Report by QinetiQ:
"Performance Investigation of Marine Radar Reflectors on the Market"

This study was commissioned by MAIB as a result of the loss of the yacht *Ouzo* (see investigation report www.MAIB.gov.UK). The work, which has been carried out by **QinetiQ, Funtington,** is designed to better inform yachtsmen of the most appropriate choice of radar reflector for their craft from among those currently being produced. The quality of the study has been independently assessed for MAIB by two other experts in the field.

The QinetiQ tests have measured the radar cross section of the reflectors in a controlled environment. While this gives a very good comparison, it is <u>not</u> a comprehensive set of measurements, in that it cannot take into account different radar parameters, clutter, target RCS/range/aspect etc.

There are other studies that have been carried out in the past, the results of which have been widely published in the yachting press and other public fora.

Yachtsmen are offered the following advice:

- You are urged to carefully consider the findings of this study (along with other relevant research and studies) and then to fit the most effective and appropriate radar reflector for your circumstances.
- You may also like to bear in mind that, if fitting a passive reflector, a simple but effective rule might be to fit the largest reflector that your boat can sensibly display.
- Ensure your reflector is properly installed

Finally, it is <u>essential</u> for yachtsmen to be aware that, notwithstanding the type of radar reflector fitted, in certain circumstances their craft may still not be readily visible on ships' radars and thus they should always navigate with caution.

Performance investigation of marine radar reflectors on the market

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1 Introduction

1.1 General

This report has been written to compare a selection of radar reflector types in terms of their free space radar cross section (RCS) performance. It will allow yachtsmen and small boat owners to make an informed judgement regarding the type and size of reflector to fit in order to have the best chance of being detected by the radar of other ships.

The report describes free space radar cross section (RCS) measurements carried out on 9 radar reflectors and compares the results both graphically and statistically.

The report covers measurements taken at X-Band (9.41GHz) only. SOLAS Chapter 5 requires that all vessels over 300 tonnes carry an X Band radar and all ships over 3000 tonnes to also carry an S Band radar as well. All commercial shipping should be at least using X Band radar. For this reason all of the reflectors available are designed to operate at X Band. It should be noted however that passive reflectors will offer some performance at other frequencies including S Band. All the testing and the modelling presented in this report has been performed at X Band.

To assist with quantifying the performance the results have been compared to the RCS performance aspects of ISO8729 [1] and to its draft replacement [2], this was carried over a limited set of elevation angles. ISO8729 also covers environmental testing of radar reflectors which has not been covered by this report.

This report also includes a brief section dealing with radar propagation effects of target detection at sea relating to a commercial vessels ability to detect radar reflector of various sizes (RCS) carried by a yacht.

1.2 Effect of RCS on the probability of detection

Computer modelling of radar detection in an overwater environment was carried out to demonstrate the effect of altering a radar reflectors RCS will do to its probability of being detected on a typical navigational radar as fitted to SOLAS vessels and highlight the importance of a radar reflector with good performance.

The predictions were made using QinetiQ's naval electromagnetic environment simulation suite (NEMESiS). NEMESiS is an advanced propagation tool that simulates how microwave energy propagates through the atmosphere and interacts with the terrain.

These predictions are only valid for the specific case shown below; different radar antenna heights, sea conditions and target heights will affect the probability of detection against ranges shown.

Table 1 shows the modelling parameters for the radar.

Parameter	X-Band radar
Peak power (kW)	25
Pulse Duration (μs)	0.75
Transmit gain (dB)	26
Receive gain (dB)	26
Noise (W/Hz)	2.006e-20
Loss (dB)	5
Polarisation	HH
Azi Bw (deg)	2
Radar	Bridgemaster
CFAR	0.0001
Antenna height (m)	30

Table 1 Modelled radar parameters

The probability of detection at close ranges deteriorates as the incident sea state increases due to an effect known as sea clutter where radar returns are made by wave crests or other parts of a broken sea surface. These are presented on screen as random returns which can mask the presence of true target reflections. The clutter responses can have a significant RCS but do not have any consistency of location so modern radar does have anti clutter techniques to improve discrimination but these will always work better if the true target has an RCS above a certain threshold.

The parameters shown in table 2 were used to model the reflector and the seas state for this scenario.

Parameter	Value
Target RCS (m^2)	$1m^2$, $2m^2$, $4m^2$ & $10m^2$
Target height (m)	4m
Swerling	1
Wind speed (knots)	16
Land clutter	Necaps
Sea Clutter	GIT [3]

Table 2 Modelled target and scenario parameters

The Naval Environmental Clutter, Attenuation and Propagation Specification (NECAPS) describes a 5ft swell as a moderate to rough sea state, which is created by a wind speed of approximately 16 knots. This parameter has been used to simulate the 5ft swell in the model.

Figure 1 shows the results of this modelling. It is generally accepted that a competent radar operator will recognise a true target (as apposed to clutter returns) if it paints in the same place for at least 5 out of 10 radar scans (50% paint). This definition of detection is also used by an ARPA (automatic radar plotting aid) to both detect and maintain track of a target.

The graph in figure 1 shows the effects of the clutter field as the highly variable response to each target RCS in the region up to 4nm, this is actually caused by both clutter and multipath (another phenomena of overwater propagation), further explanation can be found in ref [4].

The modelling shows that when using a radar reflector with an RCS of 1m^2, 50% probability of detection is only achieved between 2.6 and 3.1nm and again between 4.6 to 9.1nm. More importantly it clearly illustrates the beneficial effects of increased RCS and consistency of return, particularly at close range.

For radar reflectors with an RCS of 2m^2 and above the probability of being tracked inside 2nm increases significantly.

With a radar reflector of RCS of at least 4m^2 50% probability of detection is achieved beyond 10nm from 4.5nm.

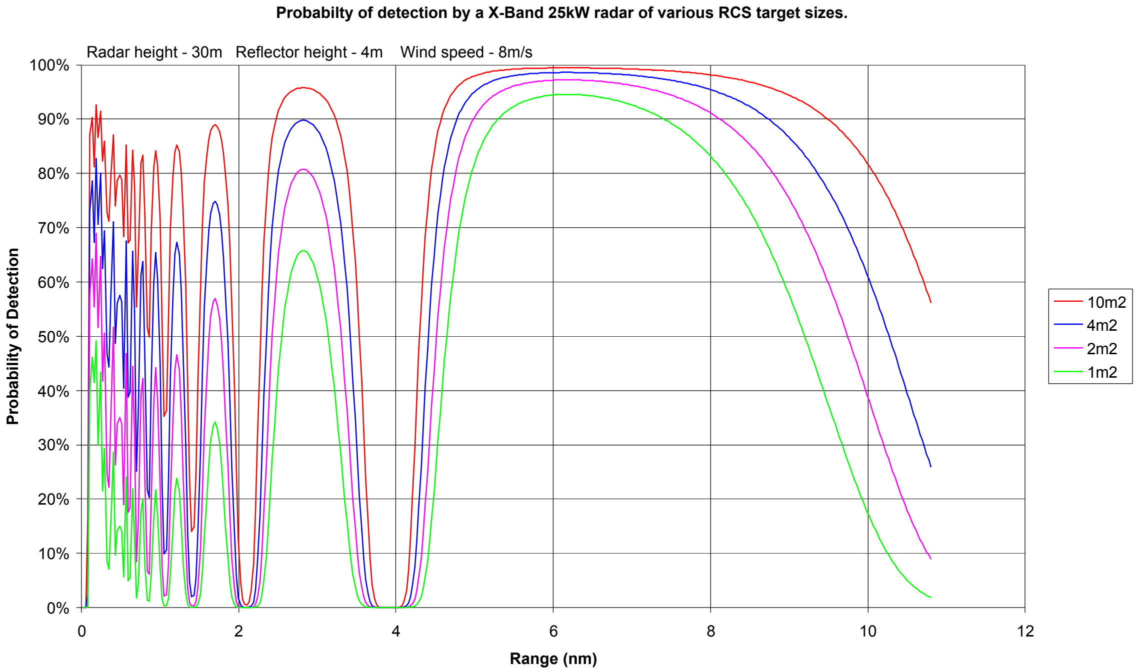

Figure 1 Plot showing the probability of detection when tracking targets of different RCS vs. range.

2 Description of Test

2.1 Items for test

9 reflectors were chosen for the testing and comparison to represent a cross section of radar reflectors available in the UK. These reflectors were generally sourced from local chandlers and offer a typical performance. Where it was difficult to source a reflector, data has been taken from a previous MCA report produced in 2003 and the results used for comparison.

These targets are described in the table below, table 3, and the following sections;

Reflector	Dimensions	Weight	Price
Plastimo 16" Octahedral	300 x 300 x 415mm	0.65kg	£16
Plastimo 4" Tube	590 (L) x 100mm (D)	0.9kg	£40
Davis Echomaster	320mm diameter		£60
Viking Large Tri-Lens	160 x 160 x 80mm	5.5kg	£300
Viking Standard Tri-Lens	120 x 120 x 60mm	2.5kg	£130
Echomax 230	610 (L) x 248mm (D)	2.4kg	£130
Firdell Blipper 210-7	595 (L) x 240mm (D)	1.8kg	£130
Sea-Me	416 (L) x 50mm (D)	0.4kg	£500
POLARef 11	279mm (D)	≈5kg	≈£2000

Table 3 Radar Reflectors supplied for the testing regime.

The data presented above was sourced from manufacturers and chandlers websites; the prices should be taken as approximate at the time of report issue.

2.1.1 Plastimo 16” octahedral reflector

Plastimo 16” is a push fit octahedral reflector constructed from three aluminium diamonds slotted together, these panels are locked in placed by plastic corners pieces. This reflector only had mounting holes for an upright position (not the generally recommended “catch rain” position). The Plastimo 16” Octahedral reflector is pictured in this mounting position in figure 2.

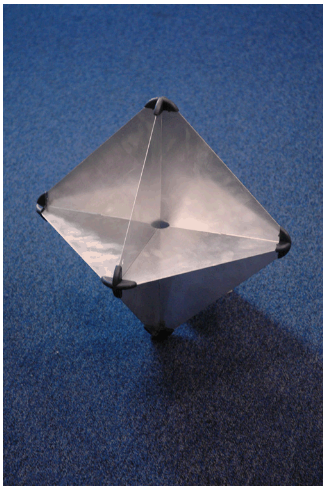

Figure 2 Photo of the Plastimo 16” Octahedral reflector

2.1.2 4” Plastimo tube reflector

4” tube is the larger of the two tube reflectors currently on the market; it consists of an array of dihedrals stacked in the vertical plane which are encompassed within a clear plastic body. Manufacturers instructions show it vertically mounted. A Plastimo tube reflector is shown in figure 3.

Figure 3 Photo of the Plastimo Tube reflector.

2.1.3 Davis Echomaster

The Davis Echomaster is a push fit octahedral reflector constructed from three aluminium circular panels which are slotted together, these panels are locked in placed by plastic corners pieces. This octahedral is designed to be mounted in the catch rain position, and is shown below in this position in figure 4.

Figure 4 Davis Echomaster radar reflector

2.1.4 Viking Large Tri-Lens

The Viking Large Tri-Lens is the largest of the Viking (also marketed as Rozendal) Tri-Lens range of radar reflectors, it uses three luneberg type lens reflectors spaced 120° apart and is encompassed by a moulded plastic case. At 5.5kg it is the heaviest reflector currently on the market. The large Tri-lens is pictured below in figure 5.

Figure 5 Photo of the Large Tri-Lens reflector

2.1.5 Viking Standard Tri-Lens

The Viking Standard Tri-Lens is the medium sized Tri-Lens, it utilises three luneberg type lens reflectors spaced 120° apart and is encompassed by a moulded plastic case. The Standard Tri-lens is pictured below in figure 6.

Figure 6 Photo of the standard Tri-Lens.

2.1.6 Echomax 230

The Echomax 230 reflector comprises a vertical stack of three aluminium corner arrays enclosed in a plastic case. It relies upon interactions between each of the arrays to produce large peak responses. This reflector is only one supplied which has been type approved to ISO8729 [1]. The Echomax 230 reflector is pictured in figure 7.

Figure 7 Photo of Echomax 230 reflector

2.1.7 Firdell Blipper 210-7

The Firdell Blipper is outwardly of a similar design to that of the Echomax 230 but it uses a vertical spiral array of 7 corners. It relies upon interactions between each of the corners to produce large peak responses. The reflector is encompassed within a plastic case. The Blipper 210-7 reflector is pictured in figure 8.

Figure 8 Photo of a Firdell 210-7 reflector

2.1.8 Sea-me Radar Target Enhancer (RTE)

The Sea-me RTE is an active system, which receives a radar pulse, amplifies it and re-transmits it. It contains a receive antenna, amplifier and transmit antenna contained within a plastic case/radome. This transponder will only perform against X-Band radars; unlike the passive reflectors it will not offer any performance in S-Band. The Sea-me RTE is shown below in figure 9.

Figure 9 Photograph of the Sea-me RTE.

2.1.9 POLARef 11 radar reflector

The POLARef 11 reflector is a precision radar target generally used for the calibration of radars. It is a luneberg lens which operates over its complete azimuth range. This reflector is usually made to order but has been included as a baseline to demonstrate what is achievable from a passive reflector. The POLARef 11 reflector is shown in figure 11.

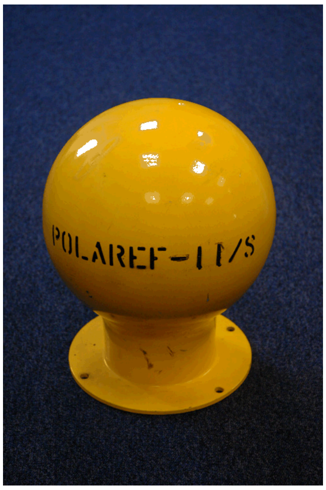

Figure 10 Photograph of the POLARef 11 reflector.

2.2 Measurement set-up

2.2.1 Anechoic chamber

RCS measurements were carried out on the radar reflectors in the anechoic chamber at QinetiQ Funtington (figure 11). The chamber is a 15m long, 6m wide and 5m high screened room clad with radar absorbent material (RAM). The radar transmit and receive horns are mounted side by side and are positioned in the middle of the wall at one end of the chamber. At the other end, the reflector is positioned at the same height as the horns on a radar invisible mount (polystyrene cone) fitted to an azimuth-over-elevation positioner which is screened by a small RAM wall.

The facility uses a HP8530 vector network analyser with a HP8511A frequency converter unit as the calibrated radar. The system is computer controlled and the positioner data is synchronised with the measured RCS, which is plotted in real time. The RCS system is calibrated using a 300mm-diameter sphere with an RCS of $0.039m^2$. The background clutter from the chamber is removed using an automated background subtraction method measured when the chamber is empty.

The equipment used for these measurements are calibrated annually, they were last calibrated on the 7^{th} of August 2006. Within this facility, over this frequency range, RCS measurements can be made to an accuracy of ±0.5dB.

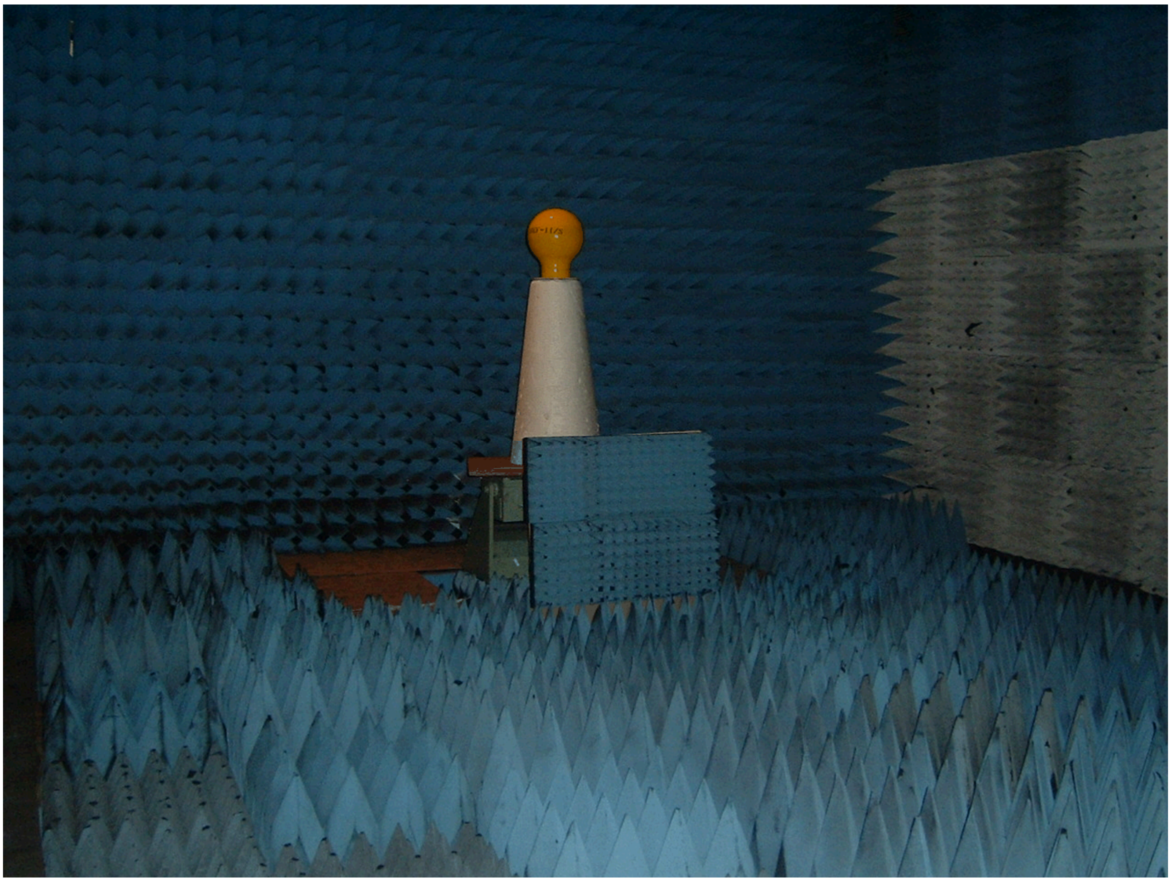

Figure 11 Picture of a POLARef in the Anechoic Chamber at QinetiQ Funtington

2.3 Test matrix

The typical test parameters used for this measurement program were;

- Azimuth angles = 0˚ to 360˚ recorded every 1˚
- Frequency = 9.41GHz (centre of maritime X-Band frequency band)
- Polarisation = Horizontal
- Elevation angles = minimum of 0˚, 5˚, 10˚ & 15˚

For the stacked array radar reflectors (Echomax and Firdell) additional tests were carried out over ±3° in accordance with ISO8729[1], this data was combined to produce the 0° plot.

3 Description of Results

3.1 General

In order to compare the reflectors, azimuth RCS measurements were taken over a number of elevation angles. Based on these measurements, RCS graphs and statistics have been produced showing:

- maximum RCS in m^2
- average RCS in m^2
- total angle above $2.5m^2$ (at 0° elevation ISO8729 [2] requires this to be >240°)
- total angle above $0.625m^2$ (for all other elevation angles, ISO8729 [2] requires this to be >240°)
- Stated performance level – this is the lowest level which a 10° null width occurs (for the replacement [3] to ISO 8729 this is required to be $>7.5m^2$ up to 10° elevation for motor cruisers and sailing vessels such as catamarans which are designed for small angles of heel and 20° elevation for all other sailing vessels)

These statistics are based around the performance requirements of the current ISO8729 specification [1] and the future ISO 8729 Ed. 2. The draft revision is based on IMO Resolution MSC.164(78) which provides the concept and level for the Stated Performance Level (SPL) [2].

3.2 Plastimo 16" Octahedral reflector

The RCS of the Plastimo 16" radar reflector over the elevation angles 0˚, 5˚, 10˚, 15˚ & 20˚ is shown in figures 12 and 13 below. They show the RCS of the reflector when mounted in the upright and the catch rain positions.

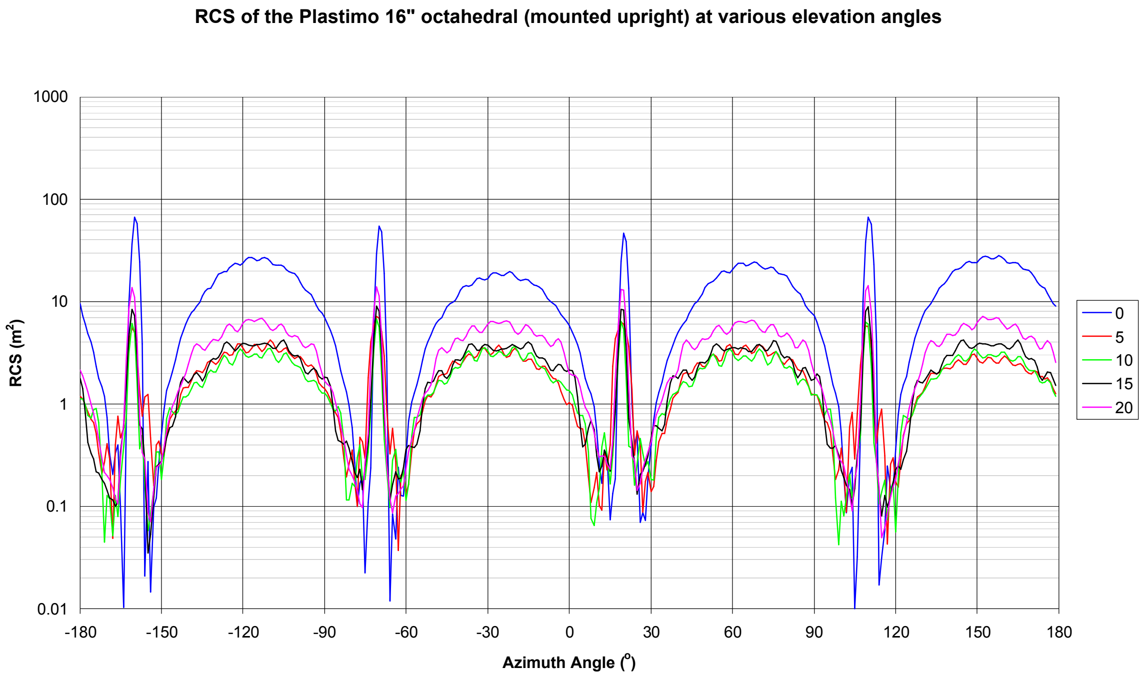

Figure 12 Plot of linear RCS of the Plastimo 16" Octahedral reflector when mounted in the upright position.

In the upright position (as designed) the peaks are very large for a small reflector and reach an RCS of $66m^2$ at 0˚ elevation and the shape is very regular. The drawback with this reflector mounted in this fashion is the very large nulls between the peaks. At 0˚ elevation the stated performance level (taken from table 4) is $1.29m^2$, this value gets worse as the elevation angle is increased.

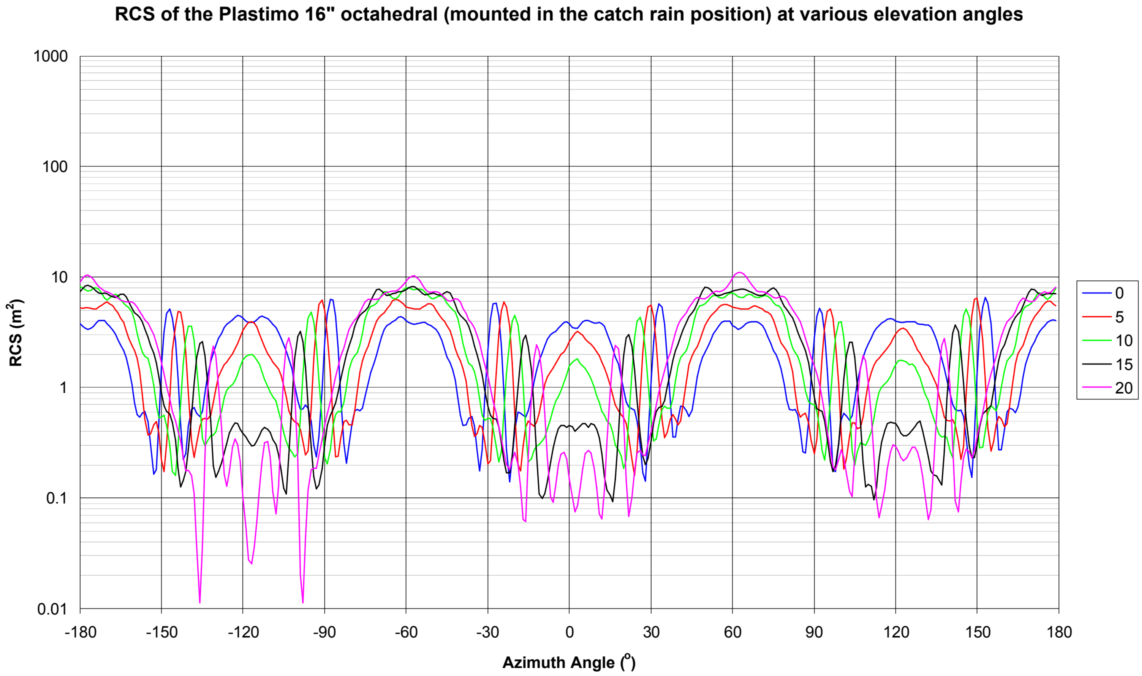

Figure 13 Plot of linear RCS of the Plastimo 16" Octahedral reflector when mounted in the catch rain position.

When in the catch rain position the RCS has lower peaks but is more balanced with azimuth angle variation, it has six peaks each having an RCS of $4m^2$ at 0° elevation. As the elevation angle increases it is noticeable that three of the six lobes increase in RCS to $10m^2$, whereas the other three decrease to levels around $0.5m^2$. The average RCS is more consistent over the elevation range in the catch rain position.

Reflector	**Elevation Angle**	**Maximum RCS (m^2)**	**Average RCS (m^2)**	**Total angle > $2.5m^2$**	**Total angle > $0.625m^2$**	**Stated Performance Level (m^2)**
Plastimo 16 inch Octahedral	0	66.76	11.92	264	302	1.29
Plastimo 16 inch Octahedral	5	25.53	1.97	132	280	0.54
Plastimo 16 inch Octahedral	10	7.17	1.75	117	277	0.47
Plastimo 16 inch Octahedral	15	4.40	2.17	153	258	0.30
Plastimo 16 inch Octahedral	20	6.79	3.41	212	280	0.47
Plastimo 16 inch Octahedral in catch rain position	0	6.50	2.32	171	279	0.81
Plastimo 16 inch Octahedral in catch rain position	5	6.38	2.44	148	258	0.82
Plastimo 16 inch Octahedral in catch rain position	10	8.15	2.77	138	263	0.61
Plastimo 16 inch Octahedral in catch rain position	15	8.42	2.87	149	215	0.43
Plastimo 16 inch Octahedral in catch rain position	20	11.07	3.07	152	214	0.26

Table 4 Statistics of the Plastimo 16" Octahedral reflector in its 2 mounting positions.

3.3 Plastimo 4" Tube reflector

The RCS of the Plastimo tube radar reflector over the elevation angles 0˚, 1˚, 5˚, 10˚ & 15˚ is shown in figure 14. At 0˚ the RCS response looks fair with 8 lobes achieving between $6m^2$ and $9m^2$, but as soon as the reflector is tilted even to as little as 1˚ these maxima fall away to levels of between 0.4^2 and $4m^2$. As the elevation angle increases the performance degrades even more, at 5˚ and 10˚ the stated performance level is $0.03m^2$ and there is only 1˚ of azimuth where both plots exceed $0.625m^2$. The statistics for the Plastimo 4" Tube reflector are shown in table 5.

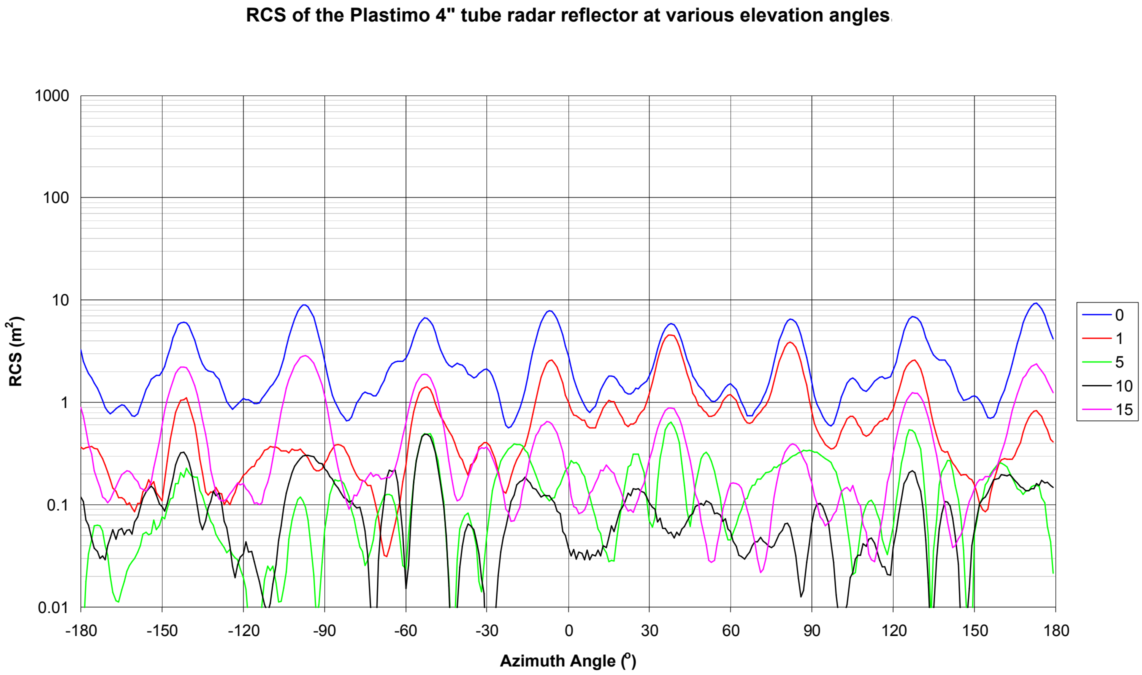

Figure 14 Plot of linear RCS of the Plastimo 4" Tube.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > $2.5m^2$	Total angle > $0.625m^2$	Stated Performance Level (m^2)
Plastimo 4 inch Tube	0	9.30	2.62	121	354	0.95
Plastimo 4 inch Tube	1	4.58	0.76	22	144	0.12
Plastimo 4 inch Tube	5	0.64	0.15	0	1	0.03
Plastimo 4 inch Tube	10	0.49	0.10	0	0	0.03
Plastimo 4 inch Tube	15	2.86	0.50	6	88	0.11

Table 5 Statistics of the Plastimo 4" Tube reflector.

3.4 Davis Echomaster Reflector

The RCS of the Davis Echomaster octahedral radar reflector over the elevation angles 0˚, 5˚, 10˚ & 15˚ is shown in figure 15. At 0˚ the RCS response shows 6 lobes achieving between 2.5m^2 and 5m^2. As the reflector is elevated it is noticeable that three of the six lobes increase in RCS to 7m^2, whereas the other three decrease to levels around 0.5m^2. The stated performance level is around 0.4m^2 until the reflector is heeled over to 15˚ where it drops to 0.2m^2. The statistics for the Davis Echomaster are shown in table 6 below

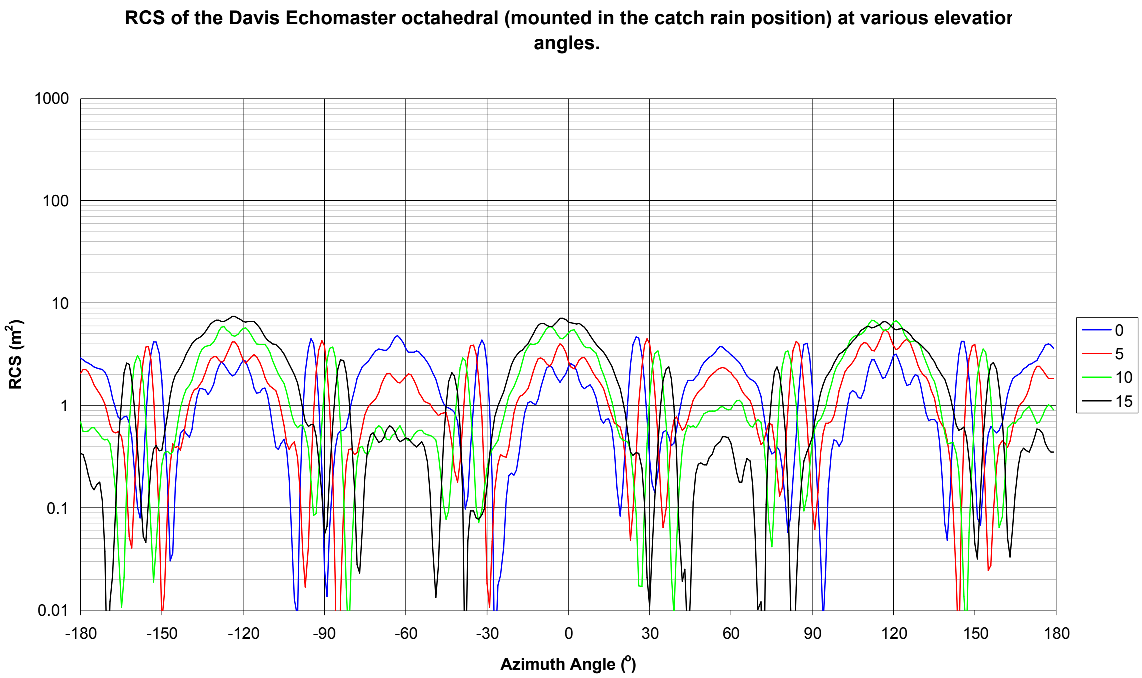

Figure 15 Plot of linear RCS of the Davis Echomaster octahedral radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Davis Echomaster	0	4.82	1.60	88	252	0.37
Davis Echomaster	5	5.47	1.57	82	252	0.45
Davis Echomaster	10	6.74	1.81	109	223	0.40
Davis Echomaster	15	7.47	2.08	119	193	0.21

Table 6 Statistics of the Davis Echomaster radar reflector.

3.5 Large Tri-Lens Reflector

The RCS of the Large Tri-Lens radar reflector over the elevation angles 0˚, 5˚, 10˚, 15˚ & 20˚ is shown in figure 16. This plot shows the RCS to be consistent with elevation, there are three very wide lobes with an RCS of between 8m^2 and 9m^2.

The average RCS and stated performance level are both high around 5m^2 and 4m^2 respectively also the reflector has most of its returns over 2.5m^2. The statistics are shown in table 7.

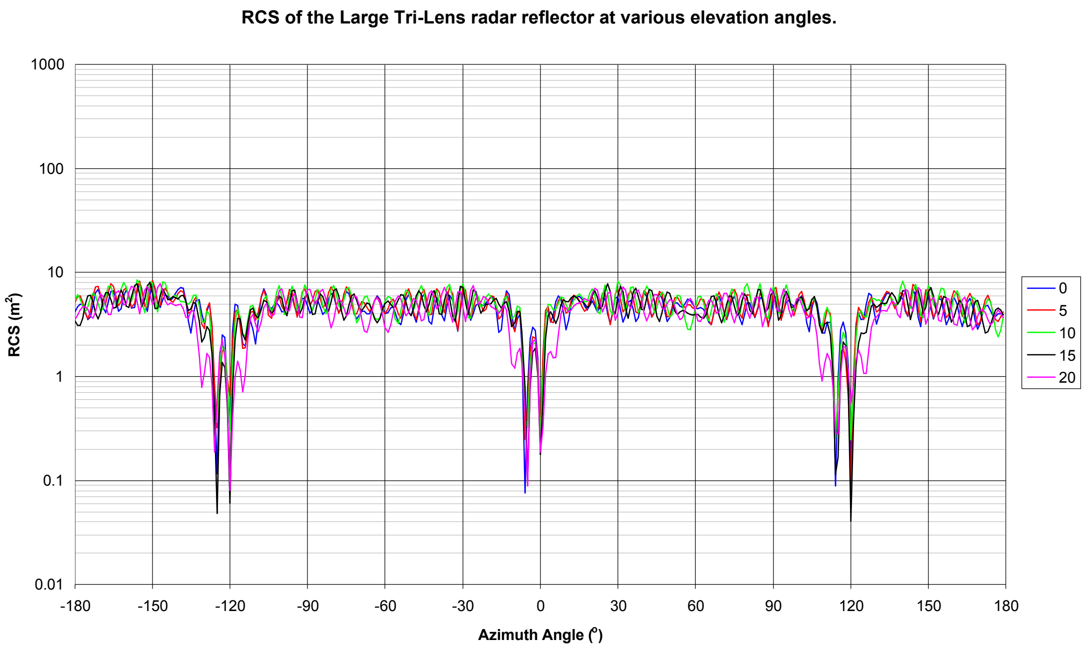

Figure 16 RCS of the Large Tri-Lens radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Large Tri Lens	0	7.94	4.49	338	354	3.36
Large Tri Lens	5	8.42	4.81	332	353	4.04
Large Tri Lens	10	8.53	4.97	331	352	3.72
Large Tri Lens	15	8.00	4.59	326	349	2.16
Large Tri Lens	20	7.85	4.26	300	348	1.95

Table 7 Statistics of the Large Tri-Lens radar reflector

3.6 Standard Tri-Lens Reflector

The RCS of the Standard Tri-Lens radar over the elevation angles 0˚, 5˚, 10˚, 15˚ & 20˚ is shown in figure 17. The RCS level remains fairly consistent with changes of elevation angle, there are three very wide lobes with an RCS of between 2m^2 and 4m^2.

The average RCS and stated performance level are both high around 2m^2; the reflector has most of its returns over 0.625m^2. The statistics are shown in table 8.

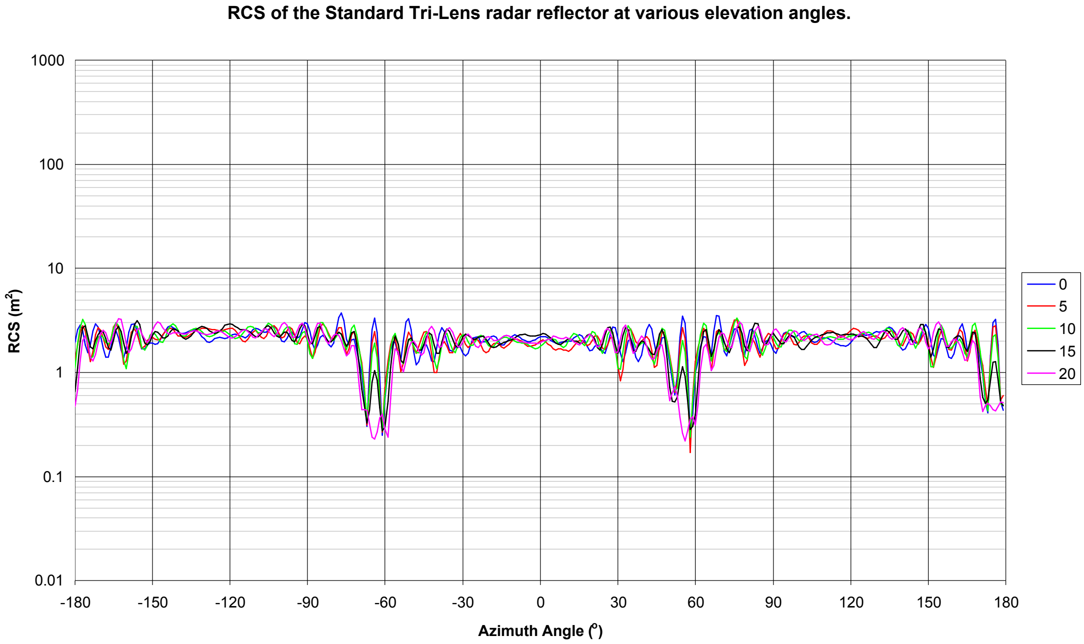

Figure 17 RCS of the Standard Tri-Lens radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Tri Lens Standard	0	3.76	2.04	63	349	2.13
Tri Lens Standard	5	3.20	2.00	59	352	1.86
Tri Lens Standard	10	3.32	2.03	59	350	1.93
Tri Lens Standard	15	3.15	2.03	59	341	1.04
Tri Lens Standard	20	3.31	1.97	57	327	0.44

Table 8 Statistics of the Standard Tri-Lens radar reflector

3.7 Echomax 230 Reflector

The RCS of the Echomax 230 radar reflector is shown below in figure 18. The plot shows some peaks up to 24m^2, but as the elevation angle increases, gaps appear in the performance of the reflector. These gaps only seem to appear in random areas of the patterns and do not appear as a gradual drop off in performance.

The statistical information on the Echomax 230 reflector shown in table 9.

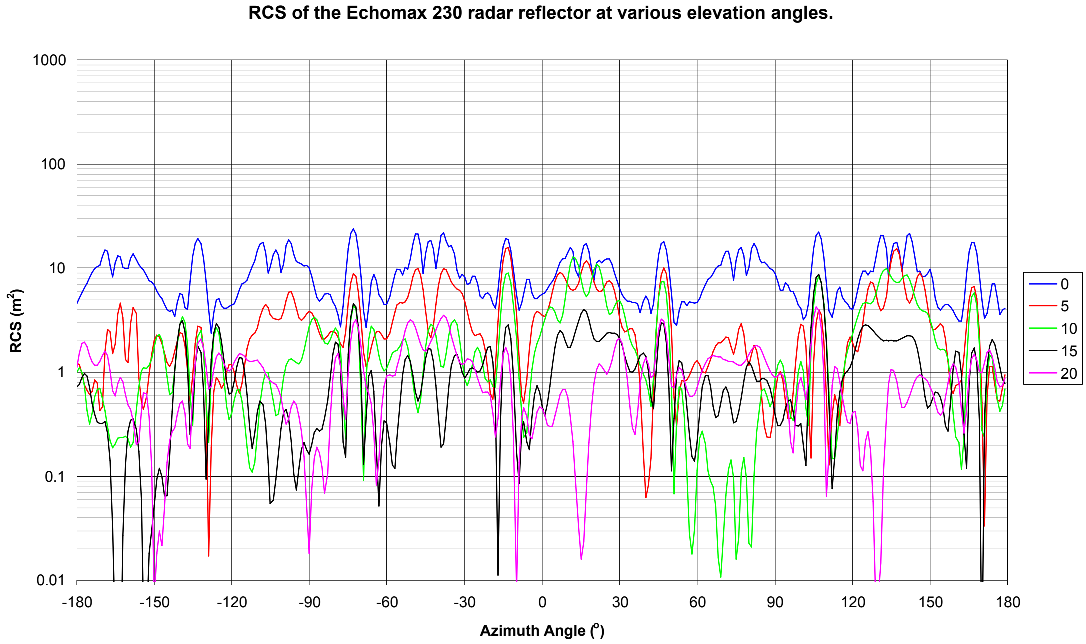

Figure 18 RCS of the Echomax 230 radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Echomax 230	-20	4.66	0.76	13	159	0.13
Echomax 230	-15	5.97	1.06	38	215	0.33
Echomax 230	-10	7.42	1.49	75	233	0.22
Echomax 230	-5	7.42	1.42	71	175	0.06
Echomax 230	0	23.95	9.29	359	360	4.70
Echomax 230	5	15.81	3.34	163	318	1.01
Echomax 230	10	12.88	2.24	108	254	0.14
Echomax 230	15	8.76	1.11	30	206	0.12
Echomax 230	20	4.25	0.98	21	228	0.27

Table 9 Statistics of the Echomax 230 radar reflector

3.8 Firdell Blipper 210-7 Reflector

Figure 19 below shows the RCS of the Firdell Blipper 210-7 radar reflector over the elevation angles 0˚, 5˚, 10˚, 15° and 20˚. This plot shows a good response at 0˚ with a peak over 11m², but as the elevation angle increases the performance degrades. To demonstrate this the statistics shown in table 10 show that although the maximum RCS stays above 5m² the stated performance level drops to 0.09m² as the reflector elevation angle increases.

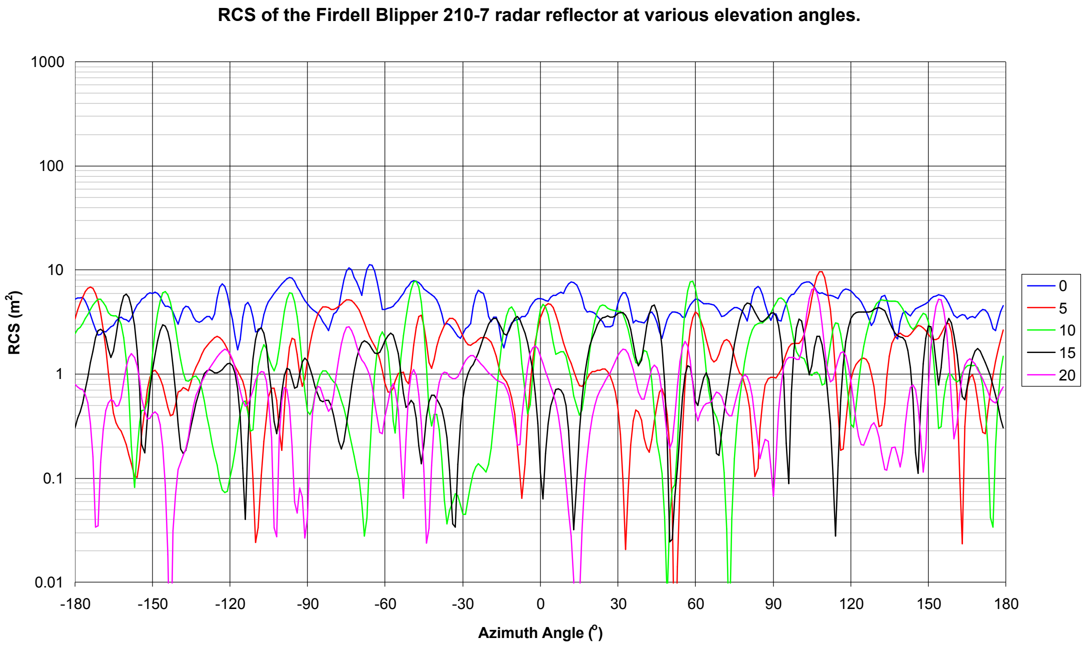

Figure 19 RCS of the Firdell Blipper 210-7 radar reflector.

Reflector	Elevation Angle	Maximum RCS (m²)	Average RCS (m²)	Total angle > 2.5m²	Total angle > 0.625m²	Stated Performance Level (m²)
Firdell Blipper 210	-20	2.81	0.73	5	179	0.24
Firdell Blipper 210	-15	4.46	0.80	16	175	0.11
Firdell Blipper 210	-10	3.44	0.97	36	179	0.13
Firdell Blipper 210	-5	3.62	1.24	52	240	0.14
Firdell Blipper 210-7	0	11.26	4.72	346	360	3.07
Firdell Blipper 210-7	5	9.71	1.78	82	275	0.34
Firdell Blipper 210-7	10	7.86	1.94	119	246	0.09
Firdell Blipper 210-7	15	5.88	1.65	93	259	0.56
Firdell Blipper 210-7	20	6.72	0.90	16	196	0.25

Table 10 Statistics of the Firdell Blipper 210-7 radar reflector

3.9 Sea-me RTE

The RCS of the Sea-Me RTE is shown in figure 20, it shows the peak at elevation angle of 0° is over 300m^2 and the pattern is very smooth with gradual variations in RCS as the reflector is rotated. When the elevation angle is increased the RCS does show degradation although at 15° the RCS is still almost always above 10m^2 which is the required peak for ISO8729 [1]. At 20° the RCS is all above 3.5m^2.

The statistics for this reflector are shown in table 11. The table shows that the Sea-Me RTE doesn't drop below 2.5m^2 at any part of this testing. However, when the elevation angle is increased to 20°, the stated performance level drops below the specified stated performance level for the replacement to ISO8729[2] which is 7.5m^2.

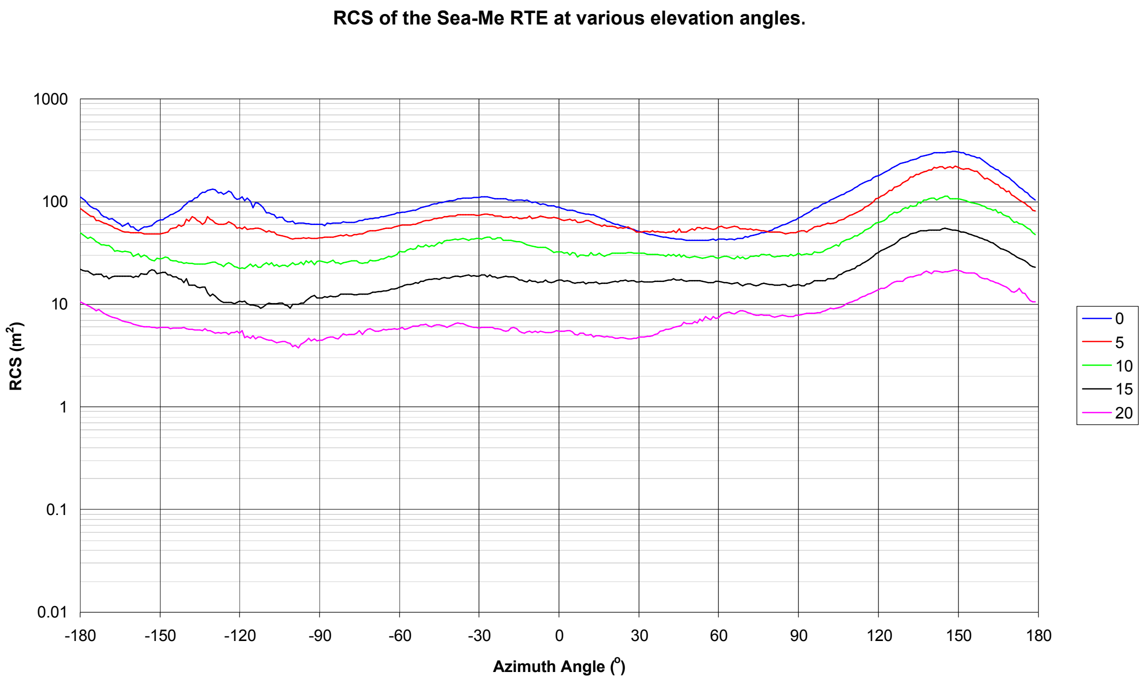

Figure 20 RCS of the Sea-Me RTE.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > 2.5m^2	Total angle > 0.625m^2	Stated Performance Level (m^2)
Sea-Me	0	308.27	104.63	360	360	42.57
Sea-Me	5	219.97	76.05	360	360	44.17
Sea-Me	10	112.89	40.92	360	360	24.87
Sea-Me	15	55.16	20.46	360	360	10.15
Sea-Me	20	21.62	8.16	360	360	4.35

Table 11 Statistics for the Sea-Me RTE

3.10 POLARef Reflector

The RCS of the POLARef radar reflector is shown below in figure 21. This chart shows that the RCS of this reflector is both high and consistent with angle. The peak RCS is very close to $10m^2$ with the minimum stated performance over all of the elevation angles being greater than $6m^2$.

The statistics shown in table 12 highlight the reflectors consistency with a minimum stated performance level of $6m^2$.

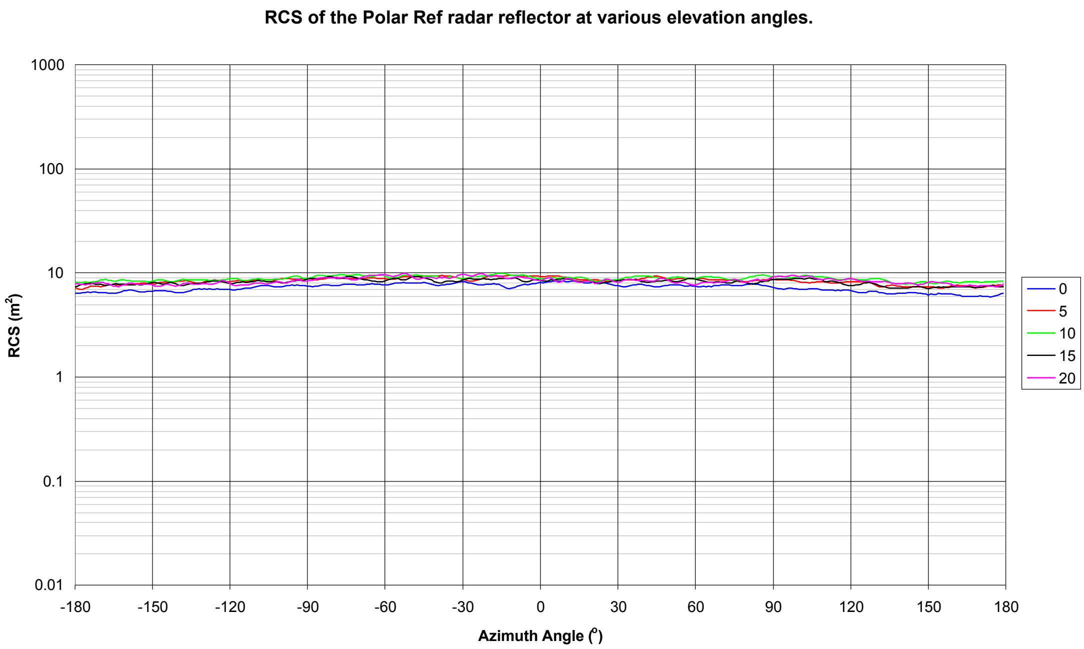

Figure 21 RCS of the POLARef radar reflector.

Reflector	Elevation Angle	Maximum RCS (m^2)	Average RCS (m^2)	Total angle > $2.5m^2$	Total angle > $0.625m^2$	Stated Performance Level (m^2)
POLARef	0	8.44	7.25	360	360	6.06
POLARef	5	9.50	8.45	360	360	7.42
POLARef	10	9.97	8.87	360	360	8.14
POLARef	15	9.29	8.22	360	360	7.33
POLARef	20	9.92	8.45	360	360	7.62

Table 12 Statistics for the POLARef radar reflector

4 Discussion of Results

4.1 Comparison of reflectors

To enable easy comparison between each of the radar reflectors, graphs have been produced showing the statistical data taken from the tables in section 3. The maximum RCS, average RCS and stated performance level are shown in figures 22 to 24 respectively.

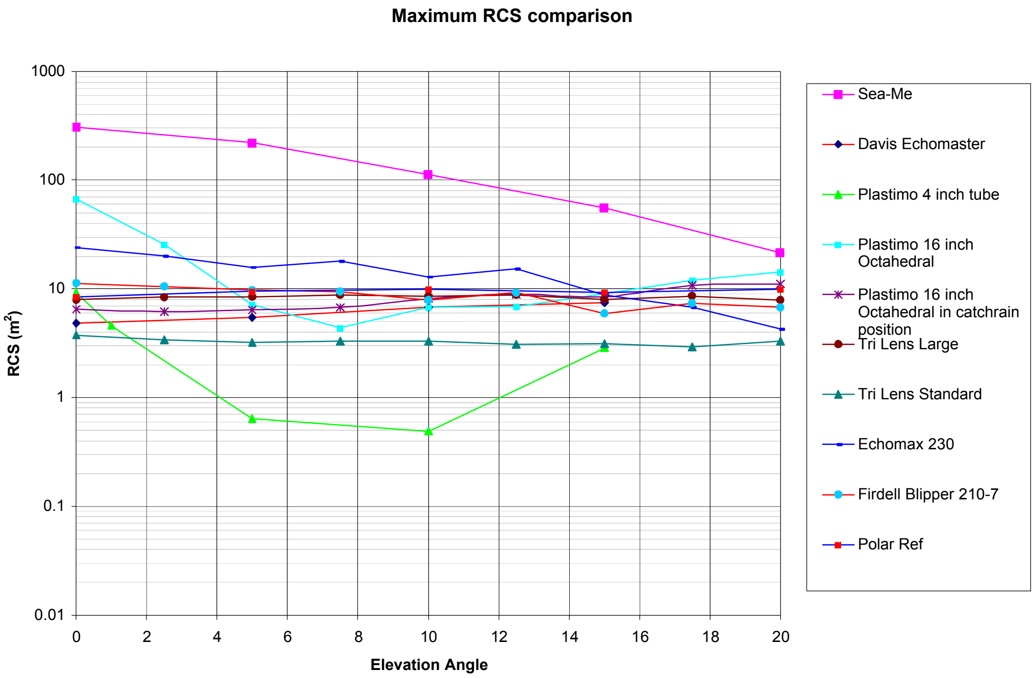

Figure 22 Comparison of each of the radar reflector's maximum RCS level.

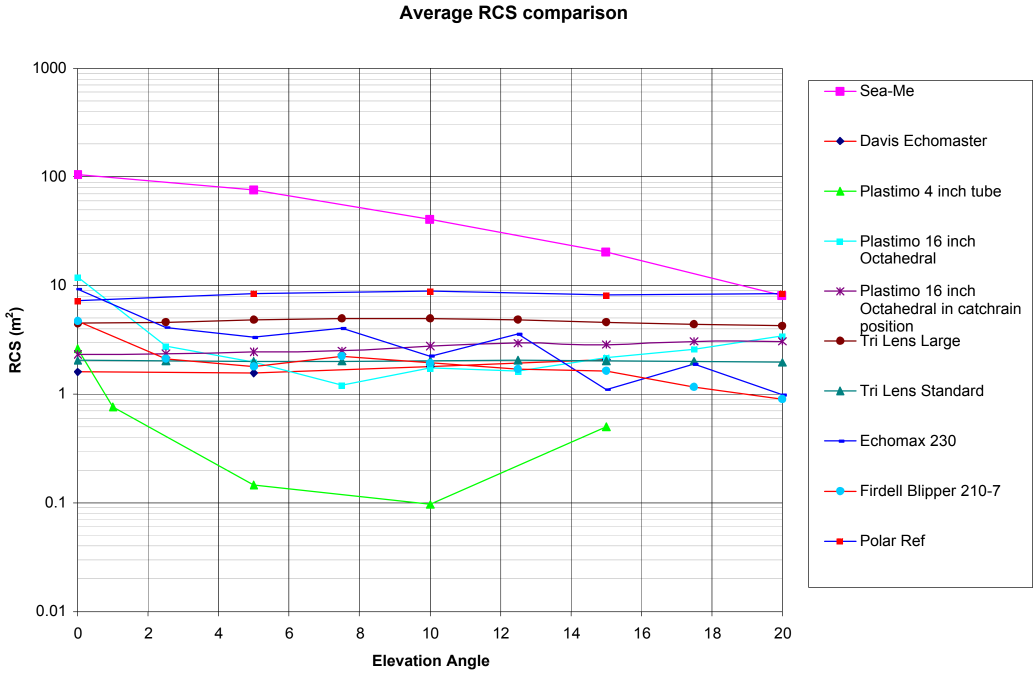

Figure 23 Comparison of each of the radar reflector's average RCS.

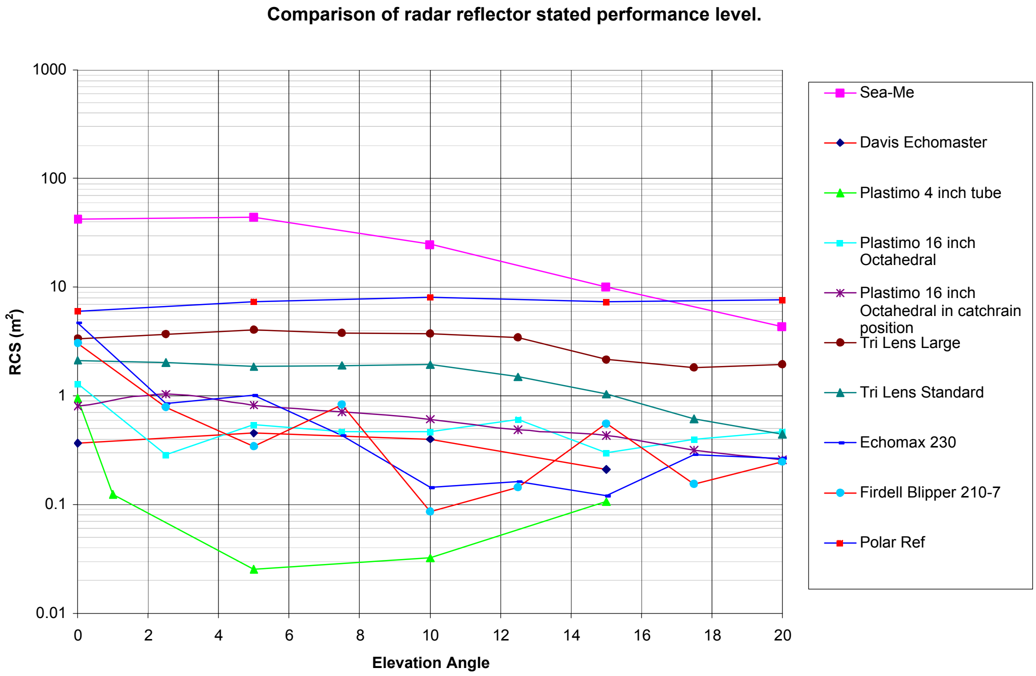

Figure 24 Comparison of each of the radar reflector's stated performance level.

As expected the active Sea-Me outperforms all of its competitors, although at an elevation angle of 20° its stated performance level is exceeded by the POLARef.

The POLARef performs very consistently and is the best performing passive radar reflector with maximums, averages and stated performance levels all falling between 6m^2 and 10m^2.

The Large Tri-Lens performs well with a good consistent RCS, it lacks the peak RCS value of some of its competitors at 0˚ but as the elevation angle increases the Tri-Lens performance doesn't fall away as dramatically as some of the others.

The Echomax 230 shows good peak and average RCS performance compared to its competitors but its stated performance level falls to around $0.2m^2$ above an elevation angle of 10˚.

The Firdell Blipper 210-7 is slightly down on the Echomax 230 in terms of peak and average RCS performance but has a very similar stated performance level.

The Standard Tri Lens shows average performance. The peak RCS was quite low at $4m^2$, but as the elevation angle increased the relative performance of this reflector increased. Above 15˚ it out performed the Blipper and Echomax in terms of average RCS.

The Plastimo 16" octahedral has a good peak and average performance when mounted in its upright position although the large nulls shown in its azimuth patterns (figure 11) bring the stated performance level down. In the catch rain position the reflector is more consistent but has a lower peak RCS.

The Davis Echomaster performed least well out of the octahedrals, it had a peak RCS of $7.5m^2$, but its average RCS and stated performance levels were only $2m^2$ and $0.45m^2$ respectively.

The 4" Tube reflector performed very poorly especially beyond 1˚ and is well behind the others in performance having an average RCS of approximately $0.1m^2$ at 5˚ and 10˚.

4.2 General summary of results

The Sea-Me RTE has a peak RCS that is very high in comparison to the passive reflectors described in this report. On the basis of these results it is the only reflector tested that would fully satisfy the performance requirements of ISO8729 [1] and the proposed specification for ISO8729 Ed.2 [2] (only up to an elevation angle of 10˚ or Category 1).

The POLARef reflector narrowly fails the current and future ISO8729 specifications [1] [2] having a peak RCS of $8.44m^2$ at 0° elevation. Although the performance is exceptionally good having a very consistent RCS over the elevation angles tested.

The Large Tri-Lens performs consistently over the elevation angles tested with very little variation in its peak and average RCS, its stated performance level is between $1.95m^2$ and $4.04m^2$ at all elevation angles tested.

The Echomax 230 demonstrates good peak and average RCS performance compared to its competitors but its stated performance level drops significantly beyond an elevation angle of 5˚. The Echomax 230 tested fails to meet the total angle $>0.625m^2$ aspect of ISO8729 [1].

The Firdell Blipper 210-7 peak RCS figures are good but the average and stated performance levels reduce when the reflector goes past an elevation angle of 5˚. The Firdell Blipper 210-7 tested fails to meet the total angle $>0.625m^2$ aspect of ISO8729 [1] at -10 and 15˚ elevation

The Standard Tri Lens performs similarly to the Large Tri-Lens although the peak RCS is low at about $3.75m^2$. It is very consistent up to an elevation angle of 20˚ with the average RCS only varying by $0.07m^2$.

The Plastimo 16" octahedral has a good peak and average performance when mounted in its upright position although the large nulls (>12˚ wide at $2.5m^2$ at 0˚

elevation) shown in its azimuth patterns (figure 11) bring the stated performance level down. In the catch rain position the reflector is more consistent although it has a lower peak RCS. It fails to meet ISO8729[1] in both orientations due to it null widths at 0° and the total angle >0.625m^2.

The Davis Echomaster has a reasonable peak and average RCS but is too small to meet the performance requirements of ISO 8729[1].

The 4" Tube reflector had a good peak RCS of 9.3m^2 at 0°. However, as the elevation angle increased the RCS rapidly decreased. Even at 1° the stated performance level had dropped to 0.12m^2.

5 Conclusions

The following is concluded;

- The Sea-Me is a good example of an active reflector (RTE) exceeding the requirements of the current and future ISO 8729 at heel/elevation angles of up to 15˚, it is also very small and light. Drawbacks are that it requires power to operate (which on a yacht is at a premium), it will only operate at X-Band and will offer no performance at S-Band.
- The POLARef shows excellence is possible but at a price, technically it just fails meet current ISO8729 [1] or its replacement [2]. The main drawbacks are it is very costly at £2000 and its quite heavy at around 5kg. It is currently used as a radar measurement standard although it could possibly be re-engineering for commercial production which could reduce the price.
- The Large Tri-Lens performs well especially at larger angles of heel and elevation, it just falls short of ISO8729 [1] having a peak RCS of 8.5m^2 but otherwise performs well. It is the heaviest reflector supplied for test at 5.5kg and costs around £300.
- The Echomax 230 narrowly failed to meet ISO8729 during this testing, but showed good peak and average RCS performance. The reflector is reasonably priced at £130 and weighs 2.4kg; the main drawback was a RCS drop-off above an elevation angle of 10˚.
- The Firdell Blipper 210-7 narrowly failed to meet ISO8729 during this testing, but showed good peak and average RCS performance. The Blipper is priced at £130 and weighs 1.8kg; the main drawback was a RCS drop-off above an elevation angle of 10˚.
- The Standard Tri Lens does not meet ISO8729 as the peak RCS was too low at 4m^2. However its consistent RCS response outperformed most of the other reflectors when heeled over beyond 10˚; it is reasonably priced at £130 and weighs 2.5kg.
- The Plastimo 16” octahedral is inexpensive at £16 and lightweight at 0.65kg but failed to meet ISO8729 in either tested position. It had reasonable peak and average performance averaging around 2m^2 but had wide nulls which kept its stated performance level down. Other drawbacks are that its mounting arrangement is by suspension only (often in an unfavourable position) and could be subject to damage.
- The Davis Echomaster failed to get close to ISO8729 during this testing. Its peak RCS is too low at 7.5m^2 and its average performance is only 1.75m^2. This reflector is priced at £60 and is lightweight; it can be mounted on a rod as well as by suspension (in the correct catch-rain position).
- The 4” tube reflector performed very poorly.
- It is concluded that either the active Sea-Me, POLARef and the Standard or Large Tri-Lens radar reflectors are the best reflectors at heel and elevation angles of over 10˚.

6 Recommendations

- Based on the results of this report it is recommended that yachtsmen always fit a radar reflector that offers the largest RCS practicable for their vessel.
- The RCS of the radar reflector should have a minimum consistent RCS of $2m^2$.
- The Sea-Me is the recommended product if power is available
- If power is not available then the passive Large Tri-Lens reflector is recommended
- The 4” tube reflector is not considered suitable due to its poor performance. It is also recommended that the 2” tube reflector is not suitable since the performance of this target will be even lower.
- It is recommended that poorly performing radar reflectors are not fitted as it is possible that the user could be lulled into a false sense of security believing that their chances of detection has been enhanced.

7 References

[1] BS EN ISO 8729:1999 - Ships and marine technology. Marine radar reflectors

[2] Future ISO 8729 Ed. 2, currently in draft is based on IMO Resolution MSC.164(78) provides the concept and level for the Stated Performance Level (SPL).

[3] Method for modelling sea surface clutter in complicated propagation environments. IEE proceedings. Volume 137, Issue 2, April 1990 - GD Dockery

[4] Introduction to Radar Systems - second edition– M.I. Skolnik chapter 12.2, 1980

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Abstract This report has been written to compare and contrast a selection of radar reflector types in terms of their radar cross section (RCS) performance. It will inform yachtsman and owners of small craft which reflector has the best performance and therefore which reflector to fit in order to give the best possible chance of being seen on radar by commercial shipping. This task has followed on from investigative work carried out by QinetiQ Funtington into the loss of the yacht Ouzo over the period 20th to the 21st of August 2006.			
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