Self-Structuring Antenna Concept for FM-band Automotive Backlight Antenna Design

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1. Introduction

The self-structuring antenna (SSA) was first introduced at the AP symposium in July, 2000. [1, 2] Since then, the SSA concept has been further developed through both experiment [3, 4] and simulation [5]-[12]. Various methods of simplifying the antenna template, and the repercussions of doing so, have been explored [5, 6]. The effect of switch failure on the performance of the SSA has also been studied [8, 9], and the application of various algorithms to the control of the self-structuring antenna has been explored [11, 12]. Much of this work has been involved with automotive applications, including the effect of the automobile on SSA performance [7], alternative and complementary SSA template layouts [4, 10], and simplification of the antenna template [6].

The study of the SSA has shown much promise for use in an automobile environment; however, the addition of the necessary switch technology adds a new level of complexity to existing antenna systems. Some of the benefits of the SSA can be obtained with existing systems by using the SSA concept to design a fixed antenna. This work uses the principles of self-structuring antennas to design a fixed automotive backlight antenna. A genetic algorithm (GA) is utilized in this design, with a cost function optimizing both VSWR and gain.

2. Self-Structuring Antenna Concept

The self-structuring antenna is based on the idea that a large number of possible configurations will provide suitable antenna characteristics under changing operating conditions [13]. To provide this large number of configurations, the SSA grid is composed of a fairly large number of simple, on/off switch elements. Since these switches have a binary nature, a self-structuring antenna with N switches provides 2^N possible configurations. As the number of switch elements being used increases, the possibility of using exhaustive searches becomes impractical, and search algorithms become necessary. Binary search algorithms, such as the genetic algorithm, are a natural choice for control of the SSA because of the use of simple on/off switches [12]. These search algorithms are used to optimize the SSA based on a cost function which evaluates the performance of the SSA in a given configuration, based on any number of important parameters. Several possible parameters which could be used to construct the cost function are VSWR, input impedance, antenna efficiency, and gain.

3. Backlight Antenna Design using Self-Structuring Antenna Concept

The self-structuring antenna concept can be used to design a fixed FM-band automotive backlight antenna by starting with a self-structuring antenna grid placed in the upper rear window of a car, above the heater grid, as shown in Figure 1. The inset of Figure 1

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Overview

- Motivation and Goals
- Self-Structuring Antenna (SSA) Overview
- SSA in an Automobile Environment
- Genetic Algorithm Parameters
- Simulation Results
- Conclusions and Future Work

Goal

- The self-structuring antenna is a reconfigurable antenna which is able to achieve required performance through reconfiguration of an antenna template in a feedback system

- This work looks to design a backlight antenna that will have a fixed state using self-structuring antenna concepts in the design phase

Motivation and Goals

Motivation

- Utilizing the SSA in the design phase does not require the additional complexity of the control system to be added to the automobile
- Reduce upfront design cost by taking advantage of an SSA to design a fixed antenna utilizing a genetic algorithm
- Non-intuitive designs can be obtained using the SSA

Goals

- Minimize Standing Wave Ratio across the FM Band
- Constrain gain in the azimuthal plane to between -10dB and +5dB
- Reduce pattern drop outs

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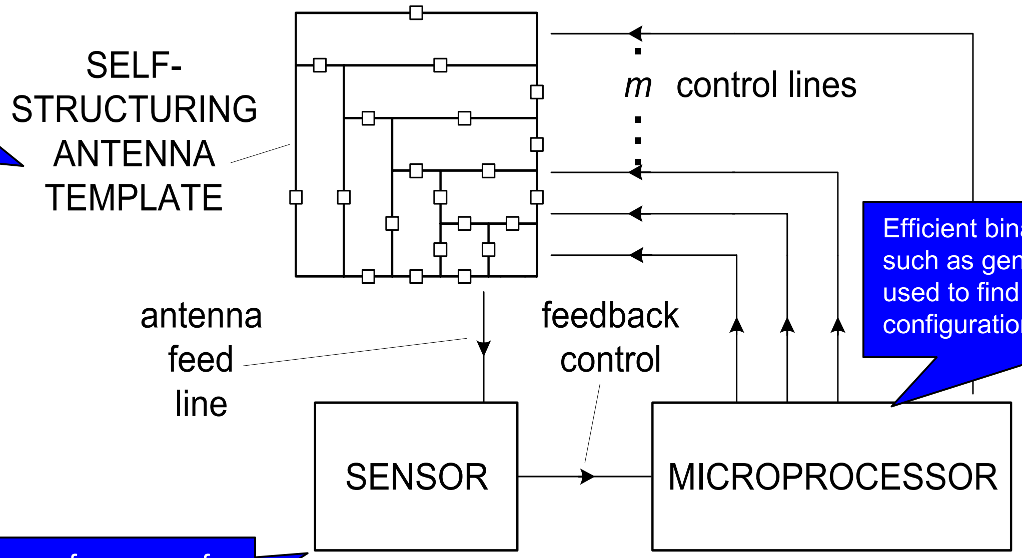
Self-Structuring Antennas

The Self-Structuring Antenna (SSA) is a new class of adaptive antenna that changes its electrical shape in response to the environment by controlling electrical connections between the components of a skeletal "template."

N switches in a template consisting of interconnected wires or patches gives the SSA system the capability of arranging itself into 2^N configurations, or "states."

This diversity is the basis of the SSA's functionality



SELF-STRUCTURING ANTENNA TEMPLATE

m control lines

antenna feed line

feedback control

SENSOR

MICROPROCESSOR

Efficient binary search routines, such as genetic algorithms, are used to find appropriate configurations.

Evaluation of the performance of the SSA uses criterion such as signal strength, VSWR, or gain.

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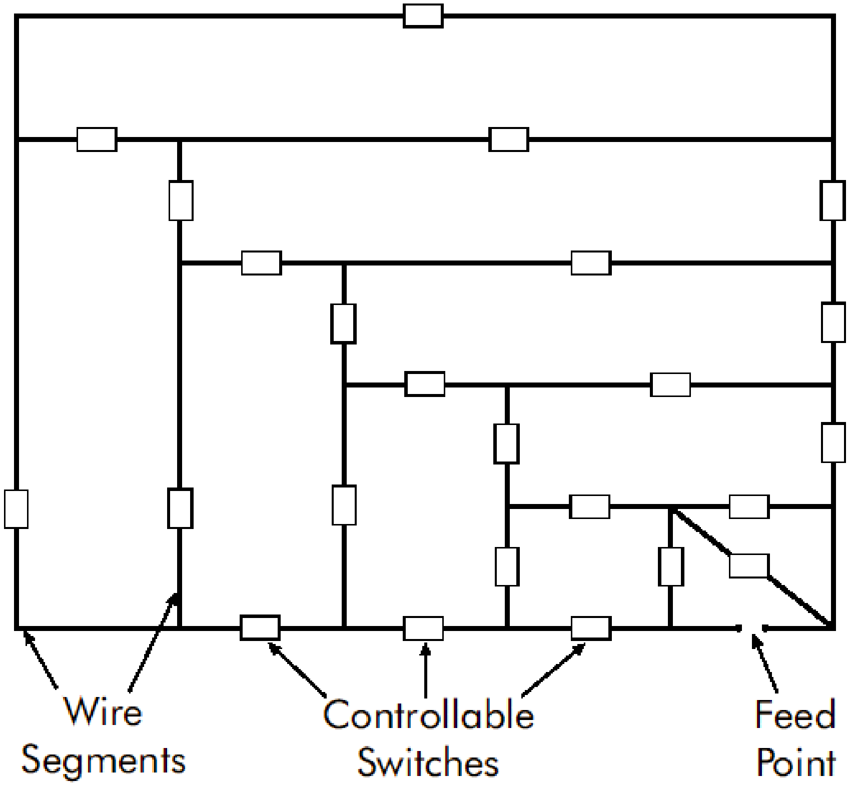
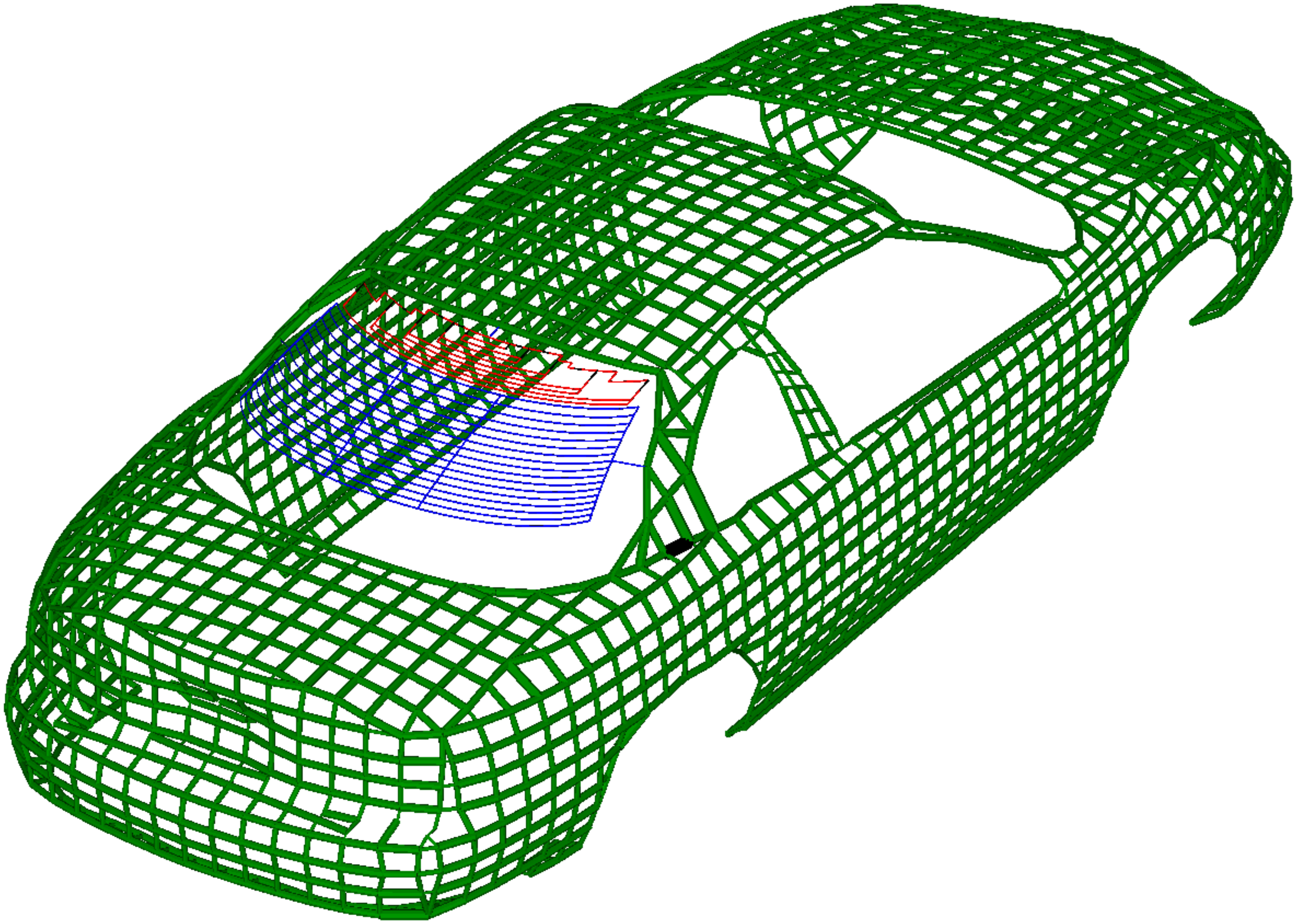
Self-Structuring Antennas

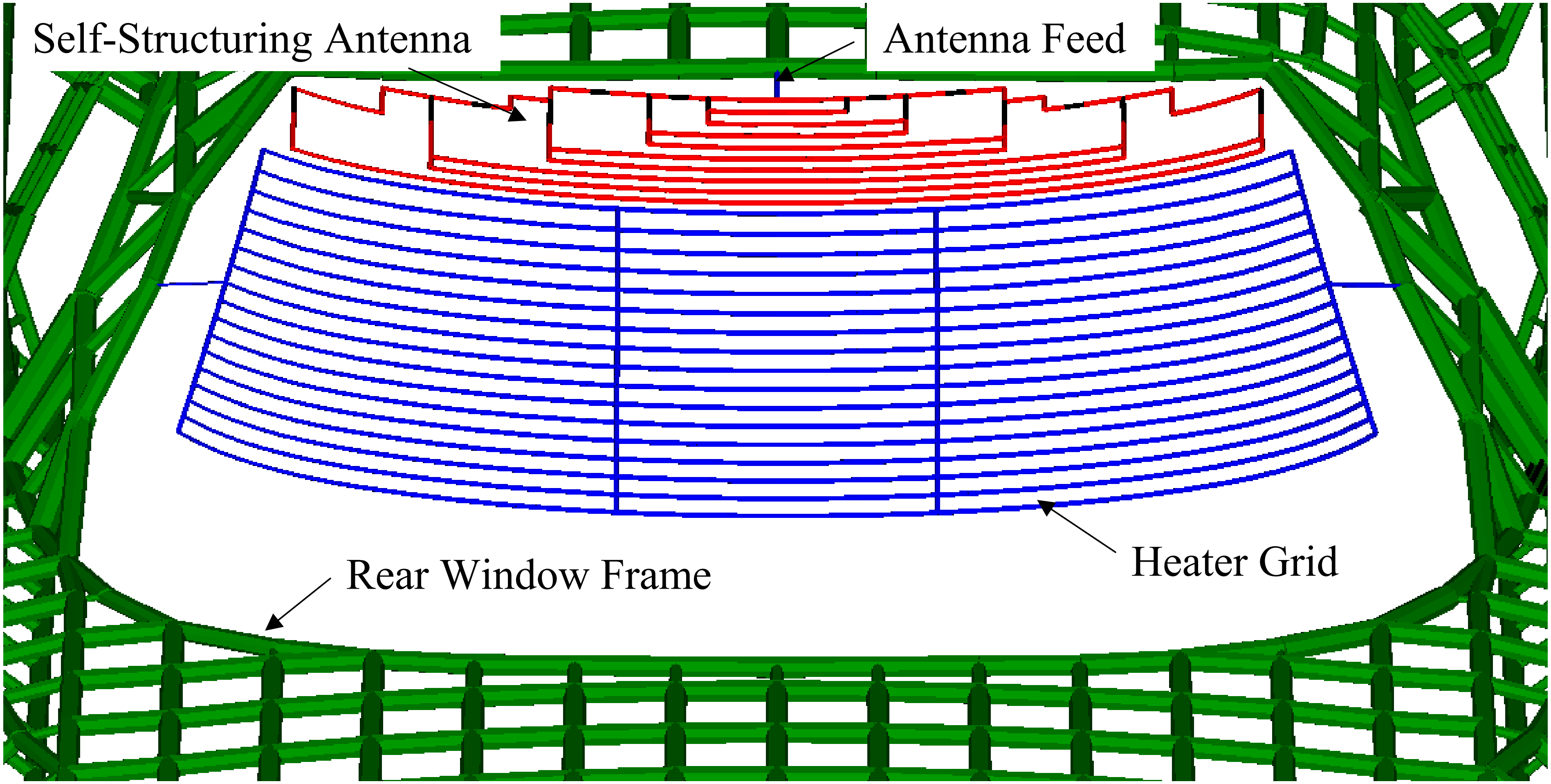
- The template is comprised of a large number of wire segments or patches interconnected by controllable switches.
- The template can be highly structured or random and can be placed on a planar or conformal surface.
- For each configuration, the states of the switches determine the electrical characteristics of the antenna.
- For a template with n switches, there are 2^n possible configurations.



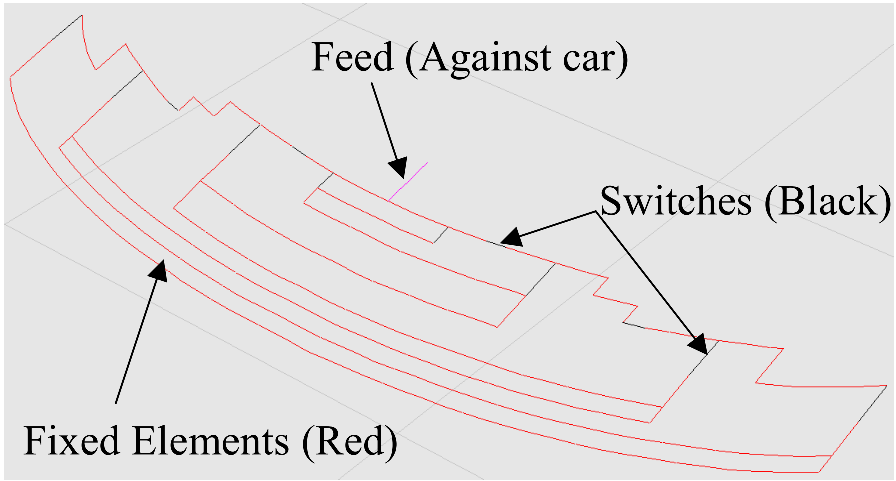
Self-Structuring Antennas



Self-Structuring Antennas

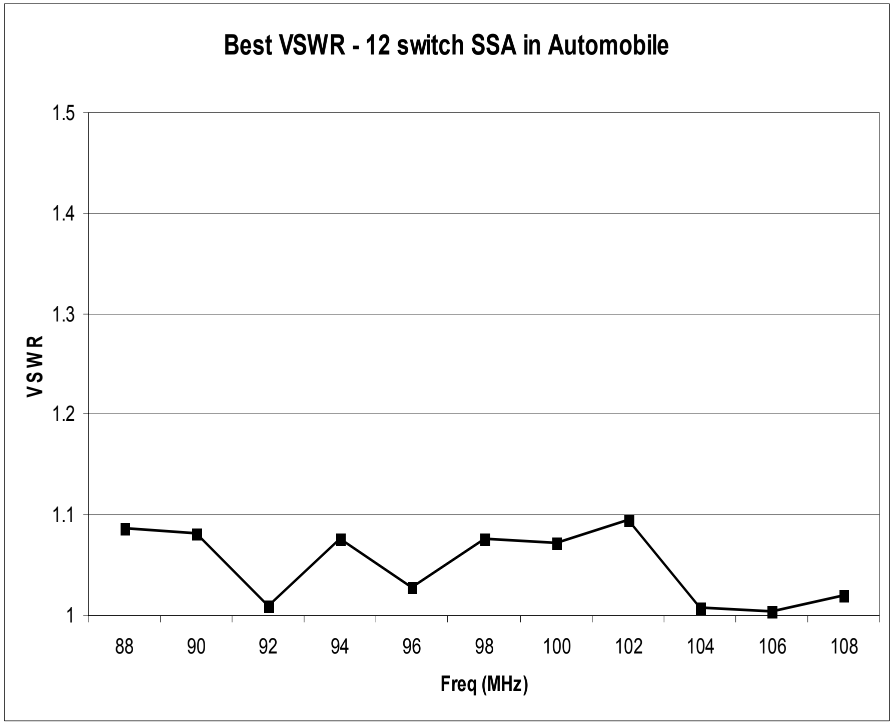


Self-Structuring Antennas



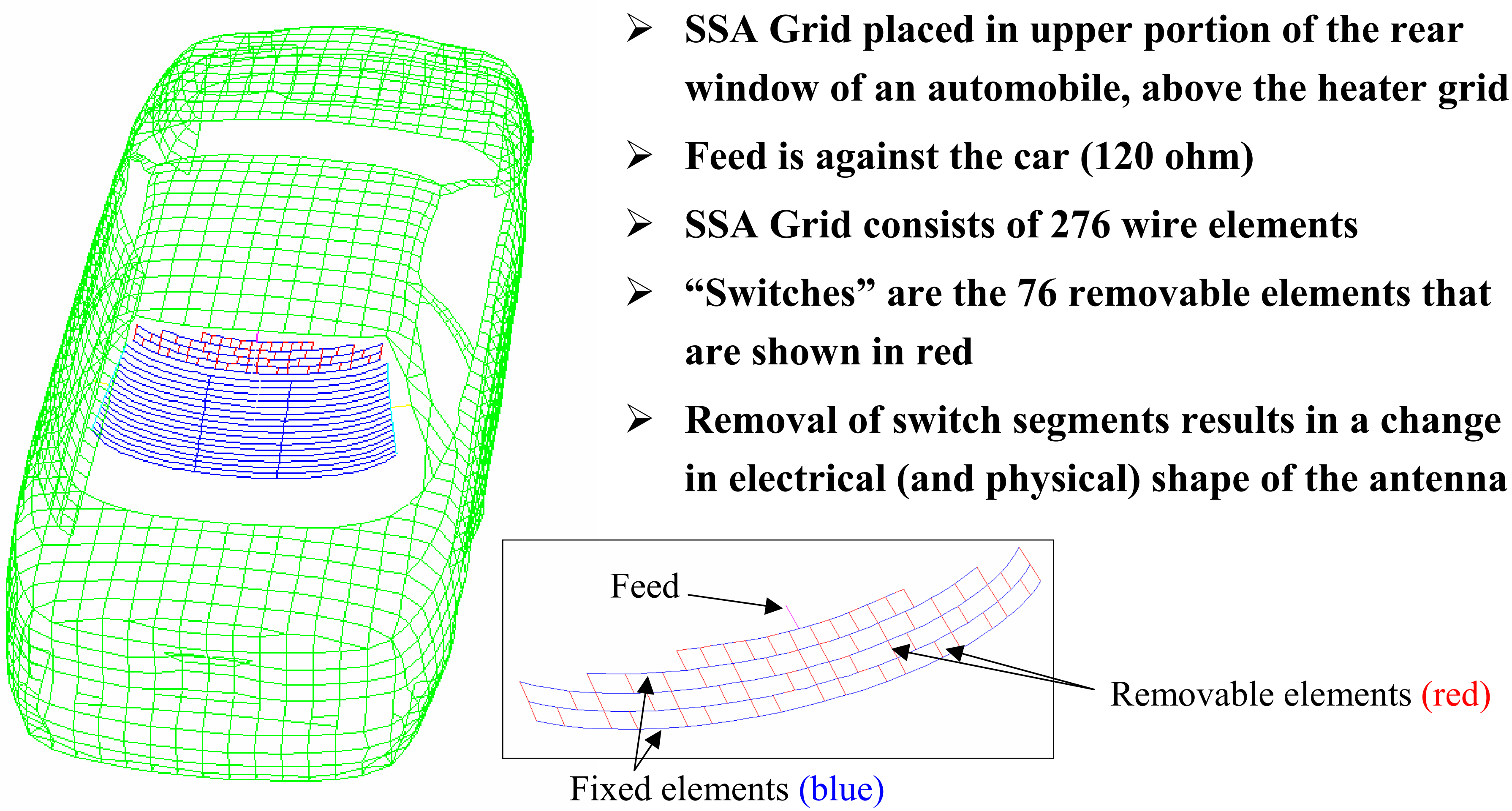
- Past studies of the SSA in an automobile have shown a reconfigurable VSWR of under 1.1 obtainable across the FM Band

- Fixed antenna will be placed in the same location as the SSA for these studies

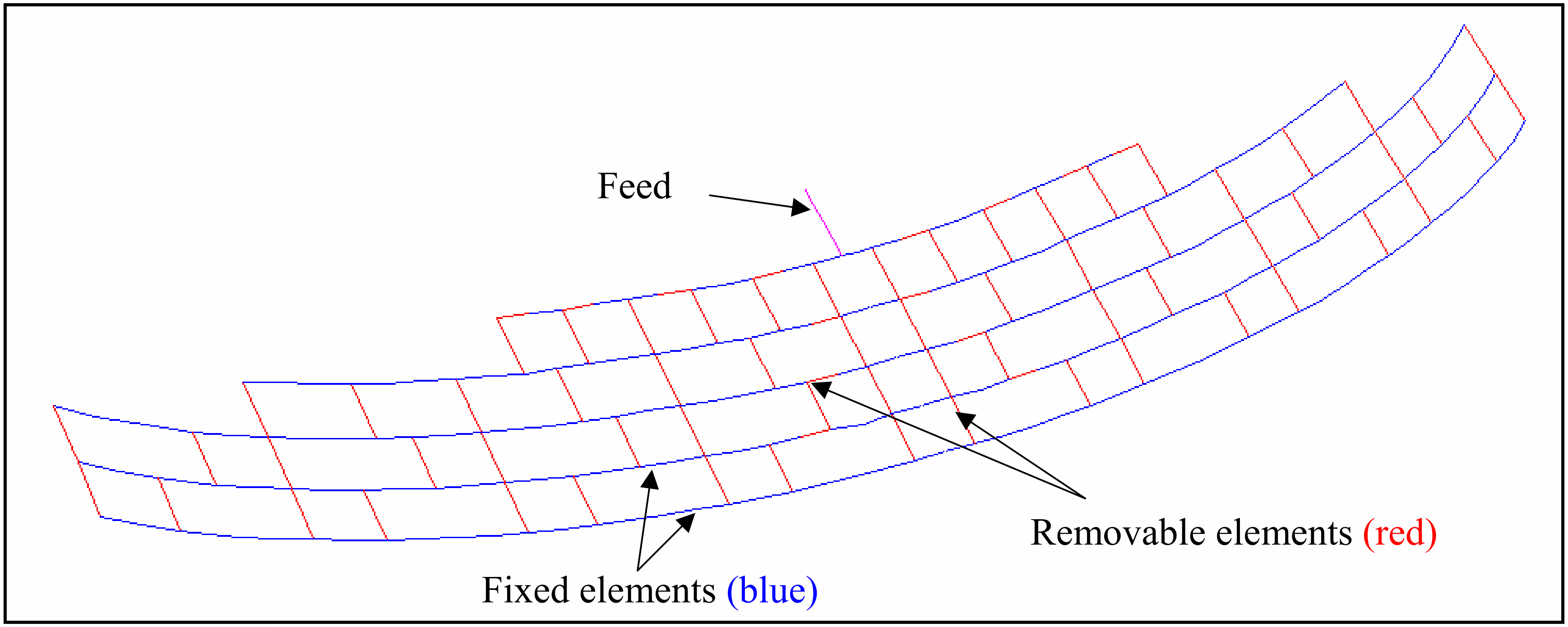


Automobile Environment

- **SSA Grid placed in upper portion of the rear window of an automobile, above the heater grid**
- **Feed is against the car (120 ohm)**
- **SSA Grid consists of 276 wire elements**
- **"Switches" are the 76 removable elements that are shown in red**
- **Removal of switch segments results in a change in electrical (and physical) shape of the antenna**



Automobile Environment



- **Feed is against the car (120 ohm)**
- **SSA Grid consists of 276 wire elements**
- **"Switches" are the 76 removable elements that are shown in red**

Genetic Algorithm Parameters

- **Initial Population of 200 random chromosomes which contain all information necessary to describe an individual**

Sample Chromosome
1101 1001 0010 1001 1111 1001
Switch Configurations

- **Consists of the binary state of the switch segment**
  - **1 = removed**
  - **0 = not removed**
- **Crossover Probability = 0.9**
  - **Probability that a mating pair will exchange information**
- **Mutation Probability = 0.1**
  - **Probability of a random bit in the chromosome changing states**
  - **Provides a mechanism for exploring new regions of the solution space**
- **An elitist strategy, which places the strongest individuals in the mating pool multiple times, is employed to aid in convergence time**

Genetic Algorithm Parameters

- **Constrain gain between -10dB and +5dB in the azimuthal plane**
  - **Fitness function based on this constraint at every 5 degrees (N=72)**
- **Constrain VSWR to be less than 1.1**
- **Fitness function found as:**

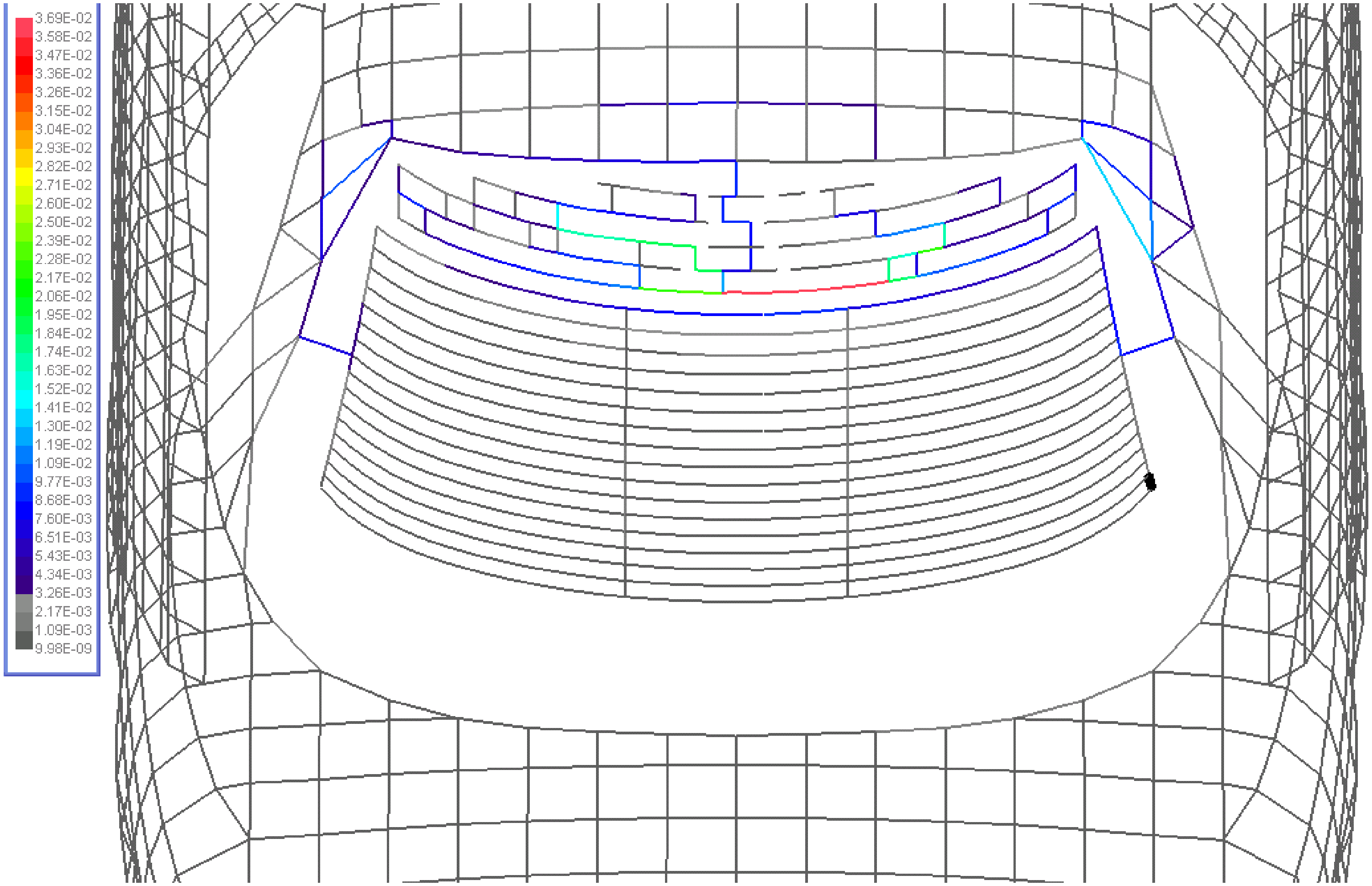
$$fit(f) = w_{vswr}\left(SWR_{meas} - SWR_{\lim}\right) + \sum_{n=1}^{N} w_{n,gain}\left|gain_{n,meas} - gain_{n,\lim}\right|$$

where:

$$w_{vswr} = \begin{cases} 0 & SWR_{meas} \le SWR_{\lim} \\ 1000 & otherwise \end{cases}$$

$$w_{n,gain} = \begin{cases} 0 & -10dB \le gain_{n,meas} \le 5dB \\ 1 & otherwise \end{cases}$$

Simulation Results – 88 MHz



VSWR = 1.086

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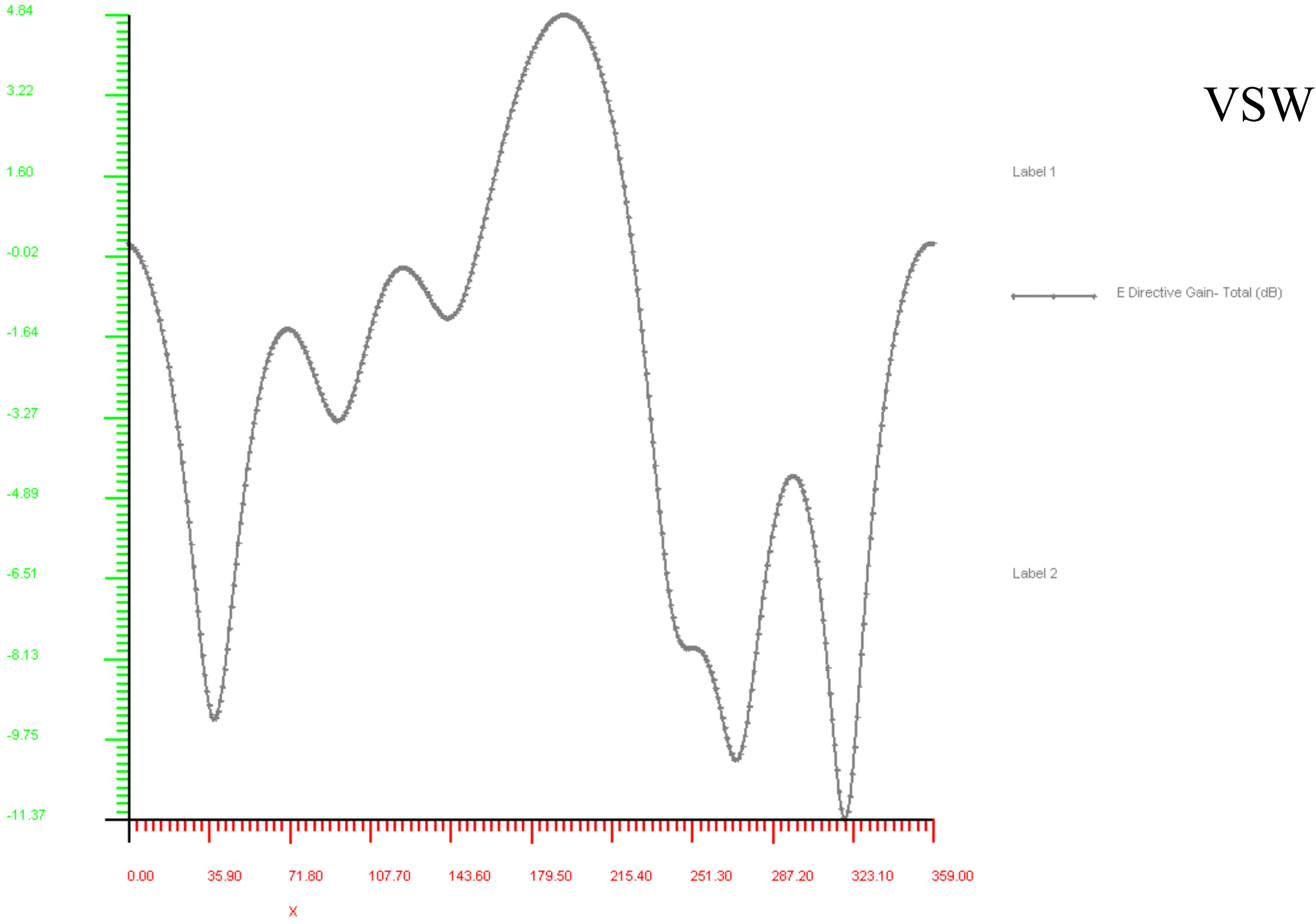
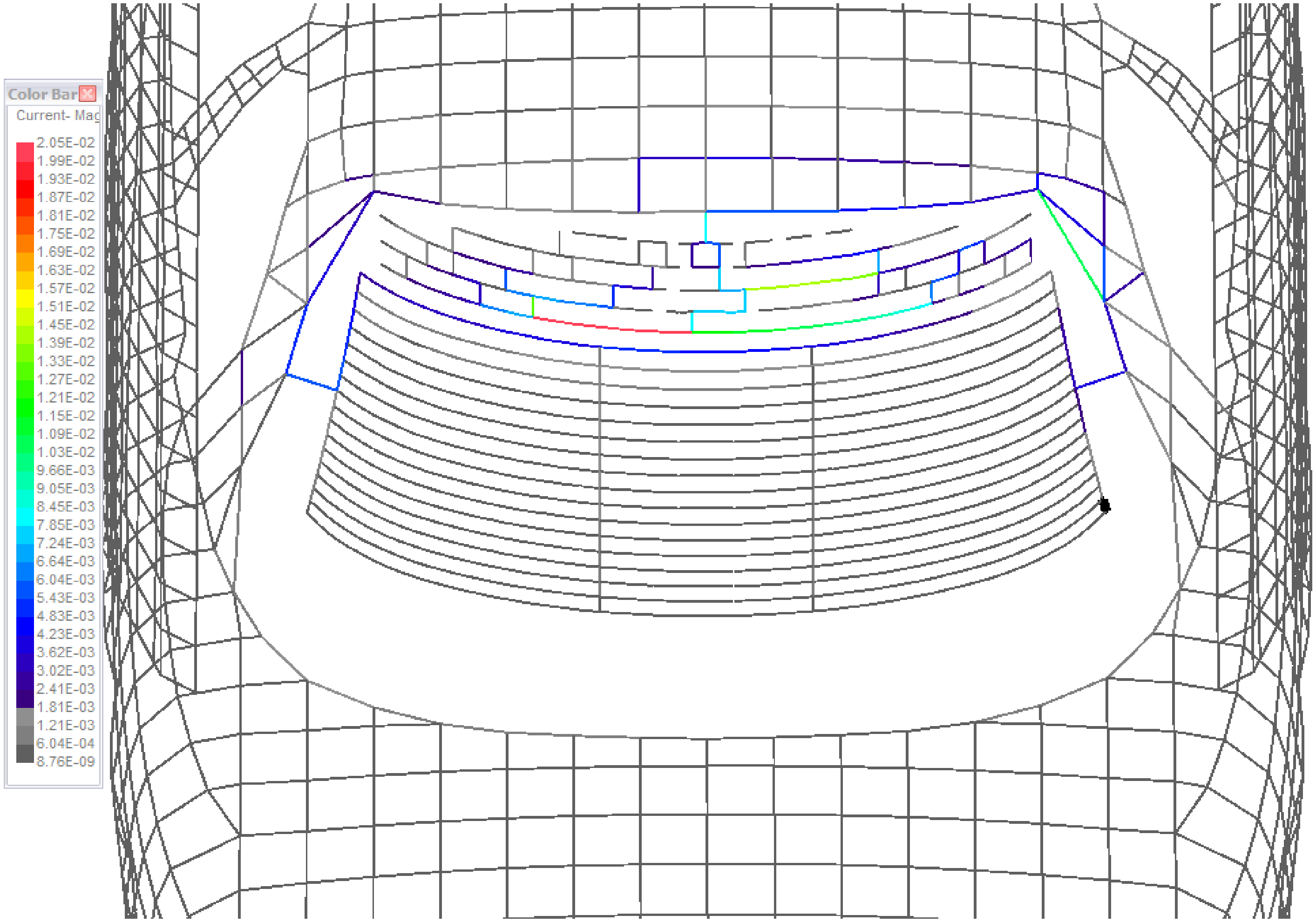
Simulation Results – 88 MHz



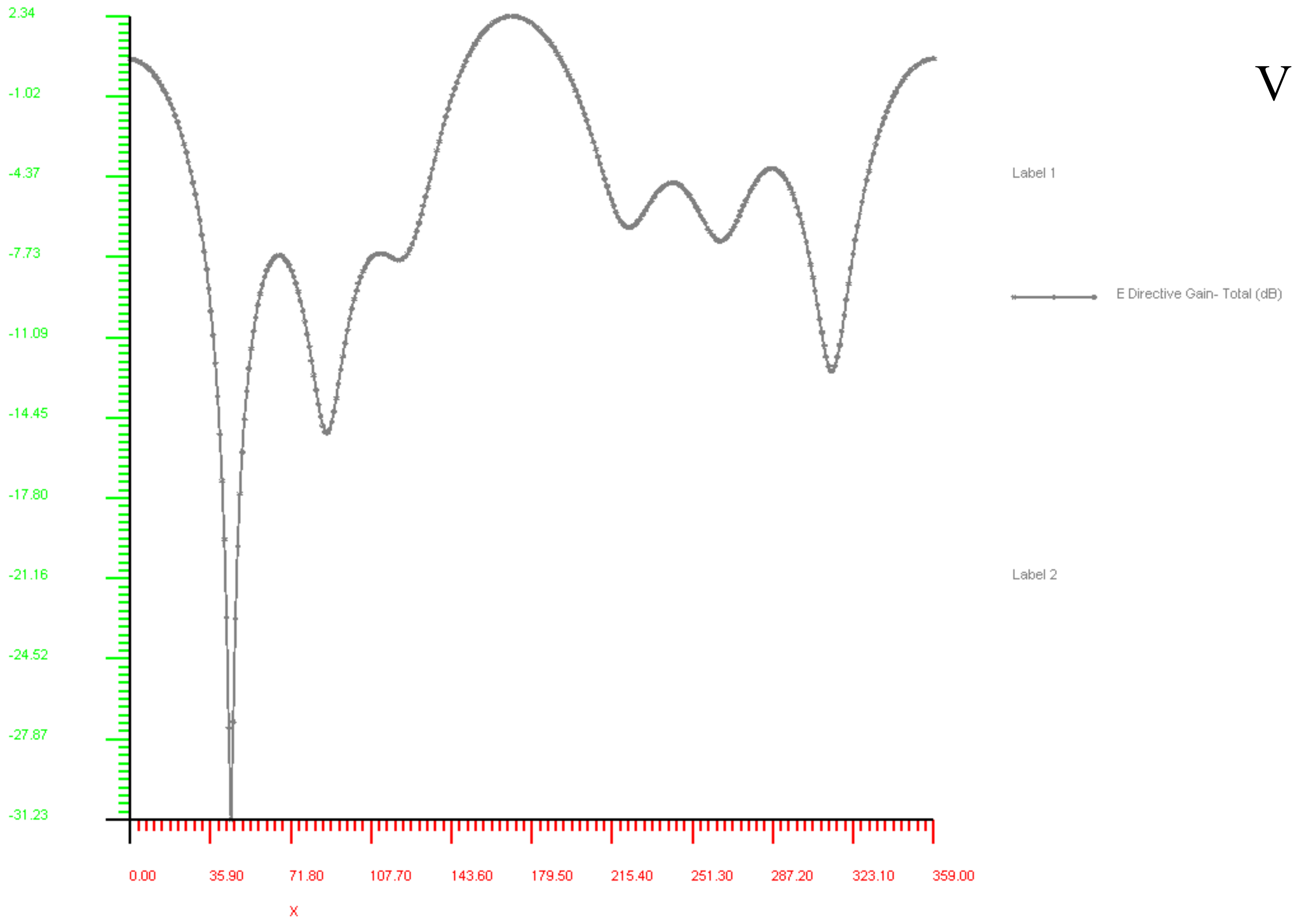
VSWR = 1.086

Simulation Results – 92 MHz



VSWR = 1.09

Simulation Results – 92 MHz

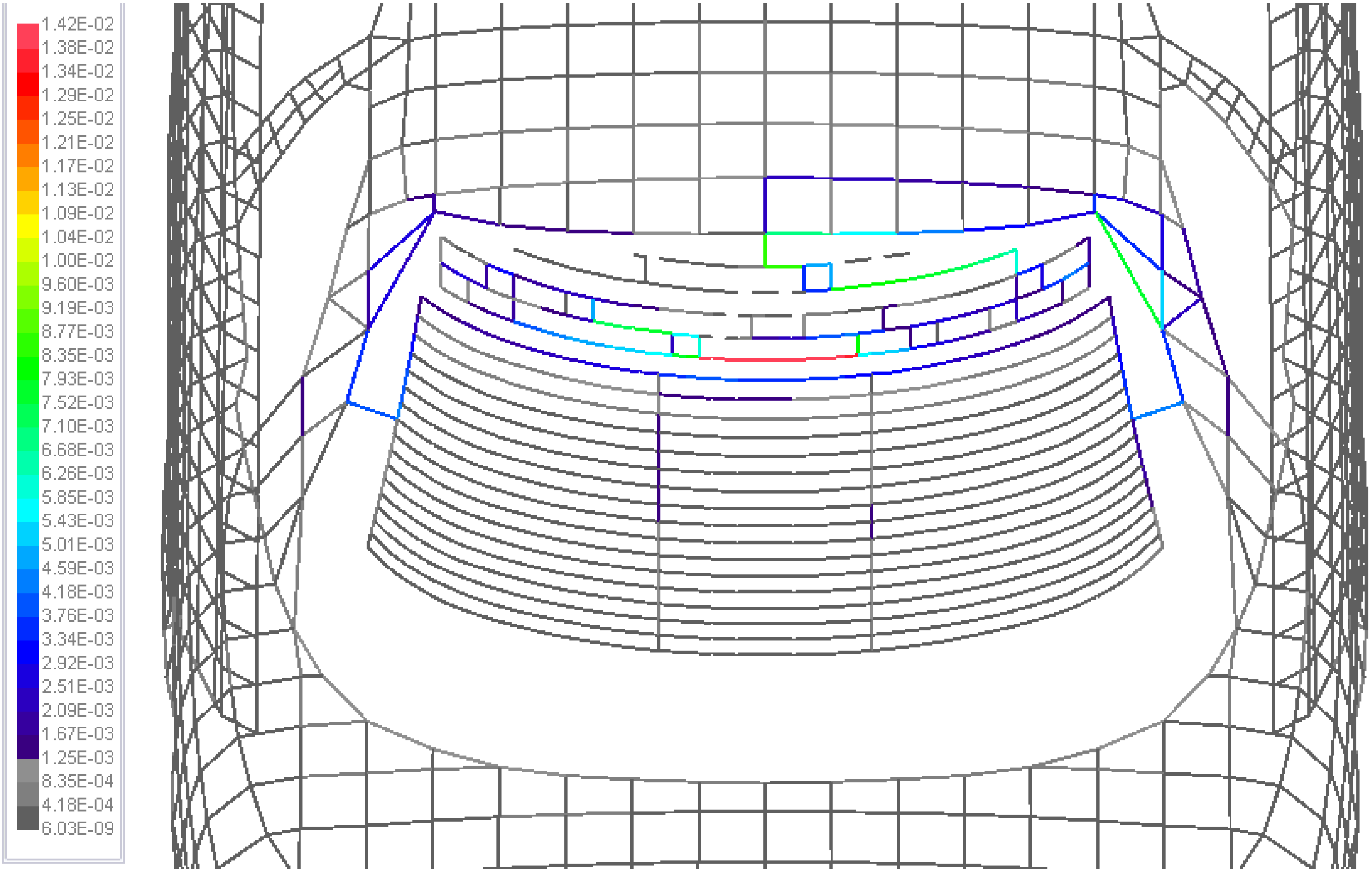


VSWR = 1.09

Simulation Results – 96 MHz

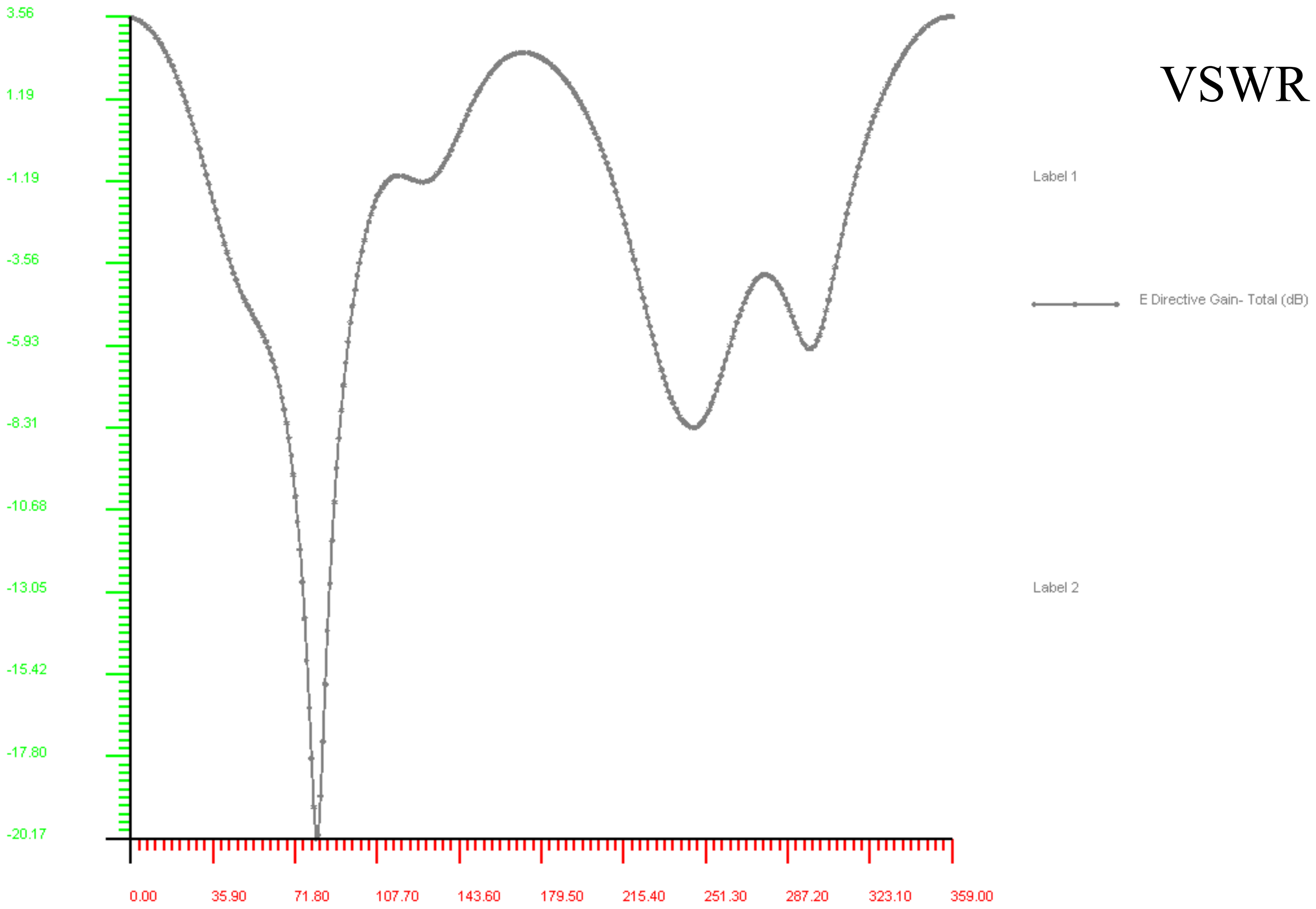
- Results for 96,100,104 MHz will be presented in a similar fashion

Simulation Results – 108 MHz



VSWR = 1.038

Simulation Results – 108 MHz



VSWR = 1.038

Conclusions & Future Work

- To be added

Backup Slides

Appendix A – Genetic Algorithms

Appendix A

Genetic Algorithms

Genetic Algorithms

GA's are based on the principles of genetics and Darwin's concept of natural selection.

- Advantages
  - Relatively efficient
  - Not as fast as gradient methods, but much faster than random or exhaustive searches.
  - Does NOT require derivative information.
  - Tends NOT to get stuck in local minima.
  - Does NOT require initial guesses.
  - Can handle discrete or discontinuous parameters and non-linear constraints.
  - Can find "non-intuitive" solutions.

Genetic Algorithms

- **Chromosomes**
  - **Contain all information necessary to describe an individual.**
  - **Composed of DNA in nature or a long binary string in a computer model.**
  - **Chromosomes are composed of genes for the various characteristics to be optimized.**
  - **Chromosomes can be any length depending on the number of parameters to be optimized.**

- **Encoding**
  - **Defines the way genes are stored in the chromosome and translated to actual problem parameters.**

SSA Example
1101 1001 0010 1001
Switch Configurations

Antenna Synthesis Example

1010	0101	0010	1111
Length	Diameter	Height	Radius

Genetic Algorithms

- Fitness
  - A single numerical quantity describing how well an individual meets predefined design objectives and constraints.
  - Can be computed based on the outputs of multiple analyses using a weighted sum.
  - Definition of good fitness functions is highly problem dependent.

Genetic Algorithms

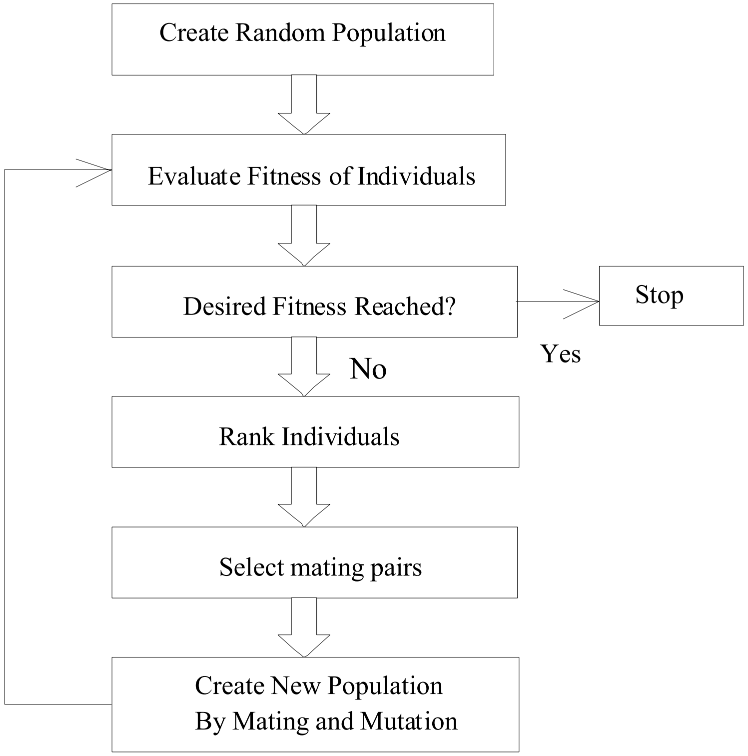
- **Cross-Over**
  - **A method of exchanging genetic material between two parents to produce offspring.**
  - **Single Point Cross-over**

Parent A: 110110 11110
Parent B: 011011 01110
Cross-Over Point ⬆

Offspring A: 110110 01110
Offspring B: 011011 11110

Simple GA

- Population size depends on the problem size.
- Fitter individuals have a higher probability of mating and passing on their genetic information to subsequent generations.
- Less fit individuals have a non-zero probability of mating to preserve diversity.
- Mating is simulated by combining the chromosomes of two individuals at a randomly chosen crossover point.
- Mutation is simulated by randomly changing a few bits in the chromosome of the offspring.
  - Provides mechanism for exploring new regions of the solution space.
  - Prevents premature convergence to local minima.
- Evaluate fitness of new generation and repeat process for a specified number of generations or until a desired fitness level is attained.



Create Random Population

Evaluate Fitness of Individuals

Desired Fitness Reached?

Yes

Stop

No

Rank Individuals

Select mating pairs

Create New Population
By Mating and Mutation

shows a close-up view of the SSA grid, which consists of 276 wire elements, with 76 of these denoted as "switches", which are shown in red. These switches are portions of the SSA grid which can be removed to give different electrical shapes to the backlight antenna. The choice of which wire elements are removed takes place through the use of a genetic algorithm using a program called GA-NEC, which serves as an interface to the NEC-4 engine. The cost function used to compute fitness in the genetic algorithm is constructed using a weighted combination of VSWR and gain. Here the goal is to optimize the VSWR to a value of less than 1.1, and the gain to between -10dB and +5dB at various angles in the azimuthal plane. The GA begins with an initial population of 200 individuals, consisting of the random binary state of each switch segment (1 = removed, 0 = not removed). The genetic algorithm uses crossover and mutation probabilities of 0.9 and 0.1, respectively, along with an elitist strategy, to optimize the design of the backlight antenna.

4. Results

Backlight antennas have been designed for various individual frequencies in the FM-band. Figures 2-4 show automotive backlight antenna designs for use at 88, 94, and 108 MHz, with the antenna fed against the car using a 120 Ω characteristic impedance. These figures show the designs found at each discrete frequency, as well as the currents on the antenna, car body, and heater grid. Here, VSWR was used as the cost function, with values of 1.24, 1.06, and 1.14 found for 88, 94, and 108 MHz, respectively. The design of backlight antennas using optimization of both VSWR and gain across the FM band is ongoing.

5. References

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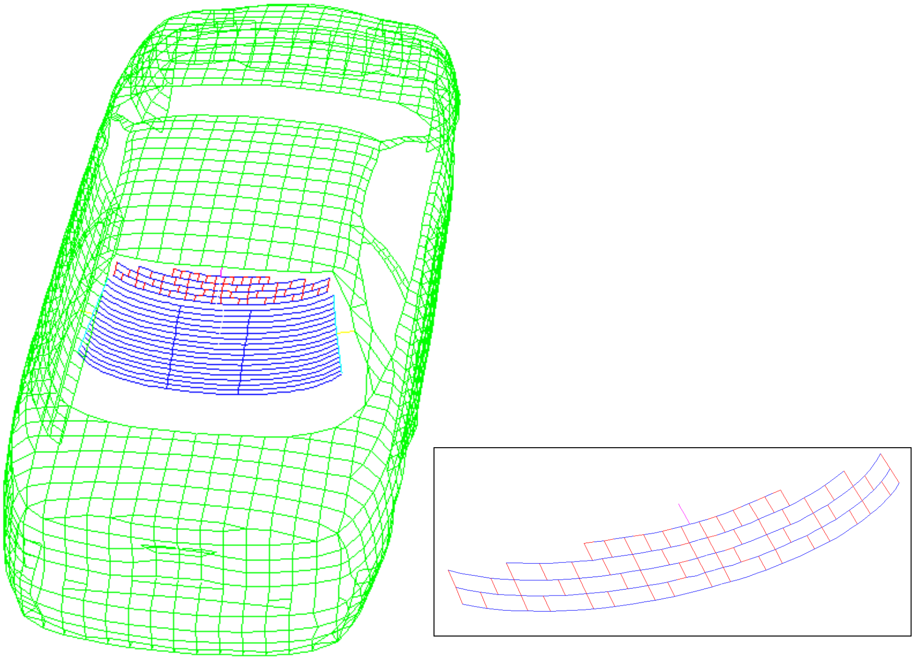

Figure 1: Wire grid model of car with heater grid and self-structuring antenna (SSA) grid. Inset: Enlarged view of SSA grid showing removable elements in red and fixed elements in blue.

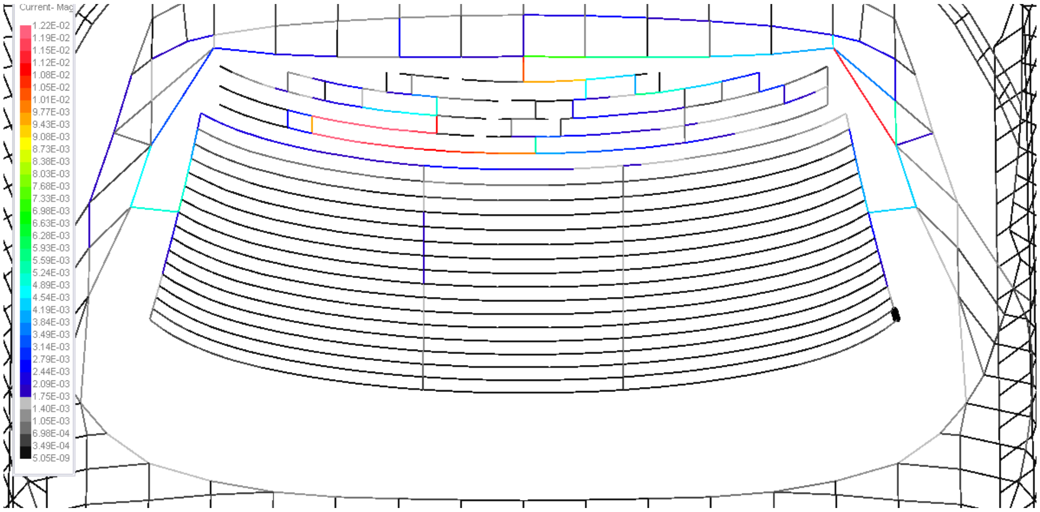

Figure 2. SSA designed backlight antenna with current (amps) at 88 MHz (VSWR=1.24)

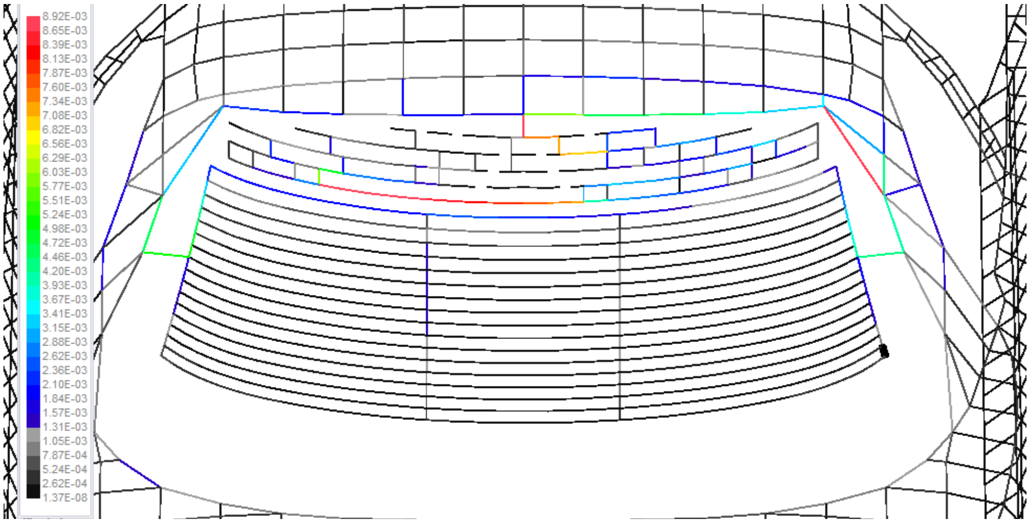

Figure 3. SSA designed backlight antenna with current (amps) at 94 MHz (VSWR=1.06)

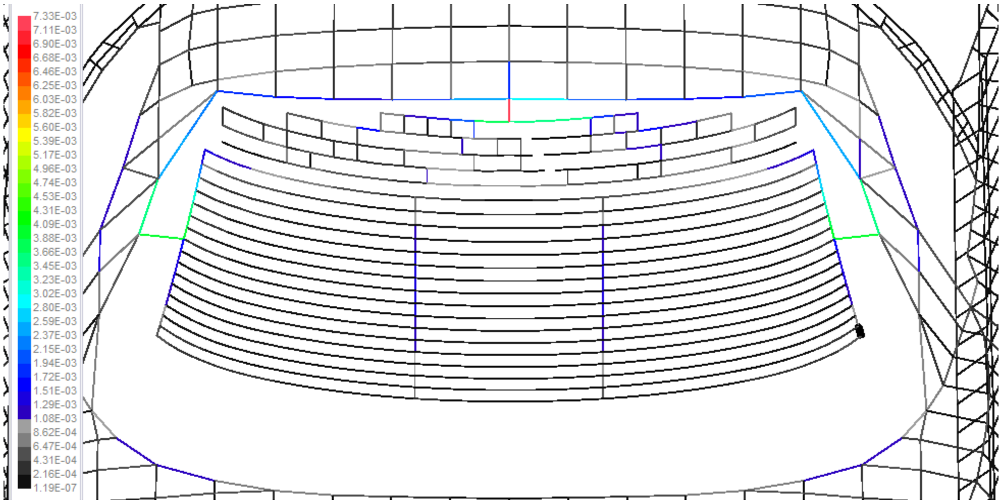

Figure 4.SSA designed backlight antenna with current (amps) at 108 MHz (VSWR=1.14)