Electrically Small Folded Ellipsoidal Helix Antenna for Medical Implant Applications

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Outline

• Choices of antenna for medical implant applications
• Modeling of folded ellipsoidal helix antenna
• Simulations of folded spherical helix and folded ellipsoidal helix electrically small antenna (ESA)
• Fabrication of folded ellipsoidal helix antenna utilizing selective laser sintering
• Examples of a 423 MHz copper wire antenna and a 1.55 GHz silver printed antenna
• Summary
Choices of Antenna for Medical Implant Applications

• High bandwidth, high efficiency antenna is in need for various medical implant applications
  – Implanted wireless telemetry
  – Wireless power delivery

• 2-D planar ESA
  – Inexpensive, easy to fabricate
  – Easy to integrate with circuits

• 3-D helical ESA
  – Higher efficiency, higher BW
  – Suitable for “antenna on package”, can save real estate inside package for implanted devices
Spherical Helix and Ellipsoidal Helix Antenna

• Folded spherical helix antennas\(^{[1]}\) is a good choice for “antenna on package”.
  – High bandwidth (low Q)
  – High radiation efficiency
  – Compatible for spherical package

• Ellipsoidal helix antenna is a “stretched version” of spherical helix antenna
  – Still high bandwidth
  – Still high radiation efficiency
  – Compatible for ellipsoidal package (more popular)
  – Ellipsoid eccentricity is an additional design variable that can fine tune the antenna to self-resonant

Modeling of The Folded Ellipsoidal Helix Antenna

- The standard ellipsoid body in Cartesian coordinate system is represented as
  \[ \frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{h^2} = 1 \]

- Modeling a k-turn, M-arm folded ellipsoidal helix
  \[
  \begin{align*}
  x_n &= a \sin \delta_n \sin \phi_{m,n} \\
  y_n &= b \sin \delta_n \cos \phi_{m,n} \\
  z_n &= h \cos \delta_n
  \end{align*}
  \]
  where
  \[
  \delta_n = \cos^{-1} \left( \frac{n}{N} \right) \\
  \phi_{m,n} = 2\pi k \frac{n}{N} + 2\pi \frac{m}{M}
  \]

- \(a=b=h\) is the case of spherical helix, in our design we focus on the case \(a=b \neq h\).
Antenna Design Process

MATLAB Script

NEC Freq Sweep

Meet the design?

No

Geometrical specifications

Adjust the geometrical parameters

Simulation Parameter | Value
--- | ---
Wire diameter (cm) | 0.1
Wire conductivity (S/m) | $5.8 \cdot 10^7$
Number of segments $N$ | $60 \cdot \# \text{ of arms}$
### Spherical Helix Simulations

(Fixed # of turns, vary # of arms and $a$)

| # of turns | 1   | 1   | 1   |
| # of arms  | 1   | 2   | 4   |
| $a$ (cm)   | 0.80| 0.85| 0.91|
| $ka$       | 0.338| 0.359| 0.384|
| $Z_{in}$ (Ω) | 3.82 + j0.11 | 16.8 – j0.08 | 83.1 - j0.25 |
| $BW$ (MHz/MHz) | 22/2017.5 = 1.1% | 40/2017.5 = 2.0% | 64/2017.5 = 3.2% |
| Rad. Eff.  | 88.04% | 88.71% | 89.07% |

- Number of arms $\uparrow$ $\rightarrow$ Rin $\uparrow$, BW $\uparrow$ while radius and Rad. Eff. remain $\sim$constant
- However, there is a limit to wire density due to mutual coupling
- More arms increases input resistance and antenna BW
Spherical Helix Simulations

(Fixed # of arms, vary # of turns and a)

- Number of turns ↗ Rin ↘ (more parallel wires), a ↘ (more wire length per unit vol), BW ↘ (strongly correlated w/ a), while Rad. Eff. remains ~constant
- More turns reduces required radius for resonance

<table>
<thead>
<tr>
<th># of turns</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td># of arms</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>a (cm)</td>
<td>1.47</td>
<td>0.91</td>
<td>0.65</td>
</tr>
<tr>
<td>ka</td>
<td>0.62</td>
<td>0.384</td>
<td>0.275</td>
</tr>
<tr>
<td>Z_in (Ω)</td>
<td>210 - j0.67</td>
<td>83.1 - j0.25</td>
<td>46.9 - j0.94</td>
</tr>
<tr>
<td>BW[1] (MHz/MHz)</td>
<td>212/2017.5 = 10.5%</td>
<td>64/2017.5 = 3.2%</td>
<td>27/2017.5 = 1.3%</td>
</tr>
<tr>
<td>Rad. Eff.</td>
<td>89.19%</td>
<td>89.07%</td>
<td>90.42%</td>
</tr>
</tbody>
</table>
Ellipsoidal Helix Simulations

(Fixed # of arms, fix # of turns, vary h and a)

<table>
<thead>
<tr>
<th># of turns</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td># of arms</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>a (cm)</td>
<td>0.90</td>
<td>0.91</td>
<td>0.89</td>
<td>0.87</td>
</tr>
<tr>
<td>h (cm)</td>
<td>0.45</td>
<td>0.91</td>
<td>1.34</td>
<td>1.73</td>
</tr>
<tr>
<td>Aspect Ratio(h:a)</td>
<td>0.5:1</td>
<td>1:1 (Spherical Helix)</td>
<td>1.5:1</td>
<td>2:1</td>
</tr>
<tr>
<td>k *max {a, h}</td>
<td>0.380</td>
<td>0.384</td>
<td>0.566</td>
<td>0.731</td>
</tr>
<tr>
<td>Z_{in} (Ω)</td>
<td>18.5 + j0.35</td>
<td>83.1 - j0.25</td>
<td>188 + j0.21</td>
<td>338 + j0.58</td>
</tr>
<tr>
<td>BW (MHz/MHz)</td>
<td>20/2017.5 = 1.0%</td>
<td>64/2017.5 = 3.2%</td>
<td>135/2017.5 = 6.7%</td>
<td>217/2017.5 = 10.8%</td>
</tr>
<tr>
<td>Rad. Eff.</td>
<td>100.00%</td>
<td>89.07%</td>
<td>87.59%</td>
<td>87.70%</td>
</tr>
</tbody>
</table>

• Height ↗ Rin ↗, BW ↗ while resonant radius and Rad. Eff. Remain constant
• Height can be adjusted to tune Rin (side benefit: BW increases)
3-D Antenna Fabrication Utilizing Selective Laser Sintering

• The complicated structure of ellipsoidal helix can be taped out using selective laser sintering (SLS)
A 1-Turn 2-Arm 423 Mhz Wire Antenna

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of turns</td>
<td>1</td>
</tr>
<tr>
<td># of arms</td>
<td>2</td>
</tr>
<tr>
<td>a (cm)</td>
<td>4.0</td>
</tr>
<tr>
<td>h (cm)</td>
<td>7.0</td>
</tr>
<tr>
<td>Aspect Ratio (h:r)</td>
<td>1.75:1</td>
</tr>
<tr>
<td>kh</td>
<td>0.62</td>
</tr>
<tr>
<td>$Z_{in}$ (Ω)</td>
<td>51.5 – j1.6</td>
</tr>
<tr>
<td>BW (MHz/MHz)</td>
<td>26/423 = 6.15%</td>
</tr>
<tr>
<td>Rad. Eff.</td>
<td>87.78%</td>
</tr>
</tbody>
</table>
A 1-Turn 2-Arm 423 Mhz Wire Antenna

Simulated and measured $S11$ of the 423MHz wire antenna
# of turns 1
# of arms 2
a (cm) 0.80
h (cm) 1.50
Aspect Ratio (h:a) 1.875:1
kh 0.636
$Z_{\text{in}}$ (Ω) @ 2.025 GHz 52.8 – j0.44
BW (MHz/MHz) 112/2025 =5.53%
Rad. Eff. 88.53%
S11(db) @ 2.025 GHz -31.175
Measured S11(db) @ 1.55 GHz -21.985
Summary

• Spherical and ellipsoidal helix antenna have potential to be used for medical implant applications as “antenna on package”
• Performance of both spherical and ellipsoidal helix antennas are simulated, the ellipsoidal helix one has better self-resonance
• A 423 MHz copper wire ellipsoidal helix antenna and a 1.55 GHz silver printed antenna are successfully fabricated by selective laser sintering rapid prototyping method
Thank You !