THE HUBER MILLS digital power report
Powering the Telecosm
December 2000/Issue 11
Published by Gilder Publishing, LLC

The Silicon Car

Infineon has a rock-solid history in automotive powerchip technologies and joins International Rectifier as a leader in providing silicon-driver technologies for the automotive platform

A Mercedes at Comdex? There it was at the Las Vegas Convention Center, a CLK 55 coupe, and a test track, too – courtesy of its manufacturer, the first non-tech company to sponsor the world's biggest computer trade show. A showcase for digital cell phones, GPS navigation, and e-mail appliances in a luxury car's dashboard? Yes, in part. But the important silicon is headed deep under the hood.

The silicon computer – the microprocessor – came of age on the desktop. The silicon driver – the intelligent, matter-moving synthesis of smart chip and powerchip – will come of age on the chassis of the automobile. It won't stop there. Silicon that can seize control of a car can seize control of just about anything mechanical. It didn't start there either – smart chip-powerchip technology has been evolving for years in aircraft, submarines, ships, locomotives, big trucks, industrial robots, and machine tools. Which is like saying that IBM (IBM) mainframes preceded Intel (INTC) and Apple (AAPL). So they did. But as Lenin once remarked on the subject of tanks, quantity has a quality all its own.

The world produces 50 million new cars and light trucks per year, along with 400,000 heavy duty trucks. Counting trucks in car-equivalents, the "installed base" is about 500 million cars. To put things in electrical units, the "generating capacity" in the annual production of new cars alone is about 5,000 GW – 30 percent more than all the stationary power plants (coal, oil, gas, nuclear) on the world's electric grid. If all those automotive engines ran flat out at the same time, they could generate about 35,000 GW of motive power – twelve times as much as the electric plants.

So this is where the massive leading-edge R&D investments will occur, where the economies of scale will cut in, where costs will be slashed, where the exotic, expensive, and temperamental high-tech assemblies will be shrunk down and hardened into economy-transforming, mass-market commodities. This, in short, is where the rest of Powercosm – the other 90 percent of it – will unfold.

Many companies have been quietly pushing silicon into the inner recesses of the automobile, and for quite some time. Inevitably in a field this big, a lot of different players will capture some piece of the action going forward. Some will be old-guard, some new. Electrical engineering companies moving aggressively on to the mechanical engineer's turf – Aura Systems (AURA), El Segundo, CA, DENSO (DNZOY), Delphi Automotive (DPH), Furukawa Electric (FUWAY), Magneti Marelli, Lear (LEA), Bosch, Visteon (VC), Yazaki, Johnson Electric (JELCY), Matsushita (MC), TDK (TDK), Tyco/Electronics (TYC), Yuasa, and Emerson Electric (EMR).

MOSFET powerchips will be at the heart of just about everything they build. Manufacturers will include Siliconix Inc. (Malvern, PA, 80 percent owned by Vishay Intertechnology), Intersil (ISIL) spun out of Harris (HRS) in 1999, ON Semiconductor (ONNN) spun out of Motorola (MOT), also in 1999, Toshiba (TOSBF), Philips, Hitachi (HIT), ST Semi (SGS Thompson), and Powerex (a GE/Mitsubishi joint venture). But the two most likely to emerge as the Intel's of automotive silicon are International Rectifier (IRF) and Infineon (IFX). We put International Rectifier on our panel in April, for its leadership in developing the IGBT, the MOSFET's more powerful, but slower, cousin. Infineon was the semiconductor division of the German giant Siemens (SMAWY), until it was spun out as a separate company on April 1, 1999.

The Car-Wide Web

We're not talking about automotive e-toys, here. The high-speed Internet is surely coming to the car, and plenty of companies will prosper bringing it there. (See the August 2000 issue of our sister publication, the *Gilder Technology Report*.) The heavily digital dashboard will need high-9s electric power, too. But the big Powercosm story in this space is a lot bigger than that.

We're not talking about fuel cells, either, nor any of the fond green hopes to retire the internal combustion engine. That might happen some day, after everything else in the car has been richly siliconized, but it won't happen before. For the next decade, at least, it isn't the piston-cylinder combustion architecture that will be displaced. It's all the rest.

What rest? Pretty much everything else that comes before or after the combustion. Which is to say, just about all the click-click bang-bang tangle of stuff that transforms the raw explosive force on the piston into a harmonious cruise down the highway – all the stuff it takes to get fuel and air into the cylinder and ignite it, and then turn a moving piston rod into traction, steering, braking, and cooling, all the mechanical links, belts, pressurized hydraulic fluids … and electrical currents.

The car's powertrain will be transformed from mechanical-hydraulic to digital-electric by a constellation of servo motors and silicon electric drivers. They will need two things – sufficient raw power to do the heavy lifting, and sufficiently precise control of that power. High-9s power, in other words, move components exactly when and where they're supposed to move.

As discussed in *Powerchip Paradigm II: Broadband Power*, the control is the tough part. It requires, first of all, digital intelligence. A decade ago the raw computing power wasn't available, but is today. The power of the Pentium more than suffices for most applications, though the leading edge vendors generally design their own application-specific microprocessors. Very accurate and reliable sensors are equally essential to ascertain position, speed, and acceleration at any moment, so that the smart chips can dispatch just the right amount of power to get things to the right place 10 milliseconds hence. A wired (first copper, but eventually fiber optic or wireless) communications bus is required, as well, to knit together the various controllers and sensors, from headlights to tailpipe on the car-wide Web. "You've got ice," the wheels inform the engine. "The commander-in-chief has just slammed his foot on the pedal," the brakes respond. Whereupon cooler digital heads take control and attempt to orchestrate a soft landing.

And finally, it takes arrays of powerchips to dispatch precisely modulated, and often large, power transients to the servo motors. High-9s power, in effect, but shaped, synchronized and modulated just so, to move the payload – the wife and kids – quickly and safely to the soccer field. The "driver" itself – the silicon device that modulates the power that sends electric power to the actuator — is the critical enabling component. The most critical component is, in other words, our old friend the powerchip.

Drive by Wire

Cars are already partly electric. They have been since Rudolf Diesel's ingenious original 1897 design for a self-igniting engine was (largely) superseded by the spark-ignition gasoline alternative. In due course, the hand crank and magneto on the Model T gave way to a battery and 6 V "grid," (standard until the 1950s), then to a 12 V grid, which quietly became the 14 V grid (when the engine is running) in today's vehicles. Today's grid is already pretty elaborate – over 5,000 feet (70 pounds) of copper wire, hundreds of connectors, five dozen fuses, and dozens of relays. Power electronics already account for about 20 percent of the typical car's cost. Scattered under the panels and hood you already find some four to six dozen MOSFET powerchips – about $250 worth of silicon alone. Electric demand on the automobile platform has been rising about 4 percent per year for the past decade. The total electric load now runs about 1 kW, with a peak load up to 2 kW.

But that's still not much in the larger scheme of things. The *real* powertrain in the Buick is the 100 kW (peak)/ 20 kW (average use) mechanical one – the one that begins at the piston rods, and ultimately powers everything else in the vehicle. The gap between 2 kW and 20 kW defines the "other 90 percent" of the Powercosm. Not the electrical power that drives microprocessors and other traditionally electric components, *but the microprocessor-controlled electrical power that will eventually drive everything else – the traditionally mechanical components.* Silicon-controlled electric power is taking over the mechanical space because smart chip and powerchip together are finally capable enough, and cheap enough, to take over, and because they make things lighter, cheaper, more capable, efficient, and reliable, than the mechanical and fluidic systems they replace. The quantity of powerchips in a typical car will grow at least five to ten fold.

"Motion control" begins with on-off electrical switches and circuit breakers. There are hundreds of them in existing cars – controlling such things as locks, mirrors, windows, and heaters – and they're still overwhelmingly electromechanical, dependent on moving metal contacts. Until quite recently, silicon switches were too expensive to beat out electromechanical ones; but now they are cheaper, and also smaller, lighter, faster, more robust, and easier to control. Put intelligent powerchip switches every-

Editors Peter W. Huber
Mark P. Mills
Publisher Lauryn Franzoni
Managing Editor Debi Kennedy
Designer Julie Ward
President Mark T. Ziebarth
Chairman George Gilder

The Digital Power Report is published monthly by Gilder Publishing, LLC. Editorial and Business address: P.O. Box 660, Monument Mills, Housatonic, MA 01236. Editorial inquiries can be sent to: peterhuber@gildertech.com or markmills@gildertech.com. Single-issue price: $50. For subscription information, call 800.261.5309, e-mail us at help@gildertech.com, or visit our website at www.Powercosm.com

where, and the stage is set for intelligent management of the car's total load – so that a heater, say, can be briefly turned off when a sudden surge of power is needed in brakes or steering. The entire silicon-rich electrical bus then gets a lot thinner and lighter.

Belt-driven radiator cooling fans are on their way out, too. Next year, Chrysler (DCX) minivans will be the first to incorporate a truly advanced, silicon-controlled electric cooling system for the entire engine (a 300 W to 800 W load). Electric water and oil pumps will soon take over across the board, because they can maintain much more precise control of temperature and pressure, and only run as needed.

In 2001, the Mercedes SLK will incorporate the first commercial, electro-hydraulic brakes (supplied by Bosch). Rather than transmitting force directly to an array of hydraulic valves, the brake pedal will instruct an electric pump to raise hydraulic pressure – unless anti-skid sensors in the wheel overrule you. The pay-off: brakes that are more powerful, easier to modulate, and less prone to fade. Electric controls are simultaneously worming their way into existing throttle and transmission systems. BMWs and Corvettes already have electronic throttle control, in which the gas pedal sends electrical instructions to a CPU that electronically controls the fuel injection system. High-end automatic transmission systems are already controlled by a suite of smart chips and powerchips, that take their cues from the driver, the wheels, and an array of engine sensors.

These technologies, however, are mere harbingers of much bigger developments ahead – the electrification of the other 90 percent or so of the car's powertrain, all the mechanical and hydraulic systems that distribute power under the hood, the length of the chassis, and out to the wheels.

The linchpin for all the rest will be the introduction of the integrated alternator/starter motor. Before engineers can electrify any serious fraction of the rest of the car's (emerging) 20 kW load, the engine must get hooked up to a good sized electric generator. One big enough to convert a substantial fraction of the engine's output into raw electric power from the get-go.

Ironically, today's car comes equipped with just the opposite – an electric starter motor that's big enough to turn over the whole engine, but not a generator big enough to handle comparable amounts of electric power flowing in the other direction. Almost every car today gets its electric power from a belt-driven Lundell synchronous alternator – a low-cost, electrically inefficient design (only about 50 percent efficient) that can't generate more than about 3 kW (and equally important, falls 60 percent below peak ability at engine idle). The next generation integrated alternator/starter motor will likely show up first in the 2003/4 model year of BMWs and Benzes, followed within a year by Ford (F) and GM; about half of all new cars will have one within seven years. The pay-off: abundant electric power, generated efficiently, less weight, and a virtually instant engine start as well.

A 42 V grid to replace the existing 14 V grid is the other half of this threshold transformation. Standard & Poors forecasts 42,000 vehicles per year adopting the 42 V in 2002, with one-fourth to one-third of global production going 42 V by 2010. Why the change? As discussed in our June 2000 DPR, it takes a very fat electrical bus – a lot of heavy wire – to distribute any significant amount of power over a low-voltage DC grid. The 42 V choice strikes an acceptable balance road between high voltage (which can deliver a lot more power) and safety. With stray hands reaching under the hood, and gasoline on the premises too, voltages can't go safely much higher than that. The 42 V standard emerged recently from the Society of Automotive Engineers and an MIT global consortium. Mercedes Benz helped launch the MIT project, but all major auto makers and their OEMs quickly signed on.

The car's powertrain will be transformed from mechanical-hydraulic to digital-electric by a constellation of servo motors and silicon electric drivers

With the right electric power plant in place, the stage will be set for the aggressive electrification of all the rest. Drive-by-wire electric power steering (100 W average, 1000 W peak load) will appear in some production vehicles in 2001. Columns, rods, gears, hydraulic pumps, lines and valves will give way to sensors, a 32 bit CPU (with an 8 bit back-up for safety), powerchips, and an array of powerful direct-drive electric motors that move steering control arms attached directly to the wheels. The sensors will be in the steering wheel itself, of course, as well as in the wheels and brakes – with the digital hardware overriding the human wetware when appropriate. The pay-off: better steering, a lighter car, and ultimately a cheaper one too, when economies of scale kick in.

All-electric brakes – a major step beyond the electric-assisted braking – will emerge in tandem. Here again, mechanical linkages, hydraulic pumps, and steel hydraulic lines will again give way to a 42 V, microprocessor-controlled powertrain, a fiber optic communications bus, and silicon powered direct-drive electric motors right next to the wheels. Arrays of sensors will again track not only pressure on the brake pedal but every key aspect of the brakes and the car's response. Each wheel will be independently controlled and overall braking performance will be far better. And again, the new systems will end up smaller, lighter, more reliable, and ultimately much cheaper, than the mechanical-hydraulic systems they'll replace.

Passive, reactive, energy dissipating springs and shock absorbers will give way, as well, to an active, proactive array of powerful linear motors that move wheels vertically as needed to maintain traction beneath and a smooth ride above. Look-ahead technology will anticipate bumps in the road and move wheels ahead of the (vertical) curve – leading to dramatic improvements in traction, ride comfort, and fuel economy.

With smartchip-powerchip technologies, silicon will eventually displace the steel camshaft on every valve engine on the planet

The most complex part of the engine is the communications network that links the primary output (force in the rotating crankshaft) to the primary input (fuel and air flowing into the cylinders), together with exhaust gases flowing out. This particular network is hard-wired all right. A timing chain or belt connects to a camshaft (or two) with elliptical lobes that push down on spring-load valves to open and close the input and outputs on the cylinders. All the "intelligence" is embodied in the camshaft's meticulously machined, irregularly shaped lobes. As communications infrastructures go, this has a lot more in common with two tin cans on a string – or, to be generous, a fancy semaphore – than with an Ethernet LAN. Put each valve under precise, direct, digital-electric control – open and close each one as dictated by current engine temperature, terrain, load, and countless other variables – and in effect, you continuously "retune" the engine for peak performance. Belts, shafts, and chains melt away. Everything shrinks, everything gets lighter and every aspect of performance improves – dramatically.

With the smart chip-powerchip technologies now emerging, it's a safe bet that silicon will eventually displace the steel camshaft on every valved engine on the planet. The first camshaft-free electric valve engine on the road will likely be a Navistar International (NAV) diesel, developed in collaboration with Siemens Automotive. The immediate performance pay-off: substantially higher low-end torque – critical for trucks, or for melting rubber if you're a teen-ager cutting loose from a stop sign. Ford forecasts a 10 percent to 15 percent boost in torque for cars, Navistar more for trucks.

The last step will be the largest: silicon and broadband electric power will knock out the entire gear box, drive shaft, differential, and related hardware – all of which disappear when direct electric drives finally end up turning the wheels. At that point, the entire output of the engine (or fuel cell or microturbine) 50 kW to 100 kW or more will be immediately converted into electricity, which will then be controlled by smart chips and shaped by powerchips throughout the car. It will take heavy duty wiring and good-sized silicon drives and electric motors to propel an electric SUV down a highway at 70 mph – but they'll still be far smaller than the steel structures in today's powertrain. Cars will shed many hundreds of pounds, with substantial improvements in every key aspect of performance.

A far-fetched scenario? All-electric drives already control fighter jets and submarines. General Electric's (GE) 6,000 horsepower diesel-electric AC6000CW locomotive is powered by an enormous diesel-fueled engine-driven generator; everything beyond is electric. Komatsu's 930E – a monster mining truck with 300 ton capacity – is propelled by a 2 MW Detroit diesel-electric generator. Everything else, right down to the 18-foot wheels, is driven electrically. Electric drives are taking over because an electrical bus can convey far more power in much smaller, lighter conduits, and convey it far more precisely and reliably, than even the best designed mechanical drive train. Silicon is smarter and faster than gears, linkages, and valves, however elaborately they may be shaped and assembled. An electric wire is far lighter and more compact that a metal shaft conveying the same amount of power. With the functionality of silicon powerchips rising, and their costs dropping by orders of magnitude every few years, the only issue is when, not if, the silicon will displace the steel.

MOSFETs

The silicon that will rule in this space is the power MOSFET (Metal Oxide Semiconductor Field Effect Transistor). The original bipolar junction transistor (BJT) remains a dominant architecture for the extremely-low-power silicon switch. It's good for microwatts and bits, but not for watts and motive power. The current it takes to keep a BJT "on" (i.e. open to current flow) can run as high as 20 percent of the throughput itself. This makes the device inefficient at best; when called upon to switch higher currents, the BJT simply burns out. By contrast, the "field effect transistor" (FET) is switched on by a low-voltage electric field. Current-handling capabilities are boosted by etching thousands of MOS cells in parallel, on a single die – usually thousands per silicon wafer.

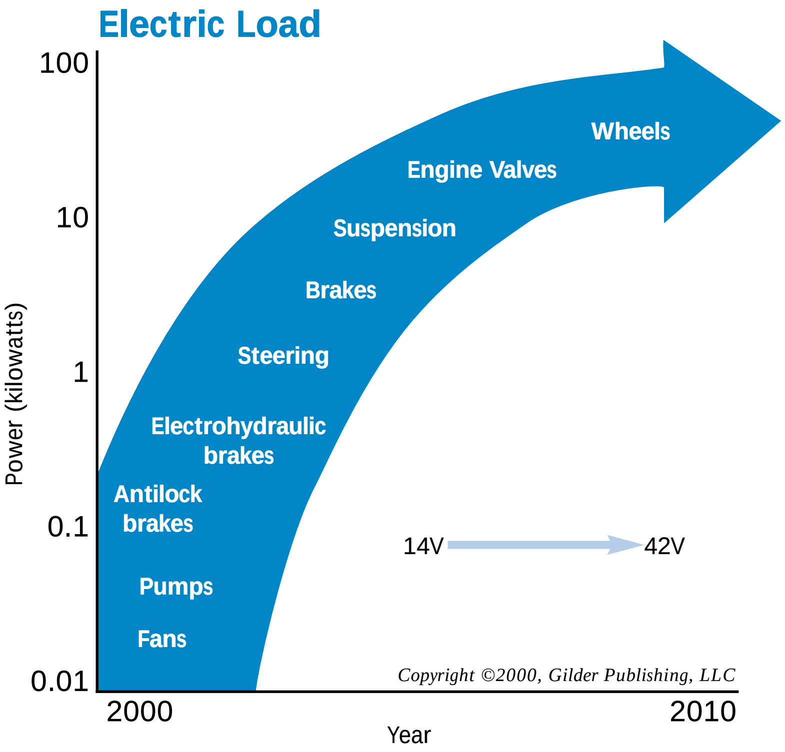
Until recently, however, MOSFETs remained confined primarily to types of low-current applications: low voltage/low power ones in such things as phones and camcorders, and high voltage, higher power – but still relatively low current – elsewhere. What makes FETs easy to switch is also what keeps them comparatively reluctant to conduct a current – they tend to have a relatively high "on resistance" at high voltages, but low on resistance at lower voltages. On the automobile platform, as it happens, really high voltages are unacceptable. So you push voltage as high as safety permits, 42 V, and then do the rest with current. Lots of it, 100 amps (A) for an electric starter, 50 A for electric steering. (A kitchen electric stove top is under 20 A.)

Other powerchips, IGBTs in particular, are better with high currents, but their top speed is hundreds of kHz. Accurate control of direct drives requires MHz speeds and up. (Valves and wheels don't move at such speeds themselves, but the control device has to be orders of magnitude faster than the object being moved, if position, speed, and acceleration are to be minutely controlled.) An industrial motor controller runs at 20 kHz; it requires powerchips switching at 5 MHz. MOSFETs have a second advantage – they fail "open circuit" when currents and temperatures rise; other devices fail in "short circuit" mode. In effect, MOSFETs can, therefore, serve as their own fuses.

So the MOSFET is the powerchip of choice on the automotive platform. Building a practical one that will actually fit the engineering and economic realities in Detroit remains quite a challenge, however. To handle higher voltages you have to make thicker MOSFETs. But that tends to push up the on-resistance. Which means more heat, worse fuel economy, and shorter life – the same penalties as bad lubrication in the conventional click-click bang-bang set-up. The MOSFET also has to be optimized to bridge the exceptionally wide chasm between junky power on the car's electric grid, and the very precisely modulated power required to move direct-drive motors accurately. However much it gets improved, the car's alternator will remain a lousy source of electrons, with voltage, current and frequency varying sharply as loads within the car itself, and from the highway beneath it, rise and fall. And the MOSFET has to withstand a horrendous range of environmental conditions, from 175°C near the cylinder head to the -40°C of an Alaskan winter.

Finally, the MOSFET has to get cheap. It takes a lot of silicon area to handle 20 kW, and the silicon itself is the single largest cost factor in the electrification of the car. Moving up from 14 V to the 42 V platform has already helped a lot – silicon areas have dropped by some 80 percent as a result, and it is the higher voltages that now permit all-silicon switches to displace electromechanical switches even in such routine things as heaters or window motors, where speed isn't critical. But cost always becomes a major factor in products built for the mass market, and nowhere more so than in the manufacturing of cars.

Bottom line: don't look for any under-funded start-ups to engineer chips to these kinds of constraints, or to mass-produce powerchips in the billions for the likes of GM, Ford, DaimlerChrysler, Honda (HMC) and Toyota (TM). This is an industry with extraordinarily exacting requirements. It is going to be supplied by Intel-like powerhouses, with very deep engineering skills and advanced production capabilities. Not companies like the Intel of 1974 – companies like the Intel of today.



Direct drives take control under the hood, system by system. An integrated starter/alternator displaces existing separate components, and a 42V power bus replaces today's 14V standard. The end point: an all electric powertrain, from wheels to sunroof, headlights to tailpipe.

International Rectifier (IRF)

We first wrote about IRF eight months ago, emphasizing its leadership role in developing IGBTs. That powerchip plays a key role in the provision of high-9s power to microprocessors in stationary set-ups, set-ups ranging from room-level UPS's to data-center silicon power plants (June DPR) to flywheels (August DPR), microturbines (July DPR), fuel cells (September DPR), and the massive silicon switches in the grid itself.

IRF's position is stronger still in the MOSFET market. The basic architecture of the high-power MOSFET was invented by IRF in 1978. International Rectifier and Siliconix made some key technical breakthroughs in 1995. Many other companies produce MOSFETs today, but all (some two dozen in total) still pay royalties to IRF. IRF retains the largest global share of power MOSFETs in all markets. Its MOSFETs are found on motherboards, alongside the mobile Pentium III, in most AMD Athlon's, and in the new Sony Playstation 2. Fully half of IRF's revenues now derive from IT-related power silicon.

Meanwhile, however, and with very little publicity, IRF has built up an even more commanding position in markets for powerchips that control direct-drive electric motors. IRF supplies eight out of the top ten manufacturers of smart motor drives used in factories. It is a major provider of powerchips for energy efficient appliances – powerchips, mated with low-cost, low-IQ smart chips that run your refrigerator more efficiently and curtail "sleep mode" wastage of electric power throughout the home. Over 90 percent of that market is served by a single, low-cost module that IRF manufactures, consisting of a proprietary IC integrated with a powerchip.

But by far the most important new market now unfolding for IRF is the one for MOSFETs in cars. Year by year, IRF has improved its MOSFET designs, pushing down the on-resistance, pushing up their ability to handle high currents and high power, and pushing down prices at the same time. IRF now clearly ranks as leader among the few companies that have developed MOSFETS in what is the sweet spot for automotive purposes – 42 V high-power (and therefore high-current) performance.

IRF has the technology and the credibility in the automotive industry, thus an excellent chance of solidifying an Intel-like dominance for automotive powerchips

Alex Lidow, the company's CEO, has been preaching the silicon power gospel for years, and putting a lot of IRF's money behind it. As early as 1993, IRF began standardizing the design features and manufacturing operations for MOSFETs — the only way to push costs down to levels acceptable in the global auto industry. And IRF has recently developed a series of new products targeted specifically at the 42 V automotive platform. Last September, IRF introduced a HEXFET power MOSFET – a "stripe planar" device that replaces a large number of discrete cells by, in effect, merging groups of cells into a long, flat (planar) stripe. This reduces wasted silicon in between individual cells (in effect, using a smaller number of bigger, but skinny and long, cells) and raises packing density, doubling the number of devices per unit area. End result: a 40 percent reduction in the all-important on resistance. The device also has an industry-leading maximum temperature rating of 200° C – ideal for the environs of a car engine.

For fifteen years now, IRF has been quietly supplying silicon and silicon modules to major OEMs of the auto industry – companies like Siemens, Bosch, Delphi, Visteon, and Ford. Thus far, major auto companies have let only five silicon contracts to supply Electronic Power Steering – IRF won four of them. The industry has also awarded only two contracts for the integrated starter/alternator; IRF won both. Half-a-million Chrysler minivans will ship next year with IR-enabled smart motors for the cooling fan (replacing the fan belt), and the numbers will rise from there. For the emerging electric steering market, IRF is working with Nidec (Japan), which supplies both industrial motors and 80 percent of all motors in disk drives.

IRF has the history, the technology, and the credibility in the automotive industry. It has, in short, an excellent chance of solidifying an Intel-like dominance of the market for automotive powerchips.

Infineon (IFX)

This is a huge market, however. And the world's major car manufacturers aren't going to converge on a single, sole-source supplier for something as critical as their silicon. So there'll be at least a second major player.

With somewhat different strengths, Infineon clearly runs in the same technological league as International Rectifier. Like IRF, Infineon has a long (twenty-five-year) history in developing power semiconductors for automotive applications. It produces a very broad range of power MOSFETs, including a robust line-up designed specifically for the automotive sector and the new 42 V bus. The company has successfully pushed down the on resistance of its powerchips. And it has developed MOSFET packaging and connection technology with extremely low inherent inductance – an important factor, because switching hundreds of amps at high speed in inductors creates damaging stray voltage peaks.

Infineon's "SMART" MOSFET comes in two basic designs. The lower-power design consists of a single large IC, in which the control circuit and power driver are etched on a single silicon die, pioneered by Infineon in 1996, creating the ultimate convergence of smart chip and powerchip technologies. For higher currents and powers, Infineon has developed their "TOPchip," the next best thing to fabrication on a single silicon die. Using a sophisticated polymer, Infineon literally glues a smart chip on top of a large power MOSFET, with the two halves connected via short wire bonds. The result again is a faster, more reliable, integrated smart chip-powerchip.

There are many more designs in the Infineon catalogue. The company's SIPMOS is optimized for very efficient low-power switching. Its SFET2-PowerMOSFET has been designed for steering, ABS, and combined starter/alternator, and figures at the center of Infineon's family of DC/DC converters. These are highly efficient, low-loss 500 W to 1400 W "bricks," with 70 kHz to 200 kHz switching speed. (For more on distributed power architectures and bricks, see the May DPR.) Such bricks will be essential for the highest-power applications – driving electric valves, for example – where voltages will have to be boosted well above 42 V on the very doorstep of the direct-drive motor. DC/DC converters will also be used extensively during the lengthy interim period when legacy 14 V devices have to coexist with 42 V devices on the same platform.

As the SMART and TOPchip designs illustrate, Infineon has emphasized the development of integrated silicon solutions, with components optimized to work together, and often packaged together with sensors, transceivers, and CPUs – just the kind of complete, plug-and-play modules that the auto industry strongly favors. The company developed the first stand-alone Controller Area Network (CAN) for use on an auto engine in 1992, and now manufactures a range of 6, 16 and 32 bit-based CAN modules. Infineon also makes the opto-electronics and transceivers for the high-bandwidth and safety-critical communications bus.

Finally, the company makes a wide range of high-quality sensors for temperature, pressure, position, distance, direction, speed, magnetic fields, and electrical flows. Infineon's state-of-the-art magnetic "Hall" (linear magnetic) sensor, for example, is used in such applications as electronic throttle control, among other applications. It performs much better than the potentiometers traditionally used to sense position and speed: it's more accurate, responds faster to rapid position changes, has less friction, is less prone to wear, and is less sensitive to variations in temperature and other environmental factors.

The main Powercosm-related question mark for Infineon is one of focus. Infineon manufactures a wide range of smart chips and memory chips, along with a range of chips for wireless, fiber optic and related telecommunications applications (the latter, areas where it is more widely recognized). When it separated from Siemens, the seven billion Euro/year Infineon organized itself around five businesses: automotive & industrial, wired communications, wireless telecom, memory chips, and chips for security and credit cards. Much of its business, in other words, isn't centered squarely in the Powercosm, and that could conceivably drag down what are (in our view) Infineon's most promising powerchip products. While Infineon over all saw 13 percent annual growth through the end of this past September, their automotive division grew twice as fast. But few companies of any fiscal consequence are pure plays, and silicon-drivers dictate, in any event, a uniquely demanding integration of both smart chip and powerchip capabilities.

And Infineon clearly has a rock-solid history in automotive powerchip technologies. Infineon (when it was the Siemens Automotive Group) was one of the early and aggressive developers of powerchips, and remains a leader in providing integrated silicon-driver technologies for the automotive platform and motion control generally. Siemens itself remains Infineon's largest customer; other major customers include Visteon (VC), Bosch, Mansmann-Sachs, Hella, Delphi, Motorola and TRW – all major suppliers of integrated electric modules to the auto industry.

In sum, Infineon has both a long and successful history in manufacturing smart chip-powerchip silicon drivers and a line-up of state-of-the art MOSFETs going forward. It invests a remarkable and critical 21 percent of sales in R&D. It ranks alongside IRF in the race to siliconize the automobile.

The Silicon Car

Most of the "electric car" hype centers on such things as fuel cells, and the primary power plant. It *assumes*, in other words, the electric powertrain and electric wheel drive downstream. That gets things exactly backward. The downstream technologies are being rolled out commercially today. The combustion engine may never be overtaken, but the rest surely will be. Honda, Toyota, and other companies that have put their focus on the so-called "hybrid-electric" have got it just right. Keep the internal combustion engine, for now at least; get on with electrifying the rest.

The case against combustion is rooted in regulation and environmental policy, not in any fundamental technological advance or advantage. As discussed in our September DPR, the most hyped substitute, – the fuel cell is a very old idea, and one tied to what remains an inherently fragile and unreliable technology, the proton exchange membrane. The silicon revolution, by contrast, is quintessentially technological. The powerchips are working with the market, not against it. They deliver what ordinary drivers really want – better performance, more safety, and lower cost.

Regulatory imperatives still matter, but as it happens, the silicon addresses them too. All-electric steering alone boosts fuel efficiency 1 percent to 3 percent by reducing weight and, more importantly, by drawing power from the engine only when needed, rather than continuously as occurs with mechanical power-steering systems today. An integrated starter/alternator is lighter and smaller too, and it can use the battery to boost torque intermittently, which means more power from less engine, which boosts efficiency by another 20 percent or more. (This is in part how the Toyota Prius hybrid achieves it's remarkable fuel efficiency today – the combustion engine runs primarily as a generator to recharge the battery.) Electrically actuated engine valves offer astounding 10 percent to 40 percent gains in efficiency, and even larger reductions in emissions. Even all-electric suspension has an efficiency pay-off – less gas from the tank ends up heating the oil in the Monroe shocks.

The improvements compound with each additional smart "client" added to the car-wide Web. Torque, traction, braking, skid control, fuel economy and emissions all depend on the complex interaction of engine, battery, suspension, steering and brakes; the magic lies in the intelligent coordination of all the parts, which direct silicon drives make possible. The more silicon you add, the greater the pay-off from the silicon already in place. So once the siliconizing gets going seriously, it doesn't stop. The end will indeed be an electric car – electric in the places that matter, not necessarily the core power plant, but all that surrounds it.

And the key enabling technology here isn't electric at all – it's only semi-electric, semi-conducting. It's the powerchip. It's silicon. The truly electric car may never come. The silicon car most certainly will.

Peter Huber & Mark Mills
November 27, 2000

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	11/27/00 Price ††	52wk Range	Market Cap	Customers
Powerchips: Power MOSFETs	Infineon (IFX)	11/27/00	43 3/4	43 3/4	35 15/16 - 88 1/4	27.3b	Siemens, Visteon, Bosch, Mansmann-Sachs, Hella, Delphi
	International Rectifier (IRF)	*(see below)*					DaimlerChrysler, Bosch, Bose, Delphi, Ford, TRW
Insulated gate bipolar transistors (IGBTs)	IXYS (SYXI)	3/31/00	6 25/32	20 1/16	2 1/4 - 45 3/8	490m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
IGBTs	International Rectifier (IRF)	3/31/00	38 1/8	35 11/16	19 15/16 - 67 7/16	2.2b	Nokia, Lucent, Ericcson, APC, Emerson, Intel, AMD, Ford, Siemens
	Advanced Power (APTI)	8/7/00	15	26	15 - 49 5/8	204m	Alcatel, Ericsson, ITI, Power-One, Advanced Energy Industries, Emerson
Ghz Power RF Powerchips: LDMOS	UltraRF (SPCT)†	10/31/00	11 3/4	15 1/2	11 3/8 - 31 3/4	170m	Nokia, Samsung, Lucent LGC, Alcatel, Nortel
Network Transmission and UPS: High-temperature superconductor	ABB***	9/29/00	96 61/64	93 1/2	N/A	N/A	National Grid (UK), Microsoft, Commonwealth Edison, American Electric Power
	American Superconductor (AMSC)	9/30/99	15 3/8	28 13/16	17 3/4 - 75 1/8	579m	ABB, Edison (Italy), ST Microelectronics, Pirelli Cables, Detroit Edison, Electricite de France
Power: Heavy-Iron-Lite	General Electric (GE)	9/29/00	57 13/16	49 1/8	41 41/64 - 60 1/2	487b	Reliant Energy, Enron, Calpine, Trans Alta, Abener Energia, S.A.
	Catalytica (CTAL ➪ CATX)*	9/29/00	12 3/8	12 3/4	7 1/2 - 16 1/4	741m	GE, Kawasaki Turbines, Enron, Rolls Royce, Solar Turbines
Electron Storage & Ride-Through Flywheels	Active Power (ACPW)	8/8/00	17**	17 1/2	16 7/16 - 79 3/4	692m	Enron, Broadwing, Micron Technologies, PSI Net, Corncast Cable, ABC
	Beacon Power (BCON)	11/16/00	6**	6 1/4	6 - 7 7/16	241m	Century Communications, Verizon, SDG&E, TLER Associates, Cox Cable
Hydrogen Generation	Proton Energy Systems (PRTN)	9/29/00	17**	13 1/4	12 1/16 - 36	424m	Matheson Gas, NASA
Distributed Power Generation Microturbines	Capstone Turbine Corp. (CPST)	6/29/00	16**	26	16 - 98 1/2	1.9b	Chevron, Williams ECU, Tokyo Gas, Reliant Energy
Fuel Cells	FuelCell Energy (FCEL)	8/25/00	49 7/8	56 1/8	10 1/2 - 108 3/4	865m	Santa Clara, RWE and Ruhrgas (Germany), General Dynamics, LADWP
Micropower Nano-fuel cells	Manhattan Scientifics (MHTX)	8/25/00	2 3/4	2 9/32	1 3/32 - 8 5/8	N/A	Incubator (no customers)
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59	74 5/8	40 1/2 - 75 3/8	31.9b	Citicorp, Verizon, Nokia, Motorola, Cisco, Exodus, Qwest, Level 3, Lucent
	Power-One	*(see below)*					
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	22 3/4	61 11/16	7 3/32 - 89 13/16	4.5b	Cisco, Nortel, Teradyne, Lucent, Ericsson

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 judgment 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. IPO reference dates, however, are the day of the IPO. 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. 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 interests in the companies.

* *On August 2, Catalytica (CTAL to become CATX) announced plans to merge with DSM, (Heerlan, Netherlands). The Combustion Systems unit and Catalytica Advanced Technologies, will be spun off together, to shareholders, as "Catalytica Combustion Systems" (CATX) in December 2000. This will leave Catalytica's third subsidiary, Catalytica Pharmaceuticals (largest current source of corporate revenue) with DSM.*

** *Offering price at the time of IPO.*

*** *ABB's plans to list its stock on the NYSE have been "delayed due to the volatility of the U.S. equity markets." ABB plans to provide further information on this issue in February.*

† *Cree Inc. (CREE) announced their intention to close a deal by late December 2000 or January 2001 to acquire UltraRF from Spectrian (SPCT) for 908,000 shares of Cree common stock and $30 million in cash, and a two-year agreement to supply Spectrian with chips.*

†† *This Digital Power Report was printed prior to the end of the month. The current price for the this report is the press date rather than the last day of the month .*