Cross section of the ETS-VIII Retroreflector Array

by
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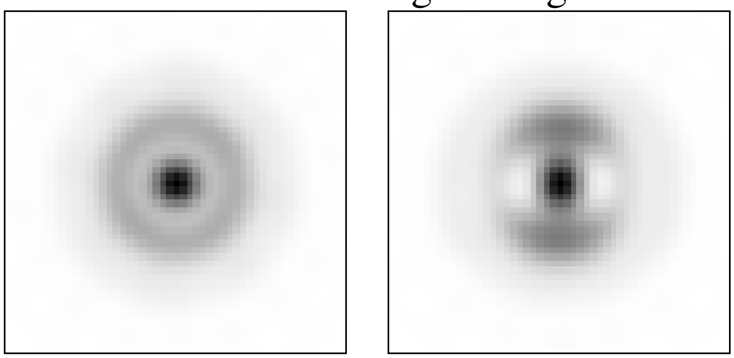
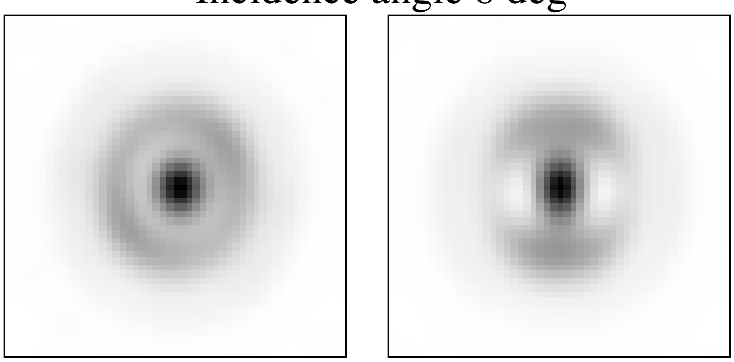
The ETS-VIII satellite has a planar array of 36 circular uncoated cube corners 1.6 inches in diameter. The dihedral angle offset is specified as .5 arcsec. The actual dihedral angle offset of each cube corner was provided by the manufacturer. The cross section of the array has been computed as a function of polarization and incidence angle. The figures below show the diffraction matrix of the array for circular and linear polarization at 0 and 8 deg incidence angle on the array.

Incidence angle 0 deg



Circular Vertical

Incidence angle 8 deg



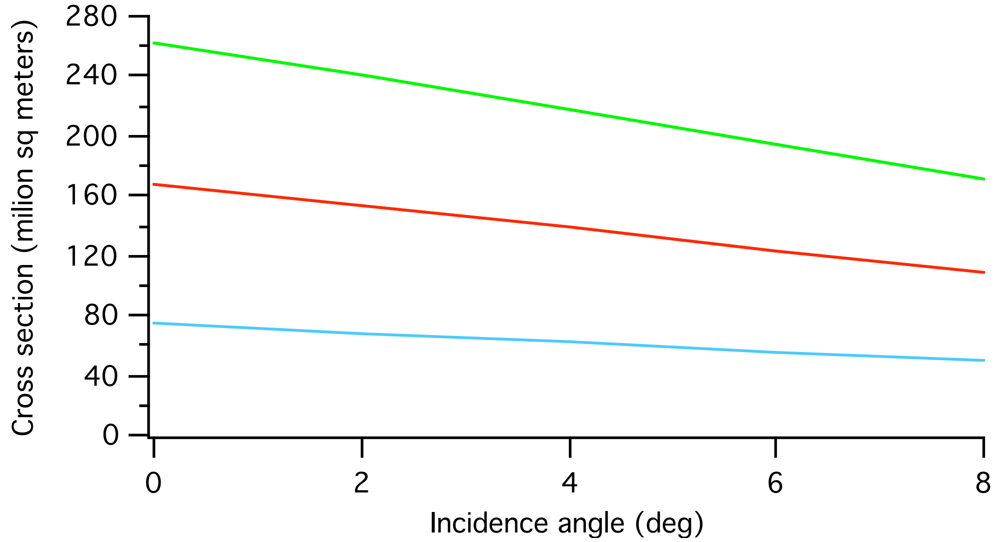
Circular Vertical

At normal incidence the diffraction pattern has circular symmetry for circular polarization. For linear vertical polarization the diffraction pattern is asymmetrical as a result of the interaction between the polarization and the dihedral angle offset.

At 8 deg incidence angle the diffraction pattern is slightly oval for circular polarization. For linear vertical polarization it is asymmetrical. The velocity aberration of 18 microradians puts the receiver on the ring outside the central peak. For circular polarization there is not much variation with the direction of the velocity aberration. For linear polarization the cross section depends on the angle between the velocity aberration and the polarization vector.

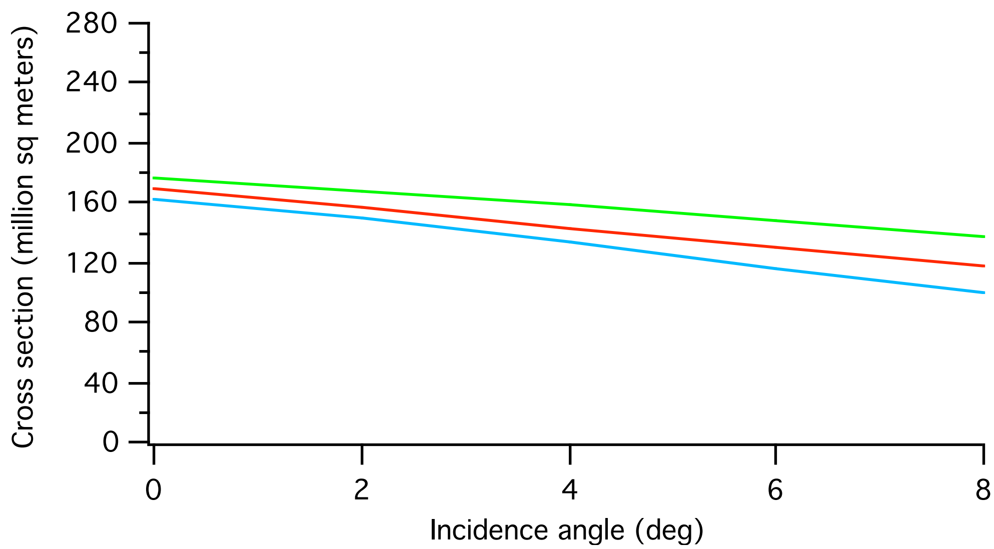
The figures below show the cross section vs incidence angle.

Linear polarization



ϕ	μrad	Minimum	Average	Maximum	Max - Min
0.	18.0	74.9211146	168.0714592	262.5278845	187.6067699
2.	18.0	68.1029657	153.4990546	240.7941383	172.6911726
4.	18.0	61.7740094	138.5805192	218.0135367	156.2395273
6.	18.0	55.2565578	123.6396719	194.2223537	138.9657958
8.	18.0	49.5777806	109.2762497	171.2168708	121.6390902

Circular polarization

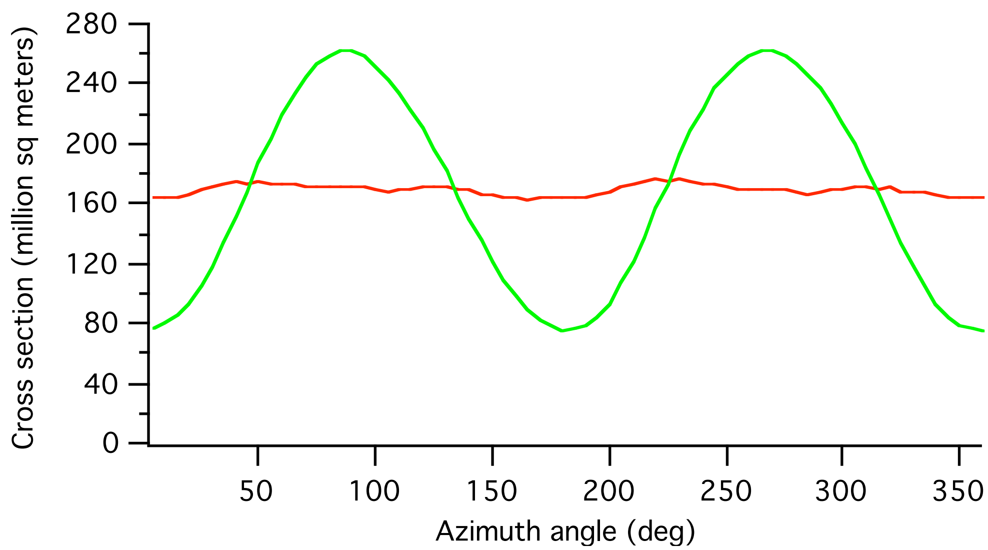


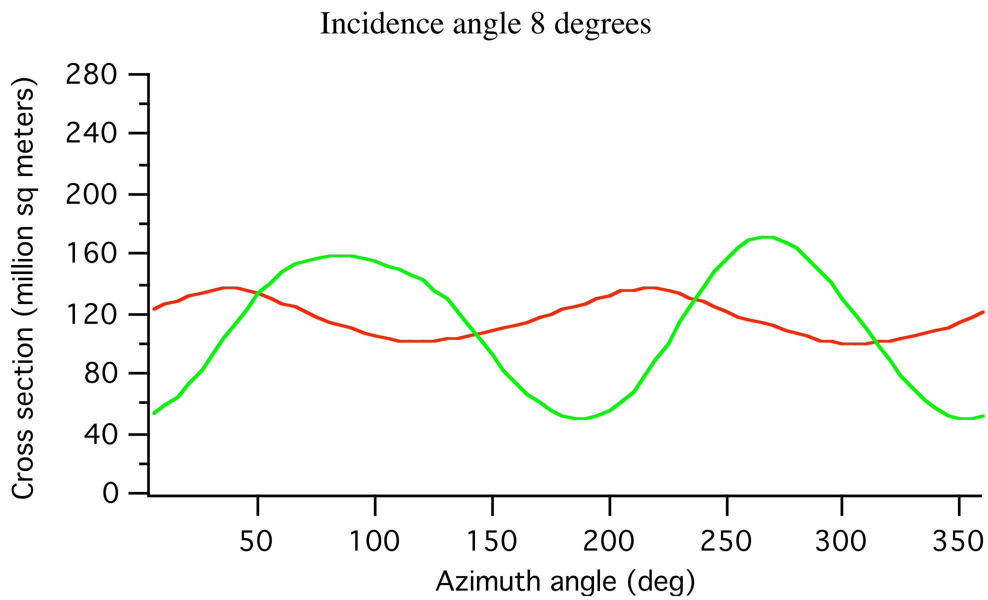
ϕ	μrad	Minimum	Average	Maximum	Max - Min
0.	18.0	162.8369981	169.1154523	176.7910628	13.9540648
2.	18.0	148.9271882	156.1983793	167.9120999	18.9849116
4.	18.0	133.1623969	143.0808965	158.1616152	24.9992183
6.	18.0	116.3366982	129.9517639	147.9697942	31.6330960
8.	18.0	100.2285993	117.1769863	137.6133349	37.3847357

The plots above show the values of the cross section in million square meters around a circle of radius 18 microradians in the far field diffraction pattern. The tables show the incidence angle, velocity aberration in microradians, minimum, average, maximum, and maximum minus minimum value around the circle. The three lines in the plots are the following:
Green = maximum value around the circle
Red = average value
Blue = minimum value
The plots for linear vertical polarization show the most variation because the pattern is asymmetrical. Circular polarization shows the least variation. The pattern becomes slightly oval for off normal incidence angles for circular polarization.

The plots below show the cross section around a circle of 18 microradians.

Incidence angle 0 degrees

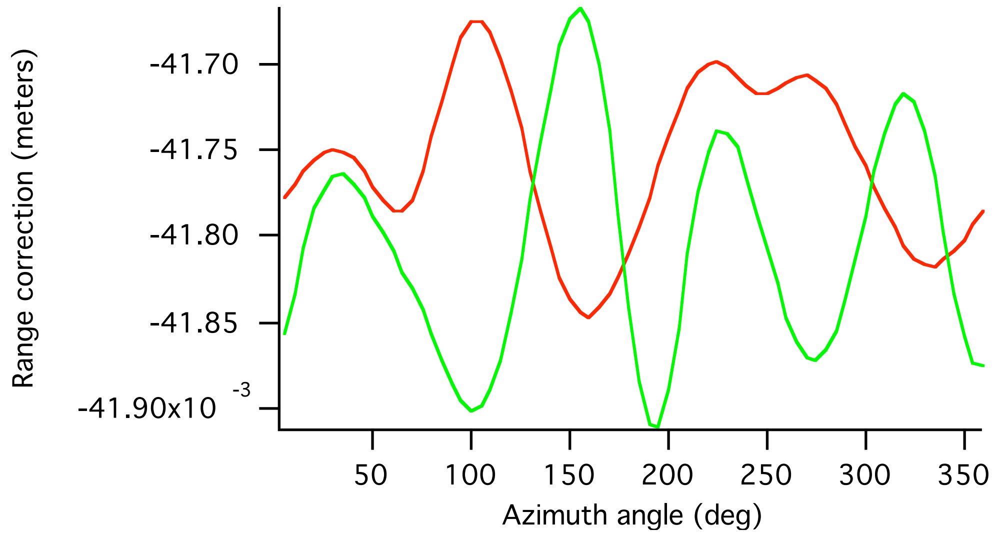




In the plots above the two curves are the following;
Green = linear vertical polarization
Red = circular polarization
Both plots are at the same scale to show the decrease in cross section with incidence angle. At normal incidence the cross section is fairly constant for circular polarization. At 8 degrees incidence angle the cross section for circular polarization shows some variation around the circle.

At normal incidence the range correction is constant at all points in the far field pattern because all the cube corners are at the same distance along the line of sight. At 8 degrees incidence angle the cube corners are at different distances along the line of sight. The figure below shows the variation of the centroid range correction around a circle of radius 18 microradians.

Incidence angle 8 degrees



The two curves are as follows;
Red = circular polarization
Green = linear vertical polarization
The range correction is in meters with respect to the center of the front face of the array. Since the exponent in the plot is 10^{-3} the numbers shown on the vertical axis are millimeters. The range correction is negative indicating that the effective reflection point is closer to the center than the front of the array. At normal incidence the range correction is the length of the cube from vertex to face times the index of refraction 1.461 of the quartz. The range correction varies from about -41.66 to -41.9. This is a peak to peak variation of about .24 millimeters. The reason the variations are so small is that the array is planar. The incidence angle is the same on all cube corners so the diffraction patterns are all about the same. The small variation comes from the fact that the dihedral angle offsets are slightly different in each cube corner due to manufacturing imperfections.

Because the satellite is in a geostationary orbit the satellite is always viewed in the same part of the sky. The incidence angle on the array is always the same. The magnitude of the velocity aberration is always the same. The cross section depends only on the polarization of the laser.

The cross section in million square meters for each of the 5 stations able to track ETS-VIII is shown in the table below for various possible polarization states. The columns are:

Station	Name
Cir	Circular polarization
Horiz	Horizontal polarization (parallel to the horizon) pointing to the right
Vert	Vertical Polarization pointing up toward zenith
Max	Maximum cross section
Min	Minimum cross section
aberX	X component of velocity aberration (microradians) parallel to the horizon pointing to the right
aberY	Y component of velocity aberration (miocroradians) pointing up toward zenith
ϕ	Incidence angle on the array (degrees)

Station	Cir	Horiz	Vert	Max	Min	aberX	aberY	ϕ
Changchun	142	201	59	212	48	-17.3	-6.4	7.1
Koganei	144	226	51	227	51	-17.8	-2.8	5.8
Stromlo	141	225	54	227	52	18.0	1.3	5.7
Tanegashima	150	209	70	229	50	-16.5	-7.2	5.5
Yarragadee	115	149	112	214	46	13.4	-12.4	6.4

The maximum cross section is when the polarization is parallel to the velocity aberration. The minimum cross section is when the polarization is perpendicular to the velocity aberration.

Summary

ILRS is developing a standard for retroreflector arrays for high altitude satellites. Actual ranging experience is the most helpful thing for a project manager in deciding what array to use.

Need comparative signal strength measurements between existing high altitude satellites:
ETS-VIII, GPS, GIOVE-A, COMPASS, GLONASS

Need all data related to calculating signal strength.
For uncoated cubes:

- Linear or circular polarization?
- Direction of linear polarization

Retroreflector arrays with uncoated cubes:
ETS-VIII, COMPASS, OPTUS, LAGEOS 1&2, AJISAI, APOLLO

It is recommended that stations use circular polarization for retroreflector arrays with uncoated cubes. This gives more consistent cross section and avoids polarization dependent range biases. Circular and linear polarization give the same results for coated cubes since there are no polarization effects.