Comparing Passive Radar Reflectors

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Sailboats and small powerboats are notoriously poor radar targets and many sailors purchase a passive radar target enhancer (RTE), or radar reflector, to improve their vessel's signature. In this article I summarize a method I developed for describing and comparing RTE, and use it to compare seven of the common passive radar reflectors on the market. Details can be found in my recent book "Radar Reflectors for Cruising Sailboats; Why They Work; How to Evaluate Them; What the Limitations Are". Active radar target enhancers and some miscellaneous devices are discussed in other articles in this series.

Radar Cross Section

The strength of the radar signal reflected by a target is related to the "radar cross section", or RCS. Larger RCS means that the target will be detected: at greater range, by lower power radar sets, in poorer weather conditions, and more consistently. Consistent detection is especially desirable for collision avoidance because unless your vessel is detected on every sweep of the radar it may be missed by a human operator and it may be ignored by ARPA (Automatic Radar Plotting Assistant) software.

Radar reflectors cannot be completely described by a single RCS value. Rather, the RCS depends on the orientation of the radar reflector relative to the radar that is painting it. The orientation, or aspect, is simply the relative bearing of the radar from your vessel and the elevation angle of the line of sight to the radar relative to your deck. For a radar dead abeam, the elevation angle is your vessel's angle of heel; for a radar dead ahead or astern the elevation angle is your vessel's pitch angle. A complete characterization of a radar reflector includes the RCS at all bearing angles, or azimuths from 0 to 360 degrees and all elevations angles from –90° to +90° although a smaller range of elevation is usually adequate.

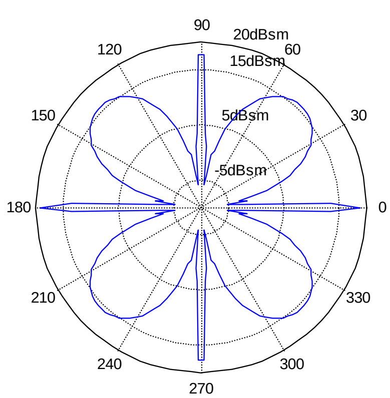


Figure 1. Example Polar Diagram

Polar diagram

Radar cross section is commonly presented in a "polar diagram". To obtain polar diagram data, the target is mounted on a rotating platform in an indoor radar range (radar anechoic chamber). A carefully calibrated radar system records the strength of the reflected signal as the platform rotates through 360 degrees and graphs RCS against azimuth as shown in Figure 1. If the radar reflector described by the polar diagram shown in the figure is on you vessel, you would present a strong target to the radar for relative bearings from 30 to 60 degrees, from 120 to 150 degrees, from 210 to 240 degrees, and from 300 to 330 degrees, and for very small ranges of bearing around 0, 90, 180, and 270 degrees. At other bearings you would present a small target and would probably not be detected.

A polar diagram describes the RTE as long as it is vertical (elevation = 0). It does not represent performance if the RTE is tilted away from the vertical, as would be the case if the RTE is mounted on a vessel that is rolling or pitching in a seaway or simply sailing at a constant angle of heel. Consequently, single polar diagrams do not provide enough information to compare radar reflectors that are to be used on sailboats. Manufacturers sometimes provide several polar diagrams for different tilt angles but this is not common practice and, even when the data are available, it is not easy to visualize performance given multiple polar diagrams.

Analytic RCS diagram

The data visualization problem may be overcome by a single quantized, color-coded RCS diagram (sometimes referred to as a Target Pattern Map or TPM) showing the data from many polar plots. Such a diagram is easier to interpret than multiple individual polar plots but obtaining enough anechoic chamber data to produce a detailed diagram is costly and time consuming.

My solution was to develop analytic models of all common RTE, calculate RCS over the entire range of aspect, and present the results in a color-coded *analytic RCS diagram*. An analytic approach is possible because all RTE are made of a few different simple basic elements which have been thoroughly analyzed and described in the technical literature. Basic elements such as flat plates, dihedrals (two plates at right angles), and trihedrals (three plates at right angles to each other) can be combined analytically to represent any RTE if the physical structure is known. The *color-coded diagram* allows one to visualize RCS over a large range of aspect and compare RTE with a common display. The *analytic* diagram avoids extensive anechoic chamber testing and is useful even when such data are not available.

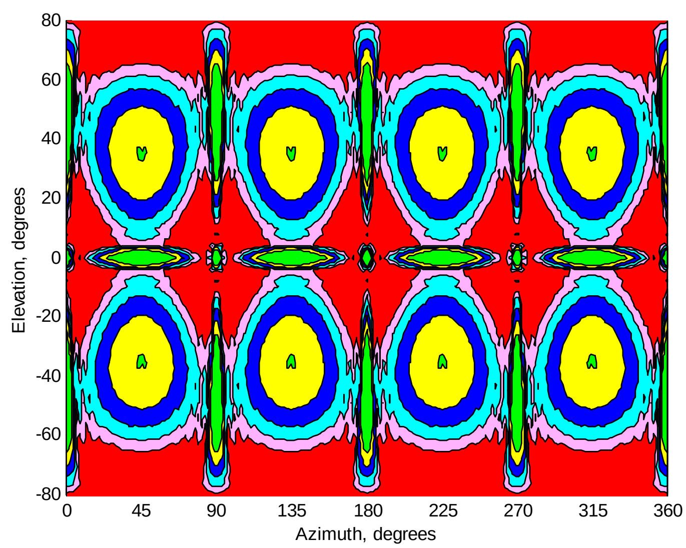


Figure 2. Example Analytic RCS Diagram

Figure 2 shows the analytic RCS diagram for a Davis Echomaster 12½" octahedral mounted in the "normal" orientation. RCS magnitude is quantized so that only six colors are needed. In my work I have used green to indicate an RCS greater than 10 m^2; yellow between 5 and 10, dark blue between 2.5 and 5, light blue between 1.25 and 2.5, purple between 0.625 and

1.25, and red less than 0.625 m^2. The 2:1 spacing of contours allows 6 colors to cover a large range of RCS. 10 m^2 and 0.625 m^2 are the maximum and minimum values specified in the ISO 8729 international standard. Essentially, green is good, RCS decreases progressing from yellow to purple, and red means you probably won't be detected.

Examining the diagram, the major feature is the eight circular areas of green, yellow, and dark blue centered at about 35 degrees elevation. These correspond to the eight corner cube "pockets" that are the main element of the octahedral. The narrow vertical and horizontal green areas come into play at certain aspects. This diagram is interpreted as follows. The main response consists of eight cones oriented about 35 degrees above and below the horizontal. There is good response at very small elevation angles, roughly ±4 degrees, but even at zero elevation there are small ranges of azimuth for which the response is red. Consequently, this RTE would be marginally useful as long as the vessel on which it is mounted does not heel more than four degrees, or heels about 35 degrees. For heel angles between a few degrees and about 20 degrees there is a lot of red, you would present a very small RCS to the radar, and you probably would not be detected at most azimuth angles. There is more red than green or blue over the range of aspect encountered by monohull sailboats so the octahedral, in normal orientation, may not be the best choice. On the other hand, there is a lot of green and blue for elevation angles less than four degrees so this would not be a bad choice for something that does not tilt much.

Comparison

The accompanying table shows analytic RCS diagrams for the most common passive radar reflectors on the market: Davis Echomaster 12½ inch octahedral (in each of the common mounting orientations), Firdell Blipper 210-7, Echomax 220, Lensref DL-8A, Cyclops #3, Mobri S-4, and large Tri-Lens. Elevation angle was limited to ±30 degrees to emphasize the range of heel angle of interest to sailors. Annotation points out the major features of each diagram to help the reader visualize each unit's performance.

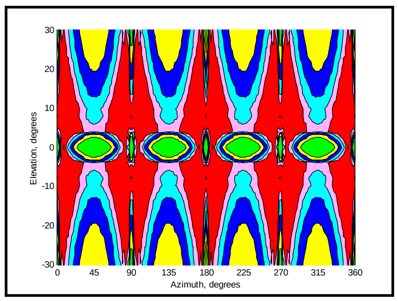
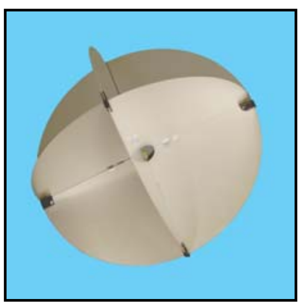
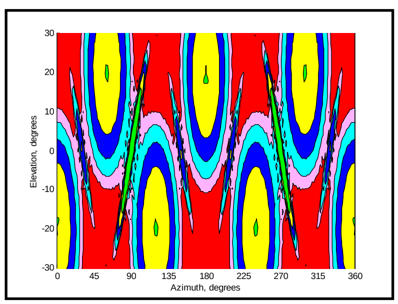
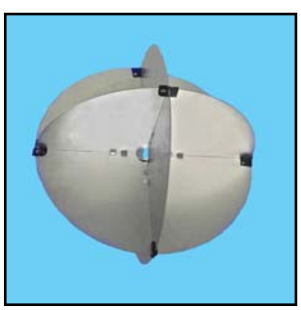
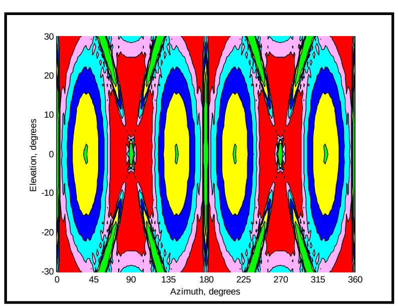
Conclusion

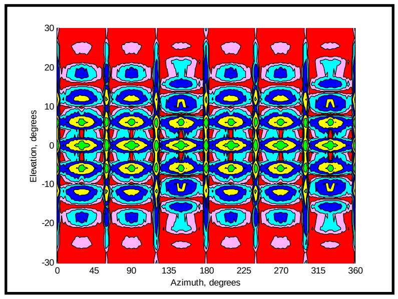
RCS is not the only criterion for selecting an RTE. Cost, mounting, weight and windage aloft, power consumption, reliability are also important. The application is also important, i.e. collision avoidance, search and rescue, fixed navigation aids. Even the type of vessel and expected sailing conditions are important for collision avoidance because of different ranges of heel angle. However, the analytic RCS diagram succinctly summarizes the variation of RCS with aspect and enables one to compare RTE using a common basis.

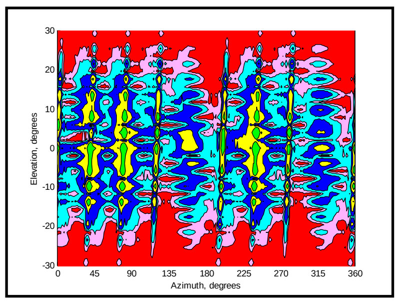
COMMON PASSIVE RADAR REFLECTORS
ANALYTIC RCS DIAGRAMS

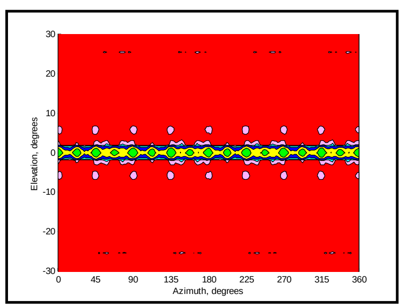
RADAR CROSS SECTION LEGEND

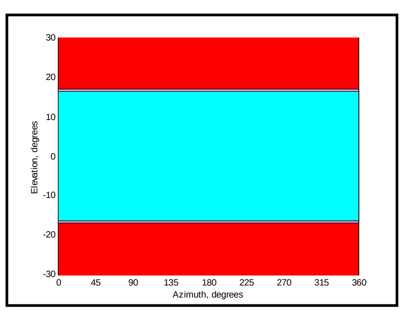
Above 10.00 m^2	2.50 to 5.00 m^2	0.63 to 1.25 m^2
5.00 to 10.00 m^2	1.25 to 2.50 m^2	Below 0.63 m^2

Unit	Analytic Diagram	Comments
		**Davis Echomaster 12½" Octahedral, Normal Orientation** Much of the horizon covered by green at very small elevation angles but not much coverage from a few degrees elevation to 15° or so. Note the gaps (red) at zero angle of heel. Not the best choice for a vessel that heels
		**Davis Echomaster 12½" Octahedral, Catch Rain Orientation** Small to moderate coverage at all azimuths up to about 10° elevation. About half of the region above 10° elevation is red. No gaps (red) up to 10° heel, but not very strong return either. Good compromise between strong return and gaps.
		**Davis Echomaster 12½" Octahedral, Double Catch Rain Orientation** Moderate coverage to 20° elevation in four areas but lots of red for two 90-degree wide azimuth sectors. Probably the worst of the three octahedral orientations.

<table>
<tr><th>Unit</th><th>Analytic Diagram</th><th>Comments</th></tr>
<tr><td></td><td></td><td>Echomax EM220

Very little green. Not much coverage for elevation greater than about 16° and almost none for elevation greater than 20°.
RCS varies significantly with aspect, possibly producing intermittent response as vessel moves in a seaway.</td></tr>
<tr><td></td><td></td><td>Firdell Blipper 210-7

Very little green. Not much coverage for elevation greater than about 16° and almost none for elevation greater than 20°.
Three “notches” of red starting at 10° elevation in four azimuth sectors. RCS varies significantly with aspect, possibly producing intermittent response as vessel moves in a seaway.</td></tr>
<tr><td></td><td></td><td>Mobri S-4

Quite strong response at all azimuths for elevation less than a couple degrees. Almost nothing for greater elevation. Not recommended for vessels that heel. Definitely don’t mount it on upper spreaders
A similar unit is manufactured by Plastimo.</td></tr>
<tr><td></td><td></td><td>Lensref DL-8A

Constant 2 m^2 RCS over all azimuth and up to 17.5° elevation. Zero elsewhere. Good in benign conditions and on vessels that don’t heel more than 15 degrees.</td></tr>
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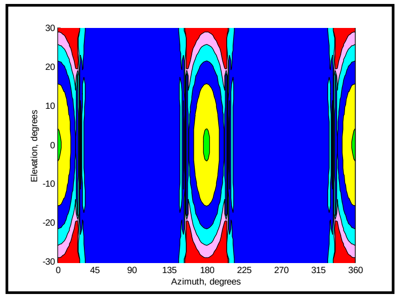
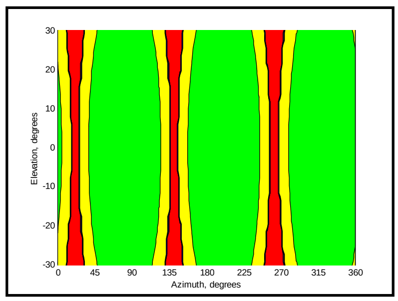
Unit	Analytic Diagram	Comments
		**Cyclops #3** Constant, moderate RCS over large fraction of the range of aspect to more than 30°, elevation except for two azimuth sectors in which the moderate response extends to 20°. Four narrow bands of azimuth in which the response is problematic; these show up as black on the diagram due to the rapid variation of RCS with azimuth.
		**Tri-Lens Large** Constant, large RCS over almost entire range of aspect up to more than 30° elevation.

References

1. P. G. Gallman, *Reflector Choices*, Sail Magazine, (in Know-How) September 2006, pp 96-100.
2. P. G. Gallman, *Radar reflector performance*, Ocean Navigator, March/April 2006, pp 52-55
3. P. G. Gallman, *Can you see me now?* (effect of radar reflector mounting height), Cruising Tips, Sail Magazine, February 2007, pp 40-42.
4. P. G. Gallman, *How effective are active radar reflectors?*, Talking Back, Ocean Navigator, January/February 2007, pp 56-57
5. P. G. Gallman, *Why you should have radar*, Ocean Navigator, November/December 2007, pp 42-50.
6. P. G. Gallman, *Should you trust your GPS?*, Ocean Navigator, November/December 2007, pp 21-22.