Safety At Sea Studies - 1995 Radar Reflector Tests

RADAR REFLECTORS

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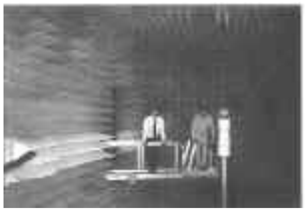
Almost nothing provokes as much fear in the hearts of sailors as the thought of a collision with a ship. Rogue waves and killer storms, maybe, but there are a lot more ships than either of those. The good news is that a ship keeps a careful watch and they always use radar, so avoiding a collision is simply a matter of a good radar reflector.

Or is it? Just how well do radar reflectors work, anyway?

Thanks to the generous cooperation of SRI International, in Menlo Park, CA, we had an opportunity to find the answer to that question. West Marine provided samples of 10 commercially available radar reflectors, which were tested in SRI's large radar test chamber, normally used for testing such things as satellite antennas and stealth bombers.

Participating In the tests were Eldon Fernandes, the operator of the range and an employee of SRI; Dick Honey, a Sr. Principal Scientist at SRI; Stan Honey, Vice President of Technology for News Corporation and a former Research Engineer at SRI; Chuck Hawley, Technical Director for West Marine; and Jim Corenman, Sailor at Large.



Each reflector was mounted on a pedestal

SRI's Eldon Fernandes, a development

inside SRI's anechoic chamber.

engineer for the Remote Measurements Laboratory, assists with the data logging.

Characteristics of Marine Radar

Marine radar comes in two flavors, X-band and S-band. Ships will typically carry both, while small vessels are limited to the smaller X-band units. X-band radar operates at a frequency of approximately 9.4 GHz (9400 MHz), with a wavelength of 3.2 cm, while S-band operates at approximately 3 GHz, with a longer wavelength of 10 cm. X-band radar offers greater resolution and detection of smaller targets, but is more susceptible to interference from rain and seas (sea clutter). S-band radar has longer range and less interference from rain and sea clutter, but has less sensitivity for small targets.

A ship will typically use her X-band unit near shore, due to its higher resolution and ability to detect smaller targets. In conversations with ship's officers, nearly all indicated that in offshore waters they depend entirely on the S-band unit set to a 24-mile scale. The advantage of S-band in this situation is longer range, less interference from rain, and reduced interference from sea clutter (a factor of about 2½, or -4 dB).

This is not good news for radar reflectors, however, since performance falls off as the square of wavelength. This means that, at least in theory, a given reflector will have an S-band return of only one tenth (-10 dB) compared to its X-band performance. In a situation where the return from the sea state is the limiting factor, part of this loss is made up by reduced sea clutter, but the effective return will still be reduced to one fourth (-6 dB) compared to X-band.

A digression on units of measurement … Radar reflector performance is normally characterized in terms of Radar Cross Section, or RCS, measured in square meters (m^2). The measurement of RCS is referenced to a conductive (metal) sphere of the specified cross-sectional area, using the familiar $p\ r^2$ formula for the area of its cross section. Performance of a reflector is expressed in decibels (dB) relative to some reference, typically a 1.0 m^2 sphere, but occasionally some other reference. Decibels are a relative measurement, and are log-based, with 3 dB representing a factor of two, and 10 dB representing a factor of 10. So saying that a signal is 3 dB below a 1.0 m^2 reference (or -3 dB) is the same as saying it is half as big, or 0.5 m^2.

One thing that helps put everything into perspective is to consider that the radar return from a typical duck is about 0.1 m^2, so our 1 m^2 reference sphere can be also described as 10 duck units, or 10 du's. Not very big. So having properly introduced the technically hip decibel units, we will now go on and talk about things we can visualize, like square meters and duck units. Everyone understands that, when it comes to radar reflectors, more ducks is better.

The central question, of course, is just how many ducks does it take to be seen by a ship? There are as many answers as there are ships and radar operators, but the typical response that keeps coming back is that the lower limit of detectability using X-band radar in a moderate sea is 1 to 3 m^2 (10-30 du's). GEC Marconi (the manufacturer of the popular Firdell Blipper), states[i] that 2.5 m^2 is "generally accepted in the radar business as the 'threshold' of radar detectability" at X-band, and proposes a minimum *average* RCS of 2.5 m^2 (25 du's), with no gaps below 2.5 m^2 that are larger than 5° x 5°.

In response to the question of how far away a sailboat can be picked up on radar, the most common answer is three to six miles without a radar reflector if it can be picked up at all, and a better chance of picking it up with a reflector. These numbers are purely anecdotal, based on conversations with ship's officers, but are consistent with those reported in *Radar Detectability* *and Collision Risk*[ii].

These detection ranges are certainly less than those of us who sail small vessels would hope for, and less than we've somehow been led to believe. What we will try to accomplish in the space that remains is to sort the truth from the claims, and bring some perspective to bear on the problem of visibility at sea.

The one thing that is key to the performance of any reflector design is size. The reflective performance of any type of reflector is proportional to the *fourth* power of its linear size. In other words, doubling the size of a reflector results in an increase of effective area of 16 times, or a 12 dB increase. Stated differently, an increase in size of a reflector of 19% will double its performance. Further, as the smallest dimension of a reflector gets down to a few wavelengths of the radar signal, it quits acting as a reflector and starts to act as a lump of metal. Remember that a wavelength is 3.2 cm (1¼") for X-band, and 10 cm (4") for S-band. So small detectors must be looked at with a great deal of suspicion, as there really is no substitute for size.

Another issue is the increasing reliance upon ARPA systems aboard ships. These systems automatically capture and track radar targets, and provide a warning to the watch when a close approach is predicted. An ARPA system will only work with targets that are visible on the radar, however, and typically a minimum of three consecutive "hits" is required on the ship's radar before a blip is acquired as a target. This puts a premium not only on the strength of the return, but also its consistency.

Fig. 1
Passive Radar Targets

The Reflectors Tested

Most radar reflectors are variations on the 3-sided corner reflector, also known as a corner cube or a trihedral reflector. The principal echo from a trihedral reflector will be strongest when its "pocket" is oriented directly towards the radar. As the trihedral reflector is rotated off this axis in any direction, the echo becomes weaker, and drops by half (-3 dB) at an angle of 12° to 20° from the axis of symmetry, depending on its specific shape (see fig. 1). With increased rotation, the return continues to drop to almost zero as one of the three sides approaches an edge-on attitude to the radar. When one edge is exactly edge-on, there will be a strong but narrow return, caused by the other two edges acting as a dihedral (2-sided) reflector, or one side acting alone as a flat plate reflector. These returns can be very strong, but so narrow in angle as to have little value.

Octahedral Reflectors

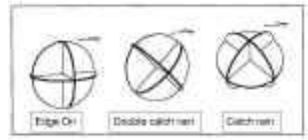
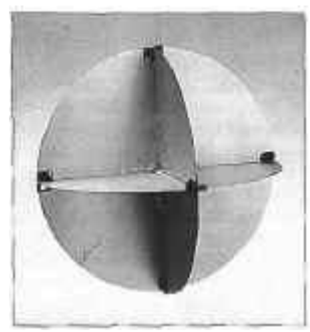


Figure 2. From left to right: An octahedral reflector edge-on to the radar, the double catch-rain position and the catch-rain position.

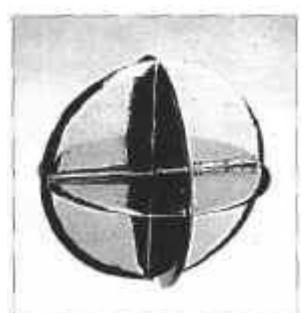
The classic octahedral reflector is made of three planar circles or squares of metal intersecting at right angles, forming eight trihedral reflectors. In the usual "catch rain" position, one trihedral will face up and one down, and the remaining six are arrayed around a circle, three oriented 18° above the equator, and three 18° below. This optimizes the return from the "pockets", and avoids the nulls or gaps as best as is possible, but only at a 0° angle of heel.

Considerations of heel angle has led to the "double catch rain" position (see fig. 2), with one planar surface oriented vertically along the vessel's axis, and the other two planes ±45° from the vertical. This is not the ideal with no heel angle, but moves towards the "catch rain" position as the boat heels.

Davis Echomaster and Emergency



The Davis Echomaster is available in standard and deluxe models. The deluxe has a mounting harness. Mounted in the double catch-rain position, it rated very well.

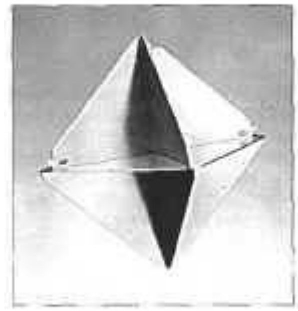


The Davis Emergency is made of foil laminated over foam. Square alignment of the plates is important to its effectiveness.

We tested three octahedral-type reflectors. Two Davis products were included, the 6.25" radius spherical Echomaster, model 153, and the Emergency model 151. The Emergency model has circular plates of 5.5" in radius, and is constructed out of foil laminated over a foam core. It can be disassembled into three disks for storage if desired. The Echomaster Deluxe is constructed from anodized aluminum disks and has a radius of 6.25". It comes with a plastic and stainless bracket which attaches to the intersection of all of the plates, although it was removed for our tests. When installed, this bracket makes is easier to suspend or mount the device in the so-called "catch rain" position.

Holland Yacht Equipment

The HYE has no provisions for mounting other than small holes in the corners



The Holland Yacht Equipment (HYE) #1274 is an aluminum octahedral reflector with triangular pockets. This means that the plates from which it is made are square before assembly, and the plates intersect across the diagonal of each plate, thus forming the triangular pockets. It measured 4.7" in radius, and is constructed such that the slots in each plate assure alignment when assembled which is accurate to a few degrees. Other than small holes in each corner, the HYE has no provision for mounting.

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Other Trihedral-based Reflectors

The Firdell Blipper

Firdell Blipper (model 210-5, model 210-7) was disappointing.

The Firdell Blipper is not an octahedral reflector, but it still uses the basic trihedral corner reflectors. Rather than eight corner reflectors oriented around a sphere as in the case of the octahedral reflector, the Firdell uses ten trihedral corner reflectors oriented approximately 36° to each other, and optimized for angles close to the horizontal. The theory is that by avoiding the regular geometry of the octahedron, the deep nulls can be avoided. Its a good theory, but the problem is that in order to fit the corner reflectors into a package of reasonable size, the individual reflectors must be made fairly small, with a radius of only 4" in the case of the popular 210-5. Since the performance of a trihedral reflector is proportional to the fourth power of its size, this is a serious loss. For example, a circular 6.25" trihedral element (such as the Davis Echomaster) will have an RCS 2.5 times (4 dB) greater than a 4" trihedral element such as the Firdell.

We tested two models of the Firdell Blipper, the popular 210-5, which measures 20" in height and 8½" in diameter, and weighs 3¾ pounds, and the slightly (10%) larger 210-7. Both are designed to be mounted vertically, either on the forward side of a sailboat mast, suspended vertically using a small halyard, or mounted vertically on a flat surface. It should be noted that mounting the Firdell (or any reflector) on the front of a mast will shadow it from the rear, making it ineffective over an angle that can be 90° or more.

Mobri

Mobri reflectors are available in two diameters, neither of which performed well.

The cylindrical Mobri reflector is another variation on the trihedral theme, but in this case they are stacked in either a 2" or a 4" diameter cylinder. With the radar beam exactly at right angles, they act as a series of dihedral reflectors, but even small heel angles cause it to operate in a deep null with little reflection. The series of end plates that would form the third side of each trihedral are too small to be effective, even in X-band, and are operating too close to edge-on at small heel angles. The smaller 2" diameter unit suffers an additional problem in that the 1" radius of each dihedral reflector is less than a wavelength even at X-band. Both Mobri reflectors have provision for hanging the cylinder from top and bottom, or can be strapped to a wire or spar. The manufacturer suggests mounting one on each cap shroud above the spreaders, which would provide a reflection at two narrow angles of heel, rather than just one.

High Gain Rotation

The High Gain Rotation is a plastic sphere with a gimbaled quadrahedral reflector inside. In this photo, it is shown cut open.

The High Gain Rotation is an 8" diameter plastic sphere with a gimbaled quadrahedral reflector inside. Unable to determine how the gimbaling was accomplished, we cut open the plastic shell after testing. It has two intersecting aluminum plates which are embedded in a combination float/ballast base, which in turn floats on what appeared to be water. This allows the reflector to remain vertical through 360° of pitch and roll. It does not allow the attitude of the reflector surface to be known while testing, however, since it is completely enclosed in the sphere and it is free to rotate. In addition, the effect of rapid boat movement is difficult to predict, since the period of oscillation of the reflector will be in and out of phase with the motion of the boat. Our test gave little insight into the workings of the High Gain Rotation, except that its performance at 0° and 20° of heel was very similar, which would be expected.

Cyclops

The Cyclops 1 (the smallest of three models) has a sturdy masthead mount.

The Cyclops 1 is the smallest of the three Cyclops models, and has trihedral reflectors facing fore and aft and biconic reflectors facing athwartship. It designed to be masthead mounted, and has a provision for attaching masthead lights above it. It is a sealed plastic dome, with pointed ends fore and aft, and measures 13"L x 10.5"W x 7"H.

Non-Trihedral Reflectors

Lensref

The Lensref is expensive, but because it works on the Luneburg ens principle, return of the X-band signals was very good. Unfortunately, performance drops off beyond about 18° heel. Gimbaling or damping roll would help a great deal.

The Lensref is a Luneburg lens device, and is the one significantly different reflector that was tested. The Lensref is an 8" diameter sphere with layers of plastic (frequently likened to the layers of an onion) which vary in their index of refraction. By focusing the radar energy to a reflective band around the "equator" of the lens, and then back along the same path to the source of the energy, a claimed 360° reflection is achieved. It has a 10 mm bolt at its top and bottom which can be mounted in an optional mast bracket, or bolted to the top or bottom of a vertical surface.

The angle of heel is limited, however, by the width of the metalized band that provides the actual reflection. Beyond about 18 degrees of heel the focused beam misses the metalized band completely, and the reflector quits working. Providing a wider reflective band would increase the range of heel angles, but at the expense of overall performance since more of the "front" surface (towards the radar beam) would be covered. Mounting the Lensref on a gimbal would significantly enhance its performance under sail.

Radar Flag

The Radar Flag reflects satisfactorily at 0° heel when flat, but in the draped position in which it would be used on a staff, it is practically invisible, giving an average return of just 4 ducks.

The Radar Flag is a fabric U.S. flag measuring about 20" x 11.5". Sewn inside the fabric is a metallic cloth which has reflective properties. The flag is intended to be flown on a conventional staff at the stern of a boat, to be allowed to flap like a normal flag. Construction is nylon, with heavy sewing for reinforcement.

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The Tests

We were very fortunate in being able to secure the use of the radar testing facilities at SRI International in Menlo Park, California. The tests were conducted in SRI's large anechoic chamber, which measures 20′ x 20′ x 40′. The target is centered near the far end of the chamber, on a radar-transparent pedestal that can be rotated through 360°, and the axis of rotation can be tilted up to 12°. A calibrated broad-band microwave transmitter/receiver is located in the wall at the opposite end of the chamber to accurately measure the reflected signal.

The walls, ceiling and floor are completely covered with semi-conductive, radar absorbing foam pyramids which absorb any stray radar signals and prevent any reflections back to the receiver, except those from the device under test. A retracting gangway extends through a door in one wall (also covered with foam pyramids) to provide access to the test pedestal.

The chamber is calibrated in terms of absolute RCS, and optimized to measure the very small radar returns from certain types of military aircraft. The background return is on the order of -60 dB (a millionth of a square meter). Calibration was checked before and after each days testing.

An HP minicomputer provided data logging and azimuth-elevation control of the test pedestal. Data was taken simultaneously at 3.05 GHz (S-band) and 9.41 GHz (X-band), recorded directly to disc and plotted to a laser printer. The data was subsequently converted to text files and transferred to floppy disc files for further analysis.

The first series of tests were performed during a two-day period, October 20-21, 1994. For each test, the gangway was extended, and the reflector being tested was secured to the test pedestal with non-reflecting tape and foam. The chamber was then closed, and the reflector was rotated at 1° increments through 360° while data was recorded. Each rotation required about 20 minutes.

Fig. 3. Test orientation for a "heeled" reflector (catch rain position shown).

Most of the reflectors were tested twice. A first test was done with the major axis perpendicular to the radar beam, corresponding to a reflector mounted upright on a vessel with no angle of heel, and viewed from every angle around the vessel. A second test was done with the reflector secured at an angle to the pedestal, corresponding to a reflector mounted upright on a heeled sailboat while a ship steams a circle around it. In this latter case the radar beam strikes the reflector at angles along an inclined plane, both above and below its equator (see fig. 3).

The Results

The results of selected individual tests are shown in graphical form as figures 4 to 8. Radar Cross Section in m^2 is shown as polar plots for both X-band and S-band, indicating the strength of the reflected signal in that would be seen by a ship steaming in a circle around a reflector located in the center. For each plot the outer ring represents the minimum RCS threshold (2.5 m^2 for X-band and 1.0 m^2 for S-band), and the inner ring represents 1.0 du, one duck unit.

Using the criteria for minimum reflectance described above, Table 1 was prepared as a summary for all of the devices tested. For each radar band, the first column indicates the average Radar Cross Section (RCS) in square meters for the reflector, using the recommended RMS (Root Mean Square) average. The second column indicates the percentage of angles that were greater than the minimum threshold (2.5 m^2 for X-band), an indicator of the "visibility" of the reflector, or the probability of being seen by a ship at an unknown horizontal angle. The third column indicates the largest angle that was less than this threshold, i.e. the angular width of the largest "blind spot". For S-band, a minimum threshold of 1.0 m^2 was used, reflecting the 4 dB reduction in sea state return experienced at S-band, allowing a smaller return to be detected.

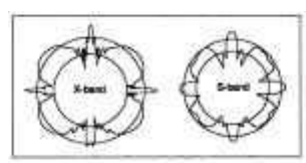
Table 1. Ranking of Reflectors Based on a Minimum Return of 2.5~m^2	**X-band**			**S-band**			
Reflector	**>2.5m^2**	**RCS(m^2)**	**Gap°**	**>1.0m^2**	**RCS(m^2)**	**Gap°**	**Fig.**
Davis Echo Master, Vertex Up, Heel=0∞	**63%	7.00	17	57%	1.71	21	
Davis Echo Master, Double C.R., Heel=0∞	48%	5.05	31	13%	0.90	78	4, 9
Davis Echo Master, Double C.R., Heel=20∞	43%	4.54	36	19%	1.02	78	
Lensref (4î R) Heel=0∞	30%	2.37	103	0%	0.44	---	5
Davis Echo Master, Catch Rain, Heel=0∞	26%	2.00	54	0%	0.49	---	
Davis Echo Master, Vertex Up, Heel=10∞	**19%	3.81	85	11%	0.89	142	
Davis Echo Master, Vertex Up, Heel=20∞	**13%	3.52	85	20%	1.03	79	
Firdell Blipper Model 210-7; Heel=0∞	11%	1.66	43	26%	0.74	66	
Radar Flag (Flat), Heel=0∞	9%	3.89	157	11%	3.38	149	
Firdell Blipper Model 210-5 (4î R), Heel=0∞	7%	1.39	96	8%	0.49	185	6, 10
Firdell Blipper Model 210-5 (4î R), Heel=20∞	6%	1.22	175	2%	0.36	292	
Davis Emergency (5.7îR), C.R., Heel=0∞	2%	1.25	117	0%	0.30	---	
Lensref (4î R), Heel=20∞	0%	1.32	---	0%	0.18	---	
Mobri (2îR), Heel=0∞	**0%	1.08	---	0%	0.46	---	

Cyclops #1 (5.4îR), Heel=0∞	0%	0.57	---	0%	0.22	---	
Cyclops #1(5.4îR), Heel=20∞	0%	0.52	---	0%	0.24	---	
HYE (5î) Catch Rain, Heel=0∞	0%	0.47	---	0%	0.12	---	
High Gain Rotation (4î R), Heel=20∞	0%	0.42	---	0%	0.27	---	
Radar Flag (Draped), Heel=0∞	0%	0.40	---	6%	0.38	169	7
High Gain Rotation (4î R), Heel=0∞	0%	0.38	---	0%	0.22	---	
Mobri (2îR), Heel=20∞	**0%	0.37	---	0%	0.17	---	8
Mobri (1îR), Heel=0∞	**0%	0.22	---	0%	0.16	---	
Mobri (1îR), Heel=10∞	**0%	0.07	---	0%	0.04	---	
(** Note high sensitivity to angle of heel for this orientation and reflector)							
C.R. = catch rain							
R = radius							

The table data are sorted first by X-band "visibility", the percentage of return greater than the threshold, then by average RCS for the reflectors with no return above the threshold.

Using this criteria, the Davis Echomaster was the clear winner, but showed the deep nulls associated with an octahedral reflector. The peaks were as high as 25 m^2, but these peaks were too narrow to have any real significance. S-band performance was lower than X-band, but by less than the expected factor of 10.

Fig. 4. RCS plot of the Davis Echomaster in the double catch rain position with 0° heel.

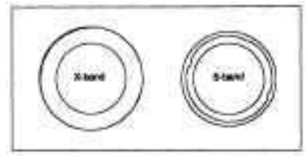


The best overall performance for the Davis was not in the often-recommended "catch rain" position, but in the "double catch-rain" position, which has the advantage of very little degradation of performance with heel. The average RCS was 5.0 m^2 upright, and 4.5 m^2 heeled 20°. Visibility was not great, however, at less than 50% (see fig. 4).

The vertex-up position provided the best performance with a 0° heel angle, but quickly deteriorated as the reflector was heeled, and is not recommended.

The Lensref was a close second in this tabulation, with an average RCS of 2.4 m^2 (see fig. 5). Interestingly, this is just a fraction below the somewhat arbitrary threshold of 2.5 m^2. If we arbitrarily assign a threshold of 2.0 m^2 instead of 2.5 m^2, then the Lensref goes straight to the top of our chart, with virtually 100% of the return greater than the threshold (i.e. no gaps), an outstanding performance amongst this lot. Only three of the Lensref data samples came in at less than 2.0 m^2, and then only by one or two hundredths, truly splitting ducks. Performance of the Lensref on S-band is pretty marginal at 0.4 m^2 average RCS, due to its small size compared to the wavelength.

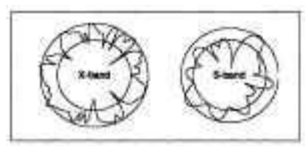
Fig. 5. RCS plot of the 8" diameter Lensref with 0° heel.



The limited angle of heel is a serious limitation for the Lensref for a sailing application, as angle of heel is often greater than the 18° limit of the device. Fitting a gimbal would solve this limitation neatly, but would need some engineering to avoid uncontrolled swinging, as the Lensref is not a lightweight device.

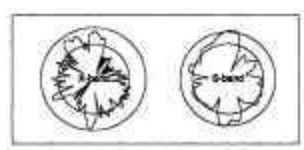
The poor performance of the Firdell Blipper was surprising, given its popularity and reputation. When measured at X-band with no heel, the 210-5 model fitted to most boats was only visible over 7% of the horizontal angles, and only a few peaks exceeded the 2.5 m^2 threshold (see fig. 6). The average return was 1.4 m^2, or 14 ducks, and the largest gap was over 90°. When heeled to 20°, the performance of the 210-5 deteriorated about 20%. The larger 210-7 model had a 20% higher average return of 1.7 m^2. Measured at S-band, the 210-7 performed about 50% better than the smaller unit, and was "visible" for 26% of the angles compared to 8% (with a 0° angle of heel).

Fig. 6. RCS plot of the Firdell Blipper 210-5 with 0° heel.



The Radar Flag reflector gained a high ranking in its flat configuration, spread out in a vertical plane. In this orientation it exhibited a very strong return perpendicular to the plane of the flag, but almost no return at other angles. It was "visible", with a return above the threshold, for only 9% of the angles. In a more typical "drooped" orientation, the Radar Flag was essentially invisible, with an average return of only 0.4 m^2 (4 ducks), and not above the threshold at any angle (see fig. 7).

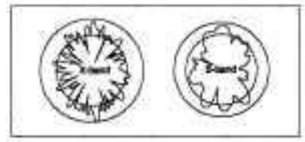
Fig. 7. RCS plot of the Radar Flag (draped) with 0° heel.



The Davis Emergency reflector is the last of the lot to provide a return above the threshold at any angle, but is far from its bigger brother. The other reflectors were generally limited by their small size.

The two Mobri reflectors performed as might be expected, and were essentially invisible. Only the larger 4" diameter (2" radius) device came anywhere near detectability, with an average return at a 0° angle of heel of just over 1 m^2, with no deep nulls. On S-band, the average return was almost 0.5 m^2, not enough to be detected, but better than most. When heeled, however, things fall apart and the return drops to a few duck units (see fig. 8). The smaller Mobri is invisible under all conditions, and, with its minimal windage, might make a nice addition for the Stealth Bomber.

Fig. 8. RCS plot of the 2" radius Mobri with 20° heel.



RADAR REFLECTORS (cont'd)

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Target Pattern Maps

Following this series of tests, the data was shared with some of the manufacturers. GEC Marconi, manufacturers of the Firdell Blipper, responded that to quantify reflectance in a single plane does not represent the best way of looking at reflector performance. Specifically, they asserted that, with respect to the Firdell Blipper, the large nulls that were observed in the horizontal plane would be small in the vertical direction, and that only a one or two degree change in elevation angle (i.e. heel) would move from a null to a peak. It was further asserted that presenting the data in the form of a three-dimensional Target Pattern Map was the only proper representation of reflector performance.

A Target Pattern Map (TPM) is a method of representing three-dimensional data on paper, where azimuth (horizontal) angles are shown on the horizontal X-axis, elevation data is shown on the vertical Y-axis, and the strength of the return is shown by color or gray-scale shading. Color is dramatic, but unfortunately expensive to reproduce.

A study of GEC Marconi's published TPMs reveals two interesting anomalies. First, the comparison to a 12" octahedral shows peaks of barely 2 m^2, while a 12" diameter spherical octahedral reflector (such as the Davis) would be expected to have a peak RCS associated with the axis of the "pocket" of each trihedral reflector of 8.3 m^2. The answer to this mystery may lie in the formula for the return for a triangular trihedral. An octahedral made from 8½" square plates would form triangular trihedrals, and would measure 12" (i.e. a 6" radius) across the largest dimension. The theoretical peak return for this device would be 2.2 m^2, which corresponds to the Bell/Lark TPM. So the comparison must be to a 12" triangular octahedral, not a spherical octahedral such as the Davis Echomaster.

The second problem with GEC Marconi's data is with the characteristic of the peaks for the Firdell Blipper 210-7 shown in the TPM. A preponderance of peaks are shown greater than 3 m^2, with a vertical interval from peak to peak of about 3°, the basis for GEC Marconi's statements that the "gaps" are "only between 1 and 2 degrees wide[iii]". The vertical peaks and nulls are the result of interference effects between vertically spaced reflector elements, which will either add or cancel as the heel angle is changed. Both the size and the vertical spacing of the reported peaks, however, are consistent with a device much larger than the 210-7.

A second series of tests were performed on 26 March, 1995 to investigate these assertions. The computer-controlled target pedestal elevation control was used to take data at elevation angles from -12 to +2 degrees and azimuth angles over 180 degrees without remounting the reflector. That range of angles was felt to be representative, and was within the time available in the chamber. Data was collected for the Davis Echomaster and the Firdell Blipper 210-5.

Fig. 9. Target Pattern Map (TPM) of the Davis Echomaster in the catch-rain position.

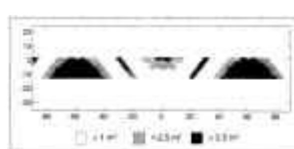
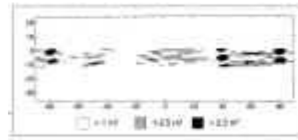


Fig. 10. Target Pattern Map (TPM) of the Firdell Blipper 210-5.



Interestingly, it was not possible to reproduce the results reported in the Bell/Lark paper. The Davis Echomaster showed the expected pattern, with a broad reflectance peak corresponding to the axis of each trihedral corner reflector, and a sharp peak matching the orientation of each planar surface. The returns associated with each trihedral reflector peaked at just over 6 m^2, compared to a theoretical peak of 9 m^2. The average (RMS) return was 2.6 m^2 for the Davis over the area tested, consistent with the earlier tests.

The Blipper results that we obtained were quite different from those that were reported in Bell/Lark. The areas of low reflectance extended much further in elevation than reported, with a vertical interval of 6 to 7° between peaks. The overall average RCS was 1.6 m^2, only slightly higher than our previous more limited tests, and only a very few peaks exceeded 3 m^2. The issue of the size of the gaps seems a bit moot given the small size of the peaks. Figures 8 and 9 show the TPM data that we obtained for the Davis Echomaster and the Firdell Blipper respectively. The 210-7 is approximately 10% larger than the 210-5 tested, and would be expected to show peaks about 40% higher but only 10% smaller vertically, not a significant difference.

While TPM's are certainly a more comprehensive way of looking at reflector performance, for these types of devices a simple horizontal scan at two or three heel angles is more than sufficient to characterize the reflector. The additional complexity of a Target Pattern map is not justified for any of the reflectors tested here.

Conclusions

The first conclusion is that there is no substitute for size when it comes to radar reflectors. The devices that offer smaller size and lower windage simply don't work as well. With regard to the Firdell Blipper, it is a well packaged and clever device, but the models tested were not large enough to have much real value aboard a vessel. Larger versions would accomplish what GEC Marconi claims, but are not practical on small vessels.

The Davis Echomaster (in the "Double Catch Rain" position) and the Lensref performed the best of all of the devices tested. The Lensref has no nulls, which is a tremendous advantage in terms of being seen, but the overall reflectance is marginal. If a Lensref is fitted on a sailing vessel, it should be gimbaled or made adjustable. The Davis Echomaster had stronger peak reflectance, but also large holes, which means that a large target would not consistently be presented on a ship's radar.

None of the reflectors would be more than marginally useful in offshore situations where only S-band were being used, except perhaps in calm sea conditions.

The marginal performance of radar reflectors in general does not mean that they should not be carried. On the contrary, anything that improves a vessels radar visibility is worthwhile, particularly short-handed vessels and those without radar themselves.

Beyond that, it needs to be again pointed out that the best defense where shipping is concerned is a good offense. A ship's radar may only see a sailboat three or four miles away, but that same sailboat can typically see the ship 12 miles away by radar, and visually at least 8 miles away in clear weather. The small boat is both better equipped and more highly motivated to avoid the potential collision.

Footnotes:

[i] Be Seen Or Be Sorry, Kenneth Parker, from GEC Marconi
[ii] Radar Detectability and Collision Risk, Bell and Lark, The Nautical Institute
[iii] The Plain Manis Guide to Radar Reflectors, Dr. Steve Bell, from GEC Marconi