MICROWAVE AND IMAGE BASED TECHNIQUE FOR CRACK DETECTION IN AIRCRAFT MATERIAL

A DISSERTATION

Submitted in partial fulfilment of the Requirements

for the award of degree of

MASTER OF TECHNOLOGY

in

ELECTRONICS AND COMMUNICATION ENGINEERING

(With specialization in RF and Microwave engineering)

By

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JUNE 2019

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
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CANDIDATE' S DECLARATION

I declare that the work carried out in this dissertation report titled **"MICROWAVE AND IMAGE BASED TECHNIQUE FOR CRACK DETECTION IN AIRCRAFT MATERIAL"** is presented on behalf of partial fulfilment for requirement of award of the degree of Master of Technology with specialization in RF and Microwave Engineering submitted to the department of **Electronics and Communication Engineering, Indian Institute of Technology Roorkee**, under the supervision and guidance of **Prof. Dharmendra Singh**, Professor, Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee.

I further certify that the matter presented in this report has not submitted for the award of any other degree or diploma.

Date: June 2019 (Deepak Singh Rawat)
Place: IIT Roorkee

CERTIFICATION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: June 2019
Place: IIT Roorkee

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Abstract

The Millimeter wave (MMW) frequency operates in the region of (30-300) GHz and has been a part of incredible interest among researchers due to its unique features such as fine resolution, size reduction and higher data rate. These features make it an ideal for use in applications like, quality monitoring, personal screening, wireless communication, medical imaging, etc.

The use of MMW frequency in stand-off imaging due to its non-ionizing radiation feature as compared to ionizing X-rays moreover its ability to penetrate through materials which is not there in the visible and IR systems. It has a higher resolution capability which makes it prominent for use in microwave imaging hence MMW imaging is a better modality for defining adequate details of the targets which are useful to identify target's characteristics like, deformity, corrosion, crack, internal damage, void etc. The MMW technique has many advantages hence it can be applied in the different scientific, industrial and military applications.

MMW imaging is has rapidly lengthened in the field of non-destructive testing for quality monitoring in various industrial and military applications. The critical analysis of image processing techniques in context to MMW imaging is presently becoming a new area of research. However, focus is required in this direction to develop an effective MMW imaging methodology for precisely detecting a surface flaw in the materials. The following tasks have been carried out in this dissertation work: -

The following tasks have been proposed out in this dissertation work: -

(i) ***Task 1:*** Study of MM wave imaging with material surface.

(ii) ***Task 2*:** Application of Signal processing techniques for Image enhancement.

(iii) ***Task 3:*** Development of Crack detection techniques.

This dissertation consists of six chapters. *Chapter 1* consists of the introduction, motivation, challenges involved in the microwave and image based techniques for crack detection, problem statement, objectives and framework of the dissertation.

Chapter 2 provides a literature review for the considered tasks with their limitations and research gaps.

Chapter 3 explores the capability of SFCW radar system design and imaging parameters, for the non-destructive evaluation of the various objects to evaluate their condition. The study and analysis of the MMW imaging system explores the capability of MMW frequency for detecting the defect in the test materials having different relative permittivity. By using active imaging system, the radiation is generated to illuminate the target to form an image by using the target reflectance distribution obtained from the surface of the material.

Chapter 4 consists of the methodology used for detecting the surface damage in different materials with procedure and experimental setup adopted for data collection of different samples. For collection of data a stepped frequency continuous wave (SFCW) active imaging radar system was used at MISTA Lab of IIT Roorkee, India by using a vector network analyser (VNA) operated in the frequency range of (55-65) GHz. For the data acquisition

C-scan methodology was used which provides the length and width information of the target.

The acquired data undergoes the following signal processing steps: -

(i) Frequency to Time domain (IFFT) conversion.

(ii) Time to spatial domain conversion

(iii) Relative calibration

(iv) Time gating

After applying the above steps a C scan image is generated which is known as raw C-scan image. The main aim of this chapter is to form a raw C scan image of the material.

Chapter 5, This chapter deals with the analysis of the raw C scan image obtained and further enhanced to determine the defect by using the post-processing steps to remove clutter. The various materials whose image is analyzed consist of metal, wood, alloys and concrete bricks.

In *Chapter 6,* the contributions made in the dissertation are summarized and scope of future work is outlined. The MMW imaging system used in image formation and analysis for different materials especially sample aircraft material will help to ease the task of the military aviation.

Acknowledgements

I would like to take this opportunity to thank all those persons, whom without their support I could not have reached at this destination.

I would like to admire and honor my supervisor 'Prof. Dharmendra Singh'. He has been always there to help me both technically and morally. I am very much thankful for his excellent guidance and inculcating research skills in me. His physical intuition and ability to resolve and simplify complex problems has always helped me excel my project. It is his zeal that I could have been able to accomplish my project work in an advanced topic of MMW frequency imaging with limited resources in hand. Without his untiring efforts, stimulating discussions, and motivational examples I would not have been writing this page for completion towards my project.

I will never forget the company of my fellow students and friends. I am thankful to my present colleagues of Microwave Imaging and Space Technology Applications (MISTAL) lab
Sqn Ldr Varun Parashar, Amit kushwaha and Chandan kumar for the congenial cheering work environment and for the round of discussions altogether.

My special thanks go to Jaydeep Singh Baghel, Mandar Bivalkar, Rakesh Singh and Ramveer Singh for helping me out in my project work, experimental setup and patiently proofreading my dissertation to help me in presenting it in a better way. I wish to convey my appreciation and my deepest prayers to all of them to achieve success and happiness in their future endeavours.

I am thankful to lab technicians Mr. Raja Ram and Mr. kamveer for helping me out in measurement and making arrangement of experiments required for the dissertation work.

Table of Contents

List of Figures

List of Tables

List of Symbols

τ	SFCW pulse width
c	Speed of light
R	Range
Γ	Complex reflection coefficient
θ	Elevation angle
Φ	Azimuth angle
λ_0	Free space wavelength
ϕ_n	Phase difference of n^{th} SFCW pulse
ΔR	Range resolution of imaging radar
ΔCR	Cross-range resolution of imaging radar
Ω	Impedance in ohms
λ_g	Guided wavelength in the dielectric
S_{11}	Reflection coefficient
N	Number of frequency points in SFCW radar
f_n	n^{th} discrete frequency step
Z	Target distance from radar
Δf	Frequency step size of SFCW radar

List of acronyms

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
ADS	Agilent’s advanced design system
BW	Band width
CR	Cross range
DFT	Discrete Fourier transforms
DUT	Device under test
EM	Electromagnetic
HPBW	Half power beam width
IFFT	Inverse fast Fourier transform
MMW	Millimeter wave
NDT& E	Non-destructive testing and estimation
RADAR	Radar ranging and detection
SAR	Synthetic aperture radar
SFCW	Step frequency continuous wave
TEM	Transverse electromagnetic
TOSM	Though open short and Match
VNA	Vector network analyzer

Chapter 1.

INTRODUCTION

The Millimeter wave (MMW) frequency operates in the region of (30-300) GHz and has been a part of incredible interest among researchers due to its unique features such as fine resolution, size reduction and higher data rate. These features make it an ideal for use in applications like, quality monitoring, personal screening, wireless communication, medical imaging, etc. The use of MMW frequency in stand-off imaging due to its non-ionizing radiation feature as compared to ionizing X-rays moreover its ability to penetrate through materials which is not there in the visible and IR systems.

It has a higher resolution capability which makes it prominent for use in microwave imaging, hence MMW imaging is a better modality for defining adequate details of the targets which are useful to identify target's characteristics like, deformity, corrosion, crack, internal damage, void etc. The MMW technique has many advantages hence it can be applied in the different scientific, industrial and military applications.

MMW imaging is has rapidly lengthened in the field of non-destructive testing for quality monitoring in various industrial and military applications. The critical analysis of image processing techniques in context to MMW imaging is presently becoming a new area of research. However, focus is required in this direction to develop an effective MMW imaging methodology for precisely detecting a surface flaw in the materials. Presently, the imaging radars are enormously used in various fields extending from weather patterns, mapping the earth and to create the images of objects buried in the ground, or hidden behind obstructions. The MMW frequency capability to penetrate through a material can produce characteristic information of the target hence MMW, seems to be a good imaging tool for quality and condition inspection of aviation industry material towards wear and tear, internal defect and prolonged usage defects, without hampering its characteristics property.

In view of aforesaid MMW features and combining it with the different image processing techniques a fault detection robust methodology and capability is essentially required to be developed for a defect scanning for the quality check of materials.

1.1 Motivation

The Indian Air Force has been established to protect and safeguard the Air space of our country for accomplishment of the given task it has been equipped with the aircraft, state of the art weapon systems and highly motivated personnel. All together with all of its assets it is the fourth largest the Air Force of the world. The primary responsibility of air force is to safeguard Indian airspace and conduct aerial warfare during an armed conflict to achieve this task it is equipped with state of the art Aircraft, Missiles, Radars and Weapon systems.

To be in ready state of War, personnel are trained continuously on their respective system. The equipment forms the backbone of this technology sensitive force are maintained, at an operational readiness level, so that they can be used at the time of hostility. Aircraft are one of the major asset in the inventory of the Air force, whose maintenance is one of the important and critical task it is however time consuming activity, for example, an aircraft requires hours of maintenance after being flown, during the maintenance of the aircraft it is subjected to various checks, results of these checks determines the further usage of the aircraft.

To assess the condition of the airframe various NDT techniques are applied which take enormous amount of time as microwave techniques have distinctive characteristics over other NDT techniques, from the study it is evident that a new and efficient method is required which is Real Time Fast, Portable and can accurately identify the position of defect and calculate its dimensions. However, there are many challenges in the development of an imaging radar system. The system performance should minimize the ambiguities and inaccuracies in targets and should be able to function properly in controlled environment.

1.2 Aim and Objective of this Dissertation

MMW imaging is has rapidly lengthened in the field of non-destructive testing for quality monitoring in various industrial and military applications. The critical analysis of image processing techniques in context to MMW imaging is presently becoming a new area of research. However, focus is required in this direction to develop an effective MMW imaging methodology for precisely detecting a surface flaw in the materials.

The MMW frequency capability to penetrate through a material can produce characteristic information of the target hence MMW, seems to be a good imaging tool for quality and condition inspection of aviation industry material towards wear and tear, internal defect and prolonged usage defects, without hampering its characteristics property. To assess the condition of the airframe various NDT techniques are applied which take enormous amount of time also the challenge is to develop a NDT technique which must possess the undermentioned characteristics:

(i) Accurate

(ii) Less time consuming

(iii) Highly efficient

(iv) Identification of the characteristics of defect

(v) Less time consuming

(vi) Manpower constraint

(vii) Simple Hardware

(viii) Portable

(ix) Consume low power

(x) Fast with real time processing

(xi) Robust

The MMW imaging has rapidly lengthened in the field of non-destructive testing for quality monitoring in various industrial and military applications. To meet the challenges MMW Imaging for fault analysis provides the viable solution. The critical analysis of image processing techniques in context to MMW imaging for fault and damage assessment is presently becoming a new area of research. However, the challenge is to develop an effective MMW imaging methodology for precisely detecting a surface and subsurface flaw in the materials.

1.2.1 Problem statement

The evaluation of structures without impairing their properties is very important for the failure analysis so as to prevent the system from failure hence this type of evaluation can be carried out by using the Non Destructive testing, which is used for evaluating the airframe and other sub parts of the aircraft.

MMW imaging is has rapidly lengthened in the field of non-destructive testing for quality monitoring in various industrial and military applications. The critical analysis of image processing techniques in context to MMW imaging for fault and damage assessment is presently becoming a new area of research. However, the focus is required to develop an effective MMW imaging methodology for precisely detecting a surface and subsurface flaw in the materials.

The following tasks have been proposed out in this dissertation work: -

(i) ***Task 1:*** Study of MM wave imaging with material surface.

(ii) ***Task 2*:** Application of Signal processing techniques for Image enhancement.

(iii) ***Task 3:*** Development of Crack detection techniques.

1.2.2 Types of aircraft maintenance

The maintenance of aircraft is divided into three basic categories they are: -

(i) O Level maintenance. The **'O' (Operational),** level maintenance comprises of Built in tests of various system components of aircraft and visual checks on the airframe, post O level checks aircraft can fly on daily basis up to a fixed flying hours. Once the fixed flying hours are exhausted the aircraft is subjected to more complex set of checks.

(ii) I Level Maintenance. The **'I' (Intermediate),** level maintenance comprises of thorough checks on aircraft system, replacement of some mandatory components and more exhaustive checks.

(iii) D Level Maintenance. The **'D' (Depot)**, level maintenance is done on aircraft after it finishes its life i.e. after a certain number of years/flying hours. In this the aircraft is completely stripped opened and checked for further usage based on the condition of airframe.

The 'D' level maintenance is very critical and most time consuming, as aircraft life is to be renewed again, moreover the airframe is to be checked thoroughly so as to detect any deformity or defect in airframe, panels and pipelines, if a potential defect is missed on the airframe then it can cause a failure at later stage which can be catastrophic. The maintenance is hugely dependent on the non-destructive technique which is enormously time consuming.

1.2.3 Non Destructive testing

The NDT is the process of evaluating an object without imparting the physical property of the object. It is a very broad field that plays a serious role in the inspection of the structural component and systems to perform in a reliable fashion. NDT is implemented to assure the reliability and prevent errors due to the fault in the equipment which is subjected to continuous loading, aged over a period of time.

NDT test characterize and locate flaws that might cause planes to crash, reactors to fail, pipelines to burst, and variety of troubling events. These techniques require a high level of operator skill and accurately analyzing the test results is difficult as the results can be very subjective. The NDT methods are performed on various materials which are listed below: -

(i) Metals.

(ii) Plastic.

(iii) Ceramics and coatings.

These methods help us to detect surface and subsurface flaws or any type of defect which can cause a catastrophic failure.The Various Non-Destructive Techniques used for assessing the condition of airframe in an aircraft is given in Table 1: Comparison of various NDT techniques below: -

Table 1: Comparison of various NDT techniques

Sl. No	Technique	Usage	Advantages	Limitation
1.	Visual Inspection	Detection of defect on surface	(a) Simple and effective (b) In expensive equipment	(a) Small flaws are difficult to detect. (b) Sub-surface defects cannot be assessed. (c) Skill based job.
2.	Dye penetrant	Detection of defect on surface	(a) Simple and effective (b) In expensive equipment	(a) Manpower extensive and skill based job. (b) Not feasible for large areas.
3.	Radiograph y	Subsurface flaws	(a) Sub surface flaws can be seen	(a) Radiation protection (b) Not feasible for airframe due to large size of equipment.
4.	Magnetic Particle	Can detect Surface, near surface and layered flaws in material		(a) Limited subsurface flaw detection capability.

1.3 Framework of the project

The complete framework of the project work is given in figure 1.1, which is mainly categorized as generating and analyzing the C scan image of the material under test and then by image enhancement the fault (crack) is detected. Following subtasks have been performed for completing the project. Review of the problems related to the literature of each task to identify the limitations of the exiting solutions is also carried out.

Task 1 Study of MM Wave Imaging with material surface which includes following subtasks:

- To perform A, B and C scan on different materials for collecting data.
- Generate Raw C scan image of the material under test.

Task 2 Application of Signal processing techniques for Image enhancement which includes following subtasks:

- Normalisation.
- Background Subtraction.

Task 3 Development of Crack detection techniques which include following subtasks:

- Collection of different samples of the Aircraft material.
- Generate and analyse C scan image post enhancement for the aircraft material sample.

Chapter 2.

Technical Terms and Theoretical Background

The Millimeter wave (MMW) frequency operates in the region of (30-300) GHz and has been a part of incredible interest among researchers due to its unique features such as fine resolution, size reduction and higher data rate. These features make it an ideal for use in applications like, quality monitoring, personal screening, wireless communication, medical imaging, etc.

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2.1 Introduction

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2.2 Theoretical background

The radar imaging is based on the principle of spatial mapping of the distribution of target's reflection coefficient. The radar imaging is broadly divided into two types **Passive** and **Active imaging**. In the passive imaging the image is a function of reflectance distribution of emissivity and temperature of the background and the target.

In **Active imaging** radiation is artificially generated for illuminating the target, the image is formed by the target reflectance distribution. The Radar transmits electromagnetic waves towards the target which are reflected back by it then the EM waves are received back. The range (R) of the target is determined as $R = c\tau/2$, here (τ) is the two-way travel time of the wave.

The radar system used for imaging should have high range and cross-range resolutions, which can be efficiently, employed for different system applications. Pulsed or Continuous-Wave (CW) are a high-resolution radar which have high bandwidth β and short pulse width τ.

In the **pulsed radar,** a short pulse train having a very low power level is transmitted. This type of radar is cost effective and simple. However, it is incapable of simultaneous handling of high range resolution and deep penetration.

The **Frequency Modulated Continuous Wave** radar uses beat frequency (f_d) which is the relative difference between transmitted signal time delay (τ) and the returned signal is used to calculate the range (R) of the target. In the FMCW radar the receiver's sensitivity is degraded due to the use of the wide bandwidth which results in the reduced penetration depth.

In a **Stepped frequency continuous wave** radar system range resolution of wideband system is delivered incorporating the advantages of narrowband systems, that is why a step-frequency radar is very much cost effective and has an ability to achieve a high range resolution which can be exploited in the field of military aviation.

2.3 Crack detection parameters

The entire methodology for detecting a defect in a material revolves around the parameters of the radar system and the target. The radar system and the target parameters are further subdivided into the following categories as shown in the Figure 1.

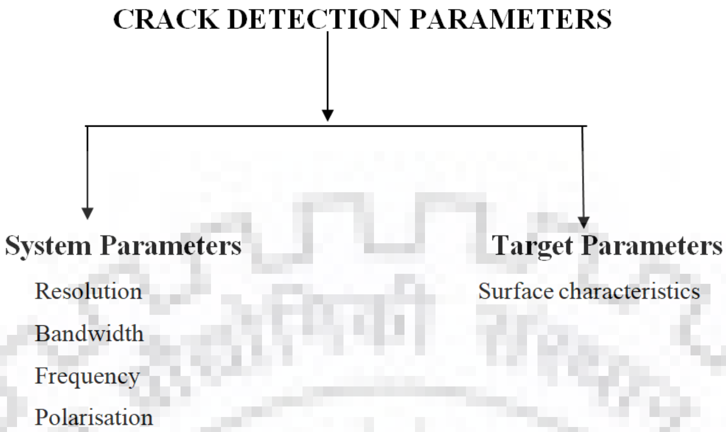


Figure 1: Classification of crack detection parameters

It is clear from the Figure 1 that the detection of a crack in a material is a function of the Radar system and target parameters which are discussed in the subsequent paragraphs.

2.4 Target parameters

The target is the material under test which has their own characteristics in terms of parameters like Reflectance, absorption of EM waves firstly it is the surface characteristic i.e. how shiny is the material as it will possess higher tendency to reflect back the EM waves from its surface. If the material is an EM wave absorbing material, then the reflection from it will be less and will be difficult to analyze the flaw in its surface or sub surface.

2.4.1 Polarization

Polarisation is the property of EM wave which describes the time varying direction and relative magnitude of the electric field vector. If a linearly polarized EM wave is sent to the surface being examined and if the back scattered signal received from surface has any form of deformity such as crack, then the received back scattered signal will have a component which is cross polarized to the incident wave which will define the geometry of the defect.

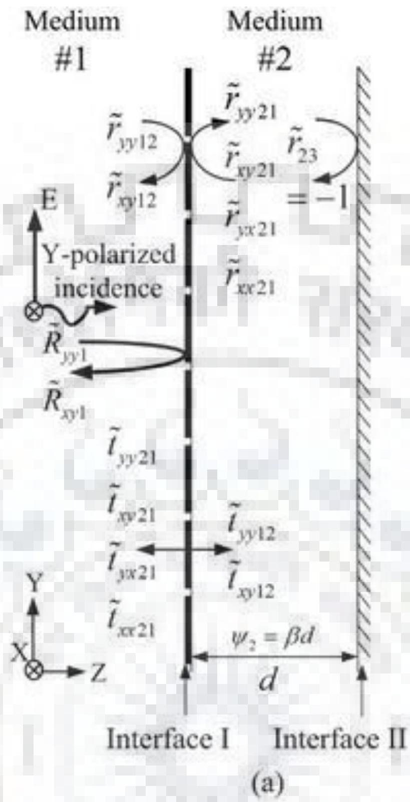
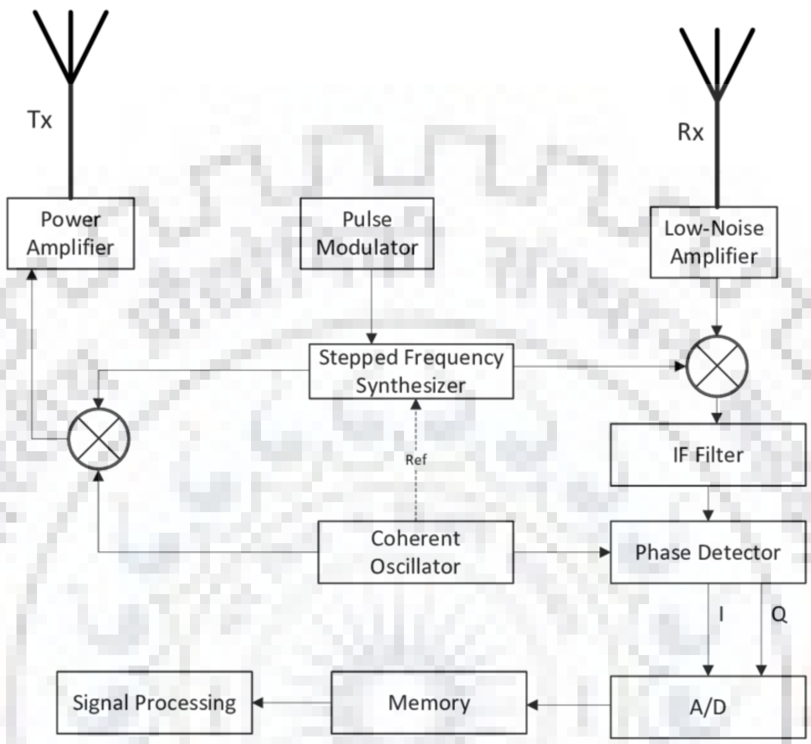


Figure 2:EM wave reflection from surface [6]

It is clear from Figure 2, a linearly polarized wave is incident on the surface of a metal, a component of the EM wave is reflected back also there is also an another component of the EM wave which strikes the crack and produces a shift in the wave phase of the EM wave, if the incident and the reflected wave can be decoupled then we can obtain the geometry of the crack.

2.5 SFCW Imaging Radar System Design

The stepped-frequency radar transmits a waveform of pulses that are stepped up in the frequency intervals of Δf Hz in the entire bandwidth β each step of frequency which is received from the target is down-converted to two narrow baseband signals called I and Q by using a quadrature mixer however before the transmission of next frequency step the I and Q signal is sampled with high precision by using the low frequency digitizers. The block diagram of step frequency radar is shown in Figure 3: Block diagram of step frequency radar [5]



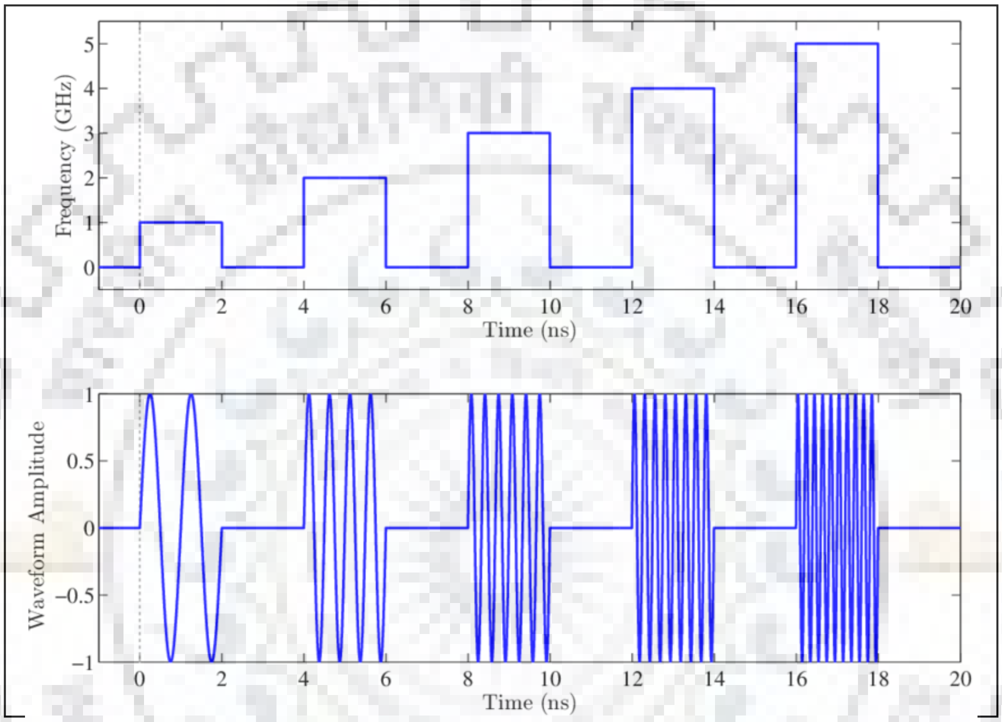
2.5.1 Working of a step frequency radar

The output of SFCW radar is initiated by the coherent step frequency synthesizer which increases the frequency by a fixed step size from one pulse another pulse. The up conversion is carried out by mixing the signals of coherent oscillator and step frequency synthesizer in the transmitter side. The output of this conversion and stable local oscillator frequency is added to generate the transmitted frequency, after pulse-modulation and amplification the obtained signal from the mixer is transmitted.

Once the target signal is received by the receiver, it is amplified and mixed with the output of the stable local oscillator for the process of down-conversion. The output of the step frequency synthesizer is mixed with the resulting signal for further down-conversion to intermediate frequency. To eliminate the multiple-time-around clutter synchronization of the step frequency synthesizer with the transmitter is carried out.

The intermediate-frequency signal which is the output signal obtained after the second mixer is passed through the phase detector by the help of an intermediate-frequency amplifier whose bandwidth is approximately equal to the inverse of the pulse width. The phase detector produces two signals called I and Q which are converted to the digital form and then can be processed.

The step frequency waveform which is generated is shown in Figure 4: Step frequency waveform



[5].

Figure 4: Step frequency waveform [5]

A step frequency waveform which is shown in Figure 4 is pulse burst waveform, in which every pulse is of constant width, however, the successive pulses have increased frequency in linearly discrete steps, by increasing the frequency in the linearly discrete steps we can obtain a large bandwidth and as the bandwidth increases the range resolution obtained is much finer. The step frequency waveform commonly utilizes a linear frequency stepping pattern as shown in the Figure 5: Linear frequency stepping [6], wherein the RF of each pulse is increased by a constant factor of ΔF Hz from the preceding pulse.

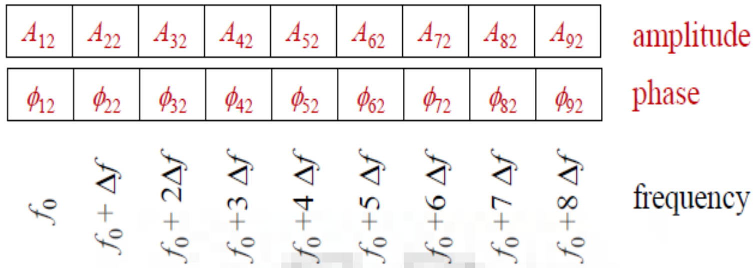


Figure 5: Linear frequency stepping [6]

The various advantages of SFCW radar are mentioned below: -

(i) Receiver sensitivity is improved by the usage of narrow instantaneous bandwidth.

(ii) Deep penetration in the material can be achieved by using the CW signals having high average transmit power.

(iii) Highly precise

(iv) Circuits can be easily designed.

Some of the limitation of SFCW radar is mentioned below: -

(i) The system is highly complex.

(ii) Cost of the system is high.

(iii) Difficult to detect the moving target.

(iv) To achieve the desired Range resolution continuous train of pulse is required.

2.5.2 SFCW Radar Parameters

➢ **Bandwidth**

In SFCW radar a large bandwidth can be realized by processing the *N* pulses of time duration (T) over the complete duration. The bandwidth if SFCW radar is given by: -

$$BW = N\Delta f \quad (1)$$

➢ **Unambiguous Range**

The unambiguous range of SFCW radar is represented by (R_{max}). To keep the unambiguous range larger than maximum expected range of the radar waveforms should be kept small by frequency step (Δf).

In SFCW radar the sampling criterion for the unambiguous range is given in the equation: -

$$\left(\frac{1}{\Delta f}\right) \geq \Gamma_{\max} \Rightarrow R_{\max} = \frac{c}{2\Delta f} \quad (2)$$

If the start frequency is *(f_0)*, stop frequency is (f_{max}), and the number of frequencies is given by (N_f), then the frequency step is given by equation: -

$$\Delta f = \frac{f_{\max} - f_0}{N_f - 1} \quad (3)$$

➢ **Range Resolution**

The range resolution is given by (ΔR); it determines the radar ability to show the closely spaced targets with a range R as two distinguishable targets. This range is determined by the bandwidth (β) of the transmitted EM waves, and given by the equation:-

$$\Delta R = \frac{c}{2B_{eff}} = \frac{c}{2N\Delta f} \quad (4)$$

The resolution of SFCW radar is increased by increasing *($N.\Delta f$)* hence the resolution is independent of the instantaneous bandwidth.

➢ **Number of Points**

In the step frequency radar, a large bandwidth can be obtained by sequentially incorporating the interpulse frequency modulation over train of pulses. To obtain a very high range resolution *N* can be increased however the fine range resolution require large bandwidth.

2.6 Analysis of SFCW radar waveform

The SFCW radar transmits a consecutive pulses of *N* frequencies which are linearly stepped up by (*Δf*) Hz, here aim is to obtain a high time-bandwidth product hence in place of using a linear FM signal, time-bandwidth product increased by stepping up a number of discrete frequencies as shown in the Figure 6.

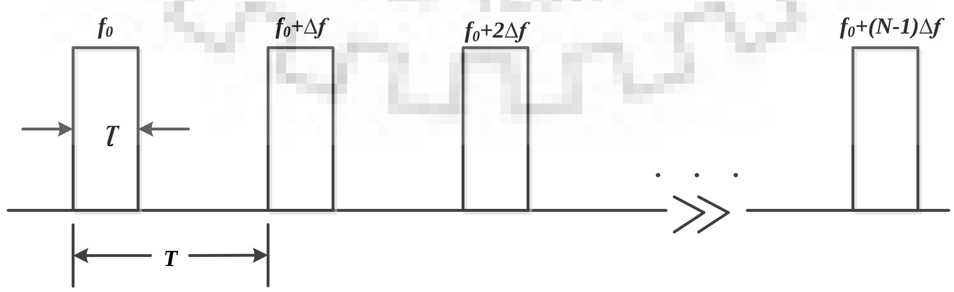


Figure 6: linearly stepped pulses [2]

If the number of coherent pulses is (N) and the frequency is linearly increased in steps, then

$$f_n = f_0 + (N - 1) \text{ x } \Delta f \tag{5}$$

From the Figure 6: linearly stepped pulses [2], the pulse width of Each pulse is (τ) seconds, time interval between the

Pulses is (T) so the reference signal for the N^{th} pulse can be written as

$$A_1 cos2\pi(f_0 + N.\Delta f)t \tag{6}$$

The round trip delay of (2R/c) is taken then the target signal can be written as

$$A_2 cos2\pi(f_0 + N\Delta f)\left(t - \frac{2R}{c}\right) \tag{7}$$

The phase detector output for the n^{th} pulse is $A\cos(\phi_n)$, where

$$\phi_n = \frac{4\pi f_0 R}{c} + 2\pi\left(\frac{\Delta f}{T}.\frac{2R}{c}\right)nT \tag{8}$$

In the equation 8, a constant phase shift is represented by the first term. The second term is the multiplication of the rate of change of frequency $\Delta f / T$ with the round-trip time $2R/c$ due to which the round-trip time is converted into a frequency shift, so here by resolving the frequency and taking the IFFT of the received signal the range can be resolved and measured.

Chapter 3.
Literature Review

This chapter presents the review of the characteristics of the MMW frequency spectrum, its uniqueness and its different applications, due to its high resolution and small, synthetic aperture it is used for the application involving non-invasive personnel screening, surveillance, medical and industry application also due to the large bandwidth and lower wavelength, it can also be used in miniature size equipment, high data rate communication systems and devices. The fields and applications of MMW are vast hence during the literature review the focus has been given only to the relevant tasks performed in the project.

Firstly, literature review related to the millimeter wave frequency features and its application has been discussed. Secondly, literature review related to the non-destructive testing has been discussed and the limitations of the NDT process have been highlighted. The uses of the microwaves for estimating the defect in a material and non-destructive targets defect analysis have been presented.

Review of the digital image analysis techniques which are being used for mining out meaningful information from the images generated by radar for pre and post processing of data has been done which is helpful in the enhancement of the generated image. Finally based on the review of above mentioned MMW applications this chapter has been concluded.

3.1 Millimeter Wave Frequency Features and its Applications

The uniqueness of MMW frequency spectrum is due to its high resolution and small synthetic aperture which can be used to develop system of miniature in size and high data rate but this improvement comes with a limitation of high atmospheric attenuation which in turn limit is the propagation ability of MMW frequency.

The free space propagation loss from (50-80) GHz is more than the loss at (10-30) GHz. The Figure 7 shows the attenuation curve at MMW frequency. The interference levels of MMW are less hence higher frequency can be reused over very short distances which allows us to develop the high throughput network.

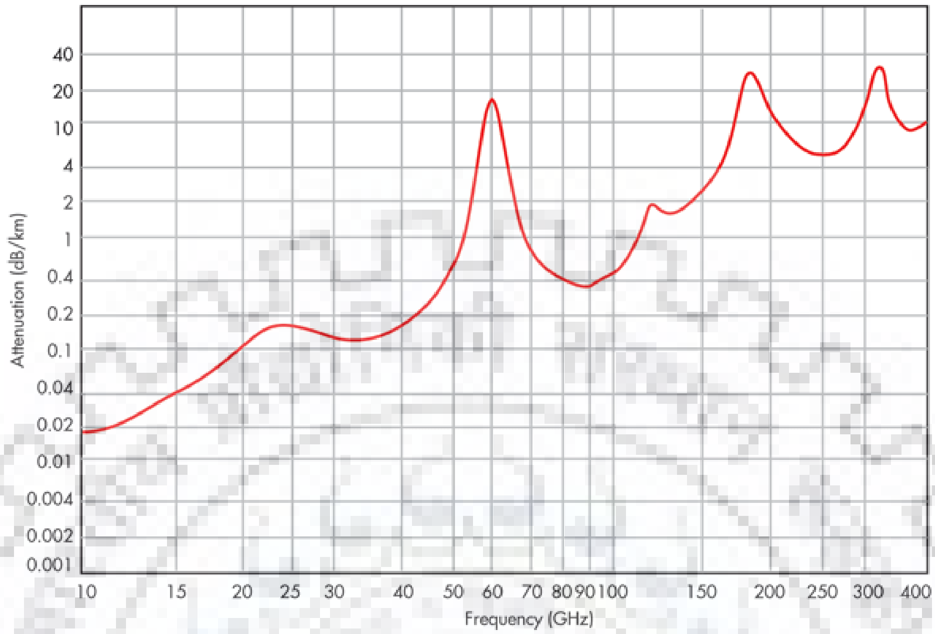


Figure 7: Frequency Vs Attenuation curve of MMW frequency [1]

Various research works have been going on around the world exploiting the vast number of applications that MMW offers, like, stand-off concealed target detection, active or passive imaging sensor, precise measurements of air and sea surface temperature using 60 GHz rotating radiometer, non-destructive moisture monitoring and disinfestations of artworks at 150 GHz, non-contact vital sign detection at 94 GHz, collision-predicting sensors for automatic braking systems for automobiles at 35 GHz and 60 GHz, detection of cracks, void, surface anomalies, an distance measurement of the target with sub-millimeter accuracy, soil backscattering using a 60 GHz scatter meter, millimeter-wave identification (MMID) for short-range, low-power, high data-rate applications etc. MMW is now developing tremendous research interest around the world due to diversified interesting applications.

3.2 Review of Work Related to Non Destructive Testing

The NDT is the process of evaluating an object without imparting the physical property of the object. It is a very broad field that plays a serious role in the inspection of the structural component and systems to perform in a reliable fashion. It is implemented to check the reliability of the equipment and to prevent catastrophic failure due to the fault in the equipment which is subjected to continuous loading or have been aged over a prolonged period of time.

The non-destructive testing (NDT) methods are now being utilized in manufacturing, power, construction, aviation and maintenance industries. NDT does not only exist in industry but also in our everyday lives. The basic principle of NDT is to determine the integrity of an item without impairing its physical property to determine its future usage. There are various proven and standard Non-destructive testing (NDT) techniques which are utilized to check the material for its further usage, they are: -

(i) Radiography

(ii) Ultrasound

(iii) Dye penetrant

(iv) Eddy current

(v) Visual testing

(vi) Magnetic particle testing

The methods which are present have their own advantages and limitations so the methods have their own application area. For example, structure of porous materials cannot be evaluated by using ultrasonic signals because their signals cannot penetrate in the inner surface, likewise a lossless dielectric material cannot be inspected by using Eddy current methods as eddy currents cannot be induced in such materials.

In the high temperatures zones a non-contact inspection is required also sometimes it is required to test the materials usability for further use without destructing the material. For example, in aviation lighter materials and composites are used moreover they are electrically insulated, due to which standard NDT techniques are applicable to inspect them.

Due to the limitations of NDT techniques mentioned above the MMW techniques provide viable solution. The EM signals at MMW frequencies have the capability to penetrate the dielectric materials hence they are able to deliver the information regarding their inner structure. The factors such as loss factor and frequency of operation tell about the depth of penetration of dielectric material. By using the contact or non-contact methods, the MMW measurements can be carried out also for a specific type of application the information parameters provided by the measuring instrument such as bandwidth, frequency, polarization, sweep points, phase, and magnitude, these parameters can be optimized.

Microwave NDT techniques are sensitive to geometrical and dimensional variations of a defect. The polarization properties of microwave signals can be used to increase measurement sensitivity of defects of a certain orientation [2].

The Literature review related to microwave NDT imaging is classified into two measurement techniques which are: -

(i) Near-field probe imaging.

(ii) Synthetic aperture imaging.

In the Near-field probe imaging method the target surface which is being investigated for crack detection is kept in the close vicinity of the probe, which can be an open ended rectangular or a coaxial probe, this method utilizes the surface current perturbation in which any crack present inside the waveguide aperture will disturb the surface current and cause a change in the property of the reflected wave.

Few examples are Microwave Method for Detection of Long Surface Cracks in Metals, at 20 GHz, where open ended rectangular waveguide was used as a probe to examine the surface of a metal. A non-defective surface is termed as a good short-circuit load, but if the deformity in the surface exists such as crack, the reflection properties at the waveguide aperture will change and it can be seen in the in the standing wave pattern which is detected by a diode detector.

Crack inspection in cement based civil structure at X band [3], detection of corrosion precursor pitting under paint at V band [4]. The near field probe technique is advantageous as it is easy to perform and provides high resolution, however if the distance between the probe and the target under investigation changes due to any non-uniformity during the experiment it is bound to severely affect detection of the crack. To overcome the limitation of the probe imaging technique, synthetic aperture imaging by using MMW frequency radar is used as it provides a viable solution for the limitation of the above mentioned technique, by the use of MMW imaging radar a non-contact, high resolution and reliable non-destructive testing can be done.

3.3 Review of Work Related to MMW Imaging

MMW radar has been used accurately and effectively for the imaging applications in the field of security such as screening for concealed weapon detection, baggage inspection, medical diagnostic, detecting and localizing buried mines or objects.

In the MMW radar, the object or the target is first illuminated by radiation and then the reflection from the target is measured and further processed to reconstruct the image of the object. The resolution of the image is characterized by the radar parameters which are centre frequency, bandwidth, and aperture size. To accurately identify the defect in the target the image should be enhanced so as to correctly identify the defect.

3.3.1 Review of work related to Target Defect Identification

The reflected EM waves or the reflection signal from the target is intercepted by MMW imaging radar, at first it is in the unprocessed raw form hence does not carry any useful information about the target because, the intercepted EM waves also carry many desired target signal reflections and refractions due to multipath propagation, signals generated from background and system noise, etc. To discriminate between the object and the background image enhancement is carried out. A brief review of image generation and defect identification techniques is mentioned below:

Chengyan Jia [5] proposed a method which was used to detect crack on the coal surface by utilizing the MMW propagation in the frequency W-band (75–110) GHz. After developing a raster scanning MMW imaging system which used the S parameters to form the image of the target according to the difference between the dielectric parameters of cracks and those of the coal samples, after that by using an imaging algorithms images of the defected coal samples were generated.

The advantages of the system are: -

(i) Good spatial resolution by the use of short wavelength.

(ii) The developed technique can be successfully applied to detect, image, and map cracks and fissures of various sizes hidden in bulk coal samples.

The limitation of the imaging system was that the imaging of cracks in coal was possible only when the power transmitted was around 2 dBm at this power the EM waves can penetrate only about 12 cm thickness of coal.

John R. Gallion [6], in proposed a method to detected fatigue cracks in metals which were having severe surface corrosion and pitting. The experiment was performed at MMW frequencies thereby allowing it to penetrate through and interact with a visually masked crack. In this method open-ended rectangular waveguides were used to avoid any contact with the sample material. It was revealed that the crack signal characteristics is significantly different from the characteristics of the corrosion and pitting, which implies that a crack is detectable even in the presence of severe corrosion.

The technique overcomes the limitations associated with the other standard techniques which are:-

(i) Cracks under coatings such paint and corrosion can be detected.

(ii) Cracks can be detected in a noncontact manner thereby eliminating the need for removal of corrosion.

(iii) Cracks in rough or non-uniform surfaces can also be detected.

The major limitation of this technique is that interior flaw in a material cannot be detected. By using this method of crack detection a new technique for detecting cracks in severely corroded steel plates was formulated and can be effectively utilized for other applications where a crack is masked by a dielectric layer such as paint or dirt.

The other reviews are shown in the Table 2: Comparison of Reviewed papers

Table 2: Comparison of Reviewed papers

S.No	Author	Year	Technique	Result
1.	Chengyan Jia, Guoshuai Geng	2016	MMW radar imaging system for crack detection in coal	(a) Electromagnetic scattering from coal at Frequency Range of (75-110) GHz. (b) By the use of short wavelength better spatial resolution is achieved. (c) Millimetre-wave frequencies can be used to determine the depth of a small crack.
2.	John Gallion, Reza Zoughi	2013	MMW radar Imaging for Crack detection in metal with Surface Corrosion	(a) Detected fatigue cracks in metals having surface corrosion and pitting. (b) Cracks under pitting detected. (c) Cracks detected by a non-contact process hence need for surface preparation removed.
3.	L. Zhang Y. Hao C.G. Parini	2011	MMW Radar imaging system parameters	(a) Theoretical specification of Millimetre wave imaging system parameters. (b) Demonstration of concealed target detection. (c) MMW imaging array concept operating at 95 GHz.

4.	Christian Huber R. Zoughi, H. Abiri, Stoyan Ganchev	1997	Open ended rectangular waveguide	(a) Detects surface cracks under dielectric coatings. (b) Frequency 24 GHz. (c) Cracks under thick coatings detected. (d) Thin layer of dielectric improves the crack detection.
5.	Chin-Yung Yeh and Reza Zoughi	1994	Use of Microwaves for detecting cracks in metals	(a) Utilization of microwave signal for crack detection. (b) Sensor contact with the surface under examination not required. (c) Useful in high-temperature environments. (d) Polarization properties provide information on crack orientation. (e) sensitive technique as phase is reversed when crack is detected at the waveguide edge

Chapter 4.

Methodology and data collection

MMW imaging has rapidly lengthened in the field of non-destructive testing for quality monitoring in various industrial and military applications. The critical analysis of image processing techniques in context to MMW imaging is presently becoming a new area of research. However, focus is required in this direction to develop an effective MMW imaging methodology for precisely detecting a surface flaw in the materials. MM wave has is a remarkable imaging technology due to its features like high resolution, ability to penetrate through materials and most importantly a non-ionizing radiation. Its ability to form an image with an appreciable difference between the target material and the background helps to distinguish between them. The developed radar system based on target defect identification methodology has been discussed in this chapter. Different pre-processing and post-processing techniques has been reviewed for image enhancement to identify the defect in the target.

An extensive number of targets with three different deformities of different materials have been analyzed in the project. Microwave technique used for detecting surface deformity on the material which is used as a target. A flowchart in the Figure 8: Flow chart of Methodology will summarize the methodology for crack detection.

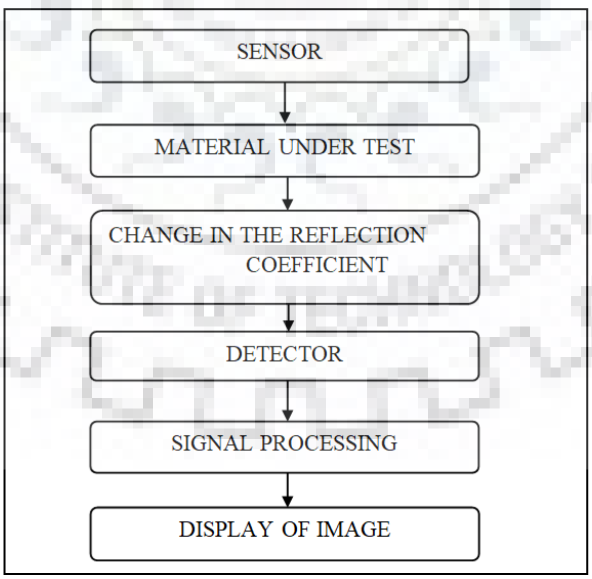


Figure 8: Flow chart of Methodology

4.1 Introduction

The MMW frequency capability to penetrate through a material can produce characteristic information of the target hence MMW, seems to be a good imaging tool for quality and condition inspection of aviation industry material towards wear and tear, internal defect and prolonged usage defects, without hampering its characteristics property. In view of aforesaid MMW features and combining it with the different image processing techniques a fault detection robust methodology and capability is essentially required to be developed for a defect scanning for the quality check of materials.

Artificially generated radiation is used to illuminate the target in the MMW radar imaging technique. The target reflectance distribution and reflectance property of the target are the main factors which controls the quality of the image formed. The quality of the image is dominated by the target surrounding, there should be no or minimum multipath reflection. There is a need for applying various suitable pre and post processing techniques which are helpful for extracting the target information from the radar reflectance data. Ground penetrating radar (GPR) and through wall imaging (TWI) also work at microwave frequency the target image quality is enhanced by applying different image processing techniques. The significance of these image enhancement techniques are still being investigated for MMW radar imaging.

A clutter is an unwanted signal which is generally a reflection from the background of the target, it significantly degrades the quality of the image in a considerable manner. There are a variety of techniques which can enhance the image and reduce the clutter some of the techniques are known as averaging, background subtraction etc. Any reflections from the background or from the multipath propagation with the target reflection are called as clutter which degrades the generated image quality.

There are various image enhancement and clutter reduction techniques which are Normalization, Background subtraction. The different techniques have their own working principles and their performance depends on the particular type of application.

- **Cross Range Resolution**

The cross range resolution is the ability of a Radar system to clearly distinguish between two closely spaced targets as shown in the Figure 9.

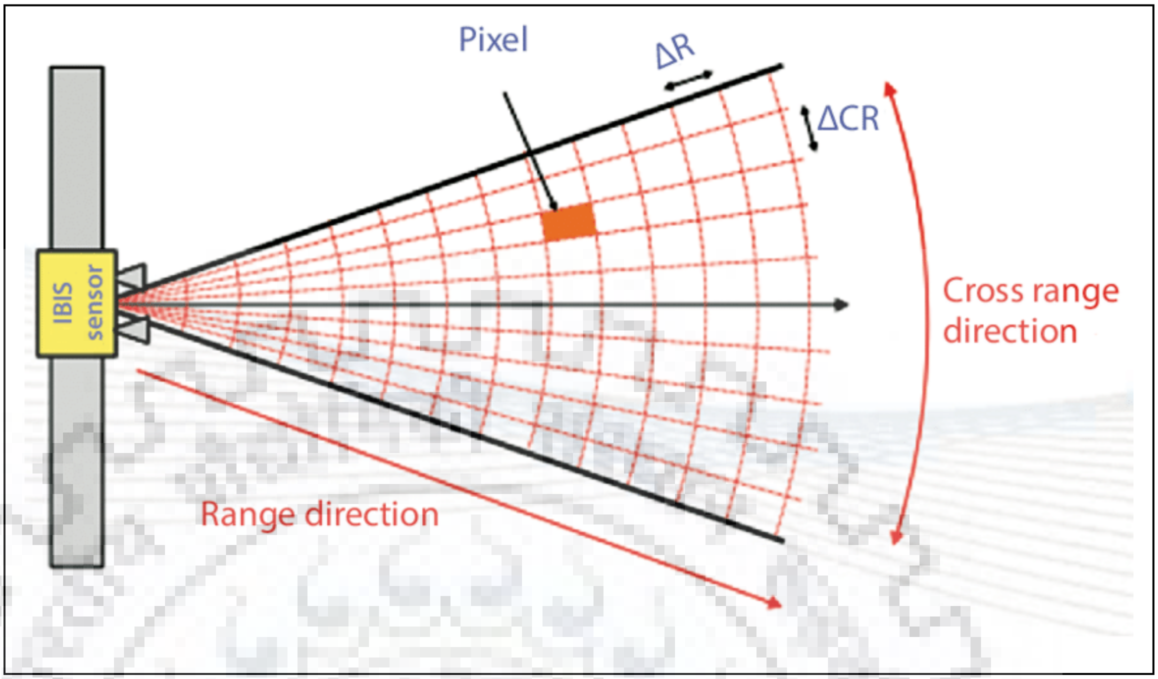


Figure 9: Cross range resolution [4]

According to synthetic aperture theory, it is given by equation 9

$$\Delta CR = \frac{\lambda R}{D} \tag{9}$$

Here,

ΔCR = Lateral resolution of the radar

λ = wavelength

R = distance of the target from the synthetic aperture

D = lateral dimension of synthetic aperture

Cross range resolution is a function of wavelength at lowest operating frequency the length of the physical antenna and distance from the antenna to the target and the resolution degrades with increasing target distance. For narrow antenna beam width, the resolution is enhanced however the cross range resolution can be enhanced by increasing the aperture of the antenna or by synthetic aperture method in which antenna moves from point to point with predefined array. Processing the data allows to synthesize an effective aperture many times the size of real aperture. The high frequency range is chosen to achieve a narrow beam width of the antenna so high cross range resolution requires selection of higher frequency.

- **Swath**

The swath is an important parameter in MMW imaging as it determines the area illuminated by the antenna in a particular plane at a fixed distance from it. An elliptical area formed by the HPBW of the antenna used and the distance at which imaging is done is swath.

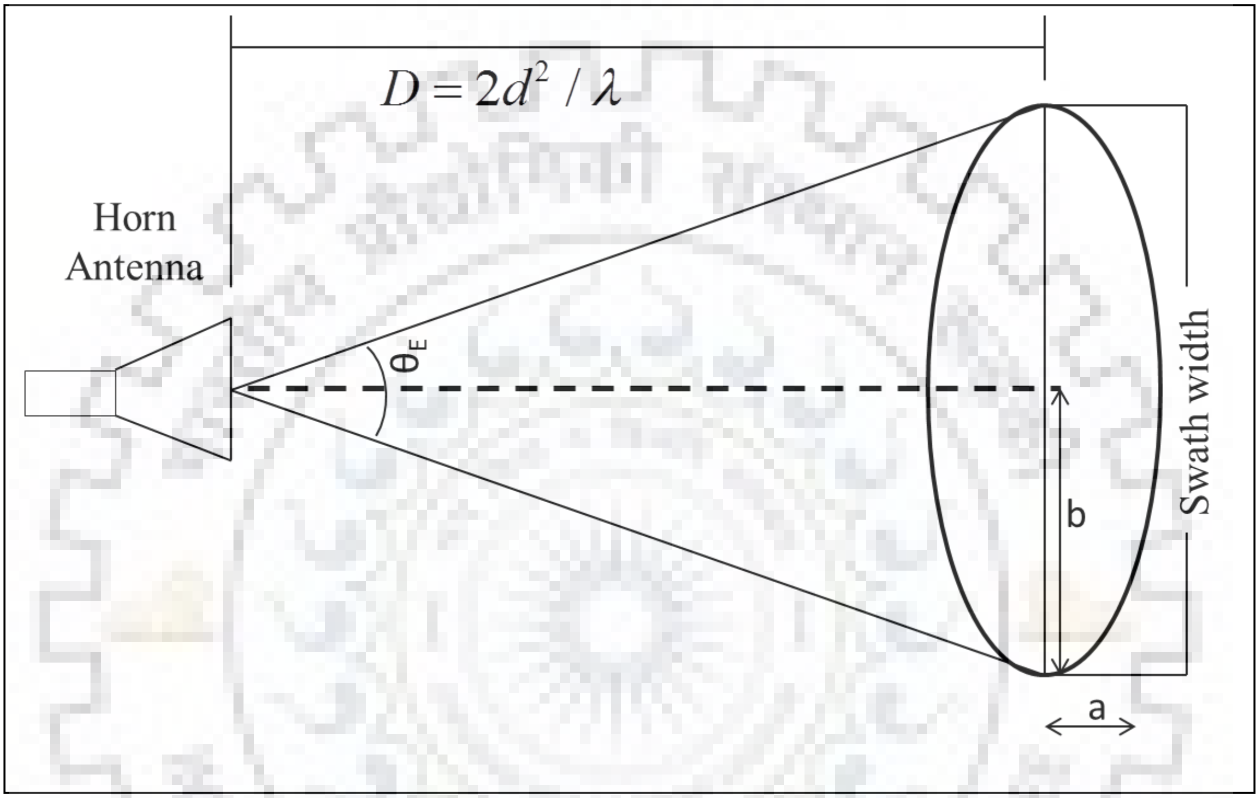


Figure10: Swath of MMW Imaging radar [10]

In the Figure10: Swath of MMW Imaging radar [10], area illuminated by the horn antenna is the swath width and mathematically it is given by the Equation 10.

$$I = \pi D^2 \tan\left(\frac{\theta_E}{2}\right)\tan\left(\frac{\theta_H}{2}\right) \tag{10}$$

4.2 Methodology used for detecting surface damage in different material

The block diagram for detection of surface damage is shown in the Figure11.

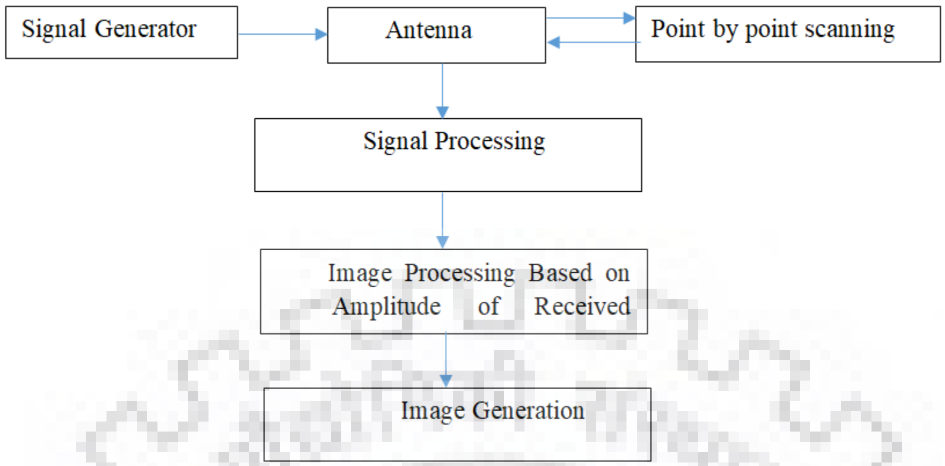


Figure11: Block diagram for detecting surface damage

4.3 Experimental Setup and Design

The experimental setup for detection of flaw in a material, with the help of MMW active imaging radar system is depicted in Figure 4.5. By using vector network analyzer "**Agilent N5247A, PNA-X**" frequency ranging from 10 MHz-67 GHz, MMW radar in stepped frequency continuous wave (SFCW) mode was assembled a pyramidal horn antenna series 261V and VNA cable **"MMW-N4697F"** of 1.85mm was used.

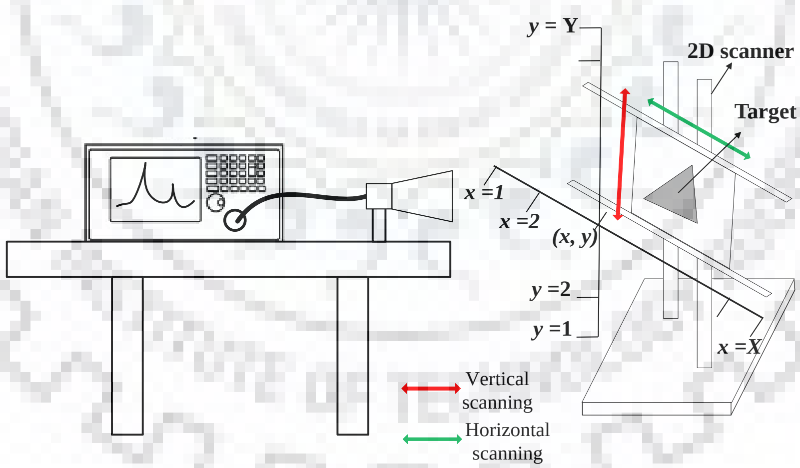


Figure12: MMW Active Imaging Radar Experimental setup [2]

Targets were mounted on a 2-D scanning frame of wood so as to slide the target in horizontal direction which depicts the (Cross range) and in upwards and downwards directions. The MMW radar system has a single horn antenna which transmits and receive the SFCW at a fixed location after one scan is carried out the target is shifted manually to the next calibrated horizontal position the process is reiterated till the entire target is scanned horizontally.

The target is now moved upwards on a calibrated scale marked on the wooden frame and thereafter the horizontal scanning process is repeated, until the whole target is covered laterally. By using this methodology, the target is fully scanned by the narrow beam width of the horn antenna from one edge to the other edge sequentially.

Figure12: MMW Active Imaging Radar Experimental setup [2] shows the scanning at any particular location of the target which is denoted by (x, y), where x denotes cross range whose range is from 1 to X and y denotes height whose range is from 1 to Y. The spacing between two consecutive scan positions in vertical and horizontal directions can be kept as per the dimension of the target. In this project various components were used to implement real time identification of a crack. Brief description of the component is given below: -

- **Vector network analyser (VNA)**

VNA is equipment which is used to measure parameters such as amplitude response, scattering parameters which are transmission and reflection coefficients of the material subjected to test. The scattering or (S) parameter possesses information regarding amplitude and phase.

In the experimental work the vector network analyser used is **"ANRITSU PNA MASTER MS2028C"** which generates frequencies from 10 MHz to 67 GHz. The power level provided by the VNA is of 10 dBm.

VNA in this experiment measures reflection coefficient. In which the analyser transmits a signal to the antenna, the radiation from the antenna strikes the material under test the VNA then measures the reflected wave. The specification of the VNA is tabulated in the Table 3: Specification of the VNA.

Table 3: Specification of the VNA

Frequency range	10 MHz to 67 GHz
polarization	Linear
RF connector	N female
Nominal impedance	50 Ω
Gain	7 dBi to 14 dBi
VSWR	< 2.5
Max. RF input power	300 W CW , 500 W PEAK

Max. height	160 mm
Max. width	250 mm
Max. length	290 mm
Weight	1.5 kg

In this experiment the operating frequency range was from 52 GHz- 64GHz, and 201 were points selected.

- **Scanner**

For positioning the sample, a wooden scanner was used. It has 30 horizontal direction positions and 20 vertical direction positions hence 600 different positions of the sample are possible. In the experiment sample was scanned in 30 horizontal positions and 16 vertical positions.

- **Antenna**

A standard gain horn antenna of 261 series was used whose specification is in Table 4: Horn Antenna series 261V Specification

Table 4: Horn Antenna series 261V Specification

Frequency range	50 GHz to 75 GHz
polarization	Linear
RF connector	1.85mm female
Nominal impedance	50 Ω
Nominal Gain	25 dBi
Max. height	36 mm
Max. width	43 mm
Max. length	99 mm
Weight	1.5 kg

- **Connection Cable:**

To transmit electromagnetic wave generated inside VNA for collection of data connection cable is used which connects the port 1 of VNA to the antenna it also carries the received signal from antenna to the VNA.

- **Personal Computer:**

A laptop having Mathworks, MATLAB software was used which was connected to the Vector Network Analyser (VNA) using a LAN connection. The PC is important for real time implementation.

4.4 Data collection and types of Scan

To obtain the imaging information of the target, the target is scanned in horizontal and vertical direction in a manner that the target is covered completely. The step by step method for data collection is shown in Figure14.

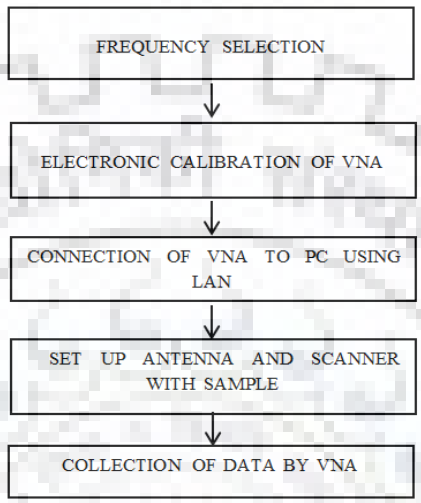


Figure14: Flow chart for data collection

Figure 13: VNA and Antenna setup

Figure 15: Experimental setup for Data collection

There are three types of scans and readings for all three types of scans which are A-scan, B-scan and C-scan for different material were taken.

4.4.1 A Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location. In A-scan, the reflected signal which is received from a target is represented as a function of signal strength and downrange distance. The Figure16 demonstrates the A-scan plot for a target which is detected. In the experiment the value of N = 201 is taken, hence, the size of the A-scan matrix will be a vector of dimension (1, 201).

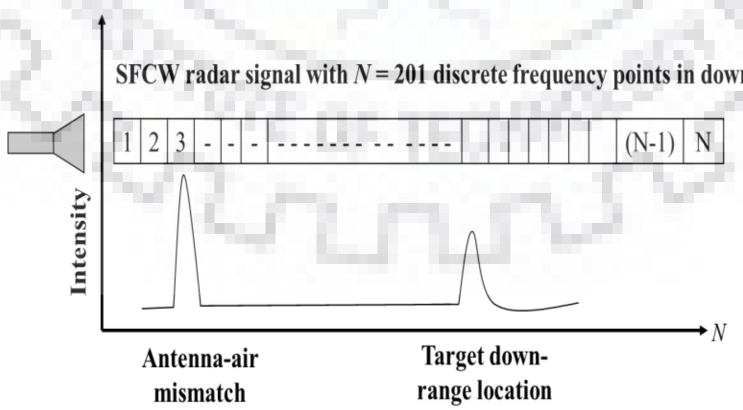


Figure16: Representation of A Scan [2]

4.4.2 B Scan

When a multiple A-scans are taken along the pre calibrated horizontal position B-Scan is formed. The B-scan provides information regarding the targets horizontal reach, which can be termed as width of the target. The limitation of the B-scan is that it cannot be utilized to determine the height of the target. Figure17: Representation of B Scan [2] represents the demonstration for achieving B-scan for this multiple A-scans are taken along horizontal scanning positions for this reason the matrix size of B-scan will be a 2D matrix whose size will be (X, 201), here the total number of horizontal scanning locations is represented by X.

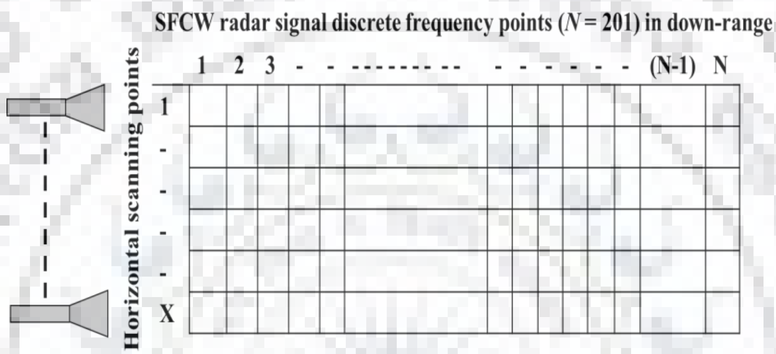


Figure17: Representation of B Scan [2]

In the B scan, sample is moved in horizontal direction step by step to complete one scan. The dimension of the target in the cross-range can be determined by using the B scan, in addition it also provides information regarding the target location.

4.4.3 C Scan

After completing one B-Scan, the target is moved upwards in the pre calibrated scanner and then again B-Scan is taken, after completing the scanning in the vertical direction and then stacking the multiple B-scans a C-scan signal is formed.

Vertical extent or the height of the target is given by the C-scan. Figure 18: Representation of C Scan [2] represents the process for performing C-scan by scanning the target in Horizontal direction which is along x-axis (x = 1, 2.. X) and vertical direction which is along y-axis (y = 1, 2.. Y).

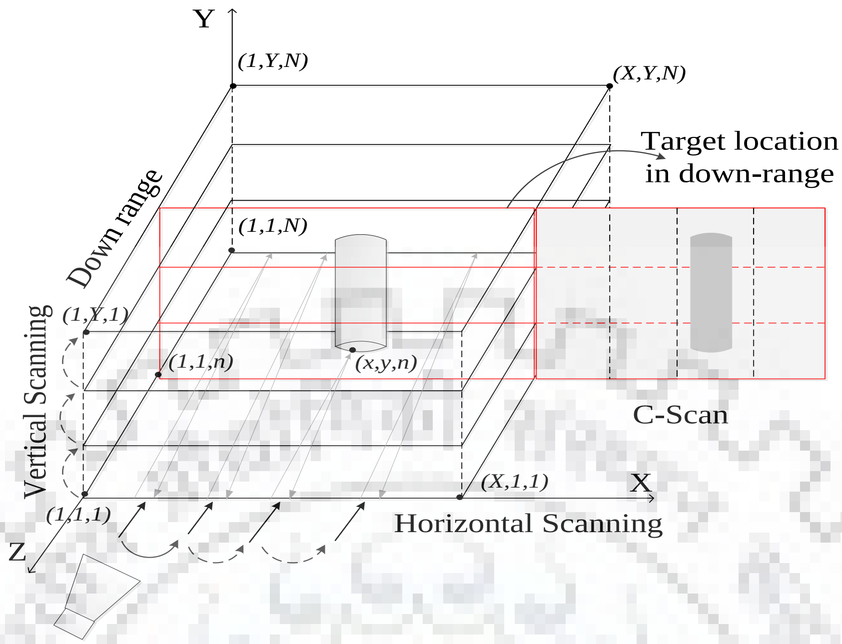


Figure 18: Representation of C Scan [2]

A 3D matrix is obtained when one C-scan is completed, size of the resulting 3D matrix is = (*X*, *Y*, *N*). In which each individual cell represents cross range location, vertical location and downrange index. The C-scan provides information for the complete target shape identification.

4.5 Flow chart for C Scan

The flow chart of the entire process followed is given in the Figure 19

The S11 parameters which were collected at 201 frequency points, after calibrating the PNA using 1-port electronic calibration process.

Calculated Down range resolution was 1.25 cm and cross-range resolution was 3.9 mm, respectively. The target under investigation was kept at a distance of 50 cm from the antenna and scanned along 30 horizontal and 16 vertical scanning positions with the inter-element spacing of 1 cm, to completely image the targets. The full A, B and C-scan were performed. The collected data undergoes different signal processing steps to enhance the image to detect the deformity.

As shown in the Figure 14. Various signal processing steps for complete target detection and determining the flaw on the metal surface have been carried out on the raw C Scan image of the target. The acquired data is in complex and frequency domain, hence before applying different image processing techniques following pre-processing steps are used in order to convert data into the desired form: -

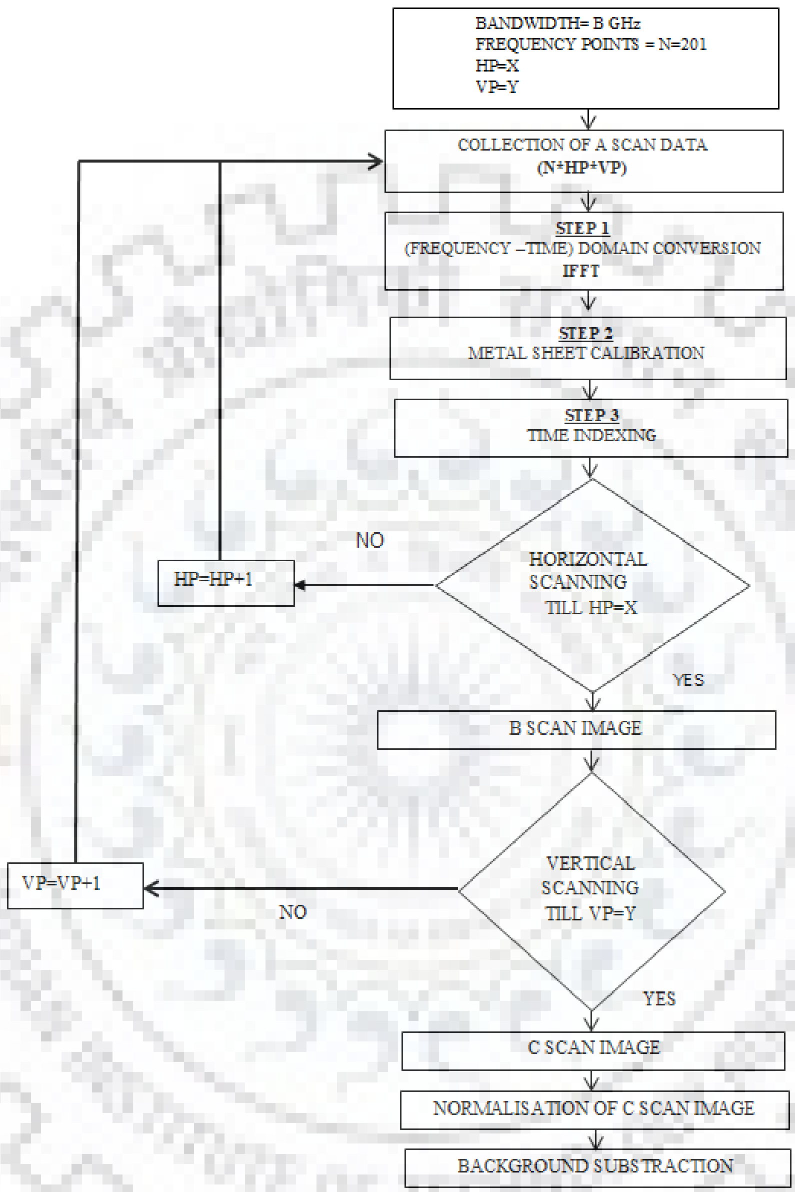


Figure 19: Flow chart for the C Scan image generation

(i) Frequency to time domain conversion (IFFT)

(ii) Time to spatial domain conversion

(iii) Calibration

(iv) Time Indexing

4.5.1 Signal pre-processing

STEP 1 (FREQUENCY TO TIME DOMAIN CONVERSION)

The SFCW radar measures magnitude and phase of received signal corresponding to the transmitted signal at each stepped frequency.

The signal transmitted at the discrete frequency step is given by f_n,

$$E_t(f_n) = E_0 e^{j2\pi f_n t} \tag{11}$$

The Received signal reflected from the target at a distance z from radar is in complex scattering coefficient form $s(z)$, with reference to transmitted signal and is given by [15],

$$S(f_n) = \frac{E_r(f_n)}{E_t(f_n)} = \frac{1}{z_0}\int_0^{z_0} s(z) e^{-j2\pi f_n\left(\frac{2z}{c}\right)} dz \tag{12}$$

The received signal is converted into time domain using Inverse Fast Fourier Transform (IFFT) and is represented as:

$$S(t) = \sum_{n=0}^{N-1} S(f_n) e^{j2\pi f_n t} \tag{13}$$

To obtain the range of the target, time domain signal is converted into spatial domain by converting signal propagation time to the corresponding round trip distance (z).

$$t = \frac{2z}{c} \tag{14}$$

STEP 2 (CALIBRATION USING METAL SHEET)

Reflection peak in the A Scan plot gives an estimate of target location. The VNA cable and antenna system add delay to the received signal, thereby shifting the target location its originating position. Hence, to get the correct distance of the target, delay calibration is done by placing a large metal sheet at the flare of horn antenna.

The corrected signal incorporating shift due to antenna system is given by equation 15.

$$S(z) = \sum_{n=0}^{N-1} S(f_n) e^{j2\pi f_n \left(2z/c - 2z_{ref}/c \right)} \tag{15}$$

STEP 3 (BACKGROUND SUBSTRACTION)

To eliminate the unwanted signals which are present in the received signal

due to:-

(i) Air–Antenna mismatch.

(ii) Reflection from background.

(iii) Interference between transmitting and receiving signal.

The mean subtraction approach is applied due to its simplicity of implementation. In this technique the mean vector of each B-scan is calculated, followed by mean vector of all these B scans. This mean vector value is subtracted from each individual A-scan

$$X_{ijk} = A_{ijk} - \frac{1}{J}\sum_{1}^{j}\left(\frac{1}{I}\sum_{1}^{i}A_{ijk}\right) \tag{16}$$

Here i=1, 2, 3… (No of downrange location)

J=1, 2, 3… (No of B Scans)

K-1, 2, 3… (No of C scans)

Chapter 5.

Experimental Results and Discussions

By using the MMW SFCW imaging radar target identification and image generation of target has been done on number of test materials of varying defects. Experimental results of pre-processing and post-processing steps are discussed in this chapter supported by the outcomes of test targets.

5.1 Analysis of the experiment carried out on Rectangular metal sheet

A metal sheet as shown in the Figure20 was cut out for the purpose of the test target. The target was placed at a distance of 85 cm. The test parameters of the experiment are listed in Table 5: Parameters for Experiment on Rectangular Metal Sheet: -

Table 5: Parameters for Experiment on Rectangular Metal Sheet

Sl.No	Parameter	Value
1.	Target Size	(12*10) cm
2.	Frequency	(9-11) GHz
3.	Bandwidth	2GHz
4.	Power	0dBm
5.	Down range resolution	7.5cm
6.	Cross range resolution	5.3mm
7.	Readings in horizontal direction	20
8.	Readings in Vertical direction	18

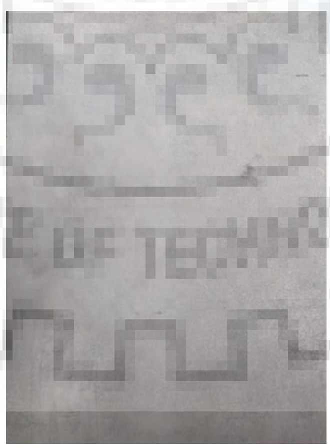


Figure20: Test Sample Rectangular metal sheet

5.1.1 Analysis of A-Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location the distance is the fixed target position. The collected data is in the frequency domain so we need to convert it into time domain this is done by applying using IFFT and then the equivalent distance can be calculated by observing the peak signal range bin and then multiplying it with the distance per range bin.

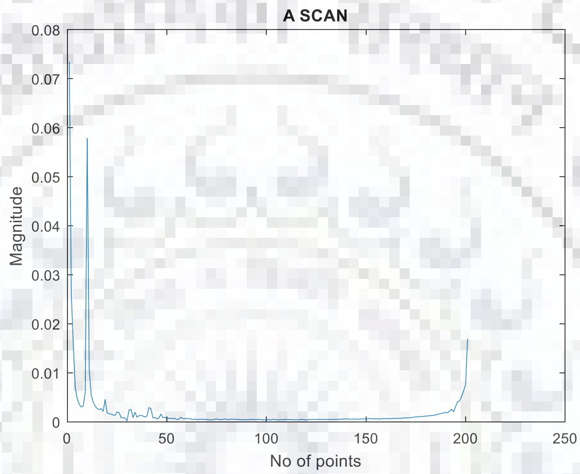


Figure21: A-Scan of Rectangular metal plate

The Figure21 shows the A-Scan of the sample Rectangular metal plate the range profile. On observing A Scan, the target is present in the Range Bin 10, on multiplying with the distance per range bin i.e. 7.5cm in this case, hence target is identified at 75 cm.

5.1.2 Analysis of B-Scan

The B-scan provides information regarding the targets horizontal reach, which can be termed as width of the target. The B Scan of the Rectangular metal plate is shown in Figure22.

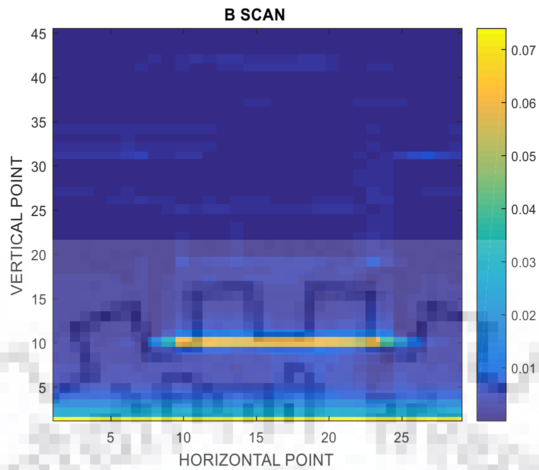


Figure22: B Scan of Rectangular metal plate

5.1.3 Analysis of C-Scan

Once the C scan is completed, the MATLAB program generates the C scan image of the sample metal piece, the image generated is the Raw C scan image and further after post processing of the image the results are shown in Figure23.

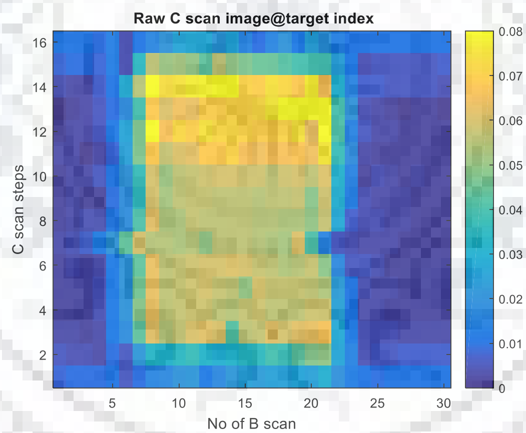


Figure23: Raw C Scan image of Rectangular metal plate

- **Post processing of Raw C Scan Image**

The obtained raw C-scan image undergoes some image enhancement steps which are Normalization and background subtraction, the resulting image plot shows improvement in target image intensity as well as its visibility. Figure24 and Figure25 show the enhanced image which are formed by applying Normalization and back ground subtraction respectively.

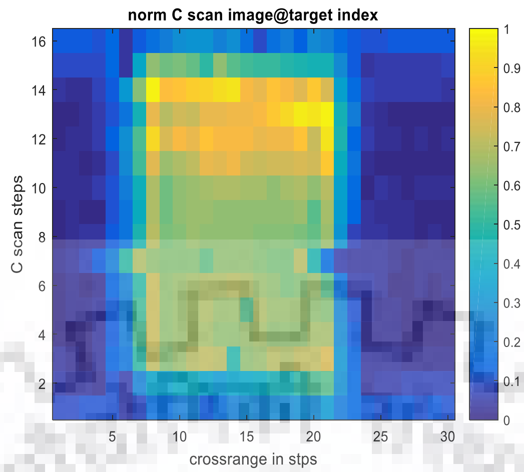


Figure24: Normalized C Scan Image of Rectangular metal plate

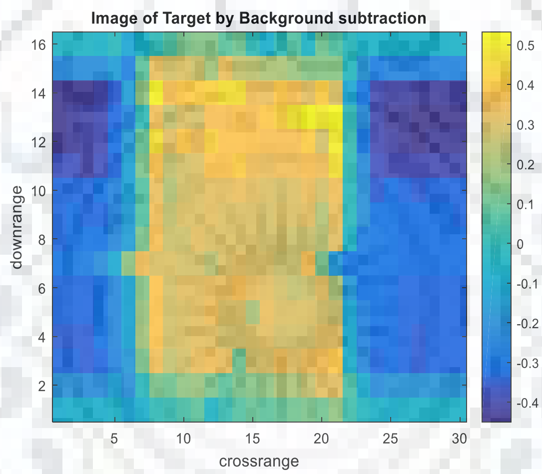


Figure25: C scan image of Rectangular metal plate after background subtraction

5.2 Analysis of the experiment carried out on Rectangular metal sheet with a rectangular cut.

A metal sheet as shown in the Figure26 was cut out for the purpose of the test target in which a rectangular cut was made. The target was placed at a distance of 60 cm. The test parameters of the experiment are listed in Table 6: Parameters for the Experiment on Rectangular Metal Sheet

Table 6: Parameters for the Experiment on Rectangular Metal Sheet with a one Slot

Sl.No	Parameter	Value
1.	Target Size	(12*10) cm

2.	Rectangular slot size	(10*4) cm
3.	Frequency	(55-65) GHz
4.	Bandwidth	10 GHz
5.	Power	0 dBm
6.	Down range resolution	1.5cm
7.	Cross range resolution	3.8mm
8.	Readings in horizontal direction	20
9.	Readings in Vertical direction	18

Figure26: Test Sample Rectangular metal sheet with a cut of (10*4) cm

5.2.1 Analysis of A-Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location the distance is the fixed target position.

The collected data is in the frequency domain so we need to convert it into time domain this is done by applying using IFFT and then the equivalent distance can be calculated by observing the peak signal range bin and then multiplying it with the distance per range bin.

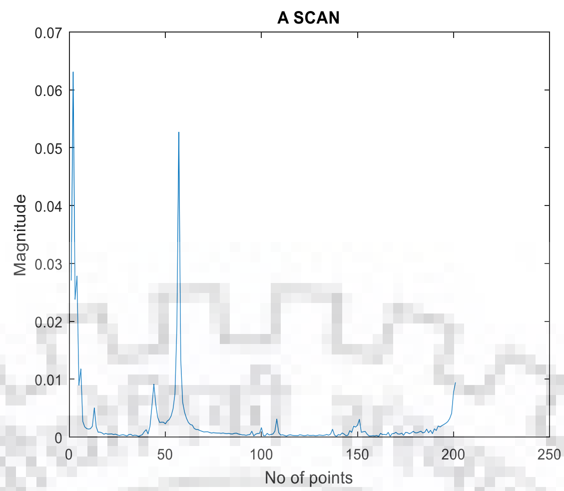


Figure27: A Scan of Rectangular metal plate with a cut of (10*4) cm

The Figure27shows the A Scan of the sample Rectangular metal plate with a cut of dimension (10*4) cm. On observing A Scan, the target is present in the Range Bin 54, on multiplying with the distance per range bin i.e. 7.5 cm in this case; hence target is identified at 81 cm.

5.2.2 Analysis of B Scan

The B-scan provides information regarding the targets horizontal reach, which can be termed as width of the target. The B Scan of the Rectangular metal plate is shown in Figure28, which shows that there is less reflection intensity at the horizontal position (14-18) which correlates with the sample which was tested.

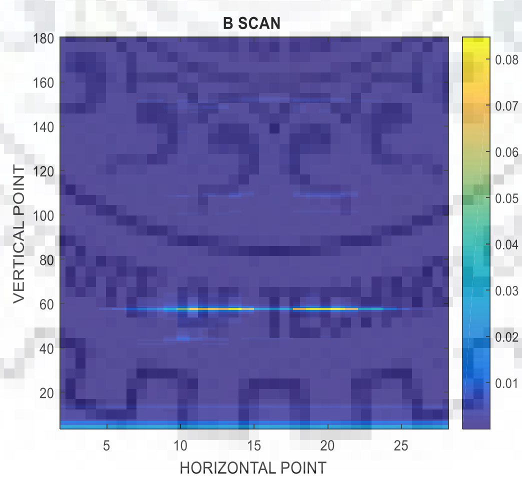


Figure28: B Scan of Rectangular metal plate with a cut of (10*4) cm

5.2.3 Analysis of C Scan

Once the C scan is completed, the MATLAB program generates the C scan image of the sample metal piece, the image generated is the Raw C scan image and further after post processing of the image Figure29 the results are shown below

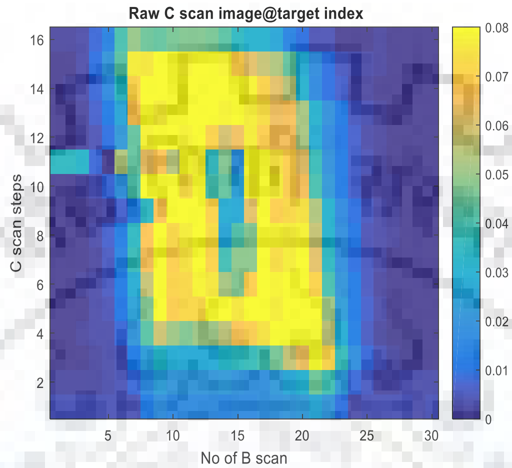


Figure29: Raw C Scan of Rectangular metal plate with a cut of (10*4) cm

- **Post processing of Raw C Scan Image**

The obtained raw C-scan image undergoes some image enhancement steps which are Normalization and background subtraction, the resulting image plot shows improvement in target image intensity as well as its visibility. Figure30 and Figure31 show the enhanced image which are formed by applying Normalization and back ground subtraction respectively.

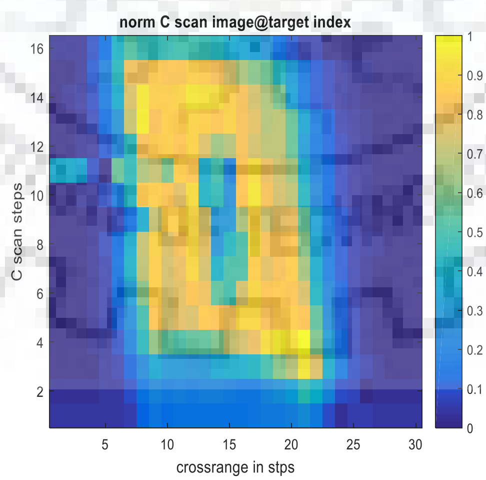


Figure30: Normalized C- Scan of Rectangular metal plate with a cut of (10*4) cm

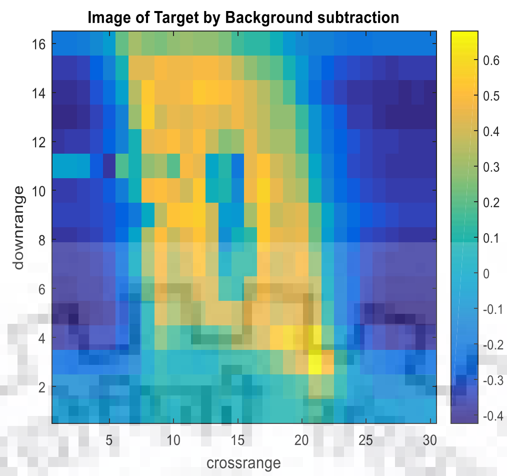


Figure31: C scan image of Rectangular metal plate with a cut of (10*4) cm after background subtraction

5.3 Analysis of the experiment carried out on Rectangular metal sheet with two rectangular cut

A metal sheet as shown in the Figure32 was cut out for the purpose of the test target in which two rectangular cut were made. The target was placed at a distance of 60 cm. The test parameters of the experiment are listed in Table 7: -

Table 7: Parameters for the Experiment on Rectangular Metal Sheet with a Two Slot

Sl.No	Parameter	Value
1.	Target Size	(12*10) cm
2.	First Rectangular slot size	(10*4) cm
3.	Second Rectangular slot size	(8*1) cm
4.	Frequency	(55-65) GHz
5.	Bandwidth	10 GHz
6.	Power	0 dBm
7.	Down range resolution	1.5cm
8.	Cross range resolution	3.8mm
9.	Readings in horizontal direction	20
10	Readings in Vertical direction	18

Figure32: Test Sample Rectangular metal sheet with a cut of (10*4) cm and (8*1) cm

5.3.1 Analysis of A-Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location the distance is the fixed target position.

The collected data is in the frequency domain so we need to convert it into time domain this is done by applying using IFFT and then the equivalent distance can be calculated by observing the peak signal range bin and then multiplying it with the distance per range bin.

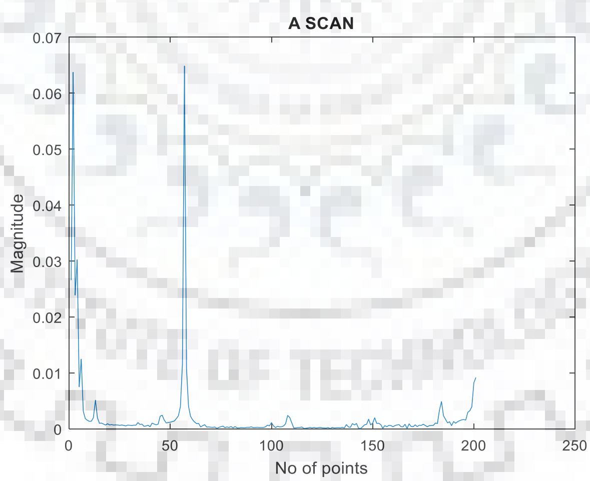


Figure33: A Scan of Rectangular metal sheet with a cut of (10*4) cm and (8*1) cm

The Figure33 shows the A Scan of the sample Rectangular metal plate with a cut of dimension (10*4) cm the range profile figure shows the target is present at Range Bin 53, on multiplying with the distance per range bin i.e. 1.5 cm in this case, hence target is identified at 81cm.

5.3.2 Analysis of B Scan

The B scan provides information regarding the targets horizontal reach, which can be termed as the width of the target Figure 34.

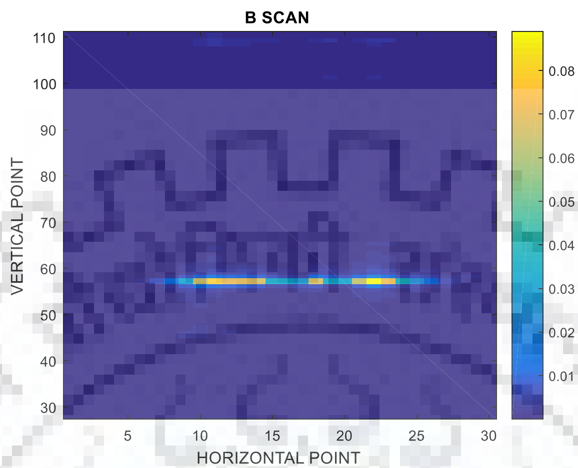


Figure 34: B Scan of Rectangular metal sheet with a cut of (10*4) cm and (8*1) cm

5.3.3 Analysis of C-Scan

Once the C scan is completed, the MATLAB program generates the C scan image of the sample metal piece, the image generated is the Raw C scan image and further after post processing of the image the results are shown below Figure 35: -

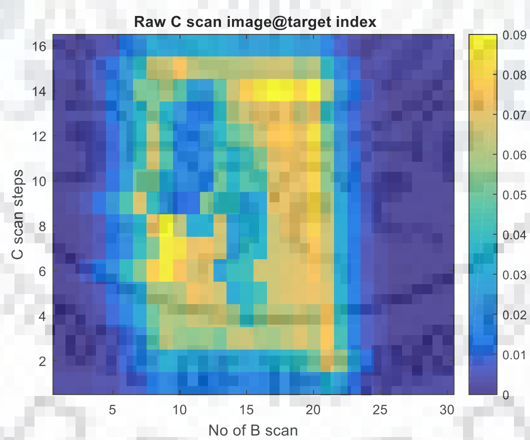


Figure 35: C-Scan of Rectangular metal sheet with a cut of (10*4) cm and (8*1) cm

- **Post processing of Raw C –Scan Image**

The obtained raw C-scan image undergoes some image enhancement steps which are Normalization and background subtraction, the resulting image plot shows improvement in target image intensity as well as its visibility. Figure 36 and Figure 37 show the enhanced images which are formed by applying Normalization and Background subtraction respectively.

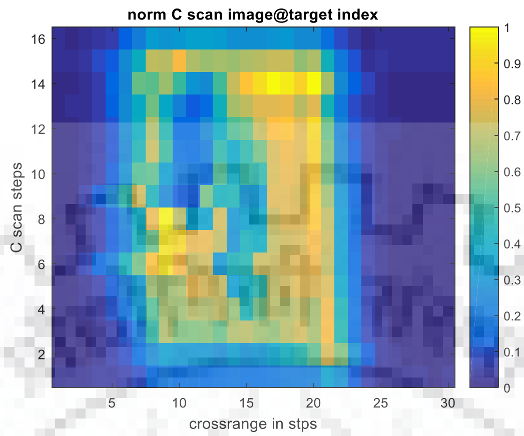


Figure 36: Normalized C- Scan of Rectangular metal sheet with a cut of (10*4) cm and (8*1) cm

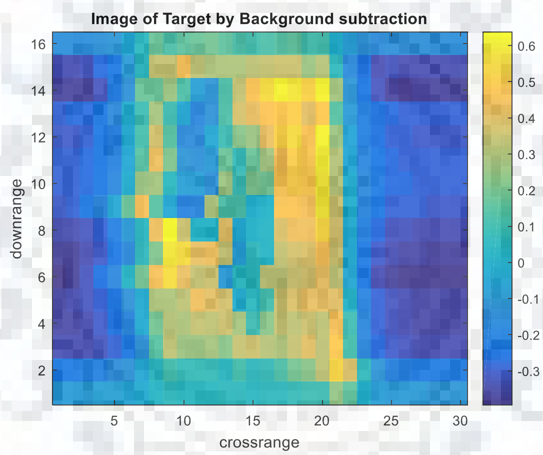


Figure 37: C Scan of Rectangular metal sheet with a cut of (10*4) cm and (8*1) cm after background subtraction

5.4 Analysis of the experiment carried out on aircraft material sample

An Aircraft material sample received for testing is shown in Figure. The experiment was aimed to determine the inter structure of the sample, for this the target was placed at a distance of 51 cm. The test parameters of the experiment are listed in Table 9: -

Table 8: Parameters for the Experiment on Aircraft material

Sl.No	Parameter	Value
1.	Length of sample	28 cm
2.	Width of sample	8mm

3.	Frequency	(59-61) GHz
4.	Bandwidth	10 GHz
5.	Power	0 dBm
6.	Down range resolution	7.5cm
7.	Cross range resolution	3.8mm
8.	Readings in horizontal direction	48
9.	Readings in Vertical direction	19

Figure 38: Front view of the Aircraft material sample

5.4.1 Analysis of A-Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location the distance is the fixed target position. The collected data is in the frequency domain so we need to convert it into time domain this is done by applying using IFFT and then the equivalent distance can be calculated by observing the peak signal range bin and then multiplying it with the distance per range bin.

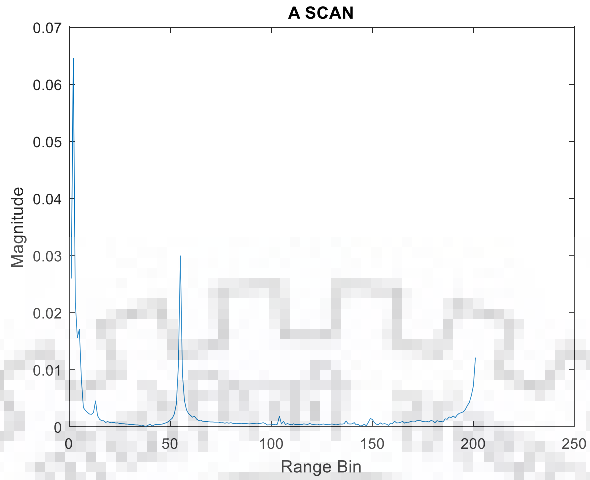


Figure 39 A Scan of the Aircraft material sample

The Figure 44 , the peak of the target is present at Range Bin 45, on multiplying with the distance per range bin i.e. 1.5 cm in this case hence target is identified at 67.5cm.

5.4.2 Analysis of B Scan

The B Scan provides information regarding the targets horizontal reach, which can be termed as the width of the target Figure 45.

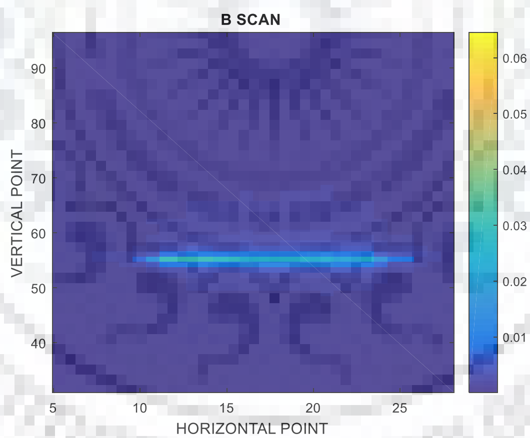


Figure 40: B Scan of Aircraft material sample

5.4.3 Analysis of C Scan

Once the C scan is completed, the MATLAB program generates the C Scan image of the sample metal piece, the image generated is the Raw C scan image Figure 46:-

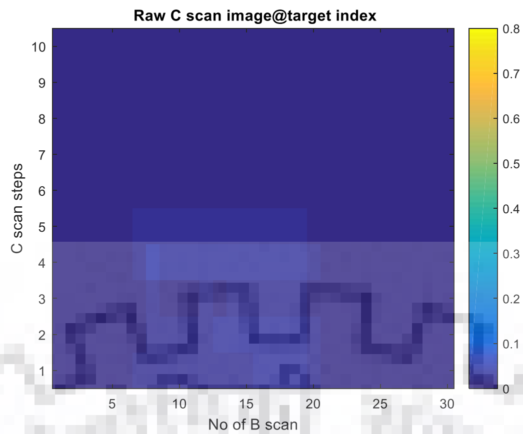


Figure 41: Raw C Scan of Aircraft material sample

- **Post processing of Raw C Scan Image**

The obtained raw C Scan image undergoes some image enhancement steps which are Normalization and background subtraction, the resulting image plot shows improvement in target image intensity as well as its visibility. Figure 47 and Figure 48 show the enhanced image which is formed by applying Normalization and background subtraction respectively.

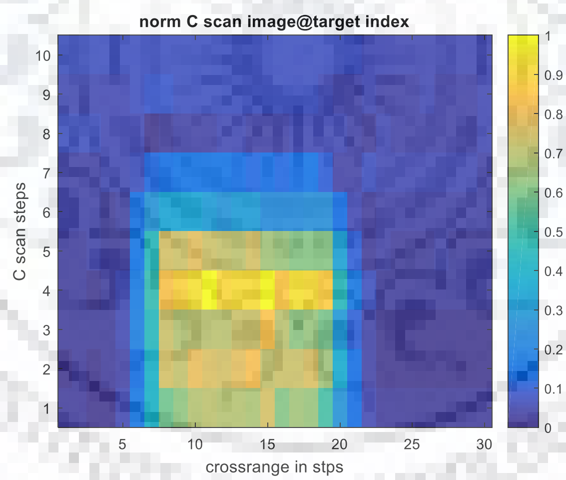


Figure 42 Normalized C-Scan of the aircraft material sample

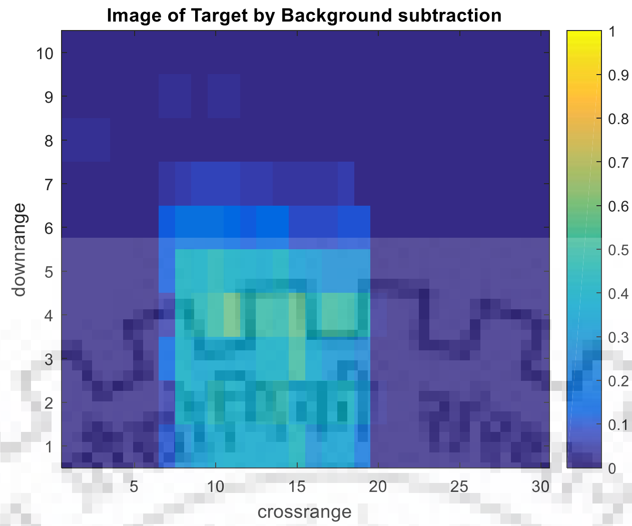


Figure 43: Image generated after applying background subtraction

5.5 Analysis of the experiment carried out on aircraft material sample

An Aircraft material sample received for testing is shown in Figure 42. The experiment was aimed to determine the inter structure of the sample, for this the target was placed at a distance of 51 cm. The test parameters of the experiment are listed in Table 9: -

Table 9: Parameters for the Experiment on Aircraft material

Sl.No	Parameter	Value
1.	Length of sample	28 cm
2.	Width of sample	8mm
3.	Frequency	(55-65) GHz
4.	Bandwidth	10 GHz
5.	Power	0 dBm
6.	Down range resolution	1.5cm
7.	Cross range resolution	3.8mm
8.	Readings in horizontal direction	48
9.	Readings in Vertical direction	19

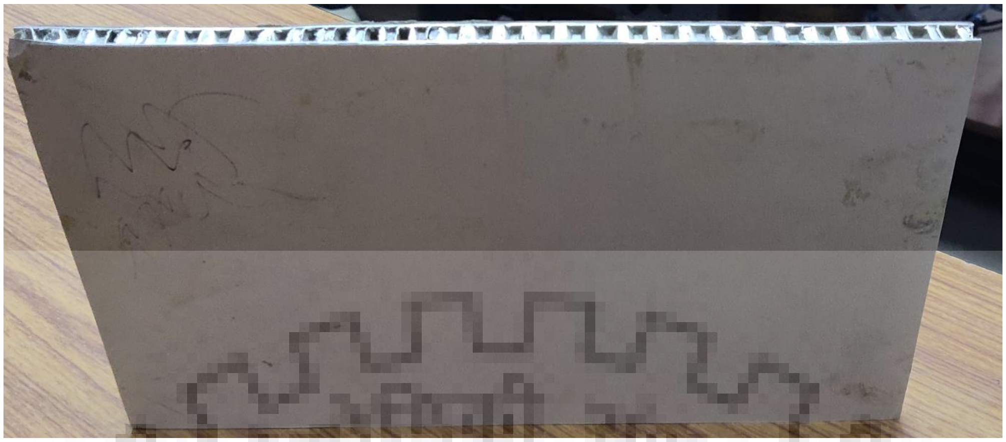


Figure 42: Front view of the Aircraft material sample

5.5.1 Analysis of A-Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location the distance is the fixed target position. The collected data is in the frequency domain so we need to convert it into time domain this is done by applying using IFFT and then the equivalent distance can be calculated by observing the peak signal range bin and then multiplying it with the distance per range bin.

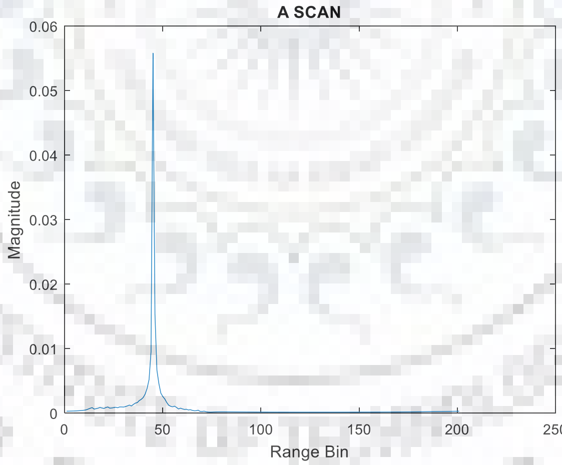


Figure 44: A Scan of the aircraft sample

The Figure 44, the peak of the target is present at Range Bin 45, on multiplying with the distance per range bin i.e. 1.5 cm in this case hence target is identified at 67.5cm.

5.5.2 Analysis of B Scan

The B Scan provides information regarding the targets horizontal reach, which can be termed as the width of the target Figure 45.

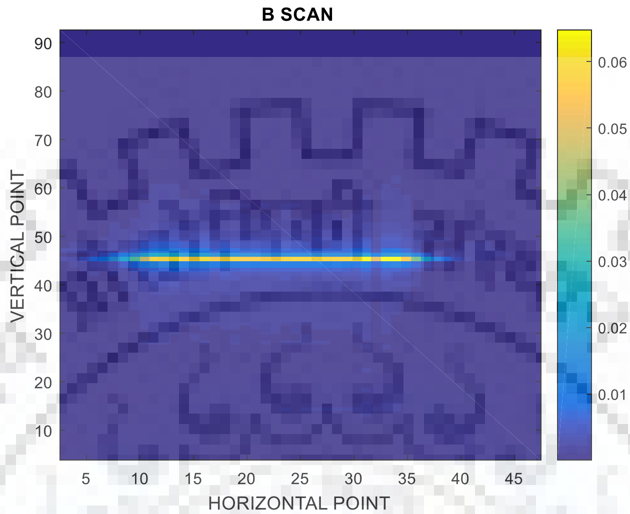


Figure 45: B Scan of the aircraft sample

5.5.3 Analysis of C Scan

Once the C scan is completed, the MATLAB program generates the C Scan image of the sample metal piece, the image generated is the Raw C scan image Figure 46:-

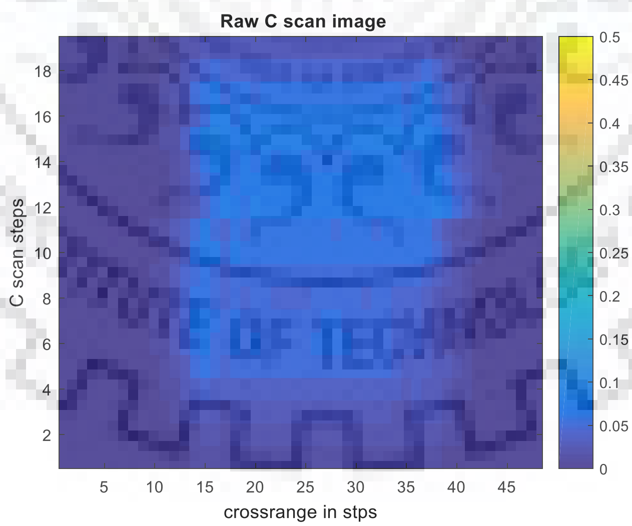


Figure 46: Raw C Scan of the aircraft material sample

- **Post processing of Raw C Scan Image**

The obtained raw C Scan image undergoes some image enhancement steps which are Normalization and background subtraction, the resulting image plot shows improvement in target image intensity as well as its visibility. Figure 47 and Figure 48 show the enhanced image which is formed by applying Normalization and background subtraction respectively.

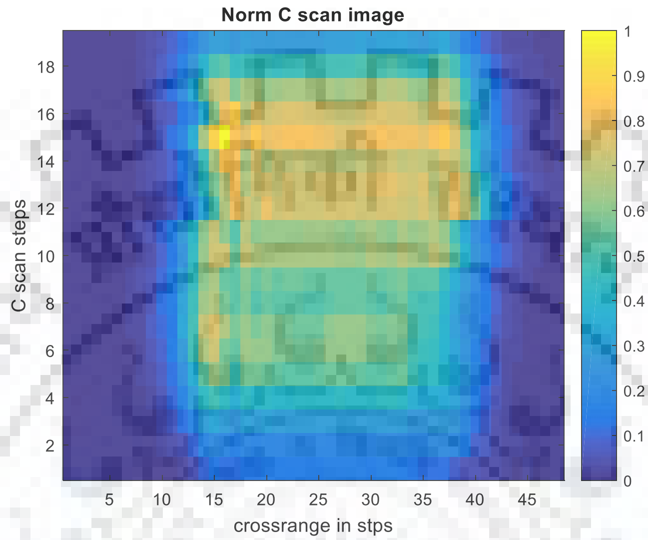


Figure 47: Normalized C-Scan of the aircraft material sample

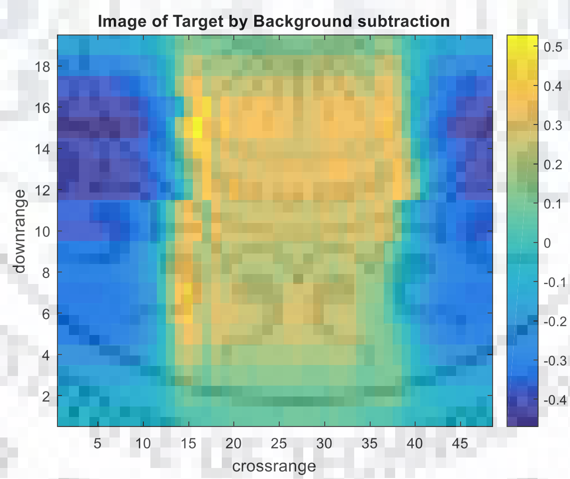


Figure 48: Image generated after applying background subtraction

On analyzing the Image post signal processing steps the inner structure of the material is little clearer, it shows the mesh is present inside the material.

5.6 Analysis of the experiment carried out on plywood sample

An plywood sample received for testing is shown in **Error! Reference source not found.**. The experiment was aimed to determine the holes in the structure of the sample, for this the target was placed at a distance of 51 cm. The test parameters of the experiment are listed in Table 10: -

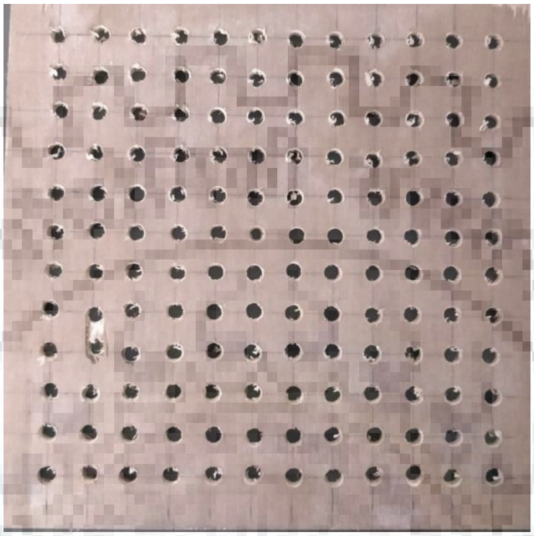


Figure 49 Plywood sample

Table 10 Parameters for experiment on plywood

Sl.No	Parameter	Value
1.	Length of sample	20 cm
2.	Width of sample	20cm
3.	Frequency	(55-110) GHz
4.	Bandwidth	10 GHz
5.	Power	0 dBm

5.6.1 Analysis of A-Scan

A scan is used for the range profile generation and is obtained by positioning the antenna at a particular position. It provides the information in downrange of the target location the distance is the fixed target position. The collected data is in the frequency domain so we need to convert it into time domain this is done by applying using IFFT and then the equivalent distance can be calculated by observing the peak signal range bin and then multiplying it with the distance per range bin.

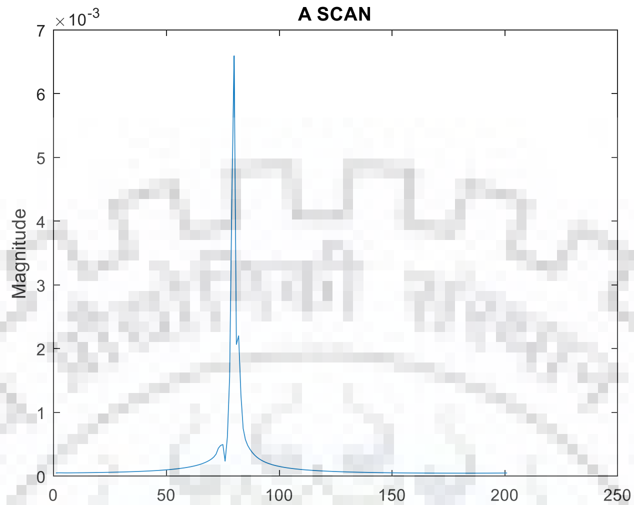


Figure 50 A Scan of Plywood sample

5.6.2 Analysis of B Scan

The B Scan provides information regarding the targets horizontal reach, which can be termed as the width of the target Figure 51.

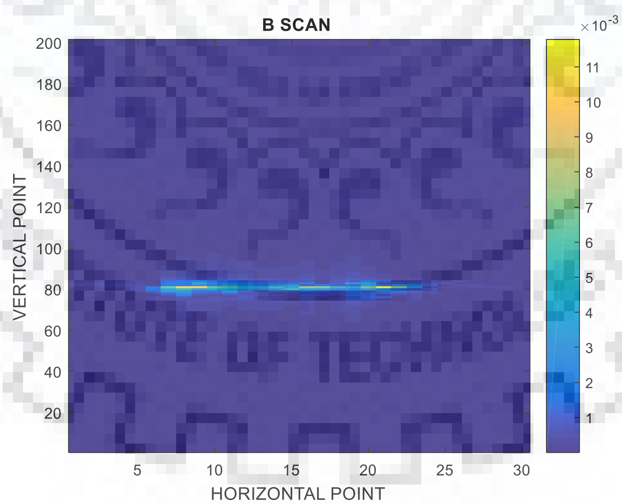


Figure 51 B Scan of Plywood sample

5.6.3 Analysis of C Scan

Once the C scan is completed, the MATLAB program generates the C Scan image of the sample metal piece, the image generated is the Raw C scan image Figure 52:-

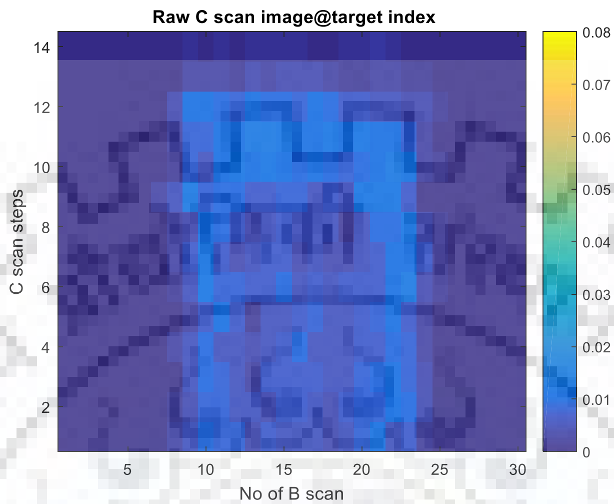


Figure 52 Raw C Scan Image of Plywood sample

- **Post processing of Raw C Scan Image**

The obtained raw C Scan image undergoes some image enhancement steps which are Normalization and background subtraction, the resulting image plot shows improvement in target image intensity as well as its visibility. Figure 53 and Figure 54 show the enhanced image which is formed by applying Normalization and background subtraction respectively.

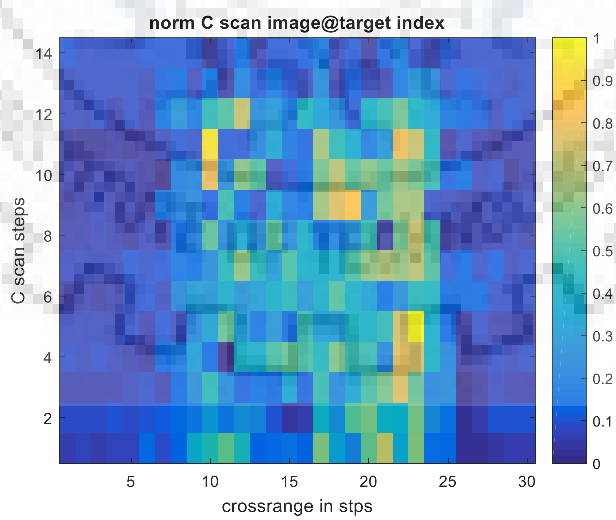


Figure 53 C Scan Image post Normalization

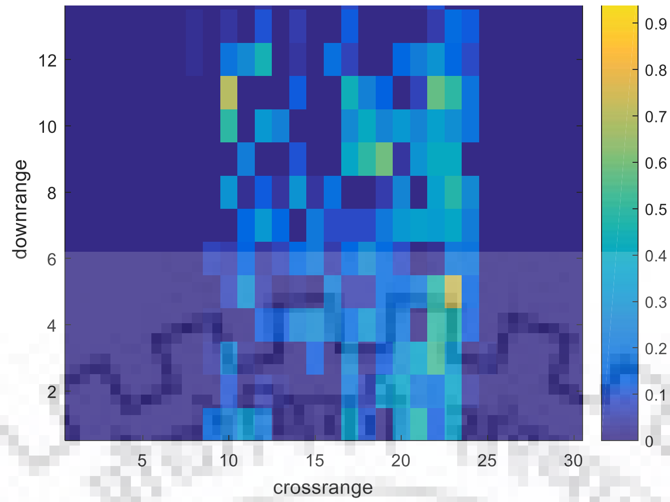


Figure 54 C Scan Image post Background subtraction

Chapter 6.
Conclusion and Future scope

The main objective of this project was to utilize the advantages of MMW frequency spectrum, its potential applications and challenges. The MMW can be efficiently utilized with high accuracy for application in variety of areas. It provides high resolution imaging and due to its lower wavelength compact systems can be made.

In a Stepped frequency continuous wave radar system range resolution of wideband system is delivered that is why step-frequency radar is very much able to achieve a high range resolution which can be exploited in the field of military aviation.

Microwave and image based technique are simple methods for detecting a flaw in the surface or sub surface of the material. The motivation behind this project work was to develop a methodology and test it on the aircraft material which addresses the challenges related to the identification of the defect in a material at correct place on the target.

6.1 Conclusion

The MMW imaging for a target by using SFCW radar which was made to operate at centre frequency of 59 GHz with the bandwidth of 10 GHz.

(i) The target defect identification was carried out by using a metal sheet and imprinting defects on its surface and then the processing of the received data was carried out.

(ii) An analysis for pre-processing steps for data processing has been done for imaging the target and it is found that for clutter reduction, image enhancement techniques, like, Normalisation, background subtraction and proved to be efficient in improving the target's image quality for a MMW imaging system.

(iii) The experiment conducted for the aircraft material, post studying the results the material is a metal, on analysing the C Scan the internal structure of the material looks like having gaps in between. The image post processing reveals that if there is some defect or flaw inside the material then by using the technique the flaw can be determined.

6.2 Future Scope

The MMW Non Destructive testing technology is a prominent technology in the wide variety of applications and its scope can be extended for other fields such as: -

(i) Material permittivity estimation.

(ii) IC inspection.

(iii) Multilayer thickness measurement.

(iv) Composite material characterization.

As per the developed methodology for target flaw detection in the surface or sub surface by MMW radar imaging, it is further possible to extend the image enhancement techniques to produce more enhanced images.

The developed methodology can be used for identifying a flaw on the other materials which are used in the aviation industry. In the experimental setup the MMW Imaging radar is stationary and the target is moved for scanning, in aviation it will be a limitation where the fuselage of the aircraft is too big or the panels which are heavy, so a movable system can be made to scan the fuselage which will help in saving the precious time and accurately identifying the defect.

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