Passive RCS enhancer field of view study

Derek GRAY and Julien Le KERNEC

James Watt School of Engineering, University of Glasgow, Glasgow, UK.

E-mail: (Derek.Gray, Julien.LeKernec) @glasgow.ac.uk

Abstract Passive radar cross section enhancers are used to increase the return from small targets like fishing boats, as well as as standards for radar systems' calibration. Alignment of small enhancers is difficult at high *mm*-wave due to the small physical size. To better understand the scan loss of a commonly used trihedral reflector, it was studied using a commercially available antenna simulator. It gave 7dBm^2 or better across a ±12° arc with 2dB variation. An equivalent area disk gave 13dBm^2 on axis only, while a spherical lens reflector gave the same RCS across a ±25° arc with 0.4dB variation.

Key words passive RCS enhancers, corner reflector.

1. Introduction

A program at Tokyo University of Marine Science and Technology aimed to develop both passive and active radar cross-section (RCS) enhancers to improve the detectability of small fishing vessels within Japanese green waters [1]. Despite such work, collisions involving small vessels continue to this day due to the lack of legal compulsion to at least carry passive RCS enhancers. Extreme low cost may encourage uptake. Passive RCS enhancers are also used as marine navigation and airport landing aids, and as calibration standard targets for radar and radiometry. A good example of field work where calibration was done using commercially available spherical Luneburg lenses fitted with reflective caps is described in [2]. Luneburg lenses are seen as a prestige solution due to the high cost [3]. As most applications, including marine X-band radar, only require a good narrow band response low cost narrowband alternatives to commercially available Luneburg reflectors are sort. Due to legacy issues, all work presented was done at 12GHz [4]. A consequence for this is that the X-band marine passive RCS enhancer recommendation ISO 8729 is modified to 6.64dBm^2 [5].

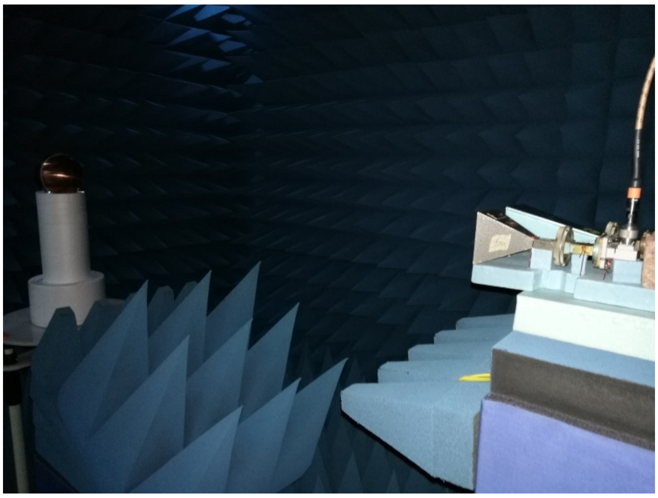

Figure 1: Photo of a passive RCS enhancer under test.

Measuring passive RCS enhancers is straight forward as the procedure is akin to measuring the principal plane patterns of an antenna. For monostatic measurements the Tx and Rx horns are placed in parallel pointed at the DUT on the rotator, Figure 1. Measuring linearly polarized responses out of the principal planes requires alignment be maintained. Both axial and polarization misalignment practical usage concerns arose from observing engineers at work calibrating 76GHz automotive radar. The commercially available antenna simulator FEKO™ produces bistatic RCS which can be amalgamated into monostatic RCS patterns using Matlab™, Figure 2.

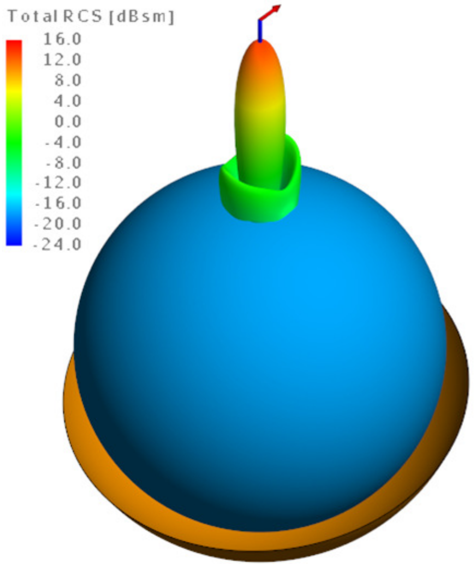

Figure 2: Full hemisphere bistatic RCS pattern of a spherical lens reflector in response to a linearly polarized plane wave indicated by the arrows; from FEKO™.

2. Flat circular disks

The on-axis peak RCS of flat circular disks can be calculated from empirical equations [6]. 50mm radius and 75mm radius disks were cut from 2mm thick 6063 aluminium and tested across X-band was shown in Figure 1. Comparing theory, full wave simulation and measurement across 8 to 13GHz, the FEKO™ results showed some resonances that aren't modelled in the theory, Figure 3. Monostatic measurement with 2 X-band horns added further complexity from the resonances in the individual horns and the coupling between those.

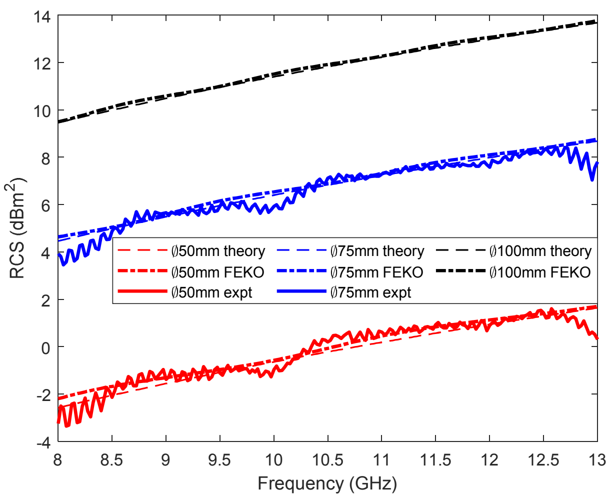

Figure 3: Theoretical, simulated and measured RCS of aluminium disks.

A 100mm radius 2mm thick PEC disk was run in FEKO™ at 12GHz in response to a linearly polarized plane wave that was scanned in zenith 1° steps to 10° and azimuth angle from -180° to 180°. The RCS in the direction of each plane wave was noted and plotted as a contour, Figure 4. The monostatic RCS was close to perfectly rotationally symmetric. The on-axis peak was 13.1dBm^2 with a sharp roll-off in all azimuth, Figure 5.

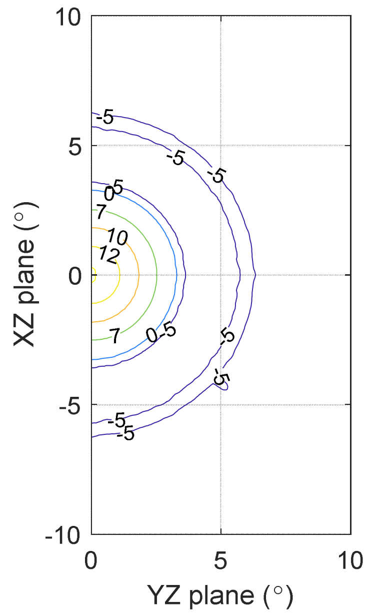

Figure 4: Monostatic RCS of 100mm radius flat disk at 12GHz; from FEKO™.

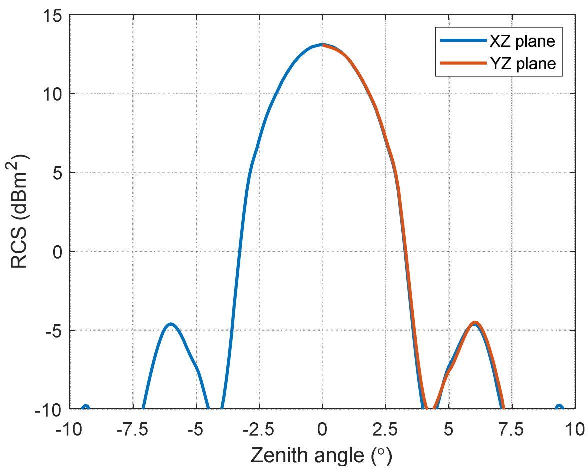

Figure 5: Principal plane monostatic RCS of 100mm radius flat disk at 12GHz; from FEKO™.

3. Trihedral corner reflector

120° rotationally symmetric trihedral corner reflectors are available from numerous manufacturers and are the most common radar calibration standard and target type.

CAD is freely available from many manufacturers such as [7]. A trihedral corner reflector with roughly the same area as the 100mm radius disk was imported into FEKO™, aligned symmetrically with one apex on the XZ-plane and simulated with plane wave illumination, Figures 6 and 7.

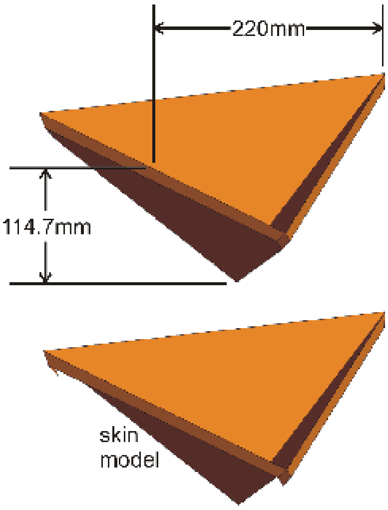

Figure 6: Annotated CAD of trihedral corner reflector.

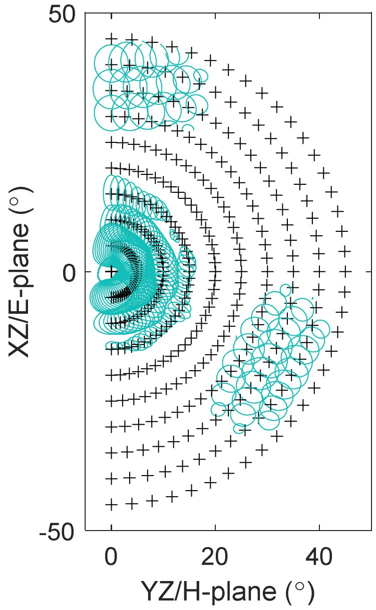

Figure 7: Bistatic RCS 4.6m² contours of trihedral corner reflector (solid model) at 12GHz; from FEKO™.

The monostatic RCS of the trihedral was close to rotationally symmetrical in 120° steps as per the structure itself, Figure 8. The "ISO 8729 mod" $4.6m^2/6.64dBm^2$ recommendation for marine X-band radar was satisfied across a ±10° arc of the axis, Figures 7 and 8. There were unwanted strong reflection responses of that order across zenith 30° to 50° range centred on azimuth angles of 0°, 120° and the mirror angle of 240° from the individual flat surfaces.

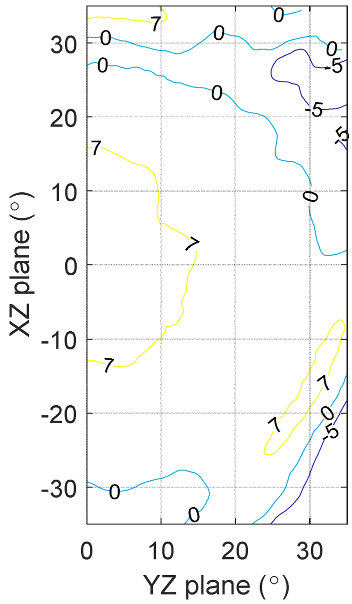

Figure 8: Monostatic RCS of trihedral corner reflector (solid model) at 12GHz; from FEKO™.

The monostatic RCS principal plane patterns show a 1.8dB null on axis, Figure 9. This null would preclude use of this type as a high accuracy calibration standard if perfect axial alignment cannot be achieved.

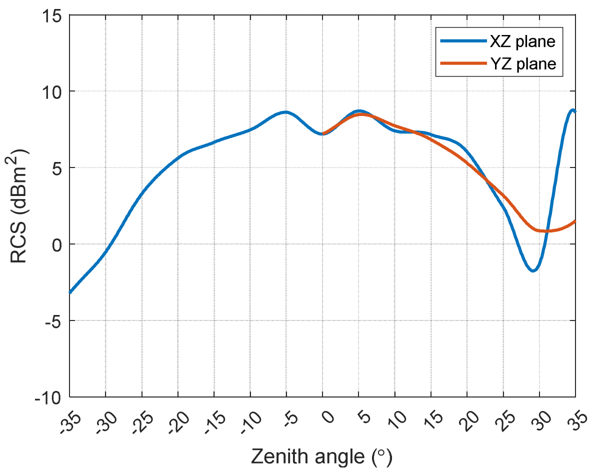

Figure 9: Principal plane monostatic RCS of trihedral corner reflector (solid model) at 12GHz; from FEKO™.

Given that the monostatic RCS response in the forward direction only is of interest here, the back walls of the trihedral corner reflector were deleted to halve the size of the FEKO™ model, Figure 6. The bistatic and monostatic contour plots were indistinguishable from those of the "solid model," Figures 10 and 11. The principal plane monostatic RCS near axis peaks and central null from this "skin model" were within 0.1dB of the "solid model" and the XZ-plane unwanted lobe at 34° was 0.3dB higher, Figure 12. The "skin model" is thus good for a first appraisal of some corner reflector design.

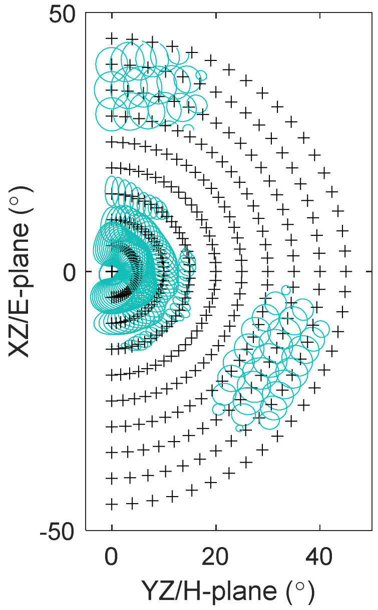

Figure 10: Bistatic RCS 4.6m² contours of trihedral corner reflector (skin model) at 12GHz; from FEKO™.

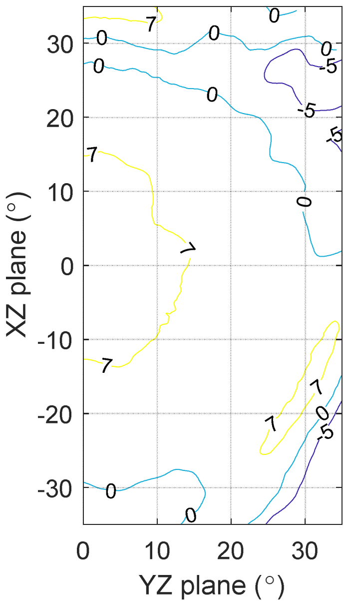

Figure 11: Monostatic RCS of trihedral corner reflector (skin model) at 12GHz; from FEKO™.

4. Double convex lens with bowl reflector

A polyethylene (ε_r=2.3) double convex lens with a reflector bowl was developed as a low weight passive RCS enhancer for light vessels [8]. Here the bowl thickness was 5mm, Figure 13.

The "ISO 8729 mod" 4.6m²/6.64dBm² recommendation was satisfied across a ±25° arc of the axis, Figures 14 and 15. At higher RCS values closer to the axis there was some asymmetry resulting from use of a square lens.

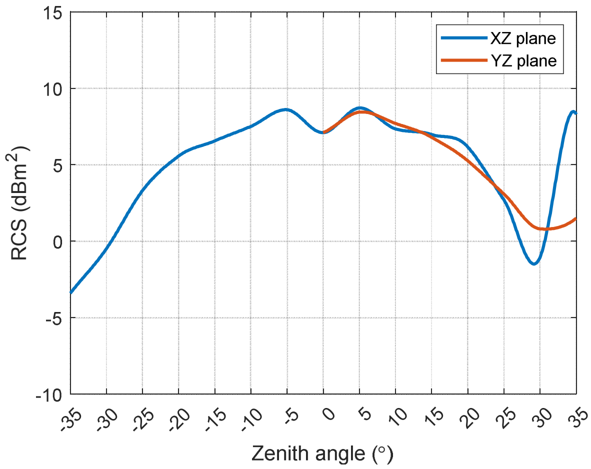

Figure 12: Principal plane monostatic RCS of trihedral corner reflector (skin model) at 12GHz; from FEKO™.

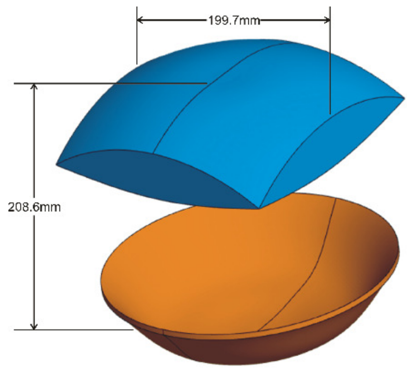

Figure 13: Dimensioned CAD of PE lens reflector.

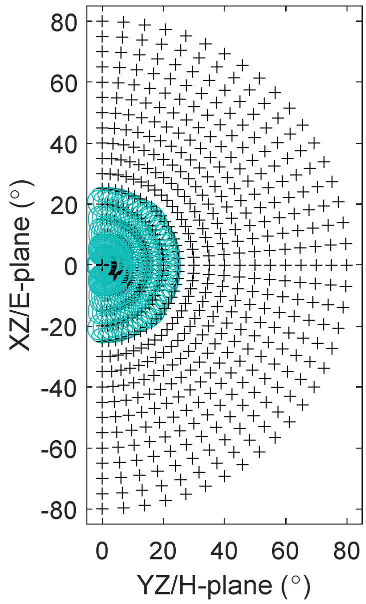

Figure 14: Bistatic RCS 4.6m² contours of double convex lens with 5mm thick reflector at 12GHz; from FEKO™.

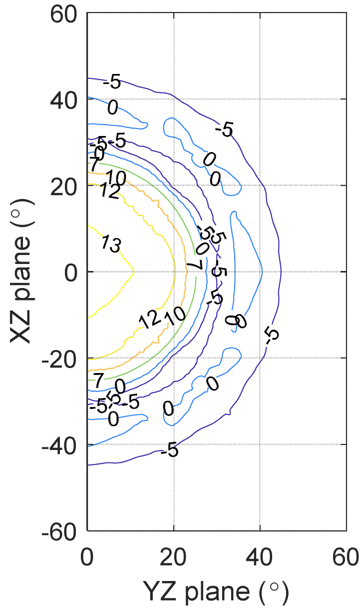

Figure 15: Monostatic RCS of double convex lens with 5mm thick reflector at 12GHz; from FEKO™.

There was a null on-axis, but it was within 0.1dB of the peaks, Figure 16. Thus, across a ±5° arc of the axis there was less than 0.1dB monostatic RCS variation compared to 2dB variation from the trihedral corner reflector making the former more suited for use as a calibration standard, Figures 9, 10 and 16. Across a ±20° arc of the axis the RCS variation was less than 2dB.

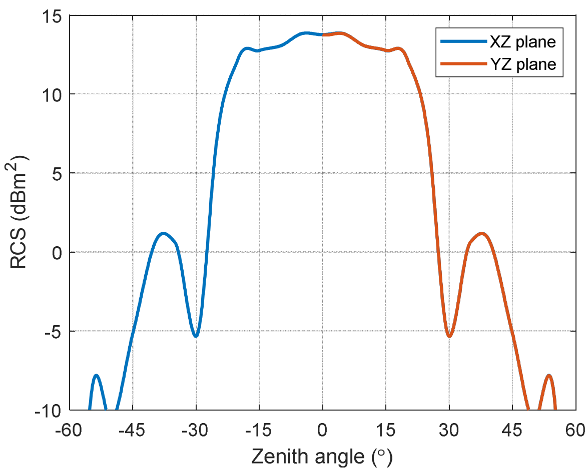

Figure 16: Principal plane monostatic RCS of double convex lens with 5mm thick reflector at 12GHz; from FEKO™.

5. Spherical lens with thin reflector

A homogeneous polyethylene (ε_r=2.3) spherical lens with an offset thin 140° reflective cap was developed as a low cost passive RCS enhancer for light vessels [5], Figure 17. It was tuned to give the highest RCS response associated with a super-directivity state.

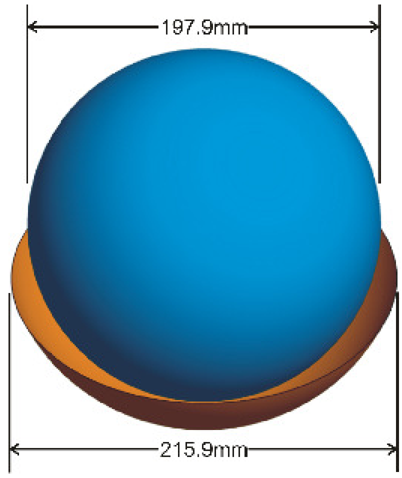

Figure 17: Annotated CAD of spherical lens with thin reflector.

The "ISO 8729 mod" 4.6m²/6.64dBm² recommendation for marine X-band radar is satisfied across a ±65° arc of the axis, Figures 18 and 19.

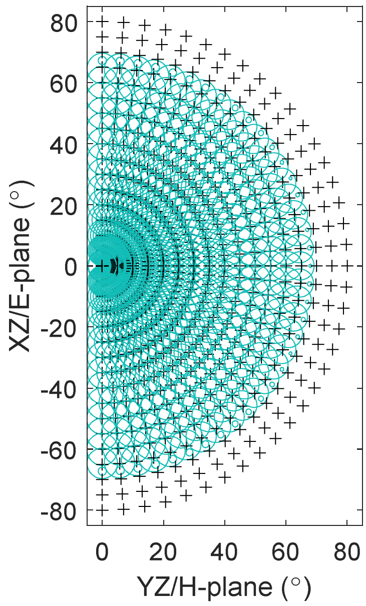

Figure 18: Bistatic RCS 4.6m² contours of spherical lens reflector at 12GHz; from FEKO™.

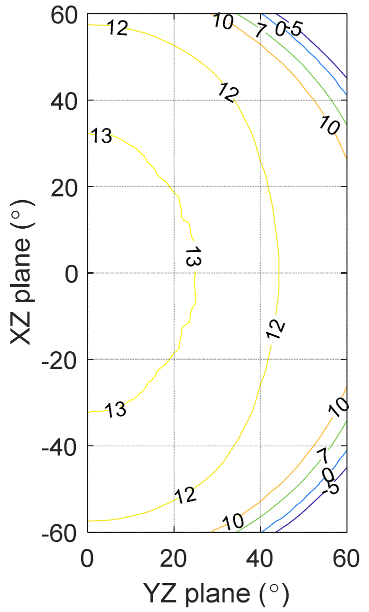

Figure 19: Monostatic RCS of spherical lens reflector at 12GHz; from FEKO™.

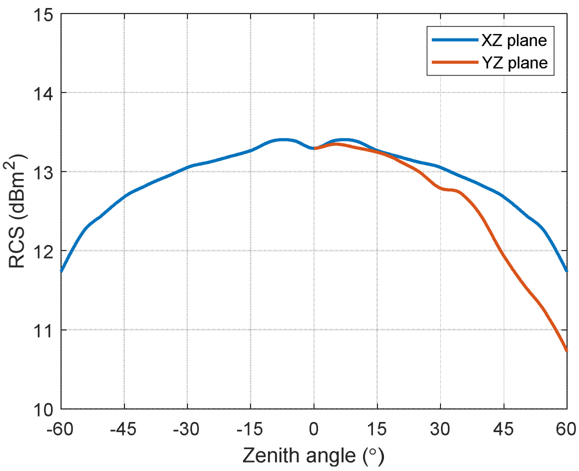

Figure 20: Principal plane monostatic RCS of spherical lens reflector at 12GHz; from FEKO™.

As for the double convex lens there was a null on-axis within 0.1dB of the peaks also making this type suited for use as a calibration standard, Figure 20. Across a ±50° arc of the axis the RCS variation was less than 2dB.

6. Conclusions and future work

A series of exotic passive RCS enhancers and a flat disk were modelled in a commercially available simulation software and were found to give superior performance as X-band marine RCS enhancers and calibration standards compared to a commonly used trihedral corner reflector.

Future work will concentrate on building and validating the exotic lens reflectors.

Acknowledgement

The authors wish to thank Dr. M. Ide of MOL Marine & Engineering Co., Ltd. for her advice, encouragement and enthusiasm.

8. References

[1] H. Heibatake, S. Hayashi & M. Ide, "A basic study on enhancement of electrical visualization for small boat," *Asia Navigation Conf. 2008*, Shanghai, Nov. 2008.

[2] F.T. Ulaby, "Measurement of soil moisture content," *CRES Technical Report 177-35*, April 1973.

[3] S. Luke, "Performance investigation of marine radar reflectors on the market," *QinetiQ CR0704527*, Mar. 2007.

[4] D. Gray, N. Nikolic & J. Le Kernec, "Scan performance of small spherical retro-reflectors," *2019 Int. RADAR Conf.*, Toulon, September 2019.

[5] D. Gray, J. Le Kernec & J. Thornton, "Small boat retroreflectors," *Int. Conf. on Radar Systems*, paper 5b.2, Edinburgh, Oct. 2022.

[6] G.C. Southworth, *Principals and applications of waveguide transmission*, D. van Nostrand Company, Inc., Princeton, NJ, 1950.

[7] www.eravant.com, accessed 17th of June, 2023.

[8] D. Gray, J. Thornton & J. Le Kernec, "Double convex lens for marine retro-reflector application," *IEICE Tech. Rep.*, Ehime Museum of Art, vol. 122, no. 182, AP2022-72, September 2022..