CHAPTER 2

EXPERIMENTAL MEASUREMENT SET-UP, DATA ACQUISISTION PROCEDURE AND PRE-PROCESSING

2.1 Introduction

Through Wall Imaging is a remote sensing technique, which emits electromagnetic waves through a wideband antenna at one side of the wall and collects signals scattered from a visually opaque substance on the other side of the wall. TWI describes the process of how to obtain an image of the spatial distribution of reflectivity of the target from scattered field data. Depending on the application, different images are needed, such as A-scan, B-scan, and C-scan image. The A-scan image provides the presence of a target location in the downrange. A-scan image is obtained by processing A-scan data, which is obtained by measuring the scattered field data at a specific position. The B-scan image provides a target extent in the horizontal direction, i.e. length of the target. B-scan image is obtained by processing B-scan data, which is obtained by collecting multiple A-scans data along a horizontal scanning line. The simple B-scan image does not provide the height of the target. The C-scan image provides a target vertical extent i.e. height of the target apart from its length. C-scan image provides essential valuable information for complete target shape identification. C-scan image is obtained by processing C-scan data, which is obtained by stacking multiple B-scans data along with the different vertical scanning directions. Researchers are primarily interested in developing the TWI system for surveillance as well as search and rescue applications. These applications require such systems to provide information about the presence and location of the target. A typical unfocused B-scan image is sufficient when the only detection of the target and its approximate position is required. However, for applications primarily in disaster areas where the victim is buried under a collapsed wall, highly accurate information such as shape and size of target apart from target location is required. For this purpose, the C-scan image of the target is required. Typical unfocussed C-scan image of target appears blurred and show ambiguity in position of target because of the different propagation times of the EM wave while the antenna is moving along the scanning direction. For this reason, the unfocussed C-scan image depicts undesired low-resolution features. Therefore, one of the most applied problems for the C-scan image is to transform (or to migrate) the unfocused image to a focused one showing the object's correct location, shape, and size.

The developed TWI methodology can be broken into the following different steps:

a) Assembling of TWI experimental measurement set-up
b) Data acquisition
c) Pre-processing that includes wall dielectric calculation and antenna delay estimation
d) Post processing techniques, such as, image formation, detection and recognition of the target.

The method of implementation and its explanation for the above mention three steps are carried out and outlined in this Chapter. However, the post processing techniques required for TWI are described in the subsequent chapters of this thesis.

2.2 Experimental Measurement Set-Up

Figure 2.1 shows schematic representation of RF measurement system for Through-the-Wall Imaging (TWI). The RF measurement system consists of a vector network analyzer, coaxial cable, C-band horn antenna and two-dimensional field scanner.

The details of RF equipment's used are discussed as follows:

Vector Network Analyzer: Commercial available Anritsu vector network analyzer (Model no. MS2037C) is used for transmitting and receiving stepped frequency continuous waveform. The vector network analyzer transmits a group of K coherent signals whose

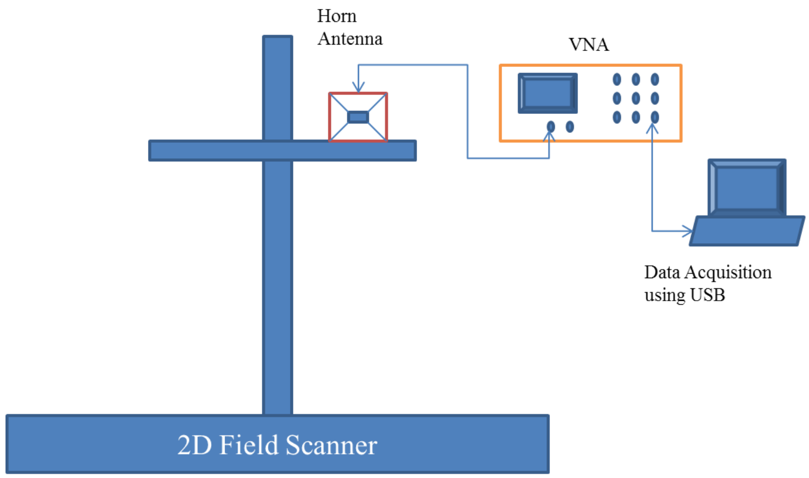

Figure 2.1. Measurement system for Through Wall Imaging.

frequencies are increased from signal to signal by a fixed frequency increment Δf. It measures and record the magnitude and phase of the received signal with respect to the transmitted signal at each stepped frequency.

Let the transmitted signal at frequency f_k is given by

$$S(f_k) = A\exp\left(-\left(j2\pi f_k t\right)\right) \tag{2.1}$$

where $f_k = f_o + k\Delta f$, f_0 is the starting carrier frequency, $k = 0, 1\ldots. K\text{-}1$ with K as number of frequencies and Δf is frequency step size, that is, the change in frequency from pulse to pulse. Each pulse is T seconds wide and the time interval between the pulses is adjusted for ambiguous or unambiguous range. Each signal dwells at each frequency long enough to allow the reflected signal to reach the receiver. Groups of K signals, also called a burst, are transmitted and received before any processing is initiated. The burst time, that is, the time corresponding to transmission of K signals is called the coherent processing interval (CPI).

EM Signals propagate toward the medium and any change within the propagation media due to presence of object will produce a reflected signal that will be captured by receiving system. If only one point object is within the unambiguous range then the signal backscattered by that object can be written as:

$$S_{11}(f_k) = a_1 \exp\left(-\alpha\left(j2\pi f_k \tau_{p_1}\right)\right) \tag{2.2}$$

where a_1 is the reflected signal strength for the K^{th} frequency and τ_{p_1} is the two way propagation delay to the object. If P point object is within the unambiguous range then the signal backscattered by P point object can be written as:

$$S_{11}(f_k) = \sum_{i=1}^{P} a_i \exp\left(-\alpha\left(j2\pi f_k \tau_{p_i}\right)\right) \tag{2.3}$$

Coaxial Cable: The coaxial cable is used to connect the vector network analyzer with the horn antenna of 6 ft in length and has a nominal loss of 2.5dB.

Antenna: C-band Horn antenna is used for transmitting and receiving the signal. The antenna as is oriented for vertical polarization. The antenna is placed on a 2D field scanner for movement in horizontal direction and vertical direction.

Two-dimensional Field Scanner: The two dimensional Field Scanner is used for the experiment. The center of the 2D scanner is located at X = 0, Y = 0, Z = 0. The positive Z-axis points into the room to be imaged and Z = 0 corresponds to the plane containing the antenna scan points. The scanner can move in two orthogonal directions, i.e., horizontal (along the width) and vertical (along the height). The scanner is cover with absorber to minimize any reflections.

The SFCW radar parameters for TWI application should be chosen carefully. The main parameters are as follows:

(i) Frequency Step Size

The unambiguous range of radar is the maximum range at which a target can be located. The unambiguous range is given by [Chandra *et al*. (2008)]

$$R_u = \frac{c}{2\Delta f} \tag{2.4}$$

From equation (2.4), if the frequency step is narrow then ambiguous range will be greater. Thus, for a certain unambiguous range, frequency step size Δf can be calculated using equation given as

$$\Delta f = \frac{BW}{K-1} \tag{2.5}$$

where BW is bandwidth of signal and K is no. of frequency points.

(iii) Gain of Antenna

In antenna radar system, with synthetic aperture techniques, the beamwidth of single antenna should be narrow [Yamaguchi *et al*. (1991)]. If the antenna beam is narrow, then it is easy to pick line of sight target signal.

(iv) Bandwidth

Range resolution is the capacity of radar to discriminate individual elements that are close to each other in down range. High downrange resolution can be obtained by using wide bandwidth that is given by [Chandra *et al*. (2008)].

$$\Delta R = \frac{c}{2BW} \tag{2.6}$$

where *c* is speed of light and BW is operating bandwidth.

The effective bandwidth is determined by the total frequency excursion, i.e., $K\Delta f$. The down range resolution of step frequency radar can be given by

$$\Delta R = \frac{c}{2K\Delta f} \tag{2.7}$$

where K is number of frequency points and Δf is frequency step size. The required bandwidth must be greater than 1 GHz to obtain range resolution in order to detect object size of few centimeters.

(v) Frequency range of operation

In radar system antenna, with synthetic aperture techniques, the beamwidth of single antenna should be narrow. If the antenna beam is narrow it is easy to pick line of sight target signal. High frequency range is chosen at which the narrow beamwidth of antenna is achieved. Thus, high crossrange resolution requirement leads to the selection of higher frequency. But at higher frequency, penetration through the wall is low. Thus there is inherent tradeoff between resolution and penetration. Better resolution and penetration are the major challenges being faced in TWI. Various types of wall material are used in different parts of the world like wood, asbestos, brick, concrete and so on. The walls made of wood are approximately transparent to radar frequencies. Thus frequencies above 10 GHz can be used for imaging. On the other hand in brick wall attenuation is more. In brick wall, one way attenuation is reported as 5dB/cm at 5 GHz and in concrete it is 10dB/cm at 3GHz [Gaikwad *et al*. (2011)]. Thus, selection of frequency range up to approximately 10 GHz can be done as long as attenuation is within acceptable limit.

2.3 Data Acquisition Procedure

The experiments are carried out in Department of Electronics Engineering, Indian Institute of Technology (BHU), Varanasi, India. The measurement set-up is kept at 220cm from wall. The target is kept at 122cm on other side of wall. The wall considered is cemented brick wall having a thickness of 14.5cm. Four regular circular, triangular, square, rectangular shapes and sizes of wooden and metallic targets are considered. The target is placed on wooden stand. The stand is covered with absorbing sheet to minimize any reflection generated from the stand. In order to acquire information of scene behind walls, data was collected at 21 horizontal and 21 vertical scan positions in the presence of target to completely cover the target. At scan position, one port *S*-parameter, S_{11} was collected at $N = 201$ frequency points, i. e., frequency step size Δf = 10MHz, in frequency range of 3.5GHz-5.5GHz in the presence of target after calibrating VNA using standard full one port standard calibration process Open Short Matched. Table 2.1 shows typical value of designed SFCW radar parameters for imaging.

Table 2.1. Typical values of SFCW radar parameters.

Radar parameters	**Value**
Frequency range	3.5GHz-5.5GHz
Bandwidth	2GHz
Number of frequency points	201
Power Transmitted	-3dbm
IF Bandwidth	10 KHz
Range Resolution	7.5cm
Antenna Type	Horn
Beam Width	20 degree
Gain	18 dB

In order to have full imaging information, target is scanned in two orthogonal directions, i.e., horizontal (along the width) and vertical (along the height), such that, target is covered completely. The complete C scan is a 3D matrix of spatial-frequency data, with each cell entry representing intensity values as a function of particular downrange, cross range and height index. Thereby, complete C scan matrix is of size 201×21×21. The complete C scan image acquaints us with target information in terms of target length and width. Data acquired in this way, undergoes several signal processing steps to extract full information of the target.

2.4 Pre-Processing Evaluations

Before forming the image of scene, two steps are very important. First, to know the characteristics of the wall, such as, dielectric constant, this effect on the quality of image, and antenna delay.

2.4.1 Wall Parameter Estimation

The wall through which the signal propagates causes refraction of electromagnetic wave at the front and rear side of the wall and propagation delay. The propagation delay occurs because velocity of waves decreases when they pass through a wall due to its dielectric constant and thickness. When attempting image formation process, these parameters should be known beforehand. Without considering the propagation effect of wall, the formed image of targets behind wall will be blurred and show ambiguity in position of target which ultimately degrades the performance of radar. The shift will be more if the wall has a high dielectric constant and thickness. Therefore, the estimation of wall dielectric is carried out using Insertion transfer method as described by Muqaibal and Safaai-Jazi (2003). The procedure for dielectric constant calculation of a wall is described in following subsection.

2.4.1.1 Experimental setup for wall dielectric calculation:

Experimental setup for wall characterization is shown in Figure 2.2. It consists of VNA, transmitting and receiving antennas. The antennas used in experiment were horn antennas. Two low loss cables were connected between the antennas and the two ports of VNA. The distance between transmitting and receiving antennas is 3 meter and wall is kept exactly at the center of both antennas. The wall is having a thickness of 14.5cm. The distance between two antennas is taken sufficiently large so that wall is far field of each antenna. The height of antenna from ground was 1m. The transmitted power, frequency range and number of frequency points are -3dBm, 3.95GHz to 5.85 GHz and 201, respectively.

2.4.1.2 Measurement procedure

After calibrating the VNA using standard two port Through Open Short Matched method. Two sets of measurements, i.e., one without wall (free space) and other with presence of wall in

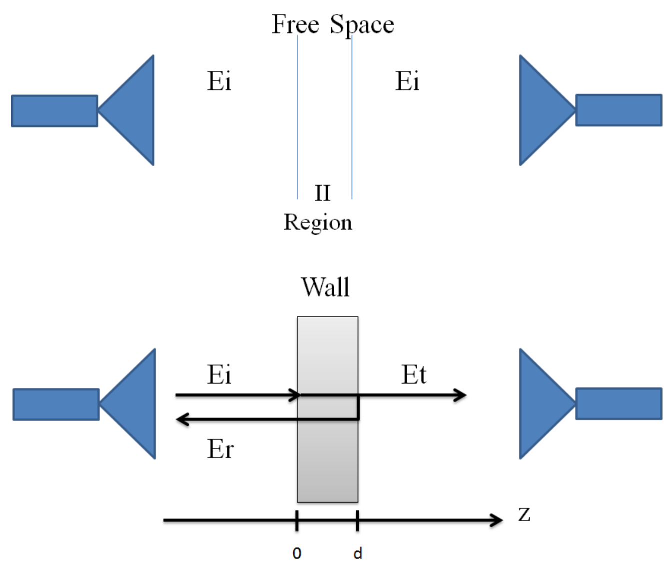

Figure 2.2. Measurement set-up for wall dielectric calculation [Muqaibal and Safaai-Jazi (2003)]

between transmitting and receiving antennas are taken. S_{21} parameter is collected using VNA at 201 points between 3.5 to 5.5 GHz by taking with and without wall between transmitting and receiving antennas. Care is taken to maintain same conditions during both measurements. The free space and through-the-wall measurement would be most accurate if performed inside an anechoic chamber where all the multipath component and reflections from the floor and ceiling are absorbed. But it is not possible in real time so effect of multipath is ignored in this case.

2.4.1.3 Wall Dielectric Calculation

After performing measurement, insertion transfer function is obtained which is defined as

$$H(j\omega)=\frac{S_{21}(j\omega)_{wall}}{S_{21}(j\omega)_{freespace}} \tag{2.8}$$

where $S_{21}(j\omega)_{freespace}$ is measured in absence of wall and $S_{21}(j\omega)_{wall}$ is measured in presence of wall. Then, calculation for wall dielectric is done by numerically solving equation (2.9) which is given by

$$\tan\left(\beta_o d-\angle H(j\omega)\right)+\frac{1-QX}{1+QX}\tan\left(\beta d\right) \tag{2.9}$$

Where

$$Q=-\left(\frac{\sqrt{\varepsilon'}-1}{\sqrt{\varepsilon'}+1}\right)^2 \quad , \tag{2.10}$$

$$\beta=\beta_o\sqrt{\varepsilon'} \quad , \tag{2.11}$$

$$X=\frac{\left[\cos 2\beta d\,(\varepsilon'-1)^2+8\frac{\varepsilon'}{|H(j\omega)|}\right]-\sqrt{\left[\cos 2\beta d\,(\varepsilon'-1)^2+8\frac{\varepsilon'}{|H(j\omega)|}\right]^2-(\varepsilon'-1)^4}}{\left(\sqrt{\varepsilon}-1\right)^4} \tag{2.12}$$

Here, $\beta_0 = \omega/c$, $\beta = \beta_0\sqrt{\varepsilon}$ and $\omega = 2\pi f$, c is speed of light. The dielectric value of wall for each frequency in the experimental band of 3.95 -5.95 GHz has been estimated. The averaged value of estimated dielectric in an experimental band of 3.95 -5.95 GHz is considered as the dielectric value of wall [Gaikwad *et al.* (2011)]. Thus, dielectric constant of the cemented brickwall wall is found to be 6.5.

2.4.2 Antenna Delay Calculation

In order to identify the delay due to antenna system, a separate experiment is carried out in same manner as proposed by Gaikwad *et al*. (2011). A metallic plate is kept at known reference distance ($R_{\text{reference}}$) of 2.20m from radar. Scattering parameter S_{11} is measured using VNA at 201 frequency points in frequency range of 3.5 to 5.5 GHz in presence of metallic plate. After receiving the data in frequency domain, it is converted to equivalent range/distance domain which is called as range profile using equation (2.13) [Gaikwad *et al*. (2011)]

$$S(z) = \sum_{k=1}^{201} S_{11}\left(f_k\right)\exp\left(j2\pi f_k(2z/c)\right) \tag{2.13}$$

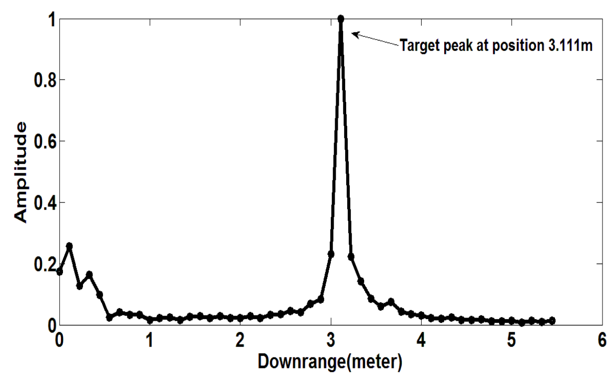

Figure 2.3. Range profile plot.

The range profile plot as per equation (2.13) is shown in Figure 2.3. The range profile shows location of metallic plate in front of antenna in downrange.

From range profile actual distance (R_{actual}) of target from radar was found to be 3.111m. Thus, antenna delay is calculated using equation 2.14 which is given by [Gaikwad *et al*. (2011)]

$$t_{delay} = \frac{R_{actual} - R_{reference}}{c} \tag{2.14}$$

2.5 Conclusion

In this chapter, details of measurement set-up, data acquisition procedure including radar parameters required for the formation of through-the-wall radar images (TWRI) is described. The pre-processing, such as, estimations of wall thickness, dielectric constant, and antenna delay calculation required before formation of TWRI has been carried out. From the experimental result, the value of dielectric constant of wall is found to be 6.5. These techniques, procedures and results will be utilized in the subsequent work described in the present thesis.