

## Performance & Analysis of Radar Cross Section Estimation of Simple Objects in Time Domain

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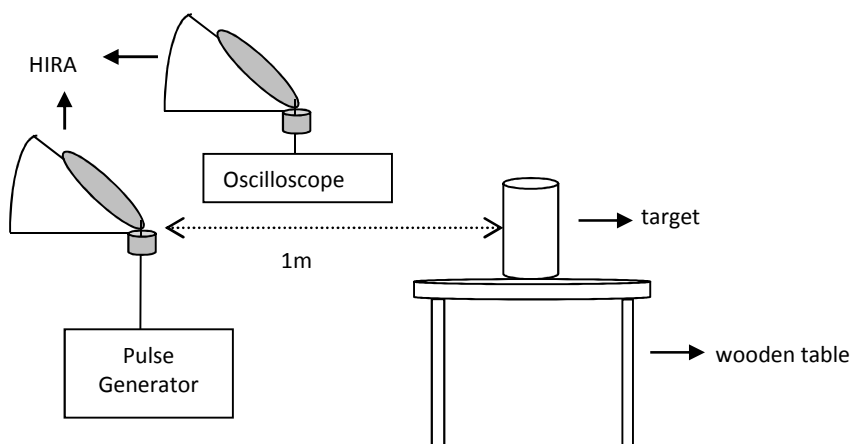
**ABSTRACT:** This paper describes the feasibility and implementation of a time domain facility for Radar Cross Section (RCS) measurements. Main advantages of measuring in the time domain are the high range resolution and the application of direct gating. The limited signal to noise ratio can be a disadvantage. The measurements have been performed with software tool XFDTD using two 2-12 GHz ridged horn antennas and rugby antennas respectively. Because the horns are not designed for transmitting transient signals, an additional system response measurement in combination with a software de convolution algorithm restores the impulse response of the object under test. Further processing separates the object response from clutter contributions. A comparison of the time domain data with calculated and measured frequency domain radar cross sections shows a good agreement. The high range resolution enables the separation of scattering mechanisms (i.e. reaction, single and multiple diffraction). It is concluded that the time domain RCS measurement system is an attractive alternative of its frequency domain equivalent. However, the decision to measure in the time or frequency domain will depend on the specific aim of each experiment.

**KEYWORDS:** Radar Cross Section (RCS), Perfect Electric Conductor (PEC), De convolution.

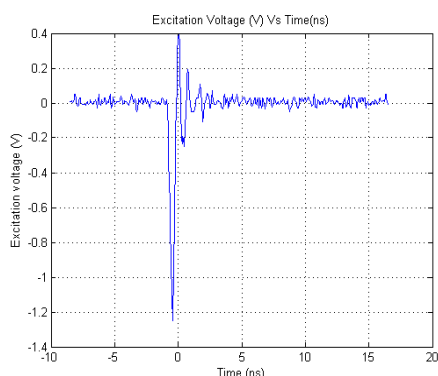
### INTRODUCTION

This paper describes the feasibility and implementation of a time domain facility for Radar Cross Section (RCS) measurements. RCS measurements have a large number of applications, ranging from model verification to a powerful design tool for ships and aircraft. RCS measurements are usually performed in the frequency domain. The International Research Centre for Telecommunication -transmission and Radar (IRCTR) already operate such frequency domain facilities. Recently IRCTR extended its facilities to perform ultra-short pulse antenna time domain measurements beyond its conventional frequency domain setup [1], [2]. These measurements successfully demonstrated the advantages and potentials of the time domain alternative [3]. Application of the time domain equipment in scattering research could also be very beneficial. Shorter measurement times could reduce the load on scarce measurement facilities and with the high range resolution scattering sources are easily identified. Time domains scattering measurements can also be used to estimate the maximum RCS of an object in a wide range of frequencies (e.g. when performing out-of-band antenna measurements). As described earlier [4,5], only specially designed transient antennas can transmit the ultra short input pulse at their feed. Because these antennas were not available at IRCTR an alternative approach has been taken. Two ridged horn antennas are used to transmit the pulse. The transmitted electromagnetic field does not have an ultra-short pulse shape, but it does contain all the information to reconstruct the impulse response of the object under test from the received signal. For this approach an additional system transfer measurement is necessary to determine the antenna characteristics [6-9]. Summarising, three measurements will be performed to extract the scattering characteristics of the object under test:

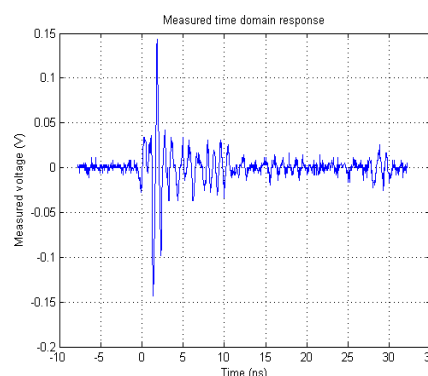
1. A system response measurement. The system response measurement determines the transfer function or impulse response of the system as described above.
2. An object measurement. The object measurement determines the total scattered field.
3. A background measurement. The background measurement determines the clutter (empty room scattering contributions and antenna coupling).



**Fig 1 Time Domain Measurement Setup to measure the impulse response of target**



**Fig 2 Excitation signal used for time domain measurement**



**Fig 3 Voltage measured by sensor at distance 1.65m away from HIRA**

The setup used in time domain is shown in the fig 1, where the transmitter and receiver antenna is focused on the target. From the fig [2,3] it is evident that the antenna coupling may occur, which has to be removed from the response output from the port 2 later. The antenna also adds some amount of distortion which has to be removed by using filter and deconvolution method. For performing deconvolution, we need three data files,

1. Response of full scene (i.e transmitter, receiver and a target).
2. Output of transmitter alone.
3. Output of receiver alone.

**MATHEMATICAL MODEL:**

A general system representation is given by

$$x(t) \rightarrow h(t) \rightarrow y(t) \tag{1}$$

Where:

$x(t)$  = Input

$h(t)$  = Impulse response of the system

$y(t)$  = Output

Therefore,  $y(t) = x(t) * h(t)$

(2)

where '\*' represents convolution.

Antenna can be considered as a linear time invariant system. So the output of the antenna is the convolved output of the input and the impulse response of the transmitting antenna. In case of GPR, there will be a transmitting antenna and a receiving antenna.

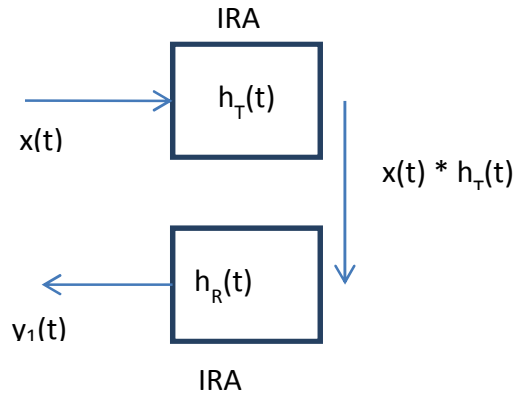


Fig 4 Antenna Configuration without target

So the output of the radar system without any scatterer is modelled [fig 4] as:

$x(t) \rightarrow h_T(t) \rightarrow h_R(t) \rightarrow y(t)$

(3)

Where:

$x(t)$  = Input

$h_T(t)$  = Impulse response of transmitting antenna

$h_R(t)$  = Impulse response of receiving antenna

$y(t)$  = Output

then,

$y_1(t) = x(t) * h_T(t) * h_R(t)$

(4)

When there is a scatterer in front of the bistatic antenna configuration, there is mutual coupling which is the leakage of the transmitter output directly to the receiver along with the response of scatterer. This coupling gives the early time response and includes no influence from the scatterer, since the response at the receiver is observed before the transmitter output had.

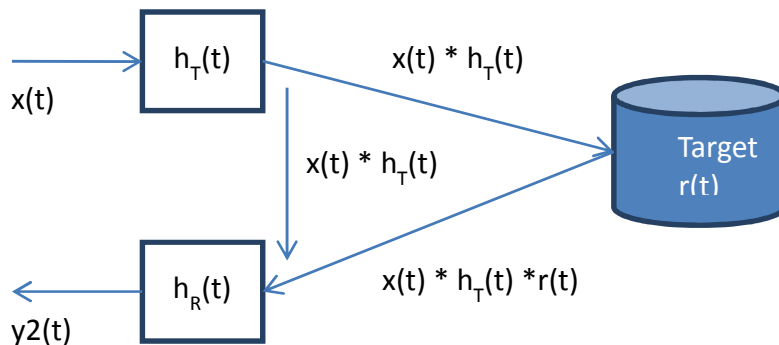


Fig 5 Antenna configuration with target

To simplify [t shown in fig 5] the output is modeled as two components:

$$y_2(t) = y_E(t) + y_L(t) \tag{5}$$

where,  $y_L(t)$  = the late time response,

$y_E(t)$  = the early time response.

$$y_L(t) = x(t) * h_T(t) * h_S(t) * h_R(t) \tag{6}$$

$$y_E(t) = x(t) * h_T(t) * h_R(t) \tag{7}$$

where,  $h_S(t)$  = Impulse response of scatterer

The early time response  $y_E(t)$  can be captured in a scene where there is no scatterer. This gives the background response. So subtracting the  $y_E(t)$  from  $y_2(t)$  will give the late time response.

$$\begin{aligned} y_L(t) &= y_2(t) - y_E(t) \\ &= y_2(t) - y_1(t) \end{aligned} \tag{8}$$

With this mathematical model, we first find out the antenna output in time domain. Once the antenna output is found out, we include the scatterer which is the target and find the response of the target. To get the impulse response of target approximately same as that in simulation we go for extended E-pulse approach in which the antenna response with target is first deconvolved with the antenna output and then convolved with the input pulse[10,11].

**PROPOSED SYSTEM**

The model of time domain measurement is implemented using the XFDTD tool by placing the transmitter and receiver horn antennas as show in the fig 6. The distance between the antenna and the object is about 1m (ideal case). The antennas are focused on the object with a slight angle tilt of 10 degree.

**PLACING THE ANTENNAS**

The antenna models are pre-loaded from the library files by clicking file -> open and choosing the appropriate file. The antenna is renamed as “Transmitter antenna” and a copy of the same is created. The second antenna is placed few meters away and renamed as “Receiver antenna”.

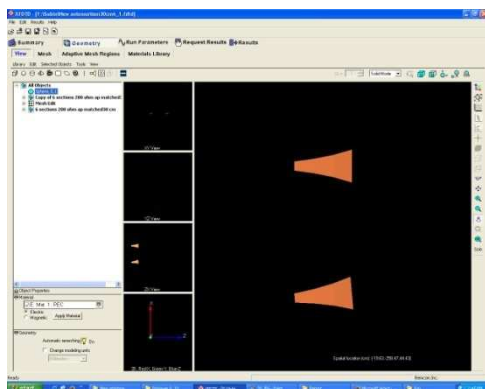


Fig 6 Transmitter and receiver antenna

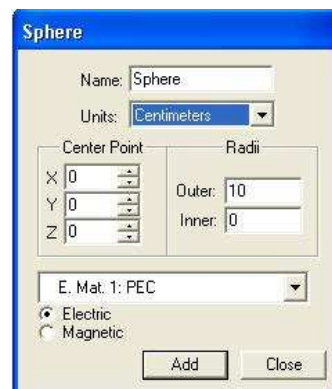


Fig 7 Sphere dialog box

**OBJECT PLACEMENT**

Now, the Sphere is placed by clicking on the icon sphere on the toolbar. A dialog box appears as shown in the fig 7, select the desired location and radius and click on add button. The sphere is added at the appropriate position as shown in the fig 8.

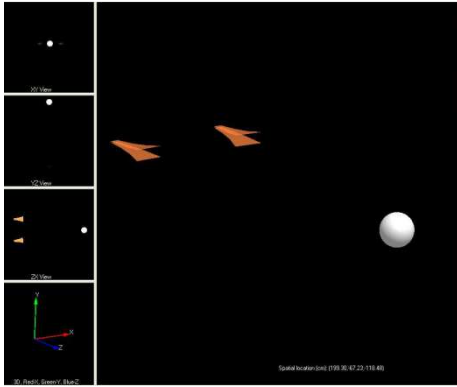


Fig 8 Full Scene of the model

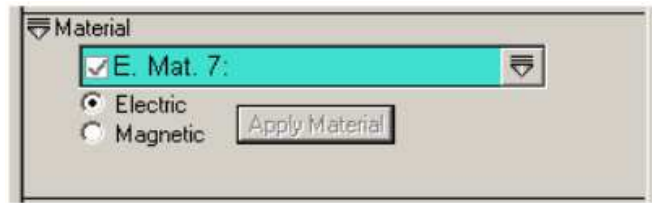


Fig 9 The material panel section of the geometry window

### THE MATERIAL PANEL

Once the sphere is placed, select the required material type from material panel which is below the objects panel. By selecting sphere in the hierarchy, and choose a material, in this case choose “Perfect Electric Conductor” (PEC) and then Apply Material button can be pressed to assign the material to the selected geometric object shown in fig 9.

### GENERATING MESH

The mesh tab is selected and required number of cells is locked as auto, now generate mesh button is selected. The mesh is created for the geometric model as show in the fig 10. The mesh size should not exceed the ram size as it poses a complexity in calculation process.

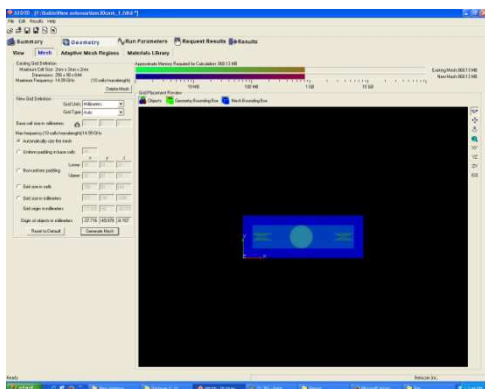


Fig 10 Generating Mesh

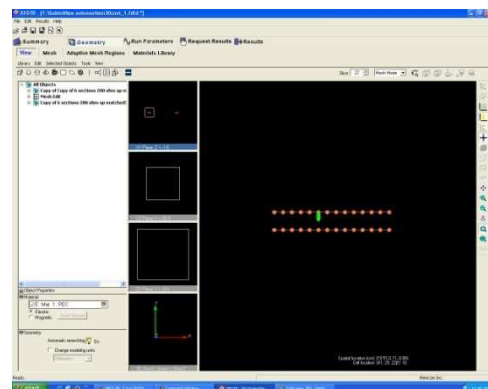


Fig 11 Placing the Component

### SOURCE WAVEFORM AND FEED

The source waveform is given as discrete type. Now shift from solid view to mesh view as shown in the fig 11, The voltage feed is given to the transmitter antenna and a normal feed is given to the receiver antenna by following the steps given below,

1. In the mesh view, scroll in and out to select the correct slice to place the feed. Then right click on the exact location select add component to place the component.
2. Now components/ports tab opens, in that field specification select the series voltage. Give the amplitude value as 1 volt and resistance as 50 ohms.
3. Once the parameters are defined correctly, click on add component.
4. Similarly the feed is placed in receiver antenna too, only difference is in field specification choose passive load.

### SAVE FAR-ZONE DATA

Under save far-zone data tab in request results, specify the phi and theta angels as 0 and 10 degree. The angles are found using the following formulas, the location of the sphere in the rectangular co-ordinate is used.

### SAVE PROJECT AND GEOMETRY

Once all the parameters for stimulation is completed, the project and geometry is saved by selecting File - > save project and File - > save geometry.

### RUN CALCULATION

The run calculation button is selected once the above steps are over. The run calculation is under the results tab. The XFDTD tool may take few hours for stimulation based on the size of the mesh. Once the calculations are done, the outputs can be plotted for different parameters.

### OBTAINING THE DATA FILES

In the current directory of the project, the data files are created. These files are located using file explorer and are obtained for calculation of RCS. These data files can be directly loaded to the MATLAB code for performing the required tasks.

### EXPERIMENTAL RESULTS

To stimulate the antennas alone, the object is now deleted from the full scene and other steps are performed similarly. The transmitter and receiver antenna alone is shown in the fig 12.

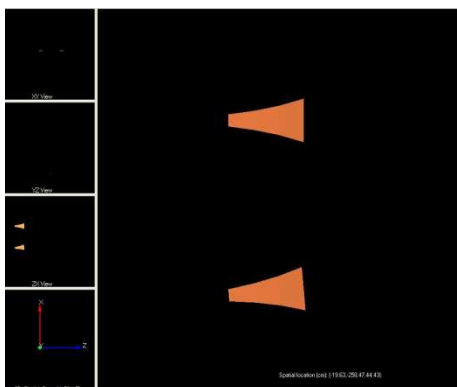


Fig 12 Stimulation of Tx and Rx antenna

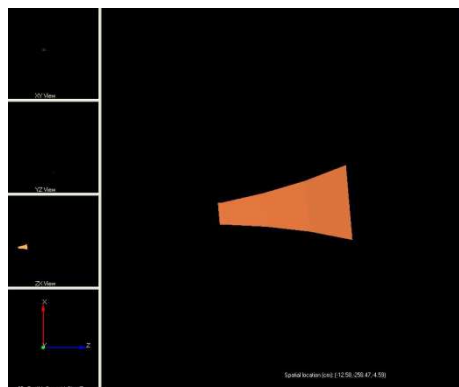


Fig 13 Transmitter alone

### WITH TRANSMITTER AND RECEIVER ALONE

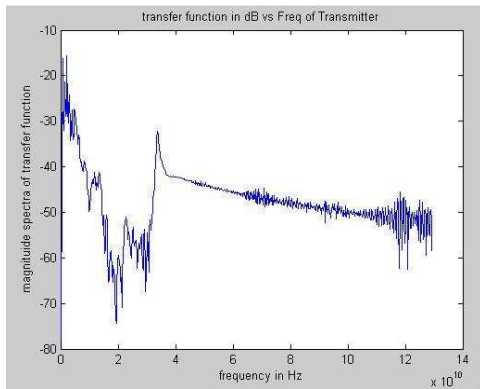
The mesh is generated for the above geometry and the project is saved. After that run calculations under the results tab is selected. Once the calculations are completed, the data files from the project directory are collected.

### TRANSMITTER ALONE

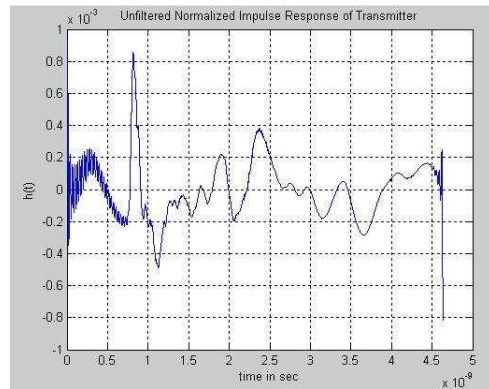
The transmitter antenna alone is stimulated and the results are obtained to find the response of the antenna. So that transfer function of the transmitter antenna alone can be found using deconvolution method shown in fig 13.

**RECEIVER ALONE**

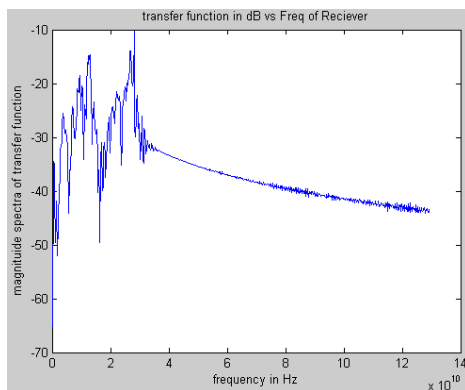
The receiver antenna alone is stimulated and the results are obtained to find the response of the antenna. So that transfer function of the receiver antenna alone can be found using de convolution method. Here for the receiver antenna, the input cannot be of discrete wave form, so the waveform of the source is given as scattered field plane wave shown in fig 14-21.



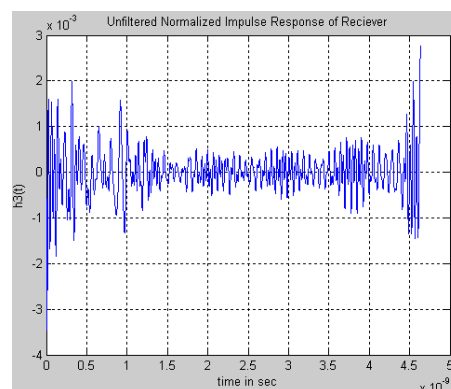
**Fig 14** Transfer func. dB Vs Freq of transmitter



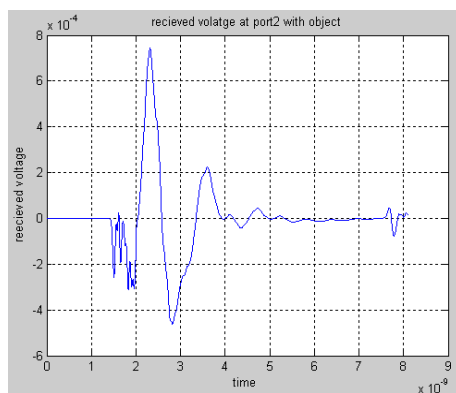
**Fig 15** Unfiltered Normalized Impulse response of transmitter



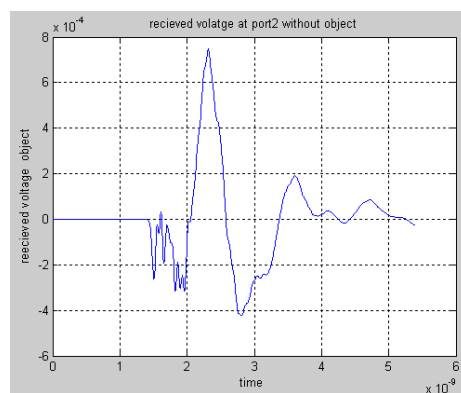
**Fig 16** Transfer func. dB Vs Freq of Receiver



**Fig 17** Unfiltered Normalized Impulse response of receiver



**Fig 18** Received Voltage at port 2 with object



**Fig 19** Received voltage at port 2 without object

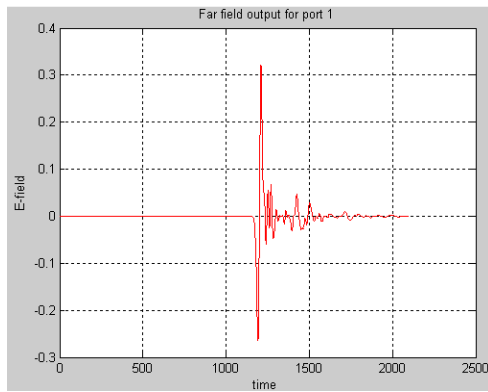


Fig 20 Far field output for port 1

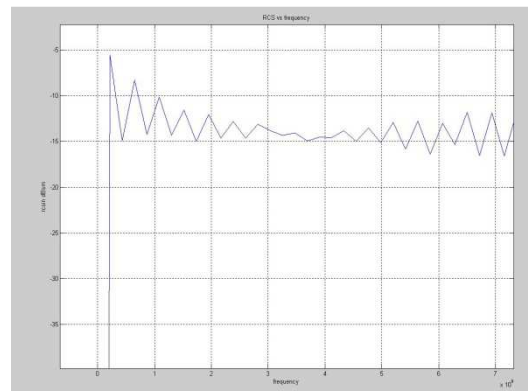


Fig 21 RCS of the sphere obtained

**INTERPRETATION AND DISCUSSIONS OF THE RESULTS**

**COMPARISON OF THE MEASURED AND PREDICTED RCS**

The measured RCS is compared with the ideal RCS of the corresponding object. In this case Sphere is used. The ideal output of the sphere is shown in the fig 22. Where the graph is plotted with RCS Vs time shown in fig 21.

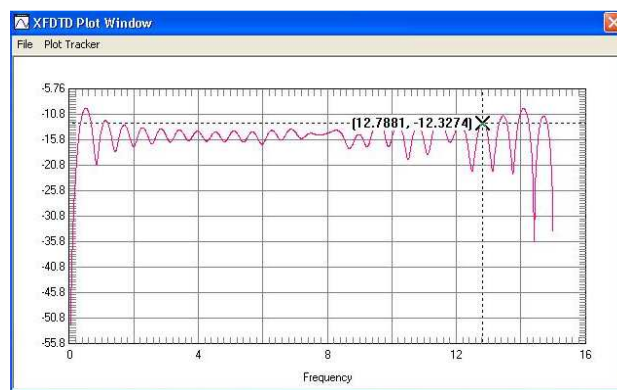


Fig 22 Ideal response (RCS) of a Sphere

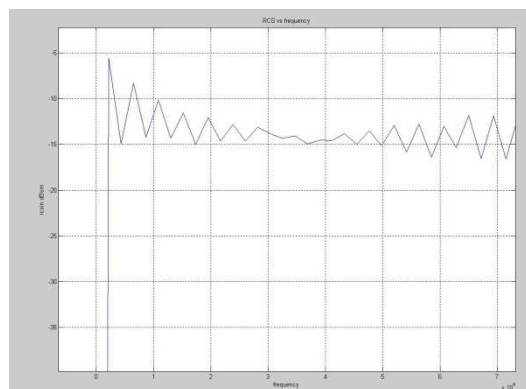
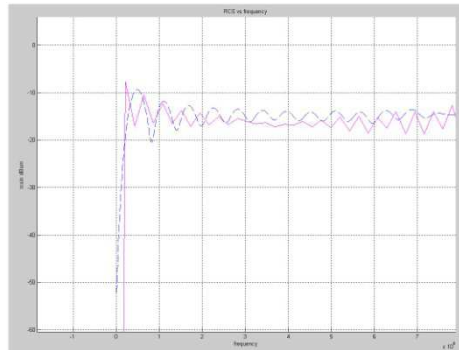


Fig 23 The RCS of sphere obtained from the stimulation tool xfdtd

The output calculated from the measured data from the xfdtd is plotted as shown in the fig 11.3 below; here the amplitude is slightly different due to some distortions caused by the antenna response. On closely examining the above two results of RCS of sphere, we can conclude by saying that RCS can be measured in Time domain unlike frequency domain,



where we need a anechoic chamber for testing. Furthermore the results obtained from the xfdtd tool can be improved in accuracy if the cell size is increased shown in fig 24.



*Fig 24 Comparison of Ideal case Sphere response with the obtained result*

## CONCLUSION

The time domain equipment can be used for high resolution Radar Cross Section measurements. The results are compared to calculated and measured frequency domain results and show a good agreement. Due the unavailability of the high performance system, the result in not exactly matching with the ideal response. If a high resolution system is used we can get the result as same as the ideal one. Instead of the system response measurement also a measurement of a (well known) reference object could provide the antenna response. This would avoid changing the measurement setup, which could be difficult in operational environments. Absolute RCS measurements can be performed by calibration of the measurement system with an exactly known object. This measurement provides a calibration curve which can be used to calibrate the object measurement.

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