Scaled Model Measurements of HF Antenna for Vehicular Platforms

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Outline

- Introduction
- Vertical Half-Loop Antenna
- Inverted-L Antenna
- Scaled Model Design
- Measurements
- Summary
HF frequencies: point to point communication from 0 to 1000s of km

Three modes of communication:
1. Ground wave
2. Sky wave (long range propagation)
3. Near Vertical Incidence Skywave (NVIS)

Near Vertical Incidence Skywave (NVIS) communication:
• 2-10 MHz
• High incidence angles
• Any polarization
• Beyond line-of-sight
Goal is to design On The Move vehicular NVIS antenna

Requirements:
- 400 Watts Power Handling
- 24 kHz bandwidth
- Low profile

Challenges:
- HF antennas have large physical size
- Narrow bandwidth
- Different grounds cause detuning
- Radiation pattern limits use of all the HF propagation modes
Q: What is the minimum size of a lossless antenna that may achieve 24 kHz BW at 2 MHz?

Analytical Results:

Antennas are much larger than AAV!

Numerical Validation:

Estimation:

\[ ka = \left( \frac{1.5}{Q_{\text{max}} \gamma_1^{\text{norm}}} \right)^{1/3} \]

where

\[ Q_{\text{max}} \approx 0.71 \frac{f_0}{\text{BW}_{10dB}} \approx 60 \]

References:


Obtaining 24 kHz bandwidth at 2 MHz within a vehicle platform is very challenging!
State of The Art Vehicular HF Antennas

**Shakespeare 120-99**
- 1.6-30 MHz
- 160 Watts
- VSWR: < 3.5:1

**Cobham 3160-99**
- 2-30 MHz
- 150 Watts
- VSWR: < 2.5:1

**Stealth 9400c**
- 4.5-22 MHz
- 150 Watts
- VSWR: < 1.2:1

**Harris OTM Loop**
- 2-30 MHz
- 150 Watts
- VSWR: < 2:1

**Codan 9350**
- 2-30 MHz
- 125 Watts
- VSWR: < 1.5:1

**Stealth 9420**
- 3-16 MHz
- 200 Watts
- VSWR: < 1.3:1

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Since antennas are electrically small, they have very low gain at 2 MHz (~ -25 dBi). These performances are reference point for our research.

1. 2-30 MHz
2. Power 150W
3. **Gain > -24 dBi @ 2 MHz**
4. VSWR < 2.0:1
5. Bandwidth N/A

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## Electrical Performance

<table>
<thead>
<tr>
<th>Propagation Mode</th>
<th>NVIS</th>
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<tbody>
<tr>
<td>Frequency Range</td>
<td>2 – 10 MHz</td>
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<tr>
<td>Polarization</td>
<td>Linear in zenith direction</td>
</tr>
<tr>
<td>IEEE gain at zenith</td>
<td>2MHz 4.7 dBi</td>
</tr>
<tr>
<td>(25cm profile, 5MHz</td>
<td>3.9 dBi</td>
</tr>
<tr>
<td>PEC ground)</td>
<td>10MHz -2.8 dBi</td>
</tr>
</tbody>
</table>

### Features:
- Linear Polarization
- Detuning of the two separate antennas potentially increases bandwidth
- Easy to tune each antenna

### Challenge:
- Very small input resistance
Vertical Half-loop: Design Evolution

Opening width **29.49m**
(\(\lambda/2 \ @ 5 \text{ MHz}\))

38.4m
\(\lambda/2 \ @ 3.9 \text{ MHz}\)

0.5m

15m

7.7m

1.5m

Run parametric studies

Start from a large wideband TEM horn

Rescale to fit a vehicle and load by a loop

Run parametric studies

Make two HMD

Make antenna less visible and mount on more detailed AAV

Mount on a rough AAV and do parametric studies
Vertical Half-loop: Performance

Geometry:
(profile 25cm)

Antenna is a strip (width 0.08m)
Backward extension is 0.25m
AAV is steel
Antennas are Cu

Effect of tracks on performance is minor
Introduction

Vertical Half-Loop Antenna

Inverted-L Antenna

Scaled Model Design

Measurements

Summary
**Inverted L: Introduction**

**Electrical Performance**

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<tr>
<td>IEEE gain at zenith (80cm profile)</td>
<td>2MHz -4.6 dBi</td>
</tr>
<tr>
<td></td>
<td>5MHz 1 dBi</td>
</tr>
<tr>
<td></td>
<td>10MHz -1 dBi</td>
</tr>
</tbody>
</table>

**Features:**
- Linear Polarization
- Offset Feeding improves match and gain
- Easy to tune, simple design

**Challenge:**
- Achieve Better Bandwidth
Inverted L: Design Evolution

1. Vary Height and Length
   - H
   - L

2. Vary Antenna Bend Radius
   - R

3. Introduce Loop / Coils

Introduce Rear Mount Configuration with lower profile

Mount on detailed AAV in Rhino Configuration and Introduce offset feeding

Mount on rough AAV with Rhino Configuration

Start from traditional vertical whip antenna

Tilt for lower profile and Conform with vehicle Geometry

Run parametric studies

16 m

H = 1.3 m

L = 8 m

Feed

1.3 m

6 m

8 m
Inverted L: Performance

Geometry:
(profile 50cm)

Antenna is a wire (radius 8 mm)
Offset Feed at 6m
AAV is steel
Antennas are Cu

Still need some extra loss to get 3 kHz bandwidth at 2 MHz
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Non-Critical features are eliminated
Complex features are simplified
Model is segmented
Individual model parts are printed
3D Printer:

<table>
<thead>
<tr>
<th>MODEL</th>
<th>MakerBot Replicator</th>
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<tbody>
<tr>
<td>Material Used</td>
<td>PLA</td>
</tr>
<tr>
<td>Layer resolution</td>
<td>100 microns</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>Max model size</td>
<td>25x20x15 cm</td>
</tr>
</tbody>
</table>

Model Specifications:

- Rafts: ON
- Infill: 15%
- Number of Shells: 2
- Print Resolution: High
- Layer Resolution: 100 microns
- Total Model Cost: $10
Copper Plating:

- Model is polished before plating
- Surface is sealed to get a non-porous base
- Conducting adhesive is sprayed on the model
- Model is electroplated with 1 Oz. Copper

Antenna Deployment:

- Scaled model antennas are fabricated with 0.081” cable
- Antenna mounted onto AAV with copper supports
- Copper support harnessed onto vehicle with copper tape for easy replacement and model reuse
- Ferrite choke is used to suppress the return currents
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Measurement scaling factor is 50x

- Frequency range of interest: 100 – 600 MHz

- Model Relevance: 2 – 10 MHz (in full scale)

- Measurements Setup:
  - With ferrite beads
  - Without ferrite beads

- Ground plane:
  - 1.2m x 1.2m (0.4 λ x 0.4 λ)
  - Made from aluminum foil coated insulation foam
Measurement Goals

- To validate simulation results
- To establish confidence in the scaled modelling process

**Inverted-L**

Goal: to see the resonance and compare measurements with modeling.

**Half-loop**

Goal: test the capabilities to measure impedance of small antennas.
Model Parameters:

- AAV and antenna are made of Cu
- PEC infinite ground plane

TEM port is at reference plane position
- Simulation results can be directly compared to measurements!

Results for infinite ground plane and 1.2 x 1.2 m² ground are very similar. No results for finite ground are shown.

Cable model:

Total length of shield is 13.4cm for half-loop and 17.5cm for inverted-L.
Very good agreement between measurements and modeling!
Reflection Coefficient

Averaging feature turned on to filter out noise

Very good agreement between measurements and modeling!
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- Summary
• Design and modelling of low profile, low cost vehicular NVIS antennas for 24 kHz bandwidth is described

• Evolution of the half-loop antenna and the inverted-L antenna to adapt to the vehicular platform of interest is shown

• Antenna performance for the two configurations of half-loop and the inverted-L is simulated

• Scaled model design and fabrication process is described in detail

• 3D printing and electroplating is used to realize the scaled model with advantages of lower cost (5x cheaper), lighter weight and faster turn in time as compared to traditional CNC machining options

• Scaled model measurements are performed to validate simulation results

• Good agreement between the measurement and simulations establishes confidence in the computational as well as scaled modelling technique
Questions

be Adventurous
be Resourceful
be Genuine
be Boulder