CAD TOOLS FOR VEHICULAR ANTENNAS

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Abstract **- The number of antennas installed on today's vehicles has increased dramatically in response to the demands for mobile telecommunications services. At the same time, aerodynamic styling issues and a hostile EMI environment have complicated the design process. Thus, automakers are investing in CAD/CAE tools for vehicular antennas in an attempt to reduce design time and eliminate costly prototyping. This paper discusses EM analysis methods applicable to vehicular antennas with emphasis on wire grid modeling via the method-of-moments. Discussion is centered on a General Motors proprietary program called AntennaCAD. This program is a user friendly interface to the NEC program and has been used in the design of vehicular antennas in the VHF band. The program is extensible to other analysis methods and is being enhanced with OpenGL graphics and automated design methodologies based on genetic algorithms.**

I. INTRODUCTION

The automobile industry typifies one aspect of today's highly competitive, global economy. It is a large, distributed effort, spread out over several continents and involving thousands of engineers and technicians. Only with the aid of modern digital technology can they hope to work together and respond to competitive pressures by cutting costs and shortening the design-to-manufacturing cycle for the new car models. Typical cycles for totally new designs vary from 30 to 18 months or less. To meet the cost-cutting goals and improve productivity, automotive manufacturers have committed to a streamlined digital process, with the ultimate goal of designing and manufacturing automobiles with minimal printed technical drawings and having the fewest possible physical prototypes.

The design process is typically composed of eight stages: concept, product design and validation, process and tooling design, tooling and component manufacture, and vehicle assembly. The process often employs incompatible software tools for different activities. In order to cut costs and shorten the process, automobile manufacturers are trying to use central and compatible tools for the entire company. They are also attempting to increase the use of digital prototypes and beginning to use virtual reality with fabricators or three-dimensional printers to produce solid output of new designs directly from computer-aided design data.

The present day design procedure for vehicular antennas uses empirical techniques and the final design requires a vehicle prototype for validation purposes. Delaying the antenna design until this point in the design cycle is unacceptable and can lead to delays in launch dates. Ideally, the antenna design process should be done concurrently with the structural, aerodynamic and styling efforts so that the antennas can make optimal use of the limited vehicle surface areas. As a practical matter, the antenna is generally not given such a high priority and the antenna designer can proceed only after the body geometry has been established.

II. ANALYSIS METHODS

Computer aided design (CAD) techniques can help in preparation and optimization of vehicle antenna systems. This design technique will reduce costs and determine the characteristics of the vehicle antenna at an early date. CAD software for vehicular antennas will be based on well known and proven analysis methods.

One of the most promising techniques is the Finite-Difference Time-Domain (FDTD) method [1]. It solves Maxwell's equations directly in space and time domains. The method is especially suited for analysis of radiating structures having arbitrary shape and composed of layers of heterogeneous materials. The FDTD method has been used for calculating the E and H fields inside a human head when it is located in the vicinity of a hand held RF terminal. Because of memory requirements, the analyzed space is usually small; however, the range of applicability has increased significantly with the introduction of advanced absorbing boundary conditions and constantly decreasing computer hardware costs.

The most popular technique is the Method of Moments (MoM). It reduces the electric or magnetic field integral equation to a set of algebraic equations that can be solved numerically. A wire grid model represents the vehicle body and antennas. While the dimensions of the model are theoretically not limited, the available computer memory and CPU speed reduces the model dimensions to a few wavelengths. MoM is especially suitable for wire antennas.

Other analysis methods include the transmission line matrix method (TLM), the geometrical theory of diffraction (GTD), the finite-element method (FEM), the boundary-element method (BEM), and the spatial network method. The ability to incorporate different analysis methods is important since it is impossible to solve all problems using only one method. For example, GTD is usually preferred over MoM for analysis of microwave antennas, while FDTD naturally gives the transient response and FEM naturally gives the frequency response. Further, the use of multiple techniques will be required to yield designs that can confidently be used without need for extensive prototyping and experimental testing. Programs incorporating multiple analysis methods to solve the same problem in the same frequency band are currently unavailable however.

A number of commercially available software packages are available for electromagnetic analysis; however, at the present time computer speed and memory requirements limit the usage of many of these packages for automotive antenna design. Specifically, problems with stair-casing and boundary conditions in FDTD calculations and the issues of mesh generation and matrix inversion become limiting factors when dealing with solutions for the complete volume of space within and near to a vehicle. The MoM wire grid surface methods are naturally more efficient than the volume methods but still require significant CPU and memory to solve a typical automotive antenna problems where the vehicle shape is complicated and it's size is on the order of several electrical wavelengths.

III. The GM AntennaCAD Program

The NEC [2] code from Lawrence Livermore National Laboratory is the most widely used and proven MoM analysis code available. By the early 1980's GM engineers were attempting to use NEC for vehicular antenna analysis, but were frustrated by it's poor input/output functions. To overcome these limitations, GM began an effort to create a more user friendly program that could tackle complicated vehicle geometries. The result of this effort is a general purpose user friendly graphical interface to the NEC program called AntennaCAD. The current version of the program runs on Windows 9X and NT class machines and provides tools for geometry translation, viewing and verification, simulation configuration, as well as data extraction and visualization.

One of the most difficult problems in vehicular antenna analysis is the translation of data from a drawing CAD format to a format acceptable for electromagnetic analysis programs. In the early days of antenna modeling at GM, engineers were forced to manually enter mesh data that was translated from blue prints or scaled from photographs of vehicle prototypes. This time consuming error prone process was part of the motivation behind the development of AntennaCAD.

AntennaCAD is now used in conjunction with another GM proprietary program called SurfSeg and standard CAD programs such as CADKEY and AutoCAD to semi-automatically create NEC compatible vehicle surface meshes directly from math data in GM's parts database. SurfSeg is a sophisticated "geometrical signal processing" program that was developed in parallel with AntennaCAD. It performs numerous functions not commonly available in standard CAD programs, including interference checking, data translation, section cutting etc. SurfSeg requires a UNIX workstation with a 3D frame buffer and significant memory and disk space to construct a model of the outer skin of the vehicle. After the surface is constructed, sections are cut along the three orthogonal directions. The curved lines are then split at intersection points and T-junctions. The point count on each curved line is then reduced using chordal deviation tests and lines with lengths below a prescribed cutoff point are removed to create a preliminary vehicle mesh. Figure 1 shows a SurfSeg screen with the outer skin of a 1995 Blazer and it's associated preliminary mesh on the left side of the vehicle.

The preliminary mesh is then exported to CADKEY or AutoCAD so that problem areas can be manually refined. Finally, the mesh is imported into AntennaCAD and radius values are automatically assigned to each segment according to color tag or segment length. The simulation parameters such as frequency, ground parameters, feed point etc. are then configured using AntennaCAD's NEC Card Editor. The NEC Card Editor provides a graphical overview and customized input templates for all NEC control commands. It also automatically creates the NEC input file with a structure that yields the most efficient calculations. A screen shot of AntennaCAD is shown in Figure 2. Here, one can see the NEC input listing, and the NEC Card Editor being used to configure a radiation pattern request.

After the simulation is configured, the AntennaCAD NEC Verify utility is used to determine if the mesh satisfies the NEC modeling rules for the prescribed simulation parameters. If there are problems, the mesh is displayed in 3D with offending segments highlighted in different colors according to the severity of the errors. Using this display, the problem areas can easily be repaired using CADKEY or AutoCAD and the mesh reentered into AntennaCAD. After the mesh successfully passes all checks, the NEC input file is written to disk and the NEC program

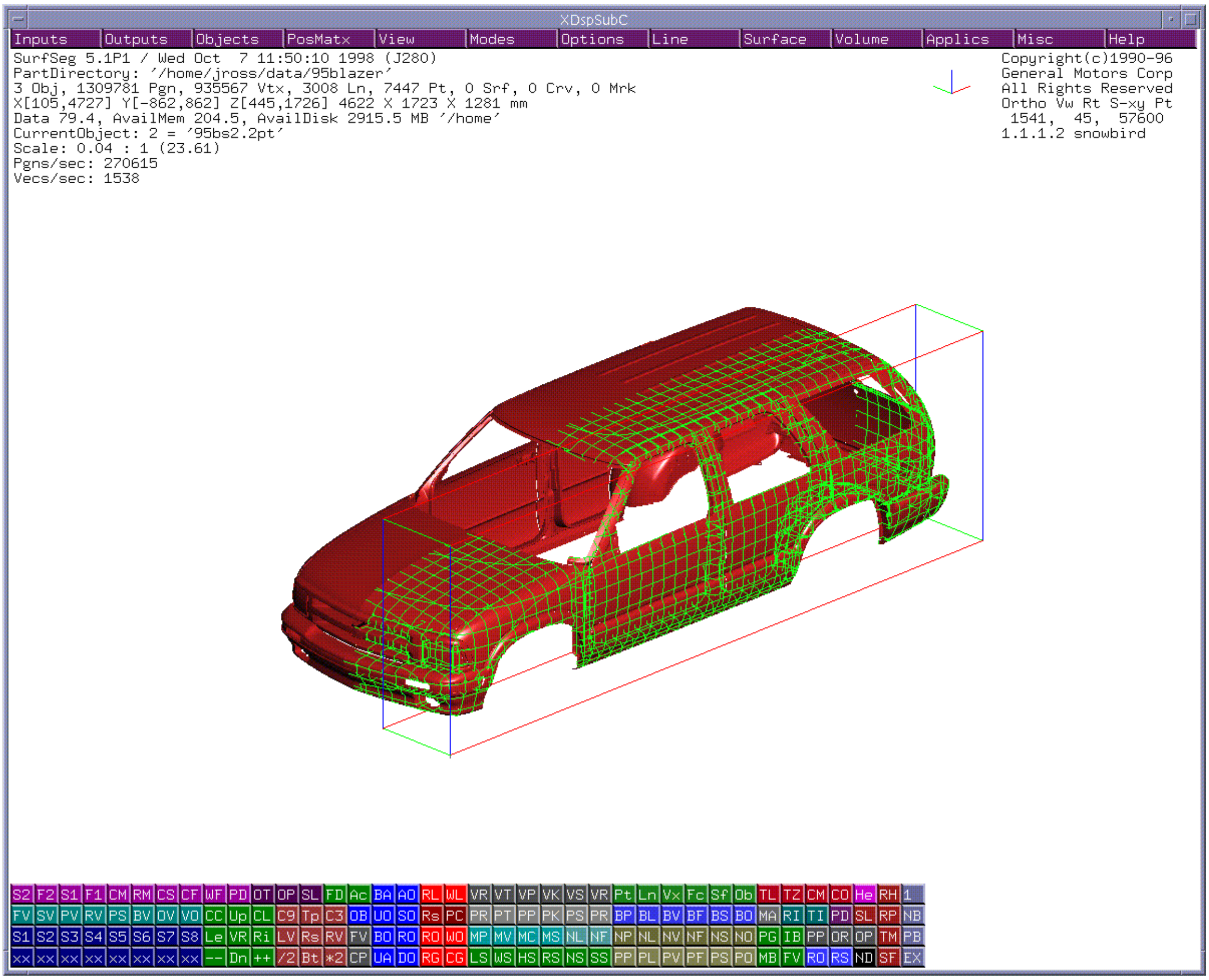

Figure 1. SurfSeg view of 1995 Blazer with preliminary mesh generated by section cutting.

is executed on a suitably equipped PC or workstation. The requirements for executing NEC vary depending on the complexity of the problem, symmetry issues and the version of NEC being used. For most work at GM, the single precision version of NEC-4 is used and problem sizes are on the order of 5000 segments with no symmetry. A 250 MHz Sun Ultra-Sparc II system with 256 MB of RAM requires approximately 1.3 hours per frequency point.

After the NEC execution is complete, AntennaCAD is again used for processing and visualization of the output data. AntennaCAD provides easy access to nearly any NEC output parameter including geometry, current, radiation and reception patterns, radar cross sections, and feed point parameters. The data can be directly displayed using a variety of plot types, including rectangular, polar and Smith Charts for impedance data. The program also has options for displaying surface currents in a false color display superposed over the structure mesh. An example of this is shown in Figure 3. Here, AntennaCAD is used to model the 1997 U-Van with a Solaray style antenna mounted in the front windshield. The Solaray antenna is composed of an optically transparent conducting film that is sandwiched between glass layers. The antenna is fed by a coaxial pigtail connection. AntennaCAD also provides 3D surface displays in both rectangular and polar coordinates. Though currently tailored for use

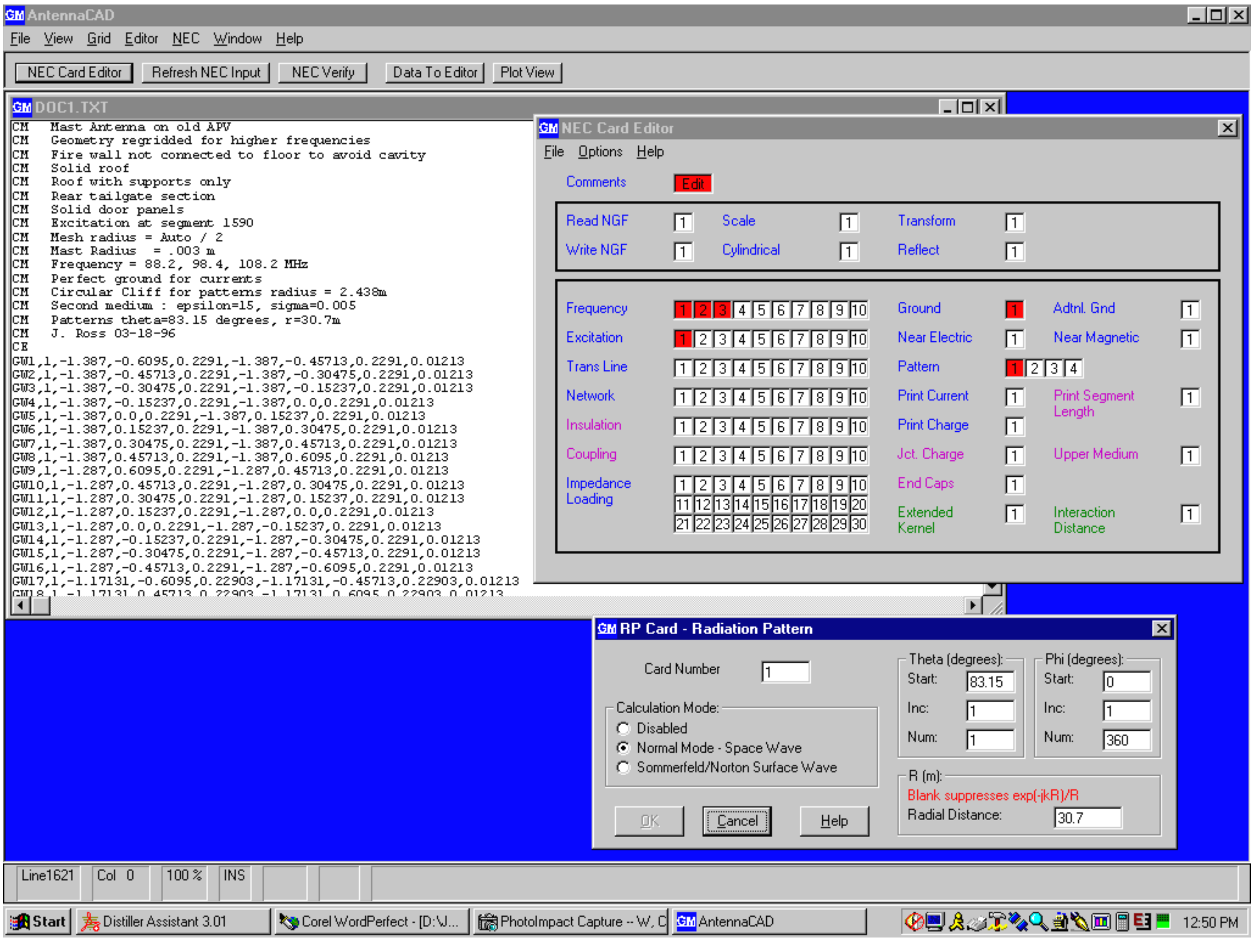

Figure 2. AntennaCAD display showing NEC input file and NEC Card Editor.

with NEC, the AntennaCAD program could be extended to include other analysis methods such as GTD or FDTD.

IV. True Automated Design Tools

Current CAD tools, including AntennaCAD, only provide a means of performing the analysis of a predetermined antenna and vehicle structure. The engineer is then left to use a manual cut and try method to search for a good design. This is a time consuming and often futile process. Ideally, a CAD/CAE tool should provide a highly automated method of designing antennas subject to vehicle and cost constraints to meet specific design objectives. Tools with this level of sophistication are not currently on the commercial market and must be developed if automakers are to see continued savings by shortening design cycles.

The AntennaCAD program is currently being enhanced to include true automated design features based on a genetic algorithm (GA) optimization method [3]. The GA is a very robust and relatively efficient global search method that is based on Darwinian principle of natural selection ("survival of the fittest") and the natural genetics concepts of evolution through mating and mutation. The GA has several key features that make it attractive for the problem of optimizing vehicular antennas. Most importantly, they do not require initial guesses or derivative information as do the calculus based search methods. The GA generally does not get stuck in local minima and can easily handle non-linear, discrete,

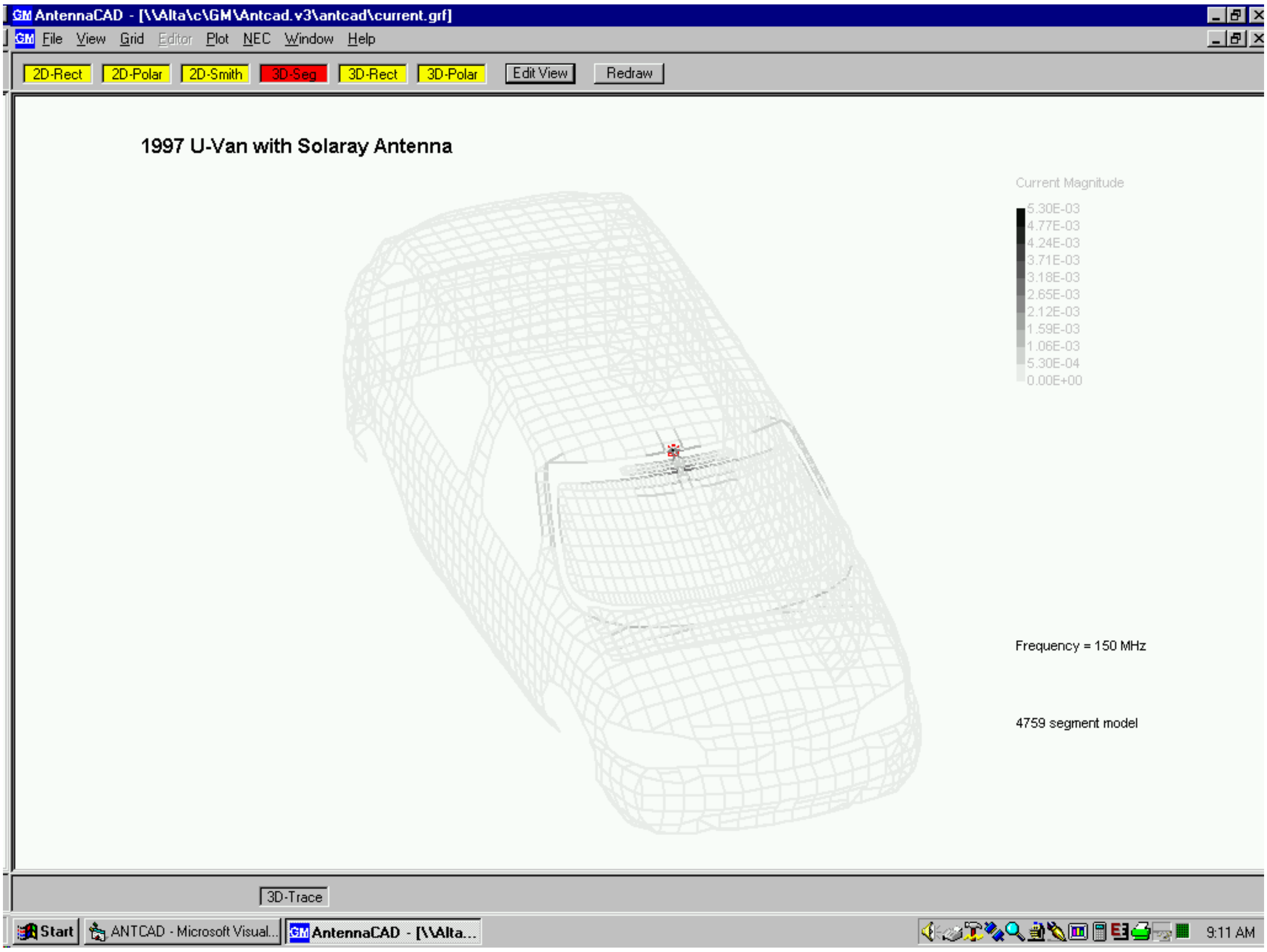

Figure 3. Current magnitude display for 1997 U-Van with Solaray antenna.

discontinuous functions and constraints. Further, the GA has been proven to be capable of finding new, non-intuitive or non-traditional classes of solutions for some problems. Finally, the GA can be easily implemented on a parallel computer or a parallel network of computers using PVM [4] software.

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