RADAR CROSS SECTION OF SOME SIMPLE AND COLLECTED TARGETS TO BE USED FOR CLASSIFICATION

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ABSTRACT

The goal of this paper is to analyze the scattering properties of different kind of targets, from simple shapes to collected targets made up of several objects, from 400 MHz to 7400 MHz to be used as patterns in a Ground Penetrating Radar in the classification stage. The data have been collected in an anechoic chamber with a vector network analyzer (VNA) set to work as a Stepped Frequency Continuous Wave Radar (SFCW). The data are analyzed in frequency and time domain in order to picture the radar cross section dependency of frequency, incident angle, polarization and target's shape. The measurement have been carried out using a bistatic arrangement with two TEM horns for linear polarization and two spiral antennas for circular polarization.

1. THEORETICAL CONSIDERATIONS

Radar systems operation is based on the interaction of electromagnetic energy with physical objects. The radar radiates electromagnetic energy towards the target and measures the signal reflected by it. As a result of the increase use of radar systems there has been an increase interest in the reflectivity properties of both, objects one wants to detect, named targets, and objects one does not want to detect, named clutter. After the World War II more and more sophisticated applications of radar systems have emerged. However, no mater how sophisticated the radar system is, it can only discriminate the changes produced by a physical body to the signal, which are limited to four dimensions: frequency, amplitude, polarization and phase. Thus, a radar system should identify the changes of the transmitted signal due to the target and should neglect the changes produced by object of no interest (clutter).

The radar cross section (RCS) of a target can be viewed as a comparison of the strength of the reflected signal from a target to the reflected signal from a perfectly smooth sphere of cross sectional area of 1 m^2. Radar cross section is the measure of a target's ability to reflect radar signals in the direction of the radar receiver, i.e. it is a measure of the ratio of backscatter power per steradian (unit solid angle) in the direction of the radar (from the target) to the power density that is intercepted by the target. The conceptual definition of RCS includes the fact that not all of the radiated energy falls on the target. A target's RCS is most easily visualized as the product of three factors:

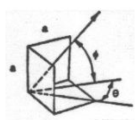
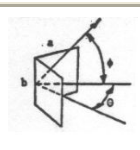
-projected cross section;
-reflectivity;
-directivity.

RCS is used in the two-way radar equation for representing the power reradiated from the target. Reflectivity is defined by the percent of intercepted power reradiated (scattered) by the target. Directivity represents the ratio of the power scattered back in the radar's direction to the power that would have been backscattered had the scattering been uniform in all directions (i.e. isotropically). RCS does not equal geometric area. For a sphere, the RCS = πa^2, where a is the radius of the sphere. There are three mechanisms that determine individually, or in combination the target reflection characteristics: diffusse reflection, specular reflection and retroreflection.

Simple shapes' RCS are known according to the ratio between their dimensions and the wavelength. Every more complex shape can be considered as the sum of simple shapes, nevertheless the complex shape's RCS will not be the sum of each simple shape's RCS: in fact, because of the coherence or no coherence between the different RCS, they can be added as well as subtracted.

According with [1] the radar cross section of different objects may be expressed as a function of their dimensions and the wavelength (Tab. 1)

Table 1

Geometry	Description Maximum RCS	Comments
	Square trihedral corner reflector $\sigma = \frac{12\pi a^4}{\lambda^2}$	Strongest radar return due to triple reflection of incident wave
	Right dihedral corner reflector $\sigma = \frac{8\pi a^2 b^2}{\lambda^2}$	Second strongest radar return due to double reflection of incident wave; decreases from maximum slowly with changing (Φ) and rapidly with changing (θ)

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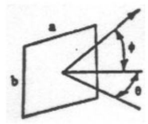
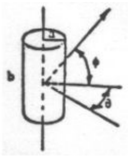
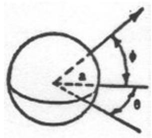
	Flat plate $\sigma = \frac{4\pi a^2 b^2}{\lambda^2}$	Third strongest radar return due to direct reflection of incident wave; decreases rapidly as incidence angle changes from perpendicular
	Right circular cylinder $\sigma = \frac{2\pi a b^2}{\lambda}$	Strong radar return as aspect (Φ) changes, but decreases rapidly as azimuth (θ) changes
	Sphere $\sigma = \pi a^2$	Produces the same isotropic return in all directions

2. MEASUREMENTS SET-UPS

The radar cross section evaluation of some simple shapes is intended to be used for a Ground Penetrating Radar in the classification stage so, the measurement set-up has to take into account the parameters of the radar. As the stepped frequency radar works from 400 MHz to 4845 MHZ in order to cover the bandwidth and to make measurements at the same frequency the VNA is set to work from 400 MHz to 7.4 GHz with a frequency step of 17.5 MHz. Another requirement is given by the antenna system which has to be the same. The measurements were made in an anechoic chamber with the VNA. The targets were illuminated with spiral antennas and TEM horns and the measurements have been carried out using both co-polarized and cross-polarized configuration.
The two antennas were placed at the same height from the ground such as to have the same influence of the ground reflection on each antenna. The two antenna systems are showed on fig.1.

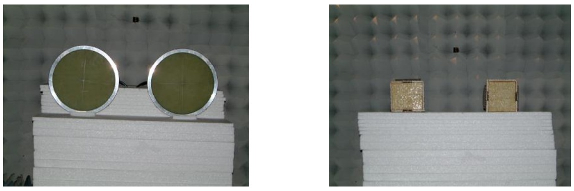


Figure 1 The measurement set up: spiral antennas on the left, TEM horns antennas on the right.

3. TARGETS' DESCRIPTION

Choosing different types ob objects for RCS evaluation is a sensitive task as it has to take into consideration a lot of factors. First one is the ratio between the objects' size and the wavelength. With this respect sometimes scaled measurements are needed because the size of the object would be too large. when evaluate the RCS of ships, airplane etc., for instance. Another factor is the surrounding environment which has to be as close as possible to the real one. From this point of view the best measurements are made in real conditions but most of the time they are not possible due to the costs involved and to the additional interferences which can not be completely removed. This is way the measurement in a special environment, as an anechoic chamber, are preferred. The third very important factor is the calibration reference. The calibration may be made directly using a reference or indirectly, knowing, usually theoretically, the value of the radar cross section. Taking into account the above reasons several objects have been measured. As was mentioned before the measurements have been carried out with two types of antennas, one circularly polarized and the other one linearly polarized. The geometrical dimensions of the objects have been chosen in accordance with the frequency range. The following objects have been used:
a. The sphere: Three kind of sphere have been measured: one of them is a tennis ball with 6 cm diameter, the other one is a 16 cm diameter lamp shade and the last one is a 26 cm diameter globe. All the sphere have been covered with tinfoil in order to increase their reflectivity.
b. Rectangular Plates: A square 25X25cm and **a** rectangular plate of 49 times 90 cm were used.
d. Collected targets: The collected target was made of two targets: the 16-cm sphere and the dihedral in vertical position 16 cm apart.

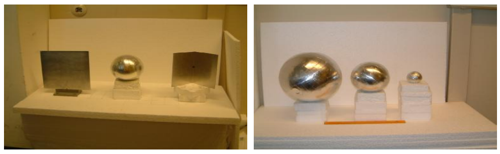


Figure. 2 Targets

4. SIMULATIONS RESULTS

In order to analyze the radar cross section of the targets some simulations have been made in monostatic and bistatic configuration. The results are showed on fig.3 and 4 for two spheres with different diameters and two plates. The first thing to notice on fig. 3 is that for the measured targets the radar cross section for monostatic and bistatic arrangement is quite the same. The second thing is that for the sphere the RCS has the three regions with respect of the ration between the sphere ray and the wavelength.: Rayleigh, Mie and optical. The third observation is that for both rectangular plates the RCS is in the Rayleigh region.

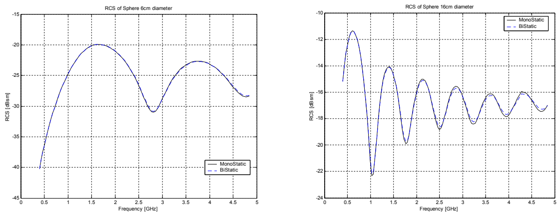


Figure 3. RCS versus frequency $E_{inc\_horizontal}$..Sphere 6 cm (left) and 16cm (right) diameter.

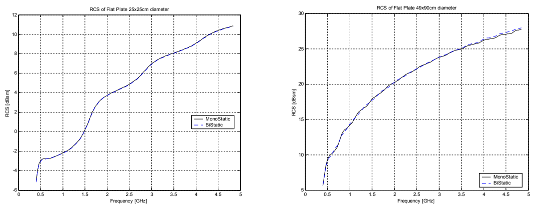


Figure 4. RCS versus frequency, $E_{inc\_horizontal}$. Square plate 25x25cm (left). Rectangular plate 49x90cm(right).

With respect of angle dependency for the plate as expected there a strong link between the RCS directivity and the dimension of the plate. As can be seen on fig. 5 the rectangular plate has higher directivity as well as higher side lobes than the square plate which has lower dimensions.

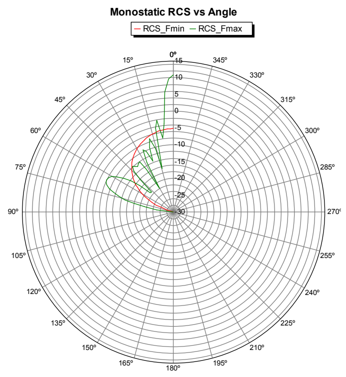


Figure 5. Square plate 25x25cm. RCS versus angle. $E_{inc\_horizontal}$

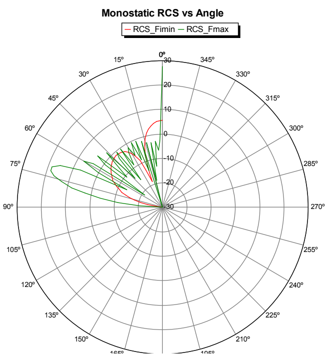


Figure 6. Rectangular plate 49x90cm. RCS versus angle. $E_{inc\_horizontal}$.

5. EXPERIMENTAL RESULTS

For each target the magnitude of the S21 parameter in frequency and time domain is analyzed. Although the measurements are made in an anechoic chamber there are still some reflections from the towers as well as from the walls of the chamber. In order to remove the contribution of these unwanted signals for each kind of target two measurements have been done, the first one with no objects (empty room) and the second with the object or object collection. Having the two sets of data the influence of the room can be removed by subtraction. The measurements of scattered field, and of RCS too, depend on the position of both antennas; as a matter of fact, because there are two antennas, the scattered field depend on the both antennas positions.

5.1 Frequency domain analysis

The measurements are carried out in frequency domain and the reflection from the towers as well as from the walls of the chambers are removed by ground subtraction (fig. 7 and 8) The transfer function of the antenna is embedded into the data and has to be removed, knowing the parameters of the two antennas systems.

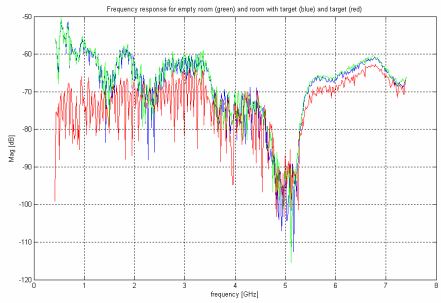


Figure 7. Frequency response of 26 cm sphere measured in anechoic chamber with spiral antennas(green-empty room, blue empty room with target, red –empty room)

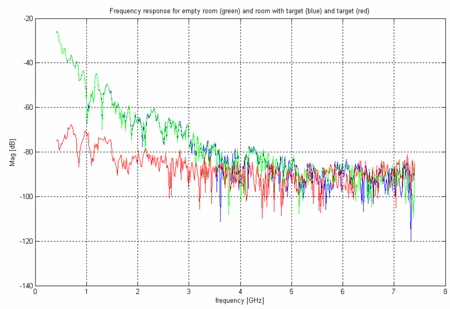


Figure 8. Frequency response of 26 cm sphere measured in anechoic chamber with TEM horn antennas (green-empty room, blue empty room with target, red –empty room).

The frequency response for rectangular plates, after removing the room contribution, measured with the two antenna systems, are showed on fig. 9 and 10, and the same measurement for collected target on fig. 11 and 12.

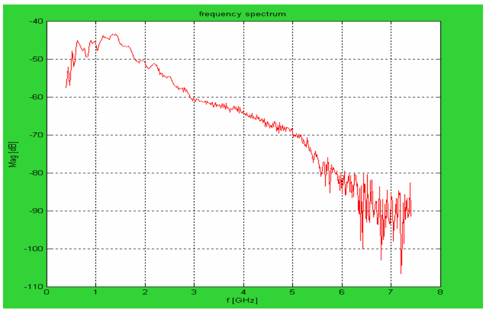


Figure 9.Frequency response of the rectangular plate measured with TEM horn copolar antennas.

Figure 10. Frequency response of the rectangular plate measured with spirals antennas.

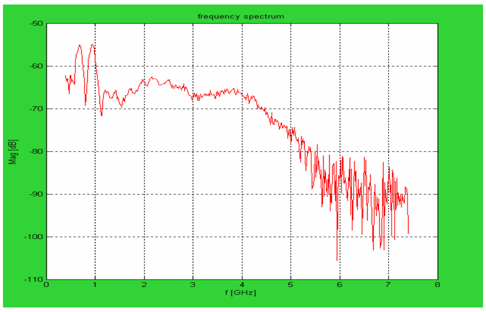


Figure 11. Frequency response of the collected target measured with TEM horn copolar antennas.

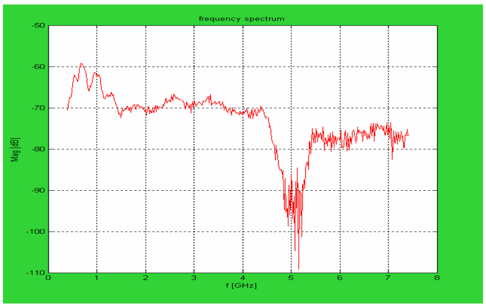


Figure 12. Frequency response of the collected target measured with spiral antennas.

It can be seen that that for frequencies above 5 GHz the TEM horn antennas have a very low sensitivity while the spirals have a gap around 5 GHz. The reflected signal goes down as frequency increases because of the antenna system behavior.

5.2 Time domain analysis

After removing the reflection from the surrounding the data are passed in time domain in order to get a range profile of the target (fig. 13-18) The time domain response is affected by the time response of the antenna systems. It can be seen on fig. 13 and 14 that the time response of the spirals is longer. It is due to the fact the Archimedean spiral is dispersive. A procedure to remove the delay within the antenna system is described in [2].

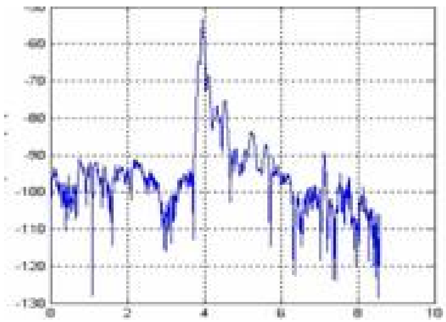


Figure 13. Time response for a rectangular plate measured with TEM horns (Oy axis signal level in dB, Ox axis distance in m)

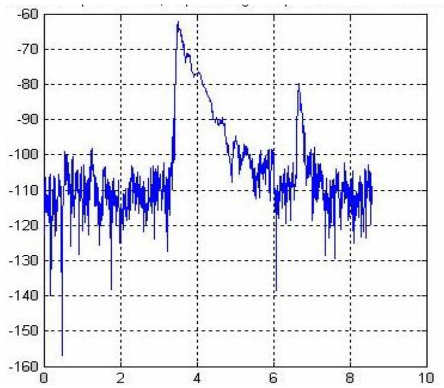


Figure 14. Time response for a rectangular plate measured with spiral antennas (Oy axis signal level in dB, Ox axis distance in m).

Although the sensitivity of the TEM horn is, at least for lower frequencies, more than 5 dB higher due to the circularly polarized waves the second bound can be identified on fig.4. The position of the object can be found by picturing the data in 3 D as presented on fig. 15.

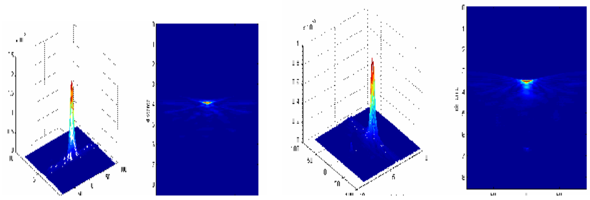


Figure 15. 3D range profile of rectangular plate measured with TEM horns (left) and spiral antennas (right).

Figure 16. Range profile for collected target measured with TEM horns.

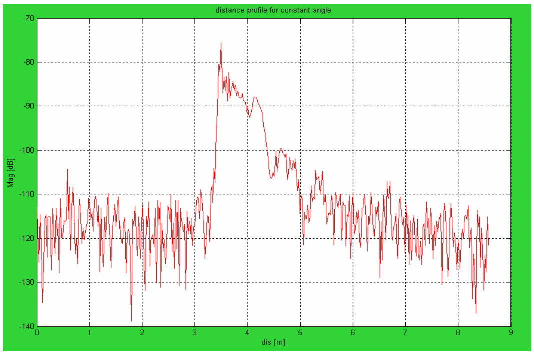


Figure 17. Range profile for collected target measured with spiral antennas.

In the case of the collected target range profile the delay within the antenna system is critical as it will provide the cross range resolution. The influence of dispersions within the antenna system against the resolution may be noticed on fig. 16 and 17 where it is obvious the lower cross resolution in the case of using spirals antennas.

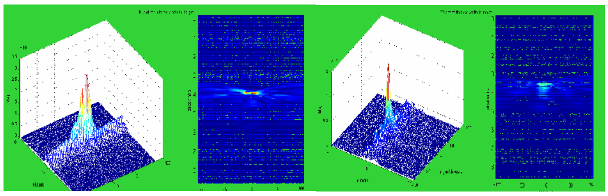


Figure 18. 3D range profile for collected targets measured with TEM horns (left) and spiral antennas (right).

6. ACKNOWLEDGEMENTS

We are in debt to Prof. Piet van Genderen from TUDelft for giving us the opportunity to acquire the data and to Keith Palmer for the help with FEKO simulations.

7. CONCLUSIONS

The measured data for different kind of targets: sphere with different diameters (6, 16 and 26 cm), rectangular plates and collected target have been analyzed in time and frequency domain.
All the measured data has to be used as references for data acquired with stepped frequency continuous wave radar and than included into a pattern recognition data base to be used in the classification stage.
The work is in progress and next step will be time delay and antenna transfer function removal [3].

8. REFERENCES

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[3] Nicolaescu I., Genderen P. van, Zijderveld J., Archimedean spiral antenna used for stepped frequency radar -footprint measurements, *Antenna Measurement Techniques Association AMTA 2002*, USA, pp 555-560, November 2002.