

NUMERICAL SIMULATION OF SELF-STRUCTURING ANTENNAS BASED ON A GENETIC ALGORITHM OPTIMIZATION SCHEME

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The self-structuring antenna 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.” The template can be highly structured or random and can be placed on a planar or a conformal surface. An example template is shown in Figure 1. The lines represent conductors and the dots switches or relays. A wide variety of shapes can be achieved by opening or closing the switches.

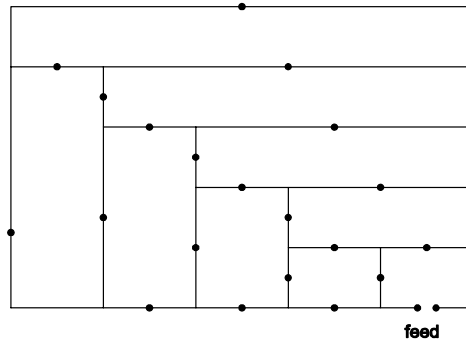


Figure 1. Example antenna template.

As shown in Figure 2, the switches are controlled using an embedded microprocessor and feedback signals from the receiver to optimize one or more performance criteria. Multiple feedback signals can be used when several qualities are desired – e.g., high signal strength,

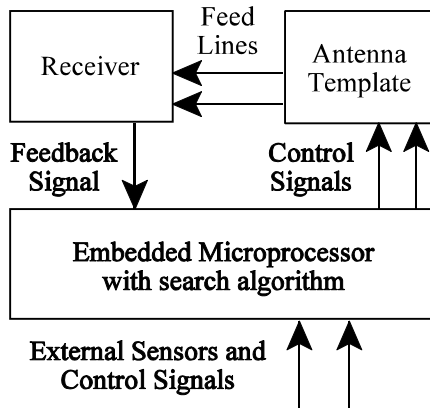


Figure 2. Block diagram.

good audio clarity, efficient multipath suppression, etc. Performance of the antenna is dependent on the control algorithm and template design. A trade-off exists between the “diversity” – i.e., the number of possible configurations - and the complexity of searching for the optimum structural arrangement. Antennas with a higher level of diversity can provide better performance, but require longer search times. The antenna of Figure 1 has 23 switches which provide 8.4 million possible configurations. In this situation, exhaustive and random searching is impractical. Thus modern search methods like genetic algorithms and simulated annealing are employed.

The goal of this research is to simulate the example template as well as other templates in free space and in the presence of other antennas and conducting objects. The simulations are performed using computer tools developed for automated design of vehicular antennas. These tools use the NEC-4 program as the EM solver and the Delphi AntennaCAD program (Ross, Nagy and Szostka, URSI National Radio Science Meeting, Poznan, Poland, 1999) for pre-processing, post-processing and visualization. The effect of the feedback-control network is simulated using the Delphi GA-NEC program. This program uses a genetic algorithm, similar to the one used in the embedded microprocessor, coupled with the NEC program to efficiently search for optimum switch configurations.

Numerical Simulation of Self-Structuring Antennas Based on a Genetic Algorithm Optimization Scheme

by

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Companion Paper

Self-Structuring Antennas

by

C.M. Coleman, E.J. Rothwell and J.E. Ross.

Session AP-56

Novel and Active Antennas and Arrays.

Wednesday 8:40 AM, Ballroom B.

Overview

Introduction to Self-Structuring Antennas

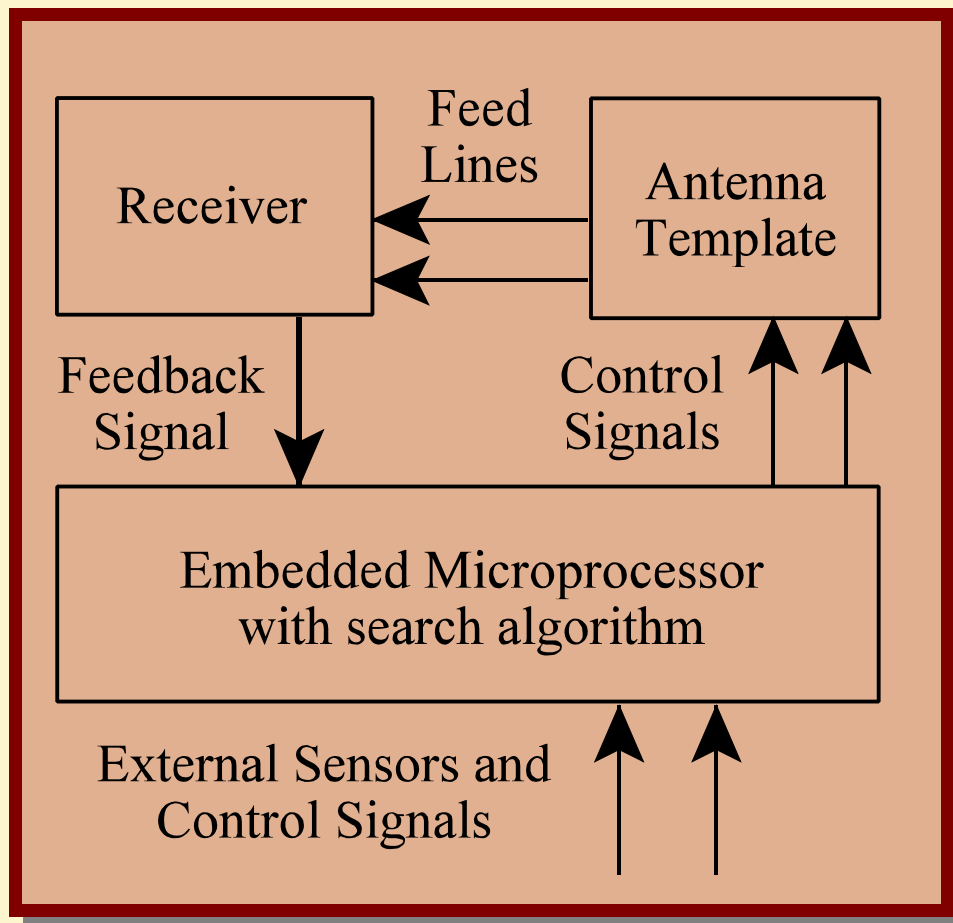
Review of Genetic Algorithms

Computer Analysis Tools

Numerical Results

Summary

- The template can be highly structured or random and can be placed on a planar or a conformal surface.
- A wide variety of shapes can be achieved by opening or closing the switches.
- Switches are controlled using an embedded microprocessor and feedback signals from the receiver to optimize one or more performance criteria.

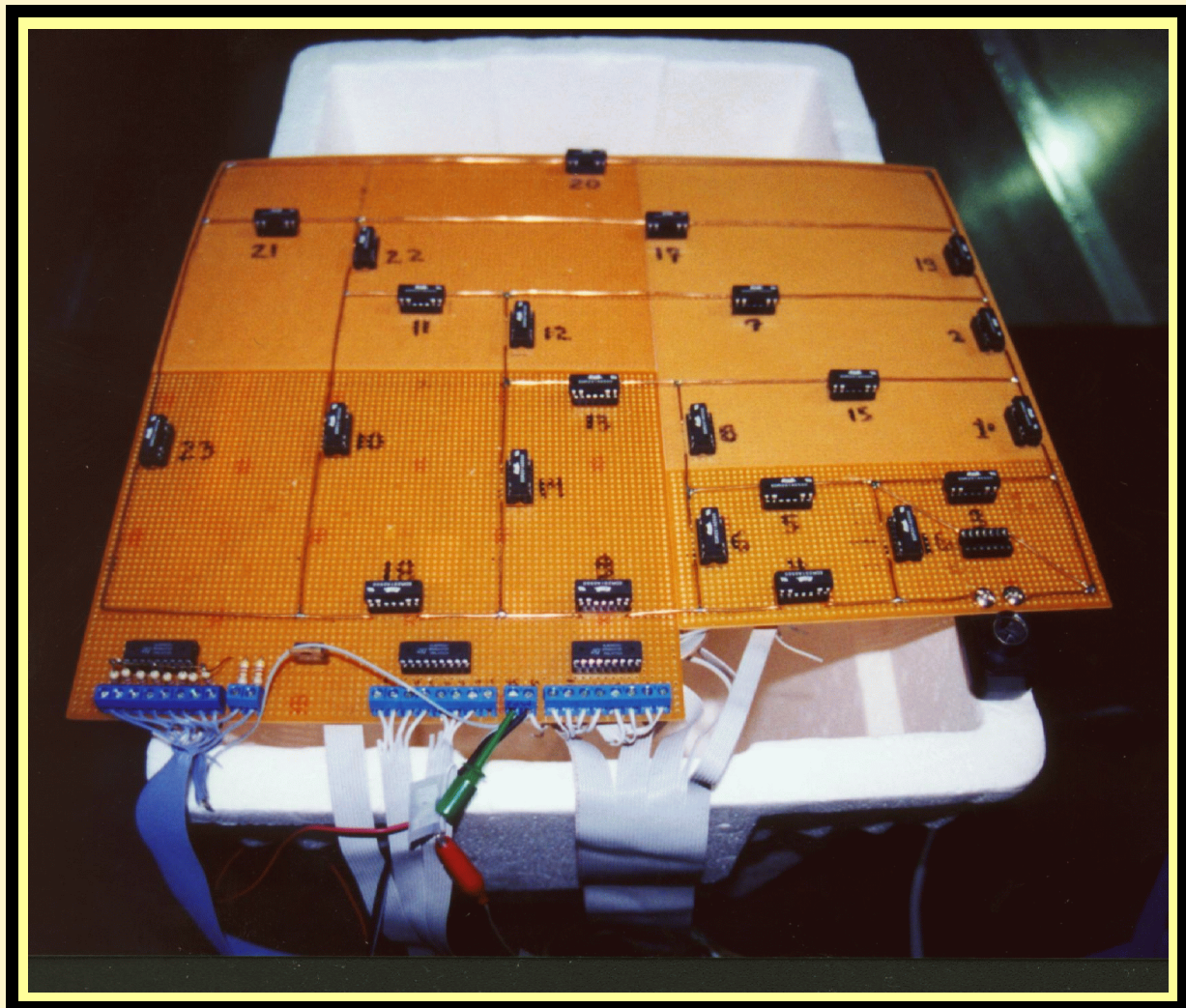


Block Diagram of SSA.

- Multiple feedback signals can be used when several qualities are desired – e.g., high signal strength, good audio clarity, efficient multipath suppression, etc.
- Performance is dependent on the control algorithm and template design.
- A trade-off exists between the “**diversity**” – i.e., the number of possible configurations - and the **complexity** of searching for the optimum structural arrangement.
- Antennas with a higher level of diversity can provide better performance, but require longer search times.
- The prototype antenna has 23 switches which provide 8.4 million possible configurations making exhaustive and random searching impractical.
- Modern search methods like **genetic algorithms** and **simulated annealing** are employed for efficient searching.
- Hardware implementation and potential applications of SSA’s are numerous and discussed in the companion paper.

Prototype SSA

Prototype SSA uses HP8510 Network Analyzer as a receiver with feedback provided via GPIB. A personal computer is used to control the state of 23 relays on the board.



Top View of Prototype SSA.

Review of 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.

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.

11101

Gene for
length

11

Gene for
radius

000110

Gene for
conductivity

101

Gene for feed
location

A possible encoding scheme for an antenna using a 16 bit binary chromosome.

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.

Cross-Over

- A method of exchanging genetic material between two parents to produce offspring.

Parent A: 110110 11110

Parent B: 011011 01110

Cross-Over Point



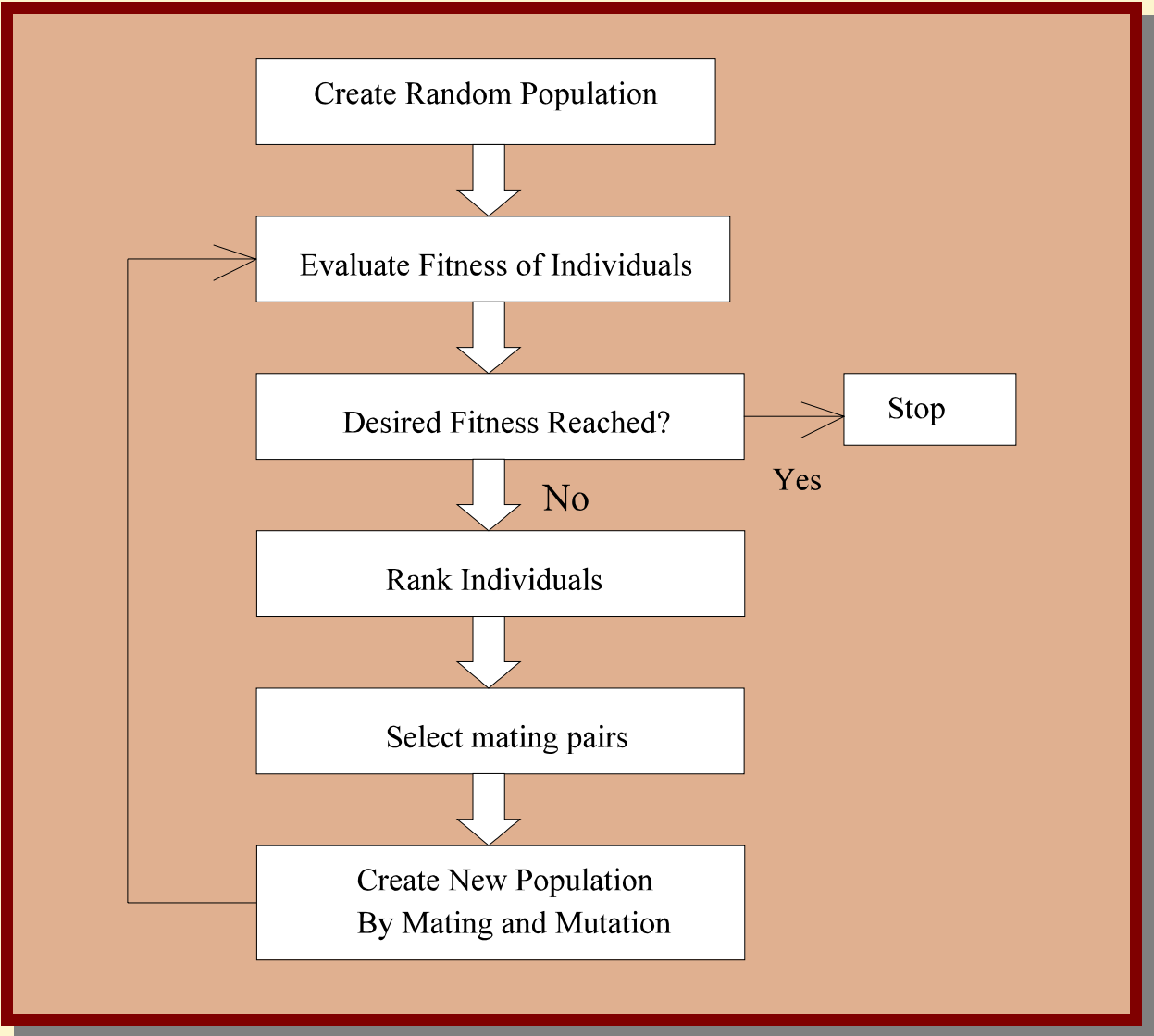
Offspring A: 110110 01110

Offspring B: 011011 11110

Example of single point cross-over.

THE SIMPLE GA

- Create initial random population of individuals. Population size depends on the problem size.
- Evaluate the fitness of each individual according to the predefined criteria.
- Select individuals for mating based on fitness.
 - ▶ *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.



Flow Diagram for Simple Genetic Algorithm

Computer Analysis Tools

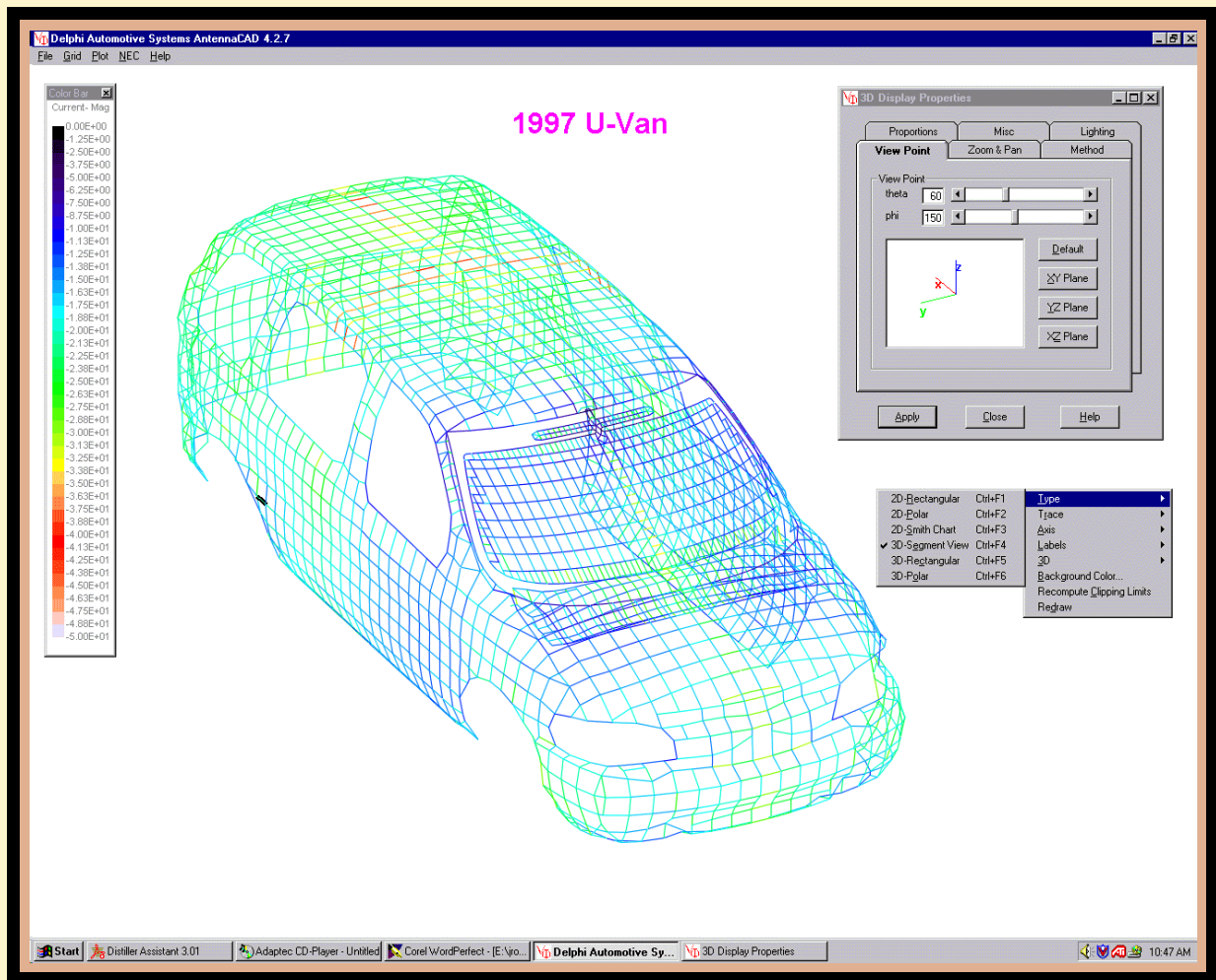
The goal of this research is to numerically investigate the characteristics of the SSA in free space and in the presence of other antennas and conducting objects.

- Simulations are performed using computer tools developed by Delphi Research Labs for automated design of vehicular antennas.
- NEC-4 from Lawrence Livermore National Laboratory is used as the EM solver.
- AntennaCAD program is a GUI for NEC and is used for pre-processing, post-processing and visualization.
- Delphi's GA-NEC program couples a genetic algorithm (GA) to the NEC program to efficiently search for optimum antenna configurations.

AntennaCAD

AntennaCAD is a Delphi Research Labs program that provides pre-processing, post processing and visualization tools for the NEC program.

- Commercial CAD programs such as AutoCAD and CADKEY are used to create and edit meshes.
- Reads and writes wire mesh data in DXF, CADL, IGES, GM SurfSeg and NEC formats.
- Cued dialog boxes for NEC control commands.
- Verifies mesh geometry prior to running NEC.
- Provides 2-D, 3-D and wire frame plots of NEC input and output data.
- Graphics based on OpenGL.



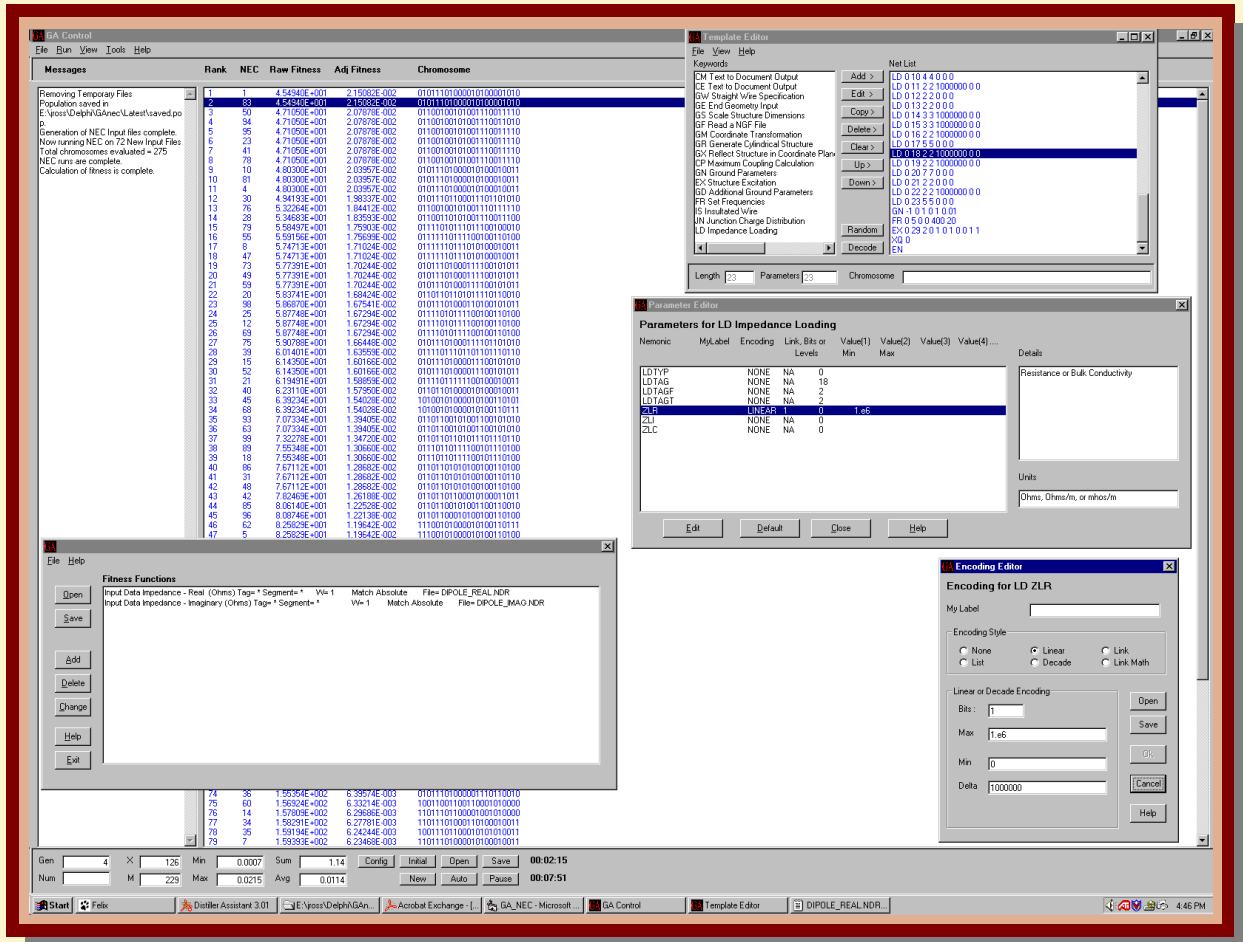
Delphi AntennaCAD display of surface current.

GA-NEC

GA-NEC is a Delphi Research Labs program that couples a genetic algorithm with the NEC program to automatically search for optimal antenna designs.

- GA-NEC can encode any parameter in a NEC input file as an optimization variable.
- Encoding methods include:
 - ▶ none
 - ▶ linear
 - ▶ decade
 - ▶ list of discrete values
 - ▶ symbolic link
- Fitness can be configured using nearly any combination of NEC output variables and user defined responses.
- NEC output variables include:
 - ▶ Charge
 - ▶ Current
 - ▶ Impedance
 - ▶ Transmit Patterns
 - ▶ Receive Patterns
 - ▶ Near Zone Fields
 - ▶ Coupling

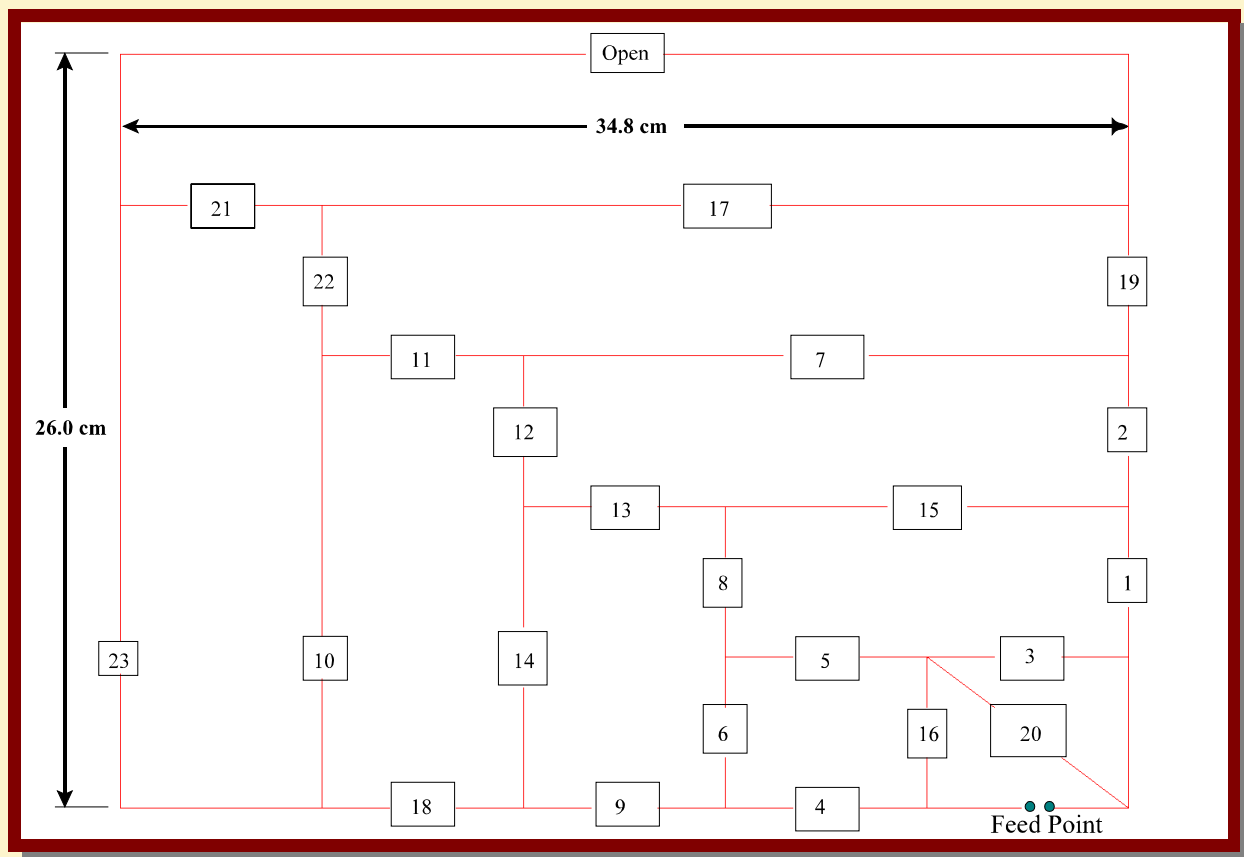
- Fitness goals include:
 - ▶ Minimize response.
 - ▶ Maximize response.
 - ▶ Relative match to specified response (Schwartz Inequality).
 - ▶ Absolute match to specified response.
 - ▶ Constrain less than specified response.
 - ▶ Constrain greater than specified response.
 - ▶ Constrain to be within a specified range.
 - ▶ Constrain to be outside a specified range.



GA-NEC display of GA-control, template, parameter, encoding and fitness editors.

Numerical Results

Due to the complexity involved in modeling control lines, the model was simplified to include only the template wires and switch elements.



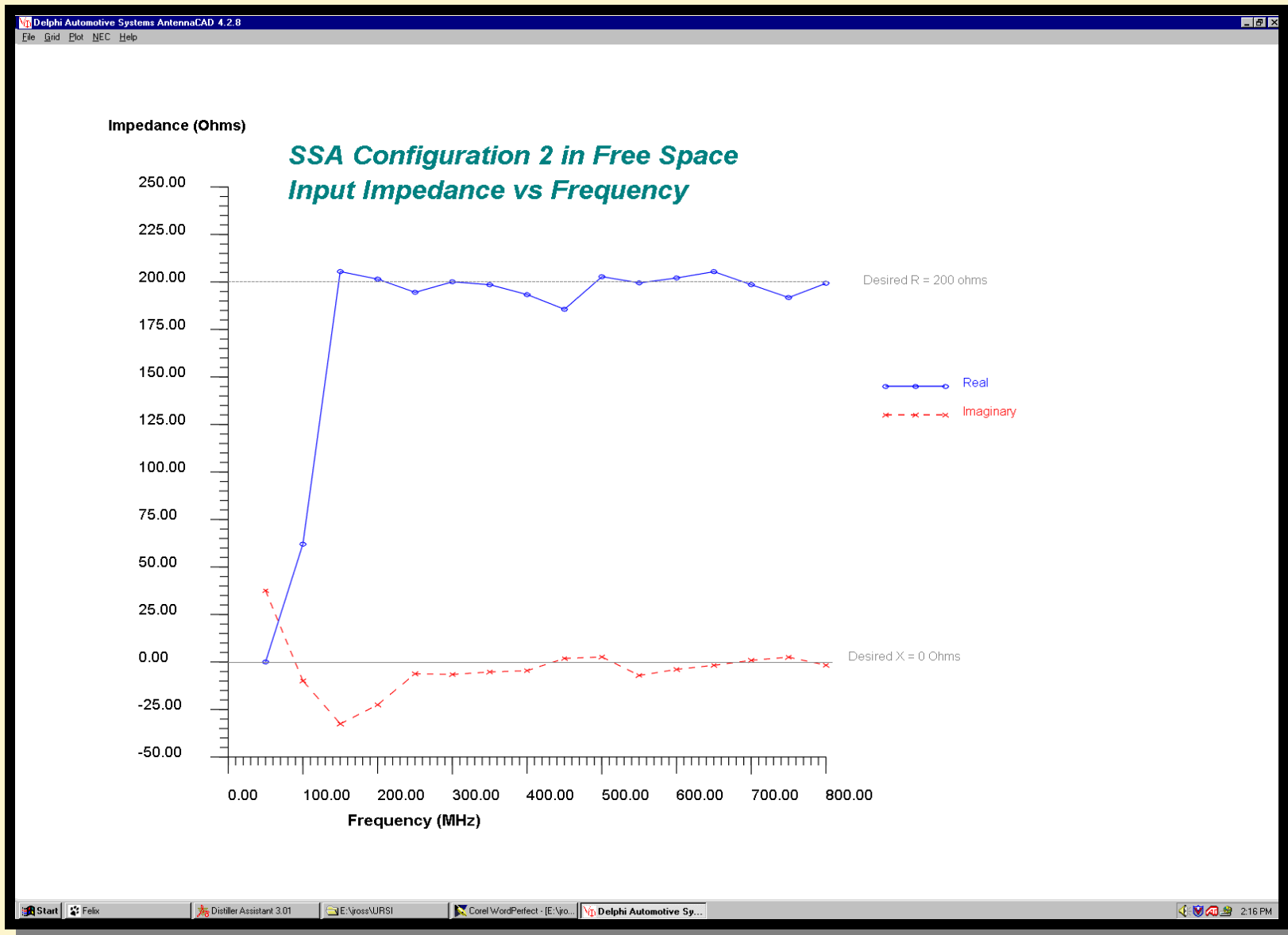
Geometry of SSA Configuration 2

Encoding

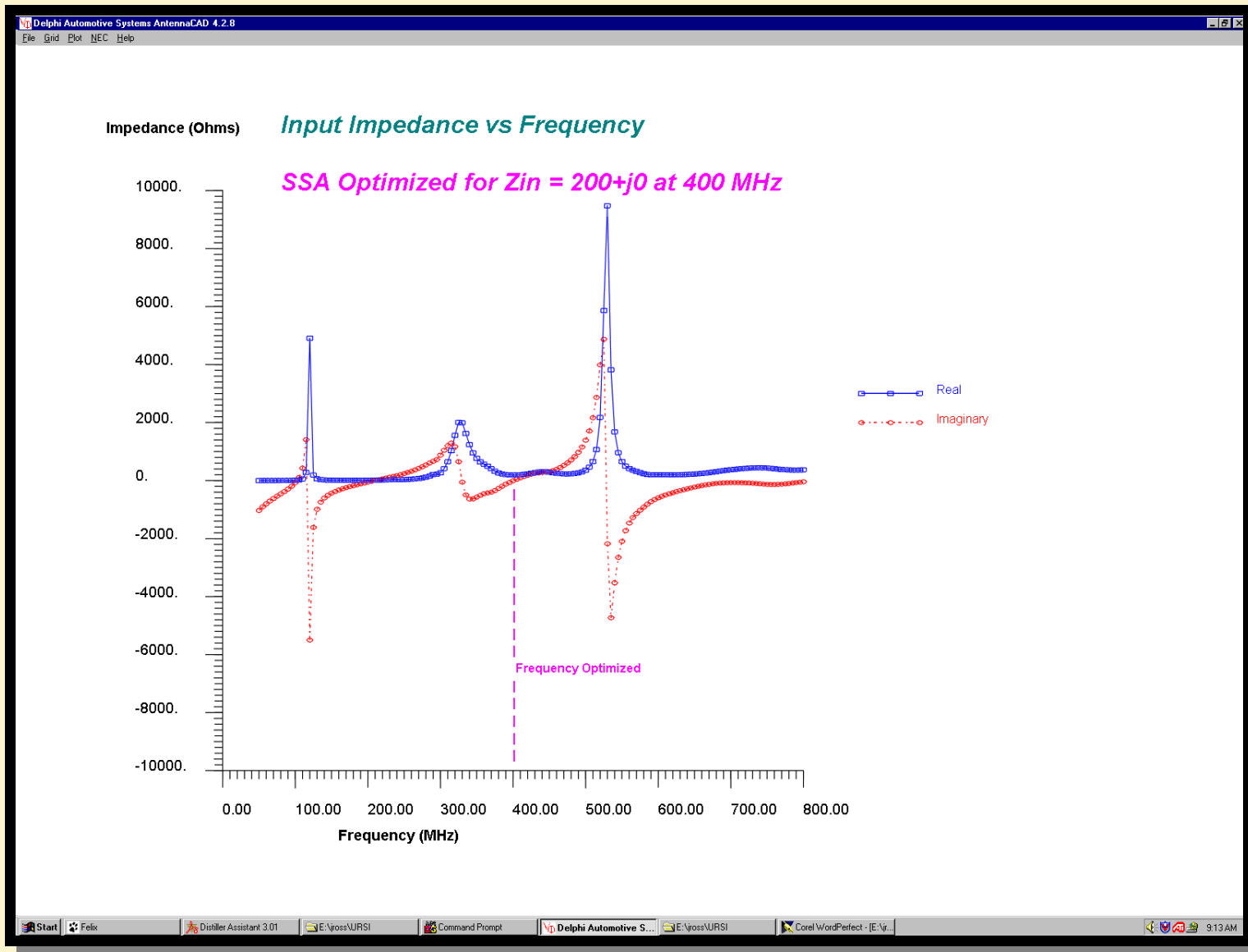
- Open switches were simulated by moving wire segments a large distance away from the antenna via the NEC GM card.
- Closed switches were simulated by simply not moving the segments.

GA Parameters

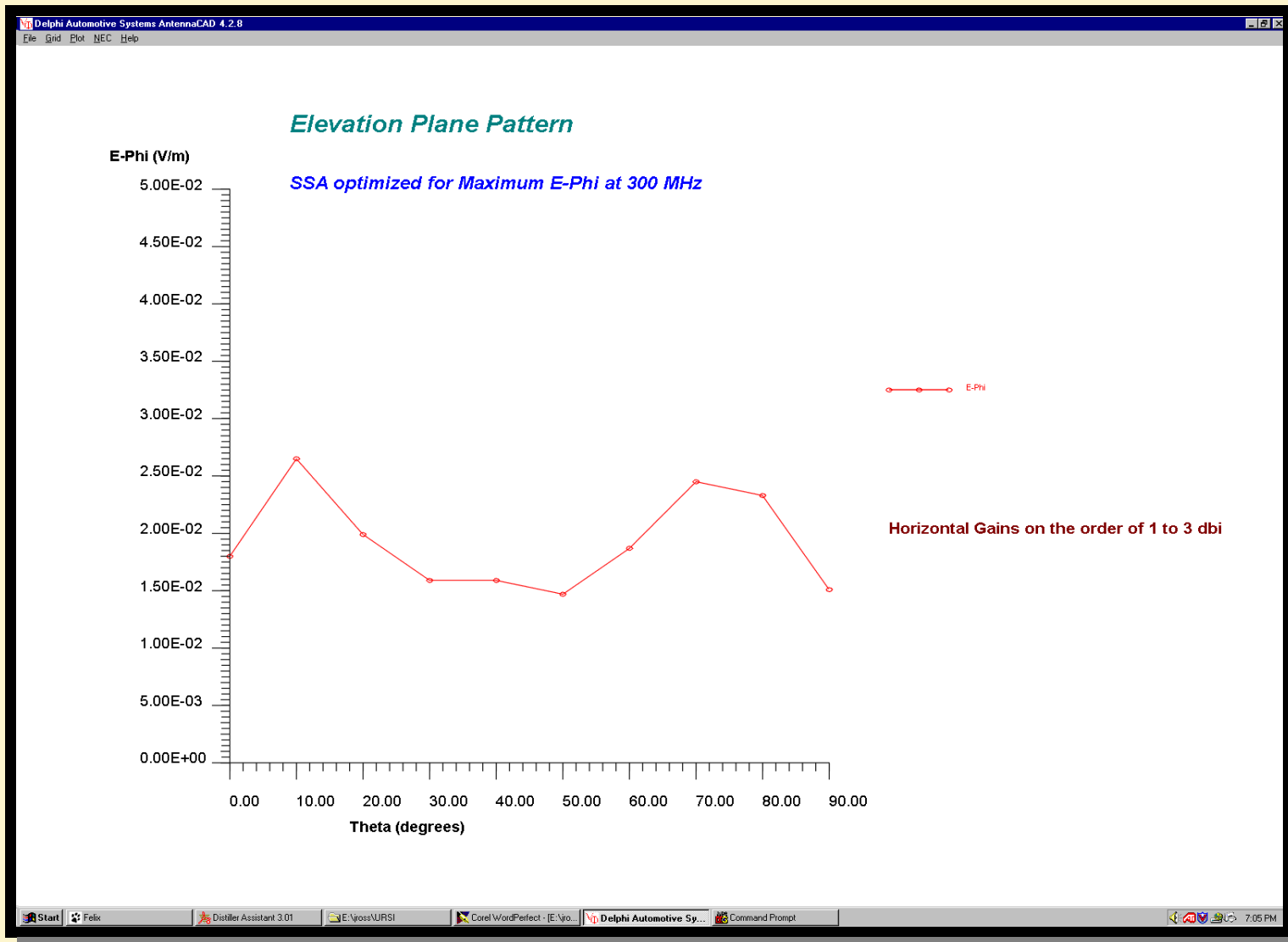
- Simple GA with “Elitist Strategy”
- Population Size = 100
- Probability of Crossover = 0.6
- Probability of Mutation = 0.01
- Generation Gap = 95%
- Maximum Generations = 50



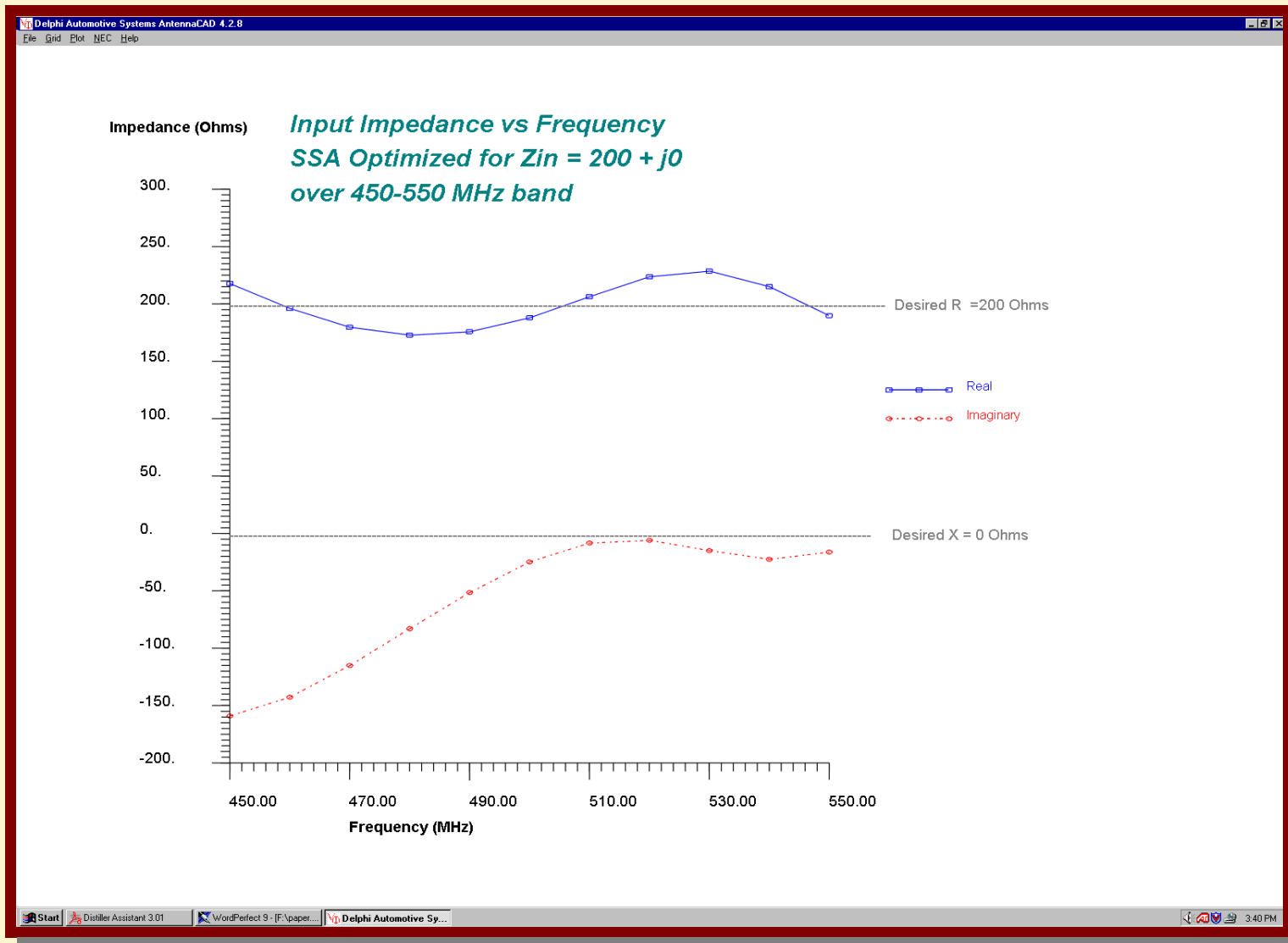
Input Impedance vs Frequency of SSA in free space.



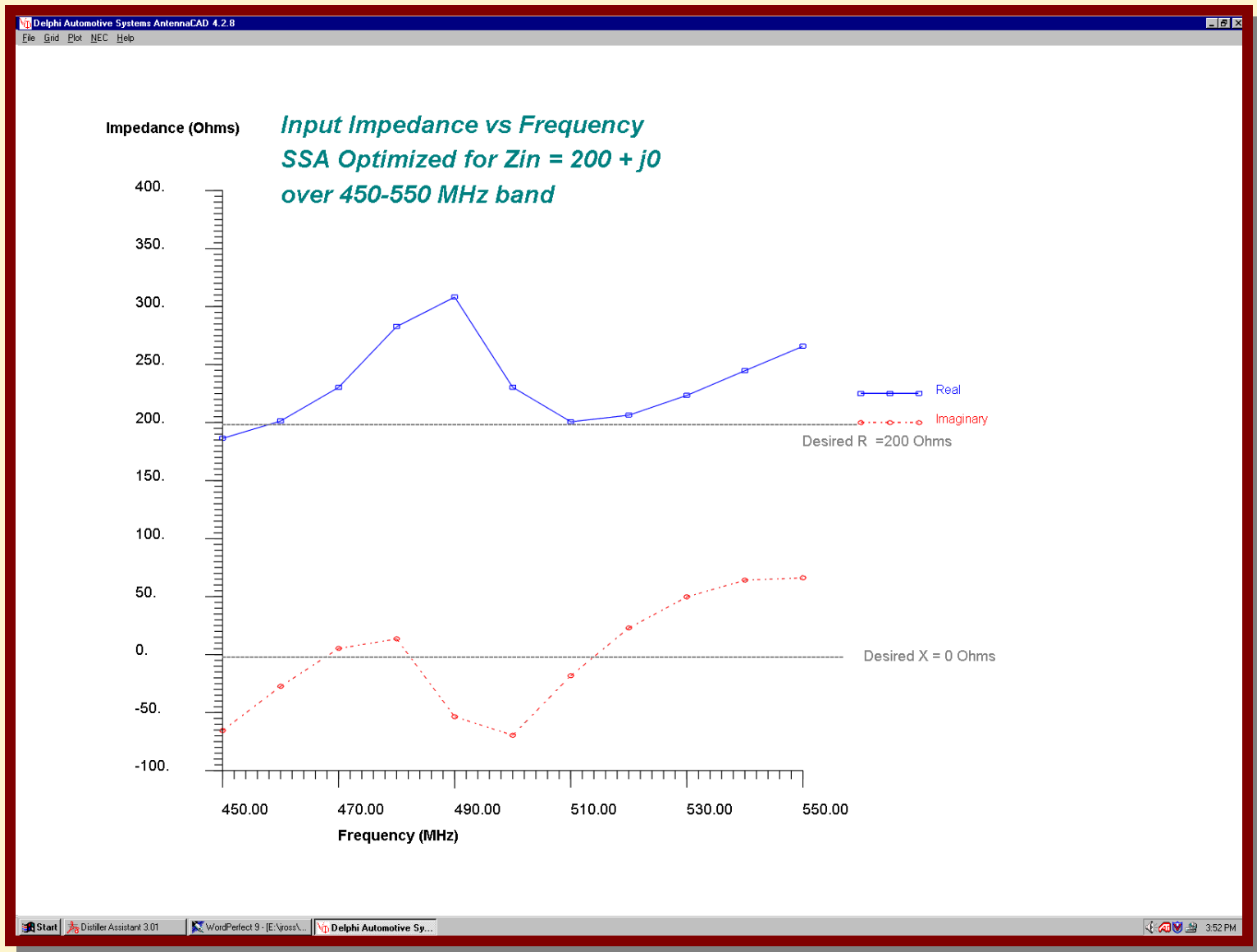
Input Impedance of SSA optimized for 400 MHz.



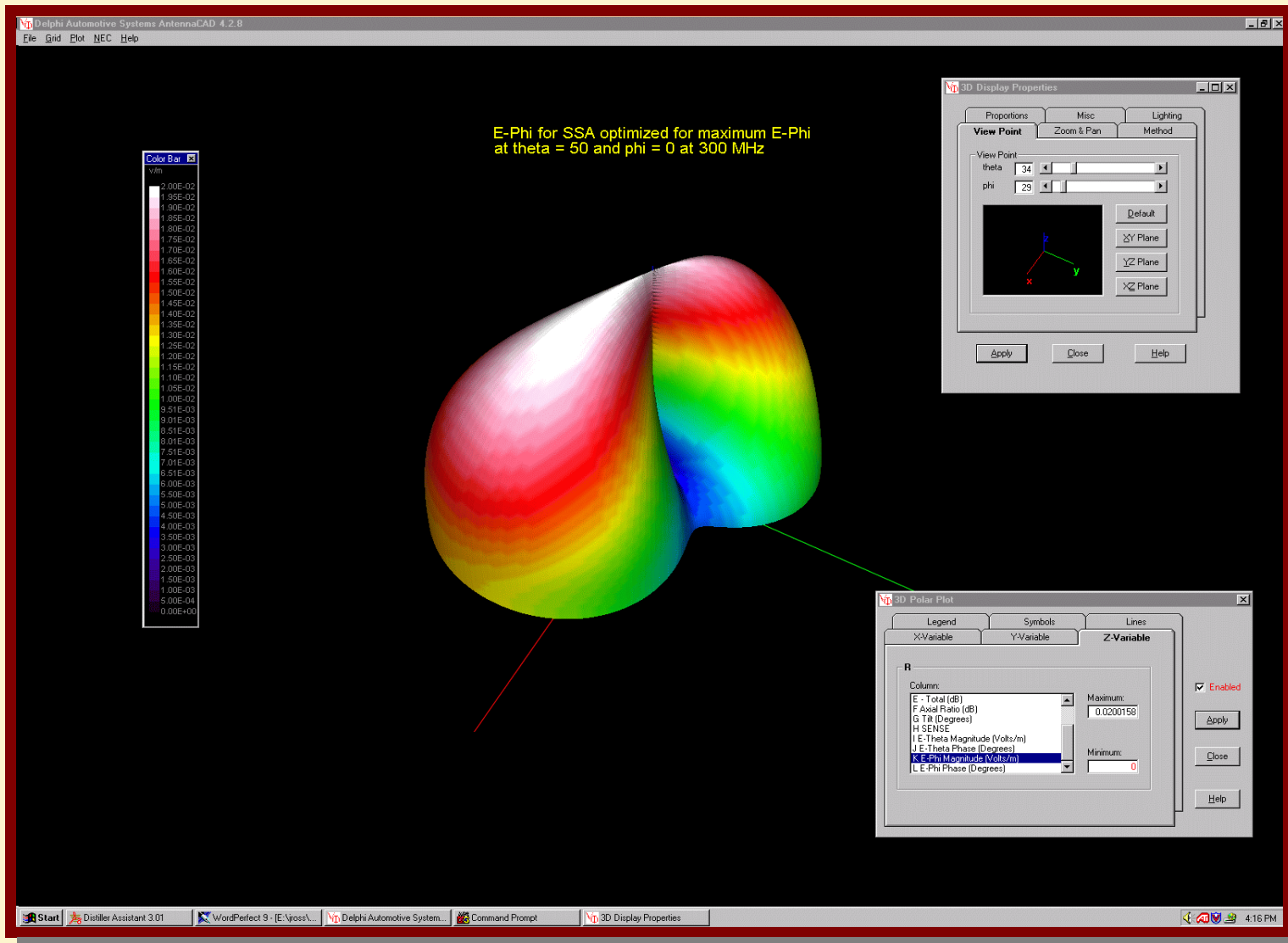
Elevation plane pattern of SSA optimized for maximal E-Phi at 300 MHz.



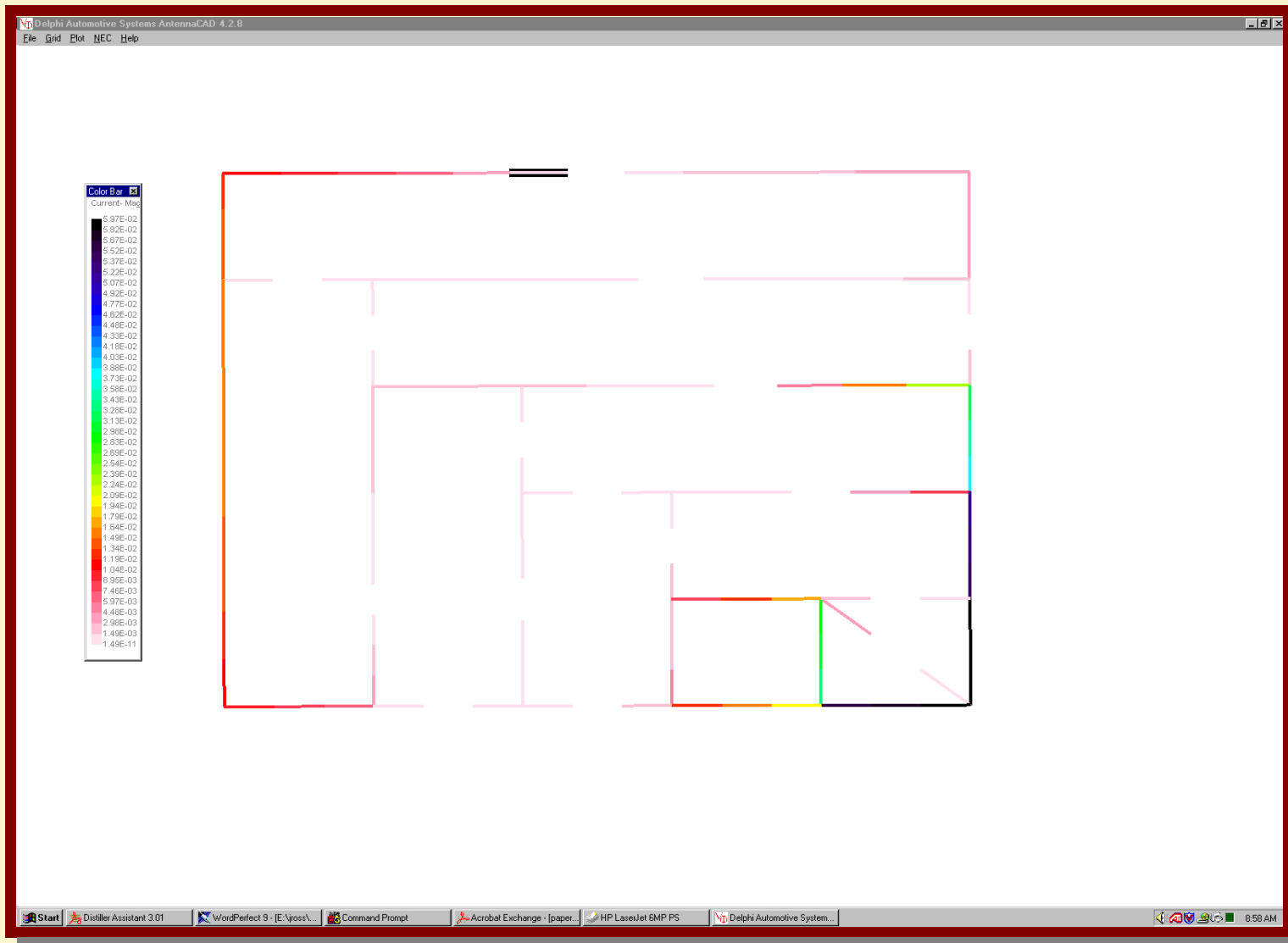
Input Impedance of SSA optimized for $Z_{in} = 200 + j0$ over band from 450 to 550 MHz.



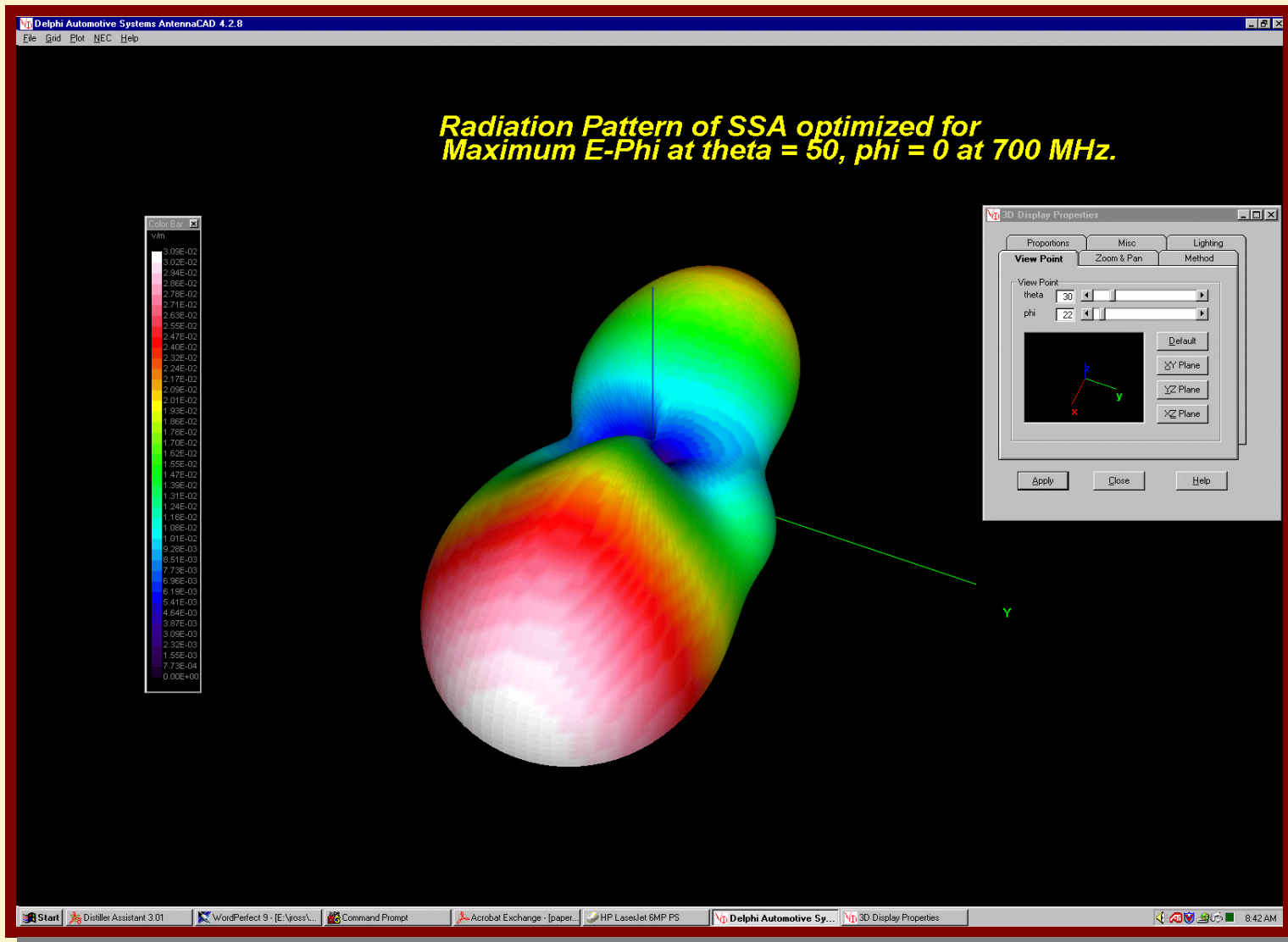
Another result showing optimization over a band of frequencies.



Radiation Pattern for SSA optimized for maximum E-Phi at Theta = 50 and Phi = 0 at 300 MHz.



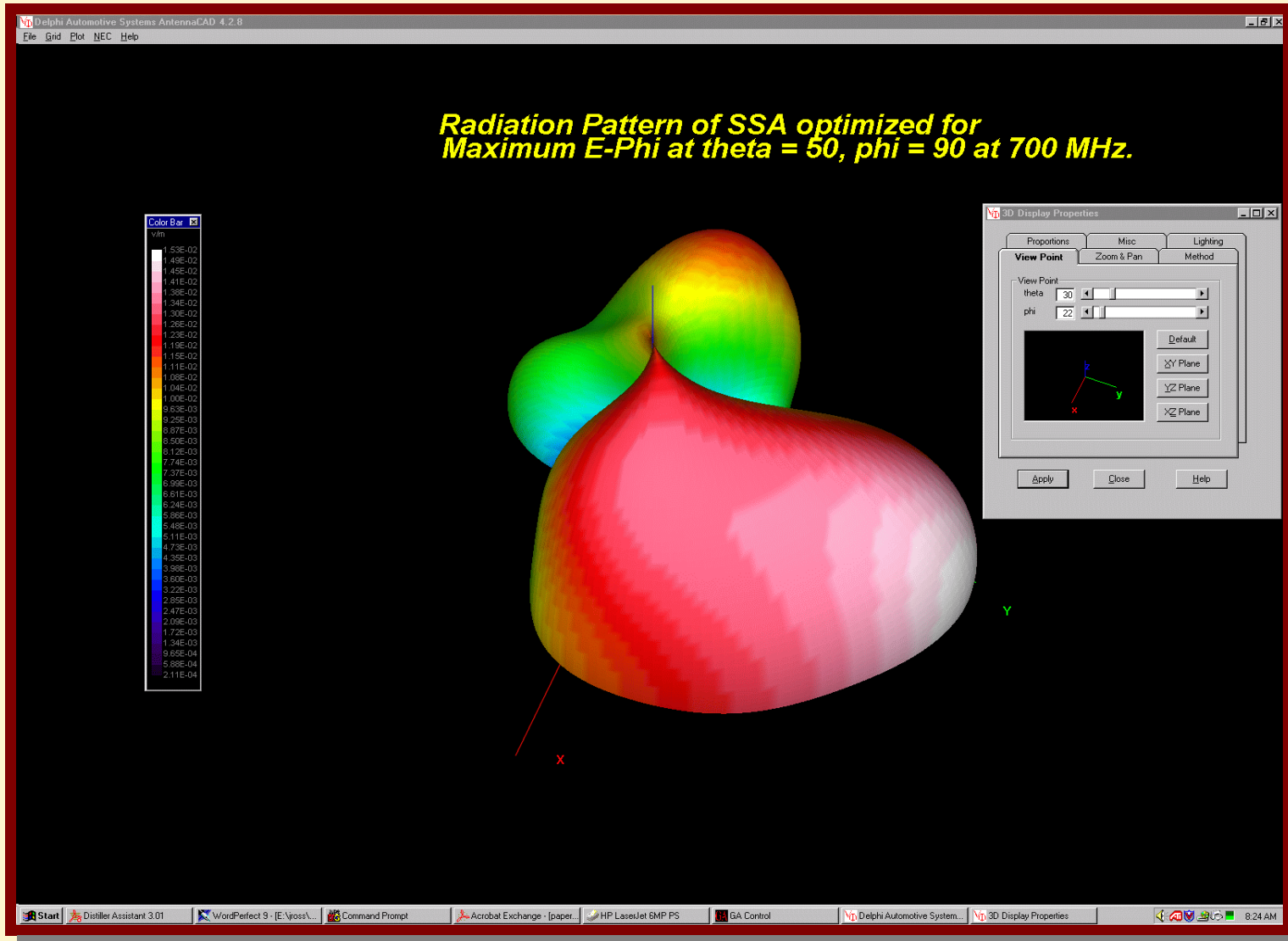
**Current on SSA optimized for maximum E-Phi at theta=50,
phi=90 and frequency = 300 MHz.**



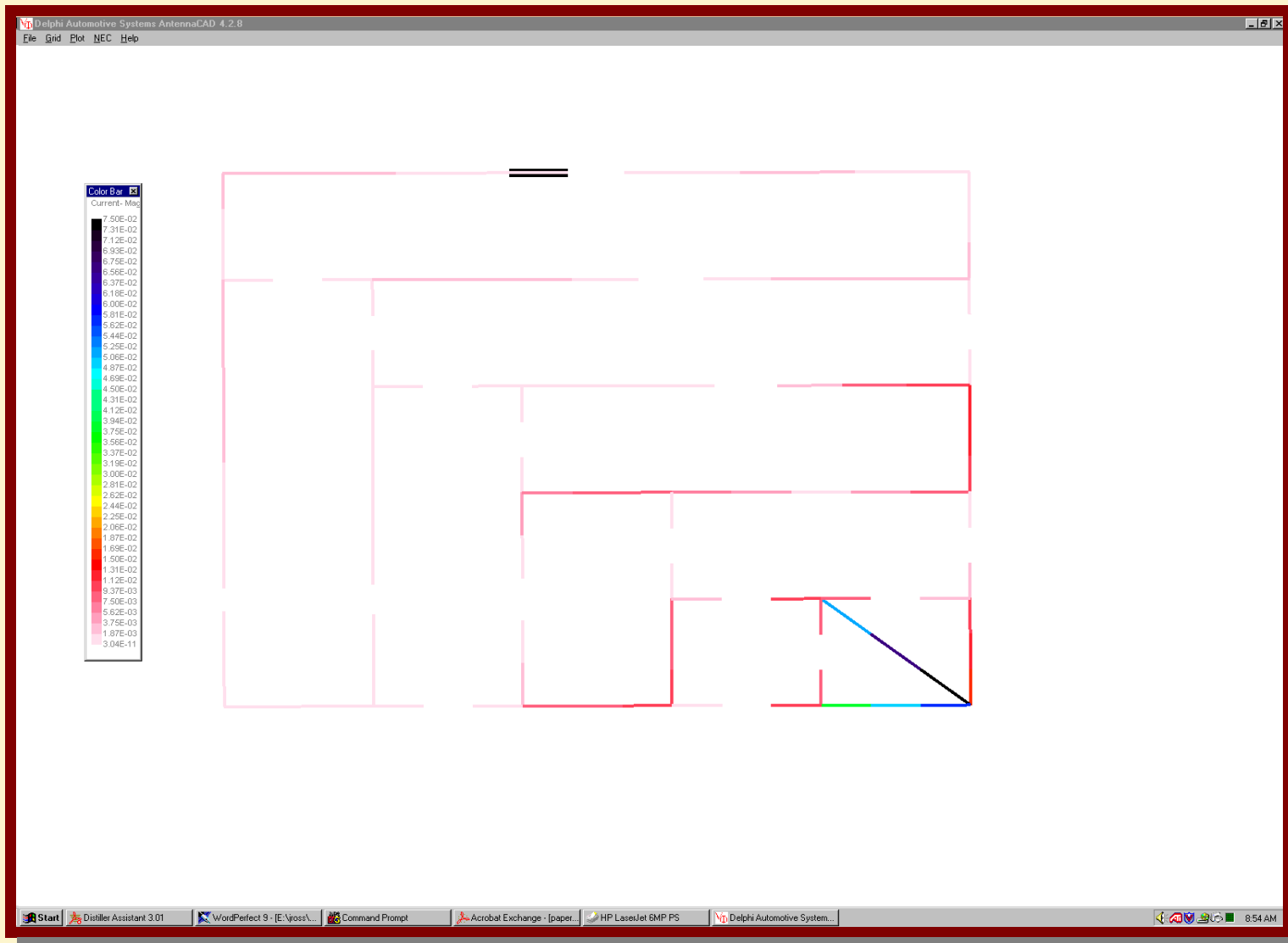
Radiation pattern of SSA optimized for maximum E-phi at theta=50, phi = 0 and frequency =700 MHz.



**Current for SSA optimized for maximum E-Phi at theta=50, phi=0
and frequency = 700 MHz.**



**Radiation pattern for SSA optimized for maximum E-Phi at
Theta=50, Phi=90 and frequency = 700 MHz.**



**Current on SSA optimized for maximum E-Phi at theta=50,
phi=90 and frequency = 700 MHz.**

Summary

Numerical results suggest that the SSA concept may have potential for solving a variety of traditionally difficult antenna design problems.

- Accurate analysis of the prototype SSA is hampered by the presence of the numerous control and power supply wires.
- Numerical simulations demonstrate that the SSA prototype can be tuned to achieve a good match over a wide range of frequencies (approximately 150 - 800 MHz).
- Optimizations that cover a band of frequencies show promising results.
- Observed that the GA generally converged faster for higher frequencies. This is likely due to the higher diversity of the antenna at these frequencies.
- Numerical simulations demonstrate that the SSA should exhibit relatively little variation in reception as the antenna is rotated relative to the source.