Virtual Prototyping of Directed Energy Weapons Enhances Military Capabilities

By Gary Sivak and Dinah Luneke

This HPCMP Challenge Project, "Virtual Prototyping of Directed Energy Weapons," was run at the ASC MSRC by Dr. Keith L. Cartwright, Principal Investigator (PI), Dr. Matthew Bettencourt, Co-PI, and Dr. Andrew D. Greenwood, Co-Investigator, Air Force Research Laboratory (AFRL), Directed Energy Directorate (DE), High Powered Microwave Division, Kirtland AFB. ASC MSRC HPC System Utilization: HP XC Cluster (FALCON) and HP Compaq (HPC05) with 4,265,060 total hours.

Shaped cathode for the relativistic magnetron

Military Crowd Control Scenario

An angry mob threatens a normally quiet neighborhood after a disaster hits, and the military is called in to work with local police to help control the hostile situation. With their mission to protect lives and preserve the peace, the soldiers focus up to a 95-gigahertz microwave directed energy beam across the out-of-control mob. The insurgents experience an instantaneous burning sensation that, while resulting in no lasting effects, causes the crowd to immediately disperse. No one sustains permanent injury. No shots are fired. The peace is restored.

Project Objective

Directed-energy devices propel energy in a desired direction at the speed of light. In addition to well known lasers, directed energy can also be found in the form of microwaves. This Challenge Project supports the generation of electromagnetic radiation in three parts of the electromagnetic spectrum: microwave (L-Band, for non-lethal attack on electronics), millimeter (W-Band, for active denial) and sub-millimeter (THz, for explosives, biological and concealed weapon detection). Dr. Keith Cartwright and his co-investigators perform virtual prototyping of Radio-Frequency (RF) systems, from pulsed power through antennas, with the Improved Concurrent Electromagnetic Particle-in-Cell (ICEPIC) High Performance Computing (HPC) software developed over several years with Air Force Office of Scientific Research (AFOSR) funding. The work focuses on exploring various types of equipment and methods for generating High-Power Microwaves (HPM), as well as developing and testing antennas to transmit this energy to targets. The effects of these focused energy beams are being researched for prototype weapons on Air Force platforms.

Research Goals

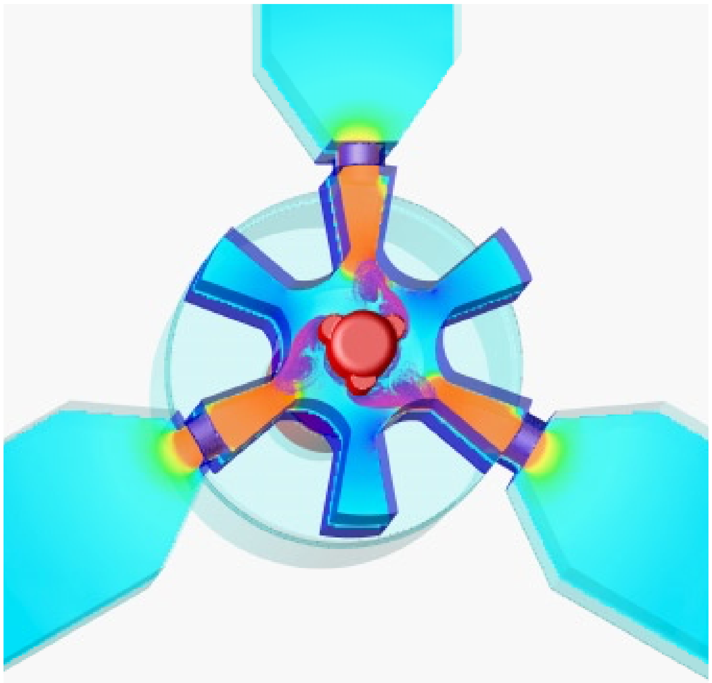
The goal of this study is to create systems that are smaller and more efficient so they fit within the physical size and energy/power constraints of warfighter platforms. While the research has an applied and focused goal, many of the results can be published in refereed journal articles on the topics of algorithm development, mathematical models and applied physics. A small HPM system gives the warfighter non-lethal capability to stop people from broadcasting or communicating. Signals can be disrupted for hours, or even days, after the mission is completed.

Understanding the Science

The concept behind high-powered microwave weapons is simple. A burst of electromagnetic energy is created and directed at an enemy's electronics. A relativistic magnetron source is similar to the magnetron located within a typical microwave oven, except it is capable of producing a million times the power for a short amount of time. For both sources, the mechanism that produces electromagnetic radiation is the same. An electron beam wave synchronizes with electrons in the same way a surfer is pushed along by an ocean wave. The electron beam loses kinetic energy, which is converted to an electromagnetic wave.

Research Results

The microwave generator, a relativistic magnetron that was designed last fiscal year by this Challenge Project, is now built and being tested in the laboratory. As a result of the simulations, the source volume is reduced by a factor of 5 while maintaining the giga-watt power level and hundreds of nano-second pulse length. To obtain better fidelity, two new models were added to the simulations. First, the physical characterization of the Carbon fiber in the cathode is studied in a controlled experiment, and these parameters are included in the magnetron simulation. Second, ion emission from the anode is included. In addition to the relativistic magnetron, a second sub-thrust with large improvements this year is the THz Traveling-Wave-Tube (TWT) for explosive, biological and concealed weapon detection. Two TWTs at 350 GHz and 800 GHz were designed by this fast-paced effort in less than four months.



Simulated Design of the High-Powered Microwave Generator

Methodology

ICEPIC, a parallel Particle-in-Cell code, simulates from first principles (Maxwell's equations and the Lorenz force law) the electrodynamics and charged-particle dynamics of the RF-producing part of the system. Such simulations require enormous computational resources. The Computational Technology Area (CTA) most closely tied with these simulations is Computational Electromagnetics and Acoustics (CEA), with some utilization of the skill set from Computational Fluid Dynamics (CFD) and Computational Biology, Chemistry and Materials Science (CCM). The CFD utilization stems from the fact that the flow of electrons in HPM devices has many mathematical similarities with traditional CFD. The CCM portion of the work involves the use of chemistry codes to simulate the electron emission from the Carbon fiber cathodes.

ASC and Other MSRC Contributions

"By running these HPC jobs at the ASC MSRC, we achieve success in all three spectrum regimes," according to Dr. Cartwright. "We also run HPC jobs at ARL, ERDC and NAVO MSRCs and at the Maui High Performance Computing Center (MHPCC). At the ASC MSRC, we validate our code over a large parameter range and then run an optimization module to finalize the relativistic magnetron design, which allows us to design the next generation system. This process continues as we refine our models and re-validate our code to achieve better comparison to experiment. Because of the number and size of the simulations, it is only possible to make progress by running these analyses on HPC resources."

"The ASC MSRC has the HPC systems we need, and we achieve excellent performance on the hardware," Dr. Cartwright says. "For our usage, the HP FALCON gives really good performance, and we are able to run an optimization of an HPM source as a CAP project with 85% scalability while utilizing almost the entire machine." Dr. Cartwright reports that they are past the point of validating and verifying the code and are now designing lab systems more quickly. "We are on the edge of a transition from simulating laboratory devices to warfighter systems."

Benefits of the Microwave Energy Beam

Applications of this focused microwave energy beam not only include crowd dispersal and counter electronics, but in the THz part of the electromagnetic spectrum, it can be used as a detector of explosives and weapons from a distance. Commercial and military applications include law enforcement, checkpoint security, facility protection, force protection and peacekeeping missions. Presently, these detectors are man portable with the THz source weighing less than two pounds. When batteries, antenna, signal processing unit and display are added, the total system weight is only about 50 pounds.

Benefits to Warfighter:
- Little to No Physical Collateral Damage
- Expands Target Lists to Include Politically Constrained Targets
- Persistent Attack Capability
- Variable Effects on C4I assets: Deny on Demand, Disrupt, Degrade and Destroy

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From Conception to Reality

An Active Denial System (ADS) exists on a military vehicle, a High Mobility Multipurpose Wheeled Vehicle (Humvee). The system is in an extended military utility assessment period, but it has not yet transitioned to mass ordering capability. It takes many years of spiral development to transition an HPM system into a deployable system. It is a significant challenge to get the final system developed, but we are getting closer more quickly by using HPC resources.

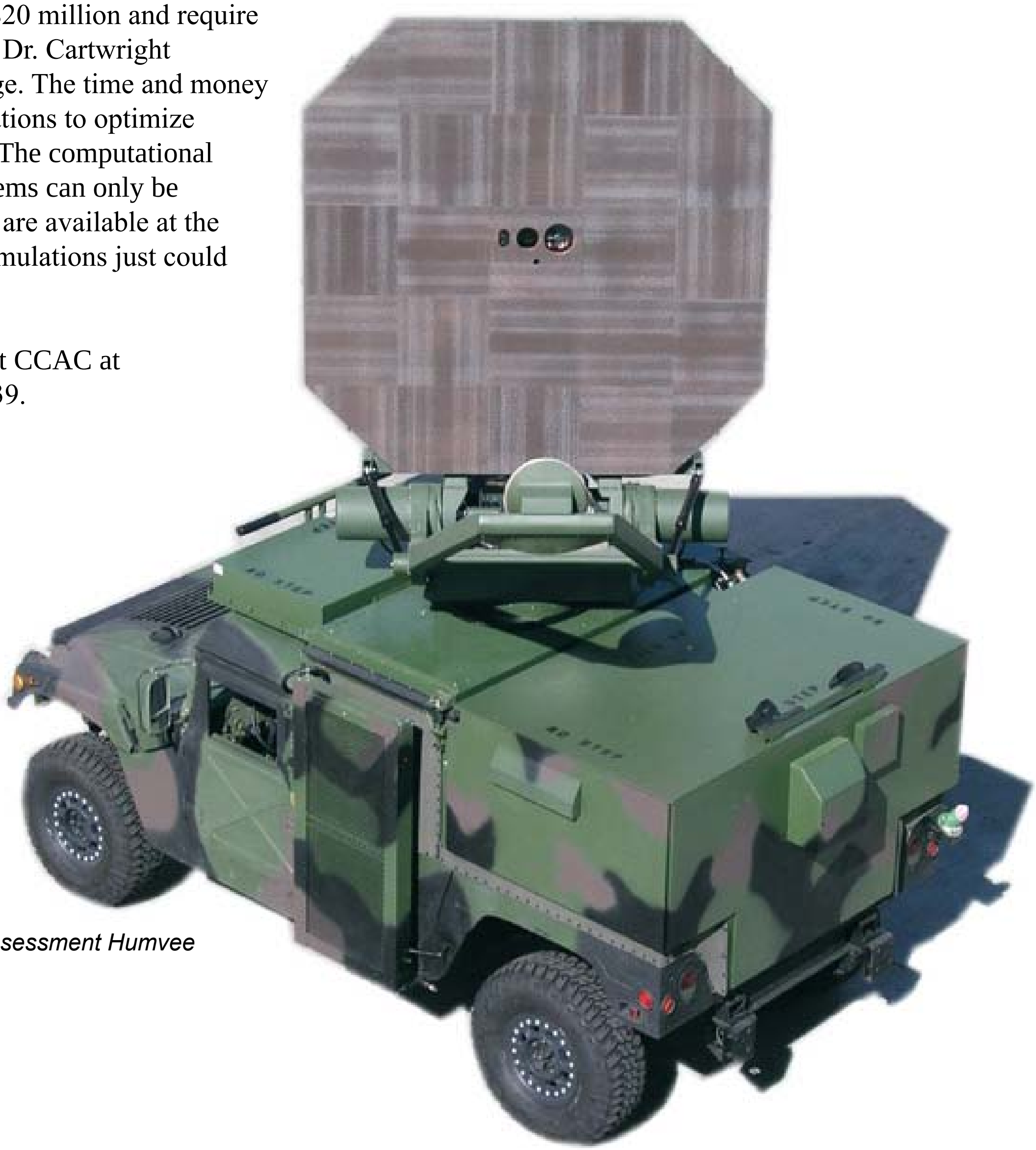
HPM Counter Electronics

Significance to the DoD

HPC simulations allow for a better understanding of these nonlinear devices, which enable a more rapid development cycle. The ability to look at the details available in these simulations enables a much more enhanced comprehension of the device than can be done with theory and experiment alone. Going from a new idea to an optimized system using simulation is significant. Skipping an experimental iteration can literally save millions of dollars and a year of time.

"For example, a system might cost $20 million and require an entire year to construct and test," Dr. Cartwright explains. "The price of failure is large. The time and money savings of using high-fidelity simulations to optimize the system before it is built is huge. The computational capacity needed to model these systems can only be obtained using HPC systems, which are available at the ASC MSRC. Without HPC, these simulations just could not be done."

For more information, please contact CCAC at www.ccac.hpc.mil or 1-877-222-2039.



ADS Military Utility Assessment Humvee