Self-Structuring Antennas

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1. Introduction

This paper presents a new antenna concept with potential for use in a variety of difficult antenna situations. The term “self-structuring” implies that the antenna changes its electrical shape in response to its environment. The shape change is not made by altering the position or physical geometry of the antenna structure, but rather by controlling the electrical connections between the components of a skeletal antenna “template.” Using an appropriate feedback signal, the structure is rearranged to optimize one or more performance criteria. For example, if the received signal strength is used as the feedback signal, the structure can be optimized for maximum signal strength, even as the antenna changes its aspect with respect to the transmitter. The received signal can also be maximized as the frequency of the signal is changed, giving the antenna system potential for very wide bandwidth. The self-structuring antenna concept lends itself to a variety of applications, including mobile antennas, generic "off the shelf" antennas, EMC mitigating antennas, and randomly deployed antennas.

2. Self-Structuring Antenna Concept

A block diagram of a self-structuring antenna system is shown in Figure 1. A typical self-structuring antenna skeleton, as shown in Figure 2, consists of a large number of wire segments interconnected by controllable switches. The states of these switches greatly influence the electrical characteristics of the antenna, such as input impedance and pattern. The switch states are controlled by a microprocessor, which makes decisions based on a feedback signal from a receiver or external sensors such as near field probes.

The success of a self-structuring antenna is highly dependent on microcomputer search algorithms. A trade-off exists between the “diversity” of the antenna – i.e., the number of possible configurations allowed by its structure – and the complexity of searching for the optimum structural arrangement. An antenna with a higher level of structural diversity should provide a more optimum performance, but will require a longer time to find the optimum configuration. For example, many existing adaptable antenna systems have a discrete number of possible configurations that can be utilized, but usually these antennas switch between a very between a very few number of configurations [1]. However, a self-structuring antenna containing 50 junctions has 2^{50} or over one *trillion* possible structures. Obviously, even a fast microcomputer cannot sort through this many possibilities in any practical real-time application. However, since the self-structuring skeleton results in a binary problem – each junction is either on or off – many recently developed algorithms can be used to optimize the structure without exhaustively searching all possibilities. Two of the most promising are genetic algorithms [2] and simulated annealing (Metropolis algorithm) [3], which have already been widely applied in the design of specific-use antennas [4], [5].

The most appropriate shape of the skeleton and optimum feeding techniques are dependent on each particular application of the antenna. However, it is doubtful if the particular skeletal shape is crucial, as long as sufficient diversity is present. Thus, malleable, plastic-based skeletal sheets would provide a flexible means of applying self-structuring antennas to a wide variety of geometrical conditions. The antenna skeletons could then be embedded in the plastic casing of a television set, a laptop computer's monitor, or a cellular telephone.

3. Prototype Antenna

A prototype self-structuring antenna was designed and constructed at Michigan State University. The skeleton of the prototype, similar to that shown in Figure 2, uses 23 controllable switches for a total of $2^{23}=8,388,608$ configurations. An HP 8510C Network Analyzer is used as the receiver for the antenna system. Measurements made by the network analyzer are used as feedback signals by a microprocessor that controls the switches on the antenna skeleton.

4. Measured Results

Measurements were performed on the prototype self-structuring antenna to determine the smallest standing wave ratio (SWR) that the antenna system could locate during its search. The microprocessor used both a simulated annealing algorithm and a genetic algorithm to search through the possible switch states at each measurement frequency. SWR measurements were performed from 45 MHz to 450 MHz with results shown in Figure 3. As seen from these results, the self-structuring antenna is able to configure itself at each measurement frequency such that its SWR is less than 1.04 for the frequency band from 50 MHz to 350 MHz for both searching algorithms. The self-structuring antenna prototype had the most trouble matching to the 50 Ω network analyzer test port cables in the band from 375 MHz to 425 MHz. The simulated annealing algorithm was able to find a minimum SWR of only 1.23 at 400 MHz, and the genetic algorithm found a minimum SWR of 1.30. Even this worst case result demonstrates the potential wideband capabilities of the self-structuring antenna prototype.

In a second test, the same antenna was used as a receiver with the fixed frequency of 300 MHz. Its aspect angle to a transmitting antenna was varied from 0 to 90 degrees (as measured from the perpendicular to the plane of the antenna) and the received signal optimized at each aspect angle. Thus as the antenna was rotated, its pattern was altered such that the main lobe was directed towards the receiving antenna. The resulting signal amplitude, shown in Figure 4, demonstrates that a strong signal can be obtained independent of antenna aspect.

5. Conclusion

A new type of adaptive antenna system, the self-structuring antenna, has been presented in this paper. The self-structuring antenna is capable of adapting to a changing electromagnetic environment by altering its electrical characteristics in response to a feedback signal from the system's receiver. Measurements were performed on a prototype self-structuring antenna system to demonstrate its capabilities for wideband use and for adapting to changing aspect angle.

6. References

[1] J. K. Tillery, G. T. Thompson, and J. J. H. Wang, "Low-Power Low-Profile Multifunction Helmet-Mounted Smart Array Antenna," 1999 IEEE AP-S International Symposium, Orlando, Florida, July 11-16, 1999.

[2] D. E. Goldberg, "Genetic Algorithms in Search, Optimization, and Machine Learning," Addison-Wesley, 1989.

[3] W. H. Press, S. A. Teukolsky, B. P. Flannery and W. T. Vetterling "Numerical Recipes, The Art of Scientific Computing, 2nd Edition," Cambridge University Press.

[4] E. E. Altshuler and D. S. Linden, "Wire Antenna Designs Using Genetic Algorithms," IEEE Antennas and Propagation magazine, pp. 33-43, Vol. 39, No. 2, April 1997.

[5] E. A. Jones and W. T. Joines, "Design of Yagi-Uda Antennas Using Genetic Algorithms," IEEE Transactions on Antennas and Propagation, pp. 1386-1391, Vol. 45, No. 9, September 1997.

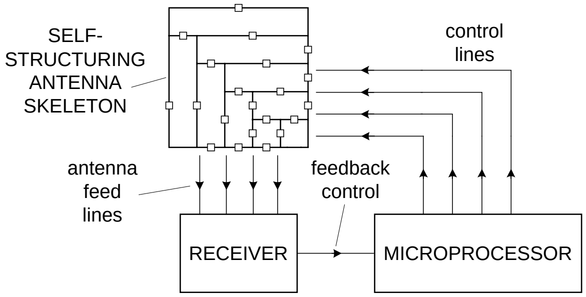

Figure 1: Block Diagram of self-structuring antenna system.

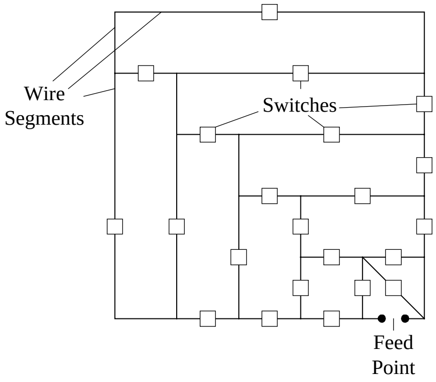

Figure 2: Diagram of self-structuring antenna skeleton.

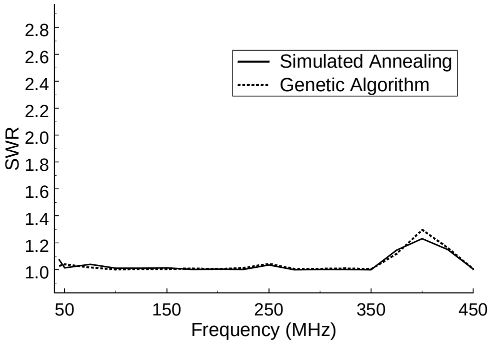

Figure 3: Minimum SWR of self-structuring antenna optimized at each measurement frequency.

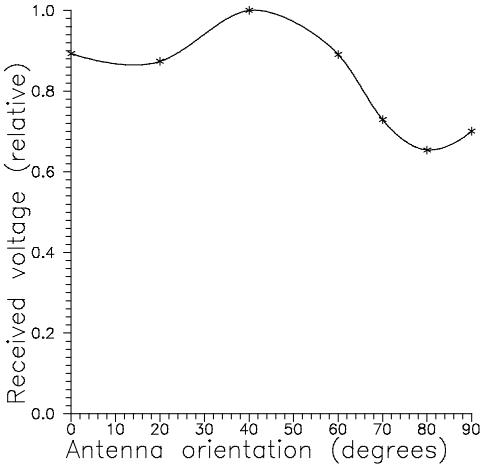

Figure 4: Signal strength measured by the self-structuring antenna as a function of aspect angle.

Self-Structuring Antennas

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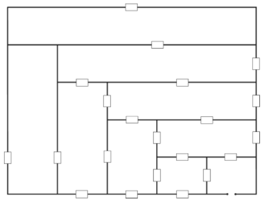
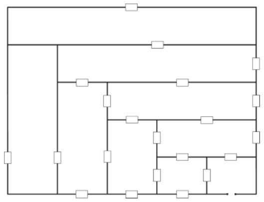
Overview



- Introduction
- Self-Structuring Antenna Concept
- Prototype Antenna
- Measured Results
- Numerical Modeling
- Conclusion

Introduction



- **Conventional antennas - Electromagnetic properties such as impedance, pattern, bandwidth are typically analyzed for a single configuration**
- **Adaptive antennas**
  - **Adaptive phased array systems – Genetic algorithms sometimes used to select the amplitudes and phases of array elements to manipulate the array's properties**
  - **Reconfigurable antennas – Relatively few number of discrete configurations, each of whose properties are often known**
- **Self-Structuring Antenna – Very Large number of discrete states or configurations, each of whose properties are possibly unknown prior to the antenna's operation.**

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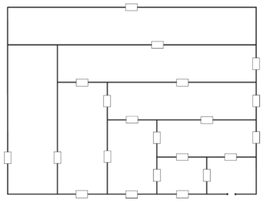
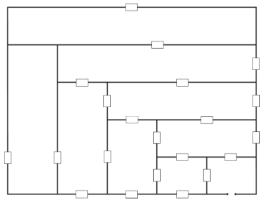
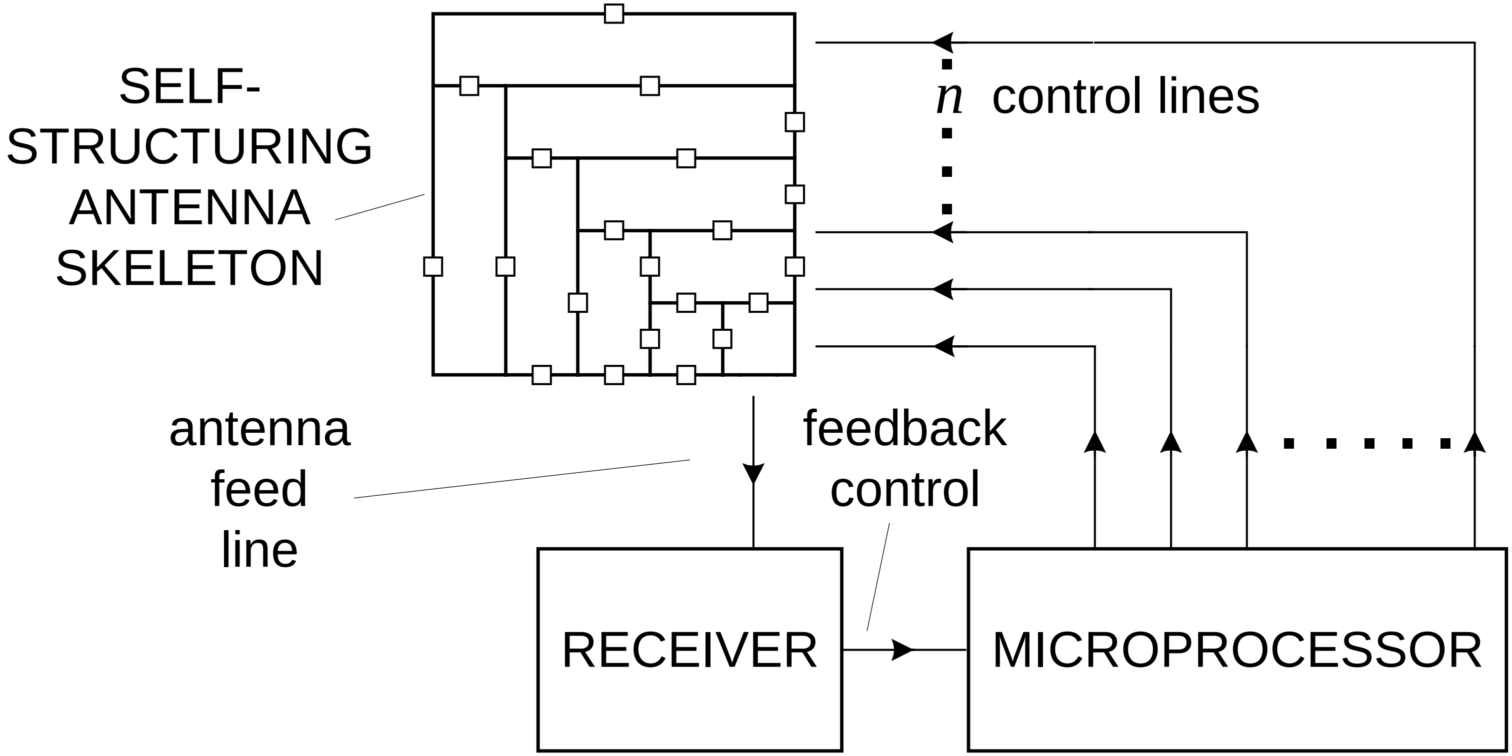
Self-Structuring Antenna Concept



- A ‘self-structuring antenna’ system:
  - Is capable of arranging itself into a large number of different possible configurations
  - 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 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 Antenna System





SELF-STRUCTURING ANTENNA SKELETON

n control lines

antenna feed line

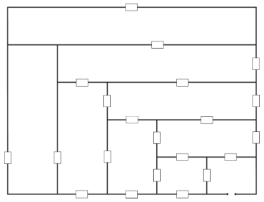
feedback control

RECEIVER

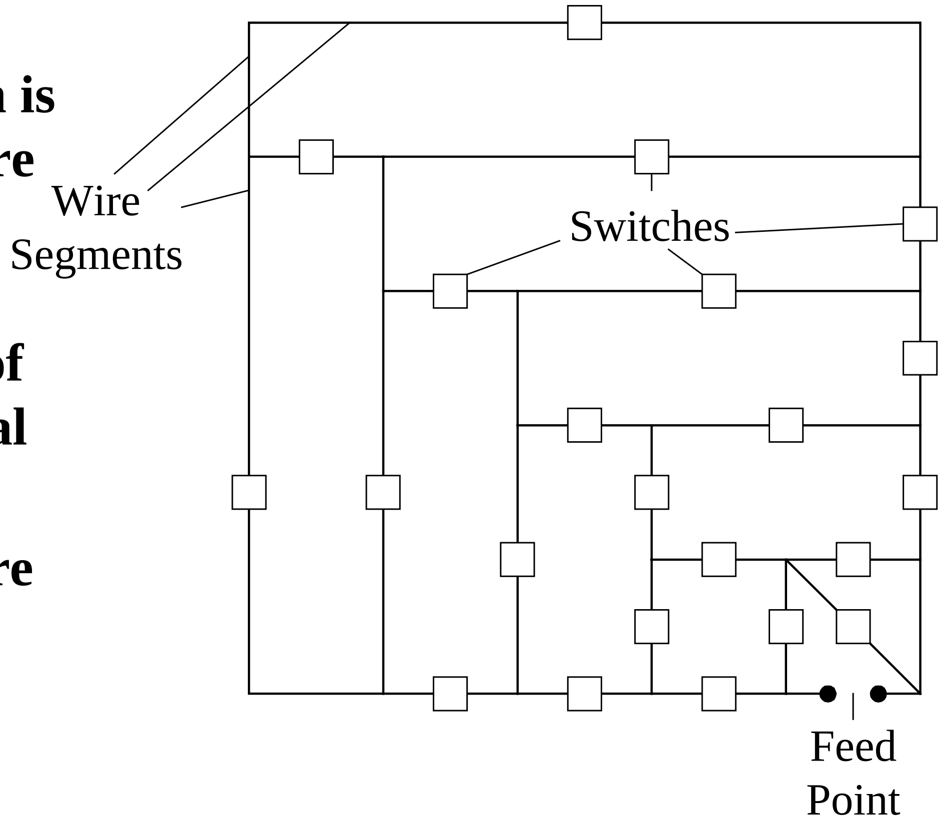
MICROPROCESSOR

Block Diagram of Self-Structuring Antenna System

Self-Structuring Antenna Skeleton



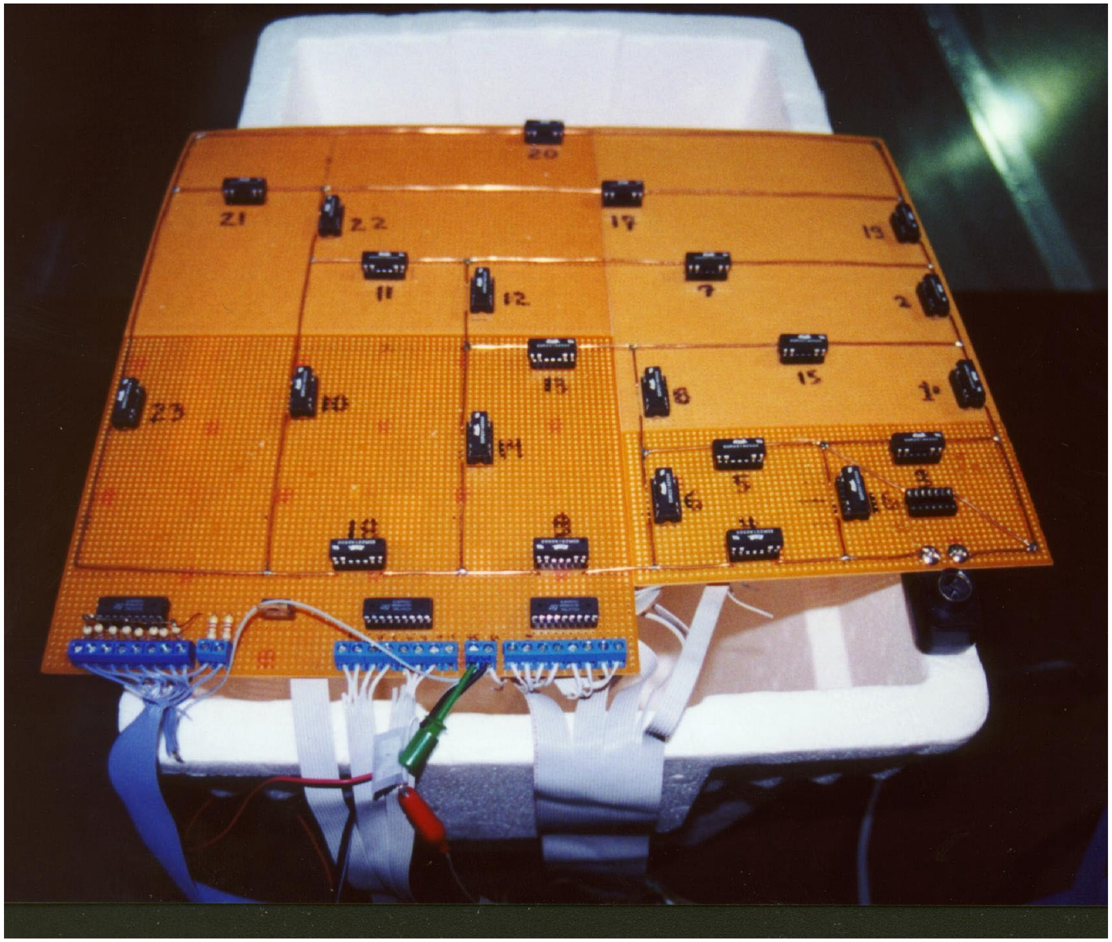
- **A self-structuring antenna skeleton is comprised of a large number of wire segments interconnected by controllable switches.**
- **For each configuration, the states of the switches determine the electrical characteristics of the antenna.**
- **For a skeleton with *n* switches, there are 2^n possible configurations.**
- **An asymmetric topology provides more diversity and less repeated states than a symmetric topology.**



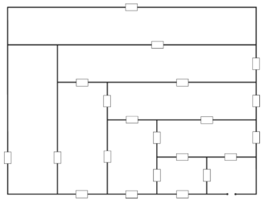
Example Self-Structuring Antenna Skeleton

Prototype Self-Structuring Antenna

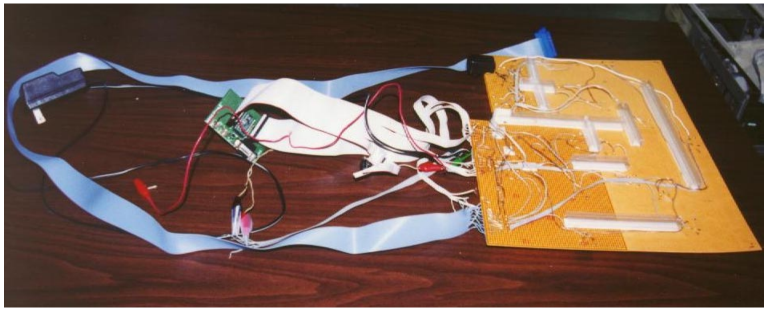
- **A working prototype self-structuring antenna has been built at Michigan State University.**
- **The prototype has 23 controllable switches. This allows for 2^{23} or 8,388,608 possible configurations.**
- **The skeleton measures 13.7” by 10.25”**

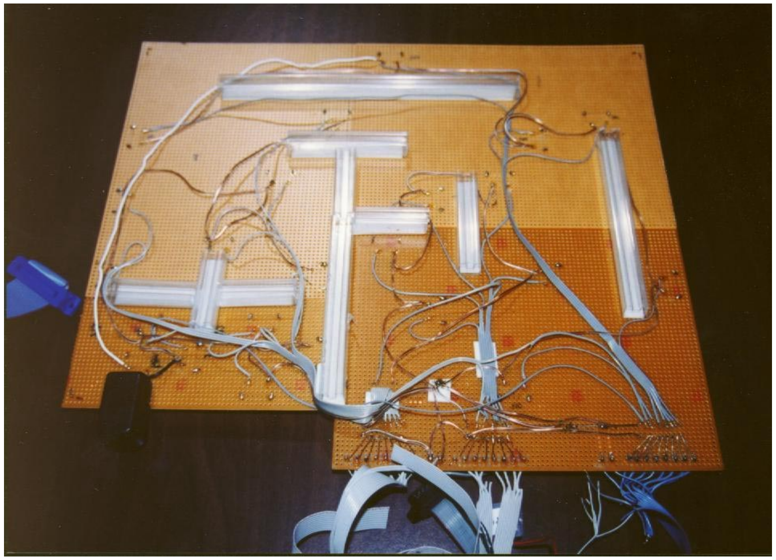


Prototype Self-Structuring Antenna



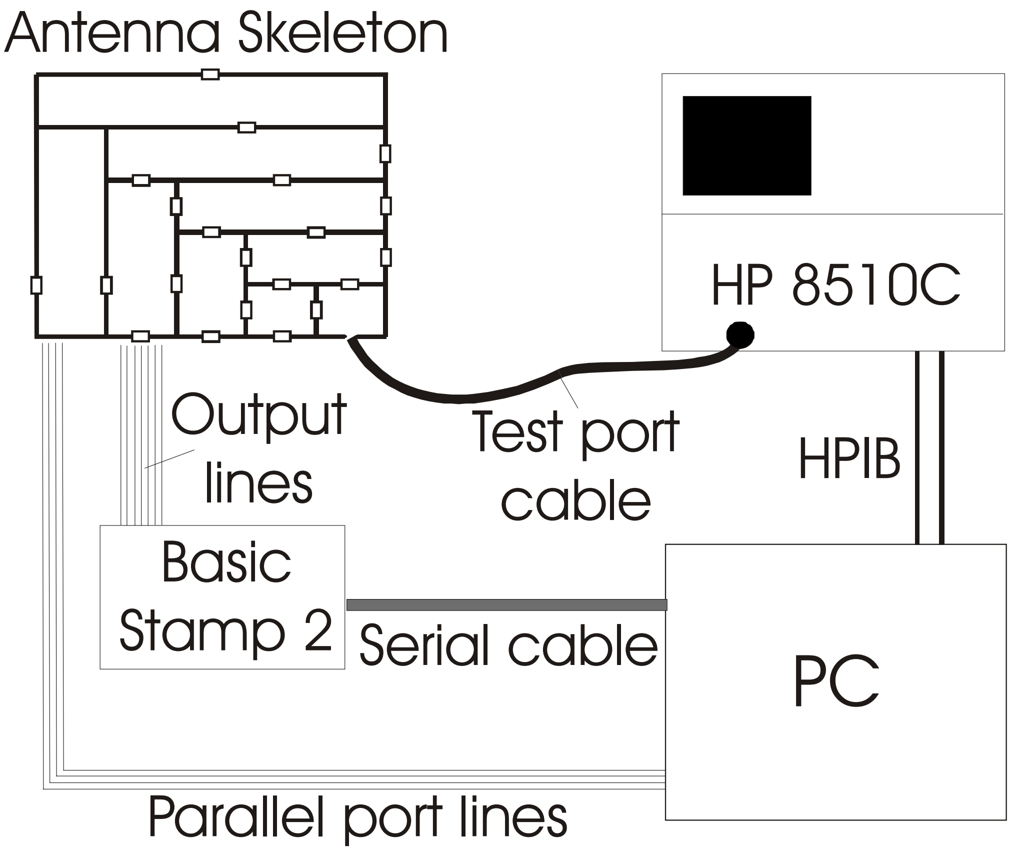
- There are many long control and power lines that are connected to the prototype antenna.
- The back of the perfboard shows the control wiring to the switches.
- Coupling to these conductors was not suppressed for some of the measurements.



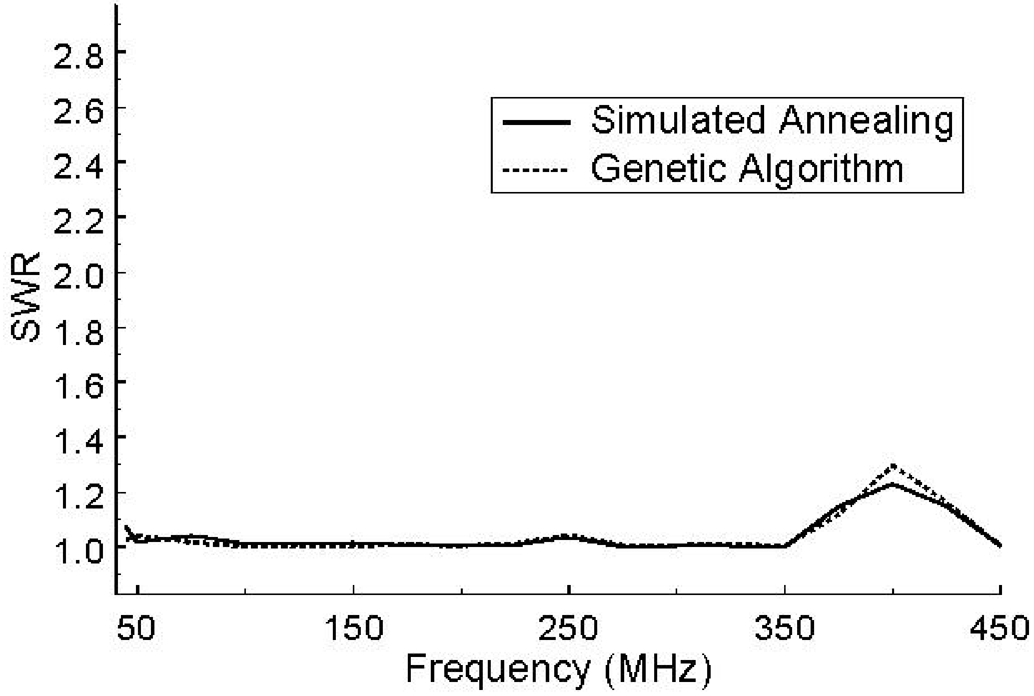


SWR Measurement Setup

- **The prototype uses an HP 8510C Network Analyzer as the receiver and a personal computer as the microprocessor.**
- **A PC controls 8 switches through its parallel port, and it uses its serial port to talk to a Basic Stamp to control the remaining 15 switches**



Measured SWR Results



Measured SWR of Self-Structuring Antenna Optimized at Each Frequency

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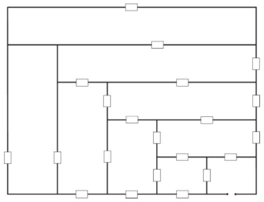
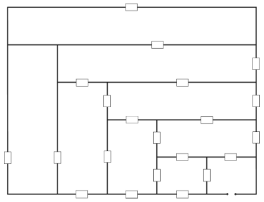
Measured Results: Average SWR

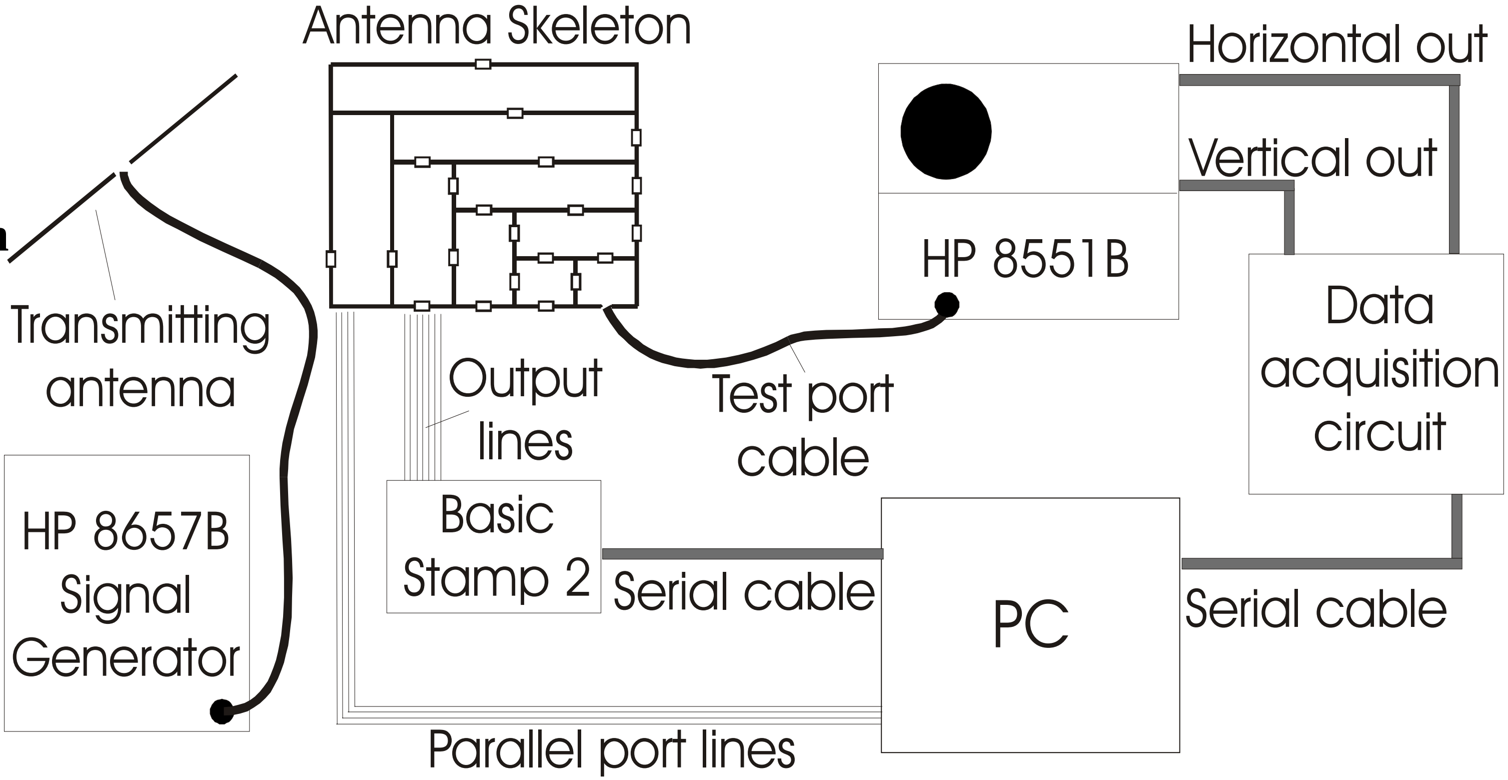


- Measurements were also performed to find the lowest SWR over a band of frequencies for a single configuration.
- Using a simulated annealing algorithm, the prototype system was able to find single configurations with minimum average SWRs over the following bands:
  - 100 MHz to 200 MHz: 1.41 average SWR
  - 200 MHz to 300 MHz: 2.07 average SWR

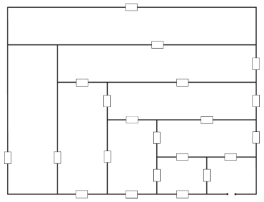
Reception Optimization Measurement Setup



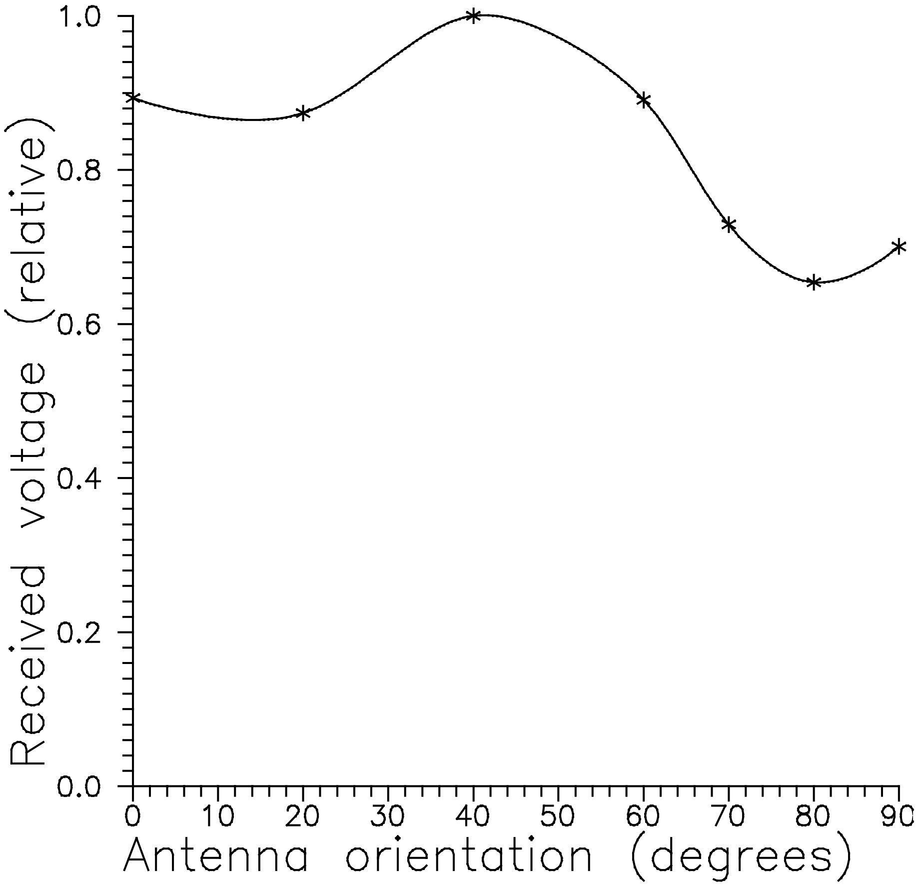
- For reception optimization measurements, the prototype uses an HP 8551B Spectrum Analyzer as the receiver.



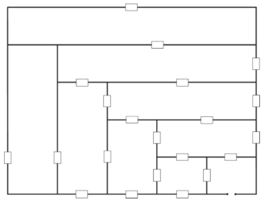
Reception Optimization Measurements



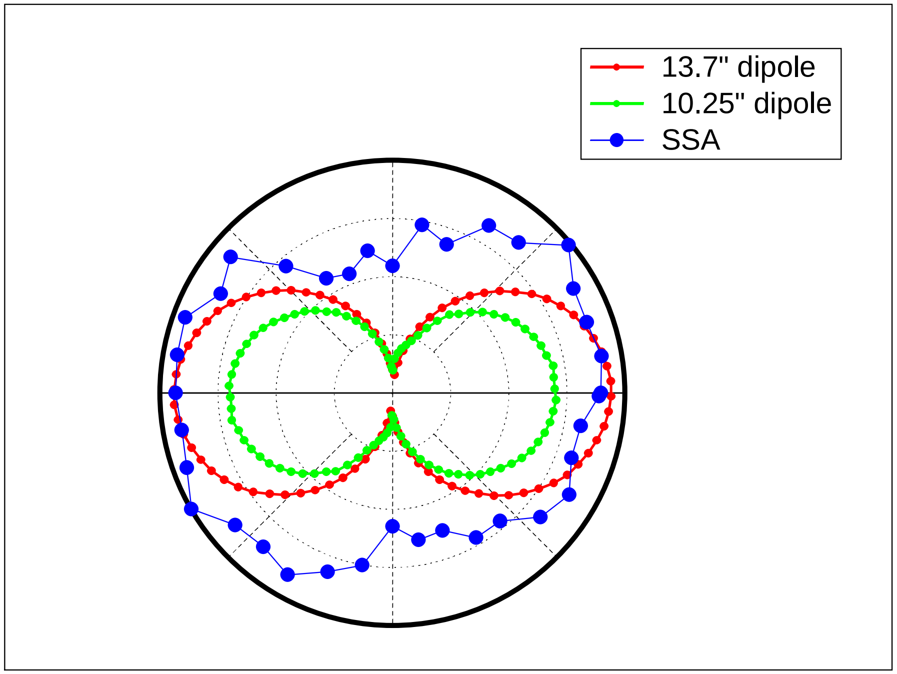
- **The prototype antenna was optimized at every aspect angle from 0 to 90 degrees at 300 MHz. The prototype was able to find a configuration that received a strong signal at each angle.**



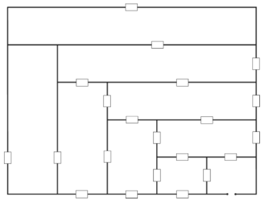
Reception Optimization Measurements



- More reception measurements were performed at 275 MHz for a different axis of rotation. The prototype was able to find a configuration with a strong signal at every angle.
- As a comparison, the patterns of two dipole antennas were measured with lengths equal to the width and height of the prototype antenna.

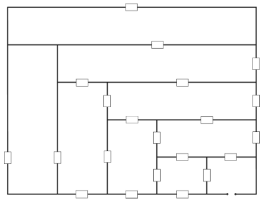


Measured Results Summary



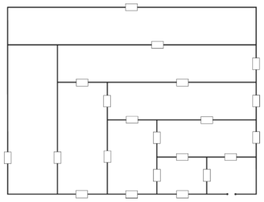
- SWR and reception measurements have been made on the self-structuring antenna prototype.
- The prototype antenna was able to find configurations with a low SWR for many frequencies over a broad frequency band.
- The prototype antenna was able to obtain a strong signal at every aspect angle where the antenna was optimized.

Numerical Modeling

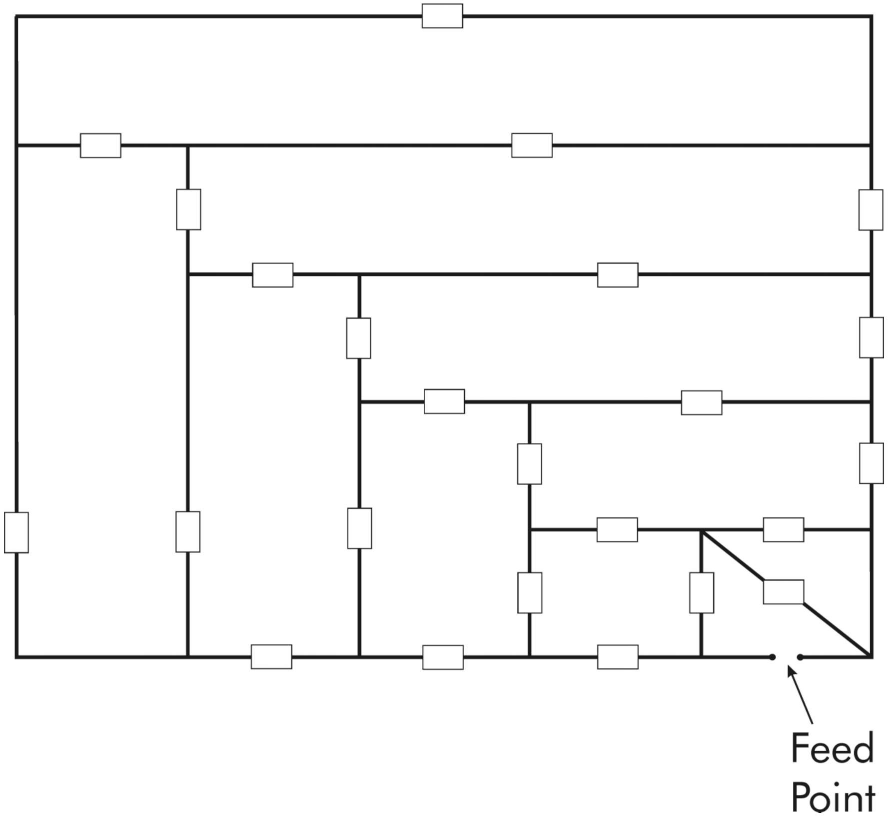


- Numerical modeling of the self-structuring antenna has been performed to show proof of principle of the self-structuring concept.
- The results of this work were presented Monday morning: “Numerical Simulation of Self-Structuring Antennas Based on a Genetic Algorithm Optimization Scheme” by J. E. Ross, E. J. Rothwell, C. M. Coleman, and L. Nagy.
- The numerical simulation focused on a self-structuring antenna skeleton with no control or power lines.

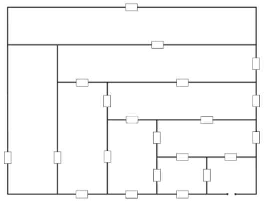
Numerical Modeling



- A genetic algorithm was used to optimize the skeleton’s input impedance from 50 to 800 MHz. The target impedance was 200 Ohms.
- NEC was used to calculate the input impedance to the skeleton.
- The self-structuring antenna skeleton was able to find configurations with acceptable input impedances from about 200 to 800 MHz.

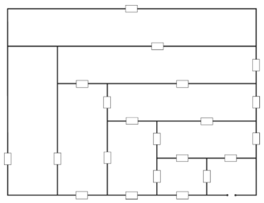


Possible Applications for a Self- Structuring Antenna



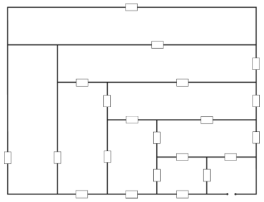
- **The self-structuring antenna lends itself for use in a variety of applications where the electromagnetic environment of the antenna is possibly changing:**
  - **Mobile antennas**
  - **Randomly deployed antennas**
  - **Partially disabled antennas**
  - **Generic “off the shelf” antennas**

Future Research



- Constructing improved prototype antennas
- More received signal and SWR measurements
- Geometries for antenna skeletons
- Extended numerical modeling
- Study of efficient searching algorithms
- Statistical analysis

Conclusion



- A new type of adaptive antenna has been presented. The self-structuring antenna system has possible applications in several difficult changing antenna environments.
- A working prototype antenna has been constructed and tested.
- SWR and received signal measurements have been performed on the prototype antenna.
- Numerical modeling performed on the self-structuring antenna has provided promising results.
- Future research on the self-structuring antenna is planned for Michigan State University and John Ross & Associates.