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Electric Ship Research at the Naval Postgraduate School

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Abstract—This paper gives an overview of current research at the Naval Postgraduate School on electric ships. Various academic departments and groups are studying directed energy weapons, electromagnetic railguns and aircraft launchers, power systems, infrared and acoustic signature reduction, and thermal management for electric ships. Researchers in each of these areas describe their recent and ongoing work.

I. INTRODUCTION

The Naval Postgraduate School (NPS) is an academic institution whose emphasis is on study and research relevant to the interests of the Navy, the Department of Defense, and the Department of Homeland Security. Nearly 1500 students attend the school, including officers from the five U.S. uniformed services and approximately 30 other countries. Additionally, about 6000 officers and defense civilians take non-degree executive, professional and distance-learning courses through NPS. There are about 300 faculty at the school, most of whom are civilians. In addition to teaching, the faculty conduct military-relevant research in many areas, some of which is classified.

NPS is a leader in the design of future electric ships. Our research includes work on pulsed power sources, the design and integration of directed energy weapons, railguns, and EM aircraft launch systems, and reducing the IR and acoustic signatures of electric ships. Below is a brief description of recent results and current research in each of these areas.

II. DIRECTED ENERGY (BLAU AND COLSON)

The NPS Directed Energy (DE) research group consists of four physics faculty, six graduate students, and a computer specialist. Over the past 15 years, we have graduated over 50 MS students and four PhDs with DE-related theses. Our students take courses in computer simulations and weapon systems, in which they study relevant DE systems such as free electron lasers (FELs), and they use what they learn in these courses, together with their military experience, to contribute to our research and to develop their theses.

Each year, we publish about a half dozen papers and give about a dozen conference presentations, with students actively involved in both publications and presentations. Supporters of our program include Admirals Mathis and Cohen and Captain McGinnis. Our primary funding sources are ONR, JTO and NAVSEA. We collaborate with many universities, laboratories

and companies, including University of Maryland, University of Texas, Stanford, AFIT, Jefferson Lab, Los Alamos, NRL, Advanced Energy Systems and Northrup Grumman. In addition, we participate on many national panels that decide issues on the development of directed energy weapons research.

A. Directed Energy Naval Missions

The primary naval mission for a directed energy weapon is close-in defense against sea-skimming cruise missiles, a serious threat to the fleet for which there is currently no adequate defense. A missile 10 km away, approaching at Mach 1, will impact in less than 30 seconds. Traditional defensive weapons such as the Phalanx gun may not be able to destroy the missile before it gets close enough to cause damage to the ship. A speed-of-light weapon such as an FEL could destroy the missile at a distance of 5-10 km, by burning a hole through the missile surface; the structural damage would cause the missile to self-destruct and fall harmlessly into the ocean. A typical engagement would require about a MW of power on the target for a few seconds. Other threats that a DE weapon could address are small watercraft and small aircraft, and perhaps even theater ballistic missiles.

B. FEL Weapon System Design

Students and faculty in several NPS departments recently collaborated on the design of an all-electric ship incorporating FELs for ship defense and railguns for shore support [1]. The ship would have about 100 MW of available power that would be shared between the electric drive and weapon systems [2]. A typical FEL engagement would require about 10 MW of power from the ship over 5 seconds, to deliver 1 MW to the target, assuming an overall system efficiency of 10%. Note that this engagement would only consume a few gallons of ship fuel to generate the required electric power, costing a small fraction of a traditional weapon engagement, with an essentially unlimited magazine.

An FEL [3], [4] creates light by accelerating electrons to relativistic speeds, then “wiggling” them in a series of alternating magnets called an undulator. The electrons bunch on a microscopic scale and radiate coherent light. The wavelength of the light is determined by the energy of the electrons and the properties of the undulator. The light is then stored and amplified in a optical resonator, consisting of an evacuated

cavity enclosed by two mirrors, one of which is partially transparent to outcouple a portion of the light, for use in this case as a laser weapon.

An FEL has a couple of important advantages over a traditional laser. First, the wavelength is selectable over a broad range of the spectrum, from microwaves to X-rays. The operating wavelength of an FEL is determined by the properties of the electron beam and undulator. For our application, this allows us to select a wavelength that is best for atmospheric propagation and/or target damage, and also to adjust the wavelength for different weather conditions or targets. Also, an FEL can potentially be high-power without thermal degradation, because there is no chemical or solid-state medium in the cavity, only electrons which are removed at almost the speed of light before they have a chance to heat up.

Over the past 25 years, hundreds of FELs have been operated around the world. The most powerful one is at Jefferson Lab (Jlab), which has produced up to 10 kW of average power. Our research group at NPS has been closely involved in the design of this FEL, including modeling and simulation efforts, and we are now studying more powerful lasers based on the Jlab design.

There are a couple of features of the Jlab FEL that are significant for FEL weapon design. The first is the use of a superconducting accelerator, which can boost the electrons up to the required energy in just a few meters. The second feature is that after the electrons are used to create and amplify light in the undulator, they are recirculated back to the accelerator, where most of their energy is recovered, greatly enhancing overall system efficiency, and reducing the shielding requirements and weight of the beam dump.

One issue that still needs to be addressed is heating of the cavity mirrors. For the Jlab FEL, liquid-cooled titanium sapphire mirrors have been developed, that can withstand optical intensities on the order of 100 kW/cm². However, an FEL weapon system will need to produce much greater power than the Jlab system, and also be compact enough to fit on a ship, pushing the limits of what the mirrors can withstand. At NPS, we developed the concept of a short-Rayleigh length FEL design in which the mirrors are more curved than normal, creating an optical mode that is strongly-focused in the center of the optical cavity, but spreads out more at the mirrors to reduce the intensity [5]. We have done extensive modeling of such a design [6], and believe it is quite feasible, although it has yet to be tested experimentally.

C. Current and Future Research

We are currently involved in design plans for more powerful FELs, based on the Jlab design and using short-Rayleigh length cavities. An important issue that we are studying is the effect of system vibrations on laser performance; this is a serious consideration for putting a laser on a ship. We use our simulations to study the effects of shifting or tilting system components such as the mirrors and the electron beam [7]. We are also looking at other ship integration issues such as power

and cooling requirements, and the common elements for other systems that may be on electric ships, such as EM launchers and railguns. In particular, one of our current students is studying pulsed power systems in depth, including the pros and cons of shared versus separate supplies for each weapon system, and he is developing a model of a ship electrical system in collaboration with University of Texas. This model will be used to study the operation of these systems in various realistic scenarios.

We also simulate the propagation of laser beams through the atmosphere, looking at effects such as absorption, scattering, turbulence, and thermal blooming [8]. We have developed a simple model for classroom teaching of atmospheric propagation, and some of our students have extended this model and applied it to their thesis research, studying issues such as the difference between small-scale and large-scale turbulence effects [10]. This work is being done in collaboration with USNA, NRL, and LLNL.

Our students also develop concepts of operations (CONOPS) for using laser weapon systems in realistic naval scenarios, combining their military expertise with knowledge they have gained in NPS courses and thesis research [6], [9], [10]. The results of these CONOPS studies are being used to develop more realistic start-to-end models of DE weapon systems, in collaboration with Advanced Energy Systems, Northrup Grumman, and AFIT. Additionally, our students have studied the feasibility of employing DE weapons on other platforms such as tactical aircraft and C130s [11].

III. ELECTROMAGNETIC RAILGUNS AND AIRCRAFT LAUNCHERS (MAIER)

Electromagnetic railgun and launcher research at NPS focuses on innovative solutions to known technical problems, i.e., on technical approaches that are not being investigated at places with established milestones and declared methods. Lacking preset programmatic milestones, researchers at NPS have more freedom to try to solve difficult problems in alternate ways. The technical problems being researched at NPS fall under the categories of power conditioning [12], barrel design and life [13], and armature/projectile design [14].

A. Power Conditioning

Four students work on the possibility of using low-voltage high-density energy storage in place of either the inertial energy storage or high-voltage capacitors. CDR Jerry Stokes has examined the possibility of replacing the large generators that presently are planned to power electromagnetic aircraft launchers (EMALS) on carriers with ultracapacitors and a pulse forming inductive network (PFIN) [15]. He finds that ultracapacitors that may soon be available could provide the power for EMALS with an efficiency of about 25%. Although the size of the PFIN/ultracapacitor storage scheme is still large with present capacitors, maintenance, reliability, safety, and cost favor the PFIN. LT Dagmara Moselle is designing a high-voltage, high-current “double pole” mechanical switch

to handle the rather slow current switching requirements of the PFIN. ENS Michael Graham is examining the counter pulsing technique for fast switching of high currents [16]. This technique is certain to work, so the issues are those of size and convenience. LT Thomas Mays may start work on the PFIN with the intent of assembling and testing the first module of a 250 kJ railgun power supply storing energy at relatively low voltages (≈ 350 V).

B. Railgun Barrel Design

LT Juan Ubiera is testing a monolithic railgun barrel design. If successful, this barrel will significantly reduce manufacturing costs. Results so far are promising.

LT Brian Black is assembling a 24-long conventional railgun facility to provide test bed for various rail materials and projectile designs/materials. Parts have been ordered but assembly has not started.

C. Railgun Armature and Projectile Design

Capt. Jim Brady (Army) is designing a railgun projectile suitable for infantry direct-fire battlefield support. His approach is to examine many of the issues that influence the practicality of a round, e.g., shape, aerodynamics, target effect, caliber, range. He hopes to eliminate the sabot commonly used in railgun rounds and to limit effective range to less than 5 km.

LT Juan Rodarte has designed armature shapes that promise to make the current distribution over the rail-armature interface more uniform than is now the case [14]. The purpose is to eliminate the high current density hot spots that tend to occur at the edges and corners of conventional armatures. He has used a finite element code to solve the physical problem from first principles, and has developed projectile designs that differ from the usual C-shaped armatures most common in railgun research to maintain pressure on the rails.

IV. POWER SYSTEMS FOR ELECTRIC SHIPS (ASHTON)

The Power Systems option in the Electrical and Computer Engineering (ECE) Department was re-established in 1991 with an initial investment from NAVSEA03 and matching funds from the school. Within two years of the first power electronics class beginning, the power systems laboratory opened to augment the course material. Over the last decade, the school has been equipped to support thesis and class projects related to the all electric warship. For almost two decades prior to 1993, this was not the case. The option supports two full-time faculty members who concentrate on two specific areas within power: electronic converters and motors. A total of five graduate courses and one undergraduate refresher course define the option. Terrestrial power was not included due to vast differences in characteristics when compared to non-infinite bus structure present on military vessels. The distinct variation between a tradition and Navy centric power systems education is NPS's specialty.

Since 1992, more than seventy students, overwhelmingly Navy, have graduated from NPS via the completion of a

power systems thesis. These graduates are populating billets responsible for Navy decisions and acquisitions concerning the electric warship. Most of the theses efforts required hardware construction as well as simulation validation for completion. While there have been exceptions, most student's research has augmented existing faculty funded programs. The faculty has been actively involved in research projects concerning naval shipboard power, which include traditional high power dc-dc converters, soft-switching inverters and phase-controlled rectifiers along with more exotic topologies such as Science Applications International Corporation's (SAIC) Pulse Frequency Modulation (PFM) technology. The PFM, now known as the AC-Link, is a commercial product line via Princeton Power Systems (PPS). Aspects of the above research comprise both control and hardware development. Other past research projects included funding from Integrated Power System (IPS), Power Electronic Building Blocks (PEBB) and Integrated Fight-Through Power (IFTP) programs. Student contributions to these programs have been encouraged.

In 1993 LCDR Blalock was the first at NPS to develop a hardware-in-the-loop testbed for converters using a dSpace Digital Signal Processing (DSP) controller card programmed through the use of MATLAB Simulink. Now ONR is pursuing this development technique for medium voltage hardware. As part of the initial thrust by the Navy for a dc distribution system, LTs Badorf and Salerno developed prototype hardware and controller cards for a 200kW converter as a team effort with L3 Communications Power Systems Group (PSG) in Anaheim, CA. The Reduce Scale Advanced Development (RASD) dc-dc converter from the NPS-PSG team still resides in building 77H at NSWC Philadelphia. NPS has also partnered with Penn State and NSWC on the Auxiliary Resonant Commutated Pole (ARCP) inverter with the aid of LTs Floodeen, Hansen and Oberley. LTs Stallings and Whitcomb were involved in an effort to compare the attributes of a hard-switched converter with a comparable soft-switched version. LCDR Govier of NPS and Todd Lewis at NSWC developed a motor controller platform to study the controllability of a new type of Permanent Magnet (PM) machine. Other students have been involved in programs that supported the following research efforts: Marine AN/MRC-142 Uninterruptible Power Supply (UPS), Petite Amateur Navy Satellite (PANSAT) Power Supply, Universal Controller, and Trident RAD-Hard DC-DC Converters.

One of the faculty members, Associate Professor Robert Ashton, is actively contributing to ongoing efforts at the Naval Surface Warfare Center (NSWC), Philadelphia with the Land Based Engineering Site (LBES) which contains a variety of high power converters, inverters and phase-controlled rectifiers. He is an integral part of the Advanced Machinery Technology Branch (Code 985) NSWC, Philadelphia where he has a permanent office occupied approximately five months each year. At the request of specific vendors such as SatCon, Cambridge and Power Systems Group, Anaheim, Dr. Ashton has performed extended-time on-site technical advising to assist company engineers with various Navy power

electronic hardware development projects. He was a panel member for the FY2001 Naval Research Advisory Committee (NRAC) titled "Roadmap to an Electric Naval Force" and an "Execution and Demonstration Plan" technical advisor for Future Naval Capability (FNC) for the Electric Warship and Combat Vehicle. As a member of the Navy's technical team for IFTP and DDX, he has been actively reviewing hardware development at General Atomics, San Diego, PSG, Anaheim, DRS PCT, Milwaukee, DRS-PTI, Fitchburg, DRS-EPT, Hudson, SatCon, Baltimore, SatCon, Cambridge and Alstom Corporation, Rugby, UK.

A good portion of past NPS reimbursable research programs have been listed above. Current funding in the power systems area includes ONR's Fuel Cell program and ongoing development efforts for DDX. Assistant Professor Alex Julian has been responsible for the DSP controller for a 625kW fuel cell inverter with a power-section constructed by PSG. Prof. Ashton is currently on the Integrated Project Team (IPT) for the development of a 36.5MW homopolar motor drive (ONR) and is a committee member for DARPA's High Voltage SiC Switch program. Prof. Ashton has several thesis students assisting with other converter efforts for ONR and NSWCCD. Captain Souhan is now completing a follow-on thesis on a new control algorithm for an existing Cascaded Multi-Level Converter (CMLC). The CMLC, constructed at NPS by CDR Crowe, was close-loop controlled by Ensign Barlow via a dSpace card. These three theses are supplementing research performed by Prof. Keith Corzine at University of Missouri, Rolla for ONR and NSWCCD. Further a parallel-hybrid inverter is under development by LT Bittle who is continuing the work of Major White and Captain Fillmore.

In addition to thesis contributions, a number of former power system NPS students have been selected to occupy key positions related to the electric warship. Currently, CDR Crowe is the Deputy Director of Total Ship Power Systems Division NAVSEA 05Z3B. Another former power systems option student, LCDR Arrington, is assigned to the Program Executive Office (PEO) Ships PMS500I in support of the Integrated Power Systems Office under the DDX program. Finally, CDR Mercer is assigned to the PEO Ships as the Ship Construction Manager for the LPD-17 program. CDR Mercer formally held CDR Crowe's current position. The faculty that compromise the power systems option of the ECE department will continue to assist the military with quality graduates to fill the existing and future key billets.

V. ELECTRIC WARSHIP SIGNATURE REDUCTION (MILLSAPS)

Professor Knox Millsaps is conducting research on methods for reducing Infrared (IR) and acoustic signatures on next generation surface combatants. Electric powered and propelled ships provide unique opportunities to reduce signatures below current levels.

A. Infrared Signature Reduction Research

The most significant threat to navy surface combatants is from dual mode (RADAR with terminal IR guidance) cruise missiles. Current surface combatants use a passive eductor/BLISS system to reduce the thermal signature which reduces the lock on range and increases the effectiveness of countermeasures. Further reductions in IR signature can be beneficial in increasing a platform's survivability.

The Marine Propulsion Laboratory (MPL) at the Naval Postgraduate School has contributed to the development of low observable gas turbine exhaust systems for several existing warships, including the DD-47 and the DDG-51 classes, as well as creating systems for technology demonstrators, including the exhaust stacks for the Low Observable Multi-Function Stack (LMS), which was part of the Top-Side 21 program for low observable conformal superstructures and mast/antennae integration, funded by the Office of Naval Research (ONR) and managed by the signature directorate (code 70) of the Naval Surface Warfare Center, Carderock Division.

Previous research created the low observable exhaust system technology for the DD-21 (now DDX) as reported in recent student theses [17], [18], [19]. This research created concept and demonstrated the hardware for an exhaust system with enhanced performance that is approximately one-half the height of a conventional eductor/BLISS in current use. This leads to much lower top side weight and hence greater stability margin, as well as a greatly reduced super structure size leading to a reduce radar cross section (RCS).

Current research is focused on advanced concepts, such as thermally driven systems as described by Gombas as well semi-active and fully active and signature suppression systems for exhausts that will significantly improve the signature performance which concomitantly reducing the engine performance penalty associated with purely passive ejector systems.

B. Acoustic Signature Reduction

Research into reducing or "smearing" the acoustic signature created by the power and propulsion systems by means of randomly varying the frequency or speed of operation has been conducted. Advance signal processing techniques, including wavelet and Joint Time-Frequency distributions techniques such as the Wegner-Ville JTF distribution and short time FFT were used to assess the effective of various schemes.

VI. THERMAL MANAGEMENT FOR ELECTRIC SHIPS (KELLEHER)

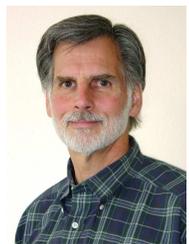
There are many engineering challenges associated with the design of an all electric warship. The introduction of the integrated power system, electric weapons, modern combat systems with new high power radars presents serious challenges in the area of thermal management. The high power electronic controls for the electric propulsion systems require cooling to maintain the proper operating temperature. Loss of cooling can result in sudden system failure. High power radars need to dissipate very large quantities of waste heat. Solid state laser weapons must dissipate over ninety percent of the input

energy or risk severe damage to the solid optical components. Electromagnetic rail guns have particularly severe challenges associated with the removal of thermal energy. In this case failure to adequately remove the waste heat can cause thermal stresses that severely impact rail gun operation at the expected firing rates of 6 to 12 rounds per minute.

These thermal management issues must be addressed in the context of the closed environment of the warship. The ultimate heat sink is the ambient environment, either the ambient air surrounding the ship but most often the seawater environment. The nature of the most demanding heat loads to be dissipated on an all electric warship are such that they are intermittent and of very high magnitude. This demands a great deal of care in the design of the thermal management systems. The Mechanical and Astronautical Engineering Department at the Naval Postgraduate School has been investigating the characterization [22] and modeling of the thermal management systems for an all electric ship. Presently the work is addressing the use of artificial neural networks [23] to develop more efficient models to predict the behavior of the shipboard thermal management systems. This work is being supported by the Office of Naval Research.



Joseph A. Blau Dr. Blau joined NPS in 1989. His current title is Research Associate Professor. His research interest is computer simulations of Free Electron Lasers. Over the past 20 years he has developed, along with Prof. Colson, a set of programs for simulating FELs on desktop workstations. His recent research, and an aspect of his Doctoral Dissertation, has been on novel undulator designs and short Rayleigh length optical cavities for high power FELs. He also teaches courses on computer simulations and free electron lasers.



William B. Colson Dr. Colson joined NPS in 1989. His research is centered on the theory and simulation of free-electron lasers. Prof. Colson has been the Principal Investigator of 45 research contracts with LANL, LLNL, SPAWAR, AFOSR, ONR, NASA, NRL, LBL, and NSF. He has published 120 research papers, holds 3 patents, and has given 62 invited lectures. He has been a Guest Editor for IEEE Journal of Quantum of Electronics, and is a Co-Editor of a book entitled Free Electron Laser Handbook. Prof. Colson has advised over 48 M.S. thesis students and 4 Ph.D. dissertation students at NPS. He is a fellow of the American Physical Society, a member of the American Association for the Advancement of Science, the American Association of Physics Teachers, the Optical Society of America, the American Society of Naval Engineers. He was awarded the 1989 Free Electron Laser Prize.



William B. Maier II Dr. Maier joined the NPS faculty in 1995. He has since been working on technological research. Prior to joining the Physics Department here at NPS, he spent 30 years of research and management at the Los Alamos National Laboratory. His research interests include railgun technology, classical field theory, electrical discharges, optical instrumentation, chemistry and spectroscopy of cryogenic solutions. He was awarded the United Kingdom Science Research Council Fellowship in 1979, and received an NPS certificate of recognition for instructional performance in 1996. He has published approximately 100 articles.



Knox T. Millsaps Knox T. Millsaps is currently on the Faculty and is the Associate Chairman in the Department of Mechanical and Astronautical Engineering at the Naval Postgraduate School where he is Director of the Marine Propulsion Laboratory. His current research interests are in turbomachinery leading edge and tip/endwall aerodynamics and heat transfer, high-efficiency mixing, rotordynamics, hypersonic flows, condition-based maintenance, and low observable technologies. He worked for Pratt and Whitney in Florida and Connecticut working for Om Sharma and Bob Ni on unsteady and three-dimensional flows. Knox received his Ph.D. in Aero/Astro from MIT in 1991 and was a post doc and later a visiting professor (1998) at the Institut für Thermische Strömungsmaschinen, Universität Karlsruhe, working with Prof. Sigmar Wittig. In 2000 and 2001 he was a Congressional Fellow in the Office of Congressman John M. Spratt Jr., the Ranking Member on the House Budget Committee, Assistant Minority Leader, and a Senior Member of the House Armed Service Committee. He is the Chairman of the ASME IGTI Marine Committee, Chairman, Council of Chairs, and Member of the Board of Directors.



Matthew D. Kelleher Professor Matthew Kelleher received the BS in Engineering Science in 1961, the MS in 1963 and the PhD in Mechanical Engineering in 1966, all from the University of Notre Dame. His Doctoral thesis was an investigation of conjugate heat transfer in natural convection on a conducting wall. During the academic year 1966-67 he held the position of Ford Foundation Fellow at the Thayer School of Engineering at Dartmouth College. In September of 1967 he joined the Faculty of the Naval Postgraduate School in Monterey, California. He has served as Chair of the Mechanical Engineering from 1992 to 1995. While at the Postgraduate School he has held various visiting appointments including NASA/ASEE Summer Faculty Fellow at NASA AMES Research Center and Stanford University; Visiting Scientist at the Naval Research Laboratory; Visiting Professor at the University of Notre Dame; Senior Academic Visitor at Oxford University; and Associate Director for Ship Systems at the Office of Naval Research International Field Office (now ONR Global) in London. Professor Kelleher currently holds a dual appointment as Professor of Mechanical Engineering and Professor of Systems Engineering. Professor Kelleher is a Fellow of the American Society of Mechanical Engineers. He has long been active in the Heat Transfer Division of ASME. He has served twice as Chair of the National Heat Transfer Conference Coordinating Committee. He has also served as Associate Editor of the Journal of Heat Transfer. In 1996 he was recipient of the ASME Dedicated Service Award. He is also a registered Professional Engineer in the state of California. Over the years he has conducted research in the areas of natural convection heat transfer; heat pipes; electronics cooling; boundary layer drag reduction; and computational modeling of the spread of fire and smoke in a shipboard environment. His research sponsors have included the National Science Foundation and the Office of Naval Research. His present research interests are in the modeling of complex thermal management systems.



Robert W. Ashton Robert W. Ashton graduated from Virginia Polytechnic Institute with a B.S.E.E. in 1982. He worked for Unisys Corporation as a Component Engineer until returning to school in 1986. He received his M.S.E.E. in 1989 from Worcester Polytechnic Institute. He earned a Ph.D. in the area of power electronics while a fellow with Northeast Utilities in Connecticut. He currently holds the position of Associate Professor in the Department of Electrical and Computer Engineering at the Naval Postgraduate School (NPS) in Monterey, CA.

During his first two years at NPS, he successfully developed a Power Electronics and Motors laboratory, which contains both education, and research based equipment. He is actively involved in research projects concerning naval shipboard power, which include traditional high power dc-dc converters, soft-switching inverters and phase-controlled rectifiers along with more exotic topologies such as Science Applications International Corporation's (SAIC) Pulse Frequency Modulation (PFM) technology. Aspects of the above research comprise both control and hardware development. Some of his recent research projects include funding from Integrated Power System (IPS), Power Electronic Building Blocks (PEBB) and Integrated Fight-Through Power (IFTP). He is actively contributing to ongoing efforts at the Naval Surface Warfare Center (NSWC), Philadelphia with the Land Based Engineering Site (LBES) which contains a variety of high power converters, inverters and phase-controlled rectifiers. He is an integral part of the Electrical Equipment and Cable Technology Branch (Code 813) NSWC, Philadelphia where he has a permanent office occupied approximately five months each year. At the request of specific vendors such as SatCon, Cambridge and Power Systems Group, Anaheim, Dr. Ashton has performed extended-time on-site technical advising to assist company engineers with various Navy power electronic hardware development projects. He was a panel member for the FY2001 Naval Research Advisory Committee (NRAC) titled "Roadmap to an Electric Naval Force" and is currently an "Execution and Demonstration Plan" technical advisor for Future Naval Capability (FNC) for the Electric Warship and Combat Vehicle Other work includes various independent-consulting projects with Navy orientation, the latest with Anteon Corporation. As a member of the Navy's technical team for IFTP, he has been actively reviewing hardware development at General Atomics, San Diego, Power Systems Group, Anaheim, Eaton Corporation, Milwaukee, SatCon, Baltimore and Alstom Corporation, Rugby, UK.

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