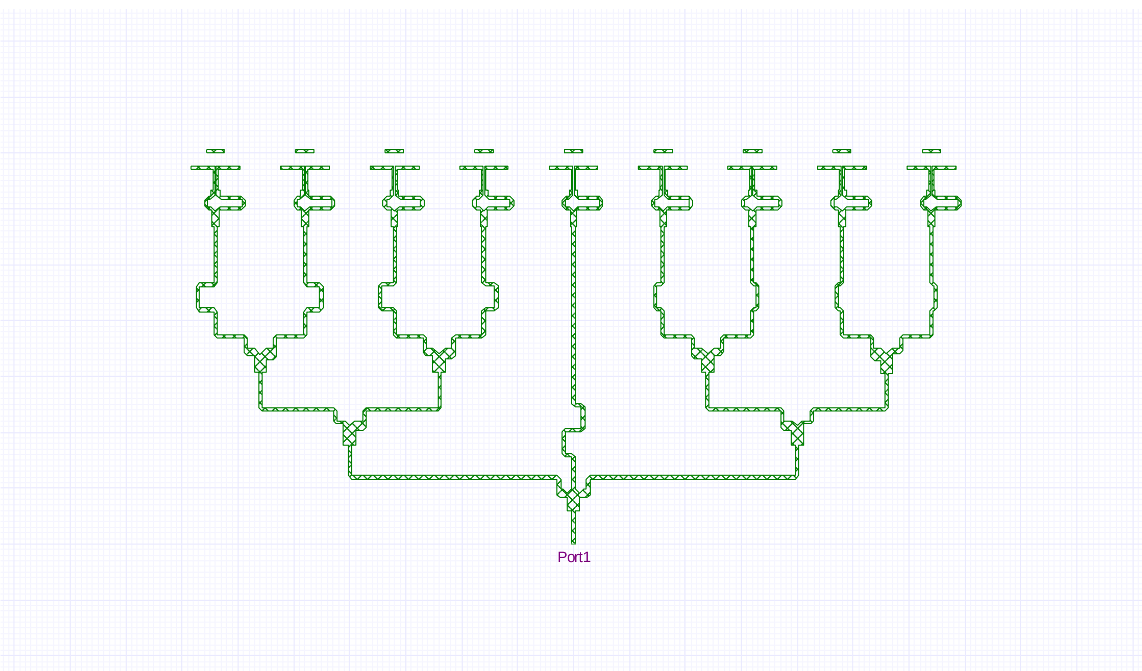


Figure 29 The layout of the 9-element array

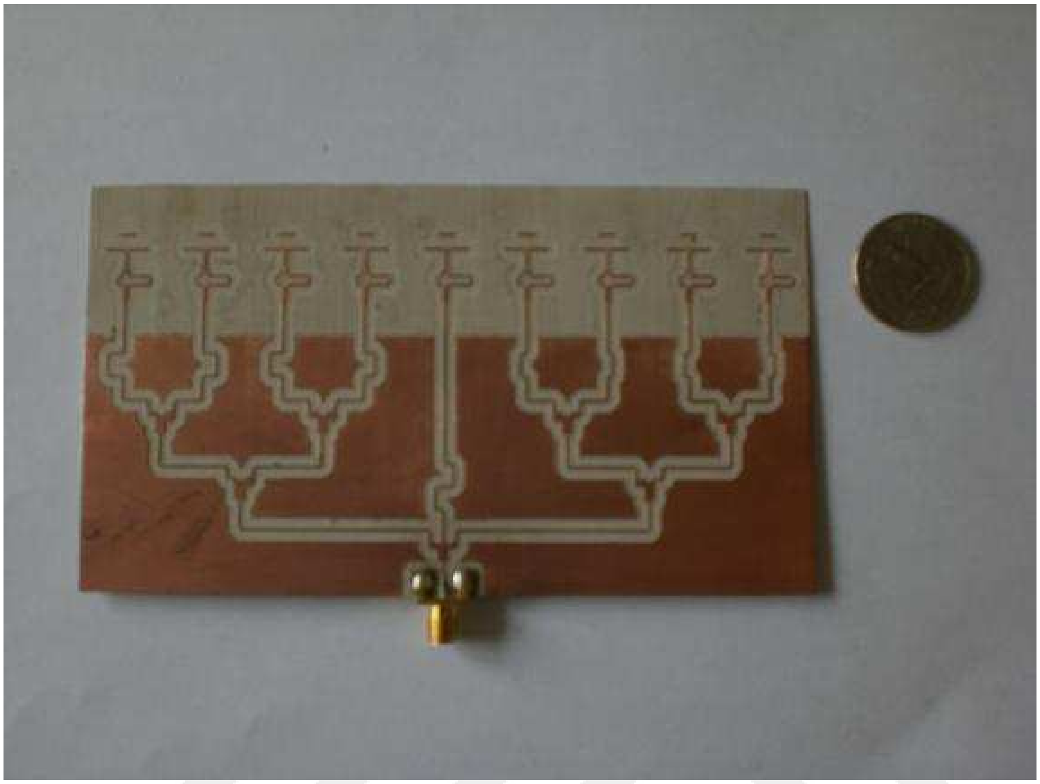


Figure 30 Actual 9-element array

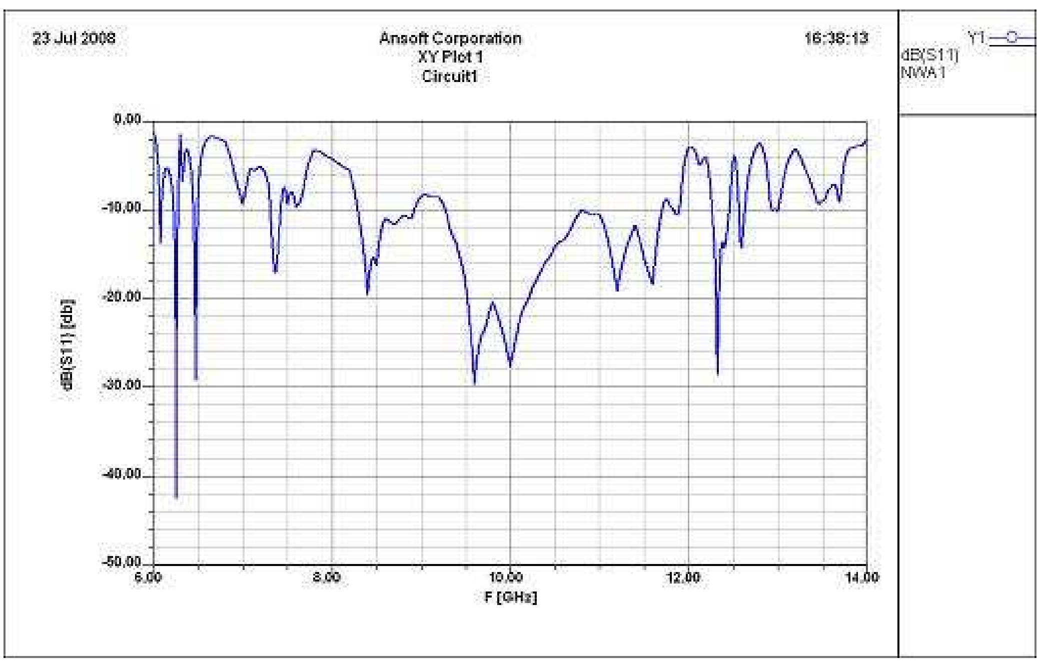


Figure 31 Simulated return loss for 9-element array

Figure 32 Measured return loss for 9-element array

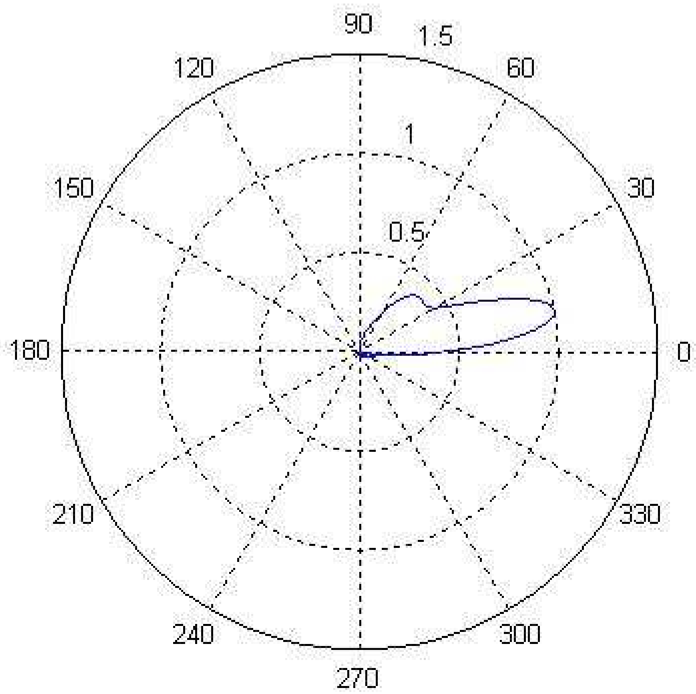


Figure 33 Radiation pattern of 9-element array using array theory

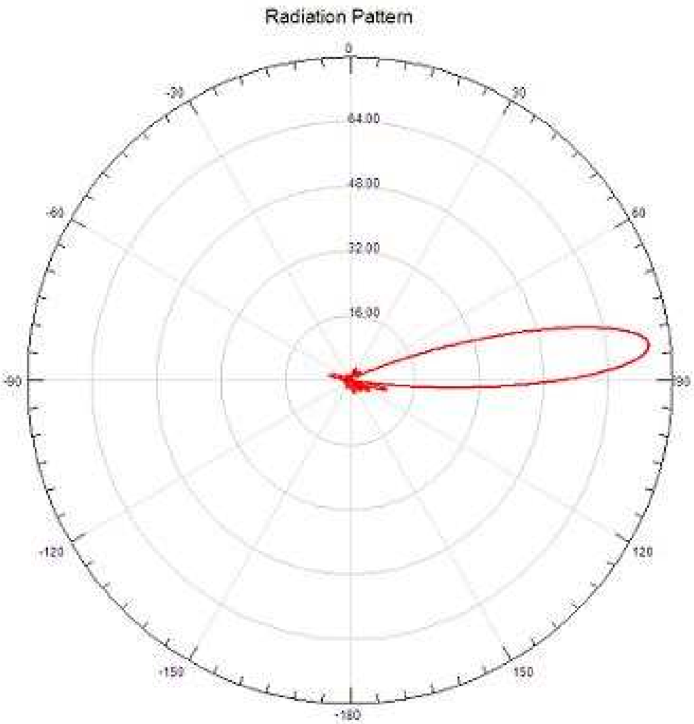


Figure 34 Simulated radiation pattern for 9-element array

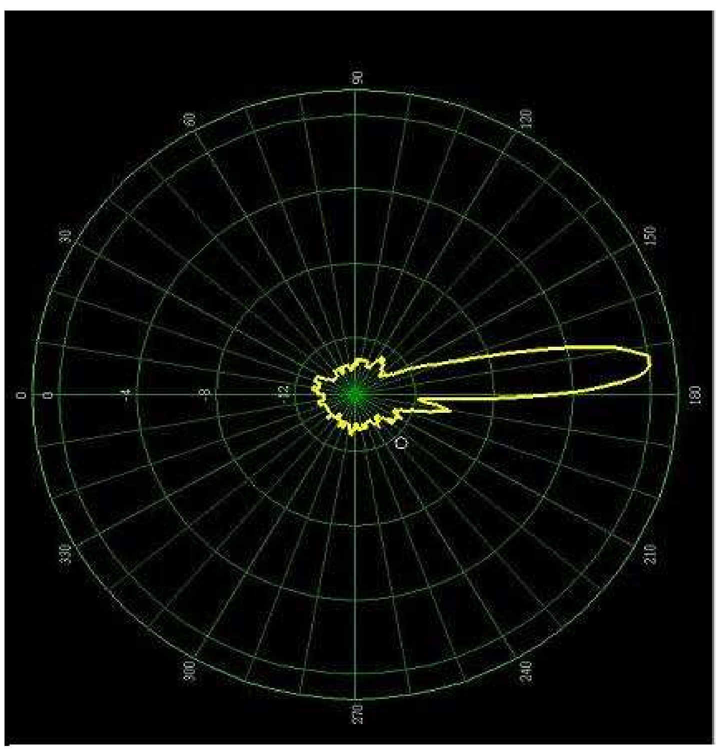


Figure 35 Measured radiation pattern for 9-element array

5.3 17 AND 33-ELEMENT ARRAY

The array theory and the simulation results are presented here for 17 and 33 elements. Figure 36 and 37 show the radiation pattern of 17-element array for array theory and simulation. Figure 38 and 39 show the radiation pattern of 33-element array for array theory and simulation respectively. As we increase the number of elements the radiation pattern becomes closer to the ideal desired radiation pattern.

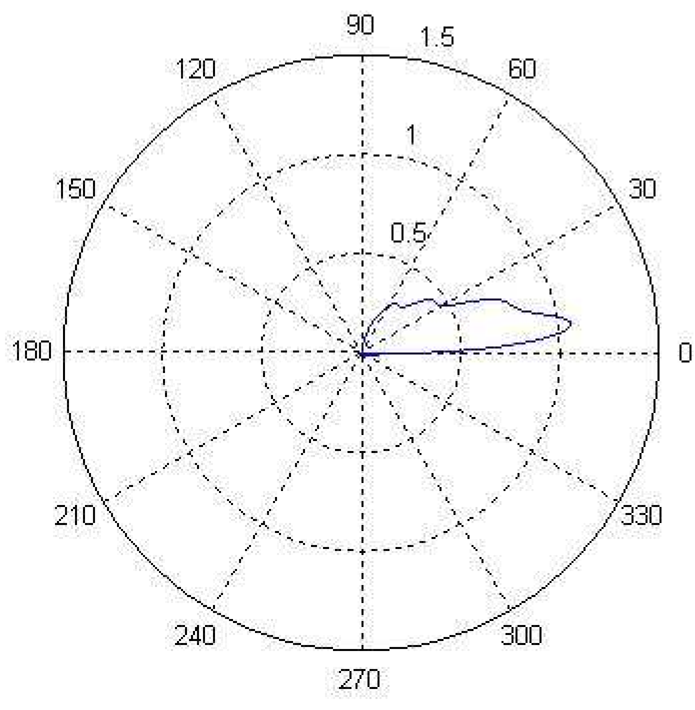


Figure 36 Radiation pattern of 17-element array using array theory

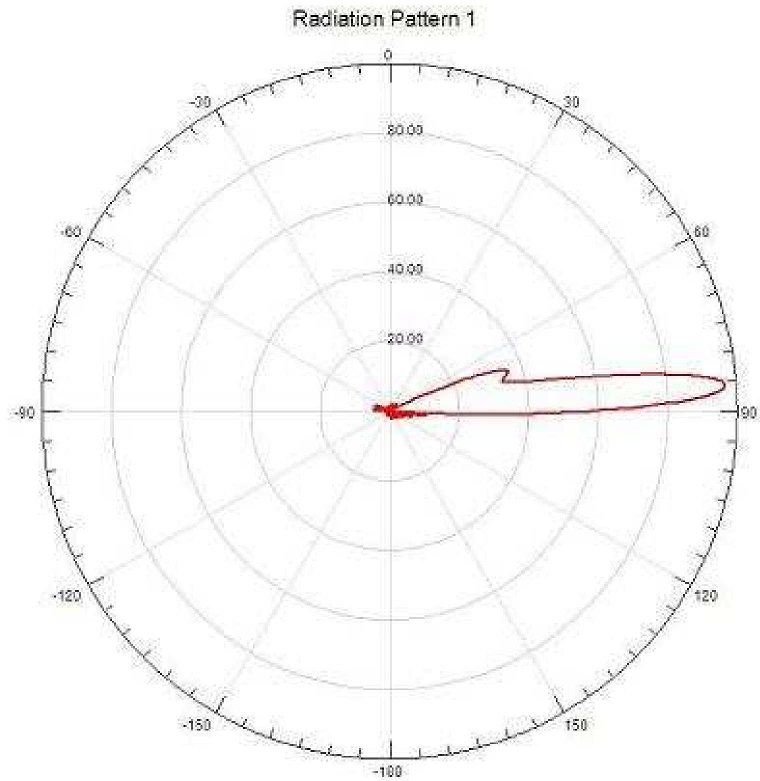


Figure 37 Simulated radiation pattern for 17-element array

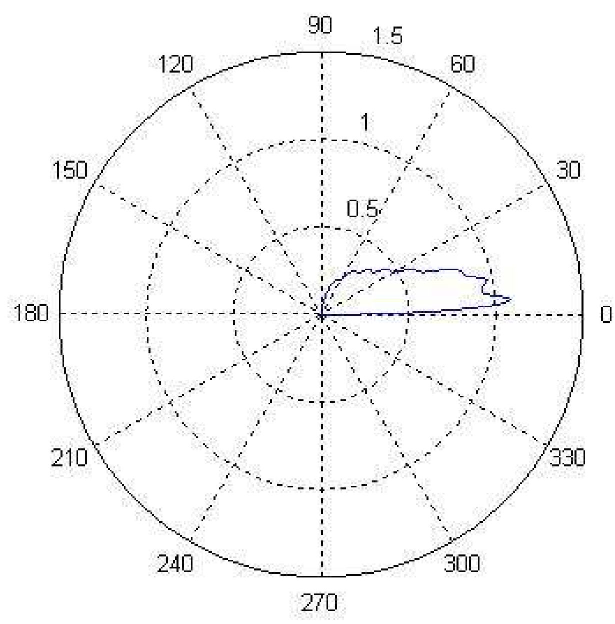


Figure 38 Radiation pattern of 33-element array using array theory

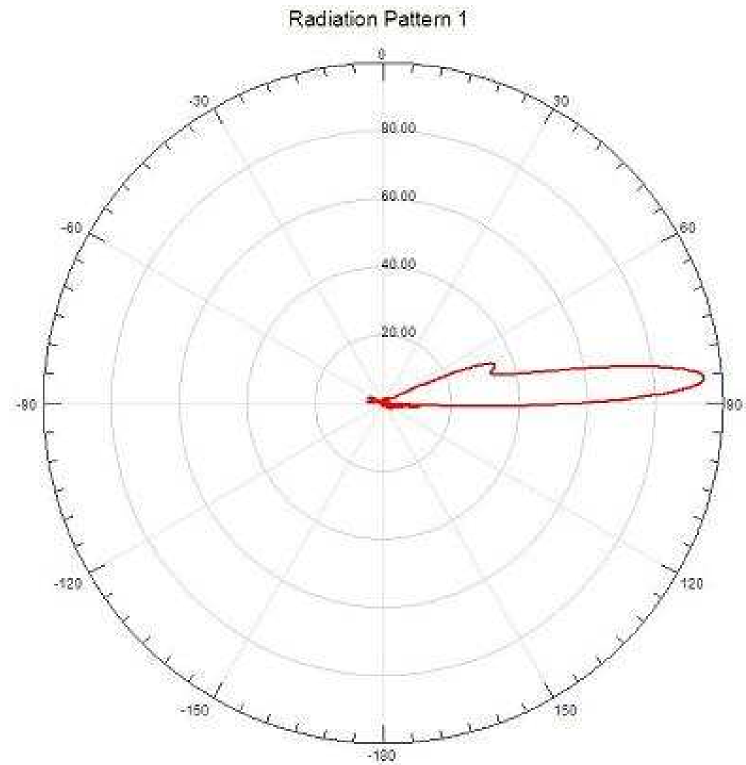


Figure 39 Simulated radiation pattern for 33-element array

Figure 40 Measurement Environment

6. CONCLUSION

In this work, we have designed, built and tested the quasi-yagi antenna array for 3, 5 and 9 elements. 17 and 33 elements are only designed and simulated. The return losses and radiation patterns of these arrays were obtained and discussed. It is seen that the results of the array theory, computer simulation and measurement agree well.

Feeding the elements of an array with different amplitude and phase values is the difficult part of the design process. It is seen that it is crucial to feed each antenna with proper excitation coefficients. Increasing the number of array elements helps to get a better radiation pattern but it also makes the design more difficult and more complex.

7. APPENDIX

7.1 MATLAB PROGRAMS

1) Antenna Synthesis Program for Isotropic Sources

This program calculates the desired radiation pattern and finds out the excitation coefficients for given array elements. Then it recalculates the radiation pattern using the coefficients. The code was written for odd number of elements.

```
clear all;
close all;
clc;
 % Enter the number of array elements.
%This loop calculates the desired radiation pattern
N=input('Enter number of phased array elements (odd number)=   ');
for k=1:2048
    f(k)=(k-1)/1024;
    if f(k)<=sin(pi/180)
        y(k)=pi/180;
        z(k)=1;
        P(k)=0;
        G(k)=0;
        theta(k)=atan(y(k));
    elseif f(k)<=1/sqrt(10)
        z(k)=(3/4)*(1-f(k)^2)*(1+sqrt(1-(8/(9*(1-f(k)^2)))));
```

```
    y(k)=sqrt(0.25^2-(z(k)-0.75)^2);
    P(k)=z(k)/(1-f(k)^2);
    G(k)=P(k)*z(k)/sqrt(y(k)^2+z(k)^2);
    theta(k)=atan(y(k)/z(k));
elseif f(k)<=1/sqrt(2)
    z(k)=(1/(4*f(k)))*sqrt(1-f(k)^2);
    y(k)=0.25;
    P(k)=0.25^2/(z(k)*f(k)^2);
    G(k)=P(k)*z(k)/sqrt(y(k)^2+z(k)^2);
    theta(k)=atan(y(k)/z(k));
elseif f(k)<1
    z(k)=(1-f(k)^2)/2;
    y(k)=sqrt(0.25^2-(z(k)-0.25)^2);
    P(k)=0.5;
    G(k)=P(k)*z(k)/sqrt(y(k)^2+z(k)^2);
    theta(k)=atan(y(k)/z(k));
elseif f(k)==1
    y(k)=0;
    z(k)=0;
    P(k)=0.5;
    G(k)=0;
    theta(k)=pi/2;
else
```

```
        y(k)=0;
        z(k)=1-f(k);
        P(k)=0;
        G(k)=0;
        theta(k)=f(k)*pi/2;
    end
end
thetad=theta*180/pi;
figure(1)
plot(thetad,G)
figure(2)
plot(f,P)
figure(3)
polar(theta,P.*cos(theta))

Q=ifft(P);
for m=1:2048
    if m<=(N+1)/2
        QR(m)=Q(m);
    elseif m<=2048-(N-1)/2
        QR(m)=0;
    else
        QR(m)=Q(m);
```

```
    end
end
for m=1:2048
    PS(m)=P(m)*((-1)^(m-1));
end
QS=ifft(PS);
for m=1:2048
    if m<=1024-(N-1)/2
        QSR(m)=0;
    elseif m<=1024+(N+1)/2
        QSR(m)=QS(m);
    else
        QSR(m)=0;
    end
end
PR=fft(QR);
PSR=fft(QSR);
figure(4)
bar(abs(QSR),0.1)
xlim([1020-(N-1)/2 1028+(N+1)/2])
figure(5)
bar(real(QSR),0.1)
xlim([1020-(N-1)/2 1028+(N+1)/2])
```

```
figure(6)
bar(imag(QSR),0.1)
xlim([1020-(N-1)/2 1028+(N+1)/2])
figure(7)
for m=1:2048
    if real(QSR(m))==0
        phaseQ(m)=NaN;
    else
        phaseQ=(180/pi)*atan(imag(QSR(m))/real(QSR(m)));
    end
end
bar(phaseQ,0.1)
xlim([1020-(N-1)/2 1028+(N+1)/2])
figure(8)
plot(real(PR))
figure(9)
plot(abs(PR))
figure(10)
polar(theta,abs(PR).*cos(theta))
figure(11)
plot(imag(PR))
```

2) Function for Desired Radiation Pattern

```
%function [DP]=Pattern(theta)


dt=0.1758;

theta=0:dt*pi/180:2*pi;

l=length(theta);


theta1=0:0.88*pi/180:pi/2;


for i=1:1:103

   DP(i)=.75+.25*cos(theta1(i));

end


for i=104:1:246

   DP(i)=.75*(sin(theta(104))/sin(theta(i)));

end

for i=246:1:512

   DP(i)=.46*cos(theta(i));

end

 for i=512:1:l

    DP(i)=0;

end

polar(theta,DP)
```

3) Antenna Synthesis Program for Quasi-Yagi Antenna

```
clear all;

close all;

clc;


N=input('Enter number of phased array elements (odd number)=   ');


theta=0:0.1758:360;

theta=theta*pi/180;


RESULT = DLMREAD('1.csv',',',1,1);

YagiP=RESULT';

YagiP=YagiP./max(YagiP);



for i=1:2048

   if i>=513

       YagiP1(i-512)=YagiP(i);

   else

       YagiP1(3*512+i)=YagiP(i);

   end

end
```

```
[DP]=Pattern(theta);

AF=DP./YagiP1;

Q=ifft(AF);
for m=1:2048
   if m<=(N+1)/2
      QR(m)=Q(m);
   elseif m<=2048-(N-1)/2
      QR(m)=0;
   else
      QR(m)=Q(m);
   end
end
for m=1:2048
   PS(m)=AF(m)*((-1)^(m-1));
end
QS=ifft(PS);
for m=1:2048
   if m<=1024-(N-1)/2
      QSR(m)=0;
   elseif m<=1024+(N+1)/2
      QSR(m)=QS(m);
```

```
    else
        QSR(m)=0;
    end
end
PR=fft(QR);
PSR=fft(QSR);
 figure(4)
 bar(abs(QSR),0.1)
 xlim([1020-(N-1)/2 1028+(N+1)/2])
 figure(5)
 bar(real(QSR),0.1)
 xlim([1020-(N-1)/2 1028+(N+1)/2])
 figure(6)
 bar(imag(QSR),0.1)
 xlim([1020-(N-1)/2 1028+(N+1)/2])
 figure(7)
for m=1:2048
    if real(QSR(m))==0
        phaseQ(m)=NaN;
    else
        phaseQ(m)=(180/pi)*atan(imag(QSR(m))/real(QSR(m)));
    end
end
```

```
 bar(phaseQ,0.1)
 xlim([1020-(N-1)/2 1028+(N+1)/2])
 figure(8)
 plot(real(PR))
 figure(9)
 plot(abs(PR))
figure(10)
yeniP=abs(PR).*YagiP1;
yeniP=yeniP./max(yeniP);
polar(theta,yeniP)
figure(11)
plot(imag(PR))
l=length(QR);
for i=1:N
    Amplitude(i)=abs(QSR((l/2)-(N-1)/2+i))/QSR(l/2+1);
end
 for i=1:N
    Phase(i)=(pi/180)*phaseQ((l/2)-(N-1)/2+i);
end

Amplitude
Phase
```

REFERENCES

[1] Robert E. Collin, Francis J. Zucker, *Antenna Theory Part 1*, New York: McGraw-Hill, 1969.

[2] John D. Kraus, *Antennas,* New York: McGraw-Hill, 1988.

[3] http://www.ece.rutgers.edu/~orfanidi/ewa/.

[4] S. A. Schelkunoff, *A Mathematical Theory of Linear Arrays*, Bell Syst. Tech. J., vol. 22, pp. 80-107:1943.

[5] D. K. Cheng, M.T. Ma, *A New Mathematical Approach for Linear Array Analysis*, IRE Trans. Antennas Propagation, vol. AP-8, pp. 255-259, May 1960.

[6] Randy L. Haupt, Dougles H. Werner, *Genetic Algorithms in Electromagnetics,* Wiley-IEEE Press, April 2007.

[7] William R. Deal, Noriaki Kaneda, James Sor, Jongxi Qian and Tatsuo Itoh, *A New Quasi-Yagi Antenna for Planar Active Antenna Arrays,* IEEE Trans. Microwave Theory and Techn., vol.48, no.6, pp.910-918, June 2000.

[8] Noriaki Kaneda, W. R. Deal, Jongxi Qian, Rod Waterhause and Tatsuo Itoh, *A Broad Band Quasi-Yagi Planar Antenna,* IEEE Trans. Antennas Propagation, vol.50, no.8, pp.1158-1160, August 2002.

[9] Ansoft Corparation, www.ansoft.com

[10] ROGERS Corporation, Chandler, AZ.

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