

# **Faculty of Electrical and Electronic Engineering Technology**



# THE ROTT TERMINAL MALATOIA MELAN

# NURATIKAH BINTI MOHD RADZALI

**Bachelor of Electronics Engineering Technology with Honours** 

2023

# DESIGN AND ANALYSIS OF METALLIC WAVEGUIDE FOR X-BAND RADAR REFLECTOR

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electronics Engineering Technology with Honours



# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

### **DECLARATION**

I declare that this project report entitled Design and Analysis of metallic waveguide for xband radar reflector is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



# APPROVAL

I approve that this Bachelor Degree Project 1 (PSM2) report entitled Design and Analysis of metallic waveguide for x-band radar reflector is sufficient for submission.

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# APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.



#### DEDICATION

#### Bismillahiromanirohim

To my beloved mother, Hjh Junainah binti Ripot, and father, Hj Mohd Radzali bin Hj Mamek, thank you for all your support. It very encouraging me to keep walking the path that I made. Even though we are not always being together but your 'doa' always with me. Thank you for being there with me, thank you for being born, thank you for giving your level best in taking care of me and my stubborn (in a lovely way) siblings. Next, to my lovely siblings, thank you for always being annoying and lovely. That really help me a lot in overcome my own fear in facing a problem while doing this project. As a first born, I will always pave the way of everything in this world. Nothing can stop me in my own journey, my own story or my own fate. I will live my life to the fullest and with no regret. I will try my level best in becoming a good daughter, sister and most important is a good



#### ABSTRACT

In this era of globalization, there are varous technologies that are increasingly sophisticated and many that furthur facilitate communication between people. With this improvement in communication, there are various breakdowns that have been done in communication. Among them is communication for civilians and also for the military. Communication that establish for the population is where, the communication done by the telecommunication company launch a telco which allows the residents to communicate with each other. In the context of military, in order to maintain the national security, various technologies are used to avoid enemy attacks. Communication in the military necessarily prioritizies classified information. Next, telecommunications is so important for both parties. Thus there is the X-Band frequency which is reserved for communication between the people and used in the military with a frequency range of 8GHz to 12GHz. The objective of this paper is to design a waveguide in the range of X-Band frequency to be used in measuring the results of Scattering Parameters for reflectarray cell unit. Next, to optimize the sze of the waveguide and unit cells measurements in reducing the cost of fabrication and materials used in designing the waveguideguide and unit cells reflectarray. In addition, analysis was performed on both design objects in various types of materials in order to find and discover ways to reduce the design cost and size of waveguide shape. In this case, the process for designing a waveguide for a reflectarray is to design a unit of cells and waveguide in the X-Band frequency range. Next, optimize the waveguide size to find out the differences in the use of different materials. Fabrication is done for unit cells and waveguide to see the Scaterring Parameters results using Vector Network Analysis, then observe the differences based on simunlations and measurement results made. As a results, it can be seen from Scattering Parameters in dB will be around 10GHz. This paper shhows the processing that takes place in designing a waveguide in the X-Band frequency range 8GHz-12GHz.

#### ABSTRAK

Pada era globalisasi ini, terdapat pelbagai teknologi yang semakin canggih dan banyak yang lebih memudahkan perhubungan antara manusia di dunia ini. Di dalam peningkatan dalam komunikasi, terdapat pelbagai pecahan yang telah dilakukan dalam komunikasi. Antaranya adalah komunikasi bagi civillian dan juga bagi pihak kententeraan. komunikasi untuk penduduk adalah dimana, perhubungan yang dilakukan oleh syarikat telekomunikasi mengeleuarkan telco yang yang membolehkan para penduduk berhubung antara satu sama lain. Dalam konteks kententaraan pula, demi menjaga keselamatan negara, pelbagai teknologi digunakan untuk mnegelak dari serangan musuh. Komunikasi dalam kenteteraan semestinya kesulitan maklumat diutamakan. Seterusnya, telecomunikasi begitu penting untuk kedua-dua belah pihak. Dengan itu wujudla, frekuansi X-band ynag dimana dikhaskan untuk komunikasi diantara penduudk dan digunakan dalam kententeraan dengan julat frekuansi 8GHz sehingga 12GHz. Objektif kertas ini adalah untuk mereka bentuk waveguide dalam julat frekuansi X-Band untuk digunakan dalma mengukur hasil keputusan Scattering Parameters bagi unit cell reflectarray. Seterusnya, untuk mngoptimasikan saiz ukuran *waveguide* dan *unit cells* dalam mengurakan kos pembutan dan material yang digunakan dalam mereka bentuk waveguide dan unit cells reflectarray. Selain itu, analisis dilakukan keatas kedua-dua objek rekaan dalam pelbagai jenis material demi mencari dan menemui cara mengurangkan kos rekaan dan saiz bentuk waveguide tersebut. Dalam kerstas ini, process yang dilalui unutk mereka satu waveguide untuk reflectarray adalah dengan mereka bentuk unit cells dan waveguide dalam julat frekuansi X-Band. Seterusnya, mengoptimasikan saiz waveguide untuk mengetahui perbezaan pengunaan material yang berbeza. Fabrikasi dilakukan bagi *unit cells* dan *waveguide* untuk melihat hasil keputusan Scaterring Parameters mengunakan Network Network Analysis, seterusnya membuta perbezaan berdasarkan simulasi dan hasil ukuran yang dibuat. Hasil yang boleh dilihat, Scatering Parametrs dalam dB akan berada di sekitar 10GHZ. Kertas ini menunjukan pemprosesan yang berlaku dalam mereka bentuk *waveguide* dalam julat frekuansi X-Band iaitu 8GHz-12GHz.

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### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Background

X-band frequency is a microwave radio of the electromagnetic spectrum within (8GHz-12GHz). This usually using for the military and civil radar application. These radar use reflector antennas which have evolved from the big, huge parabolic reflector. Electromagnetic radiation with frequencies be are referred as radio frequencies (RF). Radio frequencies is divided into groups that have similar characteristics, called bands. X-Band is one of the bands with the range of 8GHz-12GHz. These frequencies are among those referred to as microwaves because the wavelength is short on the order of centimeters.

#### 1.2 Problem Statement

X-band frequency range is usually for the military and civil radar application. Usually, these radars use the reflector antennas which have evolved from the huge parabolic reflector to the recently proposed planar reflector. The waveguide is also providing a crucial role in performance characterization and optimization of such reflector antennas. The design optimization and analysis of metallic waveguides for these x-band radar reflector antennas. A slight design of fabrication error can cause an adverse effect on the performance of the antenna as the radar.

## 1.3 Project Objective

The main aim of this project is to propose a design optimization and analysis of metallic waveguides for the x-band radar reflector antennas. Specifically, the objectives are as follows:

- a) Design an x-band waveguides to be used for scattering parameter (S-Parameter) measurement of reflect array unit cells.
- b) To optimize the size of the waveguide in order to save the cost and material.
- c) To investigate the possibility of using different materials in order to optimize the waveguide parameters.

# 1.4 Scope of Project

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To avoid any uncertainty of this project due to some limitations and constraints, the scope of the project is defined as follows:

- a) To design a unit cell of reflectarray and waveguide using CST Studio Suite.
- b) To analyze the reflection loss and the reflection phase through the unit cells results from CST Studio Suite.
- c) To fabricate the unit cells and perform Scattering Parameters measurements
- d) To fabricate the waveguide and perform Scattering Parameters measurements. UNIVERSITI TEKNIKAL MALAYSIA MELAKA
- 1.5 Expected Outcome

Based on this paper, using CST Studio Suite in designing a unit cell of reflect array and the rectangular waveguide in the range frequency of X-Band. The analysis on the reflection loss and reflection phase needed through the unit cells results in CST Studio Suite for analyzing the if any problem may occur while designing the unit cells of reflect array and rectangular waveguide. The fabrication will take place after the finalization in analysis on the unit cells and waveguide. The result from Scattering Parameters will be perform.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

Antennas are particularly important requirement in establish a communication line. In establish a different application like satellite communication system, point to point microwave links and radar application needed a high gain antenna. Reflector antennas, lens antennas or antennas array can all provide high gain.[1] The advantages of reflector and array antennas were combined and known as reflectarray antennas and it more convenient for some application rather than a bulky parabolic reflector antenna[2][3]. Does not required any complex feeding network is the main advantage for reflectarray antenna [1]. The feed usually illuminates a planar reflecting surface with locally controlled the surface impedance to produced fixed or reconfigurable radiation pattern[2]. Planar reflectarrays show a promising potential in various communication applications due to their advantage of easy fabrication, low cost, and capability of beamforming [4]. However, reflectarrays suffer a drawback of narrow gain bandwidth. For planar reflectarrays with a small or medium aperture, the narrowband behaviour of microstrip radiating units is the primary factor which limits the bandwidth of the whole array [4].

#### 2.2 X-band Radar

Radar systems are widely utilised in a variety of applications, including military applications such as identifying enemy weapon, as well as civilian applications such as automotive radar, often known as navigation in cars.[5]. Radar reflectors are widely employed in radar, navigation, and control systems as navigation signs, markers, and buoys in controlling the movement of water or air transport. The number of reflectors in the Radar Cross Section (RCS) is critical, as is the width of the scattering pattern.[6]

Frequency range	Wavelength	Characteristics and uses
1-2GHz	30-15cm	Large antenna &long-
		range surveillance
	15.7.5 am	Waathan & madium
2-40HZ	15-7.5CIII	weather & medium
		ancinia
4-8GHz	7.5-3.8cm	Small antenna & precise
		measurement
8-12GHz	3.8-2.5cm	Missile guidance,
		mapping, airborne
12-18GHz	2.5-1.7cm	High resolution mapping,
		satellite
18-27GHz	1.7-1.1cm	Little use
Mo.		
27-40GHz	1.1-0.75cm	Short range airport,
>		survilliance
40-100+GHz	0.75-0.01cm	Space to space radar
Data		
	Frequency range      1-2GHz      2-4GHz      4-8GHz      8-12GHz      12-18GHz      18-27GHz      27-40GHz      40-100+GHz	Frequency range    Wavelength      1-2GHz    30-15cm      2-4GHz    15-7.5cm      4-8GHz    7.5-3.8cm      8-12GHz    3.8-2.5cm      12-18GHz    2.5-1.7cm      18-27GHz    1.7-1.1cm      27-40GHz    1.1-0.75cm      40-100+GHz    0.75-0.01cm

Table 2.1 Radar Frequency Band and Characteristics [7]



Figure 2.1 X-Band frequency usage in Angkatan Tentera Malaysia (ATM) at Pusat Komunikasi Satelit Angkatan Tentera Malaysia (PKS ATM), Kem Paya Jaras



Figure 2 1 DSS-43 70-meter X-Band spacecraft communication antenna at Canberra Deep Space Communication Complex, Australia



Figure 2 2: Frequency of Bands

2.3 Waveguide



figure 2 3:(a)3-D perspective view and (b) side view of the waveguide element[3]



Figure 2.5 : Rectangular waveguide

Figure 3 shows the reflectarray of the waveguide element used in this study, which is made up of two open-ended metal rectangular waveguides. They have different y-direction widths of a1 = 3mm and a2 = 2.3mm, resulting in differing TE10 mode cut-off frequencies of f1 and f2 for the upper and lower waveguides, respectively. As a result, the waveguide element will display distinct reflection responses at different frequencies when illuminated by xpolarized incident plane waves along the -z-direction[8]. It's a rectangular, circular, or elliptical metal pipe made from materials with high electrical conductivity (copper and brass, partially plated with silver or gold or covered with a thin layer of carbon fiber). It functions to guide electromagnetic or sound waves by keeping them confined to a particular dimension over a certain distance. The propagation happen by reflecting from the internal walls of the hollow pipe. It is also a type of a metallic reflectarray where the array of a waveguides is used to reflect the incident signals. Varying the depth of waveguide can be determined by reflecting the signals phase reflection. An array of reflecting waveguides was proposed as first ever reflectarray.[9]





figure 2.7 : Magnetic and Electric flux line appear in TE and TM mode.

Band	Recommended	TE <sub>10</sub> cutoff	EIA	Inside	Outside
Duna	frequency	frequency	designation	dimension	deminsions
	range (GHz)	(GHz)	WR-XX	[inches (cm)]	[inches(cm)]
T	1 12 1 70	0.008	WR-AA WR 650	$\frac{[\text{Inches}(\text{em})]}{6500 \times 3250}$	$6.660 \times 3.410$
L	1.12-1.70	0.900	<b>WIX-050</b>	$(16.51 \times 8.255)$	$(16.016 \times 8.661)$
				(10.31× 8.233	(10.910× 8.001)
D	1 70 2 60	1 272	WD 420	$\frac{1}{4200 \times 2150}$	1 160 × 2 310
К	1.70-2.00	1.372	WK-430	$(10.022 \times 5.461)$	(11.229) 5.967
				$(10.922 \times 3.401)$	$(11.328 \times 3.807)$
C	2 (0 2 05	2.079	N/D 204	)	2 000 1 500
5	2.60-3.95	2.078	WK-284	$2.840 \times 1.340$	$3.000 \times 1.500$
				(7.214 ×	(7.620× 3.810)
				3.404)	
H(G)	3.95-5.85	3.152	WR-187	$1.872 \times 0.872$	$2.000 \times 1.000$
		1.00		(4.755 ×	(5.080×2.540)
	MALA	SIA A		2.215)	
C(J)	5.85-8.20	4.301	WR-137	$1.372 \times 0.622$	$1.500 \times 0.750$
	and the second s	3		$(3.485 \times 1.580)$	(3.810×1.905)
W(H)	7.05-1.0	5.259 🚬	WR-112	$1.122 \times 0.497$	$1.250 \times 0.625$
				(0.900 ×	(3.175×1.587)
	E			0.400)	
Х	8.20-12.4	6.557	WR-90	$0.900 \times 0.400$	$1.000 \times 0.500$
	n/wn			(2.286 ×	$(2.5401 \times 1.270)$
	chil (	11/	. /	1.016)	*
Ku(P)	12.4-18.0	9.486	WR-62	0.622 × 0.311	$0.702 \times 0.391$
	44			$(1.580 \times 0.790)$	$(1.783 \times 0.993)$
Κ	18.0-26.5	14.047	WR-42	$0.420 \times 0.170$	$0.500 \times 0.250$
	UNIVERS	ITT I LIND	NAL MAL	$(1.07 \times 0.43)$	$(1.27 \times 0.635)$
Ka(R)	26.5-40.0	21.081	WR-28	$0.280 \times 0.140$	0.360 × 0.220
				(0.711 ×	$(0.914 \times 0.559)$
				0.356)	
0	33.0-50.5	26.342	WR-22	$0.224 \times 0.112$	$0.304 \times 0.192$
				$(0.57 \times 0.28)$	$(0.772 \times 0.448)$

# Table 2.2 Standard Rectangular Waveguide Data

- 2.3.1 This is just a sample of a very long subtopic level 2 title which consists of two or more lines
- 2.3.1.1 This is just a sample of a very long subtopic level 3 title which consists of two or more lines

## 2.4 Horn Antenna

One of antenna that known as microwave antenna is horn antenna. The simplest form of antenna that deigned in under microwave. This antenna were widely used in this communication world that also involve a satellite. This frequency of microwave commonly used as X-Band frequency. 400MHz to 40GHz is the frequency range that operate stably. The shape of this antenna is like a horn and it consists of flaring metal that can direct the radio wave in beam. This antenna capable of openly radiating.



UNIVERSfigure 28:Standard Gain Horn Antenna ELAKA



figure 2 9: Simulated horn antenna at 8.2Ghz[10]



figure 2.10: Radiation Pattern for Horn Antenna

# 2.5 Reflectarray



The reflectarray antenna is a hybrid of reflector and phased array antennas. Microstrip reflectarray antennas have a low profile, minimal mass, and low cost[10]. The phase curve of the reflectarray antenna should be as smooth as practical and parallel at adjacent frequencies to maintain optimal bandwidth [10]. A conventional microstrip reflectarray consist of a printed array (e.g. patch antennas), which is illuminated by a feed antenna. At its operation frequencies, a reflectarray antenna can be substitute the traditional parabolic reflector with a lightweight planar by modifying the geometry of the radiating element.



figure 2 .12: Gain measurement for the three states in the whole band from 9.4 GHz to 11.4 GHz [10]



figure 2.13: Typical geometry of printed reflectarray antenna[11]

In development process of a reflectarray antenna, unit cell is the most important things need to be in it. It also can be known as a waveguide and a microstrip resonator. Without a mutual coupling effects the unit cell can be known as an outlying element[9]. The type and geometry of reflecting components, as well as the substrate qualities, are critical. Figure 11 shows the geometry of a resonant element for a unit cell reflectarray.



figure 2.14: (a) square patch (b) triangular slot (c) minkowski (d) square loop [11]

Table 2.3 Performance	comparison for	different resonant	elements of	of reflectarray[11]
P. P. C.	A12			

Resonant element	10% Bandwidth	Static linier range	FoM(°/MHz)
No.	(MHz)	(°)	
Square patch	318	158	0.18
Triangular slot	323	184	0.21
Minkowski patch	314	188	0.22
Square loop	204	203	0.32
al NI	1		

Table 2.4 Reflect array u	nit cell elements for highly	effcient operationc[12]
فليسب فلال		and age and

Element Type	Design NIVERSITI	Loss (dB) TEKNIKAI	Phase Range (°)	Aperture Size $(\lambda^2)$	Efficiency (%)
Dual Rings [16]	0	N/A	360	250	52
Two Rings and Patch [14]		N/A	360	130	64
Three Rings [15]		N/A	500	163	66
Hexagonal [12]		N/A	360	69.4	60



figure 2.15: Reflection phase and reflection magnitude of fractal element at different incident angles as a function of fractal length [9]



The horn antenna can function effectively. Horn antenna flare provides a smooth match between the waveguide and free space and its angle affects a lot of things including the gain and directivity.

For rectangular horn antenna formulas

$$Aperature_{E} = \sqrt{2}\lambda L_{E}$$
$$Aperature_{H} = \sqrt{3}\lambda L_{H}$$

Aperture E is width of the aperture in the E-field direction. Aperture H is width of the aperture in the H-field direction  $L_E$  is the slant length of the side in the E-field direction.  $L_H$  is the slant length of the side in the H-field direction.

The gain of a pyramid horn antenna.

$$Gain = \frac{4\pi A e_A}{\lambda^2}$$

A is the physical area of the aperture.

D is the physical diameter of a conical horn aperture.

 $E_A$  is the aperture efficiency and isa figure between 0 and 1.

The cut-off frequencies for all modes are

$$fc = \frac{1}{2\sqrt{\mu\varepsilon}} \sqrt{\left(\frac{m}{a}\right)^2} + \left(\frac{n}{a}\right)^2$$

With cut-off wavelengths

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{a}\right)^2}}$$

# 2.8 Summary

Since the advancement of technology is growing rapidly, the advancement in telecommunications is also growing rapidly to make daily life easier. Reflectarray in X-band frequency (8GHz – 12GHz) will be create. The rectangular waveguide and horn antenna will be used to make this reflectarray antenna. Unit cell will be created to make the array itself. In this research paper, X-band frequency frequently used in telecommunication either civilian or military. With the range of 8 GHz to 12GHz reflectarray antenna will be create using a metallic waveguide along with pyramidal horn antenna.

## **CHAPTER 3**

#### METHODOLOGY

#### 3.1 Introduction

This chapter presents the proposed methodology in order to develop a reflectarray antenna. Firstly, design the unit cell along with X-Band waveguide frequency range. Next, need to analyze and optimize the size of waveguide to save the cost and the material. Investigate the different material of waveguide from the optimize and analysis result. The fabrication take place after the analysis of the waveguide complete. The network analysis using S-Parameter to make a comparison between the simulation and measurement.

## 3.2 Methodology

This thesis presents the process in creating a reflectarray antenna in X-Band frequency range. The essence of the approach used in this project is designing, analysis and fabricate. The selected approach is based on analysis, which aims to analyze and calculate in order to develop an antenna. The method (design) is experimental, which utilizes empirical modelling and statistical approach. Subsequently, Figure shows the process in developing a reflectarray antenna



## 3.3 Equipment

# 3.3.1 Simulation



figure 3 1: The logo of the CST Studio Suite software

Using CST Studio Suite to simulate and design the waveguide and the reflectarray unit cell. Integration between waveguide and reflectarray unit cell will be performed to optimize the cost and the size of waveguide.

# 3.3.2 Fabrication

Fabrication will be done to the waveguide; the material is aluminium and fabricated the reflect array unit cell using the material of FRU and Rogers 5880. The etching process will be use to fabricate the circuit (put some picture at PCB Fabrication LAB at factory). Waveguide fabrication using CNC Machine (picyture of CNC machine).



figure 3 2: PCB Developer Machines

This machine of PCB developer is process the chemical to switch on the mains. The temperature set to 40°C and developing with duration of 2 minutes. Once it done with washing with water and dry using tissue paper.



figure 3 3: Etching Developer Machines

The etching machines is mega electronics (model FAPC 300). Do the allocates of the positive board at the input roller. The temperature within 40°C to 46°C, this process requires 2-4 times to etching process depending on the board size.



figure 3 4: Photoresist Stripper Machines

The etcher machine mega electronics (model PA320) using photoresist stripper chemical that allocate the positive board in the netting and perform up and down soaking.



figure 3 5: PCS Cutter

The printed circuit board (PCB) cutter needs to ensure the board is dry before cutting the process. Aling the unwanted PCB area to towards the cutting area and move the cutter handler down fast to ensure the smooth cutting.



Figure 3.7: DMU 60 eVo High Speed

The DMU 60 eVo High Speed in CNC lab need to fabricate the metallic waveguide in the designated design in the CST.



Figure 3.8: Counter Sunk Machine

This machine used to make a screw hole on the waveguide. The process calls as countersunk screw. This needed to be done, to make sure the waveguide hold together.



figure 3 9: Vector Network Analyzer Machines

After the fabrication process, the rectangular waveguide will be analysis by Vector Network Analyzer Machines.Vector Network Analyzer Machines are used in analyzing the result of reflectarray by using rectangular waveguide.

### 3.4 Summary

In general, this paper indicates the necessary processes in creating the reflectarray antenna. Process that begins with the design of the unit cell of reflectarray and rectangular waveguide that in the range of X-band frequency. In turn, optimization the size for the waveguide to simplify and reduce the processing cost. Investigate the different material result for waveguide. Fabrication will take place after the whole analysis and simulation done.



# **CHAPTER 4**

## **RESULTS AND DISCUSSIONS**

#### 4.1 Introduction

This chapter presents the results and analysis on the development of a waveguide and pyramidal horn antenna. Rectangular waveguide used and attached with pyramidal horn antenna in reflectarray. Case studies are performed to show the radiation pattern, S-parameter result and the gain result. Using CST Studio suite, the waveguide and horn antenna have been developed and the result will be shown.









This table is the result combined for 3 material – Aluminum, Copper, and PEC. This combination will show the different result while running this result.



Table 4.2 S-Parameters for 1, 5 and  $10 \lambda$ 



# 4.2.2 Unit Cell





4.2.3 Unit Cell Connected with Waveguide

UNIT CELL WITHOUT SLOT	MATERIAL (ALUMINIUM )	DESIGN
H field	UNIT CELL WITHOUT SLOT	La Gald













Table 4.6 Unit cell with Waveguide PEC



These preliminary results and analysis of rectangular waveguide (WR90) and pyramidal horn antenna using material Perfect Electrically Conductor (PEC).

4.3 Summary



#### **CHAPTER 5**

#### **CONCLUSION AND RECOMMENDATIONS**

#### 5.1 Conclusion

This thesis showing a method in how to find a good performance for metallic waveguide in a range of x-band frequency using a few types of material. The main objective in the methodology is to make a new design also analysis a good performance for metallic waveguide to reduce the cost in making a x-band radar antenna reflector. To improve the optimization by choosing a different material and put it together in the X-band waveguide design. WR-90 is kwon as a x-band standard size. Next, for the x-band waveguide front face we using the size or 30mm for the width and 15mm for the high. The front face of the waveguide will be completed with a unit cell. Using the standard size given for the x-band frequency range and the size of unit cell, it can be seen the process of the result to optimize the size for a better result. This way we can go back to the main objective is, reducing the cost in making a x-band radar antenna reflector.

In conclusion, the research present in this thesis has succeed in contributing in understanding of the making of metallic waveguide in x-band radar frequency range. Using three type of material such as Aluminum, Copper and PEC, the outcome result shows a big different. The values will be slightly different between 0.02. if the gap in the outcome result is not excessive then it will be no problem in proving the solution in improving the performance of the metallic waveguide.

#### 5.2 Future Works

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