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Larsson, Christer; Ahnlund, Olof; Svensson, Carl-Gustaf

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# RCS MEASUREMENTS OF LO-TARGETS IN A HIGH CLUTTER ENVIRONMENT USING SAR AND ISAR

Christer Larsson
AerotechTelub AB, SE-581 88 Linköping, Sweden


Olof Ahnlund and Carl-Gustaf Svensson
Saab Bofors Dynamics AB, SE-581 88 Linköping, Sweden

## ABSTRACT

**Conventional radar cross-section measurement ranges have limitations. Indoor anechoic chamber ranges have limitations with respect to the size of the objects that can be measured. Outdoor RCS ranges cannot be used in bad weather conditions and also pose a security problem when the designs are classified or proprietary. Limitations in availability are also common for both outdoor and indoor ranges.**

**An alternative is to use a conventional lab area. The key to successful measurements of LO-targets in such high clutter environments is efficient coherent background subtraction.**

**Coherent background subtraction was performed for ISAR and SAR and compared to the zero-Doppler subtraction method for ISAR in this study.**

**The results from the measurements are compared with calculated results. We find that the ISAR and SAR techniques are comparable in performance but that it is advantageous to use ISAR for small objects due to practical reasons. We conclude that both SAR and ISAR can be utilized for LO targets.**

**Keywords**: SAR; ISAR; Radar imaging; RCS Measurements; Clutter reduction; Background subtraction

## 1. Introduction

Conventional outdoor and indoor measurement ranges have their built in limitations. The use of an outdoor measurement range is affected by bad weather such as snow, rain or wind. An outdoor range perimeter is also often difficult to secure when classified or proprietary objects are measured. An indoor anechoic chamber, on the other hand, has limitations with respect to the size of the objects that can be measured. Limitations in availability are also common for both outdoor and indoor ranges.

These limitations complicated the desired measurements on the Swedish low observable (LO) unmanned aerial vehicle (UAV) Filur using available conventional ranges. This led us to investigate other techniques. One alternative we wanted to investigate was if LO objects could be measured in an ordinary lab area, instead of using an outdoor measurement range or an indoor anechoic chamber.

There are many advantages of using a lab area while the main disadvantage of using an area without a silent zone is the high clutter levels.

## 2. Method

Coherent background subtraction [1] was performed in order to minimize the background influence on the measurements.

Another important matter to take into account when measuring LO objects is to use a support with low radar cross-section (RCS). We used a truncated pyramid shaped expanded polystyrene (EPS) support.

The background subtraction was performed using the following steps: First the empty EPS support was measured for the whole azimuth range. Secondly the target was placed on the support and measured. Angle and frequency dependent coherent background subtraction was then performed. Care had to be taken to not move the support when the measured object was placed on it in order to be able to subtract the support structure. Being able to subtract the EPS support was important for two reasons. The first reason was that the RCS of the EPS was not negligible at the RCS-levels we wanted to measure. The second reason was that when we subtracted the EPS we also subtracted the illumination shadow of the EPS at the same time. The last point meant that the only difference in the illumination of the background between object measurement and background measurement was the shadow of the measured object. For the objects we wanted to measure this was a very small effect.

Instead, or as a complement to coherent background subtraction, so-called zero-Doppler filtering [2, 3] can be used to reduce the influence of the static background. The zero-Doppler filtering used in our study was performed by removing a complex bias determined by taking the average of the RCS in a sliding angular window for each frequency and angle. We used a width of 15.5º for the sliding window, the same value as for the ISAR processing. We found that this value gave the best results. The method we used is similar to the one described in reference 3. Both coherent background subtraction and zero-Doppler filtering were investigated in this study.

Synthetic aperture radar (SAR) and inverse SAR (ISAR) were used for the described measurements. These imaging techniques are very powerful diagnostic tools when one wants to analyze low RCS scatterers. Furthermore, image gating can be used to evaluate the RCS of isolated scatterers on a target and to suppress clutter outside the region of interest. We used image-gating as the last stage in the clutter suppression process.

### 3. RCS Measurement

The measurements were performed in an AerotechTelub lab area in Linköping, Sweden. This area is an ordinary high clutter (storage shelves, steel cabinets etc) lab area, not ordinarily used for LO RCS measurements. The SAR rail and the antenna horns were set up at a distance of 17.4 m from the target in the lab area. The antennas were mounted 210 mm above the floor giving measured field maximum at 1.1 m height at the target at 5.65 GHz.

The antennas that were used were 4–8 GHz standard 17.5 dBi gain rectangular horns. See figure 1. The number of frequency steps, that gave an unambiguous range of 150 m, was adapted to the area room reverberations. We found that an unambiguous range of 150 m was sufficient to minimize these effects.

The measurement parameters are listed in Table 1.

An Agilent Performance Network Analyzer (PNA) was used for the measurements. The transmitted waveform was continuous wave (CW), without online hard or software gating.

**Table 1.** Measurement parameters.

| Measurement parameter | SAR | ISAR |
|---|---|---|
| Measurement range | 17.4 m | 17.4 m |
| Frequency range | 4.9–6.4 GHz in 1500 steps | 4.9–6.4 GHz in 1500 steps |
| Down-range unambiguity | 150 m | 150 m |
| Down-range resolution | >0.10 m | >0.10 m |
| Azimuth range | 5.41 m (17.7º) in 107 steps | 15.5 º for one image. 0.25º steps. |
| Elevation angle | 4.6º | 4.6º |
| Cross-range unambiguity | ~9.3 m | ~6.1 m |
| Cross-range resolution | >0.087 m | >0.10 m (with 15.5 º width) |
| Target height | 1.20 m | 1.40 m |
| Polarization | VV | VV |

**Table 2.** Measured objects.

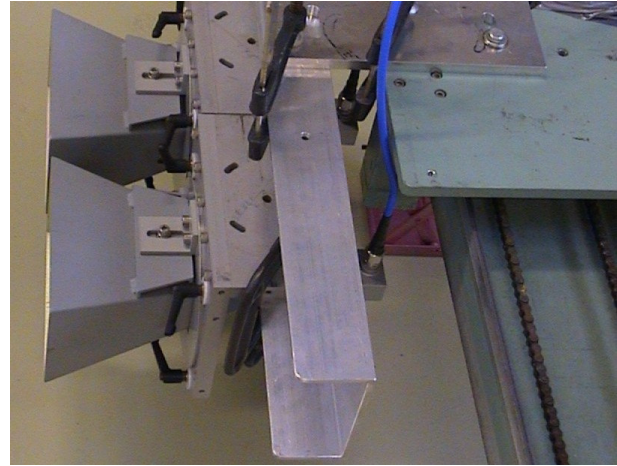| # | Measured objects |
|---|---|
| 1 | Three small steel spheres (bearing balls) with ∅=6.5 mm, 9.5 mm and 22 mm. The three spheres have an RCS of -30.3 dBsm, -42.3 dBsm and -52.4 dBsm, respectively @ 5.65 GHz |
| 2 | 5.2 mm thick Aluminum sheet LO object mock-up |



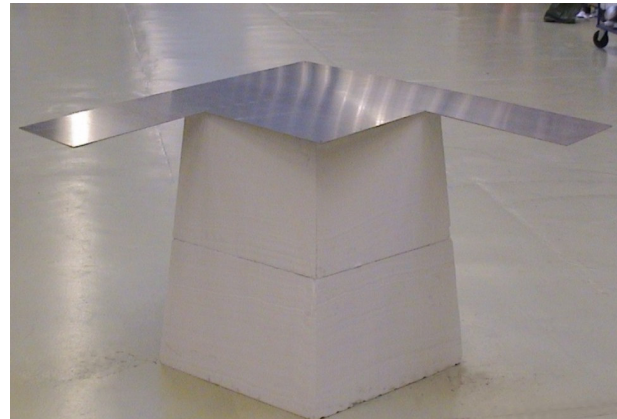**Figure 1.** The antennas mounted on the SAR-rail.



**Figure 2.** EPS support and LO target mockup (object 2).

The utilized support was built from two truncated pyramid shaped EPS blocks, see figure 2 where also the LO target mockup can be seen.

The antennas were mounted on a 5.5 m rail for the measurements. The rail provided the linear movement necessary for SAR mode collection of data. The SAR-rail can be seen in figure 3. This figure also shows object 1.

A turntable mounted under the EPS support was used for the ISAR measurements.

The measured objects that we used are listed in Table 2. Object 1 was chosen because of the low RCS and object 2 because of the similarity with a real LO object.
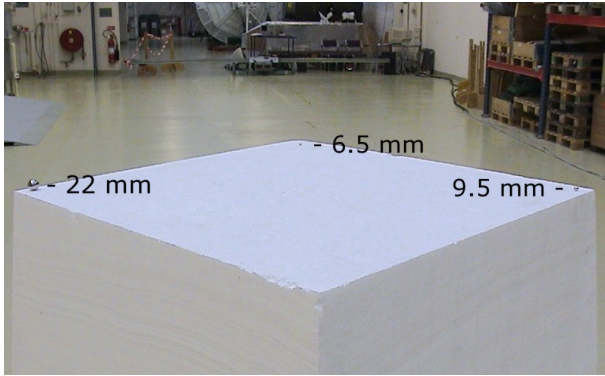
**Figure 3.** The spheres (object 1) on the EPS support. Also note the SAR-rail in the background.

This ground-bounce range had a height dependent field profile at the target. The field profile at the target was therefore measured using a field probe. Different target and calibration heights were used in the SAR and ISAR measurements due to the additional height of the turntable used for ISAR. The resulting amplitude offset was compensated for in the off-line calibration process.

## 4. RCS calculations and analysis

RCS calculations were performed for several of the measured objects. The Mie series formulas [4] were used when calculating the RCS of the small spheres. The method of moments (MoM) [5] was used when calculating the RCS of the LO target mock-up.

The program package Columbus [6], using generalized ISAR, was used for all ISAR processing and image gating. In addition, a SAR processing module was developed.

## 5. Results and discussion

Figure 4 shows a SAR-image of object 1, without background subtraction. The scattering from the background is apparent, particularly in the upper part of the figure. The two largest spheres can be seen near the middle of the figure. The smallest sphere is completely obscured by the background clutter.

Figure 5 shows the same data as in figure 4 but background subtracted. Here all three spheres can be seen, the smallest is at the position (0.2, -0.5).

We found that the measured background data could be used with good and consistent results for background subtraction if the target was measured within one hour from the background measurement.

Figure 6 shows object 1 collected in ISAR mode, background subtracted. The similarity with the SAR image in figure 5 is apparent.

Figure 7 shows image-gated data at 5.65 GHz from the same dataset as Figure 6. The figure also included dashed lines corresponding to the calculated RCS values for the spheres at this frequency. Each one of the spheres was

gated individually with a gate that was approximately 0.25 m$^2$. The calculated RCS values for the spheres are −30.3, −42.3 and −52.4 dBsm, respectively. The gated measured values in figure 7 are within ±1, ±2 and ±5 dB, respectively, compared with the calculated values. This shows that isolated scatterers of as low as −30 dBsm can be measured with good accuracy. We here define "good accuracy" to mean ±1 dB error due to the remaining background. The error becomes larger for lower RCS levels and the measurements therefore become less useful for quantitative measurements at lower levels. However, it is possible to use the method for diagnostic measurements to locate scatterers when the RCS is −50 dBsm. Diagnostic measurements are facilitated because we usually process images using the target coordinate system. The target is therefore imaged fixed as the azimuth angle to the radar changes. The small scatterer remains stationary in the target coordinate system while the remaining background clutter moves when one observes several consecutive images obtained at different angles. This means that small scatterers such as the smallest sphere become easier to detect.

It is possible to use the obtained values for the errors as an estimate of the background contribution (after background subtraction) assuming that the dominating error is the remaining background. Using figure 8 [7] we find that the measured errors are consistent with a remaining background level of approximately −50 to −55 dBsm for the area inside the image gate. Normalizing these results for the 0.25 m$^2$ gates to clutter levels for 1 m$^2$, by adding 6 dB to these results, we obtain an estimated (remaining) background level of −44 to −49 dBsm (for 1 m$^2$).

Image gating with 1×1 m$^2$ gates in the remaining background of the outside the target was also performed in the images from the dataset shown in figure 6. Some typical results are shown in figure 9. We find that the background is below −42 dBsm (for 1 m$^2$). This is consistent with the previously estimated result.

Figure 10 shows SAR processed data from a measurement of object 2. Figure 11 shows ISAR processed data from the measurement. Coherent background subtraction was used in both measurements using the same procedure as for object 1. SAR and ISAR give similar results for this object also. It is clear that the scattering from the back corners of the structure dominates at this azimuth and elevation angle for this polarization (VV).

Figure 12 shows the effect of zero-Doppler filtering of the ISAR data. Compared to figure 11, it can be seen that the middle back corner of the object is diminished because of the processing. The weak scattering from the "nose" also disappears when we use zero-Doppler filtering. This is a well-known problem with zero-Doppler filtering [3]. The method removes scattering belonging to the target that behaves as if it is clutter not belonging to the target i.e.

moves very little within the angular window. It can also be seen that some more of the volume clutter from the EPS support, in the center of the overlay, remains in the image compared to figure 11.

Figure 13 shows the comparison between image-gated and near to far-field transformed [6] data from the ISAR measurements on object 2, compared to calculated data on the same object. The correspondence between the data is very good. The level of the calibrated raw data including the antenna horn coupling is also shown in figure 13.
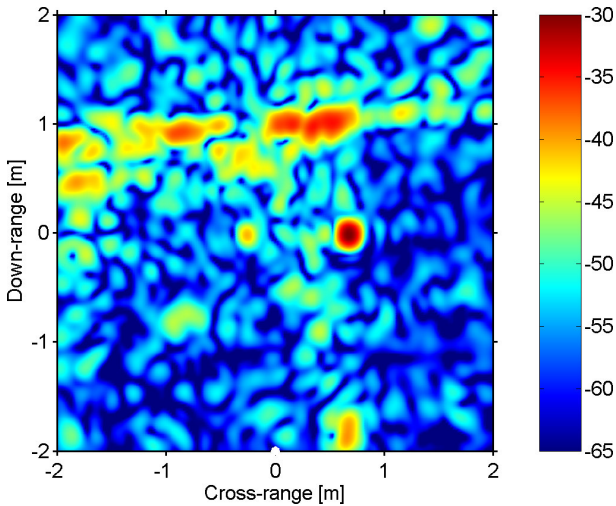


**Figure 4.** SAR image of object 1. The image was processed from raw data without coherent background subtraction. The data was Hanning filtered.
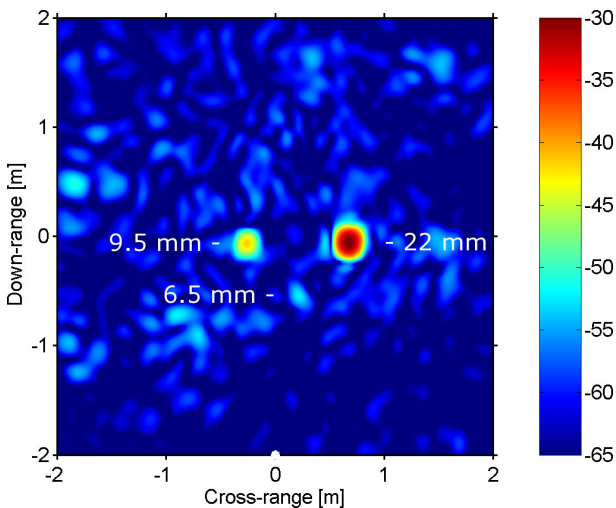


**Figure 5.** SAR image of object 1. The background was subtracted from the data. The data was Hanning filtered. The positions of the spheres are indicated in the figure.
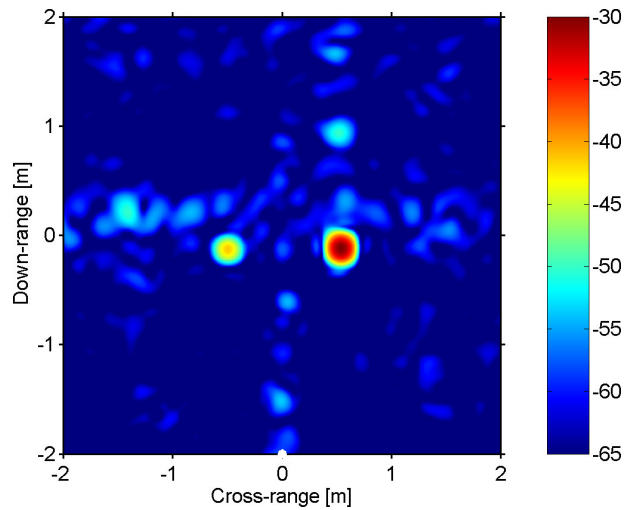


**Figure 6**. ISAR image of object 1. The background was subtracted from the data. The data was Hanning filtered.
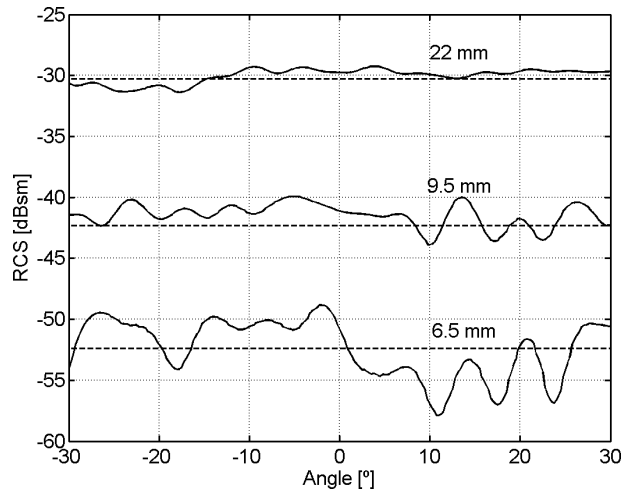


**Figure 7.** RCS obtained by image gating of the same data set as figure 7 for the three spheres in object 1. The solid lines show the measured values and the dashed lines show the values obtained from the Mie series expression.
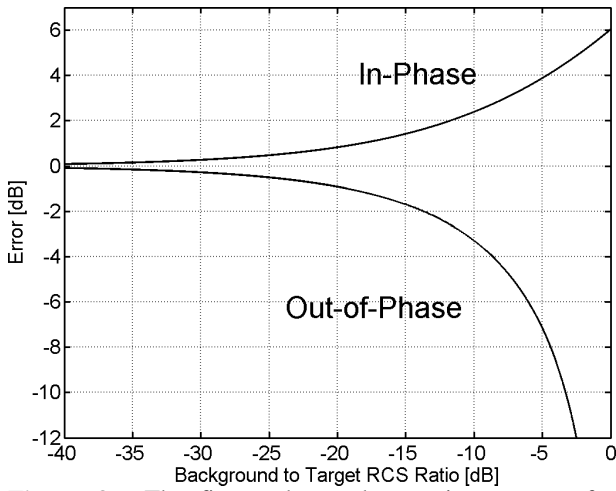
**Figure 8.** The figure shows the maximum error for different background to target ratios when the background component interferes constructively (in-phase) or destructively (out-of-phase) with the target component. Adapted from ref. 7.
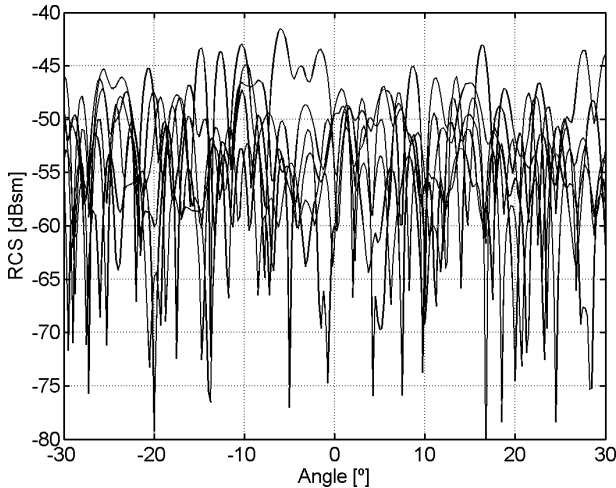


**Figure 9.** The figure shows image-gating results from six different 1×1 m² gates from the remaining background in the object 1 dataset (after coherent background subtraction) shown in figure 6. The gates were chosen such that they were outside the scattering contributions from the spheres.

### 6. Summary and Conclusions

We have investigated the use of a high-clutter ordinary lab area as an RCS measurement range. We find that SAR and ISAR imaging with coherent background subtraction are very similar in terms of resulting image quality. This means that the decision on which of the two methods to use can be based on practical considerations e.g. that it is easy to get 360° of azimuthal data using ISAR if the object can be placed on a turntable while on the other hand if the object is too large or heavy it can be measured using SAR.

We also find that coherent background subtraction combined with image gating enables us to measure objects with RCS of –30 dBsm (for 1 m²) with good accuracy. The background only contributes about 1 dB to the measurement error at that RCS level. The method can be used for diagnostic measurements on scattering features with RCS of –50 dBsm or lower especially if consecutive images are used.

The measured data after processing corresponds well with calculated data

This means that LO objects can be measured in an ordinary lab area if processing, coherent background subtraction and image gating is performed on the collected data.
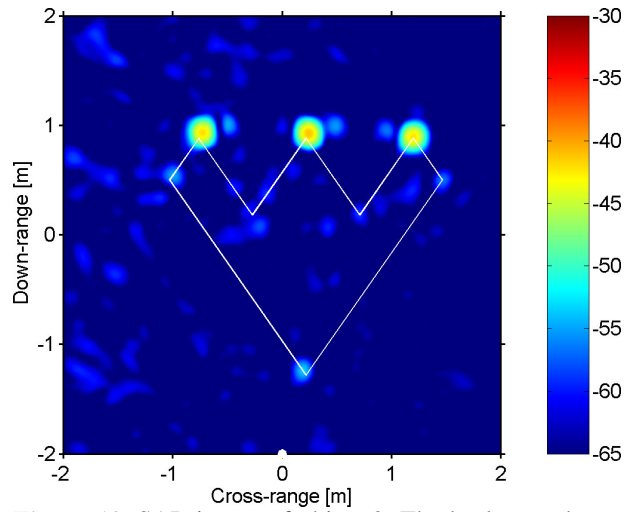


**Figure 10.** SAR image of object 2. The background was subtracted from the data. The data was Hanning filtered.
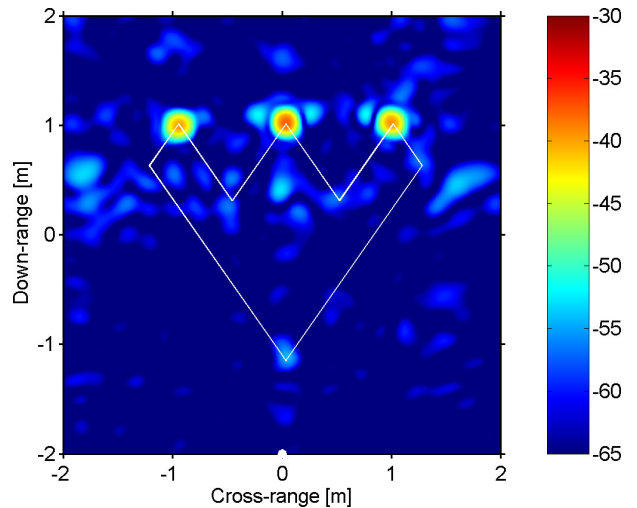


**Figure 11.** ISAR image of object 2. The background was subtracted from the data. The data was Hanning filtered.
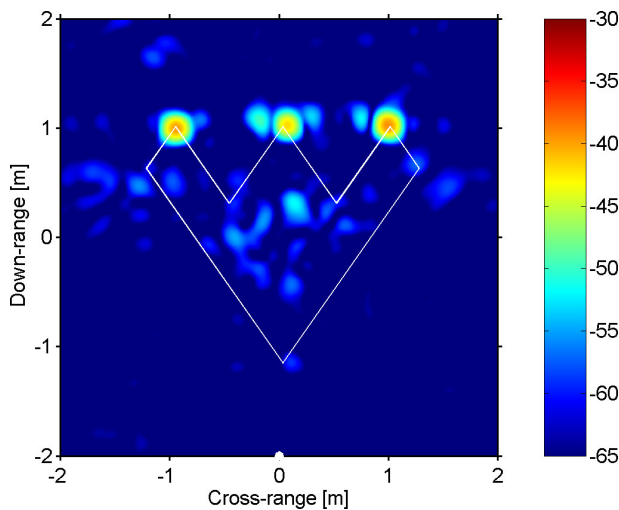
**Figure 12.** ISAR image of object 2. The data was processed using zero-Doppler filtering. The data was Hanning filtered.
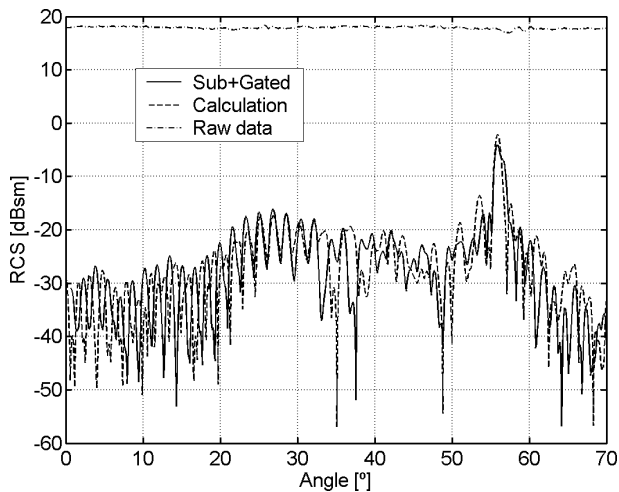


**Figure 13.** RCS obtained by image gating and near to far-field transformation of the same data set as figure 11 of object 2 (solid line), calculated RCS (dashed line) and the measured raw data before any processing or background subtraction (dot dashed line).

## 7. References

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