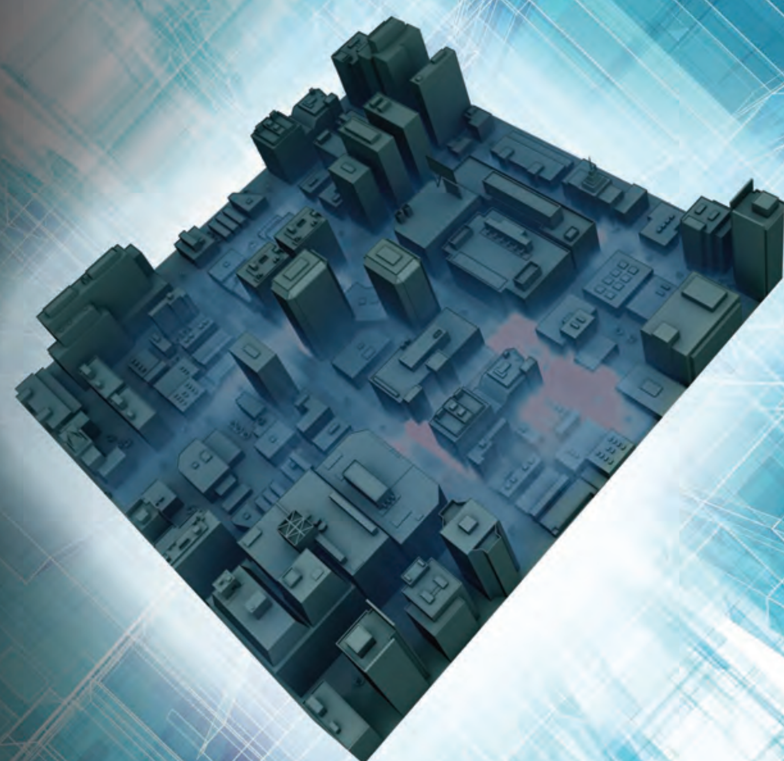
DSIAC JOURNAL

A Quarterly Publication of the Defense Systems Information Analysis Center

Volume 2 • Number 2 • Spring 2015

STINGRAY



DSIAC JOURNAL

VOLUME 2 | NUMBER 2 | SPRING 2015

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On the Cover:
High-Performance RF Model Using Ray Tracing, Provided by the SURVICE Engineering Company.

The *DSIAC Journal* is a quarterly publication of the Defense Systems Information Analysis Center (DSIAC). DSIAC is a Department of Defense (DoD) Information Analysis Center (IAC) with policy oversight provided by the Assistant Secretary of Defense for Research and Engineering, ASD (R&E). DSIAC is operated by the SURVICE Engineering Company and includes a team supported by Quanterion Solutions Incorporated, Georgia Tech Research Institute, Texas Research Institute Austin, and The Johns Hopkins University.

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MESSAGE FROM THE EDITOR

It should come as no surprise that the electromagnetic spectrum is becoming increasingly crowded. This crowding can be largely attributed to the proliferation of new technologies that are creating an insatiable demand for bandwidth. The technologies demanding a share of the spectrum cover everything from communications to the latest directed energy weapons. Accordingly, the focus of this issue of the *DSIAC Journal* is to discuss some of the contemporary challenges facing practitioners engaged in a scrum for their share of the electromagnetic spectrum.

In our feature article, Christiaan Gribble and Jefferson Amstutz discuss the development of a new tool—called Stingray—that can assist in understanding the propagation of radio frequency (RF) energy in the presence of complex outdoor terrain features, (e.g., urban environments). Such understanding is critical to the military's planning, optimizing, and analyzing of wireless communication and data networks. Simulating and visualizing RF energy propagation can be a difficult and time-consuming task, but with new tools such as Stingray, the task can become much less burdensome.

In a companion article, Brian Farmer and Martha Klein discuss how Spectrum Supportability Risk Assessments (SSRA) are becoming increasingly important and how industry practitioners should be cognizant of recent rules changes when developing new material requirements for new equipment and/or systems. In addition to the spectrum certification and the frequency assignment processes, Department of Defense (DoD) Instruction 4650.01 now requires an SSRA for the procurement of all spectrum-dependent systems, including commercial-off-the-shelf (COTS) systems.

For many of us who grew up watching science fiction shows such as *Star Trek*, there has been a growing fascination with electromagnetic weapons ever since the notion of such devices first appeared in early works of science fiction. Jennifer Weaver Tate provides a historical overview of electromagnetic weapons, taking us from where we first started in the world of science fiction to the contemporary electromagnetic weapons being developed and deployed today.

Additive Manufacturing (AM), often referred to as three-dimensional (3-D) printing or rapid prototyping, presents a significant opportunity for the DoD to enhance warfighter capability and reduce the current logistical footprint and total life cycle costs of numerous systems. In our Advanced Materials article, Paul Lein discusses some of the technological challenges the DoD must overcome to take full advantage of the potential of AM, and he highlights some current efforts to broaden its future adoption.

In recent years, manufacturers supplying products to the DoD have encountered a dramatic increase in the number of counterfeit components in the supply chain. In our RMQSI article, Paul Wagner discusses some of the tactics counterfeiters are employing to falsify

ERIC FIORE

device information, such as origin, age, content, and capability. And because the true age, specifications, and/or functions of such devices are often unknown, the effects of age and stress on the devices are also unknown, meaning the results of the product reliability models and/or testing originally used to establish product reliability may no longer be relevant.

And finally, we complete our two-part Survivability and Vulnerability series on blast visualization. Part 2 of Will Woodham's article provides a step-by-step guide for visualizing data in 3-D and for creating simple animations. In Part 1 (in the fall 2014 edition of the *DSIAC Journal*), we learned how to turn simple test data into professional-looking, full-color two-dimensional (2-D) graphs using Python and Matplotlib. However, as most people would agree, animations are generally more interesting to watch than a static 2-D illustration. Thus, Part 2 discusses how to use Python and VPython to take test data visualization to the next level by creating 3-D animations from typical blast test data. ■

OPPORTUNITIES AND CHALLENGES OF ADDITIVE MANUFACTURING IN THE DEPARTMENT OF DEFENSE

By Paul J. Lein

INTRODUCTION

Additive Manufacturing (AM), often referred to as 3-D printing or rapid prototyping, presents a significant opportunity for the U.S. Department of Defense (DoD) to enhance warfighter capability and reduce the current logistical footprint and total life cycle costs of numerous systems. However, to take full advantage of AM's potential, the DoD must understand its relevant applications and adjust resource allocation and commercialization efforts accordingly. There are also many challenges that still must be overcome before AM technologies can be widely adopted across the DoD. These challenges include a lack of industry standards, slow build rates, limited development of new raw materials, and variability in process control. This article discusses some of these challenges as well as some efforts being performed to broaden future adoption.

THE EMERGING PROMISE OF AM TECHNOLOGIES

In many discussions today, AM is being touted as the manufacturing marvel of the future, and there is a widespread enthusiasm regarding its potential to significantly innovate existing design, manufacturing, and maintenance practices. Recent examples of products being produced with AM technology include everything from a printed car to complex aesthetic designs to printable food (see Figures 1–2). And there is little doubt that AM is already making, and will continue to make, a great deal of impact in both the public and private sectors.

And this includes the military sector. The DoD's compelling interest in exploiting AM tools and technologies includes a desire for increased logistical agility and innovation in support of a rapidly changing adversarial environment. Multiple military organizations are exploring AM applications in rapid prototyping, direct parts production, and equipment repair and maintenance; and there is extensive progress being made with the tools, technologies, and materials being used to enhance AM processes.

While there will always be applications that are better handled by conventional subtractive machining (SM) techniques, many applications could take advantage of a combination of AM/SM technologies to improve manufacturing and reduce Total Life Cycle Cost (TLCC).

For the DoD to fully adopt AM technologies, a number of hurdles must be overcome. A report developed for the U.S. Army's Rapid Equipping Force (REF) listed the following recommendations for promoting military-relevant applications for AM [1]:

- Differentiating AM by technologies and applications.
- Outlining unique considerations for AM in tactical environments.
- Promoting AM-specific training and education.
- Assisting the development of testing and manufacturing standards.
- Developing legal and financial guidelines for the DoD and military contractors.
- Protecting AM-related research, development, and commercialization.

Accordingly, these recommendations will require a great deal of collaboration and advancement from both the commercial and military sectors to ensure a sensible adoption of AM technologies.

Figure 1 *(above and below)*: 3-D Printed Car Produced at the Manufacturing Demonstration Facility, Oak Ridge National Laboratory (ORNL).

DIFFERENTIATING AM BY TECHNOLOGIES AND APPLICATIONS

The AM process involves adding material layer by layer to build a product. The process begins with the creation of a software-based three-dimensional (3-D) model of the product using a computer-aided design (CAD) software package or 3-D scanning an existing product. Once the model is developed, specialized software "slices" the model into thin cross-sectional layers creating a computer file that can be sent to an AM system for manufacture. The AM system creates the product by forming each layer through the selective placement and curing of "printable" material.

Examples of the types of AM systems currently in use include selective laser sintering (SLM), which uses a high-powered laser to selectively fuse powders into the desired shape; stereolithography, which uses ultraviolet lasers to cure a photopolymer resin one layer at a time; and fuse deposition modeling, which lays down liquefied plastic or metal through a thin filament that forms into the desired shape as it hardens [2].

The President's Council of Advisors on Science and Technology defines AM as "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology" [3]. This definition suggests the potential scope of the effort to accurately differentiate the potential technologies and applications.

> Additive Manufacturing is being touted as the manufacturing marvel of the future.

Of course, in the fiscally constrained environment in which the DoD is currently operating, funding will be a major consideration in moving forward and maintaining the advantage at the tactical edge that AM can potentially provide. An initial effort to address the funding issue was the establishment of the National Additive Manufacturing Innovation Institute (NAMII) in 2012, with the goal of driving widespread adoption of AM to enhance domestic manufacturing competitiveness. The NAMII is a pilot institute designed to foster public-private partnerships between industry, government, and universities. The NAMII collaborates on manufacturing technology among six federal agencies, including the Departments of Defense, Energy, Commerce, and Education, as well as the National Science Foundation and NASA. The NAMII was awarded initial federal funding that was matched by

Figure 2: 3-D Printers Will Be Flown on Parabolic and Suborbital Research Flights to Further Develop the Application of 3-D Printing Technology to Micro- and Zero-Gravity Environments. The 3-D Printing Method Used on These Flights Will Be Fused Deposition Modeling (FDM), a Technique That Has Already Undergone Limited Testing in Microgravity Conditions.

numerous entities involved in the new partnership [4]. This public/private partnership could prove to be crucial to the successful adoption of AM technologies across the DoD. Note that the direct involvement between the university communities and the DoD is a key enabler to promoting AM-specific training and education development, which will be necessary to support an enhanced AM approach.

OUTLINING UNIQUE CONSIDERATIONS FOR AM IN TACTICAL ENVIRONMENTS

One of the key areas of interest for the DoD is the application of AM technologies in tactical environments. The U.S. Navy is currently engaged in research that would allow for the on-platform production of repair parts to reduce the logistical footprint required to maintain availability and effectiveness of the fleet. Additionally, there is an opportunity to increase efficiency and reduce cost at the depot level as well. Some early research at the Naval Postgraduate School indicates that substantial savings could be attained through thoughtful application of AM technologies [5].

The Army's REF is also working to harness the power of AM rapid prototyping to support mission requirements at the tactical edge. In July 2012, the REF deployed the first Expeditionary Labs-Mobile (ELM) to Afghanistan. This experiment consisted of two scientists equipped with a 20-ft shipping container filled with rapid prototyping tools, including Fused Deposition Modeling (FDM) systems, Computer Numerical Control (CNC) systems, and welders. The labs also included advanced communications systems to support reach-back capabilities to U.S. and other networks of scientists and engineers [1]. The ELM experiment clearly showed the potential of applying AM technologies in tactical environments by addressing unanticipated warfighter needs as they arose.

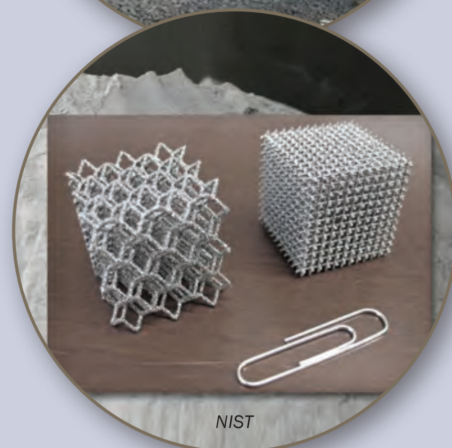

Figure 3 *(top)*: REF Director, Exponent Scientists, and RC-South LNO with the REF Expeditionary Lab in Kandahar.
Figure 4 *(bottom)*: Metal Powder Requiring Material and Process Standards (NIST Photo).

ASSISTING THE DEVELOPMENT OF TESTING AND MANUFACTURING STANDARDS

One major impediment to the adoption of AM in the DoD is the lack of established standards for the technology on issues ranging from process control to raw material qualification and testing. The American Society for Testing and Materials (ASTM) International F42 committee currently has a subcommittee working to develop such standards in materials and processes, terminology, design, data formats, and test methods. However, guidance is still lacking.

NIST also convened a workshop in December 2012 to specifically begin laying the groundwork for metals-based standards. Experts in advanced materials research believe that adequate understanding of the properties of metal materials (and the ways that AM processes affect them) remains at least 5–10 years away [1]. Further, without appropriate standards in place, there is no way to ensure that AM-manufactured products will possess the consistency that the warfighter requires on the battlefield.

DEVELOPING LEGAL AND FINANCIAL GUIDELINES FOR THE DOD AND MILITARY CONTRACTORS

One of the largest hurdles to the adoption of AM in the DoD concerns the issue of property rights. As mentioned previously, one of the proposed uses for AM technology is the manufacture of replacement parts to reduce the logistical footprint, but the DoD may not have the legal authority to proceed with this course of action. Patent law is fairly explicit in this regard. The right conferred by the patent grant is, in the language of the statute and of the grant itself, "the right to exclude others from making, using, offering for sale, or selling" the invention in the United States or "importing" the invention into the United States. What is granted is not the right to make, use, offer for sale, sell, or import an invention but the right to exclude others from making, using, offering for sale, selling, or importing that invention [6]. A majority of military systems for which AM might provide spare parts are patented by their original manufacturers, and ignoring these protections would expose DoD organizations to the potential risk of litigation, while also jeopardizing relationships with key industry partners.

PROTECTING AM-RELATED RESEARCH, DEVELOPMENT, AND COMMERCIALIZATION

Another hurdle for the DoD and its industry partners is the protection of AM-related information. As Sony Corporation of America can attest from its November 2014 cyber attack, hacking can be devastating financially and destructive to a company's reputation. For the DoD and its industry partners, the stakes are even higher when it comes to AM-related research, development, and commercialization. The risk is more than the loss of highly sensitive military designs. In the case of a security breach, the compromise of AM data files could allow an adversary to re-create and use our own technology against us on the battlefield in short order. Additionally, a breach could also allow an adversary the opportunity to modify existing AM data files without the knowledge of the DoD or a contractor, potentially resulting in replacement parts with critical failures built in to the design.

CONCLUSION

Without a doubt, AM technologies present a significant opportunity for the DoD to enhance warfighter capability and reduce the current logistical footprint and TLCC of numerous systems. Significant progress has been made, but there is still a great deal of work that must be performed to ensure a sensible adoption of AM technologies to support the DoD and the warfighter. The effort will continue to require extensive collaboration between the Federal Government/DoD, academia, and the commercial sector, as well as a sustainable funding stream. And when considering the fiscally constrained environment under which the DoD is currently operating, the funding hurdle may be the most daunting hurdle of them all. ■

BIOGRAPHY

PAUL LEIN is a senior engineer at Quanterion Solutions Incorporated. He has more than 24 years of reliability engineering experience conducting statistical analyses and applying physics of failure techniques; failure analysis; reliability centered maintenance (RCM) analysis; failure modes, effects, and criticality analysis (FMECA); prognostic model development; and advanced algorithm development for the creation of new life analysis software, including mechanical, electrical, and software components. Mr Lein is also involved in the development of new maintenance database systems and analysis techniques, including web-based repositories and tools for collecting reliability data and mathematical models for use in hardware and software reliability predictions. His experience also includes research and development of laser systems and opto-mechanical devices. He has a B.S. in photonics and applied mathematics and an M.S. in advanced technologies from the State University of New York Institute of Technology.

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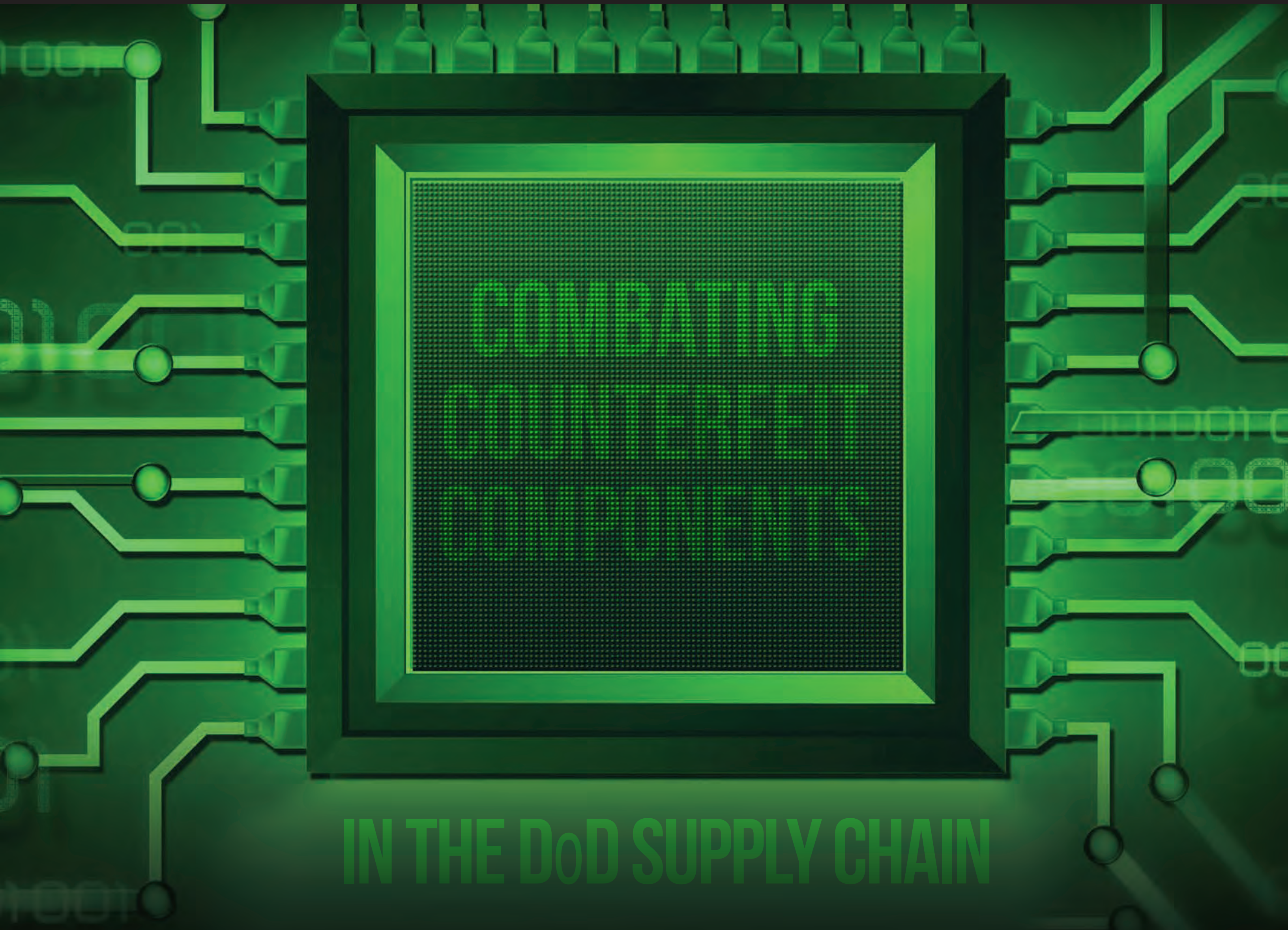
- Electrical & Electronic Equipment (804)
- Information Science (683)
- Administration & Management (597)
- Computer Programming & Software (593)
- Optics (586)
- Materials (538)
- Composite materials (533)

***See above for explanation**



COMBATING COUNTERFEIT COMPONENTS IN THE DoD SUPPLY CHAIN

By Paul Wagner

INTRODUCTION

In recent years, manufacturers supplying products to the Department of Defense (DoD) have encountered a dramatic increase in the numbers of counterfeit components in the supply chain. In most cases, counterfeits are devices that have been re-marked with false information as to their origin, age, content, or capability; and many are found to be entirely nonfunctional. Because the true age, specifications, and/or functions of such devices are unknown, the effects of age and stress on the devices are also unknown, meaning the results of the reliability models and/or reliability testing originally used to establish product reliability are no longer relevant. Aside from affecting reliability, counterfeit components could also compromise the safety of equipment.

A suspected reason for the growing number of counterfeiting incidents is insufficient control of the supply chain, which is due in part to manufacturers' increased reliance on outsourced, off-shore manufacturing, subcontractors, and even procurement [1, 2]. Although component obsolescence may also be a factor, the vast majority of counterfeit components are fake versions of genuine devices that are still in production. Whatever the cause, counterfeit components have infiltrated product manufacturing, most notably in equipment vital to the U.S. national defense, thereby jeopardizing equipment reliability and safety.

THE COST OF COUNTERFEITING

Although there is not a singular definition of a counterfeit component, the Aerospace Industries Association defines it as a "product produced or altered to resemble a product without authority or right to do so, with the intent to mislead or defraud by presenting the imitation as original or genuine [3]."

An estimated 15% of spare and replacement parts for DoD equipment are counterfeit.

A study performed by the Department of Commerce's Bureau of Industry and Security found that, in the DoD supply chain alone, the number of known counterfeit incidents rose from approximately 3,300 in 2005 to more than 8,000 in 2008 [3]. An alternate survey funded by the U.S. Navy increased the counts of incidents to 3,868 and 9,356 for the same two years. Further, experts estimate that the confirmed counterfeit incidents represent only a small portion of the actual number of occurrences, some of which go undetected, unreported, or misidentified as simply "bad parts." So how extensive is the problem?

- In 2002, the FBI estimated that U.S. businesses lose between $200 billion and $250 billion per year to product counterfeiting; about 7% of that amount is in electronics. No doubt, the problem has only continued to grow since that estimation.
- In 2010, approximately 46% of component manufacturers and 55% of integrated circuit (IC) manufacturers surveyed reported that they have encountered counterfeit versions of their products [4].
- From November 2007 to May 2010, U.S. Customs made more than 1,300 seizures (representing 5.6 million semiconductors) with trademarks of approximately 100 actual companies.

Figure 1: Men Dismantling Electronic Waste in New Delhi, India.

Whether procured through brokers, Internet sales, or even "trusted" distributors, fake components are appearing in a wide variety of DoD-related equipment, in everything from aircraft to helicopters and submarines [5]. These components have included the following:

- 75 parts in the Identification Friend Foe (IFF) system [1].
- 1,500 parts in the production and repair of the A9 missile's printed circuit assemblies [6].
- 350 parts in the beam steering control of the Navy Cobra Replacement Program [6].
- $16 million worth of counterfeit ICs sold from China and Hong Kong to U.S. Navy/defense contractors [6].
- Counterfeit IC memories in U.S. Missile Defense Agency mission computers (Lockheed Martin) for Terminal High Altitude Area Defense (THAAD) missiles. The cost to fix the problem was $2.7 million [5].
- ICs in Hercules C-130J that were actually used 1990s Samsung devices, recycled and remarked by a company in China. And according to Samsung, "it is not possible to project the reliability" of used parts [5].
- An estimated 15% of spare and replacement parts for DoD equipment are counterfeit [7].

Clearly, ICs seem to be a prime target for counterfeiting in electronics (as shown in Figure 1); however, manufacturers have also identified many other counterfeit component parts, such as wire, resistors, capacitors, inductors, connectors, fuses, relays, and virtually every major component type.

COUNTERFEITING METHODS

Figure 2 indicates some of the major types of counterfeiting methods that are affecting the country's electronic supply chains.

The primary methods currently employed to counterfeit DoD components include the following.

Remarking

Real components, new or used, functional or nonfunctional, are re-marked with false information, such as any of the following: the manufacturer, function (part number), date code, lot number, country of origin, quality level, performance grade, and package style. For many IC types, "blacktopping" (the application of a thin layer of epoxy or other colorant) is used to first obscure the original device markings; then the new or modified markings are applied (see Figure 3). Although earlier instances of blacktopping were visually evident, counterfeiters have become more sophisticated, making visual detection more difficult. In addition, there have been occurrences in the past where re-marking was purposely performed by the actual manufacturer. Although this practice is relatively rare, it can further complicate the task of distinguishing genuine parts from fakes. Thus, communication with the original manufacturers is essential to aid in detecting fake parts.

Figure 3: A Partially "Blacktopped" and Stamped Part With a False Identification Code. Part Number indicates a CLCC Package, but This Package Is a CDP. *(NASA)*

Sometimes the device may not even provide the function that its markings indicate. In the instance shown in Figure 4, the outer packaging identifies the component as an operational amplifier, but the die markings inside indicate the actual, and different, function. Such a problem is not visually apparent. X-ray inspection could detect such problems, although functional testing would, in this case, have been a more economical means of discovering this fake.

Reuse

Used components sold as new are perhaps the largest category of counterfeit devices. Electronics recycling has given rise to an influx of used components, primarily from mainland China, through brokers or other dubious outlets [2, 3, 4, 5, 8].

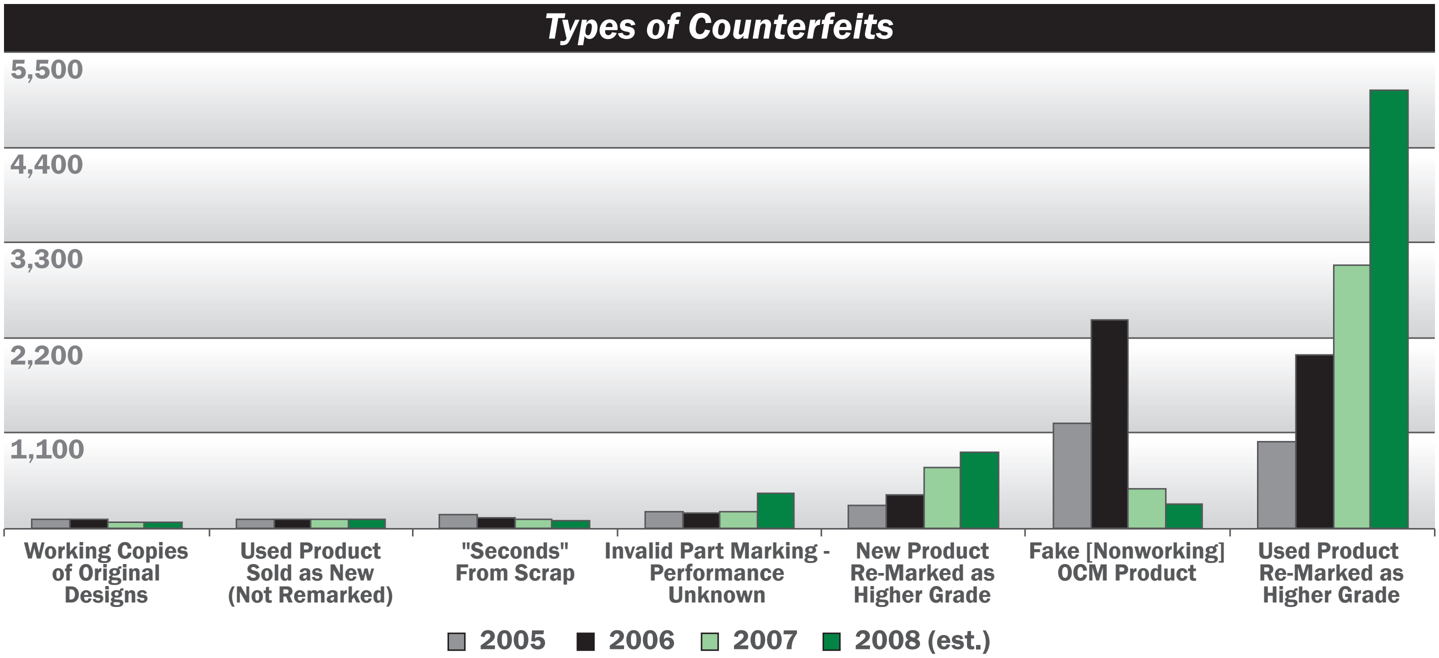


Figure 2: Counterfeit Part Methods. Source: U.S. Department of Commerce, Office of Technology Evaluation, Counterfeit Electronics Survey, November 2009.

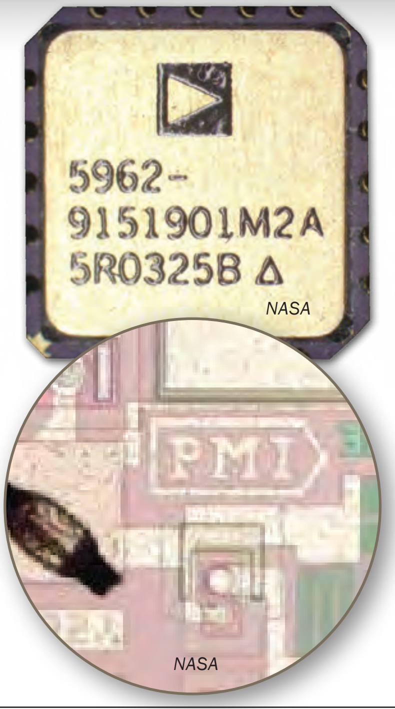


Figure 4: A Part with Falsified Function Markings. The Markings *(top)* Indicate an Op Amp From ADI, but the Part Contains Die from a Voltage Reference From PMI *(bottom)*.

China imports used/scrap electronics and (using low-cost labor) removes devices from the discarded circuit boards. Such parts later bear re-markings (date code, lot, device type, quality level, etc.) and are returned to the marketplace. And military equipment is a prime target for such devices, as MIL-spec components are increasingly difficult to find and/or have long lead times.

Figure 5 shows the metal leads of supposedly new components that bear the obvious signs of previous assembly to a printed circuit board.

Unauthorized Production

With so many IC houses, IC fabrication is often outsourced. In addition, several manufacturing facilities that produce genuine parts have been found also to have made unauthorized versions of those components, which were then

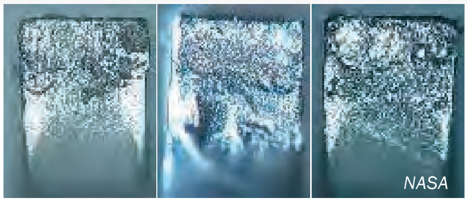


Figure 5: "New" Circuit Board Leads Showing Evidence of Prior Assembly and Use.

sold through another outlet. These components may have been overruns that may or may not have undergone proper testing or were fallouts that did not meet specification and should have been scrapped. Although the number of these reported incidents has been minimal so far, the devices' genuine appearance (even under X-ray) means that identifying such parts can be extremely difficult, and may easily go undetected. And even when these devices fail, the failure may be misidentified as a random failure of a genuine part.

False Approval Markings

Agency approvals or listing markings are usually required when product safety or compliance with a standard (such as Underwriters Laboratories [UL], Conformance European [CE], Canadian Standards Association [CSA], Federal Communications Commission [FCC], etc.) is required. Because obtaining and maintaining approvals can be costly, unscrupulous manufacturers may skip the required approval process, yet will claim compliance and apply false markings. Target devices in this category typically include fuses, wiring (insulation), switches, relays, and circuit breakers. The various approvals and listings help to ensure safe operation of a product, so false approval markings represent a potential safety hazard to the user.

In all of these examples, the counterfeit part likely has a different or degraded function than that of a genuine part. Counterfeit parts often bear several of the previously listed abnormalities, with many of them being both used and re-marked. At best, counterfeit parts can increase the failure rate of a product in an unpredictable manner. At worst, counterfeit parts can malfunction and create a safety hazard.

SECURITY

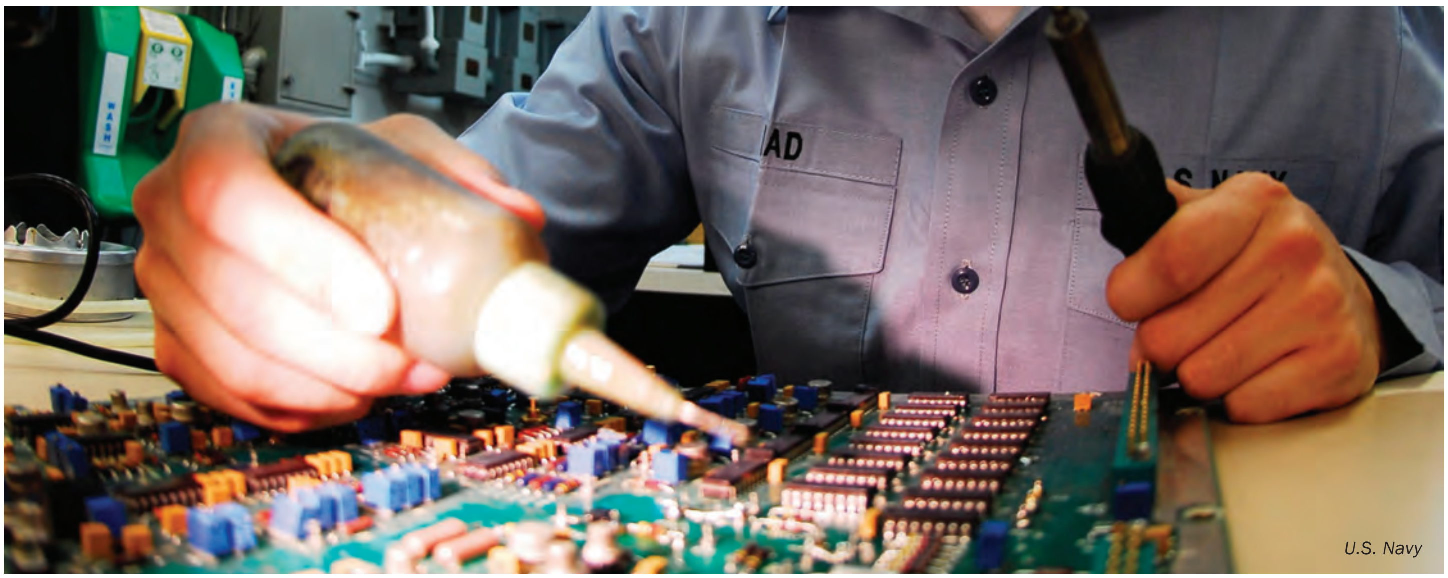
Most of the public attention related to counterfeit electronics has been associated with re-marking and reusing devices. Another area of potentially greater security concern is the possibility of inserting trojan circuits, especially into programmable devices. Such circuits could steal information and relay it to an "enemy," or they could, on command or "randomly," prevent the device from operating as designed. Unlike software viruses or trojans, hardware-based equivalents are much more difficult to detect and could be impossible to "patch" or defeat. Researchers have demonstrated how "backdoors" into supposedly secure programmable devices (field programmable gate arrays [FPGAs]) could be exploited to insert such circuit functions [9].

Another security concern is the potential for copying complex programmable devices. Many articles have been written on this subject, and many FPGA and microprocessor manufacturers have offered additional means of ensuring the security of their devices [10, 11, 12]. Whether designers will take full advantage of these security measures remains to be seen.

COUNTERMEASURES TO COUNTERFEITING

One possibility for helping to differentiate between genuine parts and counterfeits in the future is to include a form of unique marker on genuine parts. The U.S. Defense Advanced Research Projects Agency (DARPA) Supply Chain Hardware Integrity for Electronics Defense (SHIELD) program proposed such a solution with an item called a *dielet.* Such a device could contain an encryption engine and sensors to detect tampering and could be affixed to components, either by the manufacturer or after the fact, without affecting the device's functionality. Although the proposal did not garner immediate support, in early 2015 DARPA issued a pair of contract awards, one to Northrop Grumman Corp and another to Draper Labs, specifically to develop robust dielets [13]. The keys to this solution will be low manufacturing cost and, to be completely effective in combating counterfeits, adoption by all major manufacturers.

A similar initiative uses botanical DNA ink technology in the device package to provide positive identification of device authenticity. Developed by Applied DNA Sciences, which is working with the Defense Logistics Agency (DLA), a DNA-embedded ink (SigNature DNA) provides a marker that reportedly cannot be altered or copied. As with the dielets, the DNA markers are initially targeted for use with larger microcircuits, such as microprocessors, FPGAs, and memories [14].


U.S. Navy

Another partial solution, developed by SRI International under DARPA's Integrity and Reliability of Integrated Circuits (IRIS) program, is an Advanced Scanning Optical Microscope (ASOM) designed for the Navy to aid in the forensic analysis of ICs that are suspected of being counterfeits. ASOM uses a narrow infrared laser beam to scan a device down to nanometer levels to reveal details of device construction. ASOM presently appears to be a one-off design (not yet a standard product) and is likely quite expensive at this time. IRIS also has a goal of developing IC test methods and diagnostics to characterize the reliability of devices via testing small sample sizes based on the current understanding of physics-of-failure (PoF) mechanisms.

Other detection methods include chemical testing for blacktopping, the use of X-ray fluorescence and spectroscopy techniques, as well as parametric and functional testing [15].

While dielets and/or DNA markers could certainly aid in combating future counterfeits, virtually all investigations into the problem of counterfeit electronics have concluded that tighter control of procurement processes and the supply chain is the best immediate solution. While China is the source of the majority of counterfeit components, China did not cause the problem. A DoD investigation identified a number of inadequacies in processes of *equipment manufacturers* that led to lax control of their supply chain and components, opening the door that allowed counterfeits to be assembled into products.

The key to combating counterfeiting is to design, operate, and maintain a system to detect/avoid counterfeits.

Based on the Society of Automotive Engineers (SAE) International Standard AS5553A [16], the recently passed Defense Federal Acquisition Regulation Supplement (DFARS) Case 2012–D055 recommends the following process improvements aimed at combating and eliminating counterfeit components in products. While the recommendations are aimed at suppliers to the DoD, they are also good practices for any organization (manufacturer and service) that wishes to avoid counterfeits. They apply to confirmed counterfeits as well as suspected fake devices. The key to combating counterfeiting is to design, operate, and maintain a system to detect/avoid counterfeits. This includes:

- Training personnel to avoid, identify, and report counterfeits.
- Flowing down requirements (through the supply chain) for counterfeit detection/avoidance.
- Ensuring that only original manufacturer sources, or suppliers that obtain parts exclusively from such sources, are used.
- Maintaining traceability of all components throughout the supply chain, and keeping informed of counterfeiting information and trends.
- Instituting procedures to identify counterfeit parts. This task can be extremely challenging as both false positives and false negatives are commonplace, even with seasoned inspectors. Affordable, commercial equipment is necessary.
- Inspecting/testing parts with appropriate pass/fail inspection criteria. Again, there are no hard and fast rules that will be 100% accurate; thus, building a knowledge/example base is essential.
- Continually reviewing databases, the Government-Industry Data Exchange Program (GIDEP) reports, and other sources of counterfeiting information (e.g., NASA, ERAI, Independent Distributors of Electronics Association [IDEA], etc.).
- Reporting and quarantining counterfeit parts.
- Controlling obsolete parts.

For guidance as to general processes for ensuring that components are genuine, refer to IDEA-STD-1010B [17] and Components Technology Institute (CTI) Counterfeit Components Avoidance Program (CCAP) 101.

Finally, the new International Organization for Standardization (ISO) 9000-2015 standard due to be released in late 2015 will include an emphasis on risk assessment as related to a company's practices [18]. Certainly, one of the risks to consider is that of encountering counterfeit components when an organization decides to outsource its manufacturing, procurement, or service activities or to adopt other practices that could compromise the traceability of components. Embracing ISO 9000-2015 could help companies make careful, well-informed decisions about their business practices and avoid risky practices that could jeopardize the reliability and safety of the products they manufacture.

While the suggested solutions would admittedly place a greater burden on both component and original equipment manufacturers (OEMs), these solutions should help manufacturers and service organizations to regain control of the supply chain and proactively root out counterfeits. And this control will help ensure that products consist only of genuine parts as defined by the design documentation and that the product design will be able to maintain the prescribed reliability and safety requirements.

For additional information on counterfeit device data and avoidance methods, the following resources are recommended:

Data

- NASA QLF Web Site
- GIDEP
- ERAI Counterfeit Parts Notifications

Guidance and Technical

- CTI-CCAP-101
- IDEA-STD-1010B [17]
- SAE AS5553A [16]
- DFARS Case 2012–D055, Federal Register 48 CFR Parts 202, 231, 244, et al., Defense Federal Acquisition Regulation Supplement [19]
- DARPA -BAA-14-16 SHIELD Program
- DARPA IRIS Program. ■

BIOGRAPHY

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DTIC SEARCH TERMS:
Counterfeit Components Parts

RESULTS: 3,640

- Government & Political Science (914)
- FBIS Collection (464)
- Economics & Cost Analysis (438)
- Foreign Reports (424)
- International Relations (396)
- Government (Foreign) (385)
- Economics (370)
- Sociology & Law (355)
- Policies (312)
- Theses (291)

*See page 8 for explanation ▸

STINGRAY

HIGH-PERFORMANCE RF ENERGY PROPAGATION MODELING IN COMPLEX ENVIRONMENTS

By Christiaan Gribble and Jefferson Amstutz

INTRODUCTION

Understanding the propagation of radio frequency (RF) energy in the presence of complex outdoor terrain features, such as in urban environments, is critical to the military's planning, optimizing, and analyzing wireless communication and data networks. Unfortunately, simulating and visualizing RF energy propagation can be a difficult and time-consuming task: RF energy propagates throughout these environments via a combination of direct line-of-sight (LOS), reflection, and diffraction, all of which must be modeled accurately to obtain high-fidelity results. Moreover, features within the environment—trees, buildings, etc.—typically exhibit different permittivity and absorption properties with respect to the energy being measured and, therefore, also impact simulation fidelity. Finally, energy produced from a single transmitter may arrive at a given point in space from a variety of paths, each with a different length and, thus, with different time-delay characteristics.

Fast prediction and visualization of RF energy propagation in urban environments are of particular interest to military planners desiring to quickly set up temporary networks to support operational goals. Such networks include both cellular communication and wireless data networks. A fast prediction and visualization tool would improve the speed with which these networks could be deployed and would improve the quality of these networks under specific mission scenarios or for specific regions within an environment. Such a tool would also improve network coverage, provide estimates of signal strength at various points throughout the environment, estimate time-delay of multipath signals, and provide data for power allocation in the deployed transmitters.

Unfortunately, many of these tasks are difficult to accomplish with existing models. These models run slowly for moderate to large numbers of transmitter/receiver pairs, in part because they are not designed to take advantage of modern multicore computer architectures. Moreover, these models do not account for noise caused by multipath scatter but instead use unacceptably large estimates for its effects. As a result, many organizations lack the tools required to execute rapid visual analysis of network operations involving RF propagation within the time limits or data quality required to satisfy their requirements.

One promising solution for these challenges is StingRay, an interactive environment for combined RF simulation and visualization based on ray tracing (Figure 1). StingRay is explicitly designed to support high-performance, high-fidelity simulation and visualization of RF energy propagation in complex urban environments by exploiting modern multicore computer architectures, particularly Intel's Xeon processor family. High-performance RF simulation is achieved with Intel's Embree ray tracing kernels [1], and Intel's OSPRay rendering engine [2] provides high-fidelity visualization of the resulting data. The combined simulation and visualization approach allows analysts to interactively configure all aspects of the simulation scenario, including the underlying physical environment (Figure 1, top) and visualizations of the resulting data (Figure 1, middle and bottom), providing the flexibility to quickly identify the propagation phenomena of interest and ultimately reduce time-to-insight.

Optical, or Whitted-style, ray tracing [3] simulates the propagation of visible light in complex three-dimensional (3-D) environments and elegantly handles dominant visual phenomena such as reflection, refraction, and shadows (Figure 2). RF energy is also a form of electromagnetic energy (albeit at a highly different frequency than visible light); thus, ray tracing offers a possible approach for simulating physical phenomena in the RF domain. We build on state-of-the-art optical ray tracing techniques to simulate RF energy propagation, or so-called *radio frequency ray tracing* (RFRT), in complex urban environments.

RFRT offers several advantages over traditional RF simulation methods. First, modifications to an optical ray tracer that are necessary to capture important physical phenomena, such as diffraction and interference, are fairly straightforward. Second, RFRT generates the full signal trajectory, allowing computation and visualization of signal characteristics that are extremely costly, or even impossible,

Figure 1: High-Performance RF Model Using Ray Tracing.

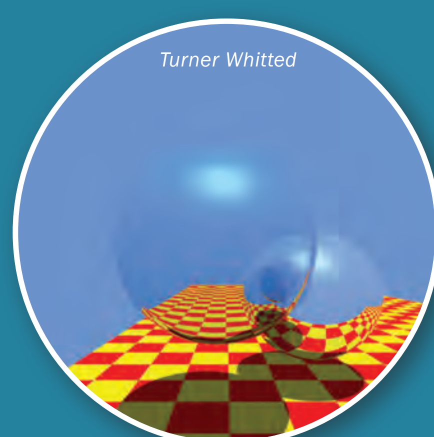

Figure 2: Ray Tracing for Light Transport Simulation.

with other methods. Finally, RFRT scales effectively, both with geometric complexity and with processor count. These characteristics, combined with nearly 35 years of research in high-performance optical ray tracing techniques [4], make ray tracing an ideal method on which to base a highly interactive combined RF simulation and visualization tool for understanding RF propagation phenomena.

In succeeding text, we discuss the key components of our combined RFRT simulation and visualization approach, we examine simulation performance on a workstation-class desktop computer, and we show several visualizations highlighting the advantages of an interactive environment for understanding RF energy propagation.

RF RAY TRACING

Ray-based methods have been used to approximate the solution of wave equations for electromagnetic fields in nondissipative media for at least four decades [5, 6]. Typically, these methods proceed in two steps. First, ray paths connecting source and receiver are found; in complex environments, this step is often the most time-consuming. Second, the wave equation is applied to compute field transport along identified ray paths. Classical ray-based approaches that operate in this manner typically require many hours of run time to simulate areas out to 1 km or more.

In contrast, our approach to RF modeling uses ray tracing techniques from computer graphics [3, 7]. Simulations in the optical domain model the scattering of ordinary incoherent light, and the effects of multiple rays are combined by adding powers of individual rays. This approach can also be used to predict the small area average received power and the fast fading statistics of signals in the RF domain. Moreover, our ray-based approach can easily incorporate phenomena such LOS transmission; multipath effects from specular reflection, diffraction, and diffuse scattering; and environmental conditions such as fog and rain.

In particular, Monte Carlo path tracing [7] formulates a solution to the wave equations for electromagnetic fields using a geometric optics approximation that models interesting visual phenomena. Path tracing probabilistically selects just one path of a (possibly) branching tree at each ray/object interaction. This approach drastically reduces the number of ray/object interactions that must be computed, thereby improving computational efficiency. We adapt the path tracing algorithm (see Algorithm 1) to compute energy propagation characteristics, including those arising from wave-based phenomena, in the RF domain.

Together with our collaborators at the University of Utah, we previously developed the Manta-RF radio frequency ray tracing system [8, 9, 10]. As in classical ray-based techniques, Manta-RF uses the ray concept; however, transport properties are computed directly by launching many rays—on the order of 10^8 to 10^{11} or more—and using the statistical properties of ray distribution and density to represent received power. Whereas classical rays are defined by the order and location of their interactions with environmental features, rays in Manta-RF are more appropriately described as RF photons—discrete packets of electromagnetic energy in the RF portion of the spectrum. Validation against several measured datasets shows that a Monte Carlo approach to ray-based RF simulation offers high-fidelity results comparable to those produced by classical ray-based methods (Figure 3). StingRay builds on the ray-based RF simulation techniques developed for Manta-RF but leverages recent advances in ray tracing [1] and visualization [2] application programming interfaces (APIs) to provide a fully interactive combined RF simulation and visualization environment.

STINGRAY

Combined simulation and visualization of various physical phenomena, including RF energy propagation, promotes deeper understanding of these phenomena, thereby reducing time-to-insight for mission planning tasks. However, the complexity of typical RF analysis scenarios, including the underlying physical environment and the sheer number of ray/object interactions, can lead to issues with scale and visual clutter. Such issues necessitate a flexible, interactive environment in which analysts control both inputs and results at run time.

Algorithm 1: RF simulation with Monte Carlo Path Tracing.

```
function TraceRay(ray, depth)
    event ← Objects.Interact(ray)
    if event then
        ray ← GenerateRay(newDirection, newEField)
        TraceRay(ray, depth+1)
    end if
end function
```

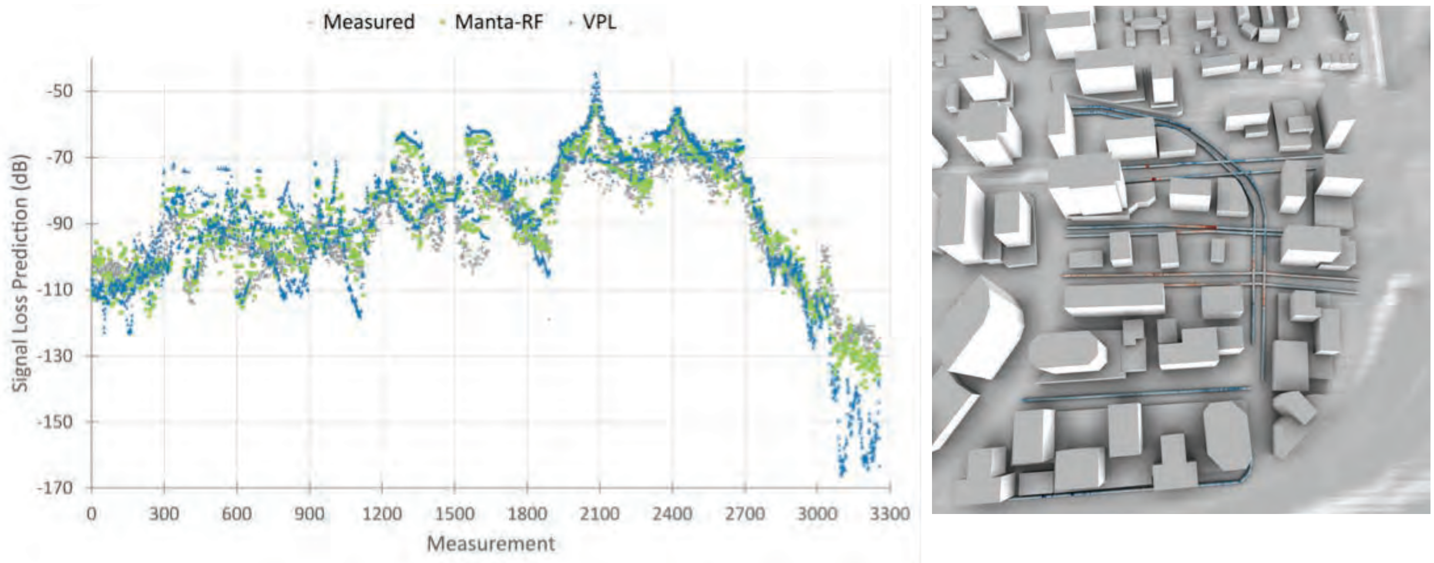

Figure 3: High-Fidelity RF Simulation via Monte Carlo Path Tracing, Comparing Signal Loss Predictions Using RFRT and VPL [11] (left) Against Measured Data from Rosslyn, VA (right). (Data and image courtesy of Konstantin Shkurko, University of Utah)

StingRay satisfies these constraints via an extensible, loosely coupled plug-in architecture. The simulation and visualization components promote flexibility with user-controlled features, while an extensible graphical user interface (GUI) enhances a user's ability to perform debugging and analysis tasks by enabling easier navigation and exploration of the data in real-time.

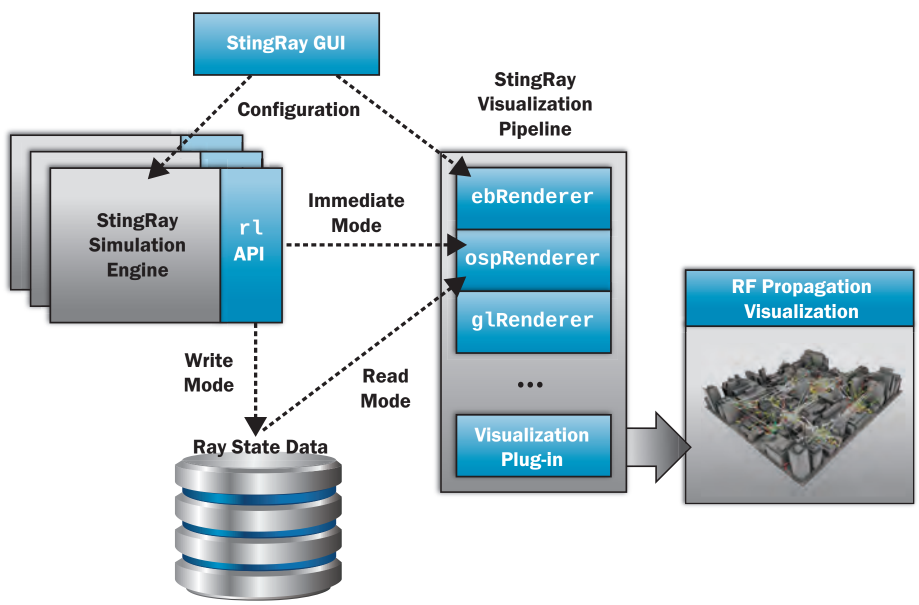

Figure 4: StingRay System Architecture.

SYSTEM ARCHITECTURE

The key components of the StingRay system architecture (Figure 4) combine to form an analysis process that is functional, flexible, and extensible. The design of StingRay leverages the following concepts:

- **Plug-In Architecture.** StingRay is built around a set of configurable components that follow a specific design pattern to create a flexible infrastructure in which to implement RF simulation and visualization. We provide a set of core components to perform common tasks, but the plug-in architecture enables a programmer to create new components and extend the core facilities with arbitrary functionality.

- **Pipelined Rendering.** StingRay uses a pipeline model for rendering, coupled with lazy evaluation for necessary values to avoid recomputation in later stages. The pipeline model leads to a layered visualization approach in which results of individual components are combined, under control of the user and at run time, to achieve the desired result.

- **Extensible GUI.** The simulation and visualization components are integrated via an extensible GUI to enable comprehensive control of the entire analysis process. These components can tailor their user interface, exposing input parameters in a manner consistent with the functionality they provide. These features provide fine-grained control of the entire analysis process, making StingRay ideally suited to a wide variety of mission planning tasks.

As shown in Figure 5, this design enables layered visualization within the spatial domain of computation by compositing visual elements from several components to generate the final image. Here, glyphs depicting ray paths are composited with a rendering of the simulation domain, providing insight into the dominant energy transport paths in this environment.

SIMULATION ENGINE

As noted in previously, our approach to RF modeling builds on ray tracing techniques from computer graphics [3, 7]. Optical ray tracing computes light transport paths recursively from sensor to source to capture important visual phenomena, and therefore provides a possible approach for simulating various phenomena in the RF domain. However, to do so accurately, the basic algorithm must be modified to handle two particular phenomena important to RF energy propagation: diffraction and interference.

RF simulation and visualization are critical to planning, analyzing, and optimizing wireless communication and data networks.

Diffraction describes the apparent bending of waves around small obstacles and the spreading of waves past small openings (Figure 6[a]). Diffraction effects are generally most pronounced for waves with wavelengths similar in size to the diffracting object. For visible light, and thus for optical ray tracing, diffraction is typically ignored because its effects are vanishingly small at normal scales. However, for RF simulation, effects from diffraction can be significant; accuracy thus dictates that we model these effects. Specifically, StingRay captures so-called *edge diffraction*, in which obstacles act as a secondary source and create new wavefronts.

To model edge diffraction, we first determine when rays are near edges that cause diffraction. We accelerate this process by computing and storing proxy geometry for all the possible diffraction edges (ignoring concave and flat edges) as an offline preprocessing step. Then, during simulation, when a ray interacts with diffraction edge proxy geometry (Algorithm 1, line 3), the incident ray is terminated, and a diffraction ray is generated according to the Geometrical Theory of Diffraction [12], as described by Moser et al. [13] and traced through the scene.

Interference refers to the phenomena in which two waves superimpose to form a resultant wave of greater or lesser amplitude (Figure 6(b)). As with diffraction, the impact of interference is typically ignored in optical ray tracing, as the effects are too subtle to detect at typical scales. Similarly, however, in RF simulation, interference can have a significant impact on the perceived energy at a receiver, and accuracy again dictates that we model interference effects.

To model interference, we simply account for the phase of the wave represented by each ray and use phasor addition when accumulating energy at the receivers (Algorithm 1, line 2).

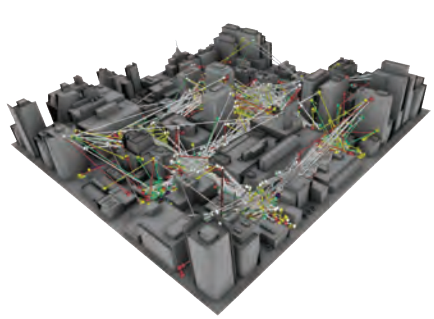

Figure 5: StingRay's Layered Visualization.

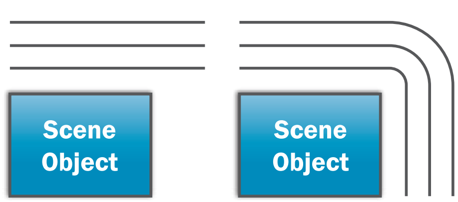

Figure 6a: Diffraction in Ray-Based RF Simulation.

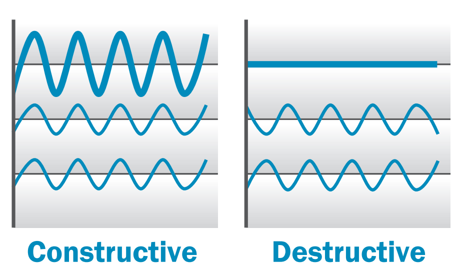

Figure 6b: Interference in Ray-Based RF Simulation. (Original version: Haade via Wikimedia Commons)

The StingRay RF simulation engine implements the key RF propagation phenomena using a collection of C++ objects, including:

- Scene Geometry
- Diffraction Edge Proxy Geometry
- Ray Path Loggers.

The simulation functionality is exposed to client applications through a multi-threaded controller object that provides a straightforward API.

At its core, the simulation engine invokes Embree to efficiently trace rays through the physical environment defined by the scene geometry. The actions following a ray/object intersection are determined by the type of object intersected (Algorithm 1, lines 2–7). For example, a sensor sphere simply accumulates ray power and terminates traversal, whereas scene or proxy geometry generates a simulation *event* that encapsulates information about the ray/object interaction, including the object's material properties. These properties define how a ray interacts with the intersected object, and may result in recursive traversal of new rays to capture specular reflection or diffraction.

StingRay implements a novel RFRT methodology based on Monte Carlo path tracing.

PERFORMANCE

We achieve high-performance RF simulation using Embree to compute ray/object intersections quickly and efficiently. Embree implements a highly optimized ray tracing engine for Intel Xeon family processors, including Xeon Phi coprocessors. To accelerate ray traversal, Embree employs numerous algorithmic and code optimizations, as determined by application characteristics and the underlying processor architecture. Embree provides state-of-the-art ray tracing capabilities for applications across a variety of optical and nonoptical simulation domains.

Importantly, ray-based simulation techniques—including RFRT—belong to a class of problems considered to be *embarrassingly parallel*; that is, each unit of work is independent of every other unit. In RFRT, the rays composing one path are completely independent of the rays composing every other path, and can be processed independently on separate processors. Thus, simulation performance scales well with processor count (Figure 7), allowing tradeoffs between performance and fidelity based on the number of available processors.

VISUALIZATION

As noted previously, we adopt a layered visualization approach in which elements from separate visualization components are composited to generate the final image. StingRay currently supports several visual elements for RF visualization:

- Underlying Scene Geometry
- Diffraction Edge Proxy Geometry
- Ray Glyphs.

StingRay also supports visualization of scalar volume data generated from simulation results: client applications can configure the engine to capture detailed information regarding the full path generated for each transmitter sample. These data allow computation and visualization of signal characteristics that are extremely costly, or even impossible, with other RF simulation methods. For example, RF energy characteristics at arbitrary locations in the environment can be visualized by collecting ray paths during simulation, converting the data to a scalar volumetric representation, and rendering the resulting data using traditional volume rendering techniques or as participating media (Figure 8).

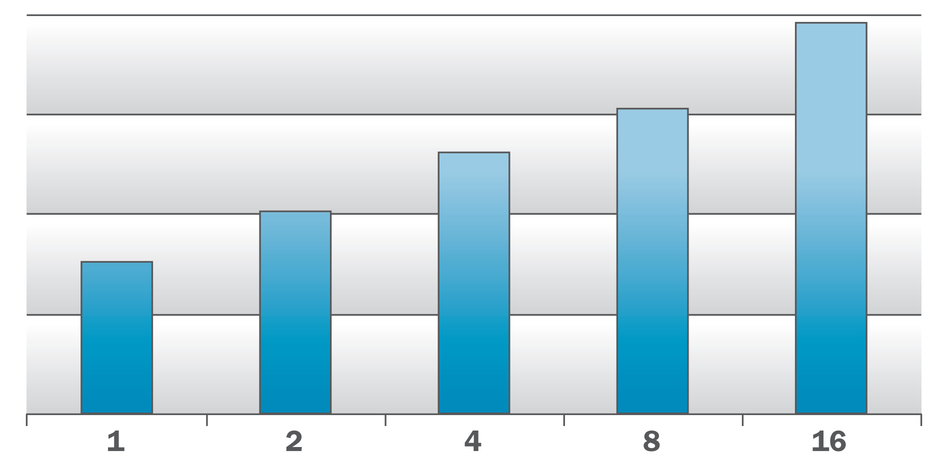

Figure 7: Simulation Performance as a Function of Processor Count, Allowing the Balancing of Performance and Fidelity Based on the Number of Available Processors.

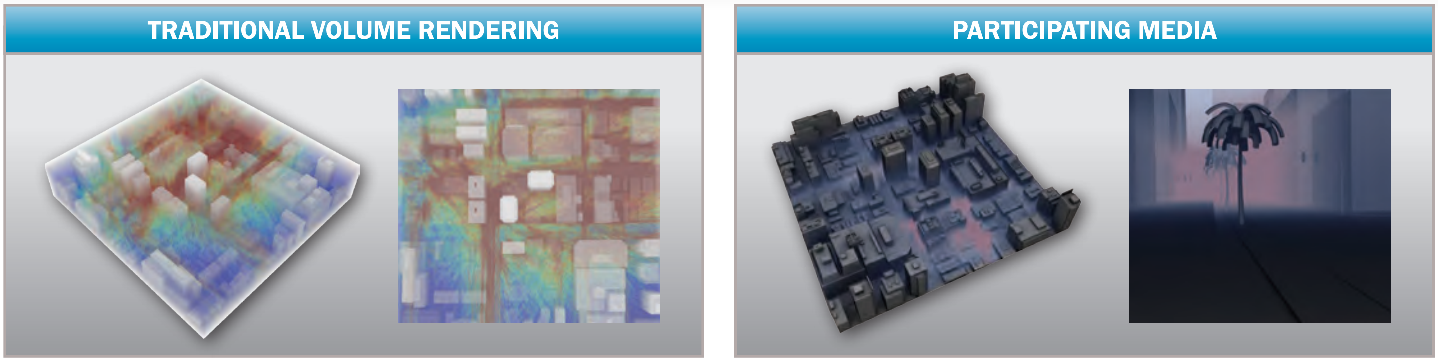

Figure 8: Scalar Volume Data Generated From RF Simulation Results.

CONCLUSIONS AND FUTURE WORK

RF simulation and visualization are critical to planning, analyzing, and optimizing wireless communication and data networks. An interactive tool supporting visual analysis of RF propagation characteristics in complex environments enables analysts to better understand RF propagation phenomena in a timely manner. StingRay provides an interactive combined RF simulation and visualization environment that satisfies these constraints. The tool combines the best-known methods in high-performance ray tracing and visualization with low-level, architecture-specific optimizations for modern multicore processor architectures, thereby enabling a highly interactive environment for predictive simulation and visualization of RF energy propagation in complex environments.

StingRay implements a novel RFRT methodology based on Monte Carlo path tracing. This approach probabilistically selects just one path of a (possibly) branching tree at each ray/object interaction, which drastically reduces the number of ray/object interactions that must be computed and, ultimately, improves computational efficiency. Additional efficiency improvements could be gained by leveraging more sophisticated ray tracing algorithms from the computer graphics literature.

For example, bidirectional path tracing (BDPT) is a Monte Carlo ray tracing algorithm that generalizes the classical path tracing algorithm (Figure 9). Paths originating from both source (red) and receiver (blue) are first computed using the classic algorithm; path vertices are then connected using occlusion rays (green, black), and energy is accumulated at the receiver for unoccluded paths (red+green+blue). Results show that BDPT performs better than classical path tracing for environments in which indirect (non-LOS) contributions are most significant. We would like to investigate the application of BDPT to RF simulation to further improve the performance and accuracy of StingRay. ■

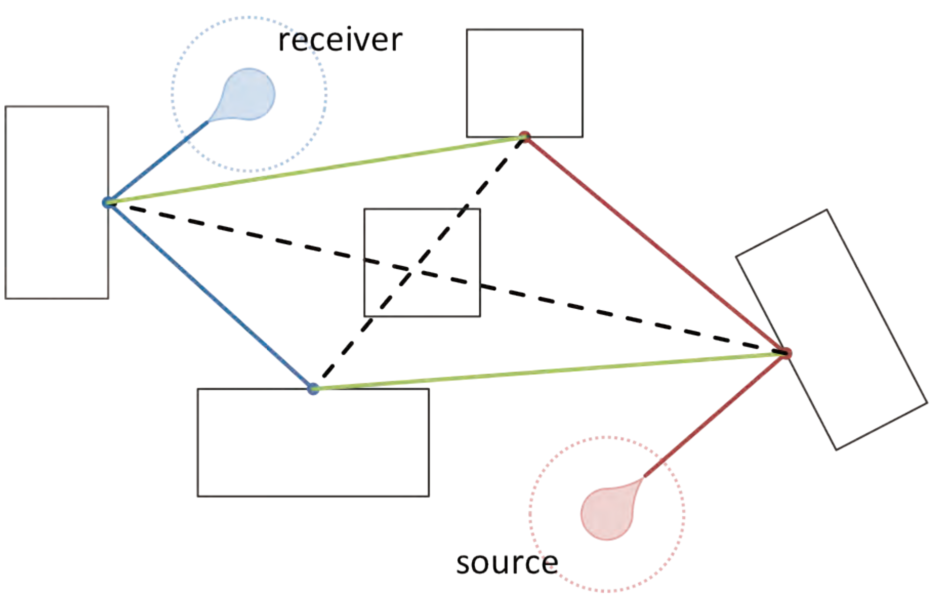

Figure 9: Bidirectional Path Tracing for Improved Computational Efficiency.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of the Intel Parallel Visualization Engineering Team, including Jim Jeffers, Ingo Wald, Carsten Benthin, Greg P. Johnson, Greg S. Johnson, Brad Rathke, and Sven Woop. We also thank Erik Brunvand, Thiago Ize, and Konstantin Shkurko of the University of Utah, Lee Butler of the U.S. Army Research Laboratory, and Henry Bertoni of NYU Polytechnic for their contributions to the early research, development, and reporting efforts that led to the RF simulation methodology on which StingRay is based.

BIOGRAPHIES

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IS HIGH-PERFORMANCE COMPUTING FOR YOU?

If you are interested in faster times to solution, improved analysis, sounder decision support, higher-quality products, and increased organizational productivity, then the answer is "yes!" What's more, once potential users discover that the supercomputing resources needed to achieve these benefits are available to Department of Defense (DoD) users free of charge, the answer often is "absolutely yes!"

High-performance computing (HPC) enables sophisticated and increasingly realistic modeling, simulation, and data analysis that can profoundly advance theoretical knowledge and expand the realm of discovery, thereby generating leading edge research and development. The massive processing power and data storage capabilities of HPC also make it possible to conduct experiments that are otherwise impossible or impractical to execute and permit the analysis of extremely large datasets that were previously intractable.

For example, consider the assessment of hypersonic air vehicle concepts. Once modeled in an HPC system, air

continued...

IS HIGH-PERFORMANCE COMPUTING FOR YOU? - continued

flow points can now be examined under conditions that are impossible to measure in a wind tunnel or that are physically unachievable on a test range. And this is just one example; the possibilities are endless. Ultimately, the question to ask is “Does supercomputing provide the means to obtain better or added information that would help the United States make better-quality decisions and develop superior products for our Warfighters?” Once again, the answer is “yes!”

While some Defense organizations can execute software codes on slower, less capable, workstations and computer clusters, these organizations are often unable or unwilling (due to time constraints) to run new, complex problems at higher resolution that

DTIC SEARCH TERMS:

RF Energy Propagation Modeling

RESULTS: 51,000

- Electrical & Electronic Equipment (2,500+)
- Radio Frequency Wave Propagation (2,300+)
- SBIR (Small Business Innovation Research) (2,300+)
- Symposia (2,216+)
- Export Control (2,200+)
- Active & Passive Radar Detection & Equipment (1,700+)
- SBIR Reports (1,700+)
- Foreign Reports (1,500+)
- Radio Communications (1,400+)
- Algorithms (1,300+)

*See page 8 for explanation ▸

> High-performance computing (HPC) enables sophisticated and increasingly realistic modeling, simulation, and data analysis.

can lead to further breakthroughs and better tools for future generations. In short, these organizations may be unnecessarily compromising future value for the sake of time. Still other organizations fear high HPC startup costs without fully appreciating the colossal benefit reaped after the initial technical investment.

Furthermore, many U.S. competitors and adversaries clearly understand the HPC return-on-investment and are aggressively pursuing supercomputing as a way to gain a competitive advantage. Thus, more than ever, the DoD needs to outcompete its foes to maintain the U.S. technological edge. Just getting the job done is no longer sufficient; organizations must evolve to support the establishment of an advanced computational foundation for future generations.

Because of these concerns, the DoD High Performance Computing Modernization Program (HPCMP) was established by Congress to provide DoD-funded HPC capabilities, subject-matter expertise, and technical assistance to help DoD scientists and engineers to leverage HPC in their work. The DoD HPCMP develops and fields massively parallel, state-of-the-art supercomputers and storage systems at five DoD Supercomputing Resource Centers (DSRCs) located across the nation. The program supports both classified and unclassified computing capability that can be accessed remotely.

In addition, the HPCMP also manages the Defense Research and Engineering Network (DREN), providing high-bandwidth, low-latency connectivity among DoD Research, Development, Test & Evaluation (RDT&E) sites, academia, research laboratories, and the DSRCs. Most importantly, the DoD HPCMP also provides help desk support and subject-matter experts in 11 computational areas to facilitate transition and execution of codes onto DoD supercomputing systems and provides licenses for the most predominant scientific and engineering software packages. And once again, all of these services and capabilities are funded and provided to DoD HPCMP users at no cost.

If you are interested in further information on how to access DoD HPC and the aforementioned resources, please contact the DoD HPC Help Desk at 877.222.2039. Additional information may also be found at http://www.hpc.mil.

DOD HPC MODERNIZATION PROGRAM

DIRECTED ENERGY WEAPONS:

FROM *WAR OF THE WORLDS* TO THE MODERN BATTLEFIELD

H. G. Wells' A Martian-Fighting Machine in Action in The War of the Worlds [1].

By Jennifer Weaver Tate

An almost noiseless and blinding flash of light … this invisible, inevitable sword of heat": When H. G. Wells first wrote these words more than 100 years ago in his classic novel *The War of the Worlds* [1], they were not much more than the stuff of science fiction. However, with the significant developments in directed energy weapon (DEW) technology that have occurred in the century since that time, these "swords of heat" have clearly emerged from the pages of fiction to full-blown scientific reality.

Interestingly, the first working laser was described as a solution looking for a problem. But it didn't take long for innovators to develop the laser's unique ability to generate an intense narrow beam of light that could be harnessed for science, technology, medicine, and a wide range of other disciplines. And today, lasers are everywhere—from research laboratories to retail checkouts, medical clinics, communications networks, and now, advanced weapons.

HISTORY

The coherent optical oscillator first imagined by Theodore "Ted" Maiman of Hughes Research Laboratory (HRL) was called the maser (Microwave Amplification by Stimulated Emission of Radiation). Contemporary masers emitted electromagnetic (EM) waves across a broader band of the EM spectrum, so Charles Townes suggested using "molecular" to replace "microwave" to be more linguistically accurate.

> The first working laser was described as a solution looking for a problem.

Russian physicists described theoretical principles of the maser's operation in 1952. Independent of Russian work, Townes and two associates built the first ammonia maser at Columbia University in 1953. Their device used stimulated emission in a stream of energized ammonia molecules to produce microwave amplification at a frequency near 24.0 GHz. Townes continued working to describe the principle of the "optical maser"—the laser (Light Amplification by Simulated Emission of Radiation)—after which Maiman created the first working laser model in 1960.

Maiman's ruby laser design resulted after HRL provided company funds to continue work from a U.S. Army Signal Corps' ruby maser redesign project. On May 16, 1960, Maiman demonstrated his ruby laser using a pulsed light source, lasting only a few milliseconds to excite the ruby. A short flash of light resulted, providing more power than previously imagined.

Lasers work by adding energy to atoms and molecules to create a high-energy—or excited—state. When excitation occurs, light waves pass through materials to stimulate more radiation. Maiman's flash-lamp design emptied the ground (lowest-energy) state of the ruby, causing a stimulated emission to provide laser action.

Continued shortening of laser light pulses has increased instantaneous power to millions of watts. Lasers now have powers as high as 1015 (a million billion!) watts. Nonlinear interactions between light and matter double and triple the frequency of light to the point that an intense red laser can produce green light.

ELECTRIC WEAPONS

Most conventional weapons rely on explosives (chemical energy) for their destruction mechanism. They either explode on target (as bombs) or create kinetic energy (as bullets). Electric weapons use stored electrical energy to attack or destroy targets and generally fall into two categories: (1) DEWs, and (2) EM launchers. Electric weapon types are shown in Figure 1.

DEWs send energy, not matter, toward a target. DEW technologies typically take the form of high-energy lasers (HELs), charged-particle beams, and high-power microwaves (HPMs). EM launchers use electrical energy to throw a mass at a target, making them distinctly different from DEWs. EM launchers are rail guns, coil guns, or induction drivers, and all use strong magnetic fields to push against projectiles. Electric guns are electric weapons, but they are not DEWs.

DIRECTED ENERGY WEAPONS

The Department of Defense (DoD) has been investing in DEWs since the 1970s. HELs and HPMs have reached the point of operational test and evaluation readiness and, in some cases, battlefield operational use.

High-Energy Lasers

HEL weapon systems have been envisioned for many years. Early on, the Navy led development with creation of the world's first megawatt-class, continuous-wave, Mid-Infrared Advanced Chemical Laser (MIRACL) at White Sands Missile Range (WSMR), NM. After testing, MIRACL ultimately engaged static and aerial targets for many years but eventually proved to be the wrong choice for the Navy's (surface) self-defense mission. Its development did, however, lead to development of the Air Force's Airborne Laser (ABL) and the Army's Tactical High-Energy Laser (THEL). All three laser systems are chemical lasers that use toxic chemicals and operate in less than optimal wavelengths; thus, they are poor choices for most naval applications.

Solid-state lasers, including fiber lasers, are electric lasers that have moved to the forefront of the DoD's research and development efforts for near-term HEL applications. Of particular interest to the Navy is the free-electron laser (FEL). The FEL's speed-of-light delivery of HEL energy can defeat high-g maneuvers of newly developed foreign anti-ship cruise missiles (ASCMs).

High-Power Microwave Weapons

Like lasers, microwave weapons have been a fantasy ever since the invention of microwave power generators. In 1932, the British government recognized that German bombers could penetrate British air space and bomb civilian populations and infrastructures. In 1934, the British Air Ministry wanted a death ray that

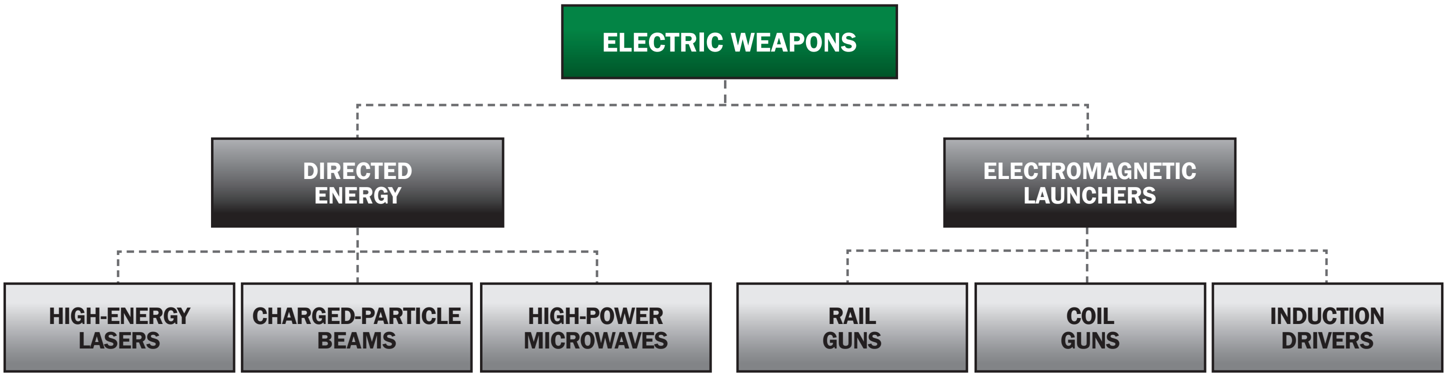

Figure 1: Electric Weapon Types (NAVSEA Image).

could kill enemy pilots and/or detonate bombs while still on enemy planes. A former meteorologist, who was also an expert on radio signals, suggested using energy reflected from aircraft. This technology is known as radar (Radio Detection And Ranging), and while it is not a DEW, its roots can be traced to the military's desire for such capabilities.

HPMs—which are high-power radio-frequency (RF) systems—have progressively increased in power density, making it now feasible to integrate the technology into weapon systems. Initial applications suffered due to their inability to obtain militarily useful outcomes. Many feasible military applications, including nonlethal, antipersonnel weapons, and nonkinetic anti-materiel weapons, have surfaced over recent years. These concepts offer unique warfighter capabilities but are difficult to achieve.

Overcoming HPM propagation losses has driven some concepts into platforms such as unmanned aerial vehicles (UAVs) or cruise missiles to deliver the HPM device to a target for close-in engagement. Field-testable prototypes have been developed to demonstrate operational utility of these concepts. In some cases, the prototypes have been, or will be, deployed operationally to support troops in theater.

> "I never, ever want to see a sailor or marine in a fair fight. I always want them to have the advantage."
> CNO Admiral Gary Roughead

21ST CENTURY TECHNOLOGIES

In January 2008, the Office of Naval Research (ONR) successfully conducted a record-setting firing of an electromagnetic rail gun (EMRG) at the Naval Surface Warfare Center (NSWC) in Dahlgren, VA (see Figure 2). The event took place in front of an invited audience, including then-Chief of Naval Operations (CNO) Admiral Gary Roughead, who said, "We should always be looking for the next big thing, to make our capability better and more effective than anything else on the battlefield." He also said, "I never, ever want to see a sailor or marine in a fair fight. I always want them to have the advantage [2]."

The Navy's first rail gun program was initiated in 2003. It facilitated a key partnership between leading scientists and engineers from industry, military, and government labs. The Phase I goal of conducting a proof-of-concept demonstration at 32 MJ of muzzle energy was achieved. Future weapon systems at full capability could fire a projectile more than 200 nautical miles, in contrast to the Navy's MK45 5-inch gun, which has a range of approximately 13 miles.

The EMRG uses high-power electromagnetic energy instead of explosive chemical propellants. Electricity generated by a ship is stored

U.S. Navy

Figure 2: High-Speed Photo of Record-Setting Firing of NSWC Dahlgren's EMRG.

over several seconds in a pulsed power system. Next, an electric pulse is sent to the rail gun to create an electromagnetic force accelerating a projectile up to Mach 6. The kinetic energy warhead uses its extreme speed to propel a projectile farther and faster than any preceding gun.

The EMRG will give U.S. sailors a multi-mission capability, allowing them to conduct precise naval surface fire support or land strikes; ship defense; and surface warfare to deter enemy vessels. High-velocity projectiles will destroy targets as a result of kinetic energy rather than using conventional explosives, thus eliminating the hazards of high explosives on ships and unexploded ordnance on the battlefield.

Hypervelocity Projectiles (HVP) are next-generation, common, low-drag, guided projectiles that are capable of completing multiple missions from different gun systems (i.e., 5-inch, 155-mm, and future rail guns). They are configurable for various mission roles and gun systems through use of multiple Integrated Launch Package (ILP) components coupled with a modular, common airframe. With its increased velocity, precision, and extended range, the HVP will provide the capability to address a variety of current and future naval threats in the mission areas of naval surface fire support, ship defense, and anti-surface warfare using current and future gun systems.

Mission types will, of course, depend on the gun system and platform. Addressing mission requirements in the areas of naval surface fire support, cruise missile defense, and anti-surface warfare are some of the program's top goals. Likewise, mission performance will vary from gun system, launcher, and ship. The HVP's low-drag, aerodynamic design enables high-velocity, maneuverability, and decreased time to target. Coupling these attributes with accurate guidance electronics will provide low-cost mission effectiveness against current threats and the ability to adapt to future air and surface threats. Further, the HVP's high-velocity, compact design eliminates the need for a rocket motor to extend the gun range. Being able to fire smaller, more accurate rounds will reduce collateral damage and provide deeper magazine potential and improved shipboard safety. And responsive, wide area coverage can be achieved from conventional gun systems and future rail gun systems. Finally, the HVP's modular design can be configured to multiple gun systems to address different missions.

DEW technology has grown into a viable, effective, and promising solution for a wide variety of current and future applications. And that may soon include the battlefield.

Additionally, ONR's fiber laser-based system, LaWs (Laser Weapons System) (shown in Figure 3), can be retrofitted to augment capabilities of currently deployed surface combatant systems.

Figure 3: ONR's Laser Weapon System (LaWs).

Performance tests aboard the *USS Ponce* in 2014 resulted in hitting targets on top of speeding oncoming boats; destroying multiple moving, water-submersed targets; and shooting down a UAV. And all of these actions were accomplished almost instantaneously.

CONCLUSIONS

Since its depiction in science fiction cartoons a century ago, DEW technology has grown into a viable, effective, and promising solution for a wide variety of current and future applications. And that may soon include the battlefield.

ONR has demonstrated that laser weapons are now both powerful and affordable. Supported by NSWC Dahlgren, ONR's Laser Weapons System successfully tracked, engaged, and destroyed a threat representative UAV while in flight at San Nicholas Island, CA. This marked the first Detect-Thru-Engage laser shoot-down with a total of two UAV targets engaged and destroyed.

HVPs will also provide lethality and performance enhancements to current and future gun systems, allowing for future technology growth while reducing development, production, and total ownership costs.

Finally, getting the United States off gunpowder—which is one of Admiral Jonathan Greenert's primary objectives for the future Navy and Marine Corps—is also nearing reality. LaWs and EMRGs are sure to be vital to future forces with their virtually unlimited magazines, constrained only by a vessel's onboard power and cooling capabilities. And because a vessel's biggest vulnerability is its explosive-filled magazine, these technologies will also make U.S. sailors and marines safer by reducing dependency on gunpowder-based munitions.

Perhaps Admiral Roughead's "no-fair-fight" wish is closer than even H. G. Wells could have imagined. ■

BIOGRAPHY

JENNIFER WEAVER TATE is a communications manager in the Electro-Optical Systems Laboratory (EOSL) at the Georgia Tech Research Institute in Atlanta, GA. She is responsible for reviewing, writing, and editing technical articles, reports, handbooks, newsletters, and promotional and advertising materials. She previously served as the Communications Manager of SENSIAC and Managing Editor of Sensing Horizons. Ms. Tate attended Penn State and Tidewater Community College, majoring in Letters, Arts, and Sciences, and Business Administration, respectively.

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[1] *Wells, H. G. War of the Worlds. 1898 and 1906.*

[2] "US Navy Demonstrates World's Most Powerful EMRG at 10 Megajoules." *Sensing Horizons,* vol. 4, no. 1, 2008.

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DTIC SEARCH TERMS:

Directed Energy Weapons

RESULTS: 106,000

- Directed Energy Weapons (9,047+)
- Nuclear Weapons (6,630+)
- Metallurgy & Metallography (5,400+)
- Antimissile Defense Systems (1,525+)
- Lasers & Masers (1,400+)
- Laser Weapons (1,340+)
- Symposia (1,014+)
- Military Operations, Strategy & Tactics (960+)
- Test & Evaluation (951+)
- Ammunition & Explosives (890+)

*See page 8 for explanation ▸

SPECTRU

By Brian Farmer and Martha Klein

INTRODUCTION

As we ride on the cusp of a new age of electronic warfare, management and use of the electromagnetic spectrum are becoming increasingly important. In fact, the Department of Defense (DoD) has deemed the electromagnetic spectrum a critical resource and has established DoD Instruction 4650.01, which defines policy and procedures for administrating and employing this resource.

One of the key tenants of this document is the performance of a Spectrum Supportability Risk Assessment (SSRA). The SSRA is becoming increasingly important as the spectrum becomes increasingly more congested, and industry practitioners should be cognizant of recent rule changes when developing new material requirements for new equipment and systems. In addition to addressing the spectrum certification and frequency assignment processes, the SSRA is required for the procurement of all spectrum-dependent systems, including commercial-off-the-shelf (COTS) systems.

The purpose of the SSRA is to identify and assess regulatory, technical, and operational spectrum issues with the potential to affect the required operational performance of a candidate system. For example, in addition to determining that a system's bandwidth requirement complies with an individual nation's frequency allocation scheme, a new or modified system must also be evaluated with respect to the following:

- The system's potential to cause interference to, or suffer from, other military and civilian radio frequency (RF) systems currently in use or planned for operational environments.
- The effect of the system's proposed spectrum use on the ability of the extant force structure to access the RF spectrum without interference.
- How the system's spectrum use conforms to the tables of frequency allocation of intended host nations, ensuring regulatory protection from other national co-band spectrum users.
- Whether or not individual host-nation frequency allocations include enough bandwidth to fully support the system's operational mission—for example, the required data rate.

Assessing these topics of concern early in the design of equipment will save money in the long run. SSRAs will be required of programs at milestone reviews A, B, and C as part of the overall balance of program success against future risks. Figure 1 identifies a part of Table 2 in the DoDI 5000.02, Milestone and Phase Information Requirements, and it indicates that an SSRA must be developed early for any spectrum-dependent system program and that it must be updated at every major acquisition milestone. A Program Manager's (PM's) failure to obtain spectrum supportability for components in its systems could have direct consequences to the program in meeting performance, schedule, and cost objectives established by its Acquisition Review Board and to the Combatant Commander in meeting Joint Mission Area requirements.

SPECTRUM MANAGEMENT AND REQUIREMENTS

To better understand SSRAs, a little background is provided. In the DoD acquisition process, spectrum management usually begins with equipment spectrum certification, a process whereby a system is approved

SUPPORTABILITY RISK ASSESSMENTS: AN OVERVIEW

to operate in a particular spectral band. To actually operate the system, spectrum certification must be followed by obtaining a frequency assignment.

Obtaining frequencies to operate equipment in the United States is a two-step process, which is managed by the submittal of a properly filled out DD Form 1494. The first step is Equipment Spectrum Certification. The certification process assesses equipment transmit and receive characteristics to determine if the system complies with existing RF spectrum regulations. The second step, Frequency Assignment, coordinates operational use of specific frequencies within specific bands among current users so that they do not interfere with each other. The Manual of Regulations and Procedures for Radio

INFORMATION REQUIREMENT	PROGRAM TYPE[1]				LIFE-CYCLE EVENT[1,2,3]								SOURCE	APPROVAL AUTHORITY
	MDAP	MAIS	ACAT II	ACAT ≤ III	MDD	MS A	CDD Val	Dev RFP Rel	MS B[5]	MS C	FRP/FD Dec	OTHER		
PROGRAM CERTIFICATION TO THE DEFENSE BUSINESS SYSTEMS MANAGEMENT COMMITTEE (DBSMC)		•		•		•			•			•	10 U.S.C. 2222 (Ref. (g))	DBSMC Chair
STATUTORY; for DBS programs only. Due prior to obligation of funds for any DBS that will have a total cost in excess of $1 million over the period of the current Future Years Defense Program.														
Program Protection Plan (PPP)	•	•	•	•		•		✓	✓	✓	✓		DoDI 5200.39 (Ref. (ai)) DoDI 5200.44 (Ref. (aj) Para. 13a in Enc. 3, this instruction	MDA
Regulatory. A draft[4] update is due for the Development RFP Release decision and is approved at Milestone B. The PPP includes appropriate appendixes or links to required information. See section 13 in Enclosure 3 of this instruction.														
REPLACED SYSTEM SUSTAINMENT PLAN	•					•			•				10 U.S.C. 2437 (Ref. (g))	DoD Component
STATUTORY. May be submitted as early as Milestone A, but no later than Milestone B. Required when an MDAP replaces an existing system and the capability of the old system remains necessary and relevant during fielding of and transition to the new system. The plan must provide for the appropriate level of budgeting for sustainment of the old system, the schedule for developing and fielding the new system, and an analysis of the ability of the existing system to maintain mission capability against relevant threats.														
Request for Proposal (RFP)	•	•	•	•		•		•		•	•		Federal Acquisition Regulation Subpart 15.203 (Ref. (ak))	MDA is release authority
Regulatory. RFPs are issued as necessary; they include specifications and statement of work. See also Defense Federal Acquisition Regulation Supplement subpart 201.170 (Reference (al)) for the requirement for peer reviews.														
Should Cost Target	•	•	•	•		•		•	•	•	•		Para. 5d(3)(b)1 of this instruction	MDA
Regulatory. "Should Cost" is a regulatory tool designed to proactively target cost reduction and drive productivity improvement into programs. Paragraph 6e in Enclosure 2 of this instruction provides additional detail on "Should Cost."														
Spectrum Supportability Risk Assessment	•	•	•	•		•			•	•		•	DoDI 4650.01 (Ref. (am))	Component CIO or designee
Regulatory. Applicable to all systems/equipment that use the electromagnetic spectrum in the United States and in other host nations. Due at milestone reviews and prior to requesting authorization to operate (for other than testing) in the United States or in host nations.														

Table Notes:
1. A dot (●) in a cell indicates the specific applicability of the requirement to program type and life-cycle event, and represents the initial submission requirement. Moving right across a row, a checkmark (✓) indicates the requirement for updated information.
2. All of the "Life-Cycle Events" will not necessarily apply to all "Program Types."
3. Unless otherwise specified when discussed in this instruction, documentation for identified events will be submitted no later than 45 calendar days before the planned review.
4. Requires a Program Manager-, PEO-, and CAE-approved draft.
5. Information requirements that have been finalized and approved by the responsible authority in support of the Development RFP Release Decision Point do not have to be re-submitted prior to Milestone B unless changes have occurred. In that case, updated documents will be provided.
6. Incrementally Deployed Software Intensive Programs (Model #3) do not have a Milestone C and consequently are not required to satisfy the Table 2 requirements associated with that milestone.

Figure 1: SSRA Requirements in DoDI 5000.02 (January 7, 2015).

Frequency Management, issued by the Department of Commerce's National Telecommunications and Information Administration (NTIA), is the standard for both steps. The NTIA is the regulatory authority over all Federal equipment and spectrum in the United States and Possessions (US&P). The Federal Communications Commission (FCC) regulates non-Federal spectrum in the US&P.

It is important to remember that the SSRA is about *assessing risk*. The Risk Management Guide (RMG) for DoD acquisition defines *risk* as a measure of the potential inability to achieve overall program objectives within defined cost, schedule, and performance/technical constraints; it has two components: (1) the probability/likelihood of failing to achieve a particular outcome, and (2) the consequences/impacts of failing to achieve that outcome.

Accordingly, an SSRA should include the following components:

- **Regulatory Component**: Addressing the compliance of the RF system with U.S. national and international tables of frequency allocation as well as with regulatory agreements reached at the International Telecommunication Union.
- **Technical Component**: Quantifying the mutual interactions between a candidate system and other co-band, adjacent band, and harmonically related RF systems, including the identification of suggested methods to mitigate the effects of possible mutual interference.
- **Operational Component**: Identifying and quantifying the mutual interactions among the candidate system and other U.S. military RF systems in the operational environment and identifying suggested methods to mitigate for possible instances of interference. The objective is to quantify any risk that systems will not meet their performance requirements due to spectrum supportability issues.

> The SSRA is becoming increasingly important as the spectrum becomes increasingly more congested.

- **Electromagnetic Environmental Effects (E3) Assessment**: At a minimum, electromagnetic compatibility (EMC) and electromagnetic interference (EMI) are to be addressed to determine the potential for interactions between the proposed system and its anticipated operational electromagnetic emissions (EME).

Ideally, an initial SSRA is generated in the early stages of the DoD acquisition process. Early identification of major regulatory and technical issues allows program office personnel to focus attention and resources on critical spectrum issues in the later acquisition phases. The owner of the SSRA compiles input from several sources. These sources include the following:

- Technical and regulatory information are obtained from DoD databases—specifically, the:
  - Spectrum Certification System (SCS) database, which is used to generate lists of co-band and adjacent band DoD emitters, providing an overview of other systems sharing expected electromagnetic environments.
  - Host Nation Spectrum Worldwide Database Online (HNSWDO) database, which is used to identify host nation comments on previous systems in the same frequency band and with similar technical parameters as the system being acquired.
  - U.S. and non-U.S. tables of allocation, which can be obtained in many cases directly from the internet.
- The latest pertinent Host Nation supportability comments are obtained by the Program Management Office (PMO) from the Combatant Command (COCOM) spectrum managers. The COCOM spectrum managers will forward any resulting comments to the authors of the SSRA.
- The PMO defines the system's technical parameters and intended operational deployment required for spectrum support (e.g., the frequency bands of interest and the intended worldwide development, test and operational areas, and host nations).

The major result of the SSRA may be that the PMO considers options such as changing the system's spectrum use or other technical parameters or beginning consultations with the cognizant Spectrum Management Office (SMO) regarding possible courses of action. Typical courses of action can include coordinating bilateral negotiations with individual host-nations or briefing the spectrum requirements of the system to groups such as the NATO Frequency Management Sub-Committee (FMSC), the DoD Spectrum Summit, or various COCOM spectrum conferences. All PMO involvement with these groups must be closely coordinated with the cognizant service SMO and DoD representatives.

CONCLUSION

Spectrum supportability is not something that can be assumed; spectrum demands are increasing, and the amount of available spectrum is decreasing. The requirement to perform and submit SSRAs is part of the DoD effort to ensure that the military does not continue to field systems with spectrum and/or interference problems. From the list of items specified in DoDI 4650.01, one also must recognize that producing a meaningful SSRA is a significant engineering undertaking that must be thoughtfully planned and executed. An understanding of the entire gamut of required information and the sources and availability of that information, as well as the technical ability to collate, analyze, and present the data, require specialized expertise. And because the SSRA is a relatively new requirement, identifying knowledgeable and experienced help to produce and review an SSRA can prove to be challenging. Accordingly, good sources for additional guidance in this area include the "Joint Services Guide for Development of a SSRA" (available at **acc.dau.mil/library**) [1] and the Services' SMOs.

Finally, for those individuals tasked with spectrum supportability and related tasks and considerations, the following reminders are given:

- Consideration of spectrum supportability is a critical tenet for program success.
- Spectrum supportability requires application of resources and knowledgeable people.
- Spectrum supportability resources should be applied early in a program life cycle and should be coordinated with the SMO.
- Thoughtful planning and risk management regarding spectrum supportability will return big savings in terms of unanticipated rework. ■

BIOGRAPHY

BRIAN FARMER is Senior Engineer with EMC Management Concepts, a small company specializing in spectrum supportability and EMC consulting for the DoD. He earned a B.S. in aerospace engineering from Virginia Tech and an M.S. in systems engineering/technical management from The John Hopkins Whiting School of Engineering. He has worked in the EMC and spectrum engineering area since the late 1980s, first providing EMC engineering support for Navy aircraft platforms, later managing technical efforts in support of the Air Systems EMI Corrective Action Program, and now consulting to the Defense Spectrum Organization, managing EMC and spectrum training development and policy management efforts.

MARTHA KLEIN is the Electromagnetic Environmental Effects (E3) Chief Scientist for the SURVICE Engineering Company. With approximately 28 years of experience and technical expertise in E3, directed energy weapons (DEW), and nuclear weapons effects (NEW), she currently supports all aspects of the military in E3 test and evaluation to determine the operational effectiveness of military systems. She holds a B.S.E.E. from the University of Wyoming.

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DTIC SEARCH TERMS:
Spectrum Supportability Risk Assessments

RESULTS: 909

- Logistics, Military Facilities & Supplies (1210)
- Administration & Management (1066)
- Test & Evaluation (1006)
- Acquisition (817)
- Military Operations, Strategy & Tactics (800)
- Department of Defense (708)
- Defense Systems (641)
- Weapon Systems (622)
- Operational Effectiveness (594)
- Aircraft (567)

*See page 8 for explanation ▸

BLAST DATA VISUALIZATION PART 2:

Generating 3-D Animations with Python

By Will Woodham

ONWARD WITH 3D ANIMATIONS

In Part 1 of this two-part series on blast data visualization article (see the fall 2014 edition of the *DSIAC Journal*), we learned how to turn simple test data into professional-looking, full-color two-dimensional (2-D) graphs using Python and Matplotlib. However, most people would agree that animations are generally more interesting to watch than a static 2-D illustration. Thus, in Part 2, we now discuss how to use Python and VPython to take test data visualization to the next level by creating (three-dimensional) 3-D animations from blast test data that one might have on hand.

First, let's examine a few sample data plots produced by a Python program called *Test_Data_Animate.py*. This application is available at **http://www.piezopy.org/** under the code snippets pull-down menu. To operate this program, one will need a text file containing acceleration data from accelerometers mounted to four corners of a test plate exposed to blast loading. As illustrated in Figure 1, the program works by calculating velocity and displacement using composite trapezoidal rule numerical integration, as well as plots acceleration, velocity, and displacement data.

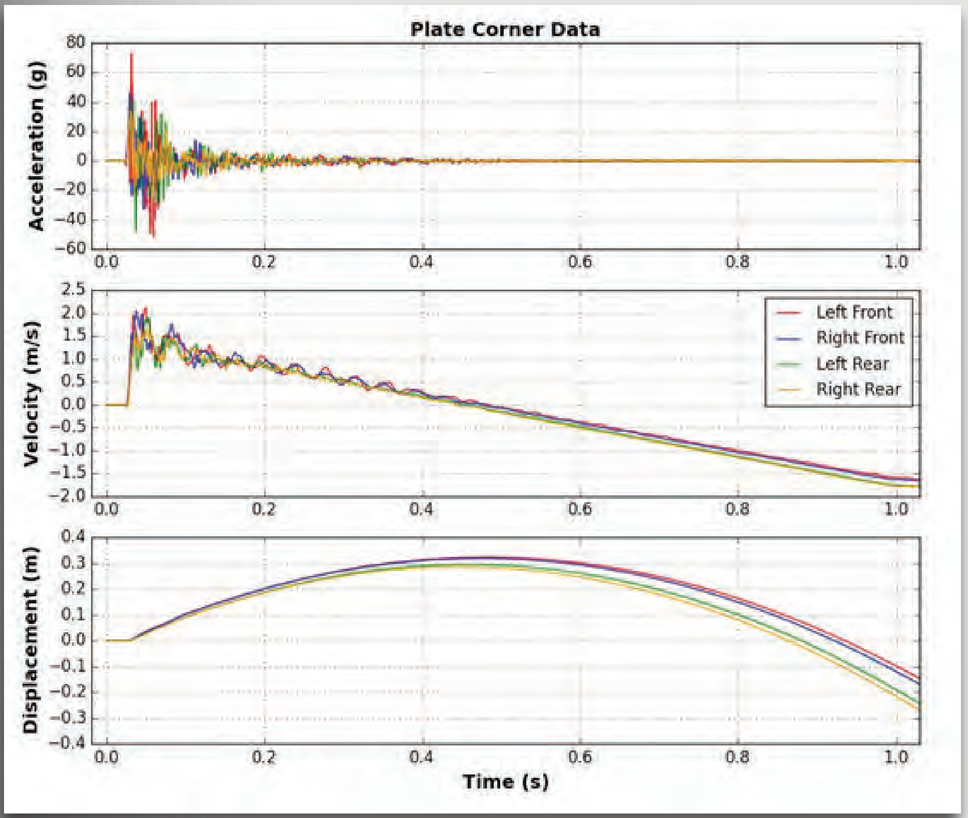

Figure 1: Sample Blast Test Data.

Using these data, the program generates a navigable 3-D display window containing a 3-D animation of the motion of the plate, as illustrated in Figure 2. (One can also observe the full-motion video of this animation at **http://www.piezopy.org/** under the videos pull-down menu.)

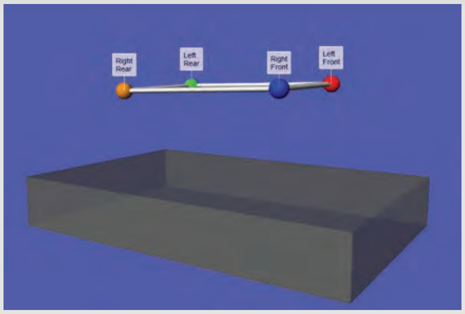

Figure 2: 3-D Animation of Blast Test Data.

Before we dive into a detailed description of the code's operation, let's take a step back and consider the physics and math used to create an animation based on these data and what we know about its origins. If one had the opportunity to watch the actual test, one would have seen the plate exposed to the blast physically move in response to the blast loading. Capturing the motion that took place in the physical world and recreating this motion in the virtual (computer-based graphics) world is our goal. So how do we do this? First, we must recognize that the motion of an object is simply a change in its position with respect to time. Change in position is also known as displacement, which is typically measured in our physical space in three dimensions. To create a 3-D animation, one needs to be able to track the physical displacement of an object in all three dimensions and then translate the data into a virtual 3-D coordinate system. So displacement is needed in three dimensions. However, as mentioned previously, our measured test data will only provide the acceleration in the vertical dimension for the four corners of a plate. Fortunately, we can derive what we need from this measured data assuming the following statements are true:

- The plate has a starting position that is parallel with the ground.
- The horizontal and lateral positions of one of the corners remain constant throughout the test.
- The length and width dimensions of the plate do not change.

If all of these conditions are true, then we can leverage these initial conditions and physical constraints to derive the horizontal and lateral displacement of the plate from the relative vertical displacement at the four corners. So how do we get displacement from acceleration? This is where some mathematics comes in. Calculus provides us a convenient method for describing the rate of change of something with respect to something else—for example, the rate of change of displacement with respect to time (velocity) or the rate of change of velocity with respect to time (acceleration). Because acceleration is related to velocity and displacement, with a little calculus we can derive the displacement data we need for our animation from the acceleration data we measured during the blast test. To do this, let's first refresh our understanding of calculus and how we are going to apply it in this application.

There are two main branches of calculus, differential calculus and integral calculus, and they are inverse operations of each other. Differential calculus will be applied to take us from displacement to velocity and from velocity to acceleration by calculating derivatives. Integral calculus will be applied to take us in the opposite direction by calculating integrals. So in our application, we use integral calculus to go from acceleration to velocity to displacement. More specifically, we use numerical integration, for which we have some readily available Python functions based on validated algorithms. Armed with this information, let's step through *Test_Data_Animate.py* a few lines at a time to examine exactly how the Python code can be used to derive velocity and displacement data from acceleration data and how we can generate a 3-D animation from these data.

Our first step is to import the required modules, as indicated in the source code pictured in Figure 3, to extend Python's capabilities to include scientific computing (*numpy*), a plotting graphics library (*matplotlib*), text file reading and writing (*csv*), numerical integration (*scipy.integrate*), a 3-D graphics module (*visual*, aka vpython), and a time clock utility (*time*).

```
#import python modules
import numpy as np
import matplotlib.pyplot as plt
import csv
from scipy import integrate
from visual import *
import time
```

Figure 3: Python Module Import Source Code.

The next section of the program contains three separate functions: *samplecount()*, *construct()*, and *samplerate()*, as indicated in the source code pictured in Figure 4. These are subprograms that take in input arguments from the main program and return an output as requested by the main program.

```
#function to count number of samples in a data file
def samplecount(proj_folder,data_file,hrows):
    with open(proj_folder+data_file, 'rt') as f:
        reader = csv.reader(f, delimiter=',')
        row_count = sum(1 for row in reader)
    n=row_count-hrows
    return n

#function to construct a data array
def construct(proj_folder,data_file,col,n,hrows):
    da = np.arange(0,n, dtype=float)
    i=0
    with open(proj_folder+data_file, 'rt') as f:
        reader = csv.reader(f, delimiter=',')
        for j in range(hrows):
            next(reader)
        for row in reader:
            np.put(da,[i], row[col])
            i=i+1
    return da

#function to calculate sample rate
def samplerate(n,t):
    sr = int(n/(t.max()-t.min()))
    return sr
```

Figure 4: Required Python Functions.

The following steps are executed by the main program.

Step 1: Identify the data file and specify the data to be read in from the file.

The source code pictured in Figure 5 is used to accomplish this step. We described file structure of the *Plate_Inputs.txt* file in Part 1 of this article series.

Step 2: Read the data into separate arrays for each data column.

Before we read the data into arrays, we need to count the number of data rows to be processed. This will provide the length of each data array, which is the number of samples (*n*) for each measurement type. A call to the *samplecount()* function, pictured in Figure 6, with the required inputs is used to obtain the result. The *samplecount()* function uses the *csv* module to count the total number of rows in the file and then subtracts the number of header rows to get *n*.

Now that we know the number of samples, we are ready to read the data values into five separate arrays: *t* for the time measurements, and *LF_a*, *RF_a*, *LR_a*, and *RR_a* for the vertical acceleration measurements. Five separate calls to the *construct()* function, pictured in Figure 7, are used. The *construct()* function uses the *csv* module to read each measurement in a specified column of data and then stores these values in the assigned array.

Step 3: Calculate sample rate (*sr*) and time step (*dt*).

The sample rate (*sr*), given in samples/second, is the rate at which data were recorded during the test event. The time step (*dt*), given in seconds, is the reciprocal of sample rate and is the time interval between samples. Both *sr* and *dt* are used in the animation process. To make these calculations more straightforward, we can shift the time array to start at zero and convert the time data units from milliseconds to seconds, as pictured in Figure 8. A call to the *samplerate()* function on line 86 with the required inputs is used to obtain sample rate. The time step is easily obtained by the calculation on line 89.

Step 4: Use numerical integration to calculate velocity and displacement.

Numerical methods are used for solving equations or mathematical models too complicated or too time-consuming for an analytic solution. Using integral calculus to obtain velocity and displacement data from our blast response data is a perfect example of this type of problem. There are numerous methods available for numerical integration. We will focus on a method called composite trapezoidal rule numerical integration, which is well-suited to our task.

To refresh everyone's memory, there are two types of integrals in calculus,

```
55  #identify data file
56  proj_folder = 'C:/Users/Admin/Documents/PyData/blast/'
57  data_file = 'Plate_Inputs.txt'
58
59  #specify number of header rows
60  hrows = 6
61
62  #identify data columns
63  #Column 0 = Time (ms)
64  #Column 1 = LF Corner a (g)
65  #Column 2 = RF Corner a (g)
66  #Column 3 = LR Corner a (g)
67  #Column 4 = RR Corner a (g)
```

Figure 5: Identify Data File and Data Columns.

```
69  #count number of samples
70  n=samplecount(proj_folder,data_file,hrows)
```

Figure 6: Count Data Samples.

```
72  #read data and create arrays
73  t = construct(proj_folder,data_file,0,n,hrows)
74  LF_a = construct(proj_folder,data_file,1,n,hrows)
75  RF_a = construct(proj_folder,data_file,2,n,hrows)
76  LR_a = construct(proj_folder,data_file,3,n,hrows)
77  RR_a = construct(proj_folder,data_file,4,n,hrows)
```

Figure 7: Read Data and Create Arrays.

```
79  #shift time array to start at zero
80  t = t - t[0]
81
82  #convert ms to seconds (if necessary)
83  t = t/1000
84
85  #calculate sample rate
86  sr = float(samplerate(n,t))
87
88  #calculate time step
89  dt = float(1.0/sr)
```

Figure 8: Source Code for Calculating *sr* and *dt*.

definite and indefinite. An indefinite integral is solved for all values of *x* in a function *f(x)*. A definite integral is solved for a specified interval of *x* values in a function *f(x)*. Solving the definite integral of a function is graphically equivalent to calculating the area under the curve between limits *a* and *b*, as illustrated in Figure 9.

The trapezoidal rule is a method of approximating the area under the curve by replacing a complicated function with a straight line function. The new function is easy to integrate and reduces the problem to an algebraic equation, as illustrated in Figure 10.

Although this approach makes calculation of the area approximation easy to do with a computer, it does not provide an accurate result, as indicated by the large error shown in the region bounded by the original function and the straight line. However, the error can be reduced by dividing the interval between limits *a* and b into sub-regions or segments each containing a trapezoidal shaped area approximation, as illustrated in Figure 11.

> Capturing the motion in the physical world and recreating it in the virtual world is our goal.

The method can then be applied to each segment and the results added together to obtain the integral approximation for the entire interval. The resulting equations are called composite integration formulas. As the number of segments used in this process is increased, the error is reduced. However, for test data such as the blast response data we are using, the maximum number of segments is limited by the sampling rate of the data. For a given interval of data with *n* samples, the maximum number of segments is *n*-1.

Fortunately, our data were sampled at a high enough sampling rate to obtain a solution with reasonable accuracy. To implement the composite trapezoidal rule for our acceleration data, we will use an algorithm developed for Python called the *scipy.integrate.cumtrapz()* function. This function is indicated in lines 95–98 of the source code pictured in Figure 12, and it is used to obtain velocity from our acceleration data. It is used again on lines 101–104 to obtain displacement from velocity. Because our acceleration data were recorded in

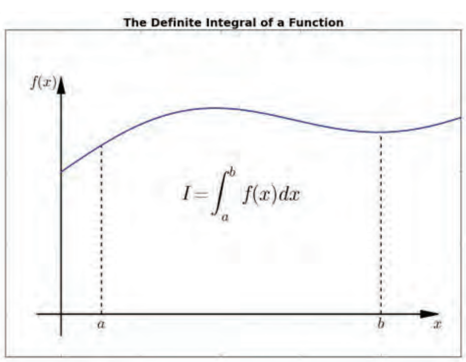

Figure 9: The Definite Integral of a Function.

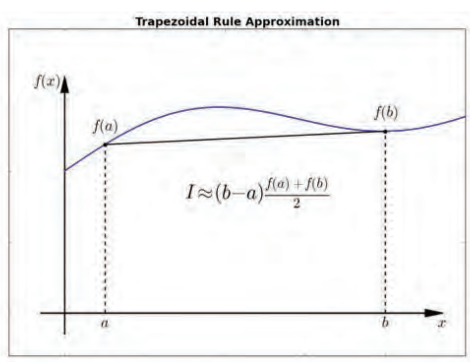

Figure 10: Trapezoidal Rule Approximation.

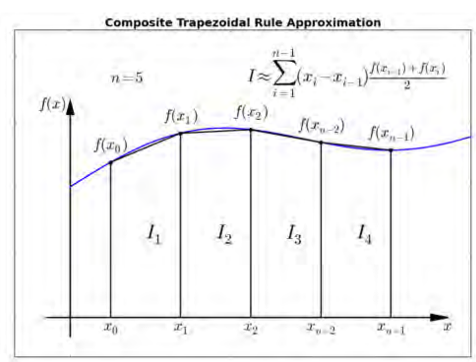

Figure 11: Composite Trapezoidal Rule Approximation.

```
#Define Acceleration due to gravity on Earth
G = 9.81 #meters per second squared

#Calculate Velocity Data in (m/s)
LF_v = integrate.cumtrapz((LF_a*G),t,initial=0.)
RF_v = integrate.cumtrapz((RF_a*G),t,initial=0.)
LR_v = integrate.cumtrapz((LR_a*G),t,initial=0.)
RR_v = integrate.cumtrapz((RR_a*G),t,initial=0.)

#Calculate Displacement Data in (m)
LF_s = integrate.cumtrapz((LF_v),t,initial=0.)
RF_s = integrate.cumtrapz((RF_v),t,initial=0.)
LR_s = integrate.cumtrapz((LR_v),t,initial=0.)
RR_s = integrate.cumtrapz((RR_v),t,initial=0.)
```

Figure 12: Python Velocity and Displacement Algorithm.

units of g force, we must convert those data to units of meters/second^2 to obtain the desired units for velocity and displacement.

Step 5: Plot acceleration, velocity, and displacement.

The source code pictured in Figure 13 generates a set of three graphs showing acceleration, velocity, and displacement with respect to time for the four corners of our test plate. A more in-depth description of 2-D plotting with Python and Matplotlib was discussed in Part 1 of this article series.

Step 6: Set up the 3D animation environment.

Now that we have the displacement data we need, we can start to set up the 3-D environment that we will use for our animation. This is where the VPython 3-D graphics module called "visual" comes into play. VPython makes it easy to create navigable 3-D displays and animations. First, we define the 3-D scene with the source code pictured in Figure 14, lines 157–162.

```
#Plot the Data
fig1 = plt.figure(figsize=(11,9))
ax1 = plt.subplot2grid((3,3), (0,0), colspan=3)
ax2 = plt.subplot2grid((3,3), (1,0), colspan=3)
ax3 = plt.subplot2grid((3,3), (2,0), colspan=3)

#Plot Acceleration
ax1.plot(t, LF_a, 'red')
ax1.hold(True)
ax1.plot(t, RF_a, 'blue')
ax1.plot(t, LR_a, 'green')
ax1.plot(t, RR_a, 'orange')
ax1.grid()
ax1.set_xlim(-0.02,1.03)
ax1.set_title('Plate Corner Data', fontsize=14,\
    fontweight='bold')
ax1.set_ylabel('Acceleration (g)', fontsize=14,\
    fontweight='bold')

#Plot Velocity
ax2.plot(t, LF_v, 'red')
ax2.hold(True)
ax2.plot(t, RF_v, 'blue')
ax2.plot(t, LR_v, 'green')
ax2.plot(t, RR_v, 'orange')
ax2.grid()
ax2.set_xlim(-0.02,1.03)
ax2.legend(('Left Front', 'Right Front', 'Left Rear',\
    'Right Rear'), fontsize=12)
ax2.set_ylabel('Velocity (m/s)', fontsize=14,\
    fontweight='bold')

#Plot Displacement
ax3.plot(t, LF_s, 'red',lw='1')
ax3.hold(True)
ax3.plot(t, RF_s, 'blue',lw='1')
ax3.plot(t, LR_s, 'green',lw='1')
ax3.plot(t, RR_s, 'orange',lw='1')
ax3.grid()
ax3.set_xlim(-0.02,1.03)
ax3.set_xlabel('Time (s)', fontsize=14, fontweight='bold')
ax3.set_ylabel('Displacement (m)', fontsize=14,\
    fontweight='bold')

#Save the figure
fig1.savefig(proj_folder+'Plate_Corner_Plots.png')

#Display the graph
plt.show()
```

Figure 13: Python Data Plotting Algorithm.

In the source code pictured in Figure 15, we define (on line 165) a 3-D object called "ground," which takes the form of a semi-transparent box. We then define the length (L) and width (W) dimensions of our test plate on lines 169–170. On lines 173–177, color-coded spheres are created to represent the corner points of our test plate. On lines 180–182, a multi-segmented curve is added to define the plate edges. Finally, we add labels on lines 185–196 to help identify each of the corners of the test plate.

```
#Define the 3D scene
scene1 = display(title='Test Data Motion Simulator',\
    x=0, y=0, width=1280,height=720,center=(0.5,0,0.5),\
    background=(0.3,0.3,1))
scene1.range = 1.8
scene1.forward = vector(-0.4,-0.1,-0.6) # look forward
scene1.autoscale = False
```

Figure 14: Defining the 3-D Scene.

```
164 #Define ground plane
165 ground = box (pos= (0.5,-0.375,0.33), length=2,width=1.33,\
166 height=0.3,color=(0.5,0.5,0.2),opacity=0.5)
167
168 #Define Plate Dimensions
169 L = 1.0
170 W = 2*L/3
171
172 #Define plate corner points
173 R = L/20
174 LR = sphere(pos=vector(0,0,0), radius=R, color=color.green)
175 RR = sphere(pos=vector(0,0,W), radius=R, color=color.orange)
176 RF = sphere(pos=vector(L,0,W), radius=R, color=color.blue)
177 LF = sphere(pos=vector(L,0,0), radius=R, color=color.red)
178
179 #Define plate edges
180 profile = curve(pos=[(LR.x,LR.y,LR.z), (RR.x,RR.y,RR.z),\
181     (RF.x,RF.y,RF.z),(LF.x,LF.y,LF.z),(LR.x,LR.y,LR.z)],\
182     radius=0.015, color=color.white)
183
184 #Add labels
185 LFlabel = label(pos=(LF.x,LF.y,LF.z), text = 'Left\nFront',\
186     color=color.black,background=color.white, yoffset=30,\
187     border=6,font='helvetica',height=14)
188 RFlabel = label(pos=(RF.x,RF.y,RF.z), text = 'Right\nFront',\
189     color=color.black,background=color.white, yoffset=30,\
190     border=6,font='helvetica',height=14)
191 LRlabel = label(pos=(LR.x,LR.y,LR.z), text = 'Left\nRear',\
192     color=color.black,background=color.white, yoffset=30,\
193     border=6,font='helvetica',height=14)
194 RRlabel = label(pos=(RR.x,RR.y,RR.z), text = 'Right\nRear',\
195     color=color.black,background=color.white, yoffset=30,\
196     border=6,font='helvetica',height=14)
```

Figure 15: Defining 3-D Objects.

If we were to stop here, the program would generate the navigable 3-D display illustrated in Figure 16. To make objects move within the display, we need to add more code and use the displacement data we obtained earlier to create an animation sequence.

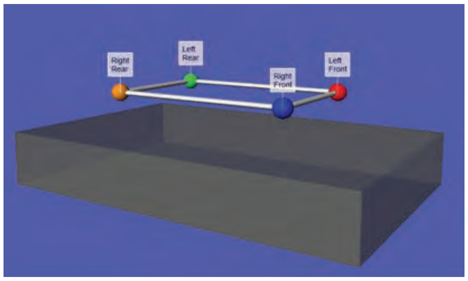

Figure 16: 3-D Objects at Start of Animation Sequence.

Step 7: Create a 3-D animation sequence

The source code pictured in Figure 17 is used to set up the animation sequence by creating an initial "pre-shot" time delay or countdown on line 199 so that when the display is first rendered, no motion is taking place until the time delay is completed. Before the animation loop begins on line 206, the initial value for the time variable (*t1*) is set to the first value in the time data array on line 202 and the loop continuation variable is set to true on line 205. The animation loop contains a rate() statement to limit the number of loop iterations/second on line 208. In this case, we use the sample rate (*sr*) as the limiting factor.

```
198  #Countdown to blast detonation
199  time.sleep(3.0)
200
201  #Initialize start time
202  t1 = t[0]
203
204  #Run animation
205  run = True
206  while run:
207      #Define rate
208      rate(sr)
```

Figure 17: Animation Source Code.

In lines 211–214 of the source code pictured in Figure 18, the test plate corner marker vertical position (*y*) values are updated based on the previously calculated vertical displacement array values corresponding to the current time (*t1*) value. Maintaining constant plate length and width dimensions and using Pythagoras's theorem allow for the updating of the horizontal (*x*) and lateral (*z*) corner positions on lines 215–218. The plate edges are then updated to correspond to the new corner positions on lines 221–223, and the label positions are updated on lines 226–229. Advancing of the time step on line 232 prepares the way for the next pass through the animation loop. Finally, lines 235–236 terminate the animation loop when *t1* reaches a value greater than the last value in the time array.

```
210  #Update corner positions
211  LR.y = LR_s[int(t1/dt)]
212  RR.y = RR_s[int(t1/dt)]
213  RF.y = RF_s[int(t1/dt)]
214  LF.y = LF_s[int(t1/dt)]
215  LF.x = np.sqrt(L**2-(LF.y-LR.y)**2)
216  RR.z = np.sqrt(W**2-(RR.y-LR.y)**2)
217  RF.x = np.sqrt(L**2-(RF.y-RR.y)**2)
218  RF.z = np.sqrt(W**2-(RF.y-LF.y)**2)
219
220  #Update plate edges
221  profile.x = [LR.x, RR.x, RF.x, LF.x, LR.x]
222  profile.y = [LR.y, RR.y, RF.y, LF.y, LR.y]
223  profile.z = [LR.z, RR.z, RF.z, LF.z, LR.z]
224
225  #Update labels
226  LFlabel.y = LF.y
227  RFlabel.y = RF.y
228  LRlabel.y = LR.y
229  RRlabel.y = RR.y
230
231  #Advance time step
232  t1 += dt
233
234  #Terminate animation loop at end of data
235  if t1 > t.max():
236      run = False
```

Figure 18: Creating the Animation Sequence.

Creating 3-D animations is not difficult and can be quite useful for visualizing test event motion.

The VPython navigable 3-D display window remains open for user interaction after the plate animation has completed with the plate objects in their final positions at the end of the event, as illustrated in Figure 19.

Notice the plate appears to be partially buried in the ground object. This is

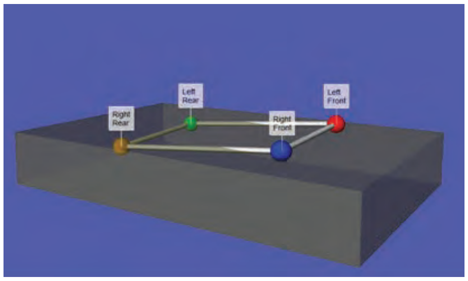

Figure 19: 3-D Objects at End of Animation Sequence.

a plausible situation in a blast event due to the crater created by the blast. That said, a word of caution is probably appropriate here with regard to data quality. Depending on several factors, including the placement and type of accelerometers used, the test data one has on hand may not be suitable for calculation of velocity and displacement and would therefore be unusable for animation purposes.

In conclusion, it has been shown here that if one has a suitable set of test data, creating 3-D animations using Python and VPython is not difficult and can be quite useful for visualizing test event motion. And with a little imagination and a proper application of math and physics, the animation possibilities are virtually limitless. ■

BIOGRAPHY

WILL WOODHAM is an employee of the SURVICE Engineering Company, supporting blast test data analysis for the U.S. Army Tank Automotive Research Development and Engineering Center. He has extensive experience in vehicle design and blast survivability analysis and is the author of a blog (at www.piezopy.org) advocating the development and use of open source software tools (such as Python) for blast data visualization and similar applications. Mr. Woodham holds a B.S. in Mechanical Engineering from the University of South Florida and an M.S. in Product Development from the University of Detroit Mercy.

DTIC SEARCH TERMS:
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*See page 8 for explanation ▸

NEW RELEASE ALERT - *Updated Brawler Version 8.1*

DSIAC would like to announce the latest release of Brawler Version 8.1 with respective documentation. Version 8.1 includes the following enhancements:

- Addition of Laser Warning System (LWS).
  - Avionics device that detects laser energy from a Directed Energy Weapon (DEW).
- DEW Acquisition/Tracking/Pointing (ATP).
  - More detailed modeling of the Acquisition/Tracking/Pointing systems for DEWs, including modeling of a Coarse Tracker and Tracking Illuminator, as well as Turret Slewing. Also includes pilot ability to see the ATP track.
- DEW Aimpoint Prioritization.
  - Ability of the user to prioritize and/or exclude target aimpoints for DEWs .
- Other DEW enhancements.
  - Addition of an optional Minimum Fire Time and Missile No-Reengage Time for the DEW.
- Addition of Missile vs. Missile (MvM).
  - Ability to fire a missile at another missile.
- Scripted Motion Players.
  - Adds scripted players, which move in a prescribed dimensional path defined by the user, without regard to aerodynamics. These players do not make any maneuver decisions, but do make all other decisions, such as avionics and weapon usage.
- Avionics/Weapons Characteristics & Status Block Uplifts.
  - Directed Energy Weapon, Missile Launch Warning, and Infrared Search and track characteristic and status block memory items have been uplifted to Fortran 2008-type instances.


U.S. Air Force

- New/updated TMAP models.
  - List is included in the classified release.
- Completion of 22 Software Change Requests (SCR).

CONFERENCES AND SYMPOSIA

APRIL 2015

Joint Undersea Warfare Technology Spring Conference
31 March–1 April 2015
Admiral Kidd Conference Center
San Diego, CA
http://www.ndia.org/meetings/5260/Pages/default.aspx ▸

Ground Robotics Capabilities Conference & Expo
7–8 April 2015
Crystal Gateway Marriott
Arlington, VA
http://www.ndia.org/meetings/5380 ▸

31st Space Symposium
13–16 April 2015
The Broadmoor Hotel
Colorado Springs, CO
http://www.spacesymposium.org/ ▸

SPIE DSS Expo
20–24 April 2015
Baltimore Convention Center
Baltimore, MD
http://spie.org/x6765.xml ▸

2015 Armaments Systems Forum
20–22 April 2015
Baltimore Marriott Inner Harbor
Baltimore, MD
http://www.ndia.org/meetings/5590/Pages/default.aspx ▸

Threat Weapons Effects 2015
28–30 April 2015
Ben E. King Commando Auditorium
Hurlburt Field AFB, FL
https://www.signup4.net/public/ap.aspx?EID=JASP90E&OID=50 ▸

Directed Energy to DC Exhibition
28–30 April 2015
The Rayburn House Office Building
Washington, DC
http://www.deps.org/DEPSpages/DE2DC15.html ▸

MAY 2015

AHS International's 71st Annual Forum and Technology Display
5–7 May 2015
Virginia Beach Convention Center
Virginia Beach, VA
https://vtol.org/events/ahs-71st-annual-forum-and-technology-display ▸

19th Test Instrumentation and the 14th Directed Energy T&E Workshops
12–15 May 2015
Tuscany Suites
Las Vegas, NV
http://www.itea.org/component/content/article/35-share/conferences/325-19th-test-instrumentation-and-the-14th-directed-energy-t-e-workshops.html ▸

The SpecOps Warfighter West Expo
12–14 May 2015
MWR Fest Tent
Joint Base Lewis McChord, WA
http://www.specopswest.com/Content/Welcome ▸

14th Annual Naval IT Day
14 May 2015
Vienna, VA ▸

Insensitive Muntitions & Energetic Materials (IMEM) Symposium
18–21 May 2015
Sheraton Roma Hotel
Rome, Italy
http://www.imemts2015.com/ ▸

The Association of the United States Army
19–21 May 2015
Sheraton Waikiki
Honolulu, HI
http://ausameetings.org/lanpac/ ▸

Defense Intelligence Information Enterprise
19 May 2015
George Mason University
Fairfax, VA
http://www.afei.org/events/5A07/Pages/default.aspx ▸

Intelligent Ships Symposium (ISS) 2015
20–21 May 2015
University of Pennsylvania Annenberg Center
Philadelphia, PA
https://www.navalengineers.org/events/individualeventwebsites/Pages/ISS2015.aspx ▸

JUNE 2015

2015 Armament Small Arms Forum
1–3 June 2015
Hanover Marriott
Whippany, NJ
http://www.ndia.org/meetings/5610/Pages/default.aspx ▸

International Conference on Icing of Aircraft, Engines, and Structures
22–25 June 2015
Hotel International Prague
Prague, The Czech Republic
http://www.sae.org/events/icing/ ▸

Mega Rust 2015: Naval Corrosion Conference
23–25 June 2015
Newport News Marriott
Newport News, VA
https://www.navalengineers.org/events/individualeventwebsites/Pages/MegaRust2015NavalCorrosionConference.aspx ▸

Note: For the latest listing of events related to Defense Systems, please visit www.dsiac.org/events ▸

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