Large-Scale Design and Optimization Using Cluster Computers

Tom Cwik*, Gerhard Klimeck and Frank Villegas

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Dr., Pasadena, CA 91109

INTRODUCTION

The NASA/JPL goal to reduce payload in future space missions while increasing mission capability demands miniaturization and integration of active and passive sensors, analytical instruments and communication systems among others. Currently, typical system requirements include the detection of particular spectral lines, associated data processing, and communication of the acquired data to other systems. At high frequencies, advances in lithography and deposition methods result in more advanced components for space application, with sub-micron resolution opening a vast design space. Even relatively low frequency systems demand confined volume, low mass and component integration. Though an experimental exploration of this widening design space—searching for optimized performance by repeated fabrication efforts—is unfeasible, it does motivate the development of reliable software design tools. These tools necessitate models based on the fundamental physics and mathematics of the component for an accurate model. The software tools must lead to convenient turn-around times and include interfaces that promote efficient use. The first issue is addressed by the application of high-performance computers and the second by the development of graphical user interfaces driven by properly developed data structures. These tools can then be integrated into an optimization environment, and with the available memory capacity and computational speed of high performance parallel platforms, simulation of optimized components can proceed.

In this paper we outline the use of a genetic algorithm running on cluster computers to synthesize optimized designs for infrared filters and a synthetic aperture radar antenna. A standard genetic algorithm package, integrated with design software specific to the filter or antenna, and executing on cluster computers is described. This framework is being developed for a wide range of applications. It is also currently being used in nanotechnology modeling efforts.

CLUSTER COMPUTERS

Many software packages exist for high-fidelity modeling and analysis of electromagnetic components. To push component development from point designs to ones that exhaust a parameterized design space, while still using high-fidelity modeling software, requires the utilization of high performance computers. Recent developments in parallel and distributed computing have resulted in relatively low cost yet powerful computing systems that can be used for global optimization algorithms such as the class of evolutionary algorithms and high-fidelity modeling packages used in this work. A cluster computer is an ensemble of commodity off-the-shelf personal computers connected via commodity network switches that use (typically open source) operating system software. Because of the performance afforded by the individual commodity CPUs, relatively high network bandwidth rates and readily available protocols and parallel libraries, this collection of computers yields performance equal to specialized parallel supercomputers on a CPU-to-CPU basis. Because the cluster computer can be configured with a few nodes, and can scale to as many nodes as a commodity network switch allows, this machine provides powerful low-cost capabilities not previously available.

Three generations of cluster computers have been developed in the High Performance Computing group at the Jet Propulsion Laboratory. The latest generation consists of dual-processor Pentium III 800 MHz processors combined with 2GB memory per node. Currently 20 nodes are interconnected through a commodity 100Mbs switch (with a future delivery to increase this to 2.8 Gbs bandwidth). Key software components include the Linux operating system and the Message Passing Library (MPI) for communication between nodes, and various Fortran and C compilers.

PARALLEL GENETIC ALGORTIHM ENVIRONMENT

Genetic algorithm optimization employs stochastic methods modeled on principles of natural selection and evolution of biological systems [1]. They are global, multi-parameter and do not require constraints on continuity of the solution space. A genetic algorithm optimization consists of a sequence of procedures that leads to an optimized result. This sequence is common among all genetic algorithms with variants at each stage. Because each step in this sequence would require variants dependent on the problem being optimized, a goal of this work is to provide a software framework that is suitable for the class of design problems considered in this paper, as well as related classes. For example, an interface into the range and types of parameters encountered (real-valued component dimension values, integer valued number of layers in a frequency selective surface, or exponent based parameters when modeling semiconductor device dopant densities) shall be developed. Similarly, an effective means for introducing the fitness function evaluation, i.e. the actual calculation of the electromagnetic result, is necessary. This step requires the insertion of large complex engineering modeling codes, typically written in C or Fortran with associated complex input sets, into the software framework. Ideally there would be little modification of the modeling software when using the genetic algorithm package.

The parallel genetic algorithm environment being developed uses an object oriented approach to interface a parallel genetic algorithm package with the engineering modeling codes (that may include preprocessor CAD and meshing packages or input data generators), and a fitness function module. The entire environment executes on the cluster computer. The evolutionary algorithm used is PGAPack, a parallel genetic algorithm library [2]. This package consists of a set of library routines supplying the user multiple levels of control over the optimization process. The levels vary from default encodings, with simple initialization of parameters and single statement execution, to the ability to modify, at a low-level, all relevant parameters in the optimization process.

In the optimization process, input variables are initially set. These include numbers of generations, population size, selection, crossover and mutation types. Specific files and values that guide the parameterization of the problem are also defined. These will be the limits on engineering parameters in the design, and mappings of parameters in CAD, meshing packages or data generators that in turn construct input parameters for the modeling software.

APPLICATION RESULTS

Two electromagnetic modeling applications are considered for optimization in this paper. The first involves the design of multi-bandwidth infrared filters for multi-spectral imagers–a frequency selective surface operating in the infrared portion of the spectrum. The second operates at the opposite end of the spectrum, a synthetic aperture radar low-profile antenna operating across a wideband 100-1000MHz.

A multi-bandwidth infrared filter array consists of an array element within a two-dimensional periodic cell. The filter bandwidth, center frequency and polarization properties are dependent upon the shape and size of this element. Different element shapes are used for different applications depending on the design specification. The analysis code predicts transmission and reflection coefficients based on a discretization of the periodic cell into a grid of metal and non-metal elements [3]. This parameterization of the design is encoded as a binary string in the genetic algorithm. The fitness function for this application is driven by the requirement of a prescribed center wavelength and bandpass with minimal shoulders outside the bandpass region. Figure 1 shows results for a bandpass design centered just under a 4μm wavelength. The final design consists of the aperture shown, with prescribed transmission response, genetic algorithm result and measurements also shown in the figure.

A second application considered in this paper is the synthesis of a low-profile broadband synthetic aperture radar antenna [4]. An annular patch above an air substrate ($\varepsilon_r = 1$) was the chosen configuration for bandwidth considerations. Although the calculated gain of the nominal radiating element was better than 5dB at broadside from 200-800MHz with a VSWR of 2.5:1, the final specifications called for a 10:1 bandwidth. Genetic algorithm optimization was thus chosen in an attempt to achieve this goal. The initial implementation resulted in a parametrization of the periphery of the patch, thus allowing the algorithm to

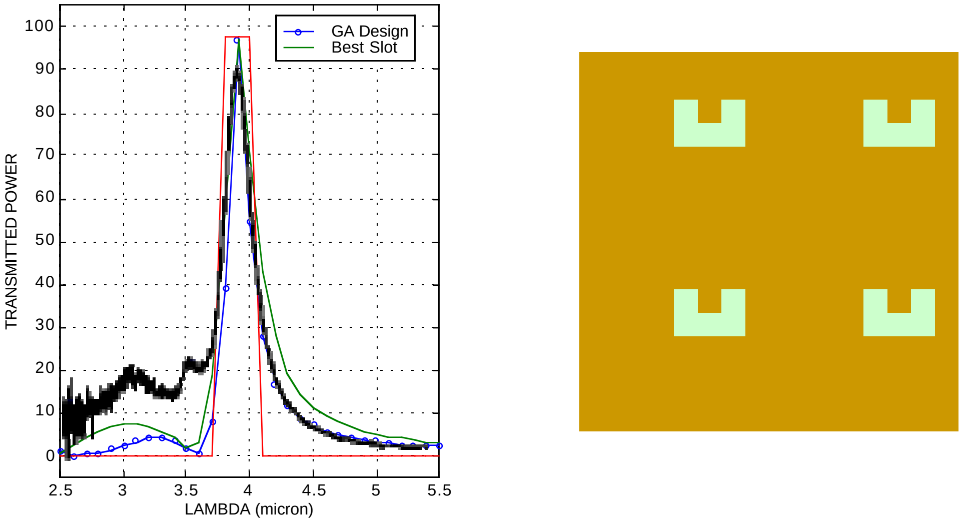

Figure 1. Results of genetic algorithm design of infrared frequency selective surface. The right figure shows 2x2 portion of final aperture design. Lighter color is aperture within an aluminum layer (darker color) depositied on calcium floride substrate. The prescribed transmitted response is shown in red in the plot on the left. The blue curve is the response from the genetic algorithm, and the black curve overlaying the figure are preliminary measurement data. The green curve is the best linear slot design for the specifications forming the red prescribed response. The period of the unit cell is 2.52µm square, the incident field is normally directed. This unit cell was discretized into a 16x16 grid.

expand or contract the patch width and length at will. The probe's input VSWR and far-field values in particular observation directions were chosen as the target variables. Further results will be presented with this paper.

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