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Analog Power

Microsemi's business rules the deepest recesses of the Powercosm

Analog Power? In a digital power report? Hard-wired analog power-control circuits are dumb. They aren't programmable. Their primitive logic, such as it is, is fuzzy. But they are also blindingly fast, compact, frugal—and ubiquitous. Like the reptilian brain at the back of every mammal's skull, an analog metronome establishes the clock speed and supplies the first layer of order deep within every array of digital (i.e., on-off) MOSFETs, IGBTs, bipolar transistors, and Pentiums.

Analog technology has been pushed the furthest on the three most demanding platforms in the Powercosm–satellites in outer space, medical implants inside the human body, and very high frequency (RF and optical) amplifiers. Launching superfluous ounces into orbit is astronomically expensive, and you can't haul around a car battery with your pacemaker, so you relentlessly pursue ultra-high power density and energy density instead. To handle more power in less space, you have to dissipate less of it as heat, or your circuits melt—and escaping heat is also the key to building ultra-linear power supplies for RF and optical amplifiers.

Our journey into the catacombs of analog power began last November, with a manufacturer of RF powerchips—UltraRF, then a subsidiary of Spectrian (SPCT), now a subsidiary of Cree Inc. (CREE). Microsemi (MSCC) is a second major player in the broad market for high-performance RF and analog powerchips. For four decades Microsemi has led the way in developing power technology for military and aerospace customers. It still supplies most of the diodes and transistors purchased as discrete components (rather than as circuits) by the U.S. military (65 percent) and telecommunications satellite markets (85 percent). Some 20,000 Microsemi diodes form a 3-mil thick layer on the space station's solar panels. Almost every telecom satellite launched contains half-a-million dollars or so of Microsemi product.

And now, suddenly, the same technology is cascading into wireless base stations, cell phones, laptops, PDAs, wireless LANs, DSL line cards, cable modems, hybrid electric cars, and fiber-optic systems. Silicon and glass require exceptionally reliable power. Portable digital devices need it exceptionally light and compact, too. High-speed wireless devices need it exceptionally cool, i.e., power efficient, too, because their delicate amplifiers are poisoned by heat. The inflationary Powercosm, the whole digital, mass-market mainstream, now needs Pentagon-quality power. Microsemi is supplying it.

Diode: Idiot Savant of the Powercosm

Microsemi has all the right cosmetics, which is to say, none at all. We found no artistic waterfall in the atrium when we visited the company's unremarkable warehouse-like headquarters on a forgettable street in Santa Ana, California. There was no atrium at all, in fact no New Age slogans on the wall, no B-school plans scrawled on napkins, no vaporware. The glitziest thing we stumbled across on the premises was a brightly lit color display of someone else's product—a Compaq (CPQ) iPaq PDA. When we asked (not before), Microsemi's CEO Jim Peterson let on that the display owes its portable brilliance to a fluorescent light powered by one of Microsemi's many proprietary circuits. So does the new color Palm (PALM), HP's (HWP) Pocket PC, Intel's (INTC) Wireless Webtablet, Ericsson's (ERICY) Smart Phone, the GoReader and RCA e-books, the in-dash PC from Becker, and Rockwell's (ROK) in-flight entertainment system.

We liked the iPaq's screen, and we said so. We were soon bathed in an ebullient torrent of technical detail – as ebullient, we must concede, as we could have expected from any virtual visionary. But there's nothing at all virtual about Microsemi's business, it's a business of real hardware, developed over decades of diligent, painstaking R&D, and now sold in surging volumes to serve as the analog metronomes, filters, control circuits, and amplifiers that rule the deepest recesses of the Powercosm. Half of Microsemi's business is power management; another 18 percent is protection from power transients, and the rest centers on the manufacture of discrete diodes, photodiodes, transistors, and other power devices destined to land at the center of some other manufacturer's high-9s, high-power-density product.

The company's technological wizardry begins with the very simplest of such devices, the humble diode. Sir John Ambrose Fleming patented the first one in 1904. You can buy one for a dime at Radio Shack—though Microsemi's best will run you $20 to $100. Either way, your money buys you a single passive gate, open to current flow in one direction, closed in the other. To this day, diodes remain (by a wide a margin) the most widely used semiconductor chips in the world. From Microsemi's dust-mite sized Powermite to the massive four-inch diameter, grid-level diodes from the likes of Hitachi (HIT) and ABB, diodes are everywhere. They're in power supplies, base stations, cell phones, home stereos, Gameboys, and fetal heart monitors. Most diodes are so cheap, however, that total sales add up to only about $3 billion a year.

So why should anyone care about the single-gate diode any more, in this the era of hundred-million-gate gigahertz-speed microprocessors? Because diodes run way faster than all things "digital," gigahertz Pentiums included. Diodes are, in effect, atomic-level switches–they "switch" on and off because the basic physics of a junction between certain dissimilar materials overwhelmingly favors current flow in one direction. The diode is thus the idiot savant of logic devices, idiot in that it is entirely passive (it has only two wires), and thus instinctual rather than smart; savant in that its feeble brain runs blazingly fast.

That's the defining virtue, too, of everything else in the huge market for analog devices and circuits, from power transistors on out. On the overall scale of solid-state intelligence, they all rank closer to a housefly than to a Java programmer. Their limited intelligence derives from the clever design of hard-wired circuits, and from raw speed. This may not sound like rocket science, but it just so happens that the companies that built the Saturn Vs and ICBMs think it is, and have thought so for decades, and they have reason to know. When it comes to handling more power, faster, in a smaller package, the best analog structures can fly circles around any high-IQ digital chip you can find anywhere.

Limited intelligence notwithstanding, analog circuits can be configured as hard-wired circuits that perform a few core functions extremely well. The ultra-precise clock within every digital machine, for example, begins with an analog circuit. Analog circuits can generate electrical pulses, or filter them out, at almost any frequency and power level, and in any band you like. Or they can be optimized to run feedback control loops that continuously readjust an electrical input to push an output toward some desired target.

For relatively simple, but essential, basic functions like these, nothing can beat them. Analog devices are inherently smaller, higher power, and faster, than their digital counterparts. Which means that the digital future will forever depend on its hard-wired analog infrastructure, just as the frontal lobes of the Java programmer's brain rely on hard-wired, house-fly-quality intelligence at the back of his skull, to control his heartbeat, breathing, and reflexes.

Diodes: Beyond Silicon

Microsemi has been building semiconductor analog circuits since it was incorporated in 1960—well before an unknown academic by the name Andy Grove published his path-breaking 1967 textbook, *Physics and Technology of Semiconductor Devices.* The company was formed to build semiconductor components for military and aerospace customers; some of its first diodes were used in the Minuteman missiles.

The perfect diode is a perfect conductor in one direction, and a perfect insulator in the other. The Schottky diode is the most basic architecture: a simple junction, metal to semiconductor. Schottkys are inherently faster than other architectures, but less able to withstand high reverse voltages. "P-N" diodes rely instead on a junction between two different dopants infused into silicon (or some other semiconductor) — antimony (say) providing surplus electrons at the "n" (negative) side, and boron (say) creating a dearth at the "p" (positive) side. A third geometry, the PIN diode, has an undoped layer of "intrinsic" silicon sandwiched between the p and n.

Microsemi's diode magic begins with materials. The quantum physics at the p-n junction is exquisitely sensitive to the basic chemistry of its constituent parts. Substrates are pushed to twelve-9s levels of purity; dopant concentrations are calibrated in parts per trillion. Microsemi builds diodes on silicon, of course. And gallium arsenide (GaAs). And a clever, metal-infused polymer (on which Microsemi has achieved switching speeds of 25 GHz). And – most recently—silicon carbide (SiC).

As we first noted in April 2000, SiC has electrical and thermal properties an order of magnitude better than either silicon's or gallium's. But SiC is exceptionally difficult to form into large, fault-free, crystalline wafers, and equally difficult to dope and fabricate into functioning devices. No one was yet making junction SiC devices in commercial quantities when we wrote about it a year ago. Since then, however, Cree has begun manufacturing bigger, and thus less expensive, SiC wafers. In February, Infineon (IFX) announced plans to ship commercial SiC Schottkys this year. Microsemi promises commercial production of SiC Schottkys before the end of the next

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quarter. Which means that between them, Infineon (which joined our panel last December) and Microsemi are destined to push the unassuming diode's speed-voltage performance an order of magnitude or two beyond anything achievable today.

The theoretically perfect diode can block any reverse voltage; it can also flip from perfectly closed to perfectly open in zero time, when the voltage flips the other way. Schottkys flip in the terahertz speed territory–too fast to worry about—but they can't handle high reverse voltages—silicon Schottkys typically break down around 100 V, gallium arsenide Schottkys, around 250 V. Microsemi's SiC Schottky already handles reverse voltages of 480 V, and the company will probably push the limit steadily up from there, toward the SiC Schottky's theoretical limit of several thousand volts. PN and PIN diodes have a higher inherent capacitance, and are therefore slower than Schottkys, but they can withstand much higher voltage. Microsemi has pushed silicon PN diode speeds to an industry-leading 2.5 GHz; it has simultaneously pushed its silicon PIN diodes to industry-leading reverse-voltage breakdown of 4,500 V, and speeds of 12 GHz.

Microsemi has achieved these record speeds by pushing down both the inherent capacitance and the on-state resistance of the diodes it builds. Many of these gains have come from superior assembly and packaging that we turn to shortly. But here again, the move to SiC promises stunning performance improvements in the longer term, because SiC diodes have two orders of magnitude lower on-state resistance than Si diodes. SiC is a much better thermal conductor too. Both of these qualities push SiC devices toward much cooler operation, which means they can handle more power in less space without melting themselves or their surroundings, which makes possible smaller, cheaper, higher-power circuits, that can be run at higher frequencies.

Surge-suppression applications require a diode that runs backwards (so to speak), popping open to dump current out of a circuit when the voltage inside rises above some dangerous threshold. To protect a CPU that's running on 1-volt power, and that will be destroyed by a 3- to 5-volt surge, you need a safety relief valve that will instantly pop well below that threshold. But building a very-low-voltage, fuse-like diode is a considerable design challenge, too. Once again, Microsemi leads the industry with a 1.4-volt silicon, Schottky-based device that's ideal for protecting CPUs.

Beyond materials and architectures, it is packaging that separates the high-speed, high-voltage, high-power diodes from the rest, and determines which can best withstand hostile thermal and radiation environments. Packaging begins with chemical nitride or oxide "passivation" layers coated on the semiconductor surface to protect the ultra-pure junction from contaminants. Microsemi uses over 100 different passivation techniques, almost all of them proprietary, almost all originally developed to meet military and aerospace specifications. The methods are as much art as engineering science, they're remarkably hard to reverse engineer, and they generally rank among the most valuable IP that a diode manufacturer like Microsemi can own.

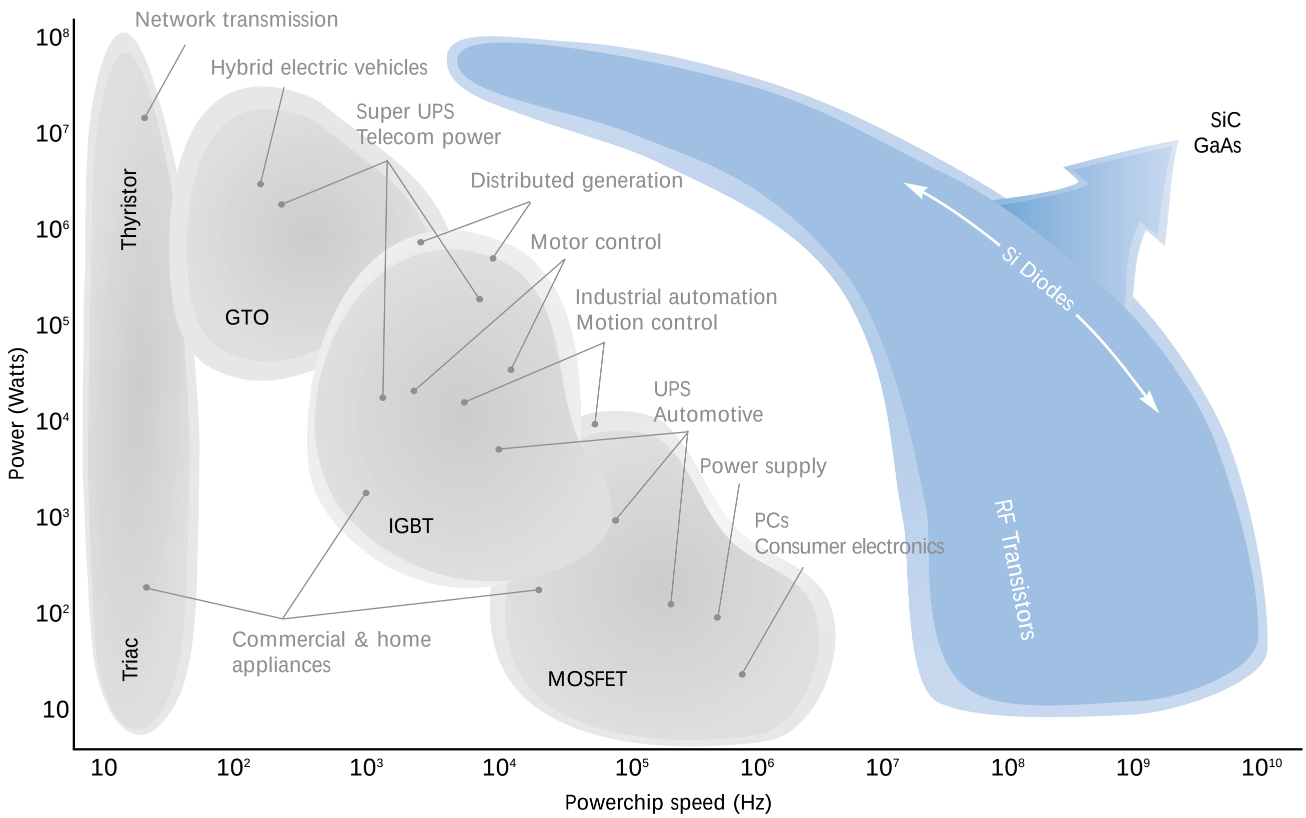
Then there are the electrical connections between the semiconductor and the external circuitry. Wire bonds are typical—but they turn into radio antennas when currents oscillate at RF frequencies, and into stovetop heating elements when current levels rise. These bonds thus sharply degrade performance, and they are also the most common point of failure. Microsemi's proprietary know-how replaces wire bonds with a direct titanium-palladium-silver solder connection to the semiconductor. And instead of using epoxy to glue the diode to its casing, Microsemi brazes a bond at 900°C; this sharply improves both electrical and thermal conduction. Semiconductor junctions aren't supposed to be able to survive such temperatures, but in Microsemi's hands, they somehow do.

Microsemi's packaging expertise extends as well to the overall encapsulation. Microsemi's patented Powermite package seals the device in a military-grade epoxy that locks into a metal bottom, providing mechanical strength, in a process that is carefully calibrated to compress the diode without destroying the crystalline semiconductor within. And for exceptionally harsh environments, the company has developed a protective glass-like coating to seal its devices. The skill resides not only in the packaging recipes, but also in the unusually deep diffusion process that Microsemi uses to build the critical junctions beforehand–a process that locates the junctions well away from the device's surface.

Across the range of materials, architectures, and packages, the pay-off for building smaller, faster, higher-voltage, more efficient diodes is the one that invariably matters the most in the Powercosm—more precise control of more power in less space. Most of the payoff comes not in the diode itself, but in the more complex components that it serves. The IGBT, for example, is the power switch of choice for a wide range of higher-power applications (*April 2000, Jan 2001 DPR*). Heat build-up often reduces — by 30 to 50 percent – the peak power an IGBT switch can handle. But almost half of the heat typically comes from energy losses in the diodes that control the voltage that flips the IGBT open or closed. Replace Si with SiC diodes in IGBT control circuits, and the dramatic improvements in overall thermal performance yield equally dramatic gains in power density, size, and high-frequency capabilities.

Comparable gains are possible in surge suppressors, power suppliers, audio amplifiers, and RF amplifiers. And in medical implants, where the real competition for a more efficient diode isn't a less efficient one, it's a replacement battery installed periodically by a surgeon with a scalpel. SiC is also uniquely attractive to military and space customers because of its exceptionally high tolerance for radiation. And it is uniquely capable of withstanding the hellish temperatures encountered by jet-turbine control systems, or by the sensors mounted on gas-well drill heads.

Powerchip Hierarchy



Diodes are, in effect, atomic-level switches–they "switch" on and off because the basic physics of a junction between certain dissimilar materials overwhelmingly favors current flow in one direction. The diode is thus the idiot savant of logic devices, idiot in that it is entirely passive (it has only two wires), and thus instinctual rather than smart; savant in that its feeble brain runs blazingly fast. That's the defining virtue, too, of everything else in the huge market for analog devices and circuits, from power transistors on out.

Microsemi promises it will achieve the next step in SiC, a commercial PIN diode, within six months or so. When it does, the SiC PIN will be a natural candidate to replace electromechanical relays, or the constantly failing Si PIN diodes, in high-temperature applications such as semiconductor processing equipment.

We don't mean to suggest that Microsemi's future is tied to SiC. To the contrary, Microsemi is pushing speed, power, and efficiency across materials and architectures, and most of its skill resides in more mundane things like passivation and wire bonds and outer packages. All SiC devices, Microsemi's included, are still exotic curiosities, at least ten times as expensive as Si or GaAs alternatives. With that said, Microsemi has crossed a tremendously promising technology threshold in bringing its first SiC power component to market–a threshold that could quickly push out the performance boundaries of analog circuits far beyond their present limits. And so far as price goes, if there is one immutable law of semiconductor history, it seems to be that materials engineers eventually win, semiconductors submit, outputs rise, costs drop, and yesterday's unimaginable twelve-9s-pure, 3-inch wafer ends up almost as affordable as a Ritz cracker.

Photodiodes and Power Transistors

Among their other remarkable properties, semiconductor junctions can capture photons (light) to move electrons. Run the process the other way, and instead of a photodiode you have a light-emitting or laser diode.

Microsemi is currently a small vendor ($1 million a year in sales) of silicon and GaAs photodiodes. So far, it has left the fabrication of the photodiodes themselves to others, drawing instead on its packaging expertise to address high-stress applications like military gyroscopes, optocouplers, optical repeaters, and laser output regulators. With a transparent epoxy window, for example, Microsemi's Powermite package becomes "Optomite."

But Microsemi is now completing construction of a photodiode fab of its own. Along with other GaAs photodiodes, the fab will manufacture a new silicon photodiode optimized to precisely sense ambient light levels. Coupled to a display screen's power circuit, this device will automatically adjust screen brightness in any laptop, handheld, or cell phone. The challenge here was to develop a passivation layer that is transparent to visible light but opaque to infrared radiation. Microsemi delivered.

Microsemi is also pushing photodiode technology into new, higher-performance materials – this time, indium-gallium-arsenide on an indium-phosphide substrate (InGaAs/InP). Until quite recently, the only application for InGaAs/InP was in RF diodes (and to a small extent, as triple-junction photovoltaics for satellites). Conventional GaAs photodetectors are fast enough for the 1-Gb to 2.5-Gb infrared optical systems commonly used in short-haul applications. But a new generation of 10-Gb optical transponders requires different materials and packages. InGaAs is inherently faster, and the InP substrate provides superior thermal conductivity.

InGaAs isn't easy to work with, however. Zinc, the critical dopant, is an especially nasty material to handle as a vapor, which is how you have to handle it in a chip fab, so building the fab gets very expensive. And only a few batches of wafers are needed to manufacture all the InGaAs photodetectors a company is likely to sell in a year, at current levels of demand. Microsemi, however, is already the leading manufacturer of RF power transistors on a close cousin material (InGaP) that also relies on a zinc diffusion process, and Microsemi can manufacture photodiodes on the same line. The company announced plans to sell an InGaAs photodetector last December, and it began shipping in March, ahead of schedule.

Low-speed (2.5-Gb GaAs) detectors now run about $1 a piece. The 10-Gb InGaAs devices go for up to $100. The emerging 40-Gb InGaAs/InP detectors are expected to run in the $8,000 range, once in production. Microsemi expects to be shipping samples of the 40-Gb devices by year's end. It's betting on very rapid growth in the market, too. Its new fab, which will be fully operational by early summer, will be able to produce 100 InGaAs/InP wafers per week. That's some ten times more than the total wafer production today from any of the four prime contenders in this space, two independents (Telcom Devices, PerkinElmer (PKI)/EG&G) and two captives (Epitaxx owned by JDS Uniphase (JDSU), Ortel owned by Lucent (LU)).

RF power transistors define Microsemi's third core area of component expertise. In deals completed in 1996 and in January 2000, Microsemi acquired the two leading manufacturers of military RF chips—SGSThompson's RF transistor group, and Motorola's (MOT) RF bipolar transistor operations. Microsemi had already acquired the RF power business of L-3 Communications (LLL) some years earlier. As a result of this roll up, Microsemi now clearly ranks as the leading manufacturer of high-performance InGaP bipolar transistors; it also dominates the smaller market for military-grade silicon bipolar RF transistors. Across the board, RF power transistors are now a very high-growth business, because the mushrooming, civilian wireless market is now moving into the high frequency bands that until recently, were used only by military and aerospace radios.

Here again, Microsemi is pushing the core technology–the heterojunction bipolar transistor—on to new materials, this time indium-gallium-phosphide on a gallium-arsenide substrate (InGaP/GaAs). Microsemi acquired the expertise in its March 2000 purchase of Infinesse, a technology leader in manufacturing these exotic RF transistors (originally founded by the TRW (TRW) and Rockwell military and satellite engineering teams). As frequencies move well beyond 1 GHz, InGaP/GaAs is more reliable, more linear, and more electrically efficient than silicon alternatives. And though military and space markets spurred the initial development, these transistors are now migrating rapidly into high frequency wireless amplifiers used in 3G mobile phones and base stations, and high-speed LANs.

Over the course of four decades, Microsemi's engineers have become master designers of analog power circuits

Passivation and packaging are once again critical. At ultra-high frequencies, every microscopic wire and connection, along with the microscopic architecture of the transistor itself, can dramatically affect linearity and overall performance. Here, Microsemi has bypassed troublesome wire bonds with its patented FlipChip design. Microsemi lithographs connections directly on to the active chip surface, and then mounts the active side face down, which makes possible direct-solder ("wireless") connections to the chip package. An added benefit is that the hot surface of the transistor now faces the circuit board, which serves as a heat sink. Lower temperature leads to more linear device performance, and makes possible more compact packaging. Microsemi's FlipChips are now used in applications ranging from pacemakers to power amplifiers.

Master of the Analog Universe

Beyond basic material physics and device packaging, the art of analog power lies in the circuit, the hive rather than the individual bee. Over the course of four decades, Microsemi's engineers have become master designers of analog power circuits. Much of the business has grown directly out of Microsemi's development of discrete components for specific, customer-defined applications. In providing a minutely detailed description of the high-end diodes and RF power transistors it needs, the customer hands Microsemi an opportunity to propose a complete circuit redesign. Medical implant maker Medtronic, for example, asked Microsemi to develop diodes to block transients in defibrillators; Microsemi ended up redesigning the entire defibrillator power circuit, dramatically shrinking the number of components and the entire package. Ericsson wanted surge-suppression diodes for 3G base stations; Microsemi ended up supplying a complementary high-efficiency power amplifier, too.

One group of Microsemi circuits addresses the ubiquitous challenge of generating precisely clocked power. The single most power-hungry component of the fecund new family of laptops, handhelds, and Web phones is the fluorescent light behind the flat-panel color display. It takes conditioned 120-kHz power to turn the screen on instantly, and to power it efficiently and flicker-free. An implanted pacemaker requires much the same (though at a much lower frequency, of course), to ensure a flicker-free heartbeat. Both applications place an enormous premium on small size and low power consumption for long battery life. As noted earlier, Microsemi has delivered—its circuits light up much of what lands on lap, or palm, or dashboard. They also clock pacemakers and defibrillators for all the major manufacturers of these implants: Guidant (GDT), Medtronic (MDT), St. Jude (STJ), Biotronik, ELA Medical (France), Sorin Biomedica (Italy), Medico (Italy).

Microsemi's fortunes used to be hitched to the military's; now they are squarely centered in the digital-electric civilian Powercosm

Filters define a second sprawling class of analog circuits, used to block unwanted voltage transients from reaching USB hubs and DSL line cards, cell phones and PDAs, pacemakers, hearing aids, and almost every other electrically powered device that's manufactured. In different applications, these filters must handle many orders of magnitude of voltage and current. And all must function at milli- to nano-second speeds–faster than lightning, which generates a good share of the unwanted transients, faster than digital radios, whose signals might interfere with medical implants, faster than solar radiation pulses that can fry circuits in satellites, and faster than the 25 kV static sparks from dry carpets and car seats, that can fry cell phones and pacemakers. Many filters have to be placed in the same electrical path as the high-speed digital data–surges and bits share the same wire–and thus must remain transparent to the bits, but instantaneously opaque to any voltage spikes that get into the line.

Microsemi designs and builds fast, compact, efficient analog filter circuits that span a very wide range of applications. One of its circuits, for example, unites an inherently low-voltage, low-power Zener diode with a high-power transistor. This solves the vexing challenge of building a low-voltage filter that can handle high-energy pulses–essential to protect pacemakers, Ethernet LANs, DSL links, and Internet cable services. (Microsemi consolidated its position in this market with its 1980 acquisition of Siemens' Zener operations.) Other Microsemi filters suppress sparks in the fuel tanks of Boeing and Airbus jets, and protect the optical repeaters used in the deep-ocean fiber-optic cables manufactured by Alcatel (ALA), Tycom (TMC), MELCO, and Pirelli. The latter incorporate 10-kV power lines, with potentials for 25 kV. (Microsemi picked up the technology to protect such systems in its 1998 acquisition of BKC Semiconductor.) Still other filters protect PC serial ports, CPUs on motherboards, and the signal-receiving circuitry in satellites and mobile phones. Customers include Motorola, Lockheed Martin (LMT), Seagate, Mitsubishi (MBK), Guidant, Samsung, Medtronic, Boeing (BA), Palm, Alcatel, Tycom, MELCO, Pirelli, Dell (DELL) and Compaq.

Microsemi's 1999 acquisition of Linfinity brought it world-leading capabilities in pulse-width-modulation (PWM) circuits — along with Jim Peterson, who became Microsemi's CEO last January. (Peterson's career has spanned General Instruments, Rockwell and Silicon Systems, a storage company that he ran when TI (TXM) purchased it in 1995; from there he moved to Linfinity.) And PWM circuits are at the core of the Class D amplifiers that unite Microsemi's fastest diodes and power transistors. Long favored by design engineers for its efficiency and linearity, the Class D amplifier has always had one great failing, it requires bulky passives (capacitors and inductors) to filter out noise inherent in its design. But the noise, and thus the passives, disappear with sufficiently fast diodes and the use of PWM circuits that Microsemi now builds. These circuits also sharply reduce overall power consumption. Microsemi's PWM amplifiers now power the PDA and portable lighting systems described earlier. And hearing aids, cell phones, and base stations. And the solid-state Peltier circuits that cool laser diodes in laser printers, optical telecom systems, and data storage applications. And Recoton's (RCOT) 900-MHz wireless powered speaker system that you can buy for your back yard porch.

A third important class of circuits joins Microsemi's amplifiers with its photodiodes. Photodetectors can indeed convert gigabit-speed pulses of light into electrons, but just not very many electrons. The electrical output must immediately be amplified – by an amplifier that can handle the blinding speed. The output of the GaAs or InGaAs/InP photodiode is therefore fed directly into a fast GaAs or InGaP RF amplifier. No vendor has yet managed to integrate both detector and amplifier on a single substrate, but Microsemi is now pushing fast toward that goal; a commercial product is likely next year. Successfully integrating these two key, complementary components will push down costs, greatly facilitate high-volume production, while providing a much faster, lower-noise circuit, with a smaller footprint.

The Pulse of the Powercosm

Speed is what divides the analog world from the digital. To build a "digital circuit" just stick some diodes into an analog circuit, and drive it hard and fast. All digital devices are in fact analog devices on speed: capacitors flipping from fully charged to fully discharged (RAM memory), or transistors flipping from fully open to fully closed (logic gates), with the continuum of intermediate states ignored, because they pass so quickly. Analog devices came first, and will forever remain the most fundamental, the fastest, the infrastructure circuits under the vast edifice of digital power and digital logic erected above them.

For four decades, and long before digital power systems came of age, Microsemi pushed analog materials, and their packaging, and the circuits in which they were used, to meet military and aerospace demands for more power and more 9s in less space. Now, the digital chips, radios, and optical systems that are infiltrating every sector of the civilian economy depend on power as dense, fast, and reliable as the Pentagon's. Digital powerchips have come of age to supply it – but digital power doesn't displace analog circuitry, it is erected on top of it. Microsemi's fortunes used to be hitched to the military's; now they are squarely centered in the digital-electric civilian Powercosm. As recently as two years ago, military applications still accounted for over 40 percent of Microsemi's sales; that figure is now under 30 percent, and falling rapidly.

The silicon-avalanche diodes that Microsemi developed for Raytheon (RTN) to protect satellite antennae from electromagnetic pulses have landed in systems that power Pirelli's fiber-optic repeaters for undersea cables. PIN diodes Microsemi developed for use in military radiation detectors are now in Motorola's TalkAbout mobile radios. GaAs photodiodes developed for missile gyroscopes have ended up in a PDA (for ambient light detection), and handheld blood oximeters. Diodes, filters, and integrated power amplifiers used to condition power in the next generation YF22 fighter and international space station have found their way into Guidant defibrillators, Motorola phones, Compaq's handheld PDA, the GoReader e-book, Visteon (VC) automobile display, and General Electric's (GE) medical MRI unit.

Having crossed the military-to-civilian Rubicon, Microsemi's analog technology has spread fast across widely divergent civilian applications. Powermite-packaged diodes incorporated in the surge suppression circuit of a StarTac phone because their high efficiency extends battery life are also used in Corvis (CORV) Optical transponders, which are highly sensitive to waste heat. Diode-based inverters developed to power PDA backlights end up powering high-voltage implantable defibrillators, too. Because they perform such fundamental, heart-beat-like functions, Microsemi's analog devices and circuits can find applications wherever electrons move either bits or atoms.

Which is everywhere. Microsemi supplies mobile platforms (18 percent of revenue), telecom systems (16 percent) and computers/peripherals (14 percent)–-but also in military/aerospace systems (29 percent), industrial applications (13 percent), medical devices (8 percent), and automotive systems (2 percent). Microsemi's major customers include Motorola, Lockheed Martin, Seagate, Mitsubishi, Guidant, Samsung, Medtronic, Boeing, Palm, Dell and Compaq – with no single customer accounting for over 4 percent of Microsemi's revenues. And Microsemi's core skills aren't easy to duplicate. The company's business centers on its envelope-pushing mastery of materials and packaging, and applications-specific circuit designs.

One boundless (and still little noted) power market now unfolding for Microsemi is the silicon body. The global market for implantable medical devices is already $50 billion, and growing at 12 percent annually; $14 billion of which already comprises electron-based circuits requiring powerchips. Advances in power electronics now promise very rapid growth from that already substantial base, because so many new devices can now be built into packages small enough to implant, and electrically frugal enough to run on tiny batteries.

Microsemi is already the leading supplier of diodes, transient voltage suppressors and thyristors to manufacturers of electro-cardiac implants. (The other two main contenders are IXYS (SYXI, *April 2000 DPR*), and Mitel Semiconductor (MLT), which became a semiconductor pure play in February 2001). Over one million people already have electrically powered implants, and 150,000 new ones are installed every year, most of them (for now) pacemakers. Heart defibrillators represent a second large market; at least one million Americans are potential candidates for the more compact, efficient, implantable heart defibrillators that Microsemi is developing. Microsemi is working on next-generation implantable defibrillators with Advanced Power Technologies (APTI, *September 2000 DPR*); Microsemi brings the best control circuits to the table, APTI one of the highest-power-density IGBTs. Medtronic and Guidant are both using Microsemi silicon in the new class of heart "resynchronizers" they are developing, to address various forms of electro-cardiac malfunction.

The company's business centers on its envelope-pushing mastery of materials and packaging, and applications-specific circuit designs

The brain comes next. Electro-stimulation holds great promise for the treatment for epilepsy, Parkinson's Disease, and other neurological malfunctions, as well as depression, dementia, and chronic pain. Implantable therapies for irregular breathing and muscle spasticity are now on the near-term horizon. Other electro-implantables will soon pump drugs (insulin, for example), power prostheses, improve hearing, and eventually improve or even restore eyesight. All of these applications require more efficient and reliable power in less space. And for the technology that best supplies it, price hardly matters. If it's your heart at the far end of the wire, nothing is more expensive than an unexpected loss of power to your pacemaker. If it's your brain, you (or your insurer) will pay almost any price for the power that makes possible the implant that can suppress the epileptic seizure.

Where will it end? It won't. Not in the silicon body, nor anywhere else in the inflationary digital-electric Powercosm. At least not until we satiate our appetites for bits and photons and machine intelligence, and there's no reason to suppose that those appetites ever can be satiated. Microsemi currently provides about $1 of product per mobile phone; that figure is headed to $12 when the phone gets its color screen. And there'll be something beyond color – count on it. Our collective appetite for more digital power in less space won't abate, it won't even level off. Year after year we will demand more bandwidth, MIPS, more sound, more color display, in less box. Which will require more power, handled more efficiently, in a smaller package. Which, time and again, Microsemi will help to supply.

Peter Huber and Mark Mills
March 30, 2001

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	3/30/01 Price	52wk Range	Market Cap	Customers
Powerchips:	Microsemi (MSCC)	3/30/01	28.00	28	17.13 - 52.75	387m	Lockheed Martin, Mitsubishi, Medtronic, Boeing, Motorola, Palm, Compaq
	Fairchild Semiconductor (FCS) †	1/22/01	17.69	13.32	11.19 - 49.50	1.3b	GE, Emerson Electric, Rockwell, Siemens, Bosch, PowerOne, Artesyn, Invensys, IBM, Delta, Marconi
	IXYS (SYXI)	3/31/00	6.78	15.75	4.63 - 45.38	419m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
	International Rectifier (IRF)	3/31/00	38.13	40.50	27.38 - 67.44	2.5b	Nokia, Lucent, Ericcson, APC, Emerson, Intel, AMD, Ford, Siemens, DaimlerChrysler, Bosch, Bose, Delphi, Ford, TRW
	Advanced Power (APTI)	8/7/00	15.00	11.13	8.44 - 49.63	93.9m	Alcatel, Ericsson, ITI, Power-One, Advanced Energy Industries, Emerson
	Infineon (IFX)	11/27/00	43.75	37.85	31.44 - 88.25	23.7b	Siemens, Visteon, Bosch, Mansmann-Sachs, Hella, Delphi
Network Transmission and UPS: High-temperature superconductor	ABB**	9/29/00	96.95	72.58	N/A	N/A	National Grid (UK), Microsoft, Commonwealth Edison, American Electric Power
	American Superconductor (AMSC)	9/30/99	15.38	16.06	13.25 - 61.88	325m	ABB, Edison (Italy), ST Microelectronics, Pirelli Cables, Detroit Edison, Electricite de France
Power: Heavy-Iron-Lite	General Electric (GE)	9/29/00	57.81	41.86	36.42 - 60.50	416b	Reliant Energy, Enron, Calpine, Trans Alta, Abener Energia, S.A.
	Catalytica Energy Systems (CESI)	9/29/00	12.38	20.94	9.13 - 19.5	258m	GE, Kawasaki Turbines, Enron, Rolls Royce, Solar Turbines
Distributed Power Generation Microturbines	Capstone Turbine Corp. (CPST)	6/29/00	16.00*	28.38	17.75 - 98.50	2.2b	Chevron, Williams ECU, Tokyo Gas, Reliant Energy
Fuel Cells	FuelCell Energy (FCEL)	8/25/00	49.88	50.50	15.75 - 108.75	798m	Santa Clara, RWE and Ruhrgas (Germany), General Dynamics, LADWP
Micropower Nano-fuel cells	Manhattan Scientifics (MHTX.OB)	8/25/00	2.75	.77	.69 - 5.06	N/A	Incubator (no customers)
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59.00	62.00	46.25 - 79.75	26.6b	Citicorp, Verizon, Nokia, Motorola, Cisco, Exodus, Qwest, Level 3, Lucent
	Power-One (PWER)	*(see below)*					
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	22.75	14.49	14.71 - 89.81	1.1b	Cisco, Nortel, Teradyne, Lucent, Ericsson
Electron Storage & Ride-Through Ultracapacitors	Maxwell Technologies (MXWL)	2/23/01	16.72	19.25	10.56 - 22.56	191m	GM, Delphi, Visteon, Valeo, Onemocall, EPCOS, Boeing, Lockheed Martin, Rockwell
Flywheels	Active Power (ACPW)	8/8/00	17.00*	20.31	12.75 - 79.75	797m	Enron, Broadwing, Micron Technologies, PSI Net, Corncast Cable, ABC
	Beacon Power (BCON)	11/16/00	6.00*	5.25	4.81 - 10.75	203m	Century Communications, Verizon, SDG&E, TLER Associates, Cox Cable
Hydrogen Generation	Proton Energy Systems (PRTN)	9/29/00	17.00*	7.47	5.25 - 36	247m	Matheson Gas, NASA
Power: Heavy-Iron	Calpine (CPN)	1/25/01	40.44	55.07	18.13 - 56.41	15.7b	PG&E, Long Island Power, ComEd, Phillips Petroleum, ConEd (NY), New York Power, JFK Airport, Amoco, Sacramento Municipal

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 prior to 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.

** Offering price at the time of IPO.*

*** On March 21, ABB announced its "listing on the New York Stock Exchange, scheduled for early April."*

† On March 19, Fairchild Semiconductor completed its acquisition of Intersil's discrete power business for approximately $340 million in cash.