# RCS Measurements
(Chapter 8)

EC4630 Radar and Laser Cross Section

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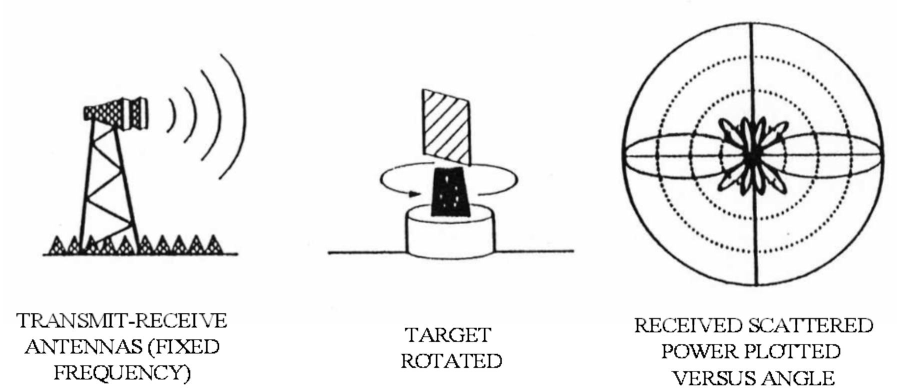
# RCS Measurements

- Measurement facilities
  - Indoor
    - offers privacy, controlled environment, security
    - limited in size
  - Outdoor
- Instrumentation
  - Frequency domain (FD)
    - continuous wave (CW)
    - gated (pulsed CW)
    - other waveforms (e.g., ultra-wideband monocycle)
  - Time domain (TD)

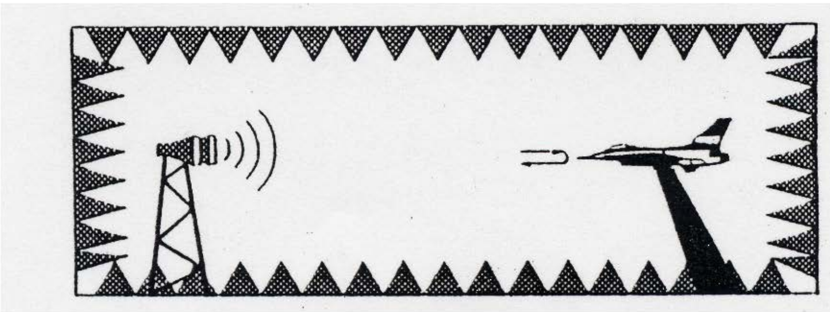
(The Fourier transform relates the time and frequency domains)

- Data analysis and presentation
  - RCS versus aspect angles for a fixed frequency
  - RCS versus frequency for a fixed aspect angle
  - color contour plots and 3-D surfaces
  - target imaging for diagnostics ("troubleshooting")

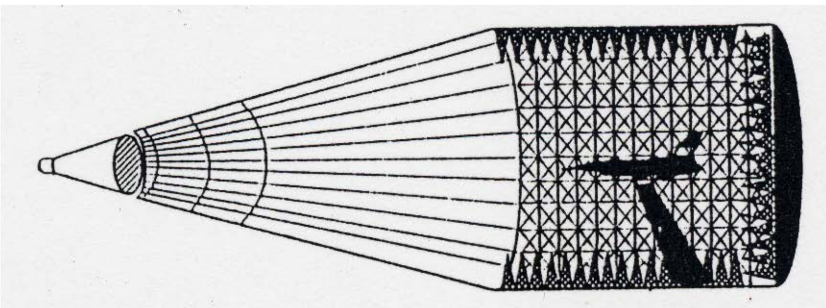
Basic measurement technique



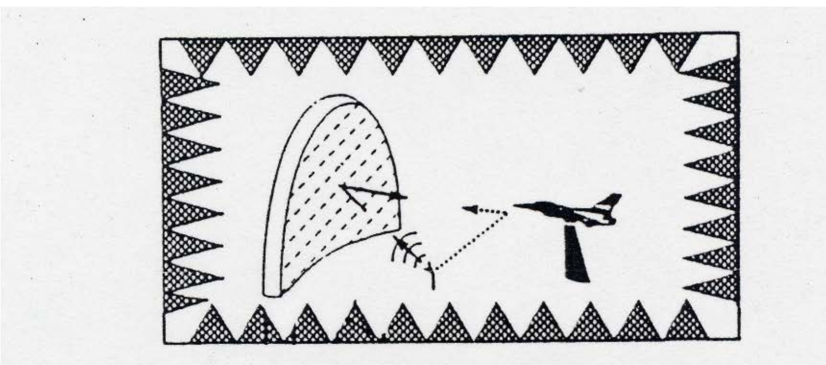
# Indoor Chamber Configurations



Far field chamber: Antennas must be far enough from the target so that a good plane wave condition exists

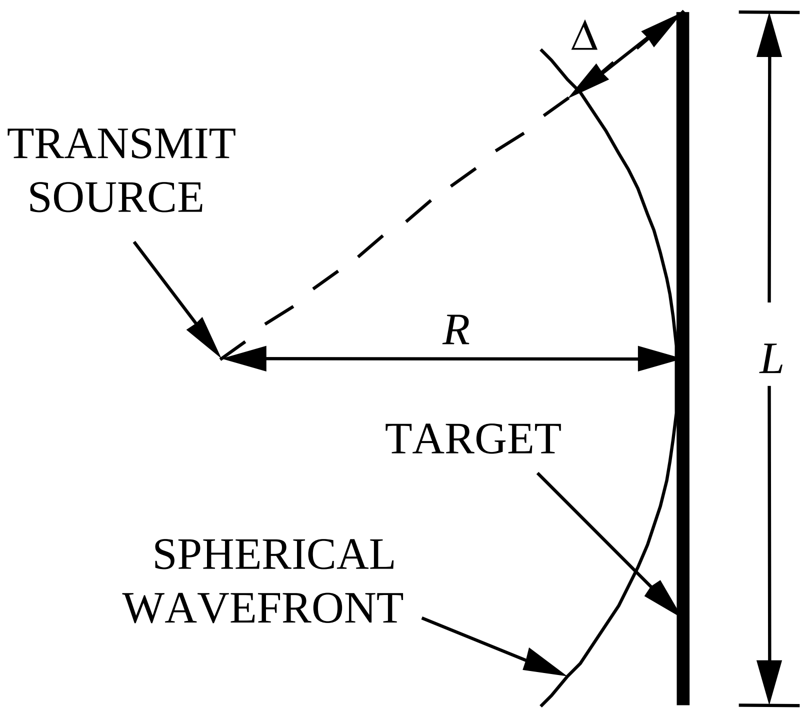


Tapered chamber: Effective at low frequencies. The tapered region acts like a horn antenna



Compact range: Plane wave is reflected from the offset reflector surface. It allows much smaller antenna-target distances

# Far Field Condition




If $R >> L$ then

$$k\Delta_{\max} = k\left[\sqrt{R^2 + (L/2)^2} - R\right] \approx \frac{kL^2}{8R}$$

$$2k\Delta_{\max} \approx \frac{\pi L^2}{4R\lambda}$$

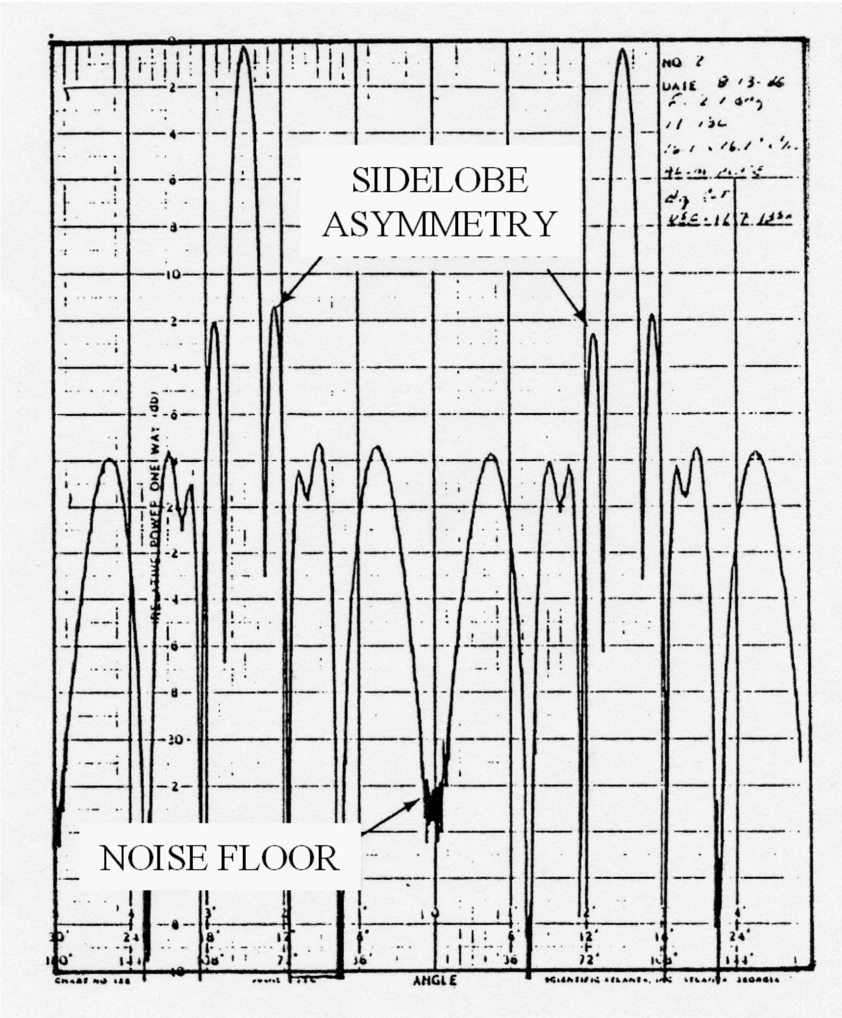
If the maximum allowable error is $\pi/8$

$$\frac{\pi L^2}{4R_{\min}\lambda} \equiv \frac{\pi}{8}$$

$$R_{\min} = \frac{(4L)^2}{\lambda}$$

Example: $L$=1 m and $f$ = 6 GHz, then $R_{\min} = 320$ m. This turns out to be overly restrictive.

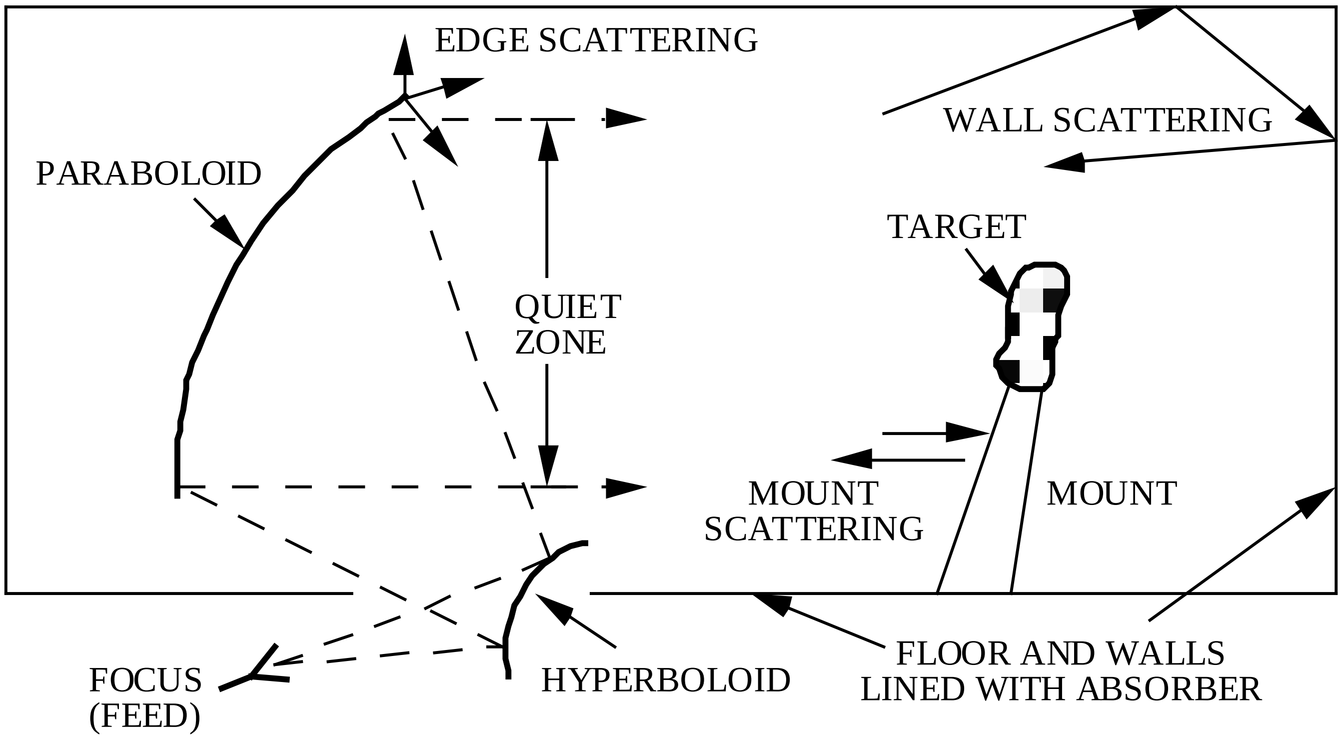
# Measures of Chamber Performance




- Quite zone: cross sectional dimension over with the amplitude and phase are planar
- Noise floor: Minimum RCS level that can be accurately measured is several dB above the noise floor
- Repeatability
    - alignment accuracy
    - chamber conditions
    - instrumentation stability
- Pattern symmetry
    - good indication of chamber errors
- Instrumentation capability
- Data processing and display/presentation capabilities
- Target size
    - pedestal/mount weight limit
    - quiet zone size

# Sources of Measurement Error

- Chamber sources
  - transmit-receive leakage
  - wall reflections
  - reflections from the mount
- Other sources
  - Calibration target misalignment
  - target misalignment
  - interactions between the target and chamber



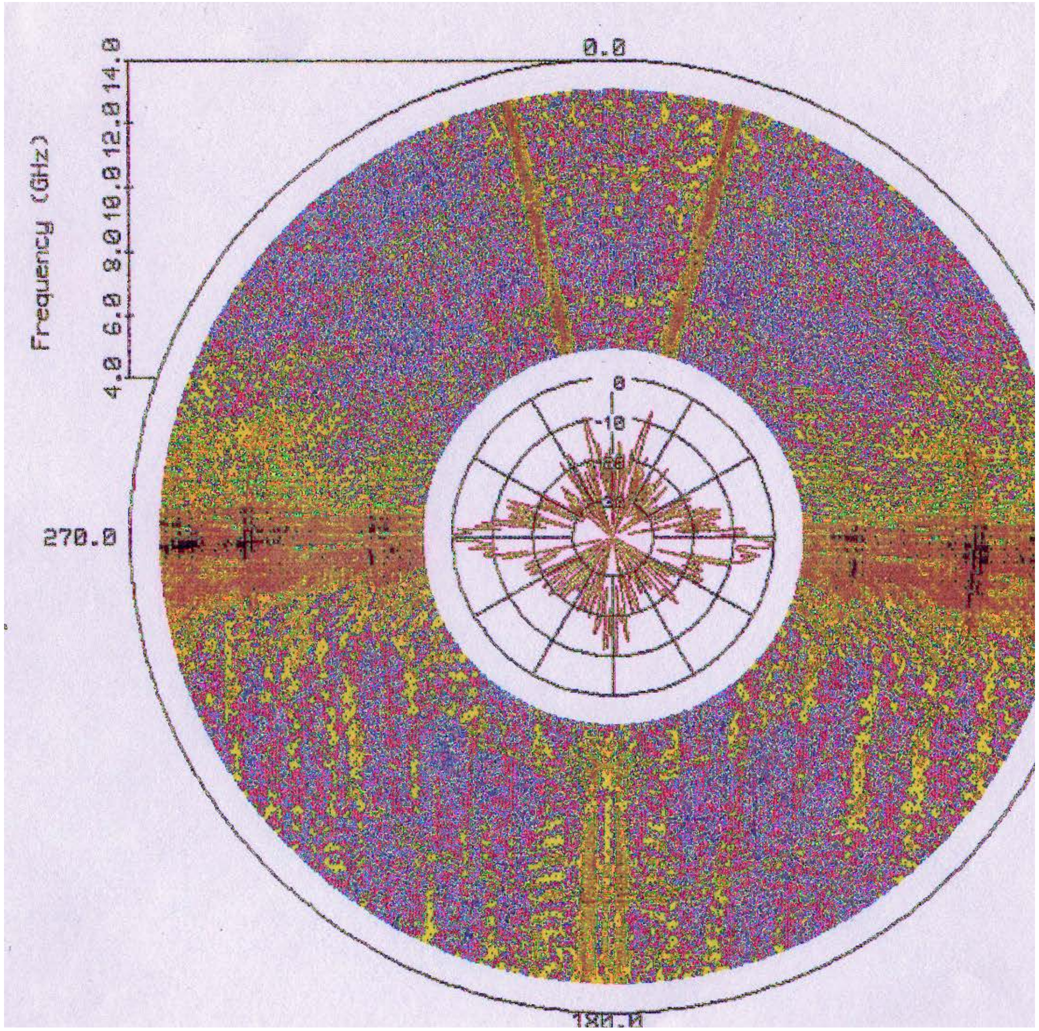
# Measurement Procedure

In order to reduce measurement error the technique of background vector subtraction is often used.

1. Calibrate the receiver using a known target (usually a sphere or plate).
2. Remove the calibration target and measure the background signal at all measurement frequencies and angles. Store the magnitudes and phases.
3. Measure the RCS with the target installed at all measurement frequencies and angles. Store the magnitudes and phases.
4. Subtract the background signal from the total signal to get an accurate estimate of the target only RCS.

Subtraction does not include target interactions with the chamber, but practically they are small.

# Sample Plot From Pt. Mugu



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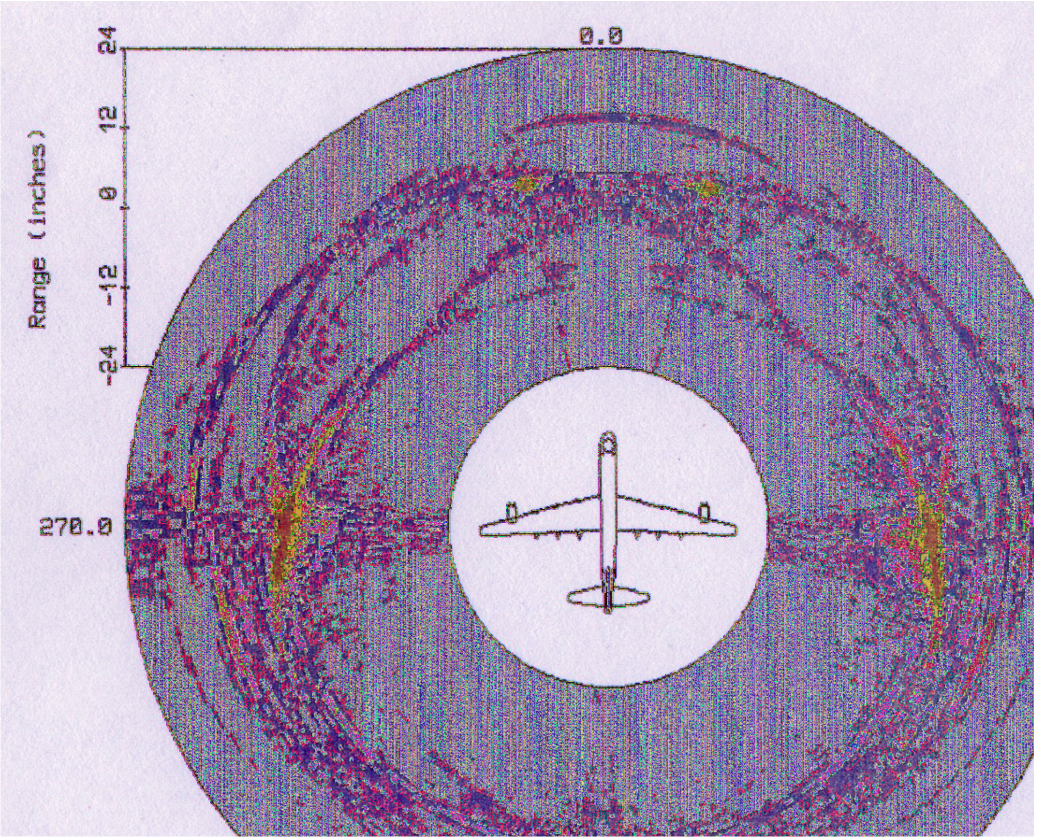
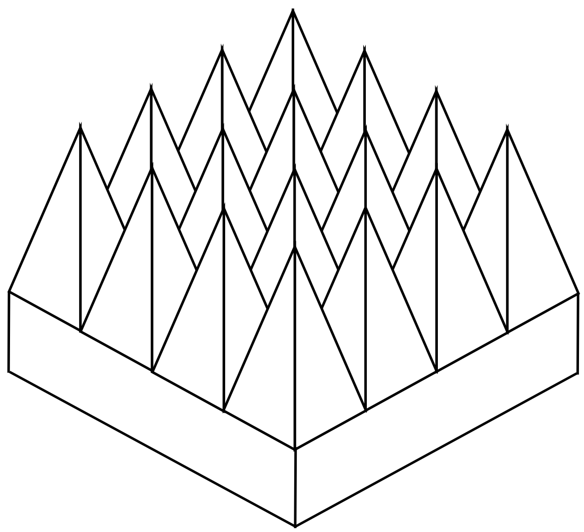
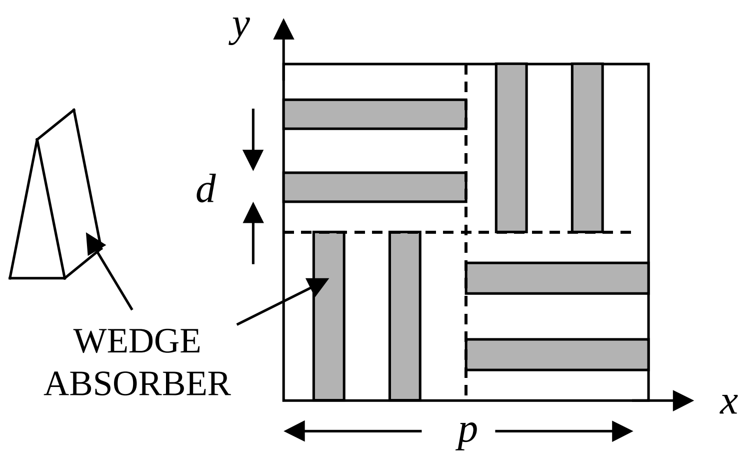


# Absorber for Chambers






Pyramidal absorber:

- Faceted faces cause dispersion of the incident plane wave
- Faces cause reflections and diffractions into other wedges
- Reflectivity of 50 dB with thicknesses of $10\lambda$ or greater.

Other shapes and arrangements (Prob. 8.7):

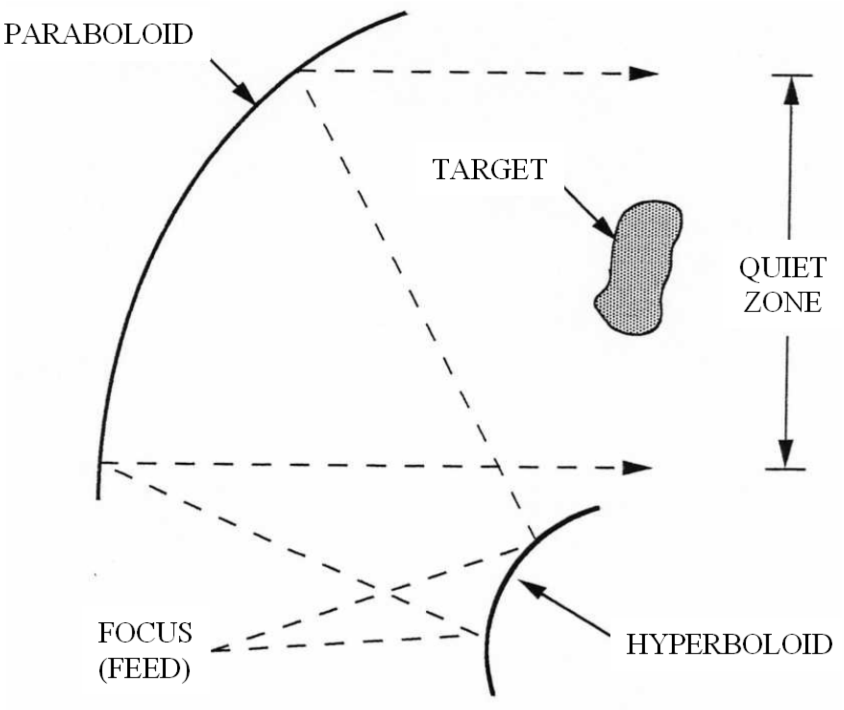
Foam with dielectric constant $\varepsilon_a$ that fills a volume fraction of space $g$ gives an effective dielectric constant that is bounded by $\varepsilon_1 \le \varepsilon_{\text{eff}} \le \varepsilon_2$ where

$$\varepsilon_1 = \varepsilon_o \frac{(1+g)\varepsilon_a + (1-g)\varepsilon_o}{(1-g)\varepsilon_a + (1+g)\varepsilon_o}$$

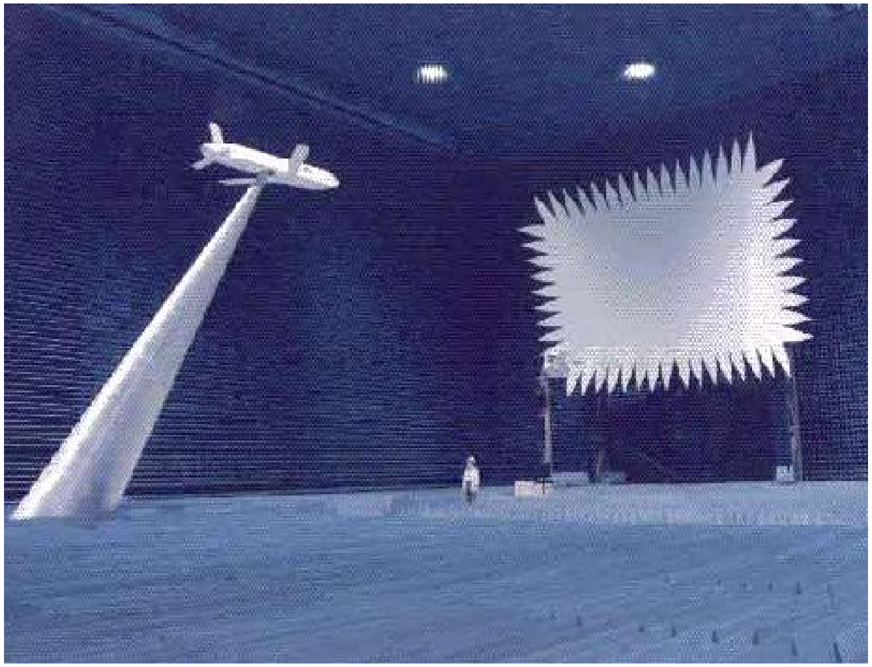
$$\varepsilon_2 = \varepsilon_a \frac{(2-g)\varepsilon_o + g\varepsilon_a}{g\varepsilon_o + (2-g)\varepsilon_a}$$

# Compact Range

Compact range using an offset reflector



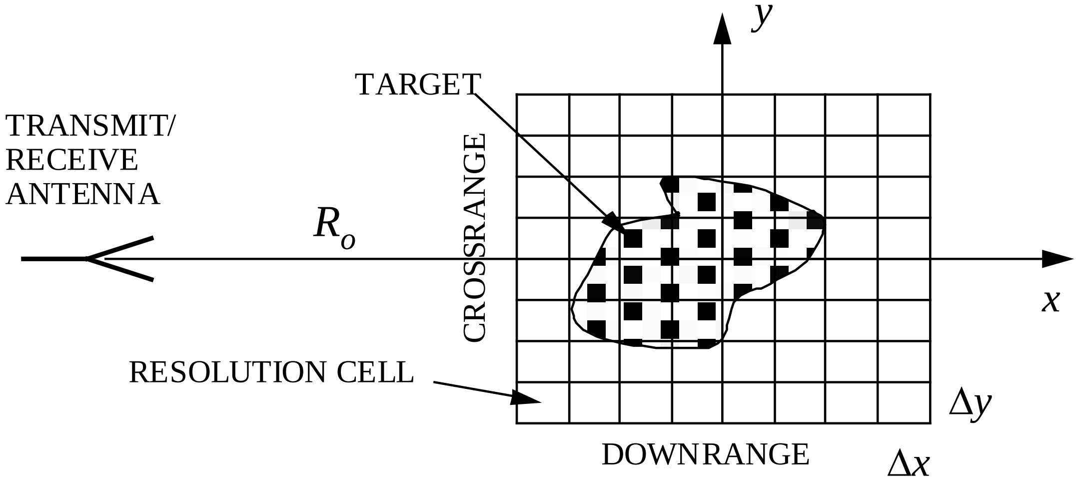

Point Mugu test range



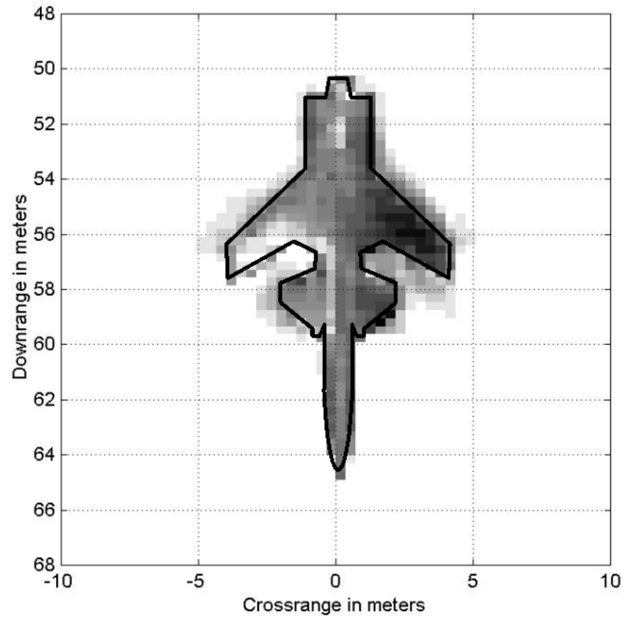
# Imaging Using ISAR

Inverse synthetic aperture radar (ISAR) is a technique used to image a target. ISAR transmits a pulse and obtains the downrange distance (i.e. range to a location on the target) from the time delay. ISAR uses the target's Doppler due to rotation to measure the crossrange. Scattering intensity is plotted for each downrange and crossrange cell. The cells form a pixel of size $\Delta x$ by $\Delta y$ in an image.

ISAR Geometry



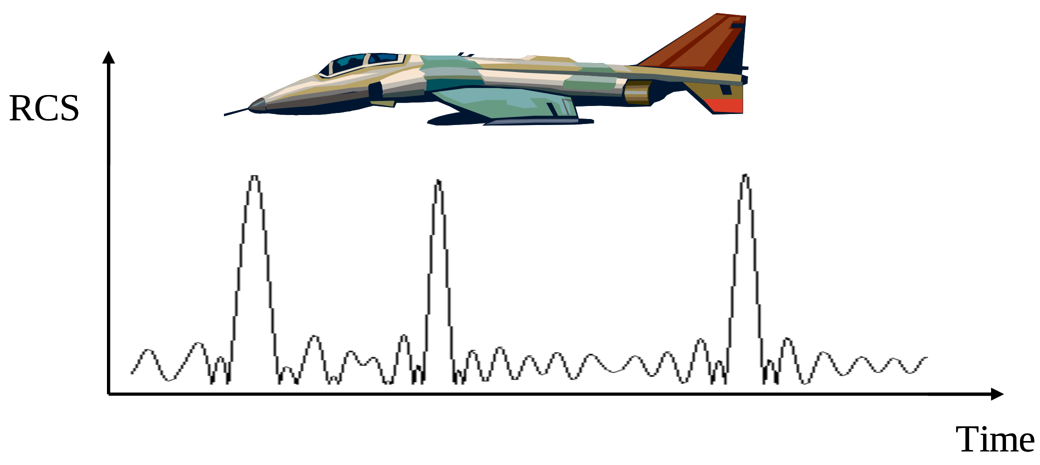

ISAR Image



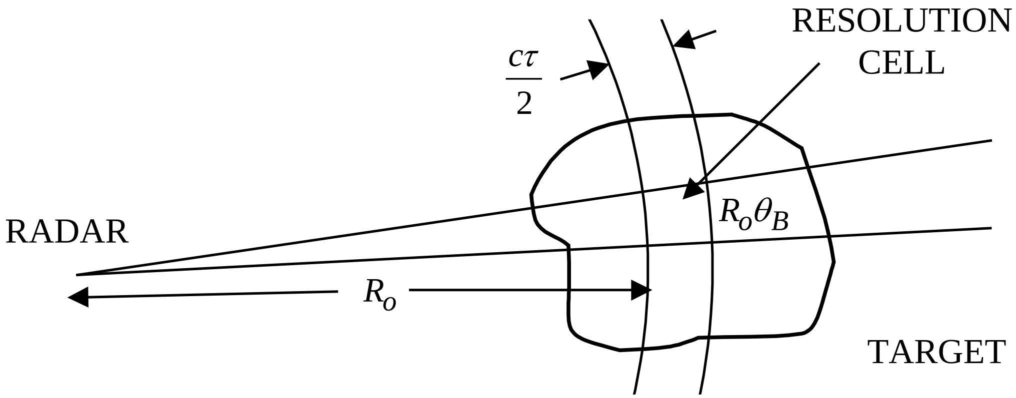
# Time Domain Ranging

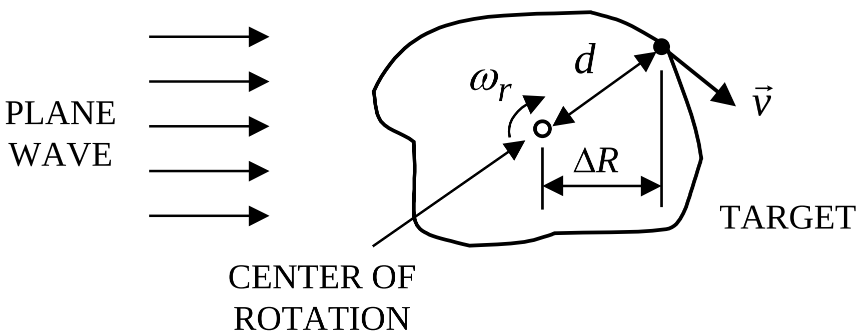
- A single pulse is transmitted
- The scattered signal is plotted vs. time
- Large returns correspond to large scattering sources on the target
- The downrange distance is found from a measurement of the round trip time delay $T_R$.

  For monostatic RCS $R = \frac{cT_R}{2}$



# ISAR Crossrange Formulas




Range to a pixel:

$$r^2 = R_o^2 + d^2 - 2R_o d\cos(\pi - \phi)$$

$$R = R_o\sqrt{1 + \frac{2d\cos(\phi)}{R_o}}$$

$$\approx R_o + d\cos(\phi) \quad R_o >> d$$

Scattered field is of the form:

$$E_s(t) \sim \cos(\omega t - 2kR_o - 2kd\cos\phi)$$

Doppler shift:

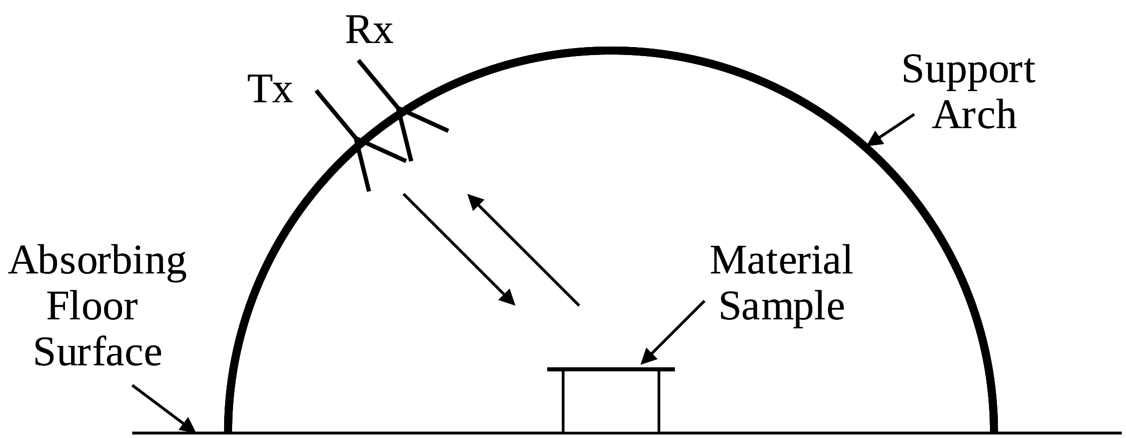
$$f_d = \frac{1}{2\pi}\frac{d}{dt}(-2kR_o - 2kd\cos\phi)$$

$$= \frac{2\omega_r}{\lambda} d\sin\phi = \frac{2\omega_r}{\lambda} y$$

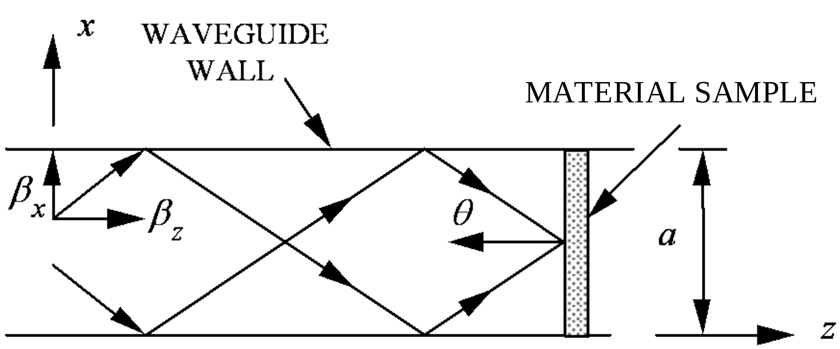
or simply use $f_d = \frac{2v_r}{\lambda}$

# Measuring Reflections From Materials

A free space arch ("NRL arch") measures the reflection from material samples




Waveguide simulators measure reflections from inserts ("coupons")




$TE_{10}$ mode is the sum of two plane waves incident at angle $\theta$:

$$E_z = E_o \cos\left(\frac{\pi x}{a}\right) e^{-\beta z}$$

$$= 2E_o \left( e^{(\pi x/a - \beta z)} + e^{(-\pi x/a - \beta z)} \right)$$

$$\theta = \tan^{-1}(\pi / \beta a)$$

# Maintenance, Testing & Validation

Special maintenance and test procedures must be used because of the unique materials and fabrication techniques used with LO platforms.

A diagnostic system is required to:

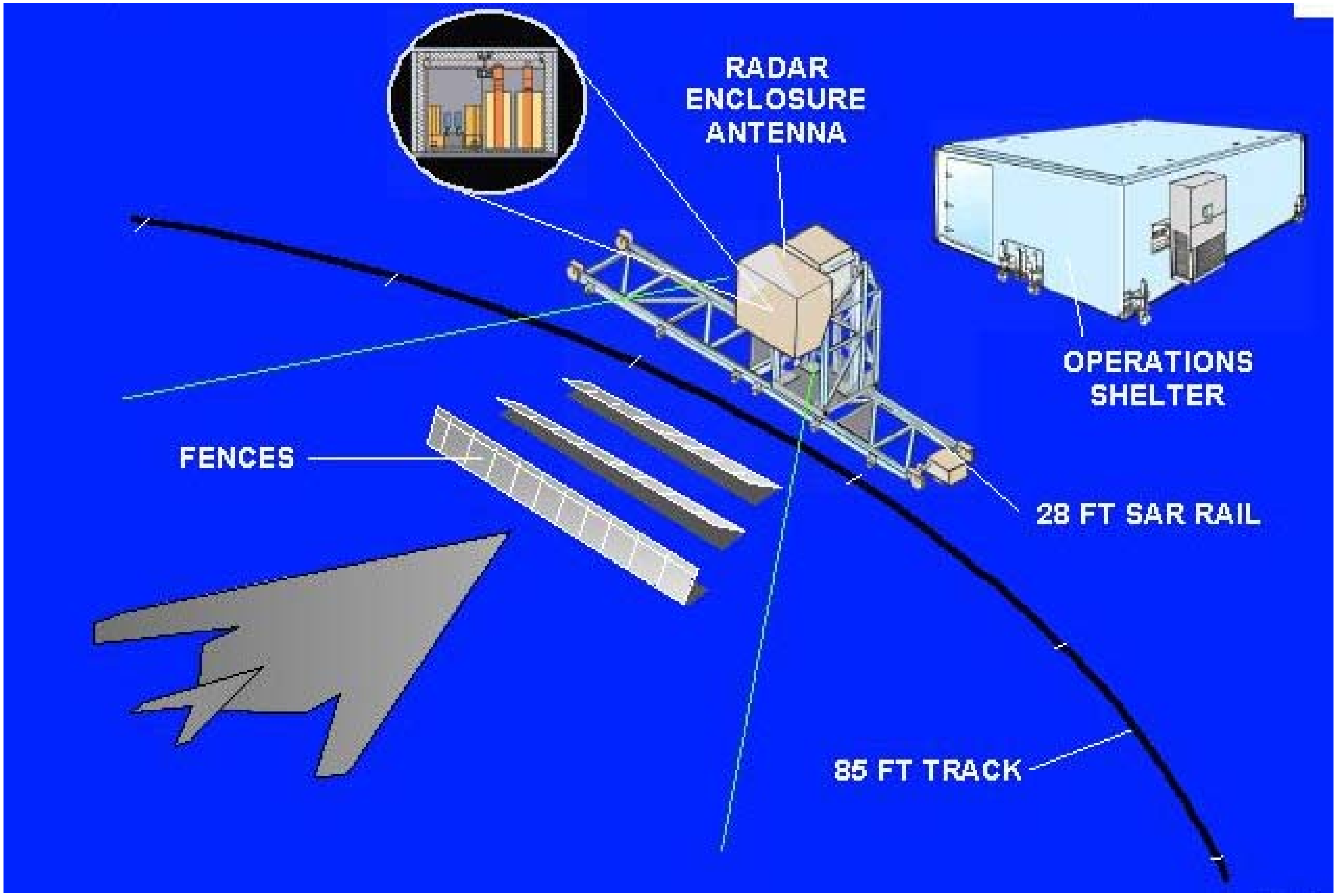
- In the field to determine when maintenance is needed
- Provide a “quick look” before missions
- Verify the integrity of repairs (either minor repairs in the field or major repairs at the depot)

For localized repairs, “mini-arches” are used to test the reflection and transmission characteristics of materials.

Diagnostic imaging radar (DIR) is used to test the integrity of LO targets in the field and at a repair depot.

When used in the field the system must be transportable, easy to set up and operate, and accurate enough to detect flaws.

# Diagnostic Imaging Radar (1)




(Courtesy of *Lockheed*)

# Diagnostic Imaging Radar (2)

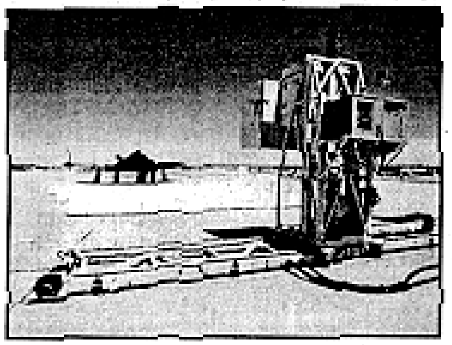
## System revolutionizes stealth maintenance

by Philip Bourgoine
F-117A DIR Program Manager

The F-117A System Program Office here recently delivered a system which has revolutionized maintenance on the F-117A Nighthawk stealth fighter. The F-117A diagnostic imaging radar, or DIR, system provides the 49th Fighter Wing maintainers at Holloman AFB, N.M., with the capability to test and verify the quality of stealth maintenance repairs on the aircraft.

This allows near-real time feedback if repairs impact the radar cross-section of the aircraft. DIR is able to identify within six inches the areas on the F-117A requiring stealth repairs.

Before the fielding of the F-117A DIR system, maintenance technicians did not have the tools to assess how repairs impacted the stealthiness of the aircraft. Previously, the maintainers could not determine where repairs were required without the input from highly skilled engineers and costly, time-consuming flight test. The average maintenance technician using DIR can now accomplish the same task with more confidence and precision in eight hours.



Air Force photo

**The F-117A diagnostic imaging radar antenna positioner undergoes testing at Air Force Plant 42, Palmdale, Calif.**

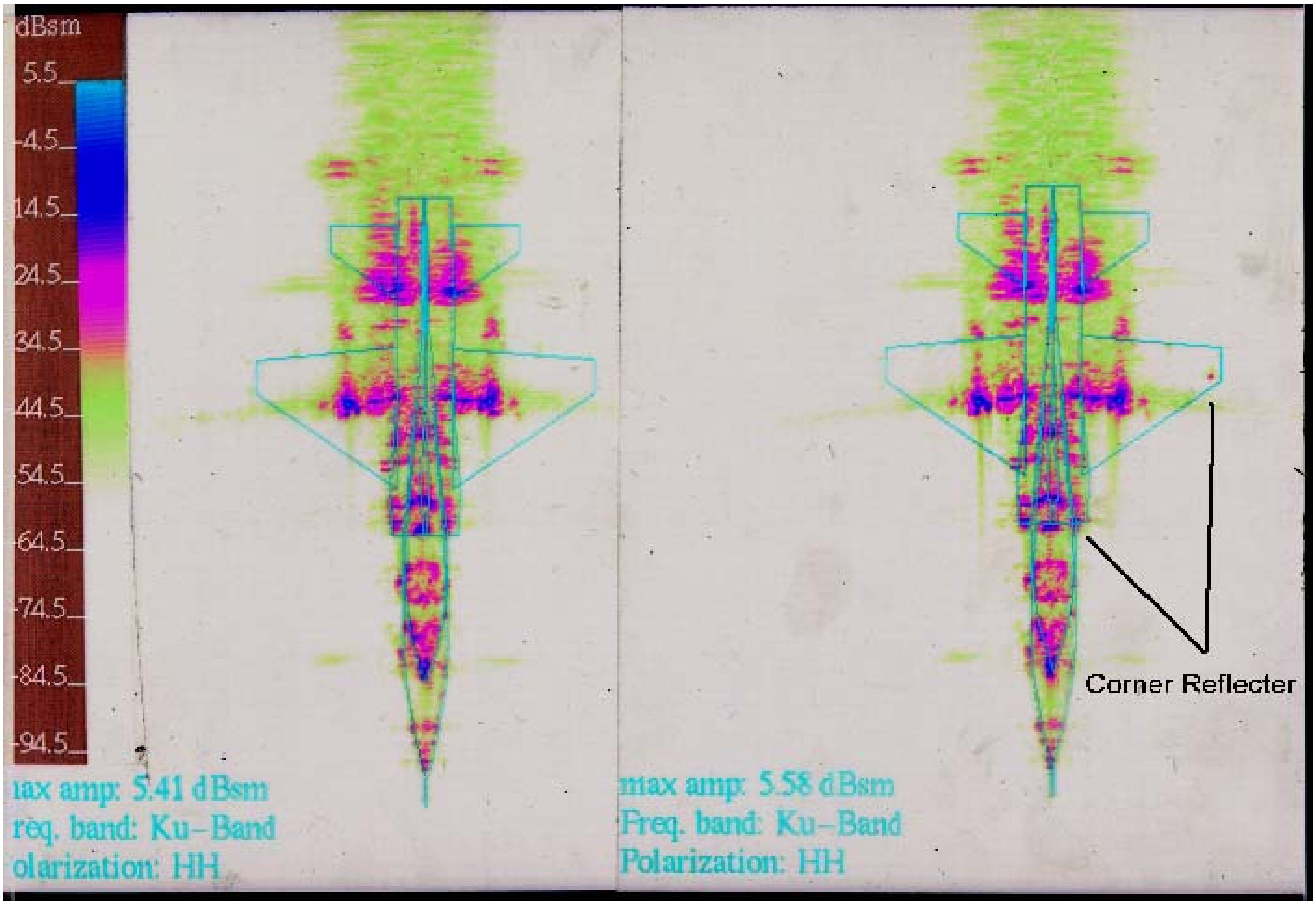
The DIR system consists of a ground-based MK V radar, a radar antenna rail system, computer workstations, a deployable shelter for the system operators and aircraft support equipment. The MK V radar is a newly developed, accurate, high-speed radar system used for a wartime mission. The information the radar gathers is processed on a workstation using collected radar data at selected frequencies.

The MK V radar, with the antenna rail, simulates the radar threat the F-117A would face. The transportable enclosure is formed from two maintenance shelters commonly used in Department of Defense. The operator can cool or heat the workplace wherever it is located.

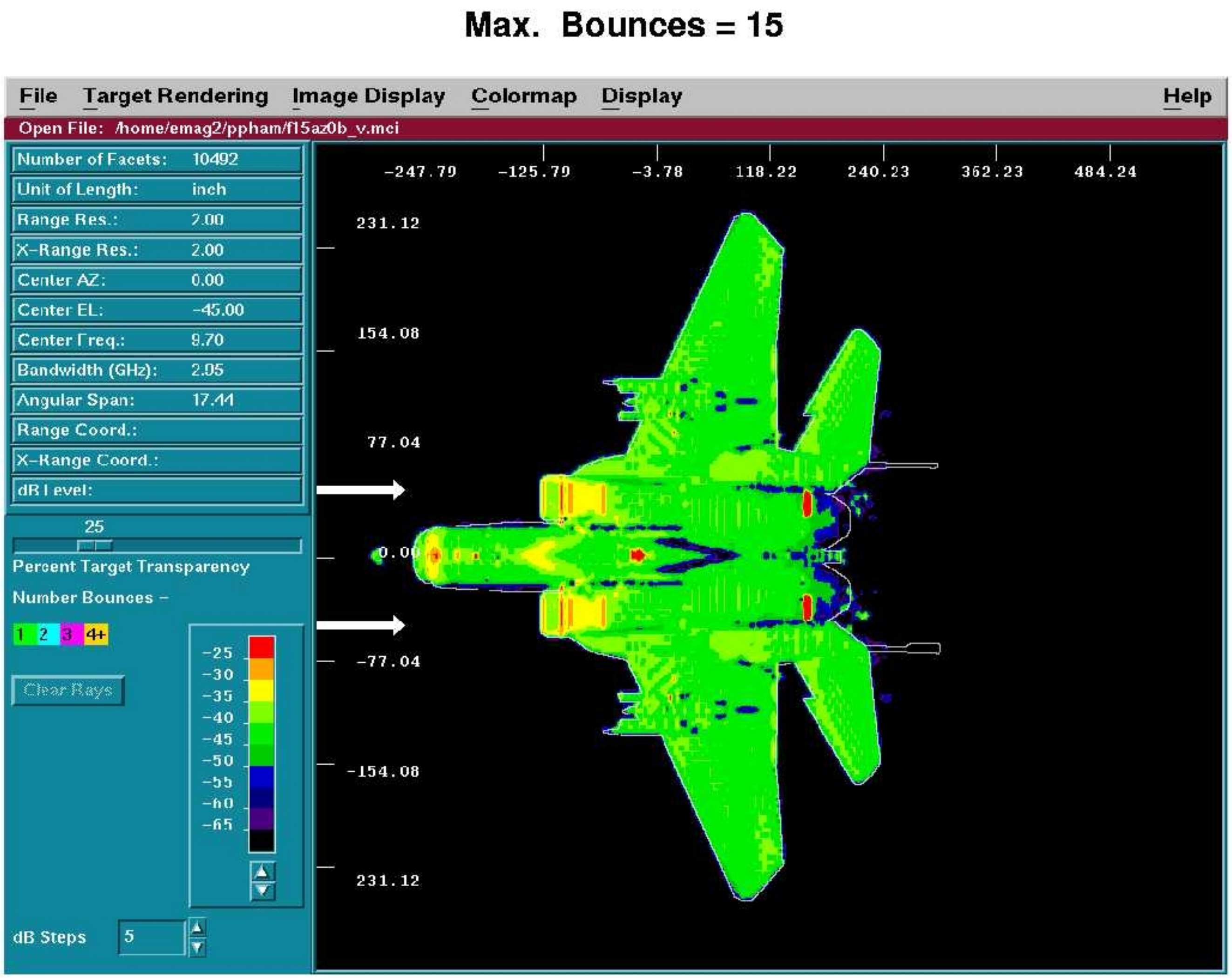
When the system is separated for shipment, the shelters are used to transport the radar and antenna rail. The pallet system developed for the DIR shelters allow the shelters to be carried on cargo aircraft without using the old 463L aircraft pallets. This saves the maintainer several hours preparing for deployment. This modification can be easily installed on any similar military shelter.

This system represents the efforts of six government and five contractor agencies. System Planning Corporation, Arlington, Va., provided the radar subsystem and the Massachusetts Institute of Technology's Lincoln Laboratories developed data analysis software. The common military shelter was modified by JAYCOR, Albuquerque, N.M.; and Lockheed Martin Skunk Works, Palmdale, Calif., did aircraft support equipment and integration support. Electronic Systems Center at Hanscom AFB, Mass., developed an integrated aircraft pallet system for the shelter.

# Diagnostic Imaging Radar (1)



# F-15 Image Using XPATCH (1)



# F-15 Image Using XPATCH (2)

**Max. Bounces = 30**