A STUDY OF SIMPLE SELF-STRUCTURING ANTENNA TEMPLATES

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Self-structuring antennas (SSAs) are adaptive antenna systems that use switches to control their electromagnetic characteristics (C. M. Coleman, E. J. Rothwell, and J. E. Ross, *IEEE AP-S Int. Symp.*, Salt Lake City, Utah, 2000). The switches connect wires and patches to create an SSA *template*. An SSA template with n switches is capable of arranging itself into 2^n discrete electrical configurations. Because of the large number of available switch configurations, evolutionary algorithms such as simulated annealing, ant colony optimization, and genetic algorithms are used to search for appropriate antenna states.

The relationship between the shape of the template, the various switch configurations, and the performance of the antenna is not well understood. Although optimal template geometries have been investigated using two-level evolutionary algorithms (C. M. Coleman, E. J. Rothwell, J. E. Ross, and L. L. Nagy, *IEEE AP-S Int. Symp.*, Boston, Massachusetts, 2001), a basic understanding of the dependence of antenna performance on the number of switches remains to be determined.

Research will be presented that concentrates on understanding SSA templates by building from simple to more complicated structures. The number of switches is first kept small enough so that exhaustive searches of the configurations are possible. Switches are then added and random samples of the possible configurations are used to characterize the templates according to input impedance and radiation pattern uniformity. Through this means, an understanding of the capabilities of SSAs and their dependence on the number of switches can be gained.

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

2. Required presentation equipment: PowerPoint display

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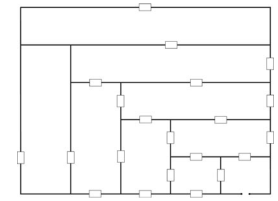
4. New knowledge contributed by paper: This study of simple self-structuring antennas and simple template geometries provides an understanding of the relationship between template complexity and antenna performance.

5. Relationship to previous work: Self-structuring antennas were introduced by the authors at the 2000 and 2001 URSI National Radio Science Meetings. The basic operation of the antenna was described in these papers.



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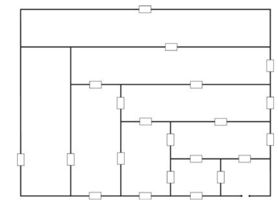
URSI B Session 69

Tuesday June 18, 1:20 pm, Seguin

Overview of Presentation



- Introduction to Self-Structuring Antennas (SSAs)
- Simulation details
- Results for increasingly complex templates
- Conclusions

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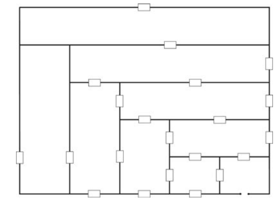
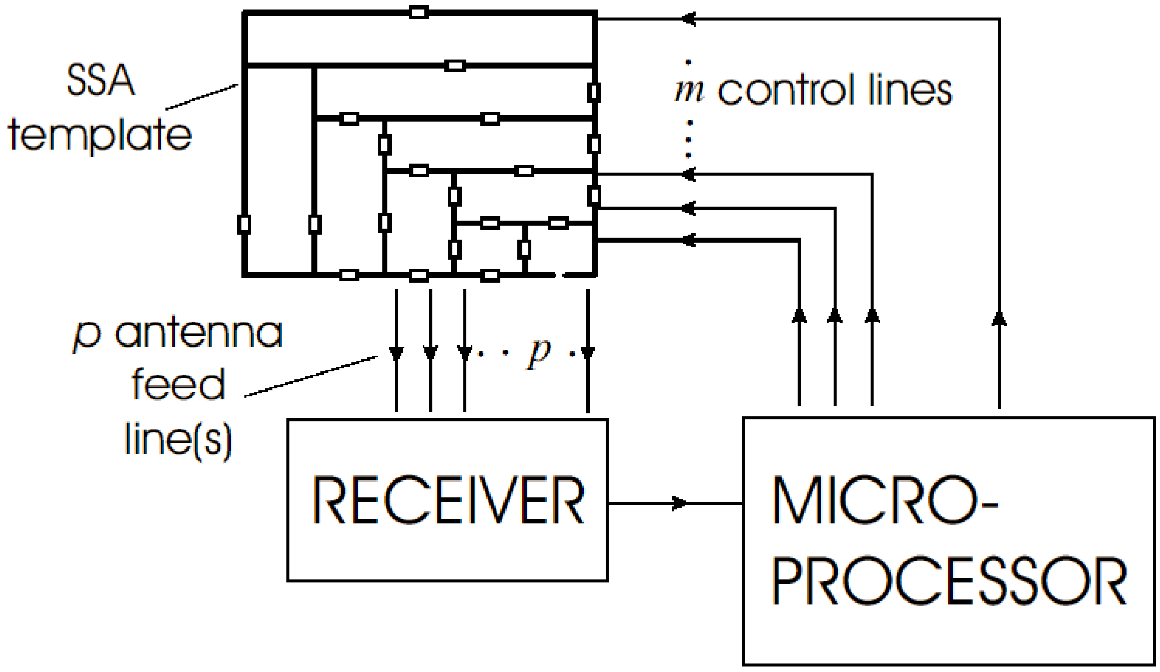
Self-Structuring Antenna Concept



- **Self-Structuring Antenna system:**
  - **Arranges itself into a large number of possible antenna configurations**
  - **Uses information from a receiver or sensor to determine fitness of each configuration and determines future configurations**
  - **Searches through possible configurations using binary search routine such as;**
    Genetic algorithms (GAs)
    Simulated annealing (SA)
    Ant colony optimization (ACO)
  - **Re-optimizes itself when its electromagnetic environment changes**

Self-Structuring Antenna (SSA)



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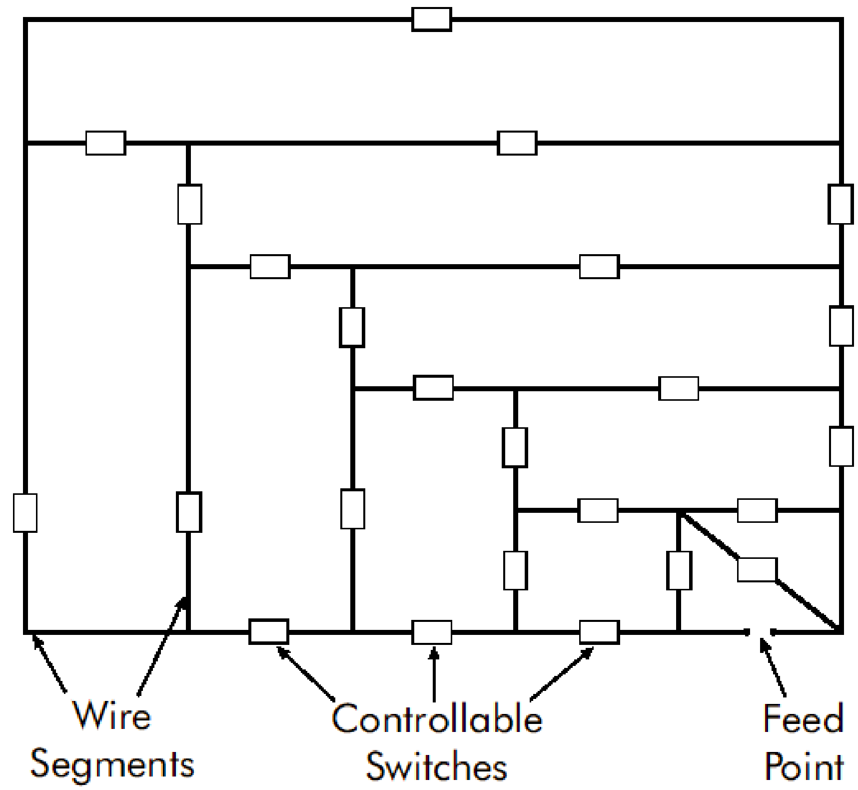
Self-Structuring Antenna Template

- **A self-structuring antenna template is comprised of a large number of wire segments or patches 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**
- **An asymmetric topology provides more diversity and less repeated states than a symmetric topology**



Investigation of Simple SSAs

- **Dependence of antenna performance on number of switches is not well understood**
- **Study templates with numbers of configurations small enough to examine exhaustively for each template**
- **Simulate using NEC-4 to obtain input impedance, SWR (relative to 200Ω), and vertical gain in the horizontal plane**
- **NEC calculations for frequency band from 40 MHz to 800 MHz**

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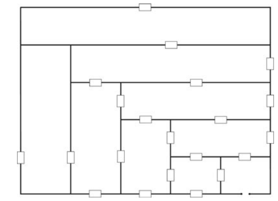
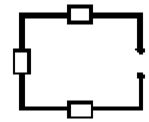
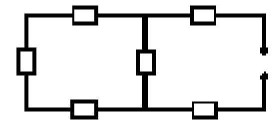
Progression of Template Layers



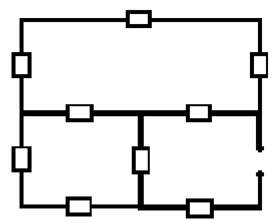
Layer	Switches	Configurations
1	3	8
1.5	6	64
2	9	512
2.5	12	4096
3	15	32768
3.5	18	262144



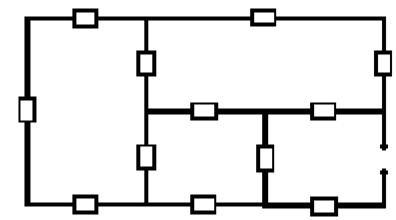
Layer 1



Layer 1.5



Layer 2



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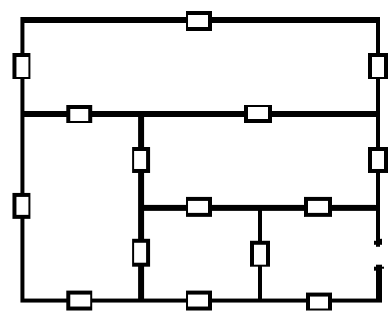
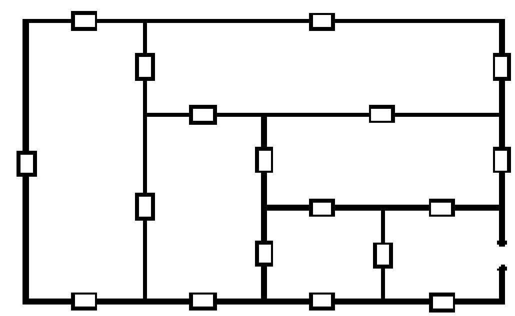


Layer 3



Layer 3.5

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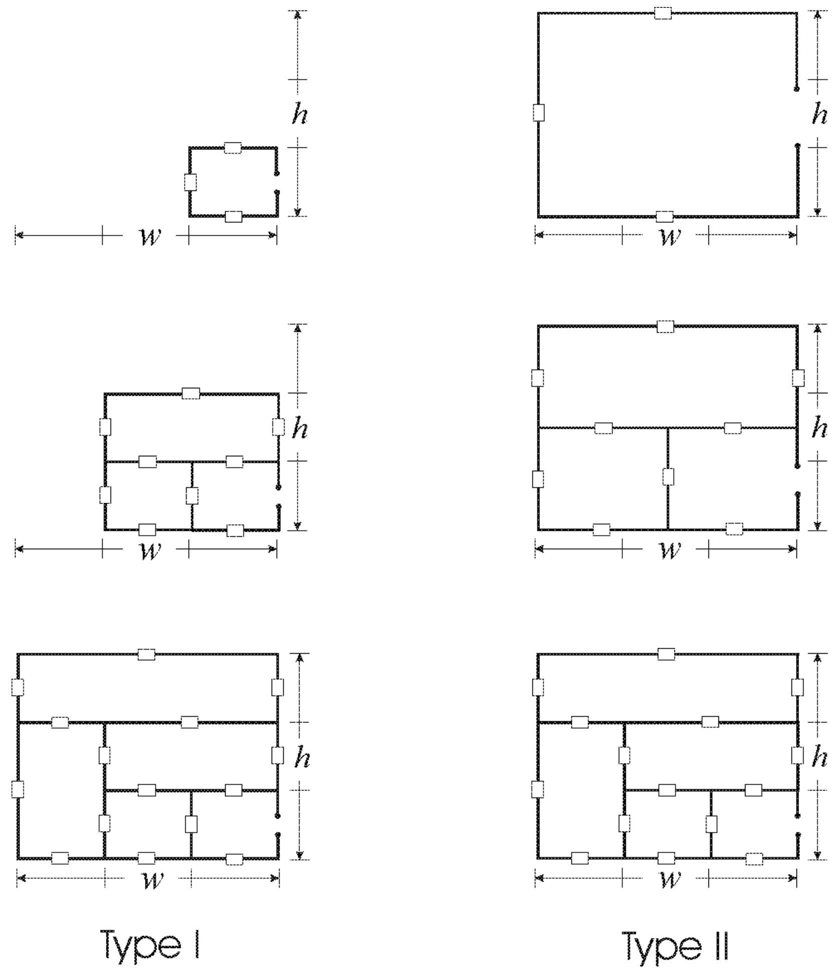
Migration Paths for SSA Geometries

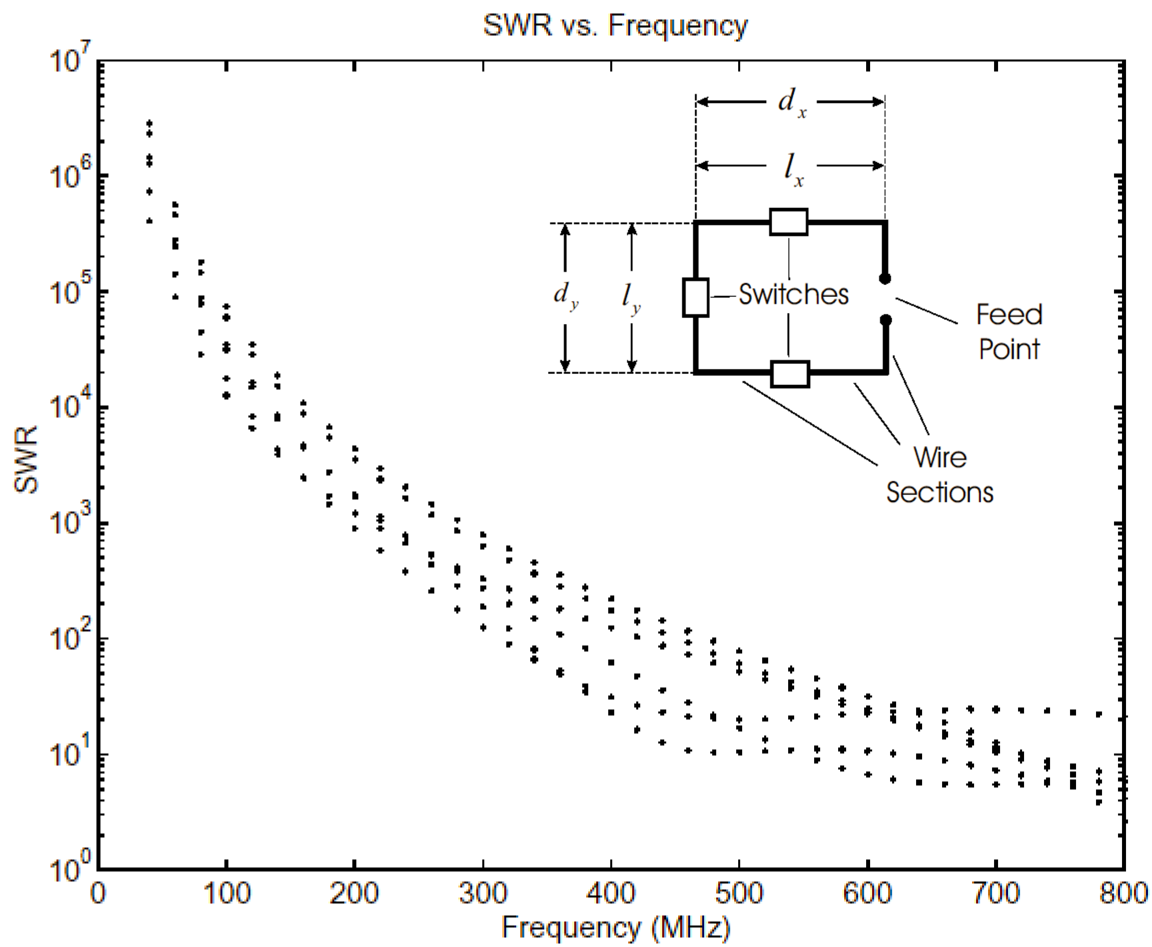
- **Two migration paths were considered:**
  - o **Type I**
  - o **Type II**

- **Type I was selected for this phase of the research program:**
  - o **Outer dimensions; 60 cm x 60 cm** (w x h)
  - o **Frequency band; 40-800 MHz**
  - o **Wavelength range; 0.08 λ - 1.6 λ**



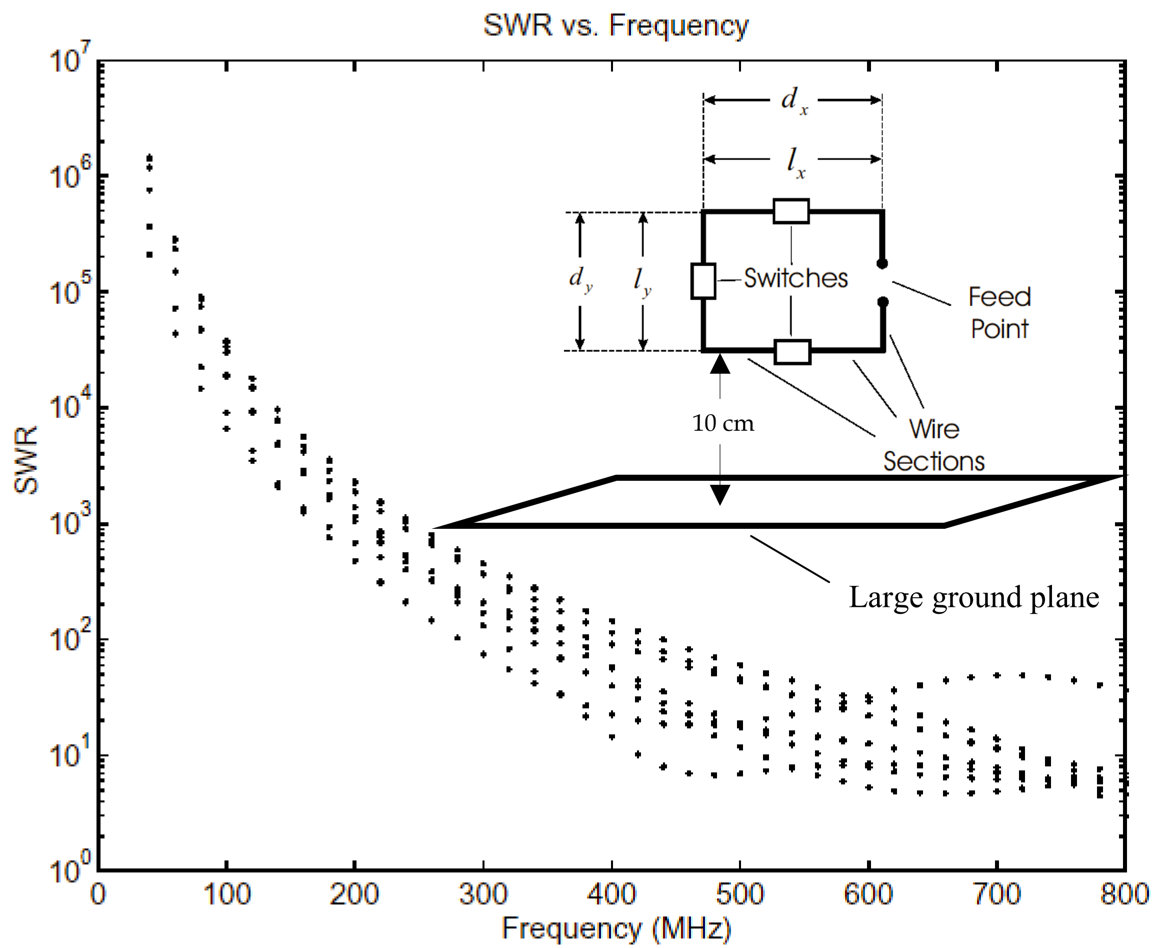
Layer 1 Template

- **3 switches, 8 configurations**
- **Dimension: 8.57 x 8.57 cm**
- **0.011λ-0.23 λ x 0.011λ-0.23 λ**
- **Exhaustive sample**



Layer 1 Template Above Ground

- Vertically oriented
- 10 cm above ground plane



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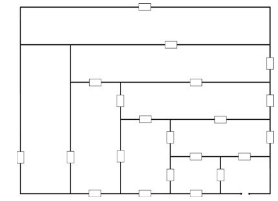
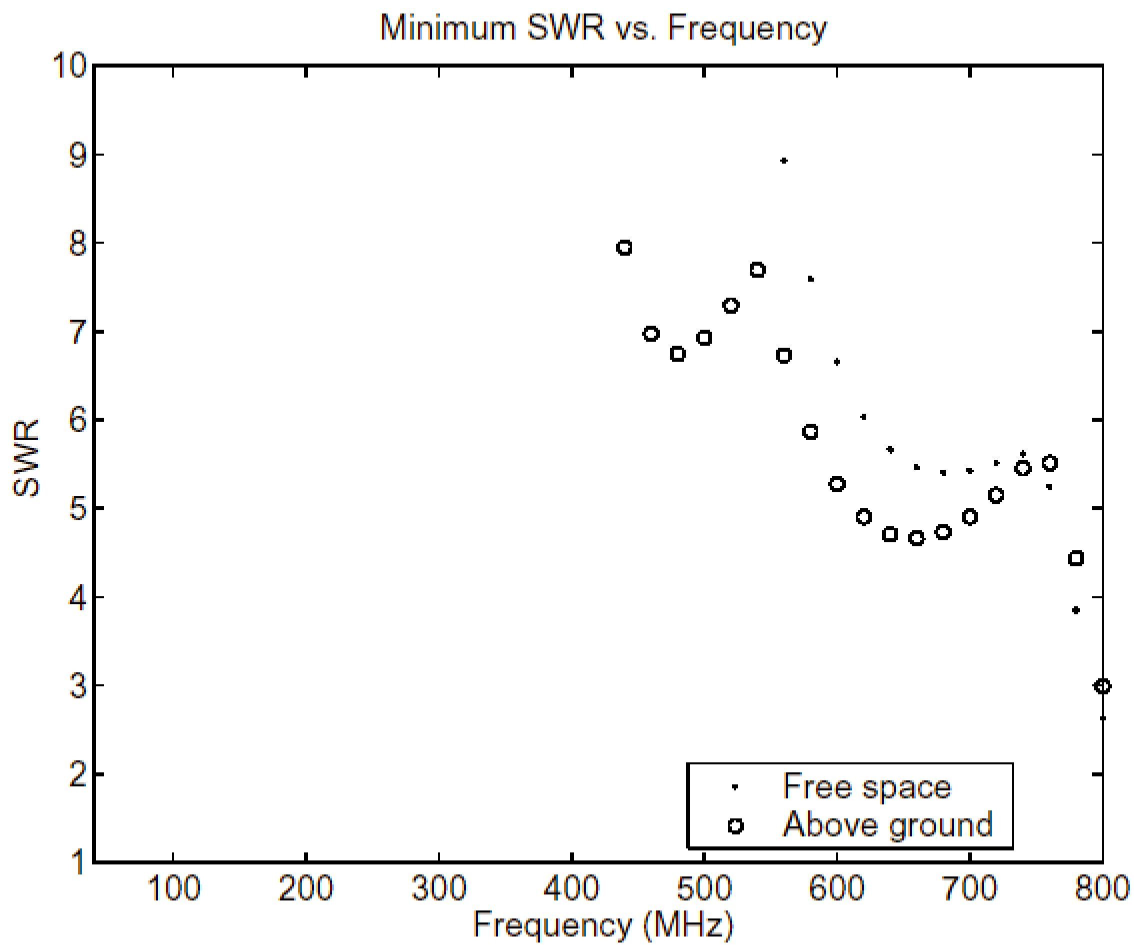
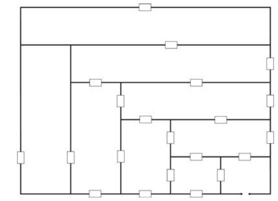
Layer 1 Template

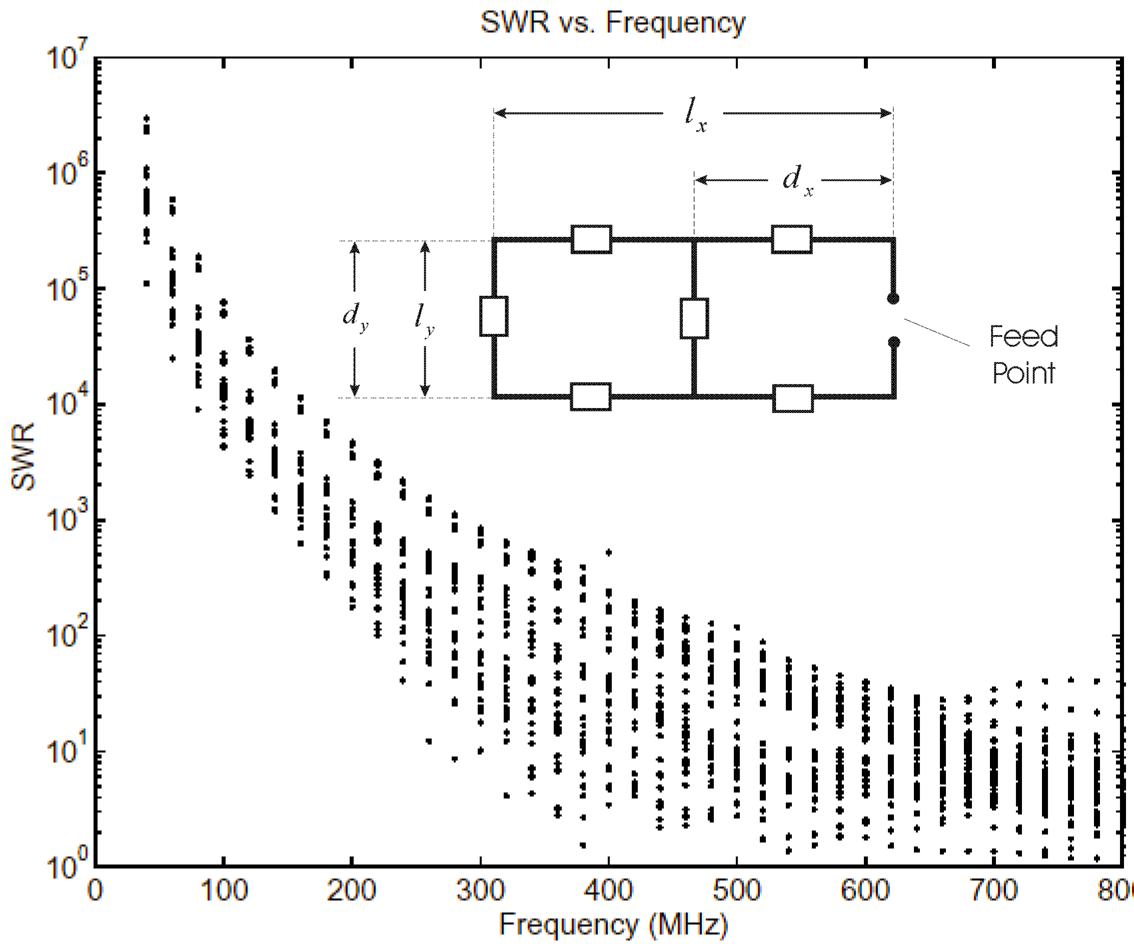




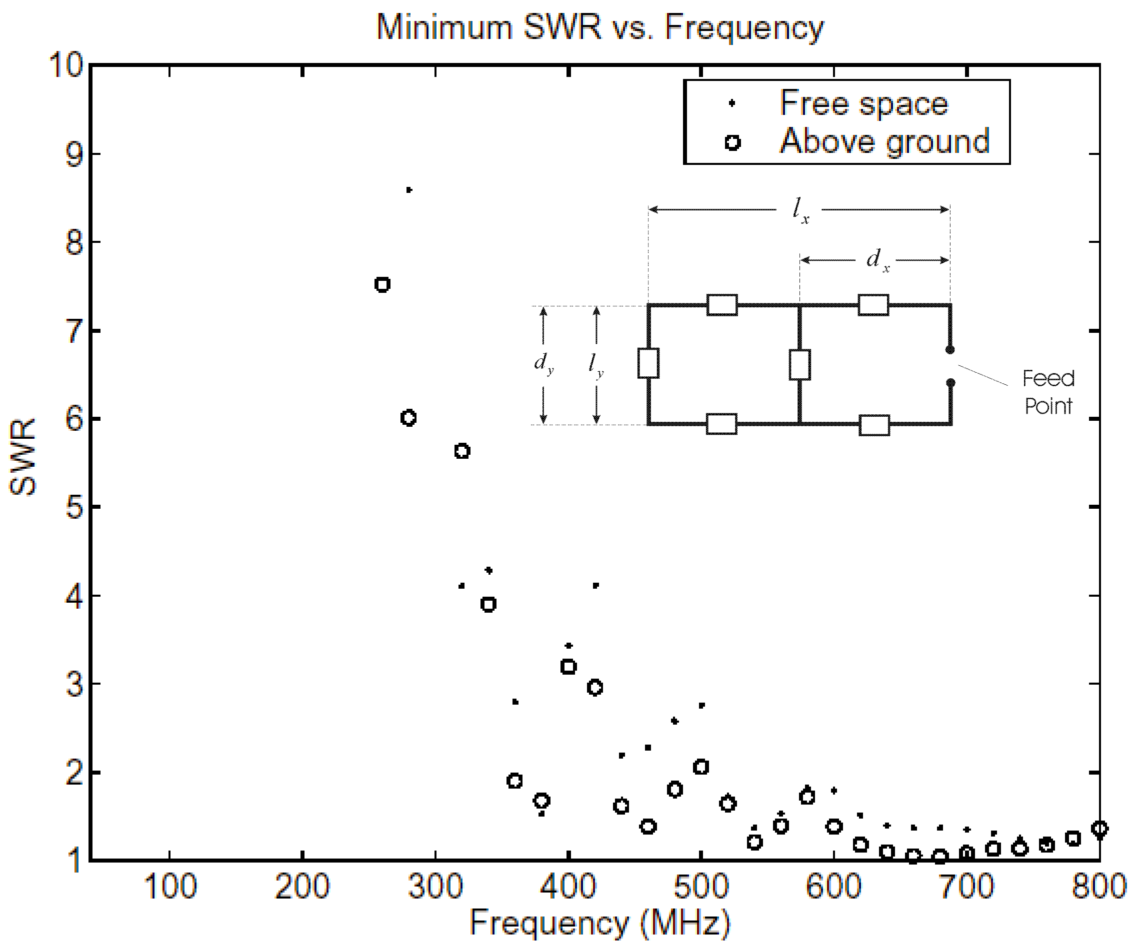
Layer 1.5 Template



- 6 switches, 64 configurations.
- Dimensions: 17.1 x 8.57 cm
- 0.011λ-0.23 λ x 0.022λ-0.46 λ
- Exhaustive sample

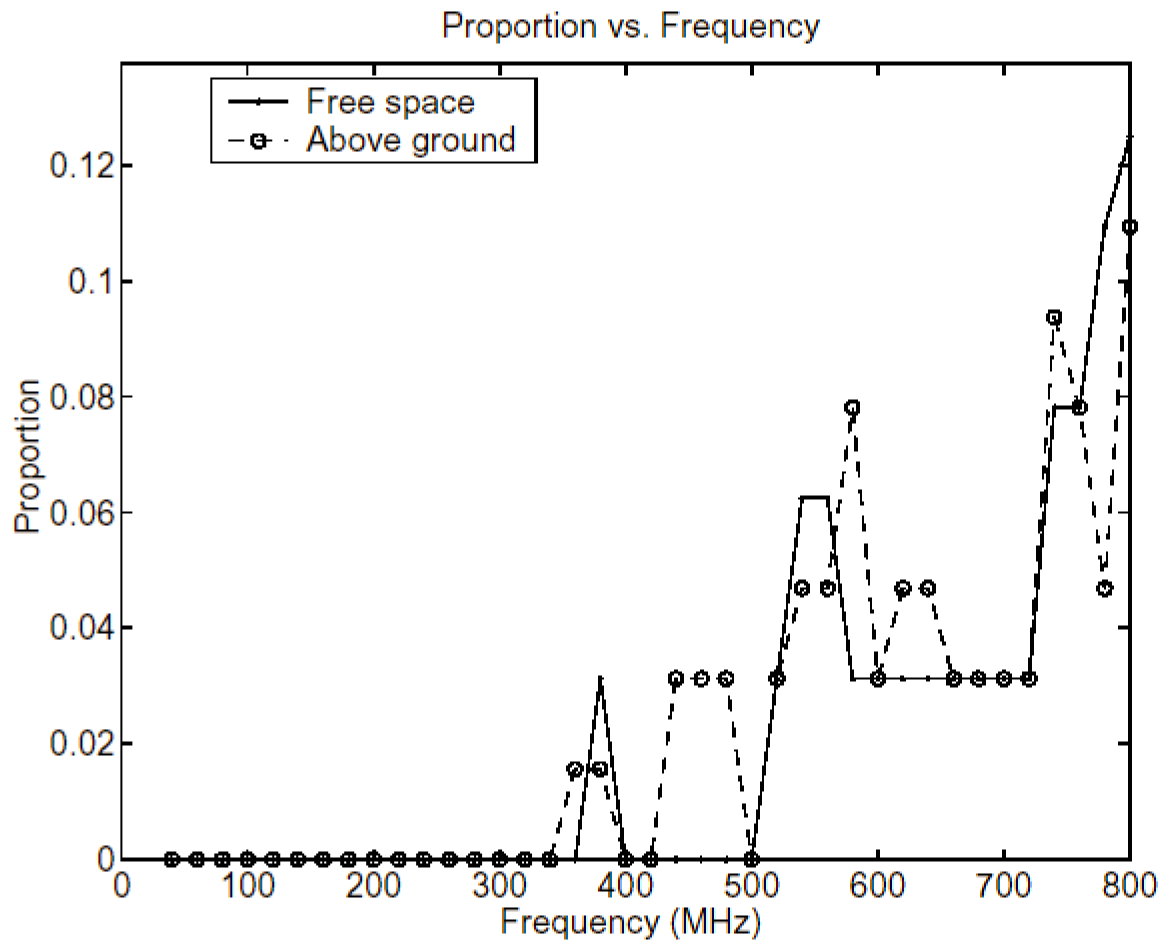


Layer 1.5 Template

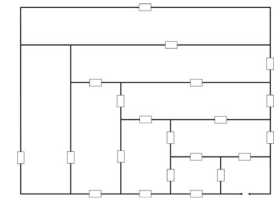


Layer 1.5 Template

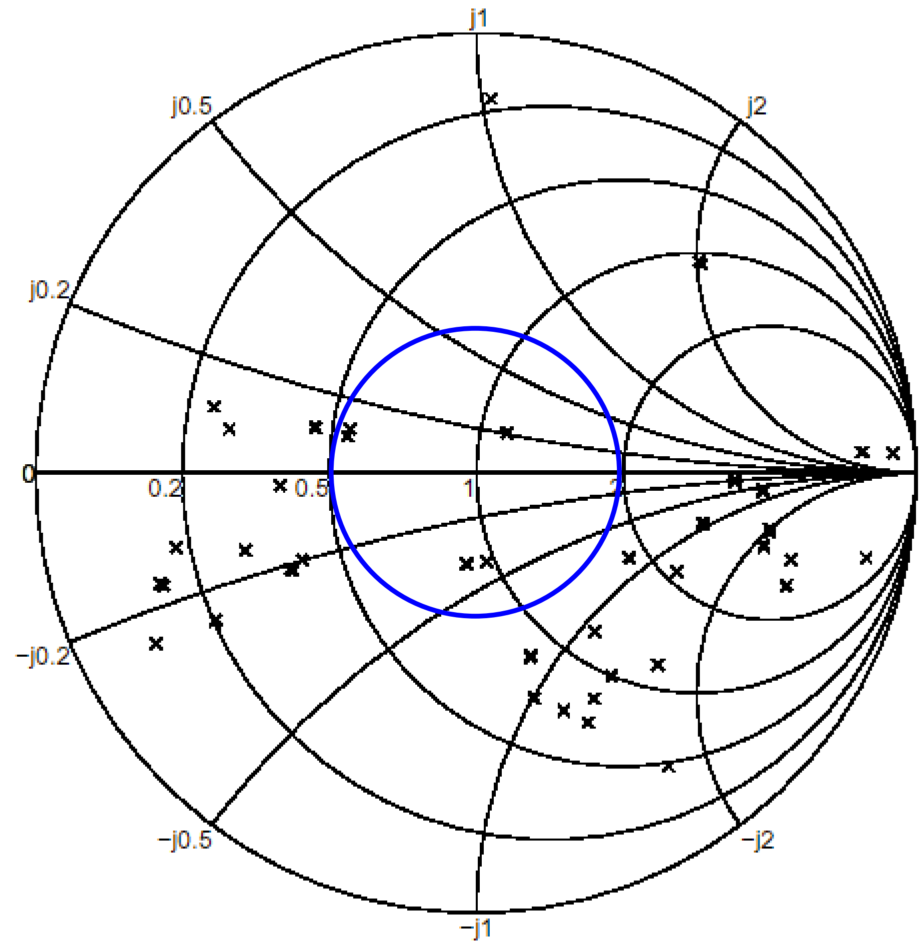
- **Proportion of configurations with SWR< 2**



Layer 1.5 Template

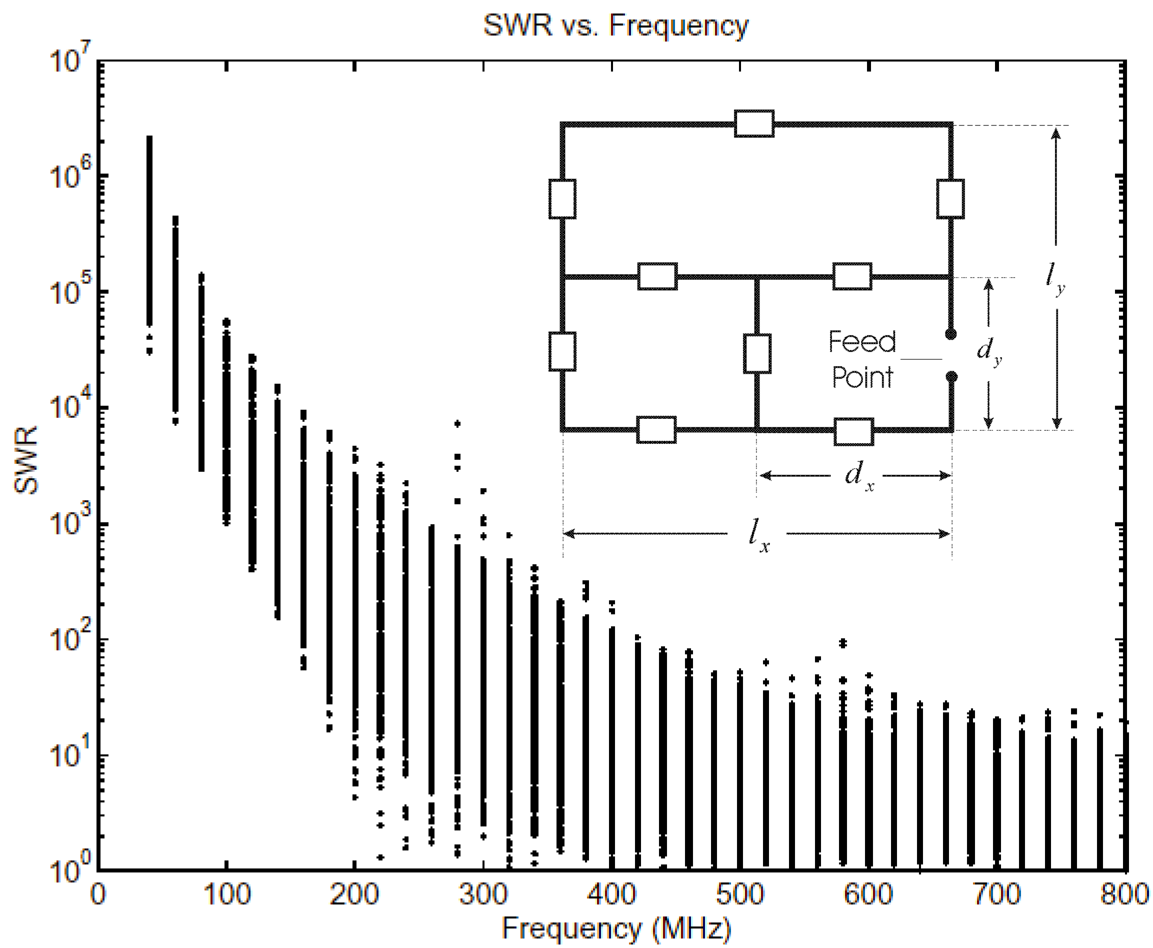


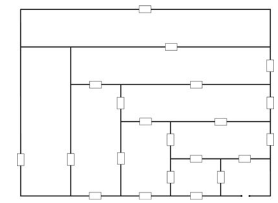
- Smith chart (normalized to 200Ω) at 800 MHz for all 64 configurations
- A few of the configurations have SWR<2



Layer 2 Template

- **9 switches, 512 configurations**
- **Dimensions: 17.1 x 17.1 cm**
- **0.022λ-0.46 λ**
- **Exhaustive sample**





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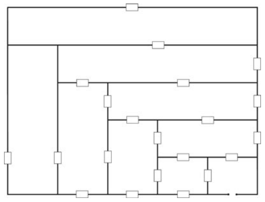
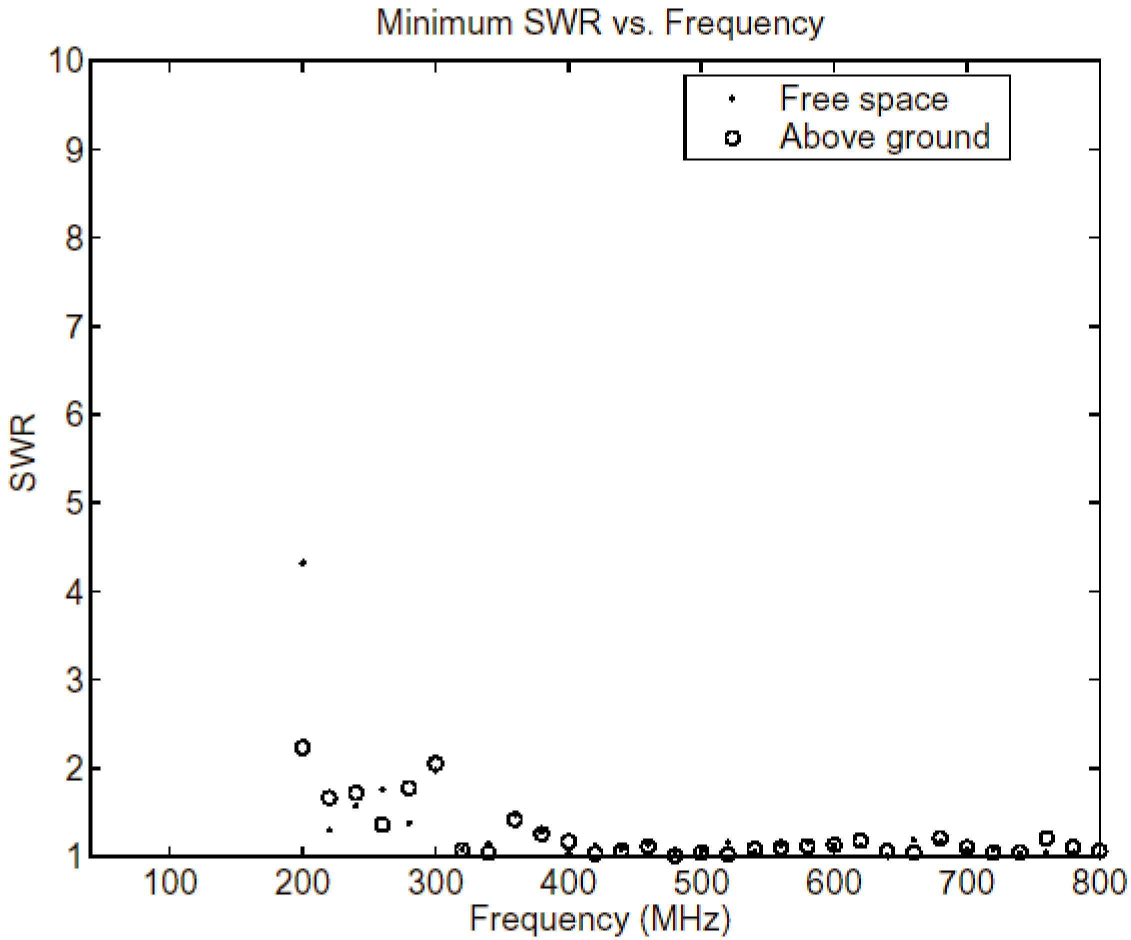
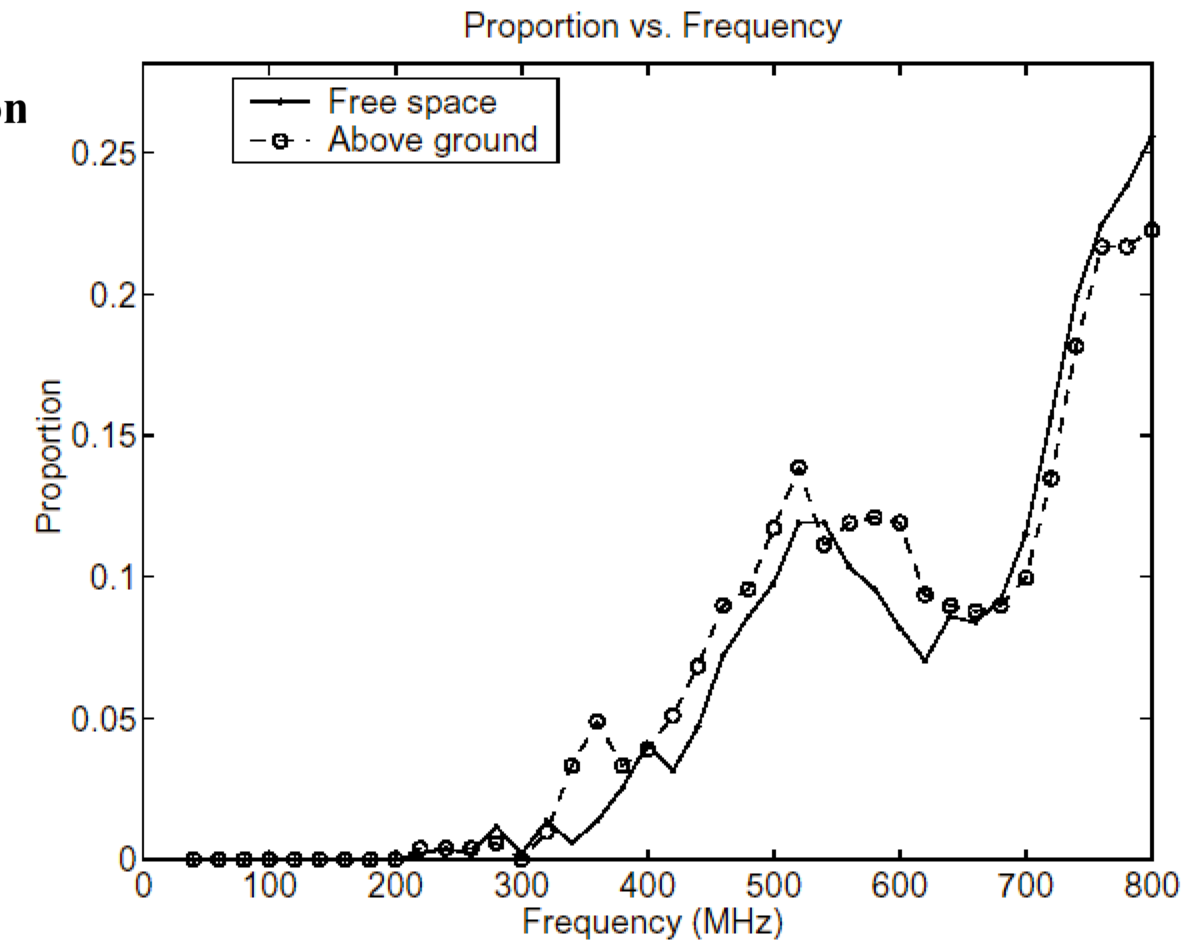
Layer 2 Template





Layer 2 Template

- **Proportion of configuration with SWR<2**



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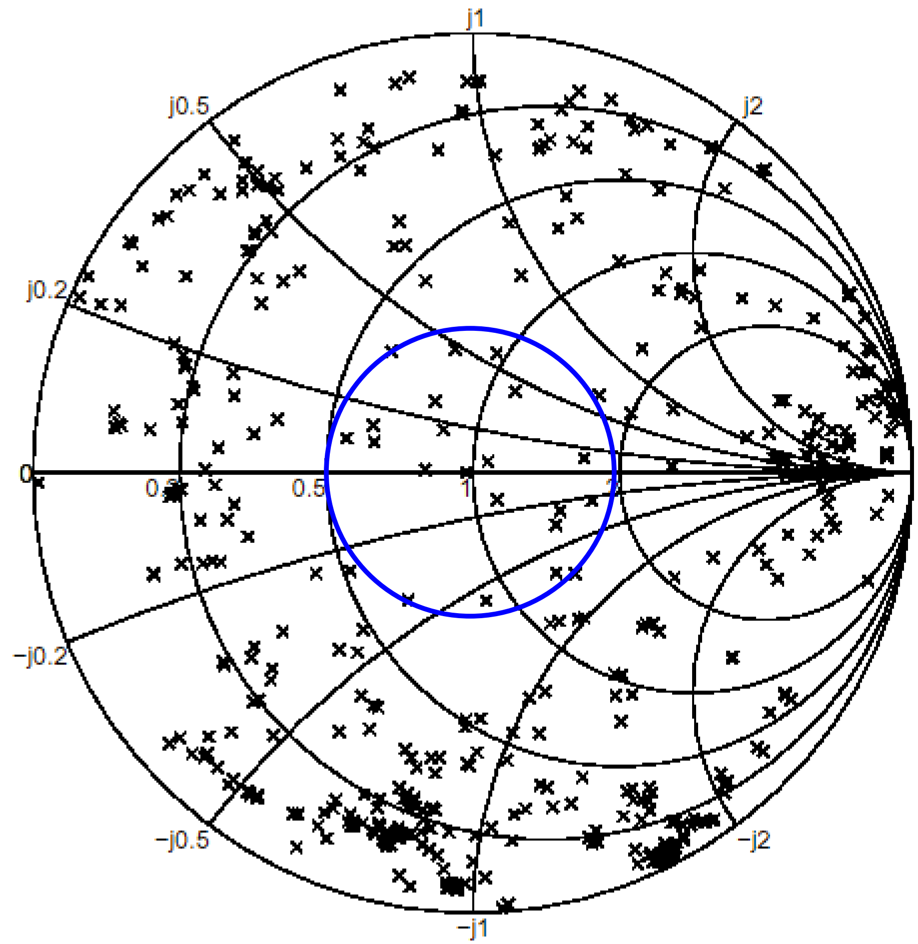
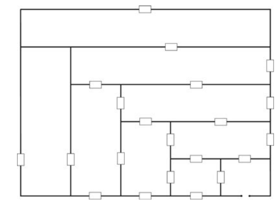
Layer 2 Template

- **Smith Chart at 400 MHz normalized to 200Ω**

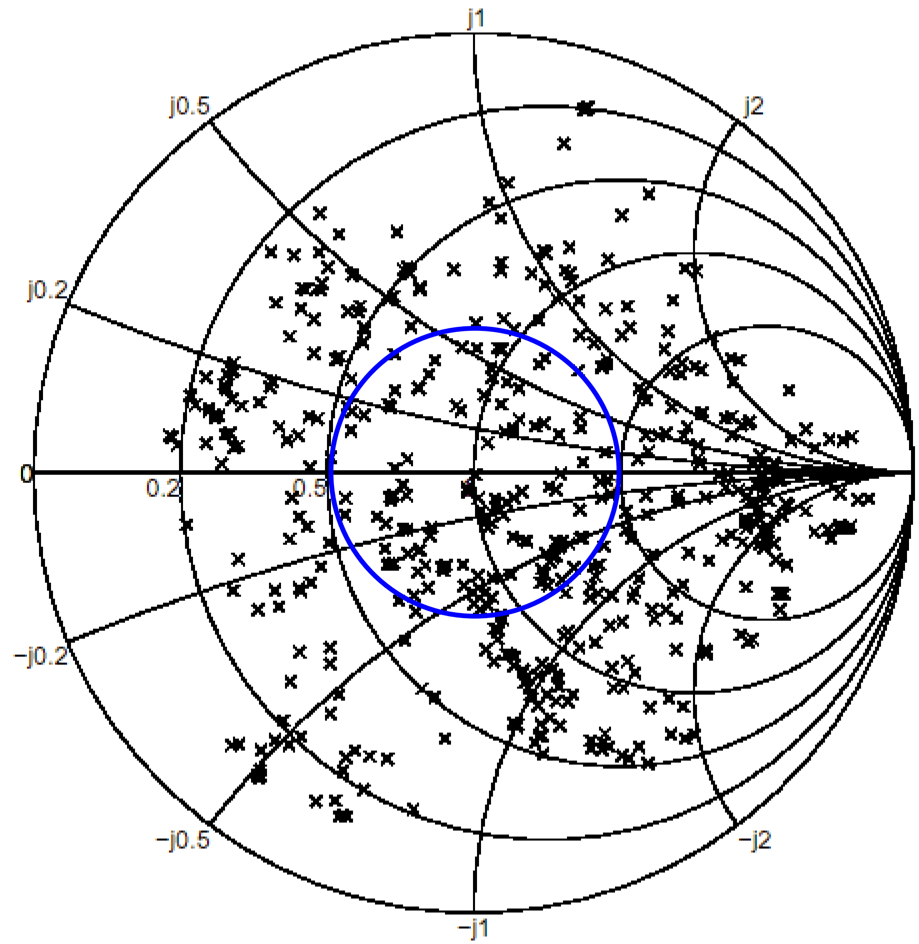
- **Notice the grouping of impedances in several areas**





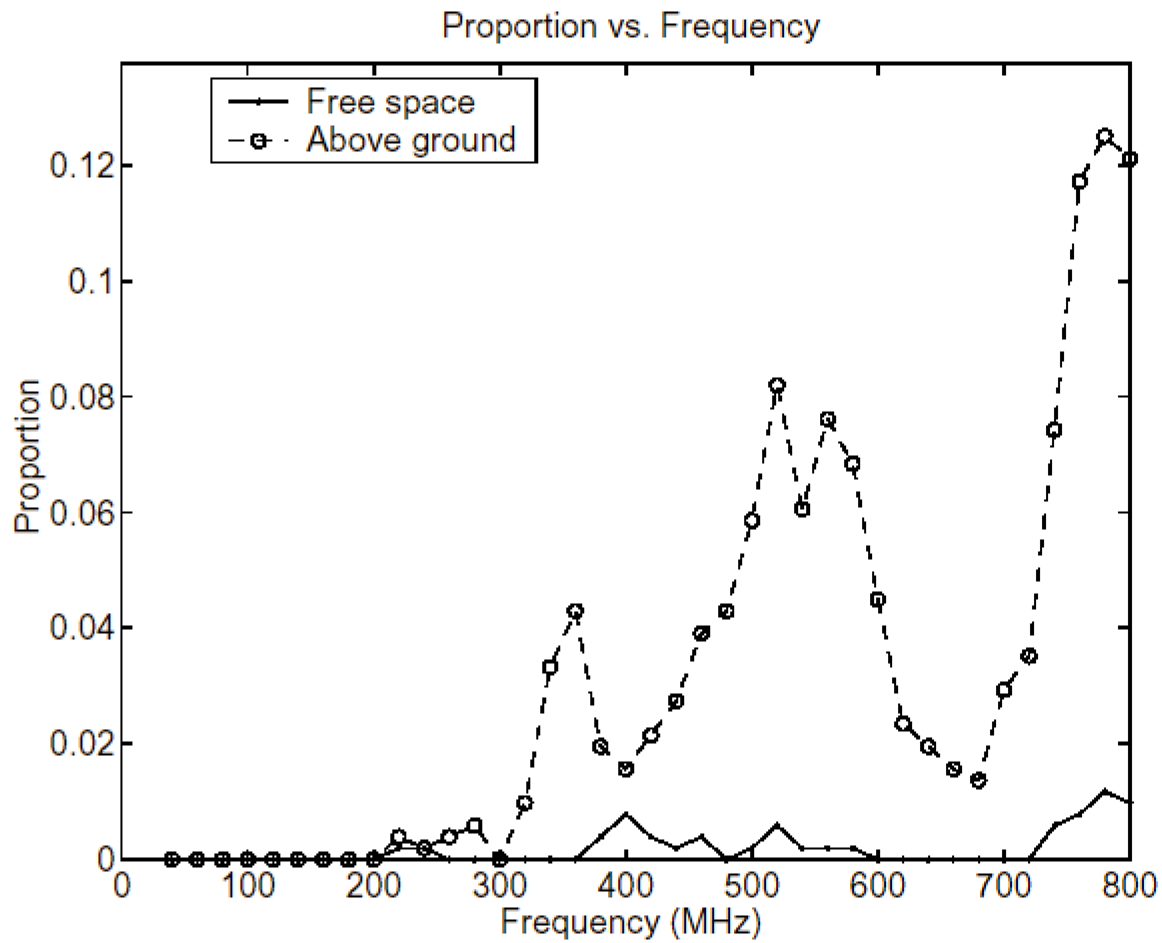
Layer 2 Template

- **Smith Chart at <u>800 MHz</u> normalized to 200Ω**

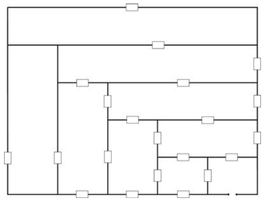


Layer 2 Template

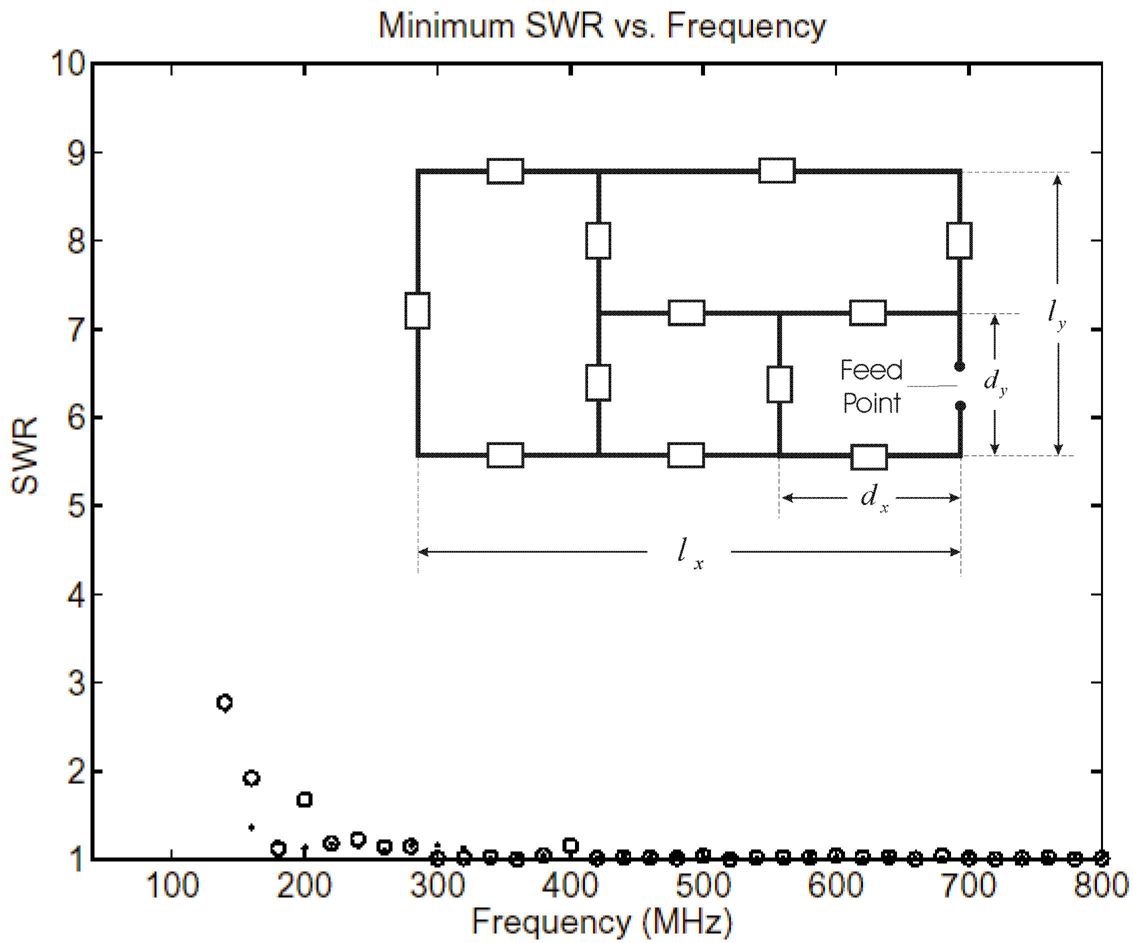
- **Proportion of configurations with SWR<2 <u>and</u> minimum vertical gains in the horizontal plane above 0 dBi**



Layer 2.5 Template

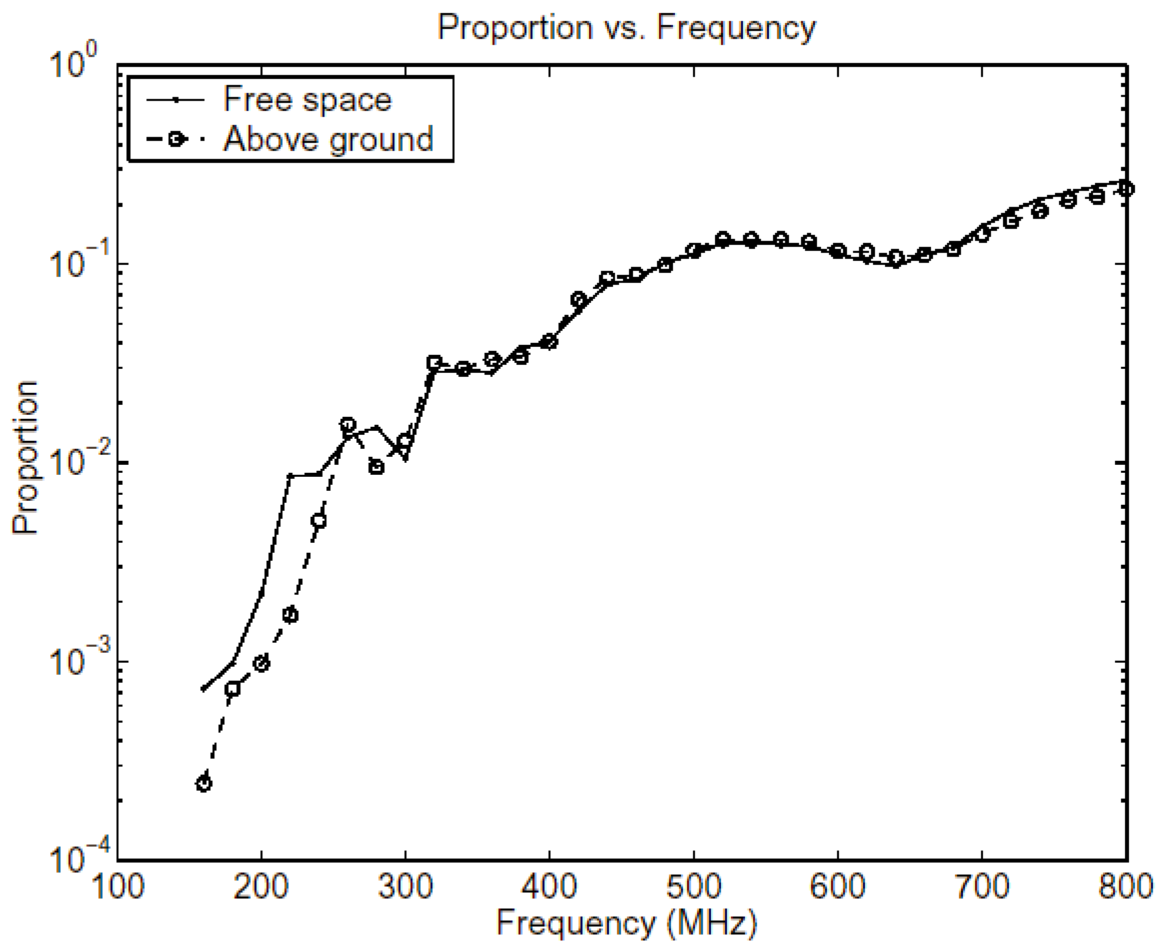


- **12 switches, 4096 configurations**
- **Dimensions: 25.7 x 17.1 cm**
- **0.034 λ -0.685λ x 0.022λ-0.46 λ**
- **Exhaustive sample**

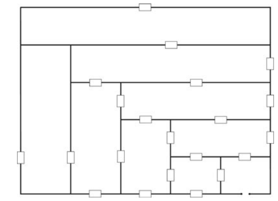


Layer 2.5 Template

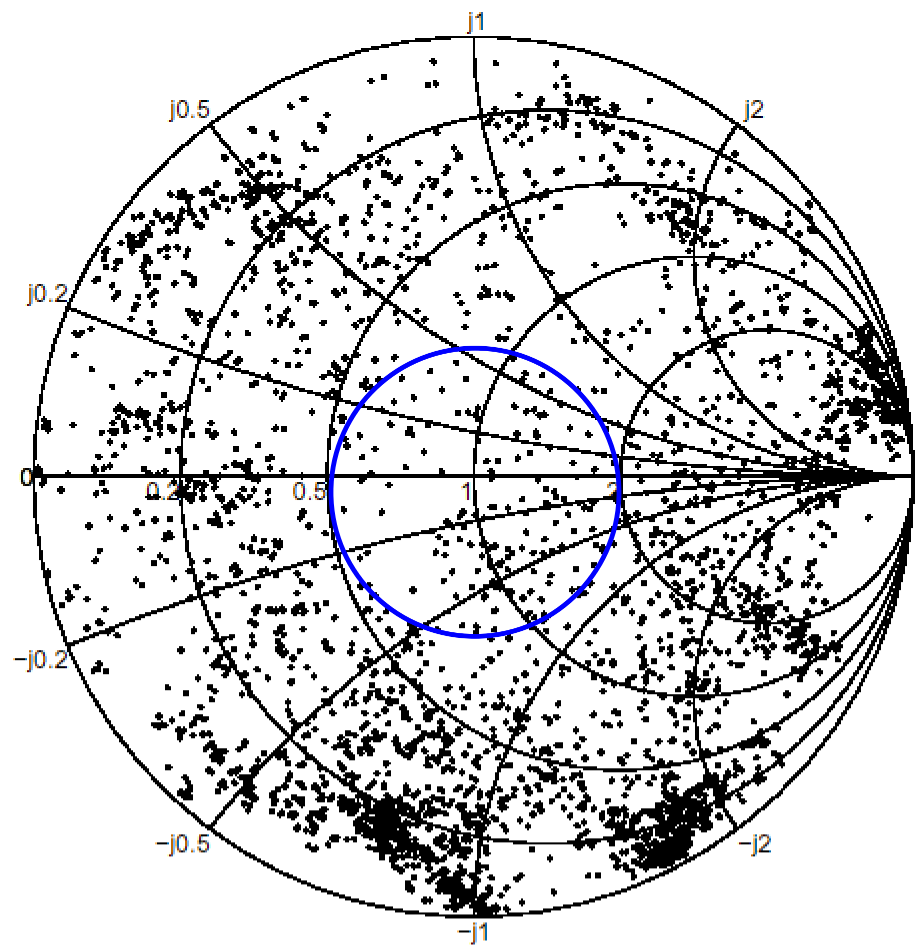
- **proportion of configurations with SWR<2**



Layer 2.5 Template



- **Smith chart (normalized to 200Ω) at 400 MHz**
- **Configurations exhibit a wide range of input impedances with heavy groupings in several regions**



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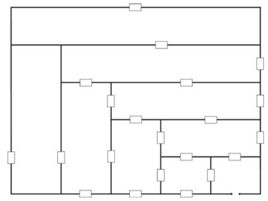
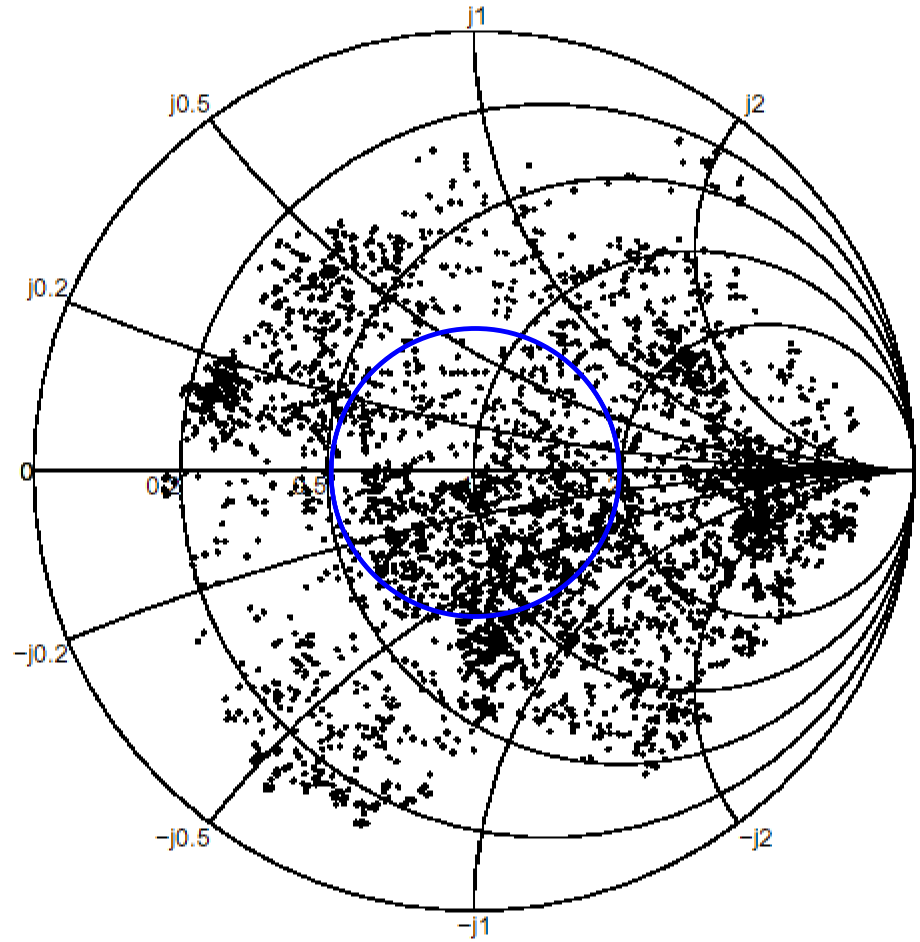
Layer 2.5 Template

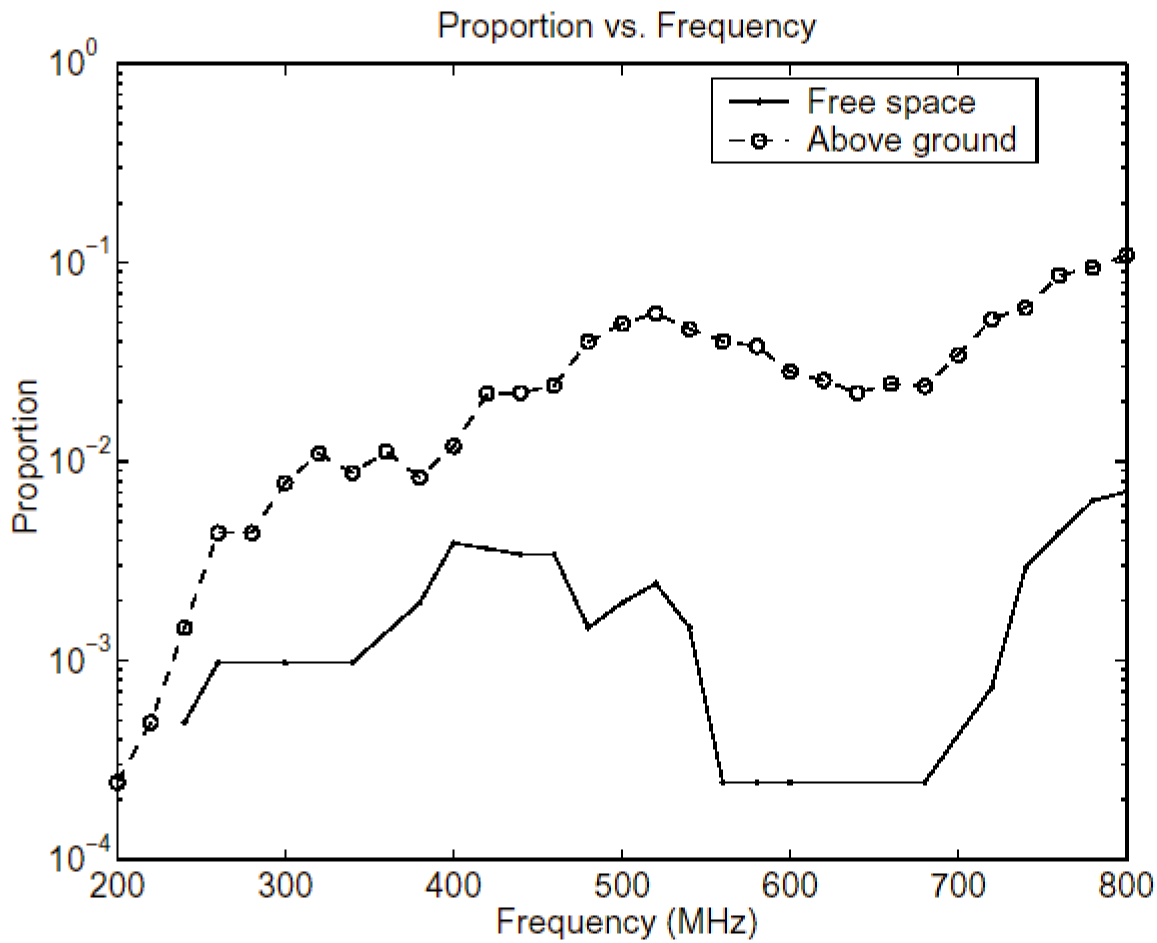


- **Smith chart (normalized to 200Ω) at 800 MHz**
- **Configurations exhibit a wide range of input impedances**

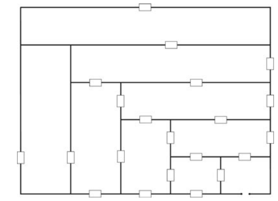


Layer 2.5 Template

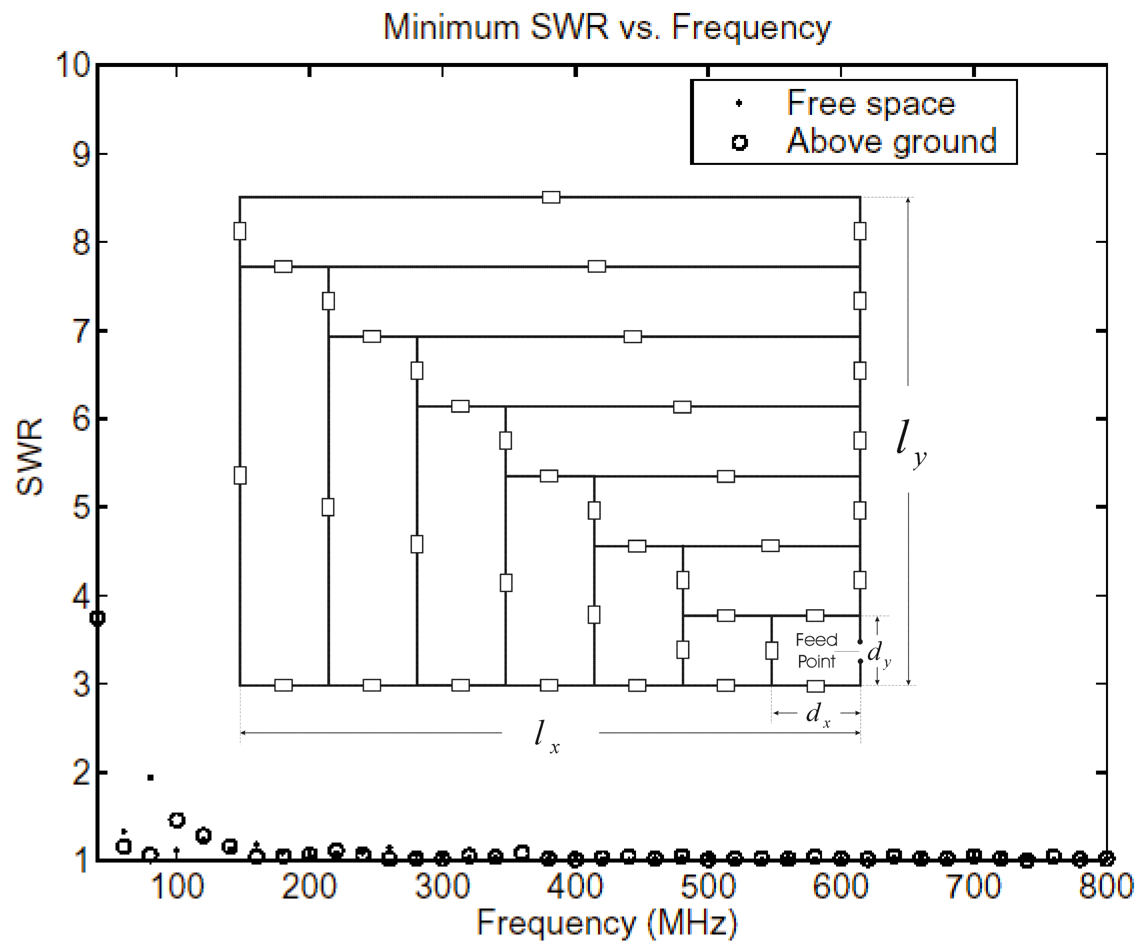
- **Proportion of configurations with SWR<2 <u>and</u> minimum vertical gains in the horizontal plane above 0 dBi**



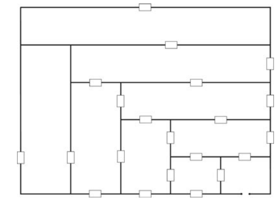
Layer 7 Template



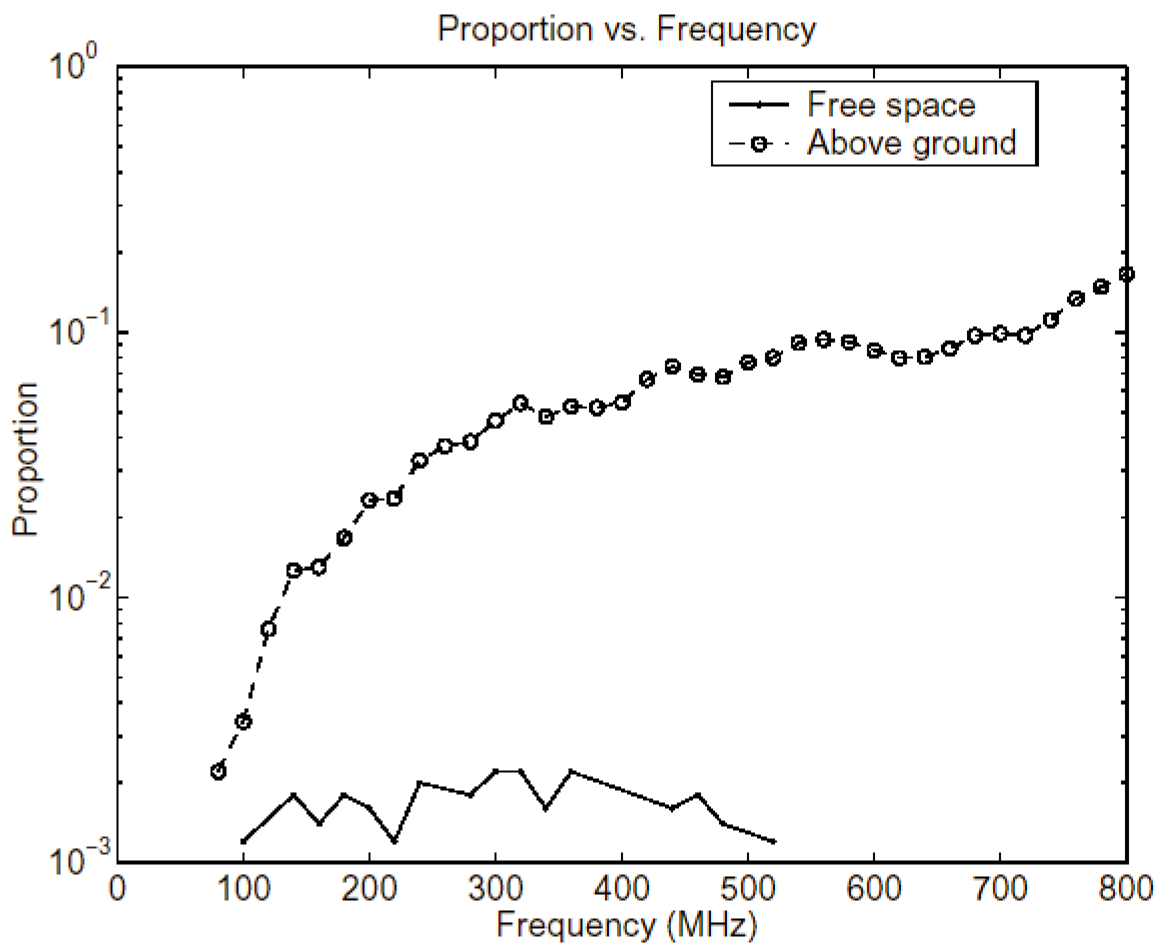
- 39 switches, 539,755,813,888 configurations
- dimension: 60 cm x 60 cm
- 0.08 λ - 1.6 λ
- 5,000 random configurations evaluated



Layer 7 Template



- **proportion of configurations with SWR<4 <u>and</u> minimum vertical gains in the horizontal plane above 0 dB**
- **dimension: 60 cm x 60 cm0.08 λ - 1.6 λ**
- **estimated from 5000 random samples**



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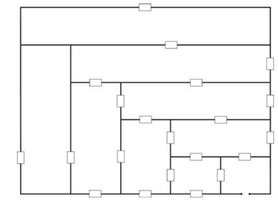
Conclusions



- Good results (SWR<2, gain>0 dB) obtained over two octaves (200-800 MHz) with 9-12 switches (512-4096 configurations)
- Good results (SWR<4, gain>0 dB) obtained over greater a decade (80-800 MHz) when a large number of switches are used
- More samples are needed for larger switch numbers to determine proportion of good states