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THE MAGAZINE OF TECHNOLOGY INSIDERS
02.08

SPECIAL ISSUE:
DREAM JOBS 2008

SIGRID CLOSE STUDIES SHOOTING STARS WITH THE WORLD'S BIGGEST RADARS

AUSTRALIA'S TRANSCONTINENTAL SOLAR CAR RACE

WIRELESS'S VIRGIN TERRITORY

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THE EXTRA MILE: David Downey designs and then field-tests fitness products; Roger Hill builds computers to track penguins in Antarctica; the Nuna 4 solar car races through Australia.

PHOTOS: DOWNEY: COLBY LYSNE; HILL: RICK DAHMS; PENGUIN: EUREKA/ALAMY; NUNA 4: HANS-PETER VAN VELTHOVEN

COVER: CHIP SIMONS

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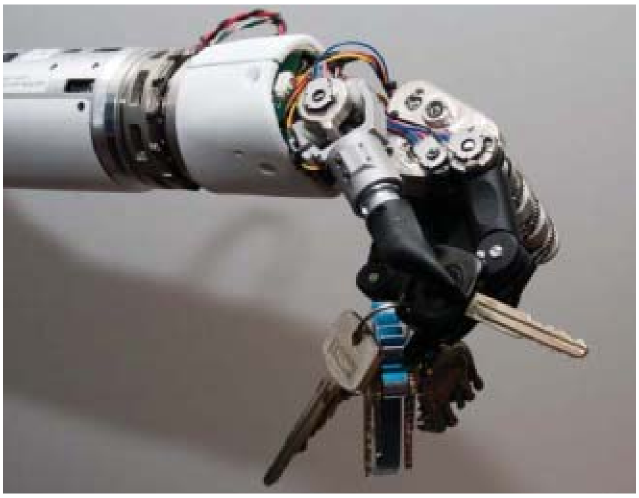

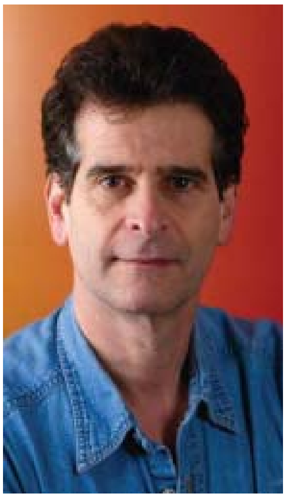

THE LUKE ARM [above] empowers its users to handle a cordless drill as artfully as a set of keys; Dean Kamen [right] hopes to start clinical trials this year.

PHOTOS, FROM LEFT: DIRK VAN DER MERWE; DEKA RESEARCH; NASA

AT SPECTRUM ONLINE

DEAN KAMEN'S ARTIFICIAL ARM

WWW.SPECTRUM.IEEE.ORG

DEAN KAMEN—perhaps best known for inventing the Segway—let *IEEE Spectrum*'s Sarah Adee tour his company, DEKA, where he has been working on a prosthetic arm for the U.S. Defense Department.

The Luke Arm, named for the extraordinarily lifelike prosthesis worn by Luke Skywalker in *Star Wars*, can be adapted to any amputation and any user interface: it can even be wired directly into the nervous system. Kamen explains how he is reinventing the prosthetic arm to take it from "the Flintstones," as he says, into the 21st century.

ONLINE FEATURES:

FEELING A LITTLE FLAT? *Spectrum*'s Josh Romero looks at how long-promised technologies will finally let you capture, display, and re-create the three-dimensional world in all its splendor.

LEARNING FROM KATRINA In the next installment of the video series exploring engineering lessons taken from Katrina, Denise Wilson examines the continuing impact of the disaster on local residents.

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NASA HELPS SOCIETY CELEBRATE 50 YEARS

Learn how the IEEE Electromagnetic Compatibility Society was able to get its commemorative anniversary pin on the recent *Endeavor* shuttle mission. NASA mounted the pin on a plaque and presented it to the IEEE.

IEEE COMPUTER SOCIETY LAUNCHES CAREER SITE

Keep up with technology advances and new business approaches on the IEEE Computer Society's Build Your Career Web site, which features online technical courses, training aids, and columns that address industry issues.

CONFERENCE COVERS RFID

Find out about the technical and policy challenges facing radio-frequency identification technologies at the IEEE International Conference on RFID, set to take place 16 to 17 April in Las Vegas. Topics will include antennas and security and application issues.

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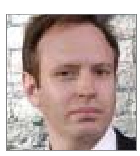
SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

contributors

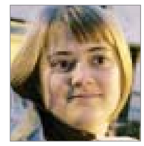
DEAN ADAMS is a journalist and television producer based in Bangkok. He traveled to northwest Thailand to interview Salinee Tavaranan [p. 36] and found the experience enlightening. "[It] made me understand that alternate sources of energy are much easier to implement and maintain than I'd thought possible. Approached thoughtfully, they work with nature, rather than against it. It opened my eyes."

COLBY LYSNE, based in Kansas City, Mo., has shot suits, athletes, and artists for dozens of national magazines. "Photographing Dave Downey at Garmin's world headquarters was a blast," Lysne says [p. 27]. "We didn't even get in trouble for watering the floor. Now that's a great corporate culture!"



ROBB MANDELBAUM, a freelance journalist based in Brooklyn, N.Y., reports in Update on the first big upgrade since the 1870s of the technology used worldwide to stop freight trains [p. 12]. Look for his feature article on the struggle to deploy this revolutionary technology in a forthcoming issue of *IEEE Spectrum*.

PAUL McFEDRIES, who writes our Technically Speaking column [p. 21], is a technical and language writer with more than 40 books to his credit. He also runs Word Spy, a Web site and mailing list that tracks new words and phrases (http://www.wordspy.com).



MORGEN E. PECK, one of our interns in 2007, wrote the lead story in Update [p. 7], about a questionable technology for breast-cancer screening. Using her background in neuroscience, Peck has reported on electronic treatments for migraines and the effects of brain implants on human behavior for Spectrum Online.

VASIK RAJLICH is the programmer of Rybka, currently the highest-rated computer-chess program in the world. He was profiled in our 2007 Dream Jobs report [February]. This month the former international chess master reviews *King's Gambit: A Son, a Father, and the World's Most Dangerous Game* by Paul Hoffman [p. 20].

BEHZAD RAZAVI, an IEEE Fellow, is a professor of electrical engineering at the University of California, Los Angeles. In "Gadgets Gab at 60 GHz" [p. 40], he shows how tapping into the upper reaches of the radio-frequency spectrum can make the wireless home a reality.

CHIP SIMONS, who photographed Sigrid Close for our cover and her Dream Jobs profile [p. 24], got hooked on photography working for his high school newspaper. He realized that it improved his social life and allowed him to miss class for official business. He and Close bonded, Simons says, and "shared a moment," reminiscing about the times each had lived in eastern Pennsylvania.

CLOCKWISE FROM TOP LEFT: WORAWALAN BOONRAVIKUL; CHRISTOPHER GUDAS; ANGELINA HUANG; EMILY NASH; RANDI SILBERMAN; STEVE CHELLBERG

back story

TINE LAVRYSEN

Dispatch From Down Under

BEFORE THE reporters covering the Panasonic World Solar Challenge were released into the wilds of Australia, a safety officer sat them down and delivered a rapid-fire set of instructions: Remember to constantly refuel. (You might find yourself stranded 300 kilometers from the nearest town.) Don't scramble around in the brush. (Australia is home to 12 of the world's deadliest varieties of snakes.) Don't drive at night. (You might hit a kangaroo.)

Associate Editor Sandra Upson [above], preparing for her solo trek across the continent, began to wonder whether it was such a good idea after all. Sure, no one knew which of the solar cars would successfully reach Adelaide, 3000 km away. But would *she* get that far? Mildly terrified, she stopped by a grocery store to pick up a dozen cans of Red Bull.

She didn't need them. During her drive through the vast empty spaces of the outback, the sight of a grazing emu or, inexplicably, a cross-country bicycle rider helped ward off drowsiness. Then there were the dead kangaroos, mostly roadkill, and the large vultures that flapped languidly above the bodies.

Travelers who find baby kangaroos, or joeys, in the pouches of their fallen mothers take them to a rescue center run by Chris "Brolga" Barns, in the oasis of Alice Springs. He rears them until they're old enough to return to the wild, supporting the effort with donations from tourists, who line up to hold sleeping kangaroos for AU $5 a hug.

As Barns explains it, it's all for the best in this, the harshest of all worlds. Exhaust fumes from cars driving through the arid landscape leave traces of moisture, and those droplets support the growth of vegetation, which in turn attracts animals to the shoulder of the highway. Upon meeting a clan of solar racers, Barns praised their vehicles for their kangaroo-friendly lack of emissions. ❑

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 first Update page is in *IEEE Spectrum*, Vol. 45, no. 2 (INT), February 2008, p. 7, or in *IEEE Spectrum*, Vol. 45, no. 2 (NA), February 2008, p. 13.

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There's polite murmuring about working toward a standard, but that could also be players, sotto voce, choosing up teams

spectral lines

One Format War Is Over. Is Another Beginning?

PAUL SAKUMA/AP PHOTO

FORMAT WARS. They've been the Achilles' heel of the consumer electronics industry, and the bane of consumers, since the VHS vs. Betamax hostilities of the early 1980s. Standards-setting organizations like the IEEE and industry consortia hold countless meetings to avoid them, yet they break out with astonishing regularity.

The battle of the blue disks seems, finally, to be over. For several years now, two separate industry alliances, one led by Sony, Panasonic, and Philips, the other by Toshiba and NEC, have clashed over the next-generation digital disk format.

Both contenders—Blu-ray Disc and HD-DVD—use blue lasers to read and write data and have exquisitely high-quality video resolution. The biggest differences between them: Blu-ray has larger storage capacity and is more expensive; HD-DVD has slightly less storage and is cheaper. Neither advantage has been compelling. And since moving from DVD to either Blu-ray or HD-DVD means getting a new player and a high-definition TV, consumers haven't exactly been stampeding to the stores to change over. On top of which film studios have been putting out high-definition home movies in both formats, which always gives consumers pause.

But days before the 2008 International Consumer Electronics Show (CES), in January, Warner Brothers—a studio that had been bankrolling HD-DVD big time—announced it would no longer support that format. The HD-DVD alliance immediately canceled its long-scheduled CES press conference, a move that signaled surrender.

So if you've been on the fence about upgrading your home video system, go ahead and climb down on the Blu-ray side.

But just as one conflict ends, a new one is heating up. Oh, the sides are politely murmuring about working toward a standard, but those murmurs could also be the sound of players choosing up teams.

At stake? The ability to send free, over-the-air local television, broadcast to cellphones and other consumer electronics devices, over U.S. broadcasters' existing spectrum.

At CES, Woo Paik, president and CTO of LG Electronics, brought out prototypes of what LG calls MPH devices—Mobile Pedestrian Handhelds. He said the company will be ready to ship products about a year from now. Then Samsung's director of digital media, J.W. Park, brought out models of what Samsung calls Advanced-VSB devices. The two sets of devices decode two different technologies that modify the U.S. digital broadcast system to receive a strong signal at normal driving speeds, something that's not currently possible.

The idea has a lot going for it. With a tuner chip added to your cellphone, iPod, or other portable device, you'll be able to watch local news, sports, weather—anything you can get over the air. It'll be an inexpensive extra for manufacturers and a nice feature for consumers. It'll cost broadcasters a bit to add the necessary equipment to their towers, but they'll benefit from the larger audiences.

But, alas, now there are at least two competing technologies for a prize only one can win: no broadcaster is going to put multiple sets of equipment on its towers, and no consumer is going to change devices or swap out cards while driving down the highway. Both LG and Samsung made it clear that they're moving ahead and will continue to do so.

We'll likely hear a lot more about this as the year goes on. Stay tuned. —TEKLA PERRY

LIVE FROM LAS VEGAS
At CES, wireless was sizzling—wireless USBs, WiMedia, WiMax, HDMI, and extreme proximity wireless like Sony's new Transfer Jet technology.

The new cool gizmos use flash. High-definition camcorders that store 5 or more hours of video on a 32-gigabyte memory card will make disk and tape cameras as dated as the dry-plate kind.

forum

Letters do not represent opinions of the IEEE. Short, concise letters are preferred. They may be edited for space and clarity. Additional letters are available online in "And More Forum" at http://www.spectrum.ieee.org. Write to Forum, *IEEE Spectrum*, 3 Park Ave., 17th Floor, New York, NY 10016-5997, U.S.A.; fax, +1 212 419 7570; e-mail, n.hantman@ieee.org.

TOUGH TASERS

REGARDING THE articles on Taser guns in the December issue ["How a Taser Works"], I suggest that they left out what should have been a very critical part of the analysis. To consider the consequences of not using or having access to a Taser should be a necessary part of such a review.

As a retired peace officer, I was a victim of numerous assaults. For a variety of reasons, it is axiomatic that keeping distance from an assaulting individual is important. In my day, the tools were a gun or a stick. Sticks produce fractured skulls and other broken bones, I assure you. While I do not know any statistics, I am comfortable in asserting that there is much more danger from a fractured skull than from a Taser shot. Had such a tool been available in my day, I would have put fewer people in the hospital.

GLENN MARIN
Whittier, Calif.

TO SAY that 1.9 milliamperes is the average current available from a Taser X26, while nominally and technically correct, completely understates and misrepresents the electrical output from these devices. At pulse durations of 100 to 140 microseconds and a pulse-delivery rate of 19 hertz, the duty cycle of the Taser waveform is less than 0.3 percent. As such, the delivered average current will be relatively low. I recently measured the electrical output from a Taser X26 into a series of precision high-voltage, noninductive 300-, 1000-, and 4000-ohm loads and found that the median peak currents approach 4 amperes, with maximum peak currents exceeding 8 A. The neuromuscular-incapacitating effects of the Taser are due more to the effects of these peak currents than to the much lower stated average current.

LARRY FENNIGKOH
IEEE Member
Milwaukee

I WAS VERY disappointed with the Taser write-up. The authors are no doubt very talented, but engineer Mark W. Kroll sits on the Taser International board, and electrophysiologist Patrick Tchou received a "gift" of test equipment from Taser. This may explain why Kroll provides no details on the four court cases in which the Taser was found to be the primary cause of death and disparages three of them. Were they thrown out of court on a technicality or because the Taser was not to blame? It also may explain why Tchou doesn't complain about a current level only one-fourth of what triggers fibrillation in pigs and doesn't report on the four fatalities brought to court. I expect *IEEE Spectrum* to disqualify such one-sided articles when dealing with issues as controversial as the safety of the Taser.

MARTIN LURIE
IEEE Member
Newton, Mass.

PLAYING CLEAN

I WAS A bit dismayed to read "Playing Dirty" [December]. What Richard Thurman is doing is against the terms of service of online games. Glorifying such actions in these games is wrong. It has little to do with people buying bling on eBay and more to do with the fact that these people destroy the games. It would have been better to document how to combat this in online gaming and not treat it as the next big thing to make money.

SIMON O'DOHERTY
IEEE Member
Dublin

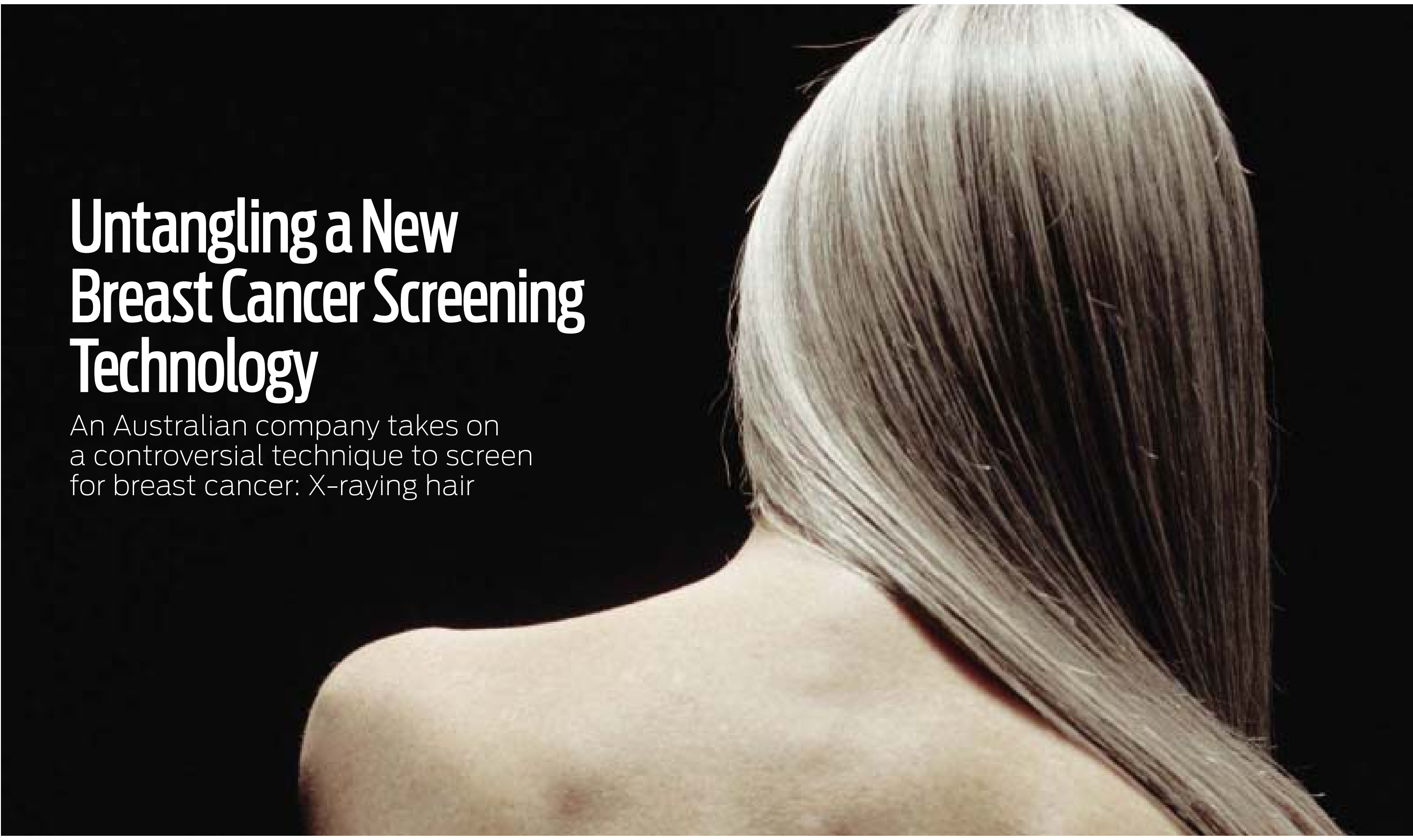
CATCHING A CODE

IN THEIR article "Controlled Chaos" [December], Antonio Nucci and Steve Bannerman described their proposed early-warning detection of viruses and worms by measuring the entropy of traffic on trunk communication lines. That may indeed protect the network; however, individual computers would still retain snippets of viral code. The authors do not address the difficult tasks of identifying the signatures of those viral codes after an attack on the network and of purging the malicious code.

MYRON KAYTON
IEEE Life Fellow, Santa Monica, Calif.

more online at www.spectrum.ieee.org

update



Untangling a New Breast Cancer Screening Technology

An Australian company takes on a controversial technique to screen for breast cancer: X-raying hair

FERMISCAN HOLDINGS, a start-up firm in Sydney, Australia, says it plans to commercialize a controversial breast-cancer-screening technology that most scientists have given up on. The technology would replace traditional X-ray mammography with a test requiring just a hair sample—and access to a multimillion-dollar particle accelerator called a synchrotron. Fermiscan is betting that women will greatly prefer offering a hair sample to suffering the discomfort of mammography. Having analyzed 800 hair samples collected from women as they go in for routine breast exams, Fermiscan says it will be ready to start offering screenings by the end of 2008. The trouble is, eight years after the technique was first reported, no independent laboratory has ever been able to make it work.

Fermiscan's test is based on technology licensed from Veronica James, a physics professor at the Australian National University in Canberra, who reported in 1999 that she could detect an abnormality in the hair of women with breast cancer. In her research, James shot a concentrated beam of X-rays at single strands of hair. When the beam hit the hair, the diffracted X-rays formed a pattern on the detector related to the molecular structure of keratin, a protein found in hair. James claimed to find a diffuse additional ring in the diffraction pattern from hair samples of women with breast cancer.

After she published her results, many women were eager to ditch the discomfort of their yearly mammograms. "All the women who were at our breast-cancer clinic were saying: 'Don't give me any of these tests. Here's some of my hair,' " says Keith Rogers, a medical-imaging expert and professor of materials science at Cranfield University, in Swindon, England. He was one of the first to try to reproduce James's work. When Rogers failed to find the same diffraction pattern, James publicly rejected his results, claiming that Rogers had not properly followed her methodology. James, who formerly consulted for Fermiscan, declined to comment for this article.

At least seven research groups, including one with which James

A HAIRY PROBLEM: An Australian firm plans to launch a competitor to X-ray mammography. The technique finds marks of breast cancer in the X-ray diffraction pattern of a woman's hair.
PHOTO: JOHNNY HERNANDEZ/GETTY IMAGES

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

"It would be bloody wonderful if it worked" —MEDICAL IMAGING EXPERT KEITH ROGERS REGARDING FERMISCAN'S TECHNOLOGY

update

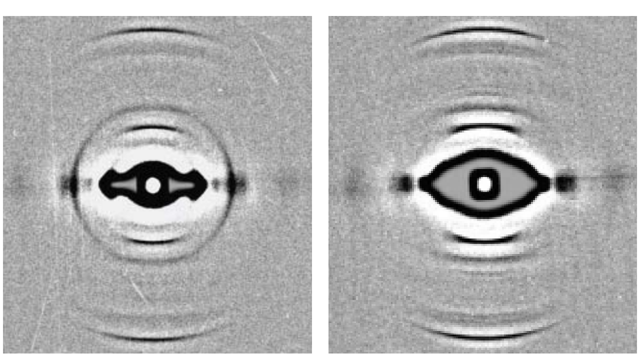
briefly collaborated, have now tried and failed to reproduce her results. "Some very eminent people have tried to reproduce it," says Rogers. "The irritating thing is I so much want to believe her, but I can't find the proper evidence."

Halfway through its recent trial, Fermiscan claimed that hair analysis has an 82 percent probability of detecting breast cancer in a person who has the disease, nearly matching the best results from mammography trials. However, hair analysis has only a 77 percent chance of correctly confirming that people without the disease really don't have it, making the test less reliable than some mammography trials.

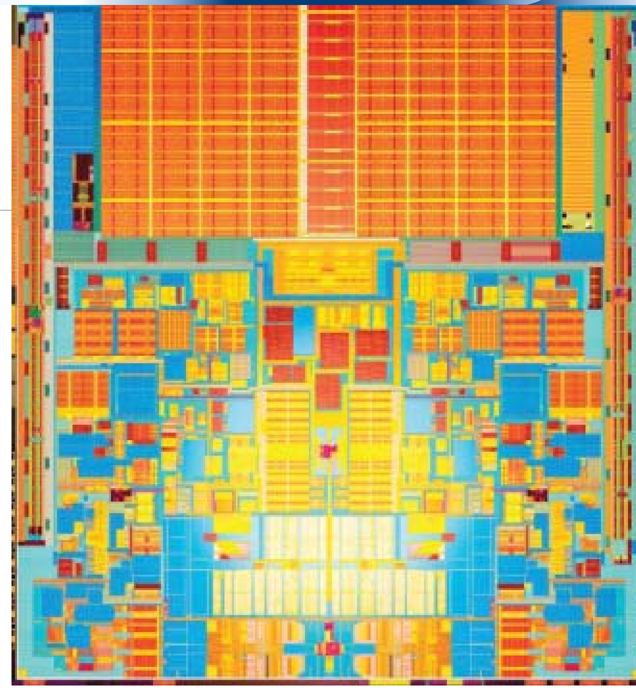
If it succeeds, Fermiscan could wedge itself into a lucrative market. About 1 million mammograms were conducted in 2007 in the United States alone, according to the U.S. Food and Drug Administration. Companies such as GE, Hologic, and Siemens are encouraging clinics to upgrade and purchase digital and three-dimensional X-ray mammography machines at a cost of hundreds of thousands of dollars per unit.

The Fermiscan test will cost the consumer about US $200 per sample, says David Young, Fermiscan's managing director. That's more than the $50 to $150 it costs for a mammogram in the United States, but with Fermiscan the clinic wouldn't need to purchase and maintain its own imager. The Fermiscan test should take just 24 hours to complete, including the time it takes to ship the hair to the Advanced Photon Source at Argonne National Laboratory, in Illinois, where Fermiscan has its tests done. Young says that the company will first market its services in Southeast Asia, through a joint venture with regional health-care provider Avia Reed International, in Singapore.

Although most scientists in the field have given up on the technique, some remain hopeful that it will work. "I wish [them] really well because it would be bloody wonderful if it worked," says Rogers. —MORGEN E. PECK



EYE-OPENING: X-ray diffraction patterns from the hair of women with [left] and without [right] breast cancer. PHOTO: FERMISCAN



INTEL

Intel Makes A Big Jump In Computer Math

Long the ugly stepchild of computer arithmetic, division is getting a much needed makeover

WHAT DOES the mortgage crisis have to do with microprocessor architecture? It turns out that calculating prices for those financially dubious mortgage-backed securities is a division-intensive process, and division has long been the weak link in a microprocessor's arithmetic operations. With Intel's new crop of 45-nanometer processors, code-named Penryn, the company is making the first substantial upgrade in its processors' divider since the original Pentium came out in 1993. The speedup doubles the number of bits calculated with each tick of the processor's clock and will make a substantial difference to financial and scientific computing. And because Intel powers so much of the computer market, the development could tempt programmers to retreat from the less accurate but faster software tricks they've used as a substitute for division.

"Divide had become the long pole in the tent," says Steve Fischer, the lead architect for Penryn. "We tried at least to chop the pole in half. It's still long compared to some functions. But it's a lot better."

The new divider is a variation on the old one, known as SRT Radix-4. SRT (for Sweeny, Robertson, and Tocher) is basically a souped-up version of long division that generates two bits of the answer with each step. The new Radix-16 divider works fundamentally the same way but computes four bits in each step. Getting those other two bits was no simple task. "I would say that the divider really pushed the edge in terms of the max clock frequency performance for

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Penryn," says Fischer. Of all the processor's new architectural tricks, the divider was most dependent on the chip's 45-nm features and redesigned transistors [see "The High-*k* Solution," *IEEE Spectrum*, October 2007].

The new divider is a nod to the importance of scientific and financial calculations, which require precise manipulation of large floating-point numbers—a standard number format that includes a sign, an exponent, and a fraction, all in a 32-, 64-, or 80-bit package. "Sometimes software has avoided the use of the divide in [favor of] a look-up table or some approximation. Scientific work can't rely on that," says Fischer.

Peter Markstein, a retired computer-arithmetic expert who worked on the floating-point units for the Intel and HP Itanium architecture and the IBM Power architecture, thinks the new division rate might influence how software is written. "People who use the Intel architecture will, I think, be more inclined to use division and not look for ways to avoid it," he says. Because they'll be taking fewer inexact shortcuts, computer simulations and other scientific programs could come up with better answers. (The Power and Itanium architectures do division with software that relies on a circuit called a fused multiply adder.)

Penryn's floating-point divider pulls it ahead of the division scheme used in processors made by its main rival, Advanced Micro Devices, for 32-bit quotients. But Penryn only matches AMD's divider for 64-bit numbers, according to Chuck Moore, chief engineer for AMD's next generation of processors. Since its Athlon chip debuted in 1999, AMD has been using a technique called convergence. Unlike in SRT, which calculates bits of quotient at a steady pace, convergence operates at an accelerating pace, says Debjit Das Sarma, principal member of the technical staff at AMD. Though convergence takes more clock cycles than SRT Radix-16 to get to 32 bits, it takes fewer cycles to go from 32 bits to 64 and would take fewer still to go to 80 or beyond.

In future processor architectures such as Bulldozer, due out by 2010, AMD does not expect the number of clock cycles required to finish a floating-point division to change much. But the company is going for "a substantial improvement" in the number of those divisions the processor can work on at once, says Moore.

Despite some dedicated effort by the two Silicon Valley rivals, "nobody is satisfied with these division times," says David Matula, a professor of computer science at Southern Methodist University, in Dallas, who has consulted for and competed against AMD in the past. He believes that makers of scientific software would be satisfied only if division took no more than twice as long as multiplication. Still, "I'm glad Intel is in the game again," he says. —SAMUEL K. MOORE

REINVENTING THE WHEEL

TO PREVENT ROLLOVER accidents, new cars sold in the United States since 2004 have been outfitted with tire-pressure monitors that warn the driver when tires are going flat. But the battery-powered initial version of the technology has proved expensive. A consortium of tire manufacturers hopes to cut the cost. It's testing a sensor embedded in the tires that needs no battery and can radio pressure data from the tire to electronics inside the car. The secret is a cheap, coin-size device called a PZT bimorph that harvests energy from the tire's motion via a miniature piezoelectric springboard. The tire makers are working with EoPlex Technologies, in Redwood City, Calif., which has tuned its three-dimensional printing technology to construct the complex devices on the cheap. If the new power

BRYAN CHRISTIE DESIGN

source passes its multiyear tests, carmakers may start to use wireless sensors to cut back on the kilometers of wiring in today's cars. For more, see http://spectrum.ieee.org/feb08/bimorph. ❑

Unanticipated power flows could overload lines ranging from the Czech Republic to the Netherlands

update

Can Wind Energy Continue Double-Digit Growth?

The need for backup power has been overstated, but grid interconnections are crucial

WIND NOT WANING: Wind power's rapid growth, especially in Europe, is sustainable only if grid interconnections improve. *PHOTO: ACCIONA*

WIND POWER supplies a large proportion of the electricity in countries like Denmark, Germany, and Spain, and its use is growing at an explosive pace around the world. Government incentives and the high cost of fossil fuels have combined to make wind farms a good investment for power-generation companies. But that investment comes at a price: the potentially expensive systems needed to make transmission grids run reliably, regardless of wind's famous fickleness. The question is, how much does that cost? To date, power grid studies have produced widely divergent estimates. Conclusions differ, for instance, about how much reserve generating capacity must be built to keep the lights on when the wind dies down. The uncertainties are a big problem for policy-makers, because such grid-related costs will ultimately determine how much wind power is too much.

The International Energy Agency (IEA) in Paris created a research team to do a meta-analysis of 19 national or regional wind and grid studies, under the direction of Hannele Holttinen, a senior research scientist at the Technical Research Center of Finland, in Espoo. The first draft of that analysis, issued in November, found that in some cases for every 100 megawatts of wind power, you need 100 MW of fossil, nuclear, or hydroelectric as a backup. But in general, the analysis argues, reserves can be much lower where there's ready access to a large electricity grid. Much depends, therefore, on the size of the region studied.

The IEA found that the larger the area examined, the greater the number of power plants available to fill the gap when the wind wanes. Mainly as a result of this issue, projections of how much it would cost to add needed reserve capacity differ by a factor of 10 or more—swinging from an extra €0.50 to €4 (about US $0.74 to $5.88) per megawatt-hour in regions that use 20 percent wind power.

Holttinen's team found that those models yielding the highest costs tend to ignore the modeled grid's interconnections with neighboring grids—an oversimplification that exaggerates the variability caused by wind farms and thus the cost of reserve power to balance it out, Holttinen believes. Whether those interconnections are up to the task of stabilizing wind-tossed electric grids is a real question.

Wind-farm installation in Europe grew an estimated 38 percent last year, up from 19 percent in 2006, bringing the total capacity to about 67 gigawatts (roughly the equivalent of 20 to 25 standard-size nuclear power plants). At those rates, European grid operators report, windmill construction is outstripping growth in transmission capacity. The result is that in wind-farm-rich countries such as Germany and Denmark, high winds cause large and unanticipated power flows that saturate the grids of neighboring nations. In recent years this has forced grid operators to curtail scheduled transfers of power between grids. In 2008, the grid operators warn, the unanticipated power flows could overload lines anywhere from the Czech Republic to the Netherlands.

Europe's grid operators bet they can prevent most of the wind-related overloads by adjusting their control schemes and further limiting power trades, while a pair of new 380-kilovolt transmission lines in northeastern Germany expected on line in 2009 will prevent the rest. Until then, operators say they might be forced to shut down some wind farms when the wind blows strong. —PETER FAIRLEY

Microchip Enables Electronic Gene Injection

Tiny electrodes could bring gene therapy into the brain

A NEW METHOD of inserting genes into brain cells could greatly simplify the search for brain-disorder treatments, according to research reported this month. It uses an array of electrodes, each 100 micrometers wide, to inject genetic material into individual neurons. The technique's inventor thinks it could be the key to examining thousands of genes for answers to vexing neurological problems, with the hope of one day performing gene therapy in the brain.

Gene therapy involves inserting genetic material into a malfunctioning cell to alter its activities and cure disease. Doing this in the brain would be particularly challenging, mainly because very little is known about how networks of neurons function or how to safely alter the components of such a network.

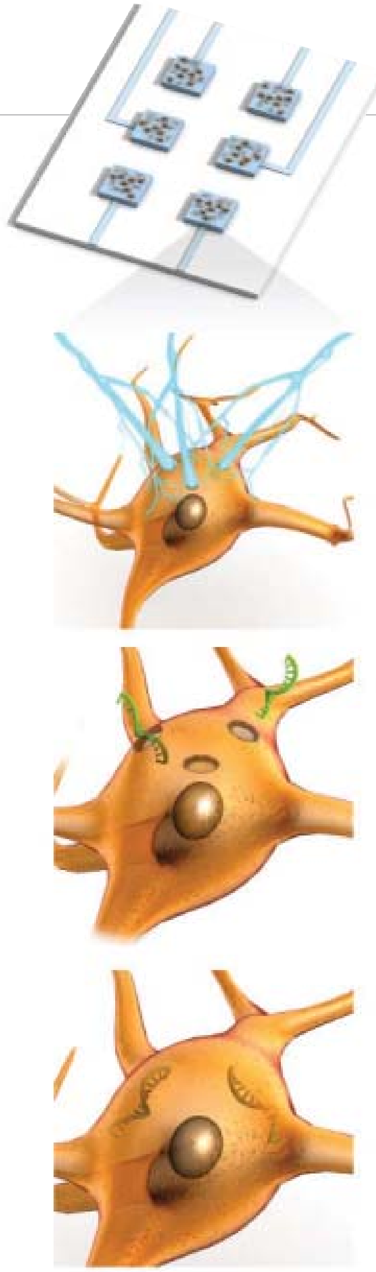
Generally, genetic engineers start by injecting into a target region a virus that has been modified to include human genes. In a technique called transfection, the virus will infect some cells and deposit its genome inside them. If things go as planned, the human genes inserted by the virus replace or restore a nonfunctional gene in the neuron. But viral transfection is laborious and difficult to control: a virus will transfect neurons more or less arbitrarily. "If you transfect the wrong neuron, you can change the overall function in a part of the brain in a really dramatic way," says Jit Muthuswamy, a biomedical engineer at Arizona State University, in Tempe.

Muthuswamy has invented a technique that uses tiny electrodes, instead of a virus, to slip genetic material into cells. The electrodes send a pulse of electricity that briefly blasts holes in the neuron's membrane. Segments of genetic material coating the electrodes can then enter the cell before it seals up again.

Each electrode can also monitor the injected neuron's electrical activity, such as the rate at which it pulses. The gene transfer might alter that activity in a recognizable way. "This is about delivering genes in a much more controlled fashion," Muthuswamy says. He and graduate student Tilak Jain describe the technique in the February 2008 issue of *IEEE Transactions on Biomedical Engineering*.

For now, the array is intended only for brain cells that have been grown atop it, not yet in humans or even laboratory animals. But that's enough for some scientists. "It's really hard for us to make sense of any nervous-system network," says Julie Kauer, a molecular pharmacologist at Brown University, in Providence, R.I., who studies individual neurons. With the array, "you could see if something affects a neuron's firing rate or changes its firing pattern."

The microelectrode arrays can also target specific types of neurons in a network. Different kinds of neurons have different electrophysiological properties. The electrodes can read these properties as if they were a neuron's signature. Thus only neurons with the proper signature might receive a zap from the electrode.



SHOCK TREATMENT: Neurons on a microchip have holes temporarily blasted into their membranes by a pulse of voltage. Genetic material can then slip into the cell through the holes and alter the cell's function.

ILLUSTRATION: BRYAN CHRISTIE DESIGN

Danilo Tagle, a program director at the National Institute of Neurological Disorders and Stroke, in Bethesda, Md., suggests that the arrays will help scientists understand neuron interactions by letting them alter one neuron at a time and watch how other neurons respond. "This technology can be adapted to answer all kinds of gene-therapy questions," Tagle says. —SANDRA UPSON

news brief

FUEL FROM SUNSHINE

At first blush, you might lump claims about a machine that turns sunshine, air, and water into fuel along with e-mails insisting that someone in Nigeria will pay you handsomely to help free up a large sum of money. But engineers at the Sandia National Laboratories, in Albuquerque, say they have created a device that can break water into hydrogen and oxygen using sunlight. In another reaction carbon dioxide can be converted to carbon monoxide, which then combines with hydrogen to make hydrocarbons such as methanol, ethanol, and even gasoline or diesel fuel. More at http://spectrum.ieee.org/jan08/5866.

PHOTO: RANDY MONTOYA

The old brake technology has "been pushed about as far as it's going to go" —Dana Maryott, BNSF Railway

update

Brake-by-Wire Comes To Freight Trains

Electronically controlled pneumatic brakes could help stop accidents and speed cargo

STEPH VENTER/GETTY IMAGES

INSIDE A large boxy building in Germantown, Md., a 150-car freight train is braking to a halt. At engineer Chuck Wolf's signal, air from each car's reservoir instantly begins pounding into the cylinder in a cacophony of clangs and chuffs. The brakes are fully set in just 12 seconds: unusually fast, but this is an unusual train. It's made up only of brake components: the air pipes that normally run underneath the cars instead arc overhead in a skeletal canopy. Wolf, who is principal systems engineer at Germantown's Wabtec Railway Electronics, is testing a revolutionary electronic system that activates all of a train's brakes simultaneously.

Developed separately by Wabtec and New York Air Brake Corp., the U.S. subsidiary of Munich-based Knorr-Bremse, electronically controlled pneumatic brakes (ECP) are intended to displace the venerable air brake system first patented by George Westinghouse in 1869 and now used around the world. New rules by the Federal Railroad Administration (FRA) may finally start to make ECP mainstream in the United States, which is home to the largest rail freight network in the world.

ECP was developed in the early 1990s as longer and heavier trains strained the Westinghouse system, which signals the brakes sequentially from the engine by draining compressed air from a pipe that runs the length of the train. It's a relatively slow process: the brake signal travels at just 152 meters per second along a train that can be three kilometers long. "We think that technology's been pushed about as far as it's going to go," says Dana Maryott, director of locomotives and air brakes at the Burlington Northern Santa Fe (BNSF) Railway.

ECP's advantages are many: improved control, greater safety, and higher efficiency—as trains stop faster and more reliably, they can also go faster, with less wear and tear. What's more, if anything goes wrong with a car's brakes, the car's onboard computer automatically takes them off-line and signals the locomotive. "The operator in the cab gets much more information than he ever had before," says Wabtec's Wolf. The ECP cable could also be a platform for sensors that one day might allow the engineer to monitor other systems, like wheels and bearings.

But the technology is also expensive, and outfitting the United States' 1.6 million rail cars and locomotives could cost US $7.6 billion, according to an FRA report. The fact that U.S. railroad companies swap equipment further complicates matters: the seven major carriers will all have to buy in for ECP to fully take hold. "ECP has great genes, but it's hard to get the railroad industry to change," says FRA deputy administrator Cliff Eby.

So in 2006, for trains operating with ECP, the FRA provisionally relaxed rules that require brake inspections en route. If universally implemented, the rule change could save the industry $125 million a year.

The rule change already appears to be having an effect. Last October in Pennsylvania, Norfolk Southern Railway inaugurated the first U.S. train to operate exclusively with ECP. The railway, the country's fourth largest freight operator, plans to equip 400 coal cars and 30 locomotives with ECP by this spring, with an eye toward replacing most of its 20 000 hoppers if the new system proves itself, according to railroad vice president Gerhard Thelen. Meanwhile, BNSF Railway, the biggest U.S. carrier by tonnage, plans to start running a container train with ECP between Chicago and the Port of Los Angeles, and an electric utility with its own fleet of coal cars will follow suit. —Robb Mandelbaum

BRAKE LINES: A train's worth of electronically controlled brakes ganged together for testing. *PHOTO: ROBB MANDELBAUM*

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

the big picture

FACE FACTS

One size never fits all. Designers use databases of North American and European body measurements to create their products but lack data to adapt the designs to Asians. That will soon change. Roger Ball, an industrial designer at Hong Kong Polytechnic University, has digitally scanned the heads of 2000 people from six regions of China in a project called SizeChina.com. From the scans, Ball created computer models of average Chinese heads. He intends to sell the models to companies that make helmets, eyeglasses, and face masks for Asians.

PHOTO: LUI SIU WAI/XINHUA/WPN

Block out your calendar to avoid meetings when you get back so you can take care of the work that piles up while you're gone; better yet, tell nobody the exact day of your return

careers

JLIMAGES/ALAMY

TRAVEL TIPS

Get more out of business trips by applying project-management skills

BUSINESS TRAVEL often comes as feast or famine, leaving some wanting less and others, more. All of us, however, need ways to make the travel itself rewarding, and the best approach is by giving it the same detailed attention you'd devote to one of your technical assignments.

If you want to travel more—to win business, forge connections with far-flung parts of your organization, or just see the world—you can wangle trips to conferences. One way is to get involved in professional societies and industry committees, many of which hold their regular meetings at conferences; another is to respond to requests for abstracts for conference papers. Your company will be happy to send you.

You can also target places that will promote business, an approach that led me to the best business trip of my career. After Pan Am went bankrupt in 1991, I marketed its Kennedy Airport maintenance facility, in New York City. I spotted an aircraft-maintenance conference in Germany in connection with the International Paris Air Show and proposed a trip to both. To my surprise, the trip was approved. The many business contacts I made helped me to get ahead.

Getting permission to travel is one thing; succeeding on the trip is another. Here are some tips:

Plan out the entire trip. At the outset, determine the end dates, the rough itinerary, key meetings and appointments, air transportation, hotels, and car rentals. I do it all on my Microsoft Outlook Calendar software, creating the trip as a recurring "appointment" and entering my itinerary in the "notes" area. It all syncs with my PalmOne personal digital assistant, but even so, I print a copy so I'll have a form on which to record my expenses. I also enter key phone numbers in my cellphone's address book.

Reserve your hotel early, even before you get approved to go, to lock in the discounted conference rate. Program your calendar to remind you to cancel the reservation within 24 hours, in case you end up not going.

Plan for craziness before and after the trip. Block out your calendar to avoid meetings when you get back so you can take care of the work that piles up while you're gone; better yet, tell nobody the exact day of your return.

Pack light, because you can always buy the odd thing you may need. Keep up on the latest security guidelines on what can and cannot go in carry-on luggage.

Avoid peak travel times. For example, savvy travelers connect through Chicago's busy O'Hare International Airport according to the season—in summertime you connect early in the day to avoid afternoon thunderstorms; in winter months you connect later to give the previous night's snow a chance to melt.

Keep your cool. Resolve not to get angry if things go wrong, as they often will. I once had to spend a day at a gate at Houston's Bush International Airport, but I got a lot of work done and read most of a book. It wasn't fun, but it wasn't worth stressing about, either.

Plan for the return trip. Ask how often the airport shuttle runs and at what time you'll need to get to the airport, then confirm the time with the airline. Once I missed a return flight from Hamburg, Germany, after both the hotel and the taxi driver had assured me I had plenty of time to make it. However, the plane boarded extra early to ensure it would get a slot at London's Heathrow Airport. Whose fault was this? Mine, because I hadn't checked with the *airline*!

Besides teaching you patience and flexibility, travel gives you far more usable experience than you'd gain by sitting in your office. Still, while the most important part of business travel is the *business* part, don't forget to enjoy the *travel* part. Bon voyage! —CARL SELINGER

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

We attracted curious glances from pedestrians, drivers, and bicyclists, who expected a growling hog but instead saw a stealthy tiger

tools&toys

Mini-Profile

By Susan Karlin

BOB SAGET: MAC NUT

Although comedian Bob Saget came off as squeaky-clean on his television show "Full House," his turns in the 2005 cult film The Aristocrats *and on his HBO special showed him swearing like a sailor. What few know, however, is that he also swears by his computer.*

"I'm a big Mac freak," he says (if truth be told, he used a coarser word than freak). "I've been using them since the Mac Plus and Mac SE—you know, the ones that look like diving helmets. I do everything on a Mac. I'm the tech support for my daughters—we're a Mac family—and my friends are always calling me to fix their computers. All the "Full House" guys were Mac boys early on—Dave Coulier, John Stamos, and I would even do videoconferencing."

The jury's still out on whether he gets a little peace on the set of the TV game show "1 vs. 100": "The folks who work there are split down the middle between Macs and PCs."

Saget hosts "1 vs. 100," which airs Friday evenings on NBC. For upcoming comedy tour dates, check http://www.bobsaget.com.

ROBERT SEBREE

A Plug-in Motorcycle

Brammo's Enertia puts bikers on the grid

TOO PRICEY? The Enertia electric motorcycle goes for US $15 000. But don't worry—you can always charge it.

PHOTO: MADDOX VISUAL

As one of us—the heavier one—approached the first major hill on a test ride of Brammo Motorsports' new Enertia electric motorcycle, we were doubtful that this light, elegantly designed bike could haul a 109-kilogram (240-pound) rider up the incline. We shouldn't have worried: it effortlessly propelled him to the top of Portland, Ore.'s West Hills.

Thanks to the central positioning of the batteries and motor, the Enertia handled the winding roads with ease, and its wide rear tire kept the wheels on the ground even when accelerating through turns. It rode and handled predictably and comfortably. The suspension was somewhat stiffer than that of most gasoline-fueled bikes, yet it took bumps, potholes, and railroad tracks in downtown Portland without trouble.

One thing was missing—the roar of the engine. The ride was surprisingly peaceful without it. We attracted curious glances from pedestrians, drivers, and bicyclists, who expected a growling hog but instead saw a stealthy tiger.

To stretch battery life, the bike is preset to draw only 150 amperes, or 60 percent of the maximum power. That gives it more than enough spunk to navigate busy traffic. The motor develops 20 kilowatts (roughly 26 horsepower), but according to Brian Wismann, the Enertia's design director, what really matters for an electric vehicle is torque—of which the Enertia's motor produces 46 newton meters (34 foot-pounds). By comparison, a 250-cubic-centimeter gas-fueled motorcycle typically provides about 28 N·m (20 ft-lbf). That means the Enertia takes off, accelerates, and rides just like a gas-fueled motorcycle.

Craig Bramscher, a veteran of several small Web-related companies, founded Brammo in 2002 to pursue his interest in specialty vehicles. In 2005, he secured a license to build the Ariel Atom, a British sports car notable for having almost no body panels—just its naked exoskeletal chassis. Soon he began looking to build an electric vehicle, but the need to minimize weight brought a change in plans. He elected to build a motorcycle—including the motor, drive train, suspension, and carbon-fiber body—from the ground up. Today most electric motorcycles are mere conversions of gas models.

Given the bike's range of 75 kilometers on a charge and a top speed of 80 km/h, Brammo is positioning the Enertia as a commuter vehicle for what it calls the new urban consumer—25 to 44 years old, interested in green products, living within 40 km of an urban center, and crucially, not necessarily a current motorcycle rider.

Those people will have to fork over US $15 000 for one of the first preproduction Enertias. (A comparable gasoline-fueled 250-cc sports motorcycle can be had for $4000 to $5500.) The price is likely to drop as production ramps up, and as a green machine, it will qualify for tax rebates in some states.

Anyway, what you save in gas may finally offset the extra initial cost. A 250-cc bike can go about 300 km on a tank of gas, which in the United States costs $7 or more, but the Enertia can go as far on four charges, totaling just $1.30. That cuts the energy cost by three-quarters. (Of course, it won't be so convenient, because each charge takes about 3 hours.)

The power source is an array of six lithium-phosphate cells from Valence Technologies, of Austin, Texas, which also supplies the battery-management system to balance the current draw from each of the batteries. Bramscher says Valence's system is the best he's seen—and super-safe to boot. "You can cut these batteries in half with a chainsaw, and they will not ignite," he says.

The designers and engineers kept the bike simple and unintimidating for novice riders. There is no clutch; the only controls are the throttle and the hand and foot brakes.

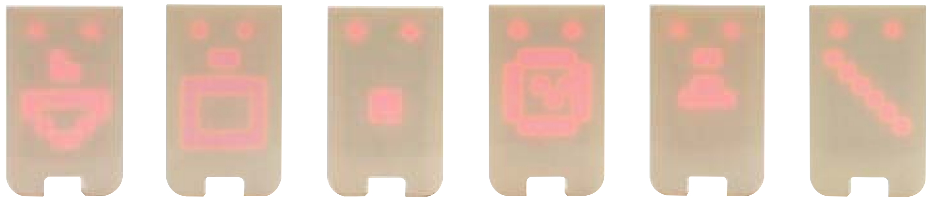
Instead of a gas cap, there's a lid that conceals the charging port, which works off 110-volt household current. Closer to the rider is the power button, and mounted above the handlebar is a small flat-panel display showing speed, the remaining charge, and how much carbon you avoided pumping into the atmosphere by taking the Enertia instead of a car.

Brammo is taking orders for delivery by the second quarter of 2008. By then the bike will also have a port that will allow owners to use their laptops to reprogram the performance characteristics of their Enertias, download ride telemetry, and more.

"We're going to let you download to the bike, change the throttle map, and alter the power settings," Wismann says. "Some hardcore motorcyclists want every bit of power available to them. We're going to give them the chance to fiddle with it." More power to the motor, of course, will come at the expense of range.

In the second half of 2008, Brammo will introduce a production version of its first model, priced at $12 000. A second model will follow, carrying both a rider and a passenger. With greater battery density and a more muscular motor, it should have a top speed of about 120 km/h, fast enough—and powerful enough—for highway driving. Sure, the Enertia is green and efficient. But it's also a fun ride.

—Brian Santo & Mark Santo



Karaoke-bot

It lip-syncs as you sing

Our favorite new desk toy is the USB-powered Tengu, which moves its LED "lips" in time with the songs you sing. Made by Solid Alliance Corp., of Tokyo, it sells for US $50. To see our own Tengu in action, visit us at http://www.spectrum.ieee.org/feb08/tengu.

invention

HIRED TO INVENT

Your company may own your brainchild

If you're an engineer, you were probably hired to invent. That means that if you come up with something that brings heaps of money to your employer, you are owed nothing beyond your paycheck.

That puts you on a different ground from that of accountants, truck drivers, and other people who were not hired to invent—they get to *keep* their patent rights. Even if they did their inventing on the job, using company resources, all the company gets is a "shop right" to use the patented invention without paying a royalty fee.

The courts haven't been all that clear on what "hired to invent" means, and therefore most companies require all new employees to sign a contract handing rights to any future inventions to the company. Your company might even require that you assign to it any patentable ideas you may have within a year after termination, to dissuade you from quitting your job to perfect an invention that you'd conceived on company time.

Of course, employers can, if they want, renounce some of their rights in your patents. Universities have generally found it worth their while to let professors share in the proceeds of their intellectual endeavors. MIT, for example, gives its professor-inventors a third of the revenue coming from their patented inventions.

Some companies also go beyond what the law requires to reward their engineers. In 2004, a survey by the Intellectual Property Owners Association found that 61 percent of the responding companies paid their employees US $1000 to $3000 upon the filing of a patent application,

TOP: RANDI SILBERMAN; BOTTOM: MICK WIGGINS

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Taking your employer to court is an all-or-nothing strategy—if you win the case, you get a lot of money, but if you lose it you may lose your job as well

and 37 percent paid from $1000 to $2000 upon the issuance of a patent. If all *you* got was a plaque, you can use these findings as ammunition the next time you talk to your boss!

You can also relocate to a country where the law leans more toward the inventor. In the United Kingdom, for example, the employee-inventor must be compensated provided the invention is of "outstanding benefit" to the employer. Germany has a similar law, but alas, the amount of the compensation depends on the employee's salary, whether or not the person was hired to invent, and a lot of subjective factors.

But don't pack your bags just yet. A 2006 study of 1983 German employees found that only 18 had received more than their usual income.

Monetary incentives to invent may have perverse results. They may encourage employees to file so many patents that their companies' legal departments (and legal budgets) can't keep up with the work. The companies may then respond by capping the number of patents staffers can file.

Employees can also get into nasty disputes over who invented what. Two engineers may conceive of a new idea for a product, and then several other engineers and a manager or two may assert that they also had a hand in it. I have even had engineers fight over whose name was to be listed first on the patent.

Companies can avoid a lot of problems by making the disclosure process as simple as possible. Here are a few tips:

- Have an attorney attend regular meetings to review project design and capture patentable ideas.
- Have patent attorneys conduct walkabout visits to teams of engineers working on specific projects to get them talking about their innovations.
- Invite engineers to lunches to familiarize them with patents and to talk about new ideas.

None of these considerations will mollify the engineer whose invention brings in billions for the company but only beans for the employee—maybe just a $1000 check and a brief mention at the corporate retreat. Although you can try to wring out more money by taking your employer to court, that's an all-or-nothing strategy—if you win the case, you get a lot of money, but if you lose it you may lose your job as well.

You can take heart in knowing that despite all these problems, invention can still do wonders for your career. According to that 2004 company survey, engineers whose inventions contributed above and beyond the call of duty reported receiving larger monetary awards, stock options, and, of course, promotions. —Kirk Teska

books

GAME OF KINGS

A specialist in other people's obsessions writes about one of his own—chess

KING'S GAMBIT: A SON, A FATHER, AND THE WORLD'S MOST DANGEROUS GAME
By Paul Hoffman; Hyperion; 2007; 433 pp., US $24.95; ISBN-10: 1401300979; ISBN-13: 978-1401300975

The world of chess is filled with colorful and obstinate men and women who have dedicated much of their lives to a pursuit few outsiders can appreciate. Paul Hoffman has a predilection both for the game and for dedication itself, having described an outstanding case of it in his biography of the Hungarian mathematician Paul Erdös, *The Man Who Loved Only Numbers* (Hyperion, 1998). Now he brings these interests together in a wide-ranging tour: *King's Gambit: A Son, a Father, and the World's Most Dangerous Game.*

Hoffman writes in an enjoyable, fast-moving style, focusing on storytelling, with brief excursions into more serious philosophical topics, all designed to lead the reader seamlessly from episode to episode. The author's credentials as a tournament player and acquaintance of several of the world's strongest players are impeccable, and his preparation is impressive. He spent years collecting material for first-hand accounts of top events, including a World's Championship in Libya, a prestigious international tournament in Moscow, and a women's training session in New York City. He quotes a wide range of players, from former world champions Garry Kasparov and Anatoly Karpov on down. These sections bring the world of chess and its many characters to life. They are the highlights of the book.

Hoffman can be a bit light at times. His stories, though always entertaining, do on occasion stretch the reader's credulity. I have a bit of trouble imagining grandmaster Bent Larsen mouthing off to a young Paul Hoffman while playing scores of amateurs simultaneously. Some of the diversions into more technical topics, such as the engineering details of computer chess, are superficial and not properly researched. We are told, for instance, that IBM's chess machine, Deep Blue, had 256 processors, that it looked at 3 million positions per second, that chess programs are "very materialistic," and that Kasparov's loss in game six of his 1997 match against Deep Blue can be attributed to his "suicidally choosing a known inferior and passive line"—all inaccurate, and all in a span of three pages. Also, some of the digressions into the author's own life are a bit long-winded.

However, these are minor flaws, and they should not detract much from a pleasant and interesting reading experience. —Vasik Rajlich

Snowclone Is The New Cliché

"If I can claim no other accomplishment when I die, at least I'll have one neologism to my name!" **—Glen Whitman, economics professor**

MODERN FOLKLORE holds that Eskimos have a huge number of words related to snow, but it's just not true—they use no more such words than we do. Still, the factoid continues to spin off phrases on the general format of "If Eskimos have N words for snow, X have Y words for Z." For example, a 2003 article in *The Economist* declared, "If Eskimos have dozens of words for snow, Germans have as many words for bureaucracy." On his blog, Agoraphilia, Glen Whitman coined a snappy name for the category to which this formula belongs: the **snowclone**. Of course, he was punning on the snow cone, which is shaved ice flavored with syrup and carried in a paper cone.

Many snowclones are firmly entrenched in mainstream culture. For example, **I'm not an X, but I play one on TV** has been around for more than 20 years. It comes from a 1986 ad for Vicks Formula 44 cough syrup, in which an actor said, "I'm not a doctor, but I play one on TV." Another example is **In X, no one can hear you Y**, which is based on the tagline of the 1979 movie *Alien*: "In space, no one can hear you scream."

However, some snowclones seem to be tailor-made for the technological world. A good example is **I, for one, welcome our new X overlords**. This snowclone is most often used ironically to indicate that one really isn't all that pleased that X has so much power but is resigned to the fact because nothing can be done about it. The original statement is "I, for one, welcome our new insect overlords," the now immortal words of a cartoon character in "The Simpsons" from the 1994 episode "Deep Space Homer." Here are just a few examples of this snowclone from recent newspaper and magazine articles: "I, for one, welcome our new robot overlords," "I, for one, welcome our new Microsoft overlords," and "I, for one, welcome our new Google overlords."

A perennial favorite among both geeks and fashionistas is **X is the new Y**, the idea behind which is the belief that some new thing "X" has become more popular than or has replaced some older thing "Y." The more specific locution **X is the new black** dominated the fashion world in the 1980s. Now the structure crops up everywhere ("40 is the new 30," "Knitting is the new yoga," and on and on). On the tech side of things, fans of the open-source movement will often tell you that "Open is the new closed," and Apple marketed the iPod Shuffle by declaring that "Random is the new order."

DAN PAGE

The snowclone **X and Y and Z, oh my!** comes from the 1939 film version of *The Wizard of Oz*, where at one point in the action Dorothy, Tin Man, and Scarecrow chant "Lions and tigers and bears, oh my!" Computer book authors seem to love this snowclone, and examples aren't hard to come by: "Collaboration and Wikis and Blogs, oh my!"; "Lines and Transfers and Bits, oh my!"

If you use the **X? We don't need no stinking X!** snowclone, you're showing utter contempt for X (albeit usually in a mocking way). This cliché can be traced back to the 1935 book *The Treasure of the Sierra Madre*, but it didn't become popular until Mel Brooks's 1974 comedy *Blazing Saddles*, in which he included the following lines: "Badges? We don't need no stinking badges!" In technology writing, probably the most common is the geek cry of "Manual? We don't need no stinking manual!"

One of the most popular snowclones right now is **I'm in ur X, Y-ing ur Z**. This comes from a famous screenshot from a game of *Starcraft* that appeared in the forums of the Web site Something Awful. An inexperienced player was up against a veteran, and at one point the **n00b** (as a gamer would call a newbie) lost track of the veteran player and asked where he was. His reply is the stuff of infamy: "I'm in ur base, killing ur doods." Endless variations on this theme are to be found, most enjoyably on sites with an **lolcat**—a cute picture of a cat to which someone has added a caption. The language used in these captions is worth an entire column. For our purposes, it's enough to know that many use the **I'm in ur X, Y-ing ur Z** format: "I'm in ur fridge, eating ur foodz" or "I'm in ur library, reading ur b00ks." ❑

SPECIAL REPORT

DREAM JOBS

STUDYING PENGUINS IN ANTARCTICA, WATCHING SHOOTING STARS IN THE SOUTH PACIFIC, TRACKING ROBOTS THROUGH THE AMAZON—YES, THIS IS ENGINEERING

FOR TOO many engineers, work is the thing you do to fill up the time between college and retirement. It need not be. Just consider the 10 technologists we've profiled in this year's "Dream Jobs" report.

Want to see the far corners of the Earth? Roger Hill and Ney Robinson Salvi dos Reis did. Hill had a ho-hum job as a medical researcher when he accepted an invitation to Antarctica. There he discovered not just his life's work—building rugged computers for studying marine life—but the love of his life. Reis wanders far beyond the lab to deploy his environmental monitoring robots out at sea and deep in the Brazilian rain forest.

Want to save the planet? Steven Camilleri does. He's designing ultra-efficient motors that could someday drive everything from household appliances to electric cars. Salinee Tavaranan is doing her part, too, by installing solar panels and microhydropower turbines in refugee camps along the Thai-Burma border.

Want to change how people see and hear the world? Bruno Putzeys is the world's leading designer of class-D amplifiers, used in high-end audio components to bring crystal-clear authenticity to digital recordings. Mark Schubin engineers televised broadcasts for the Metropolitan Opera, reaching new audiences the world over. And Ash Nehru writes software code that drives intricate interactive lighting displays, redefining the way people view art.

Want to live your childhood dream? Sigrid Close's first love was space, and now she studies meteors to see how they interact and interfere with satellite communications. Sometimes, though, *not* attaining your dream can be a good thing, too. After NASA rejected him for its astronaut program, James Brown found an even more thrilling ride, as an engineering test pilot for the F-22.

Want to run with the big dogs? Garmin International's David Downey not only designs high-tech fitness products, he also field-tests the devices by entering triathlons—and his employer couldn't be happier.

See where we're going with this? Just take a few minutes, read through the 10 profiles that follow, and you too may be inspired to rethink the meaning of "work."

And if you already have the job of your dreams, write and tell us about it at eedreamjobs@ieee.org.

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Sigrid Close

STAR STRUCK

"A HUNDRED BILLION," says Sigrid Close. That's how many meteors collide with the Earth's atmosphere every day. Most are whittled away in the ionosphere, and Close spends her days studying exactly how they disintegrate. That's right: she gets paid to watch shooting stars.

Close is the resident expert in ionospheric and near-Earth phenomena at Los Alamos National Laboratory in New Mexico. Her work regularly takes her to places like India, China, Puerto Rico, and the Marshall Islands, where she uses the most advanced space surveillance telescopes and radar to study the uppermost reaches of the atmosphere, some 85 kilometers above the Earth's surface.

Close's, and Los Alamos's, interest in shooting stars isn't purely academic. It turns out that meteors, as well as the ionosphere itself, disrupt radio signals. When meteors hit the atmosphere, they tend to melt into plasma plumes dense with heavy metals, sometimes causing big bubbles that momentarily block the path between a satellite and an Earth-based receiver. Similar disturbances, called equatorial plumes, occur naturally in the ionosphere, blossoming at sunrise and sunset, when the sun's radiation forces lighter plasma to well up as heavier plasma falls. For a satellite, Close says, the effect is as difficult to see through as ripples in a pond.

At Los Alamos's satellite operations center, Close works with a team of rocket scientists and engineers studying these plasmas to determine how and when they will cause problems. By better understanding the underlying physics, she says, aerospace engineers can better safeguard their systems. Her main responsibility is monitoring satellites for the U.S. Army's Air and Missile Defense Command, including one satellite that scans the skies for signs of clandestine nuclear tests. She also gets called in during satellite launches, which can be compromised by the meteor plasmas and the meteors themselves. "You think you're tracking a launch," Close explains, "and actually the radar is just tracking these dense plasma structures."

From an early age, Close says, "I wanted to work on something in space." As a child growing up in Allentown, Pa., she remembers her parents taking her out on clear nights "to see Mr. Moon." Her father, a computer engineer, gave her a telescope for her eighth birthday. In 1992, her love of space naturally led to a physics and astronomy B.S. at the University of Rochester in New York state.

Close then went to the University of Texas at Austin, intending to get a Ph.D. in physics. She finished her master's but went no further. "I was burned out," she says. It didn't help that a co-worker kept leaving Bible passages on her office chair exhorting women not to work. Close also wanted to spend more time on her music. Like her mother, she is a classically trained pianist. Close moved to Boston and recorded an album, *Mirrored Self*, released in 1997, an improbable blend of classical piano and post-college angst.

Close took a job at MIT's Lincoln Laboratory to study the ionosphere. Her work involved heavy doses of engineering, especially signal processing. Learning to recognize the signature of a meteor or some other object on a radar screen, she says, is a lot like learning to read Braille. At first she had trouble distinguishing the White Sands missile range, in New Mexico, from an ocean or a forest. Over time, though, she became an expert in characterizing the noise that ionospheric and meteor plasmas can inject into signals.

In 1998, MIT sent her on a two-year stint to Kwajalein Missile Range, a tiny strip of land in the middle of the Pacific Ocean. There, she did space surveillance using the ARPA Long-Range Tracking and Instrumentation Radar, or as Close puts it, "the big honking telescope."

She soon found herself traveling to other telescopes all over the world, where she monitored satellite launches and the 8000 or so operational satellites circling the planet. "Anytime anyone sent anything into space," she says, "we tracked it." Fortunately, her husband, Greg, had the kind of job—he's a science-fiction and fantasy writer—that let him join her on her travels.

In 2000, she was accepted into the highly competitive MIT Lincoln Scholars Program, which allowed her to receive her full staff salary while she finished her physics Ph.D. For her doctorate, which she completed in 2004, Close figured out how to weigh meteors by their radar signatures, using data she'd collected at Kwajalein. "If we know their weight," she says, "we know how much damage they can do."

Pretty soon, Los Alamos came calling.

"I didn't even want to work here at first," she says. Initial impressions can be intimidating. The national lab, best known as the home of the atomic bomb, sits on 162 square kilometers of desert in the middle of Bandelier National Monument. Striated cliffs tower above short, scrubby trees that dot the land like green sheep. The lab's wide border is flanked by a flimsy-looking chain-link fence. But closer to the main facility, menacing army-green vehicles patrol the grounds, aided by Terminator-like soldiers sporting camouflage and mirrored sunglasses, weighed down by guns so big they look fake.

Despite the lab's military trappings, Close says, "I can't imagine leaving." The atmosphere among the researchers and postdocs is congenial, relaxed, and prone to pranks, she says. Last year, an anonymous artist redrew the men's room stick-figure icon using Wite-Out to extend its round head into a cone. Later, during construction work on the ceilings, a rogue staffer marked dangerous areas with the exhortation to "WATCH YOUR CONE."

Beyond the silliness, the job lets Close deeply indulge her love of space. She's the proverbial kid in a candy store when she talks about her many ongoing projects. She admits that she has a tendency to take on too much. "There's so much amazing stuff going on here," she says, "it makes it hard to choose." In fact, she's already plotting her next project, funded by the Defense Advanced Research Projects Agency: taking on the troposphere. —SARAH ADEE

AGE: 37
WHAT SHE DOES: Studies ionospheric phenomena and meteors to improve satellite communications.
FOR WHOM: Los Alamos National Laboratory
WHERE SHE DOES IT: Los Alamos, N.M.
FUN FACTORS: Travels the world to study shooting stars.

SIGRID CLOSE, an IEEE member, tracks meteors and other phenomena in the ionosphere that can impede satellite communications.
PHOTO: CHIP SIMONS

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Bruno Putzeys

THE SOUND OF MUSIC

At the 2006 Audio Electronics Society conference in San Francisco, Bruno Putzeys came face-to-face with the odd cult of celebrity that surrounds a select few audio amplifier designers.

"A guy came up to me, talking about me without realizing I *was* me," he laughs. "Then he saw my name tag, and he said, 'Oh, awesome meeting you.' He shook my hand, and then he hurried off!"

Putzeys is one of the world's top designers of a type of audio amplifier known as class-D. These ultraefficient models are already dominant in multichannel sound systems, portable media players, cellphones, car stereos, and computers. Lately they've made inroads into the ostentatious world of high-end audio, where a component can cost tens of thousands of dollars. Their success there is due mostly to Putzeys.

In 2001, while working at Philips Applied Technologies in Leuven, Belgium, Putzeys designed a compact, versatile class-D amplifier module that he called UcD, for "Universal class-D." Over the past few years, dozens of amplifier models, with prices ranging from US $500 to $8500, have been built around Putzeys's modules, which are now manufactured by Hypex Electronics of Groningen, Netherlands. The amps have received mostly ecstatic reviews.

For Putzeys, the success of the UcD boards has conferred professional freedom that's pretty rare for a 34-year-old EE. In May 2005, he followed his modules to Hypex, where he is now the chief tech guru. He lives and works in a two-story building in a picturesque suburb of Leuven. The first floor is his laboratory; upstairs are his bedroom, a small kitchen, and a spacious living room with his main audio setup dominating one wall.

Putzeys's love of audio electronics began when he was 16. A friend of his father's stopped by the Putzeys home in Herent, Belgium, with an amplifier built around two pairs of EL84 vacuum tubes in push-pull configuration. Its sound bowled over the youngster: "I thought, This thing can give me a sense of the music that the other amps can't." He taught himself how to design electronic circuits with tubes, a really odd activity for a teenager in the late 1980s.

After high school, he enrolled at the National Radio and Film Technical Institute in Brussels, from which his father had graduated in 1963 (the school has since been merged into the De Nayer Instituut). While there, he became intrigued by class-D audio and did his thesis on it. After he graduated in 1995 with a bachelor's degree in electrical engineering, Philips, the Dutch electronics giant, which had sponsored his thesis work, offered him a job.

Within a few years, he'd succeeded in "annoying all the managers" until one of them agreed to let him take charge of the testing of a class-D audio IC being designed elsewhere in the company for a television set.

He didn't think much of the chip. "If you give me one month," he told his bosses, "I will make something out of discrete parts that will be much better." He made good on his promise. In three weeks, he built a 25-watt class-D amp with better performance than that of the IC amplifier a four-man team had labored over for two years.

In 2001, Philips executive George Aerts secured some research money so that Putzeys could further refine his class-D design. The goal was an amp module that would be versatile and easy to manufacture. It had to be compact and have the same output impedance and power-supply requirements as a conventional amp. And it had to be cheaper and sound better. "The idea was that there would be no excuse for not using it," Putzeys recalls.

This time, it took him eight months. He went through four generations of circuit boards without listening to any of them. Instead, he connected each board to an audio analyzer and then rejected it because the results weren't what he wanted. The fifth iteration, though, looked good. Just before Christmas 2001, he brought a pair of the amps home and connected them to the speakers in his living room. He put on a CD of Spanish classical music and selected a song by the 18th-century composer Juan Francés de Iribarren, "Viendo que Jil, Hizo Raya." He settled back in a chair and listened. It took him just a few seconds to reach a conclusion: "Straight in the bull's-eye."

At a visitor's request, he re-creates the event, with the very same CD and stereo components. The music begins to flow from the speakers, and Putzeys's eyes seem to unfocus, like he's lost in thought. There's a little grin on his face. The sound is extremely transparent, neutral, and precise, with a lovely warmth and force in the vocals.

AGE: 34
WHAT HE DOES: Designs amplifiers and other audio electronics.
FOR WHOM: Hypex Electronics and Grimm Audio
WHERE HE DOES IT: Belgium and the Netherlands
FUN FACTORS: Lives and works in the same building; listening to music is part of his job; travels widely to conferences and recording studios.

In an engineer's universe, Philips would have embraced Putzeys's UcD module, incorporating it into countless products. In the actual universe, the module basically fell through the cracks. But in April 2003, a young entrepreneur named Jan-Peter van Amerongen visited Putzeys at Philips. Some years before, van Amerongen had started Hypex Electronics, to supply amplifiers and other gear to makers of active speakers and to recording studios. He had heard great things about the UcD.

Ironically, the one thing he didn't want to hear, at least initially, was music amplified by the module itself. Much like Putzeys when he was designing the modules, van Amerongen wanted to look at the amplifier's output waveform. "The only thing he wanted to see was the output signal on an oscilloscope," Putzeys recalls. "He looked at it, and in about one minute he said, 'Okay, I want to buy a license.' He had seen so many dreadful outputs, full of RF hash. He could tell from the signal whether it was well designed."

Not long after, Putzeys left Philips for Hypex, where he has pretty much free rein to explore the boundaries of class-D. Just "for fun," he recently designed an audio amplifier with 0.0003 percent total harmonic distortion, at full power, amplifying a 20-kilohertz signal. That figure is more than 1000 times better than

some very good solid-state amps. In fact, it's an improvement that no human ear could detect. But that figure is also about *30 000* times better than that of some tube amps—a difference that's *not* beyond the ability of human ears to detect.

Besides his gig at Hypex, Putzeys is also one-fourth of a Netherlands-based start-up called Grimm Audio, in Utrecht. It specializes in high-end components for recording studios.

Outside of work, he finds time to maintain a very long-distance relationship with a woman who lives in Rwanda. He lectures at conferences around the world. And when he can, he listens to his own stereo setup, a unique assemblage of components he built himself, heavily tweaked, or received as prototypes. The system is marvelous, if ungainly. And it exemplifies Putzeys's credo about hi-fi.

"Stereo replay never actually reproduces a musical event," he says. "The only thing you can hope for is a credible illusion. But it can be a very nice illusion."
—Glenn Zorpette

BRUNO PUTZEYS, an IEEE member, takes a break at Galaxy Studios in Belgium.
PHOTO: THOMAS VANHAUTE

TO PROBE FURTHER A longer version of this article is available at http://www.spectrum.ieee.org/feb08/bruno.

David Downey

MARATHON MAN

The midday sun had chased the last of the morning's chill from the air when David Downey turned into the Garmin International parking lot, in Olathe, Kan., winding up a 20-kilometer run. He'd been out on the road for nearly 2 hours, a little longer than usual, but he wanted to enjoy the perfect fall weather while he could.

Heading for the company showers, he passed through rows of offices. One man glanced up from his screen. "Testing again, Dave?"

Downey held up his arms, displaying several watchlike devices strapped onto each. These little Garmin-made computers mapped his route, tracked his speed and heart rate, and calculated his pace. "Of course," Downey replied.

Downey is the software engineering team leader in Garmin's fitness products division. Best known for GPS navigation devices that stick on car dashboards, the company also makes tools for aviators, hikers, fishermen, and athletes.

Testing Garmin's running and biking gear is as much a part of Downey's job as writing the embedded code that makes them tick. "Usually about 11 a.m., after coding and debugging and helping the guys on my team, I'm like, 'Oh, man, time to get ready to go,' " Downey says. He checks his e-mail to see what kind of ride his bike-enthusiast colleagues are planning, compares it to the plans of his running colleagues, and decides which

DAVID DOWNEY, an IEEE member, designs products for Garmin International and tests them while training for marathons and triathlons. *PHOTO: COLBY LYSNE*

group to join. He changes out of his jeans and cotton shirt into sports gear and grabs a handful of Garmin products off his desk; some are already on the market, some are works in progress. Then he's ready to go "testing."

Downey's outside interests don't just happen to coincide with the projects he's working on. As the company's recruitment literature puts it: "Garmin seeks candidates who have a passion for the products that they're developing." That means fishermen work on marine products, recreational pilots work on aviation products, and exercise enthusiasts work on fitness products. The company encourages these passions by subsidizing sports teams, gym fees, and pilot lessons, as well as race entry fees.

When he started his career, Downey never expected that his job requirements would one day include running and biking. After getting a B.S. in computer science and mathematics from Baker University in Baldwin City, Kan., in 1983, he held software jobs at various companies, all in the southern Kansas City metro area.

In 1998, when his employer at the time, a medical device manufacturer, announced a move to California, Downey applied for a job at Garmin. Garmin turned him down.

Downey wouldn't be discouraged. During the interview, he'd learned that Garmin was about to move its line of products to ARM processors, 32-bit devices based on a reduced-instruction-set computer (RISC) architecture. He had never written code for RISC devices before, but he convinced a small company, World Wireless, to hire him to develop software for ARM-based vending machine payment systems. Six months later he reapplied to Garmin; this time he got the job. He worked first on a cellphone project, then developed a GPS system for Palm PDAs.

Then, in 2002, Garmin engineers began developing a fitness product, a souped-up watch for runners. Downey had always been into running and was on the track team in high school and college—never a star athlete, he says; he just liked doing it. He really wanted to work on the new product.

Downey hung out with the people working on the runner's watch. He ran with the developers daily as they tested prototypes and wasn't shy about making suggestions. "When I run in town, I never remember to stop my stopwatch at a stoplight," Downey says. "So I said, 'Hey, it would be really cool to have it just stop the timer at the light and start it up again when you go. It'll know by the GPS signal when you're stopped, because the location doesn't change.' " For that idea and others, the team credited Downey in patent filings.

He officially joined the fitness group in 2004. His most recent project is the Edge 605 and 705 bike computers, which began selling this year for about US $400 and $500. These handlebar-mounted gadgets use a wireless network to gather information from sensors built into the bike and strapped onto the rider; they can track, among other things, the cadence of the pedals, the force the rider exerts on the pedals, the bike's speed, and the rider's heart rate. Basic street maps come installed; riders can add memory cards with detailed route maps.

These days, Downey competes in a bike race, a running race, or a triathlon

AGE: 46
WHAT HE DOES: Develops software for GPS-based devices that help runners and bikers train.
FOR WHOM: Garmin International
WHERE HE DOES IT: Olathe, Kan.
FUN FACTORS: Gets to test the devices he designs in bike races, marathons, and triathlons.

SPECTRUM | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | qMags

at least once a month; that's as much as his family will tolerate. Every event presents another opportunity to test the company's products, though not every test goes well. In 2006, for his first "adventure" race, he wore a prototype of the Forerunner 305, one of Garmin's watchlike computers for runners. The event had three parts: an inflatable canoe race, a mountain bike ride, and a trail run. The canoe race and bike ride went fine, but the trail run had a few surprises. The trail led through a pond; Downey managed to keep the not-waterproof prototype dry by holding his arm in the air. Then the trail crossed another pond with ropes strung above it; competitors had to crawl through the water under the ropes. By the end of the race, Downey says, "the prototype was totally fried." (The commercial product is water-resistant.)

Since just after being hired by Garmin, Downey has organized the company's team for the Kansas City Corporate Challenge, a six-week festival of Ping-Pong matches, races, and other sporting events. Last year, some 180 Garmin workers participated. Lately, Downey has been focusing on recruiting more women to compete, because many events require coed teams.

Right now, swimming is a weak spot, perhaps because the company does not produce a line of products for swimmers. "Our strategy? Hire a swimmer," Downey says. With the company adding more than 400 workers annually, an engineer with a passion for swimming may soon find her dream job. —Tekla S. Perry

James Brown

ABOVE & BEYOND

James "J.B." Brown had just taken off in an F-22 Raptor on a routine test flight when 730 °C air escaping from a loose connection in one engine began melting wires and hydraulic and fuel lines. Protocol dictated that he shut down the ailing engine and fly on the healthy one, but he remembered that an F-117 had been lost by just such an action—the aircraft tumbled out of control while the pilot ejected to safety. Brown's plane was too close to the ground for him to eject. Thinking fast, he idled the bad engine and lowered the landing gear. Then, on final approach, the other engine started to fail. With just seconds to spare before the jet lost power, he landed the aircraft, shut it down, and ran from it in case there was a fire. Happily, there wasn't.

"Had I followed the emergency procedures verbatim, I could have ended up in a world of hurt," he says in a jovial Alabama twang. "But, hey, I get to fly one of the most powerful airplanes in the world. I'm a 53-year-old guy doing stuff teens dream about."

Brown is an experimental test pilot: a special breed of aviator trained in engineering who test-flies experimental craft and then conveys the problems he encounters and his suggestions for improvements in terms that his earthbound counterparts can understand. Each world has its own language, Brown explains. "Someone who's trained solely as a pilot would say, 'Yeah, it flew great.' An engineer would say, 'The short-period campaign is adequate.' As a test pilot, I'm able to translate between them."

Having logged 7600 flight hours in 124 types of airplanes, he's been specializing in the US $150 million F-22 for the past six years, routinely traveling 18 000 meters above the ground at 2600 kilometers per hour and subjecting his body to 9 g's. Nothing on Earth quite compares, he says. "I've cruised at Mach 2 and 60 000 feet, covering a mile every three seconds, watched the parallax from my plane's shock waves distort the Earth's features, stared at the blackness of space and the stars at noon, then looked at the horizon and saw the curvature of the Earth."

Brown got his first taste of flying from his father, an amateur pilot, and dreamed of becoming an astronaut. After getting a bachelor's degree in civil engineering from Virginia Military Institute, in Lexington, he entered the yearlong Air Force Undergraduate Pilot Training program in 1977. From 1979 to 1985, he flew the F-4 Phantom II in Germany and the F-5E Tiger II in England.

Pursuing the astronaut dream, he enrolled in the competitive Air Force Test Pilot School at Edwards Air Force Base, a program that requires an engineering degree and that all aspiring astronaut pilots must complete. He went on to test-fly experimental military planes, along the way rising to the rank of major.

In 1991, Brown interviewed with

JAMES BROWN, an IEEE member, and his ride of choice, the F-22 Raptor, the world's most advanced stealth fighter.
PHOTO: LOCKHEED MARTIN

AGE: 53
WHAT HE DOES: Flies the F-22 Raptor as an experimental test pilot.
FOR WHOM: Lockheed Martin Corp.
WHERE HE DOES IT: Edwards Air Force Base in California's Mojave Desert
FUN FACTORS: Can't beat the views.

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Lockheed Martin to be a test pilot and was awaiting an opening when the cold war ended and the U.S. defense budget was slashed. He then spent two long years as a United Airlines pilot traversing North and Central America. "After fighter jets, flying airliners wasn't in my blood," he laughs. "Let's just leave it at that."

All the while, he kept applying to the NASA astronaut-training program. But his third rejection proved definitive. "There was an electrocardiogram they didn't like, and they told me to go pound sand," he says.

In late 1994, Lockheed finally had a job for him. He started with the F-117 Nighthawk, the original stealth fighter, and then switched to the F-22. With the plane's avionics and capabilities well established, Brown's work tends toward modifying onboard computers, software, navigation systems, and weapons, assisting with the pilot interface of systems design, and translating between the pilots and engineers.

Despite the planes being far along in their development, there's still a constant danger that something could go seriously, sometimes fatally, wrong.

"Yes, I've lost friends, but I look at it pragmatically," he says. "There are engineering reasons why fate caught up with you." Every accident is extensively studied so as to learn from those mistakes, he notes. "We all accept that the job is risky, but if we can't eliminate the risk, then we work diligently to reduce it."

Twelve-hour days are typical. Flying days can start as early as 5 a.m. with a 90-minute premission briefing, followed by an hour of preflight tests, a 3½-hour flight with eight midair refuelings, and an hour of debriefing. Then Brown stumbles to his desk to sift through e-mails and write a flight report. He also finds time to speak at local schools, using aviation to illustrate the importance of setting goals, working hard, and avoiding distractions.

When he's not in the air, Brown's vehicle of choice is a fairly unsexy 2003 maroon Pontiac Grand Am. The ground-hugging engineering crew may drive Corvettes, he says, but the test pilots "tend to drive sensible cars because we have nothing to prove."

Of course, there are times when it's useful to pull out the fighter pilot chutzpah. Brown managed to avoid a speeding ticket that way. "The officer looked at me and said, 'What are you, a jet pilot?' And I said, 'Well, as a matter of fact....' He was laughing so hard, he let me go." —Susan Karlin

Steven Camilleri

MOTOR MANIAC

For a young engineer who used to sleep through math class, Steven Camilleri has certainly seen his life perk up. From In Motion Technologies' offices in Dandenong, a quiet suburb of Melbourne, Australia, he works on what he considers to be some of the most exciting technology in the world. He's been rebuilding one of the pillars of engineering—the common electric motor—and now he and his five-person research team are poised to see their superefficient, environmentally friendly device roll off production lines.

It all started when Camilleri was dozing through his course work as an undergraduate in electrical engineering at Northern Territory University in Darwin, Australia. Disappointed that the curriculum offered few opportunities to be creative, he delved wholeheartedly into outside projects—he made his own robots and joined the school's team to build a solar car. Along the way, he met Dean Patterson, a professor of electrical engineering at Northern Territory who was backing the solar car project, and he encountered the motor that would change his life.

"We'd built this freak motor, and it turned out everyone liked it," recalls Patterson, an IEEE Fellow. "We had some trouble with the electronics, and in 1996 Steven said he'd like to work on it and get it fixed. And he did!" A typical motor relies on brushes to make a mechanical connection between an electrical source and the rotating core. The "freak motor," designed to be more efficient and more reliable than ordinary motors, did away with brushes and instead rotated its permanent magnets and used power electronics to reverse

STEVEN CAMILLERI, an IEEE member, designed and built a unique new motor, effectively from scratch.
PHOTO: PETER BENNETTS

the direction of the current's flow. "The electronics needed to do a bit more than make the motor go. It needed to be a whole solar-car drive system," Camilleri says. "The system they had when I started had all sorts of efficiency, reliability, and packaging problems."

This brushless dc motor is distinct because it produces flux in an axial direction, rather than radially, as is more common; also, the motor is flatter than its ordinary counterparts. This configuration is not new, but the engineering behind it is extremely tricky because everything—including improving its mechanical strength and setting its tolerances—must be figured out from scratch.

After getting his bachelor's degree in 1998, Camilleri began working on his master's in electrical engineering at Northern Territory. He took a job at the university's Centre for Energy Research, and with Patterson and another veteran solar racer named Byron Kennedy, he continued tinkering with the motor.

In 2001, the three engineers formed Northern Territory's first spin-off company, In Motion Technologies, or IMT, in hopes of commercializing their novel engine for use in electric vehicles. But they discovered that car companies were reluctant to take a chance with IMT's fancy new design. "Everything we are doing is new—as in never been done or, sometimes, never even been tried," Camilleri says. "You get to rethink a lot of the paradigms, which does cause some friction with the old hands." So the company instead contented itself with demonstration projects: an unmanned aircraft for NASA, a superefficient ceiling fan, a tidal turbine.

Their luck changed after they approached Avanti Bikes, based in Auckland, New Zealand, about incorporating their motor into an electric bicycle. "It took going to a bicycle company, where they knew nothing about motors, for someone to say, 'Let's get this into production right away,' " Camilleri says. Over the next six months, he and his colleagues tackled problems they hadn't previously considered, such as silencing the motor's noisy hum. They tried countless mechanical workarounds before finally hitting on a solution: they drove a different current waveform through the engine.

Although Avanti made only 1000 of the bikes, priced at about AU $1500 each, the bicycles served as proof that the motors were reliable and could be built at an acceptable cost. This small success made the company much more attractive to potential investors, and the next steps became clearer. In 2006, Camilleri and his tight-knit team moved to Dandenong after Fasco, a large motor company based in Michigan, bought IMT.

Now, as a research-and-development manager at a large corporation, Camilleri finally has the connections and manufacturing capabilities he needs to push the motor onto the market in a significant way. He and his team have made a device that he says uses less material than a typical induction motor, is one-fifth the size of one, and handles variable speeds much better. The first applications will be in home appliances. Camilleri still hopes to see the motor used in electric vehicles someday, but he concedes that the time is not yet ripe. For now, he says, "we're surviving on household pumps and fans." They're not quite as sexy as cars, he admits, but making such mundane electric goods more efficient could cumulatively save a lot of energy and cut back on greenhouse-gas emissions. "The whole point is to get these motors in production so that our work can make a difference," he says.

AGE: 30
WHAT HE DOES: Designs and builds highly efficient brushless dc motors.
FOR WHOM: In Motion Technologies
WHERE HE DOES IT: Dandenong, Australia
FUN FACTORS: Works on the cutting edge of technology to reinvent the motor from scratch.

Camilleri is so driven by the goal of perfecting his motor that his biggest hurdle is winding down at the end of a day. His solution is to do something "180 degrees away from my day job." For the last 10 years, that has meant studying Japanese. He also practices judo and is converting an engineless 1971 Volkswagen Beetle into an all-electric vehicle.

Just as he did in college, Camilleri still seeks out activities that keep him on his toes. "A lot of engineering positions are more cookie-cutter, the same old, same old every day," he notes. "Give me leading edge every time. I don't know how they stay awake." —Sandra Upson

Roger Hill

MARCHES WITH PENGUINS

On a dark winter day in 1981, Roger Hill sat in a windowless cubby in the dungeons of Massachusetts General Hospital, in Boston, designing a computer model of blood flow and pressure inside the lung. He was a Harvard postdoc, with a Ph.D. in engineering from Oxford, researching pulmonary artery function. But what he really wanted to do was build gadgets.

Harvard professor and anesthesiologist Warren Zapol stopped by. Zapol was studying patients who survive oxygen deprivation and was also trying to understand sudden infant death syndrome, in which a baby stops breathing for no apparent reason. He thought that both situations might be related to the way marine mammals' bodily functions change when they dive. He asked Hill if he could build a gizmo that could be attached to the back of a seal and record depth and heart rate and take blood samples while the seal dived into the water.

That question changed Hill's life. Six months later, he was in Antarctica, supergluing epoxy-encased circuit boards to the backs of Weddell seals.

Today, Hill is the go-to guy for marine animal researchers around the world. He has designed computers that calculate the migration path of elephant seals by measuring sunrise and sunset; devices that track walruses across ice and through water; and tags that record the travels of great white sharks and the migration of tuna. One of his lightweight dive recorders determined that emperor penguins

ROGER HILL, an IEEE member, encounters penguins and seals in Antarctica while developing computers for wildlife research.
PHOTO: RICK DAHMS; PENGUIN: EUREKA/ALAMY

AGE: 52
WHAT HE DOES: Develops devices that can be attached to fish, marine mammals, and birds to record location, depth, and biological functions.
FOR WHOM: Wildlife Computers
WHERE HE DOES IT: In an office in Redmond, Wash.; on the ice in Antarctica
FUN FACTORS: He and his wife spent their 10th wedding anniversary tagging sharks in Belize, their 25th with seals in Antarctica.

can dive 600 meters, far deeper than anyone ever thought. These days, Hill is back in Antarctica, testing instruments he designed to study how aging affects Weddell seals.

Back to 1981: Hill and a technician built their first seal computer around the just-introduced NSC800, an early CMOS microprocessor. The device controlled a peristaltic blood pump that would function down to 1000 meters, and sensors that measured the animal's heart rate, core body temperature, and snippets of EKG signals. A fiber-optic cable let researchers download recorded data with the package still attached to the seal.

The first prototype worked—until Hill was encapsulating it in a thick coating of epoxy and glass beads (to make it neutrally buoyant), which caused it to overheat and then explode. There was no time to build a second prototype before his scheduled departure for McMurdo Station, in Antarctica, so he took circuit boards, epoxy, and bits and pieces of electronics with him. At McMurdo, he discovered that pouring the epoxy in layers instead of as a block eliminated the overheating.

While Hill assembled his gizmos, the other members of the research team selected a spot on the ice and set up the field camp, complete with a seal-size hole. Hill, Zapol, and the rest then went out to a seal colony, selected a seal, and herded it onto a sled. (Antarctic seals have no land-based predators, so they are not afraid of people.) They then drove the sled to their camp, where doctors anesthetized the seal and inserted a catheter through an artery and into the aorta. At the same time, Hill glued a neoprene pad onto the seal's back and attached the computer (about the size of a paperback book), the battery pack (a little larger than a deck of cards), and the blood-sampling equipment (slightly smaller than a can of soda) by screwing them into mounts on the neoprene.

Once the seal woke up, the group brought it over to the hole in the ice. The seal dived right in. When it resurfaced 20 minutes later, Hill plugged the device's fiber-optic cable into his Zenith Z80 desktop computer, downloaded the data, retrieved the blood sample collected mid-dive, set up the parameters for the next dive, and waited for the seal to dive again. The group repeated this process for a few days, then removed the catheter and gear, took the seal back to its original capture point, and picked up a new seal.

The research results were astonishing. It turned out that the concentration of red blood cells rose steadily during the first 20 minutes of a seal's dive; the researchers could only guess where the cells were coming from. A few years later, Zapol confirmed that the seal's spleen releases oxygenated blood cells as needed, providing new insight into that previously mysterious organ.

Meanwhile, Hill was hooked: "It was way more fun than doing work on pulmonary arteries of sick patients." He also loved the work because, he says, "I like getting my hands dirty. I liked the technological challenge." And spending long hours outdoors sure beats sitting in a windowless basement—this is a guy who, during high school and college, would regularly go off on two-week hikes through the English countryside or remote areas of Lapland.

He even met the woman who is now his wife, Suzanne Braun (now Suzanne Hill), on that first trip to Antarctica, where she was doing doctoral research on the maternal bond between Weddell seals and their pups. But she had no interest in the self-described nerd. "She took up with a helicopter pilot," Hill recalls.

The next year, though, Hill prepared to wow her. Despite his limited baggage allowance, he packed a tuxedo. Then, for the big Halloween party at McMurdo Station, Hill added fins he had borrowed from a dive locker, a black balaclava, goggles, and a funnel liberated from the biology lab; with bits of yellow tape in strategic places, he became a penguin.

The strategy worked. Braun finally noticed him, and this past October they celebrated their 25th anniversary—in Antarctica, of course.

Hill continued to build gadgets for Zapol until 1985, when the funding ran out and Hill reluctantly went back to his research on the human lung. But marine researchers who'd heard about Hill's seal work began contacting him to talk about devices that they dreamed about. For one Seattle-based researcher, he built a data recorder that measured dive depths and dive durations for freely swimming seals. The researcher, John Bengtson, was thrilled.

Emboldened by this success, Hill quit his Harvard post in early 1987, moved to Seattle, and started Wildlife Computers, in Redmond, Wash., to work on marine devices full-time. In the early days, the company worked under contract to marine researchers; later, it began building off-the-shelf products, like US $3500 fish tags that record data for a preprogrammed time period (as long as a year) before popping up to the surface to transmit the collected data via satellite. Times were lean for a while, but now Wildlife Computers is a multimillion-dollar business with 28 employees.

And that's about as big as Hill wants it. He still spends most of his day writing software or designing circuit boards, and he loves the variety. "One morning I'm trying to figure out how to make a gizmo that's going to cut the line that connects the towed tag to the animal, so that if the animal dives too deep, the tag is released and doesn't get crushed," he says. "That afternoon I'm discussing code. And in the middle of that I'm laying out the design of a new tag." On occasion, he still joins research teams in Antarctica or other remote posts.

At this point, Hill can direct his destiny. "We only make instruments that further the understanding of animals to help with their conservation," he says. "I have a complete absence of guilt about everything I do," he says. And he plans to keep it that way. —T.S.P

Ney Robinson Salvi dos Reis

INTO THE WILD

THE SMALL motorboat meanders through the Amazonian swamp. The water is a turbid brown, the jungle a thicket of twisted trees. A *cricrió* bird chirps from the treetops. The Brazilian researchers stop the boat to have a look around. Suddenly a noise breaks the calm. Buzzzzzzzzzzzzzzz.

Within seconds, an angry swarm of *cabas*, Amazon wasps with a powerful sting, envelops the boat and its unlucky occupants. To hear Ney Robinson Salvi dos Reis tell the story, you almost feel you're right there in the rain forest with him, fighting off the bellicose bugs.

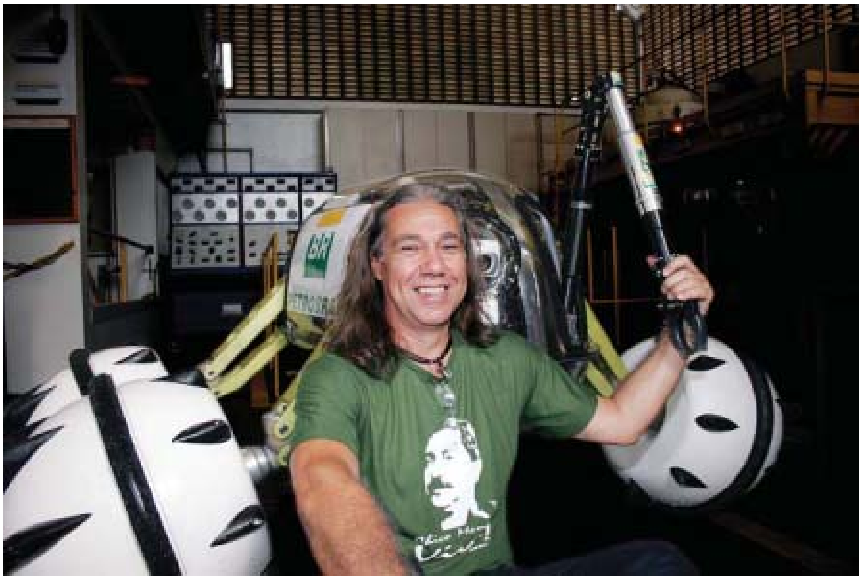
"Jumping into the water is not a good idea," Reis says. "There are crocodiles, snakes, piranhas, and a bloodsucking little fish called candiru that can enter your body orifices. So I covered my head and told the *mateiro*"—the Amazon native piloting the boat—"to get us out of there fast!"

For Reis, a robotics engineer at Petrobras, Brazil's state-controlled oil company, fleeing from wild wasps through treacherous waterways in excruciating heat and humidity is just part of the fun. He heads the robotics laboratory at Petrobras's underwater technology division in Rio de Janeiro. The company's main oil fields reside in deep waters off the Brazilian coast, so Reis's lab specializes in developing all sorts of Jules Vernian contraptions—a caterpillar-like robot to unclog underwater pipelines, a supersized hydraulic wrench that can work down to 2000 meters.

Petrobras also operates some oil fields inland, including Urucu, tucked deep within the Amazon rain forest. Sometime this year the company plans to complete a 670-kilometer-long pipeline to transport natural gas to Manaus, the region's largest city. The company will need to routinely inspect the line for leaks. That's where Reis comes in.

"You can't just hop in your 4x4 and go see if the pipes are okay," he says. "You need to cross rivers, *igarapés* [seasonal tributaries], flooded forests, and a floating cushion of aquatic vegetation that forms near the riverbanks."

So Reis's team is building a pipeline-monitoring robot that can navigate just about any kind of terrain. Shaped like a dune buggy, it has four spherical wheels the size of overinflated beach balls, which let the robot float. The outer sides of the wheels have paddles, and powered suspensions can tilt the paddled sides into the water. The machine is called Chico.



NEY ROBINSON SALVI DOS REIS, an IEEE member, designed this amphibious robot to monitor the Amazon.
PHOTO: ERICO GUIZZO

The robot's main job will be to run up and down the pipeline using gas-sniffing sensors to find leaks. The current prototype is remotely operated, but Reis's group is designing a manned version for more complex inspection and repair missions. He says the robot will also help scientists gain unprecedented access to the Amazon, letting them film animals, record bird sounds, and collect plants and water samples. "We're doing these engineering projects," he says, "to give people the ability to see, smell, hear the jungle—and protect it."

Reis's inspiration to become an engineer came from his grandmother Irene, an elementary school teacher. Growing up in Rio, the young boy would marvel at the objects she built for her classes, from a simple tin-can phone to a dollhouse with numbered windows and doors to teach arithmetic.

In 1972, Reis earned a degree in mechanical engineering from the Federal University of Rio de Janeiro and began working on the construction of nuclear reactors, iron-mining plants, and oil refineries. He took scuba-diving courses and worked on the construction of Brazil's first offshore platforms. "It was a beautiful adventure," he recalls. "I finally understood the meaning of navy blue."

In 1987, he joined Petrobras. At the time, the company was beginning to explore deeper and deeper waters and couldn't rely on divers anymore. It needed robots. Reis cofounded the robotics lab and helped the company reach some of the world's deepest oil reservoirs.

These days, when Reis is not out in the Campos Basin off Rio's coast or the Amazon jungle testing a new system, he's in the lab, making wooden models with his longtime assistant, José "Geppetto" Almir Sena, or brainstorming with the graduate students he helps advise.

On a muggy spring afternoon, Reis heads out to the lab's pool to put the robot through a round of tests. Tall and tan, with green-gray eyes and a mane of brown and silver hair, he strolls gracefully, greeting everyone he sees. *"Opa, tá bom, menino?"* he calls out to one acquaintance. "Hey, you good, boy?"

In his cramped office, Reis keeps a binder labeled "On the Anvil," full of half-baked ideas he has scribbled on scraps of paper or napkins. "You're at home, in the shower, the toilet, or whatever, and then, boom!—you're taken by the most wonderful of ideas," he says. Many of those ideas become topics for his students' doctoral dissertations.

Reis enjoys giving talks at schools and universities about his projects and the importance of science and engineering. He's found it a useful technique for recruiting new members to his lab, which now includes, in addition to his full-time staff of four, about half a dozen master's and Ph.D. students and high school interns. "Ney encourages the group to be creative, improvise, and above all, have fun," says Gustavo Medeiros Freitas, a master's student. "He wants to look into your eyes and see that you love what you're doing."

AGE: 57
WHAT HE DOES: Develops advanced robotic systems for environmental monitoring and oil exploration.
FOR WHOM: Petrobras
WHERE HE DOES IT: Rio de Janeiro and the Amazon
FUN FACTORS: Designs and builds cutting-edge robots and then field-tests them in the rain forest and out at sea.

Late last year, Reis and his team were preparing for another trip to the Amazon (he's been there more than 30 times in the past five years). He says the project is not just about going there, testing the robot, and leaving. He and his crew seek to involve local communities and hope the locals will eventually assist in operating and maintaining the robot. And what do the Amazon natives think of their futuristic wheeled visitor?

"The kids love it; they're totally unafraid," Reis says. "Once we were operating the robot, and this little boy ran toward it. I shouted, 'Be careful!' Then we stopped the robot. I took the boy in my arms and sat him on a wheel. He had the biggest smile on his face." —Erico Guizzo

Ash Nehru

EVERYTHING IS ILLUMINATED

If you happened to stroll down London's tony Regent Street this past Christmas, you may have noticed, just above the festooned storefronts and package-laden shoppers, a series of clusters of glowing translucent globes. If you'd taken a closer look, you would have realized that the globes were pulsating with color, the light-emitting diodes (LEDs) within varying their hue and intensity according to the number of passersby, the wind speed, and the amount of sunlight. And if you'd looked *really* close, you would have discovered the quad-core Xeon computers running customized software that took inputs from people-monitoring video cameras and environmental sensors to precisely choreograph the display.

Although the promotional literature identifies the display's sponsor as cellphone maker Nokia, the actual design came from a small London-based firm called United Visual Artists, which specializes in such high-tech interactive light displays. The computer code that generated the display is the handiwork of UVA's software director, Ash Nehru.

Designing artwork that the public can interact with is immensely satisfying, Nehru says. "It's great seeing how people respond—jumping up and down, waving their arms around, walking up and then turning away. It never works quite how you think it's going to work."

Nehru started coding as a kid, when his father, a mechanical engineer, brought home a microcomputer sold by the British Broadcasting Corp.'s Computer Literacy Project. In its day—the early to mid-1980s—the BBC Micro was an incredible machine. "It took one second to boot up and booted straight into the BASIC interpreter, so you could program immediately—in fact, that's all you could do," Nehru fondly recalls. The computer had a faster processor than any other machine of its time—4 megahertz—and a then-remarkable 32 kilobytes of graphics memory. Best of all, he says, "it came with well-written user guides that allowed me to learn first BASIC and then 6502 assembly language programming." Built by Acorn Computers for the BBC and sold

ASH NEHRU, an IEEE member, takes in the Christmas lights on London's Regent Street.
PHOTO: PETER SEARLE

AGE: 35
WHAT HE DOES: Designs software for creating interactive 3-D lighting displays.
FOR WHOM: United Visual Artists
WHERE HE DOES IT: London
FUN FACTORS: Is currently considering how to outfit hundreds of toy helicopters with low-power lasers and fly them in formation around central London.

for a few hundred pounds, it spawned legions of young programmers.

Nehru spent hours creating games and other programs. "I was 10, I had just moved to England from India, and I had few friends. But I had this computer."

Nehru went on to earn a B.A. in computer science from Trinity College, Cambridge, in 1994. For his first job, he had just three requirements: "It had to be in London, I didn't want to wear a suit, and I wanted to work on 3-D graphics." He might have ended up designing avionics interfaces, but instead he got hired by computer gaming company Domark Software (later acquired by Eidos Interactive).

As a member of the research group, he looked at up-and-coming technology likely to be adopted by the gaming world. He found the work technically interesting but culturally boring. "You basically spend your days figuring out how to shoot people and chop off monsters' heads," Nehru says.

On the side, though, he had been tinkering with generating live three-dimensional graphics—dancing robots and virtual go-go dancers—that could be displayed at music clubs and concerts. His debut "performance" came at a New Year's Eve bash at London's Alexandra Palace, where a crowd of 50 000 gyrated along with his animated characters. "People were going stark staring bonkers," Nehru recalls. Compared to coding games, he adds, "it was a much more immediate payoff."

Nehru quit his day job and started doing his live 3-D graphics full-time, creating dancing cartoon characters for nightclubs and pulsating light shows for raves. His work appeared throughout the United Kingdom, and he performed at the Burning Man festival a few times. He even tried his hand at being a DJ—"to no great success, of course. It was just a lot of fun."

Fun—but not lucrative. In late 2002, right around when the money ran out, he got a phone call from Chris Bird and Matt Clark, who had also been designing visuals for live concerts. They'd been commissioned by the trip-hop band Massive Attack to produce the lighting for an upcoming concert tour. Bird, Clark, and Nehru decided to "create a show that was really of the moment and connected to the people," Nehru says. The stage backdrop became essentially a computer terminal onto which raw data and messages constantly streamed. From a programming point of view, Nehru treated the concert like a video game, creating a timeline and scripts into which up-to-the-minute information—soccer match scores, local weather reports, e-mail messages from audience members—could be easily dropped.

That work "put us on the map," Nehru says. Although he'd gone into the project thinking it would be a one-off, "we worked together so well, the penny sort of dropped." Shortly after the tour ended, the three formed United Visual Artists, with the aim of creating sophisticated interactive lighting displays that blend equal amounts of art and technology.

Since then, the company has grown to a full-time staff of 13, plus a rotating crew of interns. To reach its second-floor offices in a weathered brick building in London's historic Borough neighborhood, just south of London Bridge, you can risk the semifunctional freight elevator, but it's safer and quicker to take the stairs. In the main workspace, four young designer/programmers hunch over workstations beneath a silver disco ball, while indie rock tunes waft through the air. Just beyond, in the hardware room, the guts of disassembled computers and other electronics await repair and upgrades. The place has a start-up feel. "We all work overlong hours," Nehru admits. "We haven't gotten to the point where we can just relax."

Creating new works, whether for a commercial client like Nokia or for a commissioned art exhibition or performance, is a labor- and technology-intensive undertaking. A typical project starts with a visit to the site, where a team member takes photos and video, which the entire group then reviews and discusses. "About a week later, everybody comes back with their best idea. It's very important that everybody's part of the process," Nehru says. Once the ideas have been distilled into a workable plan, "we take that to the client. Then they tell us how much money they *really* have," he says, laughing.

Nehru's chief contribution is a program called D3, written in C++, that lets the designers create a detailed and realistic 3-D simulation of what the installation will look like. The program also controls the installation once it's built. On one of the workstations Nehru calls up a recent example, a music video for the U.S. rock band Battles shot in an abandoned Welsh slate mine. The team knew they'd have at most a day to shoot the video on-site, so they needed to know exactly how the lighting would work before they got there.

Onscreen, a designer has sketched the rough outlines of the mine's walls and floor and positioned the performers and their instruments within it. The set is surrounded by tall skinny poles of LEDs, which flash, pulse, and change color in sync with the music. With some simple keyboard commands and pull-down menus, Nehru can rotate the stage, change the positions of the lights, vary their color and pattern, and then see how the illumination and shadows shift.

The program isn't exactly user-friendly, but it makes the creative process more efficient and also opens up new possibilities for the designers that they can see on the fly. United Visual Artists just licensed the program to a company that rents LED equipment and control systems for exhibit halls and TV ads.

Being the guy who makes the tools that make the art suits Nehru just fine. "Writing code is just as creative as painting a picture," he says. "You're figuring out ways to translate what's in your head into something real." —JEAN KUMAGAI

Salinee Tavaranan

POWER RANGER

THE MONSOON rains have eased, and Salinee Tavaranan and several members of her team are piled into the back of a tan pickup truck. The vehicle winds along dirt roads near the Thai-Burma border, eventually pulling through the front gates of the Mae La refugee camp. Having fled torture and economic hardship in neighboring Burma, thousands of refugees now call this place home. Many have lived here for years, in simple thatched huts without electricity or running water.

But thanks to Tavaranan and her Border Green Energy Team, Mae La and more than 20 other refugee camps and villages are no longer entirely cut off from the grid. Over the past two and a half years, BGET, a project of the Thailand-based nonprofit Palang Thai, has installed solar panels and micro-hydro turbines across the region and trained hundreds of local residents on how to install and maintain the systems. The work of BGET has in turn given the villagers access to some of the most basic amenities: lights, computers, and decent health care, to name a few.

"The most rewarding thing about this job is to be able to use my education to help people and to improve their lives," Tavaranan says, her face lighting up with a warm, enthusiastic smile.

Concern for others and for the environment was what led Tavaranan to engineering in the first place. She grew up on the beach resort island of Phuket, in southern Thailand, and thoughts about protecting the natural beauty of her hometown inspired her to pursue mechanical engineering with a concentration in energy systems at Chulalongkorn University in Bangkok. After graduating in 2001, she went on to earn an M.S. in solar energy engineering at the University of Massachusetts Lowell.

SALINEE TAVARANAN, an IEEE member, stands next to solar panels that her Border Green Energy Team installed in a refugee camp near the Thai-Burma border.
PHOTO: WALT RATTERMAN

"THE MOST REWARDING THING ABOUT THIS JOB IS TO BE ABLE TO USE MY EDUCATION TO HELP PEOPLE AND TO IMPROVE THEIR LIVES"

Tavaranan was one semester into a Ph.D. program at Lowell when she learned from a friend that BGET was looking for a project director. For her, it was a no-brainer; the mission of BGET, based in Tak, Thailand, fit perfectly with her training and her sensibilities. She applied, was offered the job, and soon found herself working in the jungles and mountains of northwestern Thailand.

Back at Mae La, Tavaranan and her team hike up a steep hill, scrambling over fallen trees and across streams, before arriving at a one-room school surrounded by lofty cliffs. Inside, students work at a dozen desktop and laptop computers. They're enrolled in a program that teaches them graphic design and programming skills that might prove marketable once they receive immigration visas and can leave the camp. The computers and classroom lights, as well as some power tools, can run all day and night now—this, due to a row of Japanese-made amorphous-silicon solar panels sitting outside and a shed full of lead-acid batteries.

BGET engineers designed the solar setup so that the panels' output is channeled to a controller that then feeds the appropriate amount of juice to the computers, lights, and tools. Any leftover energy is converted from ac to dc for storage in the battery shed. School administrators fire up a backup diesel generator only when the solar panels aren't producing enough energy—and thankfully, that's rare, because the fuel is expensive and the generator, noisy and smelly.

This coming year, BGET plans to install a solar-powered water pump at Mae La that will be used for agriculture. In addition to its work in the refugee camps, the team assists Thailand's ethnic minorities, who live in communities that are similarly impoverished, as well as backpack medics embarking on humanitarian missions inside Burma. It trains the medics to install the solar panels and microhydro turbines, and the medics can then train Burmese villagers to operate the equipment themselves.

Tavaranan eventually envisions linking up villages throughout the region into a series of interconnected minigrids, all powered by solar panels and microhydro generators. She explains that all the technology BGET installs has been designed to be simple enough for the villagers themselves to maintain.

AGE: 29
WHAT SHE DOES: Installs renewable energy sources in "off-the-grid" communities and trains locals to maintain them.
FOR WHOM: Border Green Energy Team
WHERE SHE DOES IT: In mountain villages and refugee camps near the Thai-Burma border
FUN FACTORS: Brings electricity and opportunity to people who have very little.

"The villagers see that this is the most appropriate form of energy for them, both because of the location and the situation," she says. They're not the only ones who could benefit from using more renewable sources, she adds. "Big cities might consider integrating these methods with more traditional sources of energy, to reduce their dependence on fossil fuels."

As Tavaranan and her team prepare to leave the refugee camp, sunlight bounces off a solar panel outside one of the houses. The homeowner paid for and installed the panel himself, Tavaranan points out. "That's a good thing," she says. "The more people learn to harness natural energy, the better their lives become." —Dean Adams

TO PROBE FURTHER For a video on the Border Green Energy Team and a description of one of its microhydropower projects, go to http://www.spectrum.ieee.org/feb08/rangergreen.

Mark Schubin

NIGHTS AT THE OPERA

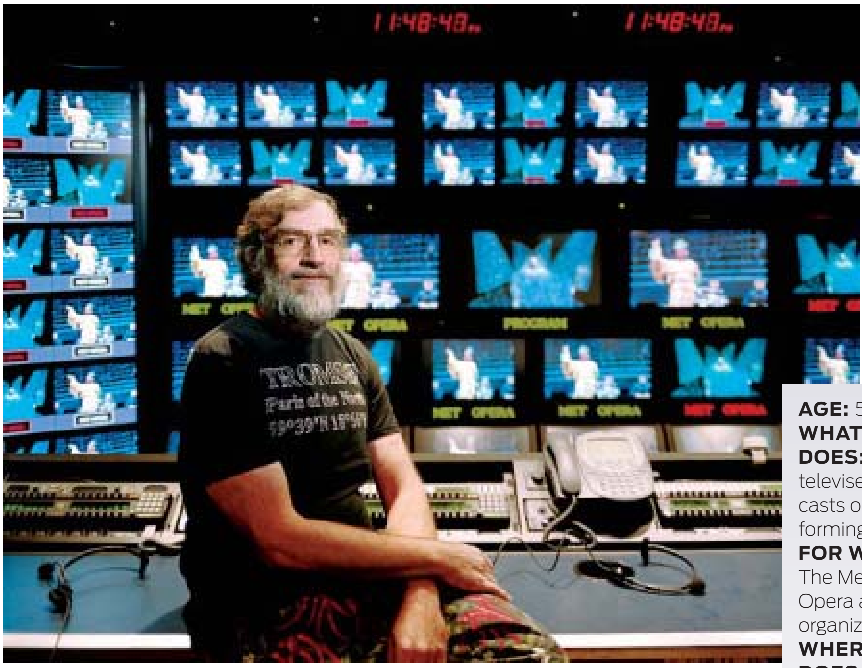
On stage, the dashing tenor Roberto Alagna pours out his love for the dark-eyed soprano Anna Netrebko, and she responds in kind. As the star-crossed lovers in the Metropolitan Opera's *Roméo et Juliette*, the pair sing with a fiery passion that would melt a stone.

But a few hundred meters away, sitting in a truck parked outside the Met's loading dock, television engineer Mark Schubin isn't moved. He's intently monitoring a huge bank of monitors and audio/video equipment, checking that the voices and instruments are all within range, that the audio and video feeds are open, and that everything technological about the otherwise gloriously overwrought performance is calm, quiet, and normal.

Most performances at the Met are done for the benefit of the few thousand ticket holders who fill the gilded auditorium. But today's show is being seen live by nearly a hundred thousand people all over the world. Video cameras and microphones in the opera house are capturing the singers' every move and note, and satellites are beaming those signals, in high definition and 5.1-channel digital surround sound, to more than 600 motion-picture theaters in 11 countries on four continents.

Pulling together the Met's second season of high-definition cinemacasts is as much a technical triumph as an artistic one, and for the last year and a half, the project has been consuming Schubin's life. He jokes that his job is "to make sure nothing goes wrong," but it's a lot more complicated, and interesting, than that.

After more than 34 years of engineering TV and radio broadcasts at the Met, Schubin is the opera's tech guru on a whole host of issues. Much like televising a professional football game or an Olympics event, engineering the Met's broadcasts



MARK SCHUBIN, an IEEE member, engineers televised broadcasts for the Metropolitan Opera.
PHOTO: OFER WOLBERGER

AGE: 57
WHAT HE DOES: Engineers televised broadcasts of the performing arts.
FOR WHOM: The Metropolitan Opera and other organizations
WHERE HE DOES IT: New York City and stages and theaters all over the world
FUN FACTORS: Tromsø, Norway, 400 meters north of the Arctic Circle, recently held an opera festival in his honor.

raises countless technical issues, and Schubin weighs in on all of them—how to upload audio and video feeds to seven telecommunications satellites and ensure they arrive in good shape at the other end; what to do if cloud cover disrupts a satellite's signal or if power anywhere along the transmission path is lost; how to shoot in light levels that often dip below 10 lux; how to frame shots that are as pleasing on a 20-meter-wide cinema screen as on a tiny TV set. The list goes on.

A big concern this past summer was how to handle the translated subtitles that go out with the cinemacasts. During the initial season, they did it by "brute force," Schubin says, sending separate audio and video channels for the German- and English-subtitled feeds. This season, they're embedding bitmapped subtitles for five different languages within the transport stream itself, so that the subtitles travel along with the audio and video signals.

Schubin has defined some of the technical standards that now govern such broadcasts, and he's overseen the transition through several generations of TV equipment, from 1970s-era manually operated tube cameras running over multicore cable to today's remote-controlled, high-definition charge-coupled-device cameras with 101x zoom lenses fed through fiber optics. When he's not engineering a shoot at the Met or elsewhere in Lincoln Center, the performing arts complex on Manhattan's West Side in New York City, he's on the road consulting at other theaters. Or he might be providing expert testimony on a broadcast-related lawsuit or writing his monthly technology column for *Videography* magazine. At this point, Schubin knows more about the intersection of opera and broadcast technology than anybody else in the world.

But when he started his career, he knew nothing about either. Even before earning a B.S. in chemical engineering from Stevens Institute of Technology, in Hoboken, N.J., in 1971, he'd decided that a traditional engineering job wasn't for him. He took a fleeting turn as publisher of a high-spirited but short-lived newspaper called the *Hoboken Herald*. After the paper folded, he spent a few happy months out of work before landing a job at a small company called Computer Television, which aimed to change the way people watched TV.

It may be hard to recall, but there was a time when catching your favorite TV show meant parking yourself in front of the tube on a set night at a set time. There were no TiVos or VCRs. Schubin's boss, Paul Klein, saw that by marrying computer and video technology, you could watch any show whenever you chose.

As the only engineer on the three-man staff, Schubin got the task of learning everything about video and computers that he could. In 1971, he helped launch the company's successful pay-per-view movie service for hotels. The following year, he founded his own company, Electronic Solutions, and in 1973 he was hired to help Lincoln Center engineer its first televised series, which eventually became known as "Live From Lincoln Center."

The first production they filmed was *Tales of Hoffmann*, the opera by Jacques Offenbach, starring Joan Sutherland in all the female leads. For the first time, people watching the close-ups of the Australian diva's face could see her emotive ability. "People kept saying, 'I knew she was a great singer, but I had no idea she was also such a wonderful actress,' " Schubin recalls. He still counts that show as one of the high points in his career, because it drove home the power of television to enhance the performing arts and reach audiences in new ways.

The Met's cinemacasts are further proof of that power. Sixty kilometers from Lincoln Center, at a suburban multiplex in northern New Jersey, the live broadcast of *Roméo et Juliette* is showing on three screens and is nearly sold out. The audience seems enraptured. Between scenes, the cameras go backstage and show singers warming up and changing costumes; other cameras take the audience down into the orchestra pit.

Harold Nakayama, a retired Air Force technician and longtime opera fan, relished the privileged view. "We got to see things that even the audience at the Met didn't get to see," he says. "That was really special." —J.K.

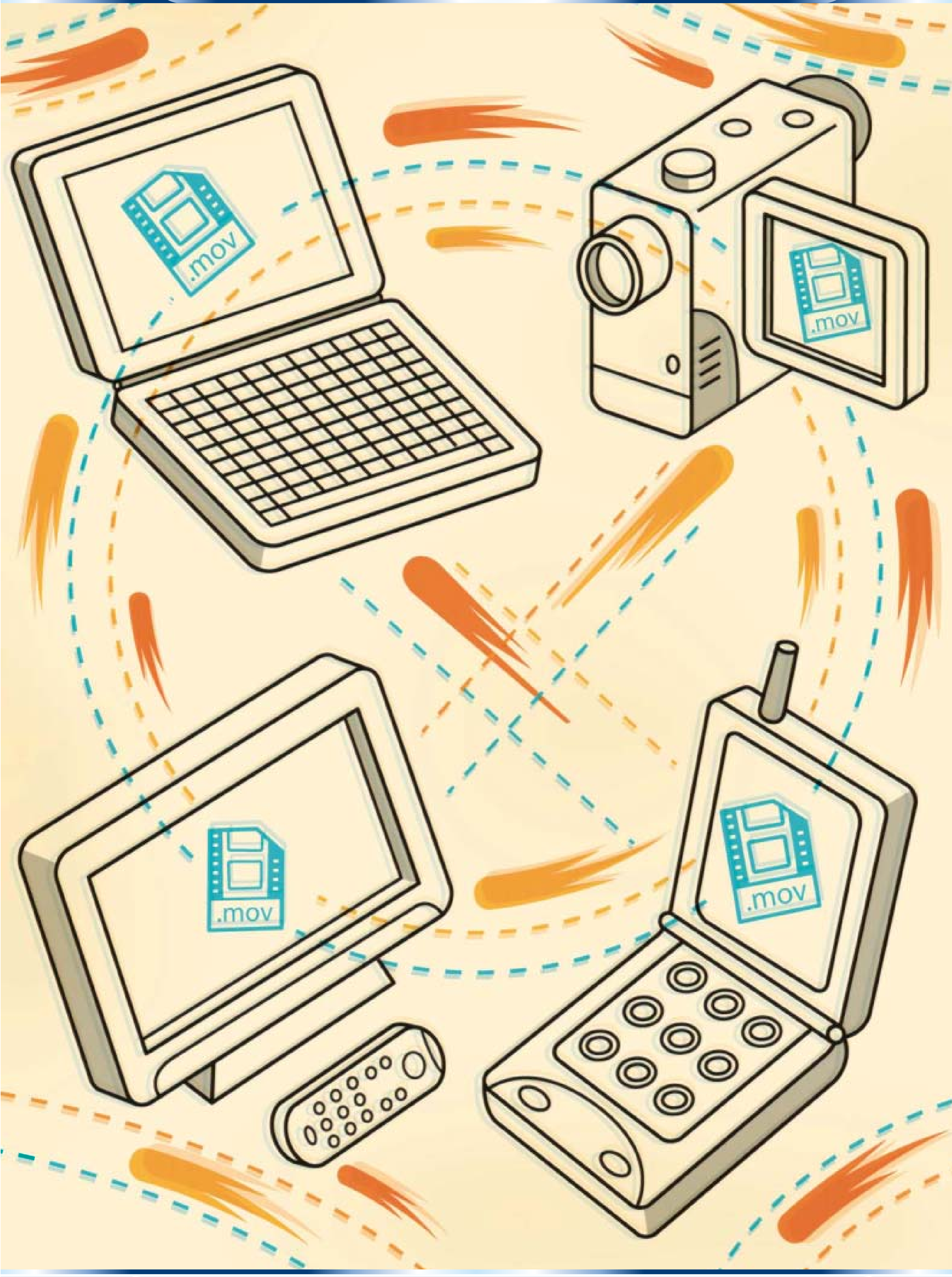
PULLING TOGETHER THE MET'S CINEMACASTS IS AS MUCH A TECHNICAL TRIUMPH AS AN ARTISTIC ONE, AND FOR THE LAST YEAR AND A HALF, THE PROJECT HAS BEEN CONSUMING MARK SCHUBIN'S LIFE

Gadgets Gab at 60 GHz

Cheap silicon transceivers broadcasting in this still-unlicensed band may usher in the hi-def wireless home

By Behzad Razavi

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags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MAY THE POWER BE WITH YOU: A useful measuring stick for wireless transmission may be found in *Star Wars: Episode IV* (1977), the first in the *Star Wars* series. The six frames shown above are taken at equal time intervals from the movie's beginning to its end and are marked to show the portion that could be downloaded in the space of 2 minutes. Bluetooth (IEEE 802.15), at 2 megabits per second, would get a few seconds of the movie; the IEEE 802.11g standard would make it to the middle of the introductory narrative; and ultrawideband would get about a tenth of the way into the movie. Meanwhile, IEEE 802.15.3—the proposed standard for 60 GHz—would make it all the way to the final credit [far right]. PHOTOS: LUCASFILM/20TH CENTURY FOX/THE KOBAL COLLECTION

People not only talk on the airwaves, they increasingly expect their gadgets to do the same. The trend began in the late 1990s with Bluetooth, which provided 1 megabit of data per second. Then Wi-Fi and the IEEE 802.11 standard pushed the rate to 100 Mb/s. Now ultrawideband systems are going five times as fast as that.

In principle, such radio links, operating over short ranges, could replace the cables that now clutter our homes and offices, eliminate the speed penalty of going wireless, and even allow portable devices to off-load computing work to a nearby base station. The devices could thus shed hardware to become smaller, lighter, and cheaper.

But it won't happen until engineers lay their hands on more bandwidth. The various 2.4- and 5.8-gigahertz systems now in common use are rapidly running out of spectrum, and the inflexible 100-microwatt constraint on ultrawideband power will likely limit it to about 1 gigabit per second. Where do we go next?

Clearly, we must look upward, but just how far up isn't so obvious. One tempting thought is to use *really* high frequencies—infrared light. Although that tactic works fine if all you want to do is switch TV channels with your remote or operate a wireless mouse, it turns out that it's hard to modulate the output of infrared light-emitting diodes fast enough for more demanding applications. So for the moment anyway, RF makes more sense, and the best prospects to be found there reside in 7 GHz of unlicensed spectrum near 60 GHz. Those frequencies are 10 times as high as anything in common use today, and with the bandwidth they provide they can carry a lot more data. Until now, engineers designing products for the consumer market have shied away from 60 GHz because of various technical difficulties, but bandwidth hunger is finally awakening their interest.

Developments in chip design have also played a part. Today's 60-GHz technology depends on relatively expensive and power-hungry gallium-arsenide semiconductors, but various researchers—including engineers at IBM, the University of California, Berkeley, and those in my group at University of California, Los Angeles—have shown that silicon chips can do the job with much less power and at a fraction of the cost. The silicon option is what makes 60-GHz communications attractive.

The allure is so strong that a special task force is now working on an extension of the IEEE 802.15.3 standard for wireless personal area networks in

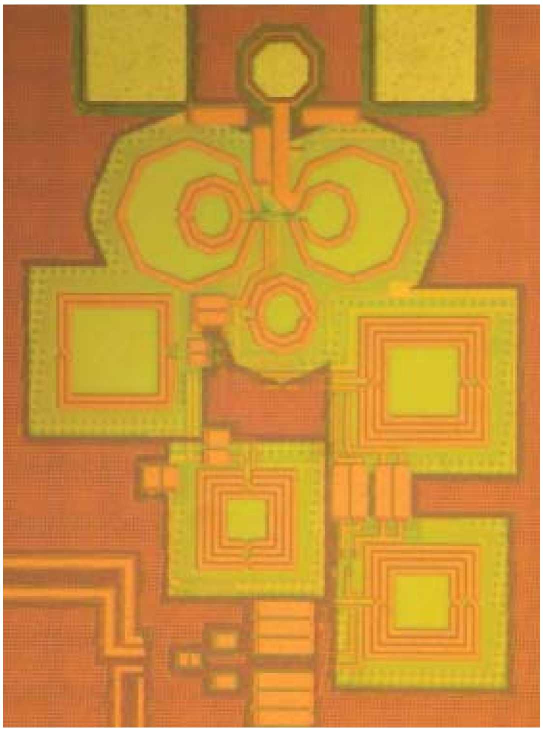
ILLUSTRATION ON PREVIOUS PAGE: HARRY CAMPBELL

IEEE 802.15.3
2–4 Gb/s

the 57- to 64-GHz band, and in 2006 a number of companies—including Matsushita, NEC, and Sony—came together to define a specification for transmitting high-definition video in this slice of the radio spectrum. Their group, called Wireless HD, of Sunnyvale, Calif., wants to link TV sets to disc players, video cameras, game consoles, laptops, and other devices at rates as high as 5 Gb/s—fast enough to transmit an HD feature movie in about a minute [see "May the Power Be With You"].

There are other advantages besides extra bandwidth and faster data rates. Because the wavelengths are so short, the antenna needn't be much bigger than the head of a pin, small enough to go on the transceiver chip. Indeed, it is feasible to integrate many antennas and transceivers into a single chip so that together they can, with proper phasing, form a beam to steer transmissions in a particular direction [see illustration, "Adaptive Antennas"]. Such phased-array antennas can also be used to boost reception. These operations can be conducted automatically so that the sender and the receiver can find each other without human intervention, constituting an adaptive-array (or "smart") antenna system.

The integration of the antenna avoids the need for wires to carry signals to and from the chip, reducing the cost of packaging by one to two orders of magnitude. Further, the absence of exposed inputs and outputs makes the transceiver less vulnerable to electrostatic discharge during fabrication and assembly. Manufacturers could thus dispense with antistatic devices, which add capacitance and degrade performance.



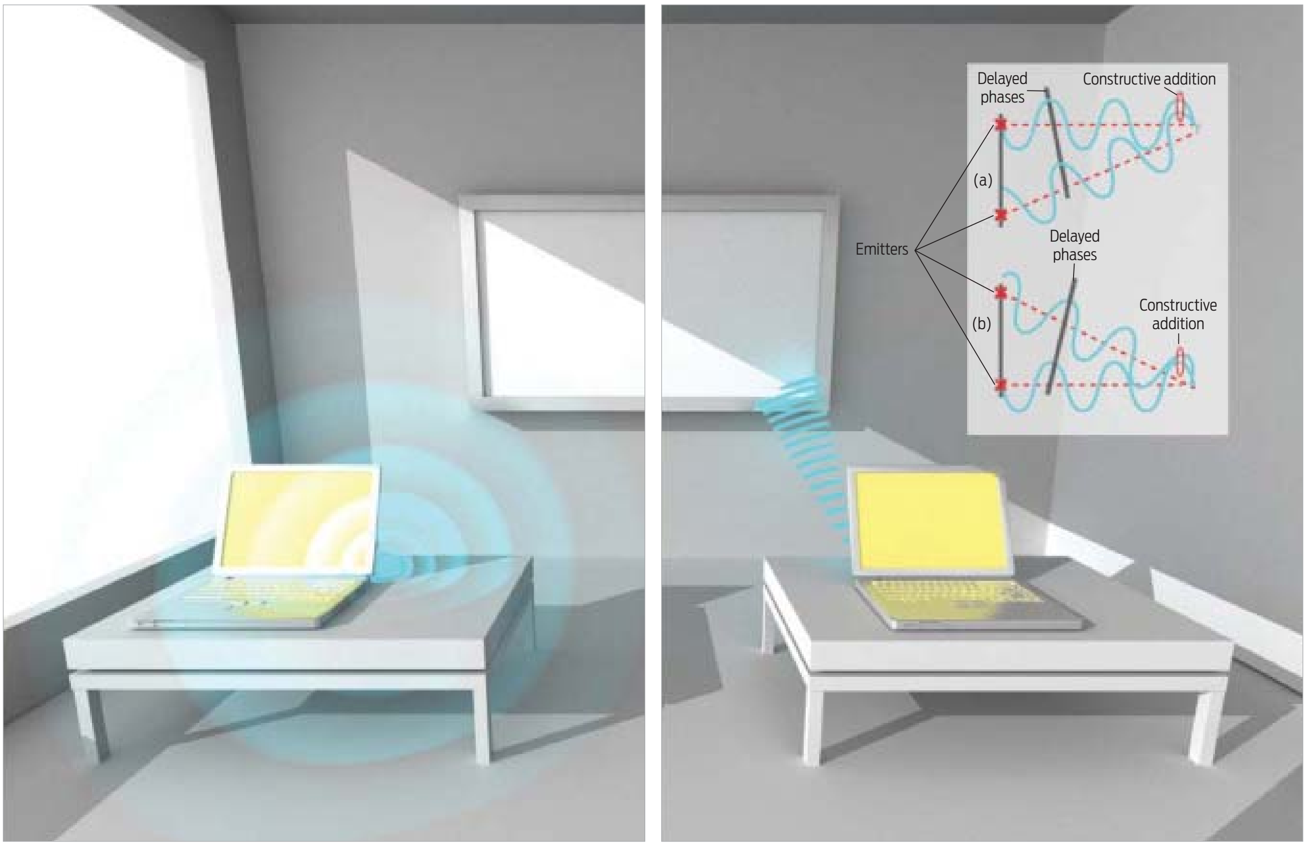
DESIGN TRICKS allow transceivers to accommodate bulky components—for instance, by nesting square and octagonal induction coils one inside the other.
PHOTO: BEHZAD RAZAVI/UCLA

These benefits do not come for free, however. Communication at 60 GHz involves significant challenges at the system, circuit, and device levels—challenges that account for why this bandwidth has lain fallow for so long. Designers can, however, get around these obstacles by taking advantage of the capabilities available at one level to relax the requirements imposed at another.

The difficulties begin with the propagation of the 60-GHz wave itself. As with any electromagnetic signal, the number of watts passing through each square meter diminishes in proportion to the square of the distance from the transmitter. On top of that, the size of the antenna scales with the wavelength, so its effective area—and so the power it can capture—varies in direct proportion to the square of the wavelength (and therefore in inverse proportion to the square of the frequency). Hence a signal broadcast at 60 GHz will convey to the typical receiving antenna just 1 percent as much power as it would have done had it been broadcast at 6 GHz. Making matters worse, 60-GHz rays are blocked by solid objects.

Some possible solutions are to transmit at very high power and to use adaptive-array antennas to send signals to their target by indirect routes, through reflection and refraction. It's better, though, to rely on lots of transceivers. If enough were strewn through an office—and even worn by the people who work there—any two devices would always be able to talk to each other directly or through a third node.

For this strategy to work, a transceiver must be made cheap enough, small enough, and fru-



ADAPTIVE ANTENNAS can form a beam and direct it to a target, greatly reducing the attenuation of power, a serious problem in the 60-GHz band, which is strongly absorbed by air. In a conventional antenna [left], the received power declines with the square of the distance. Adaptive antennas [right] use an array of emitters with delayed phases that make the waves' peaks and troughs add constructively [insert]. This trick focuses the power into a beam, which can then be steered up (a) or down (b) electronically. Advances in 60-GHz transceiver design now make it possible to fit an adaptive array on a single chip.
ILLUSTRATION: BRYAN CHRISTIE DESIGN

gal enough to run a long time on a small battery. These requirements are complicated by the 10-fold speedup in operating frequency. (Transistors have gotten faster, but not that much faster.) A major design overhaul will thus be needed. What's more, the connections between transistors have resistance, capacitance, and inductance, which tend to sap performance at these frequencies. And the high-speed, high-resolution, analog-to-digital and digital-to-analog converters needed to process gigabit-per-second data rates are real energy hogs.

The seriousness of these issues depends on just which integrated-circuit technology is used. Bipolar transistors made of silicon-germanium offer high speeds, and this technology makes it possible to fabricate high-quality passive devices, such as inductors, right on the chip, simplifying design and boosting performance. IBM has reported making 60-GHz silicon-germanium transceivers that can shoot data at 1 Gb/s for as far as 8 meters. But with multiple transceivers, analog-to-digital and digital-to-analog converters, and ever more complex signal processing, the cost of silicon-germanium becomes prohibitive.

CMOS chips are much less expensive, but the lower speed of the transistors and poorer quality of the passive devices make designing the circuits exceedingly tough. Nonetheless, the history of the semiconductor industry is littered with examples of products that were first built with bipolar technologies but were soon replaced with CMOS counterparts, suggesting that 60-GHz CMOS chips will in the end win out.

DESIGNERS CLEARLY face high technical hurdles in fashioning CMOS circuits that can handle various RF-signal manipulations at 60 GHz. Many of these operations depend on heterodyning, in which the circuitry mixes two signals at different frequencies to produce an output that contains components at both the sum and the difference frequencies. A standard AM transmitter would, for example, multiply the relatively low-frequency audio signal to be broadcast (say, a 1-kilohertz tone) with the output of an oscillator running at a much higher radio frequency (say, 1000 kHz). The sum and difference of these two frequencies (999 kHz and 1001 kHz) fall just slightly above and below that of the RF oscillator. That's why the original audio signal is said to be "up-converted" to RF. The receiver for such an AM broadcast would typically use a similar oscillator to "down-convert" the RF signal back to audio, using exactly the same heterodyning principle.

For high-speed data communications at 60 GHz, such operations can be a nightmare to implement.

For one thing, the oscillator would have to produce two 60-GHz outputs that are exactly 90 degrees out of phase. This is because the final modulated signal is produced by combining a sine and cosine. The generation and routing of these two phases, while maintaining a 90-degree difference between them, is hard at 60 GHz.

Also, controlling the precise frequency of a 60-GHz oscillator is tricky because it's running too fast to measure directly, as crystal-controlled frequency standards are limited to about 100 megahertz. The 60-GHz signal must first be fed into a frequency-divider circuit that reduces the frequency by a large factor (say, 600). Only then can the output be compared with a frequency standard, which indicates whether the rate of oscillation is faster or slower than desired, so that it can be corrected accordingly. The tactic is simple enough, but the limits on transistor speed make it difficult to fashion such frequency-divider circuits that work at 60 GHz.

Fortunately, with a little cunning, you can make a receiver work using a 40-GHz oscillator instead. The first step is to mix the output of the 40-GHz oscillator with the 60-GHz received signal. That operation down-converts the signal to the difference frequency: 20 GHz. To down-convert the signal the rest of the way, the receiver circuitry need not incorporate a separate 20-GHz oscillator; it can simply use the output of a divide-by-two frequency divider attached to its 40-GHz oscillator. Because it operates on 40 GHz rather than 60 GHz, such a frequency divider is comparatively easy to implement. What's more, it is less vexing to route signals around a chip at 40 GHz than at 60 GHz. And happily enough for designers, the transmission path can follow the receiver operations in the reverse order to avoid 60-GHz oscillators and frequency dividers. That is, the data stream to be transmitted is first up-converted to 20 GHz and only then raised to 60 GHz.

Using 40 GHz for the oscillator frequency is just one way to dodge some of the thorny problems posed by 60 GHz. The IBM transceiver takes a slightly different tack: it incorporates a 17-GHz oscillator followed by a frequency tripler to obtain 51 GHz, which is roughly 8.5 GHz below the target frequency. The 51 GHz thus can serve to down-convert the received signal to 8.5 GHz. And a divide-by-two frequency divider attached to the 17-GHz oscillator generates the 8.5 GHz needed for the second stage of down-conversion.

Although such designs avoid the need for a 60-GHz oscillator, they still require low-noise amplifiers and down-converters. These circuits typically use passive devices like inductors or transmission lines on the chip to overcome the speed limitations of the transistors. Alas, such passive components have large footprints, which normally forces them to be placed awkwardly far apart, their long interconnections creating lots of parasitic resistance, capacitance, and inductance. To alleviate this problem, designers can nest the inductor loops used to build these passive components so that the connections between them can be kept short [see illustration, "Design Tricks"].

A bigger concern is how to fabricate transmitter circuits that can deliver a lot of oomph to the antenna. For communication across a range of 10 meters at data rates of several gigabits per second, some tens of milliwatts are necessary. Performed by a power amplifier, the task requires large transistors, which are typically slow. The good news is that the upcoming generation of CMOS chips, which boast 45-nanometer gate lengths, may be up to the job of producing this much power at 60 GHz.

But that's not the whole story, because not all the power that goes into an on-chip antenna gets broadcast. The silicon substrate—just 10 micrometers below—absorbs (and hence wastes) some energy, so such antennas radiate only a fourth to a half of the power supplied to them.

Perhaps more research will lead to more energy-efficient antennas. Meanwhile, engineers can resort to off-chip antennas that operate at these tiny wavelengths. Another, cheaper, solution is to incorporate enough transmitters and on-chip antennas to compensate for the power lost to the silicon substrate. The future will tell whether we need to resort to this rather inefficient solution.

IT WILL take time for designers to master all this new technology, because the models that we use to simulate circuits can't easily handle 60 GHz. Today's transistor models are constructed as though all their capacitance and resistance came from small capacitors and resistors connected here and there. In reality, of course, the capacitance and resistance in these transistors are distributed over appreciable dimensions. So lumping things in this way fails to capture some important effects that manifest themselves most obviously at these high frequencies. Also, the electric and magnetic interactions between the passive devices and the silicon substrate are difficult to calculate from basic physical principles. For these reasons, modeling must rely on both the theoretical understanding of the behavior of the devices and on a large number of experimental measurements (which in turn can help refine the models).

The industry's vision is that we can solve these problems and that all the electronic devices in our homes and offices will be chattering furiously and wirelessly in another five to 10 years. Cables will go the way of the buggy whip. Now if the engineers at MIT can finally perfect their idea of using magnetically coupled resonators to charge batteries through the air, we'll eliminate those pesky power cords, too. Only then will we enter the *real* wireless age. ❑

TO PROBE FURTHER The IBM 60-GHz silicon-germanium transceiver is described in the Digest of Technical Papers *for the 2006 IEEE International Solid-State Circuits Conference (ISCC).*

Two CMOS transceivers for the 60-GHz band are described in the Digest of Technical Papers *for the 2007 ISCC.*

Detailed information concerning the IEEE 802.15.3 standard for the 60-GHz band is available at http://www.ieee802.org/15/pub/TG3c.html.

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

ACROSS THE OUTBACK

With Australia's desert as its raceway, the World Solar Challenge illuminates

RAY RUNNER: Blessed with a crystal-clear sky, the Nuna 4 solar car soaks up energy as it drives.
PHOTO: HANS-PETER VAN VELTHOVEN

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

ON PHOTONS ALONE

some of the best electric-vehicle technology By Sandra Upson

A LEGION OF 38 SOLAR CARS gathers in State Square in Darwin, on the northern coast of Australia. The flat, rectangular bodies hug the ground like three-wheeled UFOs, their etherealness accentuated by their motors' eerie, barely perceptible hum. Anxious racers neurotically swab their perfectly clean solar cells with feather dusters.

Helmeted drivers peer out through polycarbonate bubbles, waiting for their cue to lock down and dash across the continent. The vehicles are odd-looking and yet stately, not at all the giant cockroaches they have been mockingly described as in the past. Better to be a UFO, some are saying, than a cockroach.

The solar racers—a mix of university students and hobbyist-engineers—have converged in this remote tropical city for the ninth World Solar Challenge, the biennial transcontinental race that tests some of the world's most innovative ideas in energy-efficient transportation on some of the planet's most punishing terrain. On this humid October morning, ultracompetitive teams are polishing vehicles that easily cost more than US $2 million each, while others tinker with their homegrown labors of love.

At this Panasonic-sponsored event, the foremost eco-race on the planet, there's tech intrigue and plenty of peculiarity. One team famously delivers its vehicle to each race in suitcases, and another team consists entirely of Japanese hairdressers. The University of Michigan contingent is here, as always, but this year it includes 100 support people, weather balloons, and an unpiloted aerial vehicle. Michigan and another group, Solar Team Twente, from the Netherlands, have each outfitted their vehicle with a system of mirrors that tracks the sun to concentrate light on some of the solar cells. Even in this race, no one's ever put a solar concentrator on a car before, and its presence on these two has earned the teams cachet in the unofficial jostling for technical one-upmanship. Gossip swirls around Umicore Solar Team, from Group T, an engineering university in Leuven, Belgium, whose Umicar Infinity supposedly uses the most expensive—and powerful—triple-junction gallium-arsenide solar cells this side of low Earth orbit. Solar racers have been eyeing the Belgian vehicle even more warily since yesterday afternoon, when Umicar grabbed pole position in the qualifying heat at a nearby racetrack.

But it is the legacy of the Nuon Solar Team, from the Delft University of Technology in the Netherlands, that dominates the prerace chatter. Its Nuna cars have

STOP AND GO: Nuna 4 breaks down on the starting line and the team members inspect their motor controller; later, the solar car maneuvers through traffic in Darwin, on the first stretch of Stuart Highway.
PHOTOS: HANS-PETER VAN VELTHOVEN

won the last three races, going back to 2001. On the other hand, no member of this year's crew, other than its ex-astronaut advisor, Wubbo Ockels, has ever built a car before. And this past week hasn't been kind to Nuna 4's harried engineers, who have battled a temperamental motor controller and short-circuiting solar cells. It didn't help when Ockels announced that no previous Nuna had faced so many prerace problems.

Standing there as spectators mill around the parked solar cars, Ivo Hagemans, of the Nuna team, notes: "Everyone says, you've already won three times, you have nothing to worry about. Well, no, no, I haven't. Other people have. I have not." He surveys the car moodily, his hands shoved in his pockets.

The rules are simple. Race across 3000 kilometers of the outback, driving from 8 a.m. to 5 p.m., until you get to Adelaide, on the southern coast. Your car's only power source is a 6-square-meter solar array, which under bright sun puts out less than 2 kilowatts. If your idea of an efficient vehicle is a Toyota Prius, you've got to wrap your mind around an entirely different level of energy parsimony. Solar racers like to say that their cars run on as much energy as a hair dryer. By the time the winning car gets to Adelaide, it will have covered those 3000 km using roughly the same energy that an ordinary car gets by burning 7 liters of gasoline. The best cars travel about 90 km/h, though they are capable of going faster. "It's performance racing," says Michael Garland, a British university student freelancing as a member of Melbourne's Aurora Vehicle Association team, another perennial contender. "It may be quirky and weird, but it's top-notch engineering."

A race official looks at his wristwatch—8:00—and waves Umicar Infinity off the starting line. It glides down the street and out of sight. Then comes Aurora 101, the local favorite, accompanied by exuberant hoots from the crowd. And then Nuna 4, the weight of its celebrated predecessors pressing down on it.

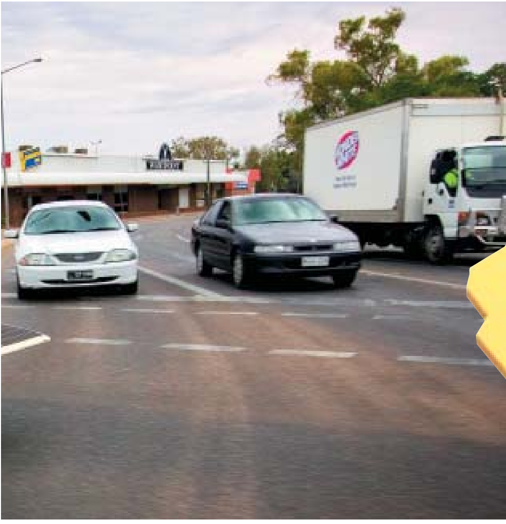
Inside the Nuna, a panicked Oliver van der Meer gestures furiously at his tiny dashboard. He taps the pedal, but the car doesn't budge. After a quick consultation, a dozen Dutch students in the team's blazing orange shirts strip off the tape that holds the top shell, with the solar array, to the car's carbon-fiber body. Solar cars navigate around them, drift up to the starting line, and disappear into Darwin. Six Nunans heave the top over van der Meer's head.

It's that pesky motor controller, which regulates the motor's rotational speed and direction. Its Hall-effect sensors are producing a bizarre reading—the lights for both "drive" and "reverse" are lit on the console. In a brushless dc electric motor, which is what most high-end solar cars use, these highly specialized sensors track the position of the motor's permanent magnet rotor. The team has seen this glitch before, but only in hot weather. It's cool this morning, so what the heck? Someone runs to a support vehicle to fetch a spare—and less efficient—controller. "Anyone have a small screwdriver?" yells Vincent de Geus, the race strategist, over the spirited bleats of a local brass band.

Out comes the troubled controller and in goes the replacement. Some crew members reattach the top shell and swiftly tape over the edges, while the rest of the crew, visibly shaken, scurry to their chase vehicles.

With 27 solar cars now in front of it, Nuna 4 plunges into the race—straight into the chaos on leafy Mitchell Street and out to the first few kilometers of Stuart Highway, which it will ride all the way to Adelaide. Here the highway's shoulder is a site of solar carnage, as a dozen teams facing early emergencies have pulled to the side of the road and ripped off the tops of their vehicles to poke and prod at misfiring components. The worst off is Michigan's solar car, whose driver had braked late in the bumper-to-bumper traffic and hit a team vehicle, crumpling the car's nose and damaging the steering system. Two rows of solar cells have been destroyed, and the driver is in tears.

The rest of the pack navigates through heavy traffic down the busiest stretch of Stuart Highway. Nuna 4 weaves easily between vehicles, overtaking solar racers and chase cars alike. Within 3 hours it's in second place, ahead of Aurora 101 but behind the leading Umicar Infinity.



WORLD SOLAR CHALLENGE RACE

Length of race: 3000 kilometers
Start: Darwin, Australia
Finish: Adelaide, Australia
Number of entrants: 38
First race: 1987
Course hazards: dust storms, strong winds, intense heat
Power source: 6 square meters of solar cells
Power output: 1 to 2 kilowatts
Gasoline equivalent: 7 liters over the course of the race
Driving time: 9 hours a day
Average weight of car: about 200 kilograms
Average speed of winning car: 91 km/h
Speed limit: Northern Territory, 130 km/h; Southern Australia, 110 km/h

MAP: BRYAN CHRISTIE DESIGN

By midday, the highway thins to one lane, and signs of civilization dwindle to the odd roadhouse amid spotty clumps of spinifex grass. On either side, spindly eucalyptus trees poke out of the hard red earth. Every 20 minutes or so, a road train pulling three trailers bombs past, blasting the cars with strong side winds.

One of those trucks' blasts dislodges the latch on Nuna 4's canopy. The bubble top flies open, and van der Meer barely manages to grab it and pull it down. With one hand on the wheel and the other holding the canopy down, he can't reach the regenerative brake anymore (which is a hand-operated toggle, unlike the foot pedal for the mechanical brake). The next 200 km become a battle between not braking, so as to not waste energy, and not cracking up. A cold sliver of air cuts at his neck while he drives.

So it is that the Nuna team makes its entrance into the outback. Around its convoy, dirty tendrils of smoke rise from patches of iron-tinged earth singed by recent fires. Where earlier local residents had lined the road to cheer them on, now only statuesque termite mounds—man-size piles of orange dirt—stand like mute sentries. The crippled racer rattles down the highway, its hollow body amplifying the reverberations to a deafening clatter. As another Nuna driver later describes it, "It was like riding inside a giant guitar."

MEANWHILE, AROUND MIDDAY, the Nuna team's strategists realize they've got a problem. In their "mission control" vehicle, the three of them are monitoring the state of the racer's lithium-polymer battery through the voltage and current readings sent over a wireless link from the solar car's motor controller. They've tailored their strategy software to calculate speeds for a day that lasts from 8 a.m. to 5 p.m., but with the half-hour delay in the start and the corresponding shift in light conditions, their algorithm is off. De Geus, the chief strategist, manually calculates the speeds, scribbling on a pad of paper as the sun's intensity wanes.

Short of crashing, the biggest disaster that can befall a solar team is draining the battery prematurely. The load on the battery is related to the drag on the car, and that drag increases with the square of the speed. Put another way, driving too fast for the conditions can do a team great harm. The strategists spend their time calculating, at 2-minute intervals, the optimal speed, taking into account variables such as how much driving they anticipate for the rest of the day and the near-term weather forecast.

Luckily for the Nuna team, the race rules and the staggered start let them recoup the time they squandered replacing the motor controller. As other cars pull off the road to mark the end of the first racing day, Nuna's scouts speed ahead to find a suitable campsite—one with unobstructed western exposure that will let them use the remaining sunlight to top off the battery for tomorrow's start.

Soon the convoy turns into a little clearing surrounded by brittle grasses. The sun starts to set, and desert flies emerge in swarms. As day one ends, the Nunans are behind the Belgian Umicar Infinity team, which has set up a bare-bones campsite 13 km ahead, butted up against tall grass a few meters off the shoulder. A few kilometers behind Nuna, Aurora 101 is doing the same. Flies clinging to their faces and shirts, the racers pitch their tents on the red gravel, tilt their solar arrays to catch a last few photons, and set up lights to examine their cars before bedtime.

DAY 2 DAWNS, at 5:30 a.m., with the Dutch ex-astronaut sitting alone in the middle of Nuna's dark campsite, strumming a few bars of "House of the Rising Sun" on his guitar. Sleepy, orange-clad figures emerge from the colony of canvas tents. They prop up the top half of the car's body, with the solar array, as the first rays of the sun peek over the horizon. They roll up their sleeping bags, make Nutella sandwiches, and dust the insides of the car. "This is the day of truth," says Ockels. "With an empty road and much less overtaking, we'll see which team really is the best."

One car from the convoy departs an hour early to collect weather data and report on road conditions—

ALL FOR ONE: Members of the Delft University racing team hold up their solar panel to capture the few rays of light creeping over the horizon.
PHOTO: HANS-PETER VAN VELTHOVEN

a euphemism for kangaroo roadkill. As 8 a.m. approaches, the day's first driver, Joep Steenbeek, steps into the solar car and tightens his helmet strap. With less than 10 minutes left, the crew attaches the top, fastens cables, and tapes over the edges to smooth them against air resistance. The race official calls time, and the team waits for a looming road train to pass. The solar car slides onto the road, the motor singing its weird whine over the road train's fading rumble.

The morning drive is smooth and sunny. Umicar Infinity coasts into the next of the race's mandatory control stops, at Tennant Creek, 7 minutes before Nuna 4. (The control stops give reporters a chance to catch up with the solar cars and the teams an opportunity to check vehicles for wear and tear.)

But all is not well in Infinityland. An aluminum bolt holding the steering system in place has snapped, causing the rack-and-pinion gears to wear down and making steering nearly impossible. With no other option, the Belgians pull aside to repair their steering system and replace the bolt with a simple clamp, and Nuna 4 slips past them. "Yeah...aluminum was maybe not the best choice of material for that bolt," says Niels Burez, who oversaw Umicar's mechanics, with a gloomy smile. "If it wasn't for these problems, we'd be passing Nuna, I'm sure."

But then the weather takes a turn for the worse, as the vehicles speed into a storm brewing over Alice Springs—the midpoint of the race, and of Australia. Nuna's suspension, strained by a persistent crosswind, finally gives in. The team stops to replace a collapsed shock absorber, surrendering 15 precious minutes. Then 80 km/h winds cause the car to yaw left so much that the left tire bursts. The unthinkable almost happens: Nuna nearly empties its battery while racing the setting sun to Alice Springs. It is forced to stop just 12 km north of the city. But when it gets there, the following morning, it is 1 hour 22 minutes ahead of the Belgian car.

THE TEAMS trickle into this odd oasis, corralled by race officials who had decided that the half-day lag between cars was bad for press coverage. Wearing a floppy hat and wraparound sunglasses, veteran solar racer Alain Chuzel examines a few vehicles in the blinding sun. Chuzel, from Phoenix, has a company, SunCat Solar, that encapsulates solar arrays for racers. Encapsulation protects the arrays from airborne pebbles and debris, which can crack cells. Because a string of cells performs only as well as the weakest in the sequence, protecting an array from damage is of utmost importance.

Usually, solar cells have minor defects, Chuzel explains. Depending on what's needed, "one man's junk is another man's gold." Once cells are selected, they are arranged in strings and coated in special materials to make them sturdy enough to bend over a car body and withstand flying pebbles.

Hans Gochermann, who has a solar-technology company in Germany, adds another step to each encapsulation. The fanciest solar cells—mostly rejects from the International Space Station, he says—are no more than 31 percent efficient, and there's an art to squeezing as much energy as possible out of those brittle semiconductor slices. He encapsulated the top three teams' arrays by texturing the cell surface with matte

LEAGUE OF THEIR OWN: Umicar Infinity [top] had top-of-the-line gallium-arsenide solar cells. The University of Michigan's Continuum [middle] sported a solar concentrator and a host of cooling fans to protect the car's interior. In spite of its much cheaper silicon array, Aurora 101 [bottom] came in third.
PHOTOS, FROM TOP: UMICORE SOLAR TEAM; UNIVERSITY OF MICHIGAN SOLAR CAR TEAM; AURORA VEHICLE ASSOCIATION

5-micrometer-wide pyramids. When light hits the surface, some of it is reflected. But instead of allowing light to bounce away, the pyramids deflect some of the rays back onto other pyramids, giving the photons a second chance to be soaked up and increasing the array's power by 4 percent. The technique is particularly effective with the oblique rays of morning and evening.

Cell encapsulation is but one of several cutting-edge microindustries that have emerged to cater to solar racing. Looking for the most efficient motor controllers on the planet? You'll find them here, most of them made by Tritium, of Woolloongabba, Australia. Tritium's motor controller—a lightweight three-phase 20-kW inverter with supposedly unprecedented power density—came from the company employees' own solar car experience, at the University of Queensland. The controller has a cruising efficiency of 98.3 percent, so very few of the car's scanty supply of watts get wasted. Tritium is hoping that, having locked up the solar car market, it can now branch out into electric vehicles and grid-connected photovoltaics.

This wouldn't be the first solar-car spin-off to become something bigger. The builders of Honda's solar cars, which dominated the races in the early 1990s, later designed the Honda Insight, the first mass-produced hybrid car. General Motors' solar car, also from that era, morphed into the company's first electric effort, the EV 1. True, it was pulled from the market peremptorily, prompting conspiracy theories and a major motion picture. And mass-market success has also so far eluded New Generation Motors, an American company licensing Australian technology, whose astoundingly efficient wheel motors—at best 95 percent—are used by most solar racers.

"These are literally the engineers of the future, as in, they're ahead of their time," says Steven Camilleri of In Motion Technologies, another race alumnus now trying to sell uniquely efficient, lightweight motors born during his solar racing days. "The world isn't ready for us," Camilleri concludes. [See "Motor Maniac," in this issue, for a profile of Camilleri.]

EARLY THE NEXT MORNING, the cars are released back onto the road. Some thin clouds scuttle across the sky, and an east-blowing crosswind continues to badger the teams.

"You have to look carefully at a cloudy sky," says Hagemans, the Nunans' logistics guru. Teams may

FINISH LINE: The Dutch support crew greeted their racer in Adelaide with a champagne toast to the vehicle. Immediately after, the teammates and their supporters jumped into a fountain to celebrate.
PHOTO: HANS-PETER VAN VELTHOVEN

adjust their speed to go faster through the cloudy parts and slow down in sunny patches, to give the battery pack more time to charge.

Dust storms periodically shatter the monotony of the drive. Sticks dance in the middle of the road, and seconds later a shroud of dust slams Nuna 4, throwing it off its course. A harrowing second later, the driver regains control.

The heat, the dust, and the battering force solar car designers to balance robustness and weight against low drag and rolling resistance. This year, the race's organizers required the cars to be a shade more practical. As a result, the vehicles now have smaller arrays, normal upright seats, and ordinary steering wheels. A German entrant, Bochum University of Applied Science's SolarWorld No. 1, with three wheels and a platypus front end, almost looks like something you'd take to pick up a few groceries. But its commodious form makes it seem bloated next to the sleek, anorexic top performers, and during the race it dawdles behind the lead cars, averaging 73 km/h. By contrast, the team proudly reports that Nuna 4 was the most aerodynamic vehicle ever tested at the wind tunnels run by DNW, a German-Dutch aerodynamics-testing facility. The Aurora 101 car also excelled aerodynamically, with a record of its own at Monash University's wind tunnel, near Melbourne.

The Nuna convoy flies through Coober Pedy, an opal-mining town with a spectacularly lunar landscape. The wind never lets up, and that afternoon they pop the left tire four times. Each change takes less than 3 minutes for the well-practiced team, but it is clear the suspension is in peril. That night, they rebuild the left suspension, change tires, and vacuum everything in sight.

It is to be the Nuna crew's last night under the outback's starry skies. The next day they push—hard—to reach the outskirts of Adelaide by the 5 p.m. official cutoff. The Belgians are about 40 minutes behind them. It is a solid lead, but not an unbreakable one, and Infinity is technically a faster car. Just one small breakdown, or one miscalculation, could blow the race.

The sunset fills the enormous sky with radiant colors. The air is chilly, and the team builds a fire with a few scraps of wood they scavenge from the blank landscape. A half-dozen skeletal trees stand out in silhouette against the purple sky, improbable signposts of a greener time. The students string colored lights around the campsite and blast dance music into the deaf, endless desert.

"SOUTHBOUND ROAD TRAIN, this is Nuna solar car team, can you hear us?" a voice crackles over CB radio channel 40. "We're from the Netherlands. What's your speed?"

"Oh, hi, solar car! Are you the front-runners?" comes the brittle reply.

"Yes, and we'd like to pass you after the next hill."

"Oh, right, no worries."

It's Thursday afternoon. The landscape is quickly turning hilly. In the Nuna chase car, strategist de Geus can't believe how the battery is holding up. "I'd set the speed at 90 and check," he later recalls. "The battery seemed fine, so I increased it to 95. It was still fine, so we went up to 100, then 105—wow! So we just kept going." It's as auspicious a start as they could have hoped for.

A few hours later, Stuart Highway cuts through Port Augusta, population 14 000, at the head of Spencer Gulf. The wispy car darts into gaps in overtaking lanes and tears past dense lines of traffic. At 4:15 p.m., Nuna is speeding along at exactly the speed limit, 110 km/h, pushing through rolling farmland toward Adelaide. The race is now against time: Umicar is nowhere in sight, but 5 p.m. is alarmingly near.

They make it. At 4:55 p.m. Nuna 4 slides across the finish line first. It averaged 91 km/h over the whole race, slower than the previous three Nunas but still remarkable considering the new vehicle restrictions these team members had to contend with. As the racer comes to a stop, the students tumble out of the support vehicles. They look around, whoop, and hug each other awkwardly. Then they start cheering for real as the truth hits home: they've won. They've saved their legacy. With champagne erupting from bottles, they drench their solar array, but no one cares.

Neither this car, nor anything like it, will blend into everyday life anytime soon. But these young engineers have pulled off a wonderful and improbable feat. They've built something outlandish and complex with little more than their own hands, some fairly simple tools, and some institutional blessings.

"The concept of a commercial solar car is completely ridiculous," reflects Sidd Bikkannavar, a race official. "But seeing them gives some people hope that a different future might exist, that there might be an alternative way of doing things." On this parched landscape, in a place where mammals have pouches and eucalyptus trees are known to explode, perhaps the idea of a different future is not so crazy after all. ❑

TO PROBE FURTHER Watch video footage of the race at http://spectrum.ieee.org/feb08/auswsc. The two books considered the bibles of solar racing are Speed of Light: The 1996 World Solar Challenge *by David M. Roche et al. (1997) and* The Winning Solar Car: A Design Guide for Solar Race Car Teams *by Douglas R. Carroll (2003).*

TECHNISCHE UNIVERSITÄT DARMSTADT

The Department of Electrical Engineering and Information Technology of TU Darmstadt, Germany, invites applications for positions of

a) Full Professor for Power Electronics (reference number 375)

effective October 1, 2009 or earlier.

The search is for an outstanding candidate who will be responsible for the research and the teaching in the above area. The candidate will also be expected to teach the basic principles of electrical engineering.

The focus of the research should be in the areas of
- Power electronics application in electrical power transmission and distribution
- New compact inverter topologies for automotive applications
- Development of dynamic, low-loss power electronic circuits
- Application of new types of power switches
- Improvement of control strategies for power electronics e.g. for drive systems, active power filters, inductive melting etc.

The successful candidate will be an authority in at least one of the above research areas and will have proven teaching qualifications. Successful experience in industry or a research organisation is desirable. It is expected that the candidate will collaborate at a national and international level as well as with groups in one of the priority research areas of the university. For further information please contact the Chair of the Search Committee, Prof. Dr.-Ing. Dr. h. c. Andreas Binder, Tel.: +49(0)6151/16-2867, E-Mail: abinder@ew.tu-darmstadt.de

b) Full Professor for Optical Communications and Photonics (reference number 376)

effective April 1, 2009 or earlier.

We are seeking an exceptional candidate in the areas of
- Optical communication systems
- Optical components
- THz components and systems

The successful candidate should have an outstanding research record in one or more of above areas and a solid record of teaching experience. The candidate will be expected to develop a high quality, independently funded research program and participate in both undergraduate and graduate teaching. Successful experience of collaboration with industry or non-university based research institutions is desirable. For further information please contact the Chair of the Search Committee, Prof. Dr. Alex Gershman, Tel.: +49(0)6151/16-3014, E-Mail: gershman@nt.tu-darmstadt.de

The positions a) and b) are tenured with a remuneration package commensurate with experience and qualifications, following the German "W-Besoldung" category. The regulations for employment are specified under §§ 70 and 71 HHG (Hessisches Hochschulgesetz). Candidates who hold a public servant status (Beamtenverhältnis) can be re-appointed under the same status. Technische Universität Darmstadt seeks to increase the number of female faculty members and encourages female candidates to apply. Eligible disabled persons will be given priority.

Please submit applications with the usual attachments and three referee names, quoting the reference number a) 375, b) 376, to: Dekan des Fachbereichs 18, Herrn Prof. Dr.-Ing. Volker Hinrichsen, Merckstr. 25, 64283 Darmstadt, Germany.

Closing date: Six weeks after publishing this announcement

FACULTY OPENING at

NSYSU-ICE, TAIWAN

The Institute of Communications Engineering at National Sun Yat-Sen University, Taiwan, invites outstanding candidates to apply for several positions at all ranks (Full, Associate and Assistant Professors) with emphasis on wireless communications, networking, broadband systems, statistical signal processing with application to communications. The NSYSU is one of the first-class research-oriented universities in Taiwan with number of graduate students exceeding that of undergraduates.

Applicants should have a PhD in EE/CS with a strong commitment to research and teaching graduate courses. A cover letter indicating the rank applied, CV with publication list, statement of interest and plans in both research and teaching, reprints of selected published papers, and three recommendation letters should be sent to:

Professor Shiunn-Jang Chern, Director
Institute of Communications Engineering
National Sun Yat-Sen University
Kaohsiung, Taiwan 80424

E-mail: chern@ee.nsysu.edu.tw
Tel: 886-7-5252000 #4475 (or #4171)
Fax: 886-7-5254475
http://www.ice.nsysu.edu.tw

Screening of all candidates will begin not before February 01, 2008 and continue until the positions are filled.

NSYSU has been named by Ministry of Education (MOE), Taiwan, R.O.C as one of the top seven research-intensive universities in Taiwan since 2002. It is also one of the 12 universities at Taiwan that have just been awarded the total 5-year, 50-billion NT$ special development fund from MOE. The EE and CS areas are consistently ranked among 5 of the best EE/CS programs in the nation.

NANYANG TECHNOLOGICAL UNIVERSITY NUS National University of Singapore

LEE KUAN YEW
POSTDOCTORAL FELLOWSHIP

Applications are invited from young and outstanding academics for the prestigious Lee Kuan Yew Postdoctoral Fellowship (LKY PDF) in the National University of Singapore (NUS) and Nanyang Technological University (NTU).

The Fellowship is tenable for up to 3 years, with possible extension for 2 further years. LKY PDFs can apply for academic positions following the Fellowship.

Gross annual salary ranges from **S$72,000** to **S$144,000** (approx US$50,000– US$100,125) with commencing salary depending on qualifications and experience. Leave and medical benefits will be provided. For details of other benefits offered and application procedure, please visit the websites of the respective University*.

APPLICATION

Interested candidates should send their complete application package, comprising all documents listed below, to the respective University *
- NTU Application or NUS Personal Particulars Form (downloadable from website)
- Detailed Curriculum Vitae; List of Publications & Educational Certificates
- 3 International Referee Reports (including contact details)
- Statement of Research Intent (details of proposed research plan)

Closing date: 5 March 2008
Successful candidates will be notified in June 2008

* For application and contact details, please see

NATIONAL UNIVERSITY OF SINGAPORE
http://www.nus.edu.sg/ore/fellowships/fellowship_lky.htm

NANYANG TECHNOLOGICAL UNIVERSITY
http://www.ntu.edu.sg/hr/recruit/research/LKY2008.htm

ieee spectrum classifieds

The Department of Electronic Engineering at Universidad Tecnica Federico Santa Maria (UTFSM, Valparaiso, Chile): invites applications for full-time faculty positions in any of the following areas: Multimedia systems, Network security, Network management, and Integration of Information and Communications Technology services. For further information, please visit www.elo.utfsm.cl/positions .

York University, Toronto: The Department of Computer Science and Engineering invites applications in Biomedical Engineering with specialization in medical devices and instrumentation at the Assistant or Associate Professor level in the tenure track stream. Details are available at http://yorku.ca/acadjobs. York University is an Affirmative Action Employer.

國立中山大學

NATIONAL SUN YAT-SEN UNIVERSITY

Department of Photonics

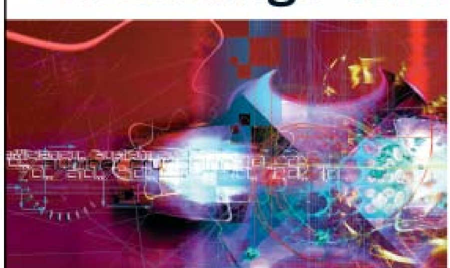
The Department of Photonics at National Sun Yat-Sen University invites applications for faculty positions at all levels. The positions open on **01 Aug., 2008**. Candidates should have an earned doctorate in the related fields of Photonics and Electro-Optical Engineering. The Department is interested in candidates with a strong commitment to the establishment of research programs, and to teaching at graduate and undergraduate levels. Technical areas of interests include, but are not limited to, opto-electronics, nano-photonics, solid-state lighting, and bio-photonics.

National Sun Yat-Sen University has been selected by the Ministry of Education to receive additional funding from the Top University Development Plan. Photonics and Electro-Optical Engineering is one of the major fields designated for further development in the university under the Top University Development Plan. Based on the high academic standing in Electro-Optical Engineering, we will start an undergraduate program in the fall semester of 2008. In addition to the Top University Development Plan, we have executed programs under other major national projects, including the Promotion of Academic Excellence Program sponsored by the Ministry of Education and the Technology Development Program for Academia sponsored by the Ministry of Economic affairs. The Department offers BS, MS, and PhD degree programs. There are 40 PhD students and about 100 MS students, plus a few post docs and research engineers.

Applications should be accepted immediately. Applicants should send a letter of interest, curriculum vitae, a list of publications, copies of the most important publications, at least 3 reference letters from academic or professional individuals, and a statement of his or her version for research and teaching to:

Professor Tsong-Sheng Lay, Chairman/ Director
Department of Photonics/ Institute of Electro-Optical Engineering
National Sun Yat-Sen University
Kaohsiung 804, Taiwan

Application materials may be sent in electronic form (PDF) to plchen@mail.nsysu.edu.tw



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By SANDRA UPSON

How Free Is Solar Energy?

Renewable-energy technologies promise to liberate us from fossil fuels. But this implies that their energy payback periods—the time it takes for a system to recover the energy used to produce it—is just as important as financial payback. If you install solar cells on your roof, you want the system to pay for itself eventually, but you also want to help your country get a grip on global warming and stop depending on foreign fossil supplies.

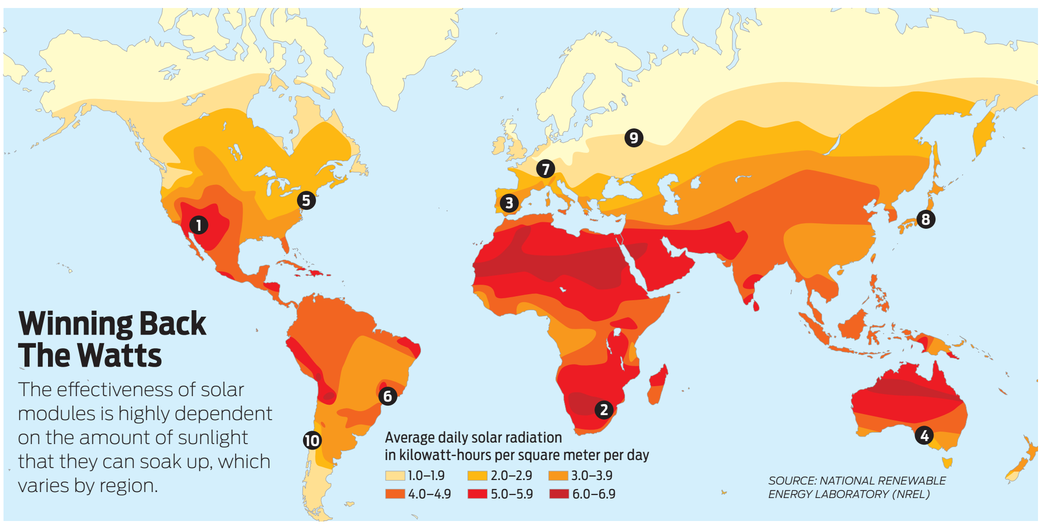
"Most people who take the initiative to put photovoltaics on their homes and businesses are looking at the economics, certainly, but they're looking beyond that, too," in the words of Gary Schmitz, a spokesman for the National Renewable Energy Laboratory, in Golden, Colo.

A key variable is how solar cells perform once installed. The energy available to them could be close to 7 kilowatt-hours per square meter per day in Phoenix or 2 kWh/m²/d in Moscow [map]. For the most common type of module, which uses multicrystalline silicon, the energy payback times can be between one and four years [chart, bottom right].

Thin-film solar cells, which eventually will be much cheaper than multicrystalline-silicon cells, have shorter energy payback periods. Cadmium-telluride cells recover their energy inputs in 10 to 22 months.

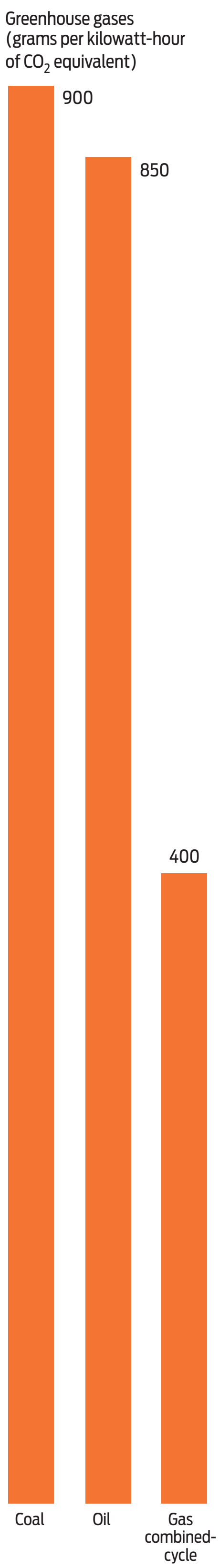
Most of the energy spent on solar modules goes into purifying the materials and encapsulating the modules. Vasilis Fthenakis, a scientist at Brookhaven National Laboratory, estimated the environmental footprint of solar systems, using assumptions about the transportation distances for materials and the amounts of energy needed to produce the cells, the modules, and their electrical and electronic subsystems [chart, bottom left].

Of course, the attractiveness of renewable technologies depends not only on their energy paybacks. But too often, energy technologies are discussed solely in terms of their direct cost to end users without taking into account surrounding factors, Fthenakis says. "Taken together, they define the total cost of a renewable energy." ❏



Winning Back The Watts

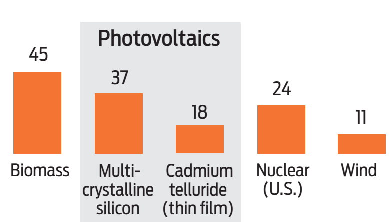
The effectiveness of solar modules is highly dependent on the amount of sunlight that they can soak up, which varies by region.



Global Warming Potential Of Energy Options

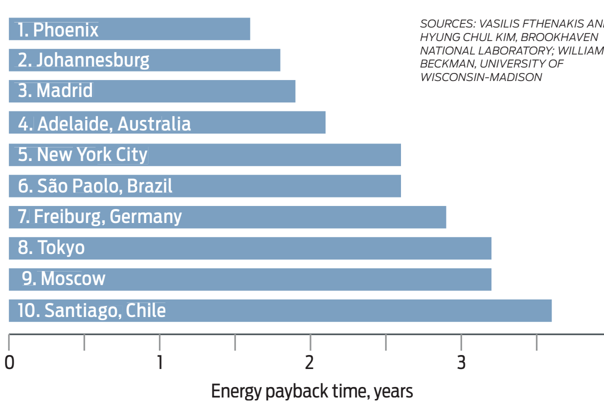
There's no free lunch, but several alternatives to fossil fuels come close.

SOURCES: EXTERNE PROJECT, 2003; KIM AND DALE, 2005; FTHENAKIS AND KIM, 2006; FTHENAKIS AND KIM, 2007; FTHENAKIS AND ALSEMA, 2006



When Solar Cells Break Even

A multicrystalline-silicon photovoltaic system needs to operate for more than a year to recover the energy invested in its manufacture. The values for 10 cities [map, above; chart, below] apply to modules tilted at an optimal angle to the sun.



BRYAN CHRISTIE DESIGN