Self-Structuring Antenna for Television Reception

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1. Introduction

A self-structuring antenna (SSA) is capable of adapting to changes in environmental factors or system requirements by altering its electrical shape [1]. A particularly appropriate application for such an antenna is television reception. The VHF-UHF TV band is nearly a decade wide, and thus antennas that operate well at low VHF frequencies may have difficulty operating at high UHF frequencies. An SSA on a fixed receiver can reconfigure itself each time the television channel is changed, while an SSA on a mobile receiver can also reconfigure itself in real time to compensate for changes in orientation.

The construction of an SSA for television reception was given as a design problem to two student groups at Michigan State University. The project fulfilled the design requirements for the embedded systems capstone course in the Department of Electrical and Computer Engineering. The first team, responsible for the design of the antenna and control hardware was made up of six individuals: *Brad Perry, Matt Freel, Tanya Anderson*, *Lance Ainsworth, Kyhia Bostic*, and *Nnamdi Oputa.* The second design team, responsible for the embedded system's interface with the television also consisted of six people: *Brian Basch, David Dempsey, Scott Butler, Christopher Lata, Vinson Lewis,* and *Kris Porter.* The two teams came together at the end of the semester to interface the two projects in order to test and demonstrate the complete self-structuring antenna system. A block diagram outlining the complete system is included as Figure 1.

2. Self-Structuring Antenna Concepts

The concept behind the self-structuring antenna is to automatically reconfigure the antenna geometry for optimum television reception. This was accomplished through the use of latching relays and a microcontroller board. The microcontroller board acquires the received signal strength from the television automatic gain control (AGC) through its A/D port. A decision is then made whether or not to reconfigure the antenna. If restructuring is required, the microcontroller sends a reset signal through the control board to place the antenna board in a blank state. This is followed by a signal that sets the relays to a chosen configuration, and the process is repeated until a satisfactory AGC level is achieved. The entire process of setting the switch states and acquiring the received signal takes only a few milliseconds to complete.

The antenna board for the self-structuring antenna was created in such a way that elements could take the form of either loops or monopoles [2]. A diagram of the self-structuring antenna board is shown in Figure 2. Relays, which control the elements that make electrical connections to the television, were placed along the edges of the board where they could be turned on and off in a fashion that would allow for maximum use of the 2^{30} possible arrangements.

3. Prototype Construction

The prototype of the Self-Structuring Antenna was created on a double-sided printed circuit board. Relays used for the antenna are single coil latching and require a control board in order to guarantee that resetting of the relays will take place. Pictures of both the control and antenna board prototypes are shown in Figures 3 and 4. The antenna board contains 30 relays, giving 2^{30}, or 1,073,741,824, possible geometrical arrangements.

With over a billion possible combinations, the employment of a genetic algorithm became necessary to insure a timely reconfiguration of the antenna for optimum television reception [3-5]. This algorithm was developed to work on several levels. First, the algorithm checks known "good" configurations in order to find a new arrangement quickly. Next, it refines and stores information about the setup in order to build on the number of configurations classified as good. Through this action, the antenna system is able to quickly reconfigure so as to keep the television reception optimal under changing conditions.

4. Conclusions

This paper has introduced a type of adaptive antenna that automatically restructures in response to its changing electromagnetic environment. The antenna changes are based on a feedback signal received from the automatic gain control of a television set. This signal is processed and the appropriate antenna structure is sought using a genetic algorithm. The antenna layout and software were developed at Michigan State University, where testing and revisions have been carried out since this project's inception as a Senior-level design project.

5. References

[1] C. M. Coleman, E. J. Rothwell, J. E. Ross, "Self-Structuring Antennas," 2000 IEEE AP-S International Symposium, Salt Lake City, Utah, July 16-21,2000.

[2] C. A. Balanis, "Antenna Theory: Analysis and Design" John Wiley & Sons, Inc., 1997.

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

[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.

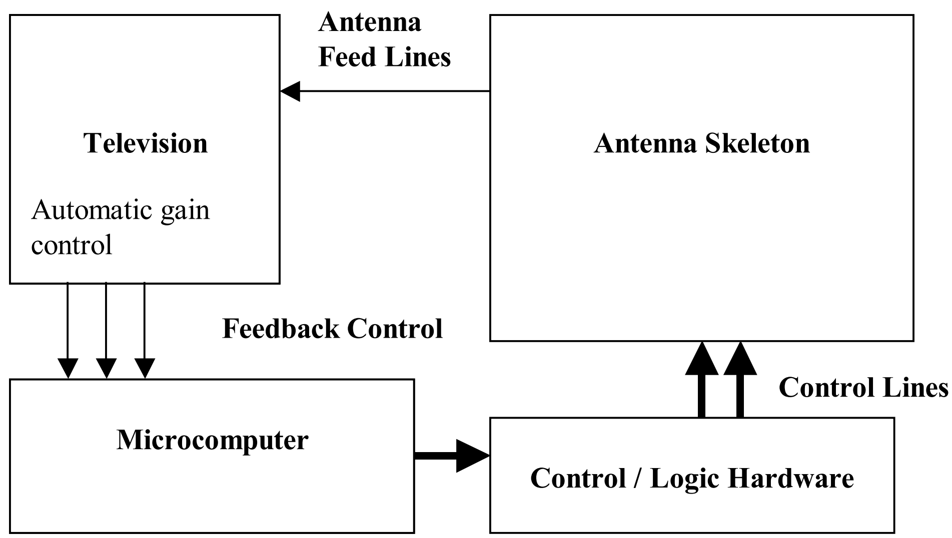

Figure 1: Block Diagram of Self-Structuring Antenna System

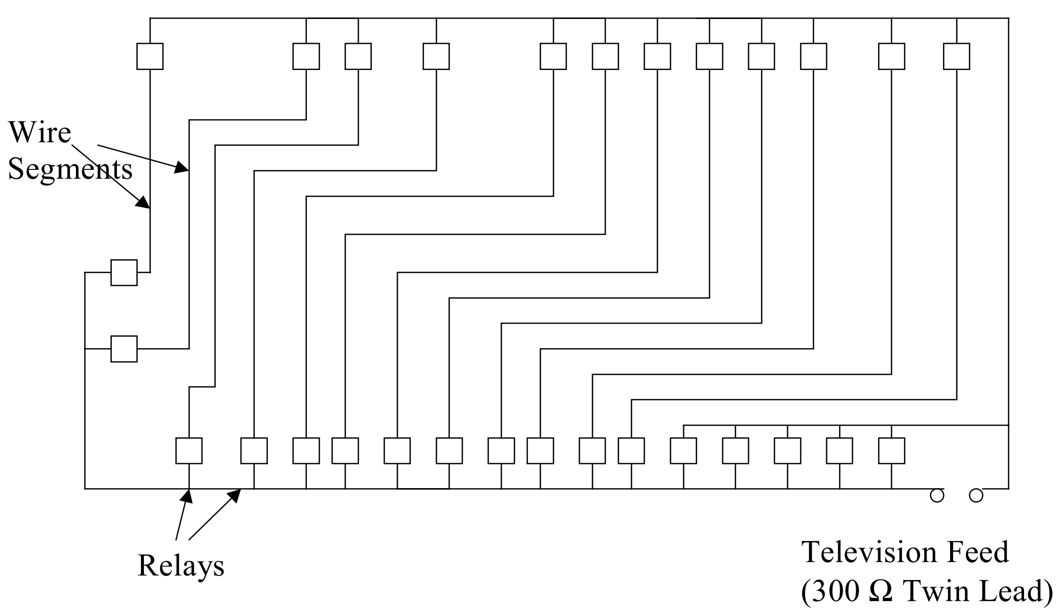

Figure 2: Diagram of Self-Structuring Antenna

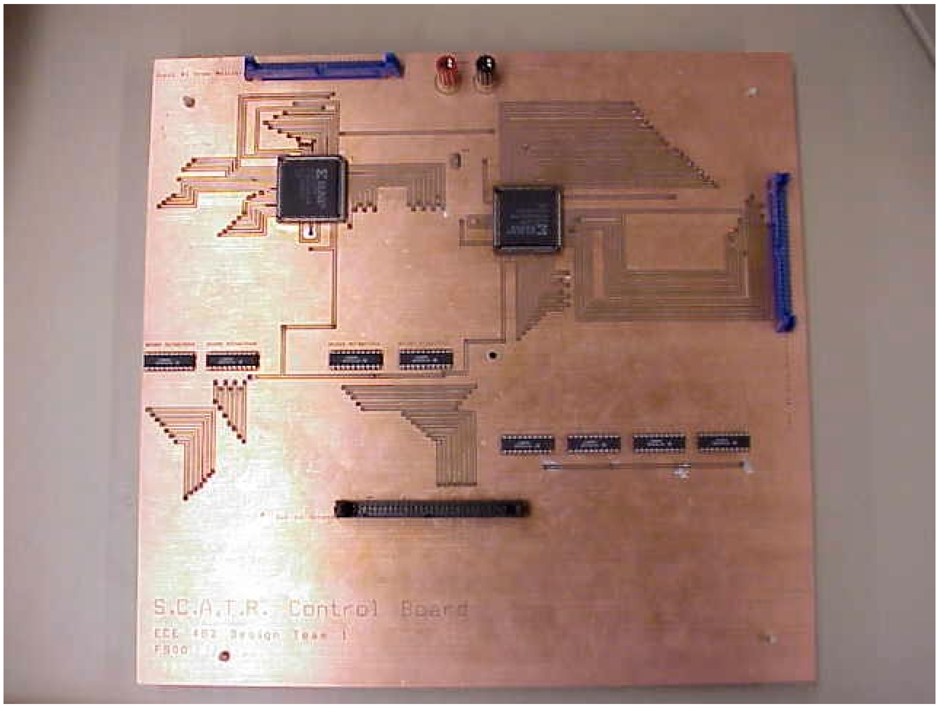

Figure 3. Control Board for the Self-Structuring Antenna

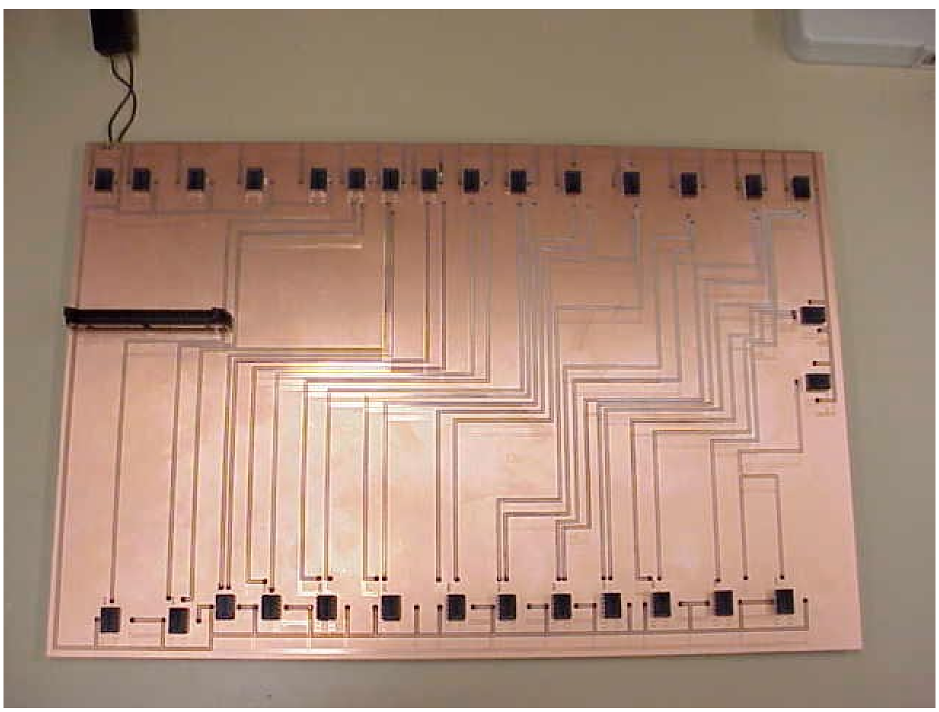

Figure 4. Self-Structuring Antenna "Antenna Board"

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AP Session 5 Monday, July 9, 2001
10:40 a.m. Commonwealth

Overview

- Goal
- Evolution of the SSA Project
- Self-Structuring Antenna (SSA) Overview
- Genetic Algorithms
- Modification of Genetic Algorithm for the SSA
- Lab Results - UHF Testing
- Lab Results - VHF Testing
- Conclusions and Future Work

Goal

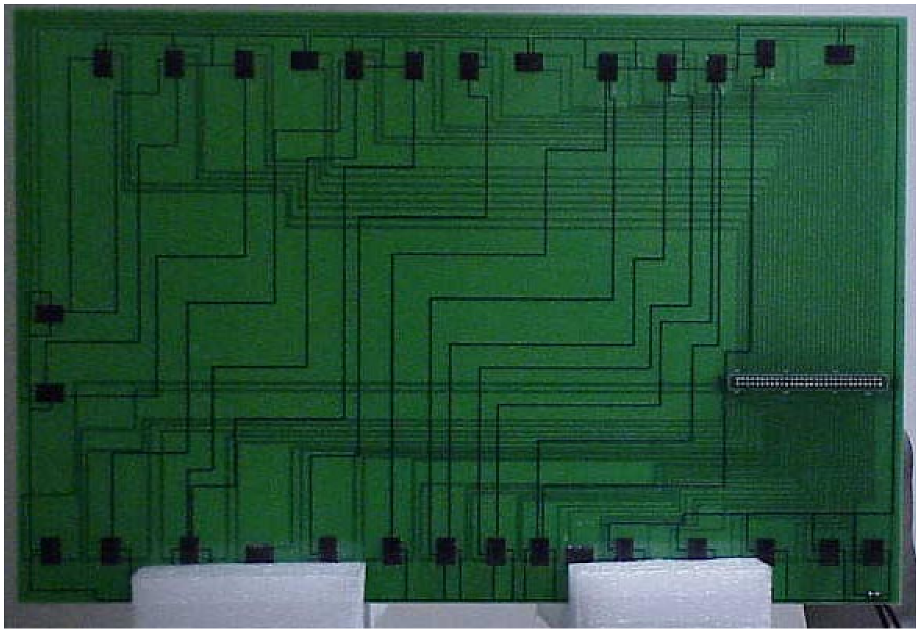

Figure 1: Self Structuring Antenna

- **Improve Television reception through the use of a self-structuring antenna**
- **Desired Application: Mobile Television Reception**
- **Find a method to determining the strength of a received TV signal**
- **Control the restructuring of this antenna with a genetic algorithm**
- **Compare the performance of the SSA to a standard UHF/VHF antenna**

Evolution of the SSA Project

- **Fall 2000: This project began as a senior design project for ECE 482 at Michigan State University sponsored by Delphi. The students who built the original prototype SSA : Brad Perry, Tanya Anderson, Nnamdi Oputa, Lance Ainsworth, Matt Freel, Kyhia Bostic, Brian Basch, Kris Porter, Scott Butler, Dave Dempsey, Chris Lata, and Vinson Lewis**

- **Spring 2001: Independent Research was carried out by Brad Perry and Brian Basch to improve upon the prototype built for ECE 482. Several new prototypes were constructed for the SSA, including the one currently in use.**

- **Summer 2001: Continued research has been carried out by Brad Perry including the addition of the genetic algorithm for control of the SSA.**

SSA Overview

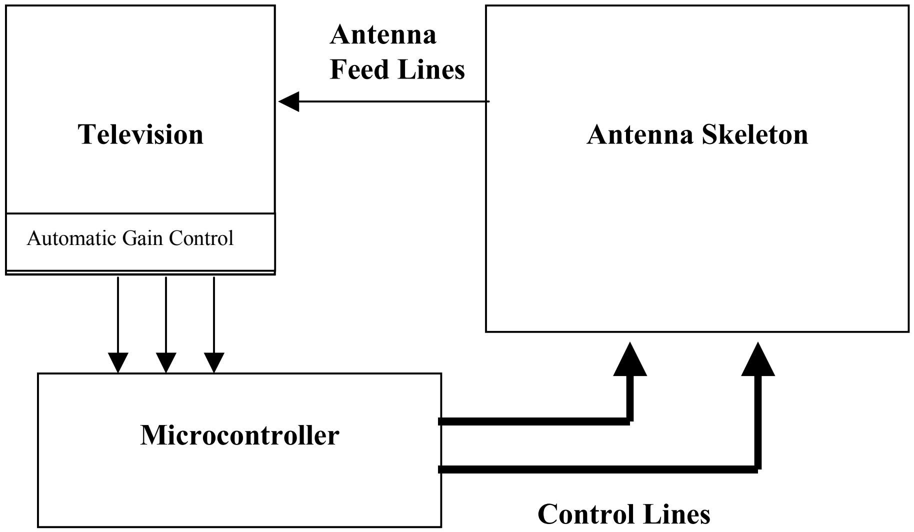

Figure 2: SSA Overview

SSA Overview

- **The SSA automatically configures itself to accommodate changes in signal strength, orientation, and atmospheric conditions through the control of simple on/off switches**

- **Signal strength is based on voltage present at the input to the automatic gain control (AGC) of the television**

- **In general, the lower the voltage at the AGC, the better the signal, however, it is possible for the voltage to dip too low, causing the vertical hold of the TV to bounce**

- **Structuring of the SSA takes place through the use of a microcontroller, utilizing non-latching, single coil relays controlled through the output ports**

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SSA Overview

SSA

- **Some relays are used to section off pieces of the board, while others are used to create various shaped elements, such as loops, which make up the antenna structure**
- **Current design: 30 relays**
- **2^{30} or 1,073,741,824 combinations -- exhaustive search is not an option**

x = 0.46 m   y = 0.305 m

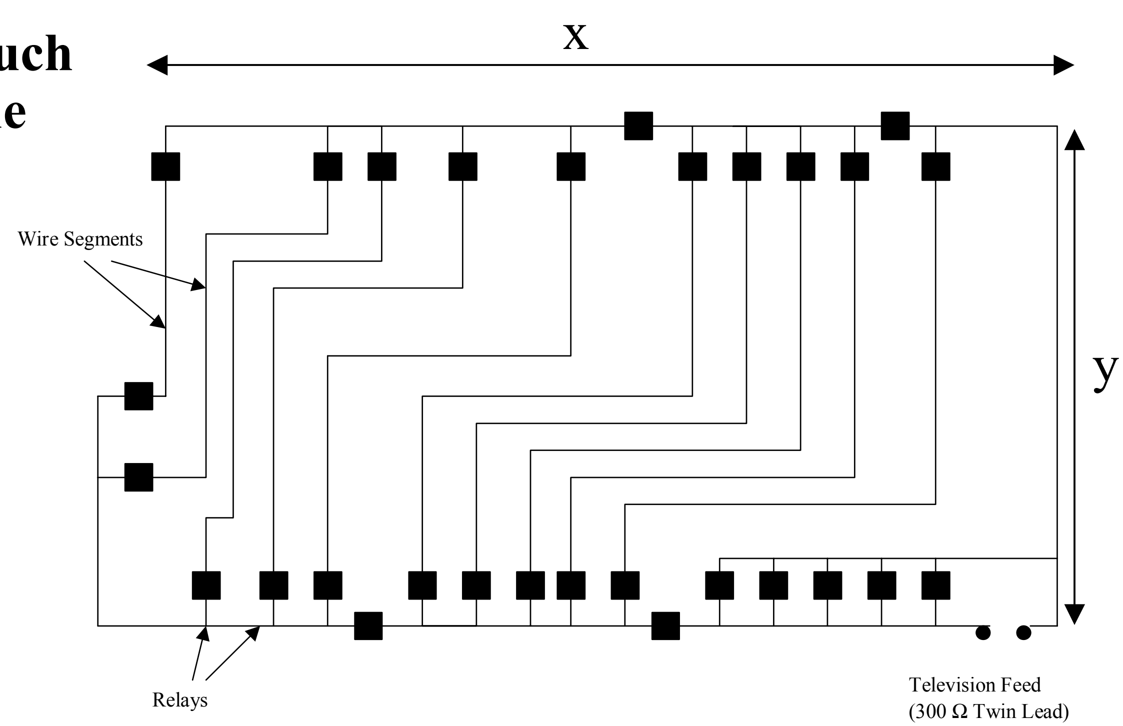
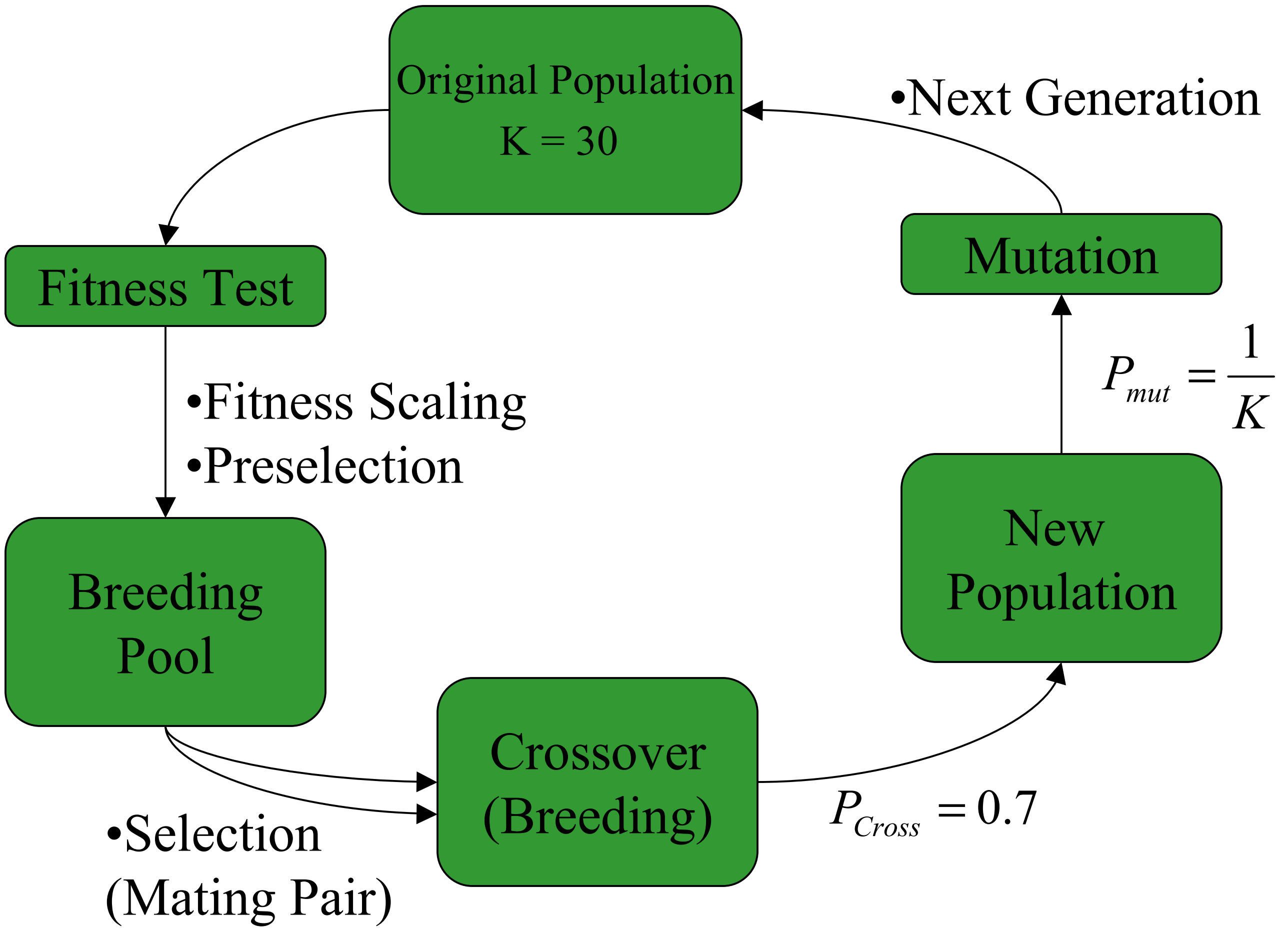


Figure 3: SSA Skeleton

Genetic Algorithms



Genetic Algorithms

- **Original Population**
  - Randomly configuration of switch states at start-up. Good states may be saved as starting points for later use.

- **Definition and Evaluation of the Fitness Function**
  - By definition, a genetic algorithm maximizes a function
  - Objective Function: $f(v) = \dfrac{0.4}{(v - v_{ideal})^2 + 0.4}$
  - v_{ideal} = target "best picture" AGC voltage
  - Maximum value of this function is unity, with fitness of 0.9 representing a good signal

Genetic Algorithms

- **Fitness Scaling**
  - Linear scaling: $F^* = aF + b$, where: F = raw fitness function and F^* = scaled fitness function

- **Preselection**
  - Preselection is based on stochastic remainder sampling without replacement
  - If the breeding pool is not completely filled at the end of this process, random selection is used to fill the group to the size of the original population

Modified GA for the SSA

- The use of a single bit-string to represent a full chromosome is unique to the genetic algorithm of the SSA
- Fitness scaling has been reduced to use only when needed, i.e., when a few combinations look to dominate the population
  - Features have been added to bypass the fitness scaling algorithm when it is deemed unnecessary
- A limited amount of elitism has been added to speed convergence of the algorithm
  - Elitism allows for strong members of the population to be passed into the next generation, in order to not lose the best combination through crossover and mutation

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Laboratory Testing

SSA

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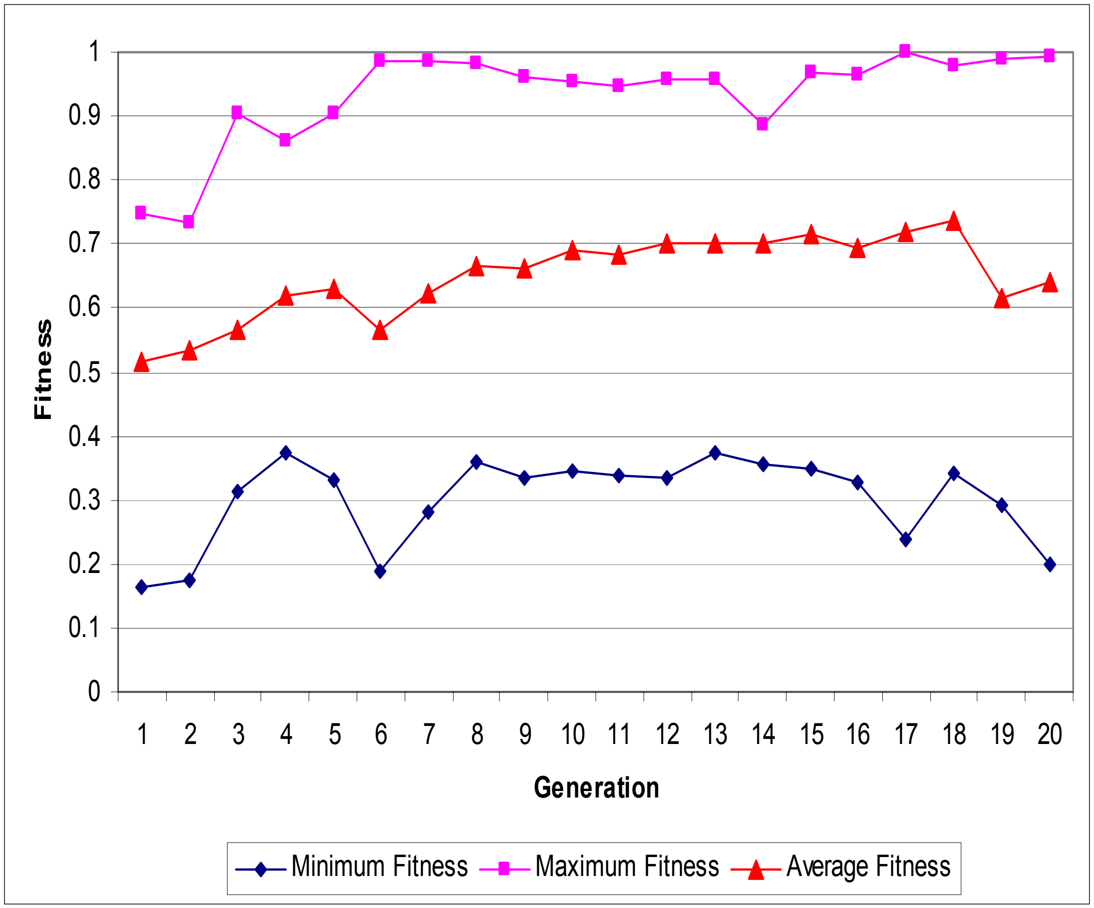
Fitness = 0.5

SSA

Fitness = 0.8

Fitness = 0.9-1.0

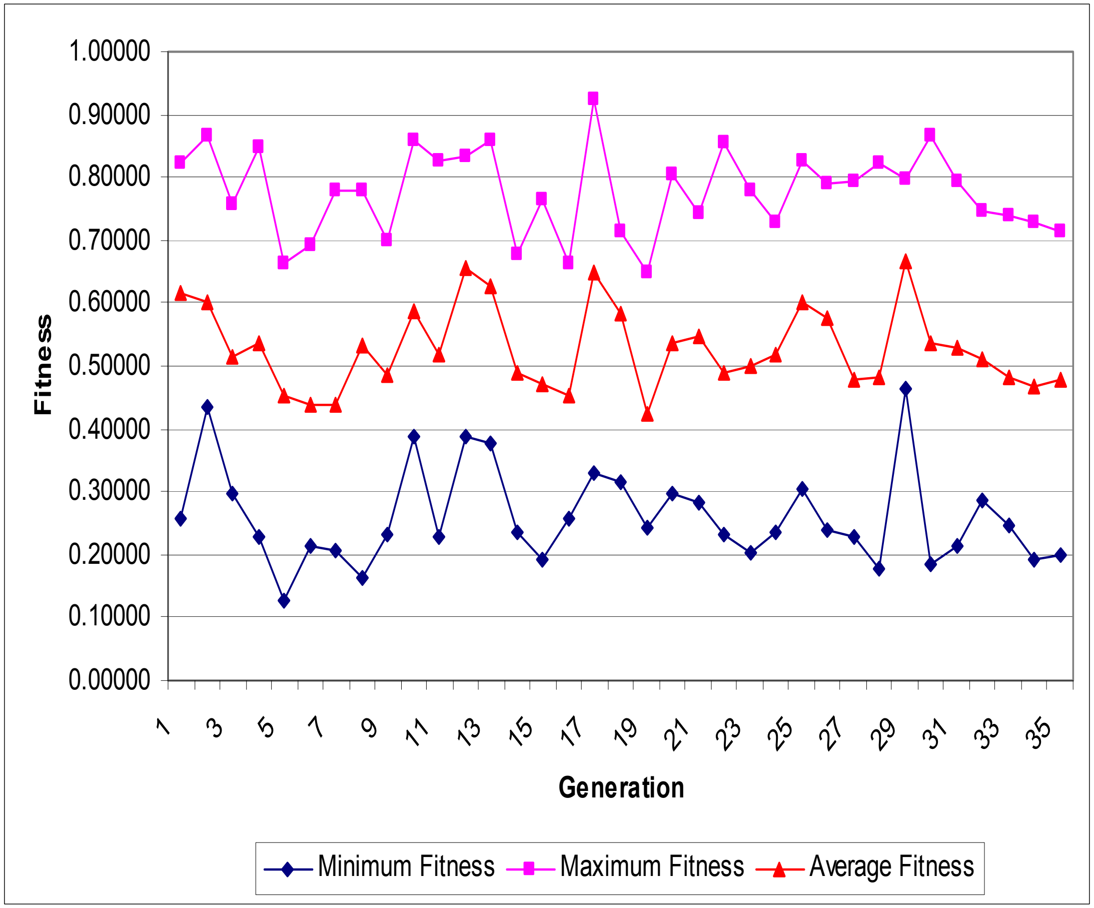
UHF Testing
Channel 23: 524-530 MHz



- •UHF Testing - Horizontal Orientation
- •Begin seeing good maximum combinations after 6 - 7 generations
- •Average rises consistently
- •Antenna Size 0.80λ X 0.53λ
- • Dips in maximum and average fitness can be attributed to fitness scaling and mutation
- • Occur less frequently with modified GA

UHF Testing

Channel 23: 524-530 MHz



- UHF Testing - Vertical Orientation
- High levels of maximum fitness not seen as in the horizontal case
- Average varies dramatically
- Most television stations in the US broadcast using a horizontal polarization, with the exception that some VHF broadcasts are circularly polarized

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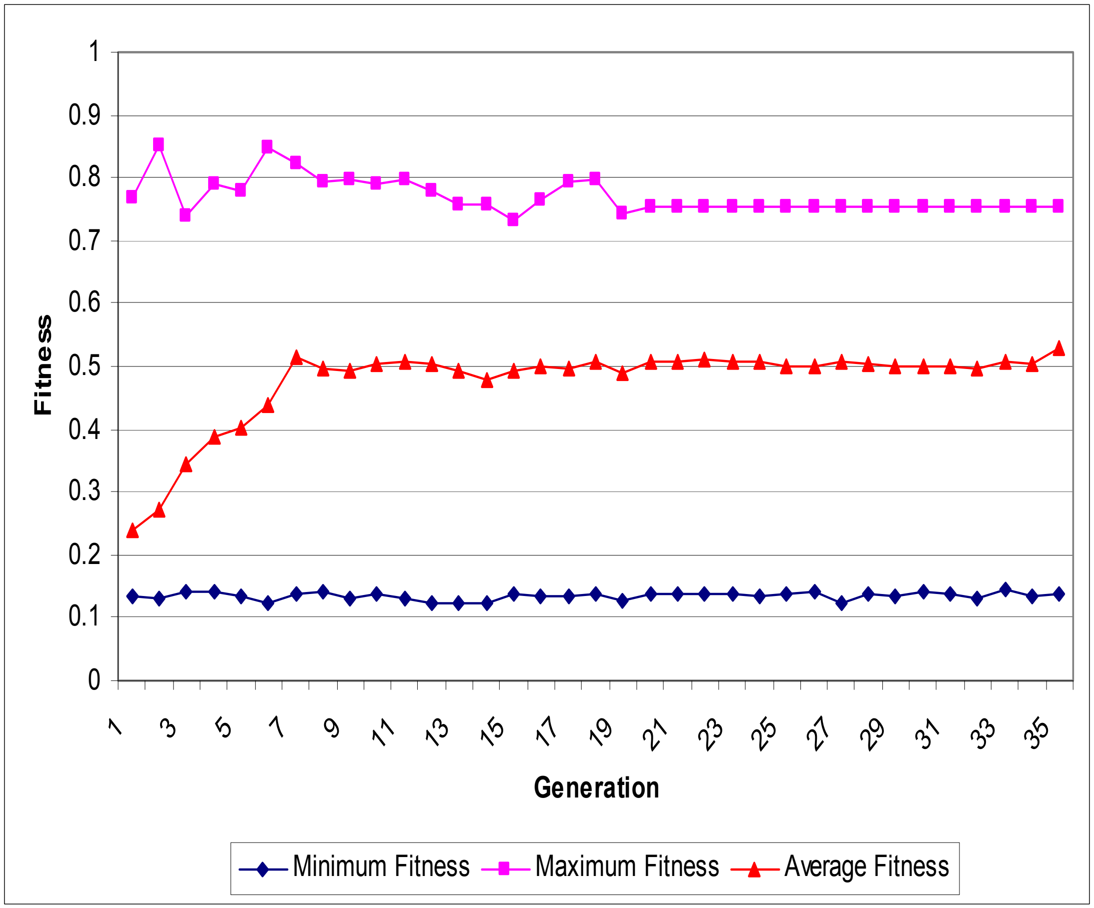
VHF Testing
Channel 10: 192-198 MHz

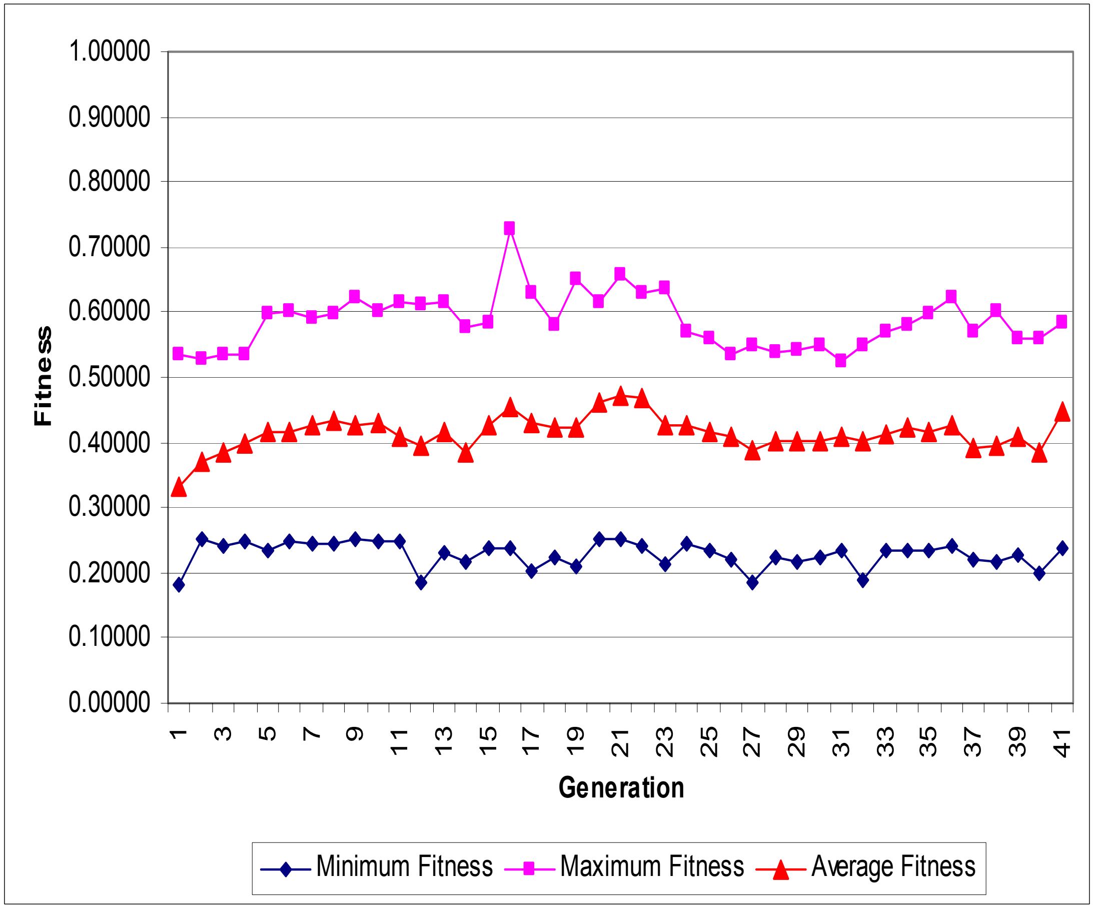
SSA



- VHF Testing - Horizontal Orientation
- Maximum fitness stays fairly consistent
- Average rises, but reaches a steady state
- Antenna Size = 0.29λ X 0.20λ

VHF Testing

Channel 10: 192-198 MHz



- VHF Testing - Vertical Orientation
- Average increases, but reaches a lower steady state than horizontal orientation

Conclusions

- **Current version of the SSA performs well for UHF television broadcasts, but does not meet desired performance at VHF (Possibly due to antenna size)**

- **Current genetic algorithm reaches peak fitness within an average of 7 generations**

Future Work

- Extension of SSA concepts to areas beyond television. i.e., Cellular Phones, Multitasking antennas for vehicles, military applications, and wireless LAN
- Optimization of antenna layout through simulation
- Improvement of the Genetic Algorithm to increase efficiency of the restructuring process
- Add features to the software to restart the algorithm when channels are changed, or when the population converges too far to be effective in the event of atmospheric or orientation changes