Radar Cross Section Measurements

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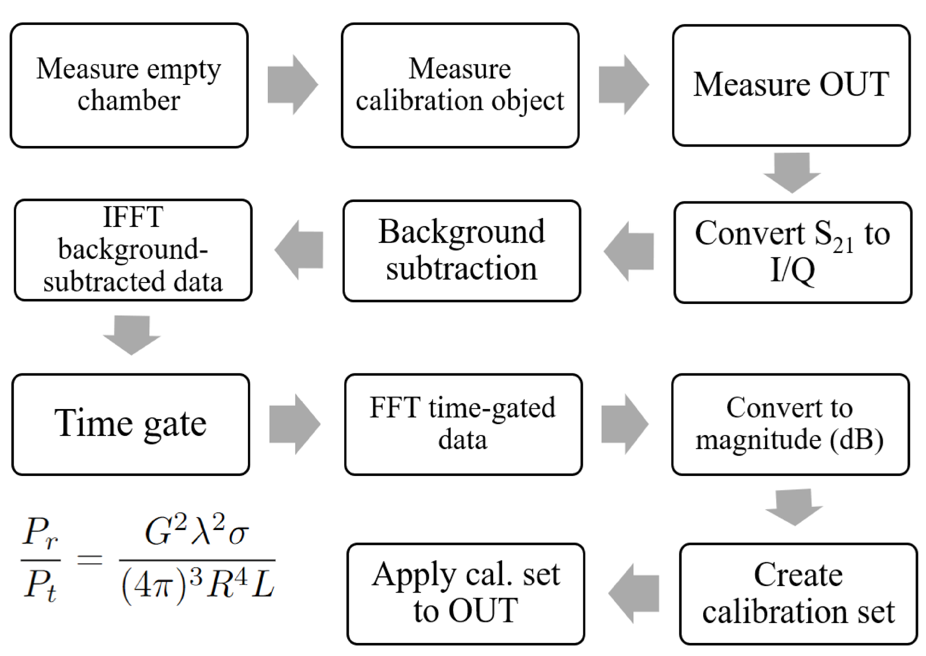
Introduction

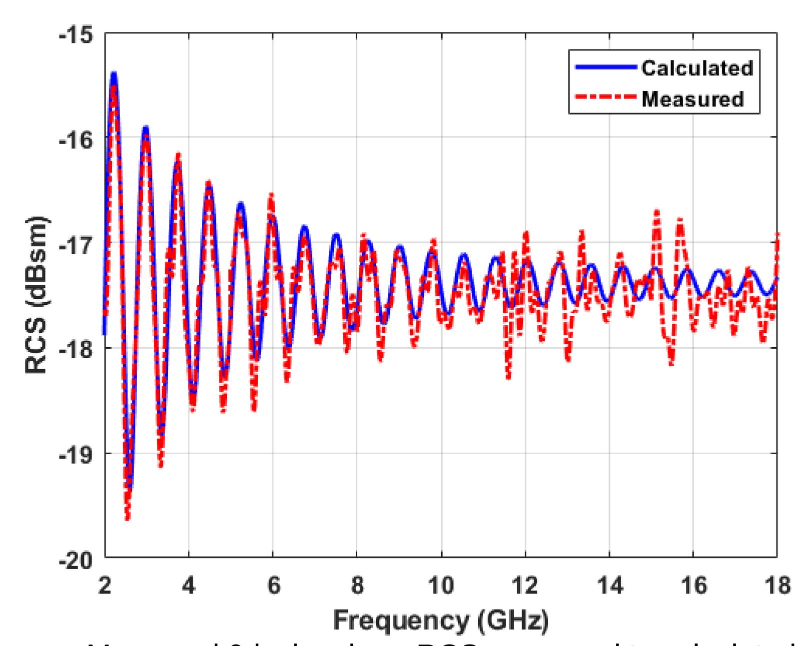
- Characterizing the RCS, which quantifies the power reflected by an object towards a radar, is critical for the detection and identification of objects in all radar systems
- This work aims to extract an accurate RCS of both single and distributed targets in any environment (anechoic chamber, indoors, outdoors, cluttered)
- Distributed target RCS can vary greatly across frequency and polarization, so wideband characterization is necessary for accurate representation
- Traditional RCS measurement methods do not perform well in cluttered environments
  - This work is the first to apply adaptive pulse compression to extract RCS which enables RCS extraction in previously impossible environments
- RCS measurements across angle can be combined to form a reflectivity map to view the overall RCS for a given frequency and polarization

Wideband Measurements

- VNA functions as a Step Frequency Continuous Wave (SFCW) radar to extract RCS
- Combines both vector background subtraction and time-gating for high accuracy

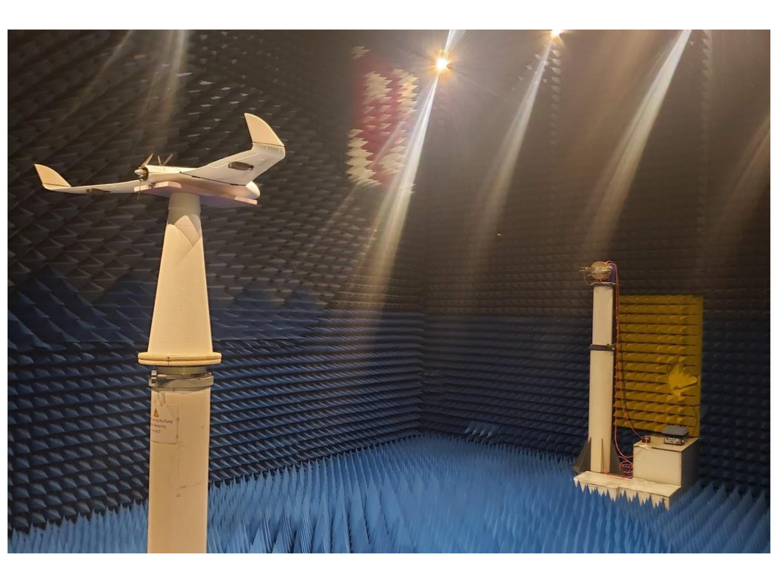


RCS Measurement Procedure

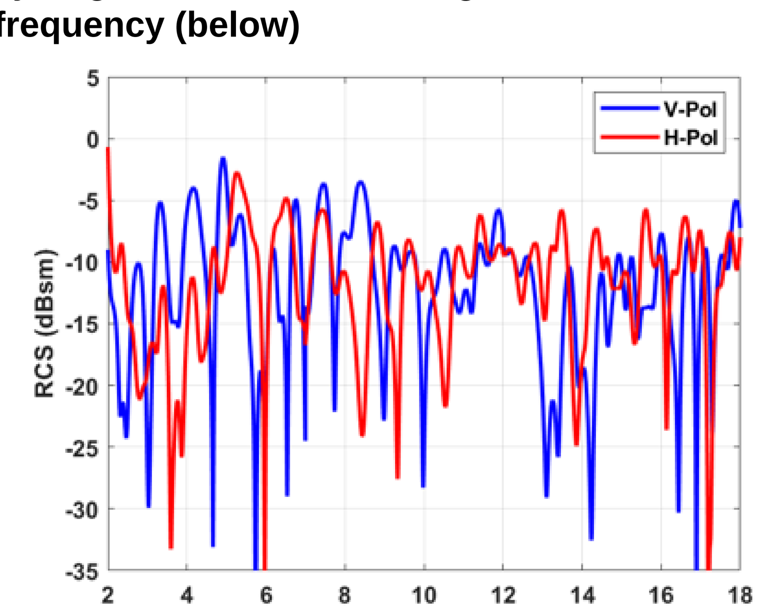


Measured 6-inch sphere RCS compared to calculated

- 6-inch sphere RCS measured with average error below 5% from 2-18 GHz (above)
- 16 GHz of bandwidth is achieved with a single setup
- Flexible post-processing techniques can be applied to any network analyzer
- Setup has capabilities to measure a variety of object geometries across angle
- Distributed object RCS can vary greatly across frequency (below)



Far-field chamber measurement configuration

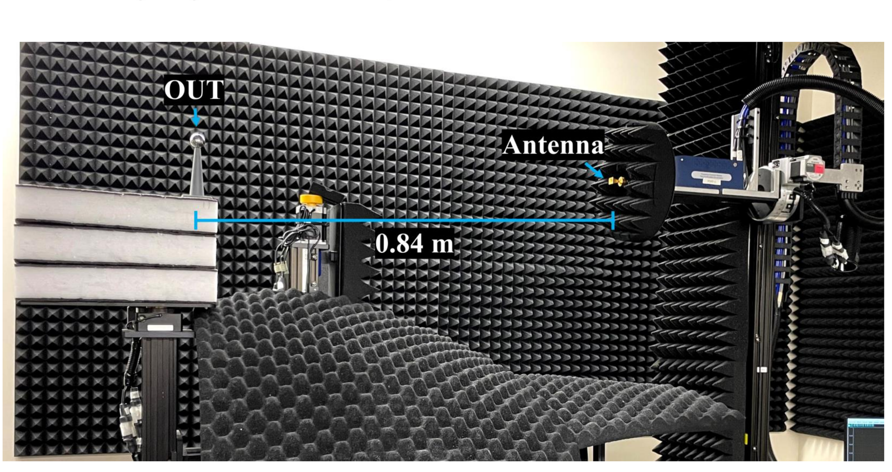


RCS of OU Skywalker UAV measured with vertical and horizontal polarization

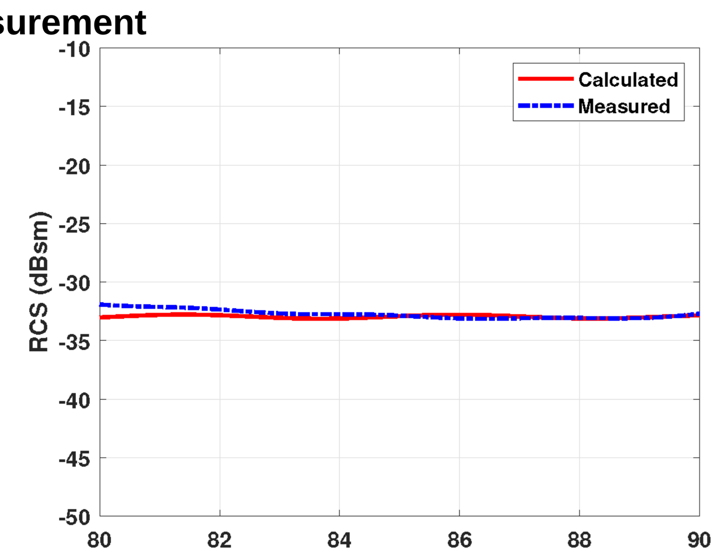
- R. E. Jarvis, J. G. Metcalf, J. E. Ruyle and J. W. McDaniel, "Wideband Measurement Techniques for Extracting Accurate RCS of Single and Distributed Targets," in *IEEE Trans. on Instrumentation and Measurement*
- R. E. Jarvis, J. G. Metcalf, J. E. Ruyle and J. W. McDaniel, "Measurement and Signal Processing Techniques for Extracting Highly Accurate and Wideband RCS," 2021 IEEE Intl. Instrumentation and Measurement Technology Conference (I2MTC), 2021, pp. 1-6
- R. E. Jarvis, "Calibration and clutter cancellation techniques for accurate wideband radar cross section measurements," Master's thesis, University of Oklahoma, Norman, 2021.

Single Antenna Measurements

- Reflection coefficient measurements (S_{11}) also measure the ratio of power received over power transmitted with a single antenna
- Sometimes only one antenna can be used for measurements due to size or cost
- Challenging to add amplifiers with bi-directional measurement



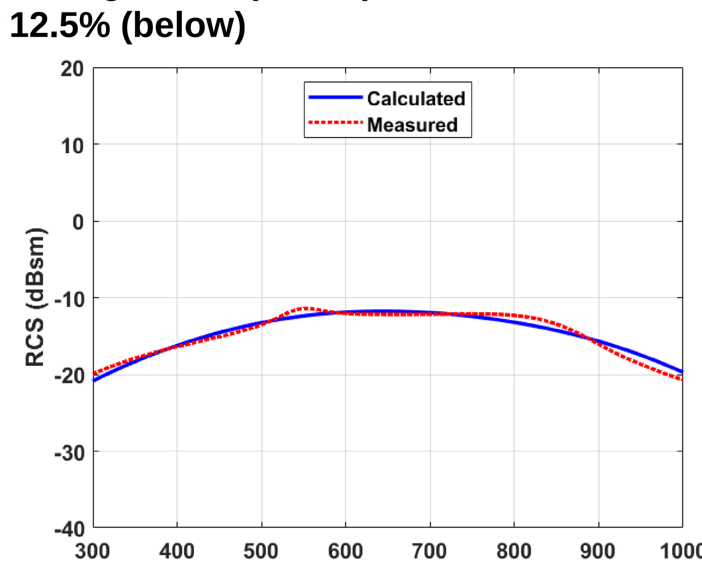
W-band measurement configuration



Measured RCS of 1-inch sphere compared to calculated values

- W-band setup extracted 1-inch sphere RCS with 3.59% average error (above)
- Outdoor UHF-band configuration yields an error below 12.5% (below)

UHF-band measurement configuration

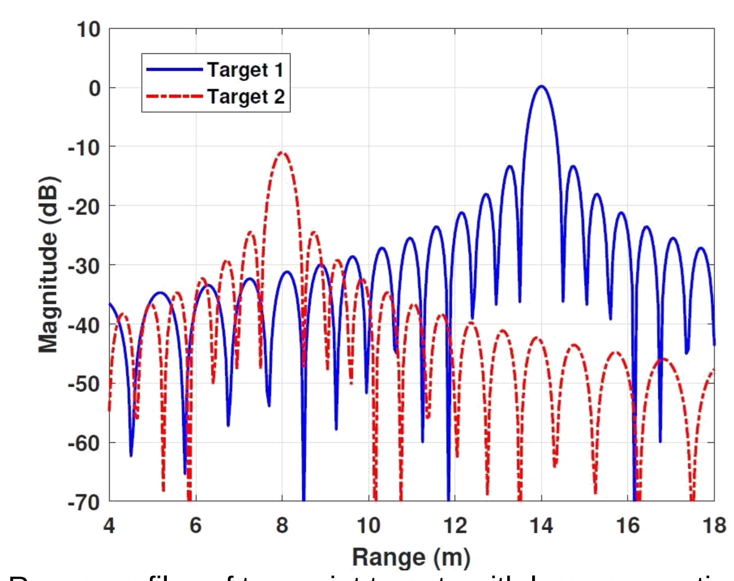


Measured RCS of 6-inch sphere compared to calculated values

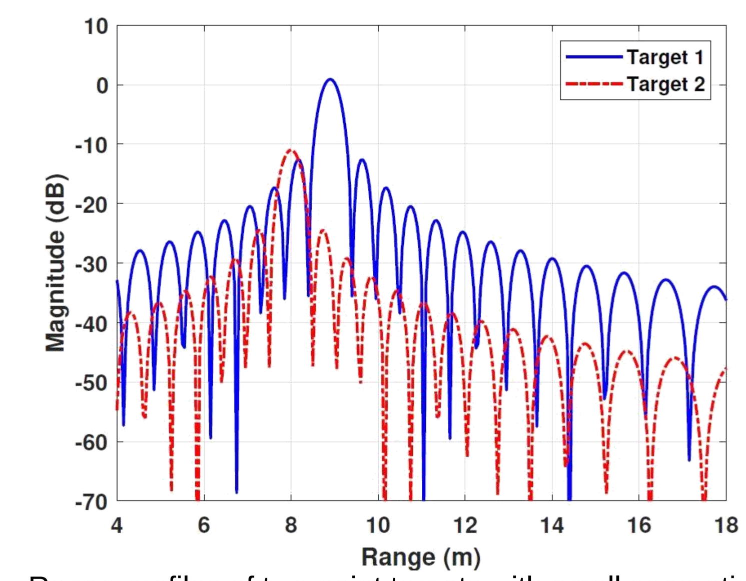
- R. E. Jarvis, R. G. Mattingly and J. W. McDaniel, "UHF-Band Radar Cross Section Measurements With Single-Antenna Reflection Coefficient Results," in IEEE Trans. on Instrumentation and Measurement, vol. 70, 2021
- R. E. Jarvis and J. W. McDaniel, "Methodology and Techniques for Highly-Precise Radar Cross Section Measurements at W-Band," in IEEE Access, vol. 10, pp. 86744-86749, 2022

Adaptive Pulse Compression

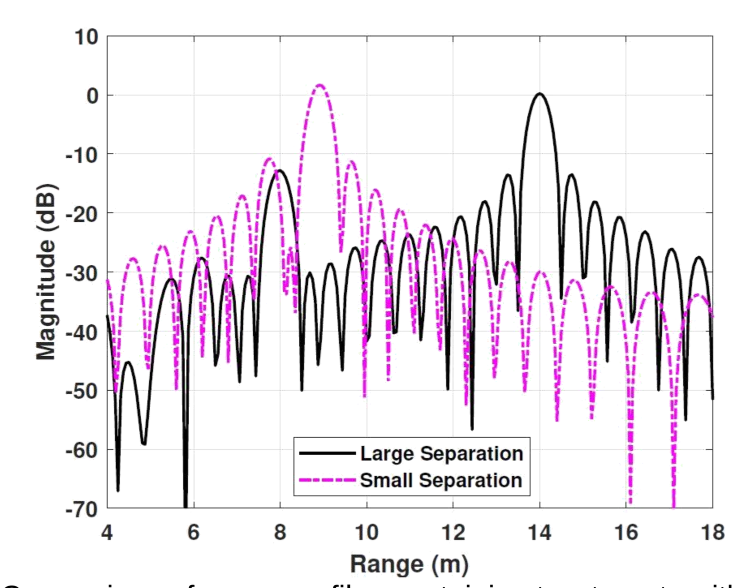
- Matched filtering (IFFT) yields range sidelobes that limit system dynamic range
- Sidelobes from a nearby scatterer can overlap with the return of interest
- Different scatterers can appear near the target: support pedestal, ground bounce, iso-range clutter
- APC is a reiterative minimum mean square error estimation technique to reduce masking of small targets within the sidelobes of nearby targets
- The below simulations depict APC unmasking a small target next to a large scatterer



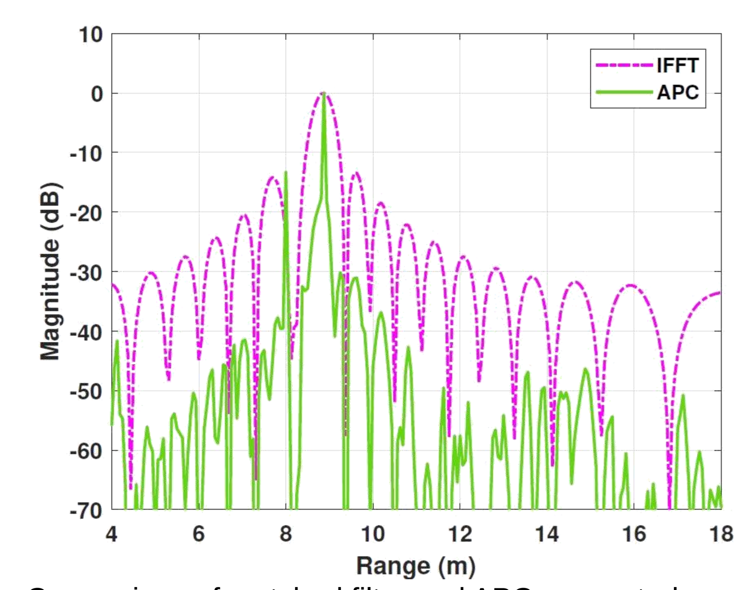
Range profiles of two point targets with large separation



Range profiles of two point targets with small separation

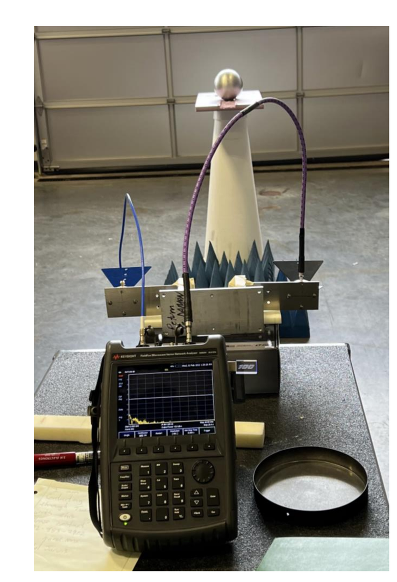


Comparison of range profiles containing two targets with small and large separations



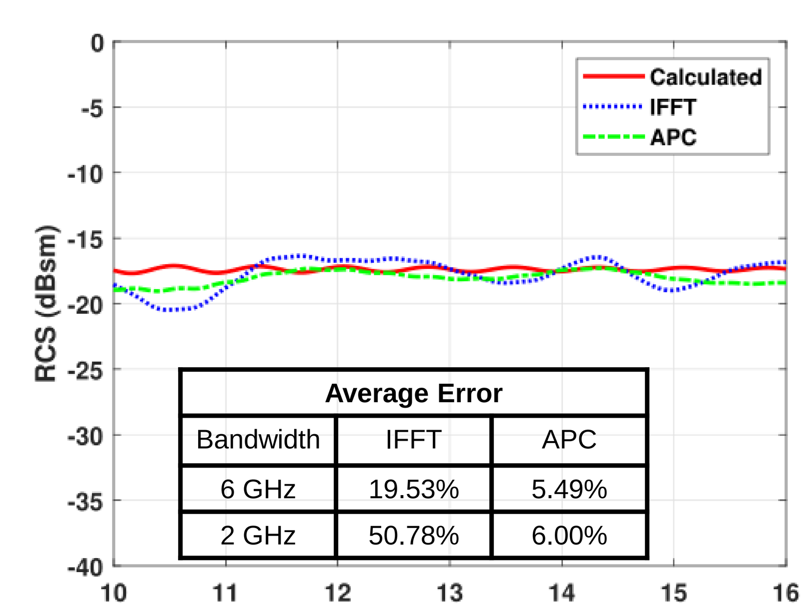
Comparison of matched filter and APC-generated range profiles of two targets with small separation

- To demonstrate APC in measurement, the RCS of a sphere is extracted with and without a metal plate placed behind the sphere
- APC reduces measurement error by 71.2%
- A metal plate is placed behind the sphere to further test APC's capabilities
- With sufficient bandwidth, traditional processing can extract RCS of the sphere placed in front of metal plate (bottom left)
- With less bandwidth, accurate results are not possible without APC (bottom right)

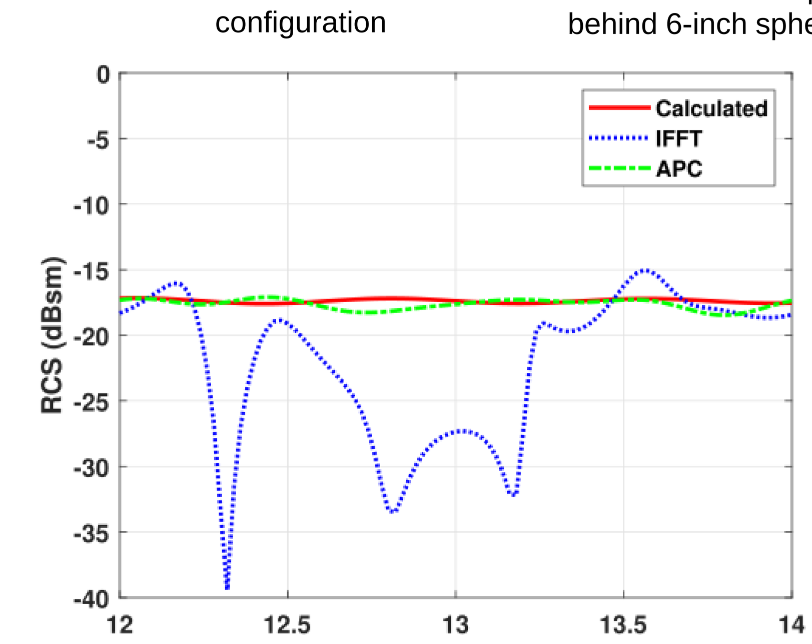


Indoor measurement configuration

Placement of metal plate behind 6-inch sphere



Average Error		
Bandwidth	IFFT	APC
6 GHz	19.53%	5.49%
2 GHz	50.78%	6.00%

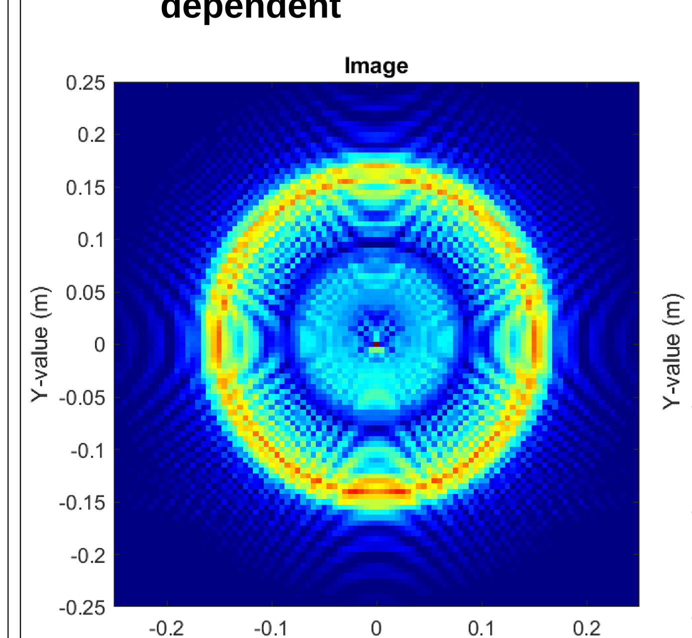


Measured RCS of 6-inch sphere in front of a metal plate with and without APC range profile estimation with (left) 6 GHz and (right) 2 GHz of measurement bandwidth

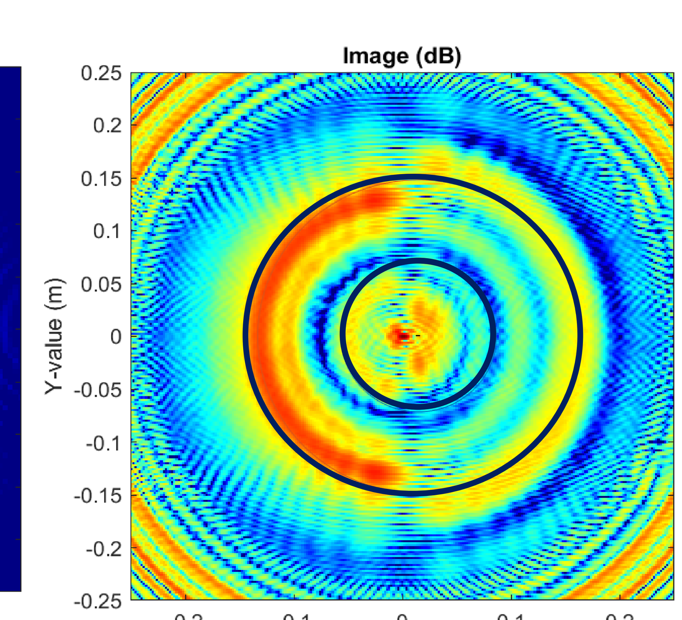
- (Under Review) The Application of Adaptive Pulse Compression in Radar Cross Section Measurements, Trans. on Instrumentation and Measurement

Imaging

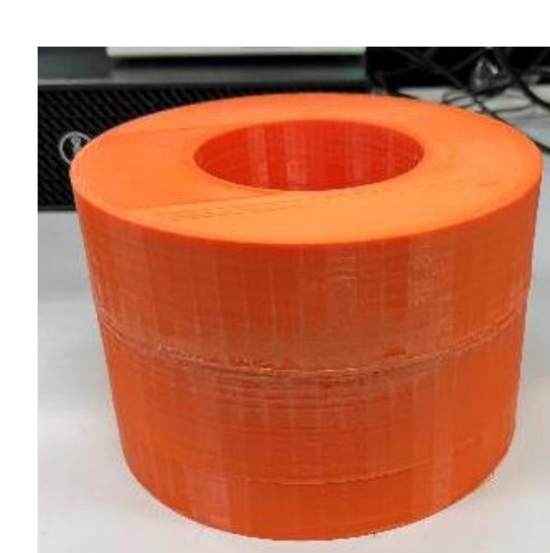
- 2-D reflectivity maps are created by applying backprojection to measurements collected over several incident angles
- Creating a clear image over wide bandwidth is difficult for distributed objects because the frequency sweep may include several scattering regimes
- Imaging dielectric materials is challenging because the velocity of wave propagation is material-dependent



Reflectivity map of 12-inch sphere measured 2-18 GHz across 360°



Reflectivity map of hollow cylinder measured 10-18 GHz across 180°



3D-printed PETG hollow cylinder

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