Design of Frequency Selective Surface as Antenna Ground Planes Using a Modular Distributed Optimization Framework

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Introduction

Design optimization has gained increasing popularity in many engineering fields. Various optimization schemes have been successfully employed, including genetic algorithms (GA) [1], gradient-based methods, and others [2]. For electromagnetics, the key drawback remains the large CPU requirements per iteration of a typical problem. Though genetic algorithms are attractive because of their global search capability, the CPU requirements can still be prohibitive.

Parallel processing is certainly a way to address the large CPU requirements expected in any optimization process. However, parallel computing platforms are not readily available and may require substantial modification of the existing tools for porting onto these platforms. In this paper, we present an approach to reduce overall computation time by relying on a large number of readily-available workstations. Furthermore, lightweight interface libraries allow us to utilize existing optimization and computational tools without alteration.

In the following sections, we describe the toolset integration and demonstrate the workstation-farming approach for the design of frequency selective surfaces (FSS). We design a simple band-reject FSS, with the aim of investigating other FSS designs to serve as ground planes of possibly broadband antennas [3].

Modular Optimization Framework Using a Grid of Personal Computers

At any given time, tens, hundreds, or even thousands of Windows-based computers (typically >90% of an organization's computing resources) sit idle. With the intent of utilizing these untapped CPU resources for electromagnetic simulations, we have developed a modular optimization framework using the Alchemi [4] library. As depicted in Figure 1(a), an Alchemi grid consists of a central server along with a number of workstations. The Alchemi framework allows researchers to submit computational tasks to the server, which in turn get distributed to the workstations for processing. Furthermore, the Alchemi software is flexible enough to bring the workstations in and out of the grid as they become available. Alchemi supports both dedicated (always on the grid) and non-dedicated (on the grid when idle) workstations.

Reusability is the key idea in our optimization infrastructure. In the past, many successful electromagnetic optimization codes have been written, illustrating that optimization is a viable design option. Unfortunately, most of these tools have been designed for very narrow purposes, and cannot be re-used for similar designs. For example, if a successful optimization code has been written to use genetic optimization to simulate a wire antenna, it is often difficult to re-use this code with other optimization schemes because

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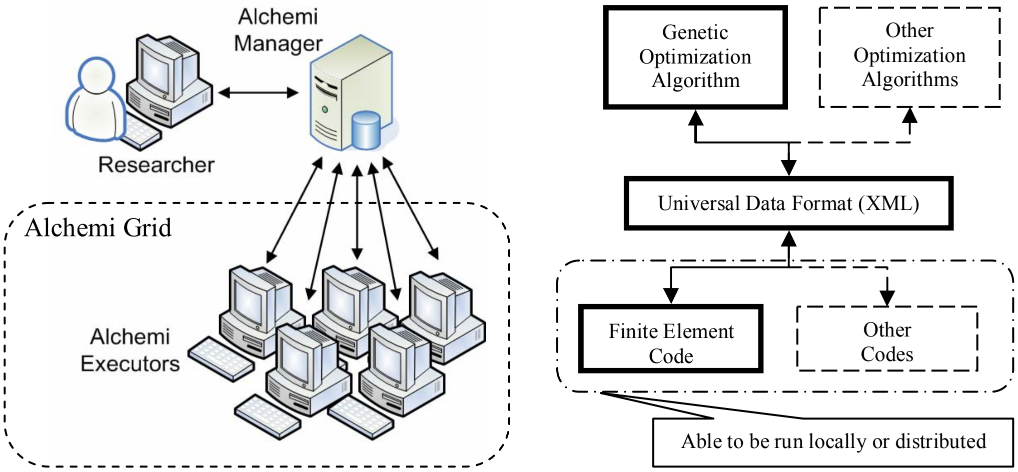
the simulation parameters are closely coupled with the genetic algorithm. The proposed framework, as shown in Figure 1(b), overcomes this shortcoming by providing a modular architecture.



(a) (b)

Figure 1 -- (a) General topology of the Alchemi computing grid. (b) Overall diagram of the distributed optimization framework.

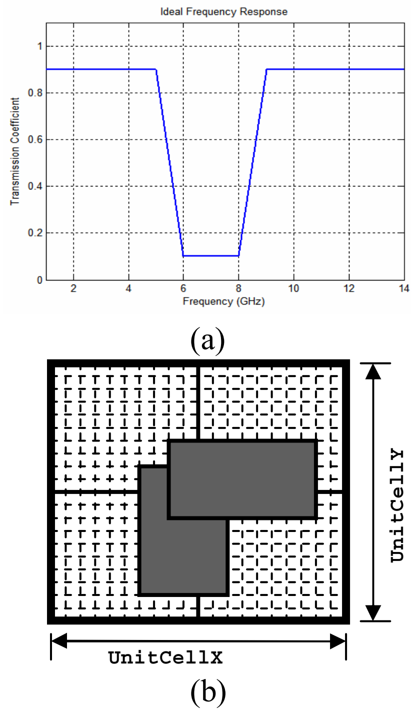
To this end, each type of optimization scheme and electromagnetic simulation code is encapsulated in a separate library. Using this approach, designers can hand-pick the optimization scheme and CEM tools best suited for their problem.

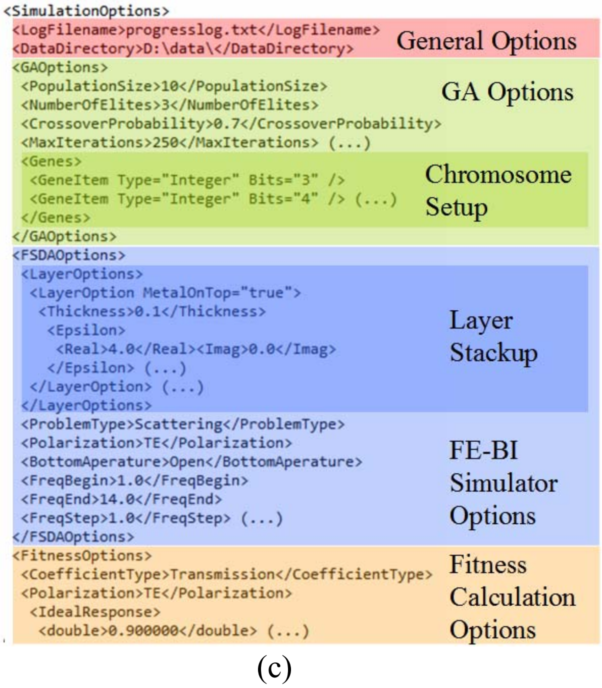
Interoperability between components necessitates a universal format for data exchange between tools. For this purpose, XML (eXtensible Markup Language) is used to translate the existing toolset format for use between tools in the distributed optimization framework. XML is a universal, versatile data storage format, and is ideally suited for this task.

FSS Design Example

To illustrate the distributed optimization framework, we pursued the design of an optimized FSS with genetic algorithms. The electromagnetic solver used is FSDA-PRISM [5], an in-house finite element-boundary integral (FE-BI) code that can simulate the reflection and transmission from arbitrary, doubly periodic structures, i.e. stacks of infinitely periodic FSS designs with different periodicities.

The specific optimization example is a filter that has the ideal band-rejection response shown in Figure 2(a). Specifically, the transmission coefficient indicates a stopband from 6-8GHz (~29%), with a linear taper decreasing from 0.9 at 5GHz down 0.1 at 6GHz. Similarly, on the opposite side of the band, the transmission coefficient increases from 0.1 at 8GHz to 0.9 at 9GHz. A two-layer FSS consisting of periodic patches is considered for realizing this band-rejection response. We also decided to fix the two substrate materials to have $\varepsilon_r=4$ and thickness=0.1 cm. As expected, the simulation is specified in terms of a unit cell, and an infinite-extent FSS is assumed in the x-y plane. A sketch of the unit cell is shown in Figure 2(b).





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  <MaxIterations>250</MaxIterations> (...)
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     </Epsilon> (...)
   </LayerOption> (...)
  </LayerOptions>
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  <BottomAperature>Open</BottomAperature>
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  <FreqEnd>14.0</FreqEnd>
  <FreqStep>1.0</FreqStep> (...)
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    <double>0.900000</double> (...)
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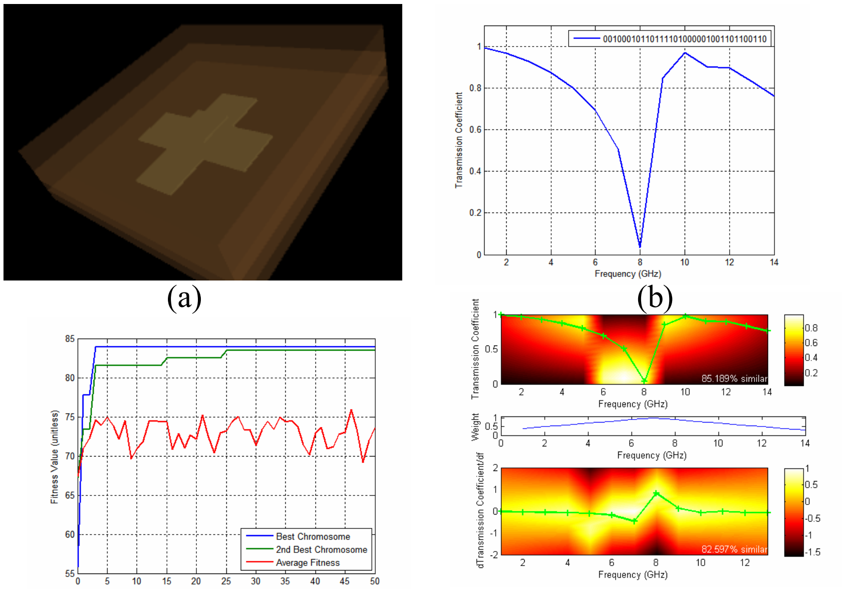
Figure 2 – (a) Ideal frequency response. (b) One layer of the unit cell of the FSS. (c) Sample XML configuration file (condensed).

For the FSS design, we chose the lower-left and upper-right corners of one patch as variables, and let the second patch be placed at a 90° rotation. In addition, both the x- and y-dimensions of the unit cell were allowed to vary within a predefined range.

All design information that defines the optimization run was aggregated into a single XML configuration file (see Figure 2(c)) which contains general options, GA-specific options (including the number of bits per gene that comprise a chromosome), simulator-specific options (including the properties of each substrate layer), and the fitness calculation parameters (such as the ideal frequency response and weighting factors). Because the GA and the finite element algorithms are provided as reusable libraries, the only code that must be written is that which is problem-specific. In this case, the problem-specific code created input files for the solver, collected output data, and determined its fitness. The GA routine, specifically the population initialization, tournament selection, crossover, and mutation, is part of the reusable code, as is the complete FE-BI solver.

During the optimization process, the genetic algorithm must evaluate the fitness of a list of chromosomes. Each chromosome is mapped to a specific variation of the input geometry (hence, a specific FSS implementation). For each iteration, all input geometries corresponding to the chromosomes in the current population are submitted to the Alchemi grid for distribution to an available workstation. Results returned from the grid are then used to compute the chromosome's fitness, which is subsequently used to determine the list of chromosomes in the next iteration.

A typical intermediate output is shown below. Figure 3(b) displays the band-rejection designed at some point during the GA optimization corresponding to the geometry in Figure 3(a). The geometry shown depicts four metallic patches, two per layer. The patches on the bottom layer have formed a cross, while the patches on the top layer have formed a small square towards the middle. The transmission coefficient response contains a dip at 8GHz as desired, but has not yet reached the ideal frequency response specified earlier in Figure 2(a). Using a grid of 12 workstations, this particular optimization run took around 3 hours – much less than the 2.5 days it would have taken with a single workstation.



(a) (b)

(c) (d)

Figure 3 – (a) 3D rendition of the simulated geometry in X3D format (an XML format that describes 3D geometry). (b) Best simulated transmission coefficient. (c) Best and average fitness for each iteration. (d) Fitness calculation using curve similarity comparison.

In conclusion, optimization is well-suited to take advantage of many idle workstations operating in parallel. A band-reject FSS design has been completed using the proposed distributed optimization framework. Additional examples and more details about the framework will be presented at the conference.

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