Optimization of LPDA Antennas with Axial Twist

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Overview

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 $\psi = 120°$ 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

Introduction to Antennas

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

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

Background on Log-Periodic Arrays

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

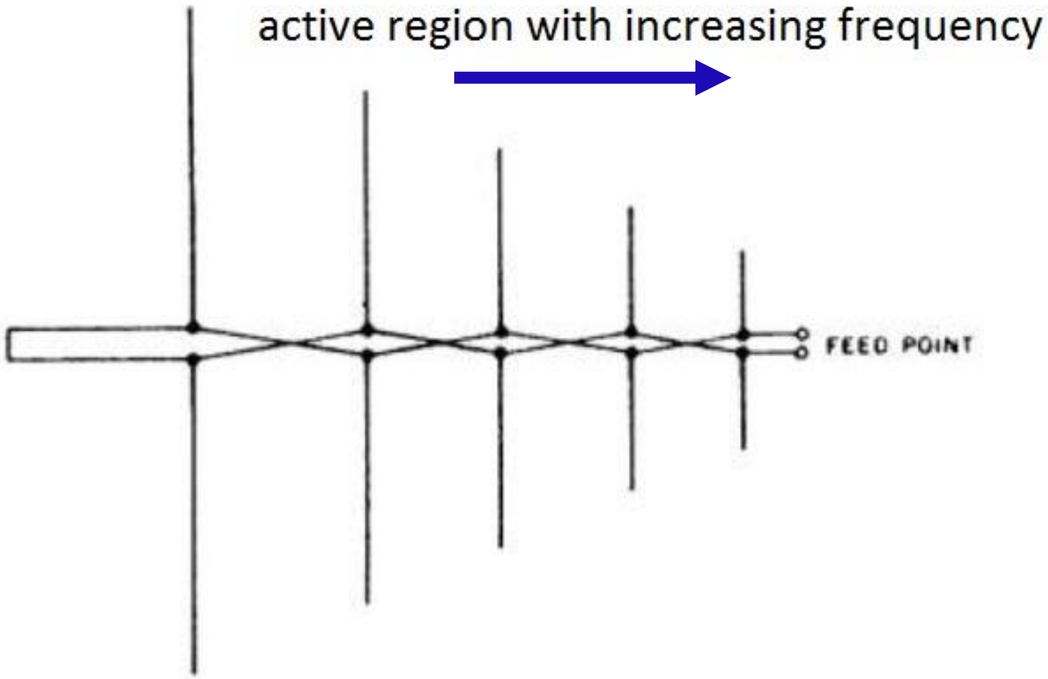
Properties:

- Directional antenna
- Operates over many frequencies
- Uniform input impedances
- Uniform VSWR

LPDA

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

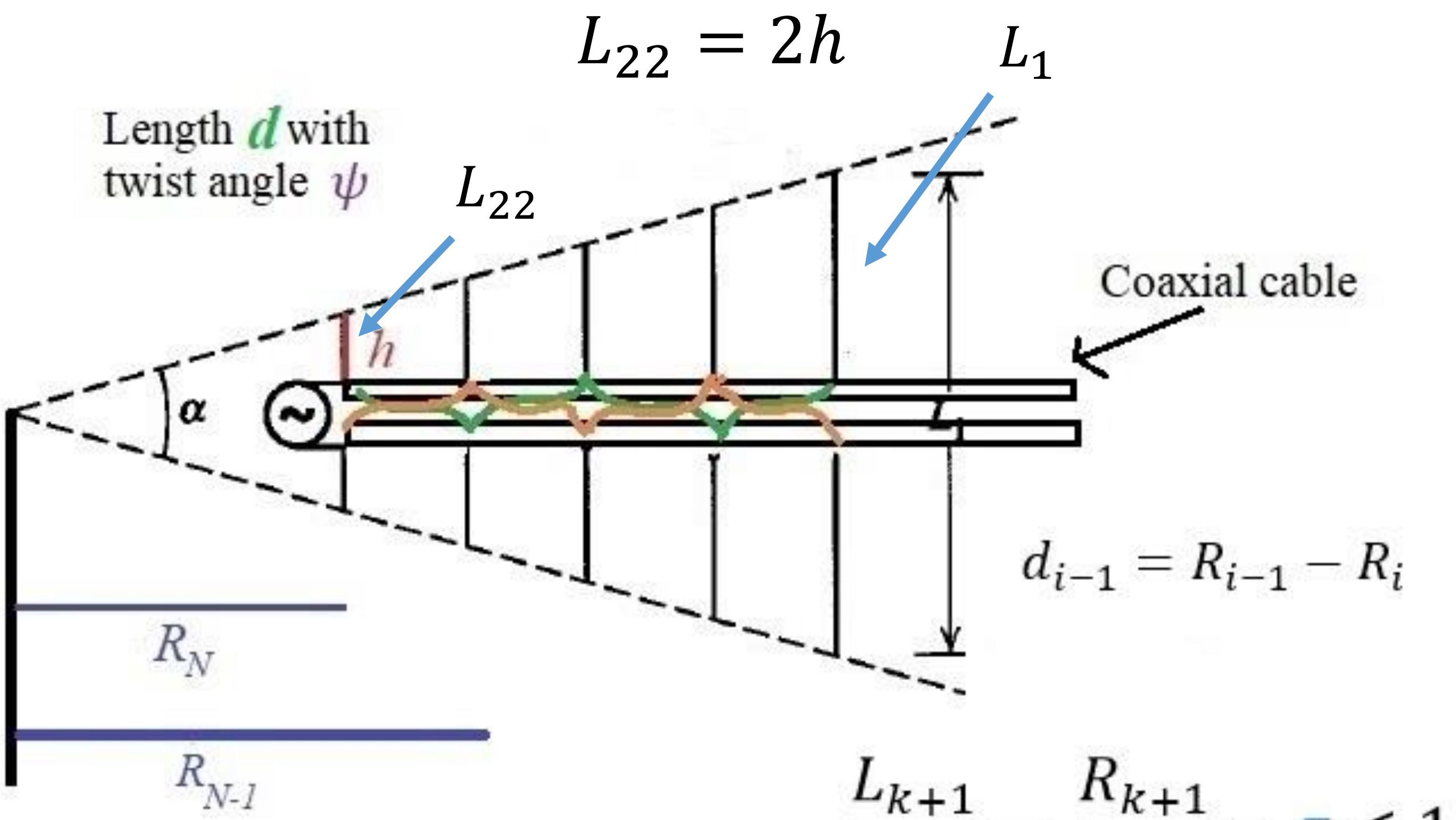
Advantages

- 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

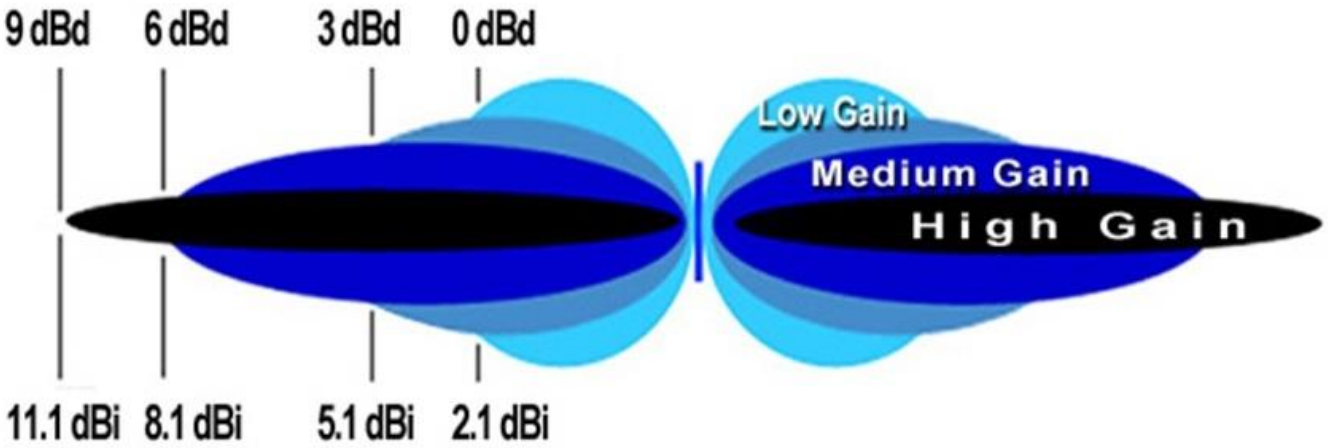
Geometry of an LPDA



$$\frac{L_{k+1}}{L_k} = \frac{R_{k+1}}{R_k} = \tau < 1$$

Gain

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).



Gain

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.

Axial Ratio (AR)

The **Axial Ratio (AR)** describes the polarization of circularly polarized antennas.

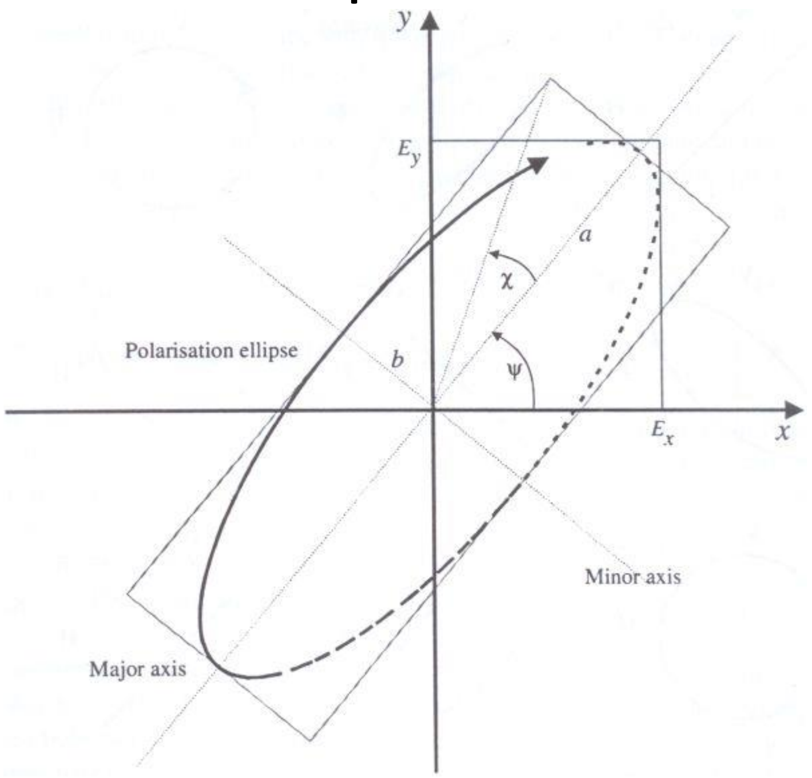
AR = length of the minor axis/major axis of the polarization ellipse

For circularly polarized antennas, AR is close to 1.

Thus, a circular polarized wave radiates energy

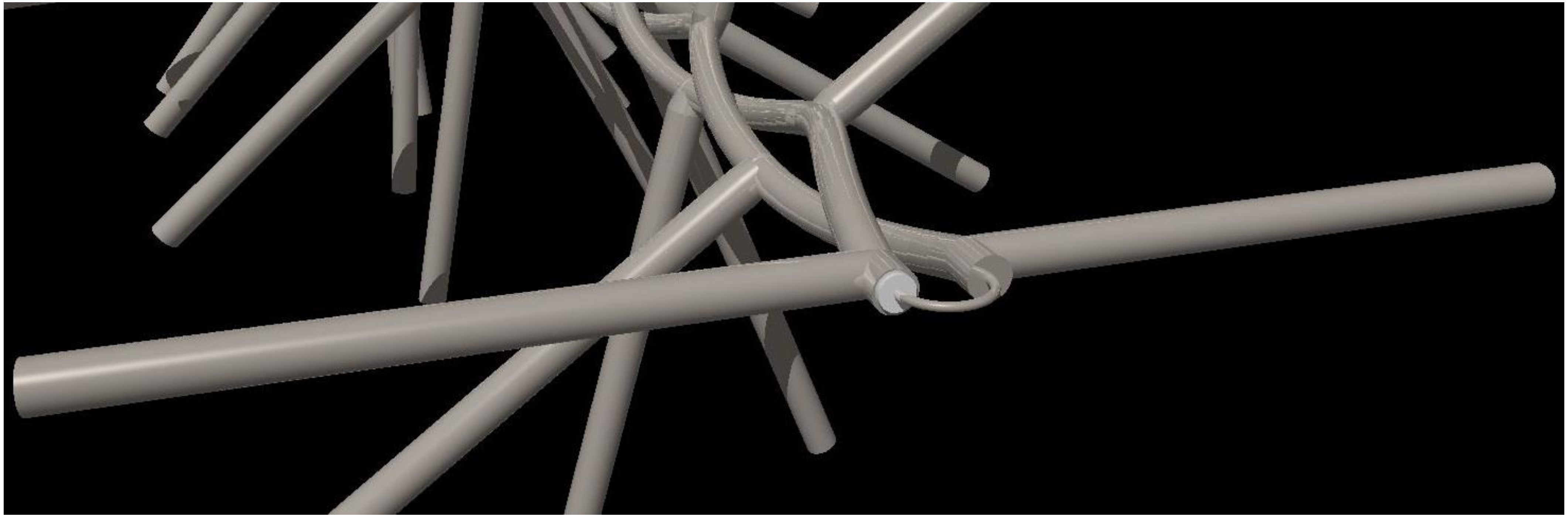
in the horizontal and vertical planes and

at all angles in between.



Twist Angle

The twist angle ψ is the angle at which both the element and the cable are twisted around the central axis.



Optimization Problem (IEEE Conf Proc)

The problem is modeled as an optimization problem with 6 variables and 8 constraints. It was modeled for an N = 26-element LPDA.

$$\underset{x}{\text{maximize}} \quad 0.3 * \frac{1}{7} Gain\, 0.3 + 0.7 * \frac{1}{0.8} AR$$

$$\text{subject to} \quad \begin{aligned} 0.04 \ \le\ & R_N \le\ 0.1 \\ 1.5 \le\ & \psi\ \ \le\ 3.0\ \ (86° - 172°) \\ 1.05 \le\ & \frac{1}{\tau}\ \ \le\ 1.3 \\ 50\ \le\ & Z_0\ \ \le 400 \end{aligned}$$

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

R_N = distance of the first element to the origin,

ψ = twist angle; $1/\tau$ = geometric multiplier;

Z_0 = impedance;

Numerical Results for Optimized 26-element LPDA

Variables	**Optimized 26-element LPDA**	**Manually created 26-element LPDA [FMS, Ref 2]**
Distance, R_N	0.05402 meters	0.055 meters
Twist Angle, ψ	2.0163 rad ~ 115.5°	2.0944 rad = 120°
Geometric multiplier, $1/\tau$	1.11 meters	1.10 meters
Impedance, Z_0	90.64 Ohms	200 Ohms
Half-length, h (not optimized)	0.015	0.015

Numerical Results

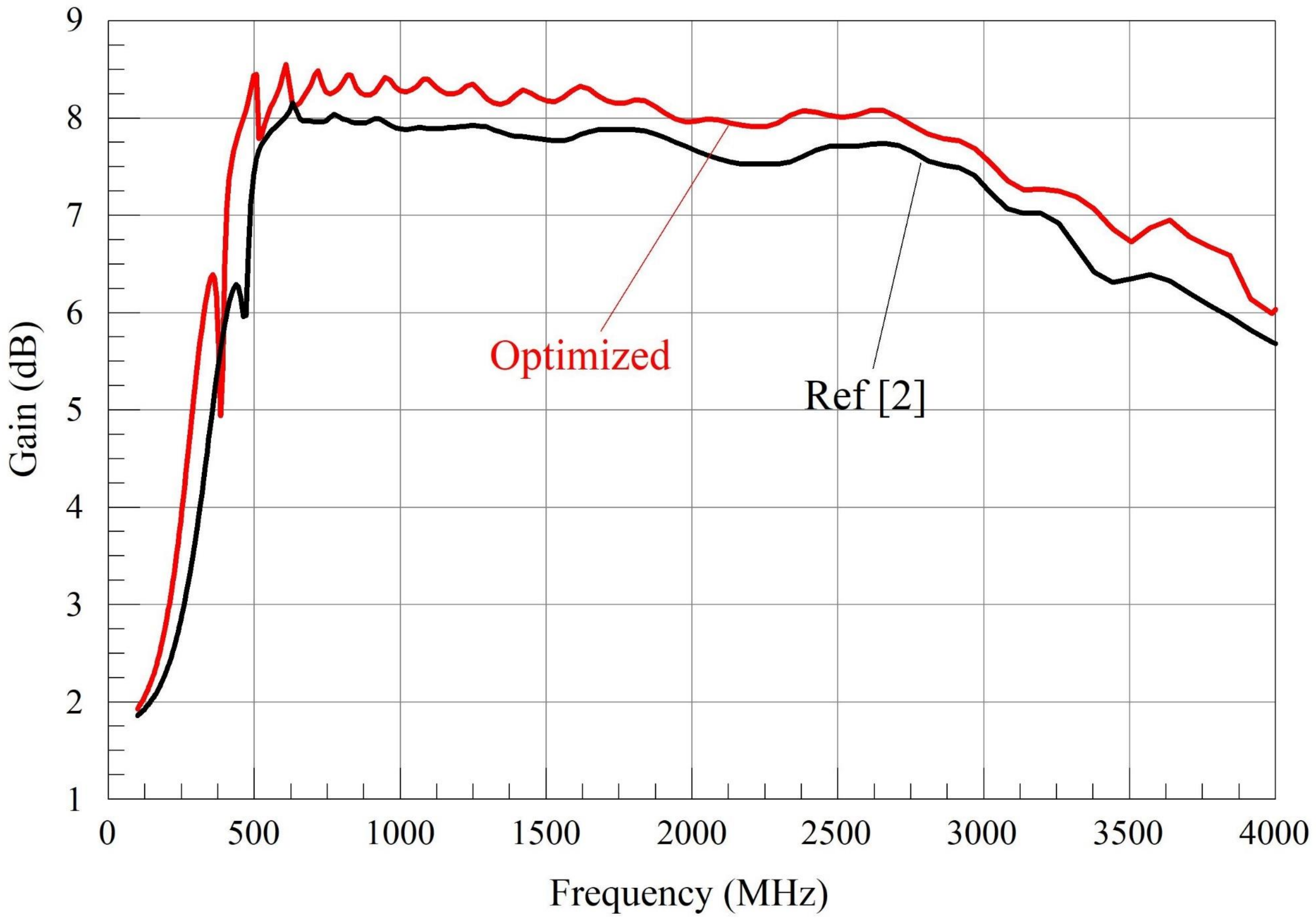
Now, we compare the Gain, AR, and VSWR on the 26-element LPDAs.

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

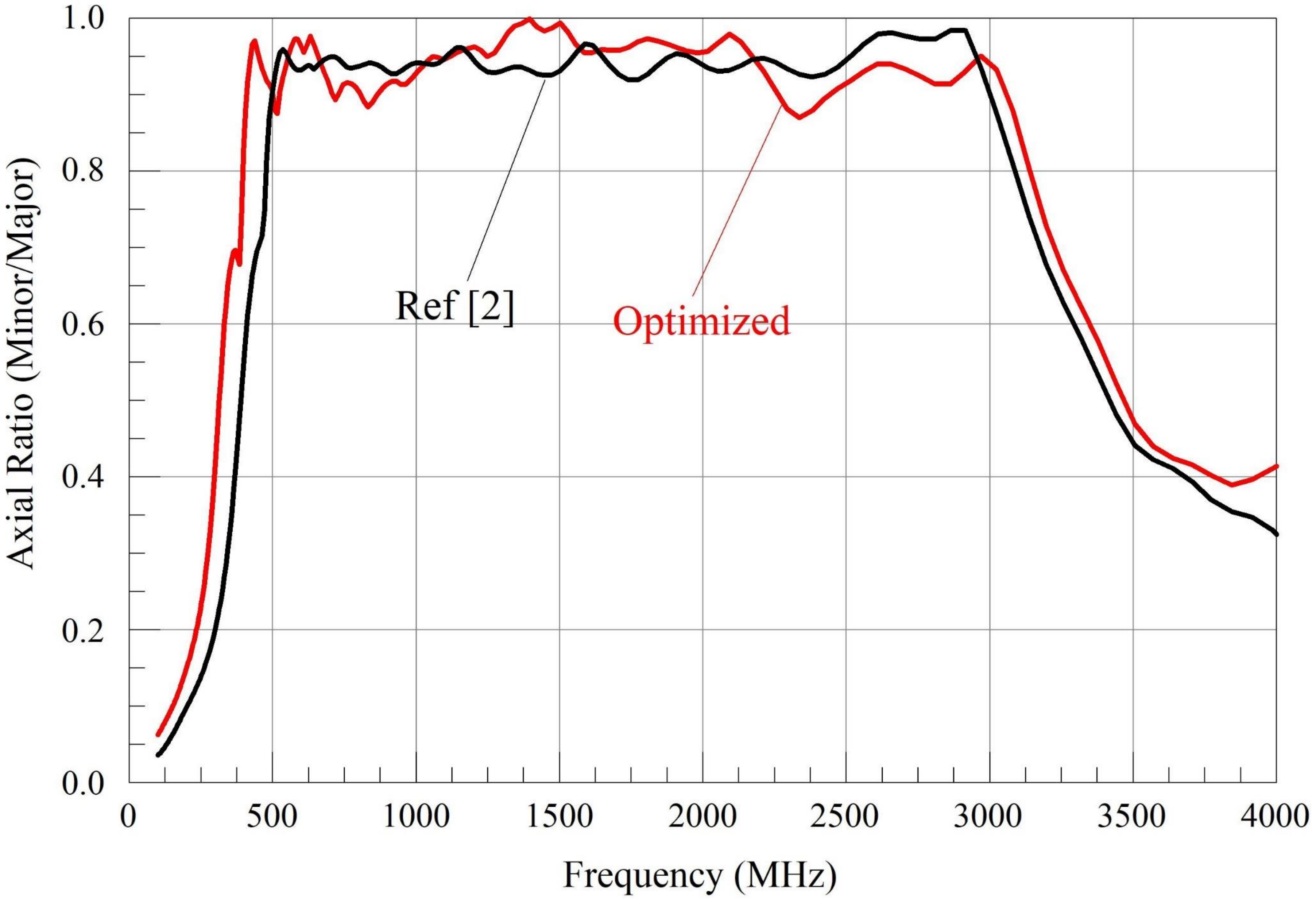
The **Axial Ratio (AR)** describes the polarization of circularly polarized antennas. Ideal to have AR close to 1.

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.

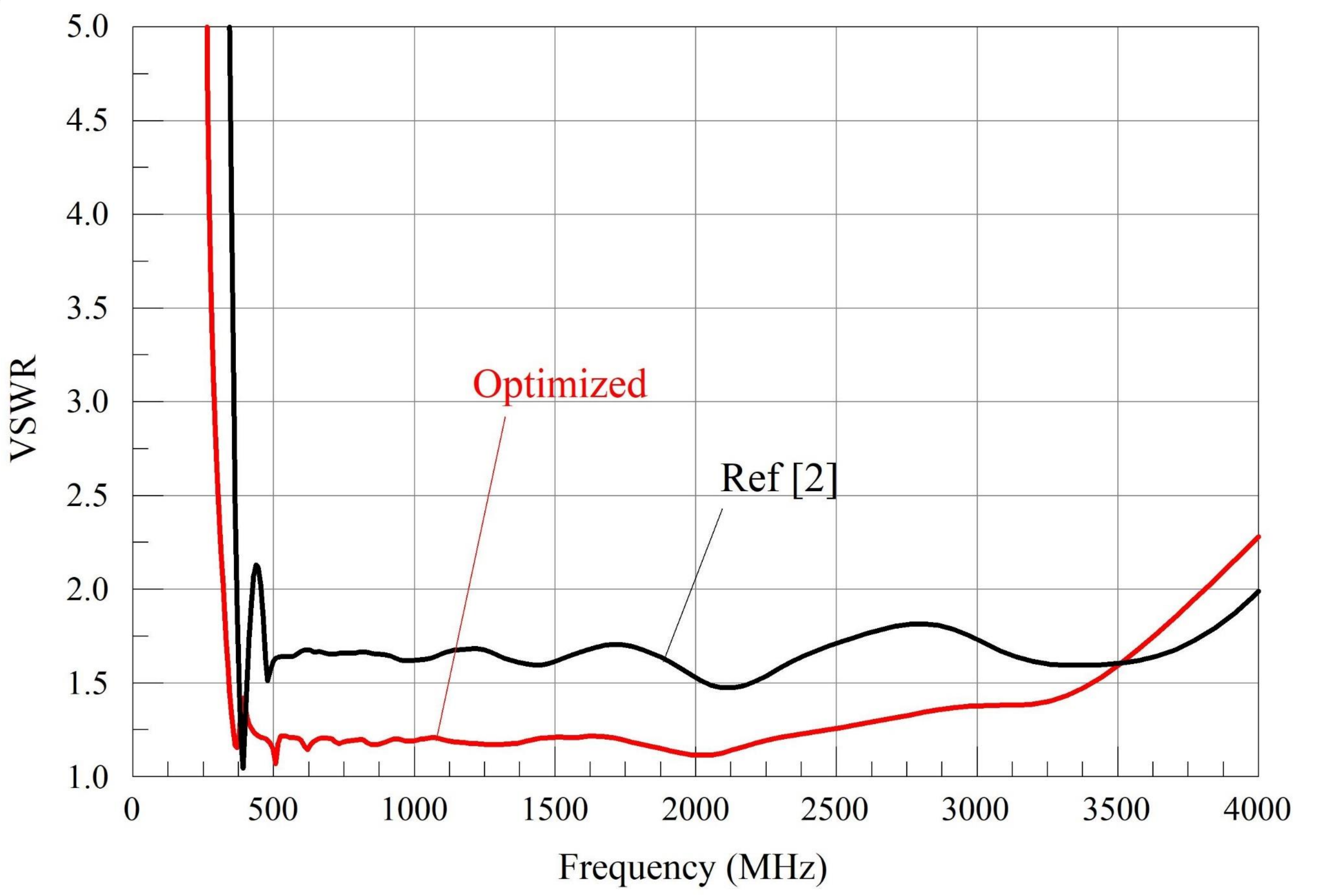
Numerical Results: Gain Comparison of 26-element LPDAs



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.

$$
\begin{array}{ll}
\underset{x}{\text{maximize}} & \frac{1}{7} Gain + \frac{1}{0.8} AR \\
\text{subject to} & 0.04 \leq R_N \leq 0.1 \\
 & 1.5 \leq \psi \leq 3.0 \ (86° - 172°) \\
 & 1.05 \leq \frac{1}{\tau} \leq 1.3 \\
 & 50 \leq Z_0 \leq 400 \\
 & 0.005 \leq h \leq 0.03
\end{array}
$$

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

Optimization Software

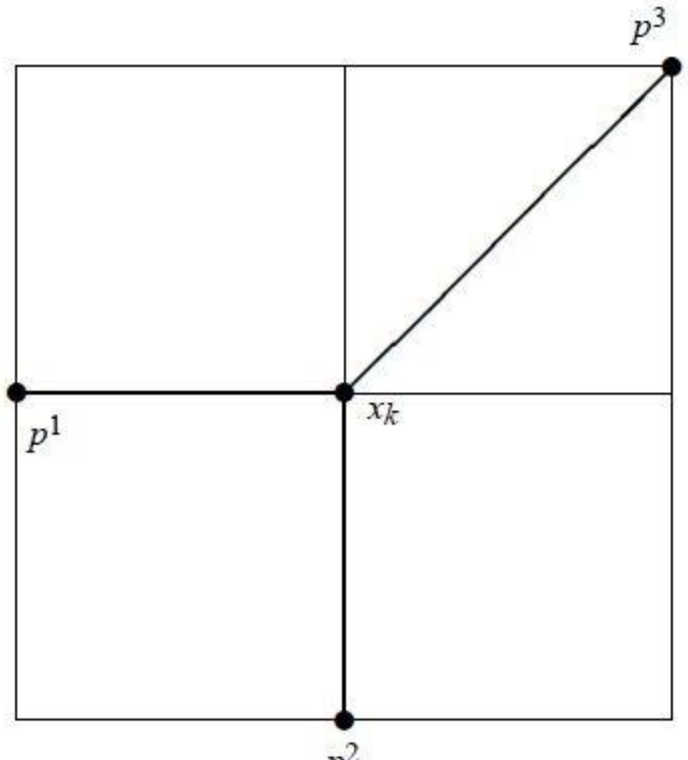
Software used

- 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.

Optimization Software

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}.



Algorithm

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
- $x_k \longleftarrow x_{k+1}$.

Algorithm: Input file for NEC-2D

```
#4 1  0.00275 0
#6 1  0.001  0
```

File 1

```
#1 1 0.080000 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

```
SU
FD FREQUENCY
FD POWER_GAIN_TOTAL 180.0 0.0
FD RADIATION_AXIAL_RATIO 180.0 0.0
```

File 3

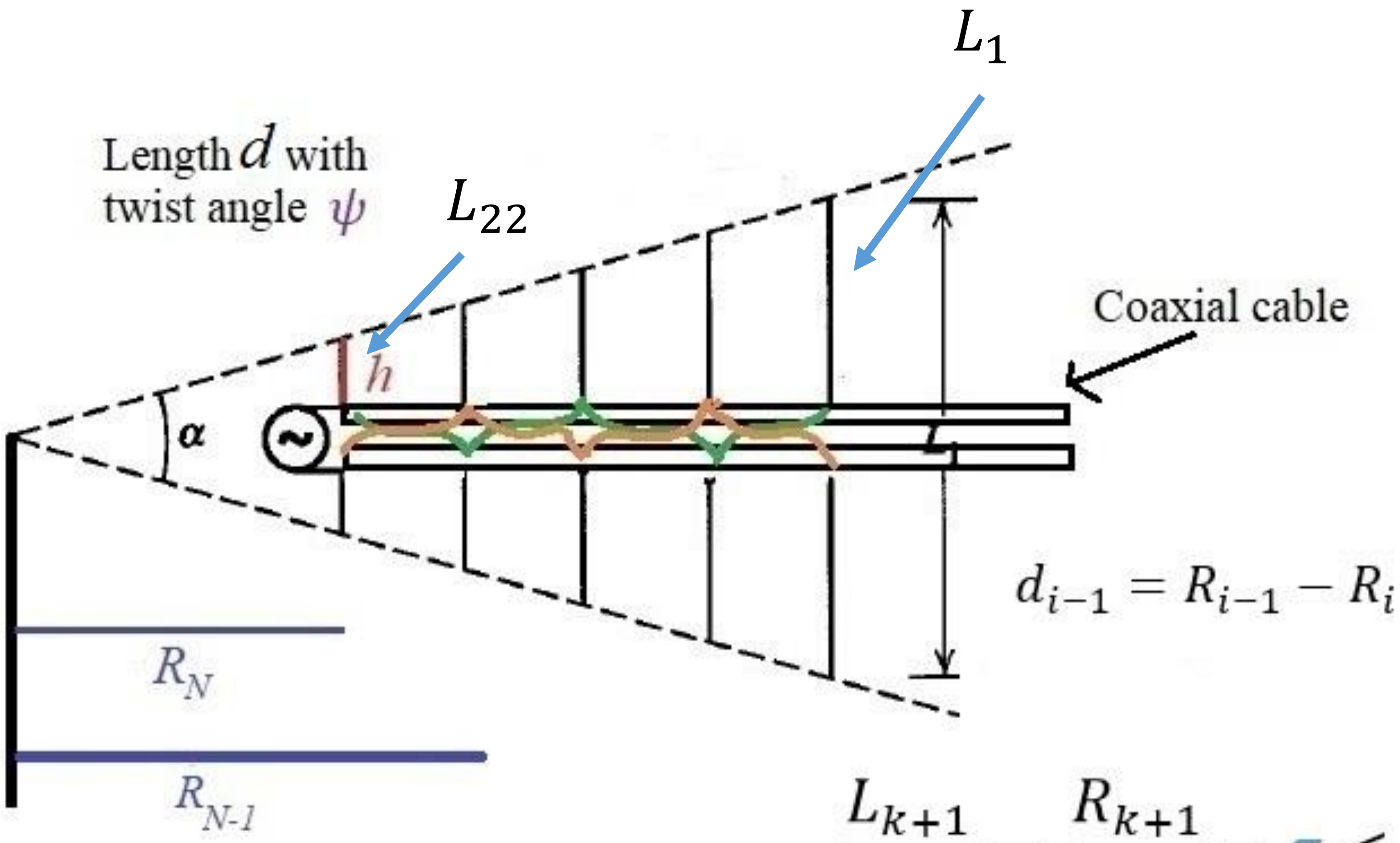
```
CM Twisted LPDA
CM First parameter is distance of first element from origin
CM Second parameter is half-length of first element
CM Third parameter is twist angle IN RADIANS
CM Fourth parameter is length of first transmission line (NOT USED)
CM Fifth parameter is geometric multiplier
CM Sixth parameter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

Numerical Results of Optimized 22-element LPDA

Optimal Values of the 22-element LPDA			
Distance, R_N	= 0.058550 meters	*Gain*	*= 7.73000*
Twist Angle, ψ	= 2.411133 rad ~ 138°	*AR*	*= 0.919310*
Geometric multiplier, $1/\tau$	= 1.129494 meters	Obj Fcn value	= 2.253423
Impedance, Z_0	= 92.994141 Ohms		
Half-length, h	= 0.014416 meters		

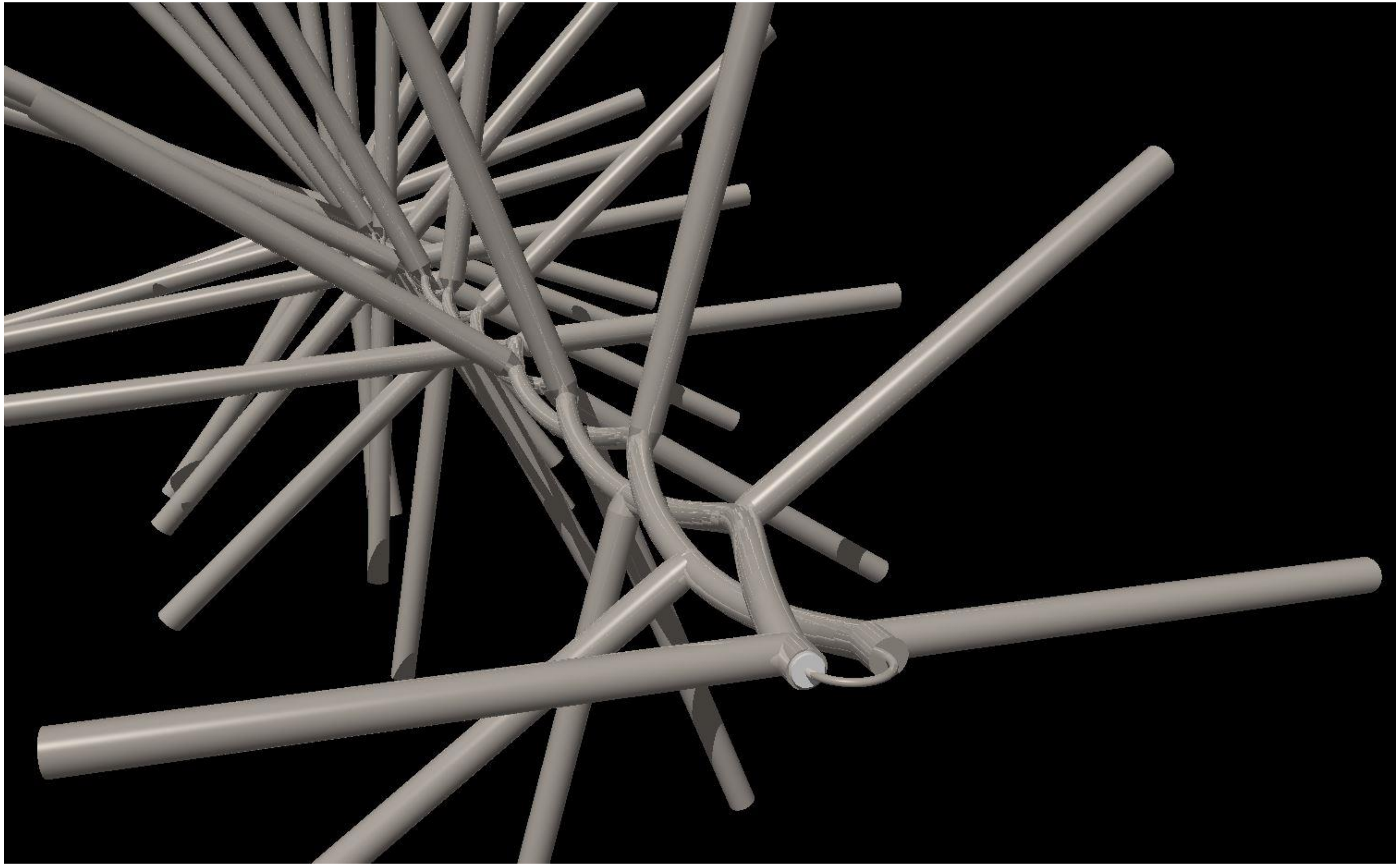
Geometry of the Optimized 22-element LPDA

$$L_1 = 14.64 \text{ inches}$$
$$L_{22} = 1.13 \text{ inches}$$
$$R_1 = 29.73 \text{ inches}$$
$$R_{22} = 2.31 \text{ inches}$$
$$\psi = 138°$$



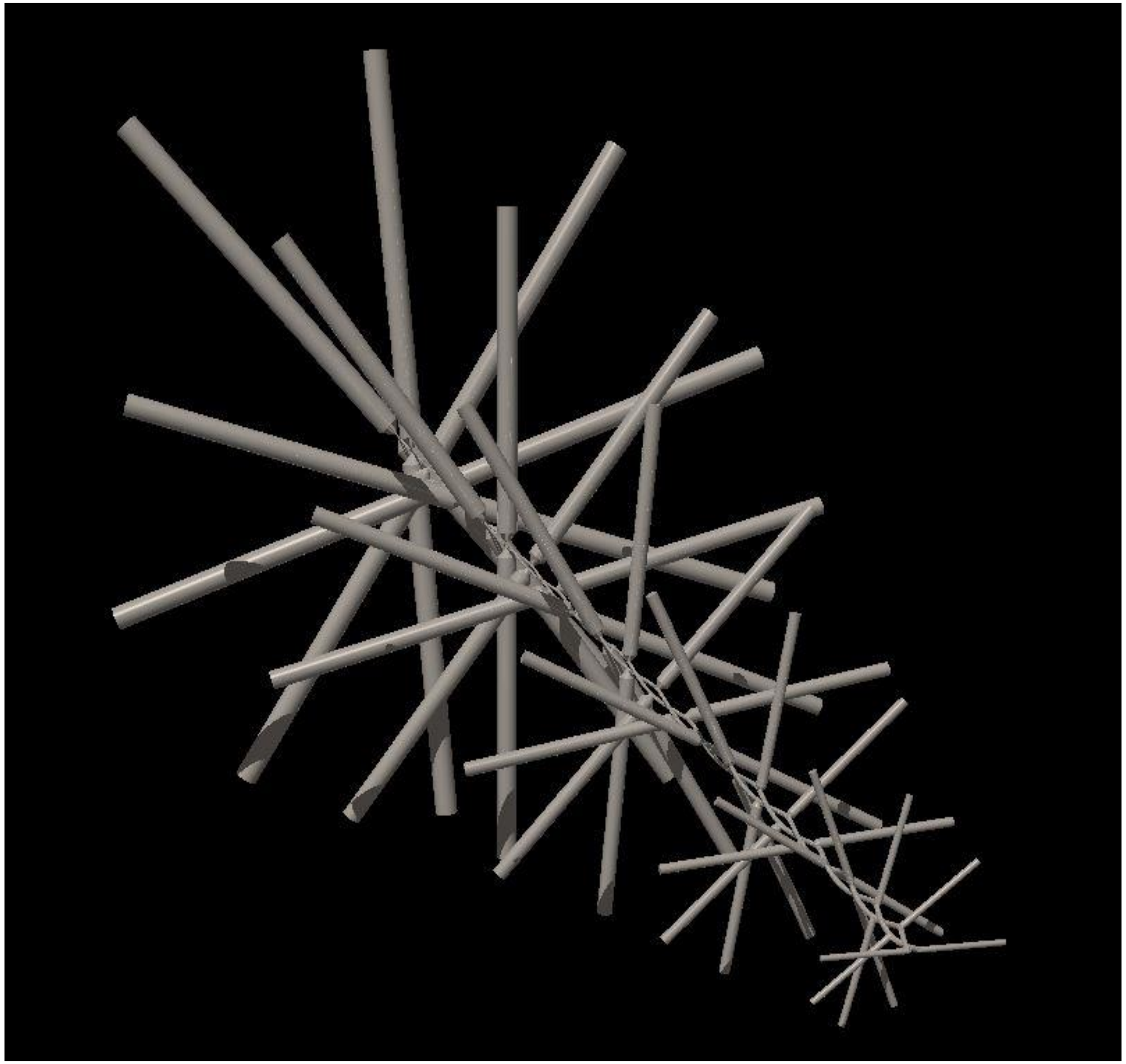
$$\frac{L_{k+1}}{L_k} = \frac{R_{k+1}}{R_k} = \tau < 1$$

Optimal Design of 22-element LPDA

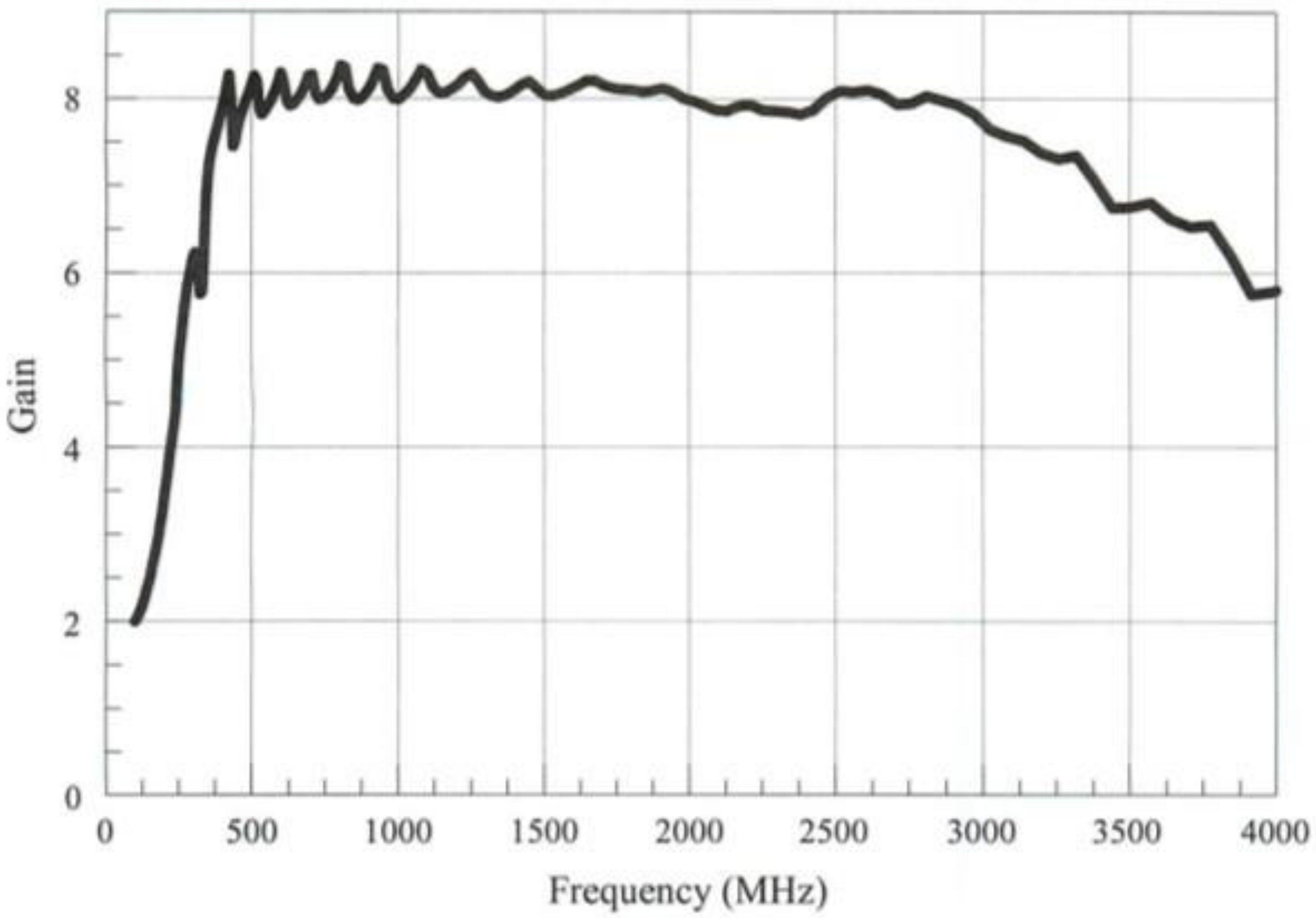


Optimal twist angle $\psi = 138°$.

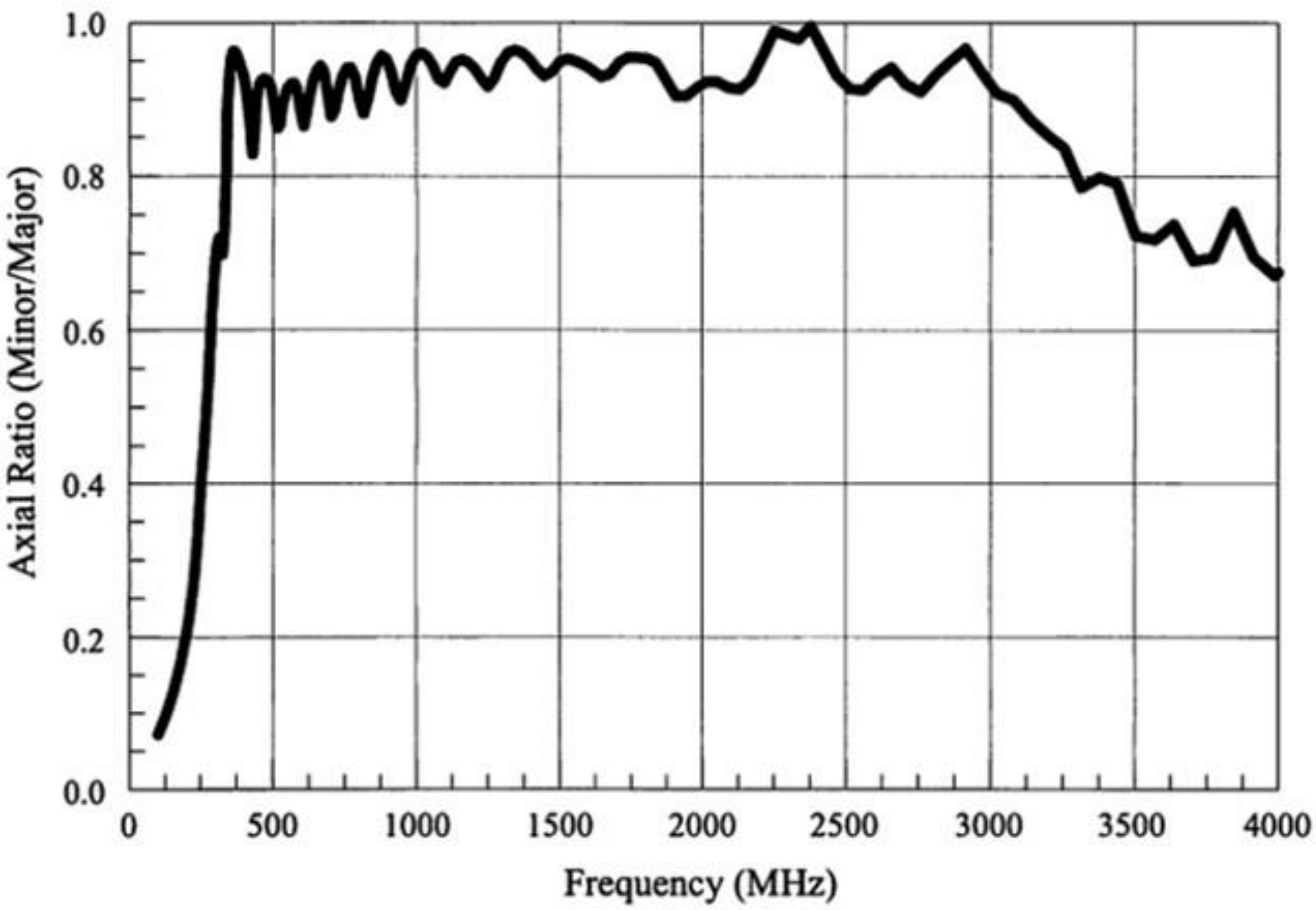
Optimal Design of 22-element LPDA



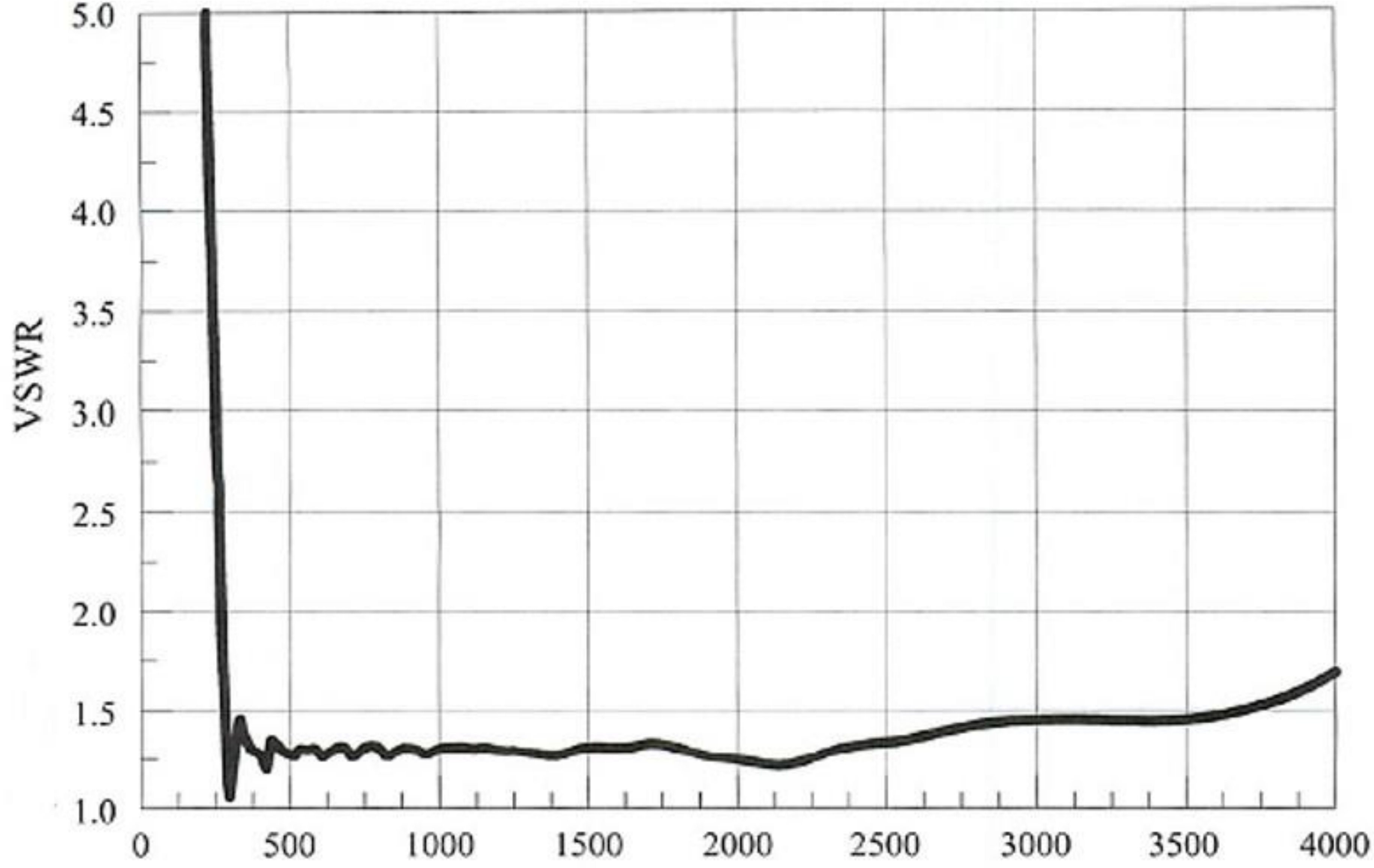
Numerical Results: Gain of Optimal 22-element LPDA



Numerical Results: Axial Ratio of Optimal 22-element LPDA



Numerical Results: VSWR of Optimal 22-element LPDA

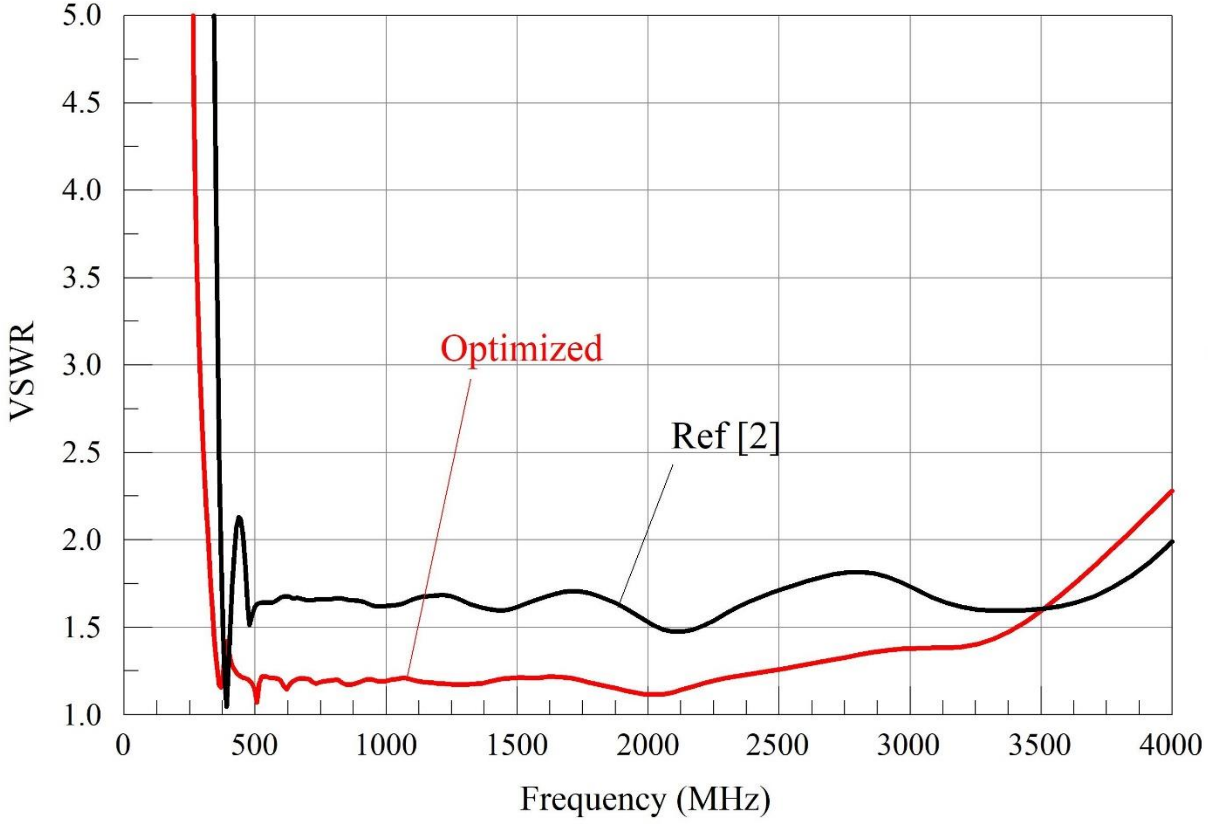


Numerical Results

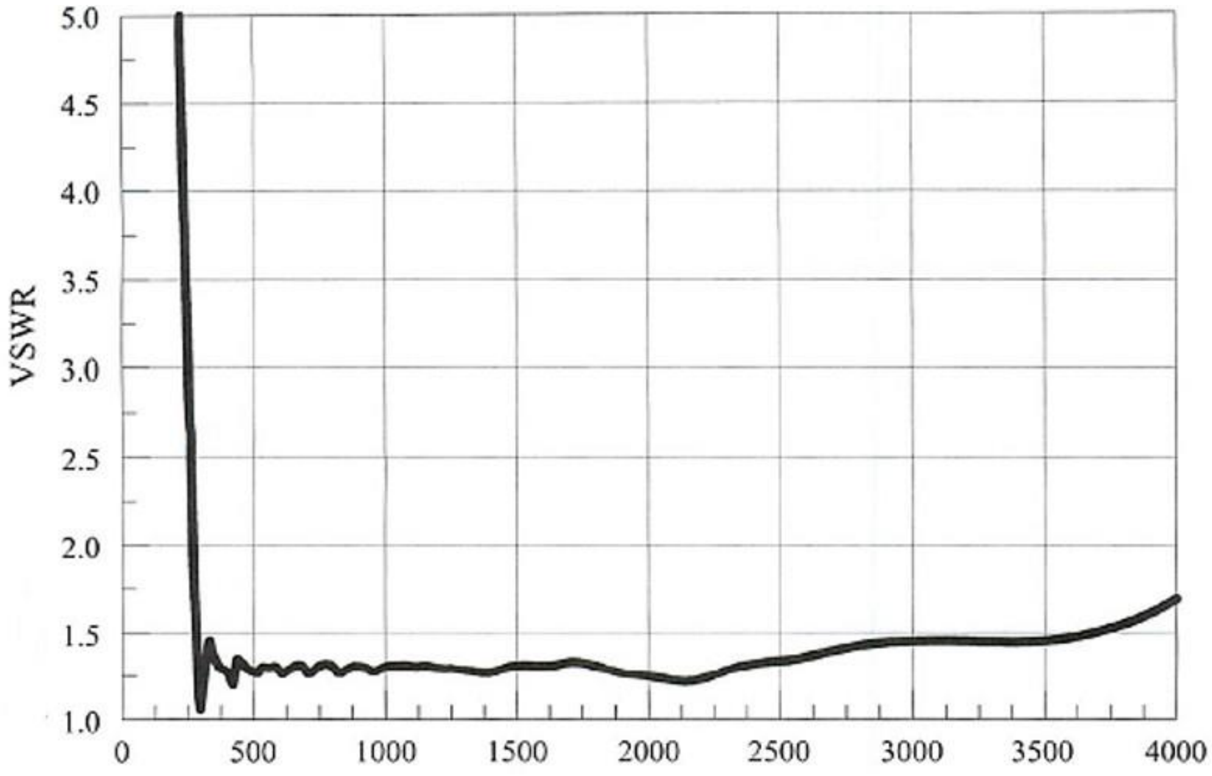
Now, we compare the Gain, AR, and VSWR on the 3 LPDAs.

Numerical Results: VSWR of 22- & 26-element LPDAs

26-element LPDA

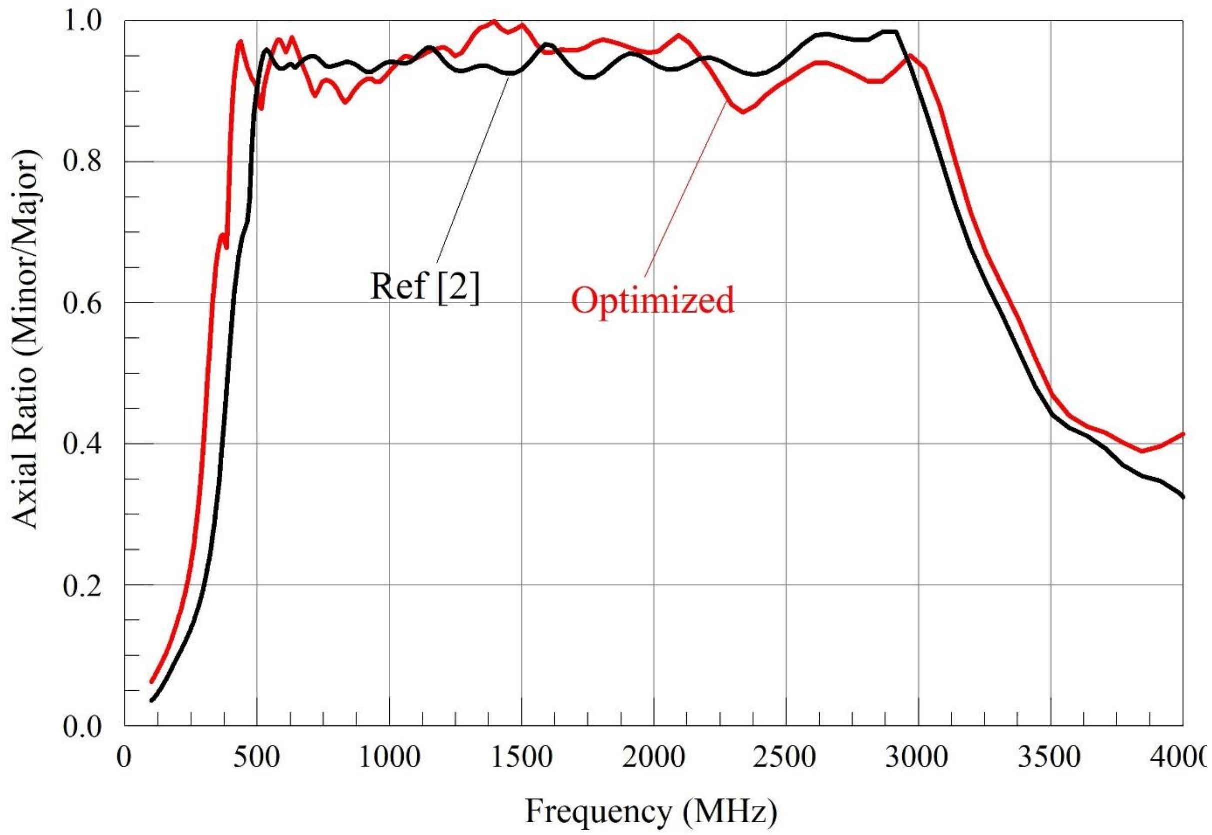


22-element LPDA

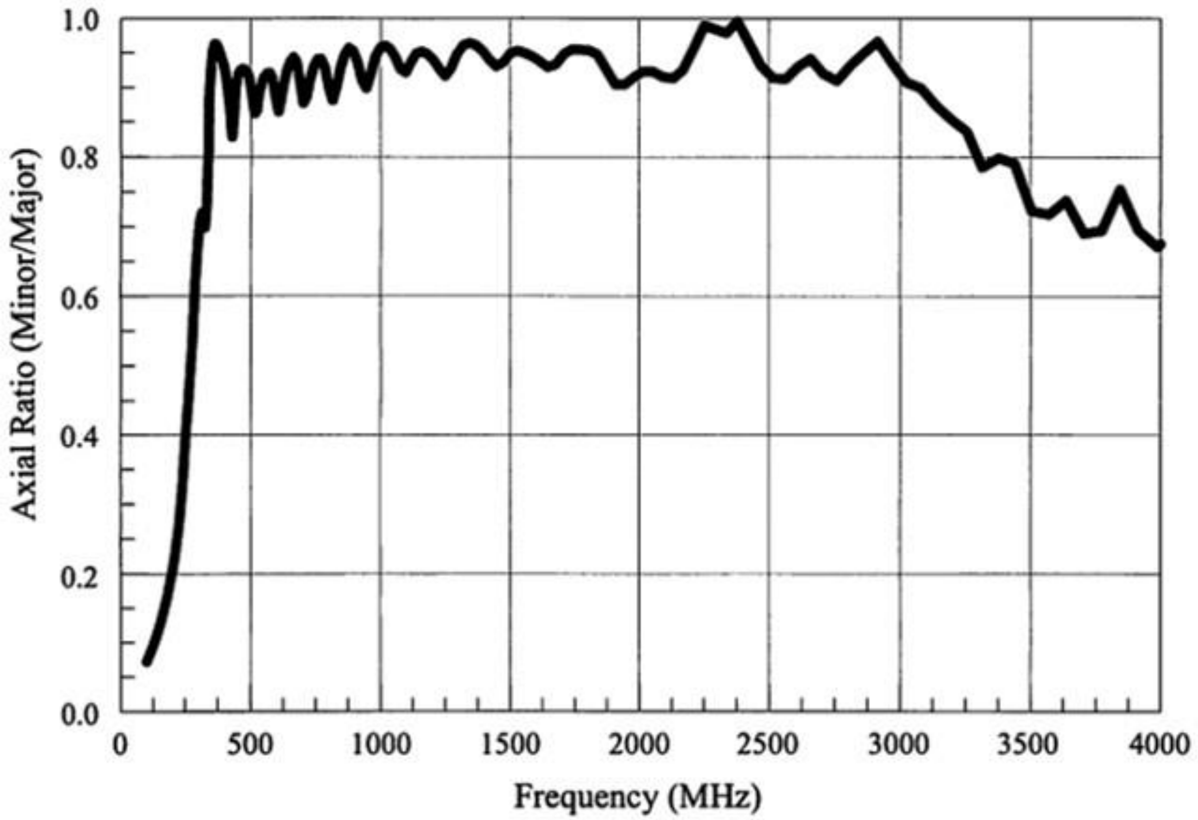


Numerical Results: Axial Ratio of 22- & 26-element LPDAs

26-element LPDA

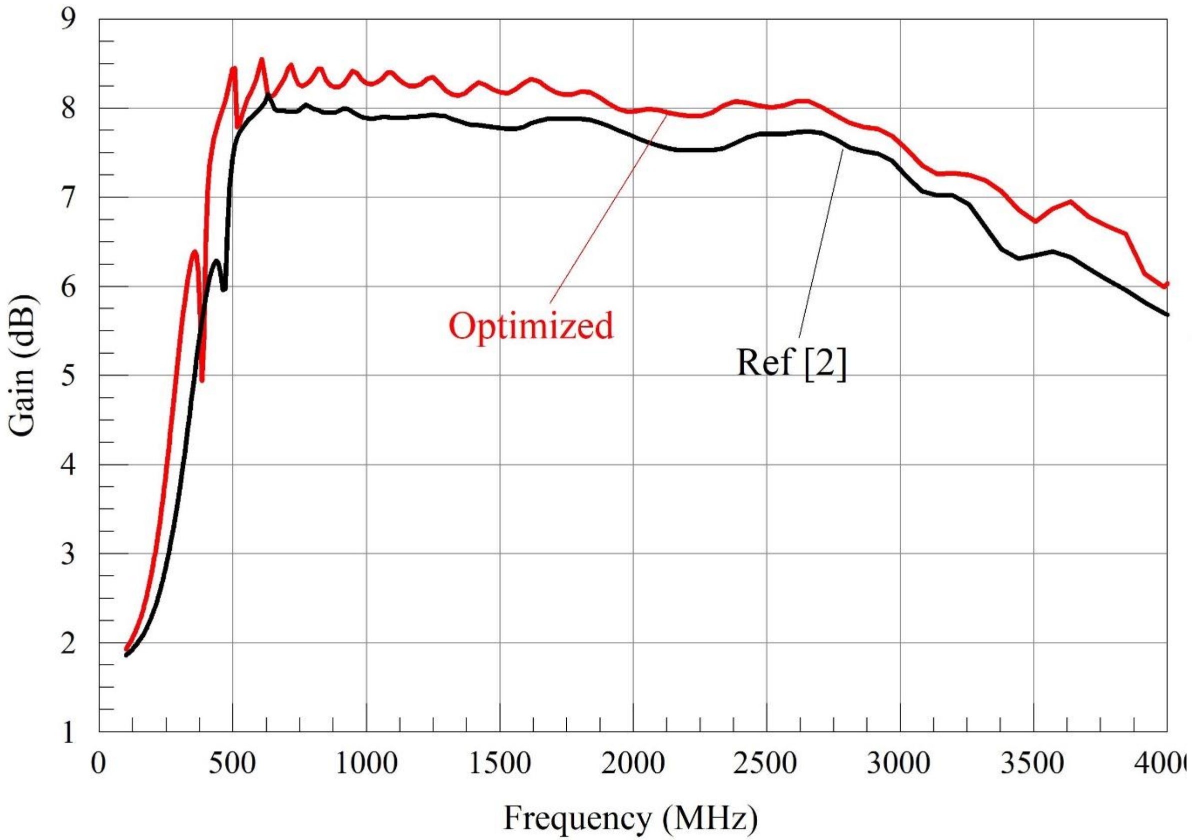


22-element LPDA

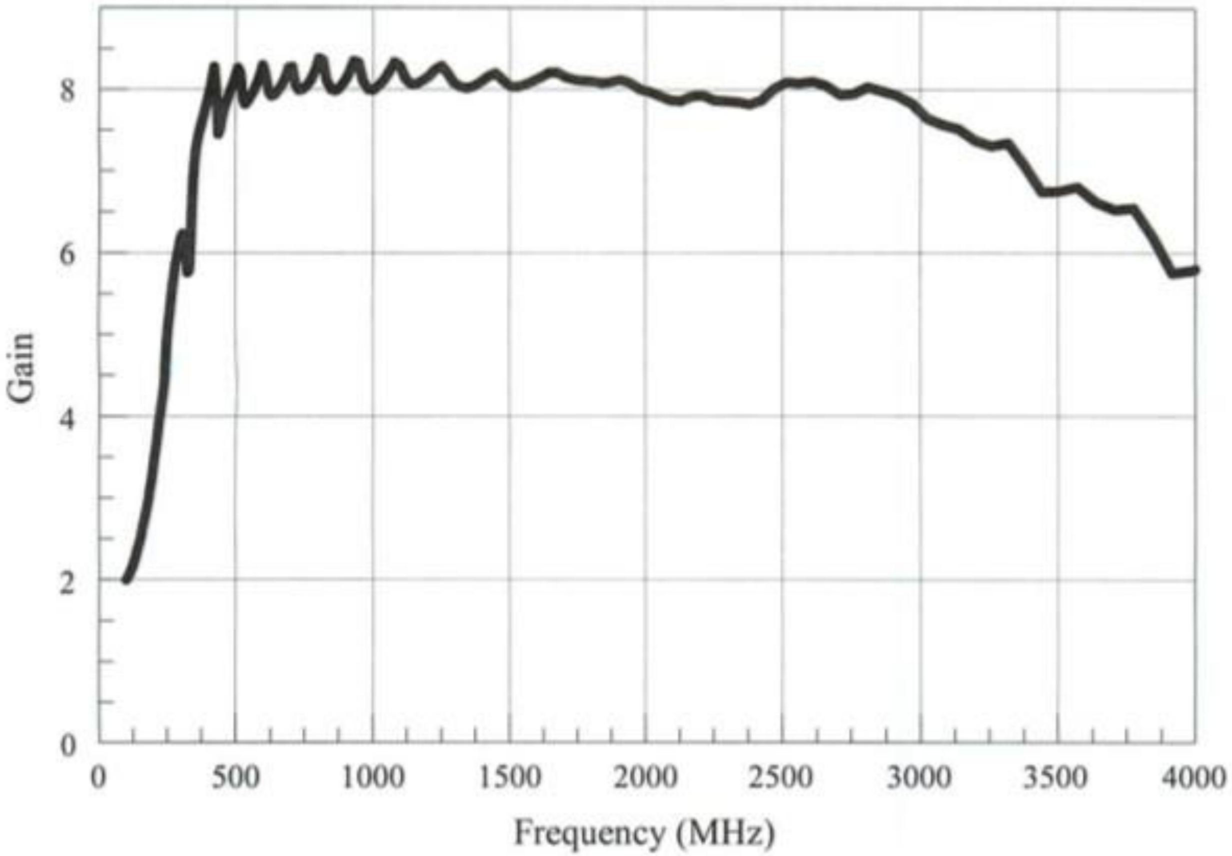


Numerical Results: Gain of 22- & 26-element LPDAs

26-element LPDA

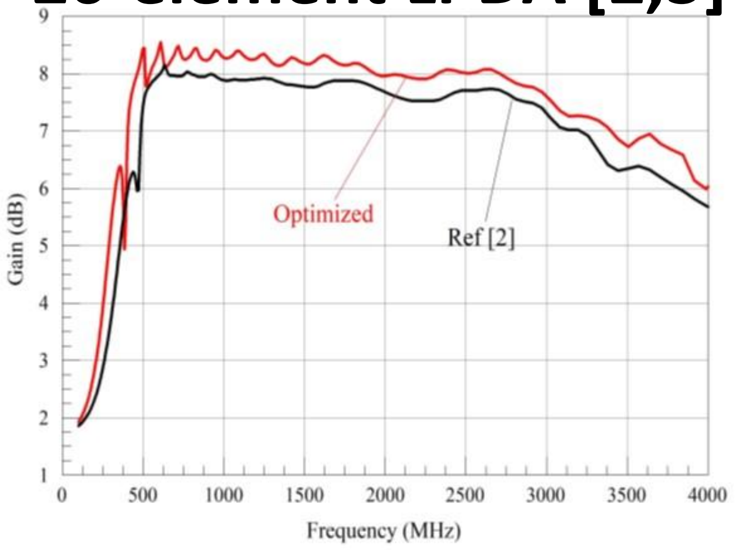


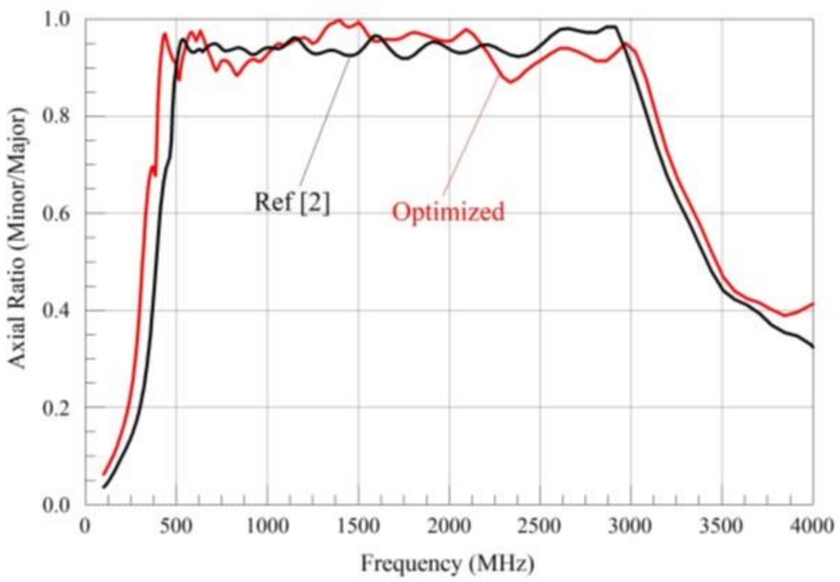
22-element LPDA

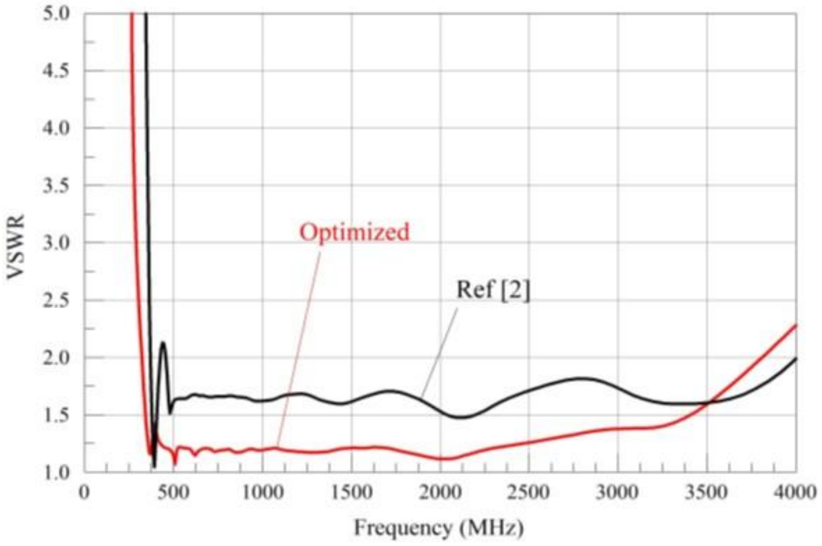


Numerical Results-Comparison of 26- and 22-element LPDAs

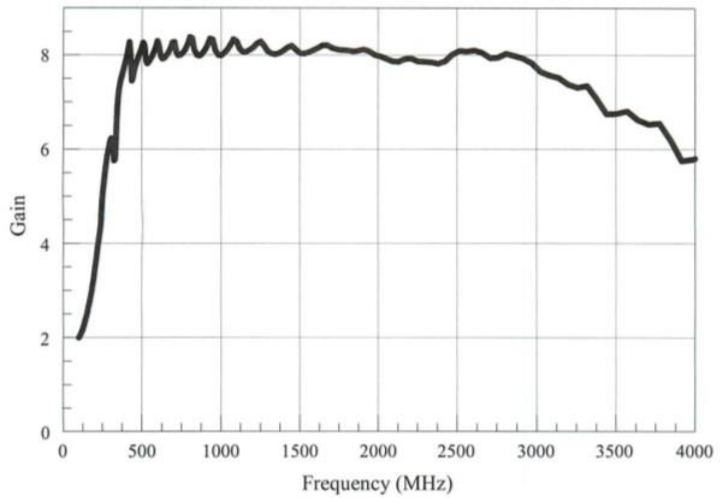
26-element LPDA [2,3]

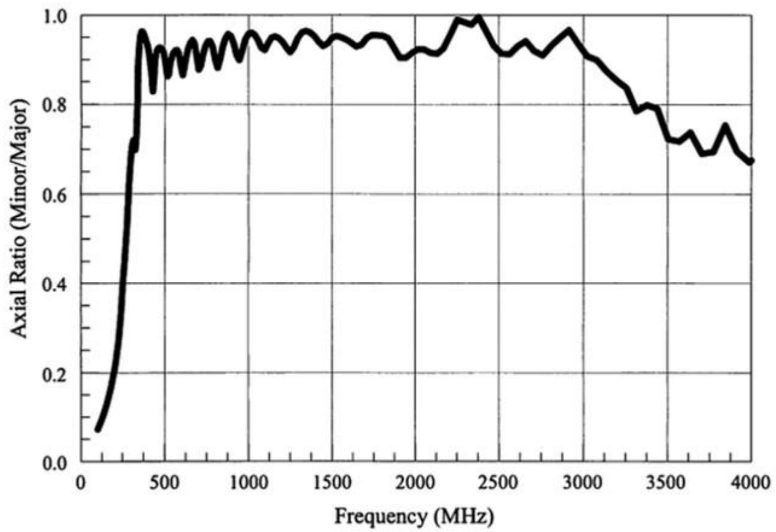


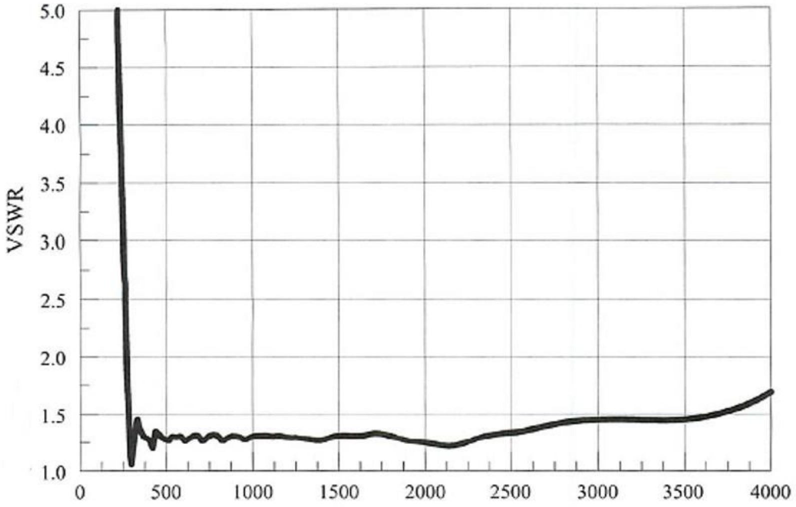




22-element LPDA







Conclusions and Next Steps

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

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

References

1. W. Stutzman and G. Thiele, *Antenna Theory and Design*, 2nd edition, Hoboken, NJ: John Wiley and Sons, 1998.
2. H. Foltz, J.S. McLean, R. Sutton, “LPDAs with Axial Twist in Each Period”, *2014 IEEE International Symposium on Antennas and Propagation*, Memphis, TN, July 6-14
3. C. Villalobos, E. Rodriguez-Hernandez, H. Foltz, “Optimization of LPDA Antennas with Axial Twist”, *Proceedings of the 2018 IEEE International Symposium on Antennas and Propagation*, Boston, MA, July 8-13

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Thank you.

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