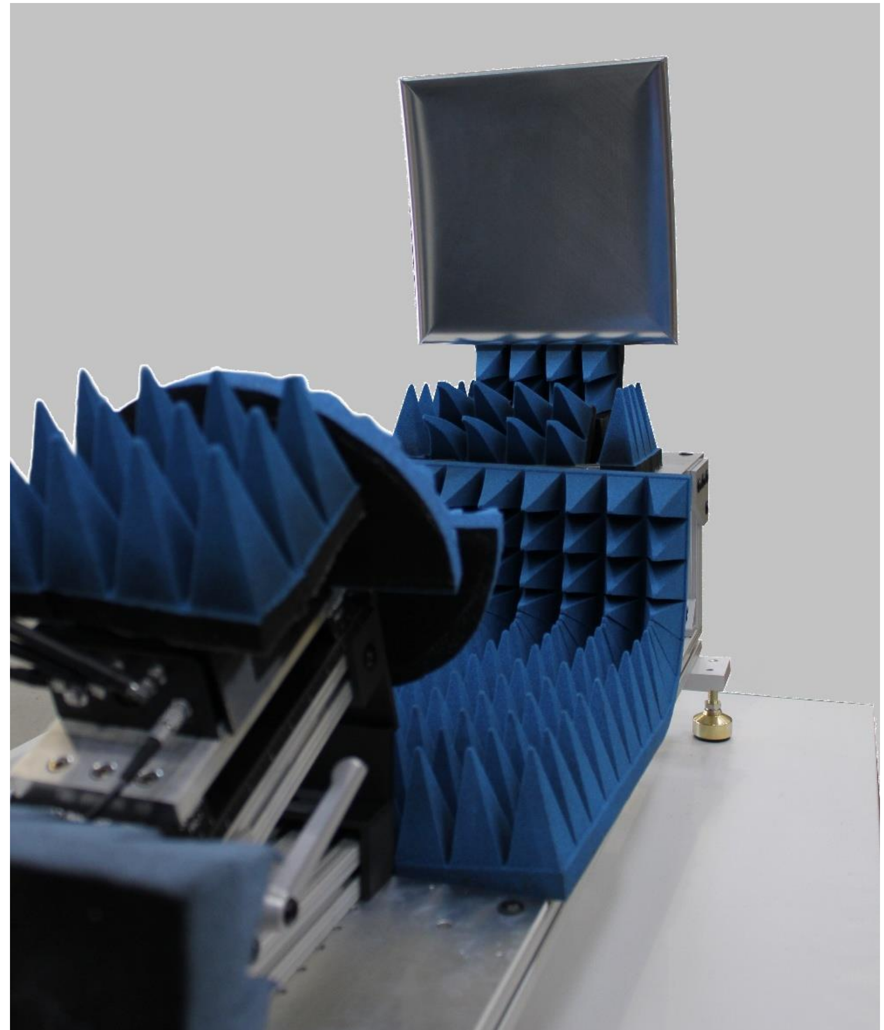
Millimeter-Wave RCS Measurements Using a Compact Antenna Test Range

IMS 2025 Micro-Apps



ERAVANT

CONTENTS

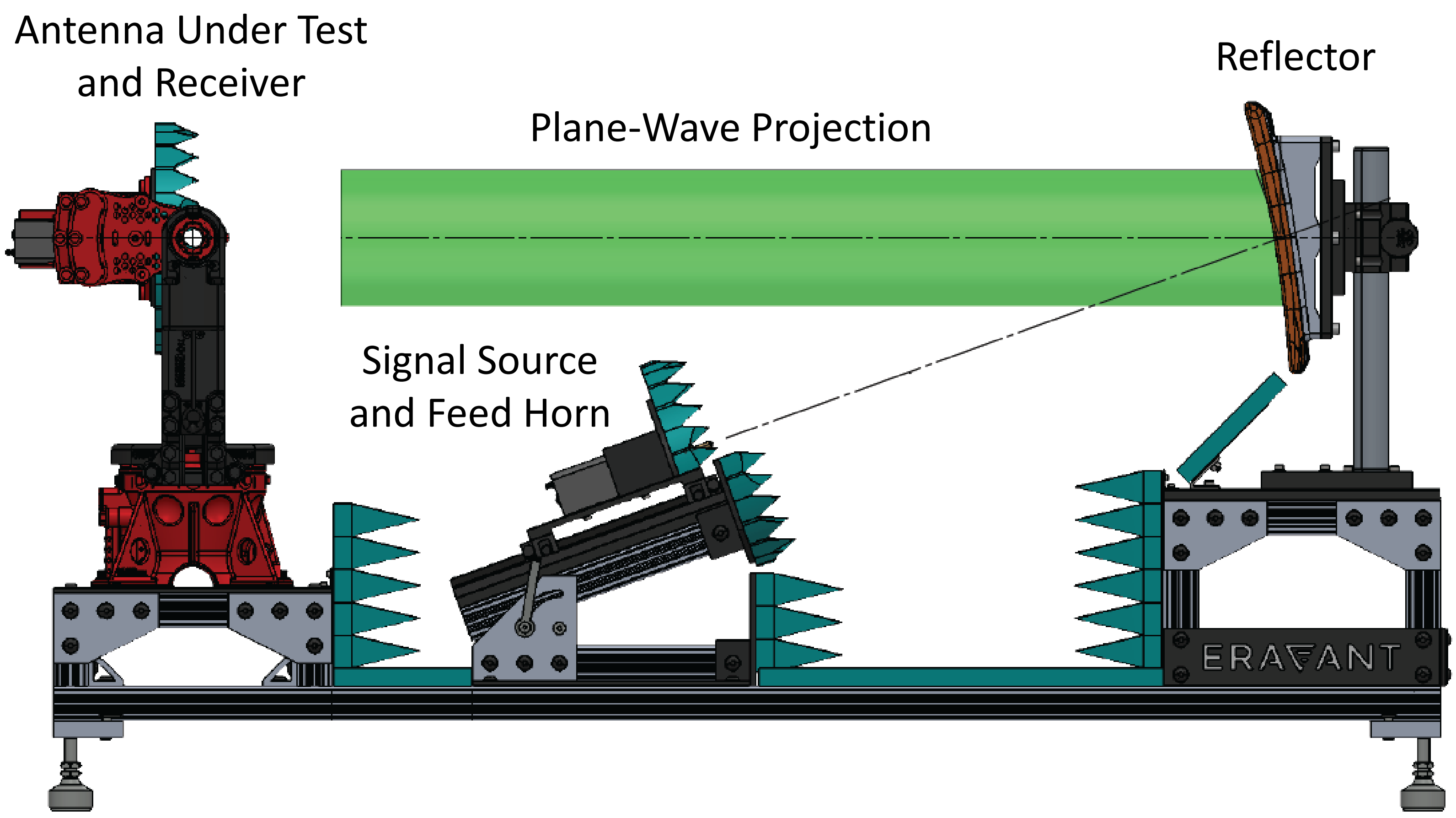
Introduction

- You can use an antenna range to measure Radar Cross Section (RCS).
- You can use far field range or compact range (CART).
  - **For mmW and sub-THz, CART is more popular.**
- Critical considerations for accuracy:
  - Minimize unwanted reflections
  - Capture the scattered signal from the target accurately

Introduction

- Measuring RCS using an antenna range involves
  - A well-planned test setup
  - Calibrated equipment
    - VNA
    - Baseline Reference - Use a known reference target, such as a sphere or corner reflector
    - Measure the background signal without the target present to identify and subtract any environmental reflections.
  - Target Measurement
    - Place the target in the designated measurement area.
    - Transmit a signal from the transmitting antenna and measure the backscattered signal received by the receiving antenna.
    - Use a VNA to obtain comprehensive RCS data.
  - Specific data processing techniques, especially when operating in the near-field or dealing with multipath environments.

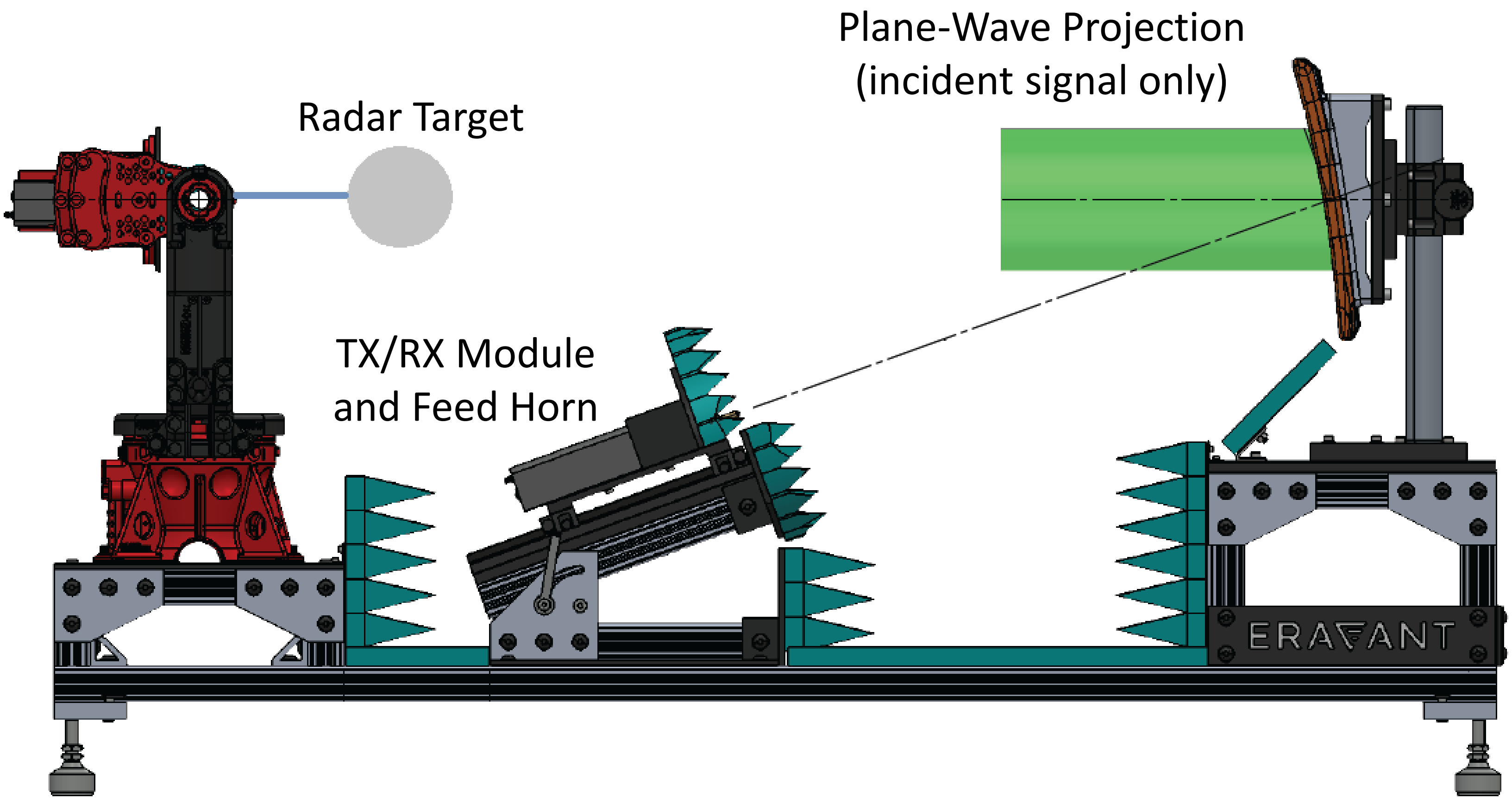
Compact Antenna Test Range



Compact Antenna Test Range

- Compactness is achieved by generating a plane-wave signal that simulates far-zone conditions for the Antenna Under Test.
- Within a limited cross-section signal strength is nearly constant vs distance from reflector.
- This project seeks to determine the practicality of using a CATR to measure RCS.
- CATR may not be the best tool, but useful.

Modified CATR for RCS Tests



Distance from CATR reflector to feed horn: 635 mm

Modified CATR for RCS Tests

- CATR is Eravant model STY-CATR-0150-OB-S1
- VNA is Copper Mountain model C4209
- TX/RX module is a VNA frequency extender, model STO-1209315-C-E1
- 60 to 90 GHz Operating Range
- Reflected power (VNA Channel A1) is measured for various target configurations
- Reference target is a polished aluminum sphere, 5 inches diameter

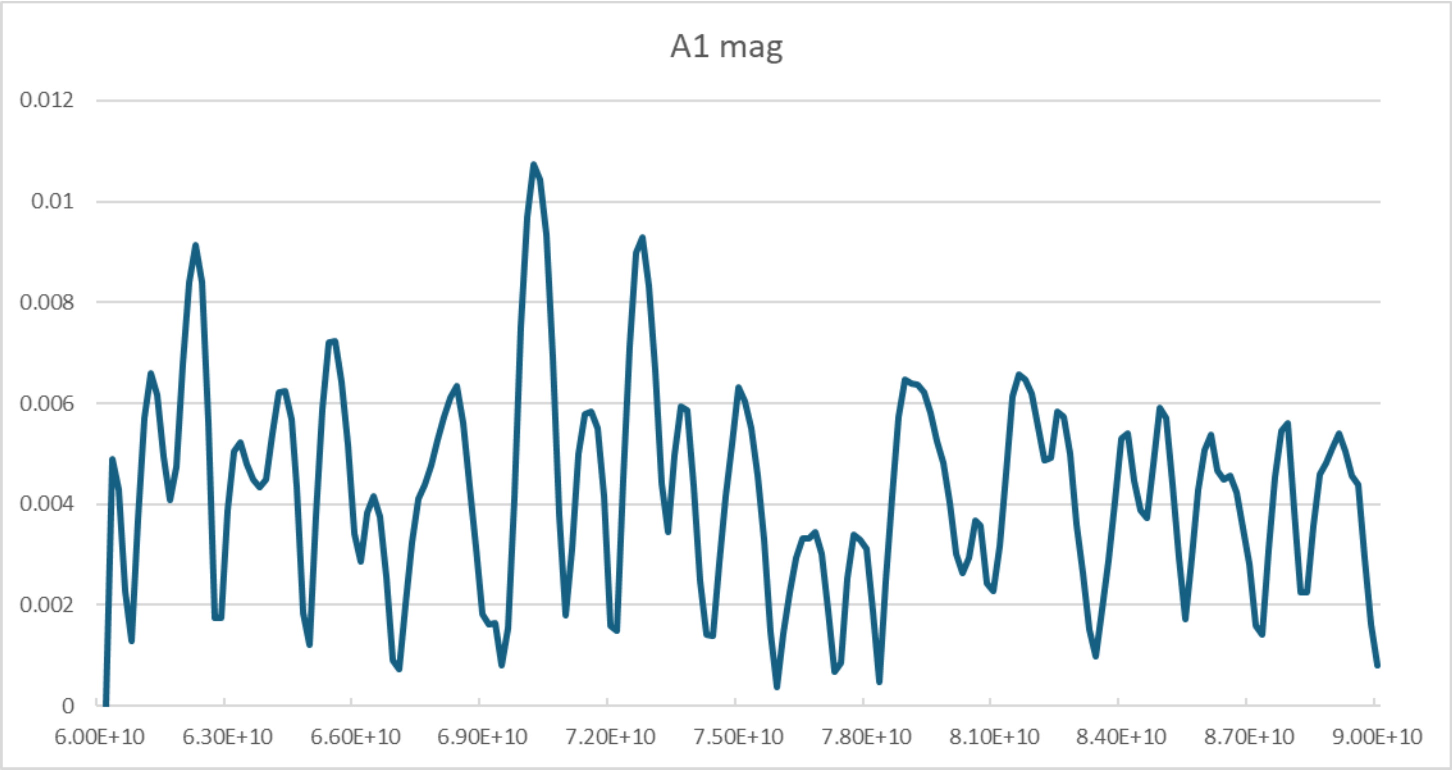
Baseline Scans

- Reflected power is measured with no target.
- Signals reflected from targets add to the baseline signal.
- Substraction yields the net reflected signal
- Dynamic range is limited by digitization noise, available transmit power, receiver noise, drift, etc.
- Too-faint signals can be buried in digitization noise, receiver noise, or shifting clutter signals.

Baseline Scans

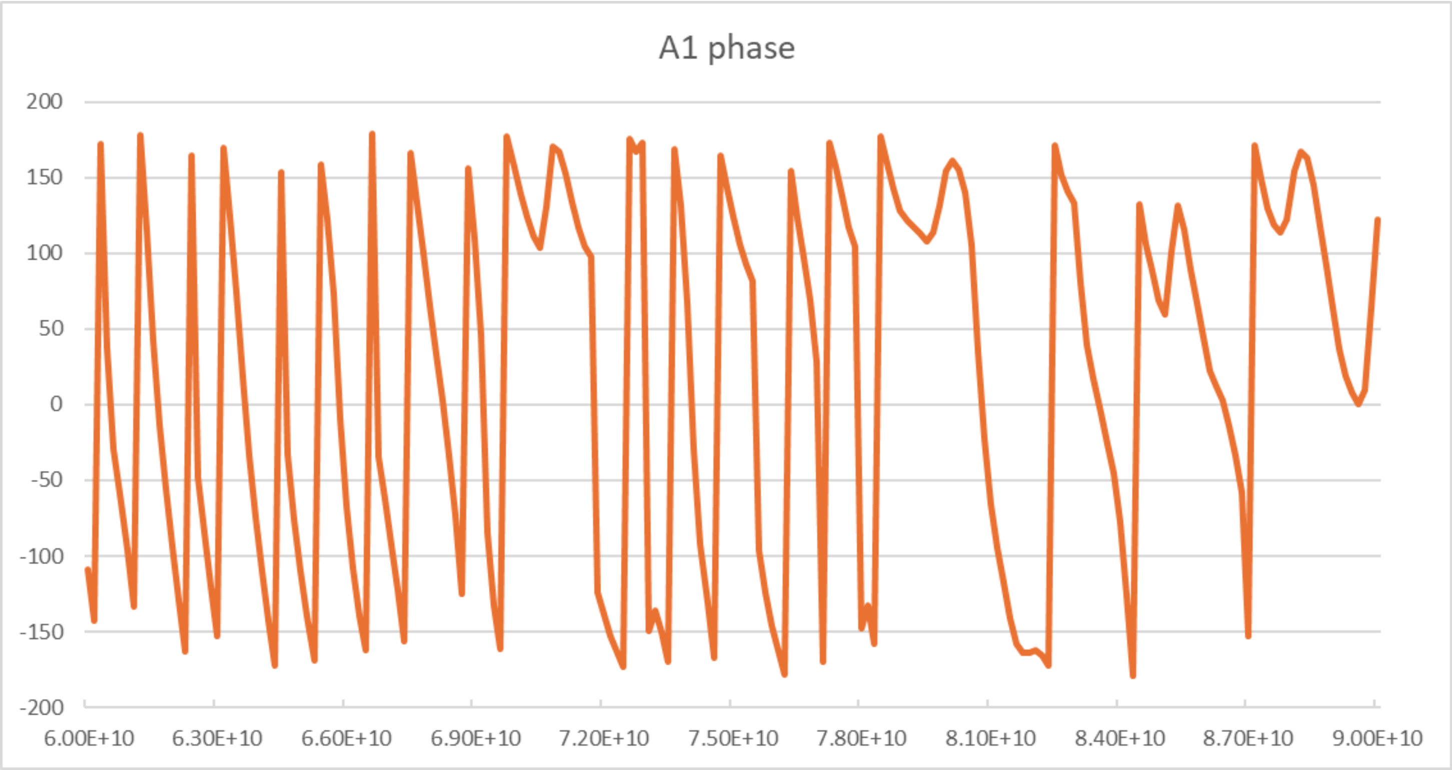
- A1 baseline data includes contributions from:
  - TX/RX module internal reflections
  - Feed antenna mismatch reflection
  - Limited TX/RX directional coupler directivity
  - Environmental reflections (clutter)
  - Parabolic reflector diffraction

Baseline Scan Example



Vertical units are milli-Watts

Baseline Scan Example

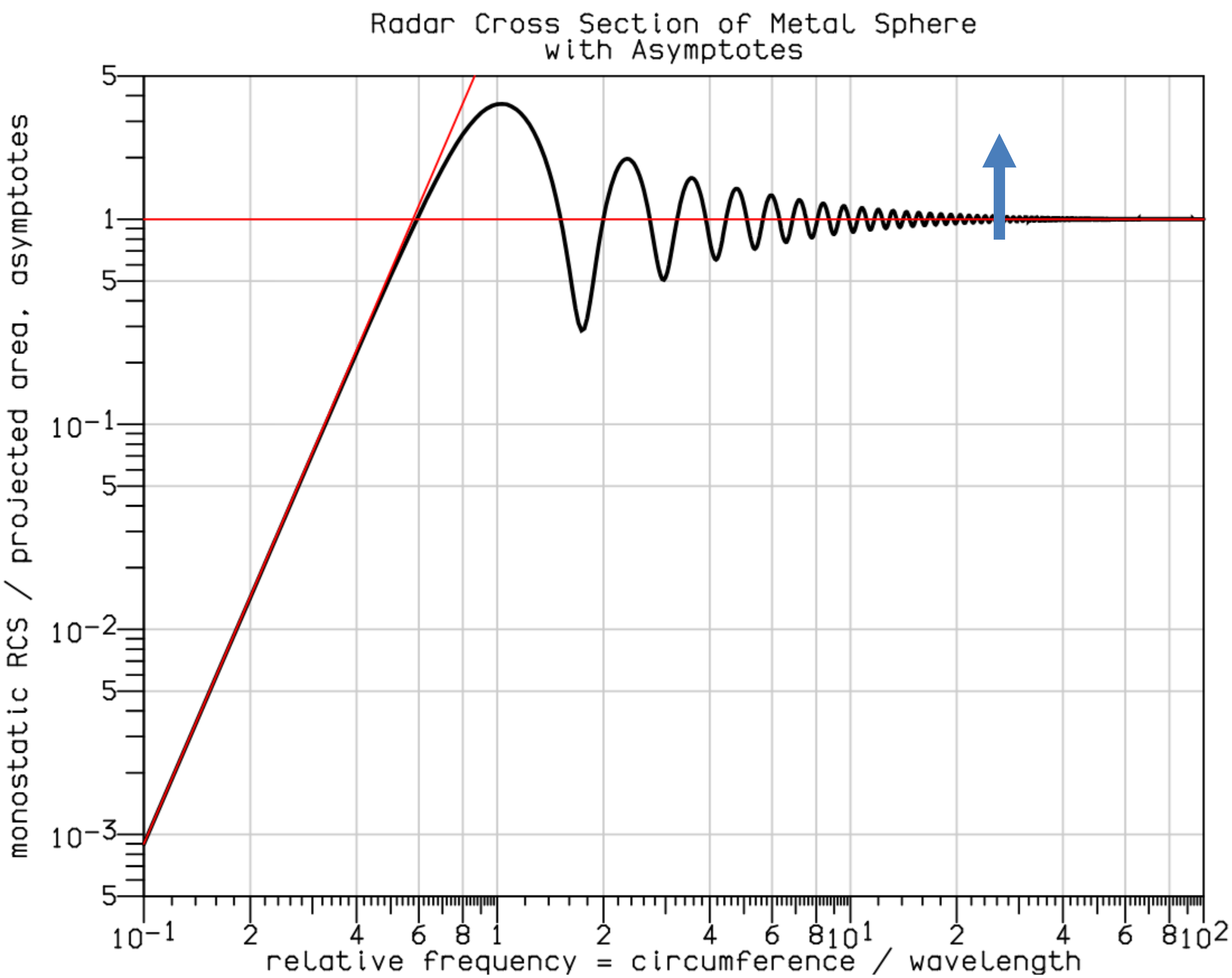


Vertical units are degrees

Sphere RCS

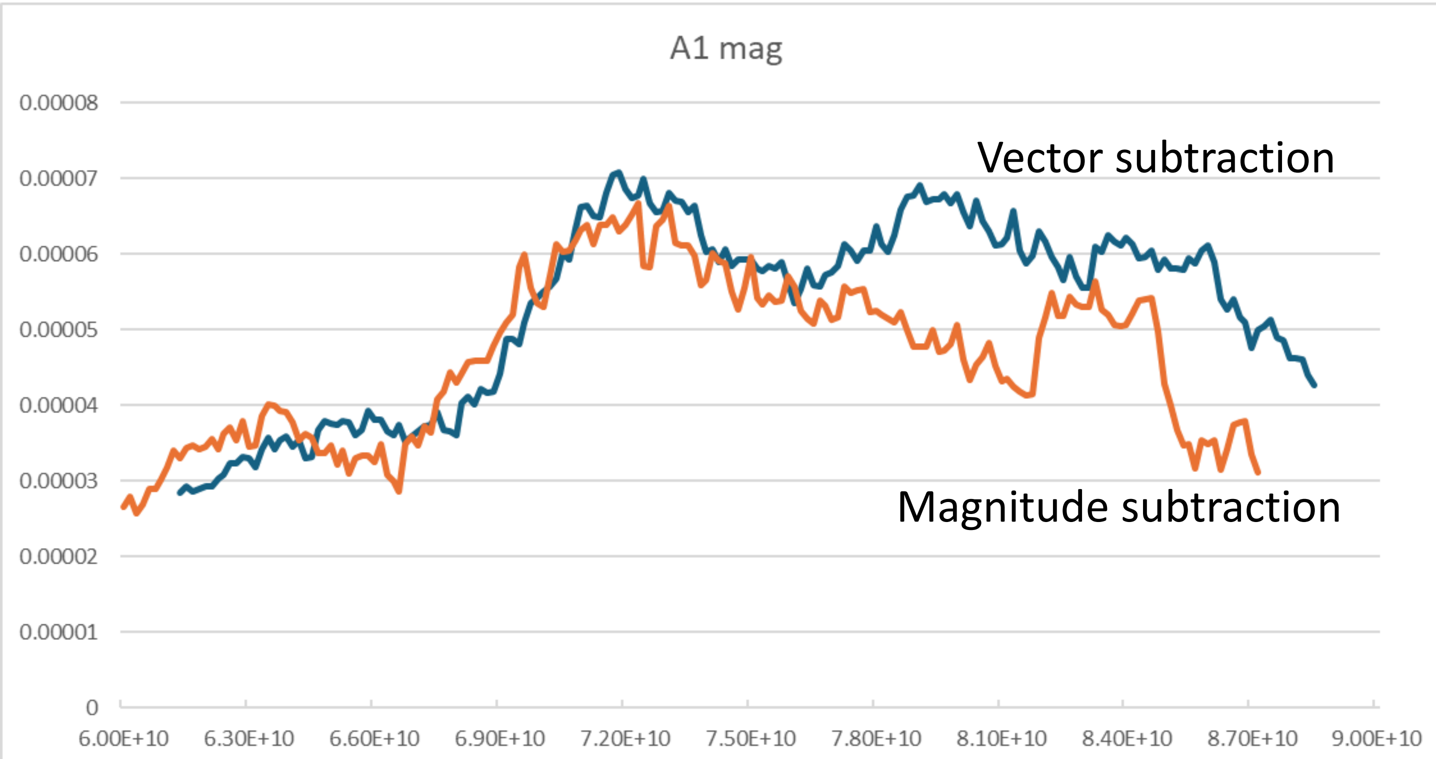
- Spherical target: $r = 2.5$ inches (63.5 mm)
- At 75 GHz, $\lambda = 4$ mm
- Circumference $C = 2 \pi r = 16$ inches (400 mm)
- $C / \lambda \approx 100$
- Expected RCS: $\sigma = \pi r^2 \approx 0.013 \text{ m}^2 = 130 \text{ cm}^2$

Sphere RCS



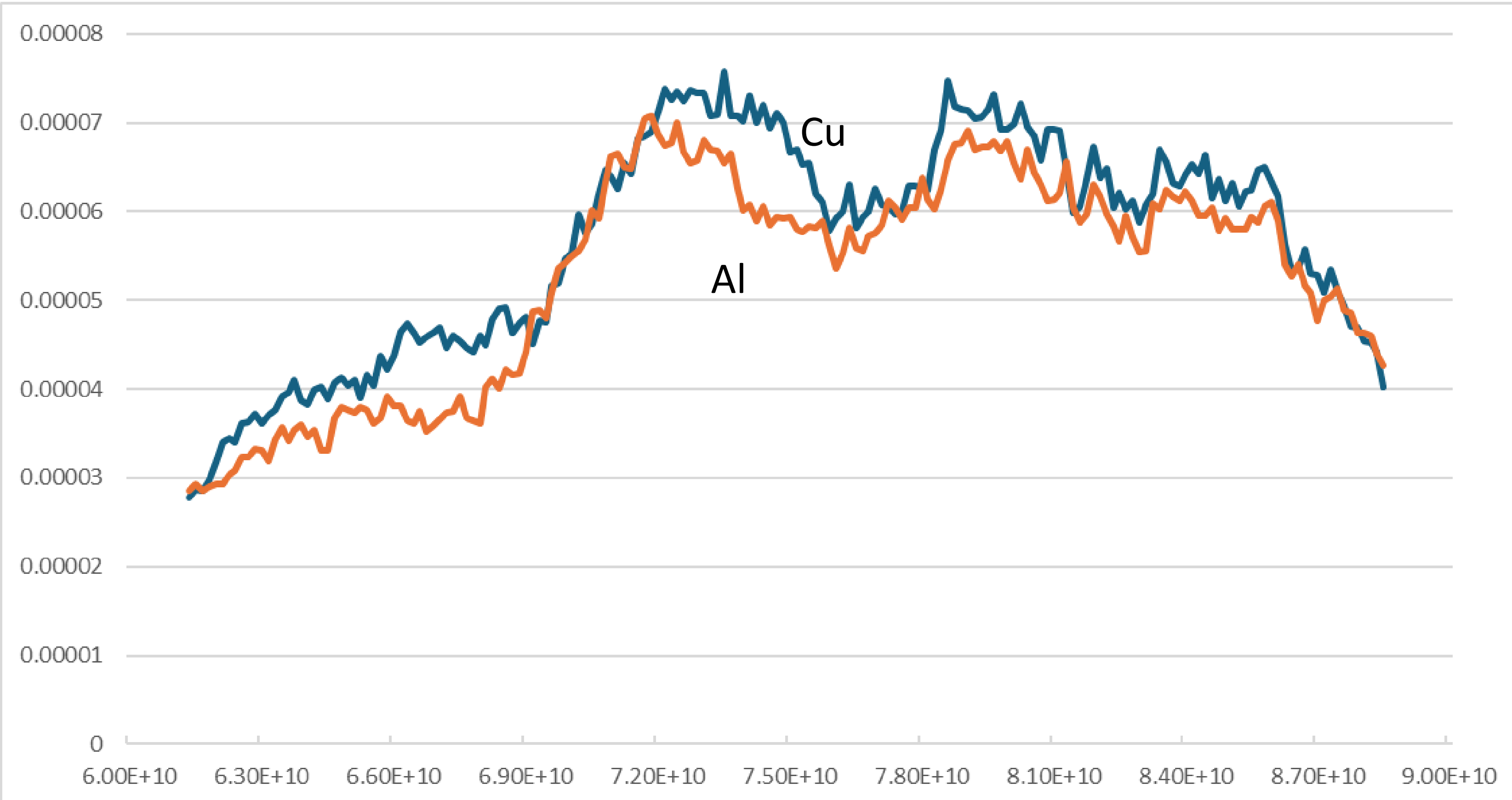
Radar Cross Section of Metal Sphere
with Asymptotes
monostatic RCS / projected area, asymptotes
relative frequency = circumference / wavelength
5
1
5
10−1
5
10−2
5
10−3
5
10−1
2
4
6
8
1
2
4
6
8
10 1
2
4
6
8
10 2

5” Aluminum Sphere Response



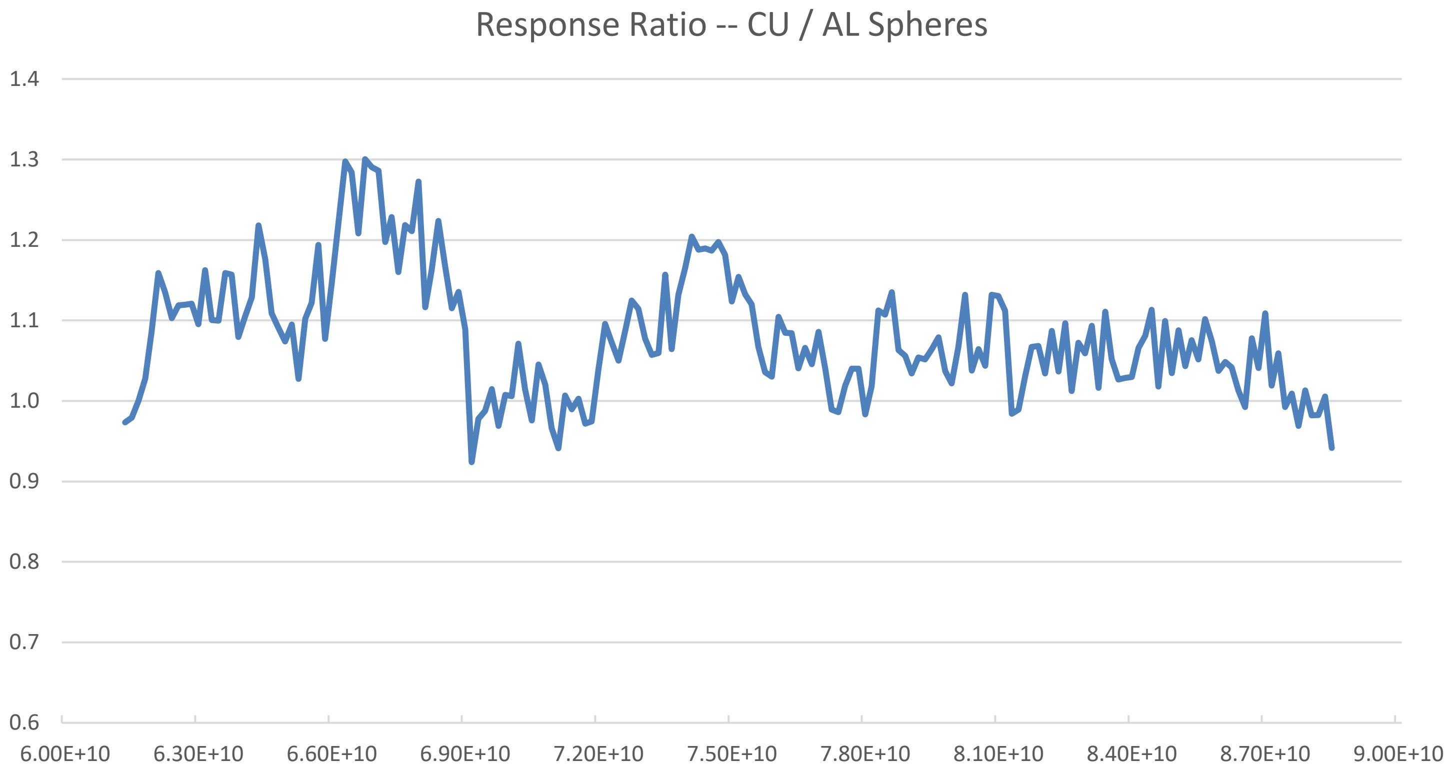
Vector subtraction captures more of the reflected signal

5” Sphere Responses, Cu vs Al



Distance from CATR Reflector to target: 600 mm

5” Sphere Responses

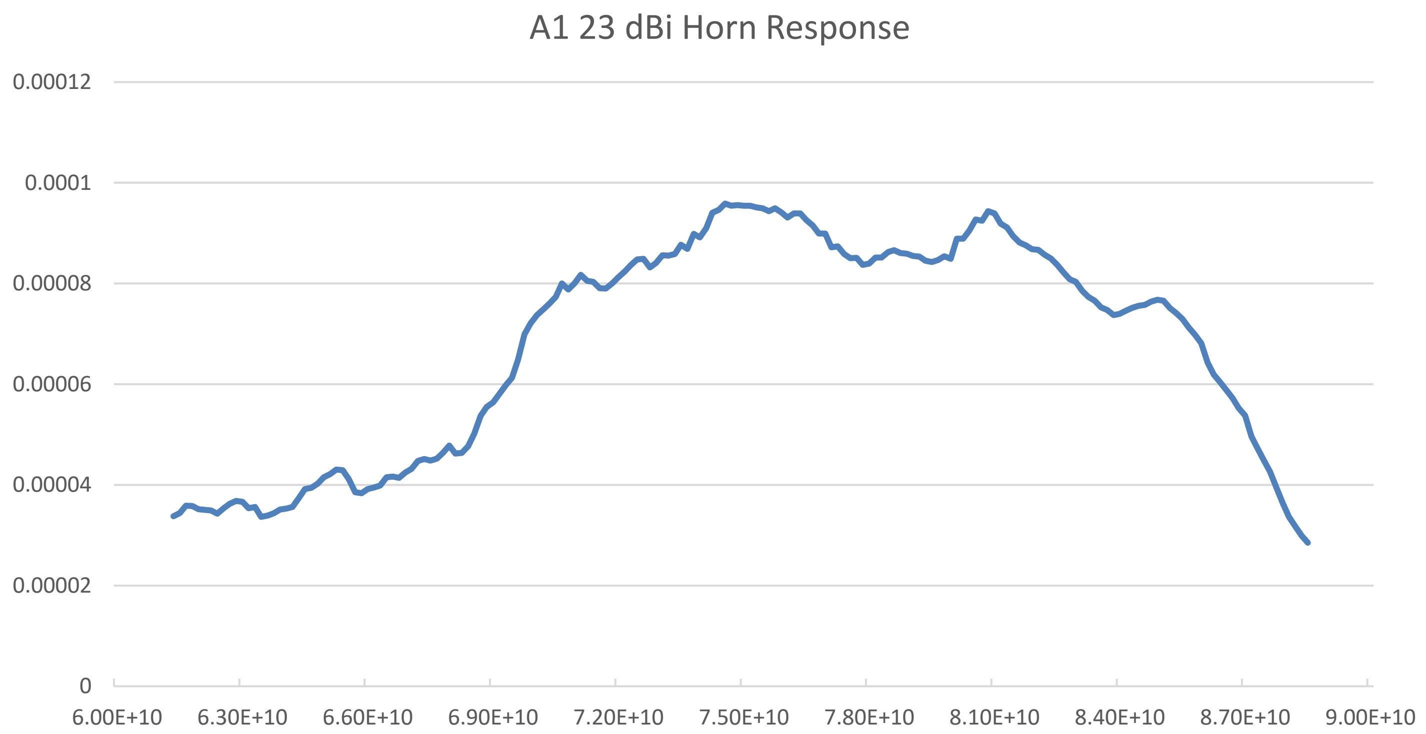


Copper sphere has slightly higher RCS than Aluminum

Short-Circuit Antenna RCS

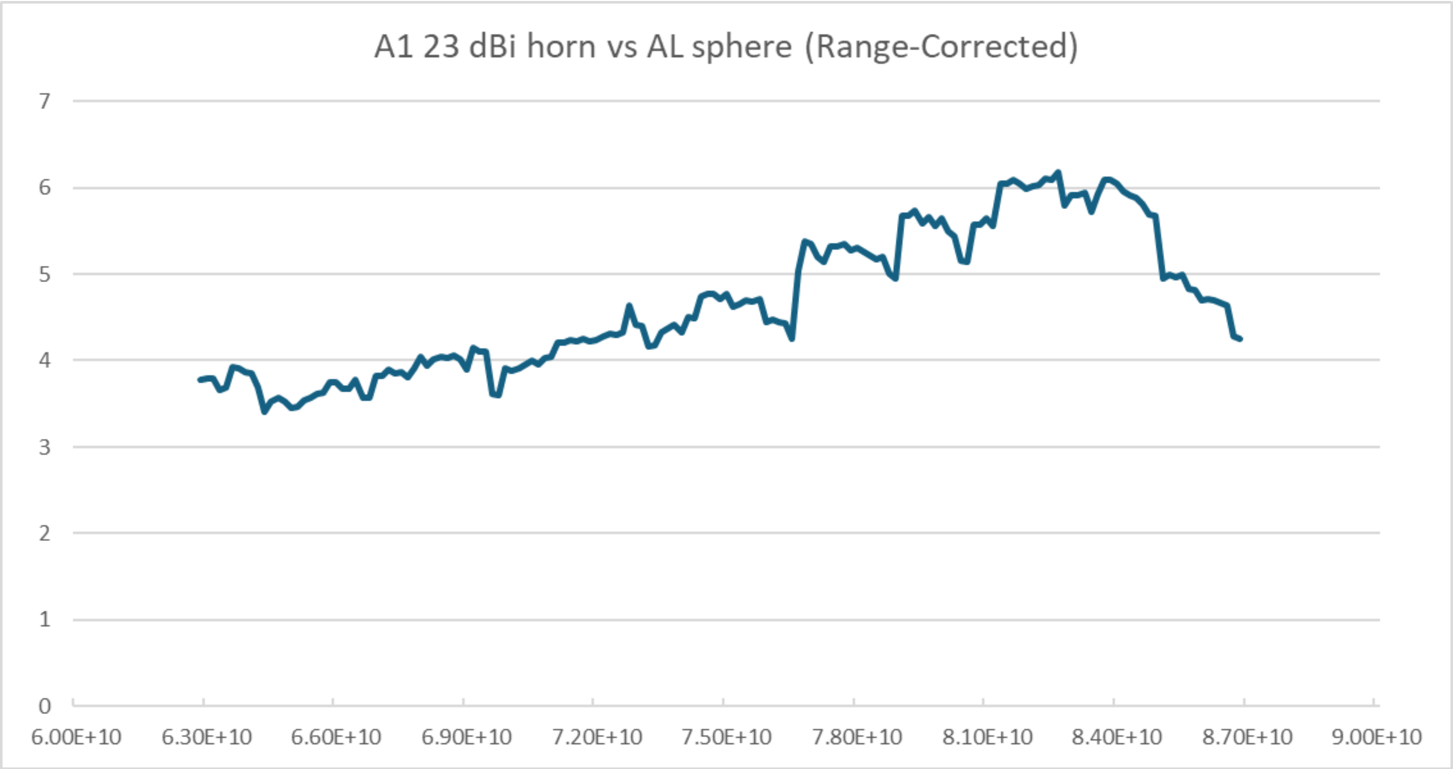
- Short-circuited antennas have predictable RCS
- $\sigma \approx G^2 \lambda^2 / 4 \pi$
  - where G = gain of antenna
- Standard-Gain Horn: G = 23 dBi or $10^{2.3}$
- Expected Antenna RCS: $\sigma = 0.051\ m^2$
- Relative to a 5” sphere, .051/.013 = <u>3.9</u>

23 dBi Shorted Horn Response



Distance from CATR Reflector to target: 1190 mm

23 dBi Shorted Horn Response



Range correction factor: $(R_{T2} / R_{T1})^2$ where R_{T2} = 1190 + 636 and R_{T1} = 600 + 635

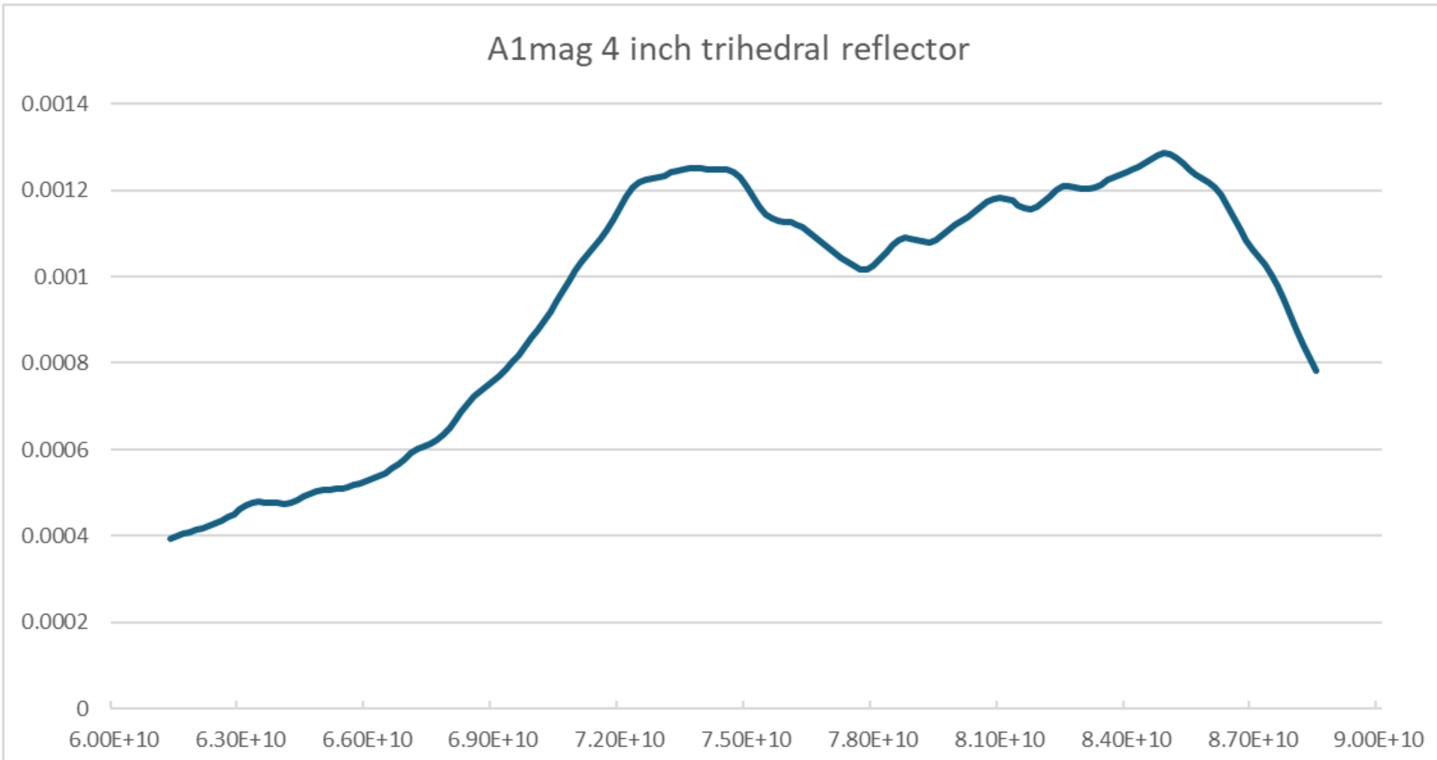
Range-Correction Factor

- The incident signal remains essentially constant, independent of distance from the CATR reflector (plane-wave approximation)
- The reflected waveform is essentially spherical and decreases in power by $1/R^2$ where R is the distance from the target to the CATR reflector, plus the distance from the CATR reflector to the feed horn

Trihedral Corner Reflector RCS

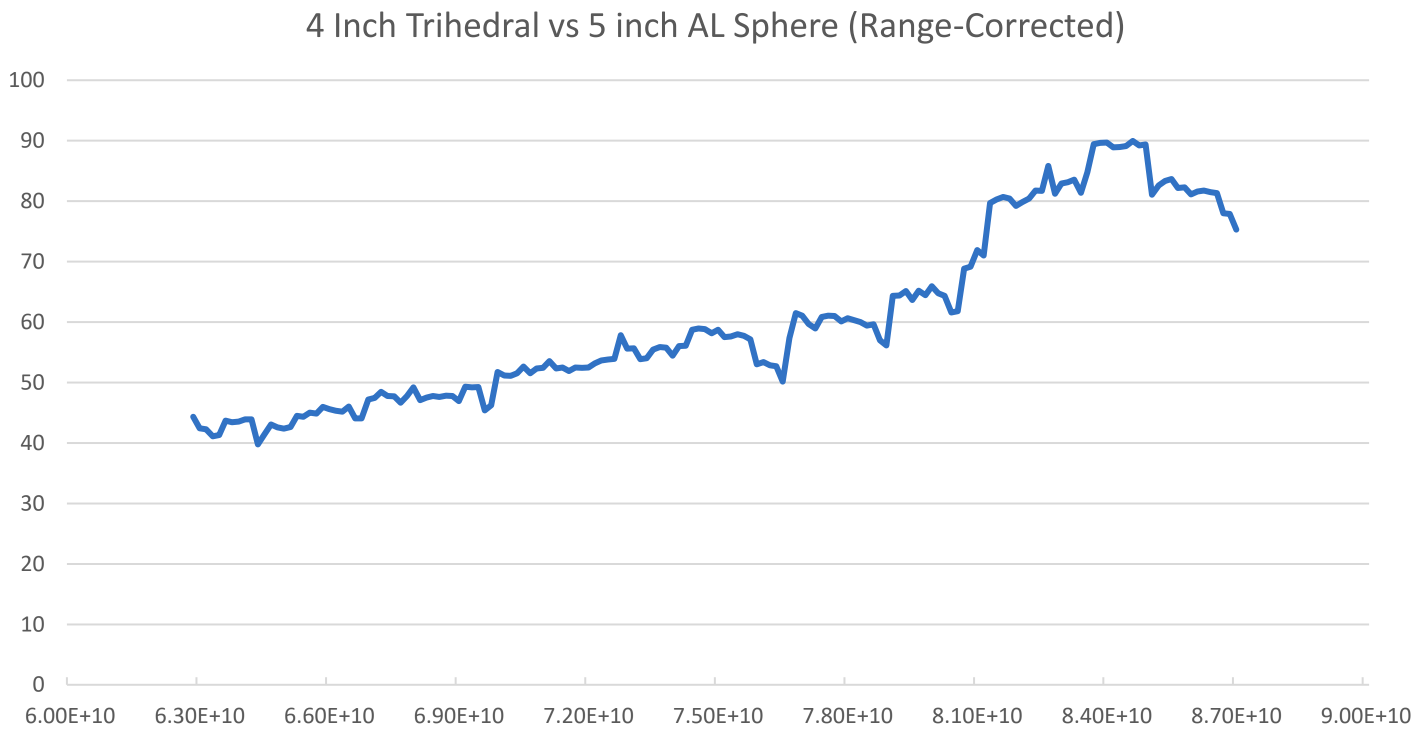
- RCS theoretically can be very large compared to the physical dimensions for the reflector
- In practice, reflectors are not manufactured with enough precision to realize RCS much greater than 1000 times their projected area
- At 75 GHz, the maximum *theoretical* RCS of a 4-inch trihedral corner reflector is about 28 m^2 (roughly 6000 times its projected area)

4” Trihedral Reflector Response



Distance from CATR Reflector to target: 1175 mm

4” Trihedral Reflector Response



The measured RCS is about 80 x .013 m^2 or <u>1 m^2</u> which is roughly 200 times its projected area

Conclusions

- RCS measurements are possible using a CATR
- The RCS of corner reflectors can be evaluated with reasonable accuracy
- Short-circuit horn antennas can be used as RCS calibration standards

References

- https://www.eravant.com/corner-reflectors
- https://www.eravant.com/products/corner-reflectors/trihedral-corner-reflectors

Author's Contact Information

Andrew Laundrie

alaundrie@eravant.com