

APPLICATION OF TWO-LEVEL EVOLUTIONARY ALGORITHMS TO SELF-STRUCTURING ANTENNAS

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A Self-structuring antenna (SSA) is capable of altering its electrical shape in response to changes in its electromagnetic environment. An SSA template is an arrangement of wires interconnected by controllable on or off switches and is the intended radiator or receiver of electromagnetic energy. The states of the switches determine the electrical characteristics of the SSA template. An embedded microprocessor is used to evaluate sensor feedback such as SWR or received signal strength to help make decisions on subsequent switch configurations. A binary search algorithm such as a genetic, simulated annealing, or Ant Colony Optimization (ACO) algorithm is used by the microprocessor to reduce the searching time required to find a switch configuration with desirable electrical characteristics. The SSA has been demonstrated in previous work both experimentally (C. M. Coleman, E. J. Rothwell, and J. E. Ross, *IEEE AP-S Int. Symp.*, Salt Lake City, Utah, 2000) and in simulation (J. E. Ross, E. J. Rothwell, C. M. Coleman, and L. L. Nagy, *URSI National Radio Science Meeting*, Salt Lake City, Utah, 2000). The SSA has recently been granted US patent 6178325.

One goal of this research is to synthesize non-intuitive template geometries with desirable capabilities. This is accomplished in part by incorporating a two-level evolutionary algorithm in the SSA simulation. The outer algorithm will generate varying template geometries (arrangements of wires and switch locations). The inner algorithm, performed for each template geometry, will evaluate the fitness of configurations (sets of template switch states) and search for optimal configurations. The NEC-4 program will be used as the EM solver to evaluate the fitness of template configurations by computing their electrical characteristics (pattern, impedance, received signal strength, etc.). The outer algorithm will generate subsequent template geometries based on information obtained from the inner algorithm.

An additional objective of this research is to use a two-level evolutionary algorithm to locate optimal search parameters for a given template geometry. An inner algorithm will search for optimal configurations. An outer algorithm will alter the parameters of the inner search algorithm to search for optimal algorithm parameters. For example, if an inner genetic algorithm is used, mutation rate, probability of crossover, fitness function, etc., will be varied. Use of these optimal parameters will reduce the time required to search for optimal configurations in experimental SSAs.

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1. Commission and session topic: B1.1 Antenna Analysis and Design

2. Required presentation equipment: Overhead projector (viewgraphs)

3. Corresponding author:

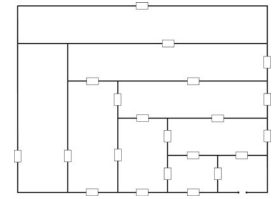
Edward J. Rothwell
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4. Interactive forum: Not requested

5. Do all authors require acknowledgement of abstract acceptance? No

6. New knowledge contributed by paper: This is the first application of a two-level search algorithm to self-structuring antenna simulations.

7. Relationship to previous work: Self-structuring antennas have been introduced by the authors in previous work. The authors have performed self-structuring antenna simulations using a genetic algorithm searching routine. This work extends the simulations using other types of searching algorithms, including a two-level approach.



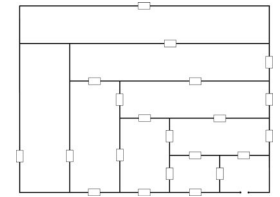
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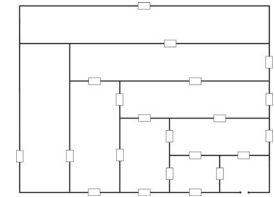
L.L. Nagy
Delphi Automotive Systems
30500 Mound Road
Warren, MI 48090-9055

Overview



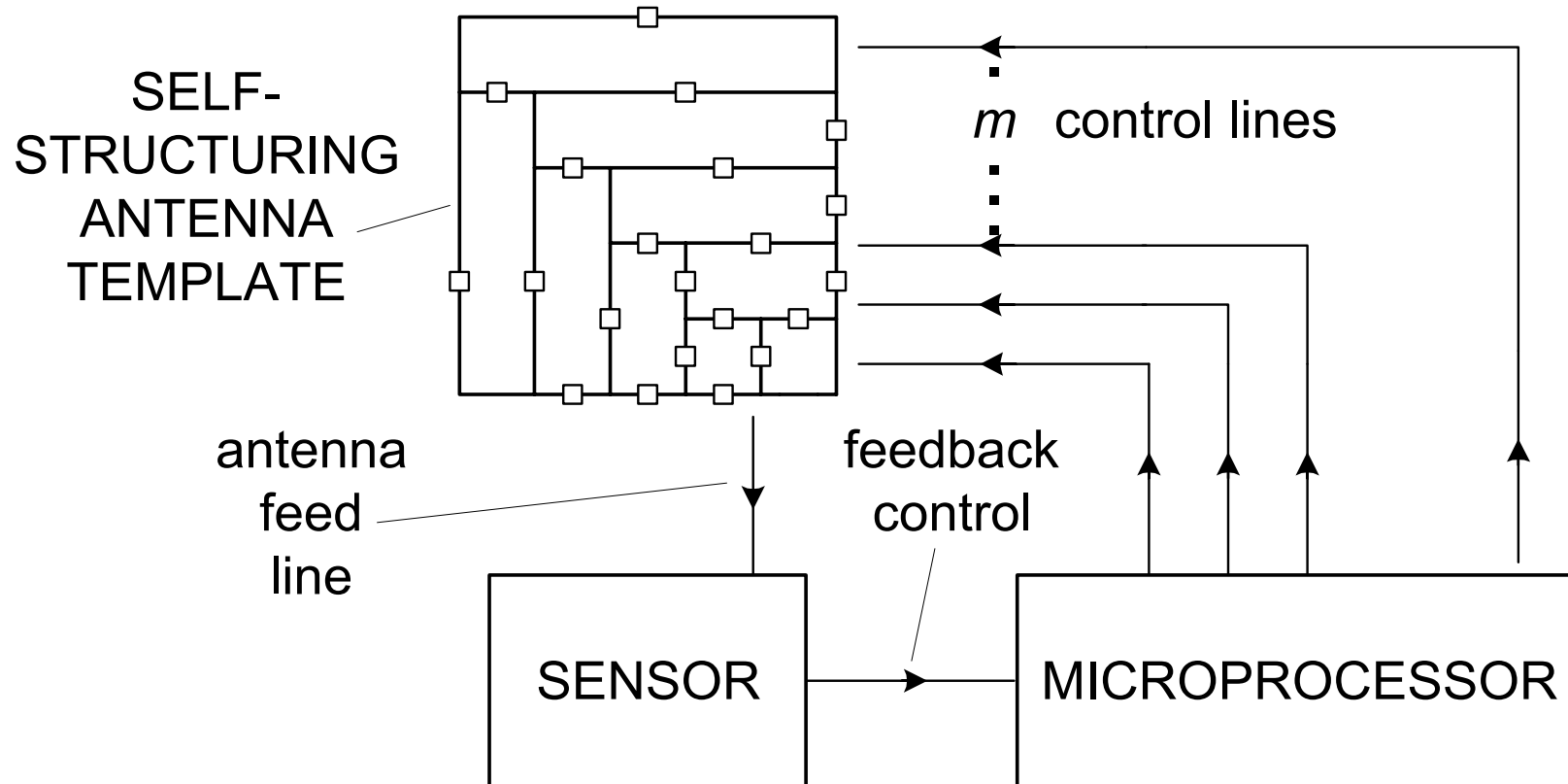
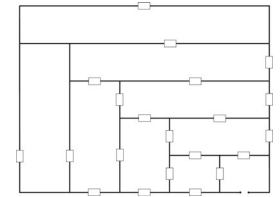
- **Review of Self-Structuring Antennas and Goals of Research**
- **Computer Simulation Program**
- **Searching Algorithms**
- **Results**
- **Conclusion and Future Work**

Review of Self-Structuring Antennas



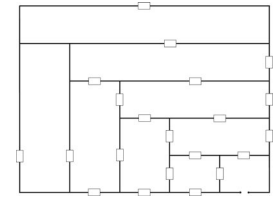
- **A ‘self-structuring antenna’ system:**
 - **Is capable of arranging itself into a large number of different possible configurations. The electromagnetic characteristics of each configuration are usually unknown at the onset of operation of the antenna system.**
 - **Uses information that it obtains from a receiver or sensor that measures the fitness of each configuration to make decisions on the future configurations of the antenna**
 - **Uses a binary search routine such as simulated annealing, ant colony optimization (ACO), or genetic algorithms to quickly search through the possible configurations**
 - **Is capable of re-optimization when its electromagnetic environment changes to provide an antenna configuration with desired properties**

Block Diagram of SSA System

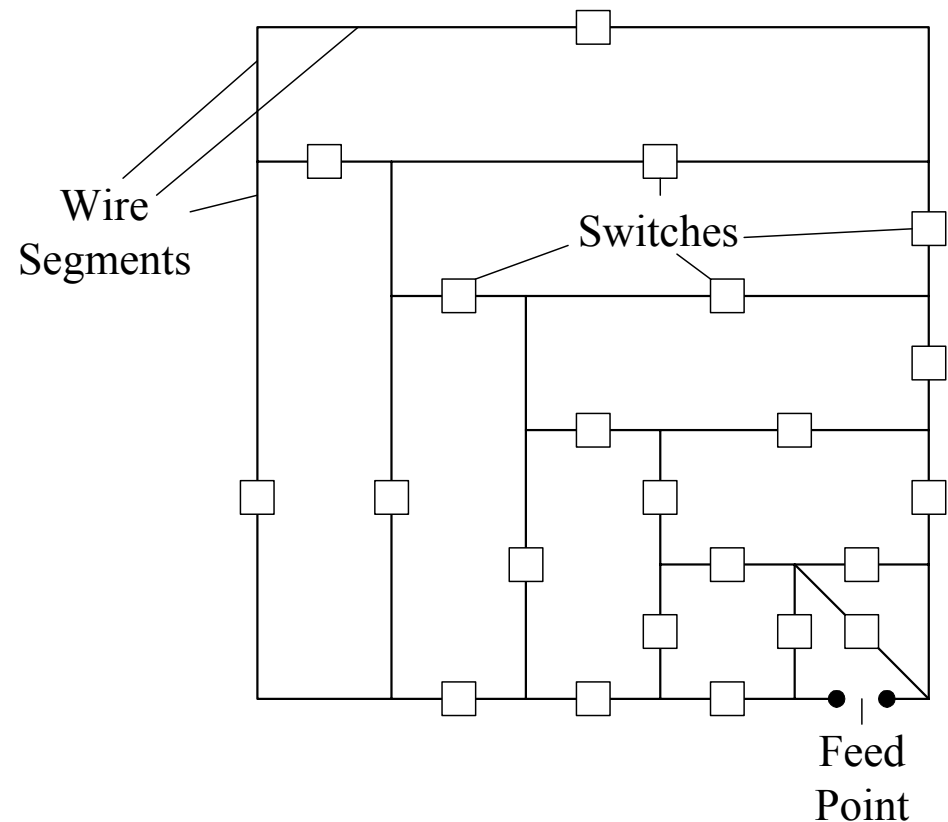


Block Diagram of Self-Structuring Antenna System

Self-Structuring Antenna Template

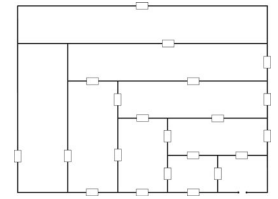


- A self-structuring antenna template is comprised of a large number of wire segments interconnected by controllable switches.
- For each configuration, the states of the switches determine the electrical characteristics of the antenna.
- For a template with n switches, there are 2^n possible configurations.



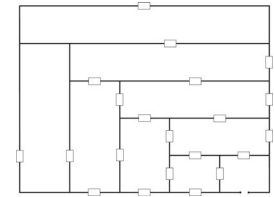
Example Self-Structuring
Antenna Skeleton

Goal of Research



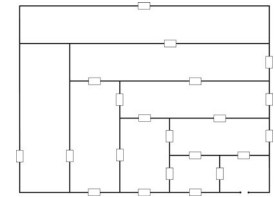
- **The goal of this research is to:**
 - **Develop two-level algorithms and use the outer algorithm to search for optimal geometry parameters of a self-structuring antenna template. The inner algorithm searches for optimal self-structuring antenna configurations.**

Computer Simulation Program

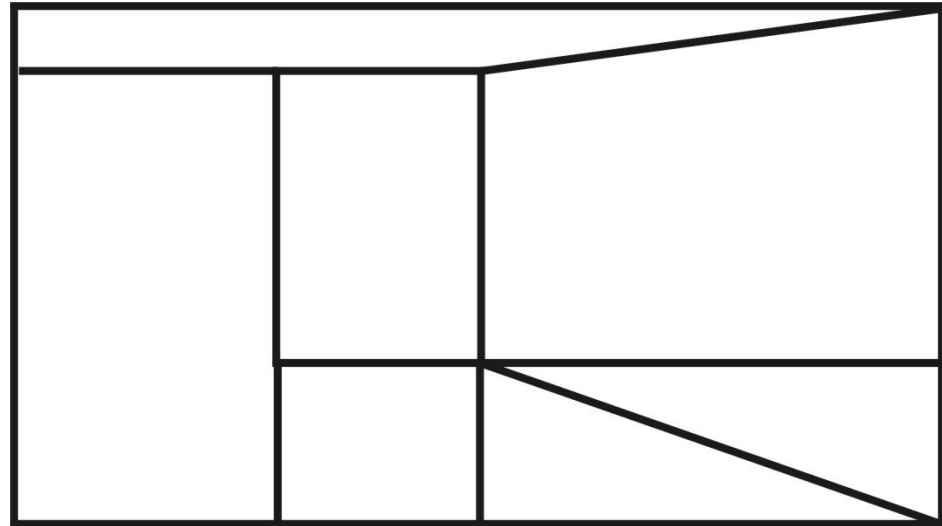


- **A C++ program was written to generate antenna geometries and simulate the operation of a self-structuring antenna.**
- **The Numerical Electromagnetics Code (NEC) is called by the simulation program as the EM solver**
- **The simulation program can run an ‘inner’ algorithm to search for optimal SSA configurations, and an ‘outer’ algorithm can search for optimal parameters for template geometries.**

Generating template geometries

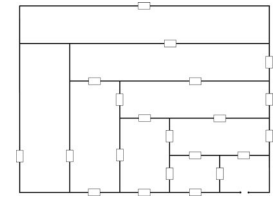


- **Layers of rectangles with different lengths and positions can be generated, as well as connections between layers.**

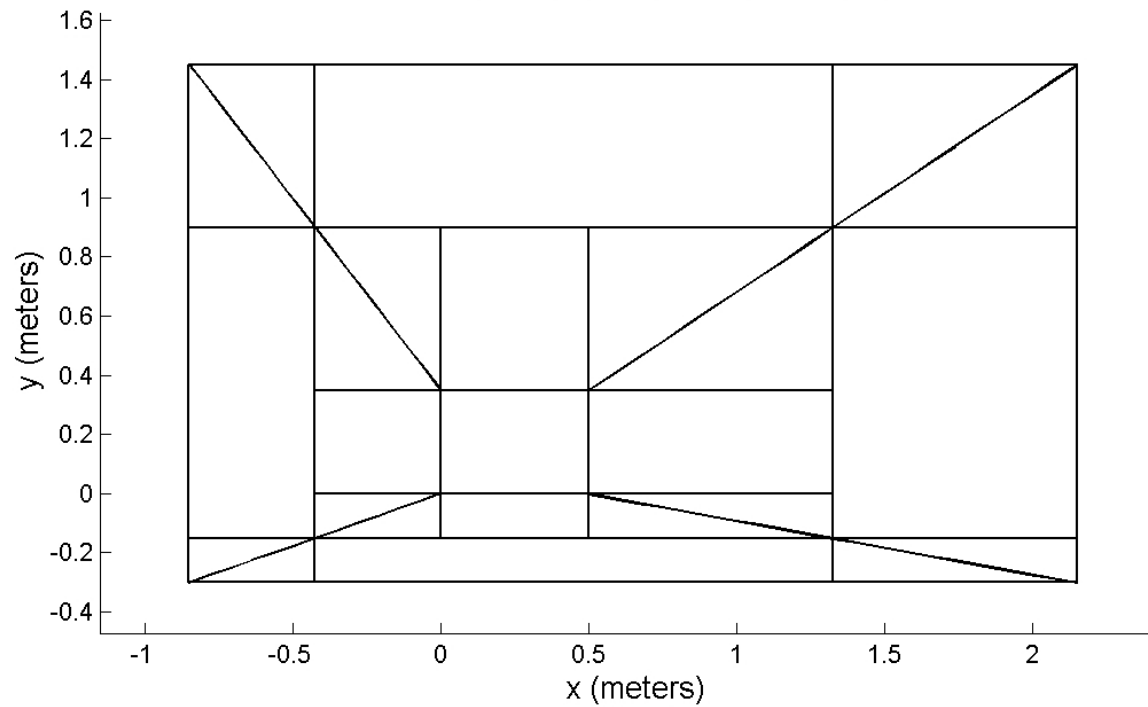


- **Switches and feed points can be placed on any wire section (rectangular arm or layer connector).**
- **The feed point is usually placed in the bottom center wire section of the first rectangle.**

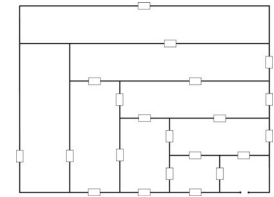
Possible template geometry



Rectangular SSA Template Geometry



Search Algorithms



- **Simulated Annealing**

- W. H. Press, B. P. Flannery, S. A. Teukolsky, and W. A. Vetterling, *Numerical Recipes*. New York: Cambridge University Press, 1989.

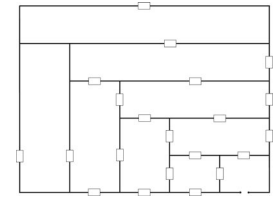
- **Ant Colony Optimization (ACO)**

- M. Dorigo and L. M. Gambardella, "Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem," *IEEE Transactions on Evolutionary Computation*, vol. 1, no. 1, pp. 53-66, 1997.
- E. Bonabeau, M. Dorigo, and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*. New York: Oxford University Press, 1999.

- **Genetic Algorithms**

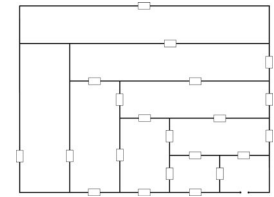
- J. H. Holland, *Adaptation in Natural and Artificial Systems*. Ann Arbor: The University of Michigan Press, 1975.
- D. E. Goldberg, *Genetic Algorithms*. Reading, MA: Addison-Wesley, 1989.
- Y. Rahmat-Samii, E. Michielssen, eds., *Electromagnetic Optimization by Genetic Algorithms*. New York: John Wiley & Sons, 1999.

Ant Colony Optimization (ACO)

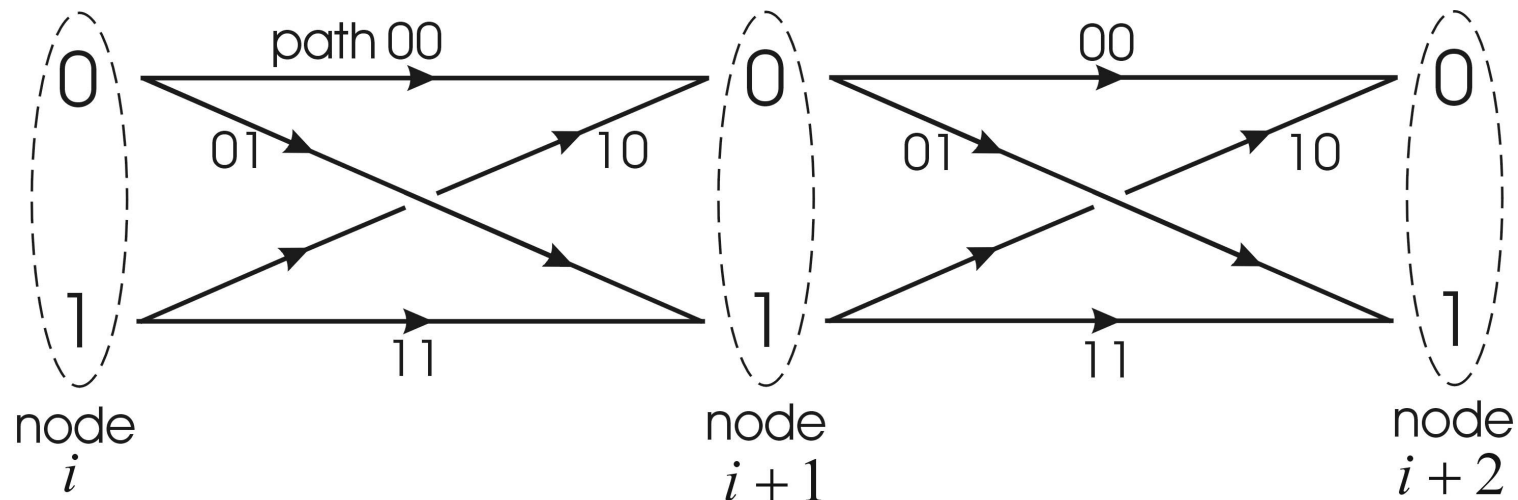


- **While individual ants are somewhat simple creatures, a colony of ants is a complex social structure that is very efficient with certain tasks, such as the foraging of food.**
- **ACO algorithms are intended to model the foraging behavior of ant colonies by simulating the behavior of simple ants.**
- **As an ant leaves its nest in search for food, it leaves pheromone along its path. When food is found, the ant returns to the nest by following its pheromone trail.**
- **The closer that a food source is to the nest, the quicker that ants can travel to the source and back. The pheromone trail is stronger along these paths than for paths leading to distant sources.**
- **The total amount of pheromone on a particular path increases the probability that an ant will choose that path.**

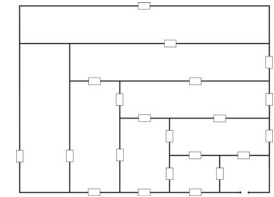
Application of ACO as a Search Algorithm



- Ants travel from node to node sequentially, leaving pheromone along the paths they choose. A node represents a binary state.
- Each ant passes each node once to complete a single cycle.
- The amount of pheromone deposited is influenced by an objective function evaluated for the entire combination of paths.
- Subsequent ant path choices are influenced by pheromone levels.

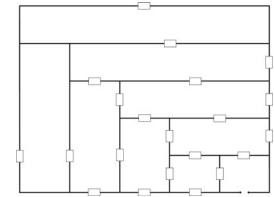


Inner Search Algorithm



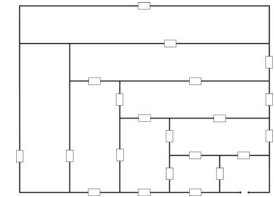
- The ‘inner’ algorithm searches for optimal SSA configurations (combination of ‘on’ or ‘off’ states of template switches) for a given template geometry.
- Due to the simple ‘on’ or ‘off’ nature of a switch state, a binary search algorithm is appropriate for searching for optimal SSA configurations.
- A fitness or objective function is evaluated for each configuration selected by the algorithm such as received signal strength, VSWR, pattern characteristics, etc. The search algorithm then attempts to locate configurations that maximize (or minimize) the fitness function.

Outer Search Algorithm



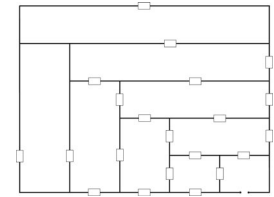
- An ‘outer’ search algorithm was employed to search for optimal SSA template geometries by encoding template parameters onto a binary string.
- Template parameters could be the lengths of wire sections, the number of ‘layers’, variables that describe the connections between layers, or other types of parameters.
- The outer algorithm selects the binary strings to represent the template geometries, and then an inner algorithm is used to search for optimal SSA configurations of these templates.
- The fitness of each template geometry is determined from the characteristics of the template found using the inner algorithm, and the outer algorithm uses these fitness values to choose subsequent template geometries.

Two-Level Algorithm Results



- Several two-level algorithm simulations were performed using an ACO for the ‘inner’ and the ‘outer’ algorithm.
- For each template geometry chosen by the outer algorithm, the inner algorithm searched for optimal SSA configurations at 3 different frequencies. The SSA was *re-optimized* at each frequency.
- The inner fitness function was chosen to minimize the VSWR (relative to $Z_0=200$ Ohms) at each frequency.
- The outer fitness function was chosen to minimize the average VSWR of the best configurations found at each frequency by the inner algorithm.

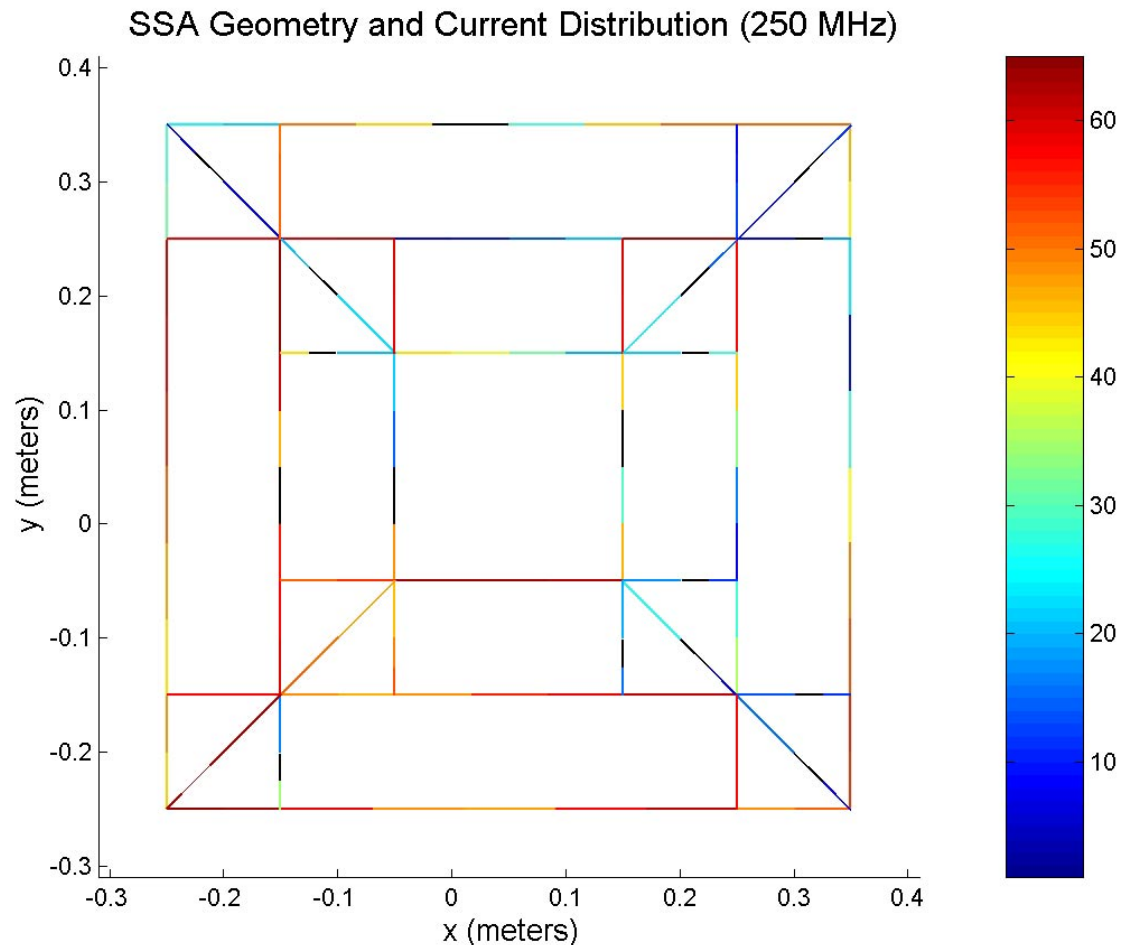
SSA Template Current Distribution Results



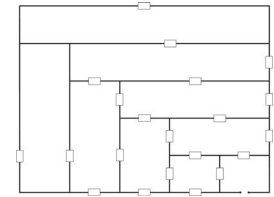
- Best template geometry found using an outer ACO algorithm. Only the lengths of the template layers were allowed to be varied.

f (MHz)	250	300	350
VSWR	1.03	1.05	1.02

Average VSWR=1.03

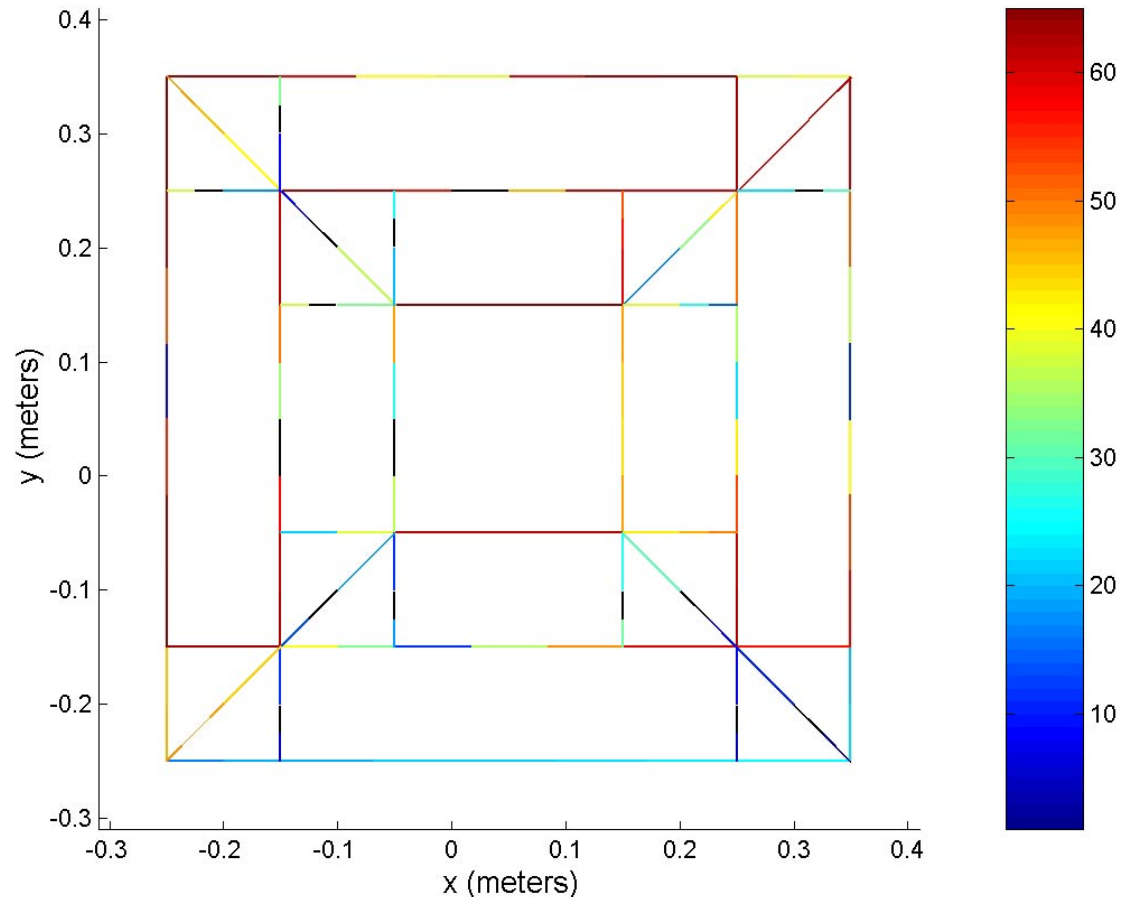


SSA Template Current Distribution Results



- The SSA was re-optimized at each frequency under study.

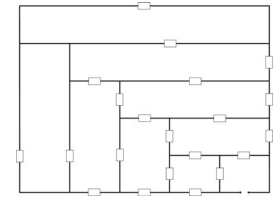
SSA Geometry and Current Distribution (300 MHz)



f (MHz)	250	300	350
VSWR	1.03	1.05	1.02

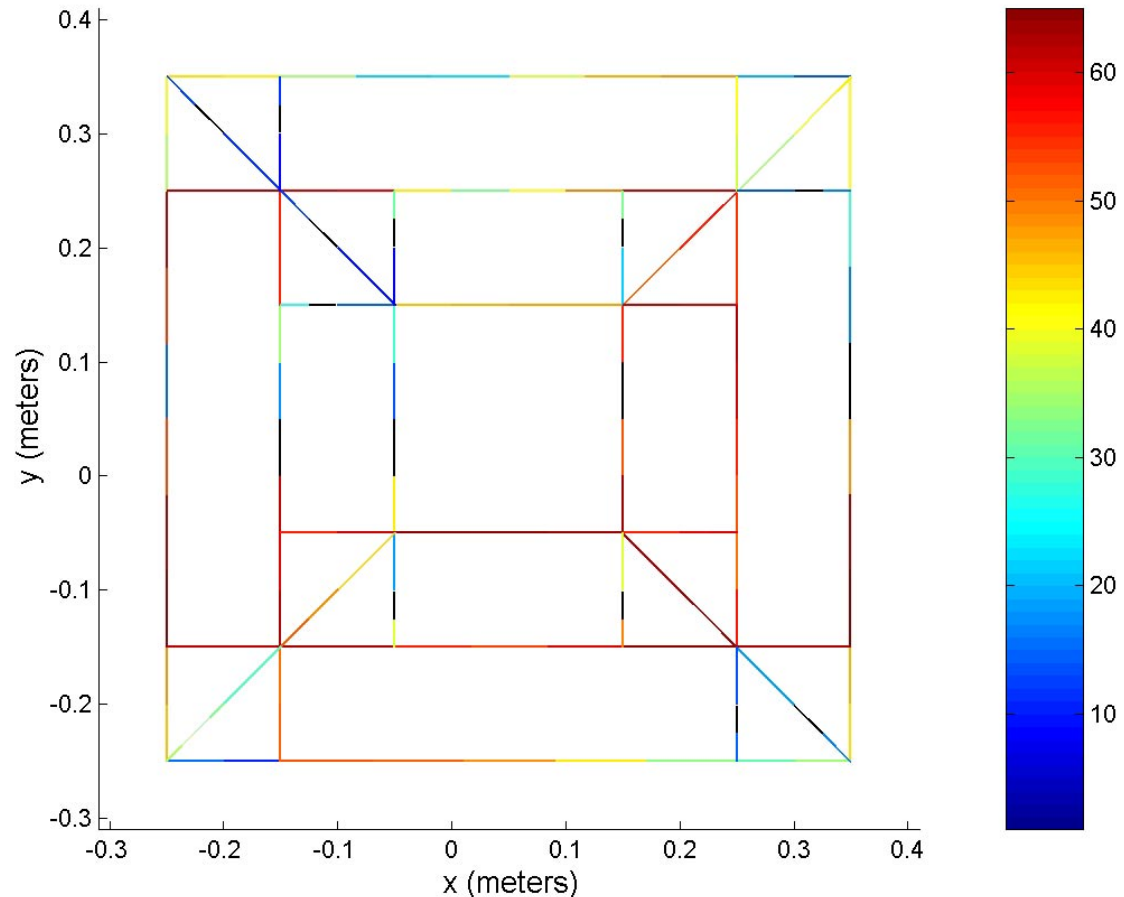
Average VSWR=1.03

SSA Template Current Distribution Results



- Notice that the current distributions differ as the frequency and SSA configuration vary.

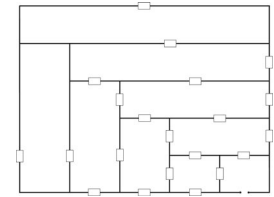
SSA Geometry and Current Distribution (350 MHz)



f (MHz)	250	300	350
VSWR	1.03	1.05	1.02

Average VSWR=1.03

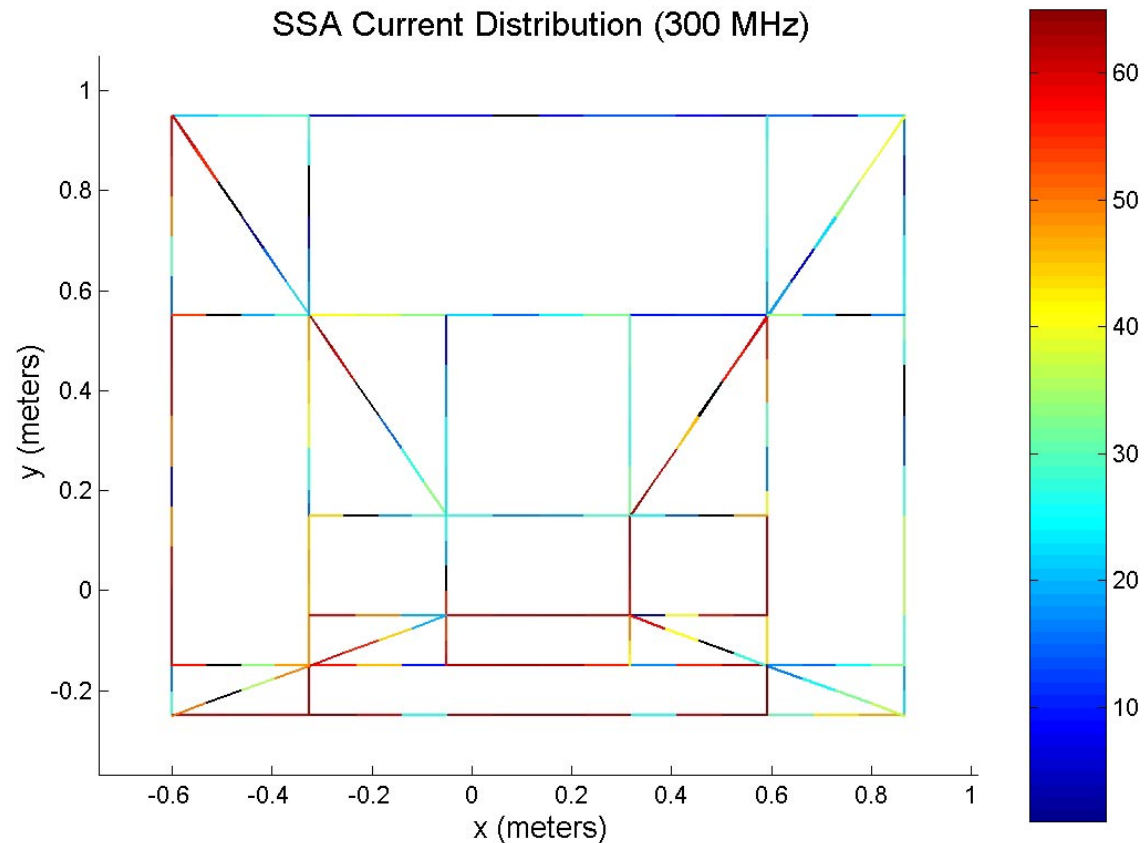
Template generated by two-level search routine



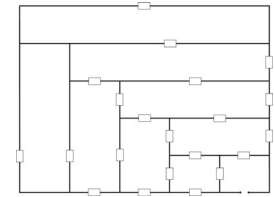
- A different two-level algorithm run produced this interesting template geometry. The shifts between layers were allowed to vary here.

f (MHz)	300	400	500
VSWR	1.04	1.06	1.14

Average VSWR=1.08



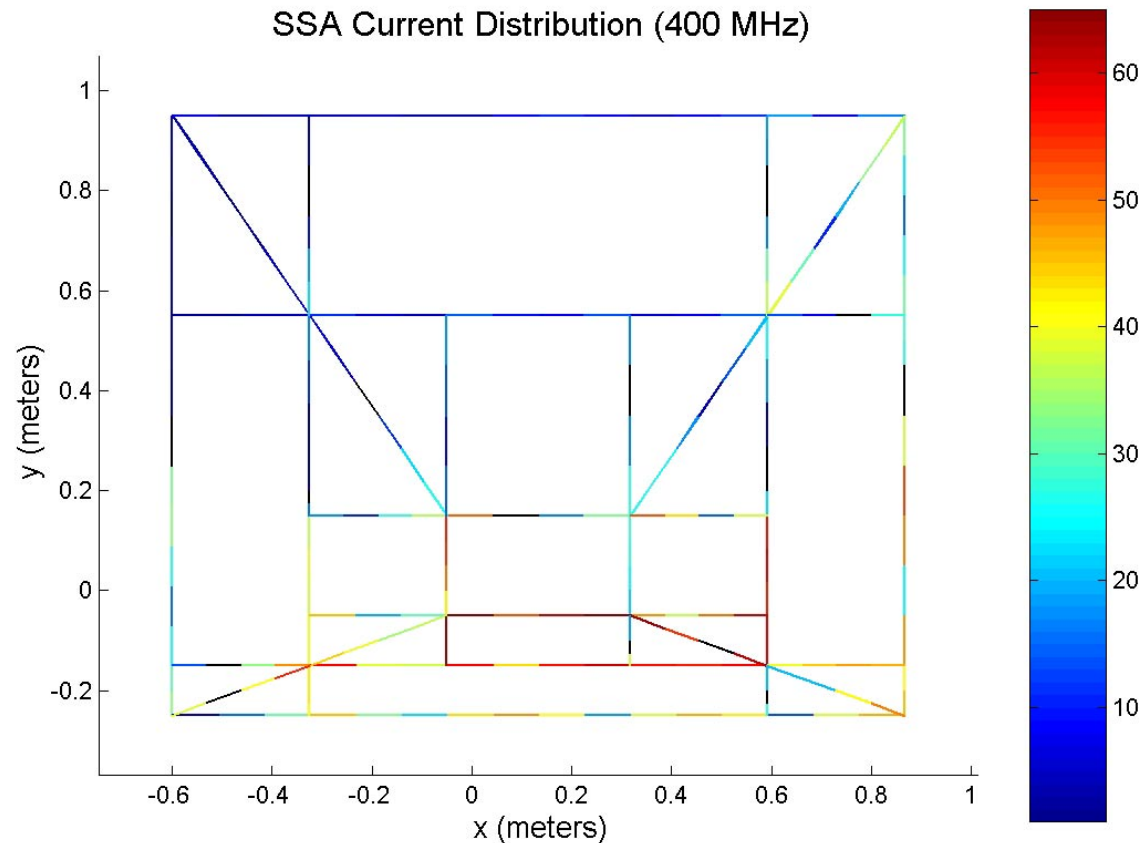
Template generated by two-level search routine



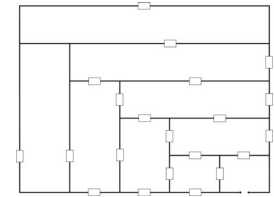
- The y-directed shifts between layers and the lengths of the sides of the layers were modified by the outer algorithm.

f (MHz)	300	400	500
VSWR	1.04	1.06	1.14

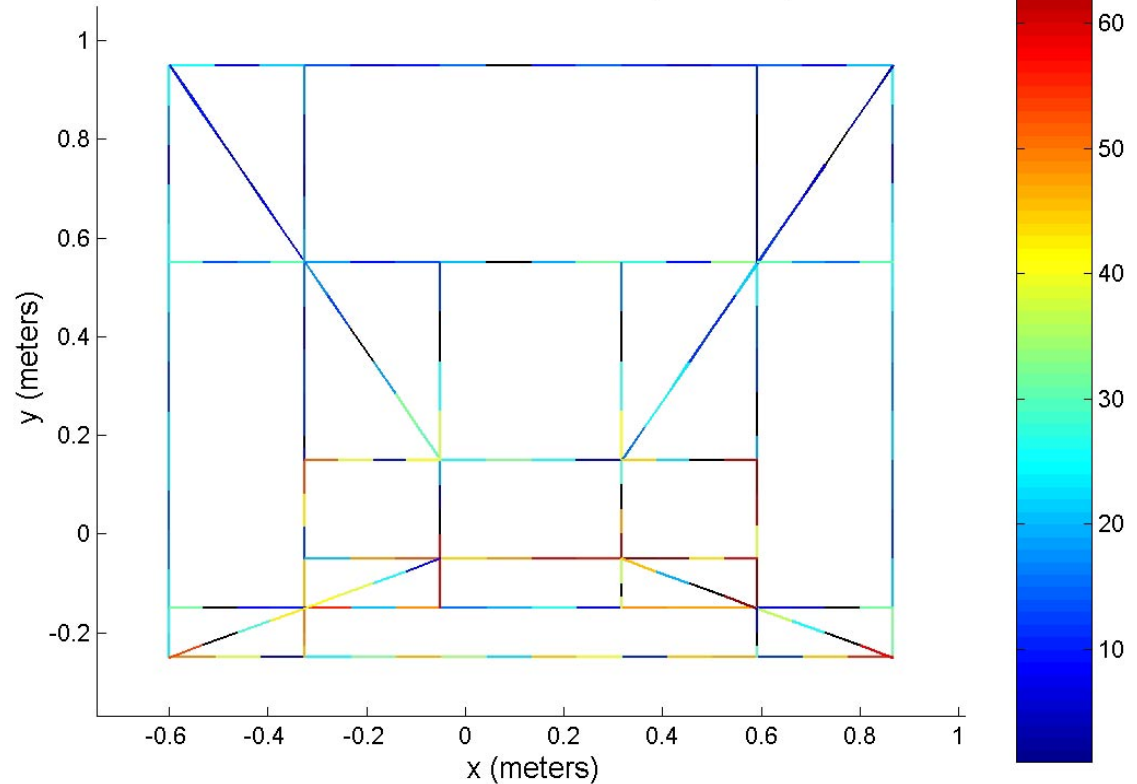
Average VSWR=1.08



Template generated by two-level search routine



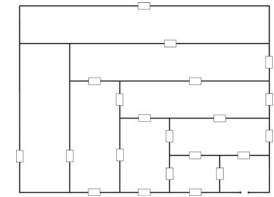
SSA Current Distribution (500 MHz)



f (MHz)	300	400	500
VSWR	1.04	1.06	1.14

Average VSWR=1.08

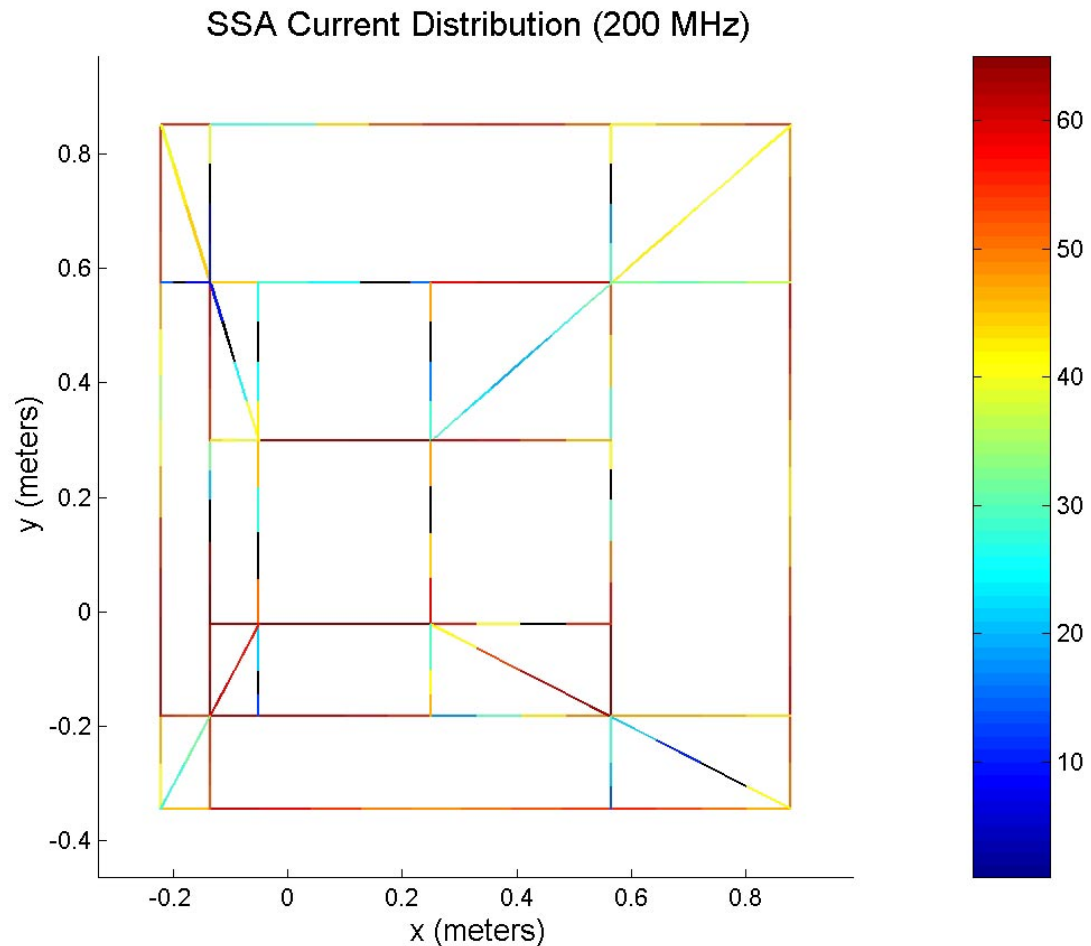
Template generated by outer ACO algorithm



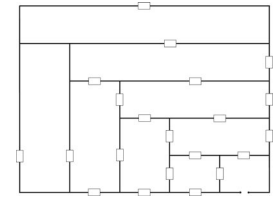
- This irregularly shaped template geometry was produced by a third outer ACO algorithm run.

f (MHz)	200	300	400
VSWR	1.02	1.02	1.02

Average VSWR=1.02

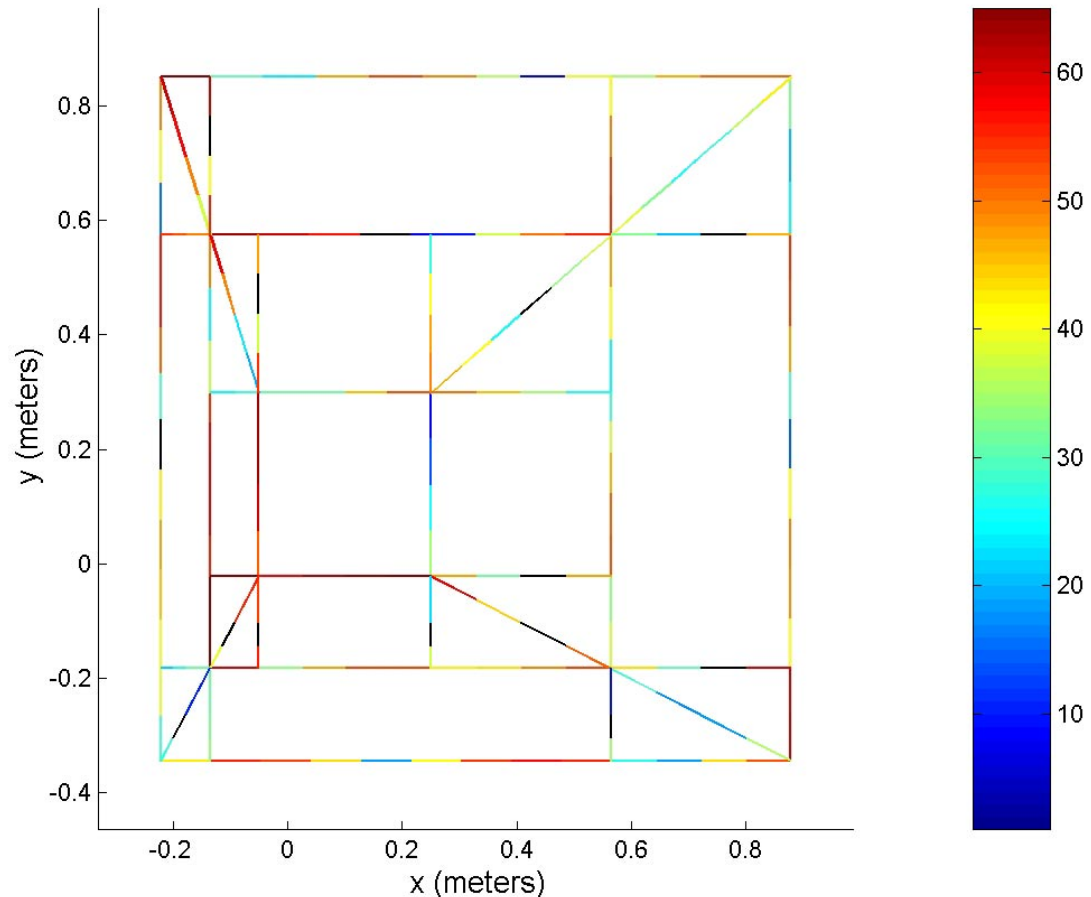


Template generated by outer ACO algorithm



- The shifts between layers and the lengths of the sides of the layers were modified by the outer algorithm.

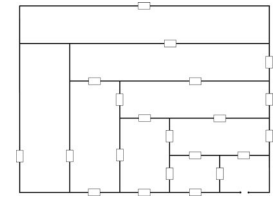
SSA Current Distribution (300 MHz)



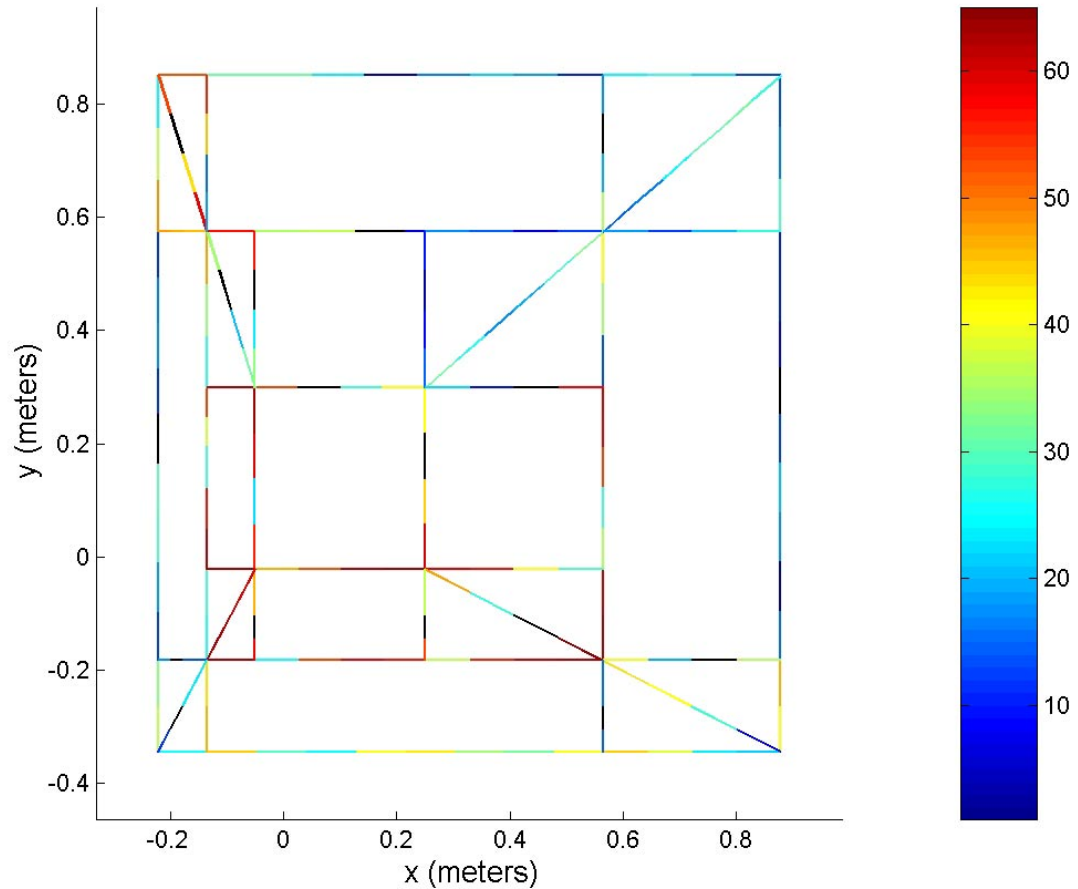
f (MHz)	200	300	400
VSWR	1.02	1.02	1.02

Average VSWR=1.02

Template generated by outer ACO algorithm



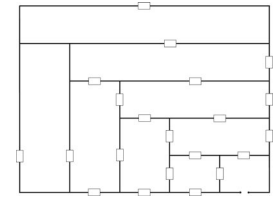
SSA Current Distribution (400 MHz)



f (MHz)	200	300	400
VSWR	1.02	1.02	1.02

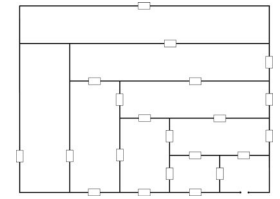
Average VSWR=1.02

Conclusion and Future Work

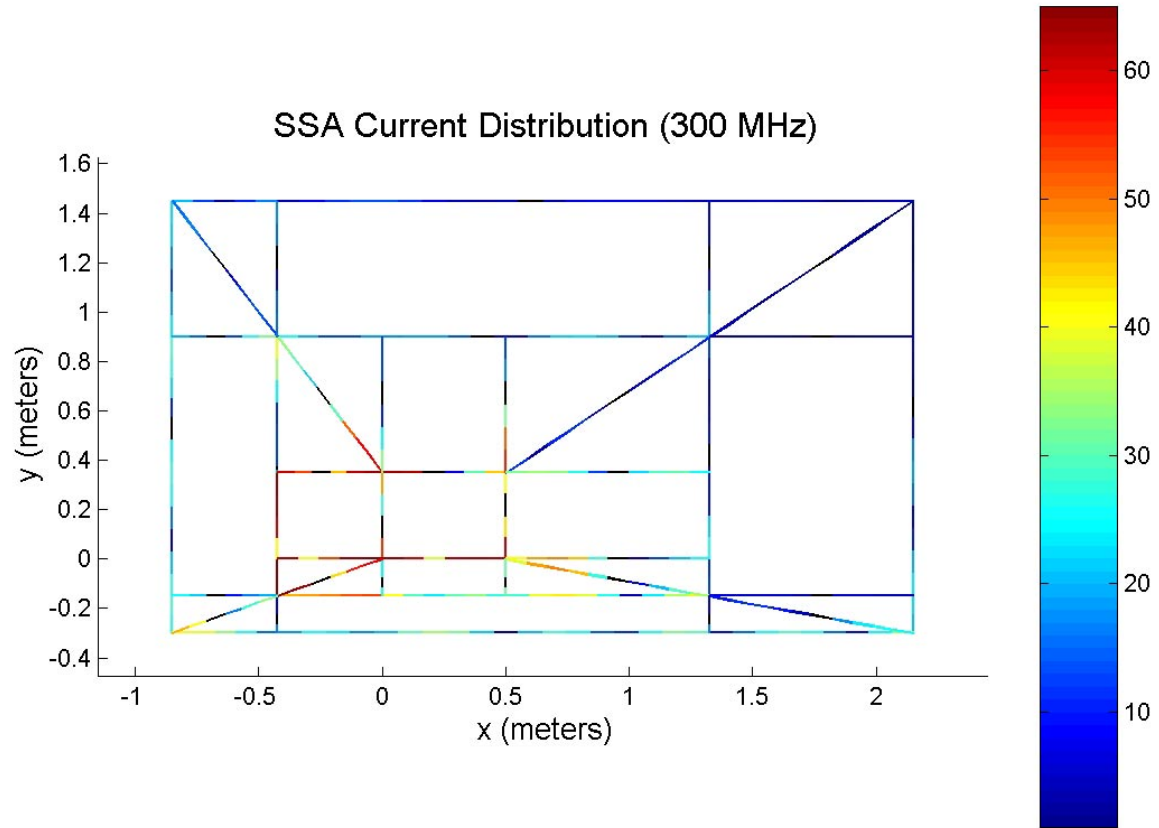
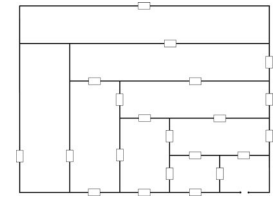


- **A computer program that uses a two-level algorithm to search for optimal parameters has been developed.**
- **Results have been obtained using this program for Ant Colony Optimization and Simulated Annealing algorithms.**
- **More research will be performed using Genetic Algorithms, other template shapes, and improved fitness functions. Statistical analysis will also be performed.**
- **Future research will also include two-level searching algorithms that use an outer algorithm to search for optimal parameters of an inner algorithm. The inner algorithm searches for optimal self-structuring antenna configurations.**

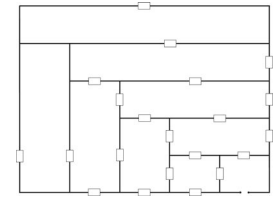
**Trash slides are after this
slide.**



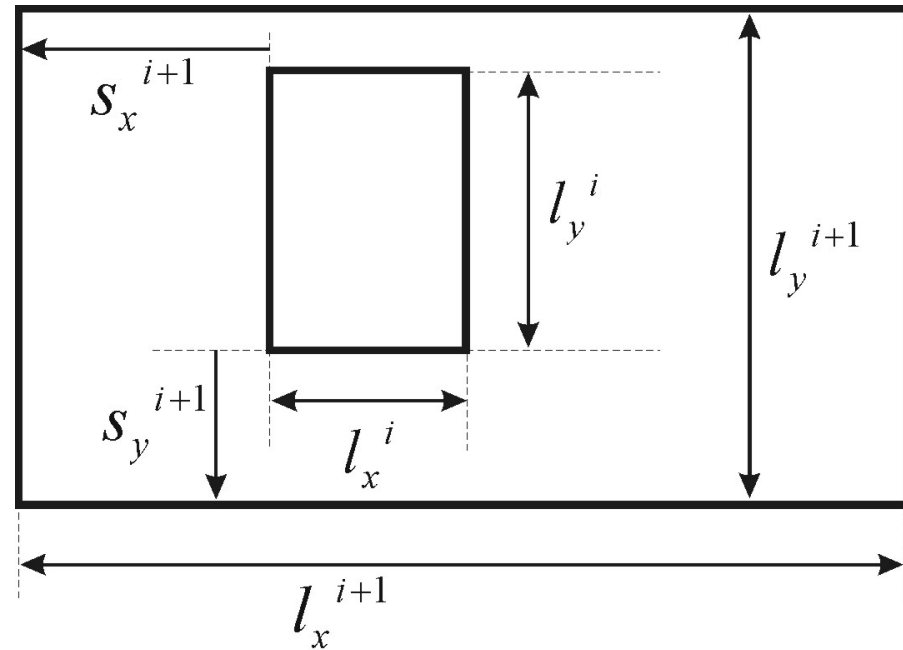
Template current



Generating template geometries (cont.)

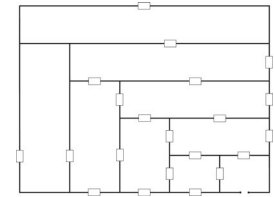


- The $(i+1)$ th layer is shown here, with s_x^{i+1} and s_y^{i+1} as the shifts from the i th layer.

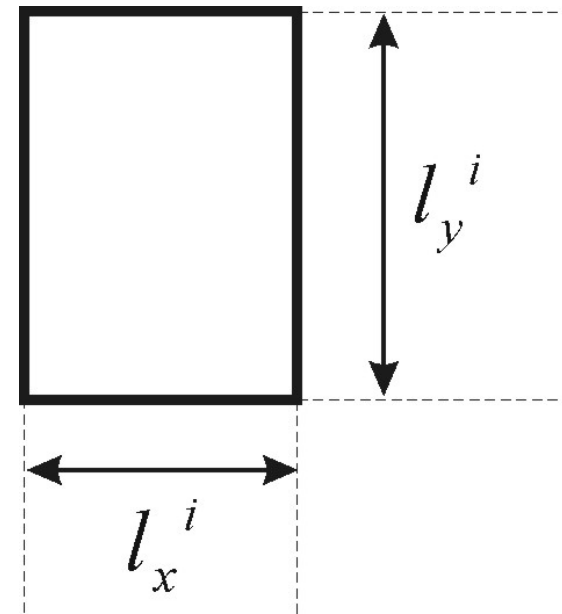


- The lengths l_x^{i+1} , l_y^{i+1} and the shifts s_x^{i+1} , s_y^{i+1} are determined by parameters and an equation or rule relating the i th and $(i+1)$ th layers.

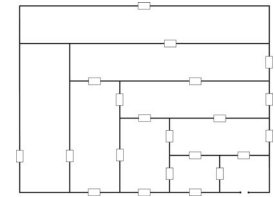
Generating template geometries



- A rectangular-based template is one of the types of shapes that the computer program can generate.
- The template is generated layer by layer, with the properties of each layer related to a parameter and / or a rule.
- The i th layer of a rectangular-based template is shown here, with l_x^i and l_y^i as the lengths of the x and y dimensions.

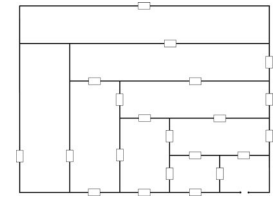


Previous Self-Structuring Antenna Work

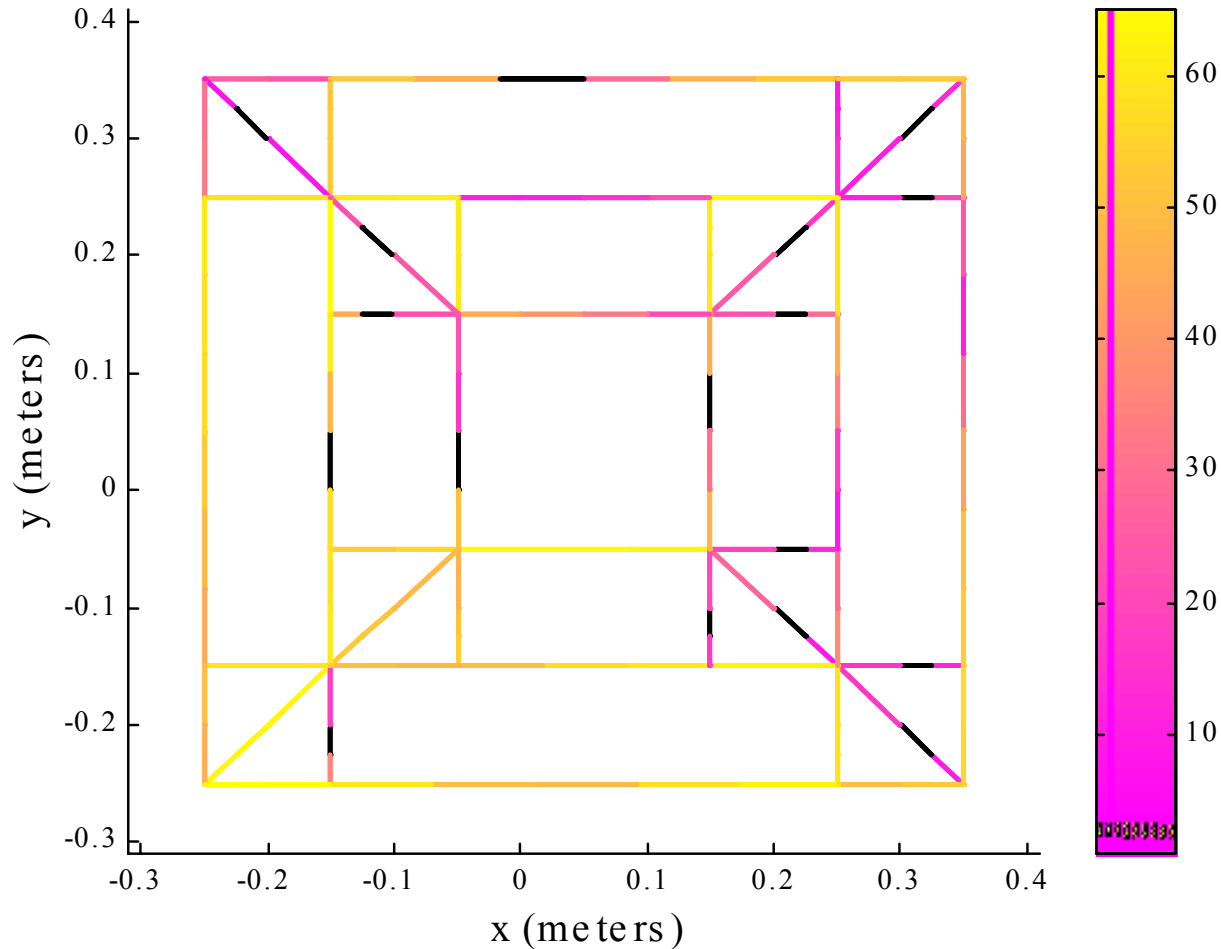


- **C. M. Coleman, E. J. Rothwell, and J. E. Ross, “Self-Structuring Antennas,” in *2000 IEEE AP-S Symposium*, (Salt Lake City, Utah), 2000.**
- **J. E. Ross, E. J. Rothwell, C. M. Coleman, and L. L. Nagy, “Numerical Simulation of Self-Structuring Antennas Based on a Genetic Algorithm Optimization Scheme,” in *2000 USNC / URSI National Radio Science Meeting*, (Salt Lake City, Utah), 2000.**

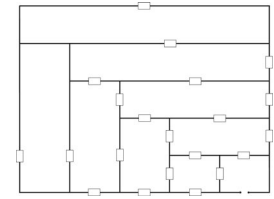
Template Generated by Outer ACO Algorithm



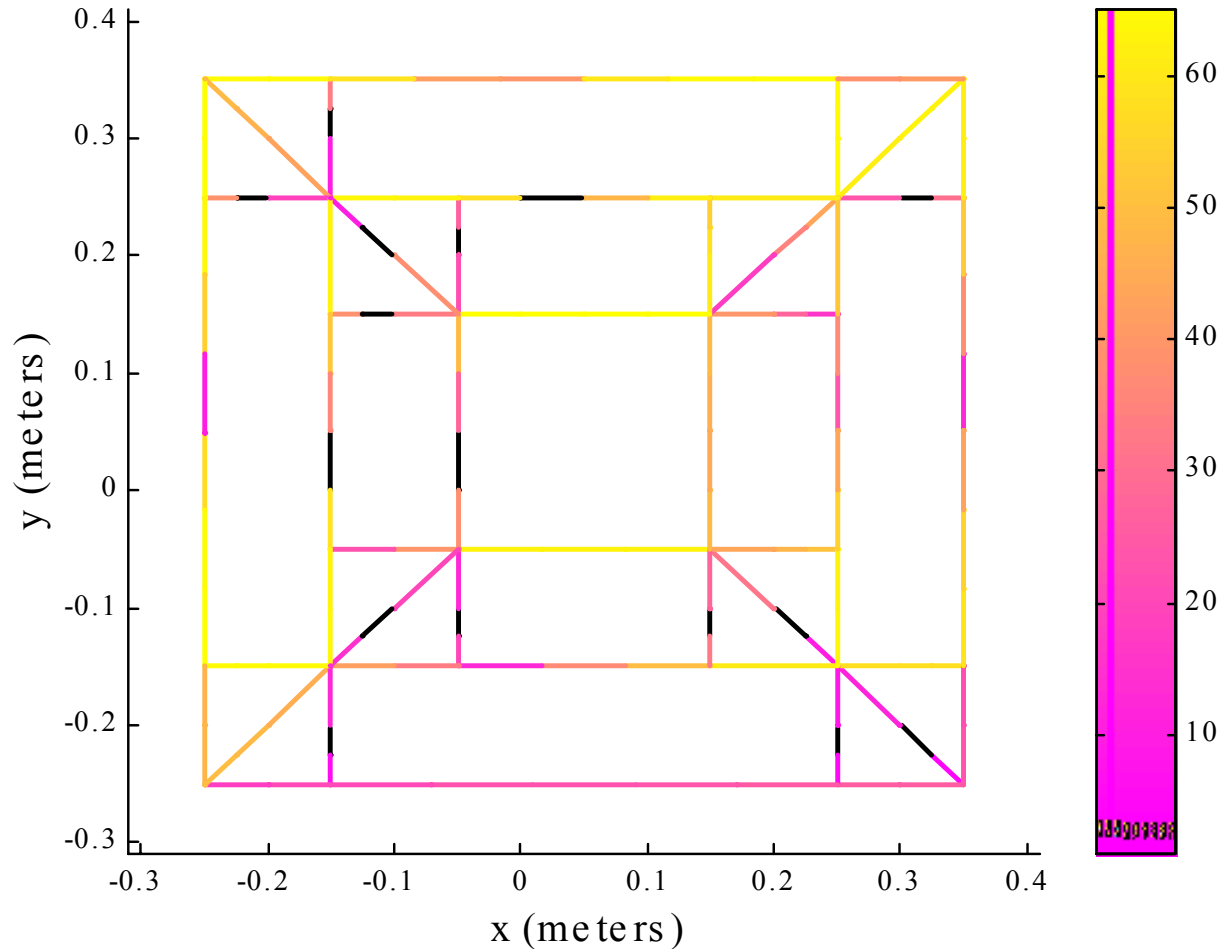
SSA Geometry and Current Plot (250 MHz)



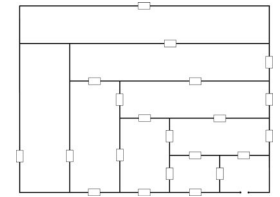
Template Generated by Outer ACO Algorithm



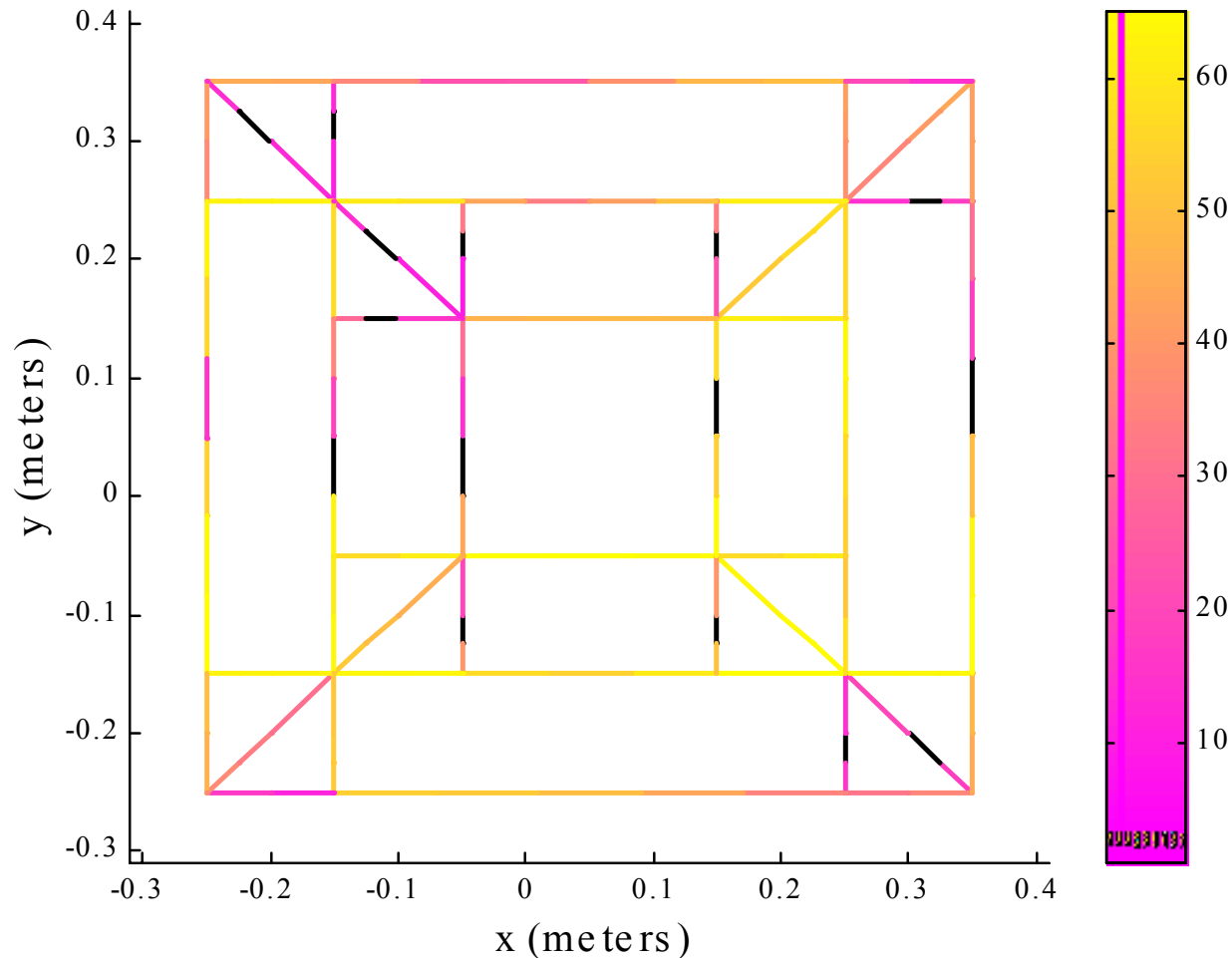
SSA Geometry and Current Plot (300 MHz)

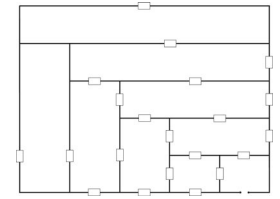


Template Generated by Outer ACO Algorithm



SSA Geometry and Current Plot (350 MHz)





SSA Geometry and Current Plot

