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Powering the Telecosm
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Cisco of the Powercosm?

Power-One is pushing silicon technology up the power curve into a commanding position among companies that power the digital infrastructure

The first great debate of the Powercosm pitted DC against AC, Thomas Edison against George Westinghouse. Westinghouse won, and the 60 Hz AC century followed: Alternating current is easier to transform (step voltage up or down), more efficient to transmit, and a natural fit with rotating machinery—generators and motors. DC applications ended up confined to the margins of the grid, and to off-grid battery-powered uses.

Then came the logic gate: RAM, microprocessors, pumped lasers—DC devices, every one of them. Run an AC signal through a silicon chip, and in precisely half a cycle—as soon as the AC voltage crosses zero—you lose every last bit in the device. For any device that relies on dynamic storage, a zero-power state that lasts for more than a fraction of a clock cycle is a shut down. Intel chips, Juniper Network routers, Sun superservers, EMC terabyte memory, Ericsson wireless base stations, or Lucent digital switches all require Edison's power, not Westinghouse's.

And lots of it. We're not talking cell phones here, but rather, racks of GHz-speed circuit boards, with the power requirements of a commercial refrigerator—all housed in buildings with appetites for fuel rivaling those of a mini steel mill or an old-economy manufacturing plant.

So there we have it: a monstrous schism. A power backbone that runs at 600kV AC, with everything on down in the public grid locked into the 60 Hz harmonic. Meanwhile, DC loads at 2 to 5 volts mushroom and multiply in catacombs of silicon at the end of the line. High-voltage AC above. Low voltage DC below. And high power flowing right down the middle, across the divide.

Only four serious contenders build the right components to bridge that divide at the key intersection on the motherboard. Two familiar telecosm-centered companies, Lucent and Ericsson; the emerging (privately held) SynQor; and the ascendant Power-One (PWER). Power-One, in particular, is now aggressively pushing silicon-centered technology up the power curve, down the cost curve, and into a commanding position among companies that power the digital infrastructure. It stands an excellent chance of emerging as the leading company managing the routing of big electron flows at the building level and on down, a Cisco of the Powercosm.

The power chasm

The AC/DC chasm is easy enough to bridge, so long as you have plenty of room to spare—for transformers (to step down voltage), capacitors and inductors (to wipe out electrical ripples), and metal fins and fans (to carry away heat). But there is no room to spare in the microcosm, or even on its doorstep. The genius of the microcosm lies in packing more gates on the silicon, more silicon in the chip, more chips on the board, more boards in the rack, and more racks in the room. Connections must be short—clock speeds are limited by the light-speed transit times of electrons between gates.

Worse still, the AC/DC divide is widening. Peak power requirements on chips and motherboards are rising as gates multiply and clock speeds rise: 15 years ago, an Intel 386 peaked at a few watts; today's Pentium hits 50W; and the industry is headed for over 100W peaks in microprocessors this year. Even as power requirements rise, moreover, the chip's DC voltages fall. More gates on a chip means thinner silicon walls between them, and voltages must fall apace or the walls won't hold. IC voltages have thus dropped from 5 to 3.3 to 2.2V and now even 1.5 in the last 5 years, with 0.5V expected before 2010.

If power requirements rise while voltage falls, current must rise even faster. To feed 50 to 100 amps onto a silicon surface, smartchip engineers multiply the number of power leads to the chip and spread them around the periphery of the package. The highest-speed chips now require radically new "ball-grid array" power connections, consisting of dozens of solder balls underneath the package.

But how do you get 50 amps at 2.2V DC to the doorstep of the chip? The obvious solution, one might suppose, is to convert from AC to DC, far from where the chips are—at the base of the rack, in the next room, or in the parking lot—and just send DC current down a long power bus. But that won't do, either.

To begin with, distributing large amounts of DC power at very low voltage requires an unmanageably monstrous electrical bus, to handle the very high currents. (The diameter of a DC electric cable for a 2.5V bus would be over 50 times greater than a 120V cable for the same power.) Moreover, state-of-the-art smartchips can demand 100 amps of additional DC power within the space of a clock cycle or two—a few nanoseconds—and then shed the same load again, a few cycles later. Low-voltage, high-current transients of that severity create new problems with induced system-wiring inductance and electromagnetic interference. A single power source in a distant rack just cannot accommodate DC transients that severe. The problems are avoided only by confining the low-voltage high-current flows to points very close to the final load. Short wires, it turns out, are as important for the electrons that provide power as they are for the electrons that carry and store the information. The ideal power supply is one situated directly next to the load that delivers amps as needed, at a perfectly steady DC voltage, but that occupies no space, and that dumps no thermal chaos (heat) into the digital order alongside.

A distributed power architecture

But no such device exists. What has emerged instead is a Distributed Power Architecture design philosophy (a concept, not incidentally, echoed at every level of the Powercosm). At the front lines of the telecosm, room-level *power plants* convert 480 VAC to 48 VDC—a voltage still high enough for reasonably efficient distribution of high levels of power, but not so high that it requires unmanageably large buses, or threatens to electrocute the system engineer every time he switches a board in a rack. *Power bricks* on the boards then make a further DC–DC conversion to deliver 1-15 VDC to the final, silicon loads. Bricks are now destined to end up on the flip side of the circuit board, directly opposite the CPU, or even parked on top of the CPU—a dedicated micropower plant for the dedicated microprocessor. So long as the power supply is cool and compact enough, this is the shortest-wire—and therefore the best possible—configuration.

The multiple redundant, two-stage, power-plant-to-brick architecture is robust. A single brick's failure shuts down (or fries) only a single board, not a whole roomful of electronics. Hot swaps are facilitated, and new, lower-voltage boards can be brought in without reengineering the whole room. Multiple bricks raise overall electrical reliability, just as redundant processors and hard drives provide more reliable MIPS and data storage.

The DC power-plant and brick have thus emerged as the two essential, complementary components that propel electrons across the prairies of silicon in the data-storage hub superserver, and wireless base station. As it turns out, silicon is also the key component inside the power plant and brick. Within a new generation of bricks we find microcosm and Powercosm turned inside out, an old architecture of analog electrical power in the middle, sandwiched between two layers of state-of-the-art clocked, synchronous, silicon devices. Here, perhaps for the first time anywhere, the technologies of the microcosm physically envelop the old technologies of the macrocosm. It is as if the cylinders of a new car came encased in silicon rather than steel.

High-powered bricks

A single threshold criterion—high power at high power density—distinguishes the few serious brick contenders from a tangle of other manufacturers, both small and large, whose bricks are either too big or too low-power to survive on the power-dense digital circuit board. Remember that this board is the most expensive, heat sensitive, and (per unit of area) power-hungry real estate in the world.

The isolated, modular, low-power DC–DC brick originated in 1975, a useful but hardly revolutionary idea. In 1984 Vicor (VICR, Andover, MA) introduced the first commercial high-power brick (100W or so). Built around a cumbersome, wire-wound transformer, it was a 4.6 x 2.4 inch monster, whose dimensions have ever since defined the footprint of the "full-size" brick.

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AT&T (Lucent), Astec, and Lambda followed with comparable bricks soon after. But high-power brick technology did not advance fast. Demand remained confined to the comparatively glacial businesses of minicomputers, mainframes, and their counterparts in the telephone industry, big electronic switches.

Rapid advances came only a decade later, and at the opposite end of the power curve, in very low-power bricks (and smaller brick-like arrangements) used to convert 5V battery to 3.3V chip power in cell phones and videocams. Today, several hundred companies serve this largely commoditized, $1.4 billion market, supplying low-power bricks for low-end servers, routers, cable modems, xDSL modems, network adapters, flat-panel displays, and storage devices. The industry's standard forecasts foresee revenues rising to about $2.3 billion by 2004.

But most of the world's digital power does not reside in the thinnest of thin—i.e., lowest of low-electrical-power—clients. Nor even in the relatively low-power PC desktop. It resides in comparatively high-(electrical)-power, high-clock-speed, 1 GHz-and-up servers and in terabit storage warehouses; it is accessed by means of optical transmission technology, electro-optical interfaces, and digital-radio base stations.

The higher-power racks, the base stations, the routers, and servers where datacom and telecom hardware converge will use most of the digital power. In those locations, the power challenge is to cram 100W and up into half-size bricks and down. The brick has to run cool without a heat sink, and must be small and light enough for automated assembly lines. It must—in sum—have the profile and physical characteristics of the smartchips that it serves.

The MOSFET breakthrough

The key technical breakthrough occurred in 1995 with the emergence of low-cost, high-performance MOSFETs, Metal Oxide Semiconductor Field Effect Transistors, from companies like International Rectifier and Siliconix. Using MOSFETs in a new high-frequency, low-loss design, Lambda Electronics (now part of the Invensys engineering conglomerate, London, United Kingdom) introduced *fully synchronous rectifier bricks* to the market. (We'll get to what that means, and how they did it, shortly.) International Power Devices (IPD, Boston, Massachusetts, acquired by Power-One in January 1999) followed with their own synchronous device in 1996, then so did Lucent, Ericsson, and one-year-old SynQor (1998).

On the demand side, the new bricks responded to the new imperative of much lower voltages in the CPUs that the bricks must power. On the supply side, they seized on the equally significant emergence of the higher power, higher speed, lower capacitance powerchip—the MOSFET (see April DPR). Spearheading the market today is a new generation of fully synchronous, all-MOSFET bricks that offer more power in less space, with faster response and dramatically lower thermal loss. Within the brick, smart, clocked, synchronized, digital silicon is displacing dumb, passive, analog semiconductor diodes.

Short wires, it turns out, are as important for the electrons that provide power as they are for the electrons that carry information

The market for high-end bricks is about $700 million today, but growing geometrically. The standard industry forecast of a $1.2 billion market by 2004 is almost certainly low by a factor of 50 percent or more. The bandwidth appetite of the telecosm will drive the Powercosm faster than conventional wisdom. The raw engineering challenges—to shrink size, boost power, and cut heat—are as great here as anywhere on the digital circuit board. And the technical advances are now coming as fast. Gene Sheridan (VP and lead engineer in telecom applications at International Rectifier), Dennis Roark (CTO and lead engineer at Power-One's IPD), and Martin Schlecht (founder and CEO of SynQor) convey a sense of commitment and excitement more typically found among the guys trying to crack 1 GHz on a CPU, or embed Java code in the Web.

Only a handful of players will emerge to dominate the high-power brick market, just as only a handful of companies have emerged to dominate the manufacture of other core building-block components of digital infrastructure. And for very similar reasons. With silicon bricks, as with other digital silicon devices, economies of scale and scope give overpowering advantage to companies that lead the way in research, development, and volume production. Virtuous circles of collaborative design and development unite leading manufacturers of bricks, CPUs, and other power-hungry digital components. Their products grow increasingly interdependent. First movers gain an overwhelming advantage.

Who are the contenders? Lucent (or the eventual buyer of its brick operations—see later), Ericsson, Astec (a division of Emerson Electric, EMR), Texas Instruments (via the 1999 purchase of Power-Trends), Celestica (CLS), and Lambda are all major players, but their power operations are buried within much larger conglomerates. Artesyn (a 12/30/97 merger of Computer Products, Zytec, and Heurikon), Datel, Vicor, and Power-One are purer plays. And finally, SynQor, three years old, highly focused and still private.

Cut to the chase

To be a serious contender a company must be building—*today*—a 100+W brick, in a half-size package, without a heat sink. Heat sink? Strange indeed to find a reference to that eighteenth-century vestige of the steam engine here at the epicenter of the digital world. But then, that is what the Powercosm is all about—bridging the chasm between power generated in the macrocosm and power consumed in the microcosm.

Size first. In a Powercosm version of Moore's Law, Power-One's IPD group has been cutting the size of bricks in half every two years, for a constant power output. Yesterday's 100W standard-size brick is a half-brick today. Within a year, quarter-bricks; shortly thereafter, eighth-bricks will deliver 200W. SynQor's recently released "Tera" is a half-brick that delivers 150W. Ray Desabato, the company's president, says he'll cut the size in half again within the next two years.

In a powercosm version of Moore's Law, Power-One has been cutting the size of bricks in half every two years, for a constant power output

The fractional-sized brick now has a lower profile than the microprocessor it serves. It can sit as the low-rise structure on the circuit board. This improves air flow—remarkably important on a board cooled by natural convection. So the microprocessor and the brick both run cooler. Improvements within the brick cut heat losses to the point where the brick can shed its heat sink.

The absence of a heat-sink on a high-power, half-size brick tells you most of what you need to know about how smart things are within. It takes a very efficient package to channel 100+W across a high-voltage drop in a small space, while generating so little heat that natural convection can handle it. SynQor's Tera series brick has no heat sink. Lucent, Ericsson, Power-One, TI's Power Trends, and Artysen's recently announced comparable products. Ironically, the heat sink lost by the brick is now likely to be gained by the CPU alongside: the power converted so efficiently by the brick ends up being dissipated inside the microprocessor. Some of the highest-performance microprocessors now come equipped with air fins or even liquid cooling systems.

Yesterday's programmers were conditioned to optimize code to save silicon. Yesterday's power electronics engineers were conditioned to do much the same, sparing the silicon, using more of everything else. Silicon powerchips were expensive. Now they're cheap, and getting cheaper fast. The winning brick companies use silicon profligately, to improve efficiency and reduce heat.

To understand how silicon enters the story, focus first on where the silicon isn't. With 48V on one side, and 100-amp currents on the other, a brick offers a 4800W potential exposure in space the size of a matchbox. For now, pure semiconductors can't provide sufficiently robust isolation, not in that small a space, not without dissipating a lot of heat. Emerging silicon powerchips will eventually consume this last interface, too, but not soon enough to meet the voracious demand for better bricks here and now.

So at the very heart of the high-power brick, one finds a last key remnant of macrocosm power technology—a transformer. Recall how a basic wire-wound transformer works: A magnetic field is used to transfer power between two physically isolated coils of wire: magnetic inductance, typically channeled through a metal armature, substitutes for direct current flow. Placing a transformer at the heart of the brick provides the needed electrical isolation between input and output.

But the transformer's magnetic fields are created by an alternating current. (To a DC current, a transformer is simply an open circuit.) So the DC-to-DC brick has to add two more internal conversions, ending up a "DC-to-AC-to-AC-to-DC" device, with the transformer taking care of the AC-to-AC stage in the middle.

The critical developments have occurred in the two layers bracketing the transformer: the DC-to-AC layer upstream (the "inverter"), and AC-to-DC downstream (the "rectifier"). They have centered, in particular, on pushing up the speed of the AC cycling that's added upstream of the transformer and subtracted downstream. Frequency is critical. The higher the AC frequency, the greater the power the magnetic field can transfer in a smaller number of windings, thus the smaller the transformer can be, and the faster it can respond to transient demands for power.

Some 90 percent of bricks still sold in the low-power brick market continue to use simpler Shottky diodes rather than MOSFETS in their rectifiers. A diode is basically an analog device that passes current in a single direction only, but that operates passively. By preventing current flow in a reverse direction it converts AC into lumpy DC (i.e., one half of the alternating cycles of AC). A 0.3-0.5V loss is inherent in its operation. Thus, as output voltage drops toward 2.2V and lower, a diode's efficiency plunges, and with it the brick's overall efficiency. Heat dissipation increases. And a heat sink becomes essential.

The alternative: use a MOSFET, first to add, then to subtract, the AC cycling. MOSFET transistors, which have much lower voltage losses than diodes, can be instructed (by logic circuits) to function like a diode, turning current on and off. But until recently, MOSFETs were expensive and had unacceptably high resistance. Today, MOSFETs are cheap; eventually, they'll expel diodes from the market entirely.

By 1997 the mass production of better MOSFETs made possible very high-power rectifier circuits in low-resistance bricks for such products as cell phones and videocams. Early bricks with bipolar transistors ran in the 20 kHz range. With the introduction of fast MOSFETs in 1995, brick clocking frequencies jumped up to several hundred kHz. These higher clocking speeds made possible the introduction of a much smaller, *planar* transformer—a few flat metal loops on a circuit board. The planar transformer's flat inductors shrank to occupy about 25 percent of a high-power brick.

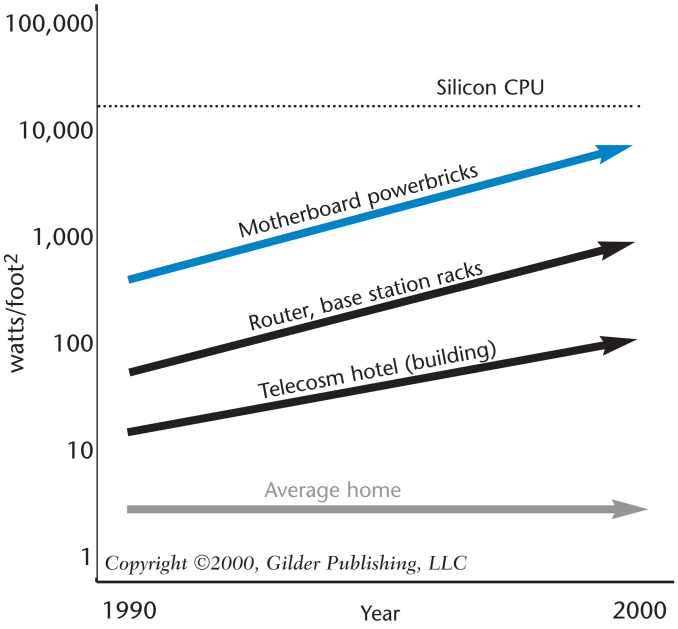
The more efficient the MOSFET, the faster it can be switched, and the smaller the transformer can be. And the higher the AC frequency, the smaller the inductors, and the cooler the package. Brick efficiencies are starting to hit 90 percent, and are now headed toward 95+ percent (old technology labors in the 60 percent to 70 percent range). Thermal losses have been declining apace. Bricks shed the heat sink and shed weight, which allowed them to be handled by VACuum pick-and-place robotics on the automated assembly-lines of the microcosm. Handling and assembly costs were shed along with copper.

The MOSFET Index

The advance of high-power brick technology can now be tracked by the MOSFET index: Add more and better silicon MOSFETs, subtract everything else. SynQor's strategy is to use more of the best, lower-power MOSFETs developed for the cell phone market by Siliconix; PowerOne/IPD's centers on using somewhat fewer, bigger MOSFET's supplied by International Rectifier and Siliconix, among others. Either way, the amount of silicon in the brick keeps rising. A MOSFET brick contains 2 to 3 times more silicon than a Shottky diode brick. Last January, Power-One/IPD introduced a brick with 6 MOSFETs. In March, SynQor announced a brick with 8 MOSFETs, and the company has just introduced its 90 amp/150W "Tera" brick that contains 10 MOSFETs. The silicon surface area in a high-power brick is now approaching half that in the GHz CPU it powers. It will soon overtake it.

MOSFETs are now on their own Moore's-law trajectory. The capacitance per MOSFET gate today is about 5 nanoFarads, and will drop ten-fold in four years. The lower the capacitance, the more efficient the device. MOSFETs are actively switched: power is pumped in and out to turn the MOSFET on and off. That process inevitably dissipates power; a lower capacitance device dissipates less. International Rectifier just announced a new generation of pre-packed multi-chipset MOSFETs for the brick market—innovative packaging and interleaving of six MOSFETs makes possible 1 MHz bricks, targeted to serve 1 GHz CPUs. IPD/Power-One engineers expect MOSFETs, and thus bricks, to be running at 2 to 3 MHz speeds within two years. At which point the planar transformer will all but disappear, its coils replaced by stray inductance simply cannibalized from thin layers of copper on the circuit board.

Power densities in the Powercosm



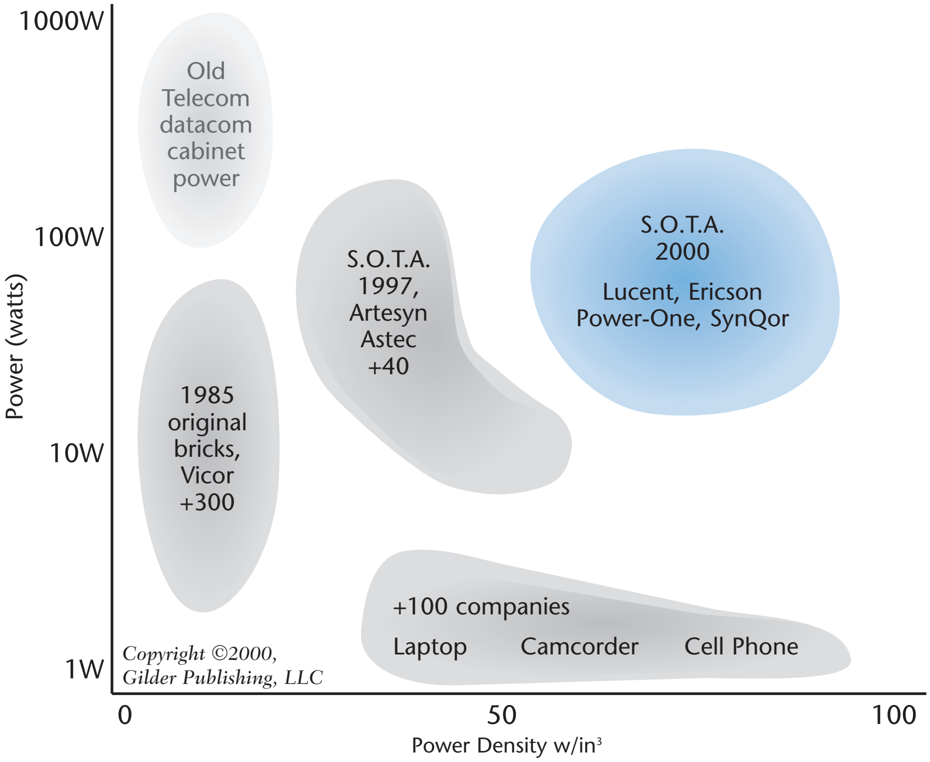
Power density is the highest and rising fastest on the DC motherboard; motherboards are multiplying in wireless base stations, routers and servers, and filling telecosm hotels.

Smarter control signal circuitry pushes down MOSFET losses, too. Both Power-One/IPD and SynQor use patented circuit topology to capture and re-use the residual gate capacitance during the brief time the MOSFET is not in use. Power-One/IPD owns two patents on resonant control circuits that pull the capacitive charge off the MOSFETs, which makes possible higher-frequency operation. The next step, according to Power One's Roark: Use Application Specific Integrated Circuits (ASICs) to collapse the total component count on a brick, down from today's 100 plus to 15 or so, freeing up real estate for more next-generation MOSFETs to further raise power density and reduce heat.

Much of the rest of brick improvement lies in the minutia of packaging and configuration. Power-One holds patents on a sealed, planar transformer. This makes possible the first "non-potted" washable brick. It eliminates the need to seal the entire brick in a black polymer shell to protect the transformer during washing to remove soldering residue. The MOSFET-based "open frame" approach further improves cooling.

Two more Power-One/IPD patents cover a technique to use metal substrates in the control board to thermally insulate the control from the power circuits in order to raise power density. And the company owns four other patents addressing techniques to minimize voltage stress at high clocking frequencies. Power-One is currently exploring a new topology that places several inde-

Powering the motherboard



Leading edge powerbricks provide the highest power in the smallest space. The Moore's law equivalent for power bricks: power rises slowly, size shrinks fast, power density rises faster.

pendent power supplies in a single brick, each one at, say, 30 amps, but "interleaved" to create a 90 amp (200W) unit; breaking the design up into 30 amp subsystems allows for faster, smaller, cooler performance overall.

A brick behind every bit

The rule of thumb for brick demand going forward: At least one brick per motherboard, often a brick per CPU, and bricks for all the other high-speed, board-mounted silicon in all high-power infrastructure applications. High-power bricks stand behind every bit in a central office telephone switch and its accessories; wireless communications equipment; microwave transmitters, receivers, and repeaters; voice processing equipment; PBXs; and internetworking equipment such as hubs, routers, ATMs, and backplanes; the boxes and rack mounts sold by Cisco, Nortel, Ericsson, Lucent, Sycamore, Avici (Nortel), and EMC.

As synchronous high-power MOSFET bricks get faster, smaller, cooler, and cheaper, they will also absorb market share from inferior substitutes in the lower-power space, too. When it comes to power technology, desktop PCs are still bottom feeders, but the synchronous MOSFET brick will be taking over the bottom, too, in short order, as GHz CPUs penetrate the low-end market. (Like their high-end brethren, PCs need a powerplant, the power supply parked in the box, to convert the wall plug's AC into useful DC, generally at the other, lower, standard 24V.) Propelled forward by the datacom and telecom demands, high-power bricks will also end up serving the major DC–DC power supply requirements in aerospace, automotive, industrial, and many conventional electronic devices as well. Cars are now going through a major reengineering of their internal electrical grid, moving from a 12V to a 42V bus to meet the proliferation of electronic devices throughout the vehicle as total loads move into the multi-kilowatt range.

Intel recently formed, with Compaq, Data General, NEC, Dell Silicon Graphics, and IBM, a "server system infrastructure" group, to establish open standards for motherboard power, and map out future requirements for the emerging generation of multi-GHz chips. Board manufacturers have a compelling incentive to collaborate closely with leading-edge suppliers of bricks. As brick and digital load get physically closer, wires get shorter, and parasitic inductance falls, response to transients improves, additional power-smoothing capacitors are eliminated, and the brick gets smaller, runs faster, and operates cooler.

A typical Pentium motherboard today requires over 100 power-management capacitors arrayed around the microprocessor to provide a last layer of assurance that electrons will be at hand for the asking when power requirements suddenly rise within the chip itself, in response to a sudden increase in demand for MIPS. Design and locate a brick where it can meet 100-amp, 2-nanosecond transients directly, and those capacitors almost vanish from the circuit board. Board wiring currently accounts for 30 percent (and rising) of power losses; innovative brick geometries and close coordination with CPU and board designs shortens wires, and thus further reduces losses. And power savings echo all the way up the power line, from circuit board to rack to room to building.

These factors all point to the emergence of a small number of dominant brick manufacturers, working in tight collaboration with smartchip manufacturers and circuit-board designers. The future of the brick now centers on silicon MOSFETs and the circuits that control them—which depend in turn on silicon switches and silicon-based control circuits. The early leaders in this space will reap the advantages that invariably accrue to early masters of digitally controlled silicon technology. They will relentlessly push performance and volumes up, and costs down. They will invest in dedicated, fully automated production lines. They will form virtuous circles with their customers, smartchip manufacturers, and board-level designers and integrators.

The contenders

It comes as no surprise to find that two telecom-equipment companies—Lucent and Ericsson—are forces to be reckoned with in the high-power, high-power-density brick space. They were in the business of delivering high-9s performance (always-on dial-tone) and thus, high-9s power, long before servers and dot.coms arrived on the scene. Last February, Ericsson introduced a new generation of cool heat-sink-free brick; 140 W in a half-size (or 70 W in a quarter-brick) with 89 percent efficiency. Lucent is currently the world's leading manufacturer of MOSFET bricks, and has about $1 billion of sales in its total power-related lines of business.

Nevertheless, Lucent announced as we went to press that it would be selling off its entire power unit, to a buyer yet to be determined. Nortel did the same (selling to Emerson Electric's [EMR] Astec division in 1998.) Ericsson likewise sold its powerplant (though not its brick) operations to Emerson for over $700 million this past January. It should have unloaded the bricks, too.

Why does it make such compelling sense for telecom equipment vendors to exit this leading edge business? Both Lucent and Ericsson make great bricks; the trouble is, both also make great equipment that depends on those bricks—and that competes directly against equipment manufactured by other major buyers of bricks. Lucent has reason to understand this problem better than most. AT&T spun off Lucent when it finally became clear that AT&T couldn't retain the trust of its major equipment customers—local phone companies—when AT&T itself was poised to become their fiercest competitor in service markets. Cisco, for example, needs better high-power bricks as much as it needs better smartchips. But it can hardly afford to rely on its main competitor as its sole or even prime supplier. So 45 percent of its brick business goes to Power-One; the balance is divided between Lucent, Artesyn, TI, and Astec; and tiny SynQor is a supplier, too. Bricks used to be specialty components of telecom equipment markets, but no longer: They are now essential, general-purpose building blocks of all high-power nodes in the digital infrastructure.

As Lucent has belatedly recognized, the market will end up dominated by a Cisco-like supplier of the building block itself, not by a vertically integrated competitor that happens to own a captive brick business buried within, however good its bricks may be. Whoever its new owner, Lucent Power will be a formidable competitor with world-class technology—even more formidable than it already is, because it will be far better positioned to sell to buyers like Cisco. This means tougher competition against Power-One—but also new opportunity for Power-One to sell bricks to Lucent itself, the world's biggest purchaser of bricks, as a potential customer. (AT&T's original divestiture of Lucent was very good for Lucent's main competitor, Nortel, for similar reasons, though Lucent continued to dominate AT&T slots.) The main open question is, what kind of brain drain will occur (or has already occurred) in the turmoil that inevitably accompanies a divestiture of this sort?

Four other companies bury the high-end MOSFET-bricks they build deep within other operations. Astec, a division of Emerson (EMR), is a major brick manufacturer, and has a limited high-end line; but Emerson is in just about everything else electrical, too. It remains a great Powercosm company; but it just isn't close to a pure-play in this particular layer. Lambda has much the same problem: It was a MOSFET-brick pioneer, but has since been acquired, first by Siebe, and then Invensys, and seems to have lost interest in the high end with few new-generation offerings. Power Trends, acquired by Texas Instruments (TXN) last November, was a pure-play contender with their 90-percent efficient, 100 W half-brick, but its product line-up is dominated by lower power bricks. Celistica, which has a limited number of high-end, heat-sink-free bricks, is also buried deep within a $6 billion contract-manufacturing operation that was spun off from IBM in 1996.

Why does it make such compelling sense for telecom equipment vendors to exit this leading edge business?

The search for a clean, focused, pure play on high-end bricks turns up only a small handful of companies. Formed through a late 1997 merger of a custom AC–DC power supply company (Zytec) and an AC–DC and DC–DC low-end power supply firm (Computer Products), Artesyn will definitely be a competitor to reckon with. A $600 million revenue company and major player in the broad global brick market, Artesyn announced in March its first ultra-high-power brick (with heat sink) for the CLEC (competitive local exchange carrier) or wireless-base-station market. And more recently still, a 75 W, high-speed, half-brick without heat sink.

Three-year-old, privately held SynQor makes nothing but very high-end, high-density bricks—its 100 W quar-

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	4/28/00 Price	52wk Range	Market Cap	Customers
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	68 1/4	68 1/4	10 1/2 - 78 3/8	$1.73b	Cisco, Nortel, Teradyne, Lucent, Ericsson
Powerchips: Insulated gate bipolar transistors (IGBTs)	IXYS (SYXI)	3/31/00	13 9/16	24 3/4	2 1/2 - 26 5/8	$299m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
IGBTs	International Rectifier (IRF)	3/31/00	38 1/8	49	9 1/4 - 51 5/8	$2.33b	Nokia, Lucent, Ericcson, APC, Emerson, Intel, AMD, Ford, Siemens
Network Transmission and UPS: High-temperature superconductor	American Superconductor (AMSC)	9/30/99	15 3/8	38 1/5	10 3/4 - 75 1/8	$729m	ABB, Edison (Italy), ST Microelectronics, Pirelli Cables, Detroit Edison, Electricite de France

Note: This table lists technologies in the Powercosm Paradigm, and representative companies that possess the ascendant technologies. But by no means are the technologies exclusive to these companies. In keeping with our objective of providing a technology strategy report, companies appear on this list only for the core competencies, without any judgement of market price or timing. Reference Price is a company's closing stock price on the Reference Date, the date on which the Power Panel was generated for the Digital Power Report in which the company was added to the Table. All "current" stock prices and new Reference Prices/Dates are based on the closing price for the last trading day of the month prior to Digital Power Report publication. Though the Reference Price/Date is of necessity prior to final editorial, printing and distribution of the Digital Power Report, no notice of company changes is given prior to publication.

ter-brick occupies the rarified space with only a few other products (primarily those of Power-One) with the highest power density in the industry, among bricks without heat sinks. And, together with Lucent and Power-One, SynQor is the only vendor with a brick that eliminates the metal plate that still serves as a modest heat sink on many other bricks. CEO Martin Schlecht, a long-time MIT professor of power electronics, emerged from academe last year to take full-time charge of the fledgling company. The company has sixty employees (headed for one hundred) and is opening a design center in Dallas, Texas, near its major customers—Nokia, Alcatel, Nortel, and Ericsson. SynQor also sells to Lucent, Cisco, and Sycamore.

Power-One/IPD has the broadest, and most diversified, line of high-power MOSFET bricks; with their new product line, they now have a model line-up 50 percent bigger than Lucent or Ericsson. (CEO Steve Goldman got his start in the business solving the problems that plagued the power supplies in the early Apple McIntosh computers.) Power-One is also the fastest growing, and the largest, pure play. The company has been buying up key Powercosm assets around the world. Its acquisition of IPD (early 1999) was followed by HC Power (March 2000) and then Powec (Norwegian supplier of power systems to Nokia, Vodafone, Ericsson, Sonera) in April 2000. HC Power produces the critical, room- and building-level AC-to-DC power plants. Power-One also acquired power supply maker Melcher (Europe) in 1998. Overall, Power-One now employs 250 power design engineers, and is quite possibly one of the most focused as well as one of the larger Powercosm teams in the world. It owns over thirty core patents in power technology, and its high-power bricks are positioned at the leading edge of the power/power-density envelope.

Power-One's operations now span the space between the 480 VAC mains and the 1-15 VDC motherboard, from building-level power plants to bricks, and that space defines the company's entire business. It owns critical technology subsidiaries that can manage power from a megawatt datacenter, to the 15 kW wireless base-station, down to the hundred-watt motherboard. (Nextel's San Diego cells and the Motorola PCS cabinets for Sprint and Airtouch depend on Power-One's HC unit.) Last January, Power-One hired a new president, former Lucent vice president and power executive Bill Yeates. If Lucent spins off its power division, it will instantly rank as Power-One's most threatening competitor—unless Power-One buys it, and puts Yeates right back in charge.

When Power-One bought IPD just over a year ago, brick sales were $29 million. IPD's sales hit $60 million last year and will at least double again this year. Current industry forecasts call for a 30 percent to 40 percent per year growth market for bricks, but the leading-edge vendors will grow much faster than that—as fast as the infrastructure of the telecosm.

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