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An Advanced Simulation Toolkit for Photon Band Gap Accelerators

CRADA No.: 308

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CRADA No.: 308

1. Parties: Simulation Technology & Applied Research, Inc.

2. Title of the Project: An Advanced Simulation Toolkit for Photon Band Gap Accelerators

3. Summary of the specific research and project accomplishments:

Photon band gap (PBG) structures have been investigated for accelerator and microwave tube applications over the past decade, and these investigations have concentrated on two distinct concepts. In one approach, a traditional accelerator slow-wave structure is created with a sequence of cavities of a new type that each contains a specially designed lattice of rods that endow it with desirable properties. Another more recent application of the same concept is to use a photonic crystal to confine the synchronous mode at the boundary of a dielectric wall accelerator (DWA), but let other modes excited by the beam escape. A related concept is the photonic crystal accelerator.

To improve the ability of scientists to develop PBG and other advanced RF structures for particle accelerators, this project made several improvements to the Analyst finite- element software package, including:

- Extension of basic scripting capabilities in Analyst to support the requirements of advanced structure modeling.
- Creation of prototype elements within Analyst for several PBG structures. These were in the form of Python scripts that implement functions with standardized signatures to define user parameters and construct associated geometric models.
- Use of the parametric models to perform driven-frequency and eigenanalysis of 2D and 3D PBG structures. Models studies included metal/vacuum and dielectric PBG devices.

The project focused on the development of capabilities that would improve the capability of Analyst to do calculations typical of those required for the development of PBG and other advanced structures. The approach was to use the advanced scripting capability in Analyst to effectively hide the complexity of a particular geometry and/or analysis process, allowing a user to focus on interpreting/using results to improve a structure rather than on managing the analysis process. The premise was that a modest investment in scripting (which can easily be done by users, but is arguably somewhat more time- consuming than creating and running an analysis of a single model in the user interface) is paid back many times over in the resulting simplicity of design iteration that comes from using the script inside the Analyst system.

The primary measure of success of this work was the ability to rapidly calculate PBG structure design variations without significant user intervention in the analysis process. Variations in the geometry of the six-cell PBG structure could be made in a few seconds of user time, including analyzing sweeps over particular geometric parameters such as rod radii (the wall-clock time was longer because of the time required to perform the analyses). This represents a very substantial reduction in user time compared to what would be required to manipulate the geometry within the Analyst user interface, or in any other commercial analysis product. Moreover, because Analyst can also run scripts to perform custom analysis sequences, it is possible to automate certain complex processes such as lattice design.

4. Deliverables:

Deliverable Achieved	Party (SLAC, Participant, Both)	Delivered to Other Party?
Model metal PBG structures	STAAR	MIT
Model photonic crystal accelerator	SLAC & STAAR	MIT
Simulate MIT PBG structure in time domain	SLAC & STAAR	MIT

5. Identify publications or presentations at conferences directly related to the CRADA.

R. A. Marsh, M. A. Shapiro, R. J. Temkin, E. I. Smirnova, and J. F. DeFord, Nucl. Instrum. Methods Phys. Res., Sect. A618, 16 (2010)

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6. List of Subject Inventions and software developed under the CRADA:

Python scripts for use in Analyst developed by STAAR, Inc.

7. A final abstract suitable for public release:

During this project we developed improvement to scripting and other functionality within the commercial Analyst finite-element analysis package to allow the creation of specialized parametric models representing several different PBG structures. The parametric models had access to existing driven-frequency and eigenmode solvers supported by Analyst, including the Omega3P eigensolver developed by SLAC/ACD. We validated the important characteristics of the approach using two separate structures:

1. Six-cell rod-lattice PBG structure prototype developed by E. Smirnova while in the Waves & Beams Group at MIT-PSFC.
2. Rectangular dielectric lattice PBG under study by K. Samokhvalova in the same group.
3. Ran time-domain simulations of prototype structure to benchmark measurements taken by R. Marsh at MIT-PSFC.

Using the advanced scripting approach we were able to rapidly create and analyze complex models representing both devices, generating standard results such as the

eigenspectrum and feed characteristics without interactive manipulation of the geometry, analysis process, or post-processing operations. Although we did not attempt to optimize these structures during the project, the parametric nature of the models allows exploration of geometric and material variations to the structures simply by changing the corresponding values in an input panel. We verified that this capability was working properly by creating several interesting variations to both structures.

8. Benefits to DOE, SLAC, Participant and/or the U.S. economy.

There are several benefits from this project:

- The rate of innovation in PBG and other advanced accelerator structure development will increase because the specialized and integrated toolkit we propose will greatly simplify the development and analysis of new designs. This will potentially lead to improved and less expensive accelerators for a variety of applications.
- Much of the proposed functionality will have application in the design/optimization of a much broader class of more traditional accelerator structures. The integrated template approach to model building and analysis will provide a much simpler interface to the necessary capabilities than traditional tools.
- Advanced finite-element time-domain capabilities will have utility across a range of microwave applications where broadband characteristics of devices are needed. Such capabilities can potentially lead to shorter design cycles for broadband devices.
- The computer and telecommunications industries are looking at photonic band gap materials and structures for use in very high speed light-wave communications and novel photonic processors. Availability of a tool for rapidly accessing the electromagnetic characteristics of a particular lattice/structure will help accelerate the development of new devices.

9. Financial Contributions to the CRADA:

DOE Funding to SLAC	$0
Participant Funding to SLAC	$300k
Participant In-Kind Contribution Value	$200k
Total of all Contributions	$500k