A Wideband Dipole Array for Directed Energy Applications and Digital TV Reception

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A Wideband Dipole Array for Directed Energy Applications and Digital TV Reception
Outline

- Problem and motivation
- The “ribcage” dipole antenna
- Comparisons with classic configurations
- Ribcage dipole antenna for communications
  - Optimized ribcage dipole with balun
  - Simulations and laboratory measurements
- Antenna array for Directed Energy applications
  - Optimized unit cell with balun
  - Customized power dividers
  - 8x8 array of ribcages: simulations and preliminary laboratory tests
  - Composite array model for antenna array pattern modeling
- Conclusions and future work
Compact High Performance RF Communications

Motivation #1

Whip antennas for HF communications

- Simple classic design
- Narrow bandwidth
- High visibility
- Needs assembly for portability

Ribcage dipole antenna

- Low profile
- Excellent performance over a ground plane
- Wide impedance bandwidth
- Uniform antenna pattern over the bandwidth
- Needs further development and funds

Phase II Army SBIR Contract #: W15QKN-08-C-0493, TPOC; Keith Braun, ARMY – AMSML - PICATINNY
Compact Portable Focused Beam Antenna

Motivation #2

Parabolic dish antennas

- Wide band
- High gain
- Focused beam
- Simple feeding
- Complex position control
- Large volume
- Not easily portable
- Highly visible

Antenna array of ribcage elements

- Wide-band, high gain, narrow beam
- Possibility of electronic scanning
- Compact, low-profile, easily portable
- Can be stowed in sub-array modules
- More complex feeding network

Phase II Army SBIR Contract #: W15QKN-08-C-0493, TPOC: Keith Braun, ARMY – AMSML - PICATINNY
The Origins of the “Ribcage” Dipole

- Volumetric dipole antenna with ribs, wings, or sleeves
- Closed ring or open sleeve
- Intrinsic additional magnetic field
Wideband Volumetric Antenna: Dipole With Sleeves

Blade Dipole

Ribcage Dipole

The ribcage dipole has wider bandwidth than blade dipole of same width and length.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Height above Ground Plane</th>
<th>Width</th>
<th>Total Length</th>
<th>(Sleeve) Depth</th>
<th>Ground Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade dipole</td>
<td>h=105 mm</td>
<td>w=30 mm</td>
<td>l=220 mm</td>
<td>NA</td>
<td>300×300 mm</td>
</tr>
<tr>
<td>Ribcage dipole</td>
<td>h=160 mm</td>
<td>w=30 mm</td>
<td>l=220 mm</td>
<td>r = 70 mm</td>
<td>300×300 mm</td>
</tr>
</tbody>
</table>
Comparison of Dipoles Over Ground Plane

Ribcage Dipole

Blade Dipole

Droopy Dipole
Optimized **Droopy Dipole** and **Blade Dipole**

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Height over Ground Plane</th>
<th>Width</th>
<th>Total Length</th>
<th>Sleeve Depth</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade dipole</td>
<td>h=150 mm</td>
<td>w=120 mm</td>
<td>l=220 mm</td>
<td>NA</td>
<td>300×300 mm</td>
</tr>
<tr>
<td>Droopy dipole</td>
<td>h=150 mm</td>
<td>w=140 mm</td>
<td>l=220 mm</td>
<td>NA</td>
<td>300×300 mm</td>
</tr>
</tbody>
</table>

- The **blade dipole** has a wider impedance bandwidth
- The **droopy dipole** has a more uniform gain over the bandwidth
Ribcage Dipole and Droopy Dipole

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Height from Ground Plane</th>
<th>Width</th>
<th>Length</th>
<th>Sleeve Depth</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribcage dipole</td>
<td>h=150 mm</td>
<td>w=25 mm</td>
<td>l=220 mm</td>
<td>60mm</td>
<td>300×300 mm</td>
</tr>
<tr>
<td>Droopy dipole</td>
<td>h=150 mm</td>
<td>w=140 mm</td>
<td>l=220 mm</td>
<td>NA</td>
<td>300×300 mm</td>
</tr>
</tbody>
</table>

- The ribcage dipole can be designed to have similar performance than the droopy dipole
The ribcage dipole can be designed to combine advantages of both droopy dipole and blade dipole (its extreme cases).

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Height From Ground Plane</th>
<th>Width</th>
<th>Length</th>
<th>Sleeve Depth</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribcage dipole</td>
<td>h=150 mm</td>
<td>w=55 mm</td>
<td>l=220 mm</td>
<td>40 mm</td>
<td>300x300 mm</td>
</tr>
<tr>
<td>Droopy dipole</td>
<td>h=150 mm</td>
<td>w=140 mm</td>
<td>l=220 mm</td>
<td>NA</td>
<td>300x300 mm</td>
</tr>
<tr>
<td>Blade dipole</td>
<td>h=150 mm</td>
<td>w=120 mm</td>
<td>l=220 mm</td>
<td>NA</td>
<td>300x300 mm</td>
</tr>
</tbody>
</table>
Optimized Ribcage Dipole

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Height from Ground Plane</th>
<th>Width</th>
<th>Length</th>
<th>Sleeve Depth</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ribcage dipole</td>
<td>h=160mm</td>
<td>w=50mm</td>
<td>l=220mm</td>
<td>40mm</td>
<td>300×300mm</td>
</tr>
<tr>
<td>Droopy-blade dipole</td>
<td>h=160mm</td>
<td>w=140mm</td>
<td>l=220mm</td>
<td>NA</td>
<td>300×300mm</td>
</tr>
<tr>
<td>Wide-Blade dipole</td>
<td>h=160mm</td>
<td>w=120mm</td>
<td>l=220mm</td>
<td>NA</td>
<td>300×300mm</td>
</tr>
</tbody>
</table>

- A ribcage dipole can be optimized to have wider impedance bandwidth than a droopy dipole and better gain bandwidth than a blade dipole
Advantages of Ribcage Dipoles

- Space optimization
- Design flexibility (more parameters)
- Wide impedance bandwidth
- Wide gain bandwidth
Ribcage Antenna With Tapered Balun

![Diagram of ribcage antenna with tapered balun](image)
Ribcage Antenna With Balun and Teflon Support

<table>
<thead>
<tr>
<th>Height from Ground Plane</th>
<th>Width</th>
<th>Total Length</th>
<th>Sleeve Depth</th>
<th>GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>h=175 mm</td>
<td>w=35 mm</td>
<td>L=210 mm</td>
<td>r=70 mm</td>
<td>300×300 mm</td>
</tr>
</tbody>
</table>
Optimized Unit Cell With Balun

- Optimized single radiating element for the array
- Optimized tapered balun for the array configuration
Simulated Antenna Array Return Loss

- Return Loss for an infinite antenna array of ribcages with tapered balun

- 1.92 x 1.92 m (8x8) array
- Equivalent to a 3 m parabolic reflector antenna

Graph showing frequency, MHz on the x-axis and |S11|, dB on the y-axis. The graph peaks at 482-1024 MHz, indicating a bandwidth of 2:1.
Optimized Power Dividers
Feeding Network for 8x8 Array of Ribcages

Master 4:1 Power Divider

8:1 Power Divider  8:1 Power Divider

2:1 Power Divider

8:1 Power Divider  8:1 Power Divider

2:1 Power Divider

8:1 Power Divider  8:1 Power Divider

2:1 Power Divider
Measured Return Loss for the 4x4 Sub-Array Module

- Replacement for conventional Digital TV antennas

- $S_{11}$ for a 4x4 array of ribcage dipoles
- It can be used for Digital TV reception in the UHF band: 400-900 MHz
Simplified 8x8 Antenna Array Pattern Modeling

- **Modeling a finite 8x8 antenna array** of ribcage dipoles with balun in Ansoft HFSS requires
  - ~ 21 hours
  - 70 GB of memory on a 64-bit Windows machine

- We have developed a simplified methodology that exploits the symmetry of the array and array excitations

- We have implemented an algorithm that allows to compute the total field pattern for the 8x8 antenna array from the analysis of one 6x6 sub-array

- **Modeling a finite 6x6 sub-array** of ribcage dipoles with balun in Ansoft HFSS requires
  - ~ 6 hours
  - 20 GB of memory on a 64-bit Windows machine
Simplified Composite Array Model

- The total array field pattern can be expressed as superposition of four array field patterns, when the quadrants Q1, Q2, Q3, and Q4 are excited.
- Only 16 elements are excited at any one time, while the remaining elements are passive and match-terminated (50 Ω).

Approximation: truncate the passive arrays by removing the two outermost rows and columns.
- Now there are four 6x6 arrays, which can be analyzed/simulated separately.
Further Simplification of the Composite Array Model

- When the array excitation is symmetric with respect to the x- and y-axes:
  \[ \bar{E}_{Q3}(\theta, \varphi) = -\bar{E}_{Q1}(\theta, \varphi) \]

- Q2 and Q4 are mirror images of Q1 and Q2:
  \[
  \begin{align*}
  \bar{E}_{Q2,\theta}(\theta, \varphi) &= -\bar{E}_{Q1,\theta}(\theta, \pi - \varphi) \\
  \bar{E}_{Q2,\varphi}(\theta, \varphi) &= \bar{E}_{Q1,\varphi}(\theta, \pi - \varphi) \\
  \bar{E}_{Q4,\theta}(\theta, \varphi) &= \bar{E}_{Q1,\theta}(\theta, -\varphi) \\
  \bar{E}_{Q4,\varphi}(\theta, \varphi) &= -\bar{E}_{Q1,\varphi}(\theta, -\varphi)
  \end{align*}
  \]

- A highly accurate representation for the far field of the 8x8 array can be obtained from the computation of a single 6x6 array (Q1)
Q1 Sub-Array Pattern

Q1 sub-array pattern at 750 MHz: E-plane and H-plane
8x8 array Gain From Simplified Composite Array Model

The array directivity $D$ is obtained by simple integration:

$$D = \frac{\left| E_{\text{max}} \right|^2}{\int \int \left| E_{\text{max}} \right|^2 \sin \theta \, d\theta \, d\varphi}$$

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Aperture Gain</th>
<th>Gain Computed from Composite Array Model</th>
<th>Total Gain (array gain - net loss in feeding network)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 MHz</td>
<td>21.1 dB</td>
<td>21.5 dB</td>
<td>19.0 dB</td>
</tr>
<tr>
<td>750 MHz</td>
<td>24.6 dB</td>
<td>24.7 dB</td>
<td>22.2 dB</td>
</tr>
<tr>
<td>1000 MHz</td>
<td>27.1 dB</td>
<td>26.4 dB</td>
<td>23.9 dB</td>
</tr>
</tbody>
</table>
Conclusions

- **Wideband ribcage dipole as a single radiator:**
  - Combines advantages of blade dipole and droopy dipole
  - Achieves wide impedance bandwidth up to 3.2:1 while maintaining good pattern stability
  - Has low profile when mounted parallel to a ground or air vehicle

- **Array of ribcage elements:**
  - Has performance similar to a parabolic antenna while occupying less volume (e.g. 3 m diameter vs 1.92x1.92 m)
  - Can be stowed and transported in smaller sub-array modules (e.g. four 4x4 sub-arrays for an 8x8 array)
  - Its gain pattern was computed using a Simplified Composite Array Model
Acknowledgement

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