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# **EIGER: Electromagnetic Interactions GENEralized**

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## **Introduction**

EIGER (Electromagnetic Interactions GENEralized), a single integrated software tool set, brings together a variety of spectral domain analysis methods. These include moment method solutions of integral equation formulations and finite elements solutions of partial differential equations.

New software engineering methods, specifically, object oriented design, are being used to implement abstractions of key components of spectral analysis methods so that the tools can be easily modified and extended to treat new classes of problems. The key components of the numerical analysis tool, and their roles, are: elements – to describe the geometry, basis functions – to interpolate the unknowns (*e.g.*, fields) locally, and operators – to express the underlying physics formulations used to propagate the energy or enforce fundamental principals. The development of EMPACK [1] provided the fundamental impetus for these abstractions which are discussed more fully in subsequent sections.

This design approach is in contrast to standard design procedures where entire codes are developed around a particular element type with a specific basis function for a single operator. Although such tools can be effectively used to model large classes of problems, it is often very difficult, if not intractable, to extend the tools beyond their initial design. Overcoming this limitation is one of the most compelling goals of this project. We have successfully overcome roadblocks encountered in extension of past development efforts, such as the extension of Patch[2] to treat wires and wire-surface junctions in the presence of non-homogeneous media. Moreover, the application base for EIGER grows as we cast a variety of Green's functions into a form compatible with the numerical procedures in EIGER.

## **Elements**

Elements are the basic building blocks that are used to describe a given geometry for numerical computation. These elements are typically the output of a commercial mesh generation package that has discretized a solid CAD model into pieces that are amenable to numerical computation.

A pre-processor then reads these elements and assigns such features as material characteristics and excitation parameters to generate the actual input for the physics code.

The EIGER suite can treat both two and three dimensional problems within its single integrated tool set. Initially, emphasis was placed on the requirements for modeling surface physics. Thus, for two dimensional geometries, combinations of linear segments or "bar" elements are currently used to describe the surface problem. Likewise, for three dimensional geometries, both linear triangles and rectangles can be combined to render accurate surface models. In addition to the basic elements for modeling 3D surfaces, wire segments are also incorporated into EIGER.

A scheme to employ higher order surface elements to more accurately resolve the geometry of curved objects has been implemented. These elements can be of arbitrary order, and will more accurately resolve the local variations of the geometry. Also, volume elements will be incorporated for treating inhomogeneous material regions along with solvers tuned for the resulting sparse systems that arise from a finite element approach.

### **Basis Functions**

Basis functions are used to locally interpolate each unknown quantity. These unknowns may physically represent surface currents or fields for dynamic operators, or potentials for statics. Both constant and linear basis functions are currently available for each of the elements described above. The characteristic integrals (for integral equation solutions) that arise in many problems require that the potentials and their gradients due to source distributions that are represented by these basis functions must be efficiently computed. Extensive efforts have enabled most of these calculations to be cast into the same basic form, thus simplifying their integration into a general purpose code.

In conjunction with the efforts to add higher order elements, extensions are currently under investigation to employ higher order (smoother) basis functions to enable a more efficient numerical solution of electrically large problems. In addition, a new formulation for singular basis functions which will incorporate known edge conditions and other known local variations directly into the numerical procedure has been developed.

### **Operators**

An electromagnetic operator is a mathematical construct that relates the field at a point to the sources which produced the field. Since previous efforts focused initially on incorporating surface physics, emphasis was placed on integral operators which are among the most efficient classes of operators for enforcing this type of physics. These operators explicitly propagate a field between locations. A variety of integral operators have been incorporated into EIGER to treat both perfect electric conductors and homogeneous dielectrics (penetrable materials). Specifically, the following operators have been included: the Electric Field Integral Equation, the Magnetic Field Integral Equation, the Combined Field Integral Equation, and the PMCHW for general homogeneous lossy dielectrics.

The basic formulation for the integral operators has been generalized and simplified so that all of the above operators are generated by simply taking linear combinations of basic coupling or interaction operators. This powerful abstraction means that a variety of other boundary conditions (*e.g.*, equivalent aperture formulations and alternative dielectric treatments) can easily be added to the code by simply choosing the appropriate set of coefficients.

## **Green's Functions**

One of the most promising features of the EIGER development is the ability to directly incorporate a variety of Green's function into the solution. In addition to the standard homogeneous free space type Green's functions, this year a completely unique capability was added to EIGER by employing a multi-layered media Green's function that can treat arbitrarily shaped objects that are penetrable. These extensions allow applications to be addressed in a variety of areas such as multi-layered electronic circuit boards, high powered optical mirrors, and geophysical problems.

Extensions to the Green's functions in the code are presently underway. General symmetry treatments have been added to the analysis code and are being incorporated into the post processor. In addition, an effort to incorporate general periodic analysis, that was previously developed, for treatment of cavities and array analysis is also underway.

## **Organization and Usage**

EIGER presently consists of three distinct phases: a pre-processor, the physics solver, and a post-processor. The combined versatility of elements, basis functions, *etc.*, suggests multiple combinations and approaches to solve models, possibly overwhelming the modeler with choices. However, this versatility also provides the flexibility to tackle portions of model with the most appropriate combinations. During this past year key steps were made to address the increased complexity of effectively using a code suite such as this. Efforts will continue to develop and extend the pre-processor interface to the physics tools to aid with the efficient usage of the tools.

An end user of EIGER has a choice of basic numerical solutions of linear systems by either direct or iterative solvers. Additional work is in progress to address solvers for advanced computer architectures. Both SMP and MPP systems are targeted.

Post processing capabilities currently include the calculation of near and far fields from the basic current solutions. Fig. 1 shows the geometry of a commercial flared notch horn antenna. The compute mesh contained about 8000 unknowns to resolve the geometrical details of the feed and the smallest wave lengths. The maximum directivity is used to calculate a directive gain for the antenna as a function of frequency and is compared to measured data for the structure in Fig. 2.

## **Acknowledgments**

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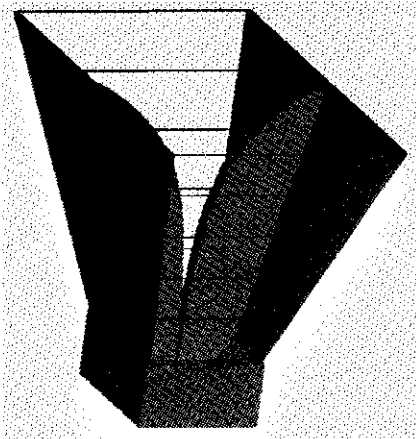


Figure 1. CAD representation of a commercial flared notch horn antenna.

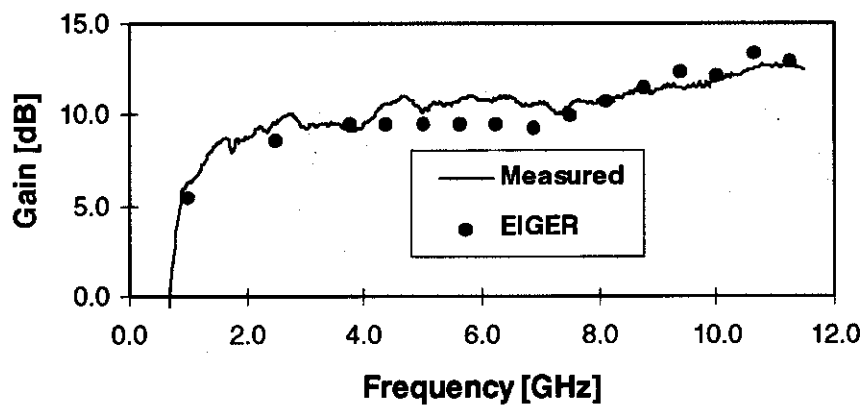


Figure 2. Antenna Gain (directivity at bore sight) vs. frequency. Both measurements and experiments are shown.

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