Genetically Engineered Miniature Multiband Fractal Antennas

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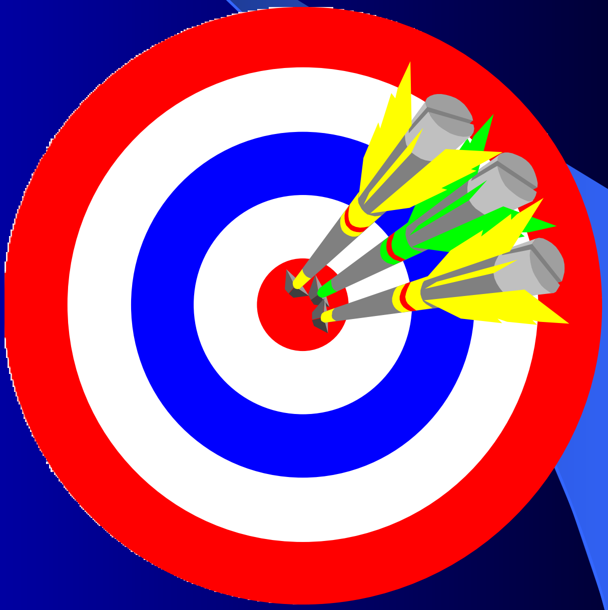
Overview

- **A review of IFS/GA technique developed for optimization of miniature multi-band Fractal Element Antennas (FEA)**
- **A new challenge in optimizing FEA**
- **An alternative approach – Matching Network**
- **Combination of loads and matching network to meet the design objective**

Goal

- **Goal is to produce antennas that are:**
  - Small
  - Efficient
  - Multi-band



Fractal Geometry Based on Iterated Function Systems (IFS)

- Proposed by Michael Barnsley at the Georgia Institute of Technology as a method to generate fractal structures
- Iterated Function Systems are one type of an affine transformation
  - Translate
  - Rotate
  - Scale (scaling always results in shrinkage)
- Coordinates of a point are transformed to a new position
- When applied to geometric figures, the figure is translated, rotated and shrunk. However, the original shape is preserved.

Fractal Geometry Based on Iterated Function Systems (IFS)

- **An affine transformation *w* is given by six numbers**
  - ***a*, *b*, *c* and *d* perform rotation and scaling**
  - ***e* and *f* perform linear translation**

$$\left(\begin{array}{cc:c} a_n & b_n & e_n \\ c_n & d_n & f_n \end{array}\right)$$

$$w_n(x,y) = (a_n x + b_n y + e_n\, ,\; c_n x + d_n y + f_n)$$

IFS Example - Koch Curve

1

$$w_1(x,y) = \left(\frac{1}{3}x + (0)y + 0, (0)x + \frac{1}{3}y + 0\right)$$

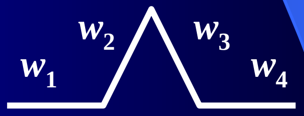
1/3

$$w_2(x,y) = \left(\frac{1}{6}x - \frac{\sqrt{3}}{6}y + \frac{1}{3}, \frac{\sqrt{3}}{6}x + \frac{1}{6}y + 0\right)$$

$$w_3(x,y) = \left(\frac{1}{6}x + \frac{\sqrt{3}}{6}y + \frac{1}{2}, -\frac{\sqrt{3}}{6}x + \frac{1}{6}y + \frac{\sqrt{3}}{6}\right)$$

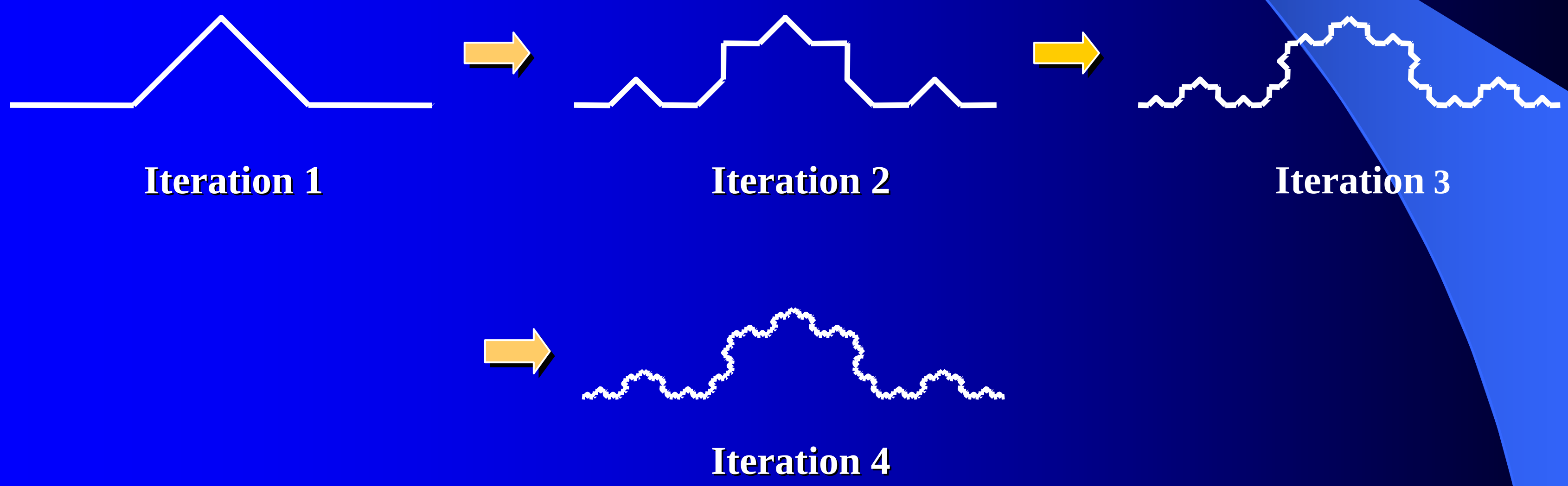
$$w_4(x,y) = \left(\frac{1}{3}x + (0)y + \frac{2}{3}, (0)x + \frac{1}{3}y + 0\right)$$

$$W(A) = w_1(A) \cup w_2(A) \cup w_3(A) \cup w_4(A)$$



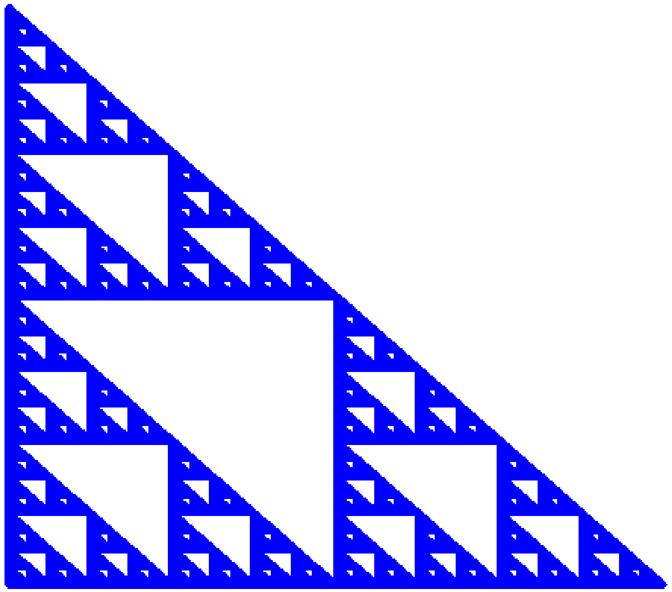
IFS Example - Koch Curve

Transformation is applied for each iteration to achieve higher levels of fractalization



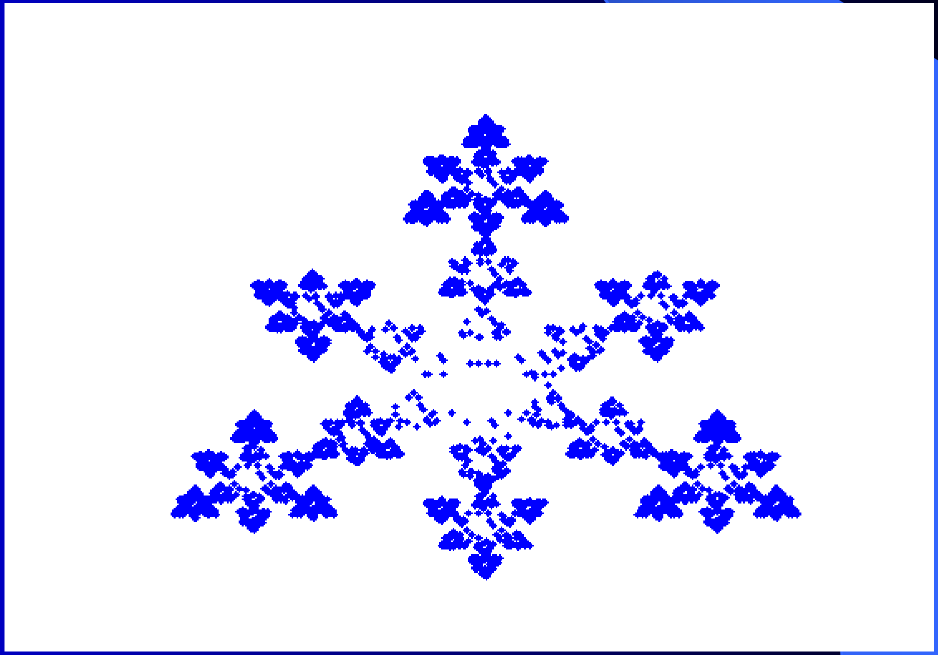
IFS Example - Sierpinski Gasket Variation

a	b	c	d	e	f
0.500	0.000	0.000	0.500	0.000	0.000
0.500	0.000	0.000	0.500	0.500	0.000
0.500	0.000	0.000	0.500	0.000	0.500



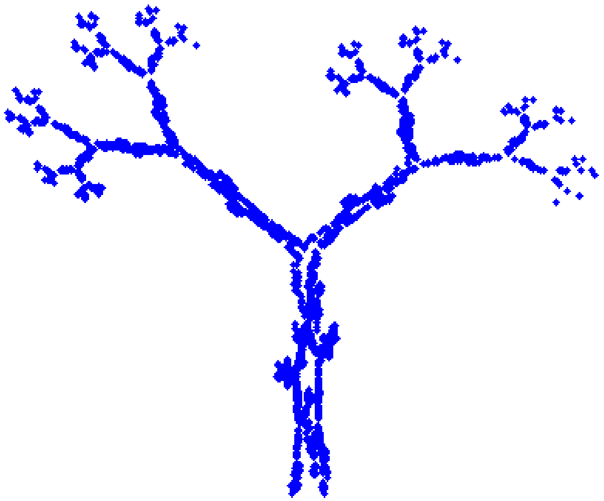
IFS Example – Fractal Crystal

a	b	c	d	e	f
0.255	0.0	0.0	0.255	0.3726	0.6714
0.255	0.0	0.0	0.255	0.1146	0.2232
0.255	0.0	0.0	0.255	0.6306	0.2232
0.370	-0.642	0.642	0.370	0.6356	-0.0061

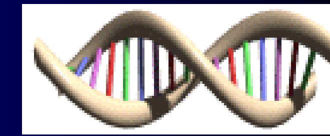


IFS Example - Fractal Tree

a	b	c	d	e	f
0.195	-0.488	0.344	0.443	0.4431	0.2452
0.462	0.414	-0.252	0.361	0.2511	0.5692
-0.058	–0.07	0.453	-0.111	0.5976	0.0969
-0.035	0.07	-0.469	-0.022	0.4884	0.5069
-0.637	0.0	0.0	0.501	0.8562	0.2513



Genetic Algorithms



- **Genetic Algorithms are an optimization procedure based on the mechanics of natural selection (i.e., survival of the fittest) and genetics**
  - **Children inherit traits from their parents and, as a result, resemble them in some fashion. This is achieved in GA via crossover and mutation operators.**
  - **Survival is based on the fitness of the individual, so that as time progresses there is an evolution in the genetic composition of individuals**
  - **The Genetic Algorithm can be viewed as a method for distilling good traits from a population of individuals, and recombining them to achieve a goal**
- **Effective when finding a global minimum in a high-dimension, multimodal function domain**

FEA Optimization

The Genetic Algorithm (GA) program is used in conjunction with an Iterated Function System (IFS) fractal geometry-generating subroutine and a Method of Moments (MoM) code to optimize the radiation characteristics of an antenna (e.g. VSWR, Gain, etc.) for the frequencies of interest.

Genetic Algorithm Fractal Design

The following parameters are simultaneously being selected by the GA

- **The geometry of the antenna (a_n, b_n, c_n, d_n, e_n and f_n)**
- **The load component values (*Ls* and *Cs*)**
- **The load locations**

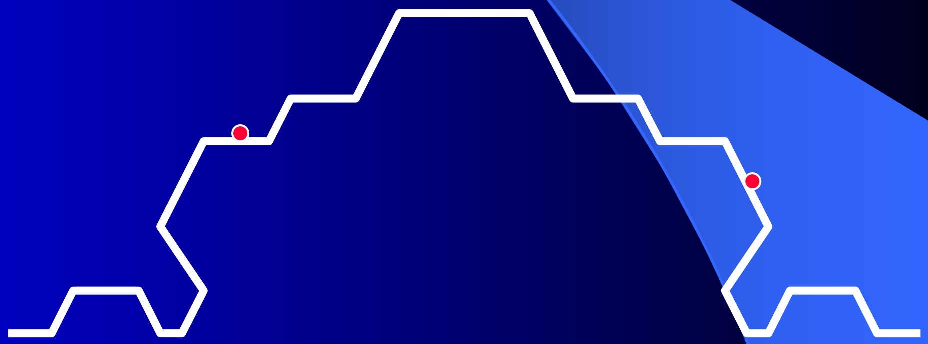
$$w_1(x,y) = (a_1x + b_1y + e_1,\ c_1x + d_1y + f_1)$$

$$w_2(x,y) = (a_2x + b_2y + e_2,\ c_2x + d_2y + f_2)$$

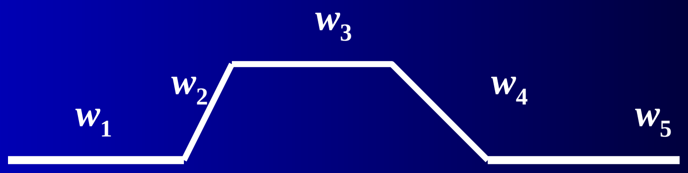
$$w_3(x,y) = (a_3x + b_3y + e_3,\ c_3x + d_3y + f_3)$$

$$w_4(x,y) = (a_4x + b_4y + e_4,\ c_4x + d_4y + f_4)$$

$$w_5(x,y) = (a_5x + b_5y + e_5,\ c_5x + d_5y + f_5)$$

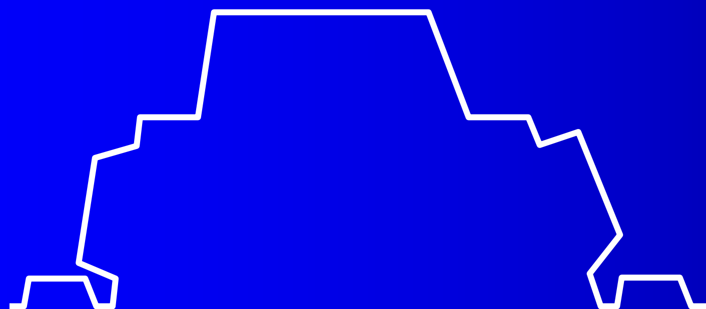


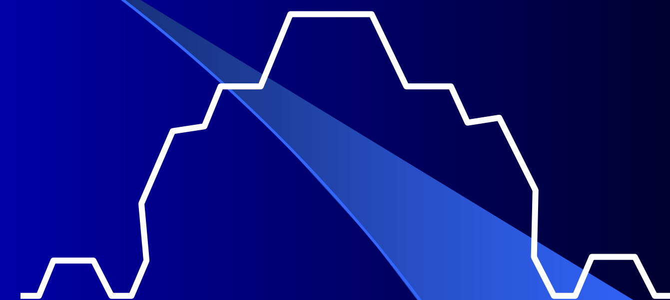
$W(x,y)=w_1(x,y)\cup w_2(x,y)\cup w_3(x,y)\cup w_4(x,y)\cup w_5(x,y)$ and

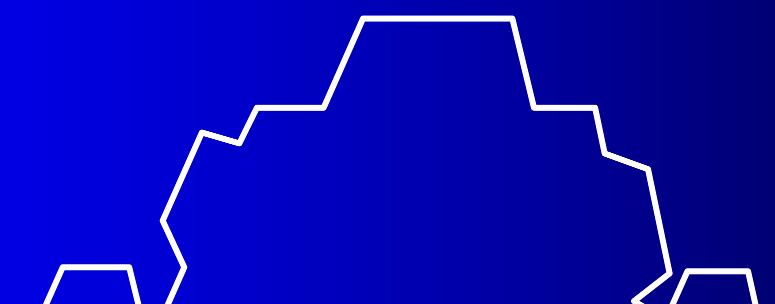


Where a_n, b_n, c_n, d_n, e_n and f_n are the parameters to be selected by the GA.

Some Examples of Genetically Engineered Fractal Antennas







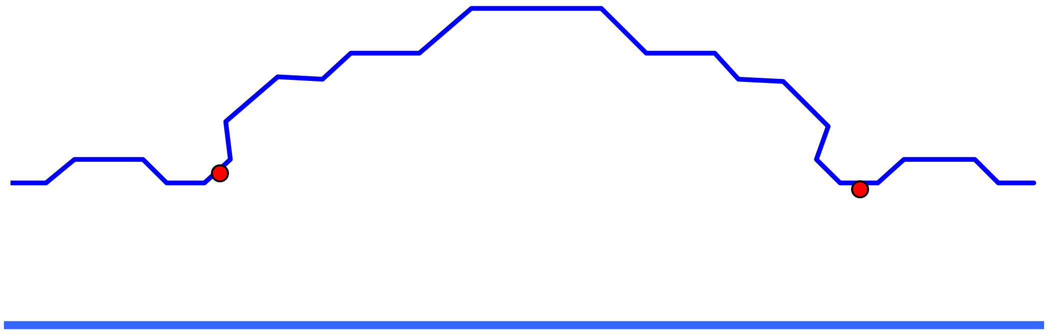
Miniaturizing A Dipole Antenna

Length of Antenna = 12 cm

Load Locations : Load1 Element 21 L1 = 15.81250 nH C1 = 0.4849 pF

Load2 Element 06 L2 = 17.98438 nH C2 = 0.7996 pF

Frequency	VSWR
1225 MHz	1.3383
1575 MHz	1.2872

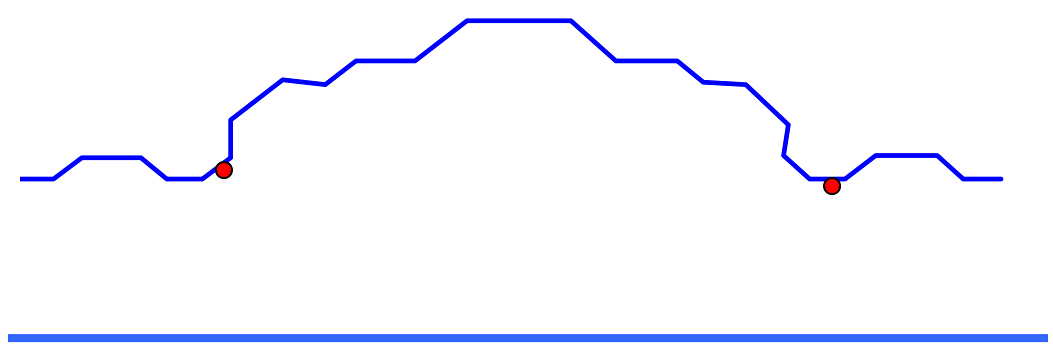


Length of Antenna = 11.5 cm

Load Locations : Load1 Element 21 L1 = 15.53125 nH C1 = 0.5376 pF

Load2 Element 06 L2 = 17.95312 nH C2 = 0.8453 pF

Frequency	VSWR
1225 MHz	1.2649
1575 MHz	1.2266

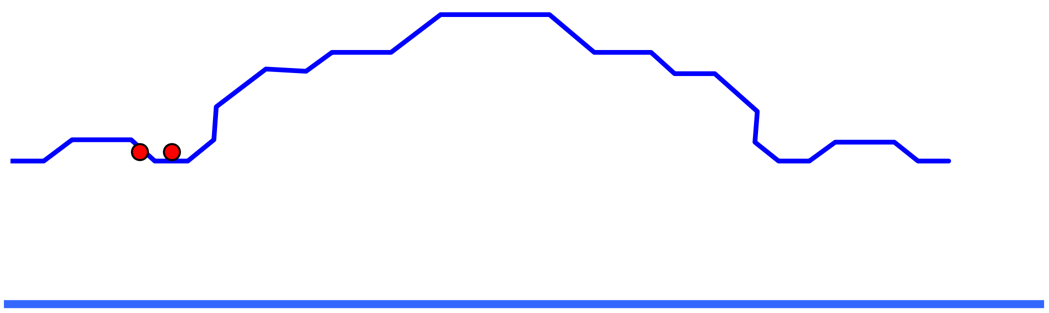


Length of Antenna = 11.0 cm

Load Locations : Load1 Element 05   L1 = 17.26562 nH   C1 = 0.4708 pF

Load2 Element 04   L2 = 17.89062 nH   C2 = 0.9648 pF

Frequency	VSWR
1225 MHz	1.0738
1575 MHz	1.3285

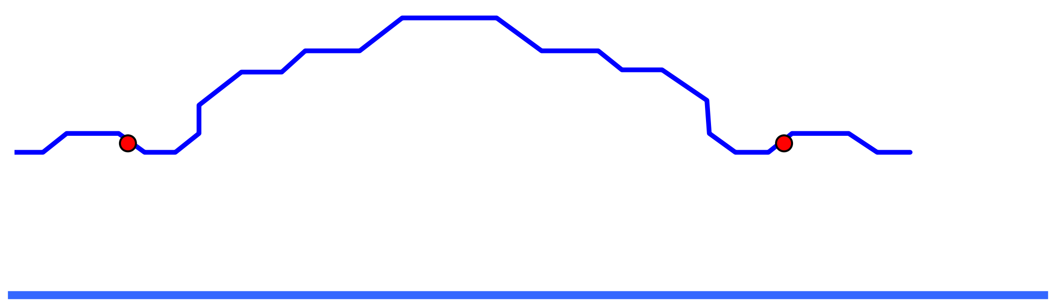


Length of Antenna = 10.5 cm

Load Locations : Load1 Element 22 L1 = 13.93750 nH C1 = 0.6414 pF

Load2 Element 04 L2 = 18.92188 nH C2 = 0.9050 pF

Frequency	VSWR
1225 MHz	1.1249
1575 MHz	1.1205

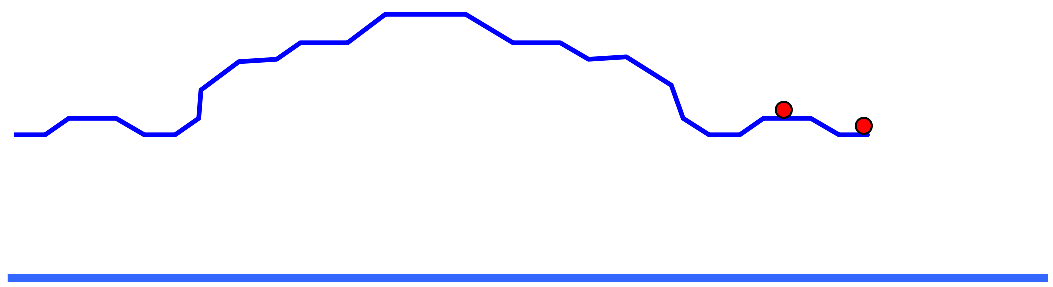


Length of Antenna = 10.0 cm

Load Locations : Load1 Element 25 L1 = 15.98438 nH C1 = 0.5746 pF

Load2 Element 23 L2 = 13.39062 nH C2 = 0.6712 pF

Frequency	VSWR
1225 MHz	1.1884
1575 MHz	1.1103

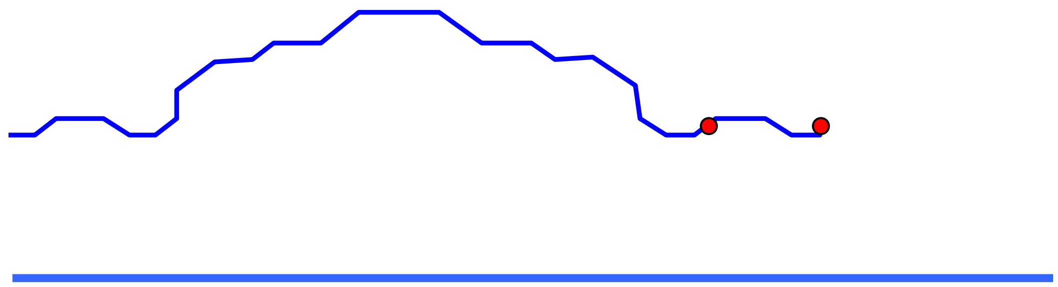


Length of Antenna = 9.5 cm

Load Locations : Load1 Element 22 L1 = 13.48438 nH C1 = 0.6941 pF

Load2 Element 25 L2 = 12.09375 nH C2 = 0.1509 pF

Frequency	VSWR
1225 MHz	1.0386
1575 MHz	1.1186

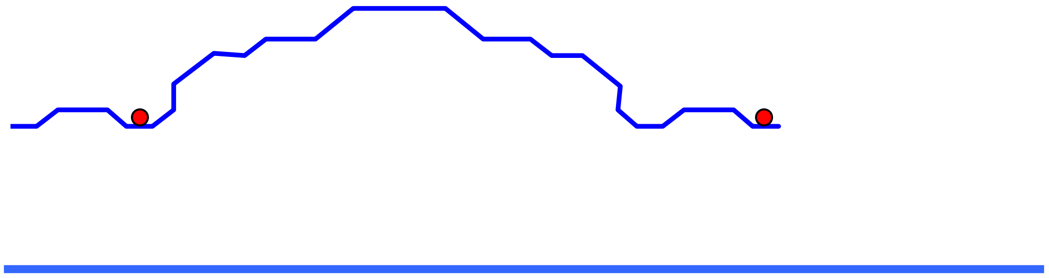


Length of Antenna = 9.0 cm

Load Locations : Load1 Element 25 L1 = 12.04688 nH C1 = 0.3302 pF

Load2 Element 05 L2 = 15.43750 nH C2 = 0.6642 pF

Frequency	VSWR
1225 MHz	1.0392
1575 MHz	1.1430

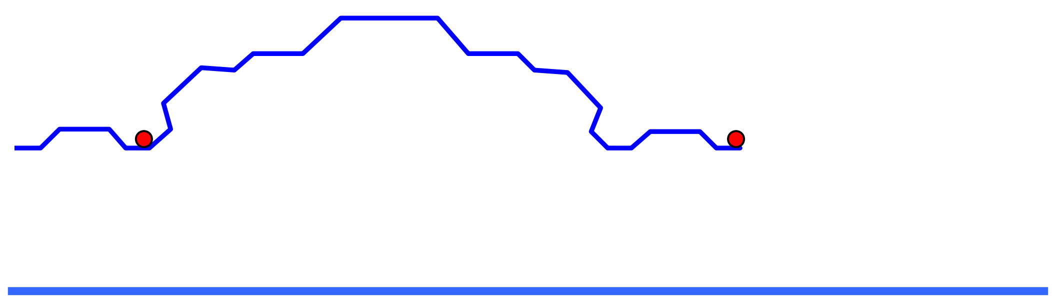


Length of Antenna = 8.5 cm

Load Locations : Load1 Element 25 L1 = 18.79688 nH C1 = 0.5570 pF

Load2 Element 09 L2 = 15.43750 nH C2 = 0.6853 pF

Frequency	VSWR
1225 MHz	1.1235
1575 MHz	1.0224

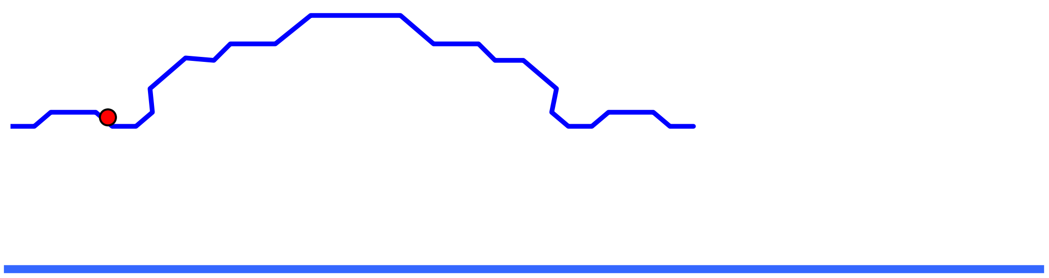


Length of Antenna = 8.0 cm

Load Locations : Load1 Element 04 L1 = 13.42188 nH C1 = 0.1457 pF

Load2 Element 04 L2 = 16.15625 nH C2 = 0.7644 pF

Frequency	VSWR
1225 MHz	1.1432
1575 MHz	1.0470

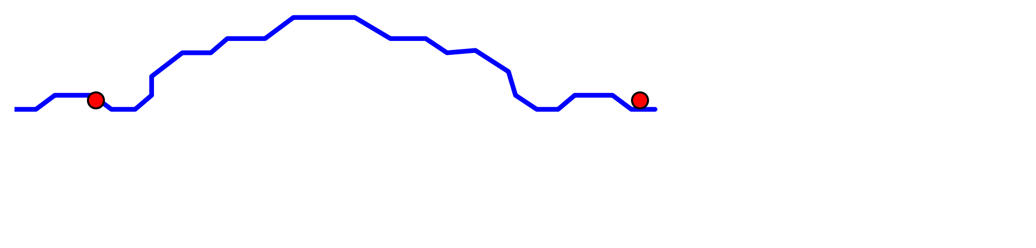


Length of Antenna = 7.5 cm

Load Locations : Load1 Element 04 L1 = 13.50000 nH C1 = 0.3671 pF

Load2 Element 25 L2 = 18.35938 nH C2 = 0.8910 pF

Frequency	VSWR
1225 MHz	1.0453
1575 MHz	1.1628

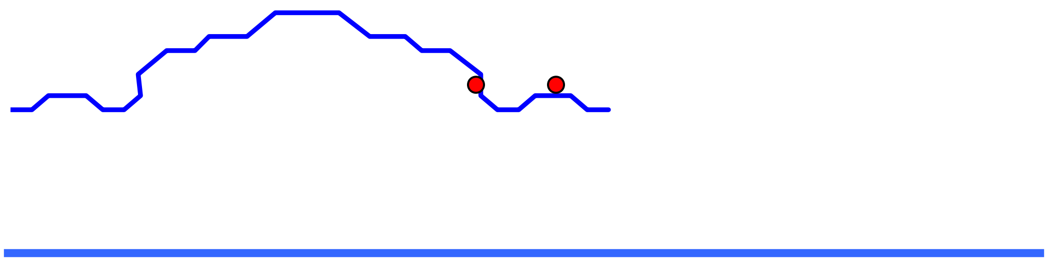


Length of Antenna = 7.0 cm

Load Locations : Load1 Element 23 L1 = 17.95312 nH C1 = 0.8119 pF

Load2 Element 19 L2 = 19.50000 nH C2 = 0.1017 pF

Frequency	VSWR
1225 MHz	1.3338
1575 MHz	1.1024

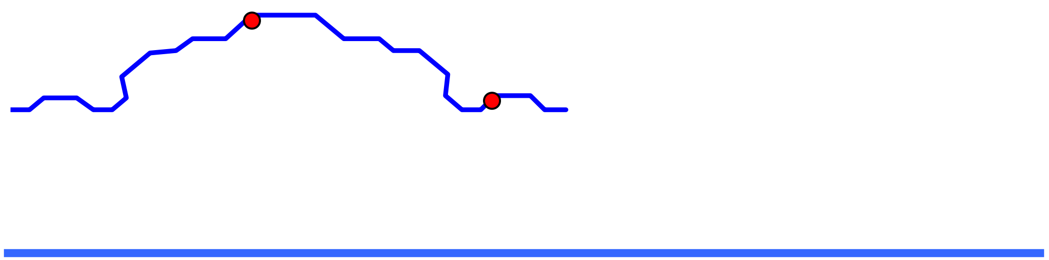


Length of Antenna = 6.5 cm

Load Locations : Load1 Element 22 L1 = 16.10938 nH C1 = 0.8962 pF

Load2 Element 12 L2 = 13.01562 nH C2 = 0.2107 pF

Frequency	VSWR
1225 MHz	1.6677
1575 MHz	1.4982

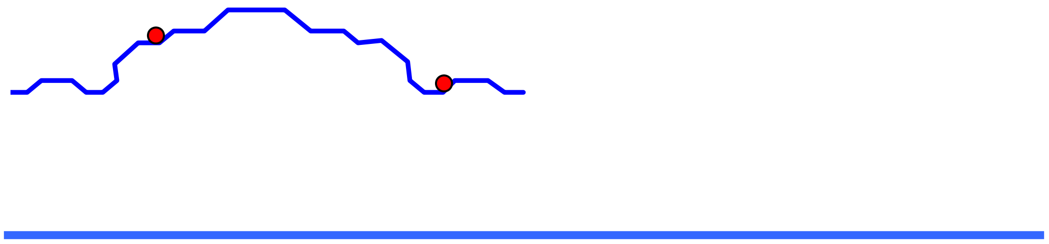


Length of Antenna = 6.0 cm

Load Locations : Load1 Element 22 L1 = 16.35938 nH C1 = 0.8962 pF

Load2 Element 09 L2 = 16.12500 nH C2 = 0.3214 pF

Frequency	VSWR
1225 MHz	1.6956
1575 MHz	1.4979

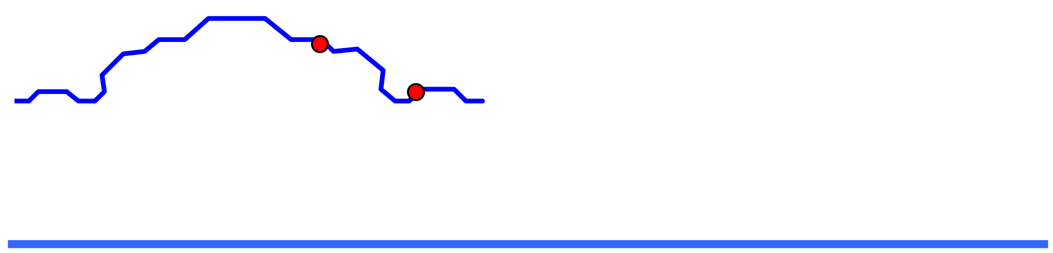


Length of Antenna = 5.5 cm

Load Locations : Load1 Element 22 L1 = 15.86914 nH C1 = 0.9308 pF

Load2 Element 16 L2 = 12.51172 nH C2 = 0.5371 pF

Frequency	VSWR
1225 MHz	1.9413
1575 MHz	1.7861



A New Challenge …

Current technology to manufacture the FEA requires the smallest possible *L & C* values in the loads

→

Less freedom and therefore potentially more difficulty for the GA to meet the design objectives

Design Accomplishments

- **Able to achieved the same design goal with smaller more practical *L* and *C* values by constraining parameters of the GA**

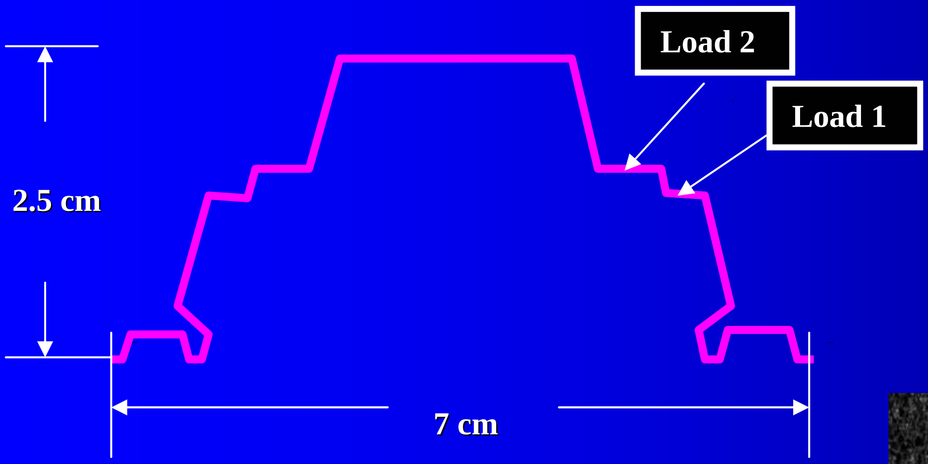
Developed New Design Schemes

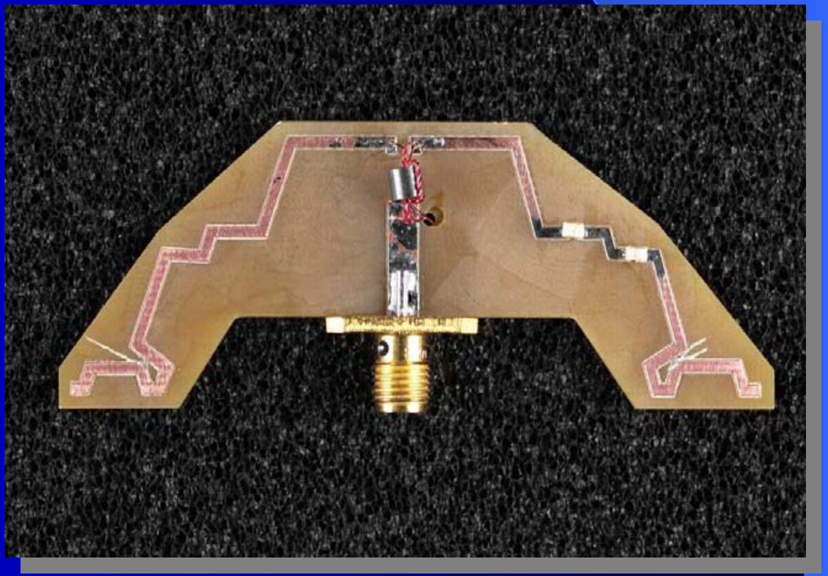
- **Matching network only – an alternative design approach to accomplish the same design objective**

- **Combination of a matching network together with loads to realize a more flexible design approach**

FEA with Small Components

(Design Example)





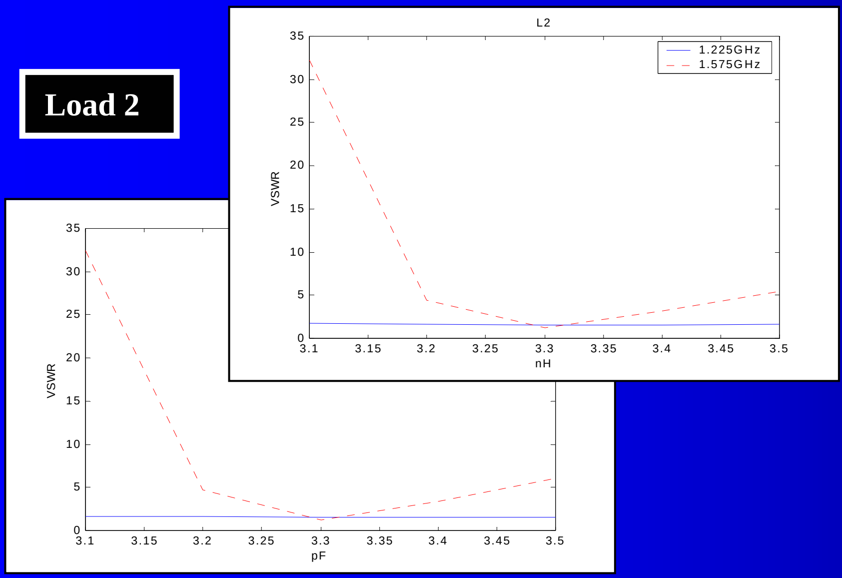
Load 1: $C1$ = 3.0 pF $L1$ = 2.7 nH

Load 2: $C2$ = 3.3 pF $L2$ = 3.3 nH

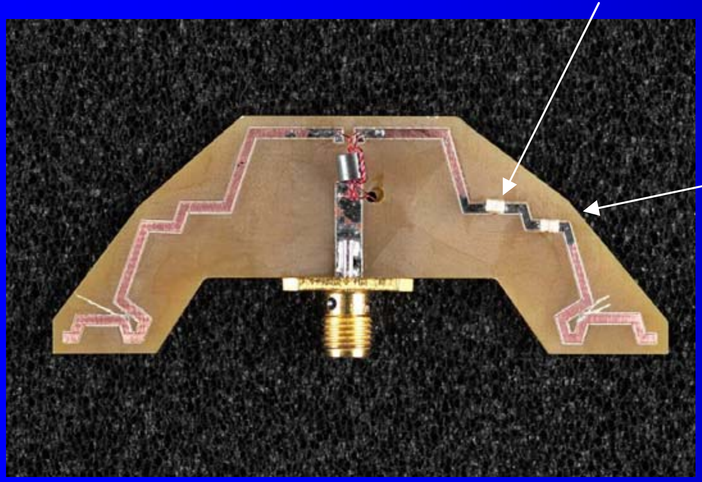
Small load component example - continued

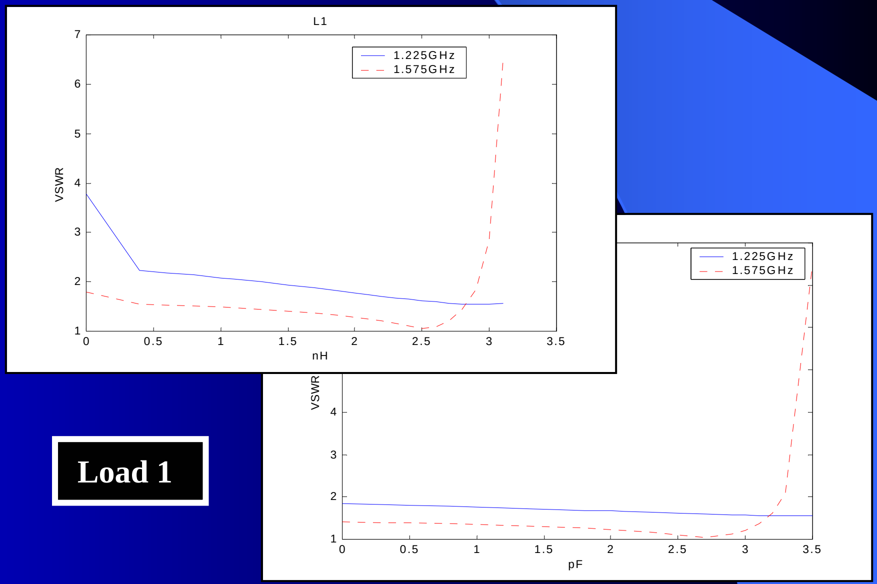
Load Component Sensitivity Study

Load 2



- Input VSWR goal is 2:1
- Resonate frequency of the loads
  - → Load 1: 1.8 GHz
  - → Load 2: 1.5 GHz (target 1.575 GHz)





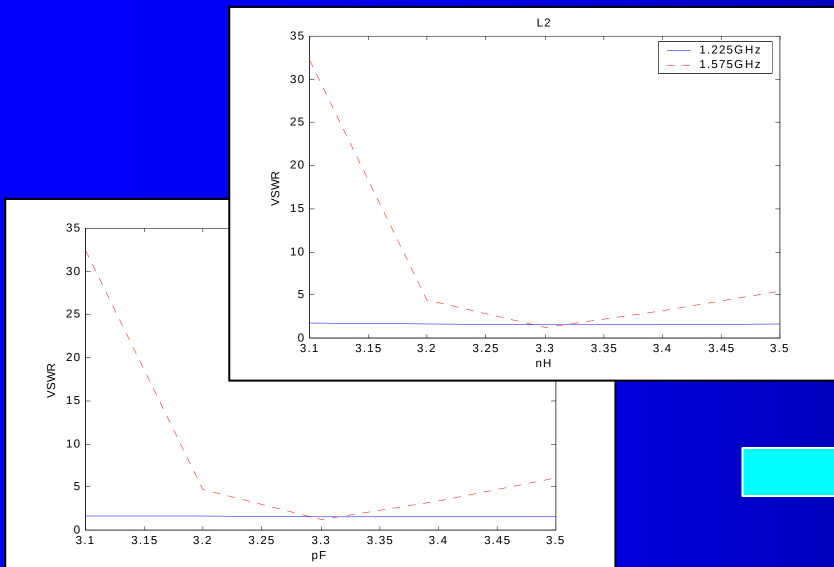
Load 1

Reduced Load Component Sensitivity Study

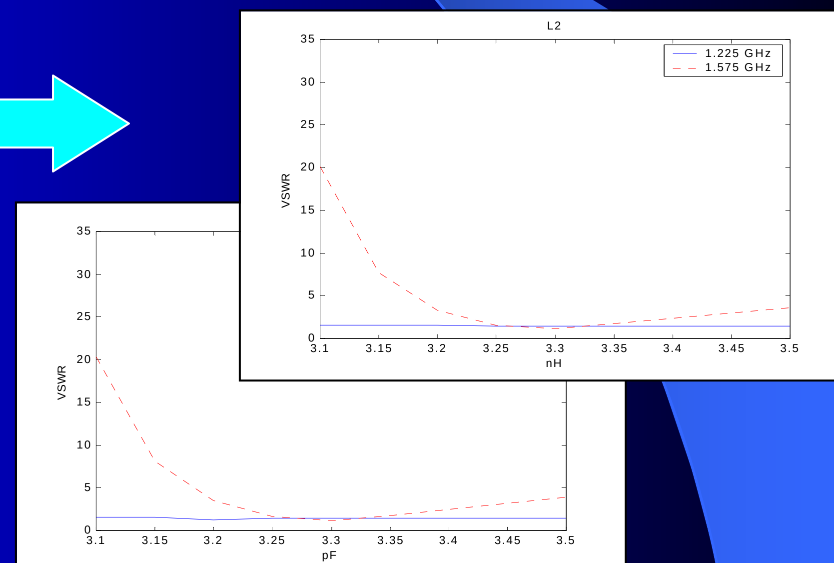
- High sensitivity requires very tight tolerances on the loads for proper antenna performance
- Values can change with changes in
  - material lots
  - manufacturing runs
  - temperature
- An effort was made to reduce the sensitivity of the load component values by optimizing for frequencies over a 26 MHz bandwidth centered at 1.575 GHz

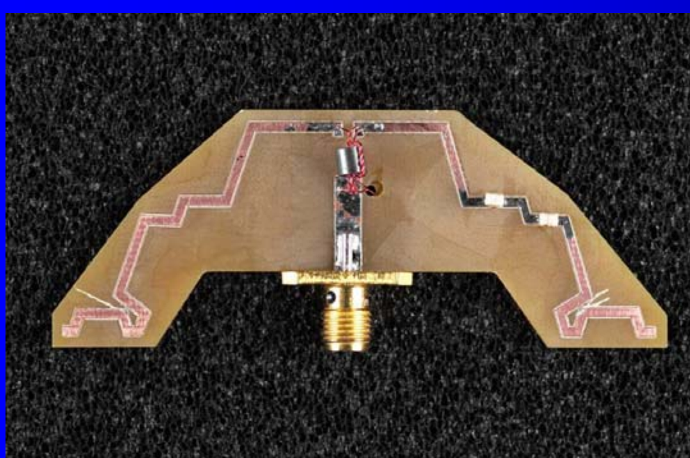
Small load component example - continued

Reduced Load Component Sensitivity Study



Sensitivity is minimized as shown for load 2





An Alternative Design Approach Using A Matching Network

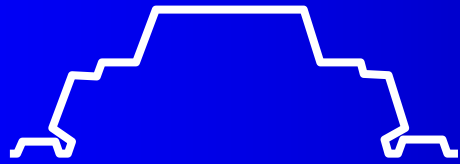
The objective of this effort was to achieve similar results to the loaded fractal antenna, but by using a reactive matching network in place of the loads on the wire.

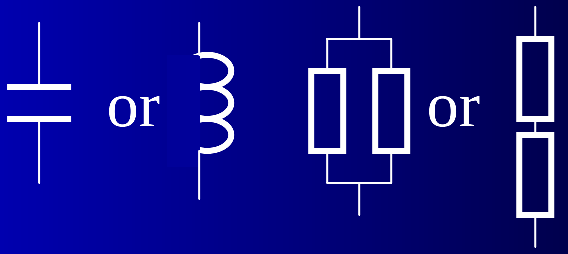
Matching Network - continued

The GA Simultaneously Optimizes

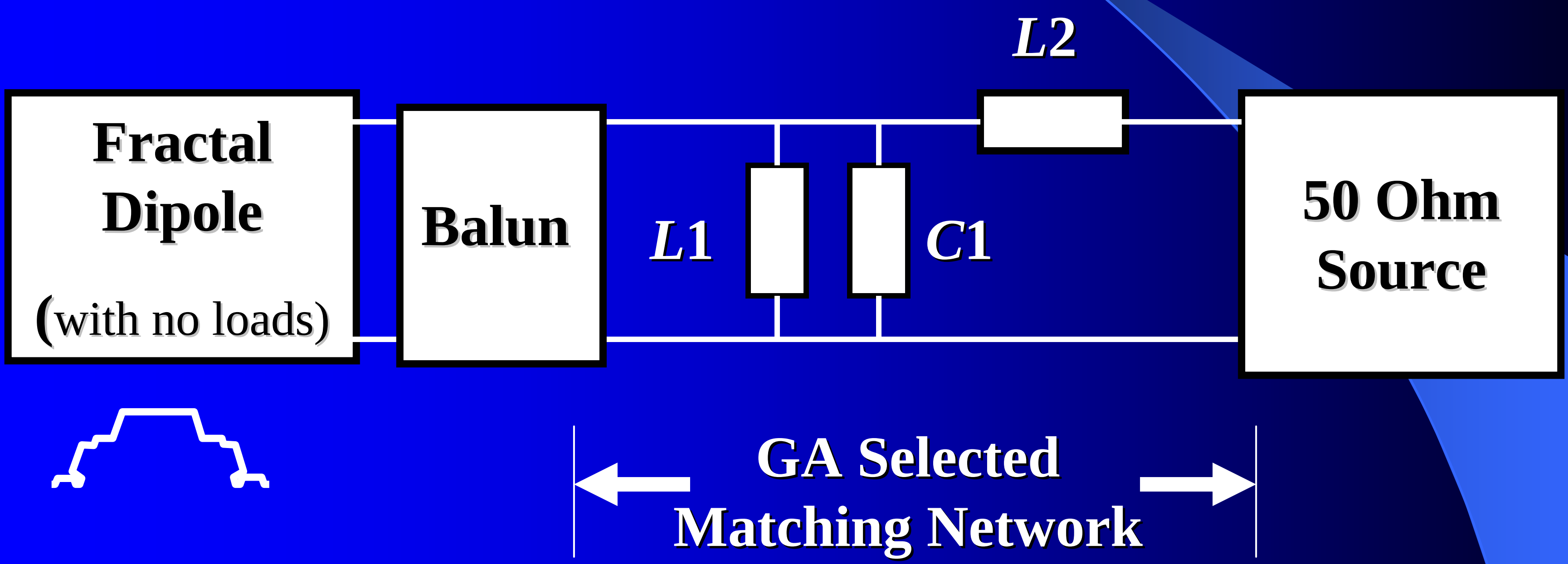
Fractal Antenna Geometry

Matching Network Topology & Component Values



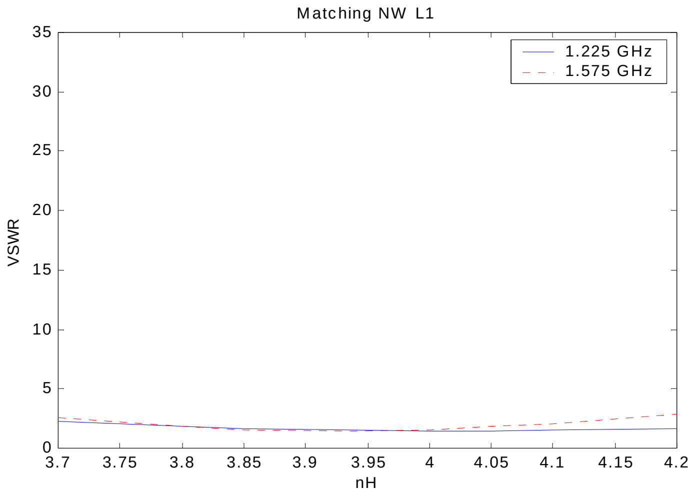


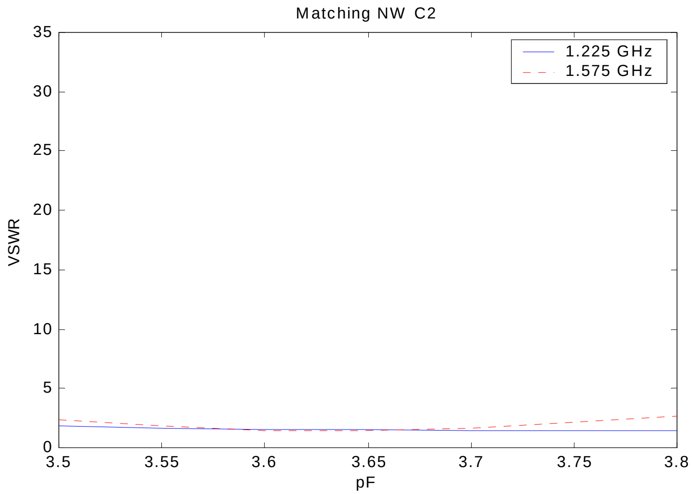
Matching Network – continued (Example)

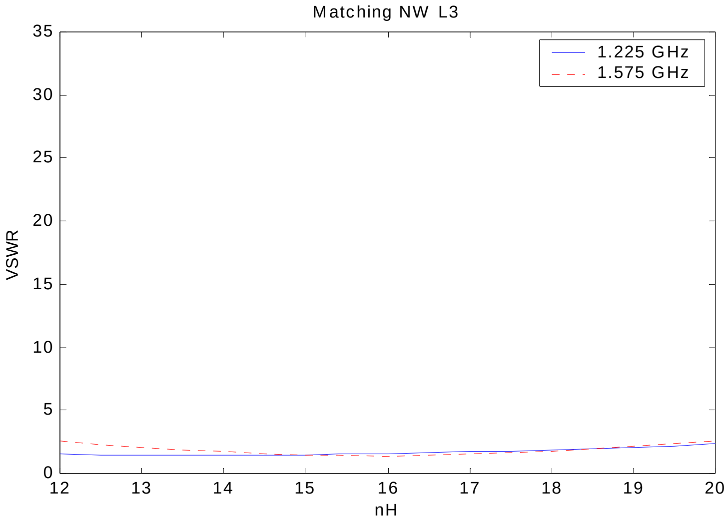


$L1$=3.938 nH $C1$=3.646 pF $L2$=15.407 nH

Sensitivity Study of Matching Network







Matching Network - continued

Advantages:

- The fractal antennas could be built (without loads) and measured impedances can be used in the GA to determine the optimal topology and component values for a matching network.
- Circumvents any problems that might be attributed to difference in wire thicknesses or shapes between simulated and measured fractal antennas.
- Allows even greater flexibility in the design of unloaded as well as loaded fractal antennas.

Matching Network - continued

Disadvantages:

- **Optimizing with matching network alone requires larger component values**

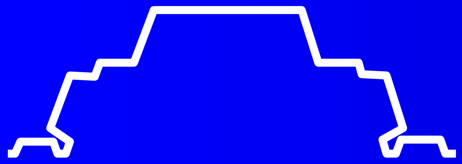
Matching Network & Loads

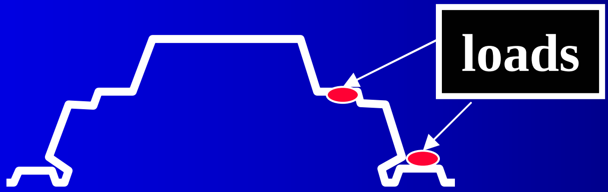
The GA Simultaneously Optimizes

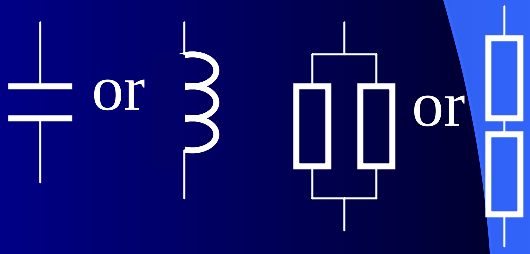
Fractal Antenna Geometry

Load Locations & Component Values

Matching Network Topology & Component Values

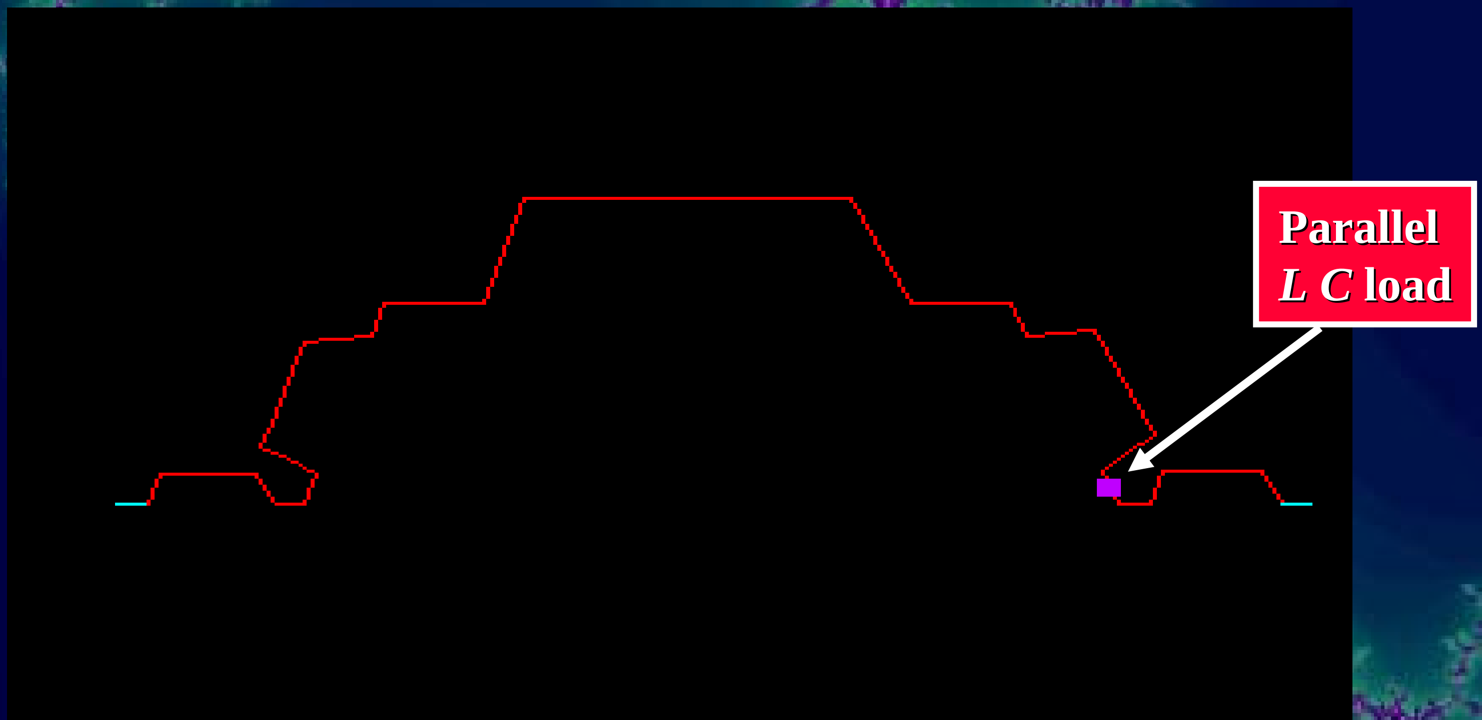






Matching Network & Loads

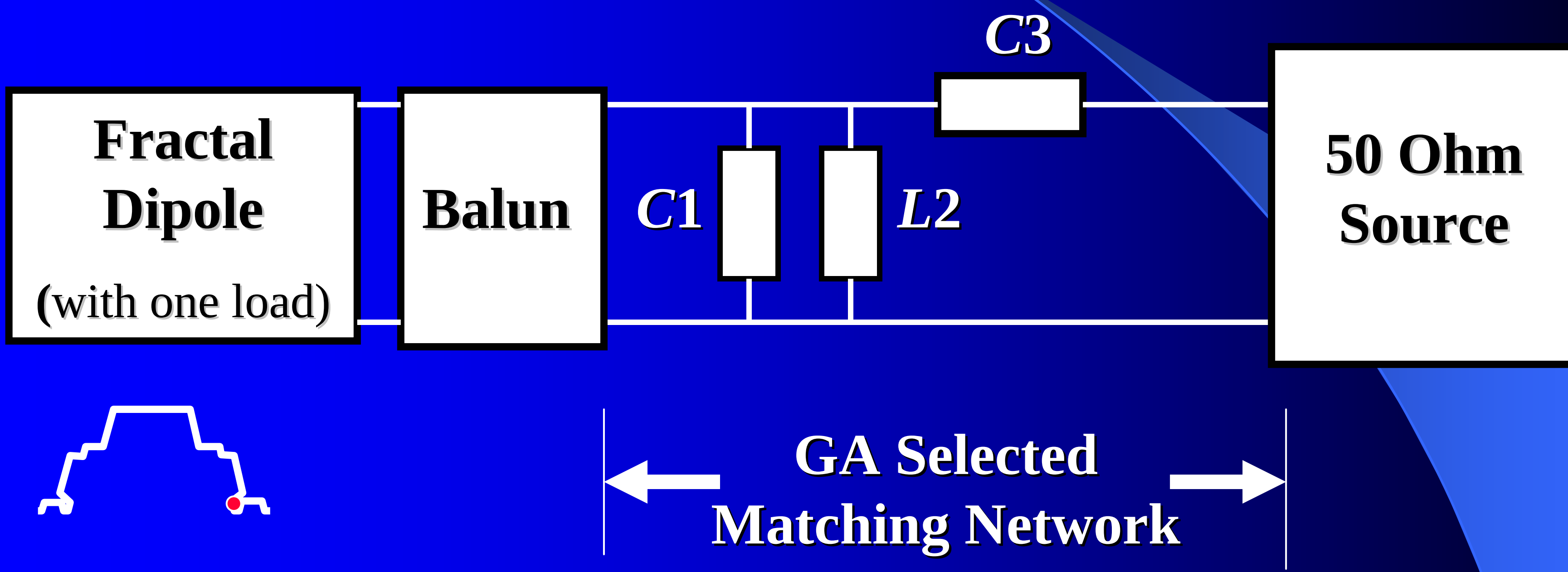
(Example)



Load values: $L = 3.3\ nH$ $C = 3.3\ pF$

Matching Network & Loads

(Example - continued)



*C*1=3.133 *pF* *L*2 = 3.184 *nH* *C*3 = 1.070 *pF*

Matching Network & Loads

(Example - continued)

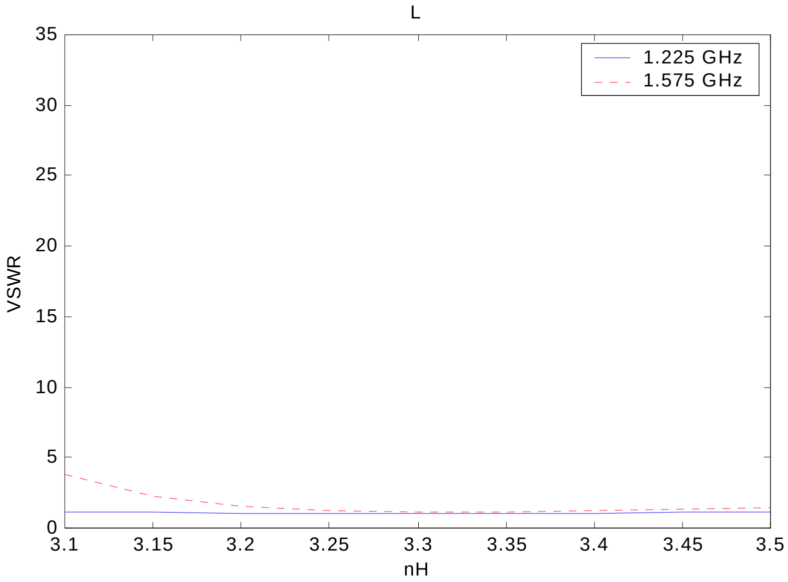
Load Values: $L = 3.3\ nH$ $C = 3.3\ pF$

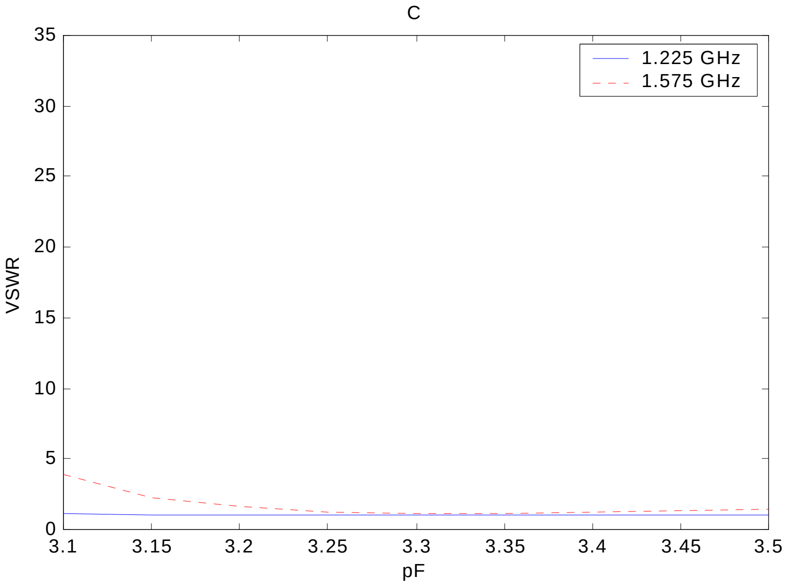
Matching Network Values:

$C1 = 3.133\ pF$ $L2 = 3.184\ nH$ $C3 = 1.070\ pF$

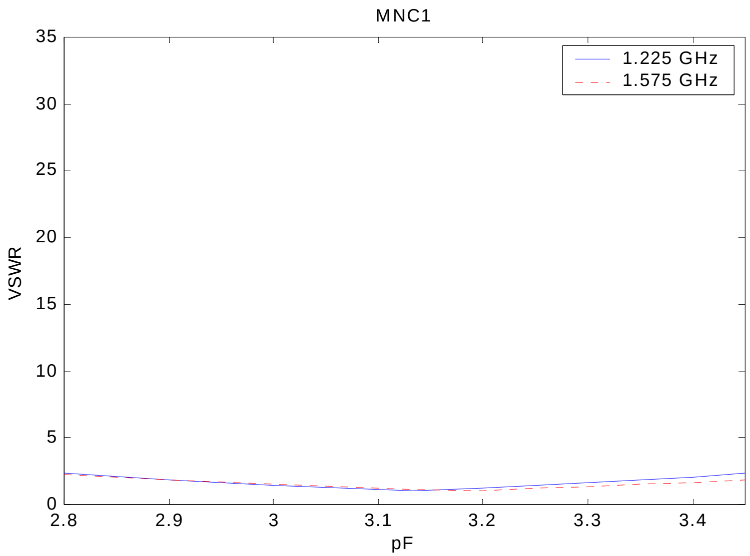
Frequency (MHz)	VSWR (goal 2:1)
1225.0	1.061111
1562.0	1.676220
1565.0	1.510146
1575.0	1.106058
1580.0	1.147770
1585.0	1.332390
1588.0	1.463225

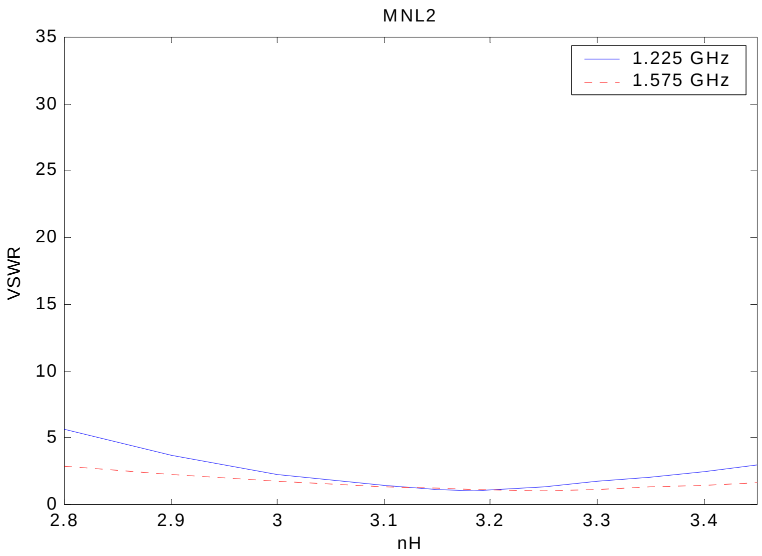
Load Sensitivity Study

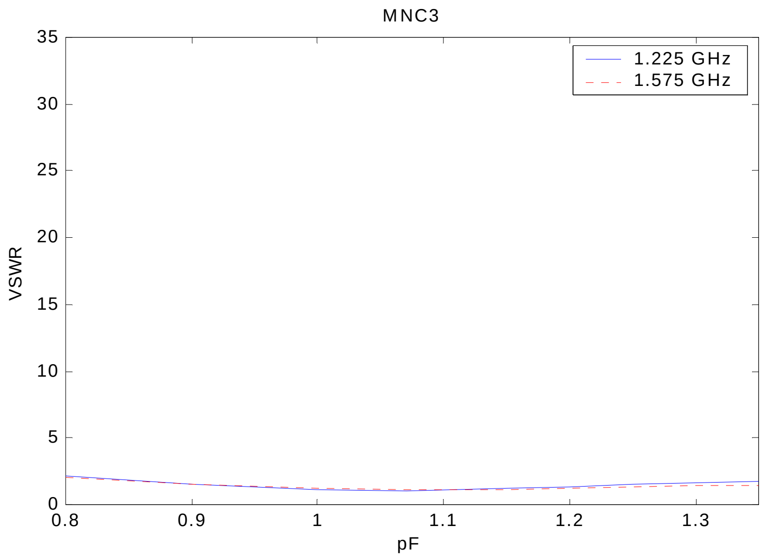




Matching Network Sensitivity Study







Summary

A powerful new tool has been developed for the design of miniature multi-band antennas with practical component values for loads and matching networks. The new technique allows the GA to simultaneously optimize:

- The fractal antenna geometry
- Load component values and locations
- Matching network topology and component values