Practical Application of Antenna Loading Techniques

Designing and building shortened antennas for home and field

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Presentation Conventions

- Antenna Drawings
  - Element in **Red**
  - Feedpoint in **Red**
  - Standing Waves and in **Black**
Standing Waves on a resonant wire

- Current ‘node’ (minimum) and a Voltage ‘loop’ (maximum) occur at the element ends
Standing Wave Relationship defines feed point impedance

- $R = \frac{E}{I}$ where $R =$ Feed Impedance
  - ‘Current Fed’ (I max) $\frac{E_{\text{min}}}{I_{\text{max}}}$
  - ‘Voltage Fed’ (E max) $\frac{E_{\text{max}}}{I_{\text{min}}}$
General Loading Principles

• Why use loading?
  – Make antennas smaller
  – Enable matching to the feedline
  – Make antennas larger to obtain higher performance
Relative ½ λ antenna size

- 10 meters  =  17.5 feet
- 20 meters  =  35  feet
- 30 meters  =  50  feet
- 40 meters  =  65  feet
- 80 meters  = 135  feet
- 160 meters = 270  feet
Loading Defined

• Reduction of an antenna’s physical ‘linear’ length by substituting ‘lump’ components and therefore….
  “maintaining resonance”

• Loading changes the current profile and therefore the characteristics of
  – Radiation Pattern
    • Gain
    • Angle of Radiation
  – Feed Impedance
  – Operational Bandwidth

• Can be made to be fairly efficient

• No reduction in the requirement for height above earth or ground/radial systems
Various methods of loading

- Coils
- Linear
- Stub
- Top / End
- Helical
Orientations

- Horizontal – center, mid point, end
- Vertical – base, center, top
Maintaining resonance

- As an antenna is shortened from resonance, capacitive reactance develops across the feed point.

- Antenna Radiation Resistance /Feed Z:
  - \( R \pm jX \)
  - For example: 56 – j324

- The –j324 capacitive reactance may be cancelled by utilizing a reactance of the opposite sign +324 (inductive reactance).

- Inductive reactance is, typically, generated by inductors/coils.
### Feed Impedance Versus Length of the Antenna

Center fed wire 35 feet above ground – 14 MHz

<table>
<thead>
<tr>
<th>Length (wl)</th>
<th>Angle</th>
<th>Impedance</th>
<th>Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2wl</td>
<td>180 degrees</td>
<td>68 ohms</td>
<td>35 – j332</td>
</tr>
<tr>
<td>3/8 wl</td>
<td>135 degrees</td>
<td>25.6 ohms</td>
<td>35 – j332</td>
</tr>
<tr>
<td>1/4 wl</td>
<td>90 degrees</td>
<td>17.5 ohms</td>
<td>13 – j875</td>
</tr>
<tr>
<td>1/8 wl</td>
<td>45 degrees</td>
<td>8.7 ohms</td>
<td>3 – j1911</td>
</tr>
</tbody>
</table>
Feed Impedance Versus Length of the Antenna

Shortening Monopole fed against ground (assumes lossless ground) 14 MHz

- $1/4\lambda_l$ 90 degrees 17’ 36 ohms (resonant)
- $3/16\lambda_l$ 67.5 degrees 12.8’ 17.2 – j173
- $1/8\lambda_l$ 45 degrees 8.5’ 6.6 - j442
- $1/16\lambda_l$ 22.5 degrees 4.2’ 1.6 – j968
Maximizing the Current Profile

All systems are resonant
83 / 63 Rule

- 83% of the radiating current is distributed over only 63% (2/3’s) of the antenna length

Loading Efficiency

83% Current

8.5% 63% 8.5% Length
Chart of the changing R Rad / feed Z of a monopole

Courtesy: Low Band DX’ing
Lumped Inductance Loading

• Applied at the higher current portions of the antenna element

• Mechanically easier implemented than end loading

• Antenna Radiation Resistance diminishes quite rapidly with the addition of $X_l$
Inductive loading

Off-Center-Loaded Dipole Antennas – Hall, K1LPL, QST Sept 1974
Sample of inductive loading

50% dipole

- $A = \%$ of Full Size Dipole
- $B = \%$ of $A$
Inductive loading

$X_l = 950$
Sample of inductive loading

50% dipole

- A = % of Full Size Dipole
- B = % of A/2
- 50% Dipole 50% position
- Xl = 950 ohms
- 2II FL = Xl = 21.16uH Coil
Inductive Reactance Generation

• Use coils / torroids
  - $X_l = 2\pi f L$  
    Formula for wire L

• Use shorted open wire stubs
  Use shorted coaxial stubs < 90 degrees long
  - $X_l = Z_0 \times \tan \text{ length (in degrees)}$
Inductive Loading Bibliography

• Off-Center-Loaded Dipole Antennas –
  – Hall, K1LPL, QST September 1974

• Designing A Shortened Antenna –
  – Lopes, CT1EOJ QST October 2003

• Homebrew Your Own Inductors –
  – Johns, W3JIP – QST August 1997

• Optimum Design of Short Coil-Loaded High Frequency Mobile Antennas –
  – Brown, W6TWW Compendium Vol. 2
Be Careful....
It’s loaded!
End Loading

- Providing structure at the element end to maintain resonance.
- Symmetrical structure eliminates radiation.
- Keeps the radiation resistance close to that of a full size antenna.
- Maintains a high current profile.
- Note: end loading takes the antenna into the 3rd dimension….not a straight line anymore.
Structure Types

“Umbrella”

“Top Hat”
End loading the F³

( forty four footer at forty five feet)

40 meter  6.25 dBi  47 degrees  34 – j429

30 meter  7.53 dBi  31 degrees  63 – j74

20 meter  8.67 dBi  22 degrees  155 + j354

12 meter  10.75 dBi  12 degrees  704 – j1167
End loading the F$^3$

<table>
<thead>
<tr>
<th>Length</th>
<th>Gain</th>
<th>Angle</th>
<th>Vs</th>
<th>Value</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 meter</td>
<td>6.25 dBi</td>
<td>34 –j429</td>
<td>6.23</td>
<td>28 – j421</td>
<td></td>
</tr>
<tr>
<td>30 meter</td>
<td>7.53 dBi</td>
<td>63 –j74</td>
<td>7.42</td>
<td>51 – j86</td>
<td></td>
</tr>
<tr>
<td>20 meter</td>
<td>8.67 dBi</td>
<td>155 +j354</td>
<td>8.48</td>
<td>118 + j316</td>
<td></td>
</tr>
<tr>
<td>12 meter</td>
<td>10.75 dBi</td>
<td>704 –j1167</td>
<td>10.02</td>
<td>2268 – j1565</td>
<td></td>
</tr>
</tbody>
</table>

Angle of radiation remained identical.

6 feet ends
End Loading Bibliography

• www.cebik.com
  – Modeling and Understanding Small Beams Pt.8
  – Where Do I Hang My Hat
  – Coils, Linear Loads, and Capacity Hats: An Overview of Small Loaded Beams

• Low Band DX-ing – ON4UN
Combining loading types

• Utilized when one type of loading gets too large or inconvenient to do the job
  – The Ground-Mounted Short Vertical
    • Sevick -- QST March 1973

• Used where loading is also used as part of the feed matching
  – Yagi with hairpin matching
Helical Loading

Constructing Efficient Helical Antennas
W2EEY – John Schultz
CQ May 1968

Helical 3 Software – Reg Edwards G4FGQ
Helical Loading

- Efficient to about 50% reduction in size
- Operational bandwidth remains good to about 50% reduction
- Wire use can be more than a linear element due to the loading effect of the helical design – DeMaw

References
- Low Band DX’ing handbook
- Constructing Efficient Helical Antennas=
  - Schultz, W2EEY  CQ 1968 -- PDF available
Helically Loaded Antennas

- Reduced size to Full Size Ratio $R/F = 0.5$
- Diameter of winding $D = 2''$
- Length of winding $L = 192''$
- Wire Diameter $d = 0.1$ #4 wire
- $d/D$ ratio $0.2$ typical
- Pitch -- turns per unit $P = 0.6$

- Total Wire length $= R/P \sqrt{P^2 + (\pi D)^2}$

- Helical3.exe -- Edwards G4FGQ
Helical Article Chart

Length Reductions As Part Of Full Size

\[ \frac{d}{D} = 1 \text{ (Nominal)} \]

\[ \frac{d}{D} = 0.1 \text{ (Nominal)} \]
Summary

• Loading changes antenna characteristics
  – Feed Impedance, Gain and Angle of Radiation

• No reduction in the requirements for
  – height above earth
  – ground-radial systems

• With expedient application of the loading the efficiency of the system can be kept high
  – Apply ‘end’ loading first
  – Apply inductive loading in the order of
    • accommodating performance (location of coil)
    • mechanical requirement (ease of construction)
Practical Application of Antenna Loading Techniques

The End

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