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Powering the 21st Century
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The Electric Battlefield

Military platforms are now experiencing a virus-like invasion of silicon, sensors, and associated electric subsystems

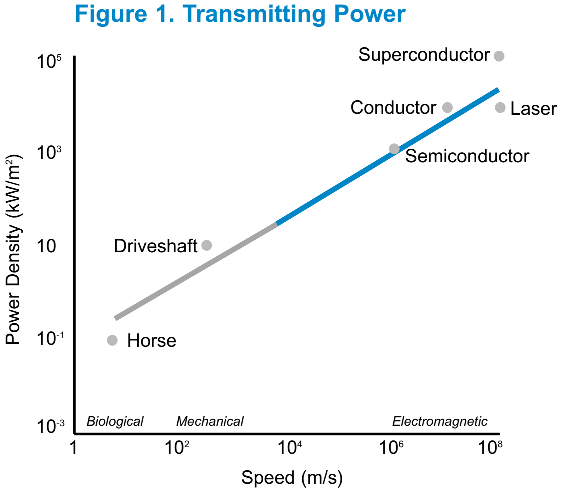
The very notion of an electrically powered battlefield seems preposterous, at first blush. How can the power behind the toaster and the hair dryer propel an artillery shell, a fighter plane, or a rocket? Where will they plug in the tanks? The short answer: In the same place they plug in submarines and the rest of the all-electric nuclear Navy.

The projection of power is the essence of war. And as we have discussed before (*Highly Ordered Power,* October 2001), the new technologies of digital power fundamentally change the calculus of war. Indeed, many of the digital power technologies that interest us most emerged from programs initiated in the 1990s by the Defense Department's leading promoters of new technology, notably the Defense Advanced Research Projects Agency (DARPA), the Air Force Research Laboratory, and the Office of Naval Research (ONR). The overarching objective has been to shrink the size and cost, and boost the power, of sensors and networks for surveillance and control and of platforms and materials that project power.

The military is going electric because tightly controlled electrons move more power faster, more precisely than any other alternative. Power of this quality lets you see, communicate, analyze, move, and destroy faster, more accurately, and from a greater distance. Power transmission—the essential technical imperative for both propulsion and the projection of destructive force—is now possible at power densities two to three orders of magnitude greater than can be achieved with the chemical propellants and explosives that have prevailed for the last century. More power, in less space, controlled and delivered more rapidly, means power that can be projected when and where desired—the essential capability on which all military success depends. (See Figure 1.)

The objective now is to integrate electronic sensing, data processing, and communications on every military platform and weapon. The most recent single, and dramatic, demonstration of what can be achieved occurred on November 3, 2002, over a desert in Yemen, when a General Atomics Predator unmanned aerial vehicle (UAV) struck and destroyed a vehicle full of terrorists. The Predator was piloted from over a hundred miles away; the real-time video signals used to assess the target and control the strike traveled much farther than that. The Air Force's new Network Centric Collaborative Targeting project now aims to integrate a vast array of data streams from sensors and systems to create multitiered electronic pictures of battlefield conditions. The Internet may be in (temporary) disfavor on the floor of the stock exchange, but its military equivalent is by far the hottest stock in the halls of the Pentagon. Like the civilian Internet, the military Internet moves bits—it is therefore electric. The power supplies behind it must be exceptionally compact, light, and reliable.

Figure 1. Transmitting Power



Some of the most important advances have come in devices and systems that operate without any vulnerable soldier's hand directly on the controls. Aircraft began migrating to fly-by-wire technologies and

Table 1. Primary Defense Contractors		
Company	**Revenues**	**Electric Tech. Example**
BAE Systems (BA.L) www.baesystems.com	$21b	Power System for Unmanned Ground Combat Vehicle
Boeing (BA) www.boeing.com	$58b	Unmanned Combat Air Vehicle, Modular Power Supplies
General Dynamics (GD) www.generaldynamics.com	$12b	Truck Fuel Cell APU, DDX Electric Drive
Honeywell (HON) www.honeywell.com	$24b	Turbine for Hybrid-electric Combat Vechicle
Lockheed Martin (LMT) www.lockheedmartin.com	$24b	Electromagnetic (EM) Gun System; Advanced Integrated Electronic Warfare System
Northrop Grumman (NOC) www.northgrum.com	$14b	Fire-control Radar, High-power Pulse RF Power Supply
Raytheon (RTN) www.raytheon.com	$17b	Directed Energy Weapons, Infrared Systems
TRW (TRW) www.trw.com	$16b	High-energy Laser Weapon
United Technologies (UTX) www.utc.com	$28b	Aircraft Electric Power Generation and Distribution Systems

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electrically actuated control surfaces decades ago; more recently, the wires have been extended, via wireless links, to permit the pilot to remain safely on the ground. Electric propulsion is now here, too, for the very important, rapidly emerging class of remotely piloted micro-aircraft. Electric motors scale down very well, but not up; with gas turbine jet engines it's just the opposite. Thimble-sized electric motors work very well; turbines of that size are overwhelmed by viscosity, friction, and thermal losses. Since the dawn of aviation, the leading-edge military aircraft have grown bigger; that trend has now been reversed; the leading edge platforms are shrinking rapidly. Mission by mission, the $2-million Predator replaces the $30-million fighter, and not far behind the Predator follow new fleets of micro-UAVs, one-tenth the size and growing smaller and cheaper, year by year. (See Figures 2 & 3.)

On water, the Navy's next-generation ship program, the DDx, defines a new chapter in the all-electric technologies that submarines and nuclear ships have relied on for decades. The next-generation aircraft carrier, the CVX, is intended to be all-electric as well, beginning with the propulsion of the ship itself, and extending even to the venerable (but beastly) steam catapults that launch and capture aircraft on the flight deck, along with most everything else below the deck.

The Army was the last of the branches to jump on the electric bandwagon—but it is now catching up fast. Electricity already rules, or is fast taking control of platforms ranging from the emerging hybrid tanks and Humvees, to autonomous mine sweepers and the robots that spelunked the Taliban's mountainous hide-outs. The "dismounted soldier" (as the Pentagon calls him) is changing in much the same way as his "mount" —he is being enveloped in electrically powered machines. An unadorned human body is a 100-watt engine, powered by food; the powered land warrior now requires another 60-watts or so of electricity for battlefield computers, communication, range finding, target tracking, and vision-enhancing technologies. And as we have described before, DARPA is funding research into "exoskeletons" for soldiers—wearable, digital-power movers that walk and run rather than roll (*Digital Movers*, February 2002).

Then there are changes now coming to the weapons themselves—they represent a huge stride beyond intelligent guidance added to formerly dumb bombs and missiles. Kinetic energy weapons destroy with mass and speed; directed energy weapons destroy with blast and heat. Chemical fuels have traditionally supplied the necessary power for both types of weaponry—propellants for bullets and cannon balls, explosives for grenades and artillery shells. But electromagnetic launchers (similar to those used to propel a maglev train) are now being used to accelerate darts and missiles to hypervelocity. The hypervelocity kinetic-energy munitions require far less magazine space, because they dispatch so much less mass to the target, and they're inherently safer (for the shooter)—the energy that ultimately destroys the target remains stored, until the end, in the fuel that powers the electric generator in the ship, tank, Humvee, or aircraft. A test model of an electric gun at the University of Texas delivered a hundred-millisecond 900 MW power pulse to accelerate thin, 12-inch tungsten darts to 7,000 mph—twice as fast as can be attained with chemical propellants, three times the speed of ordinary bullets, and fast enough to penetrate 6 inches of steel.

Directed energy weapons are going electric, as well, as radar and industrial lasers get amplified a thousandfold. The first major class of targets for these weapons is enemy electronic equipment. Designers of high-power microwave (HPM) weapons talk of the "dial-a-

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hurt" capabilities of their tunable pulsed-microwave systems. By adjusting burst rate, pulse duration, and power level, they can "deny" (i.e. jam), "degrade," "damage" (fry the most sensitive components), or "destroy." According to already de-classified reports, HPM weapons are likely to play an important role in the near term, including, if it comes, war in Iraq.

Move up in frequency, from microwave to optical bands, and you arrive at weapons capable of destroying enemy vehicles, weapons, and incoming ordnance. On November 5, 2002, two days after the Predator struck in the Yemeni desert, a TRW laser shot down an artillery shell in flight above another desert at White Sands, New Mexico. For as long as there have been catapults, mortars, and cannons it has been a cardinal maxim of warfare that there was no defense against an artillery shell after it had been launched, other than to hunker down and hide. But now—with the advent of much faster and much more precise power-projecting technology—there is.

Taken together, these changes represent a true revolution in military affairs. The changes are so fundamental, and so important, that they aren't just being built into tomorrow's weapons and platforms; they are being retrofitted into existing systems. The U.S. military's existing platforms are now experiencing a virus-like invasion of new silicon, sensors, and associated electric subsystems. A substantial share of the DoD's budget is now allocated to "recapitalizing" existing platforms with new electronics and making them "network-centric." Document after document summarizes the same, central transformation: command, control, communicate, and compute; add intelligence; add information; improve surveillance and reconnaissance; add precision to weapons; remove drivers and pilots from aerial and ground vehicles; and deploy a new generation of electromagnetic propulsions and weapons.

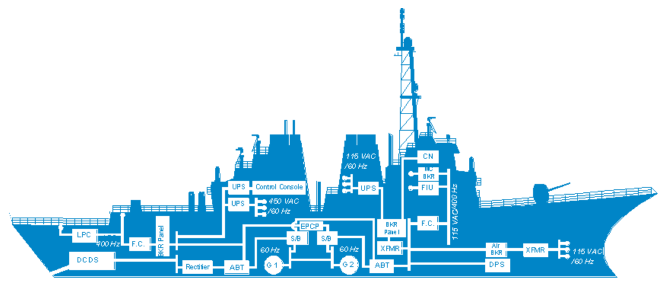
Tiered Suppliers of Tiered Technologies

The electrification of the military has far-reaching implications at every principal level of the production and control of power. New and improved classes of turbines, engines, batteries, and fuel cells are being developed to generate on-board power—the Navy, to cite just one example, has an active program with FuelCell Energy (FCEL), (*Fuel Cells II: Big and Hot,* September 2000), the only manufacturer of a fuel cell that can run on diesel fuel.

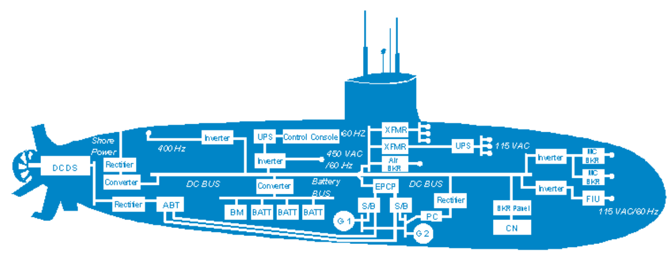
At the other pole, military requirements have done much to propel the rapid improvement in solid-state power switches and electron-to-photon conversion devices. The Army Research Laboratory Electromagnetic Gun program, now under development by Lockheed Martin (LMT) uses very high-power pulsed-

L-3's Power Vision

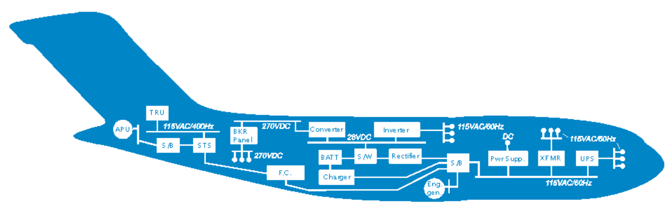
Typical Surface Combatant Power Delivery System



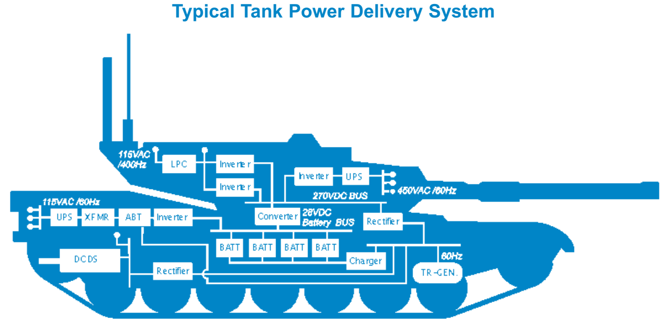
Typical Submarine Power Delivery System



Typical Aircraft Power Delivery System



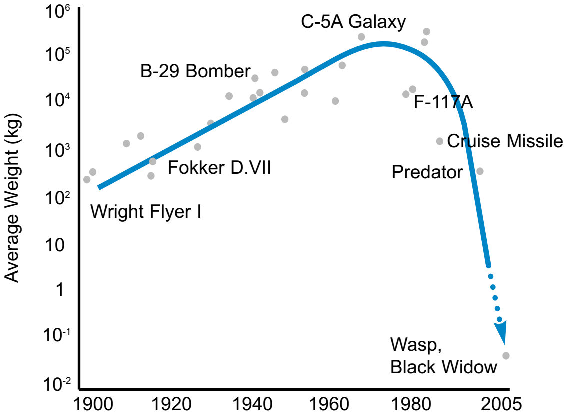
Typical Tank Power Delivery System



Power delivery systems include: Automatic Bus Transfer, Air Circuit Breaker, Auxiliary Power Unit, Battery, Battery Monitoring System, Control Console, Battery Charger, DC/DC Converter, DC Drive System, Degaussing Power System, Electric Plant Control Panel, Frequency Converter, Fault Isolation Unit, DC/AC Inverter, Line Power Conditioner, Power Supply, AC/DC Rectifier, Switchboard, Static Transfer Switch, Transformer Rectifier Unit, Uninterruptible Power System, Distribution Transformer.

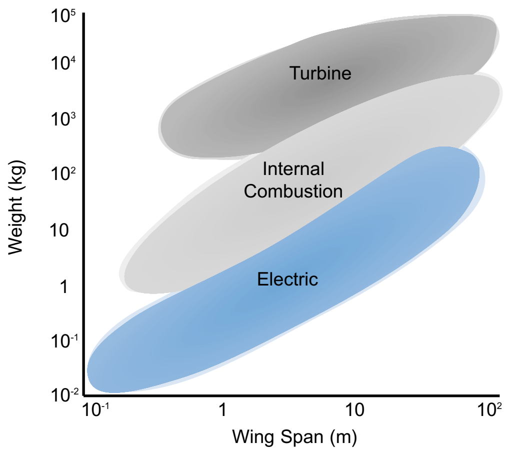
Source: L-3 Communications.

Figure 2. Projecting Military Power: Leading Edge Aviation



Sources: First to Fly.com, USAF Museum, Boeing, Aerovironment.

Figure 3. Powering Flight



Source: DARPA.

power supplies—enabled by a new class of ultrafast, high-power silicon powerchips—supplied by the privately held Silicon Power Corporation. The same ultrafast, compact silicon switches will also be used as triggers to fire conventional rockets on the Army's portable Multiple Guided Rocket Launcher. The Army is aggressively developing new solid-state lasers, to shrink the building-sized TRW system (noted above) down to Humvee-portable range. The largest so far (at least publicly disclosed) is a 10-kilowatt unit, comparable to high-end solid-state industrial lasers. Tubes still serve as the amplifiers in most very high-power RF systems, but now in sight are high-power RF semiconductors, which can attain hundreds of kilowatts, and megawatt systems, built from a new generation of gallium nitride or silicon carbide transistors developed under funding by DARPA (*Digital Broadcasting and RF Power*, September 2002).

In between these two poles, electrical power is switched, conditioned, and converted by a tremendously wide and versatile range of electric-to-electric conversion systems— "power supplies," broadly defined. As we have described before (*Power Supplies*, August 2002), every device that includes digital logic, every advanced electric motor, laser, and solid-state light bulb, radar, tactical computer, and guidance system, requires an intervening power supply of some kind to convert power from the available grid or from an on-board electric generator into some different form at the doorstep of the device. Power supplies also provide interfaces between grids, stepping voltages up or down, rectifying or inverting currents. Tiers of grids and power supplies are found on satellites, jets, tanks, trucks, passenger cars, telephone company central offices, and wireless base stations. Motor "drives" and "controllers" are special-purpose power supplies whose output can be controlled in real time by software or a human operator.

The companies that are electrifying the military platform can likewise be divided—very roughly, of course, with inevitable overlaps—into three principal tiers.

Most familiar are the very large builders of complete systems—the big four being Lockheed Martin, Northrop Grumman (NOC) (which will shortly absorb giant TRW (TRW)), Raytheon (RTN), and General Dynamics (GD). Also in this tier are the large conglomerates with enormous defense divisions – the likes of Boeing (BA), GE (GE), Honeywell (HON), and others (see Table 1). General Atomics, for example—a privately held spin-off from General Dynamics—manufactures the Predator, along with a family of other similar UAVs, together with such critical military-grade electric components as ultrahigh-voltage power supplies.

At the other pole are the suppliers of discrete devices—high-speed silicon switches, for example. Some of these companies are quite large (e.g. Intersil (ISIL), Vishay (VSH), and Analog Devices (ADI)). Others are comparatively small such as Advanced Power Technologies (APTI)—or Maxwell Technologies (MXWL) which manufactures world-class ultracapacitors that enable pulsed-power systems, high-density UPS, and hybrid drives (*Electron Cache,* March 2001). And quite a few players in this tier are privately held—a VC fund in which we're partners, for example, owns a piece of the privately held Silicon Power, mentioned earlier. The big defense contractors have largely left this end of the business, or are in the process of leaving it—they correctly recognize that at this level of things, the military does far better to buy components that are also sold, in rapidly rising volumes, to civilian markets. When they do still get involved at this level, the big players usually enter to develop a fundamental new device, which they then spin out or sell to a separate commercial entity as soon as reasonably feasible. (Such was the origin of RFMD.) This is the most economical and profitable approach to follow because these basic building-block technologies can be used across so many different military and civilian platforms.

It is the middle tier of modules, systems, and components—much smaller than a tank or jumbo jet, but much larger than an individual powerchip—that are still in limbo. Here again, the top-tier suppliers do remain involved, but increasingly they opt to deal with outside vendors whenever they can. (See Table 2.)

This is clearly the trend with power supplies and other devices in the intermediate tier of electrification technology. Historically, most major military contractors built their own power systems. But the strong trend now is toward outsourcing this middle tier as well. The reasons can be traced to the evolution of the underlying technology.

The old analog ("linear") power supplies were inherently inefficient and bulky. Application-specific, custom designs were the norm, to optimize performance. There were thousands of manufacturers. By contrast, "switch-mode" digital-power processors are much more flexible, and they are now rapidly making the transition from "application-specific" device to "general purpose" power processor. Power is now on the same trajectory as logic was in the 1980s. The technology is dominated by semiconductors and software. Common standards are spreading across platforms. Compact plug-and-play modules or blocks capable of serving a wide range of different applications are becoming the norm. And there is a strong DoD drive to standardize, which favors cross-platform solutions.

Military power systems, in short, are fast becoming platform independent. Eventually, they'll also merge with the civilian sector, but that will take quite awhile. For now, military purchasers have uniquely stringent requirements for highly reliable, fault-tolerant systems. We therefore anticipate the evolution of a handful of large, independent, cross-platform military suppliers that realize large economies of scope and scale, that know how to build equipment to "mil-spec" levels of reliability, and how to integrate their product with military-electric loads—everything from radios and radars to munitions controls.

L-3

L-3 Communications Holdings came into being in 1997, as a spin-out from the 1996 merger of Lockheed Martin and Loral. Ever since, L-3 has been acquiring complementary assets from others—eleven companies in 2000 and 2001, for a total of almost $1 billion; a $100-million acquisition of PerkinElmer's explosive detection business in January 2002, and a $1.1-billion acquisition of the Aircraft Integration Systems division of Raytheon a few months later. L-3 is now a $3.4-billion supplier of components and subsystems to every major military contractor. (L-3 (LLL) should not to be confused with Level 3 Communications (LVST) —L-3 does communications, too, but focuses on wireless and wired telecom gear that links soldiers to commanders and weapons to target computers.)

Table 2. Defense Systems Suppliers

Company	Revenues	Technology Example
DRS Technologies (DRS) www.drs.com	$500m	Naval Electric Drive, Power Conversion; Total Ship Computing Systems
EDO Corp. (EDO) www.edocorp.com	$260m	Piezo-electric Actuators, Electronic Warfare
General Atomics (Private) www.ga.com	$500m	Predator UAC, High-energy Capacitors
Goodrich (GR) www.goodrich.com	$4b	Aviaton and Missile Power Systems, Integrated Avionics
Harris (HRS) www.harris.com	$2b	Advanced Avionics for Military Aircraft and Unmanned Vehicles
Integrated Defense Technologies (IDE) www.idt-idt.com	$264m	Hybrid-electric High Mobility Multi-purpose Wheeled Vehicles
ITT Industries (ITT) www.itt.com	$5b	Night Vision, Active Sensors
Kaman Corp. (KAMNA) www.kaman.com	$870m	Electromagnetic Components for DDx Electric Drive
L-3 Communications (LLL) www.l-3com.com	$3.4b	Power Conversion, Distribution; Millimeter-wave Systems
Moog (MOG.A) www.moog.com	$704m	Electro-hydraulic Flight Controls
Rockwell Collins (COL) www.rockwellcollins.com	$3b	Synthetic Vision Technology
Teledyne (TDY) www.teledyne.com	$700m	Thermo-electrics, Fuel Cells
Titan (TTN) www.titan.com	$1b	Power Supplies and Infrared Target Simulators
United Defense (UDI) www.uniteddefense.com	$1b	Advanced Gun System for DDx w. Automated Magazine

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We first took note of L-3 a year ago, when we wrote about explosive detection technologies (*X-Ray Vision*, December 2001). As we observed then, L-3 had already partnered with Analogic (ALOG) to build one of the few FAA-approved state-of-the-art airport explosive detection systems; we also noted that PerkinElmer (PKI) would soon be selling its own world-class explosion detection unit. A few weeks after we mailed out that issue, L-3 was named as the buyer—putting the company firmly in the number-one slot in that particular market. Late this year, L-3 acquired International Microwave, a specialist in microwave and related surveillance systems (and contractor to the U.S. Border Patrol), and placed an investment in the private Millivision, a promising developer of the millimeter-wave imaging technology

(*The Power of Millimeter Waves,* November 2001).

These acquisitions and deals typify the company's evolving strategy: L-3 is well on track to becoming a leader in Homeland Security technologies, a natural complement to the solid military business that accounts for over 70 percent of its sales.

L-3's core business is, of course, defense systems: it manufactures the telecom, data, surveillance, guidance, and information systems that are incorporated in major platforms operated by every branch of all the services. To list just a handful of examples: U-2, Global Hawk, Predator, and essentially every aircraft (e.g. C-130, C-5, E-2C, F-16, F-14); the destroyers, Trident and attack subs, carriers, and Aegis cruisers; satellites of every stripe and their associated ground systems; the International Space Station, Space Shuttle; and weapons of all kinds (e.g. Patriot, Dragonfire, and many more). L-3 is at the center of the military's interoperable "Internet in the Sky" program, which provides encrypted communication links between manned aircraft, UAVs, remote sensors, and data processing centers. Last summer, L-3 acquired ComCept, the lead developer of "network-centered collaborative targeting"—a system that integrates sensors and information from multiple legacy and new platforms into a single battlefield picture. Last month, L-3 followed up with the acquisition of a company whose equipment will feed data into this system—the $180-million Wescam (WSC.TO), a leading manufacturer of electro-optic and infrared-sensor systems.

L-3 is certainly much more than a power company—it builds and integrates the critical elements of virtually all major communication, command and control, intelligence gathering, and space systems—secure, high data-rate communication systems, training and simulation systems, engineering development and integration support, avionics and ocean products, fusing products, telemetry, instrumentation, space and guidance products, and microwave components. But among the many players that are providing middle-tier modules to electrify the military power train, L-3 is the first to have built up what appears to be a critical mass of technologies and markets. L-3 now has the industry's most extensive capabilities in systems able to supply, convert, and control mission-critical power for military systems.

Comprising roughly 10 percent of the company's business, L-3's military power systems group is certainly one of the largest in the industry. The group was formed around L-3's SPD Technologies, which L-3 purchased in 1998. SPD itself was formed out of SPD Electrical Systems of Philadelphia, Pac-Ord of San Diego (installation and integration of shipboard combat systems), Henschel of Newbury, Massachusetts (electronic ship control and internal communications systems), and Power Paragon of Anaheim (power-conversion systems for mission-critical applications: UPS, static switches). As the company's website makes very clear, L-3 grasps the overarching trends in military power hardware. Highly telegraphic schematics of the principal military platforms (together with one of a modern high-rise wired for digital business) show the key power electronics subcomponents that L-3 aims to supply. (See the illustrations on page 3.) The company specializes in electrical systems for critical and harsh-environment applications in Navy ships, submarines, rotary- and fixed-wing aircraft, battle tanks, weapon systems, and outer space. It is the only fully integrated, full-line provider of electrical power systems and services to Navy vessels. And it also supplies some products to commercial computing and communications markets.

To pick just a few examples, L-3 builds a "static automatic bus transfer" that uses a complex array of powerchips, digital controls, and sensors to switch between power sources. The company's IGBT-based, microprocessor-controlled frequency converter provides defense-standard 400-Hz power—power of the type used on Aegis destroyers. L-3's DC-to-DC power conversion handles power levels from hundreds of kilowatts up to several megawatts. And destined as they are for the military, all of these systems are built to literally "bullet-proof" levels of physical robustness and electrical reliability.

L-3 devotes substantial resources to R&D, over $100 million a year of its own funds, and another $300 million paid for by its customers (one of the benefits and necessities of military programs). Among the blizzard of new and emerging products from L-3: a compact, lightweight data link for UAVs, a field-deployable (30-minute set-up) tactical ground data link, a solid-state RF power amplifier for the Ka band (millimeter wave), a next-generation Unattended Ground Sensor system, advanced motor and controls for satellite attitude correction, and a rapidly deployable integrated electronic perimeter security system using low-light level and infrared imagers.

Outlook

This is a huge market, of course. L-3 certainly isn't in it alone. In 2002, the DoD budget rose to $331 billion, of which almost $109 billion was for procurement and R&D. President Bush has proposed a $48-billion overall increase that would increase the R&D/procurement piece to approximately $125 billion. Alongside the Homeland Security Department, it defines the largest single new source of spending on digital power technologies.

Many of L-3's competitors build power systems of one kind or another. But L-3 ranks alone, among major defense suppliers and contractors, as the company that defines the production of military-electric-grade power as an end in itself.

• DRS Technologies (DRS) appears to have the second largest power conversion operation, with motor controls and electric drives—particularly in light of their expansion through a $90-million July 2002 acquisition of Eaton Corporation's (ETN) shipboard integrated electrical power distribution and control systems division.

• United Technologies' (UTX) Hamilton Sundstrand has one of the larger power systems groups as well—it provides generation, distribution, and management systems for commercial and military aircraft, as well as aerospace platforms, torpedoes, missiles, and submarines.

• Another player is what's left of the Westinghouse Electromechanical Division, now owned by Washington Group International (WGII.OB) —the company builds very high-power conversion devices, voltage regulators, inverters, motor drives, and control systems for the big pumps, motors, and generators, including the Navy's largest and most advanced high-speed generators.

• K&M Electronics one of eight groups within ITT's Defense Electronics & Services Division (ITT) is a leading supplier of miniaturized, high-voltage power supplies for lasers, night vision, oil exploration, specialty cameras, and other military, medical, and civilian markets.

• Integrated Defense Technologies (IDE) provides a range of advanced electronics and power products to the defense and intelligence industries, including hybrid-drive systems and other products for aircraft, destroyers, submarines, light-armored vehicles, and missiles.

• Boeing designs and manufactures advanced custom power supplies, including a "common module power supply" for a variety of defense and commercial aerospace, and space applications.

• TRW's electric power systems operation (focused primarily on aerospace applications) was sold for $1.5 billion to Goodrich (GR) last month—and TRW's main defense business, of course, is shortly to become part of Northrop. (Earlier this month, Northrop signed an agreement to sell TRW's automotive business for $4.7 billion to the private Blackstone Group.) At the end of October, Northrop Grumman itself sold its Electron Devices and Displays-Navigation business to L-3.

We expect more such sales and consolidations. L-3 will continue to acquire and integrate the power-technology assets to expand this critical mid-tier. The same will happen to many of the dozens upon dozens of small, private suppliers of highly specialized power-related defense technologies.

Warfare is going electric. A single form of power—electricity—will displace the far more varied mix of electrical, mechanical, hydraulic, thermal, and chemical systems that currently power lights, computers, and communications systems, move flaps, turn wheels, and propel ordnance out the barrel of a cannon. On the battlefield, as in the civilian economy, electricity already moves the bits; step-by-step, it will take over the much greater burden of moving the atoms. Electrification represents a dramatic convergence of power trains. Power systems as different as a hydraulic line and a chemical propellant will give way to electro-magnetic currents and fields. The basic form of power will get much more uniform; the digital-electric hardware will become increasingly complex, semiconductor-based, and software-defined.

Power-system design is software-intensive; very sophisticated CAD/CAM is used to optimize circuit topologies and optimize thermal performance. The constituent components of electric systems are improving very rapidly: overall performance is doubling, and costs are halving, about every three years. These trends all favor the evolution of a handful of large, independent, cross-platform power-supply manufacturers that can realize large economies of scope and scale. We expect L-3 to be a leader among them.

Peter Huber, Mark Mills, December 3, 2002

Table 3. Additional Resources

"Advanced Silicon Power Devices for Pulsed Power Applications," V. A. K. Temple, Silicon Power Corporation, European Pulse Power Conference 2002 (October 2002).

"Advanced Electric Technologies for the Fleet," David I. Roberts, General Atomics, Before the Subcommittee on Research and Development of the House Armed Services Committee (February 20, 2002).

"How Technology Will Defeat Terrorism," Peter Huber and Mark P. Mills, *City Journal* Vol. 12 No. 1 (Winter 2002).

Transforming America's Military, ed. Hans Binnendijk, National Defense University Press (2002).

Statement, Dr. Tony Tether, Director, Defense Advanced Research Projects Agency, Before the Subcommittee on Military Research and Development Committee on Armed Services, House of Representatives (June 26, 2001).

The Dynamics of Military Revolution: 1300 - 2050, Knox and Murray, Cambridge University Press (2001).

"High Power Microwaves: Strategic and Operational Implications for Warfare," Eileen M. Walling, UASF, Center for Strategy and Technology, Air War College (May 2000).

Energy Efficient Technologies for the Dismounted Soldier, National Academy Press (1997).

"Technology for the United States Navy and Marine Corps, 2000 - 2035: Becoming a 21st-Century Force," Naval Studies Board, National Research Council (1997).

Beam Weapons: The Next Arms Race, Jeff Hect, Plenum Press (1984, 2000).

"Towards Autonomous Flight for Micro Air Vehicles (MAVs): Vision-Guided Flight Stability and Control," Nechyba and Ifju, Electrical and Computer Engineering, University of Florida.

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The Power Panel

For an explanation of the ascendant digital power technology for each of these companies, see the indicated issue of the DPR.

FEATURED COMPANY	DPR ISSUE	OTHER PLAYERS IN THE ANALYZED SPACE*
Advanced Power (APTI) www.advancedpower.com	12/00	Hitachi America (subs. HIT); Mitsubishi Semiconductor (subs. MIELY.PK); ON Semiconductor (ONNN); Philips Semiconductors (subs. PHG); Siliconix (SILI); STMicroelectronics (STM); Toshiba (TOSBF.PK)
American Superconductor (AMSC) www.amsuper.com	10/00	ABB (ABB); Intermagnetics General (IMGC); Waukesha Electric/SPX (subs. SPW)
Amkor Technology (AMKR) www.amkor.com	4/02	ChipPAC (CHPC); DPAC Technologies (DPAC)
Analog Devices (ADI) www.analog.com	8/01	Linear Technology (LLTC); Maxim Integrated (MXIM); STMicroelectronics (STM)
Analogic (ALOG) www.analogic.com	12/01	American Science & Engineering (ASE); Heimann Systems/Rheinmetall Group (subs. RNMBF.PK); InVision Technologies (INVN); L3 (LLL); Rapiscan/OSI Systems (subs. OSIS)
C&D Technologies (CHP) www.cdtechno.com	7/02	East Penn (pvt.); Enersys (pvt.); Exide (EXTDQ.OB)
Coherent (COHR) www.coherentinc.com	6/01	OSRAM Opto Semiconductors/subs. Osram (Siemens, SI, sole shareholder); Rofin-Sinar (RSTI)
Cree Inc. (CREE) www.cree.com	5/01	AXT (AXTI); Nichia Corporation (pvt.); Toyoda Gosei Optoelectronics Products/Toyoda Gosei (div. 7282.BE)
Danaher Corp. (DHR) www.danaher.com	2/02	Emerson Electric (EMR); GE-Fanuc (JV GE (GE) and Fanuc Ltd. (FANUF.PK)); Mitsubishi Electric Automation/Mitsubishi Electric (div. MIELY.PK); Siemens (SI)
Emerson (EMR) www.gotoemerson.com	6/00	American Power Conversion (APCC); Marconi (MONI.L); Toshiba (TOSBF.PK)
Fairchild Semiconductor (FCS) www.fairchildsemi.com	1/01	(See Advanced Power entry.)
FLIR Systems (FLIR) www.flir.com	1/02	DRS Technologies (DRS); Raytheon Commercial Infrared/Raytheon (subs. RTN); Wescam (WSC, Canada)
Harris Corp. (HRS) www.broadcast.harris.com	9/02	AI Acrodyne (ACRO); EMCEE Broadcast Products (ECIN); Itelco (pvt.); Thales (THS.L)
Infineon (IFX) www.infineon.com	12/00	(See Advanced Power entry.)
International Rectifier (IRF) www.irf.com	4/00	(See Advanced Power entry.)
Itron (ITRI) www.itron.com	10/02	ABB (ABB); Invensys (ISYS.L); Rockwell Automation (ROK); Schlumberger Sema/Schlumberger Ltd. (SLB); Siemens (SI)
IXYS (SYXI) www.ixys.com	4/00	(See Advanced Power entry.)
Kemet Corp. (KEM) www.kemet.com	5/02	AVX Corporation/Kyocera Group (AVX); EPCOS (EPC); NEC Corporation (NIPNY); TDK Corporation (TDK); Vishay (VSH)
L-3 Communications (LLL) www.l-3com.com	12/02	DRS Technologies (DRS), Integrated Defense Technologies (IDE), and United Technologies (UTX)
Magnetek Inc. (MAG) www.magnetek.com	8/02	Ascom Energy Systems/Ascom (subs. ASCN, Switzerland); Astec/Emerson Electric (subs. EMR); Delta Electronics (2308, Taiwan); Tyco (TYC)
Maxwell Technologies (MXWL) www.maxwell.com	3/01	Cooper Electronic Technologies/Cooper Industries (div. CBE); NESS Capacitor/NESS Corp. (pvt.)
Microsemi (MSCC) www.microsemi.com	4/01	Semtech Corporation (SMTC); Zarlink Semiconductor (ZL)
Oceaneering Int'l. (OII) www.oceaneering.com	6/02	Alstom Schilling Robotics/ALSTOM (subs. ALS, France); Perry Slingsby Systems/Technip-Coflexip (subs. TKP); Stolt Offshore (SOSA); Subsea 7 (JV Halliburton (HAL) and DSND (DSNRF.PK))
Power-One (PWER) www.power-one.com	5/00	Artesyn Technologies (ATSN); Celestica (CLS); Lambda Electronics/Invensys (subs. ISYS.L); Tyco Electronics Power Systems/Tyco Electronics (div. TYC); Vicor (VICR)
Raytheon Co. (RTN) www.raytheon.com	10/01	BAE Systems (BA.L); Integrated Defense Technologies (IDE); Lockheed Martin (LMT); Northrop Grumman (NOC)
Rockwell Automation (ROK) www.rockwellautomation.com	9/01	Honeywell (HON); Invensys (ISYS.L); Mitsubishi Electric Automation/Mitsubishi Electric (div. MIELY.PK); Parker Hannifin (PH); Siemens (SI)
TRW Inc. (TRW)*** www.trw.com	1/01	Conexant (CNXT); Fujitsu (6702, Taiwan), Information & Electronic Warfare Systems/BAE Systems (div. BA.L); Northrop Grumman (NOC); RF Micro Devices (RFMD); Vitesse Semiconductor (VTSS)
Veeco Instruments (VECO)** www.veeco.com	7/02	Aixtron (AIX, Germany); Emcore (EMKR); FEI Company (FEIC); Riber (RIBE.LN); Thermo VG Semicon/Thermo Electron (subs. TMO)
Vishay Intertechnology (VSH) www.vishay.com	11/02	(See Advanced Power and Kemet entries.)
Wilson Greatbatch Technologies (GB) www.greatbatch.com	3/02	Eagle-Picher Industries (EGLP.PK); Ultralife Batteries (ULBI)

* Listed alphabetically; not a list of all public companies with similar or competing products; typically does not include private companies, except where they are large in both size and market share.

** Veeco and FEI Company announced a merger agreement on July 12, 2002; FEI will become a wholly owned subsidiary of Veeco, which will be renamed Veeco FEI and continue to trade as VECO.

*** Northrop Grumman and TRW announced a definitive merger agreement on July 1, 2002, in which NOC will acquire TRW.

Note: This table lists technologies in the Digital Power Paradigm and representative companies in the ascendant technologies. By no means are the technologies exclusive to these companies, nor does this represent a recomended portfolio. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interest in the companies.