THz Compact Range Radar Systems

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Outline

- Goals and Methods
- History
- Compact Ranges
- THz Materials Research
- Sample Images
- Future Work

ERADS Project

- **Project Directed by U.S. Army National Ground Intelligence Center(NGIC) Rivanna Station**

- **ERADS is Acronym for Expert Radar Signature Solutions**

- **Member Organizations: NGIC Rivanna Station, UMass Lowell STL, UVa Semiconductor Device Lab, NGIC Aberdeen Proving Ground, Georgia Tech. Research Institute, Tufts University.**

ERADS Project

- NGIC has supported THz components and systems development
    - ultra-stable lasers
    - materials science
    - diodes
    - multipliers
    - output couplers
    - sources
    - detectors
    - antennas

Goal

- **Address present and future DOD radar signature requirements.**

Data Uses

- **Target Classification/Recognition** (e.g., Tank, Truck or Missile Launcher)
- **Target Discrimination** (Missile Warhead, Decoy or Debris)
- **Friend-Versus-Foe Discrimination** (Our Helicopter or the Enemy's)
- **Stealth**
- **Moving Target Identification**

Approach

- Scale-Model Target Measurements in Submillimeter-Wave Compact Ranges
- Whenever Possible, Field Measurements on Full-Size (Actual) Targets
- Where Feasible, Computer Predictions Using Electromagnetic Codes with CAD Targets

Each Technique has Unique Strengths and Limitations. <u>Cross-validation is critical.</u>

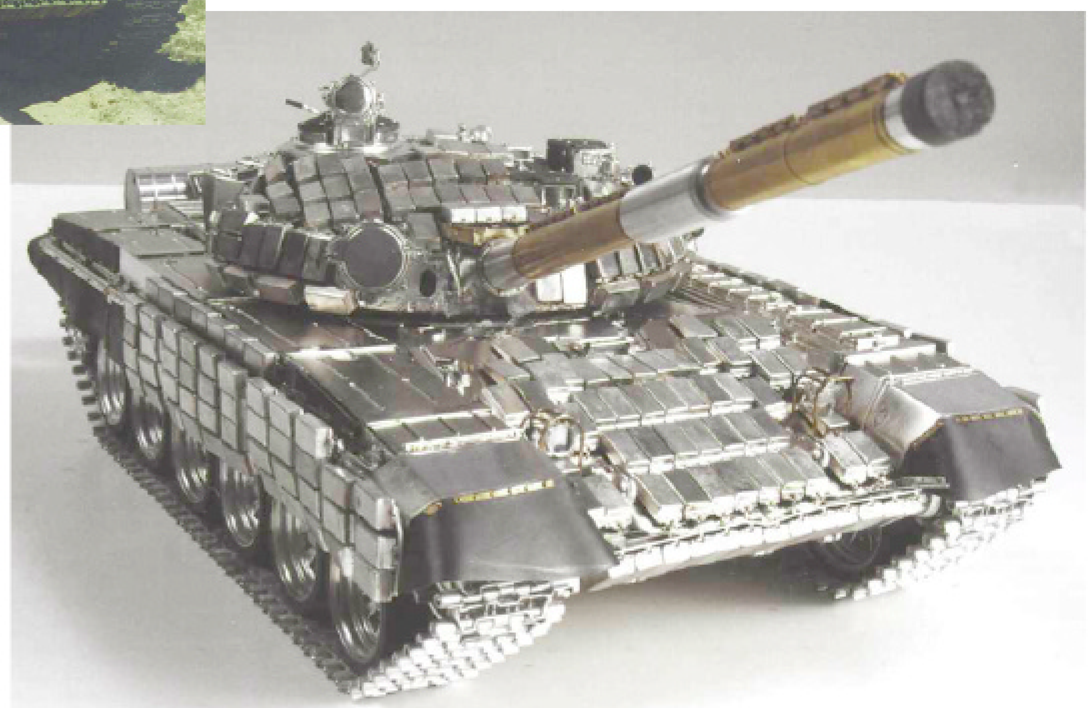
Measurements Using 1/16th Scale Models

- Measure 1/16th Scale Model of Target at Scaled Wavelength To Collect High-Resolution Target Signature Data.

- Requires High Fidelity Model of Target.

T72 Tank (With Reactive Armor)

Full Scale Target Vehicle



1/16th Scale Model

Electromagnetic Similitude

If
$$\frac{l_{Model}}{l_{Full-Scale}} = \frac{L_{Model}}{L_{Full-Scale}} = \frac{1}{S}$$

where S=scale factor (e.g. 16)

then
$$(s_{RCS})_{Model} = \frac{1}{S^2}(s_{RCS})_{Full-Scale}$$

where σ_{rcs}= the Radar cross-section of the target

For dielectrics:
$$e_{Model} = e_{Full-scale}$$

Where ε = the dielectric constant

Reflectivity of Metals

For metals: $$e_{imaginary} = s\,l$$ where σ = conductivity

then, $$s_{Model} = S s_{Full-scale}$$

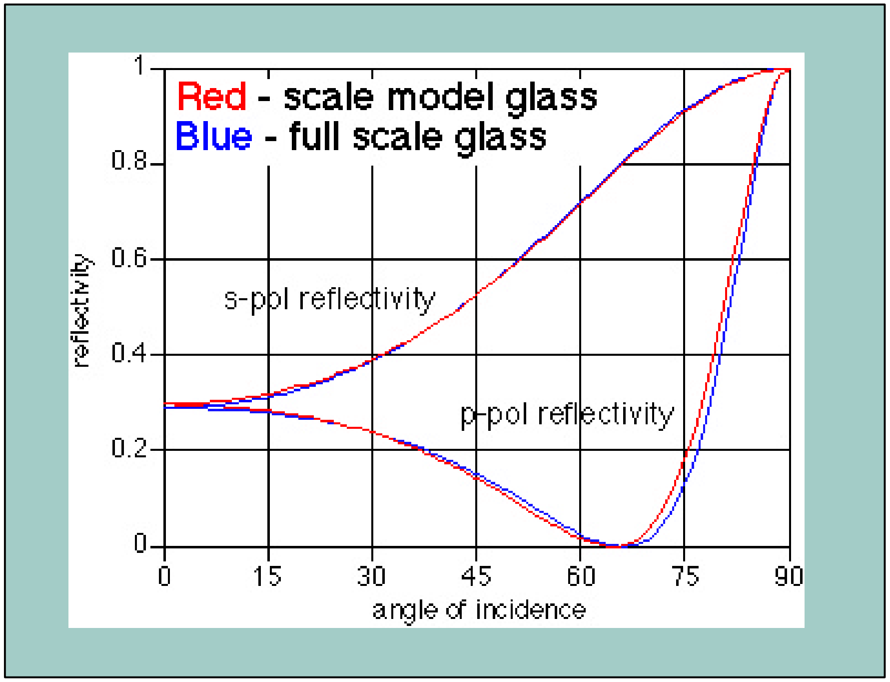
Material	σ_{DC} (mho/m)	Reflectivity(1THz)
Copper	5.7×10^{7}	0.9972
Gold	4.3×10^{7}	0.9968
Aluminum	3.5×10^{7}	0.9966
Brass	2.4×10^{7}	0.9959
Iron	1.2×10^{7}	0.9950

Metal conductivity scaling not practical but also not necessary since it leads to only a negligible change in reflectivity.

Modeling of Dielectrics

10 GHz vs 160 GHz Reflectivity of Glass

Reflectivity of glass window at 10 GHz vs. 1/16th scale model window at 160 GHz



Window thickness:
- 5 mm for 10 GHz
- 5/16 mm for 160 GHz

- **Tailored dielectric can exhibit <u>very similar</u> behavior as full-scale component**

EXPERT RADAR SIGNATURE SOLUTIONS

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History

•Maxwell's equations predict that scale models can be used to obtain radar information when measured at proportionally scaled wavelengths. Mathematical formalism worked out by Sinclair (1948).

•This technique had been used in the microwave region to simulate the results for high frequencies (where sources were not available) by using lower frequency sources (scale factors > 1).

•NGIC and STL started scale modeling program in 1981 to determine if systems could be developed to model mm-wave radar.

•Early techniques involved spot imaging using optically pumped lasers and liquid He-cooled bolometers as incoherent detectors.

Early Spot Scanning System (1981)

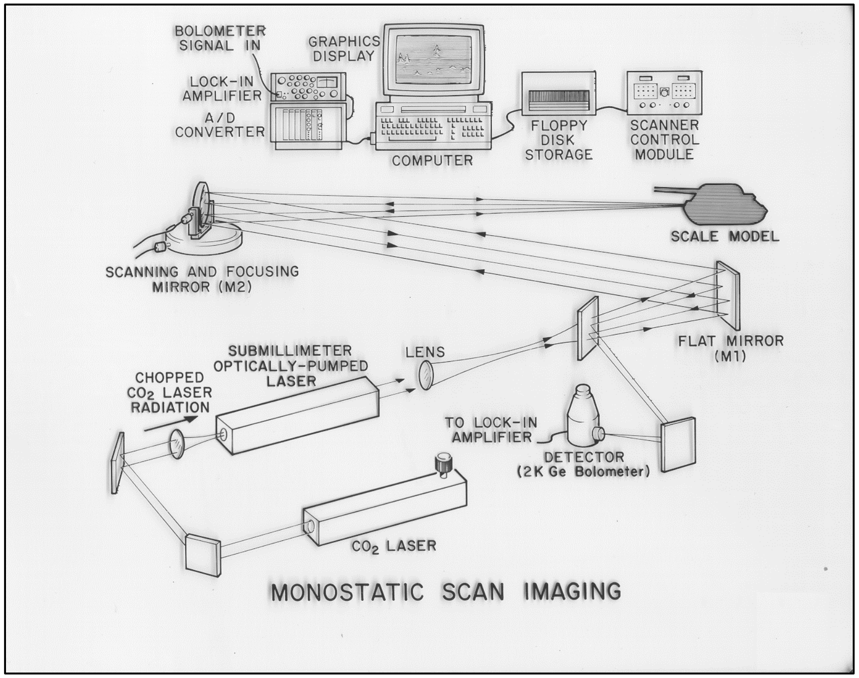
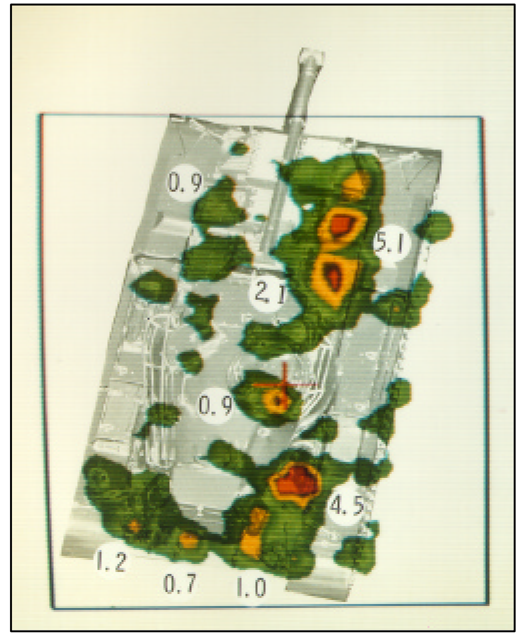


Diagram of early spot scanning system for single polarization incoherent measurements. A single laser frequency was used and focused to a spot, which was scanned across the target.

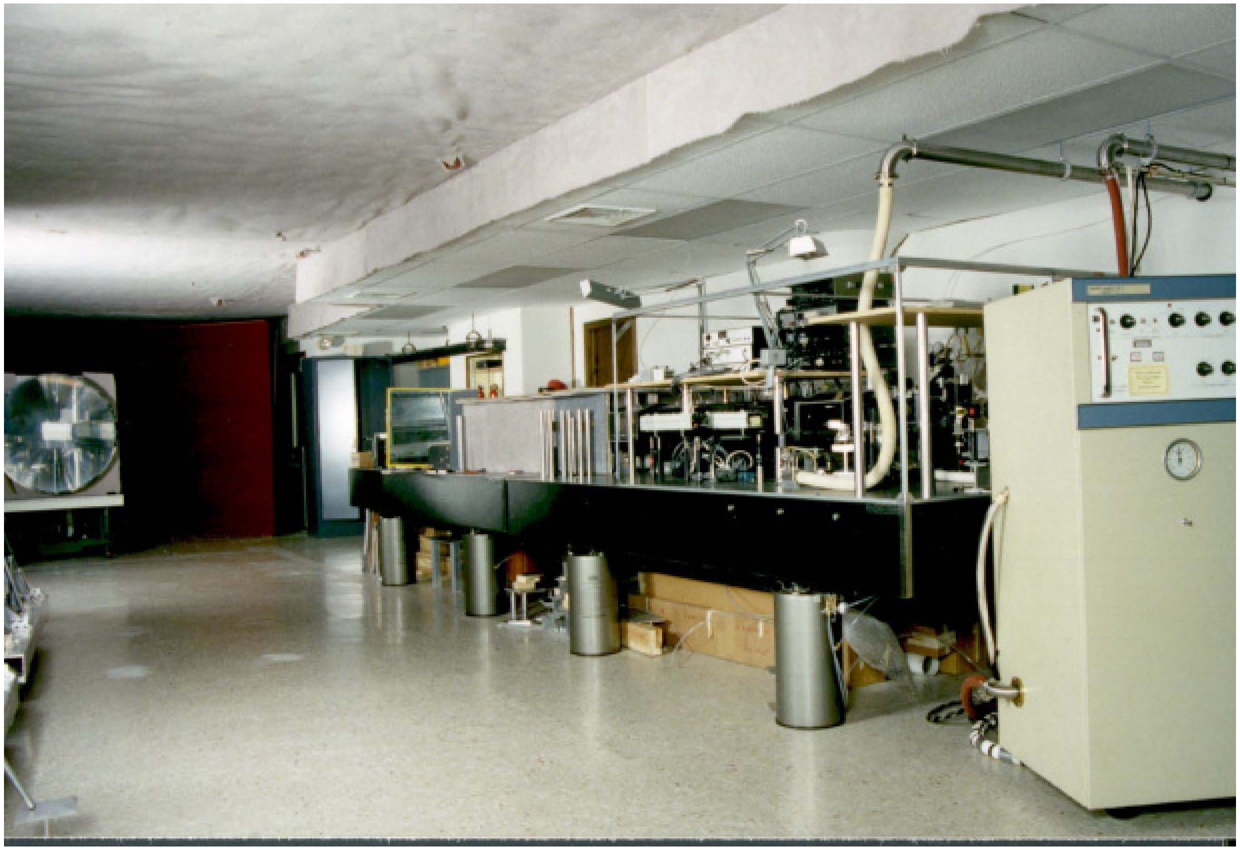


Example of early data overlaid on picture of target.

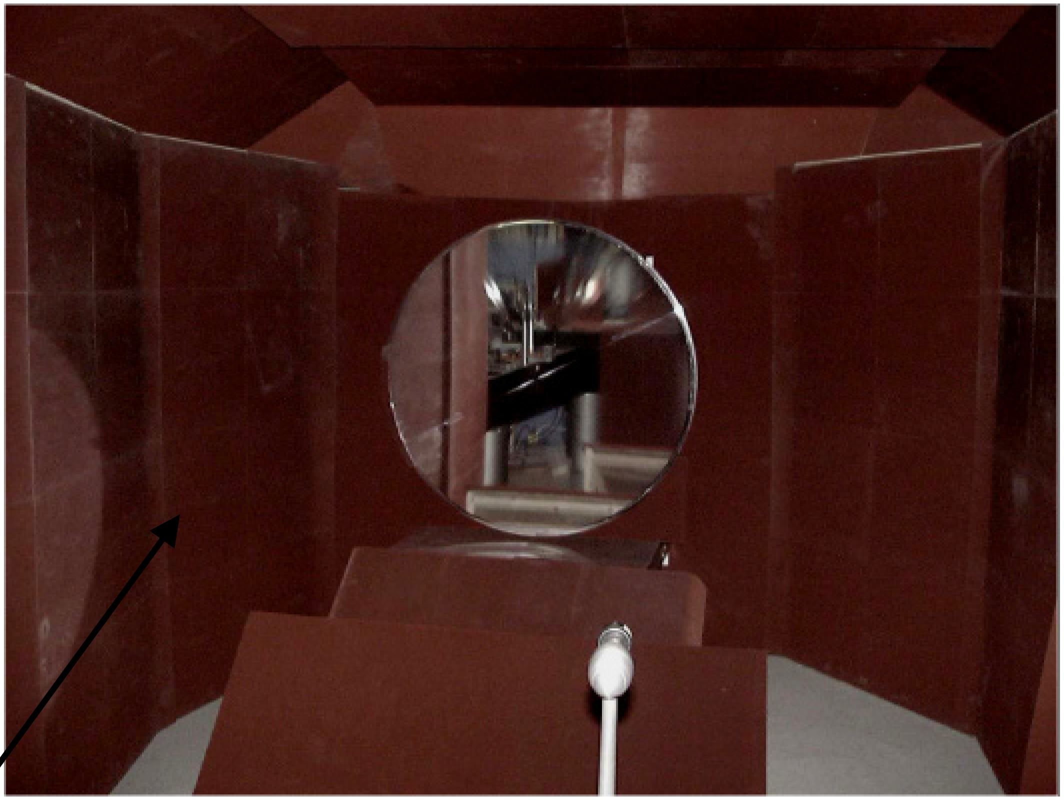
Evolution To Full Beam Illumination

- Early spot scanning systems were found to be very useful to identify radar scattering centers.
- Systems were gradually developed to simulate full beam illumination radar systems for RCS measurements.
- Early laser systems were replaced with more stable lasers and with solid state sources at the lower frequencies.
- Systems developed for full polarization measurements. (Horizontal (H) and vertical (V) transmit, and H and V receive).
- Advances in Materials Science makes it possible to produce dielectric materials that scale the the dielectric properties of real targets.
- Coherent measurement techniques developed to replace the early incoherent measurement techniques giving both amplitude and phase information, allowing image formation from RCS data.

Early Full Beam Radar System



Current Anechoic Chamber



Radar Absorbing Material

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Requirements For A Compact Radar Range

- Coherent, Broadband Two-Channel Transceiver
- Antenna (2 to 3 Times Target's Maximum Extent)
- Optics for Beam Adjustment, Transport, Frequency and Polarization Filtering
- Target and Ground Plane Support and Orientation Stage
- In-Scene Polarimetric Calibration
- Anechoic and Scaled Dielectric Materials
- Automated Data Acquisition and Processing

Current Compact Range Frequencies

Frequency	Bandwidth	Source	Power	1/16th Scale
160 GHz	24GHz	Solid State	10.0mW	Models: X -Band
520 GHz	18GHz	Solid State	0.1mW	Models: Ka-Band
1560 GHz	8GHz	Laser	5.0mW	Models: W -Band

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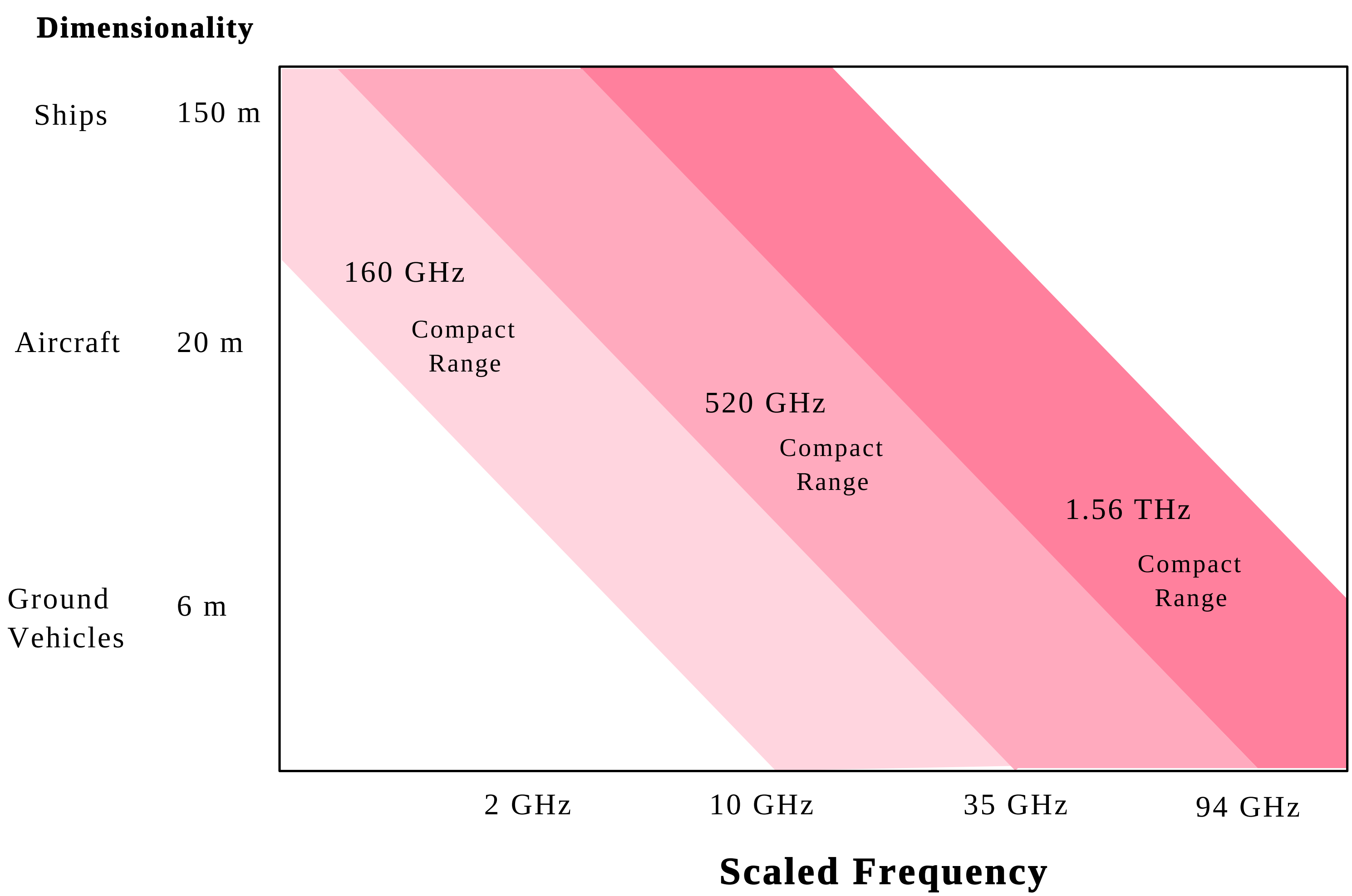
Submillimeter-Wave Compact Range Capabilities



SMS160 Compact Range Layout

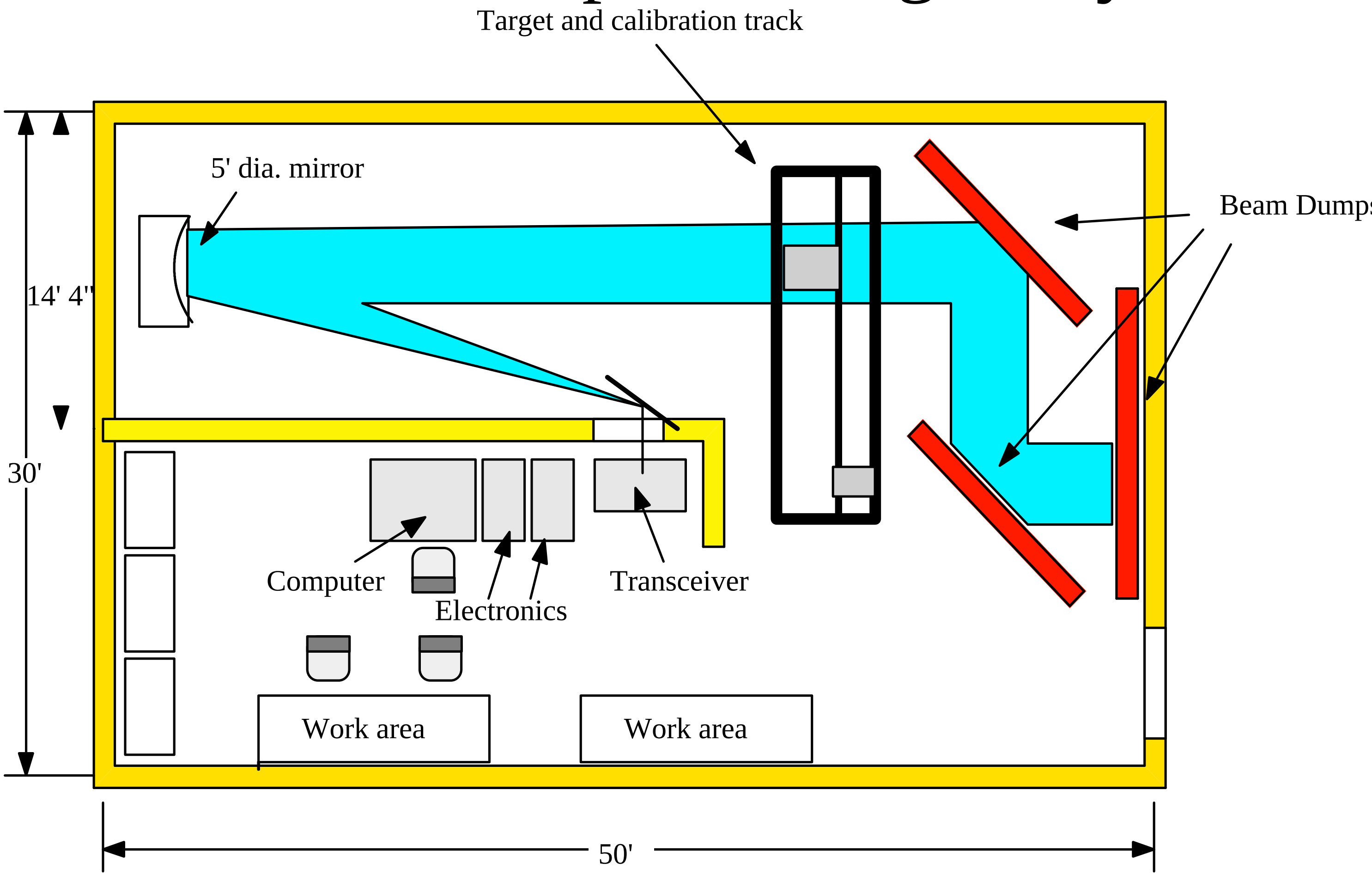
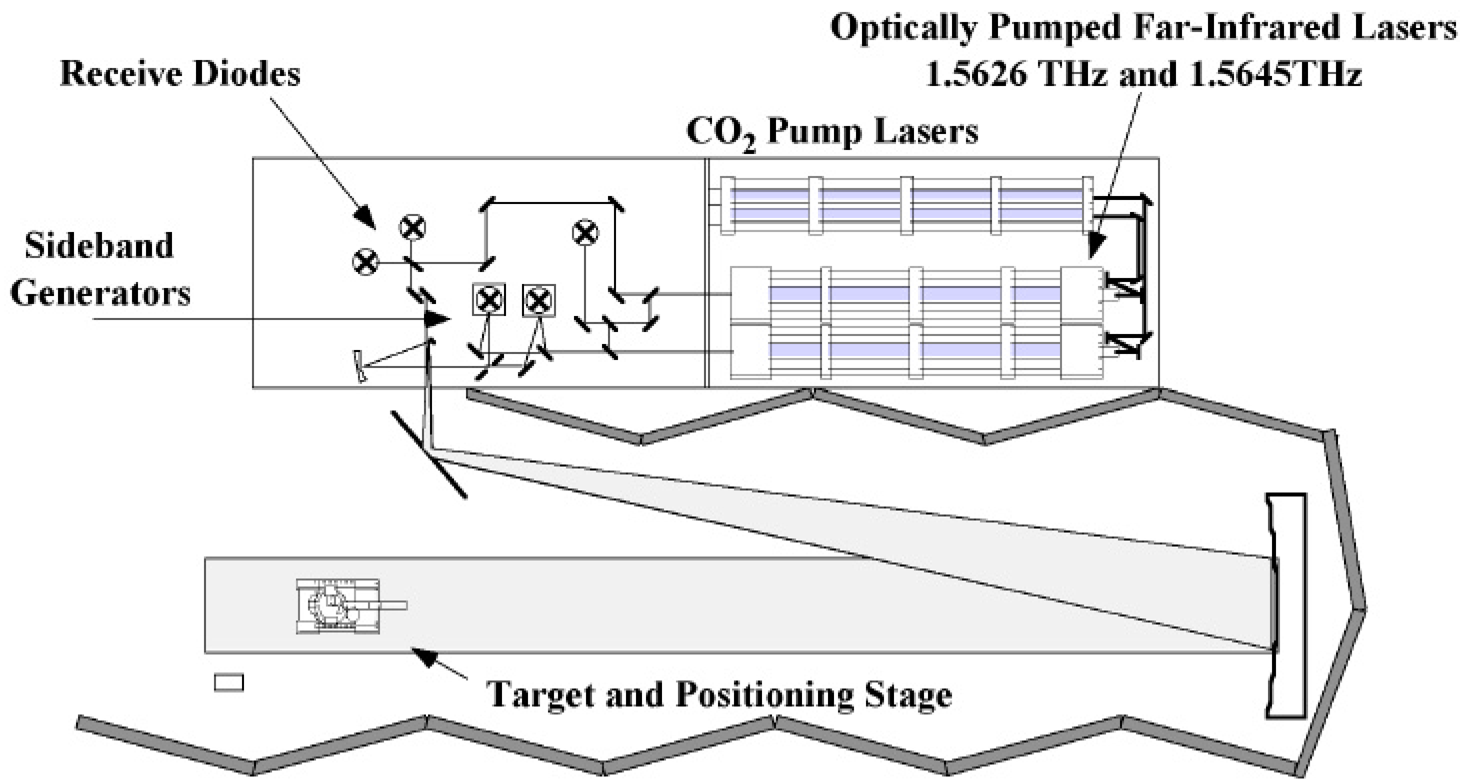
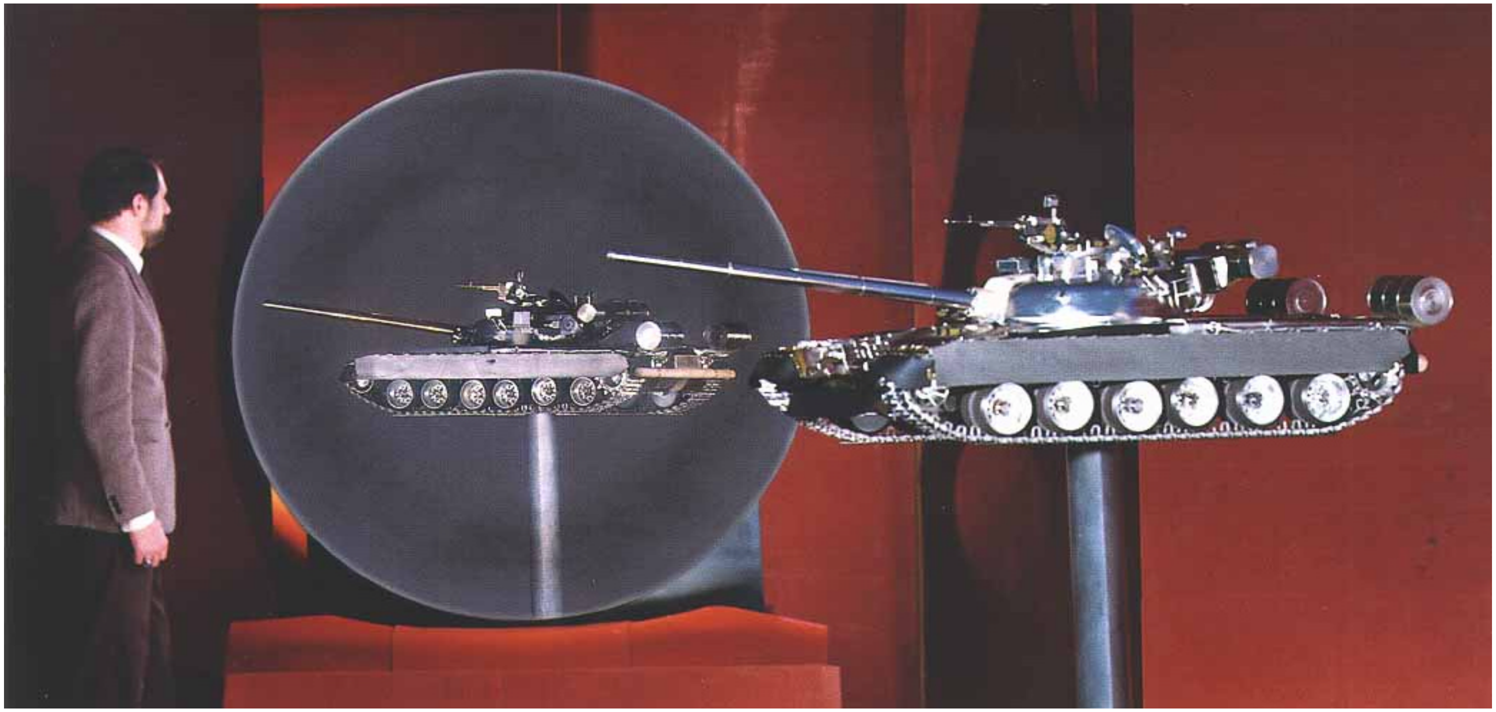


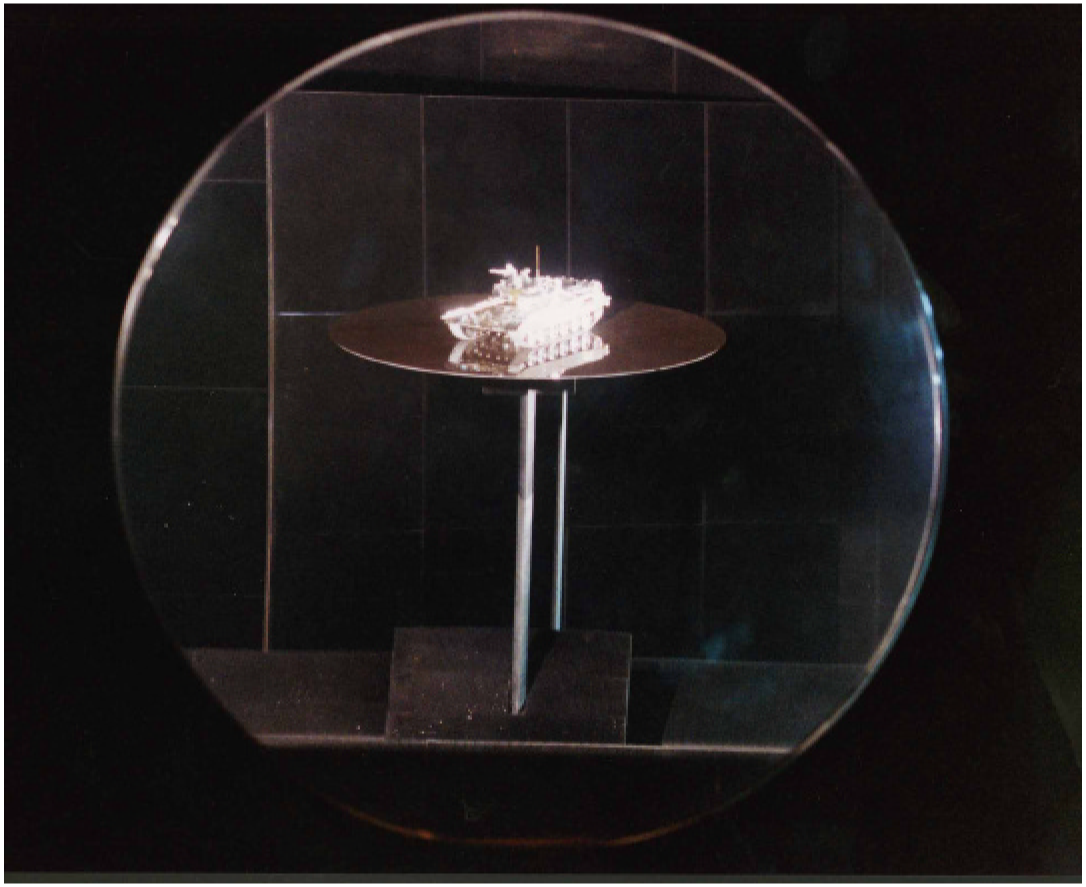
Diagram of the 1.56THz Compact Range



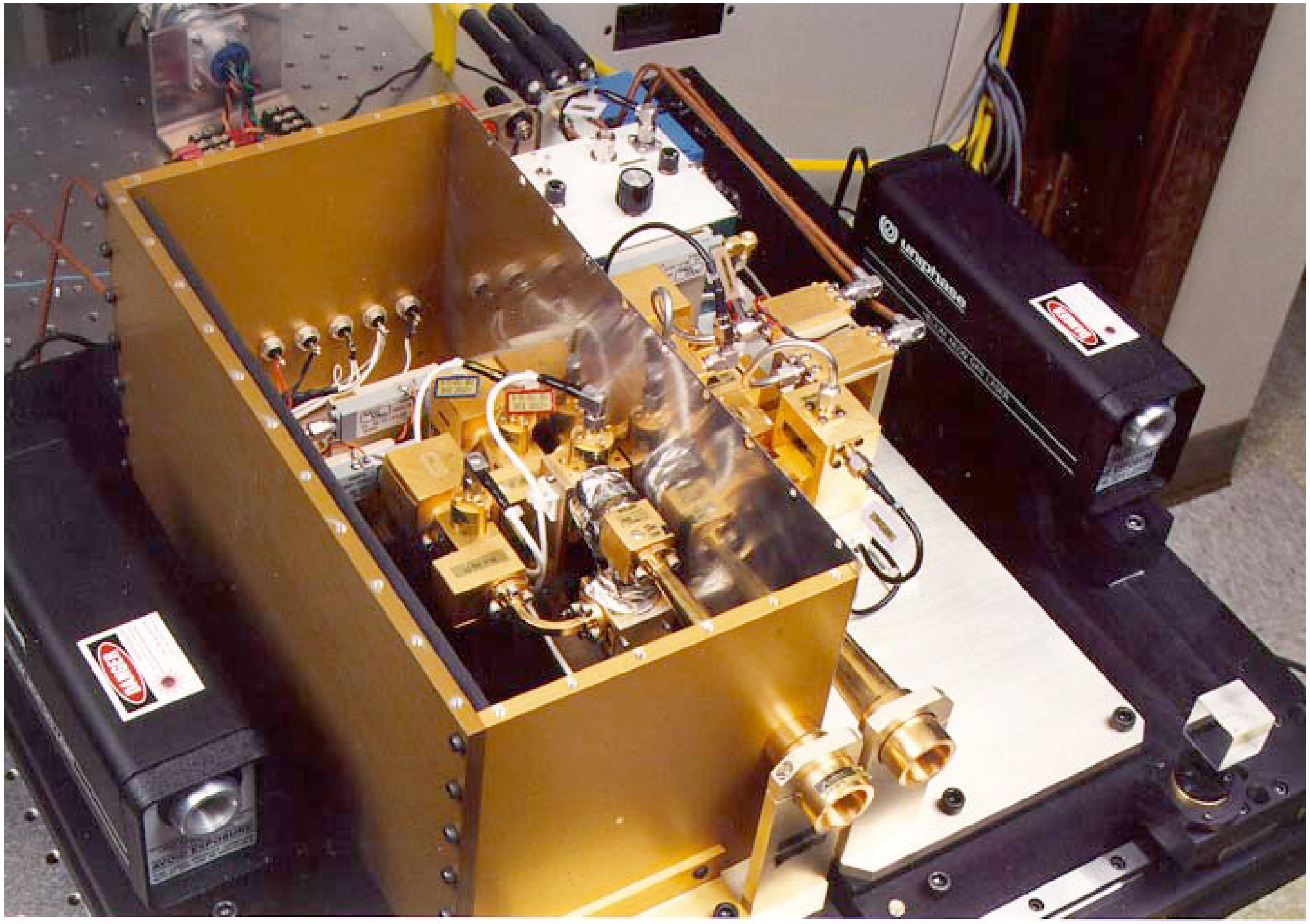
Diamond-Turned 60” Diameter Primary Antenna



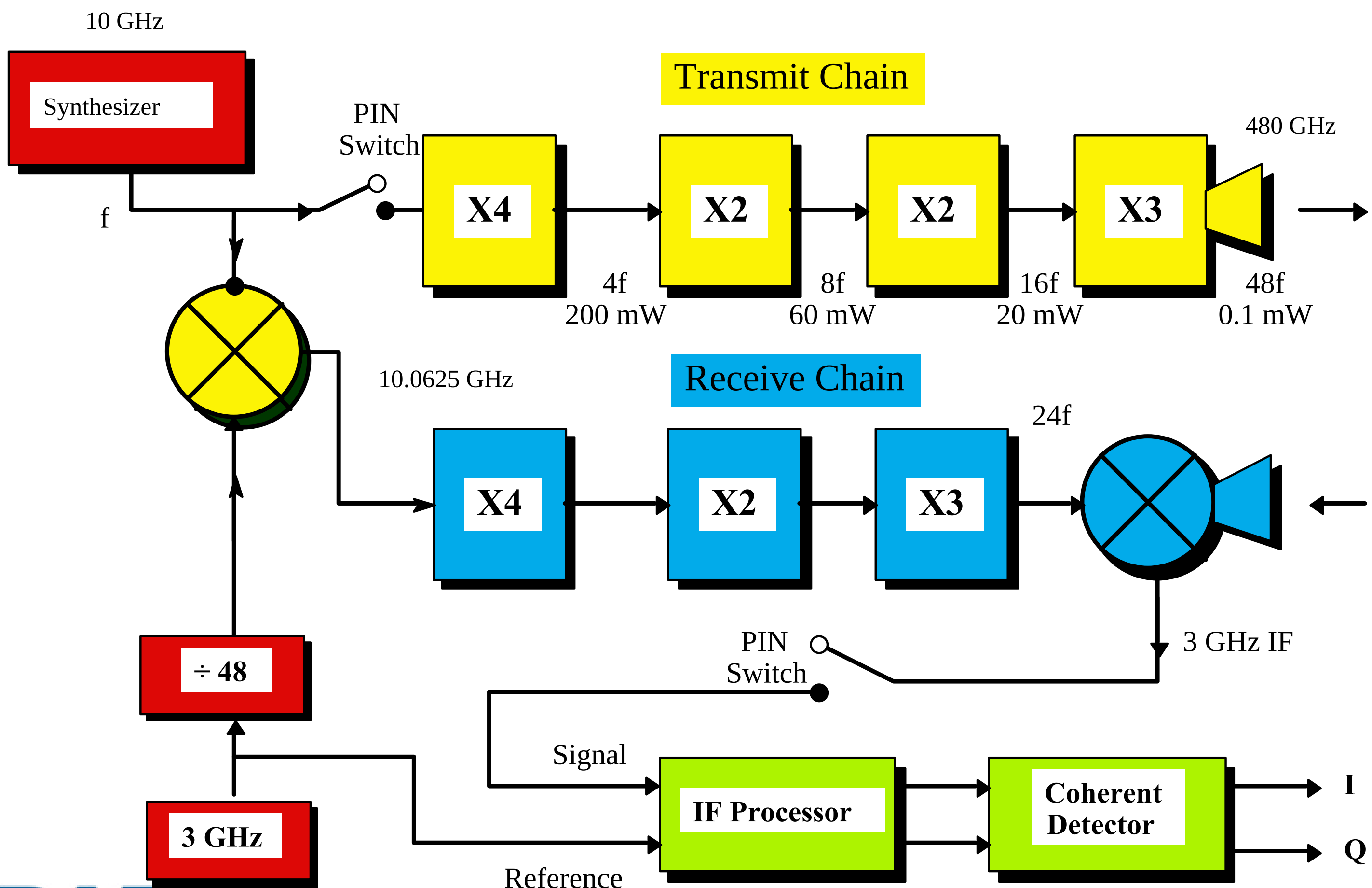
Target Pylon With Ground Plane



SMS 160 Solid-State Receiver



Submillimeter Solid-State Polarimetric Transceiver

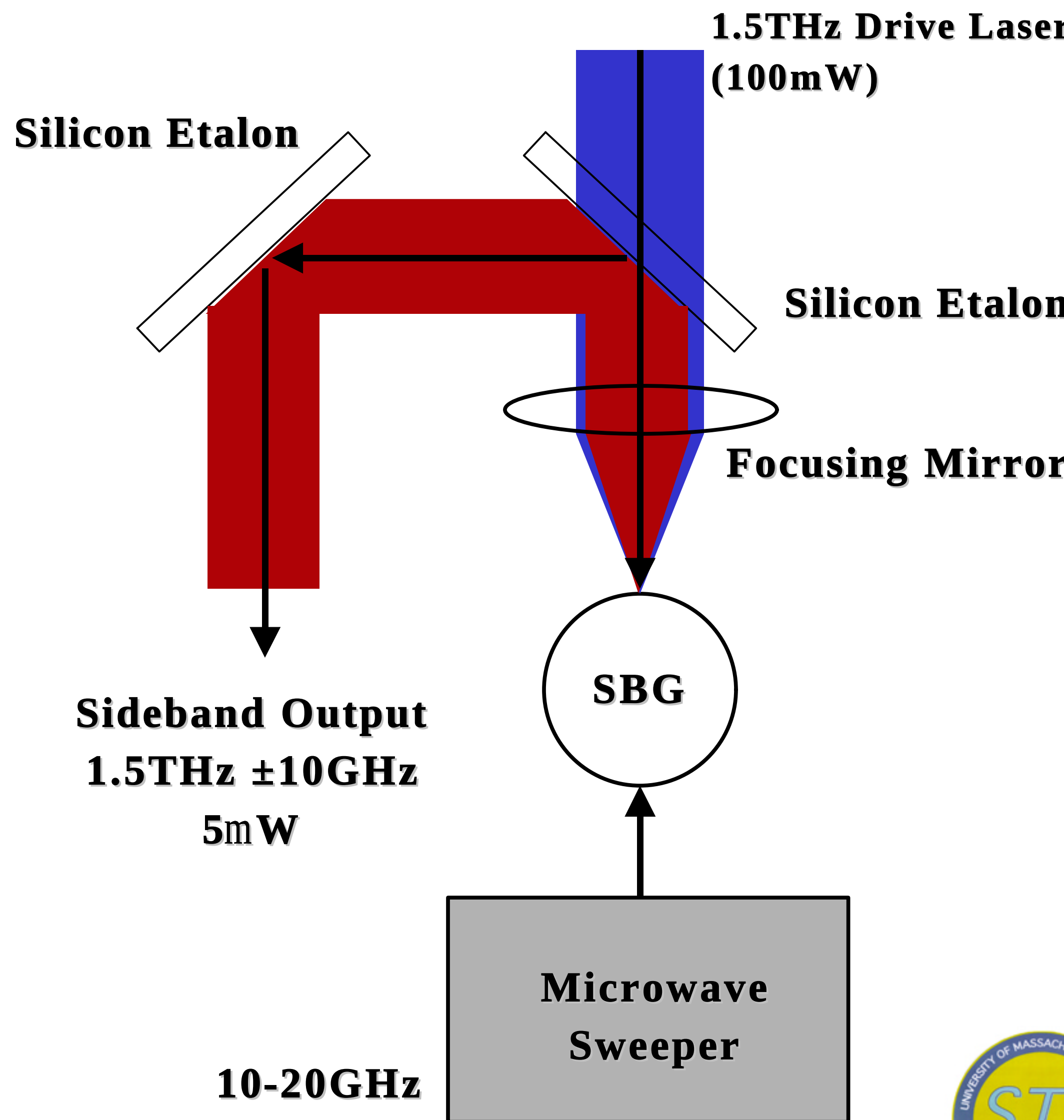


1.5THz Tunable Sideband Generation

•Etalons transmit drive laser but reflect sidebands.

•Single frequency laser is mixed with microwave sweeper to produce ±10GHz of tuning.

•Sidebands are separated by reflection from etalons.



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Terahertz Materials Research

- Provides Critical Support to NGIC's Radar Signature Acquisition Program
- 3 Primary Efforts: **Optical Design, Fabrication, & Characterization**

THz Absorbers
- Broadband anechoics
- Dällenbach narrowband absorber
- Salisbury screen absorbers
- Jaumann multilayers

THz Frequency Selective Surfaces
- Low-pass
- Bandpass filters
- Beamsplitters
- Laser optics

Scale Model Ground Terrain
- Desert sand
- Grassy soil
- Concrete
- Asphalt

Tailored Dielectric Materials
- Tires
- Windshields
- Fiberglass
- Radomes
- Trackpads

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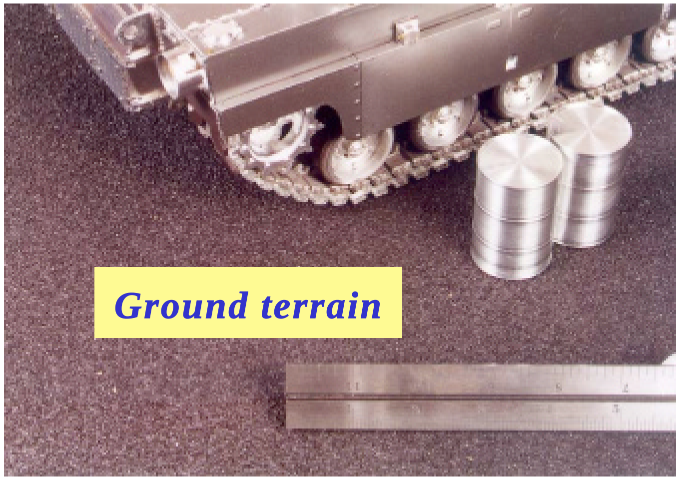
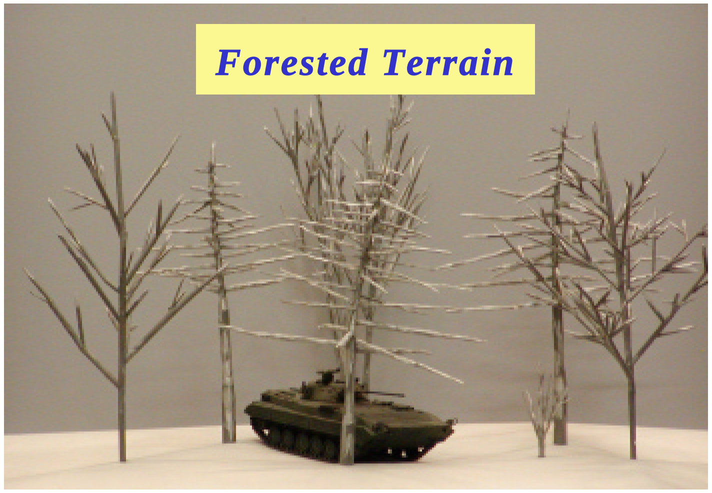
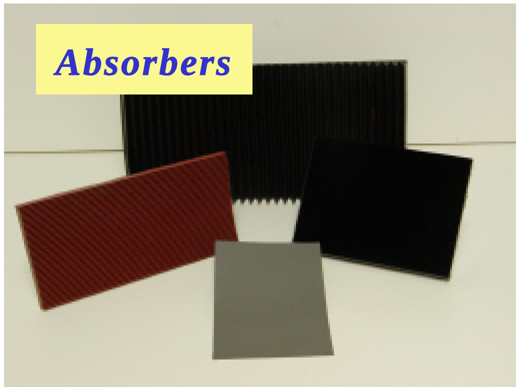
Dielectrically Scaled Targets and Scenes







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Radar Image Formation

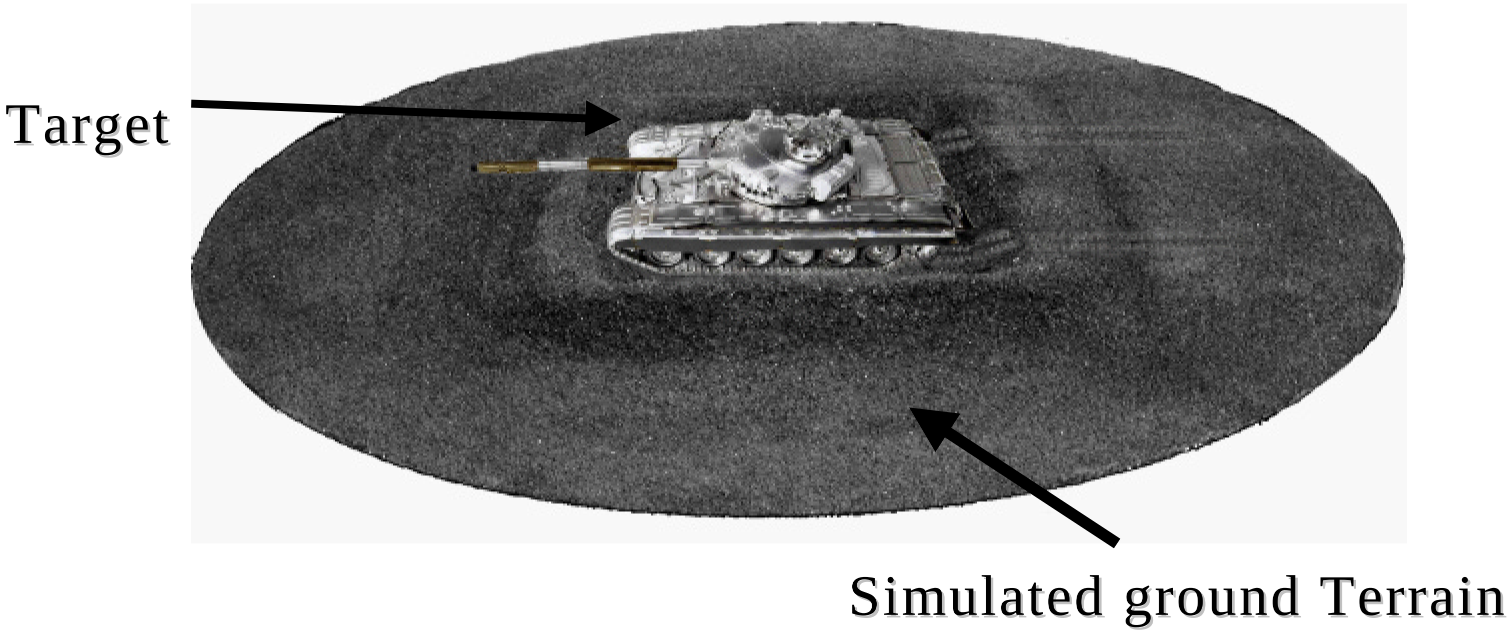
•Illuminate entire target and record backscattered amplitude and phase information (coherent RCS).

•Vary parameters in controlled fashion and use Fourier transforms to produce target images.

Typical Variables and their Fourier Transforms.

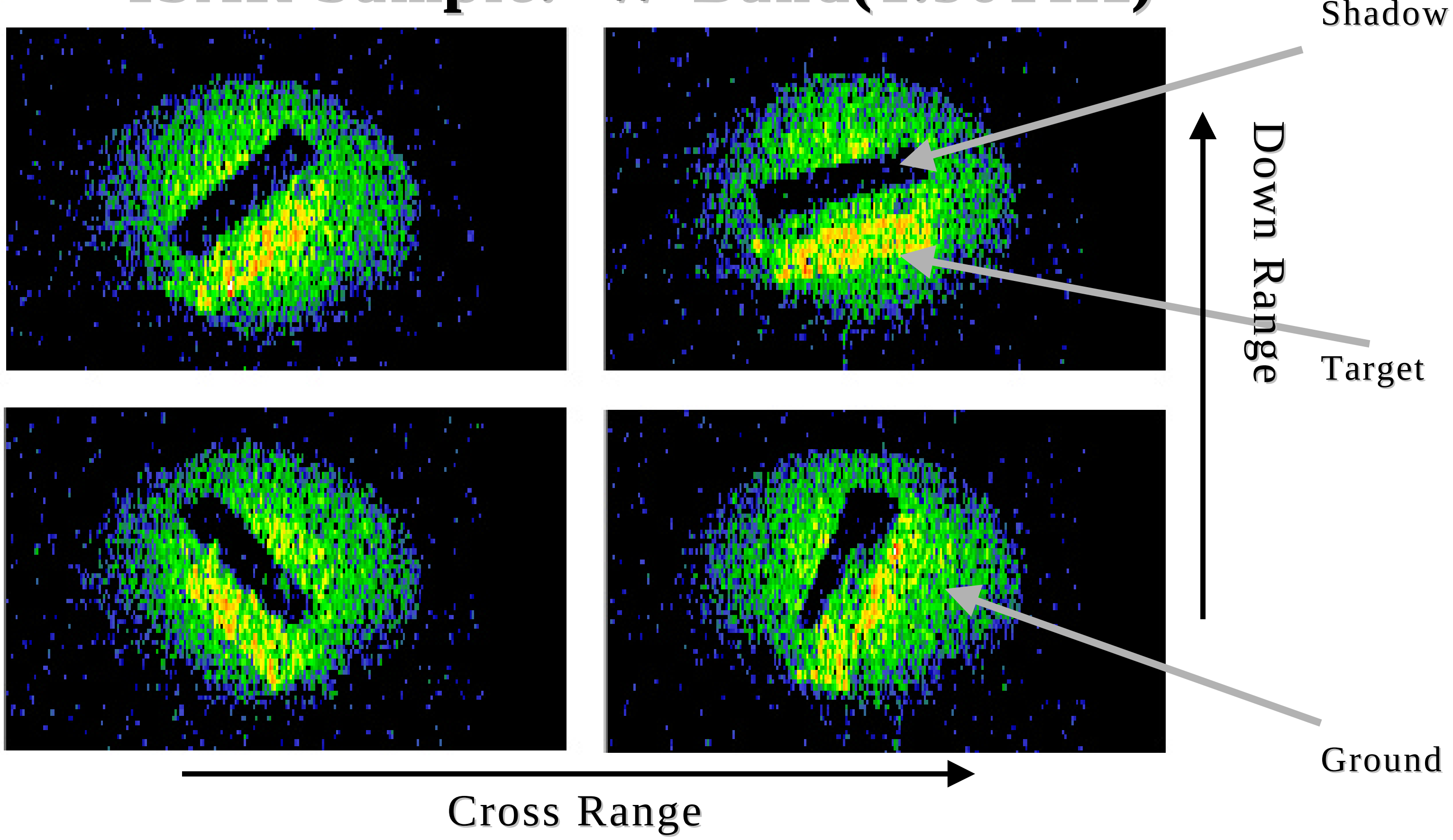
Variable		Transform
Frequency	$\xrightarrow{\text{FFT}}$	Down Range
Azimuth Angle	$\xrightarrow{\text{FFT}}$	Azimuth Cross Range
Elevation Angle	$\xrightarrow{\text{FFT}}$	Elevation Cross Range

Design of the Target's Operational Environment



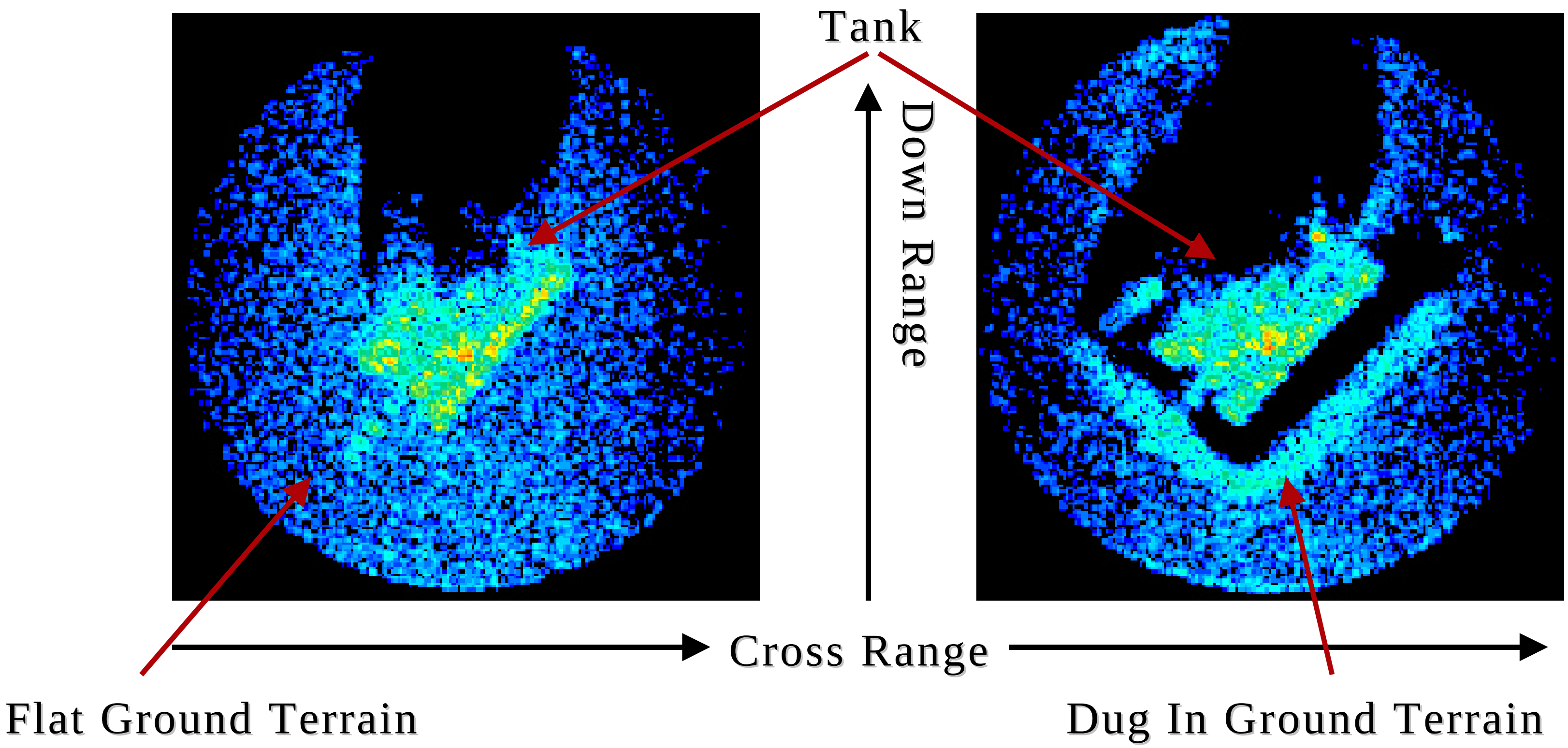
- **Modeling realistic environments requires fabricating terrain that is scaled both dielectrically and dimensionally.**
- **Target is mounted to ground terrain of interest and then measured in compact range.**

ISAR Sample: W-Band(1.56THz)



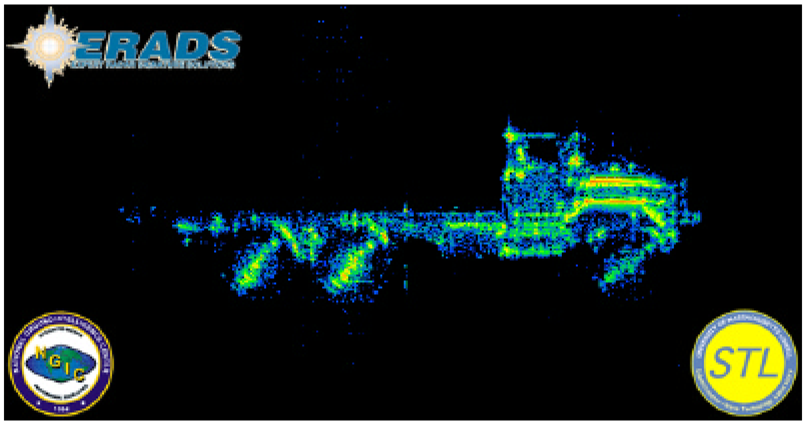
- Measure Target With Swept Frequency Radar.
- Form Image Using a Finite Azimuth Angle.
- Fourier Transform Gives 2-D Image in Range and Cross-range.

ISAR Sample: X-Band (160GHz)

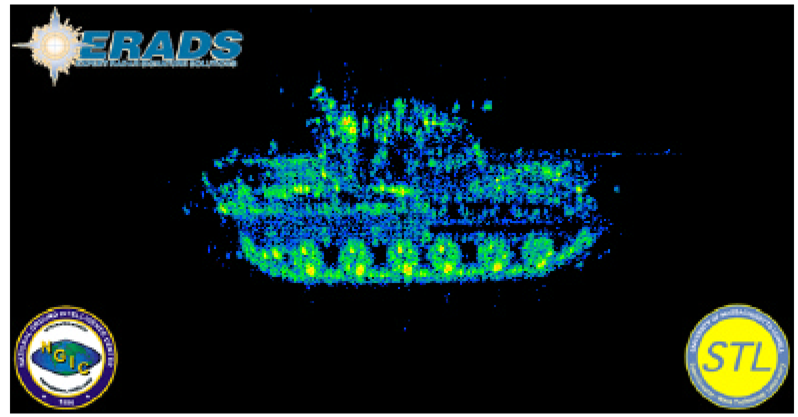


- Target imaged first on flat ground terrain then on “Dug In” ground terrain for comparison.

Azimuth/Elevation Imaging Examples: W-Band (1.56THz)



Truck



Tank

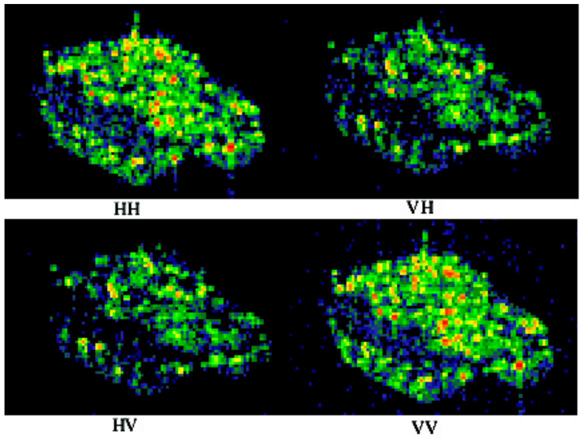
- **Measure Target With Single Frequency Radar (range is not calculated).**
- **View Target Through 5 by 5 Solid Angle.**
- **Fourier Transform Gives 2-D Image in Azimuth and Elevation Cross-range**

Identification of Scattering Centers

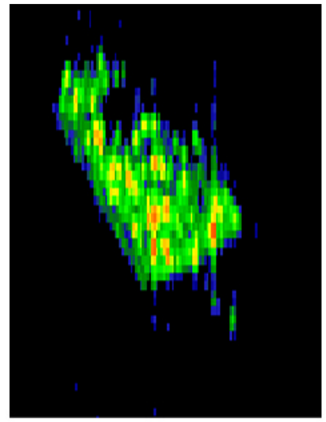
Data is overlaid with digital photograph of target.

3D ISAR: W-Band (1.56THz)

Front View



Top View



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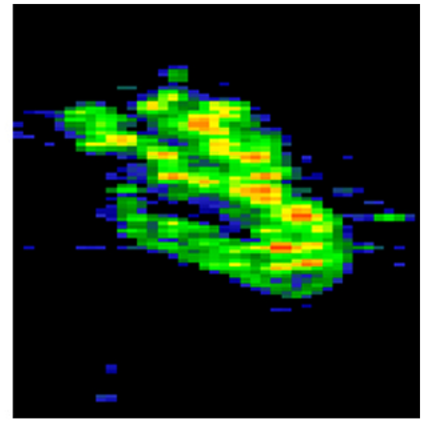
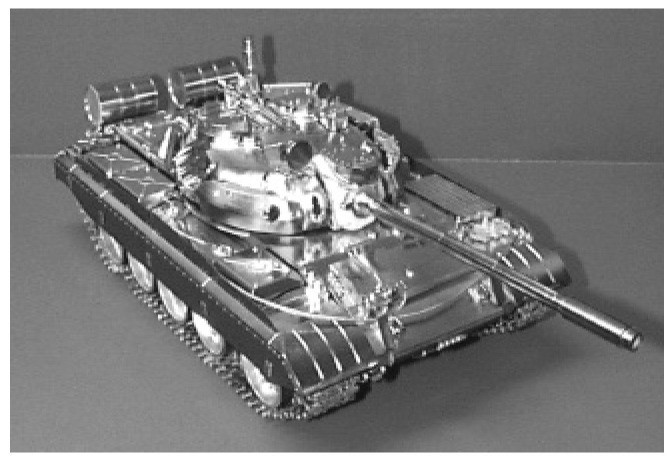
Side View



HH

- **Measure Target With Swept Frequency Radar and View Target Through 1 by 1 Solid Angle.**
- **Fourier Transform Gives 3-D Image.**



1/16th Scale Replica

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Future Directions

- **Apply Recently-Developed THz Component Technology to Existing Systems**

  Goal--1mW CW, 50 GHz Tunable Bandwidth, Anywhere Between 0.3 and 3 THz , Waveguide-Mounted Planar Diode Receivers and SBGs
- **Increase Antenna Size, Reduce Cost/Area**
- **Model Ultra-Wideband Radars**
- **Develop/Utilize New Technology, e.g., THz Quantum Cascade Lasers**