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THE MAGAZINE OF TECHNOLOGY INSIDERS

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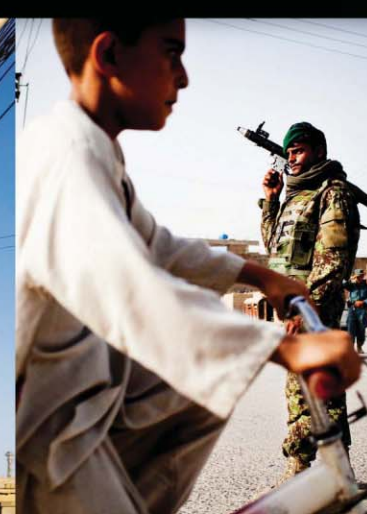
RE-ENGINEERING AFGHANISTAN

The coalition has spent hundreds of millions trying to give Afghanistan electricity. Unfortunately, it made many of the same mistakes it made in Iraq





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ieee spectrum

volume 48 number 10 international

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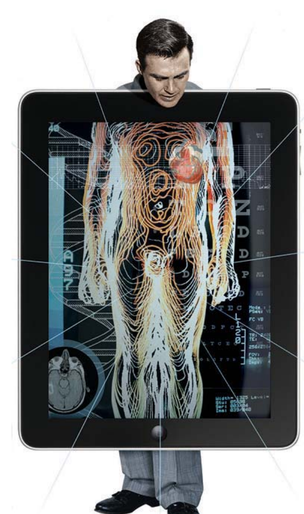
COVER STORY



COVER, CLOCKWISE FROM TOP LEFT: GLENN ZORPETTE; DAVID GOLDMAN/AP PHOTO; EMILIO MORENATTI/AP PHOTO; PAULA BRONSTEIN/ GETTY IMAGES; EROS HOAGLAND/REDUX; JEROEN OERLEMANS/PANOS PICTURES; MARKO DJURICA/ REUTERS; JOAO SILVA/THE NEW YORK TIMES/REDUX

THIS PAGE, CLOCKWISE FROM TOP: LCPL. PAIGE J. BRAY; VIKTOR KOEN; ROBERT BOSCH; ANATOMY BLUE

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UPDATE

OPINION

DEPARTMENTS

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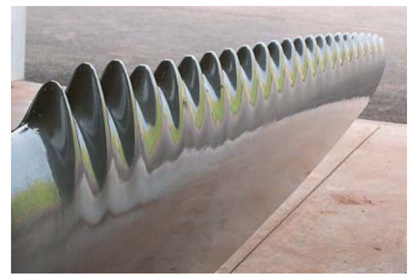
Of Whales and Wind Turbines



When you think wind turbines, you probably don't think whales. But by incorporating some structures inspired by humpback whale fins, one firm has built much more efficient turbines. And by copying the way fish swim in schools, a separate research team has figured out how to pack more turbines into wind farms. Such biomimicry could contribute to more affordable renewable energy.

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CUTTING DOWN ON SPAM Despite e-mail filters, spam has become an annoying part of our daily lives. But a group of researchers has found a way to help cut down on e-mail junk—by hitting spammers where it hurts most: their wallets.

THE IEEE JOB SITE CELEBRATES 10 YEARS It's been a decade since IEEE launched its job site for members, and the service has never been so needed. There are all sorts of features to help members find a job. And more than 5000 employers use the site to post open positions—about 1300 every month.

WEBINARS EXPLORE RISK MANAGEMENT The demand for engineers familiar with risk management is high, yet few have the training. To beef up IEEE members' knowledge of the field and boost their career opportunities, IEEE-USA has rolled out a six-part webinar on the topic.

ONLINE WEBINARS & RESOURCES AVAILABLE AT http://spectrum.ieee.org/webinar

4 October in California: The IEEE Emerging Technology Forum Series: Silicon Valley's Impact on the Automotive Industry

20 October: Plasma Modeling With COMSOL Multiphysics

24 October in California: The Emerging Technology Forum Series: Reinventing Infrastructure for High Speed Rail

27 October: Simulation of Vacuum Electronics Devices Using VORPAL

Requirements Management's Key Role in the Nuclear Industry

Modeling and Simulation of HEV and EV Power Electronics

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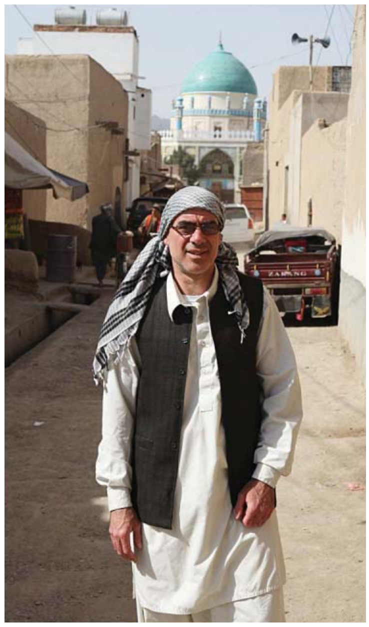
back story

Life's Bazaar

"THERE WAS A TIME before the Internet, Twitter, and even telephones that reporters physically went to an event to report on it," wrote Randall Patnode, a media scholar, in his blog recently. "They used to call this 'shoe-leather reporting'...in which the journalist went from place to place acquiring facts for a story. The reporters wound up talking to a lot of people face to face, seeing things firsthand, and collecting the gritty detail that makes storytelling rich and compelling." At *IEEE Spectrum* we still practice shoe-leather reporting. We can do so because of the support of IEEE members.

So it was that Executive Editor Glenn Zorpette found himself this past April dressed in Pashtun garb in the bazaar in Kandahar city, Afghanistan, three days after riots there killed 16 people and injured 128. Zorpette was in southern Afghanistan reporting on the multibillion-dollar effort to reconstruct the region's decrepit electrical networks. One of the things he wanted to do was see for himself whether ordinary Kandaharis on a typical day had access to electricity. But like most embedded reporters, he was spending most of his time in the field with soldiers or on military bases, where electricity is generally plentiful.

A scheduled meeting with Kandahari business leaders during a visit to the governor's palace fell through because of the riots. Then a sympathetic U.S. Army major offered to take him into the bazaar in Kandahar. It wouldn't be possible to go into the labyrinthine area with massive



COURTESY OF GLENN ZORPETTE

armored vehicles and a heavily armed security contingent, so the two went in "under the radar," dressed like locals. "I wasn't nervous until I saw the major, just before we left the base, strap on a concealed sidearm and some James Bond technology that's probably classified," Zorpette recounts.

During the stroll, which lasted about an hour, the major photographed Zorpette in front of the Grand Mosque, one of Afghanistan's most important places of worship [above]. Zorpette also saw that there was no power in the marketplace, that small, gas-fueled electrical generators were on offer in many stalls, and that the condition of the electrical lines and gear was very poor.

Of such moments are good stories—and lifelong memories—made. "Life is an adventure," Zorpette says. "Not because you say it's so, but because you work hard to make it so." ❏

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, The Data is in *IEEE Spectrum*, Vol. 48, no. 10 (INT), October 2011, p. 68, or in *IEEE Spectrum*, Vol. 48, no. 10 (NA), October 2011, p. 84.

contributors

SUSAN KARLIN lists among her achievements acting, drawing, traveling to every continent, and writing for such publications as *The New York Times*, *Entertainment Weekly*, and *IEEE Spectrum*. For this issue, she profiled Cameron Cohen [p. 22], a 13-year-old who spent a nine-month recuperation developing a lucrative iPhone app and then donated US $20 000 of the profits to help hospitalized children.

RITCHIE S. KING, who quantified programming languages for The Data [p. 68], formerly dealt with numbers full-time as a chemical process engineer. Unlike most engineers, though, he enjoyed writing reports and making charts more than any other aspect of the job. In 2009, King decided to make writing about science and technology a full-time gig. He landed an internship at *Spectrum* this past summer and is currently finishing journalism grad school and interning at *The New York Times*.

BURAK OZPINECI and **LEON TOLBERT,** both IEEE senior members, write about the rise of silicon carbide in power electronics in "Smaller, Faster, Tougher" [p. 38]. Ozpineci heads the power electronics and electric machinery group at Oak Ridge National Laboratory, in Tennessee. Tolbert is the Min Kao professor of electrical engineering and computer science at the University of Tennessee, in Knoxville. The two began working on silicon carbide devices in 2001, when a friend of a friend of a friend sent along some of the first SiC Schottky diodes. "We were hooked," Ozpineci says.

ALFRED POOR is a senior member of the Society for Information Display. At *PC Magazine*, he was a contributing editor for more than 20 years and became the publication's first lead analyst for business displays. In "LCDs' Bright Future" [p. 20], Poor explains three technological advances that will make TVs lighter and cheaper and reveals why he still is "fascinated by shiny, sparkly things."

JOSEPH M. SMITH is the chief medical and science officer of the West Wireless Health Institute, in San Diego. He is also an advisor to programs at Johns Hopkins, Harvard, and the Defense Advanced Research Projects Agency. After using what his sons called "poky" instruments like needles and scalpels in his 15 years in cardiology, he moved to a more hands-free job: championing the first wireless technology for implanted pacemakers and defibrillators at Guidant. He writes about these and related developments in "The Doctor Will See You Always" [p. 50].

RICHARD STEVENSON, author of "A Driver's Sixth Sense" [p. 44], got a Ph.D. in physics at the University of Cambridge. There he focused on gallium nitride and other compound semiconductors, the beat he usually covers for *Spectrum*. This time, he writes about an advanced yet inexpensive car-radar system from Infineon Technologies that's based on good old silicon. "With the shift to silicon, we may soon see luxury features like adaptive cruise control on economy cars," he says.

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spectral lines

Re-engineering Afghanistan: At What Cost?

THE UNITED STATES and several other countries have poured money into a technological effort that has involved hundreds of engineers and technicians, thousands of construction workers, and scores of contractors and subcontractors. It is the reconstruction of Iraq and Afghanistan, and it hasn't been going well. Reconstruction has been a sprawling enterprise, encompassing the building and refurbishment of such vital infrastructure as roads, schools, sewage systems, dams, and electrical grids. We began our coverage of this work in the fall of 2005, when Executive Editor Glenn Zorpette traveled to Iraq to report on the electricity and telecommunications projects there. Zorpette's first article, "Re-engineering Iraq" [February 2006], told a story of engineers thwarted by politics, and of enormous sums wasted because of decisions based largely on local and international politics rather than on engineering and logistical realities.

Although the on-the-ground situation is different, the same mistakes have cropped up in Afghanistan. In "Re-engineering Afghanistan," Zorpette describes what he saw and learned during a three-week trip there earlier this year. As he did in Iraq, Zorpette found generating plants with insupportably high operating expenses, and generators costing hundreds of millions of dollars that will likely be abandoned the moment coalition forces leave.

As in Iraq, the prime contractors in Afghanistan are working on a "cost-plus" basis that encourages overspending—to the ire of U.S. government auditors and analysts, who have vented their displeasure in thousands of pages of reports. Most recently, the U.S. Commission on Wartime Contracting, a congressionally mandated panel, determined that the United States has wasted or misspent between US $31 billion and $60 billion contracting for services in Iraq and Afghanistan.

Despite all that investigation, nothing has been done to avoid the pitfalls that have been so clearly and repeatedly identified in Iraq. If anything, the situation may be worse this time around. For example, for electrical reconstruction, the main U.S. government agency involved in Afghan reconstruction, the U.S. Agency for International Development, continues to rely heavily on a single contracting entity, despite recommendations to the contrary. And, as Zorpette argues in his report, this overreliance has badly compounded a complex situation.

The electrification of southern Afghanistan remains an unfulfilled promise.

DAVID GOLDMAN/AP PHOTO

Efforts to stabilize and develop a fledgling democracy would be difficult under the best of circumstances. Afghanistan is a poor country and a war zone, and it has had very little infrastructure, ever. It has never really had a central government and continues to be plagued by tribalism. There are a limited number of contractors who are willing to engage in reconstruction in a hostile fire zone or absorb the additional costs associated with these types of activities. Building a power plant in Helmand province is very different from building one in Piscataway, N.J.

Reconstruction efforts require partnerships among not only diverse governmental and military organizations but also civilian agencies. There are many good servicemen and -women and civilians working in this difficult situation—but all too often, what good they accomplish seems to be in spite of the policies and politics at play.

The most basic problem is the dearth of trained, articulate engineers in positions of political and policy influence who might steer these efforts in the direction of sound engineering. But there are many other problems—the undertaking of large, costly projects in military hot spots, in an attempt to improve domestic stability, being one of them. In the end, however, it may simply be impossible to establish a management structure that effectively controls both military and civilian agencies. Expecting effectiveness and efficiency in a war zone may be unreasonable.

IEEE Spectrum has a long history of doing first-rate journalism. We know from your feedback that you want detailed and thorough reporting on major tech-related issues of the day. We consider it a privilege to bring you news and features about cutting-edge research and technology and about the people and institutions behind it. But we have always understood that the world of engineering is big and complicated and sometimes messy. Engineering is part of—and is shaped by—a complex ecosystem that has economic, political, and social components. To report exclusively on technology as though it were separate from the world would be to present an unrealistic picture of what engineers and other technologists face in their daily working lives.

Spectrum's articles do not represent official viewpoints of IEEE or its members. We're not sure how anyone could come up with a single viewpoint that would accurately reflect those of our 400 000 or so members from around the globe. To even try would be to court disaster. So the founders of *Spectrum* wisely institutionalized its editorial independence.

Today, *Spectrum* finds itself in a unique position to cover big issues in technology and engineering in a way that essentially no other publication can match. We have readers who want more depth and analysis than they can get anywhere else. With your support, we will keep giving you just that.

—SUSAN HASSLER

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Trading at the Speed of Light

Technology has allowed the timing of financial trading to approach its theoretical limits

ONCE UPON a time, stock exchanges were packed with traders running, shouting, and elbowing one another on an open trading floor. Today, virtually all stock trading is done, well, virtually—through massive, globally interlinked computer systems. The rates of these transactions are now limited only by technology and, increasingly, by the speed of light. So a costly arms race has begun for telecommunications and network links that can give traders a competitive edge as small as a few tens of microseconds.

"Everyone is driving toward zero latency," says Graeme Burnett, who has worked for Deutsche Bank and ABN Amro Bank in the Netherlands and now runs Enhyper, a consultancy in England that specializes in financial engineering. "We've literally done every optimization you can imagine."

The impetus is a recent phenomenon called high-frequency trading. Typically, a high-frequency trading firm—or rather, its computer systems—buys and sells financial instruments while holding on to them for perhaps just fractions of a second. High-frequency traders make money by exploiting tiny and fleeting disequilibriums in the markets—say, when the price of one asset changes and the price of another that should be equivalent in value doesn't shift immediately to match.

The extent of such high-frequency trading activity in the United States—and to a lesser degree in Europe—is astonishing. (Because of certain taxes that East Asian governments impose on financial transactions, high-frequency trading hasn't made such inroads there.) X. Frank Zhang, a professor of accounting at the Yale School of Management, has researched the effects of high-frequency trading on U.S. markets and calculates that it "was responsible for about 78 [percent] of the dollar trading volume in 2009, up from near

HIGH FREQUENCY: A worker at Tradeworx, in Red Bank, N.J., watches the day's high-frequency trading transactions.
PHOTO: MIKE SEGAR/REUTERS

3.8% Sales growth for PCs in 2011, according to market research firm Gartner. The company had predicted 9.3 percent growth earlier in the year.

update

news brief

The Seaweed Solution

By swapping graphite for silicon as an electrode material, start-ups have made lithium-ion batteries that can hold twice as much energy as they used to. Silicon is better at holding charge, but because it swells so much when it's charged, the electrode tends to break up quickly. Companies in California, England, and Korea have been developing new ways of structuring the silicon so that it has room to swell, and now scientists in Atlanta have found a potentially cheaper way: A common food additive derived from seaweed can hold the silicon while allowing it to swell and shrink as needed.

zero in 1995." He admits that his estimate may be a little high but says, "Everybody would agree that it's at least 70 percent."

High-frequency trading remains quite controversial. Zhang, for example, believes it leads to harmful price volatility. And high-frequency trading (or the sudden absence of such trading at a critical time) has been implicated in the "flash crash" of 6 May 2010, when stock prices in the United States plummeted by about 9 percent, only to recover most of that loss within 20 minutes.

One reason the high-frequency traders can beat others to the punch is that they often locate their computers in data centers run by the exchanges. The New York Stock Exchange, for example, moved its computer infrastructure last year to a facility it built in Mahwah, N.J., where it also leases space to trading firms. It can command premium prices for that space because close physical proximity means fast access to the exchange's raw trading data. Most other market participants don't see that data until milliseconds later, after it's been consolidated and combined with information from other exchanges.

High-frequency traders also gain an edge by having the fastest telecommunications link possible between distant trading centers where the prices of what is being bought and sold are fundamentally related. The fate of some companies whose stocks are being traded in New York City, for example, hinges on the price of commodities being traded in Chicago, and vice versa. If the computerized trading platform in one of these cities has access to information about the market in the other sooner than anyone else—even just a few milliseconds sooner—it can execute profitable trades.

That's why Spread Networks, of Ridgeland, Miss., invested what probably amounts to a few hundred million dollars last year to install a new fiber-optic cable along the shortest route it could find between New York and Chicago and then began marketing the connection to high-frequency trading firms. The round-trip travel time of a signal along its new cable, 13.3 milliseconds, is 3 ms faster than competitors can offer. With electronic trades now taking less than a millisecond to execute, firms with access to this fast connection can profit handsomely.

13.3 milliseconds
Round-trip travel time of a signal along Spread Network's new cable between New York City and Chicago

A similar effort is taking place to link New York City and London. In June, Hibernia Atlantic of Summit, N.J., began surveying the planned route for a new cable that promises to shave 5 ms from the 65-ms round-trip travel time of the digital signals presently being sent across the ocean. And Hibernia Atlantic, like Spread Networks, is pitching the advantages of its especially fast connection to the financial community.

Hibernia Atlantic appears to be thinking quite far ahead here. One of its advisers is Alexander Wissner-Gross, a research affiliate at the MIT Media Laboratory who (with Cameron E. Freer, a mathematician at the University of Hawaii at Manoa) published an article last year in *Physical Review E* titled "Relativistic Statistical Arbitrage." That article investigates, in a rigorously quantitative way, what happens when the kinds of trading opportunities that high-frequency traders exploit are limited only by the speed of light, or at least the speed that light travels at in optical fiber.

"The naive solution is to put preprogrammed computers on either side of a low-latency link," says Wissner-Gross. That's what's happening now, and it's led to "an arms race to reduce point-to-point latencies," he says. But his research highlights a different strategy for making money. "The next phase is setting up at nodes." He means that the most advantageous position to be in, if you're trying to wring a profit from tiny discrepancies in price between two distant trading centers, is at an intermediate point between them. For example, if prices are fluctuating rapidly in New York but shifting only slowly in London, you should set up your trading machines between the two cities—but closer to the U.S. end of the connection. (Of course, this might put them, awkwardly, at the bottom of the Atlantic Ocean.)

The global financial system is indeed entering a strange new world. "You can no longer operate on the implicit assumption of absolute simultaneity," says Wissner-Gross, referring to the pre-Einstein notion of how time flows. So it seems finance is now moving into the relativistic realm. Perhaps that's why London's *Financial News* had to publish a clarification to a story it ran on 1 April, about a firm named Relativity Trading, which was reported to be able to execute trades "at the speed of light" and hoped one day to be able to execute a trade even before the decision to do so is made. It appears some readers didn't realize it was an April Fool's joke. —DAVID SCHNEIDER

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Faster Networks Seek Killer Apps

Six U.S. cities link their networks to attract app developers

THE UNITED States, once a leader in broadband technology, has fallen behind. Eleven countries can boast higher average broadband speeds, according to Akamai's latest *State of the Internet* report. But if you're lucky enough to live in a Cleveland neighborhood near Case Western Reserve University, things look different.

The 104 homes there are wired with optical fiber in an experimental network that provides impressive 1-gigabit-per-second uploads and downloads. Five other cities—Chattanooga, Tenn.; Lafayette, La.; Philadelphia; Salt Lake City; and Washington, D.C.—have similar broadband experiments providing between 100-megabit-per-second and 1-Gb/s connections to schools, businesses, and homes.

Now the U.S. government wants to knit these islands of accelerated connectivity together into a large network through a project called US Ignite, in the hope that someone will come up with killer apps that take advantage of the larger network. According to John Peha, who until recently was the government official behind the project, one of the big things holding back broader development of high-data-rate broadband in the United States is a lack of applications. "Consumer demand will only emerge if people see what's possible," he says.

The White House Office of Science and Technology Policy, Ignite's backer, plans to have the first two cities linked by the end of the year. During that period, the U.S. National Science Foundation will choose to fund six to eight projects that will demonstrate ways to use the Ignite network. Winning ideas will be awarded up to US $400 000 each.

To this point, applications have been intended only for individual city networks. Lev Gonick, chief information officer at Case Western, says Cleveland's fiber-wired neighborhood has been a hotbed of development for grassroots projects. Adjacent to the university, in a community dubbed the Case Connection Zone, telemedicine apps are becoming common, and new programs are in development, such as one that allows senior citizens to take aerobics classes together over live, connected video feeds. Dave Martin, a graduate of Case Western, turned an idea for a Connection Zone app into a start-up called Intwine Energy. The company, in Chagrin Falls, Ohio, is using smart meters and the high-bandwidth connections to figure out what works to reduce energy consumption in homes.

In Lafayette, La., a nonprofit called FiberCorps has taken a leading role in app development. Geoff Daily founded FiberCorps to develop ways to use the advanced network to benefit communities. "While we might be one of the first cities to have this physical infrastructure," he says, "we also need to focus on the social infrastructure and the role it plays in making new technologies viable."

One of FiberCorps's experimental projects is its 3D Render Farm, which allows local high school students taking 3-D modeling courses to send their render jobs to off-site servers, where images and sequences can be processed in seconds rather than in minutes or hours. His organization is also helping to set up a videoconferencing system connecting Lafayette's largest employer to its largest hospi-

VIRTUAL BAND: The U.S. government is seeking new uses for high-bandwidth home connections. This might be one: jamming with a band—all of whose members are in different places. That's what US Ignite demonstrated in 2009. Lev Gonick, at left, is the only one really on stage.
PHOTO: GLENN RICART

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tal, so that employees who fall ill can be seen by a doctor without leaving the office.

Daily says the Ignite project adds a layer of possibility to the FiberCorps projects. "Once interconnected, our fiber communities can take successful applications and scale them, proving that they work beyond the one-off model," he says.

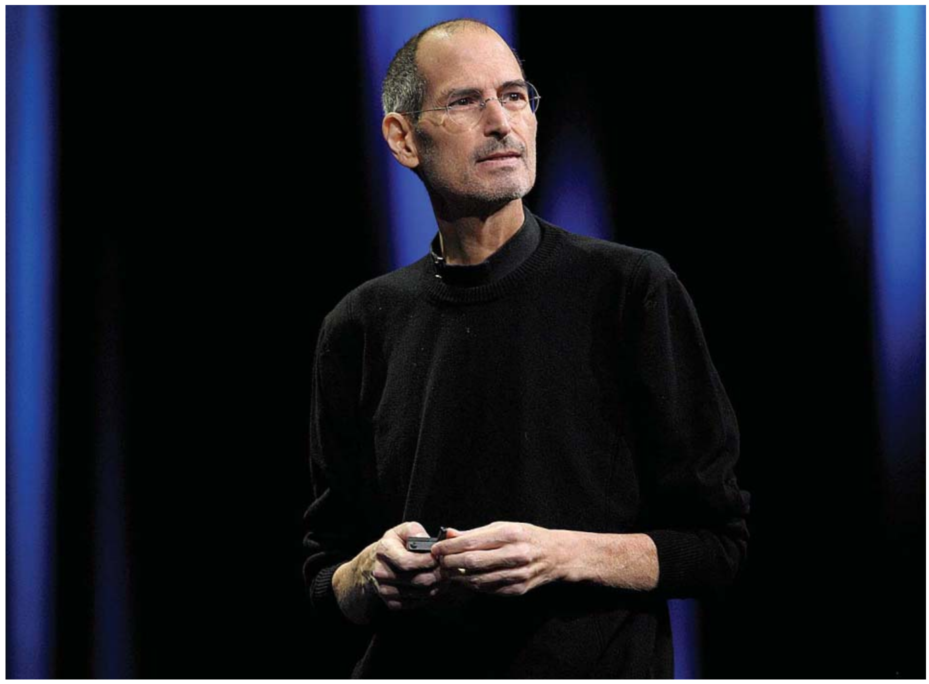
To link the cities, Ignite is partnering with the NSF Global Environment for Network Innovations (GENI). This project is intended for large-scale networking experiments that use university-based high-bandwidth infrastructure.

Project director Chip Elliot says that in all the Ignite cities, GENI is installing clusters of computers running its network protocols. Each city network will thereby be connected to the GENI backbone, which relies on two other advanced national optical networks, Internet2 and National LambdaRail.

Ignite is part of the growing momentum to use nonprofit experimental networks to pave the way for commercial infrastructure upgrades. Gig.U, for example, is another recently announced network of advanced universities, also aimed at answering the question, What would you do with robust 1 Gb/s Internet access?

Elliot—who spends all his time thinking about the next projects for Lafayette's network—says, "I have no idea what the killer apps are going to be. But helping to find them, that's about as exciting as it gets." —Marisa Plumb

commentary



DAVID PAUL MORRIS/BLOOMBERG/GETTY IMAGES

Steve Jobs in Four Easy Steps

What the electronics industry can learn from his tenure at Apple

The last time I spoke to Steve Jobs, he was screaming at me over the phone, "I'm not a failure! I'm not a failure!" His shouts got so loud, I put him on speakerphone so that my editor could hear him.

With Apple among the most valuable companies in the world because of its immensely popular products, the notion of Jobs as a failure seems ridiculous. But less than 20 years ago, in the mid-1990s, when Jobs was struggling to keep his forgettable NeXT computer company afloat, the idea of him failing—the possibility I'd raised in *The Wall Street Journal* that spurred his furious phone call—terrified him.

As he steps down as Apple's CEO, I'd hardly call him a failure now, but the reasons for his success aren't always properly understood.

Better than any of his peers, Jobs blended an understanding of technology and society, business and economics, markets and corporate power. In leading Apple past Microsoft on its way to becoming the most valuable technology company on the planet, Jobs repudiated four pillars of business and technology wisdom.

First, Jobs refused to accept that software and hardware were best designed and engineered separately. For him, the venerable insight summarized by Thomas Hughes, the grand historian of American technology, as "the system must be first" became a lodestar. Jobs understood that Apple was fundamentally a builder of technological systems, not a generator of products. As a young man, he watched IBM lose its central role in computing by handing off the PC's basic operating system to an outsider (Microsoft). When in the 2000s Microsoft struggled (and largely failed) to persuade cellphone

1.5 MILLION METRIC TONS Carbon emissions of Google in 2010. That's a bit more than those of Laos.

makers to adopt a variant of Windows, Jobs turned the industry upside down by building a cellphone with an Apple OS at its core. In embracing what traditional industrialists called "vertical integration," he propelled Apple to first place in smartphones.

Second, Jobs denied what is perhaps the most closely held article of faith of the information age: that openness and the wisdom of crowds are essential for successful technological systems. Under his leadership, Apple produced "closed" systems—devices whose basic functions could not be altered—and consumers loved them. "It's not the consumer's job to know what they want," Jobs once famously said. Though an ex-hippie, he proved to be a throwback to an earlier age of top-down leadership: A direct line runs from Henry Ford's Model T to the iPad. To Jobs, Apple's systems are always open—in the sense that their uses can be adapted to an owner's needs and desires. But as iTunes demonstrates, Apple's ability to control the content, the applications, and the purchase opportunities on its mobile devices is far greater than anything carried off by its rivals.

Third, Jobs found a way of selling Apple's products directly—through company-owned stores or online—which was perhaps his greatest and mostly unlikely business triumph. Makers of computers and consumer electronics had always offloaded the task of reaching customers to a motley crew of retailers, who provided no consistent purchasing experience or brand loyalty while shredding the manufacturer's profit margins. Again, going against convention, Jobs created the most valuable retail stores in the world (outselling Tiffany's on a per-square-meter basis). He then sold the inimitable iPhone through those stores and via one other channel (AT&T), in what was a daring business tactic that paid enormous dividends.

Fourth, Jobs found a way to dominate consumer electronics, an arena that the United States seemed to have irretrievably lost to Japan, Korea, and China. The iPod, first released by Apple 10 years ago, marked a stunning shift in global competitive dynamics in consumer electronics. No longer did U.S. firms need to presume they couldn't compete with Canon, LG, Panasonic, Samsung, Sony, and other Asian powerhouses in miniaturized digital appliances. To be sure, Jobs relied heavily on Asian production networks—Apple reportedly employs 10 times as many people in China as in the United States—but the style, engineering, and interactivity of Apple's devices are classically American.

How long Apple will be able to hang on to that domination is an open question. Some say that in Apple, Jobs built a company with his own way of thinking, so it will go on just fine without him at the helm. But whether this is true doesn't really matter in the near term: Apple has a pipeline of good products and about US $75 billion in cash.

What then is the elusive genius of Steve Jobs? Despite his infamous bad temper, his impatience, and his penchant for tantrums, Jobs is the ultimate human-centered technologist—even while he is the ultimate digital autocrat. No democracy either internally or externally, Apple has proved the merits of enlightened dictatorship, at least in realms technological. Jobs once summed up his method as "trying to expose yourself to the best things humans have done and then trying to bring those things into what you are doing." This simple credo should long motivate designers and engineers who will inevitably walk in the footsteps of this singular master. —G. PASCAL ZACHARY

G. Pascal Zachary is the author of Show-stopper *(Free Press, 1994), about the making of Microsoft Windows NT. He writes the "Scientific Estate" series for the online edition of* IEEE Spectrum.

The Fukushima Robot Diaries

IEEE Spectrum's Automaton blog has obtained and translated the blog posts of an anonymous worker at Japan's Fukushima Dai-ichi nuclear power plant. The posts describe the ups and downs of his experience as one of the lead robot operators at the crippled facility, providing a window into the complex and dangerous work environment faced by workers there.

The material—deleted just after we acquired it—also raises questions about whether Tokyo Electric Power Co., the plant's owner, acted with adequate speed and provided enough robots and supporting resources for the robot teams. But what is perhaps most significant about the blog is its technical content. By explaining what worked and what didn't, the robot operator made his blog must-read material for companies and researchers who develop robots for emergency situations.

See the whole story on our Automaton blog: **http://spectrum.ieee.org/fukushimablog1011**

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update

Footfalls for Phone Calls

New tech could charge batteries and power portable gadgets with every step

ELECTRIC SOLE: Start-up InStep NanoPower hopes to make shoes powerful.

As SMARTPHONES and other portable gadgets push the limits of handheld computing, their hunger for electricity has only increased—with no end in sight. A new technology aims to address this issue, not by seeking bigger and better batteries but by looking instead to the shoes on our feet.

When we walk, our bodies create up to 40 watts of mechanical power as heat when our feet strike the ground. A special electricity-generating cushion placed inside the soles of a regular pair of shoes can transform some of that footfall power into several watts of electricity. Over the course of a single day, the generated energy, which gets stored in a small battery in the sole, provides enough electricity to extend a smartphone's battery life or to allow someone in a developing nation without an electrical grid to power a night's worth of LED home light use.

The idea of harvesting body energy for portable electronics is certainly not new, although some of this technology is. In 1996, Thad Starner at the MIT Media Lab calculated that piezoelectric generators—solids that generate tiny currents when stressed—could theoretically generate up to 5 W of electricity at a brisk walking pace.

Starner's forecasts have proved optimistic. Today's best known piezoelectric footwear—Nike+ running shoes—aren't really harvesting energy at all. A 2007 teardown by SparkFun Electronics of a Nike+ piezoelectric pedometer, for instance, reveals that the pedometer's chips run on a separate battery. The piezoelectric part of the device is used only as a sensor, not to produce power.

By contrast, says Tom Krupenkin, associate professor of mechanical engineering at the University of Wisconsin–Madison, recent breakthroughs in microfluidics can fulfill or even exceed Starner's power projections. The key involves the properties of liquid metals such as mercury and Galinstan, a gallium indium tin alloy. When set on a dielectric-coated conductive substrate with a voltage applied across it, a droplet of liquid metal deforms and spreads across the substrate. When the process is reversed, and the liquid metal in a microfluid device is moved, it induces a voltage.

In August, Krupenkin reported in *Nature Communications* a proof of principle for this phenomenon ("reverse electrowetting-on-dielectric" or REWOD) as a means of harvesting energy. InStep NanoPower, his start-up company in Madison, Wis., is now working to commercialize the technology.

According to Krupenkin, InStep is developing a shoe sole that would store the energy from each footfall in an embedded battery. InStep says it would provide up to 10 W from each foot—enough to power a radio that communicates with your smartphone via Bluetooth and handles the phone's biggest battery-draining function: communication with cellphone towers.

"When you analyze the cellphone power budget," Krupenkin says, "you discover that the lion's share goes into the high-power RF signal."

Raziel Riemer, a lecturer in industrial engineering at Ben-Gurion University of the Negev, in Israel, says he is skeptical that InStep's technology could harvest anything close to 20 W. But, he adds, "even if they don't achieve [this]...it's not such a big deal compared to the innovation of their new method." —MARK ANDERSON

A version of this article appeared online in September.

LEFT: ISTOCKPHOTO; RIGHT: INSTEP NANOPOWER

news brief

Truth Machine?
Scientists in Estonia have discovered a way to influence whether a person lies or tells the truth, by stimulating particular parts of the brain. They used a transcranial magnetic stimulator to induce an electric current in two parts of the front of the brain. Stimulating one part made subjects more likely to lie about what they were seeing on a computer screen. Stimulating the other part made them more likely to be truthful. The experiment involved only 16 subjects, however, and the results must be replicated in an experiment with something important at stake.

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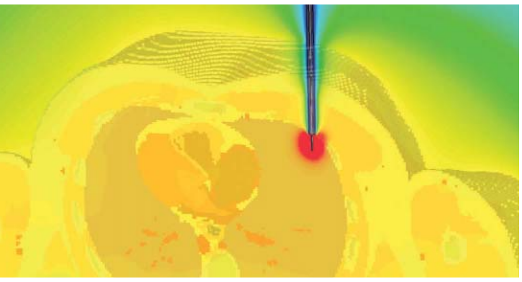

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the big picture

WATT WATERS

These rotors, capable of generating 1.2 megawatts of electricity, don't mar the view enjoyed by residents of the town of Strangford, in Northern Ireland, where they are moored. The 16-meter-long rotors, produced by Siemens, spin underwater and take advantage of the strong tidal currents that flow through a narrow strait. Though twice as expensive as offshore windmills, tidal energy collectors deliver twice as much energy as windmills of the same size. And they do so more reliably because of the predictability of the tides and their ability to change the rotors' position in order to catch both the flood and ebb tides.

PHOTO: SIEMENS

hands on

FLIGHT STATUS: A first-person-view radio-controlled airplane benefits from an on-screen display.
PHOTOS: DAVID SCHNEIDER

AUGMENTED-REALITY TV

Overlaying text on video is easy with an Arduino and an on-screen-display chip

TV PROGRAMMING nowadays includes a near-constant layering of text on top of the video—network logos, promos for upcoming shows, even pop-up commentary. That can be pretty distracting when you're just trying to watch a show, but putting some extra information over your own video can be enormously valuable. I've seen this twice with DIY projects.

Last month I described the construction of a remotely operated underwater vehicle. And in February 2010, I wrote about building a first-person-view radio-controlled model airplane. In both instances, I outfitted the vehicle with a video camera and some simple sensors. But the way these units presented the sensor measurements left a lot to be desired.

My underwater vehicle sends measurements of depth and heading to a small liquid crystal display, but that requires me to shift my eyes back and forth between the video monitor and the LCD. For my radio-controlled plane, I had also used an LCD, but I mounted it within the airborne camera's field of view so that the instrument readings were visible on the video monitor. That worked, but just barely. Often the LCD would get washed out by the glare of the sun.

In both cases, the proper solution would be to overlay the data readouts onto the video. It turns out this is rather easy to do using Maxim's 7456 on-screen-display (OSD) generator.

The 7456 isn't expensive (US $18 from Digi-Key), but it's a surface-mount chip, so prepare for myopia-inducing submillimeter lead spacing if you use it. I purchased a 28-pin SSOP-to-DIP carrier board from SparkFun ($4) and then used a flux pen, copper braid, and a variety of magnifying lenses to get the chip properly soldered to the board.

If you don't want to deal with the challenges of surface-mount technology—or don't even want to be bothered to obtain the supporting discrete components (a 27-megahertz crystal, six 0.1-microfarad ceramic capacitors, two 0.47-µF electrolytic capacitors, and two 75-ohm resistors)—you can buy an assembled breakout board for the Maxim 7456 from SparkFun ($40). Then you need only tie the reset line on the 7456 high and wire the board to the microcontroller of your choice. For me, that was an Arduino, which communicates with the 7456 over serial-peripheral interface (SPI) lines.

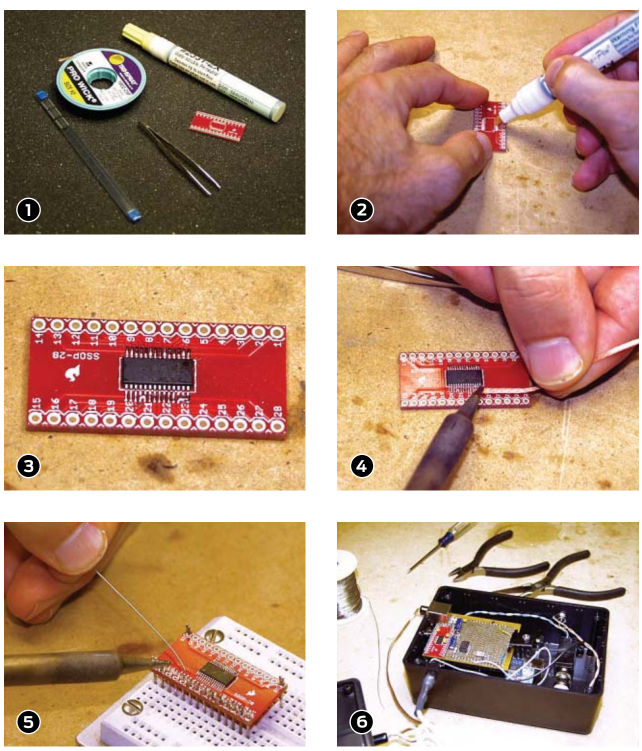
The Arduino makes the whole thing a breeze. That's because a programmer known online as kg4wsv wrote a library for printing character strings with the 7456 to specified positions on a video screen. Nor are you limited to text—the 7456 won't display graphics per se, but you can define your own graphical icons as long as they fit within a standard (16- by 16-pixel) character field. And by combining several of these, you can construct more complicated graphical doodads, such as variable-length indicator bars.

Even if you don't need graphics, you may want to learn how to upload new characters to the 7456. That's because the default set does not follow the standard ASCII sequence, strange as that might seem. You could get around this peculiarity by including a translation table in your code. But I wanted to create some of my own icons anyway, so I reshuffled the characters in the 7456 chip's nonvolatile memory so that printing ASCII on-screen would be more straightforward.

To upload new characters to the 7456, you must first create a Maxim character memory (MCM) file. For that, I used a special character editor written in Java by another member of the online community of Arduino hackers, one who goes by the name Mulder. One tip (learned the hard way): Leave the initial character field blank, because when the 7456 starts, it fills the screen with whatever is in this position.

Once you have an MCM file arranged to your satisfaction, you can upload it to the 7456, a two-step process. First you run a special "sketch" (the word Arduino programmers use for their programs) written by yet another Arduino enthusiast (dfraser) that prepares the Arduino-connected 7456 to accept the information in the MCM file. You then need some other program to send the MCM file to the Arduino. Because I developed my software on a computer running Microsoft Windows XP, I used HyperTerminal, which comes with that operating system.

The upload process can be a bit tricky. First, shut down the serial interface in the Arduino development environment, but leave your Arduino plugged into the USB port (otherwise the proper communications port will not appear as an option when you start HyperTerminal). Set the baud rate in HyperTerminal to 9600 and the hardware handshake to "none." At that point, you can happily send the MCM file out the serial port to the Arduino, which in turn sends it to the attached 7456 over the SPI lines. It will take a couple of minutes, but you'll soon have a new character set programmed permanently into your 7456.



CARRIER LANDING: Using the Maxim 7456 surface-mount chip requires a 28-pin SSOP carrier board, a flux pen, wire braid, and a pair of tweezers [1]. Apply flux to the board [2]. With some molten solder on the tip of your iron, touch it to each pad in turn. Any solder bridges [3] can be removed using wire braid [4]. Adding posts [5] then makes prototyping with the chip [6] easy. PHOTOS: DAVID SCHNEIDER

Now, when you use the Arduino OSD library to print any of your newly defined characters to the 7456, they will appear on-screen at the position you specify by first setting the position of the (invisible) cursor in your code. To make life a little easier, I added a method to the OSD library that sets the *x* and *y* position of this cursor with a single command (osd.gotoXY).

Once I'd mastered this handy chip, it was time to upgrade my two projects. For the first-person-view plane, the 7456-based OSD takes telemetry sent to the ground by radio and displays it on the video monitor. Now, while I'm taking in the view from the cockpit, I can also clearly see the plane's barometric altitude, airspeed, and battery voltages. I even programmed my system to include a variometer so that I could tell at a glance how quickly the airplane was climbing or sinking. Soon I'll add an on-screen display to the surface unit of my remotely operated underwater vehicle so that I can see its bearing and depth without taking my eyes off the fish.

I can imagine many other applications. One day I might give our 18-year-old station wagon one of those nice sonar-equipped backup cameras that some new cars come with. I could even add my own layer of visual clutter to the family's TV viewing. It could be great fun, for example, to have a set that periodically displays messages like "Do not eat another chip!" or "Why don't you ever read a book?"

—David Schneider

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tools & toys

LIGHT SCREENS: New technology from 3M [left] adds an extra layer to displays but eliminates bulky side-lighting systems. Flexible glass from Corning [center] and Asahi [right] lowers manufacturing costs as well as weight.

PHOTOS, FROM LEFT: 3M; CORNING; ALFRED POOR

LCDs' BRIGHT FUTURE

Three advances are making TVs lighter and cheaper

The LCD is an antique technology by almost any measure. Liquid crystal material was first discovered in Austria in 1888, about 10 years before the invention of the cathode-ray tube. The first liquid crystal displays—in wristwatches—go back to the early 1970s. Today, we can make LCD flat-panel displays with diagonals of 70 inches or more. And yet we've hardly scratched the surface, so to speak, of what the technology can do.

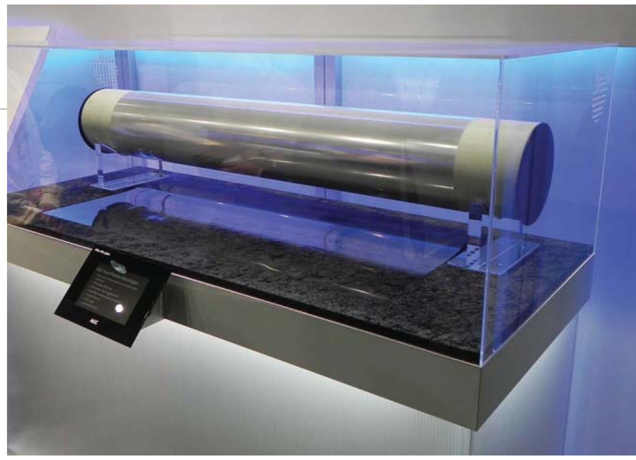
Perhaps the hottest topic in large-panel displays is stereoscopic technology, commonly referred to as 3-D. Certainly, 3-D has been a hit in movie theaters, and because a Hollywood feature nowadays can make as much money on the small screen as the big one, the studios are eager to ride that success directly into the living room. HDTV makers are doing their best to accommodate them.

It's not that difficult to create a time-multiplexed stereoscopic display with LCD panels—the main requirement is the refresh rate, and many TVs already produce images at the necessary 120 hertz. Active-shutter glasses block the image for one eye and then the other in rapid sequence, so when the panel flashes left and right images, the viewer's brain will combine them into a 3-D scene. This has been the standard approach for 3-D TVs, but the active glasses have been expensive (US $100 or more per pair) and inconvenient when you have a bunch of friends over to watch *Avatar*.

This year's disruptive technology is a Film Patterned Retarder (FPR) developed by LG Display. FPR uses alternating horizontal stripes of polarizing film, with each stripe as tall as one row of pixels. This creates two interlaced images with opposite polarization, which can be viewed with the same inexpensive passive glasses used in cinemas. LG has managed to include this additional layer and align it precisely with the LCD panel and still competitively price its FPR television sets. (LG supplies the same panels to Vizio and presumably to Westinghouse Digital as well for some of their televisions.)

Prices for both active-glass technology and LG's FPR approach are falling rapidly, and manufacturers are quickly expanding 3-D support throughout their product lines, though not without some contention—the one is criticized for the expensive and heavy glasses, the other for cutting the display resolution in half; with FPR, each eye sees only half the pixels on the screen. Fortunately, a solution to this dilemma may be coming soon.

Samsung and RealD recently demonstrated a new approach that seems to offer the best of the active and



passive designs. A second LCD panel is incorporated in the display with the sole function of reversing the polarization of the entire screen, to time-multiplex the left and right images. As a result, viewers can use inexpensive passive glasses to view the display, yet still receive the full resolution to each eye. The extra LCD layer may seem an expensive addition, but it can have a much simpler structure and does not need subpixels, color filters, or many of the other light-management films required by a traditional LCD HDTV. So it remains to be seen whether it can be produced at a competitive price.

While Samsung is adding layers, other manufacturers are looking to make LCD TVs thinner. When you ship millions of large flat-panel televisions around the world, small reductions in weight can add up to large savings in material and freight costs. Several new developments promise major gains—that is, losses—in weight.

One of the most interesting is roll-to-roll glass. Glass, with its superior uniformity and durability, has always been the substrate of preference for LCD panels. Today's batch processing uses rectangular sheets of "mother glass" substrates that go through various processing steps and then are cut into separate display panels. The largest substrates, used in Sharp's Gen 10 plant, are 2.88 by 3.13 meters. That's more than twice the area of a king-size mattress, but we may be approaching the limits of efficient batch processing of LCD panels.

Corning and Asahi Glass Co. have now separately developed 0.1-millimeter-thick glass, which is about as thick as a sheet of copy paper. Corning uses a proprietary fusion glass technology, while Asahi uses a more traditional float technique (in which liquid glass is poured onto a bath of molten metal). In either case, the resulting glass is so thin it can be rolled onto spools.

Spools of thinner glass make it possible to use roll-to-roll processing for some or all of the LCD production steps, thereby lowering costs. And with glass one-seventh the thickness of the 0.7-mm sheets in current panels, a typical 55-inch LCD TV would lose about 430 grams.

3M is taking a different approach to shedding weight—it has eliminated many of the materials required for LED edge lighting. Many manufacturers make their flat-panel televisions thinner by putting arrays of LEDs along the edge of the panel as backlights. But to distribute the light from the edges uniformly across the entire panel, a panoply of light-management materials are needed: light guides, collimating films, light-recovery layers, and diffusers. The new 3M Air Guide technology combines all these functions in a single film that is applied directly to the back of the LCD panel. An air cavity between the panel and the back of the display is backed by a reflective layer.

This new design can reportedly eliminate 90 percent of the light-management materials, resulting in a 3-kilogram reduction for a 55-inch LCD HDTV. It has other benefits as well. The light mixing is more effective, so fewer LEDs are needed—they can be spaced as far apart as 60 mm instead of the standard 12 mm without creating hot spots in the backlight. Or manufacturers can choose to use the normal spacing and thus increase reliability, because the failure of an individual LED won't affect the backlight uniformity. The mixing also makes it possible to achieve a desired color temperature with less expensive LEDs.

Because of these and other developments, LCD technology should maintain its dominant role in the display industry for years to come. For example, Sharp has announced that it is switching one of the production lines at its Gen 8 Kameyama LCD plant to use metal oxide for the active backplane instead of the traditional amorphous silicon (a-Si) layer. Sharp will use an indium gallium zinc oxide material that outperforms a-Si and approaches the lower power consumption and high resolution offered by polycrystalline silicon backplanes.

Other large-format display technologies, such as organic LEDs, will face increasingly tough competition, as LCD makers continue to increase performance while wringing out costs.

—Alfred Poor

profile

CAMERON COHEN: CHILD PROGRAMMER AND PHILANTHROPIST

After bone-tumor surgery, he donated his app store revenue to help other ailing children

IF IT HADN'T been for a life-altering medical crisis, Cameron Cohen, 13, wouldn't have found his calling as a programmer. But it's what he did with his earnings that really defines him.

Two years ago, at age 11, Cohen underwent surgery to remove a bone tumor that kept him in the hospital for 10 days and his family on edge until they learned the tumor was benign. To pass the time during a nine-month recovery period in a hip-to-toe leg brace, Cohen taught himself the programming language Objective-C. With it, he created iSketch, an app that lets you draw pictures on your iPhone and upload or e-mail them. So far, the US $0.99 program has sold some 50 000 units.

"I'm terrible at drawing, but it's fun to draw on my iPhone," says Cohen. "The few free programs I could find were really bad, and the really good ones were $5 to $10. So I thought, 'Why not make a really good drawing app for a dollar, so a lot of people can buy it?' "

Cohen had been the IT guru for his elementary school teachers at the John Thomas Dye School in Los Angeles and attended summer camps for robotics and computer programming, but he had never tried programming for an iPhone. Stuck at home, he watched iTunes U lectures on programming taught by Stanford professors and read programming manuals and Apple tutorials. By the time his brace came off, in September 2009, he'd finished the app. It was accepted by Apple's App Store that November. (It's also available on iTunes.)

His parents were stunned. "We were just happy he'd found an interest that could divert his attention away from his predicament," says his father, Jeffrey, an attorney. "So when he finally said, 'Here's what I have. Can you help me test it?' we were blown away. And then, when it was approved by Apple and he wanted to help the hospital...we were incredibly proud of him."

Which brings us to the twist that sets Cohen apart. When an unexpected flurry of units sold, he donated $20 000 to the Chase Child Life Program at the Mattel Children's Hospital UCLA (which has a unit in Santa Monica, where he'd been hospitalized), so its staff could purchase MacBooks, iPads, iPods, and video games for teen and preteen patients to use during their stays. The gesture earned him appearances on CBS and ABC News, BBC Radio, and an article in *USA Today*.

APP ALTRUISM: Cameron Cohen's 2009 hospital stay led him to program a top-selling iPhone app and give away the earnings.
PHOTO: JUSTIN COHEN

"When I was in the hospital, I had my computer and iPod Touch to distract me," says Cohen. "But I saw so many other kids who didn't have these things and were just lying there. The last thing you want to do is think about what just happened or what kind of operation you have coming up. You want to be distracted. So when I saw money coming in from iSketch, I thought it was the perfect opportunity to give back."

"The technology has been a great distraction from the stress of surgery and hospital environment, like getting IVs," says Amy Bullock, the director of the Chase Child Life Program. "It's made [the children] more compliant with their medication and allows their parents to take a breather. Cameron is an extraordinary young man."

While Cohen slowly returns to sports, particularly tennis, he recently upgraded iSketch so that pictures can be uploaded directly to Twitter and Facebook. "I like creating Web applications instead of websites—things that people can use to make everyday tasks easier," he says. "I'm planning to learn a lot more programming languages, like Python and Ruby. If it wasn't for my illness, I might never have gotten superinterested in this or learned about this side of myself." —SUSAN KARLIN

More information about Cohen and his products is available at http://www.cccdevelopmentllc.com.

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technically speaking

BY PAUL McFEDRIES

ISTOCKPHOTO

Pancake People

I think we're producing a race of people who are paper-thin—almost pancake people—who cover a lot of territory.

—playwright Richard Foreman, 2003

A FUNNY THING happened on the road to having information at our fingertips: The Internet disappeared. We now spend so much time surfing, listening, viewing, messaging, gaming, and tweeting that the Internet has quietly but decisively inserted itself into every corner of our lives.

Instead of rattling noisily along the information superhighway, we now glide silently through cyberspace. Let's look at a few new words and phrases that describe some of the things we see along the way.

During your online forays, you've probably come across your share of **pancake people**, who read broadly, but without depth. Internet pundits once feared an almost opposite phenomenon, *cyberbalkanization*—the division of the Internet into narrowly focused groups of like-minded individuals who dislike or have little patience for outsiders. That process seems well under way, only now we see the term **filter bubble**. This refers to search results and recommendations that have been filtered to match your interests, thus preventing you from seeing contrary ideas. The phrase was coined by Eli Pariser, the president of MoveOn.org, who fears that rampant personalization is creating a "unique information ecosystem for every person."

Perhaps filter bubbles explain why the Internet has been a boon to the **zombie lie**, a false statement that keeps getting repeated no matter how often it's been refuted. Here in the United States, recent repeaters of undead facts include **birthers**, who believe that President Barack Obama was not born in the United States and is therefore ineligible to be president; **deathers**, who believe that health care reform will lead to more deaths, particularly among the elderly; and **truthers**, who believe that the government perpetrated or allowed the terrorist attacks of 11 September 2001.

What's fueling this self-delusion? Some say it's **disconfirmation bias**, which is the tendency to accept supportive evidence of a belief uncritically but to actively refute or discount evidence that challenges that belief. This is why the Web is home to all manner of **manufactroversies**, which are contrived or nonexistent controversies, fabricated by political ideologues or interest groups who use deception and specious arguments to make their cases. A similar species of online nonsense is the **nontroversy**, a false or nonexistent controversy. Either can be spawned by *astroturfing,* that is, the activities of fake grass-roots organizations (the name comes from a brand of artificial grass).

Moving from the political to the personal, have you ever seen someone who looks a lot like you? The online equivalent of your doppelgänger is the **Googleganger**, a person who has the same name as you and whose online references are mixed in with yours when you *egosurf,* that is, run a Google search on your own name. Hopefully, that person hasn't written any **death tweets**, such as the one written by comedian Chris King, who tweeted, "@whitehouse I am dying inside. And I am plainly stating to you that I am going to kill the president."

There's probably no quicker route than that to **twimmolation**, the self-destruction of a person's career or reputation by sending lewd or insensitive Twitter posts. Another surefire way to **twimmolate** is to indiscriminately tweet too-intimate photos of yourself (think **Weinergate**). Most such tweeters get themselves into trouble via the **DM fail**: putting "@" (to designate a public reply) instead of "D" (for a private direct message) at the beginning of a tweet.

There's also no shortage of online rabble-rousers, exemplified by the **griefer**, a member of a game or other online venue who intentionally and repeatedly harasses others. To the rescue sometimes come **digilantes**, people who use digital tools and techniques to avenge crimes.

So life online is populated with Googlegangers and griefers, deathers and digilantes, and pancake people trapped in filter bubbles. It actually feels a lot like life off-line, which should come as no surprise. After all, we have met the Internet, and it is us. ❏

RE-ENGINEERING AFGHANISTAN

The coalition has spent hundreds of millions trying to give Afghanistan electricity. Unfortunately, it made many of the mistakes it made in Iraq

BY GLENN ZORPETTE

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THE SUN IS POKING THROUGH MIST on a humid Wednesday morning in early April as we drive west through the city of Kandahar, in southern Afghanistan. The place doesn't look too bad, considering that just a couple of days ago rioters demolished stores and homes here after word got out that a minister in Florida had burned a Koran. In Kandahar alone 16 people were killed and 128 wounded.

Our destination is the only electrical substation within city limits, a creaky relic from the 1970s outfitted with Bulgarian switchgear and other electrical esoterica, including a 25-megavolt-ampere transformer that's so old it has to be hosed down on hot days to keep it from overheating. I'm traveling with Chief Warrant Officer 5 Thomas Black, the deputy commander of the U.S. Army Corps of Engineers task force headquartered at Kandahar Airfield, the huge coalition air base to the southeast. He wants to make some voltage measurements at the plant.

I'm tagging along because I am trying to determine whether the hundreds of millions of dollars committed to electrical equipment and construction and fuel have made any difference at all in the vast, chaotic, decadelong effort to weaken the Afghan insurgency, stabilize this notoriously failed state, and push it in the general direction of the 21st century.

Our group is traveling in three military vehicles called MRAPs (mine resistant ambush protected). The one we're in weighs about 16 tons and costs about US $500 000. We're rolling down Kandahar city's main road, a broad thoroughfare with a parklike median that's lush with flowers and trees. I stare out through one of the MRAP's tiny trapezoidal rear windows, as thick as a Dean Koontz novel.

For now, at least, the streets are calm. Small groups of men and boys sit in the median, tending the plants or talking in the late-morning languor. A smoky, musty smell hangs in the air. The street is lined with small, dusty, crumbling, cubelike, open-front sidewalk stores selling produce, meat, hardware, tires, bricks, poles and thatch, and other goods. During the drive I see goats, sheep, camels, donkeys, horses, and dogs. Outside the stores are men wearing loose Afghan *qmis* shirts and *shalwar* pants. Some men glare at us; most ignore us. Scattered groups of young boys throw rocks at us. The very few women out are in full burqas, gun-metal gray, a gaping mesh oval over the eyes and nose.

Kandahar is Afghanistan's second city, behind Kabul in the north. But where Kabul has nearly round-the-clock power now, Kandahar's 850 000 people have it only fitfully, about 40 megawatts at most. For comparison, NATO's airbase nearby, with about 30 000 people, has about 100 MW.

Kandahar is primitive by any standard, a backwater of a backwater. Afghanistan ranks in the bottom 10 percent of the world in electricity use per capita, according to the U.S. Central Intelligence Agency's *World Factbook*. And that deficiency is much more acute in the south than in the north. Most Kandaharis make do with 4 to 6 hours a day at most. The transmission and distribution systems throughout the south are frayed and dilapidated, spliced and respliced by hand so many times that the lines can now handle only about two-thirds of the current they could 25 years ago. Many feeders in the region experience multiple outages a day, typically because two lines have slapped together or because the current has arced or "flashed over" old and cracked insulators.

PREVIOUS PAGE: GLENN ZORPETTE; ABOVE: JORGE SILVA/REUTERS

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POWER PLOY: Afghanistan's lack of electricity is acute in the city of Kandahar, near which Canadian soldiers patrolled in November 2009 [opposite page]. A woman walks at night near a market in Kabul [top], which benefits from electrical interconnections to Afghanistan's northern neighbors. In the stalls of the markets in Kandahar city, such as this one [left], close to the governor's palace, gasoline-powered generators are a popular offering. In Kabul, a lineman [above] works on distribution lines.

CLOCKWISE FROM TOP: DIMA GAVRYSH/AP PHOTO; JERRY LAMPEN/REUTERS; GLENN ZORPETTE

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SPECIAL DELIVERY: Engineer Fazal Ahmad [foreground] and Chief Thomas Black inspect connectors on new electrical gear in a warehouse at the Shorandam Industrial Park, near the city of Kandahar. USAID's long-term plan for the Afghan electrical grid [right] includes a line [in orange] that will connect networks in the north and south for the first time.

Here in southern Afghanistan, the local linemen scramble up utility poles in baggy garb and sandals, without safety belts, rubber gloves, or any other protective gear. Only a small fraction of the workers can read, their boss will later tell me.

As they did in Iraq, the coalition forces in Afghanistan have spent or committed tens of billions of dollars to building and refurbishing infrastructure, including roads, schools, hospitals, and water systems. It is an enormous effort involving dozens of government agencies and hundreds of contractors. Among the government organizations, the U.S. Agency for International Development (USAID) is dominant, but the U.S. Army Corps of Engineers and other military organizations have big roles as well. The Asian Development Bank and the governments of India and Germany have also funded a few large projects.

Having spent an estimated $55 billion on Afghan reconstruction over the past decade, the U.S. government is the largest contributor by far. And, as in Iraq, much of that money has been wasted or badly spent, particularly in the electrical sector. The goals of reconstruction are pretty basic: to stimulate economic activity and create jobs; to make life more comfortable and secure; to give people a more attractive alternative to the typically medieval societies imposed by insurgents. And last, but certainly not least, to win the allegiance of citizens and build their confidence in fledgling government institutions and officials who are all too often bungling or corrupt. Or both.

"If you electrify a village, a carpenter can have power tools and work after the sun goes down," notes Thomas Barfield, a professor of anthropology at Boston University who specializes in Afghanistan and reconstruction. "Electricity transforms the way people live. Once they get a taste of electricity they can't help but wonder, 'Which political system is going to deliver these things to me?' The Taliban is going to deliver a 6th-century state, while NATO is offering a 21st-century state."

And yet in the electrical sector, especially, the attempts to modernize Afghanistan have been dismal, despite the fact that the agencies and many of the contractors involved have had years of reconstruction experience in Iraq.

Of the many reasons for the disappointing results, a few stand out. The standard contracting methodology used by U.S. government development agencies in Afghanistan does nothing to discourage overspending and inefficiency. In addition, Afghanistan has a long history of relying on foreign powers, often invading ones, for its major infrastructure. This reliance has fostered a culture of passivity and a crippling deficiency of homegrown engineering expertise.

In the electrical sector, however, these factors pale alongside a couple of others. The Afghan national electric utility is unable to collect enough revenue to sustain its own operations and it has trouble simply keeping records consistently. And one of the most serious problems, according to analysts, officials, and engineers interviewed in Afghanistan and the United States, is the incompetence of USAID, an independent U.S. government agency that receives guidance from the Secretary of State. It is the dominant development organiza-

MICHAEL BEEMAN/U.S. ARMY CORPS OF ENGINEERS

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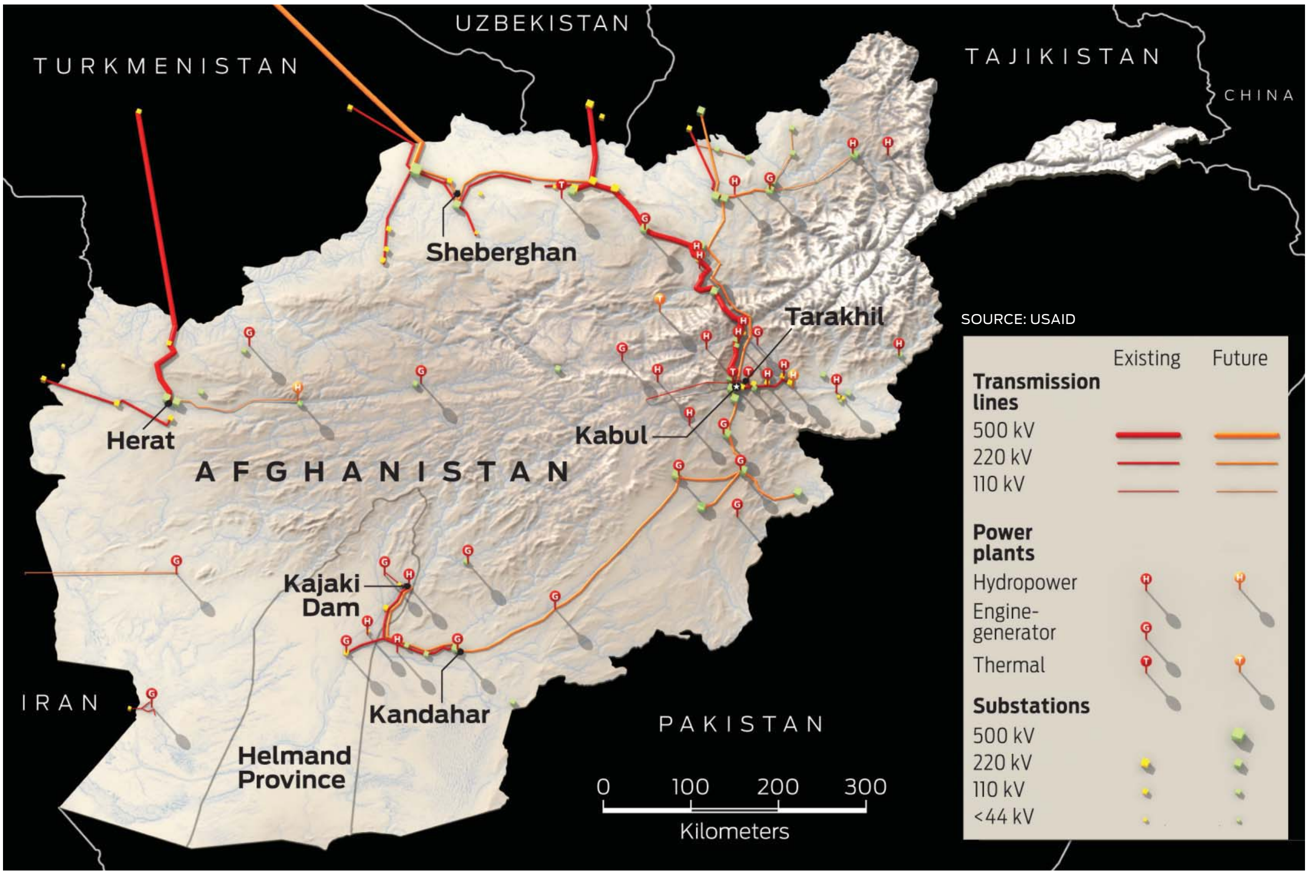

BRYAN CHRISTIE DESIGN

tion in Afghanistan, and it has, according to these observers and even its own internal documents, made major missteps in every significant electrical construction project it has undertaken in the country.

"USAID has grossly underperformed in electrical reconstruction," says Charles Tiefer, an attorney and contracting expert who serves on the Commission on Wartime Contracting, a panel appointed by the U.S. Congress to analyze why so much money was misspent in Afghanistan and Iraq.

"What you've got is an agency that has become a contract-management agency, and they're not even very good at that," adds Dov S. Zakheim, another Wartime Contracting commissioner. "They threw money at contracting with less-than-great results."

The Wartime Contracting commission released its final, 248-page report at the end of August. It concluded that between $31 billion and $60 billion of the approximately $206 billion spent on contracting in Iraq and Afghanistan was wasted, because of badly conceived projects, poor planning and oversight, and criminal behavior, such as fraud and corruption. (The $206 billion figure includes contracts for logistics and security, in addition to reconstruction.) The report also says that "money lost as a result of the inability to sustain projects could easily exceed the contract waste and fraud already incurred."

Regardless, USAID is plowing ahead. The agency recently embarked on a long-planned $1.2 billion project to give Afghanistan a modern national electrical grid. With U.S. and other NATO forces starting their drawdown from Afghanistan, the grid would be a superb legacy. But not much in the agency's record in Afghanistan suggests that the project will be completed competently and efficiently.

USAID's struggles prompt questions about what, exactly, diplomatic and military officials can take away from the Afghan reconstruction experience. In Afghanistan, as in Iraq, the coalition tested new and sometimes radical strategies in counterinsurgency, and through it all reconstruction was a cornerstone. A half dozen or more development agencies used scores of contractors and subcontractors to perform electrical and other work in Afghanistan and in Iraq, too. As the U.S. government itself has disclosed in thousands of pages of reports and analyses, far too little was achieved for the more than $100 billion spent reconstructing the two countries—even after taking into account the inevitable failures and frustrations of war-zone construction.

So, did reconstruction make a difference in the counterinsurgency? Was it worth the money and lives it cost?

WE ARRIVE at the Kandahar city substation, which is called Breshna Kot. There's a collection of diesel generators here, but none of them are running. I'm told that the utility has not been able to negotiate a contract for diesel fuel at acceptable terms. Apparently, the utility simply can't afford to pay what the suppliers charge for fuel. That's not much of a surprise; the Afghan national utility, Da Afghanistan Breshna Sherkat (DABS), is stunningly unprofitable. It charges about 6 to 10 Afghanis (about 12 to 20 U.S. cents) per kilowatt-hour, a third of what it would need simply to break even, NATO engineers tell me. And that's if most customers were actually paying for their electricity. Which they're not. At the moment, the World Bank and the U.S. government are covering the diesel fuel costs, which run well into the tens of millions of dollars a year.

Breshna Kot is what our MRAP crew is referring to as "semi-secure," so we have arrived in four MRAPs instead of three.

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IN ENEMY TERRITORY: The Kajaki hydroelectric plant, in Helmand province, generates up to 33 megawatts. Refurbishment of the plant has been slow because the area has been under Taliban control. In July, the U.S. Army Corps of Engineers finished installing a switching substation and other equipment near the plant [opposite page].

The MRAPs are left running, and we are told to leave our body armor on because the soldiers running security for our mission are skittish about the situation around us in the city. Chief Black and I are standing in the switchyard, our backs to the substation office. Besides the Bulgarian 25-MVA transformer in front of us, there are some vacuum disconnect switches, also Bulgarian. This gear connects several city feeders to an old and threadbare 110-kilovolt line that brings power from the hydro plants at the massive Kajaki Dam, 180 kilometers to the northwest, deep in Taliban country.

But right now there is no hum at all, which means there is no power coming from Kajaki.

Suddenly there is a loud *thunk*, and then another. Black smiles. The first *thunk* was the sound of the transformer being energized. The second was the substation's electrical bus being energized. Power is flowing again.

Now there's a faint hiss in the morning air. It comes from mild electrical arcs. It's the sound of decrepit insulators and incipient failure.

A rotund man with a flowing gray-and-white beard and a dazzling smile joins us. He is engineer Fazal Ahmad, the power director for Kandahar province for DABS. Ahmad explains that the power from Kajaki had been interrupted when the 110-kV line was damaged during fighting in Lashkar Gah, the capital of Helmand province.

We go into the substation building to look at the electrical bus, which interconnects the big transformer and also the now-dormant diesel generators to the lines that feed the city's seven electrical districts. "This is—what do you call it?—magic," Ahmad tells me, his eyes twinkling. Normally, a substation bus is a continuous bar of copper, but this one is broken up into five removable pieces, which allows Ahmad's technicians to channel power from either the Kajaki line or from the diesels to several of the city's feeders. This odd mix-and-match arrangement is necessary in order to keep the two power sources separate. They aren't in synchrony, so connecting them could blow the disconnect switches. Or worse.

The exposed copper bars, at 20 000 volts, give Black the heebie-jeebies. He emphatically warns Ahmad and me to be careful as we go behind the big metal cabinets to look at the baroque and dusty apparatus that makes the magic. I am struck by the resourcefulness of it, even if it's all kind of harebrained and rickety. "One substation is divided into five parts," Ahmad explains. "That's why I call it magic."

He wants to tell me one other thing, too. Out in the yard, beaming, he points to the big 25-MVA transformer. The transmission system linking the substation to Kajaki, including that transformer and the line itself, was engineered and installed by Afghans 15 years ago during the Taliban period, he wants me to know. His pride is touching.

As well it may be. Hardly any heavy-electrical installations in the country have been engineered by Afghans. During a briefing at the Army Corps of Engineers compound at Kandahar Airfield, I'd asked Black to tell me who is doing the engineering on the scores of electrical projects scattered around the country. "We're doing it," he answered, and by "we" he meant NATO—including the Corps of Engineers and various Western electrical contracting firms. "Before us, the Russians were doing it," he added. And, I later learned, before the Russians, the Americans were doing it. As near as I can tell, Ahmad is the only degreed electrical engineer working for DABS in all of southern Afghanistan.

PETTY OFFICER 2ND CLASS JONATHAN CHANDLER (2)

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A little after 11:00 a.m. a member of our security detail approaches Black. It seems an improvised explosive device has been found in the road about 2 kilometers away. The security guys urge us to wrap up our business and get out of there. But no visit in Afghanistan is complete without tea, so we repair to Ahmad's little office. There are bright turquoise walls, folding chairs, a scarred Formica coffee table, a desk heaped with blueprints and reports, and a neatly made bed in the corner for nights when it's not safe to travel. As the security team stalks around outside, we sip tea and eat sugary dates and cookies.

ELECTRICALLY, AFGHANISTAN is not one country but many. Individual feeders within a district, particularly in the south, are typically not synchronized with each other, let alone larger grids. Even if the country did have large-scale grids, power-sharing agreements would probably be difficult because of the lack of trust that often strains relationships among different ethnic groups, tribes, and provinces.

The reason why Kabul and the surrounding areas have round-the-clock electricity is that the northern provinces benefit from transmission-line connections to Afghanistan's northern neighbors: Turkmenistan and Uzbekistan (and soon Tajikistan). Those central Asian countries have a surfeit of electricity from massive hydro plants built by the Soviets decades ago. But there are no connections between Afghanistan's northern power grids and those in the south, so any surpluses of power in the north can't be shared.

What the south has, first and foremost, is the hydroelectric plant at the Kajaki Dam, which is sizable but decrepit. There is also a collection of smaller hydro plants and a smattering of diesel-fueled plants—including two brand-new ones just installed by the Corps of Engineers. These two plants, which flank Kandahar city, are each 10 MW. They were built as part of a $94 million contract that also covers one year of fuel and operation and maintenance expenses. The tiny, very fortunate minority of Kandahar residents who happen to live along one of the distribution feeders from either of these plants have electric power pretty much all the time. Anywhere else in the city, you can count on perhaps 6 hours of electricity a day at most.

It is impossible to understand the unfulfilled promise of electrification in southern Afghanistan without an appreciation of the tortuous and improbable history of the Kajaki hydroelectric plant. Built 36 years ago with funding from USAID, the plant was intended mostly to power Kandahar. But it hasn't really worked out that way. Kajaki is in Helmand province, adjacent to Kandahar province, and it generates as much as 33 MW, of which 7 to 10 MW typically end up in Kandahar city, according to Chief Black.

The rest is siphoned off in Helmand, in some places by taps placed by the Taliban. A report last year in *The Wall Street Journal* disclosed that in Taliban-controlled districts in Helmand, residents paid the Taliban directly for their electricity, and that much of the electricity was being used to pump water to irrigate opium poppies for the drug trade, which further benefited the Taliban.

The Kajaki Dam is so strategically important to Helmand and Kandahar that it was among the early targets bombed by U.S. warplanes as the war against the Taliban began in October 2001. The hydroelectric facility has two turbines, known as units 1 and 3, and space between them for a third unit, which would be known as unit 2. USAID kicked off the refurbishment of Kajaki in December 2003 by signing a contract with the Louis Berger Group, a U.S.-based contractor. Louis Berger then subcontracted with Voith Hydro to rehabilitate unit 1 and with a Chinese firm called China Machine-Building International Corp. to fix unit 3. CMIC was also engaged to build the turbine generator, transformers, and related gear for unit 2, which was to boost the output of Kajaki from 33 MW to 51.5 MW. CMIC had come to Kajaki during the Taliban years, when the Taliban had no idea how to operate and maintain it. [Answers submitted by the Louis Berger Group in response to written questions from *IEEE Spectrum* are available at http://spectrum.ieee.org/lbgq&a.]

In 2006 another U.S. contractor, Black & Veatch Corp., entered the picture. It joined forces with Louis Berger, and USAID awarded this Joint Venture, as it was known, a $1.4 billion contract for work in Afghanistan, including the ongoing restoration of Kajaki. Meanwhile, the Taliban was strengthening its grip on the area around Kajaki, with frequent rocket attacks on the site all through the summer of 2006.

In 2008 CMIC finished building the equipment for unit 2, and that gear, weighing 220 metric tons, was delivered to Kajaki in a legendary operation code-named Eagle's Summit. The area around the dam was under Taliban control, and the equipment was too heavy to fly in by helicopter. So to get the gear from Kandahar Airfield to the dam, 60 British officers spent four months devising a daring land operation that was later declared the largest logistical mission since World War II.

The mission, which involved some 4500 soldiers, began in late August with heavy bombing of Taliban positions and raids by U.S. and British special forces on Taliban-held villages along the Helmand River. On 27 August, a 100-vehicle convoy including the trucks carrying the gear set out from Kandahar and drove into the desert, usually going just a few kilometers per hour. Well ahead of the convoy was another, "dummy" convoy of about 40 Danish vehicles that took the main road near the dam, drawing fire and diverting attention from the real convoy. Bomb-disposal teams cleared scores of improvised explosive devices along the route, including 11 in a single short stretch of road not far from the dam. The convoy transporting the massive electrical gear, which was hidden in multiple shipping containers covered with posters emblazoned with quotes from the Koran, took an alternate route through the mountains mapped earlier by a British reconnaissance team. At several points the convoys were rocketed or mortared, but on 2 September, the trucks rolled into the yard at the dam with the equipment undamaged. The casualty count for the 12-day mission was one coalition soldier dead and eight wounded and approximately 200 Taliban killed.

Sadly, the heavy-electrical gear still sits unused at Kajaki. One month after Eagle's Summit, the Chinese engineers from CMIC abruptly left Kajaki. According to a USAID official in Kabul, the engineers realized that the Taliban could not be cleared anytime soon from the area around the road leading to the plant, which meant there was no chance that NATO could deliver the hundreds of tons of concrete needed to install the third hydroturbine.

Why have two different government agencies hatched plans for two different diesel plants in the same location but with different contractors? Nobody seems to know

IT WOULD get worse for USAID. That autumn, while the Kajaki third-turbine project was falling apart, another huge project started floundering. It stemmed from a 2006 decision by the George W. Bush administration to build a power plant near Kabul as part of an effort to get President Hamid Karzai reelected. The idea that the plant would help Karzai was based on "a misreading of Afghan politics," says Boston University's Barfield. Nevertheless, the notion that the plant was vital to Karzai's success was so entrenched that Afghans started mocking it as "Karzai's winter coat."

In a war zone, the rules of logic sometimes seem suspended. Still, it is hard to understand why anyone thought it was a good idea to build, in a wretchedly poor country, a plant that would consume vast quantities of extraordinarily costly diesel fuel.

The diesel plant, which was built at a village northeast of Kabul called Tarakhil, quickly became emblematic of so much of what went wrong with reconstruction in the Iraq and Afghanistan wars. Much of the story has been documented by Pratap Chatterjee of the CorpWatch news service and Marisa Taylor of McClatchy Newspapers, among others.

As at Kajaki—and, indeed, for virtually every single one of USAID's electrical projects—the primary contractor was the Berger–Black & Veatch Joint Venture. In this alliance, Black & Veatch took the lead for the electrical projects. But in keeping with the U.S. government's modus operandi in Afghanistan (and before Afghanistan, in Iraq), the prime contractor for the project wouldn't actually build the plant. For that, it would hire a subcontractor. And whereas the Joint Venture enjoyed a "cost-plus" contract with USAID that guaranteed that all of its expenses would be covered and a profit paid on top of them, the subcontractor would be on a "firm-fixed price" contract that made no such guarantees (more on that later).

In May 2007, USAID had formally agreed with the government of Afghanistan to build the plant. And yet it wasn't until 14 June 2008—13 months after that agreement—that Black & Veatch signed a $62 million, firm-fixed price contract with Symbion Power to build the plant. Symbion, a U.S.-based electrical contractor, had compiled an impressive record in Iraq. The delay notwithstanding, USAID and Black & Veatch wanted the first 70 MW in place and operating within six months—by the end of December 2008—and the rest by April 2009. It was an aggressive if not unrealistic schedule.

Why did 13 months go by before Symbion got the subcontract? A 10 November 2009 audit by USAID's inspector general says that the plant was delayed because USAID had failed to secure the title to the land where it intended to build the plant. The title problem plagued the project intermittently from May 2007 until April 2008. The audit also faults USAID for writing a project plan so vague that it did not require the contractor to provide "specific deliverables with concrete delivery dates."

"Furthermore," the audit goes on, "the contract contained no consequences for failing to provide power by the specified milestone dates." It's a lapse that the USAID inspector general said was "compounded by the inexperience of the original mission personnel tasked with preparing the statement of work."

In response to a written question, USAID's press office blamed the delay in part on a local tribe. "In early spring of 2008... the local tribe [Hotak] disrupted the construction of the perimeter wall and it took GIRoA [Government of the Islamic Republic of Afghanistan] until April of that year to settle the issue." [You can read the full text of *Spectrum*'s questions, and USAID's answers, online at http://spectrum.ieee.org/usaidq&a.]

As construction proceeded in the fall of 2008, U.S. State Department officials in Kabul suddenly took an interest in the plant. The urgency increased when rumors began flying around the site that George W. Bush, who would make his final visit as president to Afghanistan that December, wanted to flip the switch at the inauguration of the Tarakhil plant.

But at Tarakhil, Symbion was grappling with several problems. The major ones were technical. First, despite USAID's policy of favoring U.S. manufacturers, the units had been manufactured in Germany. So all the piping, connectors, and other hardware that Symbion needed to install them were in metric units. That meant Symbion couldn't use imperial-unit hardware, which was cheaply and easily available in Pakistan or Dubai. Second—and worse—the construction drawings and plans of the power plant, supplied by Black & Veatch, were "riddled with errors," according to Symbion's CEO, Paul Hinks. Hinks also said that Black & Veatch has denied this allegation.

[*Spectrum* submitted 34 questions in writing to Black & Veatch's corporate communications department. In response, Black & Veatch sent a message declining to answer the questions, citing the stipulations of an ongoing arbitration case between the company and Symbion. You can read the full text of Black & Veatch's response at http://spectrum.ieee.org/b&vq&a. In the arbitration case, Symbion is seeking about $2 million from Black & Veatch for work on the

SAURABH DAS/AP PHOTO

POWER POLITICS: A Tarakhil worker inspects machinery at the plant northeast of Kabul during its completion in May 2010. The plant consists of 18 diesel-generator sets that together can generate 105 megawatts. It is seldom used because its operating costs, around 42 cents per kilowatt-hour, are at least six times the price of electricity available from other sources.

Tarakhil plant. At press time, the case was being arbitrated by the International Court of Arbitration of the International Chamber of Commerce.]

On 29 October 2008, with Tarakhil far from finished, it fell to Michael McGovern, the head of the Berger–Black & Veatch Joint Venture, to inform William Wood, the U.S. ambassador to Afghanistan, and Michael J. Yates, USAID's mission director in Afghanistan, that the Tarakhil project wouldn't achieve the 70-MW milestone by the end of the year. In mid-January came a flurry of telephone conversations and letters between USAID's Yates and Len C. Rodman, chairman of Black & Veatch Corp., the parent company of Black & Veatch Special Projects Corp., the subsidiary working for USAID. Copies of the letters and memoranda summarizing the telephone conversations were obtained under the Freedom of Information Act (FOIA). In one of them, a letter to Rodman dated 24 January 2009, Yates expresses USAID's "extreme dissatisfaction over (1) the delay in the construction of the 100 MW Kabul Power Plant project and (2) the inability of the Louis Berger Group–Black & Veatch Joint Venture (JV) to provide USAID with critical information in a timely manner."

The FOIA documents do not mention any private discussions that executives of Black & Veatch and Louis Berger might have had that January. But subsequent events suggest that Black & Veatch and Berger decided to assign the blame to Symbion. In a telephone conversation on 16 January 2009, summarized in the documents, Rodman addressed the delays at Tarakhil, telling Yates that "this situation is a massive failure of the subcontractor." It was an odd assertion, because on 15 October, one of Rodman's direct reports, Robert N. Bell, the senior vice president in charge of Black & Veatch's operations in Afghanistan, had sent an e-mail to Paul Hinks that said: "We all recognize what a great effort Symbion is making within their own management and are simply being hampered by the Afghan locals simply being unreliable and unwilling to work. All of us are 100 percent behind you and supportive of you and please do not ever think differently."

In January, Black & Veatch fired (and then rehired and demoted) the Tarakhil project manager, Jack Currie. Currie's replacement, newly arrived at Tarakhil, promptly concluded that Symbion had already been paid too much money and refused to pay Symbion for two invoices totaling $1.85 million.

This was strange, too, in view of the fact that the Berger–Black & Veatch Joint Venture had already approved the payments to Symbion, had already passed the costs on to USAID, and indeed had already received compensation for them from USAID, according to subsequent congressional testimony and the USAID inspector general's report of 10 November 2009. The same report faulted Black & Veatch for not returning the money, which then amounted to over $2 million with interest, to the U.S. government.

On 19 May, after working at Tarakhil for nearly five months without pay, Hinks says, Symbion sent a letter to the Joint Venture terminating the contract on the grounds of material breach. In June 2009, the dispute over the uncollected invoices went to arbitration before the International Court of Arbitration. As this article went to press, a decision was expected at the end of September.

The Tarakhil plant was finally completed, by Black & Veatch, on 31 May 2010. The 10 November 2009 audit by USAID's inspector general found that cost overruns on Tarakhil amounted to $39 million, mainly because of construction and other delays. It's unclear what the total expenditures for the plant were, but almost everyone agrees they added up to more than $300 million.

And since its completion a year and a half ago, the Tarakhil plant has hardly been used. The main reason is that its diesel fuel must be imported by truck at great cost. This past April the electricity generated at the Tarakhil plant cost around 42 cents per kilowatt-hour, according to engineers and development specialists interviewed in Afghanistan. For comparison, the electricity from Turkmenistan and Uzbekistan costs around 6 cents per kilowatt-hour, a USAID official said at a briefing in Washington, D.C., on 27 June.

In an interview with the Associated Press shortly after the Tarakhil project was completed, Mary Louise Vitelli, an energy and development specialist, referred to it as "sinful." Vitelli had worked with the World Bank as an advisor to the Afghan government when the plant was being built.

Who is to blame for the idea of building this ill-conceived and absurdly oversize diesel plant in the first place? Though the Bush administration first proposed the plant, Black & Veatch seized on the idea and kept it alive. "Black & Veatch were the ones that identified the need for the Tarakhil diesel plant," a provincial reconstruction officer wrote in a letter to *Spectrum*. "Their power flow studies clearly indicated that the imported power from the 'stans to the north would be insufficient and not available in a timely fashion. Turns out the imported power arrived prior to diesel plant operations such that the diesel plant was obsolete before it even started."

In other words, Black & Veatch, a contractor that stood to make (as it turned out) roughly $25 million by building a huge diesel power plant, was the very same organization that also "proved" that the plant was necessary. USAID did not perform or commission any analysis to try to determine independently whether the mammoth plant was actually needed.

In its response to a question from *Spectrum*, USAID's press office wrote that "the plant has since proven its worth." As evidence, the response goes on to cite a May 2010 "rock slide [that] interrupted the flow of imported power from Central Asia to Kabul....[T]he Tarakhil plant was run to seamlessly fill the gap in supplies in a way that few if any consumers in Kabul even knew that the NEPS [North East Power System] line had been damaged."

USAID's figures do indeed show that on 17 May 2010, the Tarakhil plant generated 437.0 megawatt-hours—far above its typical daily output of 0 MWh. That figure means that if the plant was running at full capacity, it ran for about 4 hours that day. The avoidance of inconvenience to the residents of Kabul is certainly laudable. But does it even begin to justify an expenditure of $300 million? You decide.

You can't read the story of Tarakhil and conclude that USAID, its State Department overseers, and other U.S. government agencies learned anything significant from the many mistakes made in the Iraq reconstruction effort, even though those mistakes were documented in thousands of pages of U.S. government reports.

First, Tarakhil was a politically motivated project from the start. In the rush to get the plant done and help Karzai win reelection, common sense seems to have been cast aside. In his report on the Tarakhil project, the USAID inspector general wrote, "Mission officials commented that they had been under extreme political pressure to deliver a specified amount of additional power before the Afghan elections in the winter of 2008–2009."

Similarly, in Iraq in 2003, the State Department and the U.S. military embarked on a massive, accelerated program that resulted in the installation of dozens of generators all over Iraq—plants that, like Tarakhil in Afghanistan, have been for the most part seldom used. The program that built those plants had been driven primarily by political circumstances rather than engineering and logistical realities. The State and Defense departments in 2003 were struggling to boost Iraqi generating capacity as quickly as possible, to help build confidence in Iraq's fledgling and struggling governmental institutions. That urgency led to the decision to put in dozens of combustion-turbine generators, which could be installed relatively quickly but worked best with a fuel—natural gas—largely unavailable in Iraq. They also required maintenance expertise that no Iraqis had.

By late 2005, it was clear that the combustion-turbine idea in Iraq was a bad one and that a much smarter plan would have been to install more of what the Iraqi engineers and technicians were comfortable with: steam-thermal generators [see "Re-engineering Iraq," *IEEE Spectrum*, February 2006]. And yet in late 2006—a full year after the combustion-turbine plan was clearly starting to come unraveled in Iraq—USAID and the State Department were making exactly the same mistake in Afghanistan. They were embarking on a project to install a plant whose diesel fuel would have to be imported, at great cost. In one of the world's poorest countries, they intended to build a massive facility whose operating costs wouldn't make sense even in Chicago or Frankfurt.

Had any development officials at USAID and State bothered to heed the lessons of Iraq, a better plan would have been obvious. It would have been based on the fuels and resources available in Afghanistan and the technologies that the Afghans had some experience with. The resulting plan would have relied on hydropower supplemented with some natural-gas-fired combustion turbines.

Afghanistan is a mountainous country with enormous hydroelectric potential—an estimated 23 000 MW, according to the country's Ministry of Energy and Water. Indeed, a parallel but smaller reconstruction effort in Afghanistan, run by military officials and financed with funds from the U.S. Commanders' Emergency Response Program, has installed or repaired dozens of "micro" and "mini" hydroelectric plants. The results with these small facilities have been excellent, according to David Westphalen, the Australian colonel who is the chief engineer of the NATO force in Afghanistan and who spoke with *Spectrum* at the NATO Afghanistan headquarters near Kabul International Airport.

"It's about building for what the locals can deal with and use," said Westphalen. "We go for things that are easy to maintain."

The diesel plants, on the other hand, with their ultrahigh operating expenses, will certainly be abandoned the moment NATO forces leave. So why did coalition forces spend hundreds of millions of dollars on them? Because they wanted electricity fast, to stabilize population centers as part of their counterinsurgency strategy, and hydro plants can't be built fast.

Even so, there were quick-turnaround options other than diesel. A patchwork of gas fields near a village called Sheberghan, in northwest Afghanistan, contains an estimated 120 billion cubic meters of natural gas—enough to fuel generation to the tune of hundreds of megawatts for decades. In February 2008, the Berger–Black & Veatch Joint Venture began working on a USAID-funded project to "design and support the development" of the Sheberghan gas fields to provide power to Kabul. A year into the project, however, USAID rated its satisfaction with the Joint Venture's work: It gave the organization a "zero" rating, on a scale of zero to five. The rebuke was disclosed this past February at a hearing in Washington of the Congressional Commission on Wartime Contracting.

A few months later, on 1 June 2009, USAID killed the project, after issuing many memos complaining bitterly about the Joint Venture's lack of progress. The termination came a month after the project was supposed to have been completed. Very little had been accomplished. But $7.1 million of the project's total estimated cost of $11.9 million had been spent.

In February 2008, before construction at Tarakhil got under way and before Symbion fell out with Black & Veatch, Symbion CEO Hinks threw a party at the Heetal Plaza Hotel in Kabul. At the party, Hinks was approached by Jack Whippen, the head of Black & Veatch's organization in Afghanistan. Hinks says that Whippen told him that he, Whippen, would soon ask Hinks to submit an "expression of interest" to bid on a huge project to refurbish and upgrade the main electrical transmission system in southern Afghanistan.

At the time, Black & Veatch was under pressure from USAID to get more bidders for projects. So Whippen's disclosure didn't surprise Hinks. But what Whippen said next sure did: "We both know you can't do this job" is how Hinks remembers it. To Hinks, the message was clear: Whippen did not want him to actually submit the expression of interest.

But the job was precisely the kind at which Symbion excelled. The project was part of an initiative referred to loosely as the Southeastern Power System, or SEPS. It involved repairing and replacing as necessary the 110-kV transmission line running from the Kajaki hydroelectric plant to Kandahar and other sites. Before he came to Afghanistan, Hinks had managed work in Iraq that fulfilled the requirements of 15 contracts that together resulted in the installation of more than 1000 km of transmission lines and 12 substations. The work included a line through Al Anbar province at the height of the often insanely violent insurgency there.

If there had been an attempt to dissuade a qualified and responsible bidder from bidding on a government contract, it would have raised all sorts of red flags. [Messages sent to Whippen's e-mail address were not returned. Black & Veatch declined to make Whippen and other executives available to *Spectrum* for interviews.]

When the time came, Hinks wasn't deterred. "I thought, 'To hell with it. We're gonna bid,' " he recalls. He responded with an expression of interest, the first step in a bid. In the end, none of it mattered, because in the summer of 2008 Black & Veatch scrapped the bids without explanation.

Not long after, Whippen suggested Hinks talk to Haidar Barak, the CEO of the Afghan Electrical Power Corp. (AEPC), an Afghan-Canadian joint venture. "He [Whippen] drove us in AEPC's direction," Hinks says. Then, on 24 August 2008, Black & Veatch again put SEPS out for bids. Hinks and Barak agreed to form a joint venture to bid on the SEPS project. In the hectic weeks leading up to the final bid, as Hinks was fretting about being underbid by a potential competitor from Turkey, Barak suggested that they add at least $5 million to their $105 million bid. Stunned, Hinks asked why. In an e-mail response, Barak concluded: "I hope we are not leaving money on the table." Hinks, nonplussed, refused to increase the bid.

Weeks later, the odd suggestion started to make sense to Hinks when he learned that the Symbion-AEPC bid was the only one submitted for the project. Had Barak been told that there were no other bidders for the SEPS contract? USAID's own inspector general issues a handbook for contractors that warns explicitly about such a scenario.

Reached at his office in Kabul, Barak denied he had any such inside information. He had "no idea what he [Hinks] is referring to," he said. Then he added that "we had many, many phone conversations about price going up and price going down....It's a normal course of business in bid preparation to go up and down in your suggested price."

One year into the Sheberghan gas-field study, USAID rated its satisfaction with the Joint Venture's work: It gave the organization a "zero" rating, on a scale of zero to five

Later, Hinks and Barak met with Whippen and three USAID officials in Kabul about the SEPS project. "Out of the blue," Hinks says, Whippen suggested that they build a 220-kV line rather than rebuild the existing 110-kV line between Kajaki and Kandahar, which was what the contract specified. Hinks immediately realized it would add greatly to the cost and duration of the project and advised against it. "It made no sense," he says of the 220-kV idea.

Despite all the maneuvering, Black & Veatch did not issue a subcontract for SEPS. The "whole thing fizzled out" by mid-2009, Hinks says.

After hearing nothing about SEPS for months, Hinks wrote to Karl Eikenberry, who had been recently appointed U.S. ambassador to Afghanistan, urging him to reconsider and restart the project. Eikenberry passed the message to William M. Frej, USAID's mission director in Afghanistan, who in an e-mail to Hinks dated 29 January 2010 said that the SEPS project was "a high priority" and that as soon as the security situation around Kajaki improved, "the United States Agency for International Development will contract services for this project through its normal full and open procurement

UNDER GUARD AND OVERPRICED: The Tarakhil power plant cost more than US $300 million, of which $39 million was wasted, according to U.S. investigators.

SAURABH DAS/AP PHOTO

procedures." Frej repeated the pledge in another e-mail to Hinks on 2 February.

It turned out to be a hollow promise. Subsequent e-mails from Hinks prompted either no response or one from a low-level bureaucrat at USAID. Finally, in December 2010, USAID disclosed its intention to "sole source," to Black & Veatch, the entire $266 million contract for the SEPS initiatives (which USAID was now calling the Kandahar Helmand Power Project). Frej's assurances notwithstanding, there was no competitive bidding at all. In choosing Black & Veatch, USAID bypassed not just Symbion but also several other qualified contractors to select a company that the agency had excoriated in dozens of memos for its performance on the Tarakhil plant, the Sheberghan gas-field study, and the Kajaki hydroelectric facility.

(When USAID disclosed the contract for the Kandahar Helmand Power Project, Louis Berger was not mentioned. On 5 November 2010, after an investigation by the U.S. Department of Justice into fraudulent overbilling for projects outside of Afghanistan, Berger agreed to pay $69 million to settle a combination of criminal penalties and the findings of a civil investigation.)

In its responses to *Spectrum*'s questions, the USAID press office said that Black & Veatch was chosen mainly for expediency. It wrote: "[I]n this case, the usual bid process would have taken six to nine months"—more time than the agency could spare. "Black & Veatch was already mobilized within the theater of operations. Mobilizing a contractor not in the region under these circumstances would have resulted in significant delays."

The rationale doesn't make sense. The SEPS project was formally described in February 2008. Over the next two and a half years, USAID's contractor, Black & Veatch, issued and then abandoned or failed to act on requests for proposals for the project, typically without notice or explanation. And mobilizing a different contractor to take over SEPS could have been done in a few weeks, according to military engineers who have supervised large projects in Afghanistan.

IN RELYING on a single contractor for all its significant electrical work, USAID has managed to introduce a new wrinkle to war-zone reconstruction—one that was absent from Iraq, despite all of its woes. But this problem has just added to the larger morass, because essentially all the major problems in Iraq seem to have been transferred to Afghanistan.

The most fundamental of these is the use of cost-plus contracts. For any project it wants done, USAID hires a contractor, which is awarded a cost-plus contract. The contractor in turn hires subcontractors, which may also hire subcontractors. All of those "subs" operate under firm-fixed price contracts. "Some contracts have so many subs that by the time the funding reaches the sub-sub-sub contractor, there isn't enough $$ left to actually pay for what work is required," the provincial reconstruction officer wrote to *Spectrum*.

But never mind that for now. The basic problem is at the top: "In effect, USAID depends on contractors to help it with contractors," says Tiefer, the attorney and Wartime Contracting commissioner.

"USAID lets contracts which it essentially doesn't have the capacity to supervise or even to understand," adds Boston University's Barfield.

Under a cost-plus contract, the prime contractor keeps tabs on all of its expenses for everything associated with the project and bills the government agency for those expenses. In addition, the contractor is given a margin—typically 8 percent—as profit. The contract may also specify bonuses for goals; for example, if all the deadlines are met, the profit might be greater than 8 percent.

The problem with this setup is obvious: The more a contractor spends, the more money it makes as "profit." Cost-plus contracting was used in Iraq and was harshly criticized in at least half a dozen government reports.

A firm-fixed price contract, on the other hand, is what it sounds like: The subcontractor agrees to accomplish a task by a certain date and for a certain fixed sum. If the company encounters major and unforeseen problems, renegotiation is possible, but there are no guarantees that the company will get any financial concessions.

Prime contractors have argued that the vagaries and exigencies of war-zone reconstruction make cost-plus contracts a necessity. But that argument fails to account for the scores of subcontractors that have managed, in the face of the very same vagaries and exigencies, to stay in business under fixed-price contracts.

On a humid afternoon in April, I visit the Shorandam Industrial Park, east of Kandahar city. More than five years ago, a contractor hired by USAID tried to install ten 660-kW diesel engine-generators here. But the agency got into a dispute with the contractor and later claimed that some of the engine-generator sets were damaged by the blast of an improvised explosive device. The units went into storage, but now USAID has hired another firm—Black & Veatch, as it happens—to install them.

A U.S. military engineer shows me the 10 concrete pads, one for each generator, that USAID's original contractor had installed. The pads are laid out in a line with about 2 meters of separation between pads. Given the local climate, the engineer tells me with a shake of his head, the spacing between the pads should be at least twice that, to ensure enough airflow for adequate cooling.

Four months later, in early August, I get word from Kandahar that Black & Veatch has at last installed the diesel generators—on the very same closely spaced concrete pads that had been laid out by USAID's previous contractor.

There's another, brand-new diesel-engine facility here; it is one of the 10-MW plants put in recently by the Army Corps of Engineers. The Corps's contractor, IAP Worldwide Services, needed just four months to install it. I'm impressed but also puzzled. Why have two different U.S. government agencies hatched plans for two different diesel generating facilities in the same location but with different transformers, switches, contractors, and manufacturers? Nobody seems to know.

The day before, a NATO development official handed me a confidential document spelling out USAID's intention to put DABS, the Afghan utility, in charge of not only the huge SEPS effort but also NEPS, the parallel and similarly mammoth enterprise in the north. The utility would, at least nominally, control $906 million of the $1.2 billion budget for the projects. According to the document, USAID would act as a sort of supervisor and intermediary between DABS and the Afghan Ministry of Finance.

POST YOUR COMMENTS *online at* http://spectrum.ieee.org/afghan1011

I'm stunned. Nothing I've seen so far suggests that DABS is anywhere near capable of managing the work of dozens of contractors and subcontractors on a series of huge and complicated infrastructure projects. Over the next several days, I speak with half a dozen development experts not affiliated with USAID, and all of them think it is a terrible idea. "It's almost like we're setting them [DABS] up for failure," one of them says.

I ask the NATO official why USAID wants to give DABS more control, and the answer is, in a word, politics. The agency is under pressure from its State Department overseers to show evidence of progress before the troop pullouts are well under way. But at the same time, the administration of Afghan president Hamid Karzai has been insisting that it be put in charge of more of the budget and agenda for reconstruction. (Never mind that of the 20 to 25 percent of development funds given to the Karzai administration to manage last year, it was able to spend only about a third, according to the NATO official.) Giving DABS and the Afghan Finance Ministry control of the huge NEPS/SEPS project would seem to accommodate both parties.

But Ahmad, who is DABS's only degreed electrical engineer in Kandahar province, is skeptical of the plan. As a senior executive of DABS and power director for this part of Afghanistan, Ahmad would be in the thick of any supervisory role DABS would have of the NEPS/SEPS effort. So in a meeting here at Shorandam, I ask him about NEPS and SEPS. He shakes his head dismissively and says it would take more than 10 years to complete these huge initiatives—too long to help Afghanistan in its current precarious condition.

He'd much rather see the money and effort go toward building more small hydroelectric plants. "What we need are micro-stations, to have our own power," he says, before reeling off a list of rivers and locations in Afghanistan that he feels are ripe for hydroelectric development.

As a reporter, I have over the years dug up the occasional isolated and carefully concealed incident suggesting incompetence or wrongdoing. But I've never reported on anything quite like USAID in Afghanistan, where the examples of ineptitude, poor decisions, and apparent impropriety sometimes seemed to come swarming at me like targets in a video game.

And the problems and failures aren't limited to USAID and to electricity. "The problems are significant; widespread; and, in my opinion, insurmountable given any agency that currently exists," wrote the provincial reconstruction officer in his letter to *Spectrum*. "I went, I saw," he added. "Every day I was there, the problem became more complex—like the insect in the spider web—turn and twist, looking for a way out, only to make matters worse."

All the while, year after year, the Bush and then Obama administrations let it go on. "I'm a little surprised," says Boston University's Barfield. "Why hasn't anybody in the White House sorted this out?" By now, he says, somebody should have given USAID an ultimatum: "If you can't do it, we'll find somebody who can." But he doesn't expect it to happen. "I don't see that kind of political will," he says.

Does it matter? Yes, it does. Put aside for the moment the $53 billion (including security costs) that the United States made available to reconstruct Iraq and the $55 billion it has spent on Afghanistan. Consider instead the hundreds of people who died trying to bring modern infrastructure to the people of those two countries, according to the website Icasualties.org. It compounds the tragedy that some of them died in the service of something as poorly run as USAID's projects in those countries.

Something else perished as well: A rare and potentially momentous opportunity was squandered. Counterinsurgency is complicated and messy and hard, as I was told over and over again in Afghanistan. As theories about counterinsurgency were endlessly debated and tried out in Iraq and Afghanistan, some unconventional ideas were proposed and put to the test. None was more radical than the proposition that helping ordinary people become more comfortable and productive could be as valuable, in military terms, as killing bad guys.

Was that proposition right? We will never know for sure. ❑

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By BURAK OZPINECI & LEON TOLBERT

SMALLER, FASTER, TOUGHER

Silicon carbide will soon supplant silicon in hybrid cars and the electric grid

SOME TECHNOLOGICAL REVOLUTIONS ARE FLASHY, and some are almost invisible. We're quite familiar with the flashy ones; they've given us powerful computers we can hold in the palms of our hands, devices that can pinpoint our locations by way of orbiting satellites, and the ability to bank and shop without leaving our homes. But none of these innovations would have occurred without the technology that delivers power to them. Over the last half century, a more subtle revolution in power electronics has provided us with compact and efficient semiconductor devices that can manipulate, regulate, and convert electricity from one form to another.

ANATOMY BLUE

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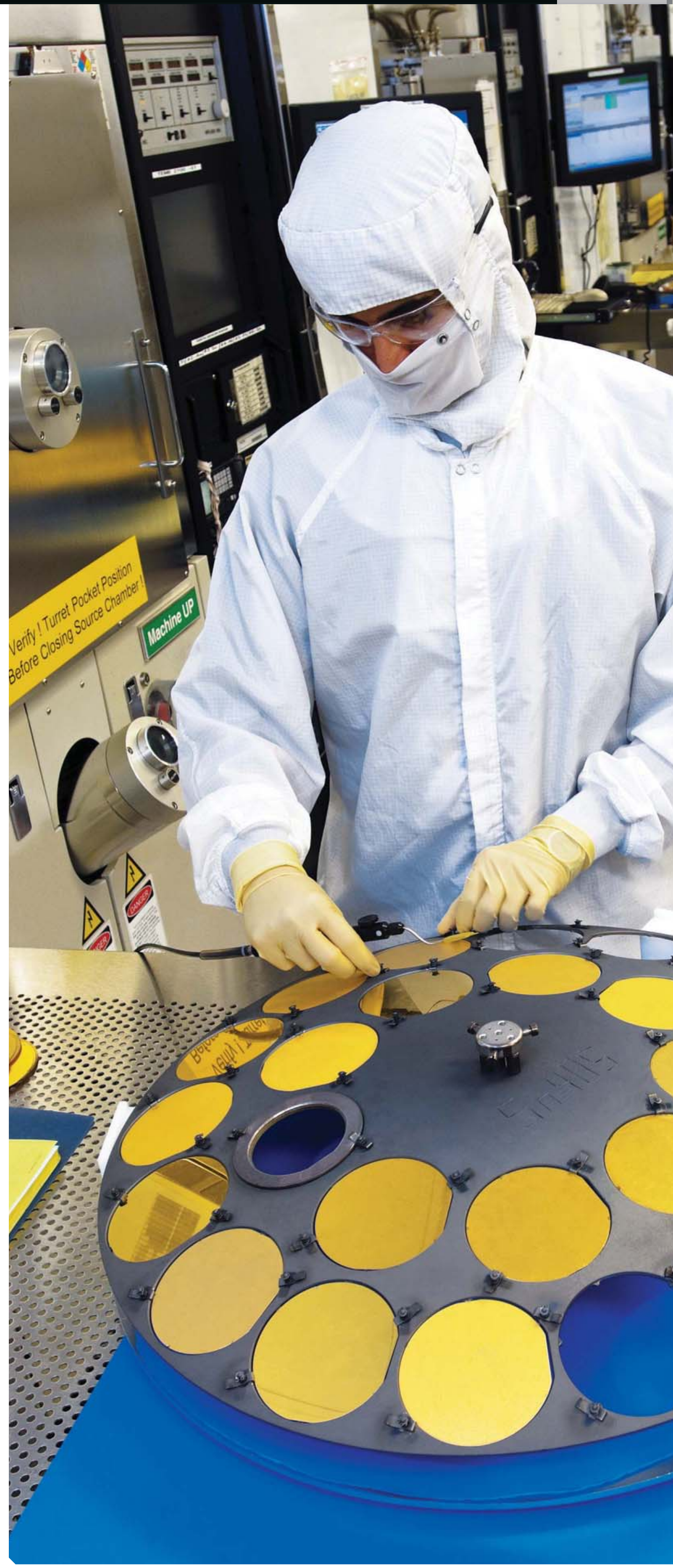
SILICON HAS LONG BEEN the semiconductor of choice for such power electronics. But soon this ubiquitous substance will have to share the spotlight. Devices made from silicon carbide (SiC)—a faster, tougher, and more efficient alternative to straight silicon—are beginning to take off. Simple SiC diodes have already started to supplant silicon devices in some applications. And over the last few years, they've been joined by the first commercially available SiC transistors, enabling a new range of SiC-based power electronics. What's more, SiC wafer manufacturers have steadily reduced the defects in the material while increasing the wafer size, thus driving down the prices of SiC devices. Last year, according to estimates made by wafer maker Cree, the global market for silicon carbide devices topped US $100 million for the first time.

Within five years, we should see this market balloon as SiC devices find their way into power electronics for hybrid and all-electric vehicles, creating simpler and more efficient power systems. SiC power devices will also become vital in solar and wind energy creation, by reducing the energy lost as electricity is converted to a form that can be used on the power grid. Eventually, silicon carbide could remake the grid itself by eliminating the need for bulky substation transformers, thereby saving an enormous amount of energy that is now wasted as electricity makes its way from power plants and other sources to its final destination. Although the field of SiC power electronics is still relatively immature, we expect it's in for a big growth spurt.

SILICON-BASED DEVICES are so mature and inexpensive to manufacture, it might be hard to believe that any material could shake silicon from its perch. But silicon carbide is quite special. Many of the material's most attractive properties stem from a single physical feature: SiC's bandgap, the energy needed to excite electrons from the material's valence band into the conduction band. Silicon carbide electrons need about three times as much energy to reach the conduction band, a property that lets SiC-based devices withstand far higher voltages and temperatures than their silicon counterparts.

One of the biggest advantages this wide bandgap confers is in averting electrical breakdown. Silicon devices, for example, can't withstand electric fields in excess of about 300 kilovolts per centimeter. Anything stronger will tug on flowing electrons with enough force to knock other electrons out of the valence band. These liberated electrons will in turn accelerate and collide with other electrons, creating an avalanche that can cause the current to swell and eventually destroy the material.



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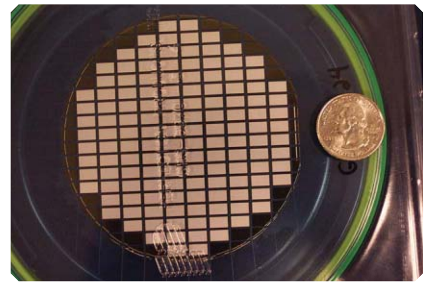
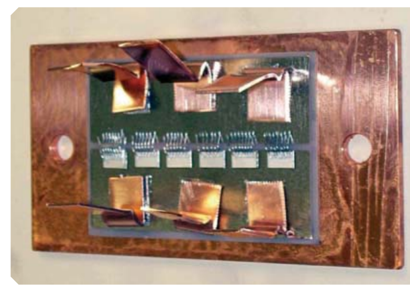




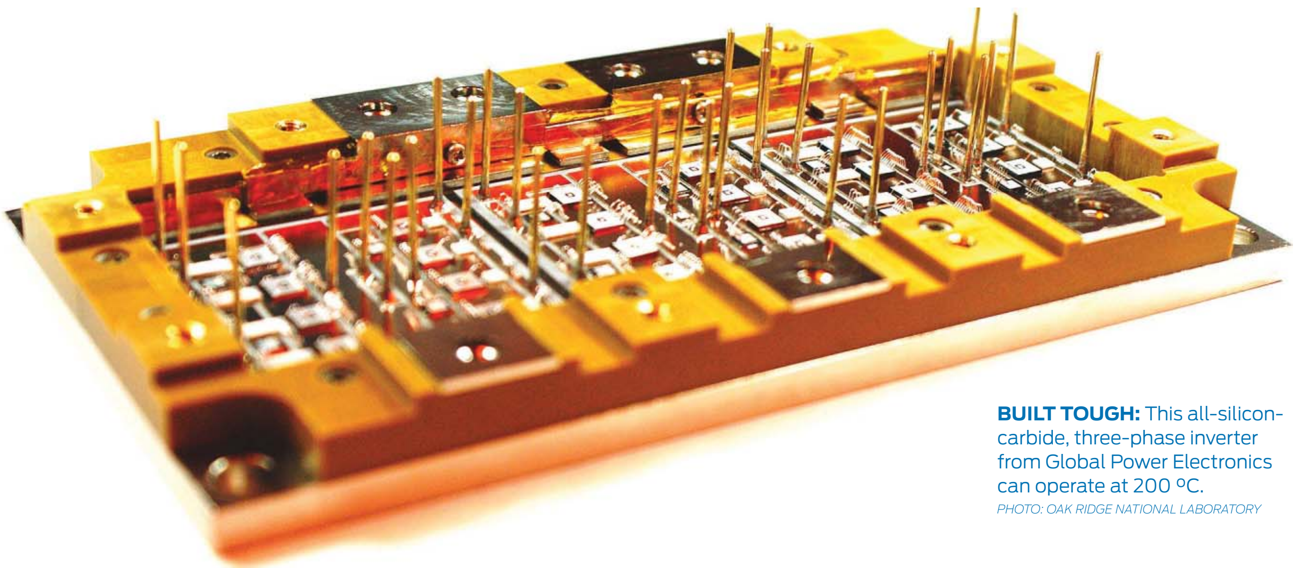
DEVICE FLOW: Four-inch silicon carbide wafers are prepared for metal deposition in a clean room at Cree [opposite]. These wafers will be used to make SiC power electronic devices, such as the 1200-volt SiC Schottky diode [above left]. SiC diodes cut from a wafer [top right] can be peeled and packaged in modules, such as this 450-ampere test module [bottom right] developed at the University of Arkansas. PHOTOS, CLOCKWISE FROM LEFT: CREE (2); OAK RIDGE NATIONAL LABORATORY (2)

Because electrons in SiC require more energy to be pushed into the conduction band, the material can withstand much stronger electric fields, up to about 10 times the maximum for silicon. As a result, a SiC-based device can have the same dimensions as a silicon device but withstand 10 times the voltage. What's more, a SiC device can be less than a tenth the thickness of a silicon device but carry the same voltage rating, because the voltage difference does not have to be spread across as much material. These thinner devices are faster and boast less resistance, which means less energy is lost to heat when a silicon carbide diode or transistor is conducting electricity.

Because of these features, silicon carbide could be used to replace slow silicon switches with alternative designs that are faster and more energy efficient. To sustain voltages beyond about 200 volts, a silicon transistor has to be quite thick. This added thickness boosts resistance, which in turn demands impractically large devices in order to maximize current-carrying capacity. To mitigate this problem, high-voltage silicon switches tend to be bipolar transistors: They use both holes and electrons. The design carries more current, but it takes time for all the charge carriers to fully exit the device. When the transistor is being switched from its "on," current-carrying state to its "off," voltage-blocking state, there is a period of overlap where the remaining charge carriers are exposed to high voltage and dragged through the device, dissipating heat.

Using silicon carbide instead of silicon in high-voltage devices will let manufacturers replace slow silicon bipolar transistors with single-carrier, or unipolar, devices such as metal-oxide-semiconductor field-effect transistors, or MOSFETs. Very few charge carriers are left behind in such devices, so the transistors can be switched quickly and far more efficiently. The faster devices also have the added benefit of more-compact and less-expensive packaging because they require smaller control circuitry.

FOR ALL ITS FINE QUALITIES, silicon carbide has been a difficult material to master. One of the biggest hurdles to its widespread use in power electronics has been



BUILT TOUGH: This all-silicon-carbide, three-phase inverter from Global Power Electronics can operate at 200 °C.
PHOTO: OAK RIDGE NATIONAL LABORATORY

in wafer manufacturing. When engineers first started working with the material in the 1970s, they struggled to grow large single crystals of the stuff—the silicon and carbon atoms had a habit of combining with one another to form a hodgepodge of different crystalline structures.

Over the years, researchers succeeded in creating larger and larger single-crystal wafers. And in 1991, a few years after the company was founded, Cree released the first commercially available SiC wafers. They were just an inch across and used mostly for research, but it was a start. Since then Cree and other manufacturers, including Dow Corning, SiCrystal, TankeBlue, and II-VI, have made steady progress in boosting the size of the wafers; these days 4-inch SiC wafers are common, and 6-inch wafers are on the horizon. A larger wafer size means that more devices can be built on each wafer, which drives down device costs.

At the same time, companies have been working to overcome another early stumbling block: a high number of defects in SiC crystals. Unlike silicon, SiC doesn't have a liquid phase. As a result, SiC crystals are grown layer by layer from vapor at roughly 2500 °C. This process is difficult to control and can easily create tiny, tornado-like tunnels called micropipes, which arise from dislocations in the crystal early in the wafer formation process.

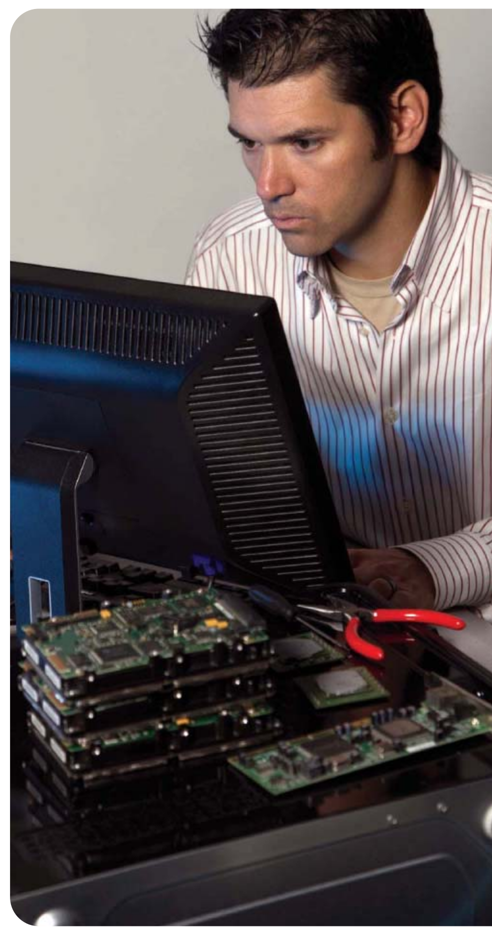
Devices built atop these micropipes don't perform as designed. Even a few micropipes per square centimeter is enough to erode device yield and thus boost costs. But as wafer producers fine-tuned manufacturing processes, they also made steady strides in eliminating such defects. In 2005, the U.S. firm Intrinsic Semiconductor Corp., later acquired by Cree, debuted 3-inch SiC wafers with no micropipes, and 4-inch micropipe-free wafers are now available.

Of course, wafers would be nothing if there weren't devices to build on top of them. In 2001, more than 50 years after the first silicon power electronic devices emerged, Infineon Technologies, based in Neubiberg, Germany, released the first commercial SiC device. It was a Schottky diode, a simple junction made from metal and semiconducting material. Schottky diodes rectify alternating currents in much the same way that a standard *p-n* junction does, but the devices exhibit much faster response times. Although they cost more than silicon diodes, SiC Schottky diodes offer a range of benefits, including better energy efficiency and reliability and cooler operation. They also eliminate the need for devices like snubbers, which would otherwise be used to protect silicon circuitry from current spikes. In less than 10 years, SiC Schottky diodes have all but replaced the silicon *p-n* diodes in switched-mode power supplies for computers, particularly those in large data centers. Manufacturers now offer SiC Schottky diodes that can withstand voltages as high as 1700 V, more than five times the maximum voltage of comparable silicon devices.

But to truly revolutionize power electronics, you need a second component: transistors. These more sophisticated devices have taken longer to realize in silicon carbide. It wasn't until 2008 that the first SiC transistors—junction field-effect transistors (JFETs) manufactured by Mississippi-based SemiSouth Laboratories—finally hit the marketplace. The number of transistor offerings has since boomed. SiC transistors with a range of architectures are now offered by the likes of Cree, Infineon, Rohm, and TranSiC. Each design has its advantages, and the jury's still out on which one will get the biggest share of the market, but the competition is clearly heating up.

AT OAK RIDGE NATIONAL LABORATORY, in Tennessee, we've been exploring how well SiC diodes and transistors work as the power electronic devices for all-electric and hybrid electric vehicles. After the battery, electronics are the key added cost to these vehicles. Electronics are needed to convert wall power into battery power, to recharge the battery from the engine or from the brakes, and most important, to operate the traction drive, which transforms battery power into electricity that can run the motors that propel the vehicle. Of all the electronics in an electric vehicle, the traction drive draws the most power.

The drive has two main parts: a boost converter that increases the DC voltage from the battery and an inverter that converts this electricity into the three-phase AC needed by the motor. The three-phase inverter in turn consists of six diodes and six transistors. In computer and laboratory simulations at Oak Ridge, we've shown that simply swapping silicon diodes with SiC Schottky diodes cuts the inverter's energy loss by 33 percent, consistent with other estimates. The reduction doubles if you also replace the *Continued on page 56*



A Driver's Sixth Sense

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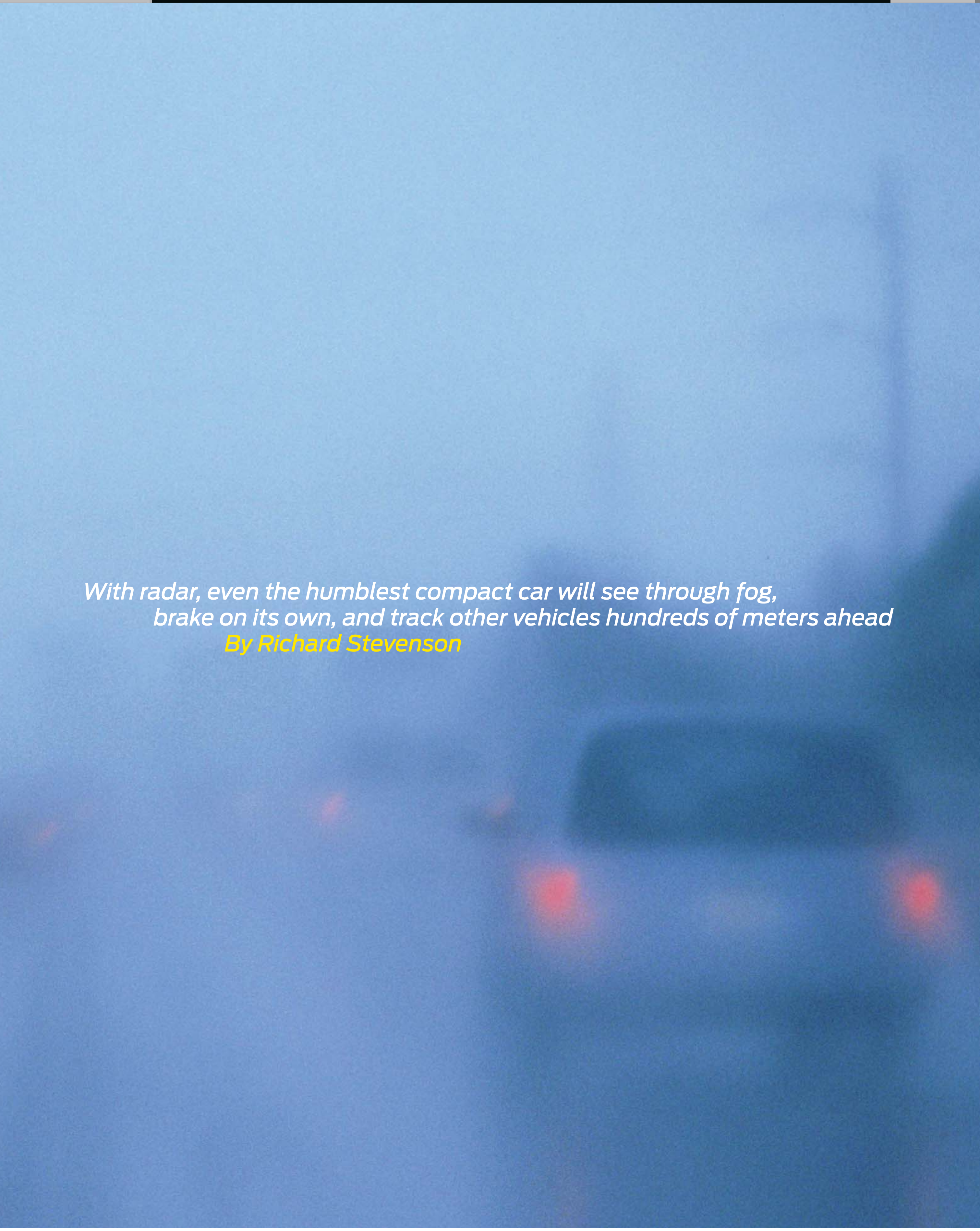

With radar, even the humblest compact car will see through fog, brake on its own, and track other vehicles hundreds of meters ahead

By Richard Stevenson

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To find out what driving's like when you have a sixth sense, I took a radar-equipped Audi A8 around the highways and byways of Stuttgart, Germany. It was great.

I couldn't help but smile when I pulled behind a huge truck and, resisting the temptation to hit the brakes, focused on steering. The adaptive cruise-control system, which uses a new radar from Robert Bosch that can see hundreds of meters ahead, did the rest. The system gently nestled the car behind the juggernaut and accelerated at my command, so I was able to pull out into the passing lane, all the while getting the most out of the 4.2-liter diesel, which rapidly propelled me to the speed I'd selected.

The system did have its foibles. Once the radar locked onto the car in front of me, and when the car turned hard to the right and then hard to the left, the radar came unlocked. So I took control, applying the brakes well before the emergency braking would have kicked in. That episode was a little disconcerting. Still, I could easily get used to this gizmo.

Most people who have driven for a while using such a radar are loath to ever give it up. And the number of such devotees will only grow as this technology—which now adds about US $1000 to the price of the car—becomes more affordable. The first commercial system appeared in Japan in 1997, on the Toyota Celsior; others soon followed in some top-of-the-line models from the likes of BMW, Jaguar, Lexus, Nissan, and Mercedes. The market has been expanding at about 40 percent a year, and as prices fall, that rate should rise.

Today's systems can dramatically reduce your risk of rear-ending someone else's car, and when most cars have such radars, *they* will also be much less likely to rear-end *you*. Once every vehicle on the road is able to sense and avoid others, there'll be no reason why they won't be able to negotiate tailing distances among themselves. Eventually, they might even be sending radio messages about their intentions to one another and to monitors on the roadway over ad hoc communication networks. Smart roads may thus emerge organically.

The first step in that evolution, the democratization of radar, is clearly under way. Next year Bosch will release a less expensive version of its radar, with a range of 160 meters, two-thirds that of the one I tested. This won't be a problem, though, because it's intended for cars that don't go nearly as fast.

Falling costs are the key, but of course, costs don't fall by themselves. Engineers have done their part by ditching the expensive compound semiconductors in their radar sets in favor of the old standby, silicon—but a special form of silicon that's been speeded up.

In the late 1960s workers at Mullard Research Laboratories, in England, developed a car radar system that operated at 10 gigahertz, and RCA used the same frequency in its 1972 system. To make the next step and cram such a radar into a small space—such as under the hood of a car—manufacturers had to shrink the array of antennas, keeping each antenna far enough from its neighbors to allow for good resolution of detail. They accomplished this task by moving first to 34 GHz, then to 50 GHz, and recently to 77 GHz. The choice of frequency has something to do with the absorption of microwaves in the air and a lot to do with legislation: The law places strict limits on power for the lower frequencies, which is why systems in the lower bands can look forward just a few meters, only enough to avoid fender benders in stop-and-go traffic.

To manage the higher frequencies, long-range auto radars have until recently required seven or more gallium arsenide–based chips to generate, amplify, and detect the microwave signals. That set of chips costs from $20 to $60—not all that much, it might seem. But those chips have to be connected and tested, and if one fails to work, it must be rooted out and replaced. This labor adds substantially to the cost of any radar based on gallium arsenide technology.

In 2009, the German chipmaker Infineon Technologies, based in Neubiberg, produced a system designed around a single silicon-based chip. Then it teamed up with Bosch and started supplying a more flexible, two-chip variant for radar systems in 2010 models of the Audi A8, Porsche Panamera, and Volkswagen Touareg. Not only are these new systems less expensive, they also have significantly better performance, allowing them to cover more than four times the area in front of the car, four times as accurately.

Even specialists in the gallium arsenide industry expect that silicon chips will grab most of the car radar market. Asif Anwar, director of the program for gallium arsenide and compound-semiconductors technologies at the market-research firm Strategy Analytics, in England, predicts that over the next three years, silicon's share of the chip market for automotive radar will grow from nearly nothing to perhaps 60 percent. Although Infineon will then have captured most of the resulting $120 million market for silicon-based radar chips, it already faces the first signs of serious competition: U.S. chipmaker Freescale Semiconductor, in Austin, Texas, has just started sending samples of its silicon-based chip to auto-

PREVIOUS PAGES: JOHN WARDEN/GETTY IMAGES motive radar makers. Other companies are surely following suit.

Infineon has thus overturned the conventional view that silicon chips would never be able to generate, detect, and amplify high frequencies. The problem is that electrons move slowly through those chips—which is why a decade ago Infineon and a handful of other companies were using the faster gallium arsenide to build automotive radar chips. But in mid-2002 Infineon got out of the gallium arsenide business. A year later it was in discussions with Bosch about automotive radar chips based on silicon.

"At that time everybody thought this was not possible to do with silicon-based technologies," recollects Rudolf Lachner, Infineon's program manager for radar technologies. "But we did some high-speed circuits, such as voltage-controlled oscillators, which worked at 77 GHz."

To realize such high speeds in a silicon transistor, Infineon's engineers inserted into the heart of the device a thin layer that was four parts silicon and one part germanium. The idea was hardly new. Indeed, it can be traced to theoretical work that Nobel Prize–winning physicist Herbert Kroemer, now at the University of California, Santa Barbara, did way back in the 1950s. However, the world had to wait until 1975 for the first real device, made at AEG Research Center (now part of Daimler) in Ulm, Germany. Infineon's claim to fame comes from boosting this kind of transistor to record speeds, thanks to improvements in internal configuration and material quality.

Adding that layer of silicon germanium alloy introduces electric fields that present the moving electron with the equivalent of a downhill path, speeding it up automatically. Now even transistors with 50-nanometer-thick base layers can reach the speeds demanded by 77-GHz automotive radar.

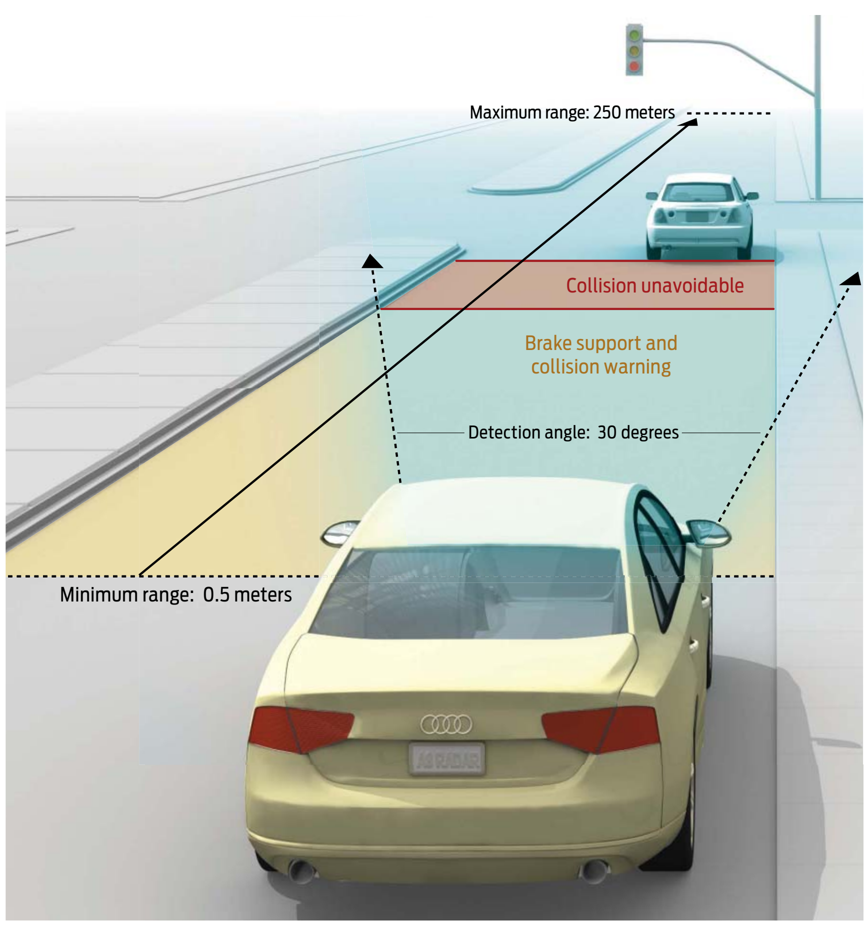
Switching to the new transistor delivers another benefit—very low noise levels. You can speed up conventional silicon transistors by thinning the base layer, but you'll just impede the flow of electrons and increase background noise. To muffle it, you could try to reduce the resistance of the base by doping the silicon with traces of boron, whose atoms each have three electrons in the outer shell, rather than silicon's four. Because there aren't enough electrons to form all the covalent bonds required, you get a "hole," or virtual positive particle, which moves freely through the crystal, increasing its conductivity. Unfortunately, increasing the base doping this way reduces the amplification, or gain. Working with a silicon germanium base layer gets around this problem because it makes its own contribution to the gain, offsetting the losses caused by doping. You can make the base doping very high, explains Lachner. "And by making it very high, you get a very low base resistance, which improves the noise behavior of your transistor," he says.

The fundamental insight stemmed from work Infineon did in the early 1990s while developing chips for next-generation mainframe computers. That project never took off. Nor was the company able to market its chips to mobile-phone vendors: As conventional transistors shrank, their lower cost proved more important than the lower power consumption of Infineon's chips. But soon after, it became clear to Infineon that this technology was a perfect fit for auto radar.

Perhaps it's the fiendishly high speeds of the autobahns that have made Germany so keen on technology to avoid collisions. Or it could be government aid. In 2004, Infineon began a three-year automotive radar program with €10 million in subsidies from the German government. That project allowed the company to collaborate with automotive radar system makers Bosch and Continental and carmakers BMW and Daimler.

I Spy...Trouble!

Radar senses the car up ahead, calculates relative motion, and anticipates a collision. At first the system flashes a light and sounds a buzzer while readying the brakes; if the driver doesn't respond, it strengthens the alert with a jerk of the car. If after all that warning the car still enters the danger zone, the radar system takes charge and slams on the brakes.



EMILY COOPER

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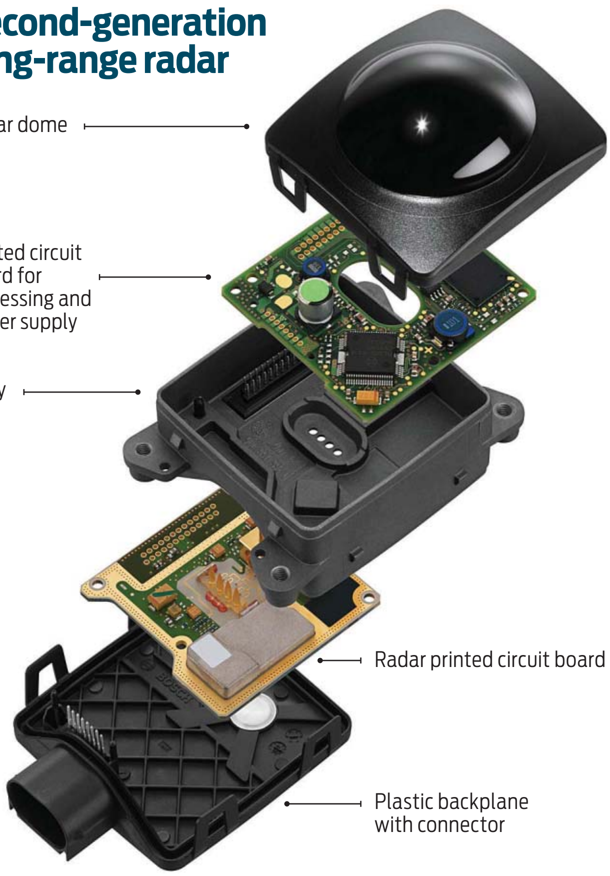
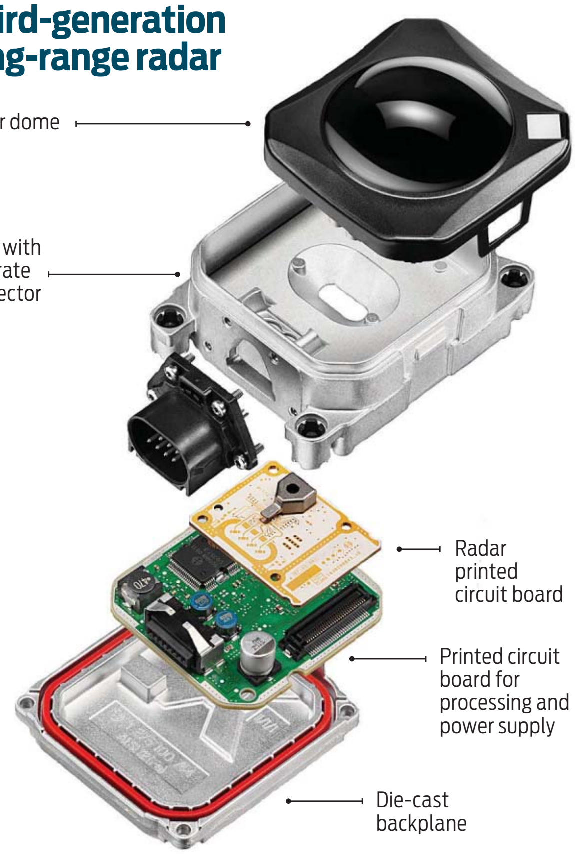
Evolution of a radar

Bosch's latest long-range system greatly simplifies the radar's printed circuit board. Instead of a handful of gallium arsenide chips to generate, amplify, and detect the 77-gigahertz microwaves, the system uses just one or two (as shown) of Infineon's silicon germanium chips.

Second-generation long-range radar



Third-generation long-range radar



BOSCH (2)

Infineon's prototype could operate up to only about 80 GHz, good enough for use in an oscillator but not in the amplifier. That's because for a transistor to deliver reasonable gain at a given frequency, it needs to top out at about three times that value. In 2007, by improving the quality of the boron-doped silicon germanium in the base, Infineon's engineers increased the transistor's maximum operating frequency to the requisite level and soon went on to produce the first commercial silicon germanium automotive radar chips, which ran at 77 GHz. Four years later, Infineon continues to churn out the chips at its huge fab in Regensburg, Germany.

Inserting the silicon germanium layer into the device requires no exotic techniques or extraordinary tools: Infineon simply uses 200-millimeter silicon wafers and grows thin silicon films on top using conventional chemical-vapor deposition. At the appropriate point during the process, a valve opens, germanium-based gases flow into the growth chamber, and a silicon germanium film forms.

One such wafer can yield thousands of chips. "This gives us enough headroom to produce as many automotive radar systems as we would like," explains Lachner. In fact, most of the fab's output of 10 000 wafers goes to other purposes. If Infineon somehow captured the entire automotive market overnight, it could easily satisfy the demand.

So why do other companies, such as TriQuint Semiconductor, in Hillsboro, Ore., and United Monolithic Semiconductors, in Orsay, France, still produce automotive radar chips based on pricey gallium arsenide? For one thing, gallium arsenide is still the biggest player in the radar market at the moment, and these firms can sell a lot of chips, at least for a few years. Also, these companies don't necessarily have silicon production lines to switch to, nor would it make sense to build a full-blown silicon fab for car radar alone.

Cost isn't the only thing driving change. It's not only cheaper to use one Infineon chip (or two, in the fancier system); it's also more effective than the handful of gallium arsenide chips it replaces. When Bosch upgraded Infineon's product during the development of its third-generation long-range radar (dubbed, unimaginatively, the LRR3), both the minimum and maximum ranges of its system got better: The minimum range dropped from 2 meters to half a meter, and the maximum range shot from 150 to 250 meters. At the same time, the detection angle doubled to 30 degrees, and the accuracy of angle and distance measurements increased fourfold. The superiority stems from the significantly higher radar bandwidth used in the systems containing the silicon-based chips, says Thomas Fuehrer, Bosch's senior manager for strategic marketing for driver assistance: "It is around 200 megahertz on the LRR2, and we are now using 500 MHz on the LRR3."

Another selling point is the new system's compact size—just 7.4 by 7 by 5.8 centimeters. "If you are comparing it with the competitor's systems, this really is a very small masterpiece," Fuehrer says. What it means is that automobile designers can stick this thing just about anywhere—even in the headlamp assembly.

The system employs four antennas and a big plastic lens to shoot microwaves forward and also detect the echoes, all the while ramping the emission frequency back and forth over that big fat 500-MHz band. (Because the ramping is so fast, the chance of two or more radars interfering is extraordinarily low.) The system compares the amplitudes and phases of the echoes, pinpointing each car within range to within 10 cm in distance and 0.1 degree in displacement from the axis of motion. Then it works out which cars are getting closer or farther away by using the Doppler effect—the change in frequency associated with motion that also causes us to perceive a train whistle to rise in pitch as it approaches us and fall as it pulls away. In all, the radar can track 33 objects at a time.

On the Audi A8, you receive two separate warnings when you get worryingly close to the car in front. First, a high-pitched alarm sounds, and a light appears on the dashboard. If that sound-and-light show doesn't work, then comes a short, sharp brake to snap you out of your stupor. "Tests and studies show that most drivers will then immediately look forward at the road and notice if they are too close," says Bernhard Lucas, head of Bosch's department for developing car radar hardware.

Even braking may not prevent a collision: Statistics gathered by Bosch show that nearly half of rear-end crashes are caused by drivers pressing the brake pedal too softly. But if that happened in the radar-equipped Audi A8, additional braking would be applied automatically.

If worse comes to worst, the braking system goes into action by itself. "In rare cases where the driver is completely unable to do anything—he is helpless or half dead—full emergency braking is applied when the crash is really unavoidable," says Lucas. Then the car decelerates abruptly, throwing the driver forward into the safety belt with up to six times the force of gravity but minimizing what would otherwise be a catastrophic impact with the car in front.

Of course, you'll probably never have to call on such emergency powers to save your life. Few people even consider such features when purchasing a car. That's why the day-to-day operation of the system is important for winning over the driver. Today, the benefits come mainly in the form of a radar-enhanced cruise control. You can set your radar to lock onto the vehicle in front and keep pace with it, braking and speeding up appropriately. You specify the following distance and the maximum allowable speed, which can be as high as 250 kilometers per hour (155 miles per hour).

It is interesting that when Audi, Porsche, and VW started making radar-ready cars last year, all three companies chose to use the radar as a driving aid rather than a full-blown autopilot. They thus reduced their liability for any accidents that might ensue. Today, it's clear that the main roadblock for a software-based chauffeur are legal worries and perhaps the fear of the unknown. Should any automaker dare to take the plunge, the technology will not be lacking. ❏

POST YOUR COMMENTS *online at* http://spectrum.ieee.org/autoradar1011

COURTING DANGER: On a Bosch test track, the black demo car approaches the dummy car too quickly, alerting the radar system, which applies the brakes in time to prevent or at least soften the crash. *PHOTO: BOSCH*

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The Doctor Will See You ALWAYS

Wireless technologies are about to transform health care—and not a moment too soon

by JOSEPH M. SMITH

IMAGINE A WORLD in which your medicine cabinet notices that you are due for a prescription refill and calls it in. A sensor implanted under your skin detects a fluid buildup in your lungs and alerts your doctor, who decides your heart medication needs an adjustment and contacts the pharmacist to change your dosage. Meanwhile, sensors in your toilet confirm that your body has adjusted well to your other medications but sees indications that you may be a borderline diabetic. Your doctor, given these readings and your family medical history, suggests that you change your diet. Noting that fact, your bathroom scale asks you to punch in a weight-loss goal and starts giving you a regular progress update. Your medical checkup isn't an annual event—it happens every day, simply as you go about your daily life.

If such ambient monitoring and intervention strikes you as a little creepy, think of it this way: It could avert a heart attack, stroke, or other medical crisis. It could keep you out of the hospital and save money for both you and the health care system. Part of the savings would come from radical changes in the management of chronic diseases, which in the United States eats up 75 percent of health care spending, or about US $1.9 trillion each year.

And a health-monitoring bathroom is not science fiction. This is what health care could look like within the decade, at least for some. Perhaps predicting such dramatic change within 10 years is overly optimistic. But the necessary technologies already exist or are close at hand, the need to reduce health care costs is real, and the current health care system demands change. What's more, a groundswell of support for wireless health care is rising from a diverse group of people and organizations. These include communities of consumers who want better ways to manage and measure their own health, like the Quantified Self movement and Health 2.0, which sponsors competitions to spur the development of new health care apps and devices. Also on board are nonprofit organizations like the West Wireless Health Institute, in La Jolla, Calif., where I work as chief medical and science officer. We focus on lowering health care costs through health technology innovation. The nonprofit LeadingAge Center for Aging Services Technologies is working to improve

VIKTOR KOEN

quality of life for the aging. For the third year in a row, the U.S. National Institutes of Health is hosting the global mHealth Summit, a conference examining the impact of mobile technologies on health care delivery, research, business, and policy. And hundreds of start-ups are exploring near-term and long-term ways to reform the delivery of health care.

Change is happening. Yes, a technological revolution in health care has been predicted before, but we are at an inflection point now, where wireless connectivity, personal cellular devices, pervasive sensing technologies, social networks, and data analytics are mature enough to make wireless medicine a reality. And there is a will as never before to find a way to reduce crippling health care costs. Already, new devices allow diseases like diabetes and chronic heart failure to be closely monitored outside the doctor's office; tools for tracking chronic kidney disease and a variety of lung disorders are sure to follow. Eventually, most health care will occur not during occasional visits to doctors' offices, clinics, or hospitals but continuously, during ordinary activities in people's homes, cars, and workplaces.

A TRIAL PROGRAM by the U.S. Department of Veterans Affairs offered an early look at what systemic change could mean. In 2003, the VA began using simple messaging devices and occasional videoconferences to let chronically ill veterans stay in touch with nurses and other health care professionals. Under this program, one of the largest of its kind in the world, 71 000 veterans are now receiving daily monitoring for such conditions as diabetes, heart disease, and post-traumatic stress disorder.

The VA's program involves veterans who typically have multiple chronic illnesses that could easily land them in the emergency room unless complications are caught early. In the initial pilot study, each patient was assigned a care coordinator and given a dedicated device—typically a gizmo from the German company Robert Bosch Healthcare called a Health Buddy, which is about the size of a landline telephone and has a small LCD screen with four large buttons to let the user keep in touch with the coordinator. The patient would regularly connect one or more vital-signs monitoring devices—a blood pressure cuff, for example, or a thermometer—to the Health Buddy and follow on-screen instructions to collect that data. The patient would also respond to questions on symptoms and behavior, such as, Have you taken your medicine? Are you feeling sad? This daily assessment was automatically uploaded to a secure server, and professionals managing the patient's care then used a Web interface to look for problems. With this system, each care coordinator was able to monitor 125 patients, following up by videoconference as necessary.

The results have been striking. A December 2008 VA study of this program concluded that it had reduced hospital admissions by 19 percent and reduced days spent in hospitals or other health care facilities by 25 percent. At $1600 per patient per year, the telehealth program costs vastly less than visiting nurses ($13 121) or nursing home care ($77 745). It's not just veterans who could benefit from such an approach. A January 2009 study by the New England Healthcare Institute estimated that use of this same technology for all U.S. patients at risk of heart failure—an estimated 1.27 million people—could save up to $6.4 billion annually through reduced hospital admissions.

As successful as it has been, the VA's system is very simple telemedicine, in many cases using dial-up telephone connections and basic devices. Add today's ubiquitous wireless connectivity and new mobile health-monitoring devices, and the benefits will be far greater.

The FIRST WAVE

These health-monitoring devices are only the beginning of the wireless revolution

IF YOU'RE one of the hundreds of millions of people in the world today with diabetes or heart disease, you could be among the first to experience the next phase of the wireless health care revolution. Wireless glucose monitors are already on the market from companies like Medtronic and DexCom, and the latest ones may soon be paired with insulin infusion pumps so they can automatically adjust insulin dosages in response to changes in the patient's glucose level.

Most of the wireless glucose monitors consist of a patch containing a processor, a transmitter, and a thin platinum electrode that slips under the skin. The monitor samples blood glucose levels at fixed intervals—typically, every 5 minutes—calculates trends, and then passes that information to the infusion pump, which uses the data to calculate when and how much insulin to release. This kind of system allows far closer control of diabetes than a manual self-administered system, avoiding the need to prick the skin, collect a blood sample, insert that sample into a reader, and then pick the appropriate insulin dose. And supplying exactly the right amount of insulin just when it's needed has been shown to prevent complications, including blindness, kidney disease, and peripheral vein disease that can lead to the loss of a limb.

ZEO

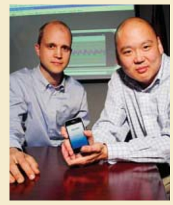
The **Zeo Personal Sleep Coach** communicates wirelessly with a headband to monitor sleep cycles. The system scores each night of sleep and lets you look at detailed information online.

MEDTRONIC

The **MiniMed Paradigm Real-Time Revel System** from Medtronic is the first to combine an insulin pump with regular monitoring of glucose levels for diabetes management.

WITHINGS

Withings's **WiFi Body Scale** uploads weight and body-mass information to a website. Users can then track trends and print graphs to share with nutritionists or doctors.



iTREM

This iPhone application may enable people with Parkinson's disease to better understand symptoms. The **iTrem** is being used in a clinical study at Emory University.

FROM LEFT: MEDTRONIC; ZEO; WITHINGS; GEORGIA TECH

People with congestive heart failure may soon benefit from a wireless monitor being developed by CardioMEMS. Its heart failure pressure-measurement system has two components: an implanted wireless sensor and an external electronics module. In the sensor device, a glass membrane shifts in response to pressure changes; the tiny movement changes the resonance frequency of an oscillating circuit in the sensor. The external module tracks these changes. This tracking method detects fluid buildup in the patient's lungs, a common complication that often leads to hospitalization. The device can detect a problem even before the patient notices major symptoms; the doctor can then adjust the patient's medication to reduce fluid levels.

Avoiding hospitalization is good for patients and for the health care system. The cost of a hospital stay in the United States for heart failure averages $10 000, and nearly 30 percent of those who are hospitalized will end up back in the hospital within 30 days. So provided the cost of the implant is kept reasonable, the potential savings from using it could be significant if it can avert even a single hospitalization.

Diabetes and heart disease are only the first of many conditions whose treatment will be improved by such monitoring tools. Down the road we'll likely see similar approaches to blunt the progress of chronic kidney disease and prevent hospitalizations for chronic obstructive pulmonary disease, emphysema, and pneumonia, among other ailments.

But you're reasonably healthy, you say, just a tad overweight and a bit too sedentary. Oh, and you should probably eat better. At least that's what your doctor keeps telling you at every annual checkup. Maybe he suggests that you weigh yourself daily and log that information in a paper diary or an Excel spreadsheet. Maybe you even tried doing that but stopped after a few days.

Chances are your doctor didn't suggest a more convenient way of monitoring your vital signs. Consider the $159 WiFi Body Scale, introduced two years ago by the French company Withings. It automatically uploads your weight and body-mass-index measurements to a secure website or mobile device and tracks trends in the data. You can view updates privately or send them to your doctor.

Or take a look at Panasonic's wireless-enabled blood pressure monitor, also introduced two years ago. This $199 consumer device has a portable wireless display that saves up to 90 of an individual's readings, which makes it easy to take to your next doctor's visit. Similar to the Withings scale, this monitor makes it easy to track trends over time and allows doctors to note any changes that might require immediate intervention or those that should be discussed with the patient.

These two devices may not seem revolutionary; after all, they're just standard products updated with telecommunications capabilities and Web interfaces. But they signal a sea change in health care. They enable physiological data, the basic vital signs collected routinely at the beginning of just about every visit to a doctor's office, to be easily and automatically recorded and monitored over time.

Tracking such information is critical to effective health care; doctors know, for example, that having high blood pressure is less dangerous than having extreme fluctuations in blood pressure, and that a sudden weight increase can signal an imminent crisis for a heart patient. But without the right technology, tracking your vital signs isn't easy, and the information may not reach your doctor in time to be meaningful.

BUDDY SYSTEM: Robert Bosch Healthcare's Health Buddy automates remote patient monitoring.

PHOTO: ROBERT BOSCH HEALTHCARE

THESE ARE just a few of the kinds of medical conditions and physical data that today can be monitored by sensors and wireless communications. Increasingly, people are turning to technology to gain a more complete picture of their overall health. In the past, the only way to obtain detailed information was through costly stays at high-end clinics or expensive medical tests. Now, however, it's both affordable and widely available. Some of these monitoring systems are stand-alone devices, while others run on popular consumer gadgets like the iPhone or even through your car.

For example, for the many people who have trouble getting a good night's rest—50 million in the United States alone—there are now a number of sleeping-aid devices either on the market or awaiting approval by the U.S. Food and Drug Administration or regulatory agencies in other countries. BiancaMed's bedside sleep monitor is one of the most promising. About the size of an alarm clock, the SleepMinder uses motion sensors to measure your sleep quality, respiration, and any incidents of sleep apnea without having to make contact with your body. From these data, it creates a report that it sends to a website, where the user can print it out to take to a doctor for discussion. This process, which recently received FDA approval, could replace a costly stay in a sleep lab, which in the United States averages $2625. In addition to helping diagnose ordinary sleep disorders, it could also point to chronic conditions that affect sleep.

A simpler device intended for consumer use is the Zeo Personal Sleep Coach, which is already available for $159. The Zeo system includes a headband with sensors that collect signals from the brain and eye and face muscles while the user moves from wakefulness into and out of deep and REM sleep. It doesn't track respiration or apnea, though. The sensors transmit their data to a bedside device that graphs the information and gives each night's rest an overall quality score.

If you suffer from irregular heartbeats or know somebody who does, a recently announced product from AliveCor may help. The company's $100 case for the iPhone 4 enables the iPhone to run electrocardiograms (ECGs). If approved by the FDA, it would allow you to monitor heart rate and rhythm abnormalities, including atrial fibrillation, whenever you feel them occurring. That's potentially a breakthrough, because patients who complain of heart rate irregularities don't often experience them on cue. To use the AliveCor device, you press the iPhone in the special case against your bare chest or hold it in your hands. Silver electrodes on the back of the case detect the heart rate, which is then transmitted wirelessly via Bluetooth to the iPhone. An app translates the data into ECG graphs and turns them into PDFs.

Meanwhile, researchers at Georgia Tech have developed an iPhone app that assesses the tremors associated with Parkinson's disease, potentially allowing doctors to better treat patients. The app, called iTrem, is beginning a clinical study at Emory University and will need FDA approval before it can hit the market.

Even Ford is getting into the wireless health care action. In May 2011, the company announced that it is developing in-car health tracking as part of its Sync system. Ford is working with companies like Medtronic that make instruments to measure blood glucose levels and software to help diabetic patients track their diet and medications. The first prototype system uses Bluetooth to connect the car to a continuous glucose-monitoring device. The system gives audio updates to the user and sounds an alarm if glucose levels fall too low, a situation that could lead to a loss of consciousness or a seizure—and be particularly dangerous on the road.

THE UNITED STATES isn't the only country whose crippling health care costs and aging population are pushing the development of alternatives to traditional health care delivery; the same holds true in much of Europe and Japan. Conversely, in developing countries, where cellphones are as prevalent as almost anywhere else in the world, the United Nations Foundation and scores of nongovernmental organizations have been implementing mobile health (mHealth) programs, successfully reaching people who have little access to health care, with a focus on things like phoned-in pill reminders for diseases such as tuberculosis, letting people know via text where they can find confidential HIV/AIDS testing, and using communications networks to track disease outbreaks and epidemics.

In some cases, the United States is behind the curve and must play catch-up. U.S. regulatory paths for approving new wireless medical devices remain unclear, although the FDA has been issuing draft guidance documents this summer and is working on the problem. The pervasive feeling in the industry, however, is that the United States is losing a competitive edge to Europe and other countries around the world. Kai Medical, for example, which makes a noncontact wireless device for continuous monitoring of respiratory rate, patterns, and activity, has already received the European Union's certification of compliance (known as a CE) for its Kai Continuous device; U.S. approval for the same device is now pending.

Expanding wireless health care capabilities will lead in the coming years to what I call the

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"health-e-home." This comprehensive health monitoring and treatment system will evolve from technology that today helps family members monitor aging relatives. For example, motion sensors installed in the home by companies like WellAware can track a resident's daily activity levels. These sensing systems do far more than detect a sudden fall. They monitor ordinary tasks like getting out of bed, opening the refrigerator, and walking around the house and can spot any changes that can signal a problem. For instance, an elderly person who starts to sleep later each day, doesn't leave home, and eats less frequently may be developing complications from medications, a worsening of congestive heart failure, or depression.

It's not a big leap, then, to imagine augmenting such technology in a few years with a smart medicine cabinet, capable of tracking medications, warning about potential interactions, reordering prescriptions, and checking expiration dates. It could also interact with other devices, like the calendar on your smartphone (to remind you that you have an upcoming trip, so you'd better stock up on your prescriptions) or your refrigerator (to remind you not to drink grapefruit juice because you're taking Lipitor). The benefits could be huge. The New England Healthcare Institute estimates that the cost of drug-related complications, including failure to take medications as directed, is as much as $290 billion annually—or 12 percent of total health care expenditures in the United States.

While a smart medicine cabinet can check that the right medicines are moving on and off the shelves as scheduled, it can't tell if the patient is actually consuming them. In the future, wireless technology integrated into medications will be able to confirm that the patient has ingested the medicine. Proteus Biomedical, based in California, has developed digestible computer chips with built-in wireless transmitters. These "ingestible event markers" are made from ingredients similar to those that bind vitamins into pills. Digestive fluids in the stomach activate the devices, which then create ultralow-power signals that can be picked up by a tiny recorder inserted under the skin or worn as a small adhesive skin patch. The recorder notes the date and time of the pill's activation along with other information, such as the type of drug, dose, and place of manufacture. It also takes a snapshot of the patient's heart rate, respiratory rate, and other physiological measurements. The detector then sends the information to a server that can combine it with data from other sensors, such as those that measure blood pressure, weight, and blood glucose, as well as information entered by the patient, such as changes in symptoms. Ultimately, such technology could be used to tailor medications to the individual.

Of course, these devices don't work alone: Somewhere the data need to be interpreted, as in the VA's telehealth program, by medical professionals. Eventually, though, as health sensors become commonplace in people's homes and in the community, the onslaught of data will quickly overwhelm clinicians, so we will have to create smart systems that automatically interpret and act on the data they gather. These systems will be faster and more accurate than human clinicians at spotting anomalies and better at identifying those cases that require human consultation.

WHILE ALL these technologies have exciting potential, the wireless revolution in health care does have a few obstacles in its path. There are regulatory hurdles, for starters. The technology of wireless medical devices is evolving at a much faster pace than our ability to contemplate all the potential consequences, good or bad. As a result, there is much confusion about what the technology might mean for patient safety, resulting in an understandable lag in regulatory guidance. To be sure, remote sensors linked to smart systems and adjustable therapies aren't perfect yet. But far, far worse is the existing health care system in the United States, with its fragmented care, overburdened clinicians, lapses in following standard clinical guidelines, and perverse incentives that boost profits for some but diminish quality and efficiency of care for many. Frankly, wireless devices don't have to be perfect to be better than what we have now.

People are also worried about privacy. They may fear that a device could be hacked or that data could be misused by employers or insurance companies. Yes, both could happen. But we can make it extremely unlikely. After all, many of us don't even think twice about using mobile apps on our phones to check our bank accounts. You should be able to make your health care information at least as secure as your checking account.

We also need interoperability standards. At present, health care is a kind of Tower of Babel, with separate devices and databases containing bits and pieces of information about us but no single system accessible by patients, doctors, and caregivers that provides a complete and comprehensive picture of an individual's health. What's also missing is a universal interface for monitoring the functioning of a human body that's as easy to understand as the gauges on a car's dashboard. That is, in the same way a car's dashboard shows us how much gas is left in the tank or if the engine is malfunctioning, we need an interface that clearly depicts health status and early warnings of disease or other trouble. This interface would bring together the data we gather about our vital signs, our medical conditions, and our varied and complex physiological responses to medications and then tell us what it all might mean.

Recent reforms in health care reimbursement policies made in U.S. legislation should help overcome these hurdles. And the creation of new models of care that cover a patient's entire treatment at a fixed price—instead of charging each time a patient shows up at the doctor's office—should offer incentives to use technologies that keep patients healthy and out of the hospital. The main thing that will drive adoption of these integrated wireless systems is the data that validate their cost-effectiveness; that will require studies and trials that go far beyond what the VA has done to date.

But I am convinced that we will get there. Eventually, we'll tie together today's trends—the expansion of tools for wirelessly monitoring and diagnosing disease, the increasing ability to remotely manage drugs and medical devices, and the growing understanding about how genetics affects susceptibilities to disease—with smart systems that learn as well as respond. And we will have a revolution in health care that changes society as dramatically as the Industrial Revolution once did. ❑

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Smaller, Faster, Tougher

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silicon transistors with SiC transistors. This boost in efficiency results mainly from SiC's lower resistance—which means it loses less power to heat—and from faster, more efficient switching.

But SiC's advantages don't end there. Because it takes extra energy to kick electrons into the conduction band, SiC's wide bandgap also makes the material much more heat resistant than silicon. Excess heat can excite so many electrons that it can interfere with a device's operation. For silicon, this thermal failure occurs at around 150 °C, but SiC devices can withstand considerably more than twice that temperature. This thermal resistance makes SiC attractive for a range of rugged applications, including military systems and electronics for oil wells, geothermal plants, and robotic spacecraft.

In hybrid and all-electric vehicles, SiC's operating temperature is high enough to obviate the need for one of the bulkiest engine components: the liquid cooling system. Hybrid vehicles need two cooling loops—one for the gasoline engine, which runs at 105 °C, and another to cool the power electronics and traction motor. Because silicon-based electronics stop performing above roughly 150 °C, and because some physical space separates the electronics from the coolant, this second loop needs to run even colder than the engine loop—at roughly 65 to 70 °C.

Liquid cooling adds significantly to the overall size of the engine, and if the liquid leaks out, it can destroy the electronics. Our simulations suggest that SiC inverters, because they can operate at higher temperatures, could reduce the size of the cooling system by 60 percent. If we combine these inverters with other high-temperature components like high-temperature capacitors, we might be able to eliminate the second loop altogether and simply cool the electronics with air. First, though, the packaging and peripheral components—the capacitors, control circuits, and drivers that turn transistor gates on and off—must also be made to withstand high temperatures. We've slowly been making progress on this front and have built drivers from scratch that work at up to 200 °C.

How efficient could SiC ultimately make electric vehicles? Electric traction drives already convert more than 85 percent of their power into usable mechanical energy, more than double the raw efficiency of a gasoline engine. But the U.S. Department of Energy (DOE) has set some ambitious goals for boosting the efficiency even further. By 2015, the agency says that drives should convert 93 percent of their power into mechanical work and by 2020, more than 94 percent. In other words, it wants future drives to lose half as much energy as present-day drives. These efficiency targets wouldn't be hard to reach by themselves, but the DOE also expects that electric traction drives in 2020 will be half the size and less than a fifth of the cost. These ambitious targets will be all but impossible to hit with silicon alone, but we think SiC has the potential to get us at least most of the way there.

ONE AREA WHERE SiC devices are already making inroads is solar power. Photovoltaic panels, whether they're mounted on a roof or spread across hectares of land, need inverters to convert the DC electricity made by the panels into AC electricity that can be fed into the power grid. This conversion process is already

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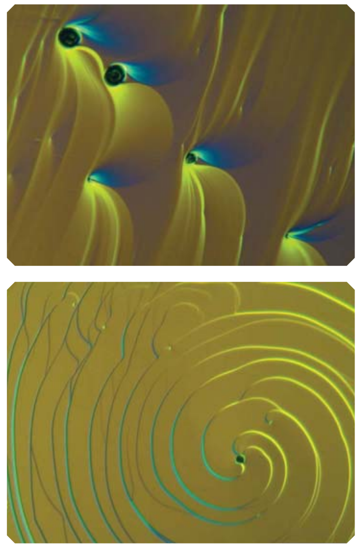
quite efficient: Silicon-based inverters lose just 2 to 3 percent of the energy they process. But inverters containing SiC diodes and transistors can easily cut that loss in half. Over the 20-year lifetime of a 10-megawatt solar plant, that could add up to hundreds of thousands of dollars in savings.

That's just for starters. Infineon has estimated that improvements in power electronics could eventually reduce electricity consumption by as much as 30 percent. To get there, the U.S. National Science Foundation funded the creation of the FREEDM Systems Center in 2008, a corporate and academic partnership that is researching ways to build a smart, flexible power grid using wide-bandgap devices. Last year, the DOE's Advanced Research Projects Agency–Energy also put money toward revamping power grid electronics. Two grants went to teams led by Cree and GeneSiC Semiconductor that are exploring ways to make SiC devices that can operate at more than 10 000 V, up to 15 000 V—well beyond the capabilities of silicon devices.



WAFER IMPERFECTIONS: Defects such as these micropipes had to be eliminated in order to boost yield and drive down the cost of silicon carbide power electronic devices. *IMAGES: CREE*

Remaking the power grid calls for SiC components that don't yet exist, including high-voltage bipolar transistors and *p-n* diodes. But if the research succeeds, it will pave the way for new devices that can connect distribution lines to higher-voltage transmission lines. At present, that job is performed by massive, multiton transformers, which dominate power substations. Someday, though, utility companies could replace these behemoths with far more efficient solid-state transformers, each the size of a suitcase.

Of course, that's still a long way off. One key technical hurdle will be continuing to improve the quality of SiC channels. Today's SiC transistor channels carry charges a factor of 10 slower than their theoretical limits, but modifications, such as better surface quality, should help.

Right now, silicon carbide is experiencing the same sorts of growing pains that silicon did in the 1950s and 1960s, when physicists and engineers saw it as a replacement for germanium. Despite the fact that SiC devices are still relatively new and more expensive than their silicon counterparts, the material has already demonstrated clear advantages over the alternatives. As more and more such devices come to market and their capabilities expand, they could start a revolution of their own. ❑

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UNIVERSITY SPOTLIGHT

FACULTY OPENING:
CAPSTONE DESIGN EXPERIENCE ELECTICAL and COMPUTER ENGINEERING
VANDERBILT UNIVERSITY

The Department of Electrical Engineering and Computer Science (EECS) at Vanderbilt University invites applications for appointment as a Professor of the Practice of Electrical and/or Computer Engineering (EECE) in the area of the capstone EECE design experience. This is intended to be a term appointment, subject to renewal upon performance. EECS research has core strengths in the areas of software integrated systems, microelectronics, robotics, medical image processing, nanotechnology and photonics, artificial intelligence, and computer animation and graphics. Applicants should have a Ph.D. degree in electrical engineering, computer engineering, or a closely related field. Professional licensure is desirable.

Vanderbilt University was ranked 12th on The Scientist's 2010 Best Places to Work in Academia (US locations), and in 2009 became the first educational institution ranked in Fortune Magazine's top 100 places to work. Vanderbilt is located in the beautiful and historic city of Nashville, which offers a full range of cultural amenities, two major professional sports franchises, an abundance of parks and outdoor recreation, a temperate climate, and a low cost of living.

Applications should be submitted electronically and must include: a cover letter (please indicate interest in this term position) with names and contact information for at least three references, a CV, and a statement of teaching philosophy. Applications received prior to 30 November 2011 will receive priority in evaluation. Vanderbilt University is an affirmative action/equal opportunity employer committed to increasing the cultural and intellectual diversity of its faculty.

EECE Design Faculty Search Committee
Department of Electrical Engineering and Computer Science
Box 351824, Station B
Nashville, TN 37235
e-mail: dan.fleetwood@vanderbilt.edu

ELECTRICAL and COMPUTER ENGINEERING
TEXAS A&M UNIVERSITY

Texas A&M University: The Department of Electrical and Computer Engineering has an opening for one tenure-track faculty at the assistant professor rank with expertise in real-time wireless networking and cyber-physical systems.

Applicants must have a Ph.D. or equivalent degree in electrical and computer engineering or related field, or have completed all degree requirements by date of hire, and must demonstrate potential for quality teaching and research.

The Department of Electrical and Computer Engineering currently has 67 faculty members and its degree programs have been ranked in the top 20 in recent years. Further information about the department may be obtained by visiting **http://ece.tamu.edu**.

Applications, including full curriculum vitae with a list of publications, a statement of teaching, a statement of research and the names, addresses (regular mail and email), of three references should be sent in a single PDF file, preferably electronically, to TAMU **Search@ECE.TAMU.EDU**, or in hard copy to:

Dr. Costas N. Georghiades, Department Head
c/o Ms. Debbie Hanson
Texas A&M University
Department of Electrical and Computer Engineering
TAMU 3128
College Station, TX, 77843-3128.

Texas A&M University is an equal opportunity/affirmative action employer. Candidates shall be considered solely on the basis of qualifications, without regard to race, color, sex, religion, national origin, age, disabilities or veteran status. The deadline for applications is November 30, 2011.

Drexel UNIVERSITY
Department of Electrical and Computer Engineering

The Electrical and Computer Engineering Department at Drexel University is seeking outstanding candidates at any rank in all areas of computer engineering for tenure-track positions. Areas of special emphasis include high-performance computing, bio-informatics, computer and network security, embedded systems and multimedia. Candidates must have a Ph.D. degree in electrical engineering, computer engineering or computer science with outstanding academic credentials that clearly demonstrate their ability to conduct independent and successful research in their areas of expertise and develop a graduate research program leading to peer-reviewed publications and external funding. Candidates must have excellent communication skills with a commitment to engage in high-quality undergraduate and graduate education in areas of computer engineering. The ECE department offers both undergraduate and graduate programs in computer engineering with several areas of specialization including computer networks, computer architecture, computer-aided design, VLSI systems and operating systems (see **http://www.ece.drexel.edu**). The department also has a very active PhD program with many outstanding students enrolled in it.

Applications should include a cover letter, complete resume, research and teaching statements and the names and addresses of three references. Copies of key publications may also be submitted. All application materials should be submitted electronically as a single pdf document via e-mail to: Moshe Kam, Department Head, Electrical and Computer Engineering Department, at the following e-mail address: **search@ece.drexel.edu**. Only online applications will be accepted. Review of applications will begin immediately and continue until the positions are filled.

Drexel University is a private, urban university located in Philadelphia, Pennsylvania, USA and is recognized for its traditionally strong technological focus and career-integrated education. Eligibility to work in the United States at the time of appointment is required. Drexel University is an equal opportunity/affirmative action employer.

UF UNIVERSITY of FLORIDA

Senior Engineer
Department of Electrical & Computer Engineering
University of Florida
Gainesville, FL

The Electronic Communications Laboratory within the Department of Electrical and Computer Engineering invites applications for non-tenure track positions at the Senior Engineer level. These are research positions performing signal processing and/or hardware design for advanced sensors and communication systems. Experience must include one or more of the following: FPGA development (VHDL, etc.), Altium Designer, Matlab, Python, or C. Applicants must have a Master's (with some relevant experience preferred) or a PhD in Electrical and Computer Engineering. Applicants with experience in the areas of FPGA signal processing and/or radar system design, analysis and testing are desired. Competitive candidates for these positions should show a proven ability to contribute to sponsored research projects and technical proposals. Applicants must be US citizens and be able to obtain a government security clearance for work on US Army projects. These positions will remain open until filled.

Applicants should upload their resumes, college transcripts, and a list of four references to include their name, address and e-mail address. To apply, please go to the link: **https://jobs.ufl.edu/applicants/jsp/shared/Welcome_css.jsp** for detailed instructions on the submission process. For additional information about the Department and University, please visit our website at **ece.ufl.edu**.

The University of Florida is an Affirmative Action, Equal Opportunity Employer and encourages applications from women and minority group members. The University is committed to building a broadly diverse educational environment that fosters multicultural skills. Applicants should include in their cover letter information about how they will further this objective. According to Florida law, applications and meetings regarding applications are open to the public on request.

UNIVERSITY SPOTLIGHT

Duke UNIVERSITY

Eruditio et Religio

Research opportunities in high-dimensional data analysis

The Duke high-dimensional data analysis group is led by Robert Calderbank, Lawrence Carin, Ingrid Daubechies, David Dunson, Mauro Maggioni, and Rebecca Willett.

We are seeking accomplished applicants for postodoctoral research associate positions. Candidates must hold a PhD in mathematics, signal processing, statistics, or computer science, and the ideal candidate will have research experience in statistical learning theory, information and coding theory, Bayesian statistics, optimization theory, geometry, graph theory, or nonparametric estimation. The associate will work with multiple members of the above faculty team on funded projects to develop high-dimensional data analysis theory and methods. The associate will also be expected to help mentor graduate students working on related projects and participate in research leading to publications in top journals. The appointment, which can begin immediately, will be for a one-year contract with potential for renewal.

Applicants should email their CV, a brief statement of their background and interests and contact information for at least three references to:
Ellen Currin, ecurrin@ee.duke.edu
Department of Electrical and Computer Engineering
Box 90291, Durham, NC 27708

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Georgia Tech | College of Engineering

EMORY UNIVERSITY SCHOOL OF MEDICINE

Georgia Tech & Emory Joint Biomedical Engineering Department

The Wallace H. Coulter Department of Biomedical Engineering at Georgia Institute of Technology and Emory University, a joint department between Georgia Tech's College of Engineering and Emory University's School of Medicine, invites nominations and applications for tenure track faculty positions in biomedical imaging at all levels: assistant, associate, and full professor. We are particularly interested in individuals with an emphasis on medical image analysis, interventional imaging, in vivo molecular imaging, and optical imaging. The candidate's research should complement and be synergistic with our existing strengths and strategic initiatives including: MRI, molecular/optical imaging, systems biology, bionanotechnology, and vaccine development. For information on our research areas please see *Research Overviews* on our website, **www.bme.gatech.edu**. For individuals having an appropriate research focus, joint appointments with other departments including Radiology and Electrical and Computer Engineering will also be considered.

Candidates must hold a doctoral degree in biomedical engineering/science or a related discipline. Candidates should have the ability to develop a funded research program, and to participate in teaching and advising of undergraduate and graduate students. Candidates meeting these minimum requirements are encouraged to submit a: 1) letter of application, 2) curriculum vitae, 3) statement of research interests and their relationship to the aforementioned thrusts, 4) statement of teaching interests and their relationship to the Coulter Department's educational programs and 5) three letters of reference to the department chair via the BME online application system.

To apply visit: **http://www.bme.gatech.edu/welcome/jobs.shtml**.
Application deadline: December 1, 2011

Applications from women and underrepresented minorities are encouraged
Georgia Tech is an Affirmative Action//Employment Opportunity Employer

LEHIGH UNIVERSITY

Power Systems Engineering for Tomorrow's Electricity Grid

Lehigh University invites applications to fill a faculty position (rank open) in power systems engineering within the Department of Electrical and Computer Engineering. The candidate should have demonstrated qualifications and interest in the design, testing, and implementation of smart electricity systems. Contacts with funding agencies, ability to lead team proposal efforts, and knowledge of industry practices and contacts will be regarded as highly desirable. This faculty hire will be part of a new cluster focused on "Integrated Networks for Electrical, Information, and Financial Flows" consisting of multiple faculty members from across the university.

Applicants must possess (1) an earned doctorate, outstanding academic credentials, and a demonstrated record of success; (2) excellent potential for interdisciplinary research; and (3) the ability and commitment to teach courses at both undergraduate and graduate levels. The position will require developing broad research agendas and externally-funded, interdisciplinary research programs; supervision of M.S. and Ph.D. students; and contributing to the smart grid cluster of Lehigh University through innovative research and teaching.

Applications should include a statement of interest, a curriculum vita, list of publications, research and teaching statements, and the names and full contact information for at least three references. Application material is due on December 31, 2011 but will be accepted until the position is filled. Applications should be submitted at: **http://www.ece.lehigh.edu/powereng**. Inquiries may be addressed to **powersearch@lehigh.edu**.

Lehigh University is an affirmative action/equal opportunity employer. Lehigh offers excellent benefits including domestic partner benefits. For further information see: **http://www.lehigh.edu/~inprv/faculty/worklifebalance.html**

NJIT
New Jersey's Science & Technology University

Department Chair, Biomedical Engineering

The Department of Biomedical Engineering at New Jersey Institute of Technology (NJIT) invites applications for the position of Chair. The department, housed within the Newark College of Engineering, offers degrees from the baccalaureate to the doctorate and currently has ten tenured and tenure-track faculty, six teaching and research faculty, additional affiliated faculty from other departments and neighboring institutions, over 200 undergraduates, and 200 graduate students. The undergraduate degree is fully accredited by ABET. The department provides an excellent scholarly environment with research programs in the areas of neural engineering, cell and tissue engineering, rehabilitation engineering, biomechanics, and biomaterials.

Collaborative research and core facilities within our University Heights community include the University of Medicine and Dentistry of New Jersey - NJ Medical School, Neurological Institute of NJ, Molecular and Behavioral Neuroscience at Rutgers–Newark, NJ Center for Biomaterials, Kessler Rehabilitation Institute and the Public Health Research Institute (PHRI).

Candidates must have an earned doctorate in biomedical engineering or a related field. The successful candidate will have a sound vision of the future of biomedical engineering and the ability to lead and advance a student-centered and research-oriented department. He or she will have a demonstrated ability to work well with others, the ability to foster an atmosphere of collegiality in an environment of shared governance, and an established record of excellence in biomedical engineering research, education, and service sufficient to merit appointment as a tenured professor in the university. The successful candidate will be currently engaged in research and will be planning to continue as an active researcher.

The new chair is expected to start in the summer or fall of 2012. Consideration of applicants will begin on December 1, 2011. Applications should include a letter, current curriculum vitae, and the names and addresses (including e-mail addresses) of at least five references. The application should also include a vision statement for research and education in biomedical engineering and the candidate's preliminary vision for the department. Please visit https://njit.jobs and search using posting #0600717 to apply. Inquiries can also be addressed to Treena Arinzeh, PhD, Chair of the Search Committee, arinzeh@njit.edu. The search will continue until a successful applicant is appointed. *AA/EOE*

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Five Faculty Positions

Department of Electrical and Computer Engineering

FIU is a multi-campus public research university located in Miami, a vibrant, international city. FIU offers more than 180 baccalaureate, masters, professional and doctoral degree programs to over 42,000 students. As one of South Florida's anchor institutions, FIU is worlds ahead in its local and global engagement and is committed to finding solutions to the most challenging problems of our times.

The Department of Electrical and Computer Engineering (ECE) at Florida International University (FIU) is seeking applicants for five tenured and tenure-track positions at the Assistant, Associate and Full Professor levels. All the positions require an earned doctoral degree in Electrical Engineering, Computer Engineering or a closely related field. Applications are invited from individuals with strong expertise in the fields of energy systems (e.g., renewable energy, smart grids and power); Integrated nanotechnologies (e.g., nanocomputing, nanophotonics, Bio and Micro/Nano systems, 3D HSoC); communications (e.g., RF electronics, UWB, wireless communication systems, cognitive radio); network and computing systems (e.g., embedded systems, security, ubiquitous computing, visualization and multimedia, petascale computing) and closely related areas. All applications require scholarly accomplishments documented by a record of publication commensurate with the position sought. Applications for the Associate or Full Professor positions also require a documented strong history of success in the completion of sponsored research and a demonstrated ability to lead significant research efforts. The positions are available to start in Fall 2012.

FIU is a comprehensive Carnegie Research University in the High Research Activity Category and one of the fastest growing and largest public research universities in the United States. In recent years, the university has added a law school and has admitted the first class for the new medical school in 2009. FIU currently offers bachelor's, master's and doctoral degree programs in 11 colleges and schools, and is No. 1 in the nation in awarding bachelor's and master's degrees to Hispanic students.

The Department of Electrical and Computer Engineering (ECE) is one of the largest of six departments in the College of Engineering and Computing. ECE currently offers B.S. and M.S. degrees in both Electrical Engineering and Computer Engineering, and the Ph.D. degree in Electrical Engineering. Both undergraduate programs are accredited by ABET. The undergraduate enrollment is nearly 600 and graduate enrollment is at 150, including 70 Ph.D. students. Further Information about the ECE Department including the current research activity can be accessed through **http://www.ece.fiu.edu**. Research centers are available for collaboration within the College (**www.cec.fiu.edu**) and at the university level (**www.fiu.edu**).

Applications must be submitted electronically to: **www.fiujobs.org** (SEARCH POSTINGS, Position Number 35521, 35522, 35523, 44655 and 45549).

Processing of applications will begin on January 15, 2012. Application materials should include curriculum vitae, a list of at least three references, and statements on teaching and research. Inquiries and applications will be kept in confidence, pursuant to the Sunshine Laws of the State of Florida. Women and minorities are strongly encouraged to apply.

FIU | FLORIDA INTERNATIONAL UNIVERSITY

FIU is a member of the State University System of Florida and is an Equal Opportunity, Equal Access Affirmative Action Employer.

UNIVERSITY of

HOUSTON

CULLEN COLLEGE of ENGINEERING

Department of Electrical & Computer Engineering

Tenure Track Faculty Positions in Control & Energy Systems

The Department of Electrical and Computer Engineering (ECE) invites applications for tenure track positions at the Assistant Professor level in the following two areas.

Control Systems: We are seeking a faculty member at the Assistant Professor level with an expertise in sensing, modeling, analytics, and computation technologies to address control problems arising in electrical energy systems and/or bio-medical systems.

Electrical Energy Systems: We are seeking a faculty member at the Assistant Professor level with an expertise in any of the following areas: advanced materials, sensing, modeling, and embedded computation technologies, to address problems arising in electrical energy area, especially the Smart Grid, Efficient transmission and distribution, Alternate sources of Energy, Cyber defense of energy infrastructure, advanced energy related analytics and algorithms, and future transportation systems.

Applicants in either area are expected to develop nationally recognized, cross-disciplinary research programs in collaboration with major energy/infrastructure related entities on campus, and around the world. Houston is a major hub of energy related industries and research. The UH campus itself offers several energy-related centers and a major new Energy Research Park.

Applicants must have an earned Ph.D. degree in electrical/computer engineering, or a closely related field within the applied physical sciences. Successful applicants must demonstrate strong potential to develop an externally funded research program, build a record of peer-reviewed publication, and develop innovative courses in the area of control systems or in the area of electrical energy systems.

The department is undergoing an exciting period of research growth driven by rising NRC rankings, a Carnegie Tier 1 status for the University, and committed leadership. The Houston area is widely considered the "energy capital" of the United States.

Candidates should send a cover letter, curriculum vitae, research statement, teaching statement, and at least three references to: Prof. Badri Roysam, Department of Electrical and Computer Engineering, University of Houston, N325 Engineering Bldg. 1, Houston, Texas 77204-4005. Electronic copies of these documents should also be sent as a single PDF file labeled "LastName-FirstName.PDF" to **ECEfacultysearch@EE.UH.EDU**. The start date of this appointment can be as early as January 2012. Applications received before **November 1, 2011** will receive priority consideration, and review will continue until the positions are filled.

The University of Houston is an equal opportunity/affirmative action employer. Minorities, women, veterans, and persons with disabilities are encouraged to apply.

For more information, please visit the department website at:

www.egr.uh.edu/ece

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The Edward S. Rogers Sr. Department of Electrical & Computer Engineering UNIVERSITY OF TORONTO

The Edward S. Rogers Sr. Department of Electrical and Computer Engineering at the University of Toronto invites applications for faculty positions at the Assistant/Associate Professor rank, with a start date of July 1, 2012, in the following four areas:

1. Electrical Power Systems

Outstanding candidates in all areas of Electrical Power Systems are encouraged to apply. Applications for this position should be addressed to Professor Reza Iravani, Chair of the Electrical Power Systems Search Committee, and sent to: **PowerSearch@ece.utoronto.ca**.

2. Electronic Circuits, Devices and Technologies

Applications are welcomed from outstanding candidates in all areas of Electronics including, but not limited to, analog, mixed-signal, RF, and VLSI circuits, as well as beyond-CMOS technology and integrated microsystems. Applications for this position should be addressed to Professor Tony Chan Carusone, Chair of the Electronics Search Committee, and sent to: **ElectronicsSearch@ece.utoronto.ca**.

3. Communication Systems

Outstanding candidates in all areas of Communications are encouraged to apply. An area of particular interest is streaming and interactive communication systems design, including the study of fundamental limits on the representation and transmission of delay-sensitive media, architectures for interactive streaming, real-time streaming in wireless networks, and distributed signal processing. Applications for this position should be addressed to Professor Raviraj Adve, Chair of the Communication Systems Search Committee, and sent to: **CommSearch@ece.utoronto.ca**.

4. Software Systems

Applications are welcomed from outstanding candidates in all areas of Software Systems, with particular interest in cloud computing and information storage systems. All areas of cloud computing will be considered, including architectures, operating systems, security, virtualization and resource management, mobile user support and applications. Areas of interest in storage systems include, but are not limited to, hierarchical storage systems, novel storage devices and technologies, mobility considerations, and energy optimizations. Applications for this position should be addressed to Professor Baochun Li, Chair of the Software Systems Search Committee, and sent to: **SoftwareSearch@ece.utoronto.ca**.

Successful candidates are expected to pursue excellence in research and teaching at both the graduate and undergraduate levels, and must have (or be about to receive) a Ph.D. in the relevant area.

The Edward S. Rogers Sr. Department of Electrical and Computer Engineering at the University of Toronto ranks among the top 10 in North America. It attracts outstanding students, has excellent facilities, and is ideally located in the middle of a vibrant, artistic, and diverse cosmopolitan city. Additional information on the department can be found at: **www.ece.utoronto.ca**.

Applicants must submit their applications by email to one of the four email addresses given above. Please submit only Adobe Acrobat PDF documents and include a curriculum vitae, a summary of previous research and proposed new directions, a statement of teaching philosophy and interests, and the names of three references.

Applications should be received by **December 31, 2011**.

The University of Toronto is strongly committed to diversity within its community and especially welcomes applications from visible minority group members, women, Aboriginal persons, persons with disabilities, members of sexual minority groups, and others who may contribute to the further diversification of ideas.

All qualified candidates are encouraged to apply; however, Canadian citizens and permanent residents will be given priority. Rank and salary will be commensurate with qualifications and experience.

UNIVERSITY OF TORONTO
The Edward S. Rogers Sr. Department of Electrical & Computer Engineering
10 King's College Road
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LEHIGH UNIVERSITY

ECE Department Endowed Chair

Sherman-Fairchild Professor of Electrical and Computer Engineering

The Department of Electrical and Computer Engineering at Lehigh University seeks nominations and applications for the Sherman-Fairchild Professor in the broad areas of nanoelectronics, integrated micro/nanosystems, semiconductor power electronics, photovoltaics, energy-efficient electronics bioMEMS, and nanofabrication. Candidates should have demonstrated the vision and leadership required to serve as Director of the Sherman-Fairchild Center and be a leader in Lehigh's campus-wide Energy, Environment, and Health Initiatives. A successful candidate will be expected to develop a strong, externally funded research program that complements Lehigh's existing strengths and has significant potential for interdisciplinary research with international impact. Excellence in undergraduate and graduate teaching and the integration of research and education are core values of Lehigh's mission.

This is a senior appointment to an endowed chair position. Using our online application, (**http://www.ece.lehigh.edu/sfcsearch**) applicants should submit a single PDF file consisting of cover letter, complete curriculum vitae, research and teaching statements, and the names and contact information for at least three references by **December 31th, 2011**, but applications will be accepted until the position is filled. A start date of August 23rd, 2012, or sooner is preferred. Nominations of potential candidates are also welcome, and will be reviewed and contacted by the Search Committee. Nominations and specific questions may be addressed to Prof. Filbert J Bartoli, Endowed Chair Search Committee, Department of Electrical and Computer Engineering, Lehigh University (**SFCsearch@Lehigh.edu**).

Lehigh University is an affirmative action/equal opportunity employer and does not discriminate on the basis of age, color, disability, gender, gender identity, marital status, national or ethnic origin, race, religion, sexual orientation, or veteran status.

KING'S College LONDON

School of Natural and Mathematical Sciences

Centre for Telecommunications Research

CHAIR IN TELECOMMUNICATION NETWORKS

(Full Professor) Ref: A9/CEE/624/11-SR

Professorial grade, salary is negotiable.

READER IN TELECOMMUNICATION NETWORKS

(Associate Professor) Ref: A8/CEE/625/11-SR

£46,696 - £54,133 per annum plus £2,323 London Allowance.

The Centre for Telecommunications Research (CTR) maintains an exceptional reputation for high quality work, which puts it in a strong position to contribute to all aspects of the creation of the universal communications systems of the future. Some 40 researchers are currently working within the CTR, including academic staff, research staff, research students and visiting academics. The CTR is a dynamic research centre, drawing in talented researchers from the world over and reacting rapidly to the changing technological landscape.

King's College London is a research-led university based in the heart of London with nearly 23,500 students (of whom more than 9,000 are graduate students) from nearly 150 countries, and some 6,000 employees.

The new posts of Chair in Telecommunication Networks and Reader in Telecommunication Networks are part of the University's ongoing strategic investment in the Centre.

Research areas of interest are:

- Advanced network architectures (Future Internet)
- IP based protocol design, mechanisms and algorithms for both fixed and wireless networks
- Cognitive and self-organising networks
- Mobile Internet
- Internet of Things
- Network management

It is essential that applicants have the enthusiasm and commitment required to contribute to the further development of the research standing of the Centre. Further information on the Centre is available at: www.ctr.kcl.ac.uk

The appointments will be made, dependent on relevant qualifications and experience, within the scales shown. Benefits include an annual season ticket loan scheme and a final salary superannuation scheme.

For an informal discussion of the post please contact Professor Hamid Aghvami on +44 (0)20 7848 2898, or via email at hamid.aghvami@kcl.ac.uk.

Further details and application packs are available on the College's website at www.kcl.ac.uk/jobs, or alternatively by emailing Human Resources at hsrecruit6@kcl.ac.uk. All correspondence should clearly state the job title and reference number.

The closing date for receipt of applications: 1 December 2011

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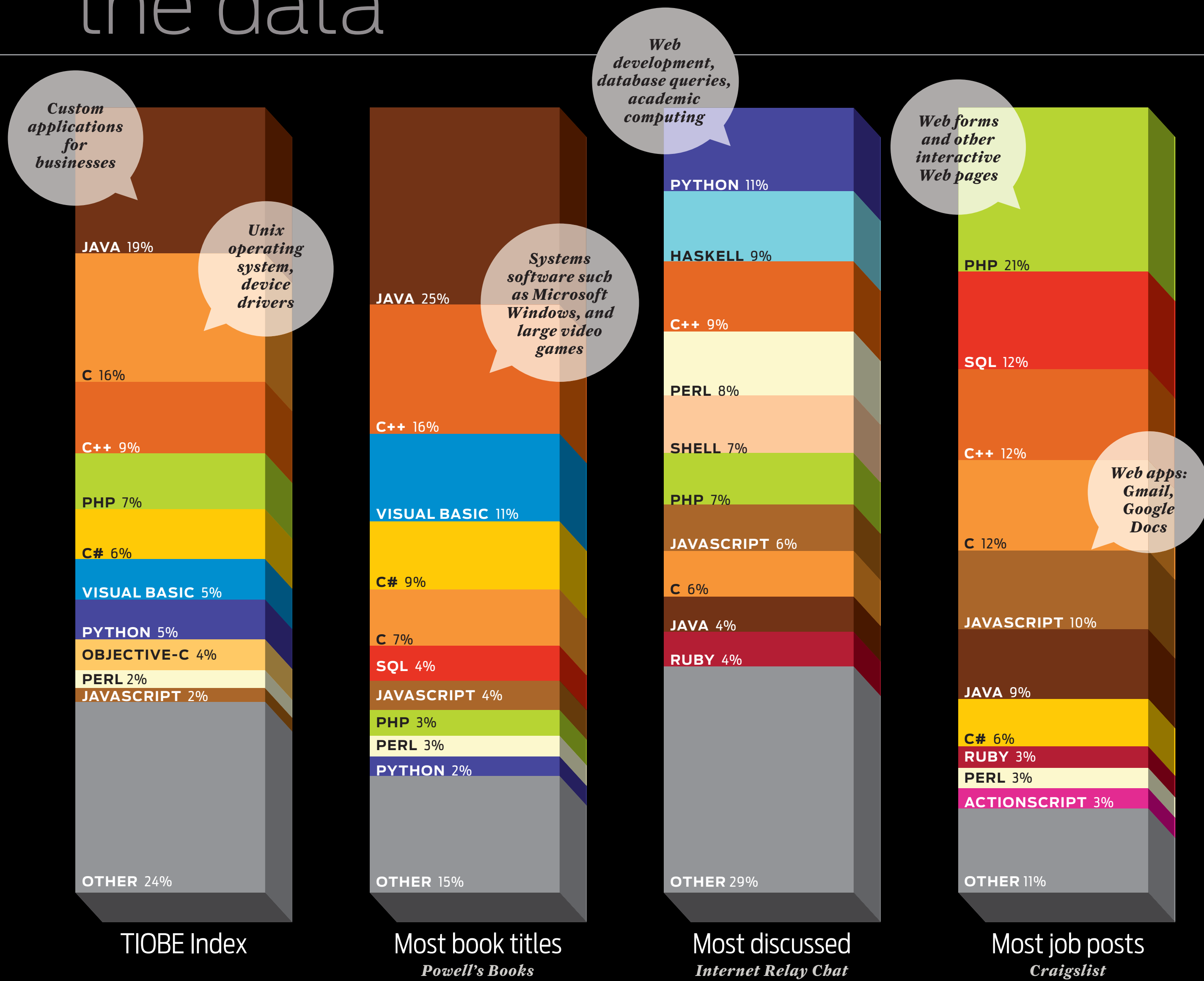

The Top 10 Programming Languages

LISTING PROGRAMMING languages is easy—Wikipedia's page has more than 600 entries—but ranking them by popularity is hard. As David Welton, curator of the site LangPop.com, points out, you can't send out a horde of researchers to look over programmers' shoulders and note what languages they're coding in. So you have to get at it indirectly.

To do that, you can search the Web and find numbers to use as a proxy. And you can tailor the search to target different kinds of popularity: Which languages are the most sought after in the job market? Check a job site. Which are used by elite programmers? Look in on their chat sessions. How established is a language? Visit an online bookstore—new and esoteric languages don't have many reference books dedicated to them.

The data here come in part from TIOBE, a software research firm based in Eindhoven, Netherlands. The analysts there produce an aggregate index each month. I also looked at Welton's LangPop.com, which shows the results of individual searches, such as on Craigslist, Internet Relay Chat, and Powell's Books.

Generally speaking, the languages being talked about by programmers online aren't quite the same as the ones at the top of the TIOBE Index or those that have spawned a lot of book titles (C++ is an exception). The most sought after by employers seem to be PHP, a language used in Web development, and SQL, which is used for writing database queries. No surprises there.

What has been interesting in recent years is the rise of JavaScript for writing Web-based applications that connect users to databases—think Gmail. In fact, JavaScript's ascent is largely due to Google's creation of the V8 JavaScript engine, a speedy compiler that powers its Chrome browser.

And then there's Objective-C, which underlies Mac OS and iOS and was barely in TIOBE's top 40 in 2008. But since then, it's climbed rapidly in popularity because people have been using it to write apps for the iPhone and iPad. —*Ritchie S. King*

SOURCES: TIOBE, LangPop.com
Because of rounding, categories may not total 100 percent.

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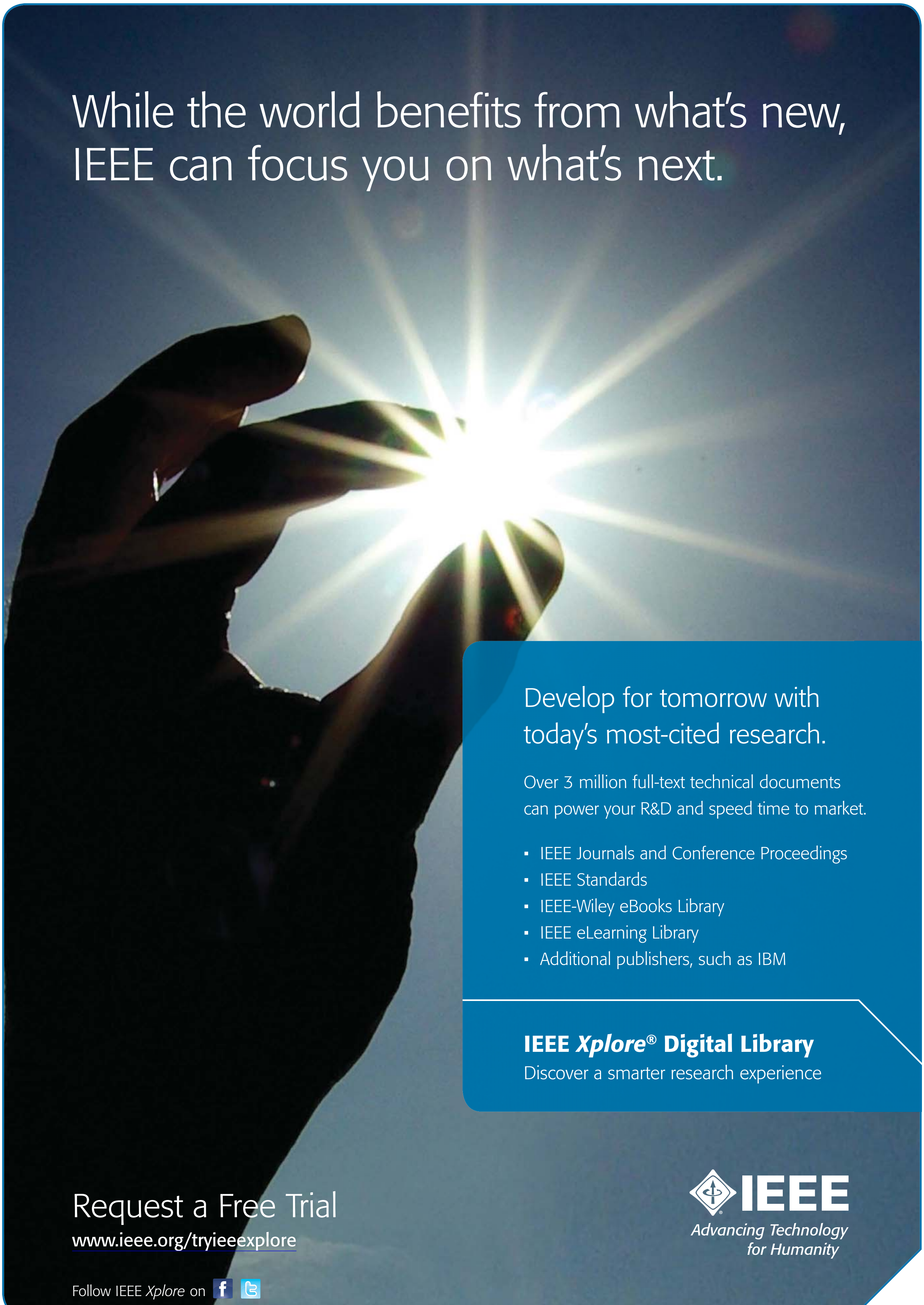
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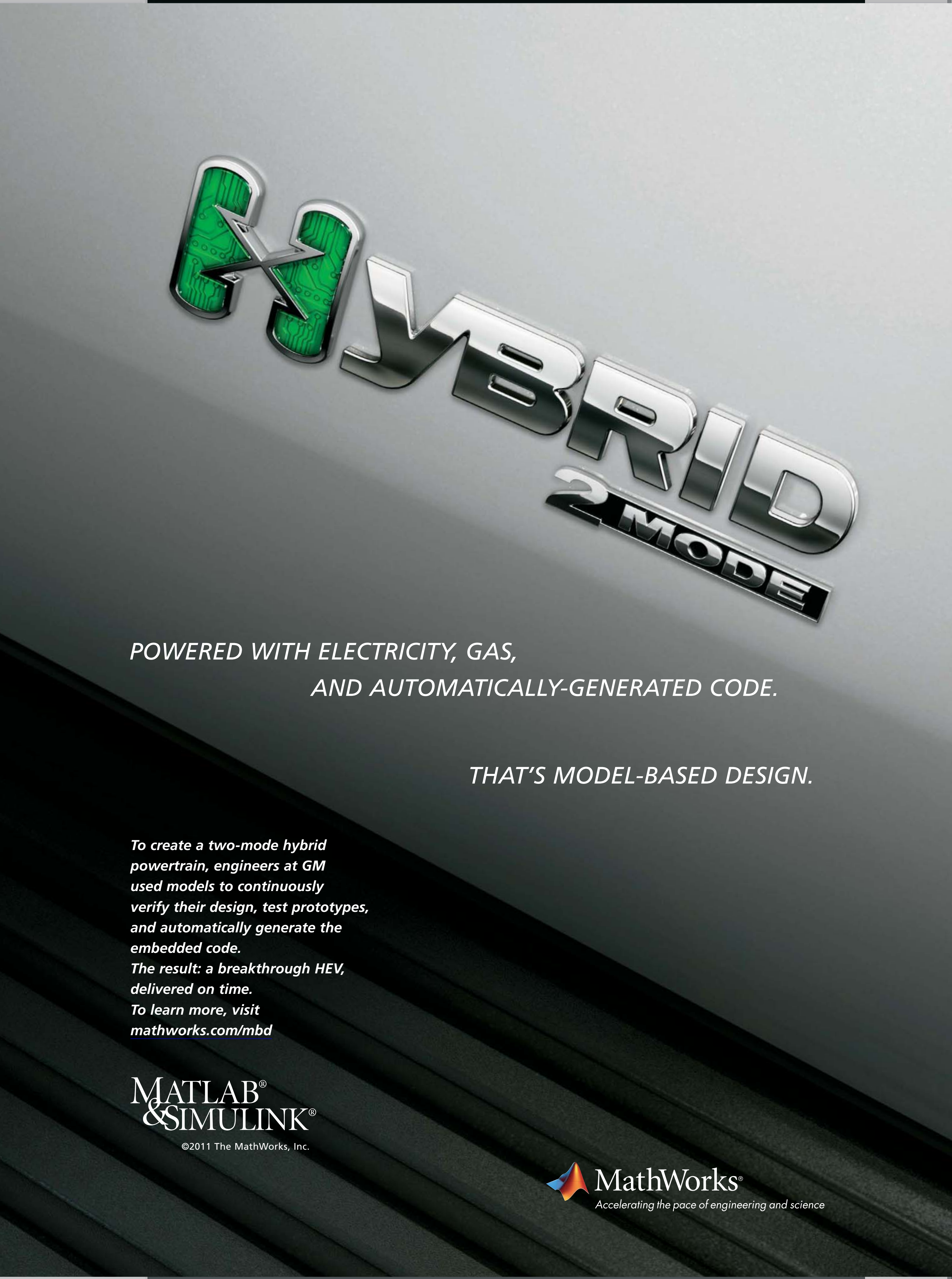
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