THE HUBER MILLS digital power report

Powering the 21st Century

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Digital Power in the 21st Century

The quantum powerchip industry is poised to grow as large as (likely larger than) its quantum sibling, the semiconductor smartchip industry.

That logic can become "digital" is obvious. Mathematicians told us it could long before engineers delivered functioning digital computers. Three years ago, we began writing about a new concept—digital power, power under the control of systems so precise, so fast, that the power becomes as tractable, ordered, and determinate as digital logic.

We noted, to begin with, the ineluctable link between power and logic, and between power and communication. In neurons, microprocessors, cell phones, and fiber-optic lines, all flows of information are flows of well-ordered power. Information may hibernate in chemicals (DNA) or tiny magnets (on metallic disks), or pits in plastic (in optical disks). But when it's awake, information is power—packets of electrons, or their quantum cousins, photons. We pointed out that bits are defined units of energy that get ordered, sifted, herded, and propelled through living tissue, silicon, the airwaves, and tunnels of copper, coaxial cable, and glass. Ordered packets of information cannot form, replicate, persist, or be conveyed until they are rendered incarnate as ordered power.

And we noted that it takes more and better-ordered power to process or communicate more bits, faster. A semaphore uses daylight, Morse's telegraph required a battery, and it takes a precisely tuned laser to send terabits of data down a strand of glass. Gigahertz-speed logic calculations on the surface of a Pentium require fantastically stable DC power, of extremely high density—the tiniest interruption or imperfection in the power flowing to the chip wipes out everything, and it's blue-screen death for the computation under way. Truly chaotic power—"black body radiation" —can neither process nor convey any information at all.

From that starting point, we proceeded, over the course of the next 36 issues, to flesh out just what we mean by digital power, and why we consider it so fundamentally important, and which companies, in our view, are innovating at the cutting edge of digital power technology. This is our last issue of the Digital Power Report; we're now fully occupied in investing venture capital in this space, and pulling together our story into a book, The Logic of Power.

The time has come to recapitulate the fundamentals, the core trends that are driving this market, and that will continue to drive it, we firmly believe, for years to come. And, in keeping with tradition, we propose one final name to add to the Power Panel, O2Micro International (OIIM) (see the Box).

Efficiency, Power, and Order

The market is willing to pay more for more ordered energy because order can do more, faster, with less overhead cost for space, weight, and waste heat. Raw heat is good for warmth, cooked food, and a bit of light. Motive power can be turned back into heat easily enough if that's what you want; a Porsche's brakes can do that, but it can also move the Porsche, which heat alone cannot do. Push up another layer to electricity, and you can move a hybrid-electric Porsche, and the all-electric factory machines that build it, and also power lights much better than a gas lamp can. Smoke signals from a bonfire can just barely move one bit per second; it takes highly ordered electricity and light to run a gigahertz chip or a terahertz fiber-optic link.

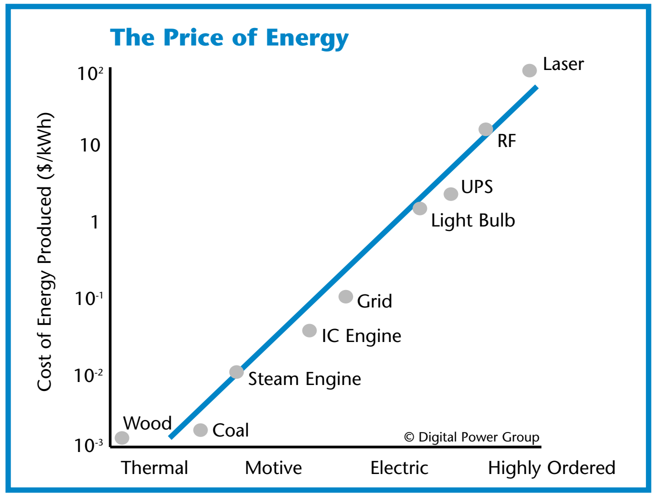
Highly ordered power let's you think, see, and move in ways that less ordered forms of power cannot match. The few analysts that address highly ordered power at all generally focus on think applications in the datacom/telecom sector. Most overlook the extent to which highly ordered power is now transforming the century-old industrial legacies of Thomas Edison, George Westinghouse, and Henry Ford. And those segments still represent most of the economy as a whole.

The U.S. economy consumed about 35 quadrillion Btus of energy in 1950; it consumes about 100 Quads today, and it will consume about 125 in 2020. Over the long term, efficiency gains yield greater economic output from each unit of energy consumed. Twice as much economic activity emerges from a unit of energy today compared to 1950. Technology drives efficiency in every sector. The amount of illumination available per dollar spent, for example, has soared with technology's progress.

Despite rising efficiency—or perhaps because of it—the burn rate rises too. We drive and fly more miles per hour, process more millions of instructions per second, and dispatch more kilobits per second—and higher speed generally translates into more energy consumed per unit of time—i.e. more power—in any given task.

And we burn more power in less space – power density rises apace. The bonfire becomes a blast furnace, which becomes a uranium reactor. James Watt's steam engine (1765) becomes Nickolaus Otto's internal combustion engine (1876), which becomes the Charles Curtis gas turbine (1914). The room-sized electric motor of the 1930s is replaced with a box-sized unit today. It takes more power in less space to propel helicopters, Porsches, and gigahertz-speed Pentiums. Like power itself, power density delivers speed. It does so by shortening distance and reducing inertia.

Finally, more ordered energy displaces less ordered. Until James Watt invented the steam engine, almost all energy was used as thermal energy—to heat and cook, and to provide some tiny amount of (thermal) lighting. Our consumption of primary (thermal) fuels has continued to grow, but today we convert about 70 percent of that energy into motive power. The motors move people and freight. And they also move electrons, a still higher-order form of energy. The fraction of our total energy consumption that's converted to electricity has grown steadily since the days of Thomas Edison. The dependence of the economy on electrons is destined to keep growing because, from Game Boys to gene sequencers, computers to car factories, silicon fabs to steel mills, factory floor to financial house, the digital technologies of our economy are completely dependent on electrons.



Far more important than the sheer increase in the volume of electrons demanded by the digital economy is the type of electricity required: unusually clean, stable, reliable electrons. Electrons for the digital economy cannot be provided reliably by the same old technologies on the same old power grid that powers our light bulbs, electric motors, or air conditioners, or at the same old price. The digital economy requires power that's rock steady, from milliseconds to days to years—far steadier than the power available directly from the grid.

Digital Power Technologies

The technologies capable of providing highly ordered power cut across all sectors, impact all power levels from microwatts to megawatts, and are manifested in thousands of configurations. But they share in common one feature. They switch and convert power in semiconductor junctions.

Building functional power devices out of atomic-scale junctions and perfect crystals is extremely difficult, but the pay-offs are commensurately big, with orders of magnitude improvements in power density, speed, and overall efficiency. And switches that occupy 1/100th of the space of the devices they replace and that operate a thousand times faster. Electron-to-photon conversion efficiencies suddenly leap from the single-digits attained in incandescent lamps and conventional lasers, up toward 30 percent. Light "bulbs" suddenly shrink from the size of a pear to the size of a poppy seed.

The old world of engineering ultimately relies on random and chaotic processes—a flame, a hot gas exerting pressure on a piston, electrons randomly exciting tungsten atoms to propel a chaotic stream of photons out of a filament. Even a rigid steel drive shaft transmits power

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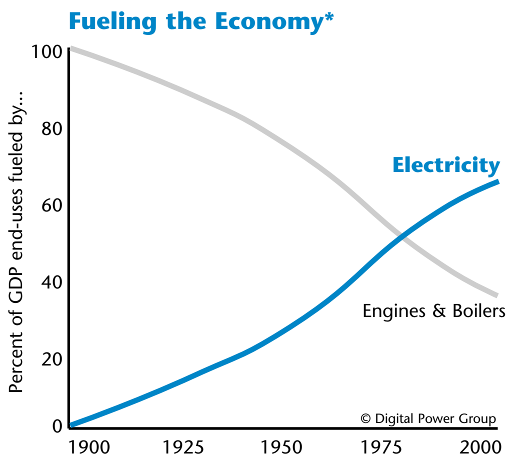

* Excludes residential energy: counts only fuels used by GDP-producing sectors; transportation, industry (incl. mining, agriculture) and services.

Source: EIA Annual Energy Review 2000; Bureau of Economic Analysis.

by way of the relatively messy mechanics of stressing steel.

The invention of the semiconductor transistor marked a very fundamental advance—a leap from three-dimensional, thermal, and mechanical technologies into the quantum recesses of atomic junctions, where electricity acts on electricity directly. Quantum technologies like the transistor transform energy not in volumes but on surfaces—atomic-scale junctions. Because they operate at these scales, they are blindingly fast and compact. And as device engineering advances, they become extraordinarily efficient.

From the get-go, they transmit, transform, and switch power at much higher power densities and higher speeds than the old-world systems they replicate. And over time, they push their way up to comparably high power levels, too.

Push the power levels down, and quantum technologies give you logic—integrated circuits, memory chips, and microprocessors. But the pay-off for pushing quantum technology up the power curve is even larger than the pay-off for pushing it down. Partly because the downscale technologies depend on the upscale—the new digital economy requires high-power quantum technologies behind it to deliver the ultra-fine power that fuels it. And more importantly, because digital power technologies—high-power quantum technologies—are taking over the old industrial economy too, which still represents most of the economy, and consumes most of the power.

Think, See, Move

While digital power devices are manifested in thousands of different products, all can be grouped into three basic, functional categories: Think, See, and Move.

It takes very pure power to store and process bits on the surface of silicon, or convey them at terabit speeds down a strand of glass, or at megabit speeds through the airwaves. The airwaves are comparatively slow because they contain many stray sources and sinks of extraneous energy that get in the way. Chaotic energy is the antithesis of digital logic. It is static on the cell phone, or a computer-crashing hiccup on the power line. Logic chips, optical communications systems, and RF radios have advanced no further than their power systems will carry them.

From CAT scans to DVD video players, the new seeing technologies convey more information—they shine brighter, see further, and penetrate deeper. Edison's light bulb lets you see too—but it is now giving way (rapidly) to the solid-state bulbs—the LEDs in alarm clocks, car dashboards, rear lights, headlamps (soon), traffic lights, and baseball parks, the laser diodes in laser printers and CD players, and so forth. Per unit of area and per unit of energy used, the new light is very much brighter than the old; it is also far more compact, efficient, and cool. Solid-state "light" now also shines in the frequency bands used by cell phones, radar, and radio and TV broadcasts. Power that is very precisely tuned and directed now makes it possible to "illuminate" —and thus "see" —through fog, flesh, deep water, and, with ground penetrating radar and precision seismography, deep into the earth itself.

These technologies are matched, on the "receiving" end, by solid-state eyeballs—charge-coupled devices in digital cameras and video cameras, gigahertz photodetectors in optical circuits, infrared detectors, piezo-crystal sensors for material analysis or haptic computing. The SQUID (superconducting quantum interference device) is a thin sandwich of conductors and superconductors assembled into an ultra-sensitive detector of electric and magnetic fields—sensitive enough to detect the currents flowing through nerve cells in the brain, or ancient geophysical changes in rocks deep in the earth, or the magnetic fields created by submarines deep in the ocean. Other quantum detectors exploit the direct interactions between electric fields and photons to detect current flows and voltage, or between acceleration and its relativistic impact on light.

Highly ordered power enables extremely precise motion; it also makes it possible to push far more power through far less motor. Digital power technologies deliver huge improvements in speed, precision, efficiency, and overall performance. Much of the time they make possible things that simply cannot be done at all with any less well ordered form of energy.

Chip fabs and disk drives require extremely precise electric motors; the precision comes from the marriage of logic chips and powerchips in motor drives. Highly ordered power moves the ink in a laser printer, embeds information on the surface of a compact disk, and—in the form of a UV or X-ray paintbrush—draws the ultra-fine-lined masks required to manufacture a Pentium. Moving down to the atomic scale, piezoelectric crystals collapse the one Hertz swinging pendulum of a grandfather's clock into a sliver of silicon vibrating at megahertz rates in a wristwatch. Lasers are used to separate isotopes, ion beams to deposit dopants into semiconductors, electron beams to assemble solid-state lasers, atomic layer by atomic layer.

Quantum Replacements for Classical Devices

The era of digital power technologies began with the invention of the power transistor in 1949, followed by the laser (1958), and the light emitting diode (1962). The family of quantum devices has grown since—a good number of them earning Nobel Prizes for their inventors along the way. Quantum control of power grew gradually from the 1960s through the early 1990s. Now, because of the rapid advance of semiconductor technol-

Players at the Interfaces: O_2Micro International

Whatever the application—think, see, or move—the digital technologies are powered by flows of current—electrons. And those current flows must be precisely controlled. The more densely applications are packed, on a motherboard, in a power supply, or in some larger package, the more exacting the control capabilities must become to accommodate the result of different components generating harmonics and noise and making competing demands for power. Mishandle the power, and at the very least you waste it; at worst, you destroy the components that use it.

Huge numbers of powerchips function at low power—Watts down to milliwatts—and in these power ranges a single "integrated" power control circuit can take orders directly from a logic device and control a power flow as instructed. High-power applications require a two- and even three-stage process—the output of an ordinary logic device just can't supply enough power to control even the gates in a high-power switch. An intermediate single-powerchip amplifier is therefore needed.

Thus, powerchips fall into three broad groups: discretes, "linear" ICs, and "mixed signal" ICs. A discrete functions as a single switch, capable of handling power flows from Watts to megawatts. A "linear" (in other words, not digital) circuit provides specific, low-power, but fast control, under instruction from an upstream logic chip, to directly control small power flows, or drive a discrete powerchip (a MOSFET) downstream to control higher power flows. A "mixed signal" powerchip integrates the logic and powerchips on a single piece of silicon. For the highest power applications, a three-stage architecture is used—logic driving a low-power powerchip, which in turn drives a high-power powerchip.

As control functions grow more complex, and power levels rise, the control circuits require more discrete components—switches, capacitors, inductors, resistors, and task-specific linear ICs. Power consumption in the control/conversion stages rises—often to the point where these functions consume half of all the power used, with only half reaching the ultimate load. So the design and optimization of the control circuits grows increasingly important.

At about $5 billion per year, the global market for linear and mixed signal powerchips accounts for a substantial part of the $9 billion (CK) total powerchip market. Sales of linear and mixed signal powerchips are projected to double in the next five or six years. The fastest growth will come in the market for mixed-signal devices—those that bridge the analog and digital divide on a single sliver of semiconductor.

About a dozen major companies rank as major manufacturers of analog and mixed-signal integrated circuits—among them Maxim Integrated (MXIM), Texas Instruments (TXN), Analog Devices (ADI), ON Semiconductor (ONNN), Fairchild Semiconductor (FCS), and STMicroelectronics (STM). Each offers a broad array of either pure analog powerchips (among many other products); most also offer some mixed-signal integrated circuits. For the most part, these companies build general-purpose integrated circuits, designed to function in a wide range of applications.

In this camp, we like market-leader Linear Technologies (LLTC) with its broad market coverage, and (in these tough times) relatively robust $560 million in sales. Linear is highly respected in the industry, and in many markets it's the company to beat. It comes as close as one can to a near pure play in analog power circuits. And unlike the other larger players in the field, fully half of Linear's business is in power management.

But the leading edge of the control-circuit market is defined by the mixed-signal architecture, which integrates logic and power on a single chip, and is propelling the industry toward a complete power-system-on-a-chip. Digital logic analyzes sensor inputs and dispatches instructions; fast analog circuits handle the power. The challenge is to integrate such capabilities on to a single piece of silicon.

Power Integrations (POWI) isn't normally ranked as a mixed-signal chip manufacturer, but the company deserves special note nevertheless. Using enormously clever analog and digital circuit, and architecture (mask), designs, POWI has built the world's only high-power AC-DC monolithically integrated powerchip that's able to convert the ubiquitous AC wall current to DC at power levels as high as 250 Watts. POWI not only integrates digital logic with analog power, but uniquely integrates both high- and low-power powerchips on the same silicon. This remarkable level of integration radically shrinks the footprint of the conventional "brick" that plugs into the wall to charge or power countless DC devices. POWI's solution is stunningly more efficient than conventional technology—if it weren't, the silicon would melt.

In the mixed-signal sector, we like O2Micro International (OIIM), which has developed some of the most impressive mixed-signal technology in the industry. With just $70 million in sales, the company attracts little notice in today's investment climate. It went public (at $40 million in sales) in the year by 2000, on the tail end of the IPO bubble; unlike many others, it has survived and even thrived in the subsequent tech implosion. Its U.S. operations are in Santa Clara, though the company is (regrettably for some analysts) incorporated in the Cayman Islands. (This does have tax advantages, however, for a company that both manufactures and sells all of its products overseas).

O2Micro is as pure a pure play as they get in this sector. It's fabless; the company's mixed signal powerchips are manufactured on standard 0.25 to 0.80 micron lines at the foundries of UMC, TSMC and X-FAB, among others. O2 has focused on power control for mobile computing, display, communications, and other consumer electronics markets—notebook computers, liquid crystal displays, cell phones, PDAs and related, GPS, and portable DVD players.

While much of the analog design world is anchored in circuit design skill and recipe, O2Micro has amassed an impressive patent portfolio, with 22 U.S. patents granted and 52 more pending (and 74 pending in various other countries) focused on systems integration and digital logic. One of the company's most intriguing patents was granted last November—for a clever design and process to tune, or optimize, the analog part of the circuit. Traditionally, the essential tuning stage of the manufacturing process has depended on physically trimming (with a laser) specific resistors on the circuit, or adding output leads for external electrical trimming of the circuit. O2Micro's solution is to build additional circuit components into the chip itself—along with an array of tiny monolithic fuses—and then blow fuses selectively during the final test, after production and packaging, to complete the final tuning. The net effect of this approach is to both increase the performance of the chip, and to substantially increase the yield in manufacturing (the latter, as is well-known, a key to lower cost).

O2 Micro's founder, Sterling Du, worked at Intel in the early 1980s and worked specifically on the generation of the industry's power management standards. Following a stint at LSI Logic, and the creation of a battery-controller start-up that was quickly sold, Du formed O2Micro in 1995, counting Sony among the company's first customers for battery-power control systems. (In portable applications, power control centers on the charging and monitoring of the battery, and in managing power distribution to the loads.) From his Intel days to O2Micro, Du's focus has been on system-level solutions to power—solutions that require a great deal of logic. Until about five years ago, logic was too expensive, and too difficult to integrate into the same silicon as the powerchips for these architectures to be widely adopted. But Du moved into the market just as that began to change. He lets leading-edge fabs produce the silicon, and EMS companies (exclusively in Asia) assemble the components into final systems; what O2Micro does is hire top-notch electrical engineers to design increasingly clever, logic-dense power circuits. Of the company's 300 employees, 168 are design engineers, located in six design centers around the world, anchored in Santa Clara, and extending dominantly in the Far East, including Singapore, Shanghai, and Beijing.

O2Micro is a major supplier of Dell's for example. O2Micro's Dell notebook charger replaced a multichip module with a single mixed single chip—O2Micro is the only company that offers such a solution. Beginning in 2001, O2Micro also became the prime supplier of the battery charging and management hardware for Compaq's notebooks. Here, a 20-component O2Micro product replaced what had been 120-component charger—and O2Micro's charger is unique in that it incorporates logic that can monitor, charge, and balance the individual cells in the battery, to extend both run-time and lifespan.

As the costs of silicon logic, and of integrating logic and power, continue to drop, and as demand for smaller, more efficient integration of these capabilities continues to rise, O2Micro should prosper.

ogy, quantum-based digital power technologies are taking over everything.

Most digital power technologies involve the quantum switching, amplification, and transformation of electrons and photons, currents and electromagnetic fields. The interactions occur at three-way junctions.

This newsletter began with the power switch. The classical electrical switch is a cumbersome electromechanical device, slow because it moves metal (an electrical contact) to control the flow of current. Its silicon replacement: a MOSFET, IGBT, or SCR—a device that moves electrons to control the flow of other electrons. Because it is slow, the old switch degrades the quality of the power it controls—it adds electrical noise. Because it is fast, the new switch is the linchpin of highly ordered electrical power—its speed lets it knit together an array of low-quality power supplies—the grid, batteries, flywheels, and backup generators, for example—into the highly relieable output of an uninterruptible power supply.

The second fundamental building block in digital power is the amplifier. Its simple function: To build a high-energy replica of a low-energy input, as in a stereo, or a laser, or an erbium-doped strand of glass. The most familiar of these is, of course, the transistor, in which one current (or electric field) controls another. The erbium-based optical amplifier is an exact photonic analogue.

The third core building block in the world of highly ordered power depends on a class of devices that classical engineering variously calls transformers, transducers, emitters, and cells, among other things—devices that take in power in one form, and put it out in another. These are as well three-wire devices, but they involve electrons in/photons out, photons in/electrons out, or interactions between electric or magnetic fields on the one hand, and light beams or current flows on the other. These are all "transformers" rather than amplifiers—they change power from one quantum state to another.

Edison invented his filament light bulb to transform electrons into photons in 1879. The semiconductor "light bulb" —a red LED—arrived in 1962. The blue LED took another 25 years after that. A classical heat pump (in a refrigerator or air conditioner) converts current flow to heat flow—by way of motor, compressor, and freon flowing through a pipe; a solid-state Peltier cooler accomplishes the same conversion at quantum scales at a p-n junction. A classical compass (plus a light bulb) will convert a magnetic field into a coded stream of photons recognizable by the eye; a Josephson junction does the quantum equivalent as a fantastically sensitive converter of magnetic disturbance to current (leading to the SQUID). A classical electric motor transforms electric power to motive—piezoelectric crystals in a watch, or at the core of an ultrasound machine, or a noise-reduction transducer, accomplishes the same conversion. And in some of the most exotic quantum applications, electric fields and acceleration act directly on light—as occurs in optical current sensors, and optical gyroscopes.

Finally, a great deal of quantum engineering centers on the seemingly humdrum challenge of building a better scaffold or wire. When a silicon carbide crystal is used as a substrate for a gallium nitride LED, the near-perfect atomic lattice of the substrate makes possible the near-perfect transport of electricity and heat through it, with a wave-like transfer of energy replacing the chaotic, diffusive transfers that govern in other materials. This can greatly improve the performance of the entire device. Sapphire is the main substitute—which tells us that superior scaffolds are worth at least as much as semi-precious gems. High-temperature superconductors, for example, are quantum wires, which, like other quantum devices, handle much more power in much less space.

The basic functions of all these devices would have been readily recognizable to electrical scientists a century ago. A silicon carbide crystal is just a conductor, like a piece of copper, only better. The old guard could have built a (slow) diode, too, by patching together a couple of slow switches and an insulator. A laser diode is a bright bulb, or a radio transmitter operating at optical frequencies—Edison and Marconi would have understood immediately. Building quantum devices out of atomic scale structures delivers nothing fundamentally new—except that it boosts power density, and thus speed, efficiency, and overall performance, by many orders of magnitude, and that changes things completely.

Why Now?

Most digital power devices have been around for decades or longer, and the physics behind most of them has been known for even longer than that. It is their engineering that has evolved very rapidly in recent years. Most significantly, the devices have been pushed up the power curve, to the point where they can find application in the power mainstream, the Watts-to-kilowatts applications that are ubiquitous in home, office, factory, and under the hood of every car, and increasingly under the "hood" of military systems.

This is most evident, once again, with powerchips. IGBTs and higher-power MOSFETs have now reached the point where they can readily refine a megawatt or so of electric power in a silicon power plant, or take care of switching, braking, valves—and in due course propulsion—in a 100-kilowatt SUV. Powerchips and the all-electric infrastructure that they enable are taking over everywhere—because they can, because the devices themselves are now both capable enough and cheap enough to replace the click-click bang-bang structures of the old mechanical world, and because the job gets done better when they do.

Solid-state light is, likewise, now poised to supersede Edison's filaments over the course of the next couple of decades. Electron-to-photon transitions can now be accomplished much more compactly and efficiently at quantum junctions than in heated filaments or excited gas cavities. Prices will fall, performance will rise, and it's only a matter of time before the cavities and bulbs disappear entirely. That transition has already occurred wherever it is important to supply more light with less power in battery-powered devices of every description, as well as in portable electronics of all kinds, and in cars, from the dashboard to the tail lights, and soon the headlamps too. Fluorescent bulbs already rely on solid-state electronics to tune the current flow to the gas in the tube; the next generation of lights will incorporate both powerchips and an array of LEDs providing more light, more control, and 90 percent less power.

Likewise with semiconductor lasers. For a long time they remained locked in the low-power think and see ends of the applications curves. But they are now moving rapidly out of it, into Watts and kilowatts. The worldwide market for laser diodes in telecom applications is currently about $3 billion, although no longer growing at the hyperbolic bubble-year rates. It is the non-telecom, the laser power market, which is growing, projected to reach $2 billion in a few short years, and grow rapidly from there, as lasers with output above one Watt move into biomedical applications, microscopy, spectroscopy, drilling, cutting, micromachining, electronics packaging, welding, brazing, and soldering.

And likewise with semiconductor sensors. Transducers detect the shadows of power. Fast, precise, reliable, tiny (and cheap) semiconductor sensors are now at hand, and destined to become embedded ubiquitously in the digital power interfaces between analog reality and the world of logic devices.

This convergence of digital logic and quantum power technologies is fundamentally changing how we build things to move things. The old, painstakingly complex arrays of belts, pulleys, gears, valves, rocker arms, and pulsing fluids are giving way rapidly to all-electric power trains. Direct-drive digital systems are smaller and lighter because electrical power requires much less transmission hardware than mechanical or fluidic alternatives. As a power-transmitting technology, an electrical wire can be far more robust, far more tolerant of hostile environments, and much more reliable than a shaft, belt, pulley, or fluid-filled pipe. This is an advantage even on a stationary assembly line, and a very substantial one when it shaves hundreds of pounds off the weight of a car or plane.

Lasers are becoming movers, too. Lasers move ink in printers and etch silicon and metal, burn hair, cauterize tissue, and reshape the surface of the eye. They supply unequaled precision in the bulk processing of work-a-day materials—heat treating, welding, polymer bonding, sintering, soldering, epoxy curing, and in the hardening, abrading, and milling of surfaces. Photon power can be aimed and focused with unequaled precision, which means that it illuminates or moves or heats more payload and less extraneous real estate.

Digital Power Markets

The U.S. economy's consumption of 100 quadrillion Btus of energy per year is almost entirely supplied by primary thermal fuels—coal, oil, gas, and uranium.

While the overall growth in capital purchases for power and power-related hardware grows relatively slowly in the mature markets of transportation and manufacturing, the invasion of quantum technologies is growing within those markets at double-digit growth rates. The overall growth of electric generation and the hardware of the trillion dollar U.S. grid follows the growth in power demand, ranging from a few percent per year in developed countries to 10 to 15 percent per year in developing countries. But again, within these mature industries one finds the beginnings of geometric growth rates for the quantum technologies that add value and functionality while meeting the just-in-time 24x7 metrics of virtually all 21st century businesses. At the other end of the growth spectrum are the industries which themselves are the progency of quantum power devices—Think, See, Move—where but-for such devices there would be no industry. These sectors themselves grow at double-digit annual rates.

Across and deep within all these sectors one finds the ubiquitous and critical enabling capabilities of powerchips, from fractional-Watt analog power ICs to megawatt grid-level powerchip modules, from few Watt LED modules to multi-kilowatt diode laser stacks. The quantum powerchip industry is by itself a $16 billion per year global market and is poised to grow as large as (likely larger than) its quantum sibling, the semiconductor smartchip industry.

Peter Huber, Mark Mills May 12, 2003
www.digitalpowergroup.com

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*
II-VI (IIVI) www.iivi.com	1/03	Poly-Scientific (subs. Raytheon (RTN)); Umicore (Umicore Group, Belgium (ACUM.BE)
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)
Applied Materials (AMAT) www.appliedmaterials.com	3/03	Novellus (NVLS); ASML (ASML)
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-3.com	12/02	DRS Technologies (DRS); Integrated Defense Technologies (IDE); 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)
O2Micro International (OIIM) www.o2micro.com	5/03	Linear Technologies (LLTC), Maxim (MXIM), ON Semiconductor (ONNN)
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)
RF Micro Devices (RMFD) www.rfmd.com	2/03	Hitachi (HIT); Skyworks (SWKS); TriQuint Semiconductor (TQNT)
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)
Sensytech (STST) www.sensystech.com	4/03	Northrop Grumman (NOC); Raytheon (RTN)
TRW Inc. (TRW)** www.trw.com	1/01	Conexant (CNXT); Fujitsu (6702, Taiwan) www.fujitsu.com, 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.

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