# Microwave Signal Spatial Domain Transformation using Signal Processing and Image Reconstruction Method

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***Abstract*—This study focused on the transformation of frequency domain signals from a planar scanning into a planar image. Computer Simulation Technology Microwave Studio is an efficient tool for 3D Electromagnetic simulation. It performed high accuracy simulation for 3D model simulation. This electromagnetic simulator is used to simulate a round phantom which has a created target inside the phantom. An antenna emitted microwave signal is being placed in front of the phantom to transmit a short pulse to the model. Scanning was performed along the fixed axis in front of the model. A mono-static antenna was used as the transmitter and receiver of the signals. The frequency domain data sets reflected and received by the antenna were imported into MATLAB software for image reconstruction. Subtraction method was used to reduce the reflection of antenna which was recognized as the unwanted noise in the signals. All time domain signals were smoothed to reduce the sharp peak and had a more continuous waveform, and arranged into matrix form. Image reconstruction function in MATLAB was used to transform the matrix envelope into a planar image. The phantom and target is identified by the different intensity of the colormap showed in the reconstructed image.**

***Keywords-Computer Simulation Technology; 2D; microwave signal; image reconstruction***

## I. INTRODUCTION

The Computer Simulation Technology (CST) Microwave Studio is an efficient tool for 3D Electromagnetic simulation that enables high accuracy simulation results. This EM simulator allows us to model any type of 3D structure without analytical approximations or experimental errors.

In this study, a simulation brain model which has a target inside is being created. A simulated ultra-wideband antenna is placed at different location and transmitting a short pulse to the simulation model. A mono-static antenna is used as the transmitter and receiver of the signals [1].

In CST simulation, the focus is in coronal view, sagittal view or axial view [2]. MATLAB is used as the signal and data processing and image reconstruction tool. The main focus of this study is on the data processing and image reconstruct from the data by using MATLAB, through certain imaging reconstruction function.

## II. PROBLEM STATEMENT

The reflected signals, $S_{11}$ that received by the mono-static antenna during CST simulation were recorded in frequency domain format. The target's location in the phantom cannot be determined through frequency domain. The data hence have to be displayed in spatial domain (image) in order to have a clear vision. In order to convert into a 2D image, a method is needed. Thus, the objectives of the study are:

- To convert frequency domain into time domain by using signal processing method.
- To transform time domain into spatial domain with the used of image reconstruction function.
- To obtain a planar image as well as 2D image which show the location of target.

Several image reconstruction method being identified regarding to the type of scanning mode. A suitable method is chosen to be used in the image reconstruction of the output data whether it is a planar scanning [3] or a cylindrical scanning [4].

The research and development of this study is beneficial to the clinical test of brain tumor microwave imaging. If the image reconstruction method works on the CST simulation data, then it can be used in the experimental testing. This study has a great potential in detecting target inside body and its image reconstruction process as it is much more economic than the advanced imaging system like MRI or CT-Scan.

## III. LITERATURE REVIEW

The image reconstruction method proposed by Tantong [5] by using the planar scanning mode is called the Single Probe Imaging through Detection and Reconstruction (SPIDR) method. Figure 1 showed the flow of SPIDR method.

Firstly, the reflected signals, $S_{11}$ which receive by the mono-static antenna [6, 7] are collected. Inverse Fourier Transformation (IFFT) is applied to the reflected signals, $S_{11}$ and transforms them into time domain. After that, a calibration process is gone through to get the resulting target signals. Subtraction method is used in the calibration process, where the reflected signals with target subtract with the reflected signals without target. The resultant signals are the reflected signals of target only. Perform these steps to all the one thousand set of data and finally map all the resultant signals into a global x-axis and y-axis to get the image.

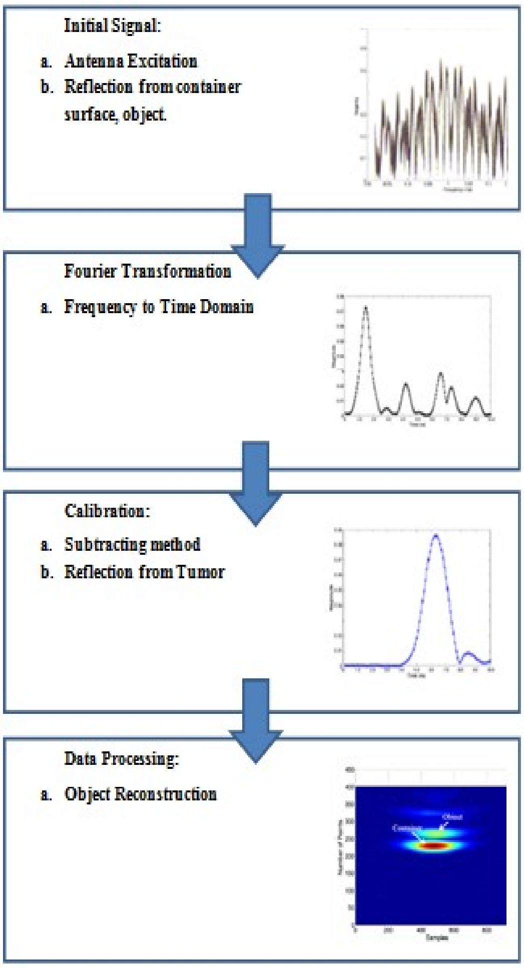



Figure 1. Single Probe Imaging through Detection and Reconstruction (SPIDR) method [5]

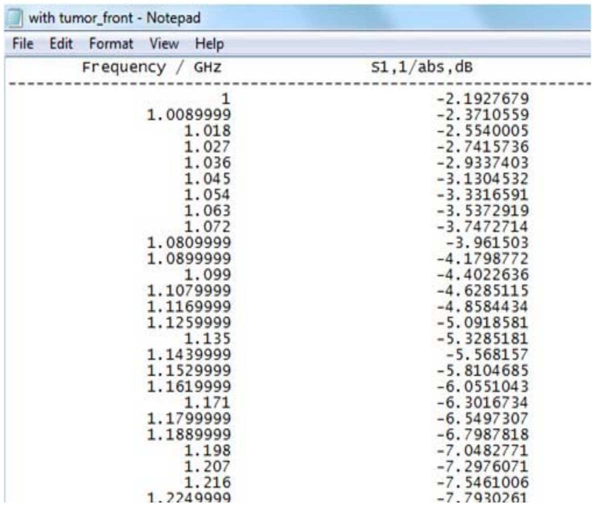
## IV. METHODOLOGY

### A. Data Acquisition

A planar scanning is used in the study. In this context only coronal scanning using mono-static antenna as the transmitter and receiver is performed. The scanning required different steps and certain function to reconstruct its image. The output is recorded and feed into another software for image reconstruction. A simulated brain phantom which has a target inside is being created. A simulated ultra-wideband mono-static antenna is placed at different location and a short pulse transmitted to the phantom. The scanning performed in coronal view, sagittal view or axial view. The output of simulation is collected and saved in text file with frequency in GHz and magnitude in dB (Figure 2).

Matrix Laboratory (MATLAB) is used to extract and perform analysis of data. MATLAB is very friendly user and it is easy to use for beginners. This software can use to perform different algorithm, simulate or modeling model, data analysis and visualization. Therefore, MATLAB R20009a is chosen for the software partition of the study.

The scanning which performed in this study is a planar scanning as done by Tantong [5]. Thirty set of data are obtained. Fifteen sets of data are the scanning with the target inside the simulated phantom and another fifteen are the scanning without target in the simulated phantom. The simulated phantom is shown in Figure 3. By using Single Probe Imaging through Detection and Reconstruction (SPIDR) method, data were transformed into time domain and undergo calibration process. Finally map all the calibrated time domain signals into a global (x, y) coordinate, a planar image will be formed.


with tumor_front - Notepad
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| Frequency / GHz | S1,1/abs,dB |
|---|---|
| 1 | -2.1927679 |
| 1.0089999 | -2.3710559 |
| 1.018 | -2.5540005 |
| 1.027 | -2.7415736 |
| 1.036 | -2.9337403 |
| 1.045 | -3.1304532 |
| 1.054 | -3.3316591 |
| 1.063 | -3.5372919 |
| 1.072 | -3.7472714 |
| 1.0809999 | -3.961503 |
| 1.0899999 | -4.1798772 |
| 1.099 | -4.4022636 |
| 1.1079999 | -4.6285115 |
| 1.1169999 | -4.8584434 |
| 1.1259999 | -5.0918581 |
| 1.135 | -5.3285181 |
| 1.1439999 | -5.568157 |
| 1.1529999 | -5.8104685 |
| 1.1619999 | -6.0551043 |
| 1.171 | -6.3016734 |
| 1.1799999 | -6.5497307 |
| 1.1889999 | -6.7987818 |
| 1.198 | -7.0482771 |
| 1.207 | -7.2976071 |
| 1.216 | -7.5461006 |
| 1.2249999 | -7.7930261 |

Figure 2. Simulation result obtained from CST simulation application

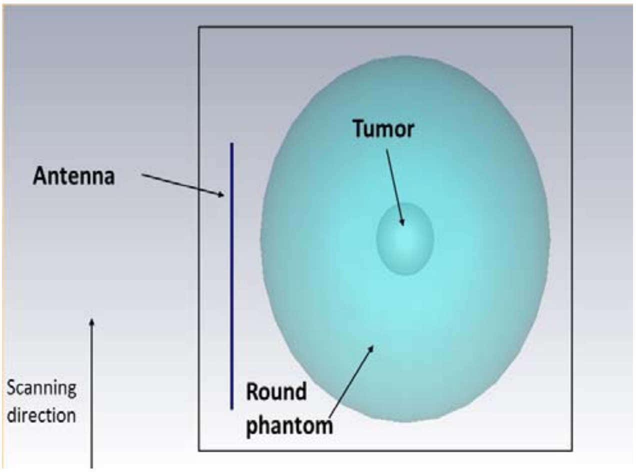


Figure 3. Planar scanning for simulated phantom in CST simulation application

*B. Signal and Image Processing*

The complete process is started with the import of raw data sets into MATLAB software. Fifteen sets of raw data with 1001 points like Figure 2 resulted from scanning of a round simulated phantom with tumor were being read into MATLAB. The raw data are in array form. The first column and second column of data which are frequency in GHz and magnitude in dB were stored into different variables. The magnitude was turn from unit dB into value before the Inverse Fourier Transformation (IFFT) being applied on it.

After the Inverse Fourier Transformation (IFFT), the frequency domain data will be turned into time domain data. The same transformation process is applied to all the fifteen sets of frequency domain data.

The fifteen sets of time domain data were being smoothed by using a "*smooth*" function in MATLAB in order to have a signal which is more continuous and smooth characteristic. All the data sets were then being arranged into matrix form.

The "*imagesc*" function in MATLAB was used to transform the matrix data into an image. The "*imagesc*" function scales image data to the full range of current colormap and display the image. Each element or data in the matrix was corresponded to a rectangular area in the image. The data of the elements were being indices into the colormap that the color of each patch was determined.

*C. Flow Chart*

Figure 4 shows the flow chart of the methodology. The study started with getting output data from the CST simulation application, then the output data is read into MATLAB. All the frequency domain data go through Inverse Fourier Transform (IFFT) and converted to time domain. Image reconstruction method is fit into MATLAB and processes the time domain data sets. MATLAB Graphic User Interface (GUI) is used to display the image with target of simulated phantom.

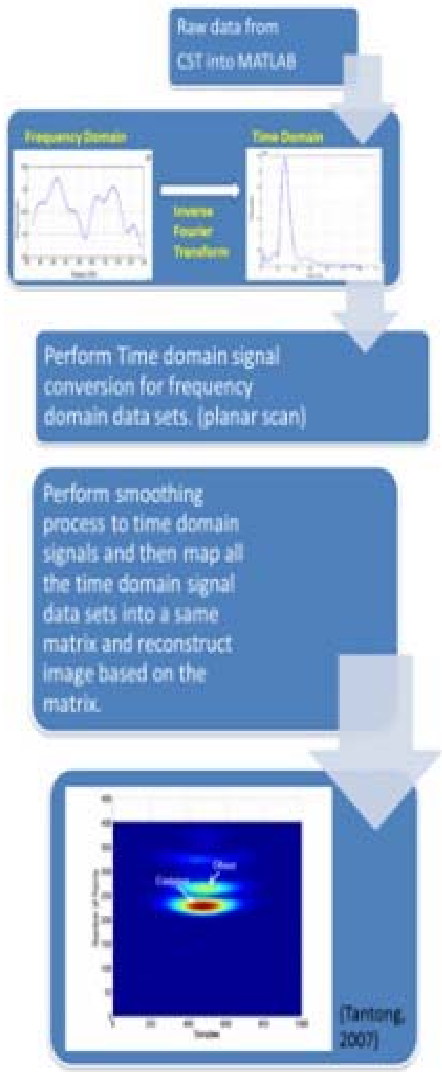


Figure 4. Signal and image processing flow chart

## V. RESULT AND DISCUSSION

This section mainly discussed about the result of signal transformation and the planar image that successfully reconstructed.

*A. Phantom with Tumor*

With regard to the frequency domain plotting in Figure 5, there is a drastic drop in magnitude of -69.57 dB at frequency of 3.53 GHz. This had indicated that there is a target with different relative permittivity ($\varepsilon_r$) [8, 9] occur in the phantom. The value of magnitude in unit dB was then being turned into "*absolute*" value which stated in Figure 6 before it was transformed into time domain.

After transformation from frequency domain to time domain, the signals give a clear vision of different magnitude when it hits phantom and target (tumor). It was shown in Figure 7. There are three kinds of reflections: antenna itself, round phantom and tumor. Time domain show the reflections of phantom start occur from time 1.61 *ns* and tumor was began at 2.1 *ns*.

A "*smooth*" function in MATLAB is being used to smooth time domain array data (Figure 8). Data was being smoothed by replacing each data point with the average of the neighboring data points defined within the span. The function is same as data in the column vector being smoothed by using a moving average filter, and the results are returned in the column vector. The data sets were then being arranged into matrix form.

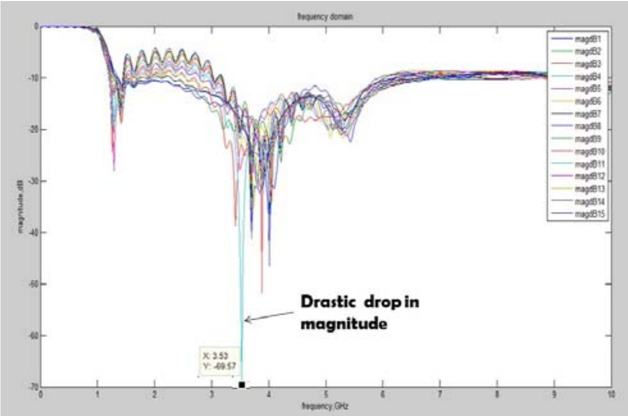


Figure 5. Reflected signal in frequency domain, dB (Phantom with target)

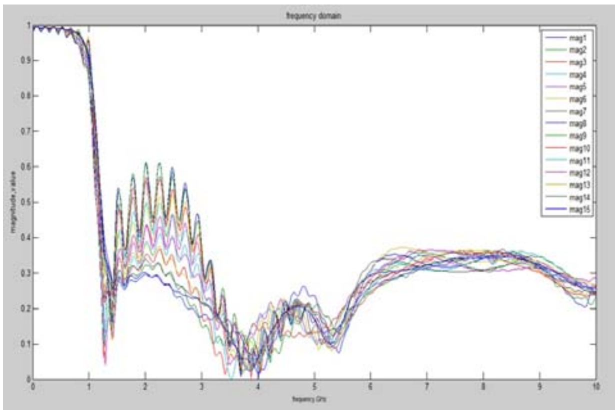

Figure 6. Reflected signal in frequency domain after ${absolute}$ process (Phantom with target)

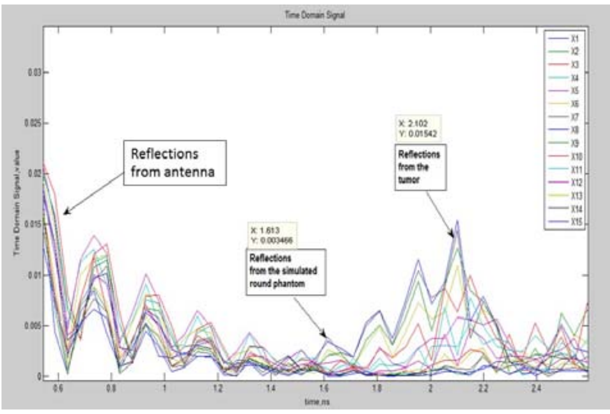


Figure 7. Reflected signal in time domain after IFFT (Phantom with target)

The "*imagesc*" function in MATLAB software was being used to reconstruct an image from the matrix. The reconstructed image showed the reflection of antenna, simulated round phantom and tumor as shown in Figure 9. The color of reflection is determined by its' intensity (amplitude in time domain).

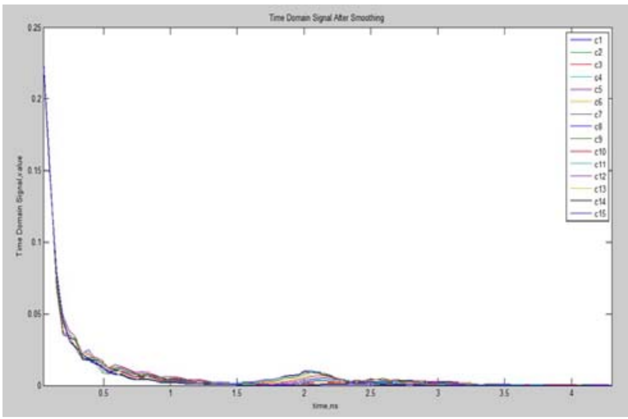

Figure 8. Reflected signal in time domain after smoothing (Phantom with target)

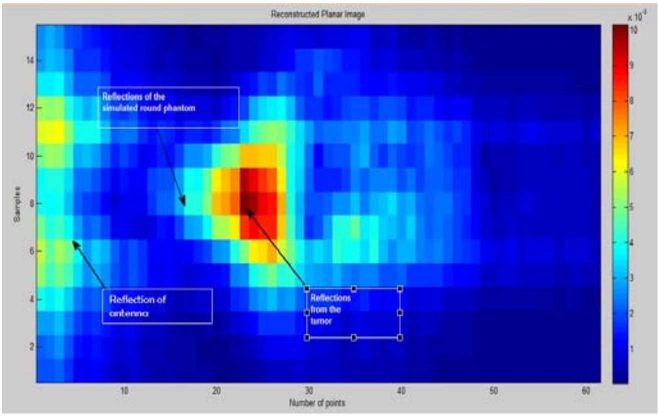


Figure 9. Reconstructed image (Phantom with target)

### B. *Phantom with Tumor after Subtraction*

Figure 10 shows the frequency domain for both phantom with and without tumor. By comparing the time domain of phantom with tumor and without tumor in Figure 11, there is a clear vision on the difference of magnitude at time 1.61 *ns* and 2.1 *ns*. The reflections of phantom start at time 1.61 *ns*, and tumor occurred at time 2.1 *ns*.

The reflection of antenna can be treated as noise and it can be removed by subtracting the time domain signals of phantom with tumor and without tumor. The reflections from the antenna have been subtracted (Figure 12) before entering smoothing phase. The same "*smooth*" function is being used to smooth time domain array data.

The resulting signals represented only the round simulated phantom and the tumor as stated in Figure 13. The resulting image in Figure 14 showed the phantom and tumor, but the reconstructed image still contained a little bit of remaining noise (antenna reflection) because of the slightly different of amplitude value for reflection.

Other than that, the radiation pattern of the antenna did not cover the whole round phantom, so the reconstructed image did not show a perfect shape of round phantom and round tumor.

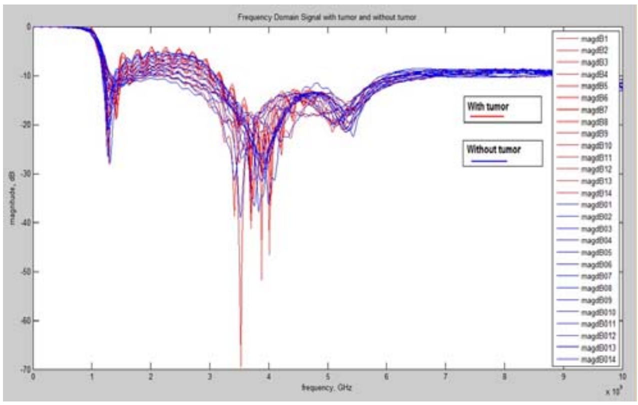


Figure 10. Reflected signal in frequency domain, dB (Phantom with and without tumor)

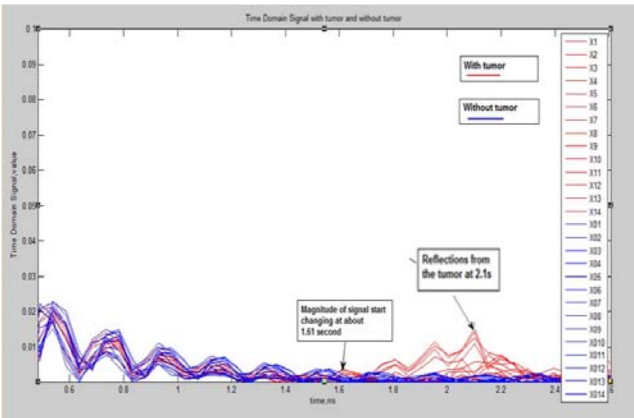


Figure 11. Reflected signal in time domain after IFFT (Phantom with and without target)

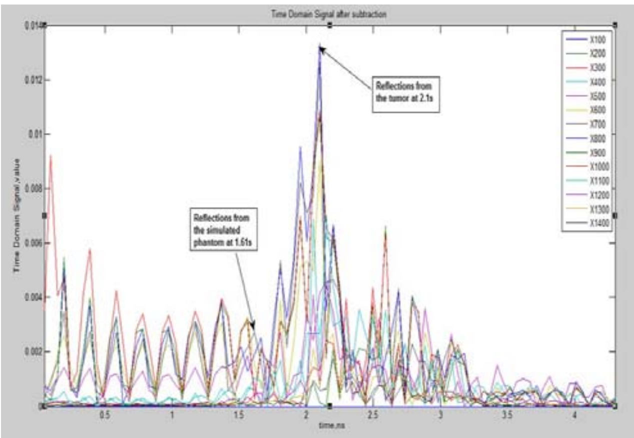


Figure 12. Reflected signal in time domain after subtraction

The planar scan can only provide the object front-surface detection. Image quality can be improved by increase the number sets of scanning instead of fifteen sets. The distance of the tumor from the surface of phantom can be calculated by using another method.

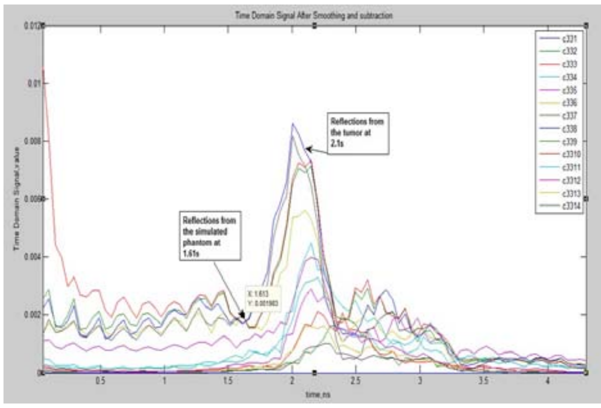


Figure 13. Reflected signal in time domain after subtraction (with smoothing)

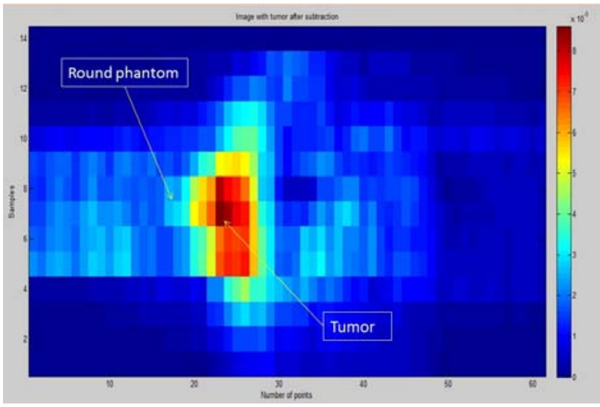


Figure 14. Reconstructed image (after subtraction)

## VI. CONCLUSION

The method that used in this study to reconstruct image from planar scanning was a simple and efficient method. The frequency domain array data was successfully being converted into time domain data by using Inverse Discrete Fourier Transform. Time domain data was transformed into spatial domain by using Image reconstruction function in MATLAB software. The planar image that was obtained showed the location of target. Subtraction method was being conduct successful in the enhancement of image quality as the wanted information was not disappeared and the unwanted noise was being reduced.

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