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. Cross-validation is critical.
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

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

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

then

$$\left( \sigma_{RCS}\right)_{Model} = \frac{1}{S^2} \left( \sigma_{RCS}\right)_{Full-Scale}$$

where $\sigma_{rcs} =$ the Radar cross-section of the target

For dielectrics:

$$\varepsilon_{Model} = \varepsilon_{Full-scale}$$

Where $\varepsilon =$ the dielectric constant
Reflectivity of Metals

For metals: \( \varepsilon_{\text{imaginary}} = \sigma \lambda \)

where \( \sigma = \) conductivity

then,

\[ \sigma_{\text{Model}} = S \sigma_{\text{Full-scale}} \]

<table>
<thead>
<tr>
<th>Material</th>
<th>( \sigma_{\text{DC}} ) (mho/m)</th>
<th>Reflectivity (1THz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>( 5.7 \times 10^7 )</td>
<td>0.9972</td>
</tr>
<tr>
<td>Gold</td>
<td>( 4.3 \times 10^7 )</td>
<td>0.9968</td>
</tr>
<tr>
<td>Aluminum</td>
<td>( 3.5 \times 10^7 )</td>
<td>0.9966</td>
</tr>
<tr>
<td>Brass</td>
<td>( 2.4 \times 10^7 )</td>
<td>0.9959</td>
</tr>
<tr>
<td>Iron</td>
<td>( 1.2 \times 10^7 )</td>
<td>0.9950</td>
</tr>
</tbody>
</table>

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 very similar behavior as full-scale component
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• 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 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

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Bandwidth</th>
<th>Source</th>
<th>Power</th>
<th>1/16&lt;sup&gt;th&lt;/sup&gt; Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 GHz</td>
<td>24GHz</td>
<td>Solid State</td>
<td>10.0mW</td>
<td>Models: X -Band</td>
</tr>
<tr>
<td>520 GHz</td>
<td>18GHz</td>
<td>Solid State</td>
<td>0.1mW</td>
<td>Models: Ka-Band</td>
</tr>
<tr>
<td>1560 GHz</td>
<td>8GHz</td>
<td>Laser</td>
<td>5.0µW</td>
<td>Models: W -Band</td>
</tr>
</tbody>
</table>
Submillimeter-Wave Compact Range Capabilities

Dimensionality

- Ships: 150 m
- Aircraft: 20 m
- Ground Vehicles: 6 m

Scaled Frequency

- 2 GHz
- 10 GHz
- 35 GHz
- 94 GHz

- 160 GHz Compact Range
- 520 GHz Compact Range
- 1.56 THz Compact Range
SMS160 Compact Range Layout

- 5' dia. mirror
- Target and calibration track
- Beam Dumps
- Computer
- Electronics
- Transceiver
- Work area

Dimensions:
- 50'
- 30'
- 14' 4"
Diagram of the 1.56THz Compact Range

Receive Diodes

Optically Pumped Far-Infrared Lasers
1.5626 THz and 1.5645 THz

Sideband Generators

CO₂ Pump Lasers

Target and Positioning Stage
Diamond-Turned 60” Diameter Primary Antenna
Target Pylon With Ground Plane
Submillimeter Solid-State Polarimetric Transceiver

Transmit Chain
- X4: 4f, 200 mW
- X2: 8f, 60 mW
- X2: 16f, 20 mW
- X3

Receive Chain
- X4: 480 GHz
- X2: 10.0625 GHz
- X3: 3 GHz IF

- PIN Switch
- Synthesizer
- 10 GHz
- 3 GHz IF Processor
- Coherent Detector
- Reference
- I
- Q

Power Levels:
- 4f: 200 mW
- 8f: 60 mW
- 16f: 20 mW
- 48f: 0.1 mW

Note: The diagram shows the flow of signals through the transmit and receive chains, along with the associated power levels and frequencies.
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 FrequencySelective Surfaces**
- Low-pass
- Bandpass filters
- Beamsplitters
- Laser optics

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

**Scale Model Ground Terrain**
- Desert sand
- Grassy soil
- Concrete
- Asphalt
Dielectrically Scaled Targets and Scenes

- Ground terrain
- Forested Terrain
- Absorbers
- Target dielectrics
- People
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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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Transform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Down Range</td>
</tr>
<tr>
<td>Azimuth Angle</td>
<td>Azimuth Cross Range</td>
</tr>
<tr>
<td>Elevation Angle</td>
<td>Elevation Cross Range</td>
</tr>
</tbody>
</table>
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)

- 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)

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