NOVEL ANTENNA DESIGN SUITABLE FOR EVAPORATION DUCT

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Program

in Partial Fulfillment of the Requirements

for the Degree

Bachelor of Engineering (Hons)

(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

June 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Youssef A. Y. Rezk

Youssef Ahmed Youssef Rezk

ABSTRACT

This project investigates a design of antenna array that might be suitable for implementation in the evaporation duct. The design investigates a novel horn antenna array that can produce high gain over a narrow beam width. The novel design is to operate in duct environment via having marine grade protection. This design will be explore the physical unique properties of the evaporation duct and utilize it to establish long distance communication over the evaporation duct.

ACKNOWLEDGEMENTS

I take this opportunity to express my profound gratitude and deep regards to my guide (Professor Varun Jeoti, Universiti Teknologi PETRONAS) for his exemplary guidance, monitoring and constant encouragement throughout the course of this thesis.

I would also like to extend the gratitude to both Dr. Micheal Drieberg and Dr. Wong Peng Wen for contious support, Mr. Asif Iqbal for their time and effort that ensured the quality of the presented materials.

Lastly, I thank almighty, my parents, brother, sister and friends for their constant encouragement without which this assignment would not be possible.

Youssef A. Y. Rezk

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LIST OF ABBREVIATIONS

PCSB…………………………….......................... PETRONAS CARIGALI SDN. BHD

WiDUCT …………………………...…………………………..…... WIRELESS DUCT

Chapter (1)
INTRODUCTION

1.1. Background

The technology of Long Distance Communication has been evolving fast in the last century. Many Challenges that were faced in the past are viewed as trivial nowadays. The revolution in wireless communication has led many of the greatest minds of the last decades to strive at providing some wide range reliable systems. However, Oceanic Trans-Horizon Communication still presents a situation where it is infeasible to have many stations between the two ends of the system over large distances per link.

The physical properties of the environment are main considerations in any communication system design. The manipulation of the channels physical parameters to be of an advantage rather than a disadvantage has devised some pioneer techniques to accommodate to specific channels. A proposed usage of the oceanic trans-horizon properties investigates the continuous change in refraction coefficient as a function of height has led to the formulation of the phenomena of the Evaporation Duct. The Evaporation Duct is a non-physical boundary that causes a signal fired at a certain range of angles to be trapped through the bending of the signal element arising from the continuous change in the refractive index.

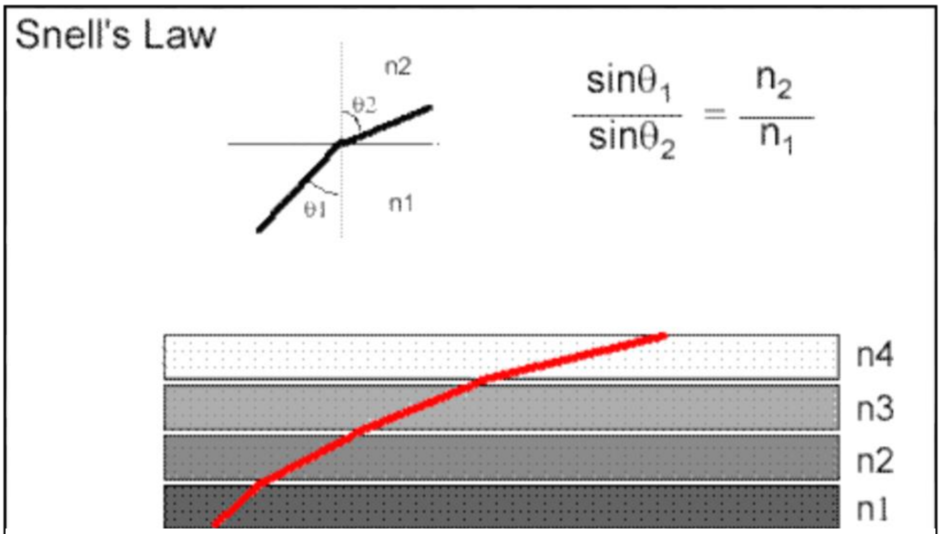

Figure 1 Snell's Law with Multiple Refractive Layers of the Evaporation Duct [1]

Higher altitudes result in lower pressures and lower temperatures hence the refractive index of the atmosphere usually falls with height. [1]

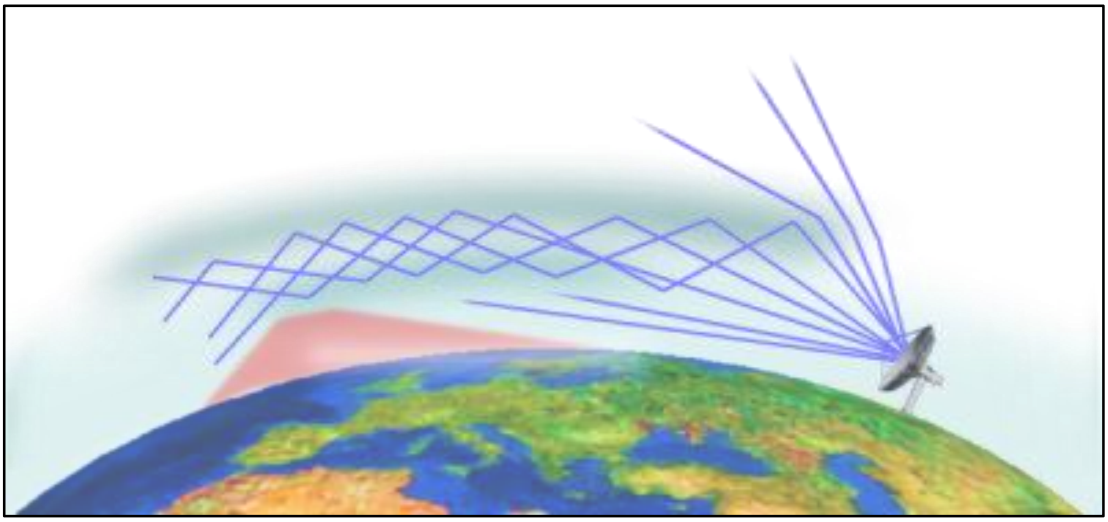

Figure 2 Signal Trapping in Evaporation Duct [1]

Antennas are the arms of any communication system. Antenna is the means by which the signal is either transmitted or received through the medium. Different antennas with different properties have been introduced and devised to accommodate to various systems. Antenna Design is a very challenging process as a lot of parameters affect the behavior of the antenna either from the environment, the physical properties of the antenna or the electrical circuit connected to the antenna.

The unique behavior of the Evaporation Duct which allows trapping of signals when fired at an angle - whose subsequent bending due to change in refractive index is less than the escape angle of the duct – results in a trade of between the a narrow beam width for transmission and a wide beam width for reception. In a Full Duplex System both antenna are to be design properly to accommodate to such parameters.

The final response of the antenna is one of the main factors determining the quality of the proposed communication system. Antennas nowadays are available in a vast variety from wire to micro-strip antennas that serves various bandwidths with different responses for different gains and beam widths as needed however, the availability of an antenna design for the sole purpose of serving a duct remains an open problem that requires in depth investigation to cater for the unique behavior of the Evaporation duct’s physical parameters.

1.2. Problem Statement

Designing an antenna with a high directive gain for WiDUCT usage that would eliminate the wind load of the conventional reflector dish antenna.

A complete communication system requires an antenna design that caters to the needed result. A communication system solution making benefit of the physical phenomena of Evaporation Duct requires a unique antenna system to be implemented.

The utilization of a proposed antenna design that could attend to the required response in the term of the directivity, beam-width, bandwidth and relative gain is the main aim of this investigation.

The proposed solution is to be used in WiDUCT (Wireless Duct) a project in collaboration between PCSB (PETRONAS Carigali SDN BHD) and UTP (Universiti Teknologi PETRONAS) to produce a reliable offshore link to cater for the needs of PCSB.

1.3. Objectives & Scope of Study

This work aims to utilize the methods in the literature in order to devise a novel model that shall aim to:

1) Investigate the evaporation duct to identify a feasible antenna design.
2) Design an antenna to cater of the evaporation duct.
3) Simulate the performance of the antenna in the duct.
4) Fabricate and validate the antenna performance.

A horn antenna array is the proposed solution.

Chapter (2)
LITERATURE REVIEW

An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves." The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) defines the antenna or aerial as "a means for radiating or receiving radio waves." [2]

2.1. Single Antenna Element Parameters

1) Directivity

For any wave the Poynting vector is given by

$$\boldsymbol{\mathcal{W}} = \boldsymbol{\mathcal{E}} \times \boldsymbol{\mathcal{H}} \tag{2.1}$$

Where $\boldsymbol{\mathcal{E}}$ is the instantaneous electric field and $\boldsymbol{\mathcal{H}}$ is the instantaneous magnetic intensity field.The average power a is given by

$$P_{rad} = P_{av} = \oiint_s \boldsymbol{\mathcal{W}}_{av} \, . d\boldsymbol{s} = \oiint_s Re\,(\boldsymbol{\mathcal{E}} \times \boldsymbol{\mathcal{H}}^*) \, . d\boldsymbol{s} \tag{2.2}$$

The radiation intensity is $\boldsymbol{U}$ where r is the distance from the source is.

$$\boldsymbol{U} = r^2 \, \boldsymbol{\mathcal{W}}_{av} \tag{2.3}$$

The Directivity is given by

$$D = 4\pi U / P\_rad \tag{2.4}$$

2) Gain

The gain is given by G where the input power is P_{in}

$$G = {}^{4\pi U(\theta,\phi)}/_{P_{in}} \tag{2.5}$$

3) Efficiency

The total efficiency e_T is given by

$$e_T = e_r \, e_c \, e_d \tag{2.6}$$

Where e_r , e_c and e_d are the reflection, conduction and dielectric efficiencies respectively.

4) Input Impedance

The input impedance of the antenna is an important parameter that helps formulate the bandwidth response by minimizing the reflection coefficient and increasing the transmission coefficient.

There are other antenna parameters that contribute to the response of the antenna as the antenna aperture and the polarization matching that are independent of the previously discussed parameters and other parameters that can be deduced from the main parameters as radiation pattern and beam-width. [3, 4]

With all of these parameters to contribute to the response of the antenna there are many antenna types that can be classified as into four main types [4]:

1) Electrically Small Antennas
2) Resonant Antennas
3) Broadband Antennas
4) Aperture Antennas

   These antenna types accommodate to vast majority of needs of communication systems.

Figure 3 Various Antenna Types [2] [3] [4]

2.2. Array Factor

This project is investigating the element of Antenna array design. The response of an antenna array is usually modeled as the product of a single element response and the array factor. [2]

The single element response corresponds to the array element response as a single antenna while the array factor is independent of the single array element where it conveys the parameters of the array such as: type, size, separation distance and phase difference where the total far field of the antenna array is given by

$$E_T = E_{S.E.} \times AF \tag{2.7}$$

Where E_T is the total antenna array field, $E_{S.E.}$ is the single element field and AF is the array factor [3].

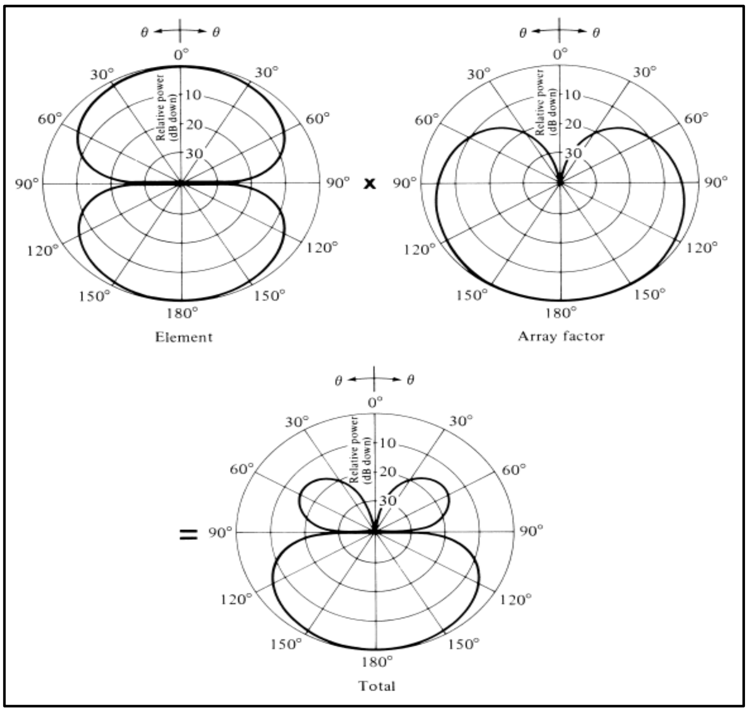

Figure 4 Antenna Array Response from Single Element and Array Factor [2] [3]

A mathematical model shall be derived based on the single element response and the array factor from the antenna array parameters to obtain the array factor that would contribute the required total response of the system.

An important factor of the antenna design is impedance matching where at high frequencies due to the phenomena of standing electric waves so the wave experiences with maxima and minima every $\lambda/2$ where λ is wave length of the wave [5]. This requires impedance matching to reduce the losses on the circuit connected to the antenna. This is done through matching the impedance seen at the input side Z_{in} to the impedance of the load (antenna) Z_A through a line of length l and impedance of Z_o as shown.

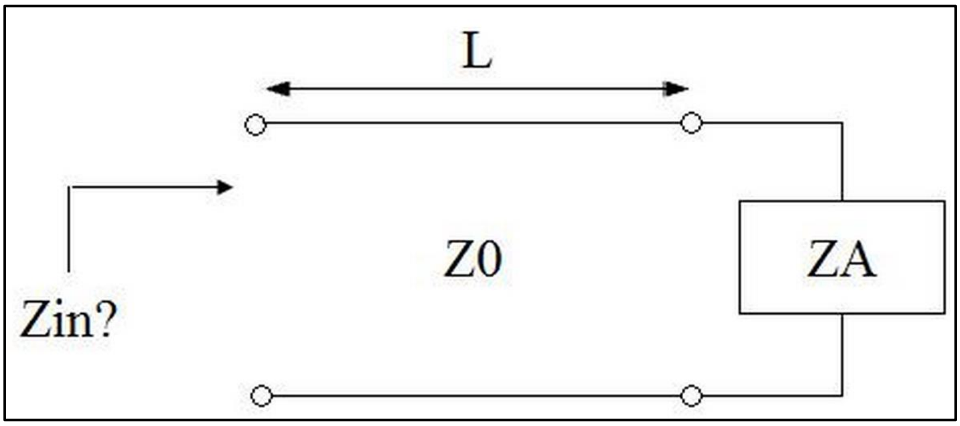

Figure 5 Impedance Matching for the Antenna [3]

After the derivation of the mathematical model, a simulation will be implemented to test the response using available software as CST, ADS, HFSS and MATLAB.

After the simulation is conducted the antenna array is to be sent to be fabricated and characterized in the laboratory prior to its usage offshore for the project. A Gantt chart illustrating the portion of the project with reports and key milestones is presented.

Chapter (3)
METHODOLOGY

To Design the antenna array there are a lot of parameters to be considered as the:

a) Single Antenna Element of the Array
b) Antenna Array Specifications
c) Electric Feed Network

3.1. Single Antenna Element of the Array

In order to select the best antenna element for the evaporation duct application there are some considerations to be made

1) Gain

In order to achieve a long distance trans-horizon a high gain antenna is needed

2) Agreement with the array

The proposed antenna should fit in the model of the array in terms of geometry

3) Economic Value

The proposed Antenna Element should be achievable in economic terms

A comparison between Horn antenna element and Micro strip antenna element shall be investigated to define which element shall be most fitting for the application in WiDUCT project.

3.1.1. Design Method of Horn Antenna

The horn antenna shall be designed using sheet metal bending manufacturing method. This method basically depends on creating a 2D projection of the 3D desired object and then rotating in in the 3D space to obtain the desired product.

The figure above shows a 2D metal sheet that is to be bent to obtain a 3 sided pyramid with a base. The same method is utilized to manufacture the horn reflector.

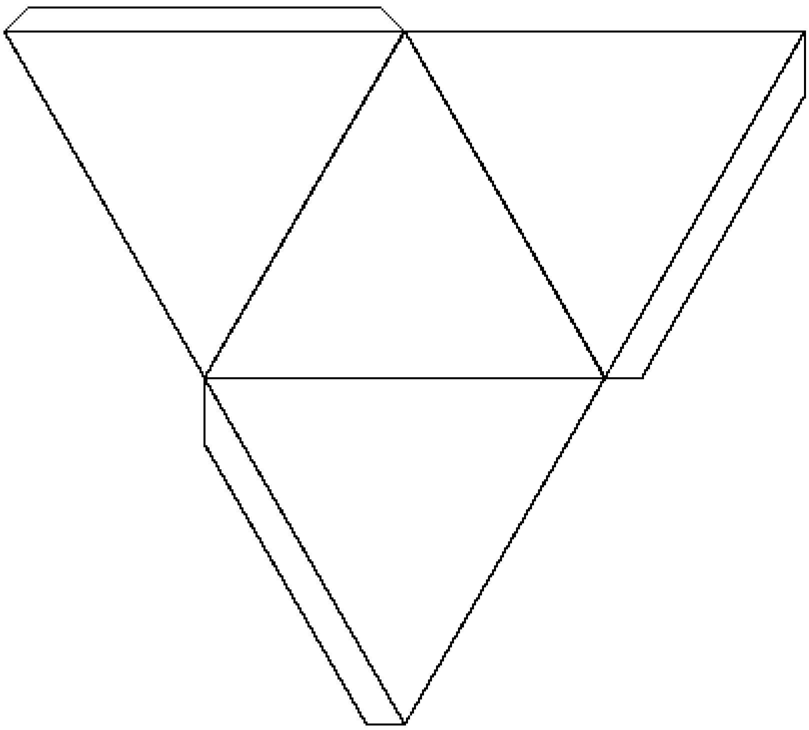

Figure 6 Metal Sheet for a Pyramid Design

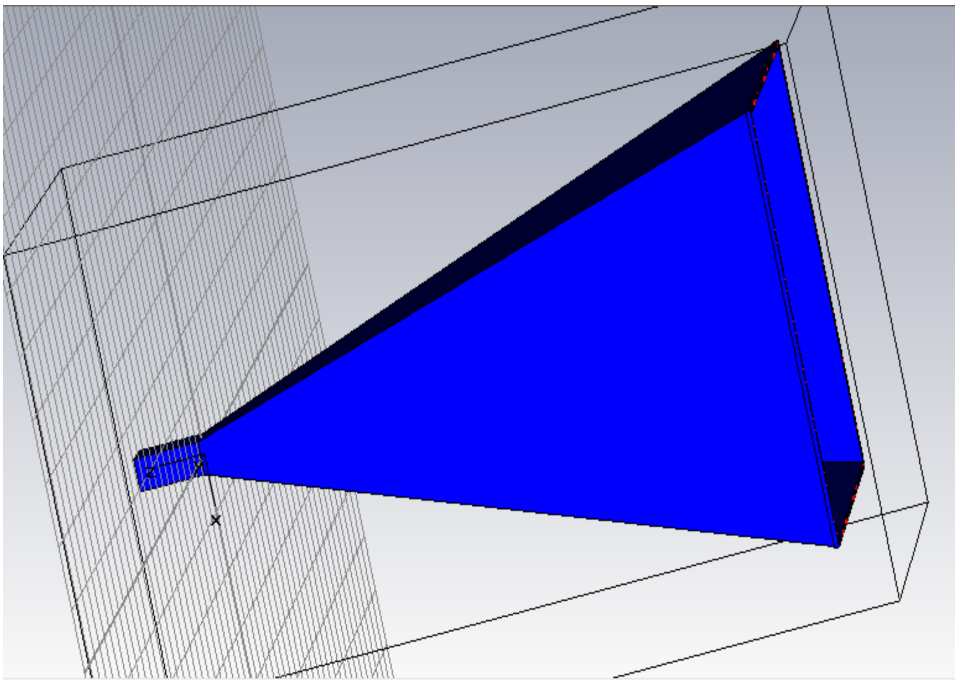

Figure 7 Horn Antenna Model using

3.2. Antenna Array Specifications

1) Array Type

The array type is the main factor that determines the behavior of the Array Factor. A uniform planar array or a combination of 2 orthogonal linear uniform arrays is of most use for the evaporation duct as it can control in the beam width in both the vertical and horizontal planes.

2) Array Size

The array size controls the behavior of the array factor regarding the beam width and contributes to the maximum lobes.

3) Spacing between Elements

The Spacing between array elements is essential in determining the number of maximum lobes. For a single maximum lobe the spacing between array elements should be less than 1 wavelength.

4) Phase Difference between Elements

The phase difference between elements controls null assignment to certain angles of the elevation plane.

Based on the results obtained from [6], an array realization of 16x4 is introduced and analyzed. The chosen spacing between elements is 5 wavelengths, this is limited by the physical dimensions of a single Horn element of the array. Phase difference is set to zero.

The chosen array size for this application is a 4x4 array size with a spacing that would agree to the geometry of the horn.

Marine Grade protection for array elements is to be investigated.

Based on the recommendations from [6] the planar array to be constructed shall be of size 16x4.

From [2], the total field of a uniform linear array can be obtained from (2.7) and the array factor is given by:

$$AF = \sum_{n=1}^{N} e^{i(n-1)\psi} \tag{3.1}$$

Where N is the total number of elements and ψ is given by:

$$\psi = kdcos(\theta) + \beta \tag{3.2}$$

Where k is the wave number, d is the spacing between elements, θ is the angle along the direction of the pattern propagation and β is the phase between array elements.

Taking the reference point as the array physical center the array factor is obtained via [2] [3]

$$AF = \frac{1}{N}\left[\frac{\sin(\frac{N}{2}\psi)}{\sin(\frac{1}{2}\psi)}\right] \tag{3.3}$$

The maximum lobes are located at

$$\theta_{max} = \cos^{-1}\left[\frac{1}{kd}\,(-\beta \pm 2m\pi)\right] \tag{3.4}$$

Where m = nN, and the angle of half beam width is

$$\theta_{Half} = \cos^{-1}\left[\frac{1}{kd}\,(-\beta + \psi_{AF={}^{1}/_{\sqrt{2}}})\right] \tag{3.7}$$

$$Beam\,width = 2(\theta_{max} - \theta_{Half}) \tag{3.8}$$

3.3. Electric Feed Network

A matching circuit with power dividers is to be designed to cater of the array arrangement. A Wilkson Power Divider of 4 stages shall be utilized to cater for the required array size of 16.

3.3.1. Horn Antenna Feed Network

For the horn antenna Array a new frequency band of interest centered at 5.8 GHz the ISM band is of free usage. The figures below illustrate the design of the feed network for the 4X4 Horn Antenna Array. The figures show the complete feed network for the 16 elements of the proposed array along with a single stage power divider network to display the detailed design of the of the network.

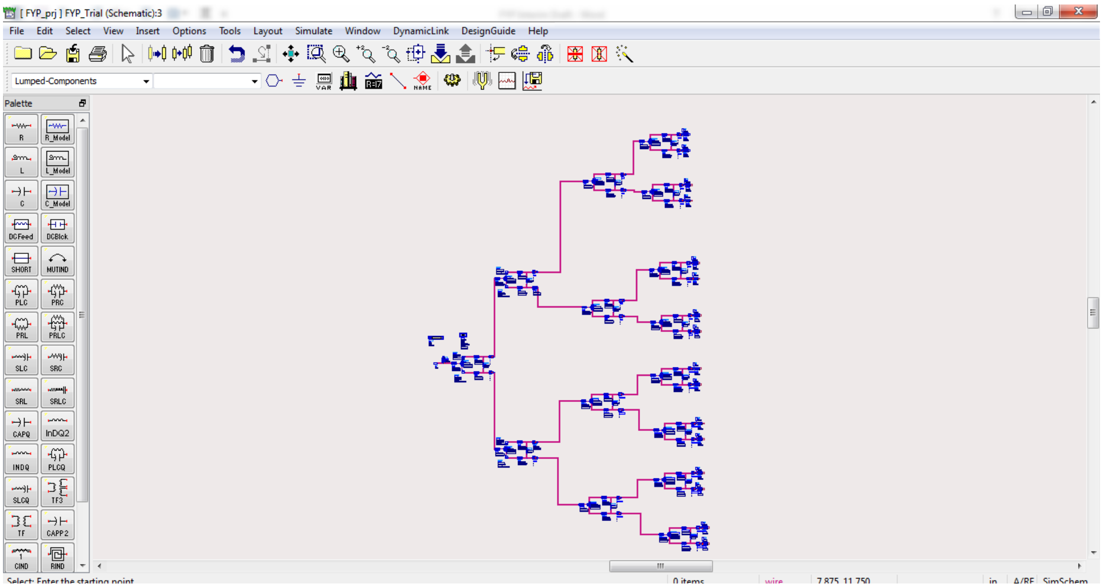

Figure 8 Complete Schematic for the feed network of the 16 Horn elements of the Array

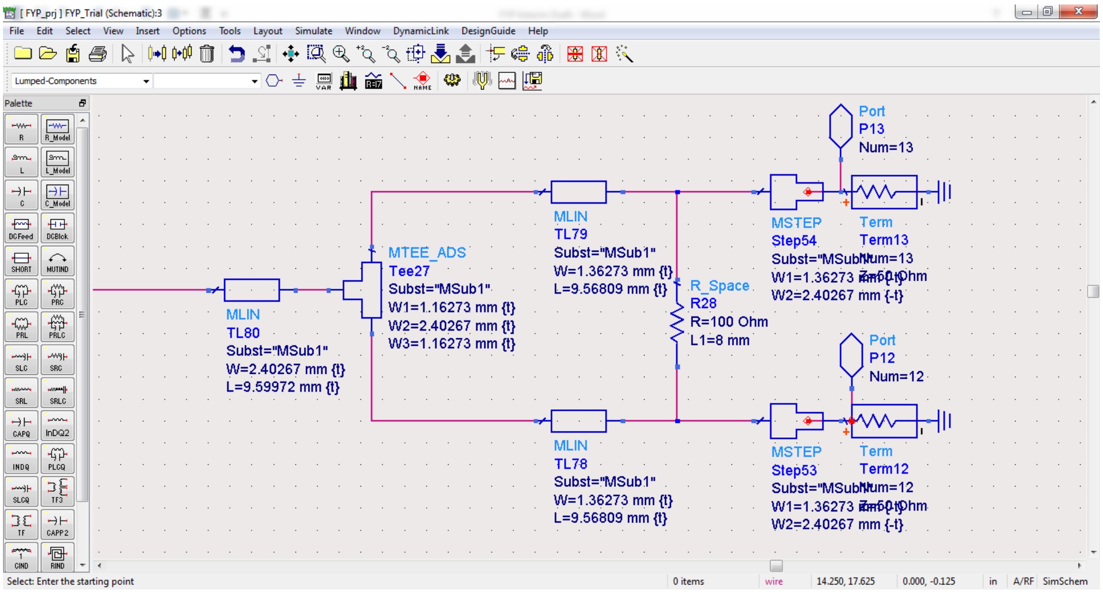

Figure 9 Single Stage Schematic for the feed network of the 16 Horn elements of the Array

The final developed feed for horn Antenna shall cater to the bandwidth of 100 MHz at a center frequency of 5.8 GHz. Due to high frequency range an SMT resistor shall be utilized instead of a lumped component to avoid intrinsic inductance and capacitance issues.

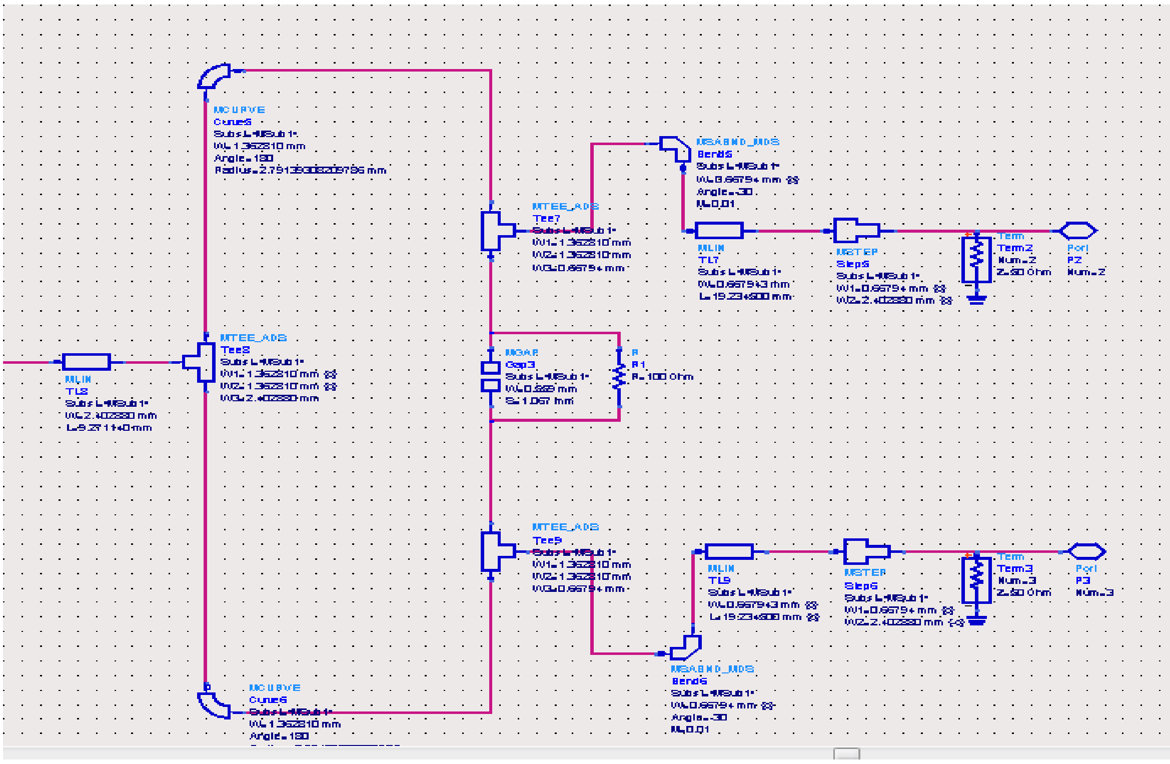

Figure 10 Single Stage Schematic for the feed network of the 16 Horn elements of the Array

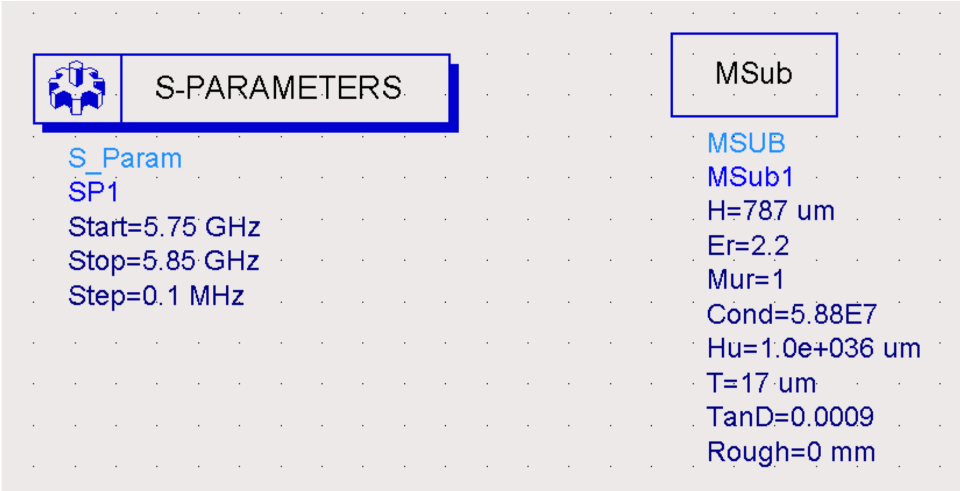

Figure 12 Simulation & Substrate Parameters

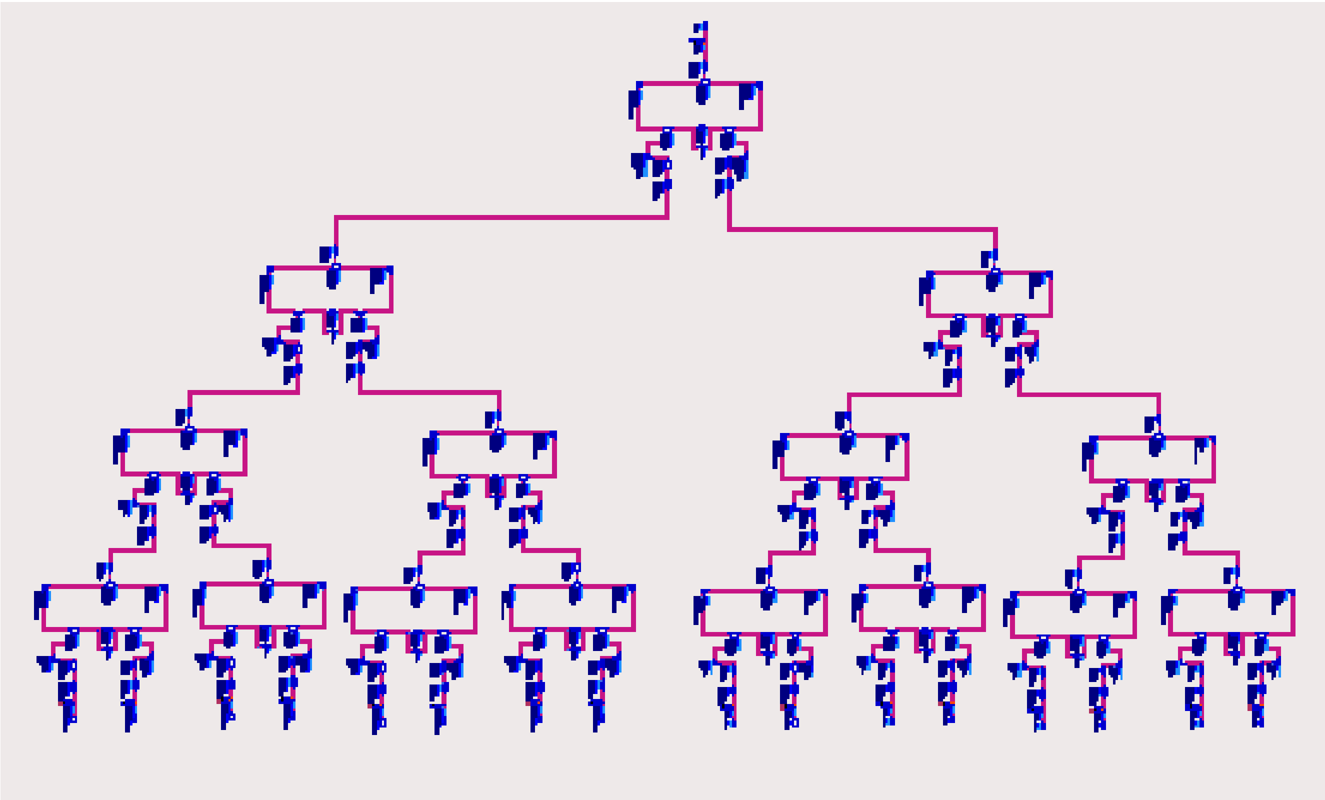

Figure 11 Complete Schematic for the feed network of the 16 Horn elements of the Array

3.3.2. Micro-Strip Feed Network

An Antenna Array of Micro strip antennas was investigated as an alternative to the Horn Antenna Array in terms of fabrication.

The Schematic for the feed network of the Patch panel antenna given is to operate at a center frequency of 5.8 GHz instead of 10.4 GHz as the former frequency belongs to the ISM free band.

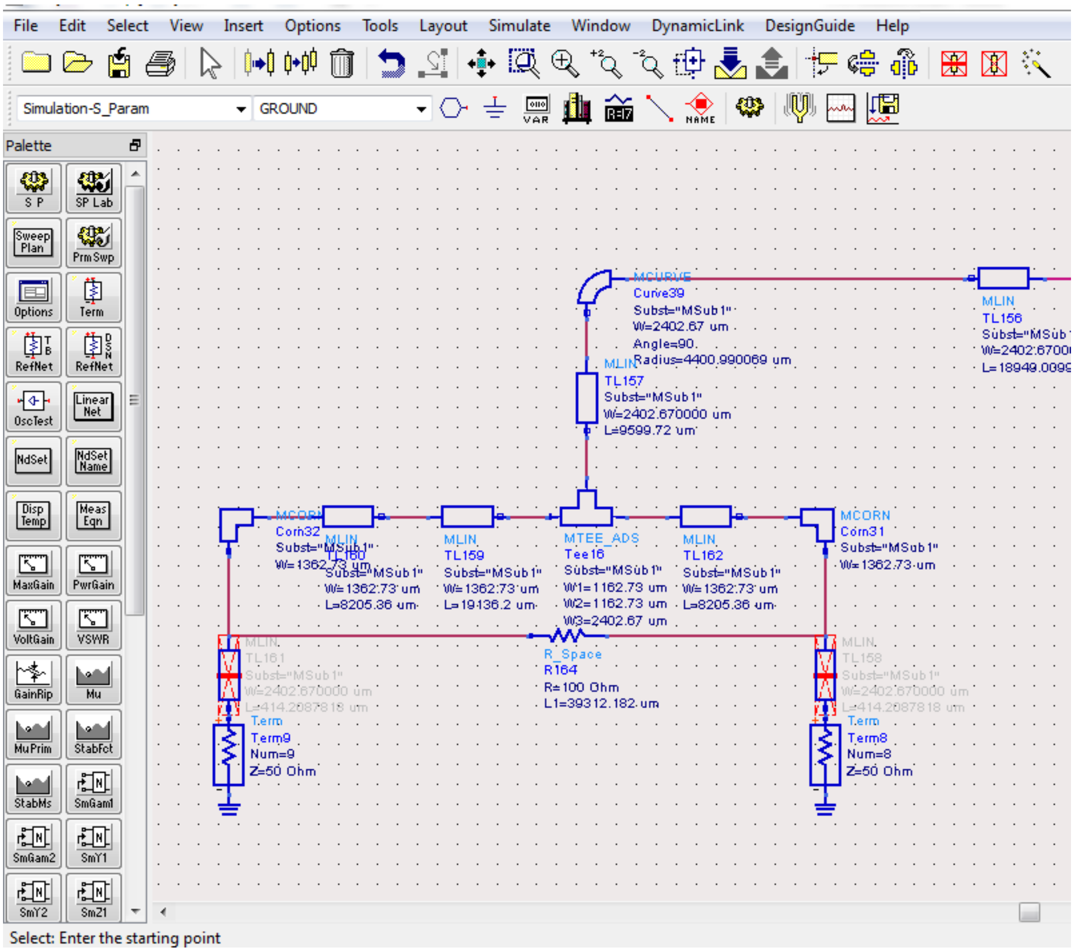

Figure 13 Single Stage Schematic for the feed network of the 16 Patch Panel elements of the Array

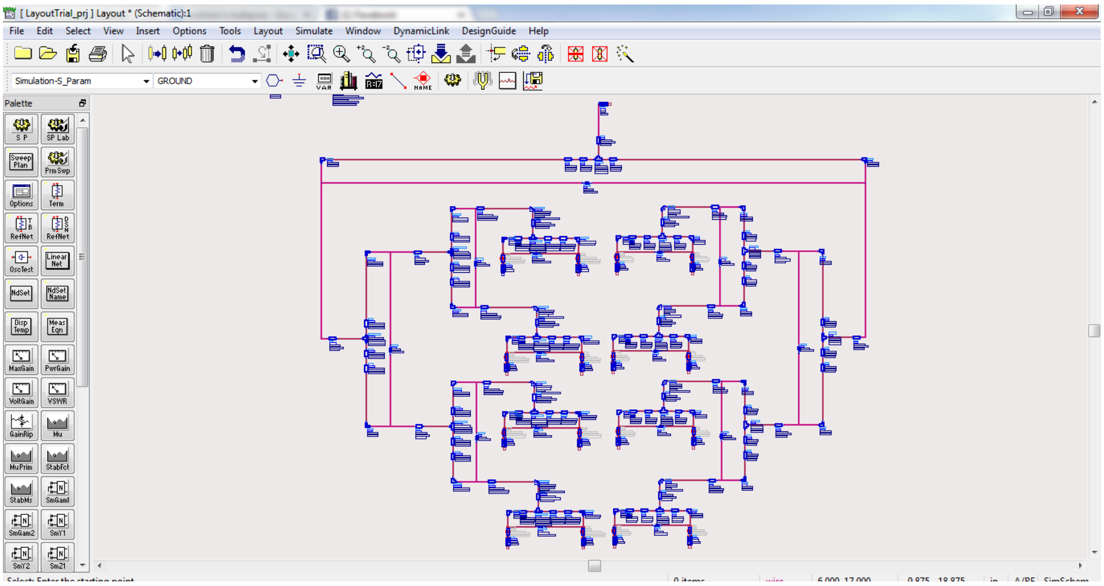

Figure 14 Complete Schematic for the feed network of the 16 Patch Panel elements of the Array

Chapter (4)
RESULTS & DISCUSSION

4.1. Antenna Element

The antenna element of a Micro strip antenna would achieve a maximum of 5 dBi gain which shall not be enough for the needed application.

A horn antenna element is investigated and although it can cater to the needs in terms of gain, the horn antenna is quite costly. A Cheap horn antenna is created using some manufacturing technologies available in the market.

The method of sheet metal bending was utilized to obtain the cheap horn reflector and a prototype is shown in the figure below.

The CST Simulation tool has been utilized to evaluate the fields for the manufactured horn reflector.

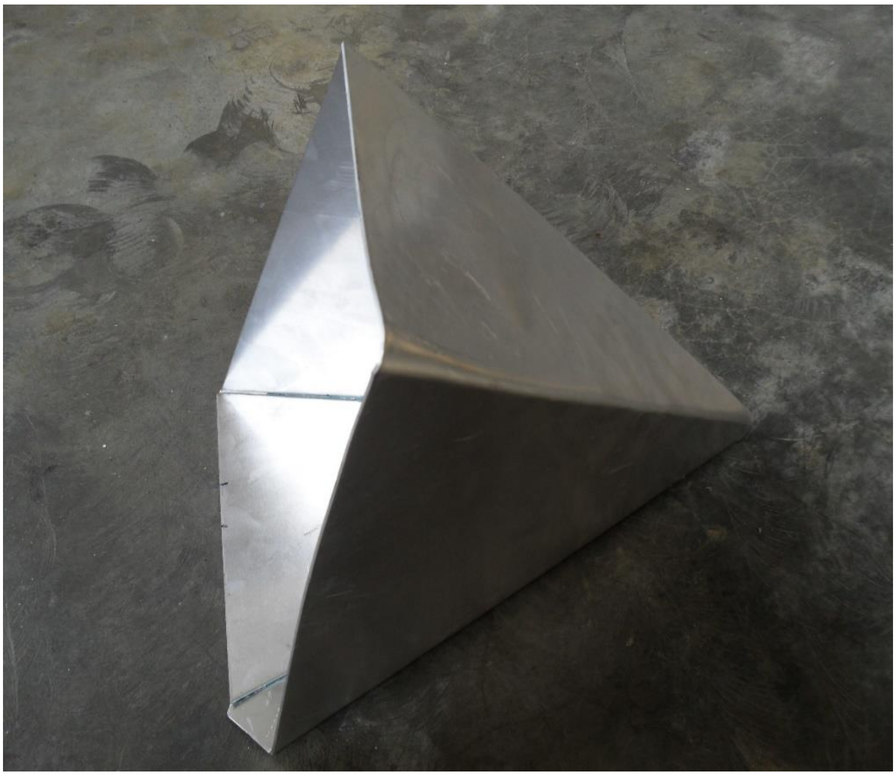

Figure 15 CST Prototype of Horn Reflector using Sheet Metal Bending

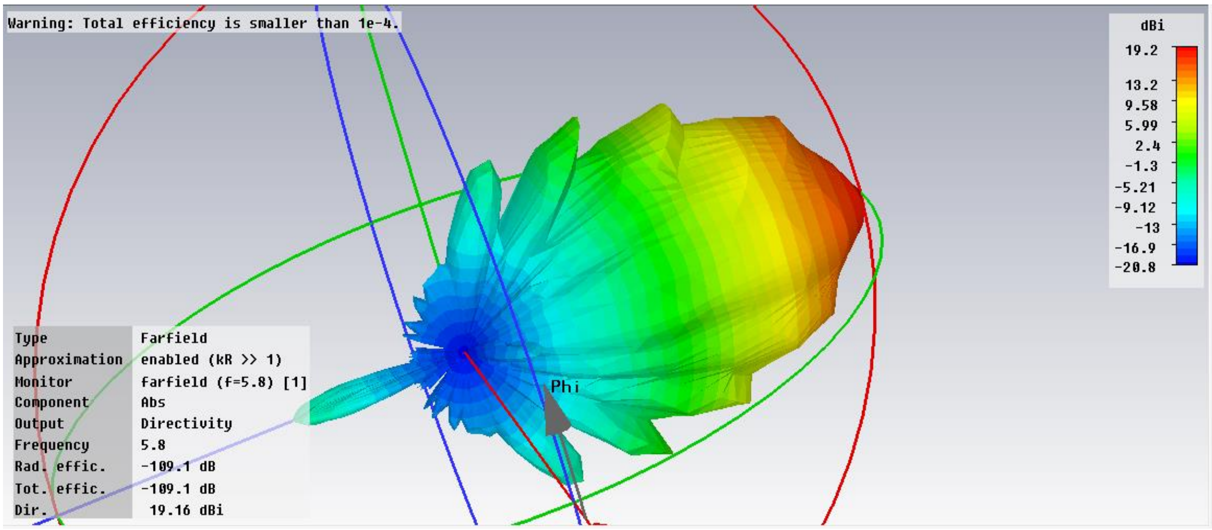

Figure 18 Horn Antenna Far-field 3D plot using CST

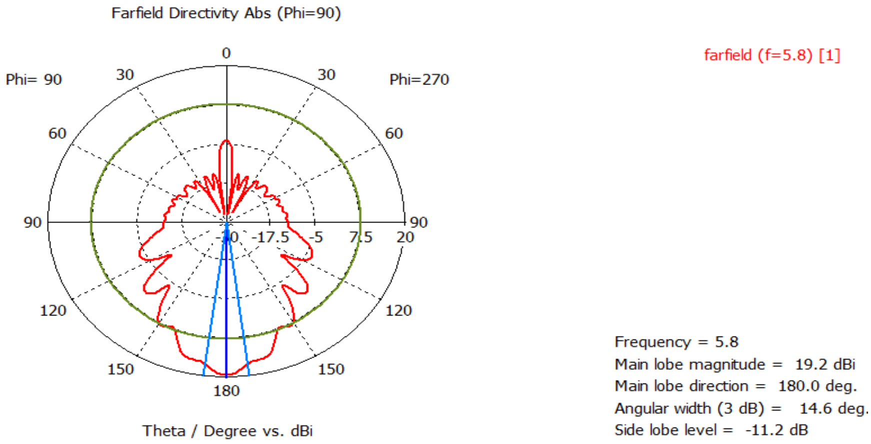

Figure 17 Horn Antenna Far-field polar plot using CST

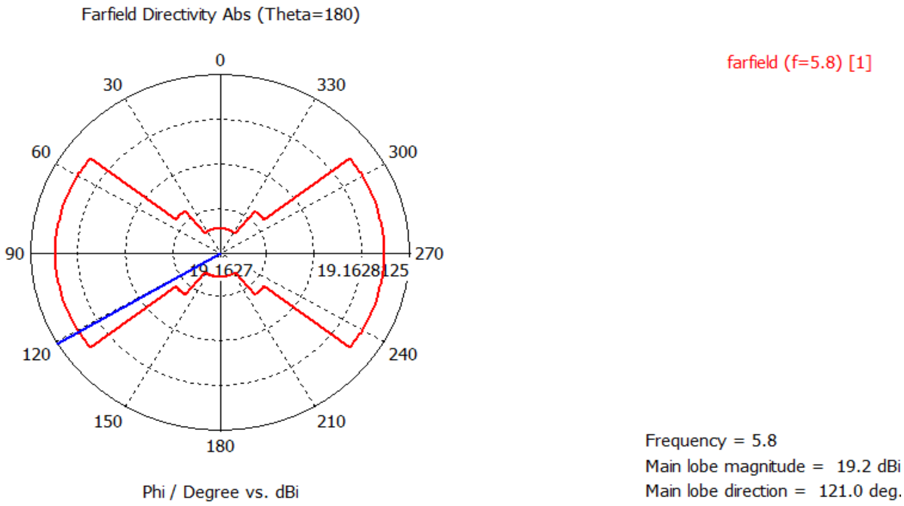

Figure 16 Horn Antenna Far-field polar plot using CST

Figure 19 Horn Antenna Waveguide Feed

Figure 20 Complete Horn Antenna components

4.2. Antenna Array

For N = 16

$f = 10.4\,GHz$, $d = 5\lambda$ and $\beta = 0$

The Array Factor is evaluated for elevation plane for the broadside linear uniform array

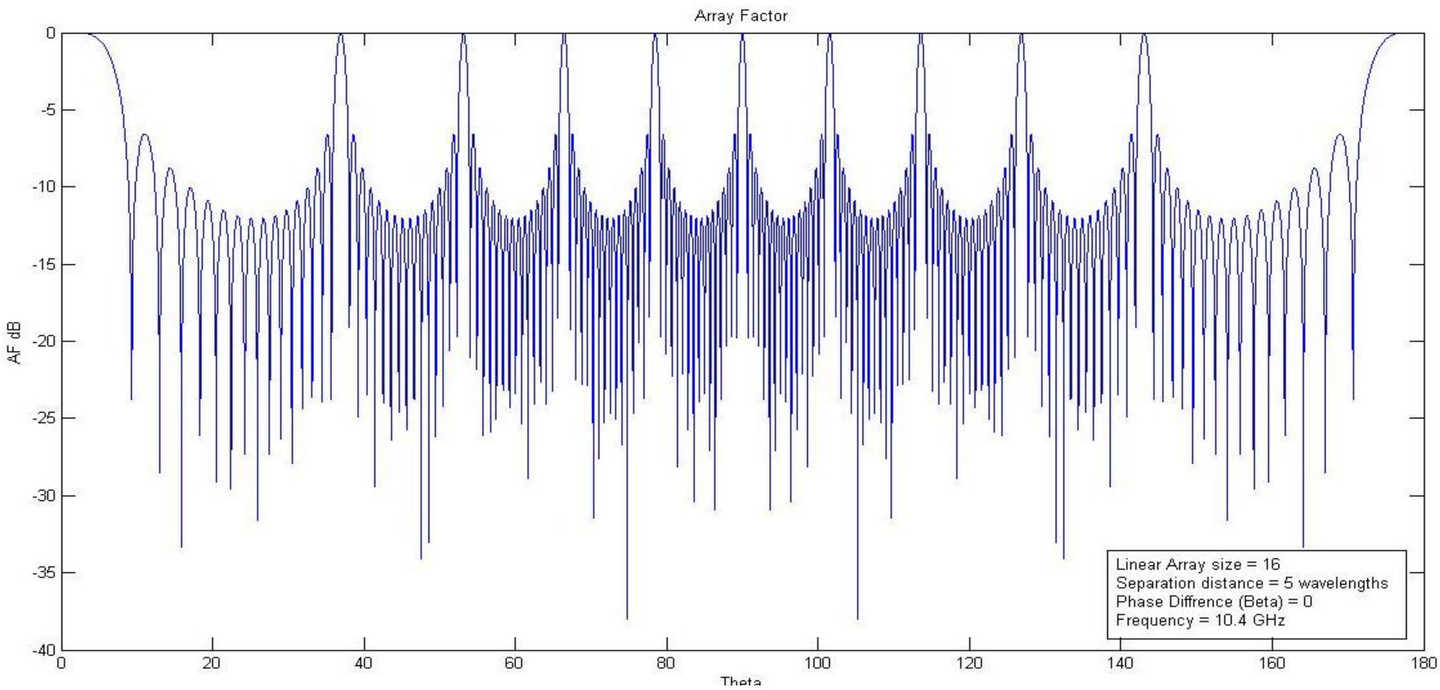

Figure 22 Antenna Array Factor Response from 16 Element Uniform Broadside Array

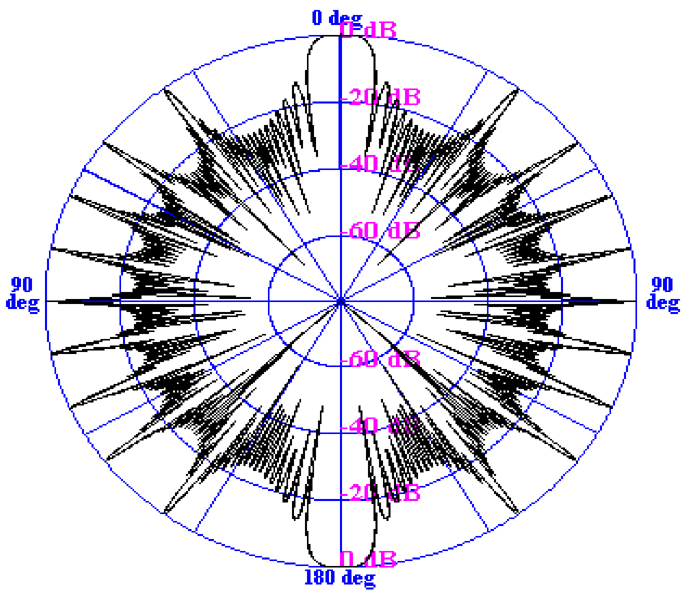

Figure 21 Polar Array Factor Response from 16 Element Uniform Broadside Array [2]

For N = 4

$f = 10.4\,GHz$, $d = 5\lambda$ and $\beta = 0$

The Array Factor is evaluated for elevation plane for the broadside linear uniform array

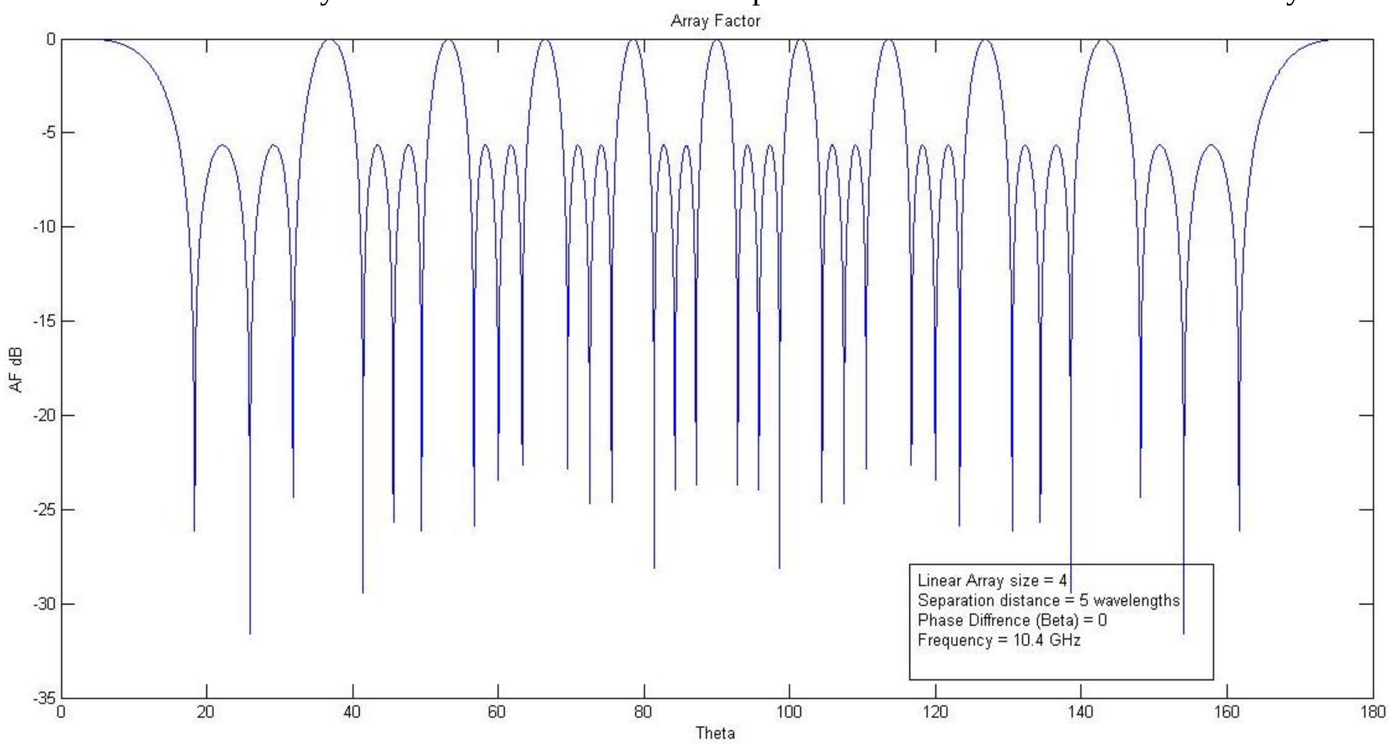

Figure 23 Antenna Array Factor Response from 4 Element Uniform Broadside Array

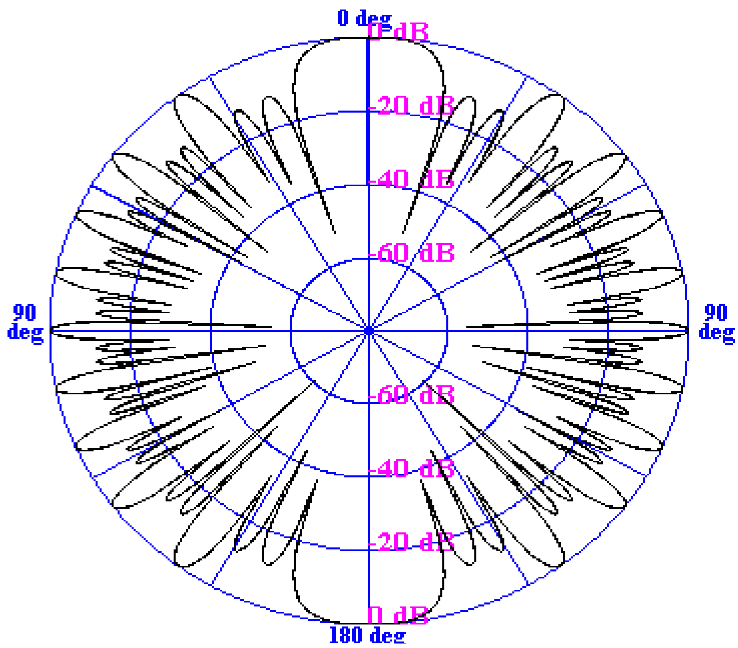

Figure 24 Polar Array Factor Response from 4 Element Uniform Broadside Array [2]

2D Array Directivity is given by [2]:

$$D = \frac{4\pi}{\Omega_A} \tag{4.9}$$

Where $D_{Array} \simeq 16 \times 4$ (4.10)

$$\therefore D\ dB = 10\ \log(D) = 10\ \log(16 \times 4) \simeq 18.1\ dB$$
$$Beam\ width\ (16) = 0.88^{o} (MATLAB\ Resultant\ Value)$$

$$Beam\ width\ (4) = 3.54^{o} (MATLAB\ Resultant\ Value)$$

Array Physical size:

For N elements there are N-1 spacing intervals. Adding half an interval at the beginning of each side and another half at the end of the side. Then each side consists of N spacing intervals.

The 16 element linear array accounts for 16 spacing intervals each of 5λ spacing resulting in side length of

$$L\ (16) = 16\ \times 5\ \times \frac{3 \times 10^8}{10.4 \times 10^9} \simeq 2.31\ m$$

The 4 element linear array accounts for 4 spacing intervals each of 5λ spacing resulting in side length of

$$L\ (4) = 4 \times 5\ \times \frac{3 \times 10^8}{10.4 \times 10^9} \simeq 0.577\ m$$

Yet this solution is costly so an alternative of a 4X4 array of spacing of 3 wavelengths and 4 wavelengths are displayed.

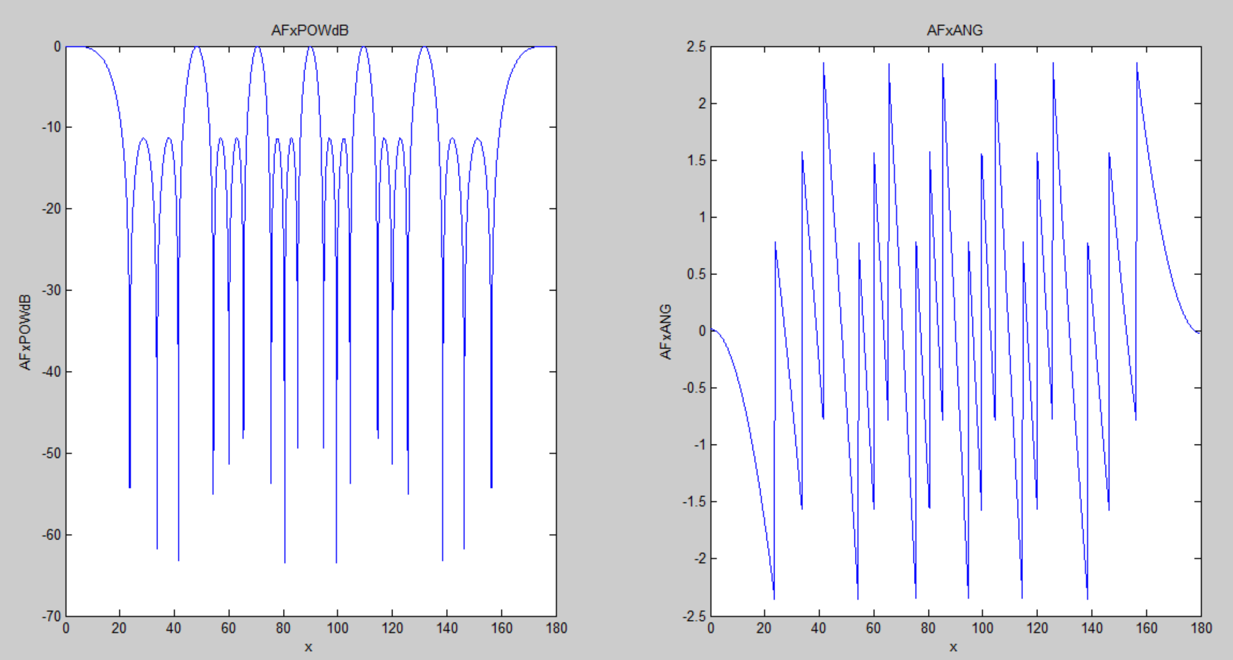

Figure 25 Array Factor Response from 4 Element Uniform Broadside Array for a 3 wavelength separating distance

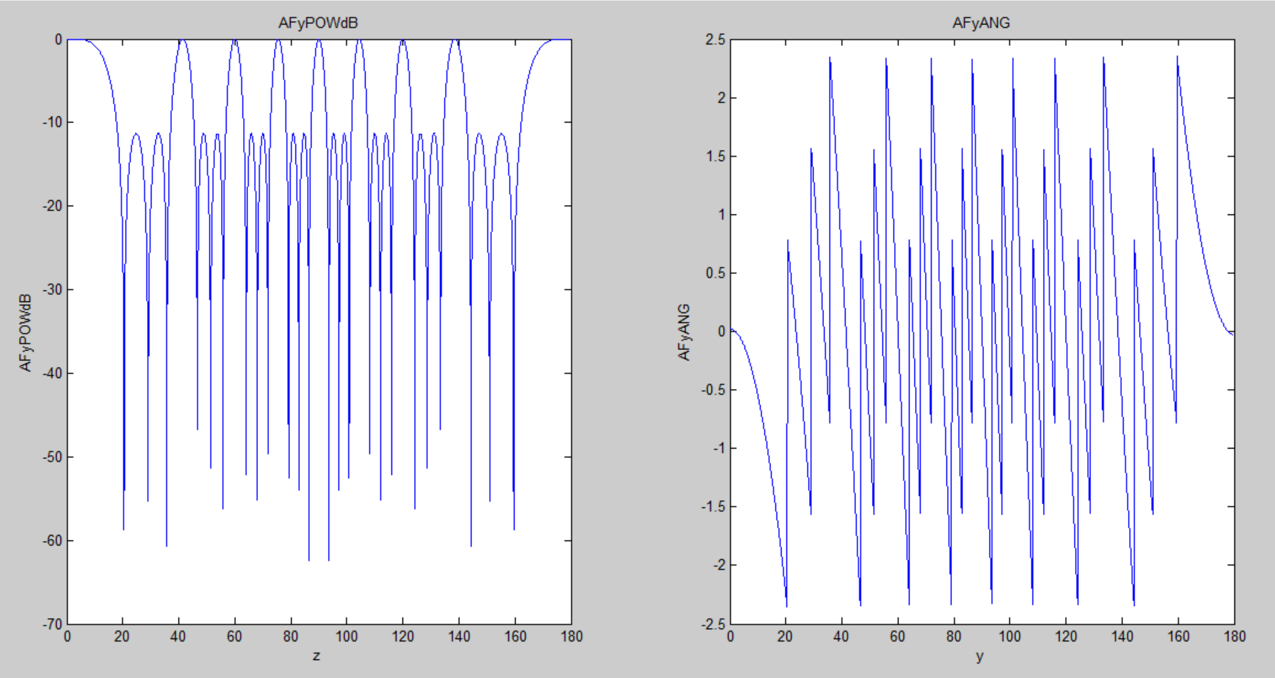

Figure 26 Array Factor Response from 4 Element Uniform Broadside Array for a 3 wavelength separating distance

4.3. Feed Network

4.3.1. Horn Antenna Feed Network

For the horn antenna Array a new frequency band of interest centered at 5.8 GHz the ISM band is of free usage. The figures below illustrate the design of the feed network for the 4X4 Horn Antenna Array. The figures show the complete feed network for the 16 elements of the proposed array along with a single stage power divider network to display the detailed design of the of the network.

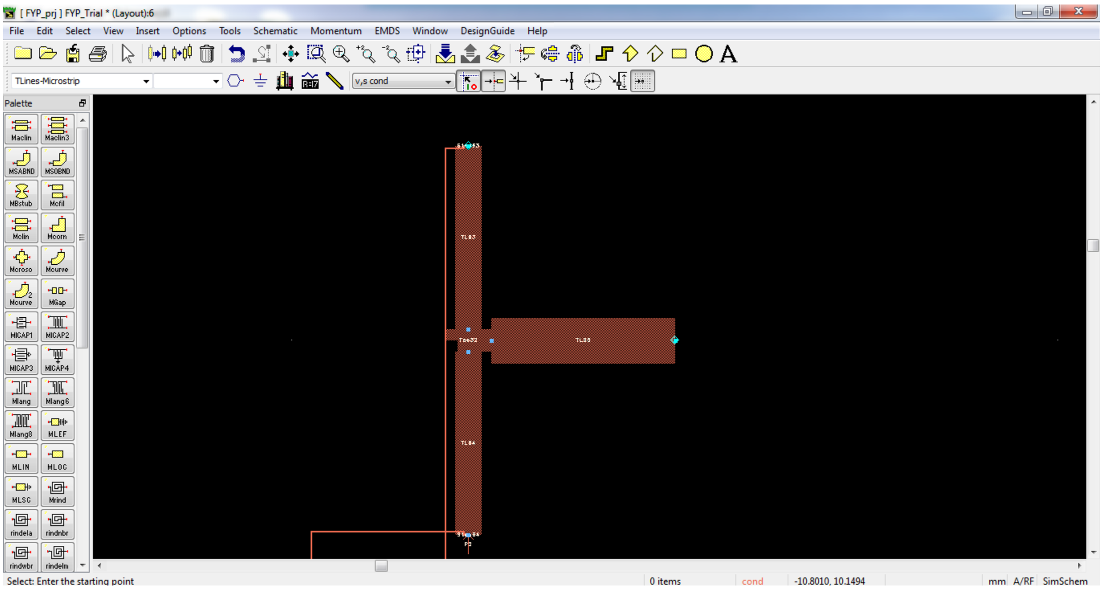

Figure 28 Layout of Single Stage Schematic for the feed network of Horn Antennas

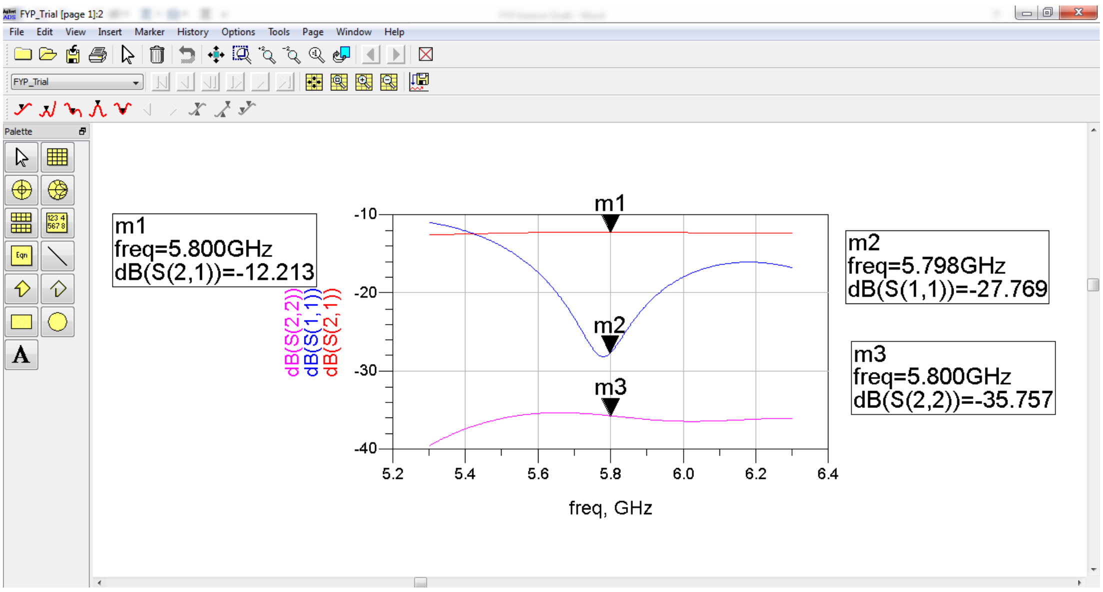

Figure 27 Electric properties of the complete Feed Network

The final developed feed for horn Antenna shall cater to the bandwidth of 100 MHz at a center frequency of 5.8 GHz. Due to high frequency range an SMT resistor shall be utilized instead of a lumped component to avoid intrinsic inductance and capacitance issues.

The Vishay SMT resistor data sheet shall be included in the appendix.

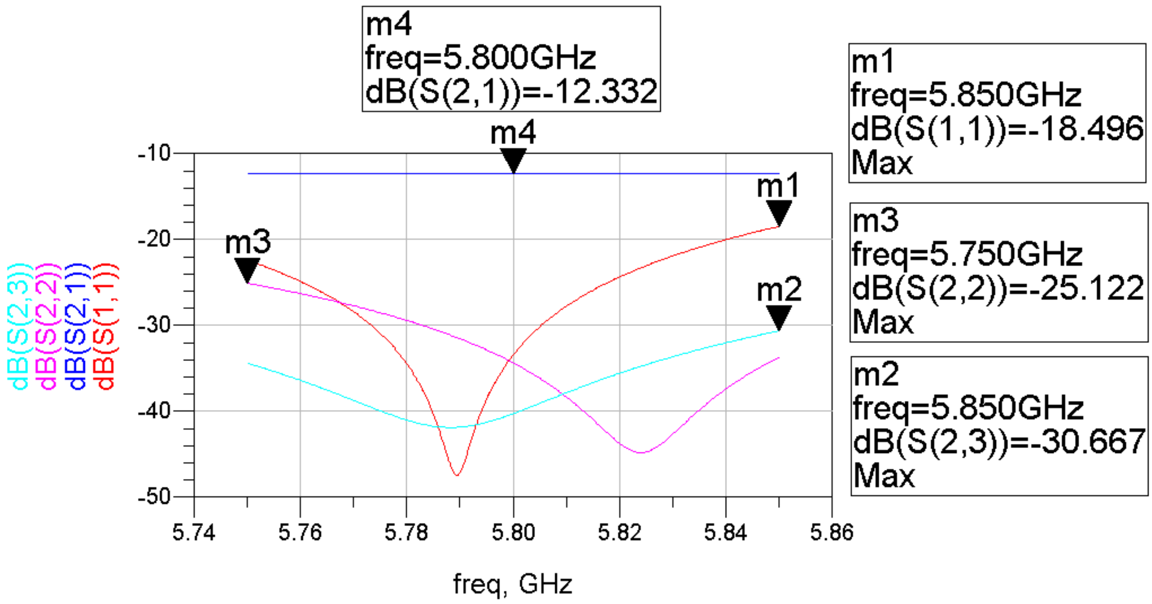

Figure 30 Electric properties of the complete Feed Network

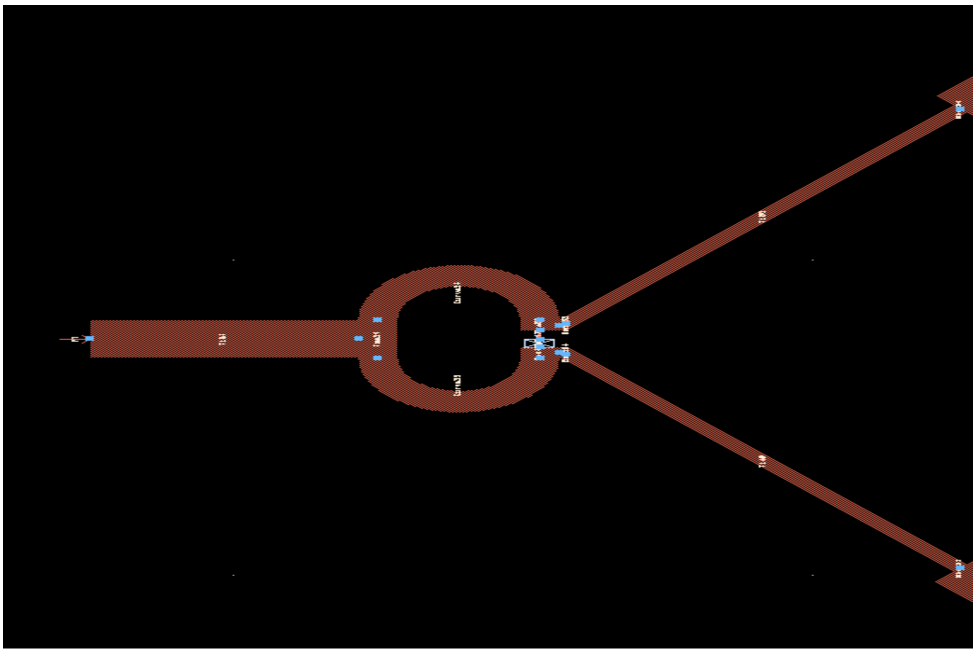

Figure 29 Layout of Single Stage Schematic for the feed network of Horn Antennas

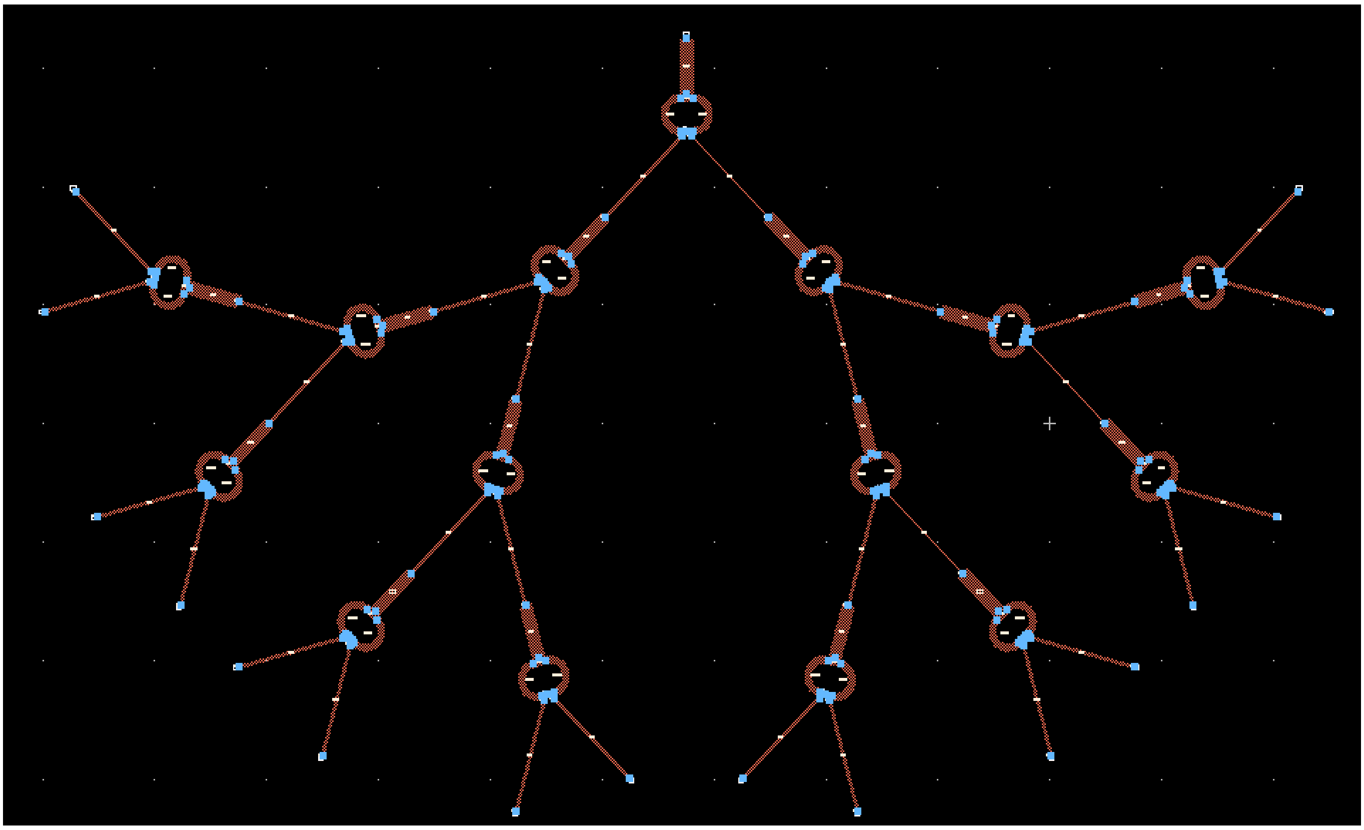

Figure 31 Layout of Complete Schematic for the feed network of Horn Antennas

4.3.2. Micro-Strip Feed Network

An Antenna Array of Micro strip antennas was investigated as an alternative to the Horn Antenna Array in terms of fabrication.

The Schematic for the feed network of the Patch panel antenna given is to operate at a center frequency of 5.8 GHz instead of 10.4 GHz as the former frequency belongs to the ISM free band.

The figure above describes the fourth stage power divider in the design of a patch panel antenna with 8 of these units to form the complete antenna array for the 4X4 antenna array.

For the Micro strip antenna Array the distance between the array elements is no longer a thing of free choice as the physical dimensions affecting the length of the micro strip lines that contributes to the electrical properties of the signal in terms of the length of the line for the Wilkson power divider.

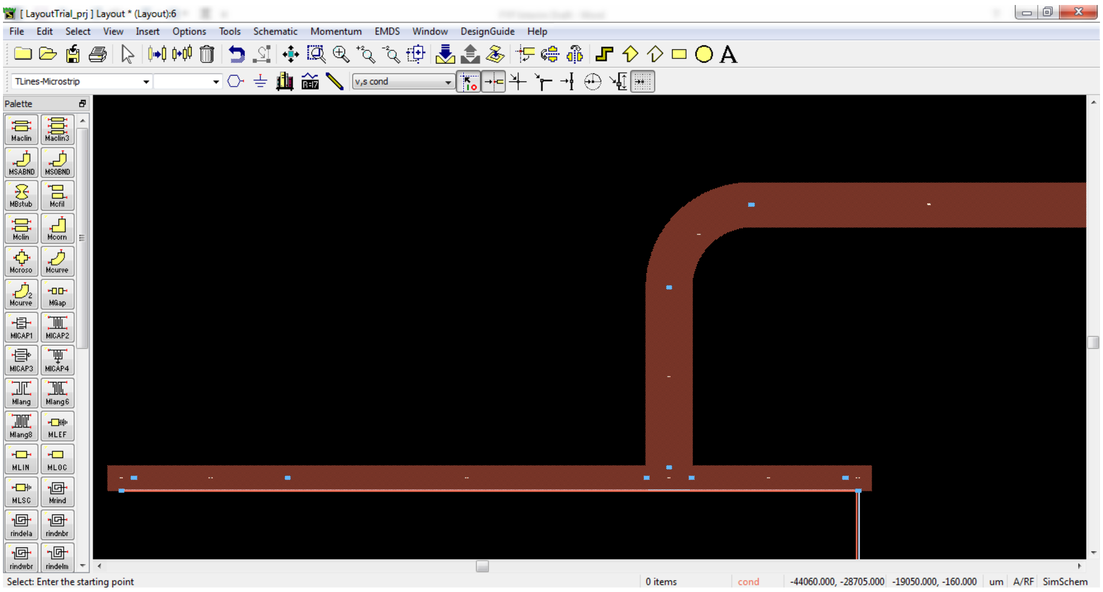

Figure 32 Layout of Single Stage Schematic for the feed network of Patch Panel Antennas

From (4.9) The Directivity of an Antenna is given by:

$$D = \frac{4\pi}{\Omega_A}$$

The Directivity for a 4 element array of spacing of app. 0.7702 Lamda is about 7.5 dB with Half Beam width of app. 17.5 degrees.

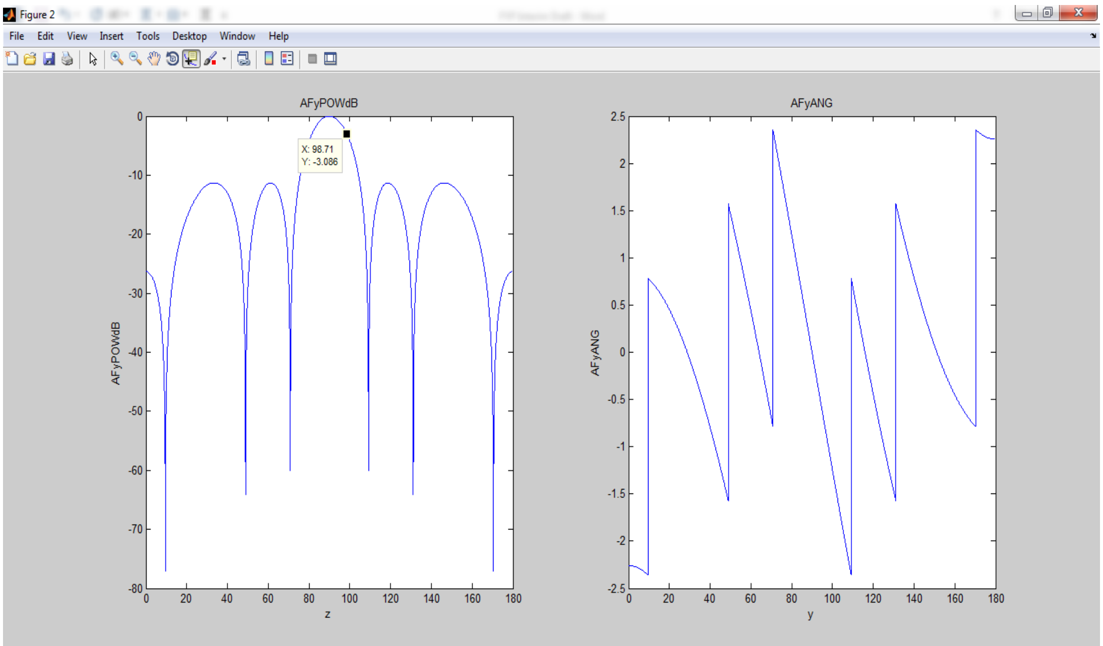

Figure 33 Antenna Array Factor Response from 4 Element Uniform Broadside Array

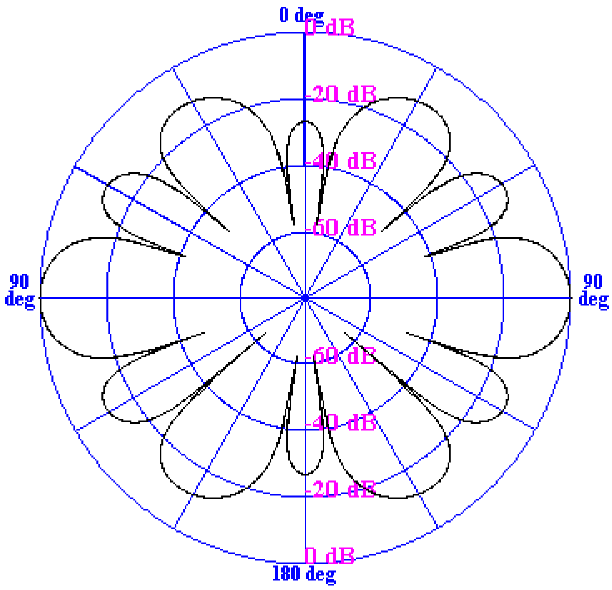

Figure 34 Polar Array Factor Response from 4 Element Uniform Broadside Array [2]

For a patch panel antenna one must calculate its physical dimensions.

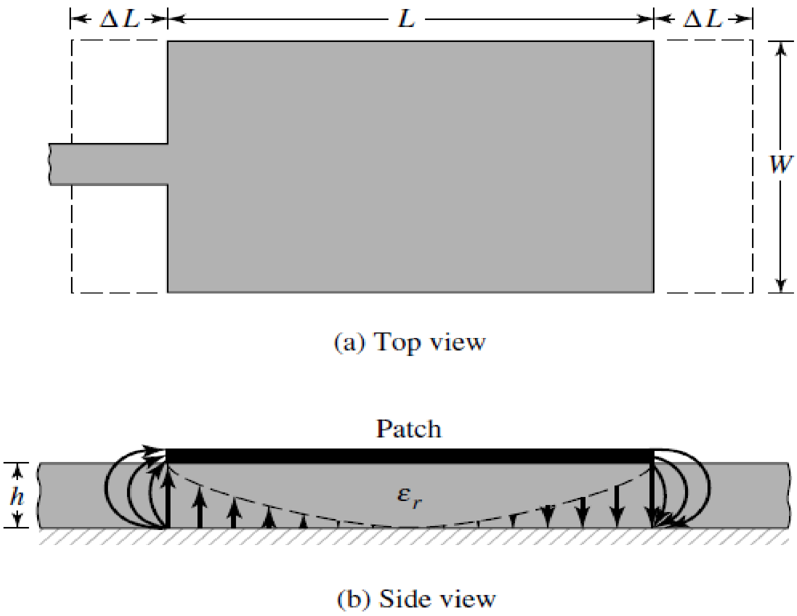

Figure 35 Physical and Electrical dimensions of Rectangular Patch Panel Antenna [2]

The Physical Parameters W, L and ΔL

$$W = {}^{V_o}/_{2f_r} \sqrt{{}^{2}/_{\varepsilon_r} + 1} \tag{4.11}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1 + 12\frac{h}{W}]^{-0.5} \tag{4.12}$$

$$\Delta L = 0.412\ \frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{4.13}$$

$$L = {}^{\lambda}/_{2} - 2\,\Delta L \tag{4.14}$$

$$W = 0.02044576073\ \mathrm{m}$$

$$\varepsilon_{reff} = 2.096239886$$

$$\Delta L = 4.142087818\ \times 10^{-4}\ m$$

$$L = 0.017034104382541\ m$$

Chapter (5)
CONCLUSION & RECOMMENDATIONS

Antenna Design is a vital part of any communication system. Due to the unique behavior of the Evaporation Duct a novel antenna design should be developed to cater for the physical environment. A proposed array solution is a very effective solution for the situation of oceanic trans-horizon communication. An antenna array can be manipulated to provide the required gain and directivity improving that of a single element to accommodate to the needs of the system.

Advanced System Design provides a strong tool in the analysis of feed network for both Horn antenna array and Patch Panel Antenna Array.

Gantt chart:

Table 1 Proposed Gantt Chart

TASK	WEEKS													
	01	02	03	04	05	06	07	08	09	10	11	12	13	14
LITERATURE REVIEW														
PROPOSAL														
MATHEMATICAL MODEL								K						
SOFTWARE SIMULATION														
POSTER										K				
FABRICATION														
TESTING													K	
FINAL REPORT														

K (Key Milestone)

Chapter (6)

REFERENCES

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Chapter (7)

Appendix

1. Vishay Resistor Data Sheet

High Frequency (up to 20 GHz) Resistor, Thin Film Surface Mount Chip

FC series chip resistors are designed with low internal reactance. They function as almost pure resistors on a very high range of frequencies. The specialized laser edge trimming allows for precision tolerances to 0.1 %.

FEATURES

- Small standard size 0402 case size
- Edge trimmed block resistors
- High purity alumina substrate
- Ohmic range (10 Ω to 1000 Ω)
- Small internal reactance (< 10 mΩ)
- Low TCR (down to ± 25 ppm/°C)
- Epoxy bondable termination available
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

Pb-free Available
RoHS* Available
HALOGEN FREE Available
GREEN (5-2008) Available

Note
* This datasheet provides information about parts that are RoHS-compliant and/or parts that are non-RoHS-compliant. For example, parts with lead (Pb) terminations are not RoHS-compliant. Please see the information/tables in this datasheet for details.

APPLICATIONS

- Low noise amplifiers
- Attenuation
- Line termination

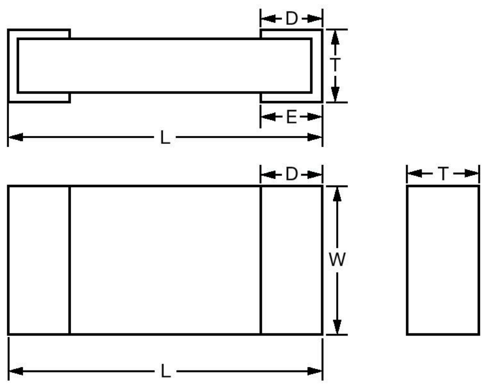
STANDARD ELECTRICAL SPECIFICATIONS

TEST	SPECIFICATIONS	CONDITIONS
Material	Passivated nichrome	-
Resistance Range	10 Ω to 1000 Ω	Case size dependent
TCR: Absolute	± 25 ppm/°C to ± 100 ppm/°C	- 55 °C to + 125 °C
Tolerance: Absolute	± 0.1 % to ± 5.0 %	+ 25 °C
Stability: Absolute	ΔR ± 0.02 %	2000 h at 70 °C
Stability: Ratio	-	-
Voltage Coefficient	0.1 ppm/V	-
Working Voltage	30 V to 75 V	-
Operating Temperature Range	- 55 °C to + 125 °C	-
Storage Temperature Range	- 55 °C to + 150 °C	-
Noise	< - 35 dB	-
Shelf Life Stability: Absolute	ΔR ± 0.01 %	1 year at + 25 °C

COMPONENT RATINGS

CASE SIZE	POWER RATING (mW)	WORKING VOLTAGE (V)	RESISTANCE RANGE (Ω)
0402	50	30	10 to 1000
0505	125	37	20 to 1000
0603	125	50	10 to 1000
0805	200	50	10 to 1000
1005	250	75	10 to 1000
1206	330	75	10 to 1000

DIMENSIONS in inches (millimeters)



CASE SIZE	LENGTH	WIDTH W (± 0.005)	THICKNESS TYPICAL	TOP PAD D (± 0.005)	BOTTOM PAD E (± 0.005)
0402	0.042 ± 0.008 (1.067 ± 0.203)	0.022 (0.559)	0.015 (0.381)	0.010 (0.254)	0.010 (0.254)
0505	0.055 ± 0.006 (1.397 ± 0.152)	0.050 (1.270)	0.015 (0.381)	0.010 (0.254)	0.015 (0.381)
0603	0.064 ± 0.006 (1.626 ± 0.152)	0.032 (0.813)	0.015 (0.381)	0.012 (0.305)	0.015 (0.381)
0805	0.080 ± 0.006 (2.032 ± 0.152)	0.050 (1.270)	0.015 (0.381)	0.016 ± 0.008 (0.406 ± 0.203)	0.015 (0.381)
1005	0.105 ± 0.008 (2.667 ± 0.203)	0.050 (1.270)	0.015 (0.381)	0.015 (0.381)	0.015 (0.381)
1206	0.126 ± 0.008 (3.200 ± 0.203)	0.063 (1.600)	0.015 (0.381)	0.020 + 0.005/- 0.010 (0.508 + 0.127/- 0.254)	

MECHANICAL SPECIFICATIONS

Resistive Element	Passivated nichrome
Substrate Material	Alumina
Terminations	Pre-soldered or gold
Lead (Pb)-free Option	96.5 % Sn, 3.0 % Ag, 0.5 % Cu
Tin/Lead Option	Sn63
Lead (Pb)-free Finish and Tin/Lead	Hot solder dip

GLOBAL PART NUMBER INFORMATION

New Global Part Numbering: FC1206E1001BBTS

F	C	1	2	0	6	E	1	0	0	1	B		B		T	S
F	C	1	2	0	6	K	1	0	0	0	B	T	B	S	T	S

GLOBAL MODEL	CASE SIZE	TCR CHARACTERISTIC	RESISTANCE	TOLERANCE	TERMINATION (1, 2 or 3 digits)	PACKAGING
FC	**0402** **0505** **0603** **0805** **1005** **1206**	**E** = 25 ppm/°C **H** = 50 ppm/°C **K** = 100 ppm/°C	The first 3 digits are significant figures and the last digit specifies the number of zeros to follow. "R" designates the decimal point. Example: 10R0 = 10 Ω 1000 = 100 Ω 1001 = 1 kΩ	**B** = 0.1 % **D** = 0.5 % **F** = 1 % **G** = 2 % **J** = 5 %	**T** = Top sided Au (gold) term Au over Ni epoxy bondable RoHS compliant - e4 **B** = Wraparound Sn/Pb solder 63 % Sn/37 % Pb w/nickel barrier **G** = Wraparound Au over Ni (gold) termination epoxy bondable RoHS compliant - e4 **TB** = Top sided Sn/Pb solder 63 % Sn/37 % Pb w/nickel barrier **TBS** = Top sided lead (Pb)-free solder w/nickel barrier RoHS compliant - e1 **S** = Wraparound lead (Pb)-free solder 96.5 % Sn/3.0 % Ag/0.5 %Cu RoHS compliant - e1	**BS** = BULK 100 min., 1 mult **WS** = WAFFLE 100 min., 1 mult TAPE AND REEL **T0** = 100 min., 100 mult **T1** = 1000 min., 1000 mult (1) **T3** = 300 min., 300 mult **T5** = 500 min., 500 mult **TF** = Full reel **TS** = 100 min., 1 mult

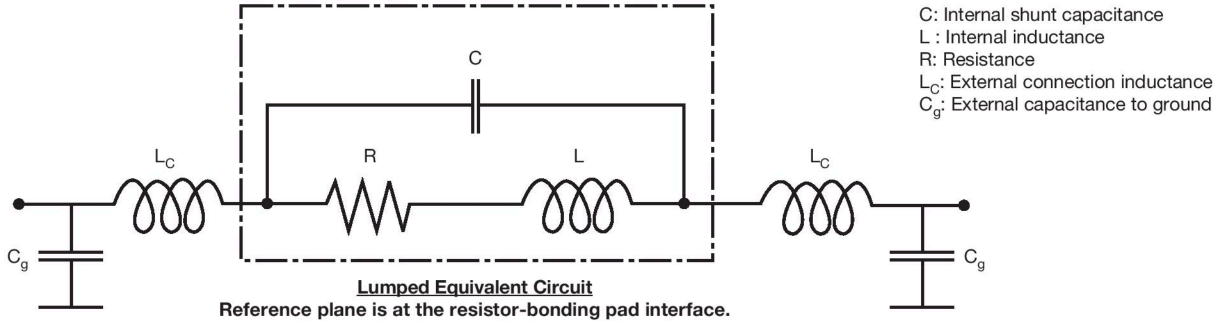
Historical Part Number example: FC1206E1001BBT (for reference purposes only)

FC	1206	E	1001	B	B	T
SERIES	CASE SIZE	TCR CHARACTERISTIC	RESISTANCE	TOLERANCE	TERMINATION	PACKAGING

Note

(1) Preferred packaging code

TYPICAL HIGH FREQUENCY PERFORMANCE ELECTRICAL MODEL AND TESTING

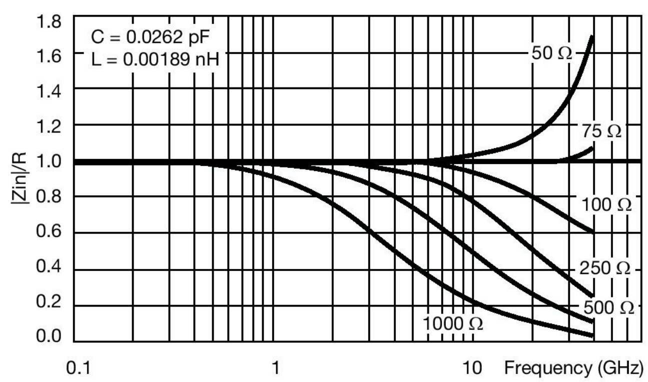


Lumped Equivalent Circuit
Reference plane is at the resistor-bonding pad interface.

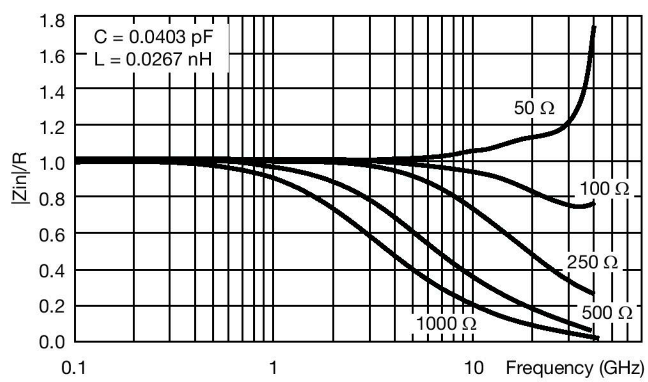
The lumped circuit above was used to model the data at the bonding pad-resistor reference plane. High frequency testing was performed by Modelithics, Inc. on parts mounted to quartz test boards. Quartz test boards were chosen to minimize the contribution of the board effects at high frequencies.

INTERNAL IMPEDANCE

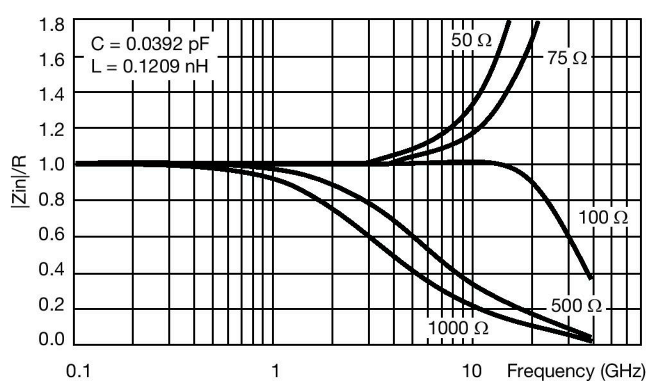
0402 Flip chip



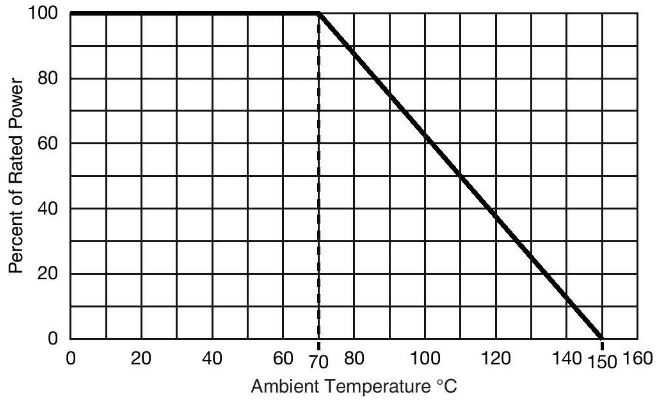
0603 Flip chip



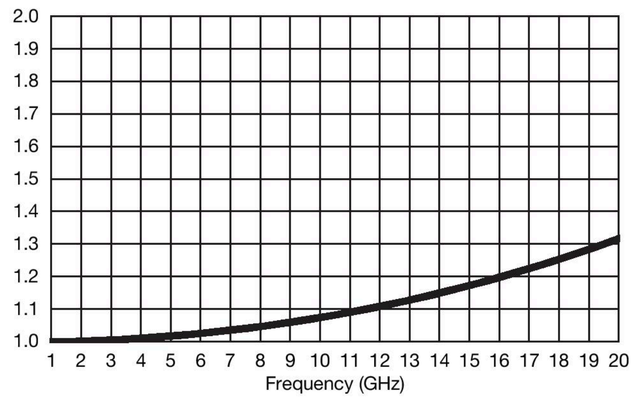
0402 Wraparound



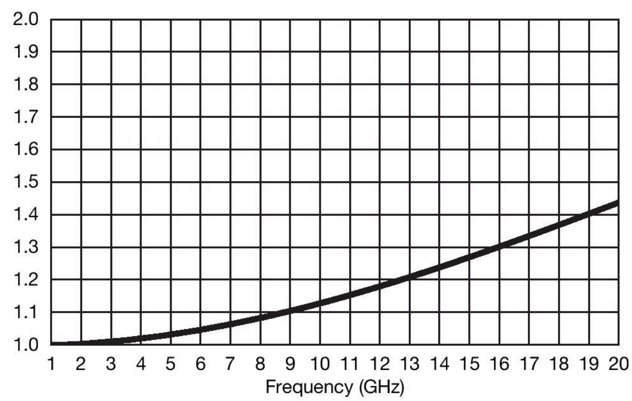
DERATING CURVE



VSWR FC Series 0402 size 50 Ω



VSWR FC Series 0402 size 100 Ω



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