Optimization of LPDA Antennas with Axial Twist

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Antennas are electrical devices that radiate or receive radio waves with the purpose of facilitating communication. Different antennas serve different purposes. In this talk, we will focus on log-periodic dipole array (LPDAs) antennas.

Previously Foltz, et al [2] introduced a 26-element LPDA with a particular twist angle $\psi = 120^\circ$ and showed that high quality polarization and gain similar to conventional LPDAs was obtained.

Now we extend the results by modeling antenna design using optimization to improve the gain and axial ratio (AR) over a frequency operation of 500MHz-3GHz. Our simulations show improved gain, AR and VSWR as compared to the previous model.
Outline

- Introduction to Antennas
- Optimization Problem for 26-element LPDA
- Comparison of 26-element with Foltz-McLean-Sutton work
- Optimization Problem for 22-, 24-, 26-element LPDA
- Methods and Algorithm
- Numerical Results
- Conclusion and Next Steps
Antennas are electrical devices that radiate or receive radio waves with the purpose of facilitating communication. Various types of antennas include Horn Antenna, LPDA, Yagi-Uda, and Slim Jim.
Introduction to Antennas

Typical parameters to consider in building an antenna include:

- Frequency
- Bandwidth
- Gain
- Axial ratio
- Directivity
- Radiation Patterns
- Front to Back Ratio
- Polarization
Log-periodic antennas were invented by R. H. DuHamel and D. E. Isbell in 1957.

Structure: a group of dipole antennas of varying sizes connected together through a common transmission line

Properties:
- Directional antenna
- Operates over many frequencies
- Uniform input impedances
- Uniform VSWR
Background on Log-Periodic Arrays

• The log-periodic array has an “active region”—the part of the antenna that radiates or receives radiation efficiently—that shifts with the frequency.

• The longest element is active at the antenna’s lowest usable frequency.

• The maximum frequency is a function of the shortest elements.
Background on Log-Periodic Arrays

Advantages

• Exhibit very wide frequency bandwidths
• Adding elements increases the bandwidth
• Gain and Front-to-Back ratio is relatively constant with varying frequencies
• Acts like a series of Yagi antennas

Disadvantages

• Have less Gain than a Yagi antenna of the same size
• To achieve good VSWR, antenna must be large
Geometry of an LPDA

\[ L_{22} = 2h \]

Length \( d \) with twist angle \( \psi \)

\[ d_{i-1} = R_{i-1} - R_i \]

\[ \frac{L_{k+1}}{L_k} = \frac{R_{k+1}}{R_k} = \tau < 1 \]
Antenna Gain is a measure of an antenna’s ability to direct or concentrate radio frequency energy in a particular direction. Gain is measured in dBi (Decibels relative to an isotropic radiator) or in dBd (Decibels relative to a dipole radiator).
Is high gain good? It depends on the application.

If you know the direction where your signal is coming from, then a high gain antenna is a good candidate.

**TV antennas**

Assume you place a TV antenna on the top of your roof. If the TV broadcasting antennas are positioned to the south of your home, then a TV antenna with a high gain is preferred.

**Cell Phones**

Cell phones are used in any orientation and communicate with a cell tower in any position. Hence cell phone antennas have a low gain.
The **Axial Ratio (AR)** describes the polarization of circularly polarized antennas.

AR = length of the minor axis/major axis of the polarization ellipse

For circularly polarized antennas, AR is close to 1. Thus, a circular polarized wave radiates energy in the horizontal and vertical planes and at all angles in between.
Twist Angle

The twist angle $\psi$ is the angle at which both the element and the cable are twisted around the central axis.
The problem is modeled as an optimization problem with 6 variables and 8 constraints. It was modeled for an \( N = 26 \)-element LPDA.

\[
\begin{align*}
\text{maximize} & \quad 0.3 \times \frac{1}{7} \text{Gain} 0.3 + 0.7 \times \frac{1}{0.8} AR \\
\text{subject to} & \quad 0.04 \leq R_N \leq 0.1 \\
& \quad 1.5 \leq \psi \leq 3.0 \ (86^\circ - 172^\circ) \\
& \quad 1.05 \leq \frac{1}{\tau} \leq 1.3 \\
& \quad 50 \leq Z_0 \leq 400
\end{align*}
\]

where \( x = [R_N, \psi, \frac{1}{\tau}, Z_0] \) and

\( R_N = \) distance of the first element to the origin, \\
\( \psi = \) twist angle; \quad \frac{1}{\tau} = \) geometric multiplier; \\
\( Z_0 = \) impedance;
# Numerical Results for Optimized 26-element LPDA

<table>
<thead>
<tr>
<th>Variables</th>
<th>Optimized 26-element LPDA</th>
<th>Manually created 26-element LPDA [FMS, Ref 2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance, $R_N$</td>
<td>0.05402 meters</td>
<td>0.055 meters</td>
</tr>
<tr>
<td>Twist Angle, $\psi$</td>
<td>2.0163 rad</td>
<td>2.0944 rad</td>
</tr>
<tr>
<td></td>
<td>$\sim 115.5^\circ$</td>
<td>$= 120^\circ$</td>
</tr>
<tr>
<td>Geometric multiplier, $1/\tau$</td>
<td>1.11 meters</td>
<td>1.10 meters</td>
</tr>
<tr>
<td>Impedance, $Z_0$</td>
<td>90.64 Ohms</td>
<td>200 Ohms</td>
</tr>
<tr>
<td>Half-length, $h$</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>(not optimized)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Now, we compare the Gain, AR, and VSWR on the 26-element LPDAs.

Antenna Gain is a measure of an antenna’s ability to direct or concentrate radio frequency energy in a particular direction.

The Axial Ratio (AR) describes the polarization of circularly polarized antennas. Ideal to have AR close to 1.

The Voltage Standing Wave Ratio (VSWR) measures how much power is reflected. A low VSWR value means that the majority of the power is delivered to the antenna.
Numerical Results: Gain Comparison of 26-element LPDAs
Numerical Results: Axial Ratio Comparison of 26-element LPDAs
Numerical Results: VSWR Comparison of 26-element LPDAs
Optimization Problem for \( N = 22\)-, \( 24\)-, \( 26\)-element LPDAs

The problem is modeled as an optimization problem with 7 variables and 10 constraints. It was modeled for \( N = 22\)-, \( 24\)-, and \( 26\)-element LPDAs.

\[
\text{maximize} \quad \frac{1}{7} \text{Gain} + \frac{1}{0.8} AR \\
\text{subject to} \quad 0.04 \leq R_N \leq 0.1 \\
\quad \quad \quad 1.5 \leq \psi \leq 3.0 \ (86^\circ - 172^\circ) \\
\quad \quad \quad 1.05 \leq \frac{1}{\tau} \leq 1.3 \\
\quad \quad \quad 50 \leq Z_0 \leq 400 \\
\quad \quad \quad 0.005 \leq h \leq 0.03
\]

where \( x = [R_N, \psi, \frac{1}{\tau}, Z_0, h] \) and

\( R_N \) = distance of the first element to the origin,

\( \psi \) = twist angle; \( 1/\tau \) = geometric multiplier;

\( Z_0 \) = impedance; \( h \) = half-length of the first element
Software used

• Numerical Electromagnetics Code (NEC), an antenna modeling software that generates antenna geometries, which uses the Method-of-Moments

• The Gain and AR values were provided by a modified version of the blackbox NEC-2D

• Matlab’s optimization software Patternsearch was used to solve the optimization problem. It is a direct search method that requires no derivative information.
Software used

• At each iteration, Patternsearch starts at an iterate $x_k$, builds a mesh of trial points $p^1, p^2, p^3, \ldots, p^n$, and evaluates the objective function at each trial point. The trial point with the largest objective function value becomes the next iterate $x_{k+1}$. 
Matlab code was written to integrate both Patternsearch and NEC-2D. Collectively, Matlab is the platform that is used to solve the optimization problem and call NEC-2D to obtain the Gain and AR values.

Given: Initial iterate $x_0$; matrix $A$ and vector $b$.

Until solution found:

- Call Patternsearch with iterate $x_k$ to obtain the trial points
  - For each trial point, create an input file
  - Call NEC-2D with the input file to evaluate the Gain and AR at the trial pts
- Call Patternsearch to obtain the next iterate $x_{k+1}$ that has the highest objective function value of the trial points
- $x_k \leftarrow x_{k+1}$. 

Algorithm
Algorithm: Input file for NEC-2D

File 1

#4 1 0.00275 0
#6 1 0.001 0
#1 1 0.08000 0
#3 1 2.500000 0
#5 1 1.175100 0
#7 1 200.000000 0
#2 1 0.009200 0

File 2

Current values at a trial point

File 3

CM Twisted LPDA
CM First parameter is distance of first element from origin
CM Second parameter is half-length of first element
CM Third parameter is twist angle IN RADIANS
CM Fourth parameter is length of first transmission line (NOT USED)
CM Fifth parameter is geometric multiplier
CM Sixth parameter is initial wire radius
CM Seventh parameter is transmission line impedance

CE

GW 1 5 \{-#2*5^0*COS(3*0)} \{-#2*5^0*SIN(3*0)} \{#1*5^0} \{#2*5^0*COS(3*0)} \{#2*5^0*SIN(3*0)} \{#1*5^0} \{#6*5^0} \{GW 2 7 \{-#2*5^1*COS(3*1)} \{-#2*5^1*SIN(3*1)} \{#1*5^1} \{#2*5^1*COS(3*1)} \{#2*5^1*SIN(3*1)} \{#1*5^1} \{#6*5^1} \{GW 3 9 \{-#2*5^2*COS(3*2)} \{-#2*5^2*SIN(3*2)} \{#1*5^2} \{#2*5^2*COS(3*2)} \{#2*5^2*SIN(3*2)} \{#1*5^2} \{#6*5^2} \{GW 4 11 \{-#2*5^3*COS(3*3)} \{-#2*5^3*SIN(3*3)} \{#1*5^3} \{#2*5^3*COS(3*3)} \{#2*5^3*SIN(3*3)} \{#1*5^3} \{#6*5^3} \}
### Optimal Values of the 22-element LPDA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance, $R_N$</td>
<td>0.058550 meters</td>
</tr>
<tr>
<td>Gain</td>
<td>7.73000</td>
</tr>
<tr>
<td>Twist Angle, $\psi$</td>
<td>2.411133 rad (~ 138°)</td>
</tr>
<tr>
<td>AR</td>
<td>0.919310</td>
</tr>
<tr>
<td>Geometric multiplier, $1/\tau$</td>
<td>1.129494 meters</td>
</tr>
<tr>
<td>Obj Fcn value</td>
<td>2.253423</td>
</tr>
<tr>
<td>Impedance, $Z_0$</td>
<td>92.994141 Ohms</td>
</tr>
<tr>
<td>Half-length, $h$</td>
<td>0.014416 meters</td>
</tr>
</tbody>
</table>
Geometry of the Optimized 22-element LPDA

\[ L_1 = 14.64 \text{ inches} \]
\[ L_{22} = 1.13 \text{ inches} \]
\[ R_1 = 29.73 \text{ inches} \]
\[ R_{22} = 2.31 \text{ inches} \]
\[ \psi = 138^\circ \]

\[ \frac{L_{k+1}}{L_k} = \frac{R_{k+1}}{R_k} = \tau < 1 \]
Optimal Design of 22-element LPDA

Optimal twist angle $\psi = 138^\circ$. 
Optimal Design of 22-element LPDA
Numerical Results: Gain of Optimal 22-element LPDA
Numerical Results: Axial Ratio of Optimal 22-element LPDA
Numerical Results: VSWR of Optimal 22-element LPDA
Numerical Results

Now, we compare the Gain, AR, and VSWR on the 3 LPDAs.
Numerical Results: VSWR of 22- & 26-element LPDAs

26-element LPDA

22-element LPDA
Numerical Results: Axial Ratio of 22- & 26-element LPDAs

26-element LPDA

22-element LPDA
Numerical Results: Gain of 22- & 26-element LPDAs

26-element LPDA

22-element LPDA
Numerical Results - Comparison of 26- and 22-element LPDAs

26-element LPDA [2,3]

22-element LPDA
Optimization of the problem resulted in a 22-element LPDA with axial twist of $\psi = 138^\circ$ resulting in improved bandwidth, Gain, Axial Ratio, and VSWR.

Next Steps: We are currently constructing the 22-element LPDA antenna for testing.


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Thank you.

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