NOVEL ANTENNA DESIGNS FOR COMPACT GROUND PENETRATING RADAR SYSTEMS AND IN-TRAFFIC AIR-COUPLED APPLICATIONS

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Outline

• VOTERS & The Radar System Requirements
• Overview Antenna Project
• Antenna Design / Development
• Antenna Characteristics
• Testing
VOTERS attempts to shift roadway and bridge deck maintenance away from periodical localized mainly visual inspections to continuous network-wide health monitoring.

Versatile Onboard Traffic-Embedded Roaming Sensors
VOTERS Concept

Vehicles of Opportunity
- Roaming around a city
- Going about their usual business
- Mounted VOTERS System
- Autonomous of driver
- Wireless connection to Control Center

• Vehicles of Opportunity collect Sensor Data containing Surface and Subsurface Roadway and Bridge Deck Condition Information at Traffic Speed
• Accurately register all data geographically and in time
• Data are transferred to a Control and Visualization Center for further analysis, visualization, and decision making
VOTERS Concept

- In order to do this we need to design and build appropriate sensing systems that can operate under those circumstances.

- We’re focusing on GPR now.
VOTERS Radar System Requirements

• Requirements for the VOTERS System
  – air-coupled
  – road-speed GPR system
  – multiple channel array - spanning the width of the vehicle
  – FCC compliant to receive certification.
Radar System Requirements

• FCC Emissions Mask
  – Specification FCC 02-48
VOTERS Radar System Requirements

• Partnered with ESS (Earth Science Systems) to build the RADAR electronics (talk at 9:30)
  – Road way speeds
  – High density spatial sampling
  – Array Capabilities

• Northeastern University was tasked to research suitable antennas
  – Development and integration with the new system
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Antenna Project Overview

- Designed and fabricated 5 new antennas
- 4 have been completed and tested
- Our goal is to pick the best antenna for the VOTERS application
Antenna Project Overview

- Frequency range
  - 1.5-3.5GHz
- Gain
  - 3-10dB
- Size
  - Under vehicle array
- Price
  - Economical
- Beamwidth
  - 40°-100°
- Polarization
  - Linear
- Input matching
  - S11 below -10dB (90% power radiated)
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Antenna Design / Development

• Flow Chart

• Antenna
  – Form Factor
    • Frequency Domain Modeling
      – 3D FEM –HFSS Software
    • Time Domain Modeling
      – 2D MOM –Momentum Software

• Board layout
  – Electrical feeding
  – Connectors
  – Packaging
    • Circuit Simulation
      – Circuit simulator –ADS
      – S-parameter block cascading analysis

• Fabricate & Measure
  – In lab testing of antenna
Antenna Design / Development

• Down Selections
  – Equi-angular spiral, conical spiral, log periodic antenna and other self-complementary structures
    • Poor time domain responses have restricted their application
    • Insufficient bandwidth
  – Horn antennas
    • Dimensions are too large for the under-vehicle mounting or deployment in a dense array
  – Resistively Loaded
    • Reduces ringing, but also reduces gain
Antenna Design / Development

- Incorporated Designs
  - Backed cavity (bowtie)
    - Unidirectional radiation with high gain
- Microstrip feeding
  - Common PCB design
Antenna Design / Development

• Incorporated Designs
  – Vivaldi
    • High gain, unidirectional
  – Bowtie
    • Low profile
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Antenna Characteristics

• Antenna parameters are measured using a network analyzer for the S11 parameters within an anechoic chamber

• Equipment parameters are post-measurement to extract only the antenna parameters
# Antenna Characteristics

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Rounded Bowtie</strong></td>
<td><img src="image1.jpg" alt="Image" /></td>
<td><img src="graph1.png" alt="Graph1" /></td>
<td><img src="graph2.png" alt="Graph2" /></td>
</tr>
<tr>
<td>(cavity-backed, rubber absorber)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 cm x 14 cm x 3.9 cm</td>
<td></td>
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</tr>
<tr>
<td><strong>Slotted Bowtie</strong></td>
<td><img src="image2.jpg" alt="Image" /></td>
<td><img src="graph3.png" alt="Graph3" /></td>
<td><img src="graph4.png" alt="Graph4" /></td>
</tr>
<tr>
<td>(cavity-backed, foam absorber)</td>
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</tr>
<tr>
<td>10.7 cm x 7 cm x 5 cm</td>
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<tr>
<td><strong>Imego Vivaldi</strong></td>
<td><img src="image3.jpg" alt="Image" /></td>
<td><img src="graph5.png" alt="Graph5" /></td>
<td><img src="graph6.png" alt="Graph6" /></td>
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<td><strong>Vivaldi-1</strong></td>
<td><img src="vivaldi-1.jpg" alt="Image" /></td>
<td><img src="vivaldi-1_s11.png" alt="Graph" /></td>
<td><img src="vivaldi-1_gain.png" alt="Graph" /></td>
</tr>
<tr>
<td>15 cm x 14 cm (length)</td>
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<tr>
<td><strong>Vivaldi-2</strong></td>
<td><img src="vivaldi-2.jpg" alt="Image" /></td>
<td><img src="vivaldi-2_s11.png" alt="Graph" /></td>
<td><img src="vivaldi-2_gain.png" alt="Graph" /></td>
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<td>10 cm x 18 cm (length)</td>
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<td><strong>Imego Vivaldi</strong></td>
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Antenna Testing

- Pulse center frequency
  - 2.5 GHz

- Bandwidth
  - 3 GHz

- The test bed dimensions
  - 4 x 2 x 0.6 ft.

- Antenna height above test bed
  - 12 in

- Data collection rate
  - 1 scan/in
Antenna Testing

Rounded Bowtie  Slotted Bowtie  Vivaldi - 1  Vivaldi - 2  Commercial Vivaldi

Time Domain Response

Antenna  Sand Surface  Rebar  Sand Floor/Metal Plate

12"  2"  6"
Antenna Testing

- Metal Bar
- Metal Sheet
- Air above sand
- Sand Box
## Antenna Testing

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<tr>
<td>Commercial Vivaldi</td>
<td><img src="image5.png" alt="Image" /></td>
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### Time Domain Response

- **Antenna**: 12"
- **Sand Surface**: 6"
- **Rebar**: 2"
- **Sand Floor/Metal Plate**: 6"

![Graph](image6.png)
Conclusion

• 2 Bowties and 2 Vivaldis were characterized
• Qualitatively tested over a sandbox
• The measured performance of the antennas along with the prototype GPR system illustrate the feasibility of using them for air-coupled, vehicle-based GPR applications.
• All of these antennas seem suited for the VOTERS application
Outlook

• Future work
  – Use latest version ESS with distance trigger capability
  – Testing over bridge decks
  – Select best antenna for Integration with other VOTERS systems on the VOTERS van
  – Implementation as an array which spans the entire width of the vehicle
Thank You

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