Radar Cross Section Measurements & Measurement Challenges

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Topics

- Understanding Radar Cross Section
- Measuring Radar Cross Section
- Challenges with Measuring Radar Cross Section

Topics

- **Understanding Radar Cross Section**
- Measuring Radar Cross Section
- Challenges with Measuring Radar Cross Section

Radar Cross Section

- Measure of the amount of power a target reflects back towards the radar receiver
- It's a quantity which fits the context of the radar range equation (denoted as sq. meters or other times dBsm)

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Radar Range Equation

Power received

Incident power density

transmitter gain

Target cross section

Power "captured" by target

Receiver gain

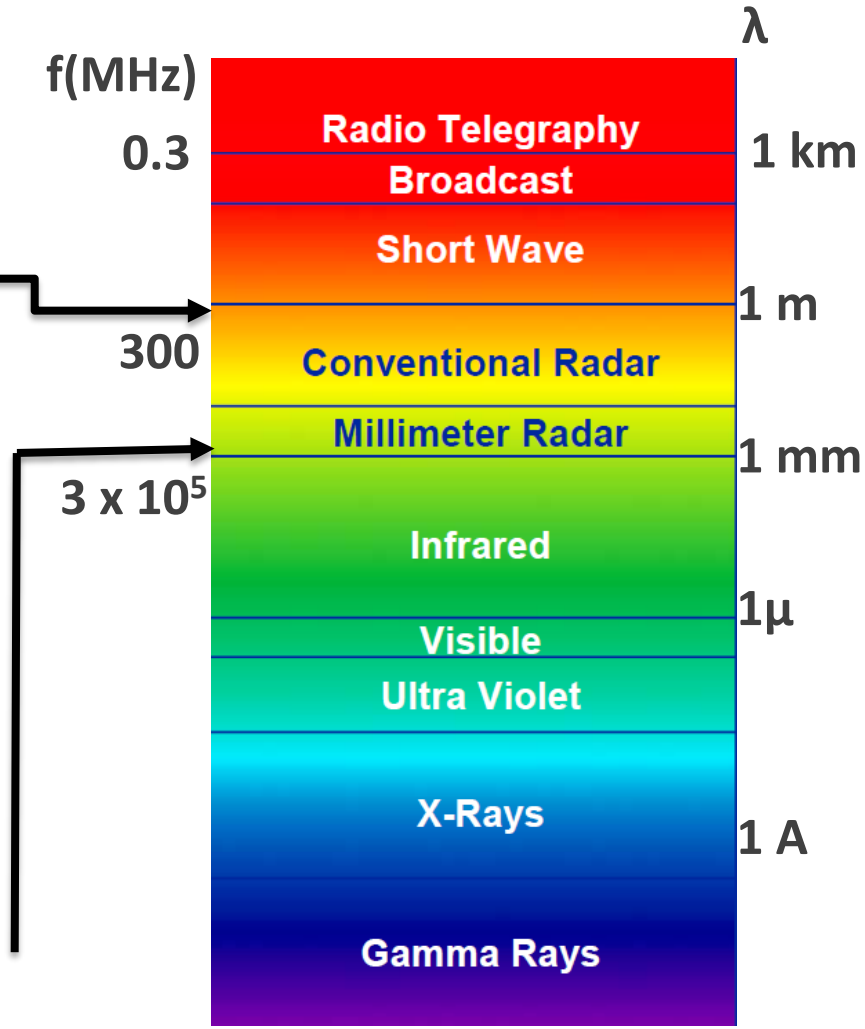
$$P_r = \frac{\left\{\left[\left(\frac{P_t}{4\pi R^2}\right)G_t\right]\sigma\right\}}{\underbrace{4\pi R^2}_{\text{Scattered power density}}} \cdot \frac{\lambda^2 G_r}{\underbrace{4\pi}_{\text{Effective antenna area}}}$$

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Frequency Areas of Interest

Radar Bands

Long Range	HF = 3-30 MHz
	VHF = 30-300 MHz
	UHF = 300-1000 MHz
Search	L Band = 1-2 GHz
Short Range	S Band = 2-4 GHz
	C Band = 4-8 GHz
Fire Control (Trackers)	X Band = 8-12 GHz
	Ku Band = 12-18 GHz
	Ka Band = 27-40 GHz
Seekers	W Band = 75-110 GHz



Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Conventions

- There are four different types measurement conventions:
- Co-pol
  - VV – Transmit in vertical polarization and receive in vertical polarization
  - HH – Transmit in horizontal polarization and receive in vertical polarization
- X-pol
  - VH – Transmit in vertical polarization and receive in horizontal polarization
  - HV – Transmit in horizontal polarization and receive in vertical polarization
- These polarizations apply to types of scattering and waves an engineer may experience throughout measurements.

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Scattering

- Scattering is important to understand when evaluating RCS data of a target in the ISAR (inverse synthetic aperture radar) Images
  - Edge Scattering
    - Plane waves scatter in cones of angles specular to edges
  - Specular Scattering
    - The only threat to the illumination of the target is normal to the surface
  - Creeping Wave
    - When a wave can attach to the surface and propagate around the back of it if it is sufficiently smooth or a large enough radius of curvature
  - Traveling Wave
    - When a wave hits a surface at a low angle of incidence and travels continuously until it is terminated by another surface or the edge of that surface
  - Multipath
    - Multiple interactions/scattering between the target and features of the target

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

RCS Affects

- Some aspects of an aircraft may impact its RCS. Below are a few items that may do so.
  - Size
  - Gaps
  - Edges
  - Pylons
  - Electronics
  - Engine manifold/Propulsion
  - Inlets
  - Engine feathers
  - Cockpit
  - Canopy
  - Shaping

This is why it's important for teams of different disciplines to work together in developing a RCS focused aircraft!!

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Topics

- Understanding Radar Cross Section
- **Measuring Radar Cross Section**
- Challenges with Measuring Radar Cross Section

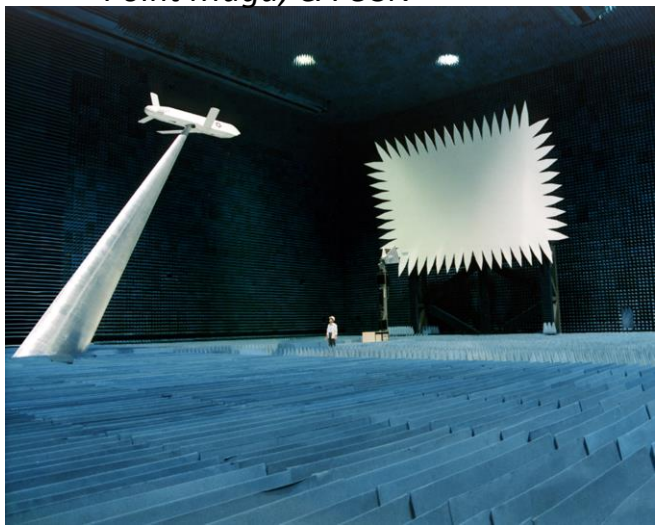
Measuring RCS

Where do we measure RCS?

- Far-field Ranges
  - Outdoor
  - Indoor (compact)

- Near-field Ranges
  - Planar near-field
  - Cylindrical near-field
  - Spherical near-field
  - Conical
  - Robotic

Point Mugu, CA USN



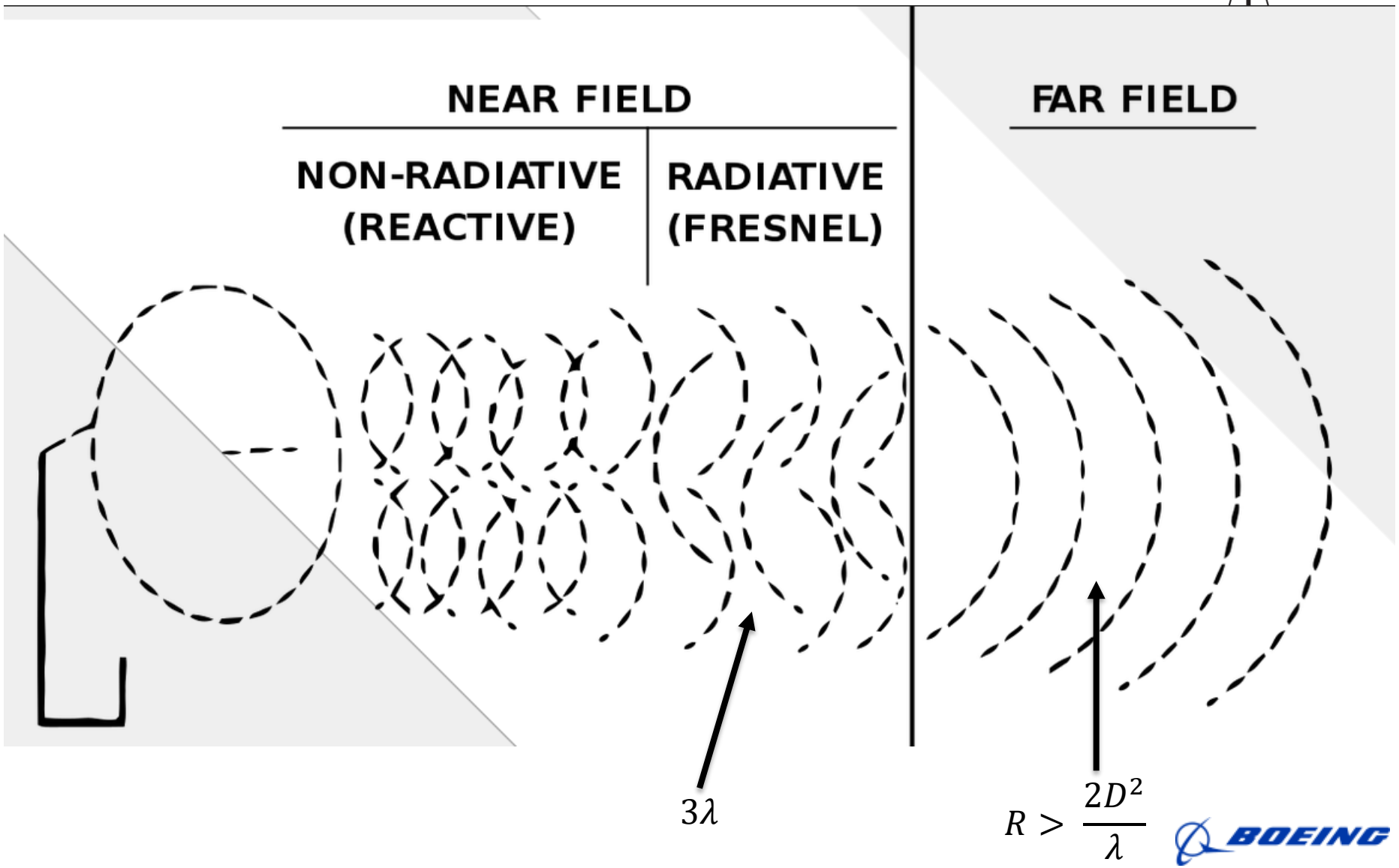
Lockheed-Martin RCS Facility Helendale, CA

Near Field Test Facility
St. Louis, MI

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Near-field and Far-field

- Couple of things:
  - As it shows, there is a definitive line between Near and Far-fields. HOWEVER, that is not the case. There is no true line between the two!
  - We want to know the pattern of the target in the true far field which is shown past the radiative (Fresnel) line
  - We also say that there is a phase deviation across the target at <22.5 degrees (this is EXTREMELY rough as this can change for each target)
  - With this knowledge of the phase front, we know we need to be some R away, i.e. bottom right.



Near-field and Far-field cont.

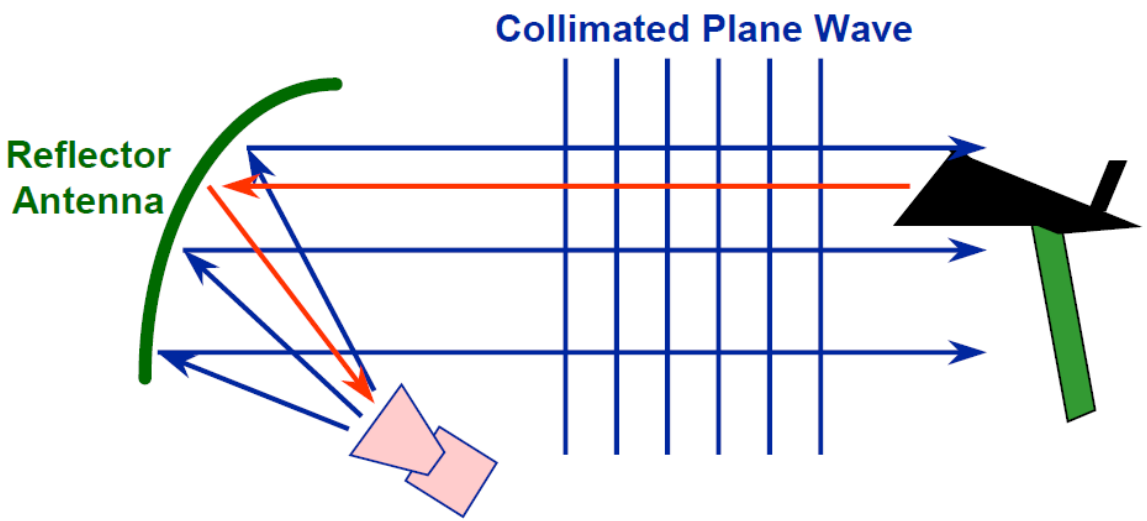
- Effects from the Near-field are present more often with simple shapes with a known RCS
  - Cylinders
  - Flat plates
  - Spheres

- Some things to look for in the near-field…
  - Filling in of nulls
  - Side-lobe amplitude reduction
  - Significant reduction in main lobe amplitude as well as growing “shoulders” with the main side lobes

- To meet Far-field criterion to satisfy RCS…
  - Far-field range approach: sufficient range between antenna farm/radar so the diverging spherical wave front is locally flat over the target
  - Compact range approach: using “optics” (radar collimator) to focus the radar beam in the near field to simulate a plane wave far closer than a far-field range

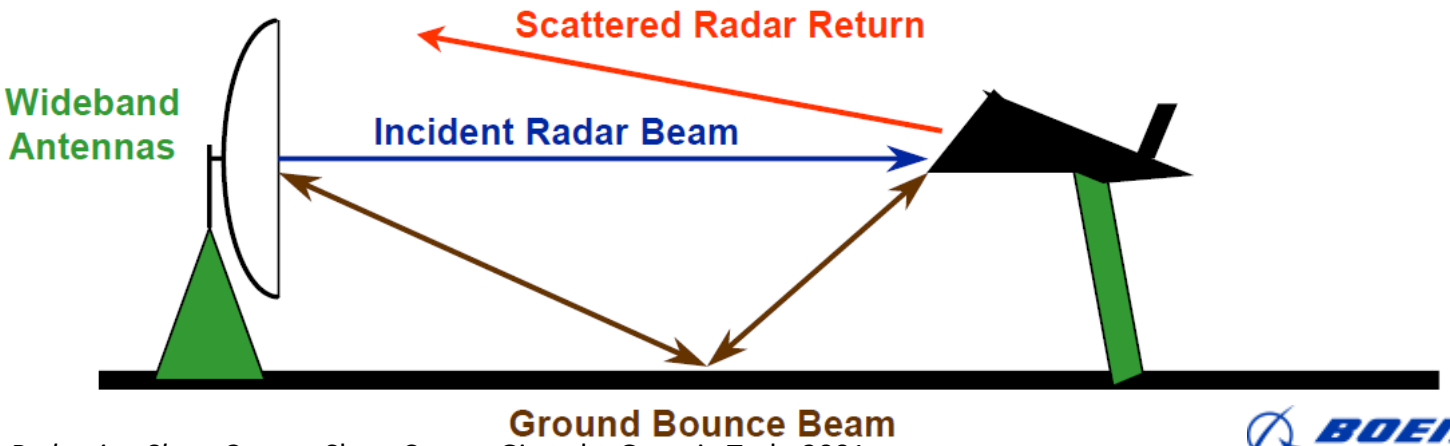
Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Types of Ranges



Compact Range
Target > 150’ from source
Far-field across all bands

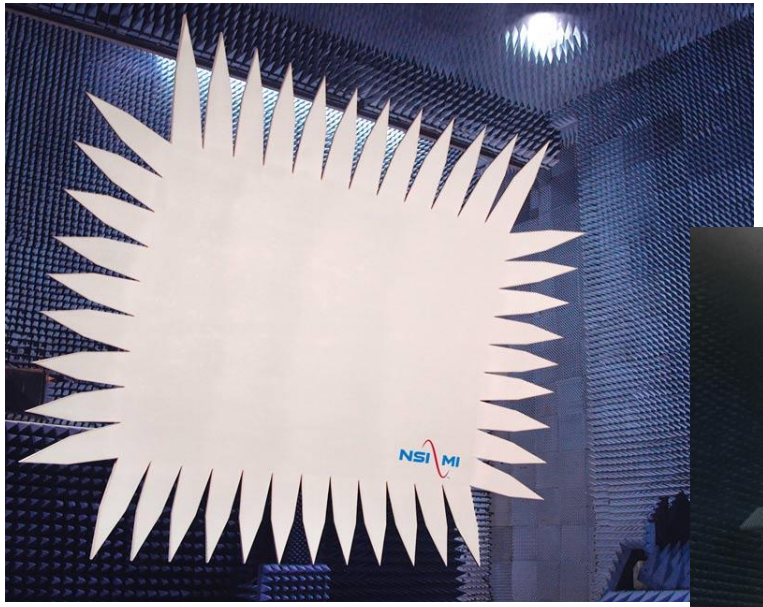
Typical Outdoor Range
Target > 5000’ from source
*Far field only at S-band and below



Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Types of Reflectors

- A few types of reflectors:
  - Parabolic prime-focus reflector w/ a rolled edge
    - Rolls the currents behind the reflector
  - Parabolic Prime focus with a serrated edge
    - Redirects the edge diffractions away from the quiet zone
- Both perform the same way, collimating the wave fronts to a quiet zone
  - They both also dissipate the surface currents away from the reflector out towards the edge

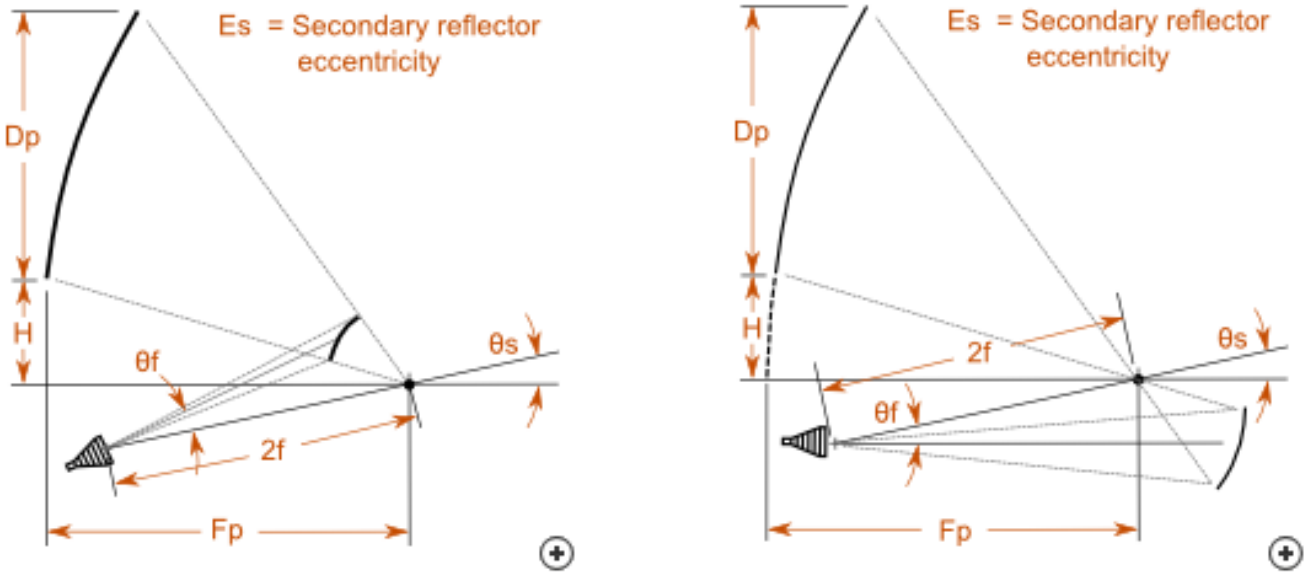


NSI-MI Compact Range Reflectors: Serrated Edge
NSI-MI Technologies Suwanee, GA

NSI-MI Compact Range Reflectors: Rolled Edge
NSI-MI Technologies Suwanee, GA

Types of Reflectors cont.

- Other types of reflector types are:
  - Offset Single Reflector
    - Utilizes a similar paraboloid and it is the simplest way to achieve the feed blockage problem.
  - Dual Reflector Cassegrain Antenna
    - Utilize the same paraboloid but also use a second reflector (hyperboloid) subsequently to reduce the ground noise and isolate the antenna from the sub-reflector
  - Dual Reflector Gregorian Antenna
    - Similar to a Cassegrain yet the Gregorian controls spillover isolation a bit better.



Dassault Systemes Antenna Magus: Cassegrain and Gregorian Reflector Systems

Other Aspects of an RCS Facility

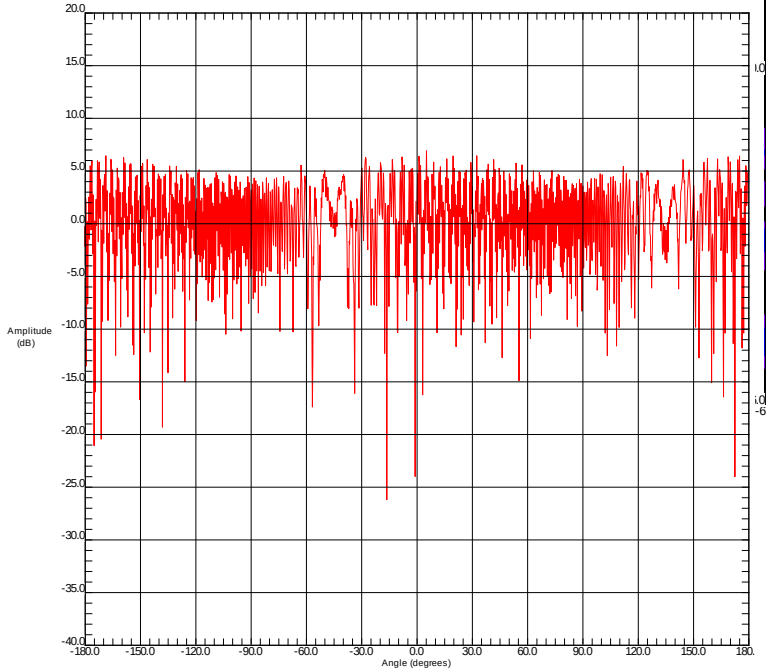
What are the main aspects of an RCS facility?

- Some bands ranging from some frequencies
  - Usually defined by the size of the range and it's "quiet zone"
  - Turntable, multi-axis, broadband, antenna farm (mainly outdoor)
- A control system to record data, process data, and display the data
  - Computers, hard drives, data processing GUI, imaging tool
- Minimize the noise in the test environment
  - Low background noise with no clutter to simulate the far-field
- Minimal clutter target support structure
- Target position and processing system
  - Pylon, strings/turntable, foam column, rotator
- Target handling system
  - Crane, model transport system
- Calibration!!
  - How do you ensure the measurement is repeatable?

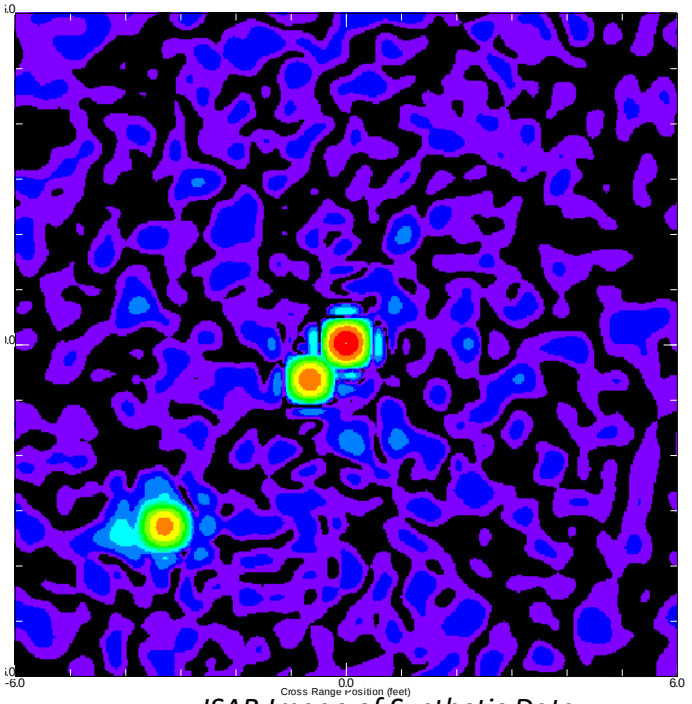
Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Data Processing

- It's important to be able to view the data in multiple forms to understand the data at hand.
- Examples of plots that an engineer may see are:
  - ISAR Images
  - Global RCS and Phase
  - Angle vs RCS
  - Frequency vs RCS
  - Polar Plots ("bug splat")



Angle vs. RCS of Synthetic Data

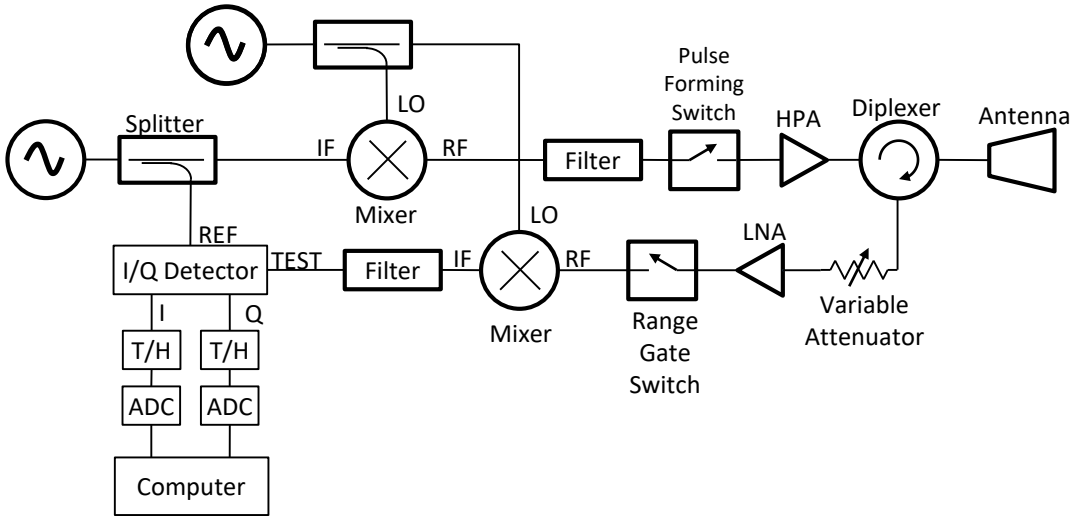


ISAR Image of Synthetic Data

Instrumentation

- Two Main Types of Radar Systems
  - Pulsed IF
  - Continuous Wave (CW)
- *Example (Pulsed-IF):*

Abbreviations:
LO = Local Oscillator
IF = Intermediate Frequency
RF = Final Frequency
HPA = High Power Amplifier
LNA = Low Noise Amplifier
I = In-Phase
Q = Quadrature
T/H = Track & Hold Circuit
ADC = Analog to Digital Converter



Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Instrumentation cont.

The way the instrumentation is set up can influence the results of RCS significantly.

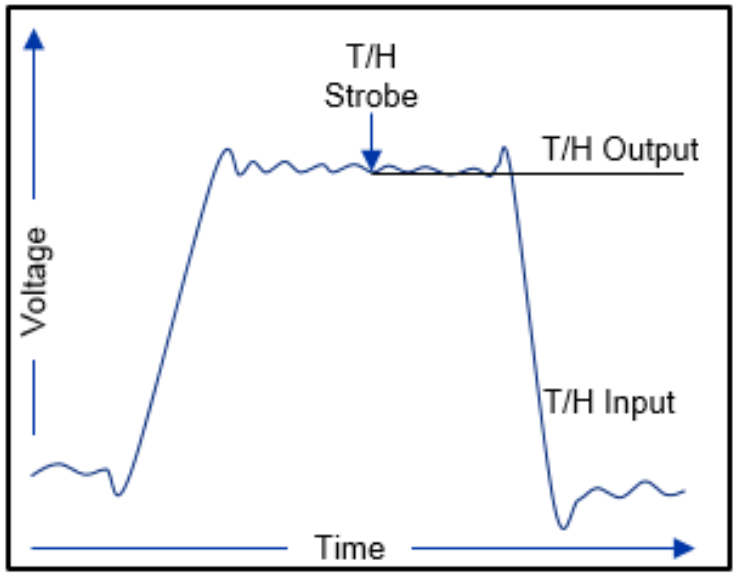
- Range gate length
  - Imaging and clutter
- Transmit power
  - Power density
- Integration gain
  - Clutter rejection
- Antenna feed gain and pointing
- Receiver stability
  - Temperature and drift
- Recorder response
- Detection mechanism
- Phase compensation
  - In-Phase / Quadrature (I/Q) linearity
  - Target motion
    - How it moves through the quiet zone
- Dynamic range
  - Saturation
  - Receiver noise

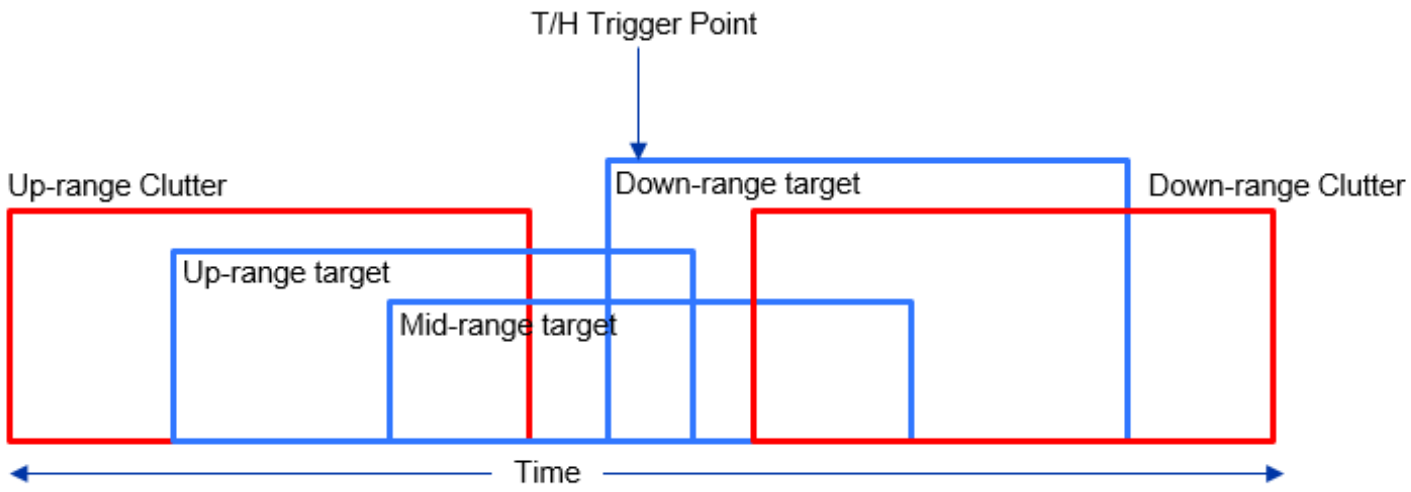
Holloman AFB, Detachment 1 - National RCS Test Facility (NRTF)

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Gating/Timing

- Gating is a crucial part of an RCS measurement
  - Most of the gating is done in a Pulsed IF type of radar system
    - Easy to control the size of the pulse and when to transmit and receive
      - Size of the pulse is dependent on target size and frequency of interest
  - Gating can have a huge impact on quality of data
    - Canceling out background and other interactions between the target
    - Producing a quality inverse synthetic aperture radar (ISAR) images





Calibration

- Calibration is one of the most important aspects
  - Calibrations tend to occur every day utilizing the same standard for repeatability and maintain the fidelity of your data
    - Spheres
      - Good for monostatic measurements (static/dynamic)
      - BAD for bistatic measurements – DO NOT PUT ON PYLON
      - Really difficult to get exactly a sphere (ultraspheres)
      - There exists and exact solution of a sphere which makes it nice for a standard
    - Flat plates
      - Large return for a large RCS (static)
      - Great for bistatic
      - Need exact alignment for a perfect return (difficult repeatability)
      - Nearly exact solution
    - Corner reflector
      - Poor bistatic (static/dynamic)
      - Large return for a large RCS
    - Cylinders
      - Great for mono and bistatic measurements (static)
      - Good for pylons (strings)
      - Near exact method of moments solution

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

How Do We Support Targets?

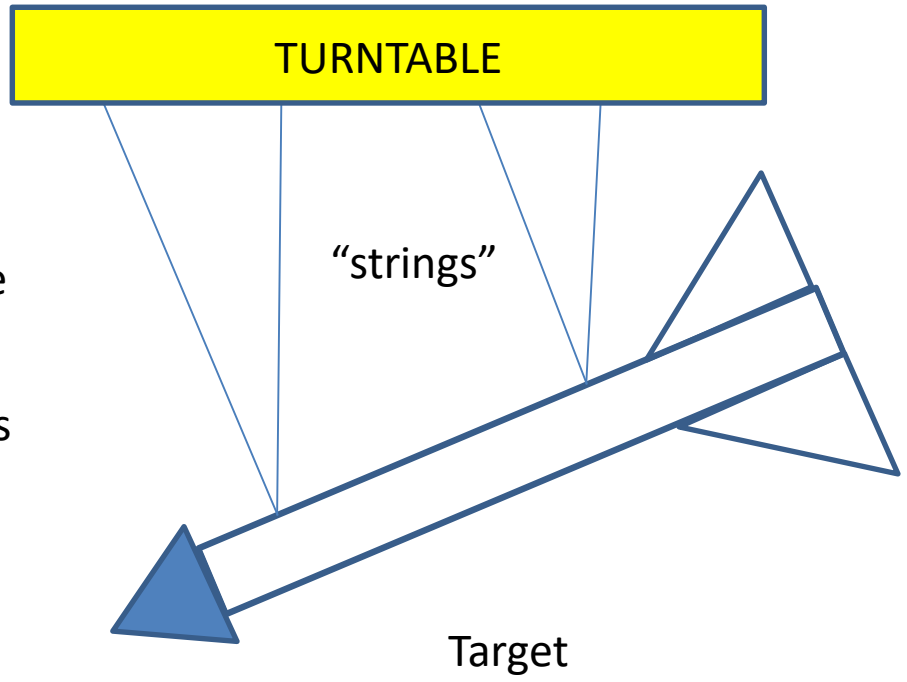
- There are a couple ways…
  - Pylon
    - Ogive-shaped for minimal reflection and maximum supportability
      - Not all are shaped like this
      - Some are diverging
    - Foam column
      - Great circle 0 degree +/- 5 degrees max
    - Rotator
      - Turntable style or…
    - Embedded rotator
      - Multitude of weight classes for different sized targets
    - Full azimuth rotation (360°)
      - Contains "slip ring" for communication and data
    - Can produce a conic cut (axis of rotation is equal to the targets rotational axis)

Holloman AFB, Detachment 1 - National RCS Test Facility (NRTF)

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

How Do We Support Targets cont.

- Strings Support
  - Use a Stewart Platform-type of configuration in conjunction with a rotating turntable
  - Suspend the target like a puppet and rotate it around
    - Options for a inverted Stewart Platform type or 3-point pick
  - Lower returns than a pylon in some cases
    - Pylon data at V-pol and VHF are very difficult to characterize
  - Target motion must be accounted for
    - Dynamic motion can cause issues with data and ISAR images



*Can use a string system as well for calibration targets and fly them around

Models and Scaling

How do we test objects that are too big and cost too much to build?

- Much, much cheaper than testing an actual target
- Don't need to add in all the complex features
  - Only the important features that produce high return or complex reflections!
- Important to scale the entire target!

- Consider model fidelity
  - Surface quality
  - Material properties

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Topics

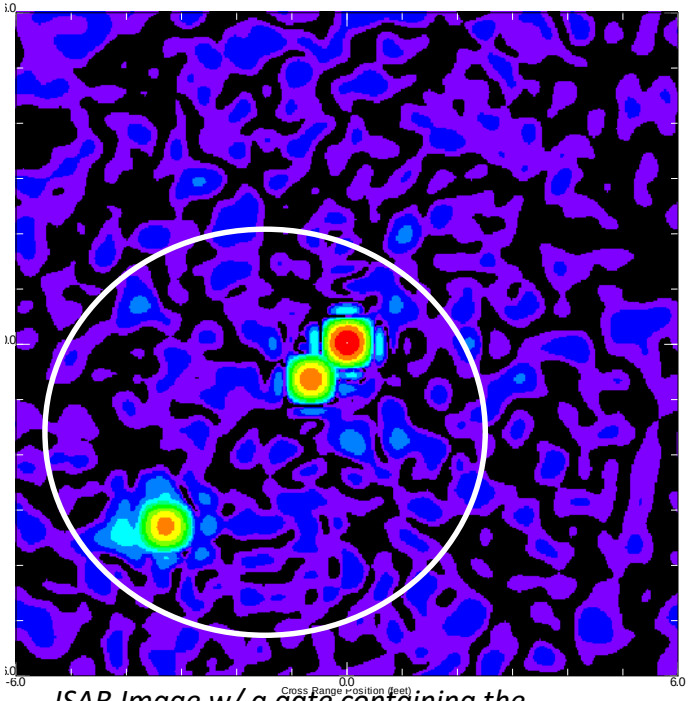
- Understanding Radar Cross Section
- Measuring Radar Cross Section
- **Challenges with Measuring Radar Cross Section**

Target Handling

- Depending on size of the target, target handling is an expensive and complicated procedure required.
  - Makes measurements look easy
- How does a model get from entering the facility to it's support structure?
  - Bridge crane to pylon
  - Lowering a pylon
  - String support (requires extensive structural analysis)

Post-Processing Techniques

- Image Edit & Reconstruction
  - How can target/range interactions be controlled? Or to isolate signature from other scattering sources?
  - Image Edit Reconstruction is a post-processing technique that performs a “what-if” analysis on your target
  - Numerous techniques that involves “gating” the target and determining if data is inside/outside the gate.
    - Requires padding, weighting, focusing and FFT’s
      - But also requires the reverse
- Zero-Doppler
  - Ex. pylon data doesn’t always go away (echoing) and a way to remove the pylon is to use zero-Doppler filtering



ISAR Image w/ a gate containing the synthetic data

Post-Processing cont.

- Near-field to Far-field Transform
  - Testing in the near-field has it's advantages, however it also does require post-processing by utilizing a Near-field to Far-field Transform (NFFFT) to be able to do this.
  - There are a number of NFFFT's out there that are able to do this.
    - Ex. Sensor Concepts Inc. (SCI) systems have a NFFFT for the number of systems they have.

Pylon and Strings

- Pylon
  - Pro's
    - Ultimate weight bearing capability
    - No strings attached!
      - No return from strings at high frequency
    - Produces a conic cut in most situations
    - Easy swap of rotators
    - Great for H-pol measurements
  - Con's
    - Not usable for "real aircraft"
    - Bad for low frequency
    - Difficult to hide the rotator
    - Foam columns don't provide much angle throughput
- Strings
  - Pro's
    - Potentially lowest returns
    - Can support large structures
    - No rotator issue
    - Virtually invisible at low frequency
    - Good for both polarizations
  - Con's
    - Not so good at high frequency, but still comparable to pylon (IER)
    - Difficult to maintain
    - Lots of structural design needed
    - Mounting scheme needed (likely using a crane or winch)
    - More chances of…lawn darts

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Conic vs. Great Circle

- Great Circle vs. Conic
  - Conic
    - Advantages
      - Simple with respect to a pylon; only one support saddle required (embedded rotator)
      - Least amount of handling
    - Disadvantages
      - Some bending moment with large elevation angles to collect all angle of attack (AOA) angles of interest
      - Go too far and you'll break the pylon
      - VERY HARD to do on strings
  - Great Circle
    - Advantages
      - Can provide high elevation views
      - Easier construction of target structurally
      - Easier for heavy targets
    - Disadvantages
      - Needs several support saddles with a pylon (easy with strings)
      - Not entirely representative of what people look for

Spillover and Multipath

- Reflector systems tend to not always contain all the energy that is transmitted out. Some of that “spills” over the reflectors.
  - Ex. control spillover by using a absorber “fence”
- Multipath is when a target scatters energy off into the side walls, ceiling, floors of a chamber/range.
  - Control this by using microwave absorber around the facility
  - Gating can used to “gate out” returns that might adversely affect your data (i.e. large back wall returns)

Instrumentation

- Amplifiers and Gain
  - Ensuring that there is enough gain within the amplifiers to ensure that the noise floor is well below what you are measuring
- Gating
  - Most of the gating is done in a Pulsed IF type of radar system
    - Easy to control the size of the pulse and when to transmit and receive
      - Size of the pulse is dependent on target size and frequency of interest
  - Gating can have a huge impact on quality of data
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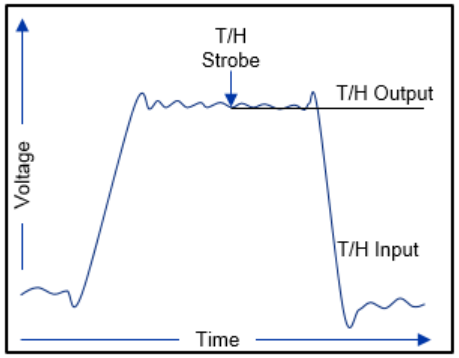

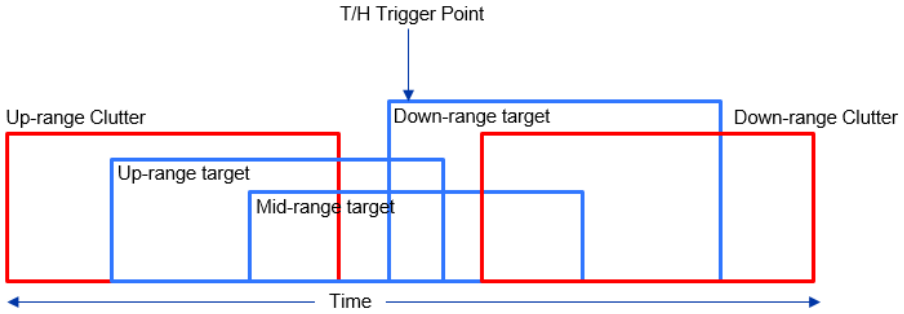

Outdoor Ranges

- Outdoor ranges require lots of space, but has some disadvantages
  - Calibration stability
  - Far-field-ness
  - EMI
  - Security
  - Personnel
  - Speed
- An advantage it does have over compact ranges is it does have the ability to test full-scale targets (assuming it has the infrastructure to do so)

Scaling

- If scaling is required, the measurements must be scaled

Selected Parameters	Full-Size Object	1/50th Scale Model
Length	100ft	2ft
Frequency of Operation	1 GHz	50 GHz
Range of Target	6.4 km	128 m
Absorber Thickness	1 in	0.02 in
Conductivity	0.28 V/m	14 V/m

Reference: Georgia Tech Research Institute; *Radar Cross Section Reduction Short Course,* Short Course Given by Georgia Tech, 2001

Questions????