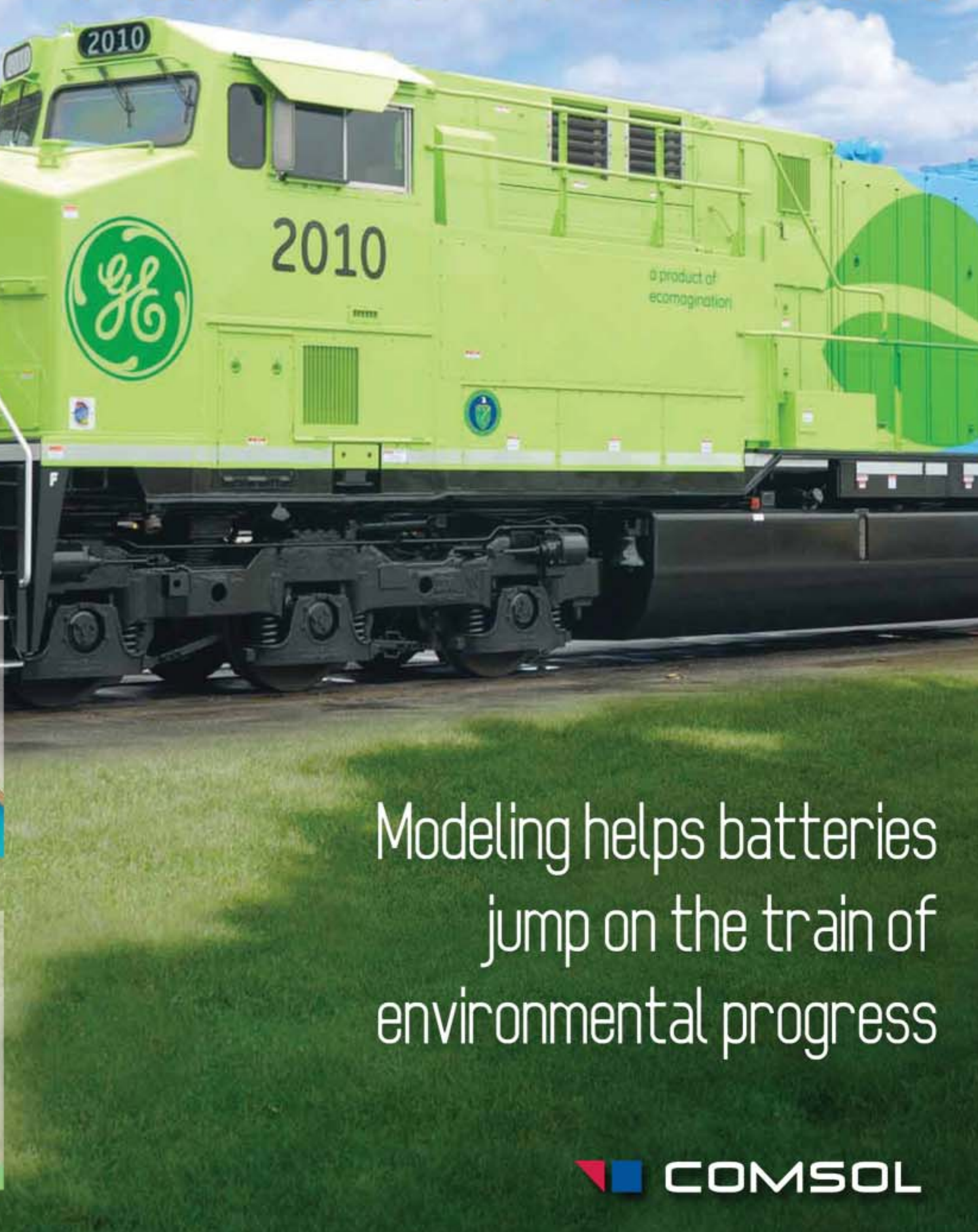
WWW.COMSOL.COM 2009

COMSOL NEWS

A TECHNICAL COMPUTING MAGAZINE



Modeling helps batteries jump on the train of environmental progress

COMSOL

Thank you!

John Vig, 2009 IEEE President

Dear IEEE member:

I want to thank you for being a member in 2009. Collectively, we marked history with the celebration of IEEE's 125th anniversary. I'm also happy to let you know that despite the economy, your IEEE professional network is larger than ever.

You are part of a community of more than 380,000 members who are making a difference in technology today—and whose work will define technology in the future. An example of this difference is the use of technology in contributing to growth of developing nations around the world. It has been shown that as a nation's number of cell phones and Internet connections increase, economic growth increases and poverty is reduced. So, who made cell phones and the Internet possible? It was IEEE's technical communities: the communications engineers, computer scientists, circuit designers, standards developers, and many others like you who helped make this possible.

In the following pages, you'll see some of the exclusive benefits and services available to IEEE members. The most important benefit is the opportunity to get involved. From attending IEEE's conferences and meetings to judging contests, serving on committees, applying technology to meet pressing humanitarian needs and much more, IEEE is the place to share your knowledge, talent and experience with your peers.

On behalf of your fellow members, thank you for continuing to making IEEE one of the most trusted voices in technology. I encourage you to make the most of your IEEE member experiences in 2010.

Sincerely,

John Vig
2009 IEEE President

IEEE Membership
Stay Connected Guide

Continue to stay connected with your IEEE membership. Follow the steps below to make sure your information is up to date.

Step 1
Visit myIEEE at www.ieee.org/myieee and log in using your IEEE Web account. myIEEE is your convenient personal portal to IEEE Web-based member benefits, account information and local activities.

Step 2
Update your Technical Interest Profile (TIP) from the **myAccount** link of your myIEEE page. myAccount manages your IEEE account information and is the primary venue for purchasing IEEE products, services and joining technical societies.

Step 3
Select your information sharing preferences in the **memberNet** module of your myIEEE page. memberNet is the complete directory of IEEE members, connecting technical and engineering experts worldwide.

Step 4
Update or set up your unique **"@ieee.org" e-mail alias**. It identifies you as an IEEE member and scans your mail for viruses.

Need help? Call the IEEE Contact Center:
+1 800 678 4333 (USA and Canada)
+1 732 981 0060 (Worldwide) / Fax: +1 732 562 6380
www.ieee.org/contactcenter

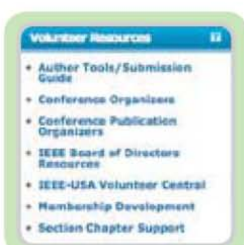
Your Personal Portal—myIEEE™

Get started with myIEEE

The myIEEE homepage is your personal gateway to every key aspect of your IEEE membership. You can customize your page to give you instant information on:

- Your member benefits
- The latest news from *IEEE Spectrum*, *IEEE Standards News* and *The Institute.*

- IEEE Sections and volunteer leadership



- Upcoming conferences

- Your society memberships and subscriptions

www.ieee.org/**benefits**

Trusted Voice

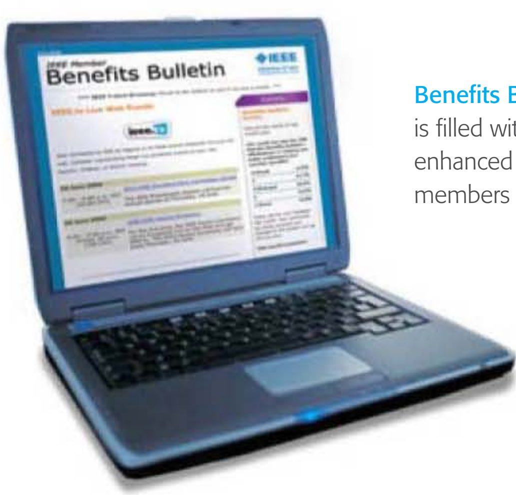
Contribute your insight. Help technology thrive.

You are now part of the world's largest technical society, bringing together more than 380,000 of the world's brightest minds. It is a community that relies on—and thrives because of—the engagement and dedication of its members.

Learn more with…

The Institute newspaper—a lively, informative chronicle of the events, activities and accomplishments of IEEE and its members. You'll receive four quarterly print editions, eight online editions and twice monthly e-mail alerts.

Section/Society newsletters—announcements about the people, activities and events making a difference in your geographic area or specific technical interest area.



Benefits Bulletin—this monthly e-newsletter is filled with announcements about new and enhanced benefits and shows what IEEE members think about key topics.

www.ieee.org/**benefits**

Global Community

Know the community.
Help it grow.

For more than 125 years, IEEE members have been creating information, building knowledge and having dialogues that have made IEEE one of the world's most trusted voices in technology. As an IEEE member, you have an extraordinary opportunity to share your knowledge and perspective with your fellow members… and the world.

Share your insight as…

Author—IEEE publishes more than 140 journals, so you'll be able to choose the best forum for your work—and gain exposure in some of the most widely read technological publications in the world. You'll also benefit from IEEE's disciplined methodology for peer review.

Visit www.ieee.org/publications.

Conference presenter—IEEE sponsors more than 900 conferences a year, so you're sure to find the right audience for your work. You can also volunteer to be a lecturer at local events—and benefit from the feedback of your peers.

Visit www.ieee.org/web/conferences.

Contest judge—IEEE sponsors dozens of contests to encourage and advance new ideas and new thinking in technology. As a contest judge, you have an opportunity to help make IEEE competitions engaging and enlightening for students and young professionals.

www.ieee.org/benefits

Profession

Expand your influence. Help drive change.

One of the key ways members help IEEE advance technology is by developing ideas, leading, organizing and expanding their influence. It's this commitment to increasing and promoting knowledge—and encouraging new and higher levels of excellence—that makes better technologists… and better technology.

Help advance the profession by…

Developing knowledge—you can drive and shape the future of the profession by helping develop standards for a broad range of technologies and industries. You can also help design technology-specific curricula for secondary schools and teacher training.

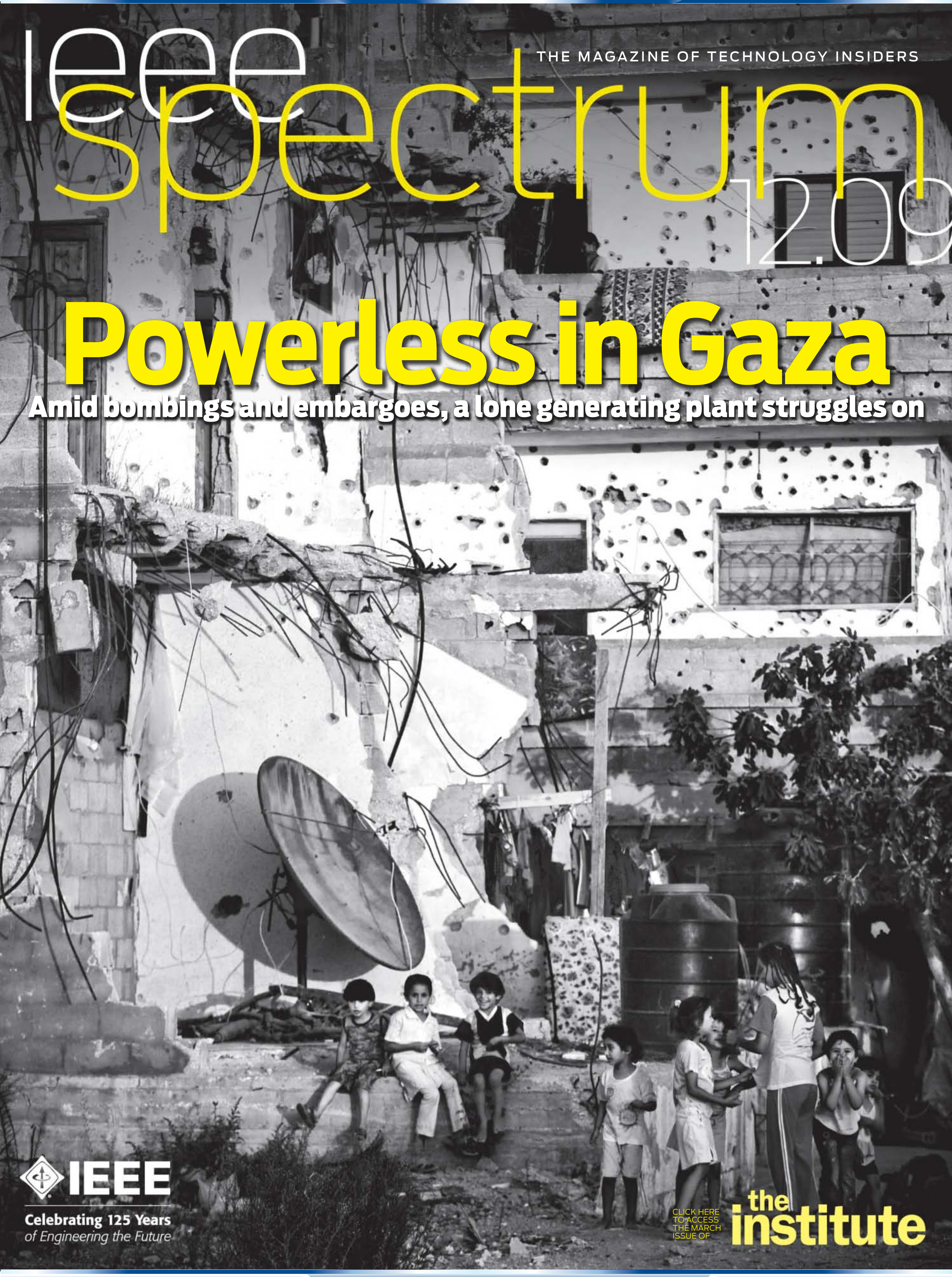
Leading and organizing—you can help provide management and leadership for section, chapter and student branches, and their activities and events. You can also help develop new conference tracks, and contests and competitions.

Promoting membership—help spread the word about IEEE's important work at technical events and forums. You can also help with local membership development, fundraising, and in recognizing the contributions of fellow members.

www.ieee.org/benefits

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

IEEE Spectrum 12.09
THE MAGAZINE OF TECHNOLOGY INSIDERS

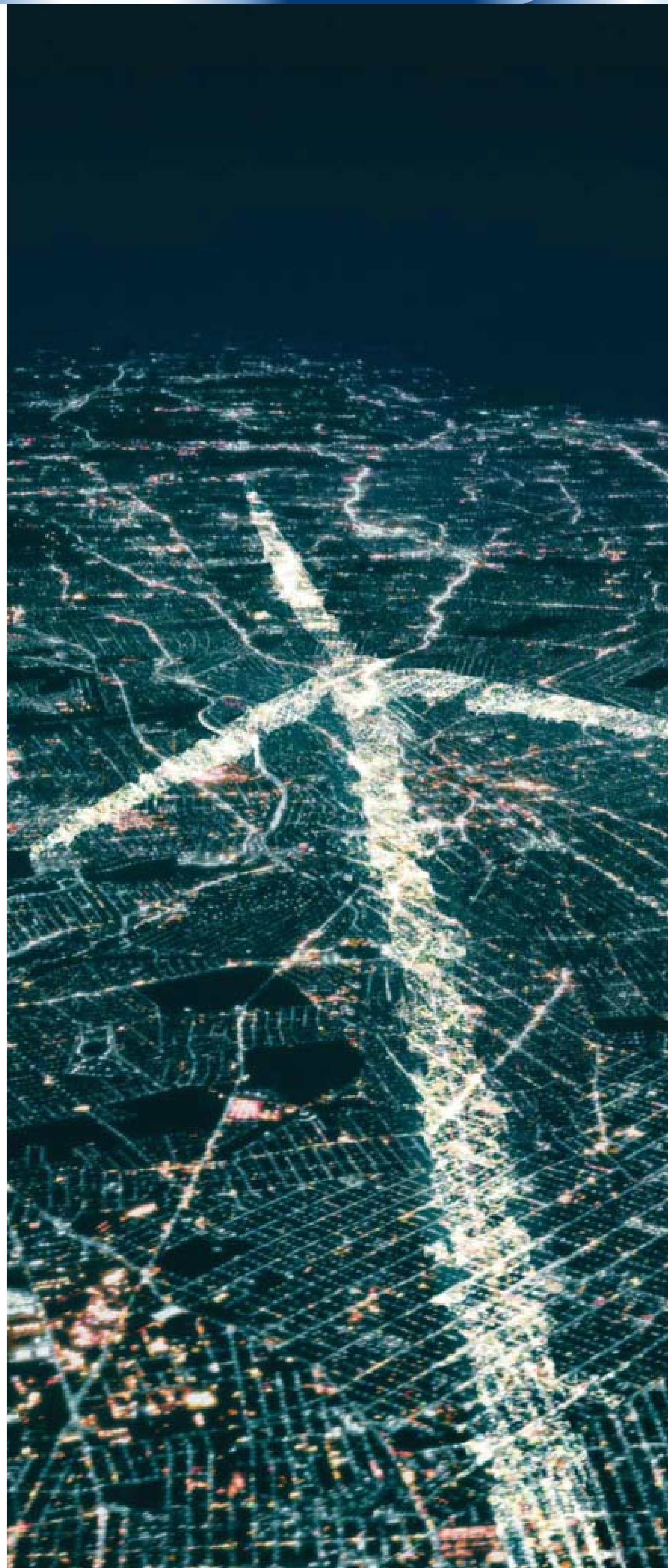


Powerless in Gaza

Amid bombings and embargoes, a lone generating plant struggles on

IEEE
Celebrating 125 Years
of Engineering the Future

CLICK HERE TO ACCESS THE MARCH ISSUE OF the institute



volume 46 number 12 international

ieee spectrum 12.09


22


36


42

ROCKY ROAD: At a planned nuclear waste repository in Finland [top], workers study the geology of their spent fuel's final home; a worker quenches a fire at Gaza's power plant after an Israeli air strike [bottom left]; HP Labs' new director, Prith Banerjee [bottom right], is taking risks—and they're paying off.

COVER: ZORIAH/DIARIES OF A SHOOTER
THIS PAGE: TOP: POSIVA; LOWER LEFT: LAURA LEON/POLARIS; LOWER RIGHT: TIMOTHY ARCHIBALD

COVER STORY

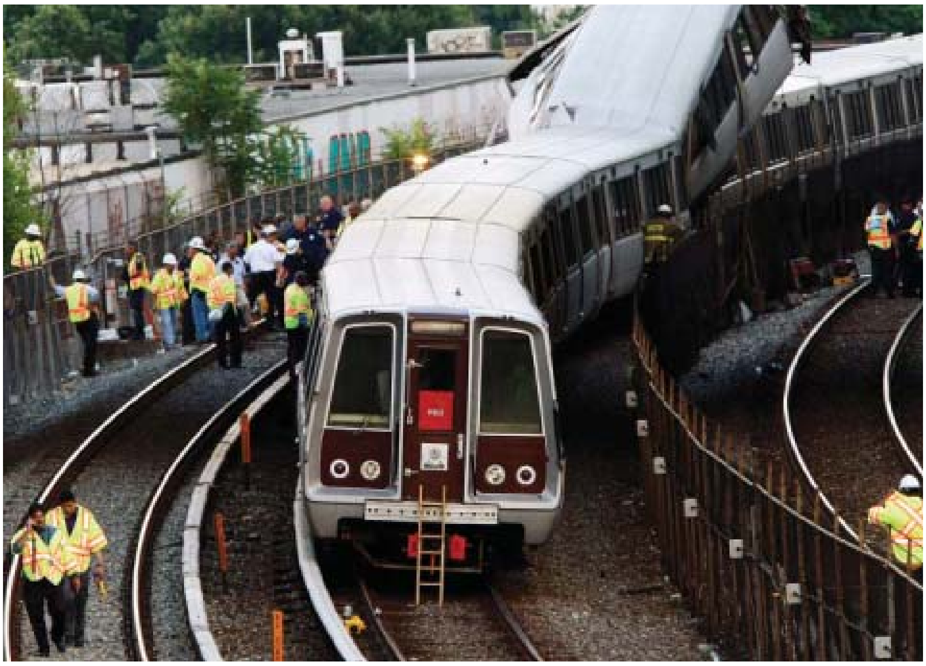
UPDATE

OPINION

DEPARTMENTS

volume 46 number 12 international

ieee spectrum 12.09



PHOTOS: TOP: WIN McNAMEE/ GETTY IMAGES; BOTTOM: RANDI SILBERMAN KLETT

View exclusive online-only content now by clicking on the headlines

SPECTRUM.IEEE.ORG

AVAILABLE 15 DECEMBER

LIVING WITH THE AUTOMATION PARADOX

As computer systems become more reliable, we increasingly trust them to help us fly our planes, drive our cars, and keep track of our children. We assume that the computer is portraying events accurately. But what if the computer doesn't tell the truth—either because it encountered a situation it wasn't designed for or because of a malfunction? How would you know? And if you did realize it, would you be smart enough to manage the consequences? *IEEE Spectrum* Contributing Editor Robert N. Charette explores these issues in light of recent accidents and asks whether we have automated ourselves out of control.

ONLINE FEATURE

TALE OF THE GPS-ENABLED CAT: KooKoo is a kitty who loves to roam. But when he started staying out for days at a time, his human companion, Mark Spezio, got worried. A tinkerer by temperament, Spezio rigged up a cat collar with an inexpensive, lightweight GPS logger and then set KooKoo loose. In *IEEE Spectrum*'s audio slide show, Spezio describes what he discovered about his cat's secret habits.

TECH INSIDER WEBINARS

Check out all webinars, including these below, at spectrum.ieee.org/webinar

UPCOMING WEBINAR
17 December:

- The Necessity of Life Insurance in Today's Economic Times *Sponsored by Marsh*

AVAILABLE ON-DEMAND WEBINARS

- Emerging Technology Forum Series: Enabling Electronics for Smart Grid Technologies and Beyond *Sponsored by Intel*
- Physical Verification: The Road Ahead *Sponsored by Mentor Graphics*
- The Future of Robotics *Sponsored by National Instruments*
- Getting the Most From MATLAB and Simulink With Symbolic Computation *Sponsored by Maplesoft*
- Reducing Physical Verification Cycle Times With Debug Innovation *Sponsored by Mentor Graphics*

IEEE.ORG/THEINSTITUTE

AVAILABLE 7 DECEMBER

STRIDES IN CANCER DETECTION: One day an ordinary screening test at your doctor's office may include checking your DNA to see whether you're developing cancer. That's thanks to the work of IEEE Fellow K.J. Ray Liu, who uses digital signal-processing techniques to extract information from DNA to identify changes that occur as cancer develops.

ANNIVERSARY WRAP-UP: Read about the various celebratory activities that took place around the globe to mark IEEE's 125th anniversary.

STUDENTS' CORNER: Learn about the top prizewinners of the IEEE Presidents' Change the World competition. The contest challenged students to develop unique solutions to real-world problems using engineering, science, computing, and leadership skills to benefit their community or humanity as a whole.

IEEE SPECTRUM (ISSN 0018-9235) is published monthly by The Institute of Electrical and Electronics Engineers, Inc. All rights reserved. © 2009 by The Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997, U.S.A. The editorial content of IEEE Spectrum magazine does not represent official positions of the IEEE or its organizational units. Canadian Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40013087. Return undeliverable Canadian addresses to: Circulation Department, IEEE Spectrum, Box 1051, Fort Erie, ON L2A 6C7. Cable address: ITRIPLEE. Fax: +1 212 419 7570. INTERNET: spectrum@ieee.org. ANNUAL SUBSCRIPTIONS: IEEE Members: $21.40 included in dues. Libraries/institutions: $399. POSTMASTER: Please send address changes to IEEE Spectrum, c/o Coding Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855. Periodicals postage paid at New York, NY, and additional mailing offices. Canadian GST #125634188. Printed at W224-N3322 Duplainville Rd., Pewaukee, WI 53072-4195, U.S.A. IEEE Spectrum circulation is audited by BPA Worldwide. IEEE Spectrum is a member of American Business Media, the Magazine Publishers of America, and the Society of National Association Publications.

back story

TIMO SEPPÄLÄ

Finland's Long Good-bye

"FINLAND IS covered with forests," a Finnish tourism Web site explains helpfully. "Finns harvest the trees to make paper. And then they use the paper to write sad songs about the life they left behind in the forest."

Associate Editor Sandra Upson mulled that over as she prepared to depart on her latest assignment. She was about to investigate plans to leave something else behind in the Finnish woods. Guided by printed Google maps (in Swedish), Upson piloted her rented Volvo past 300 kilometers of trees, flickering yellow fields, and an appreciable fraction of the country's 1.8 million saunas on the journey from Helsinki to Olkiluoto Island.

Olkiluoto is one dot in an archipelago three and a half hours away from the capital. It's a special dot, because it may well become the first permanent repository for spent nuclear fuel (see "Finland's Nuclear Waste Solution," in this issue).

The island, which is also home to two power reactors, is separated from the mainland by little more than a marsh, which is traversed by a bridge. On the island, amid crystalline streams and wild blueberries, Finland's geologists and engineers are carving an elaborate nuclear trash can into the bedrock.

To check out the tunnel complex, Upson suited up in a helmet, rubber boots, and a reflective jacket; to her waist she clipped a flashlight and an "oxybox," which would provide an emergency supply of oxygen. As she and her escorts drove into the tunnel in an all-terrain vehicle, the tall pine trees disappeared behind them and the crisp air grew damp. Far beneath the forest, she sloshed around in muddy puddles, peered into a ventilation shaft, poked at a few giant drilling machines, and then back up they went.

"This island, which seemed incredibly beautiful to me, was so run-of-the-mill to the Finns that they had no trouble turning it into a radioactive dumping ground," Upson reflects, wondering what sad songs future Finns will write about the beast interred beneath this beauty. ❏

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. 46, no. 12 (INT), December 2009, p. 9, or in *IEEE Spectrum*, Vol. 46, no. 12 (NA), December 2009, p. 11.

contributors

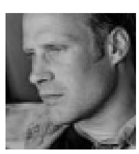
HARRY CAMPBELL says the technical challenge in creating the illustration for "Mechanical Radio" [p. 30] was trying to make it "believable, but at the same time ridiculous. It's just a cellphone. So it has to look really interesting, has to have far more content than would actually fit in a cellphone." Campbell started out doing more "cartoonish" designs for Nickelodeon and Warner Brothers, but he prefers the precise, tight-line techniques he's been using for about five years. His current style also works for more organic creations, like his political illustrations for *The New York Times*.

PAUL McFEDRIES has been writing the Technically Speaking column since June 2002. Inspired by his trip to the office—up one flight of stairs—he writes this month about telecommuting terminology [p. 21]. McFedries, a multiplatform kind of guy, recently authored user's guides for both Microsoft Windows 7 and Mac OS X Snow Leopard. He also runs Wordspy, a Web site that tracks emerging words and phrases.

CLARK T.-C. NGUYEN argues in "Mechanical Radio" [p. 30] that machining micromechanical parts into our electronics devices will lower their power consumption and make them more robust. It's about time for micromechanical circuits to have their day, he says: "You can see it starting up." Nguyen, who has pioneered advances in MEMS communication technology through his start-up company, Discera, and as a program manager in DARPA's Microsystems Technology Office, is a professor of electrical engineering and computer sciences at the University of California, Berkeley, where he received his B.S., M.S., and Ph.D. degrees.

BRE PETTIS, cofounder of the Brooklyn, N.Y., hacker collective NYC Resistor and author of this month's Hands On story, "Barbot, the Automated Bartender" [p. 18], is a man of many talents. He also filmed, produced, and starred in the related video, "Do-It-Yourself: An Automated Bartender," which you can find at http://www.spectrum.ieee.org/video/robotics/diy/barbot.

SHARON WEINBERGER is a journalist, a reporter for *Wired*'s award-winning national security blog, Danger Room, and the author of *Imaginary Weapons: A Journey Through the Pentagon's Scientific Underworld*. She examines the opposite end of the high-tech spectrum in "Powerless in Gaza" [p. 36], a look at the engineers who try to keep the lights on in that war-torn region. Her reporting trip to Gaza was supported by The Nation Institute's Investigative Fund.



ZORIAH shot this issue's cover photograph in Rafah, an area of Gaza often targeted by the Israel Defense Forces. "The children were just playing and doing what kids do best, with this amazing landscape of war framing them," he says. While he didn't set out to cover the plight of children affected by poverty and disaster, his projects have shown him "the kind of lasting effects people have when they grow up in conflict zones." His work as a photojournalist, covering social issues "that Western eyes rarely see," has taken him to 65 countries over the past seven years.

IEEE
Celebrating 125 Years
of Engineering the Future

IEEE MEDIA
STAFF DIRECTOR; PUBLISHER, *IEEE SPECTRUM*
James A. Vick, j.vick@ieee.org
ASSOCIATE PUBLISHER, SALES & ADVERTISING DIRECTOR
Marion Delaney, m.delaney@ieee.org
RECRUITMENT SALES DEVELOPMENT MANAGER
Michael Buryk, m.buryk@ieee.org
BUSINESS MANAGER Robert T. Ross
IEEE MEDIA/SPECTRUM GROUP MARKETING MANAGER
Blanche McGurr, b.mcgurr@ieee.org
INTERACTIVE MARKETING MANAGER Ruchika Anand, r.t.anand@ieee.org
LIST/RECRUITMENT MARKETING MANAGER Ilia Rodriguez, i.rodriguez@ieee.org
REPRINT SALES +1 212 221 9595, EXT. 319
MARKETING & PROMOTION SPECIALIST Faith H. Jeanty, f.jeanty@ieee.org
ADVERTISING SALES +1 212 419 7760
SALES ADVISOR John Restchack +1 212 419 7578
ADVERTISING PRODUCTION MANAGER Felicia Spagnoli
SENIOR ADVERTISING PRODUCTION COORDINATOR Nicole Evans
ADVERTISING PRODUCTION +1 732 562 6334
IEEE STAFF EXECUTIVE, PUBLICATIONS Anthony Durniak

IEEE BOARD OF DIRECTORS
PRESIDENT & CEO John R. Vig
+1 732 562 3928 FAX: +1 732 465 6444 president@ieee.org
PRESIDENT-ELECT Pedro A. Ray
TREASURER Peter W. Staecker
SECRETARY Barry L. Shoop
PAST PRESIDENT Lewis M. Terman

VICE PRESIDENTS
Teofilo Ramos, *Educational Activities;* Jon G. Rokne, *Publication Services & Products;* Joseph V. Lillie, *Member & Geographic Activities;* W. Charlton Adams, *President, Standards Association;* Harold L. Flescher, *Technical Activities;* Gordon W. Day, *President, IEEE-USA*

DIVISION DIRECTORS
Giovanni De Micheli (I); Robert E. Hebner Jr. (II); Curtis A. Siller Jr. (III); Roger W. Sudbury (IV); Deborah M. Cooper (V); Mark I. Montrose (VI); John D. McDonald (VII); Stephen L. Diamond (VIII); Frederick C. Mintzer (IX); Richard A. Volz (X)

REGION DIRECTORS
Howard E. Michel (1); William P. Walsh Jr. (2); William B. Ratcliff (3); Don C. Bramlett (4); David J. Pierce (5); Leonard J. Bond (6); Ferial El-Hawary (7); Jozef W. Modelski (8); Enrique E. Alvarez (9); Yong Jin Park (10)

DIRECTORS EMERITUS
Eric Herz, Theodore W. Hissey

IEEE STAFF
EXECUTIVE DIRECTOR & COO James Prendergast
+1 732 502 5400, james.prendergast@ieee.org
HUMAN RESOURCES Betsy Davis, SPHR
+1 732 465 6434, e.davis@ieee.org
PUBLICATIONS Anthony Durniak
+1 732 562 3998, a.durniak@ieee.org
EDUCATIONAL ACTIVITIES Douglas Gorham
+1 732 562 5483, d.g.gorham@ieee.org
STANDARDS ACTIVITIES Judith Gorman
+1 732 562 3820, j.gorman@ieee.org
MEMBER & GEOGRAPHIC ACTIVITIES Cecelia Jankowski
+1 732 562 5504, c.jankowski@ieee.org
CORPORATE STRATEGY & COMMUNICATIONS Matthew Loeb, CAE
+1 732 562 5320, m.loeb@ieee.org
BUSINESS ADMINISTRATION Richard D. Schwartz
+1 732 562 5311, r.schwartz@ieee.org
TECHNICAL ACTIVITIES Mary Ward-Callan
+1 732 562 3850, m.ward-callan@ieee.org
MANAGING DIRECTOR, IEEE-USA Chris Brantley
+1 202 530 8349, c.brantley@ieee.org

IEEE PUBLICATION SERVICES & PRODUCTS BOARD
Jon G. Rokne, *Chair*; Tayfun Akgul, George W. Arnold, John Baillieul, Silvio E. Barbin, Tamer Basar, Tariq S. Durrani, Mohamed E. El-Hawary, Gerald L. Engel, Marion O. Hagler, Jens Hannemann, Lajos Hanzo, Hirohisa Kawamoto, William W. Moses, Adrian V. Pais, Edward G. Perkins, Saifur Rahman, Sorel Reisman, Edward A. Rezek, Barry L. Shoop, Emily A. Sopensky, W. Ross Stone, Ravi M. Todi, Robert J. Trew, Leung Tsang, Karl R. Varian, Stephen Yurkovich

IEEE OPERATIONS CENTER
445 Hoes Lane, Box 1331, Piscataway, NJ 08854-1331 U.S.A.
Tel: +1 732 981 0060 Fax: +1 732 981 1721

CLOCKWISE FROM TOP RIGHT: DAVE NEFF; ALEXANDER VASILJEV; ZORIAH/DIARIES OF A SHOOTER; DEPT. OF EECS/UNIVERSITY OF CALIFORNIA AT BERKELEY; KAREN HAMMOND; HARRY CAMPBELL

spectral lines

Every Move You Make

IN THE UNITED KINGDOM, your home may be your castle, but the government will soon be able to get a rather good idea of what is happening inside it.

The British government has decided to go ahead with its plans under what it calls the Intercept Modernisation Programme to force every telecommunication company and Internet service provider to keep a record of all its customers' personal communications, showing whom they have contacted and when and where, as well as the Web sites they have visited, according to *The Daily Telegraph* and various other British papers.

The information gathered, *The Telegraph* says, will be accessible to 653 public bodies, "including police, local councils, the Financial Services Authority, the ambulance service, fire authorities and even prison governors.

"They will not require the permission of a judge or a magistrate to obtain the information, but simply the authorisation of a senior police officer or the equivalent of a deputy head of department at a local authority," *The Telegraph* says.

The only bit of good news, if you can call it that, is that the information won't be held in a central database because of privacy concerns (that seems a bit oxymoronic to me), and the full rollout will be delayed until after the next election.

If the Tories or Liberal Democrats win, they say that the intercept program will be changed in scope and function. However, as happened in the United States after the last election, once politicians are in power, promises about privacy and spying on citizens seem to become less important.

I wonder how long it will be before the British government requires people to submit their details from Google's new Dashboard, just to double-check that their Web habits are being captured properly. As Google notes,

> the Dashboard summarizes data for each product that you use (when signed in to your account) and provides you direct links to control your personal settings. Today, the Dashboard covers more than 20 products and services, including Gmail, Calendar, Docs, Web History, Orkut, YouTube, Picasa, Talk, Reader, Alerts, Latitude and many more.

The British government is also going ahead with ContactPoint, a database containing the details of England's 11 million children. As described in a 7 November *Telegraph* story,

> The computerised database contains a record for each of the 11m under-18s living in England, containing their name, address, gender, date of birth and a unique identifying number. It also holds information on their parents, their nursery or school, their GP and whether they have a social worker, health visitor or probation officer assigned to them. If the young person consents, it will also give details of sexual health or drug abuse counsellors.

Interestingly, this database is assumed by the government to be secure and private. So secure and private, in fact, that the children of celebrities and certain others—for example, the children of government officials—are to be excluded from it.

It has not passed without notice on the 20th anniversary of the fall of the Berlin Wall the irony of the British government's dogged efforts to spy on its own people in a way that would make the Stasi envious.

STEVE COLE/GETTY IMAGES

Prime Minister Gordon Brown's remarks marking the anniversary included this:

> What has happened here in Berlin tells the world that the tides of history may ebb and flow, but that across the ages history is moving towards our best hopes, not our worst fears; towards light not darkness; and towards the fulfillment of our humanity, not its denial.

So governmental spying is moving toward our best hopes, toward light not darkness, and toward the fulfillment of our humanity? George Orwell, who once wrote, "To see what is in front of one's nose needs a constant struggle," would probably be very depressed by the state of affairs in the United Kingdom—but probably not very surprised.

—ROBERT N. CHARETTE

A version of this column appeared in IEEE Spectrum Online's Risk Factor blog on 10 November. Charette is a contributing editor to Spectrum *and a self-described "risk ecologist," who investigates the impact of the changing concept of risk on technology and societal development.*

NOW RELE
COMSOL

COMSOL Desktop™ lets you organize your workflow and provides a full overview of your simulation

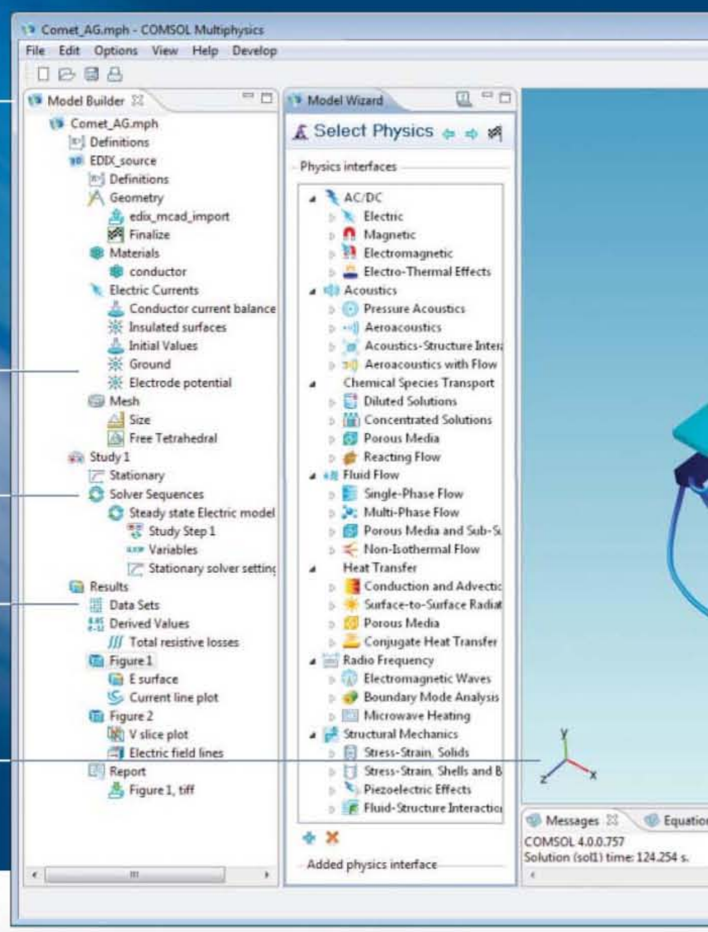
Easy to set up and solve models in the Model Builder

Settings overview with one-click convenience

Compare various designs by recording and replaying sequences of operations

Access to multiple solutions allows for instant comparison of designs

Select background color and include your own logo in the graphics area



Streamlining the multiphysics simulation process

COMSOL Multiphysics® version 4 delivers the COMSOL Desktop, an all-new user interface that sets up a workflow for maximum productivity. Building a model naturally follows along the lines of your thinking, from concept to realization. You just right-click to add more features and perform common tasks like importing CAD, meshing, specifying material properties, solving, and visualizing results. This progressive disclosure puts what you need at your finger tips, just when you need it.

forum

The

RECESSION'S

SILVER LINING

How the semiconductor industry can use the recession to create the next technology renaissance

By **Pushkar Apte & George Scalise** *Illustrations by* **Keith Negley**

COUNTLESS RESEARCH INSTITUTIONS contributed to the digital, wireless, and mobile technologies that underpin our modern world. But none contributed more than Bell Telephone Laboratories, which logged an astonishing share of the key advances of the 20th century, including the transistor, the cellphone, the digital signal processor, the laser, the Unix operating system, and motion-picture sound. We no longer have Bell Labs to fund research with long-term payback. That has prompted many to wonder: Who will pay for such research now, and where will it be done?

We say: Governments and corporations must share the burden, and they must do it in structured collaborations among universities, companies, and government agencies in which intellectual property is freely available to all participants.

We also say, the sooner we can get started, the better. The recession has left R&D spending in free fall. This year, the global semiconductor industry is expected to spend just US $200 billion on research—$50 billion less than in 2008. And times are really tough in the semiconductor equipment industry, whose R&D operations will shrivel like a salted leech from $34 billion in 2007 down to a pitiful $10 billion in 2009.

In the United States, a few basic sciences are getting a reprieve, thanks to the federal stimulus package. Of the $787 billion designated, $10 billion went to the National Institutes of Health for life-sciences research; on the other hand, there has been a steady federal funding decline for physical sciences in the United States.

In the long run, however, even the life sciences are unlikely to benefit in any meaningful way from that load of cash. A one-time infusion helps, but it also creates a classic feast-or-famine problem: The money needs to be spent by September of next year. And because there's no follow-up money to keep these programs going beyond that time, officials can't start major long-term initiatives.

But the recession isn't what's causing this problem; it's only revealing an intensifying trend in the semiconductor industry. Revolutionary innovation has been missing in action for about 40 years as the industry instead focused on incremental advances. The industry could get away with short-term research because those incremental advances got the companies where they needed to be, financially speaking.

34 INT · IEEE SPECTRUM · OCTOBER 2009 WWW.SPECTRUM.IEEE.ORG

LETTERS do not represent opinions of IEEE. Short, concise letters are preferred. They may be edited for space and clarity. To post your comments online, go to http://www.spectrum.ieee.org. Or 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.

SEMICONDUCTORS ON THE MOVE

PUSHKAR APTE and George Scalise in their article, "The Recession's Silver Lining" [October 2009], lament the lack of "revolutionary innovation" in a semiconductor industry that instead has been "focused on incremental advances" for the last 40 years. Their bias for technology revolution over evolution is very common among both engineers and the general public, but the semiconductor industry is a perfect example of why this preference is often misplaced. In the last 40 years, the cost of making a transistor has dropped by a factor of 100 million, enabling the most remarkable advances in information technology in human history. I wonder what revolutionary advances the authors expect could do better than the merely evolutionary forces of Moore's Law? If one defines a revolution as an improvement by a factor of 10, then the semiconductor industry has seen eight revolutions in the last 40 years—not bad for incremental advances.

CHRIS MACK
IEEE Senior Member
Austin, Texas

AS A U.S. Department of Defense employee from the 1940s to the 1980s, I was involved with the U.S. Army's exploitation of semiconductors in the early 1950s. The Army capitalized on the work of Bell Labs through the Industrial Preparedness Program's funding of the fledgling transistor industry. The funding of the microelectronics industry soon followed. I do not believe that semiconductor industry associations will ever take the place of a Bell Labs. With the demise of Ma Bell, we lost a valuable technology resource.

BERNARD REICH
IEEE Life Fellow
Ocean, N.J.

THE FUTURE IS GREEN

THE LETTER from George F. Steeg [Forum, "Energy by the Numbers," September] on the viability of green energy is rather shortsighted. The world's supply of stored energy in the form of coal, crude oil, natural gas, and uranium is finite. That means all sources will be depleted eventually.

However, the supply of power sent to Earth by the sun's radiation exceeds the human demand by a factor of several thousand. The sun's radiation can be used directly (photovoltaic and heat) and indirectly (wind and water) and can be stored in biomass (wood, biomethane, bio-oil). The stored fossil and atomic energy supplies being finite, the switch to renewable green energy sources will come anyway, and better sooner than later.

Using regenerative power sources to meet peak demand will be a challenge. But surely smart grids, pumped-storage hydropower plants, hydrogen, and other techniques will handle the peaks. Someday, the people of the world will be in the dark unless politicians and engineers learn to do enough arithmetic to see the light of green energy.

WALTER F. STRAUB
IEEE Life Member
Oberhaching, Germany

SAVE OUR STREETCARS

STREETCARS MIGHT be freed of wires ["Fuel Cells Could Power a Streetcar Revival," Update, September]. But it wasn't the unsightliness of overhead electricity supply wires that caused the streetcar's demise. Overhead supply isn't even necessary—streetcars can just as well be powered from an underground conduit midway between the rails.

It was the automotive industry, not aesthetics, that struck the deathblow to many streetcar systems. Two capital cities confirm these aspects of streetcar history. Washington, D.C., had a streetcar system based on underground supply within the central urban area, but in 1962 the system was closed down in favor of buses. Oslo still has a streetcar system that is continually being modernized and expanded. Electric power is supplied to the contact lines by a mix of overhead and underground cables. There have been several proposals for replacing the trams with buses, but none have been implemented, and today the city transit system is a mix of tram and bus services.

M. MICHAEL BRADY
IEEE Life Senior Member
Asker, Norway

update

more online at www.spectrum.ieee.org

PHOTO-ILLUSTRATION: SEAN MCCABE; GORDON: EUGENE I. GORDON; TOMPSETT, BOYLE, SMITH: ALCATEL-LUCENT/BELL LABS; CCD CHIP: MICHAEL F. TOMPSETT

The Nobel Prize and Its Discontents

Some imaging pioneers have a problem with the Nobel committee

The Nobel Prize is the peak honor in physics. Yet this year it celebrated not science, but technology: "the invention of an imaging semiconductor circuit—the CCD sensor." The winners were two IEEE Fellows from Bell Telephone Laboratories, Willard S. Boyle and George E. Smith.

Two other IEEE Fellows and former Bell Labs colleagues, Michael F. Tompsett and Eugene I. Gordon, say the Nobel committee has made a mistake. Their complaints reveal a lot about how inventions happen and how credit for them is given. At the heart of their complaints is that the Nobel Prize winners had little to do with the charge-coupled device's use in imaging—the reason it became so important to astronomy and consumer electronics.

According to Smith, in 1969, he and Boyle were seeking a memory technology. Magnetic bubble memory had recently been developed at Bell Labs, and it was all the rage. That technology stored data as a linear pattern of tiny magnetized spots, called bubbles, on a ribbon of magnetic material. Current passed through the ribbon would push the bubbles along in one direction so they could be read out or written sequentially.

Boyle, then executive director for the Bell Labs area that worked on silicon, worried that

BELL'S BEST: Eugene I. Gordon, Michael F. Tompsett, Willard S. Boyle, and George E. Smith [from left] each had a hand in the CCD.

update

support would be diverted from silicon research toward magnetic bubble memory. He asked his friend George Smith to help him come up with a competitor.

On a chalkboard they sketched out a concept similar to bubble memory that used charge instead of magnetic domains. The idea was to build a line of potential wells in silicon by creating capacitors out of silicon, silicon oxide, and metal electrodes. Charge—directly injected in the early CCDs—would accumulate in the wells. By applying alternating voltages, you could then move the accumulated charges from one well to the next until they reached the edge of the chip, where the amount of charge could be read out and digitized.

Both Boyle and Smith say that the device's potential for imaging was obvious to them at the time, and Smith has notebook entries to prove it. But they did not pursue that application. The CCD continued its journey at Bell Labs, under the guidance of Michael Tompsett.

Tompsett's problem with Boyle and Smith's Nobel award comes down to the citation, which includes the word *imaging*. And the CCD *imager* was invented by Tompsett, not by Boyle and Smith. So says not just Tompsett but also the United States Patent and Trademark Office.

Tompsett, who ran Bell Labs' CCD group in the 1970s, is the sole inventor listed on U.S. Patent No. 4085456, "charge transfer imaging devices." The patent, filed in 1971, covers linear scanners and area imagers.

Tompsett's key invention was a scheme called frame transfer. The invention solved a big problem with using a CCD as an imager: The CCD continued to sense light and gather charge even as each line of pixels was read out, smearing the image in the direction of the charge transfer. Tompsett's idea was to duplicate the entire CCD structure on a part of the chip that wasn't exposed to the image. He found a way to rapidly transfer the charge collected in the imaging CCD to the hidden CCD. The image was then read out from the hidden CCD, while the imaging side took another picture.

Tompsett has no illusions about what will happen in Stockholm this month. "You're not going to change [who wins] the Nobel," he says, but "it would be nice to at least share the credit." The citation for the award, he says, should be altered to eliminate any mention of imaging.

Smith disagrees. Tompsett "can be credited with good engineering but not with the concept of imaging with a CCD," he says.

Tompsett has an ally in IEEE Fellow and Edison Medal winner Eugene Gordon. At the time of the CCD's invention, Willard Boyle was Gordon's boss, Gordon was Smith's boss, and Smith was Tompsett's boss.

Gordon led the development of the CCD's precursor technology, the silicon-diode-array camera tube, which Bell Labs developed for an ultimately abandoned product, the Picturephone. In that device, light fell on the silicon-diode array, producing pockets of charge. Then a low-energy electron beam scanned the array, kicking out current in proportion to the intensity of the light.

With the Picturephone camera already in production, Gordon was not interested in a new imager. But Tompsett pushed. "If it were not for Mike's perseverance, Bell Labs would not have done any imaging work with the CCD," says Gordon.

FIRST LIGHT: Dr. Margaret Tompsett was the model in an early CCD image. PHOTO: MICHAEL F. TOMPSETT

SO WHO DESERVES the accolades? "It depends on what you're celebrating," says Carlo Séquin, who joined the Bell Labs CCD team about nine months after the project began.

"My initial assumption was the Nobel in physics goes to fundamental concepts," says Séquin, now a professor of electrical engineering and computer science at the University of California, Berkeley. "If the fundamental concept was the charge-transfer principle, then that goes to Boyle and Smith, and maybe Gene Gordon." If it's the invention of a practical CCD imager, "credit would go to Mike Tompsett, and possibly Gilbert Amelio," he says. (Amelio led commercial CCD development at Fairchild Semiconductor.)

It's easy to see why the Nobel committee went with Boyle and Smith. The CCD is synonymous with its only practical application: imaging. And according to many authoritative sources, Boyle and Smith invented the CCD. But had the Nobel nominators looked one step down the chain of invention, things might have been different.

—Samuel K. Moore with Neil Savage

8 KELVIN The temperature that a section of the Large Hadron Collider nearly reached after an errant bit of baguette got into an external circuit, according to *The Register*. The collider can fail at 9.6 K.

Room for Rent, Stellar View

Next-generation Iridium communications satellites will rent out space for scientific payloads

LAST FEBRUARY, in what seems an extraordinary stroke of bad luck, an Iridium communications satellite collided with a Kosmos-2251, a defunct Russian satellite, blowing both to pieces. Fortunately, Iridium was able to swap in one of the backups it maintains in orbit, swiftly restoring global coverage. But that freak event underscores the fact that the once maligned but now resurgent company needs some new satellites. Its quest to acquire them could make the company an important player in the geoscience community.

"At some point in time, if we didn't do anything, we'd have less than 66 satellites," says Don Thoma, Iridium's executive vice president for marketing, referring to the minimum number of satellites needed to complete the company's constellation. So Iridium, which has gained more than 300 000 subscribers since it emerged from bankruptcy in 2001, has embarked on an ambitious plan to begin launching a new generation of satellites, called NEXT, in 2014.

The new hardware will boost Iridium's communications capabilities substantially, improving the maximum data rate subscribers can obtain at least fourfold, to 1 megabit per second or more. And the new network will be entirely based on the Internet Protocol, unlike the old voice-based communications infrastructure, which was built on the fleeting premise that enough customers would be willing to pay up to US $7 per minute for voice calls placed from $3300 mobile phones.

That Iridium's NEXT satellites will provide an Internet in the sky comes as no great surprise. What's rather amazing about the new satellites is that, in addition to providing globe-spanning communications, the Iridium fleet will also host scientific payloads, likely ones designed to monitor Earth. With the exception of some crude early experiments that involved putting special cameras on geosynchronous communications satellites, this will be a first.

The amount of scientific instrumentation on each satellite will be modest: Iridium's allotment is 50 kilograms and 50 watts of power on average. "We wanted to be sure we didn't lose focus," says Thoma.

Jan-Peter Muller, a professor at University College London's department of space and climate physics, doesn't see these weight or power limits as a big impediment. "It's a very cool idea to have it on a communications satellite because you have the communications infrastructure built in," he adds.

One problem with using Iridium satellites to monitor the surface is that their orbits are optimized for communications, not for viewing. For the latter, a satellite is usually placed in a polar sun-synchronous orbit, so that it passes overhead everywhere at the same time of day, providing consistent illumination. This means that Earth-viewing instruments carried on Iridium satellites would have to cope with a changing sun angle.

Sun angle doesn't affect all kinds of investigations, though. Radar and thermal-infrared observations, and measurements of the attenuation or reflection of GPS signals, for example, are all insensitive to it. Some visible-light instruments on Iridium satellites could work perfectly well, too, such as those designed for tracking clouds as a means to measure winds.

However its hosting services are used, Iridium will not be providing them free of charge. Rather, it'll be selling the space on its satellites, most likely to government customers. The U.S. National Oceanic and Atmospheric Administration has shown interest in that possibility, as has NASA. European researchers have expressed enthusiasm, too, but the chances are slim that European funding agencies will be able to move swiftly enough to meet the Iridium launch schedule. Muller, for one, is frustrated that European governments move too slowly to take advantage. "For me, it's so obvious why this is a really good idea and why we should jump on it."

—DAVID SCHNEIDER

FRANK BEAN/GETTY IMAGES

Breaking GSM

The encryption technology used to prevent eavesdropping in GSM (Global System for Mobile communications), the world's most widely used mobile phone system, is a Swiss cheese of security holes, according to an expert who plans to poke a big hole of his own. By the end of the year Karsten Nohl plans to make the encryption keys available to everyone on the Internet. See http://spectrum.ieee.org/telecom/wireless/open-source-effort-to-hack-gsm.

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

update

Texas Instruments vs. the Calculator Hackers

Hobbyist cracks key to operating system and TI says: Cease and desist!

HACKED: Brandon Wilson replaced a TI calculator's OS.
PHOTOS: BRANDON WILSON

In August, Brandon Wilson, a 25-year-old programmer in Johnson City, Tenn., posted a giddy new blog entry on his personal home page. "83+ OS signing key cracked!" his headline read.

Wilson is a calculator hacker, and for geeks like him, the news was big. The signing key is a security code that, when unlocked, allows hackers to put their own operating systems on a Texas Instruments TI-83 Plus graphing calculator. While most people picture hackers tinkering with PCs or video games, Wilson belongs to an engineering subculture that is less known but equally passionate. Calculator hackers code games and even get USB peripherals running on their machines. "I reached a point where I could understand all there was to understand about this device," says Wilson. "That's a rewarding feeling. You can try to do that on a computer, but you'll never get there."

There's one problem: Texas Instruments doesn't want hackers modifying its calculators. Shortly after Wilson uploaded his post, TI insisted he take down the links from his site leading to the signing key. Wilson reluctantly complied, but the incident raises compelling questions about the boundaries of innovation and collaboration online.

Wilson is among several calculator hackers who have received cease-and-desist letters from TI for violating the anticircumvention provisions of the Digital Millennium Copyright Act (DMCA). "The TI-83 Plus operating system uses encryption to effectively control access to the operating system code and to protect its rights as a copyright owner in that code," wrote Herbert W. Foster, manager of business services for TI's Education Technology Group, in the letter. "Unauthorized use of these files is strictly prohibited."

On behalf of Wilson and the other hobbyists, the Electronic Frontier Foundation (EFF), a nonprofit advocacy group based in San Francisco, fired back at TI over what it calls "baseless legal threats [that] squash free speech and innovation." Jennifer Stisa Granick, civil liberties director for the EFF, argues that calculator hackers do not violate the DMCA. The DMCA protects a user's right to reverse engineer hardware in order to run home-brew operating systems or other programs. Furthermore, the EFF contends, Texas Instruments makes its software available online, so the release of the signing keys is not unauthorized distribution.

The importance of the case goes beyond calculator hobbyists and illustrates a rising trend. "What we're seeing is a real push on the part of consumers—that they want to open up their devices and have a robust marketplace for code to run on these devices," Granick says.

Duncan Smith, a University of Washington student who also received a letter from TI, thinks hacking is a way to improve the performance of the machines. "There's a general consensus in the TI programming community that we've gone about as far as we can if we're going to keep using [TI's operating system]," he says.

Tom Cross, a security technology researcher in Atlanta, received a cease-and-desist letter from TI after merely posting about the hackers on his blog, Memestreams.net. "I didn't include the key in my post," he says. "I linked to a discussion forum where this was being talked about." Cross took down his link, but not without feeling burned. "It's incumbent on Texas Instruments to be responsible with its power," he says, "and I don't think they were responsible."

The company declined to comment on the case.

But while the signing keys are gone, the modding continues. Despite the TI-83 Plus's limited specifications—a 6 megahertz Z80 processor, 24 kilobytes of main memory, 160 KB of flash memory, and a 96- by 64-pixel display—calculator hackers are cooking up new home-brewed solutions. Wilson is continuing work on his own operating system. "I would like to be left alone and not afraid of being sued just for wanting to do something with my own hardware," he says.

—David Kushner

A version of this article ran online in October 2009.

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

29:49 The winning time in this year's 3021-kilometer World Solar Challenge auto race. Japan's Tokai University ended Delft University of Technology's four-year winning streak using compound solar cells built by Sharp Corp.

Grid on a Chip

Integrating a high-voltage grid is one way researchers think they could better distribute power on chips

There's renewed interest in upgrading power grids to make regions more energy efficient. The same may be needed for the grids that distribute power on modern microprocessors.

In an effort to keep power consumption reasonable and maintain constant power dissipation, chipmakers have been moving their circuits to lower-voltage requirements, which these days are about 1 volt. But supplying such low voltage to a chip from an off-chip source requires increasing the input current to more than 100 amperes per microprocessor. Carrying such high currents around the chip on copper interconnects leads to high conductive power losses. It also means that the majority of input/output pins—as many as 70 percent—must be devoted to power distribution, leaving few available for transmitting actual data.

Only in the past three to five years has there been much research into how to get power converters onto the chips for better power distribution, says Eby Friedman, professor of electrical and computer engineering at the University of Rochester, in New York. "If you go to the best companies in the world, they're just now integrating really coarse power supplies on-chip," he says.

Tomás Palacios, assistant professor of electrical engineering and computer science at MIT, says that his new technology, a way of making hybrid ICs out of both silicon and gallium nitride, might help. He bonds together separate wafers of silicon and GaN into one wafer and then processes them, first building silicon circuits in one section of the chip, then etching away the silicon in another section and creating circuits in the GaN below. His idea is to distribute power at a much higher voltage than silicon circuits can stand, perhaps as high as 20 V. Gallium nitride electronics, which are tough enough to handle such high voltages, would then convert power to lower voltages and distribute it locally, not unlike the way electrical substations step down high-voltage electricity transmitted from power plants. At high voltage, little current flows, so there is little loss of power in the transmission conductors. And the high-current, low-voltage power travels only locally, which reduces conductive losses and frees up input/output pins.

PHOTO-ILLUSTRATION: BRANDON PALACIO; ELECTRICITY PYLONS: ISTOCKPHOTO; COMPUTER CHIP: ISTOCKPHOTO

Friedman says Palacios's idea seems credible. It's somewhat analogous to a power distribution idea that Friedman is developing. "He did it at the material level, and we did it at the circuit level," Friedman says.

Inductors and capacitors, key parts of many switched-mode converters and their accompanying filters, are difficult to shrink down to a size at which the converter can be easily integrated. That's because their electrical properties are a function of their geometry, so they can't be scaled down as easily as transistors.

Tanay Karnik, a principal engineer at Intel Labs, is exploring using a cobalt-based magnetic material as an on-chip inductor to control voltage. The material can be processed like silicon and can handle gigahertz frequencies, as opposed to the megahertz of iron-based magnetic materials. Because they're meant to operate at higher frequency, cobalt inductors can be made much smaller, thereby freeing up chip real estate.

Another approach, being followed by Fred Lee, a professor of electrical and computer engineering at Virginia Tech, is a three-dimensional design. Lee builds the inductors and capacitors on a separate chip, which he then bonds to the main chip. This solves space issues but adds cost. Friedman reports that his group is constructing a 3-D converter as well.

Having the power supply on the chip itself instead of elsewhere in a system should increase efficiency and also opens up new possibilities. With the power supply off-chip, there's no way to deliver different loads to different circuits, says Intel's Karnik. "You have an option of switching something on or off, but you don't have the option of running at 0.9 V or 1 V or 1.2 V," he says. "If all [the different devices on a chip] have the opportunity to choose their own voltage, you will get a better product." —Neil Savage

A version of this article ran online in October 2009.

update

commentary

Kyoto 2.0

What to expect from the Copenhagen climate confab

THOSE EXPOSED to some modern European history may recall the attempts made in the 1920s and early 1930 to resolve the intertwined issues of World War I reparations, war debt, and beggar-thy-neighbor protective tariffs. When international negotiations repeatedly failed, the sense was that the stage had been set for catastrophe—and, with World War II and the Holocaust, that instinct proved correct.

Something of the same feeling has attended the run-up to the United Nations Climate Change Conference, which takes place from 11 to 18 December in Copenhagen. To be sure, to those who consider climate science to be unsound or attempts to do anything about global warming to be a waste of time and money, the best outcome in Copenhagen would be no outcome. In fact, the conference may end with a mere declaration of intentions. But if that's what happens, it will be a sore disappointment to the diplomats who organized it, who say they consider a strong agreement essential.

Failure in Copenhagen is "not an option," says the conference president, Connie Hedegaard, minister for climate and energy in Denmark's conservative coalition government. The world cannot afford to see "the whole global democratic system [as] not being able to deliver results in one of the defining challenges of the century," she says.

Informally known as COP15, the Copenhagen conference is the 15th international meeting held to discuss the implementation of the 1992 United Nations Framework Convention on Climate Change, in which world membership is virtually universal. The main objective in Copenhagen is to reach agreement on a treaty to supplant the controversial 1997 Kyoto Protocol, which all industrial countries except for the United States have ratified.


PETER DAZELEY/GETTY IMAGES

To prevent what the convention vaguely called "dangerous" climate change, the protocol would have required the United States to reduce its greenhouse-gas emissions 7 percent by 2012 relative to 1990, and the European countries about 8 percent. Since adoption of the protocol, the biggest European countries have held their emissions more or less flat or reduced them, while the United States has let emissions climb perhaps 15 percent. Hardly any country has actually met its Kyoto target.

Overwhelmingly, the biggest issue at Copenhagen—the issue that could easily lead to a total breakdown—is whether rapidly industrializing countries like China, India, and Brazil must agree to binding greenhouse-gas reductions in exchange for the advanced industrial countries' committing to sharper cuts. But there are many other important issues too.

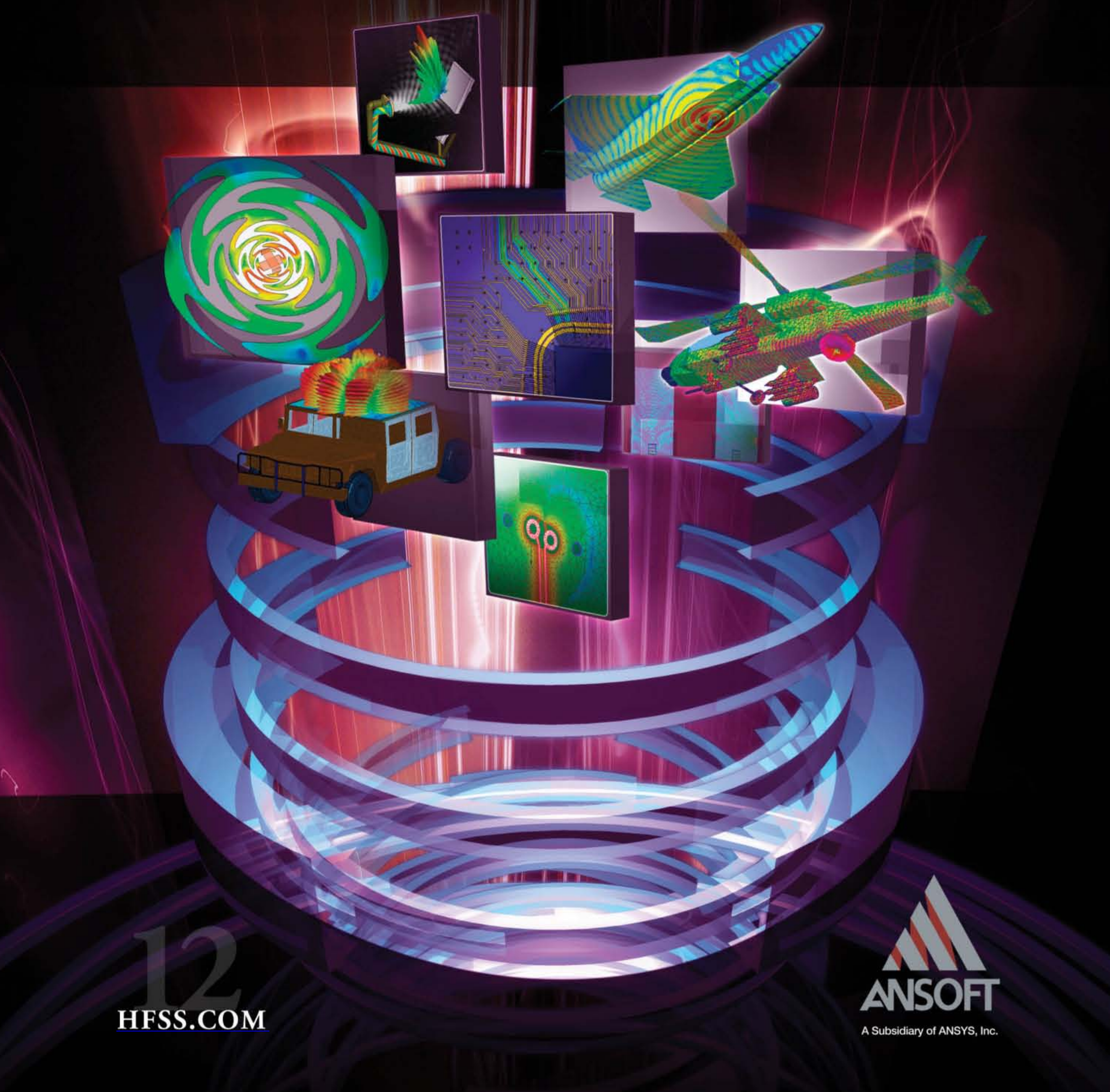
Herewith, a checklist whereby the successes or failures of the Copenhagen conference may be judged as it unfolds this month.

—WILLIAM SWEET

- ☐ **THE ADVANCED INDUSTRIAL COUNTRIES** agree credibly to carbon reductions that would keep global levels below 450 to 475 parts per million. (That level, which translates to a temperature change of 2 °C by comparison with preindustrial times, is somewhat arbitrarily considered the threshold above which climate change could become "dangerous.")
- ☐ **THE RAPIDLY INDUSTRIALIZING ECONOMIES** commit to a year when their emissions will peak. (Countries like China and India have made clear they are not ready or willing to agree on cuts, but at least they should say when they think their emissions can stop rising and start falling.)
- ☐ **COPENHAGEN AVOIDS THE TEMPTATION** of imposing trade sanctions on countries that refuse to go along with a new treaty. (European leaders have occasionally suggested slapping trade sanctions on the United States because of its refusal to implement Kyoto, and U.S. legislators now talk of similar action against China or India.)
- ☐ **RULES ARE TIGHTENED** for carbon offsets and Kyoto's "clean development mechanism," which gives developing countries financial rewards for projects that avoid carbon emissions. (Abuses are widely documented.)
- ☐ **LEADERS OF RICH COUNTRIES** promise to help poor countries adapt to the adverse effects of climate change—and really mean it (Rich countries have not delivered on measures agreed upon in the past.)
- ☐ **ADDITIONAL MEASURES ARE ADOPTED** for greenhouse gases other than carbon dioxide. (For example, methane is a much more potent warmer than carbon dioxide, and yet several hundreds of billions of cubic meters are estimated to leak from natural gas pipelines every year.)

HFSS TWELVE

Experience the high-performance computing (HPC) benefits of HFSS™v12, the industry-standard simulation tool for 3D full-wave electromagnetics. HFSS v12 is enhanced with breakthrough technology including a new parallel computing option that makes it possible to solve enormous electromagnetic field problems faster than you ever thought possible. HFSS v12 is further enhanced with new features such as volumetric meshing, curvilinear elements and mixed element orders. With HFSS you can calculate S-parameter derivatives with respect to variations in geometry, materials, and boundary conditions to evaluate design sensitivity and to speed optimization. Solve localized E and H-fields, currents, s-parameters and near and far radiated fields in your antennas, RF/microwave component designs, on-chip embedded passives, IC packages, and high-speed interconnects with even greater performance!



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

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

the big picture

LARGER THAN LIFE
Each of the two 49- by 22-meter sideline-facing screens suspended above the football field at the brand-new Cowboys Stadium in Arlington, Texas, comprises more than 10.5 million LEDs, which together draw 635 kilowatts. That's enough power to serve the total needs of 975 U.S. homes. The two "puny" 15.5- by 9-meter displays facing the end zones each draw just 80 kW. Because there are four LEDs (two red, one blue, and one green) in each pixel, the 2176- by 4864-LED sideline displays provide the same image resolution as any 1080p hi-def TV—but the players running across your screen at home are probably not seven stories tall.

PHOTO: MITSUBISHI

hands on

BARBOT, THE AUTOMATED BARTENDER

What's the perfect drink for a hacker party? Anything, so long as it's mixed by a robot

HACKER HAVEN: The heart of an automated bartender is its Geneva drive [above], which divides a continuous rotation into discrete station stops for alcohol, mixers, and bitters; NYC Resistor member Raphael Abrams [far left] oversees the Barbot as it mixes the first of many Sazeracs, a classic New Orleans cocktail [near left].

PHOTOS: BRE PETTIS

At NYC Resistor, a communal hacker space in downtown Brooklyn, N.Y., we do two things really well—hack and party. An automated bartender seemed like a natural, but as we searched the U.S. patent database for ideas, it became clear we'd have to hack one up ourselves. And so we have. An ongoing series of them, in fact.

Believe me, we looked. For example, U.S. Patent No. D496657, with the promising title "electronic bartender," turned out to be nothing more than a design for a curved flask with a flat LCD display. And while patents 3428218, 3930598, 4278186, 4411351, 4433795, 5731981, and 5913454, for "beverage dispensing systems," seem fine for pouring beer, wine, or liquor, none of them is going to mix you, say, a Sazerac (a New Orleans concoction of rye whisky—or absinthe, if you can get it—with bitters that may well be the first cocktail invented in the New World).

Barbot Series v3 is the third incarnation of our own electronic bartender. (Luckily, Barbot's first two incarnations are documented on NYC Resistor's wiki, as they are otherwise mere evanescent memories barely discernible through the fuzzy and sticky haze of parties past.) Barbot has been passed from friend to friend at NYC Resistor as an evolving and collaborative project. Raphael Abrams, a 30-year-old freelance designer and electrical engineer, is its current maestro. He pulled together most of the parts from the cabinets that line the walls of our mad-scientist workspace.

For the latest version, our normally freewheeling collective laid down one firm rule: no random drink button. Past Barbots had a large and fatally tempting random drink button that, when pressed (despite its bright red warning color), incited the machine to create hangover-inducing drinks containing random combinations of tequila, gin, and vodka.

The brain of Barbot is a configurable Twitchie microcontroller board. The Twitchie, in turn, is based on the Arduino platform, a collection

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

of development tools based on open-source hardware designs and software. Arduino-based devices interact with the world through attached sensors, controllers, motors, and other actuators. As you can see, Arduino is an ideal robot development environment—it is, in fact, crack cocaine for 21st-century hackers.

The Twitchie variant of Arduino has at its heart an Atmega168 chip running the Arduino coding environment and optimized to drive servos. Raphael originally designed the Twitchie to be part of a kit for creating quivering and twitching dolls, but its simplicity, size, and ease of use make it ideal for service as the Barbot's central brain. With a series of pins that can be brought high and low and use pulse-width modulation—a way of encoding the level of an analog signal digitally to control the amount of power sent to a load—the Twitchie receives input from a control panel and then drives a series of servos, metal-oxide semiconductor field-effect transistors, and a relay to control the Barbot's arms and liquid-delivery mechanisms.

The control panel is a shifting display of LEDs and antique glass domes with lights that indicate power and status. To initiate drink making, you key a sequence of five buttons (picture unlocking one of those spy-movie doors that sport an encoded door-entry keyboard). Upon the last button push, Barbot Series v3 lurches to life.

The robot starts moving your drink from one filling station to the next so that alcohol, mixers, and bitters can be added in succession. For this it uses a Geneva drive, a mechanism that translates rotary motion from a continuous into an intermittent form. The most common application of a Geneva drive is a motion picture projector, where each frame is advanced and held still for a fraction of a second before moving on to the next. At the first station, a servo-controlled arm swings out and delivers alcohol to the glass in exact measures, through hoses made from ¼-inch (6-millimeter) tubing, using peristaltic pumps.

A peristaltic pump uses bearings that, when they turn, put revolving pressure on a tube and force liquids onward, the way you'd force toothpaste out of a tube. Peristaltic pumps are commonly used in dialysis machines to transfer blood, because the parts that squeeze the tube never touch the liquid, thus keeping it from being contaminated.

In the next station, the mixers are gravity-fed from the top of the machine and measured with precisely timed 12-volt solenoid valves (driven by *n*-channel MOSFETS), which let the liquid into the drink. My contribution to the machine is a little bottle attachment that swings out over the glass and sprays homemade bitters into the drink. It uses two servos, one to lower the spray bottle and another to push the spray-bottle cap down with a cam gear.

Development on Barbot Series v3 began on 15 May. By early July, it was time to find some beta testers. In other words, it was time to throw a party. As the preparations at NYC Resistor began, a final check of all the fittings ended in a deluge of rye over the electronics. A short wash in the sink and a pass with a hair dryer brought it back online.

To the thumping sound of 8-bit electronic music, Barbot's whirring pumps, swinging arms, clicking solenoids, and spraying bitters held partygoers spellbound as they waited for their turn to taste the sweetness of a robot-served Sazerac.

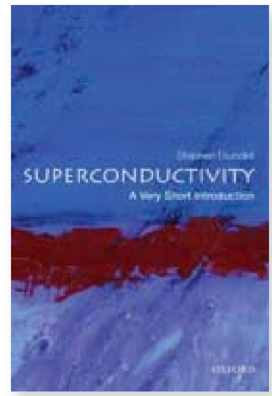
Automation is a form of magic. The spell of watching Barbot is broken only when the machine pushes a glass in your direction and its LEDs wink at you, encouraging you to drink up. A bystander remarks, "Wow, this is an actual cocktail!" —Bre Pettis

TO PROBE FURTHER
Learn more about Barbot Series v3 at http://wiki.nycresistor.com/wiki/Barbot. You can also watch a video of the machine in action at http://www.spectrum.ieee.org/video/robotics/diy/barbot.

books

Housewives of Superconductivity

An introductory book short on pages but long on explanation



Superconductivity: A Very Short Introduction
By Stephen Blundell;
Oxford University Press, 2009;
144 pp.; US $11.95;
ISBN 978-0-19-954090-7

If the coffee-table book had an opposite, it might be one of the Oxford University Press's Very Short Introductions series. Only 17 centimeters tall, these diminutive tomes may go completely unnoticed by visitors you want to impress with your familiarity with Nash equilibria and 11-dimensional string theory.

There are 200 in the series now, but the first one I read was *Superconductivity: A Very Short Introduction*, and I found it surprisingly satisfying. University of Oxford physics professor Stephen Blundell has a knack for rounding out, with surprising depth and clarity and yet a refreshing economy of words, concepts that you didn't know you didn't know. His simple and elegant explanations, pithy and accessible, make the book a pleasure.

But there's an extra treat: delightfully humanizing gossip about legendary scientists who've become as impersonal as the devices and laws to which their names are attached: van der Waals, Kirchhoff, Cailletet. At times the book reads like a spectacularly nerdy issue of *Us Weekly.* Even the godlike Faraday is found engaged in Real-Housewives-of-Heidelberg-style petty catfights and intrigues. I can't recommend this book enough! —*Sally Adee* geek life

NICK DOLDING/GETTY IMAGES

Math Quiz: Why Do Men Predominate?

It's culture, not biology

NO WOMAN has yet won one of the three top mathematics awards—the Fields, the Abel, or the Wolf. It's part of what's often called the math gender gap, which in the United States starts early—at least twice as many boys as girls score in the 99th percentile on state-level math assessment tests.

Five years ago, then Harvard president Lawrence Summers's suggestion that women lack an "intrinsic aptitude" for math and science drew a firestorm of protest, but he was drawing on a century-old hypothesis that males exhibit greater variability in many features, math included. By such reasoning, it is possible for girls to be as good as boys in math on average but to be less well represented in the upper (and lower) echelons.

This, Summers said, is one reason there are fewer women in tenured science and engineering positions at top universities and research institutions. "I would like nothing better than to be proved wrong," he added.

A recent study published in the *Proceedings of the National Academy of Sciences* might make him happy. In it, psychologists Janet Hyde and Janet Mertz, from the University of Wisconsin–Madison, used data from math aptitude tests to show that among top math performers, the gender gap doesn't exist in some ethnic groups and in some countries. The researchers conclude that culture is the main reason more men excel at the highest math levels in most countries.

"When parents are asked to estimate their child's math talent, they estimate higher numbers for their sons than their daughters despite similar grades in school," Hyde says. Teachers and guidance counselors share this bias, which is why math has served as a filter to keep young women out of science, technology, and engineering.

In some circles, the finding came as no surprise. "Female mathematicians always knew that there were no gender differences, especially since there's no difference in other countries," says Bhama Srinivasan, a math professor at the University of Illinois at Chicago, where 40 percent of undergraduate math majors are women. "My women colleagues have remarked why there should be so many studies. People raise this issue over and over rather than being satisfied."

But what of the statistics that seem to back up the hypothesis that males have greater variability? Hyde and Mertz found there are more girls in the top tier in countries such as Iceland, Thailand, and the United Kingdom—and even in certain U.S. populations, such as Asian-Americans. Furthermore, they noted that a small math gender gap correlated with a higher rank on the World Economic Forum's 2007 measures of gender equality, in which the United States ranked 31st, between Estonia and Kazakhstan. A similar correlation was found for the number of girls on International Mathematical Olympiad teams.

So how does culture shape how women do in math? Hyde says that in many countries, especially those in Asia, excellence at math is considered a result of hard work. By contrast, in the United States it is more commonly believed that people are born with or without a gift for math, a subject that in any case is thought to be hard, and not only for girls. Then there's the cultural perception of math achievers—the nerds who are heckled in one society are exalted in another. Irina Mitrea, a math professor at Worcester Polytechnic Institute, in Massachusetts, who finished high school in Romania, says she never felt discouraged there: "In fact, being good at math made you popular." Romania's International Math Olympiad team has had one of the highest ratios of females of all top-ranked teams in the past decade.

Hyde believes that the gender gap among top math achievers will continue to narrow. In the United States, more and more girls now take advanced math in high school, and they perform on par with the boys. In a 1990 study, Hyde had found that high school boys solved complex problems on standardized tests better than girls. But 19 years later, test scores of 7 million students across 10 states show that the gap is close to zero.

—PRACHI PATEL

 BY PAUL McFEDRIES

The Office-Free Lifestyle

I wonder why a company pays to transport a 170-pound body 20 miles downtown when all it needs is the body's 3-pound brain.
—attributed to management consultant Peter Drucker

GREG MABLY

ONCE UPON a time most people worked where they lived. The barn was just steps from the farmhouse, weavers wove on their own hand looms, bakers baked bread on the same hearth where they cooked dinner. The blacksmith's anvils and forges were in a workshop right next door, as were the woodworker's saws and benches. Home was work and work was home.

All that changed when the engines of the Industrial Revolution came rumbling through. The hulking factories and warehouses of mass production required huge tracts of land outside of cities and towns. The world's butchers, bakers, and candlestick makers had no choice but to ply their trades (or more precisely, some repetitive and soul-destroying substitute for a trade) in faraway enterprises. As a result, for the better part of 200 years, most workers have been leaving their homes and heigh-ho, heigh-ho-ing their way to work.

But now a postindustrial revolution is rapidly taking shape. What was once a steady stream of workers bringing their work home is beginning to look more like a raging flood. A recent Associated Press article reported that an eye-popping 20 percent of U.S. employees do some or all of their work at home. For language hounds, raging sociological floods have the added advantage of churning up lots of new words and phrases.

The granddaddy of these words is *telecommuting*, coined by University of Southern California researcher Jack Nilles after the 1973 OPEC oil embargo led energy-saving North Americans to substitute communications technologies for commuting ones. Most large U.S. corporations have or plan to have telecommuting programs, but there are still many that don't. **Closet telecommuters** or **guerrilla telecommuters** have only their bosses' permission to work at home.

If you could mind-meld with managers to determine their real concerns about **office-free** workers, the greatest fear and loathing would surely be the sneaking suspicion that remote employees are slacking off. They're concerned, in other words, that their **teleworkers** will **teleloaf**. However, the opposite seems to be true: Studies show that employees tend to work longer hours at home than at the office. If they go too far, they're said to be suffering from a malady called **teleworkaholic syndrome**. Another downside to telecommuting is that many home workers feel a sense of loneliness and isolation, a phenomenon called **watercooler withdrawal**.

It's becoming increasingly clear that a lot of people are looking for a **zero-commute** lifestyle and to become part of what some call **Generation 1099**. (In the United States, freelancers' earnings are reported on Internal Revenue Service form 1099; not surprisingly, these workers are also called **1099ers**.) Folks are remodeling their abodes to accommodate not just one person working at home but also the increasingly common work-at-home couple, resulting in a **HOHO** setup: his office/her office.

Another trend is to eschew both the office *and* the home and to work more or less permanently on the road. The result is the phenomenon of the **digital nomad**, a person who uses technology, particularly wireless networking, to work without requiring a fixed address. Practitioners of this **digital nomadism** rely on nearby Wi-Fi connections a lot, so they're also called **Wi-Fi warriors**. The tech journalist Mike Elgan calls them **lippies** (location-independent professionals).

I haven't gone that far, but I've worked out of my home since 1991. My commute, a single flight of stairs, takes about 20 seconds, unless there's a traffic jam—my wife coming downstairs while I'm going up. Most of my meetings are with the dog and often involve a quick pat on the head. The cafeteria is the kitchen, where I can make myself a cappuccino whenever I feel like it. The boardroom—in the summer, anyway—is the deck behind the house. It's a life that suits those of us who **WFH** (work from home) to perfection. ❑


PL
1650

Can copper and granite lock away spent nuclear fuel for 1000 centuries?

FINLAND'S NUCLEAR WASTE SOLUTION

By Sandra Upson

HERE ON OLKILUOTO ISLAND, the forest is king. Elk and deer graze near sun-dappled rivers and shimmering streams, and humans search out blueberries and chanterelle mushrooms. Weathered red farmhouses sit along sleepy dirt roads in fields abutting the woods. Far beneath the vivid green forest, deep in the bedrock, workers are digging the labyrinthine passages and chambers that they hope to someday pack with all of Finland's spent nuclear fuel.

Posiva, the Finnish company building an underground repository here, says it knows how to imprison nuclear waste for 100 000 years. These multimillennial thinkers are confident that copper canisters of Scandinavian design, tucked into that bedrock, will isolate the waste in an underground cavern impervious to whatever the future brings: sinking permafrost, rising water, earthquakes, copper-eating microbes, or oblivious land developers in the year 25 000. If the Finnish government agrees—

DOWN THE HATCH: At the Finnish research site for nuclear waste disposal, the access tunnel [above left] undergoes close scrutiny. A ventilation shaft [below left] brings air 290 meters underground.
PHOTOS: POSIVA

a decision is expected by 2012—this site will become the world's first deep, permanent repository for spent nuclear fuel.

Of course, not everyone shares Posiva's confidence. "It's deep hubris to think you can contain it," says Charles McCombie, executive director of the Association for Regional and International Underground Storage, based in Switzerland.

There's more at stake here than the interment of 5500 metric tons of spent Finnish fuel. More than 50 years after the first commercial nuclear power plants went operational in the United Kingdom and the United States, the world's 270 000 metric tons of spent nuclear fuel remain in limbo. After it gets swapped out of a reactor, utilities put it in specially designed pools, where chilled, circulating water absorbs the initial heat and radioactivity. After about five or six years, the fuel has cooled considerably, enabling utilities with limited pool space to load it into huge, million-dollar steel casks that are left to sit on concrete pads within guarded compounds.

The arrangement is far from ideal. The waste will emit harmful levels of radioactivity for thousands of years to come, and the casks are expected to last for a couple of hundred years, at most. The lack of a more permanent option is one of the biggest problems facing the global nuclear-power industry, which has been stalled for decades. But concerns about climate change have revived the prospects for nuclear power's future growth, daring the industry to hope for a rebirth.

Years ago, almost every country with more than a few nuclear power plants was considering some sort of permanent repository. But politics has kept most of those plans at the paper stage. In the United States, the possibility of a permanent solution to the waste problem seems more elusive than ever: This past May, after two decades and US $9 billion, the Obama administration quietly ended a plan to build a repository beneath Yucca Mountain in Nevada. With the cancellation of Yucca, just two active repository projects for spent fuel are left: the Finnish one, which is called Onkalo, as well as a less advanced one in Sweden.

Onkalo's underground tunnels won't even begin to address the global situation. But they will do the next best thing. This project, estimated to cost €3 billion ($4.5 billion), will either demonstrate that the technical, social, and political challenges of nuclear waste disposal can be met in a democratic society, or it will scare other such countries away from the repository idea for decades to come.

So far, Posiva has carved out nearly 5000 meters of tunnels and shafts, excavated more than 100 000 cubic meters of rock, and collected rock samples from 53 deep boreholes. Over the next three years, it will try to prove to the government that its canisters and deep chambers will contain radioactive waste no matter what happens to Finland. If Posiva succeeds, the repository will open for business in 2020. A hundred years later, the final canister will be buried, and the tunnels will be filled in, covered up, and artfully abandoned to a cover of pine needles and mushrooms. Finland's first nuclear era will be over.

IT'S DAMP and drippy in Onkalo's passageways. From the tunnel's entrance, a low, guttural hum reverberates in the dark. Somewhere in the blackness, a machine is drilling and blasting its way steadily downward, and construction workers are scurrying in its wake to check the ceiling for rocks that have been jostled loose in the explosions. The jumbo-size drilling machines are trundling down a 5.5-meter-wide tunnel that grows by about 5 meters a day, says junior construction manager Karoliina Lehesvuori.

Lehesvuori, a perky young Finn dressed in the reflective yellow jacket and work boots that are the uniform of Onkalo staff, drives some visitors in an all-terrain vehicle through the winding access tunnel that coils downward into the bedrock. The car's bright headlights illuminate the tunnel a few meters ahead, and its tires squish their way across the muddy floor. "We're going down 290 meters now," she alerts her passengers. The truck's tires kick up a spattering of mud onto a parked

PHOTOS: LEFT: POSIVA; CENTER: SANDRA UPSON (2); RIGHT: POSIVA. MAP: JOHN MacNEILL

ISOTOPE ISLAND: On the shore of Olkiluoto Island [far left], two nuclear reactors produce power—and radioactive waste. The entrance to the spent fuel repository [above left] is down the road. Underground, machines blast their way deeper into the bedrock [above]. Meanwhile, geologists extract samples of gneiss [left], a layered rock that underlies much of the island.

drilling machine on the left. The burly rig is painted fire-engine red, and its mechanical tentacles dangle off its drilling arm. Farther down, in a space off to the side, two workers are passing planks through some scaffolding at the bottom of a big hole. They are fireproofing a ventilation shaft, one of the two places where oxygen can enter the tunnel. Lehesvuori leans out to greet the workers with a shout that carries over the soft droning of the machines hidden below.

From all sides, water glistens on the rock face and collects into mud on the tunnel floor. The droplets are leaking into the tunnel from tiny fractures in the rock, smaller than a millimeter, at a rate of about 20 liters per minute. In tunnel terms, that's slow, and that's good news. The behavior of the water in Onkalo is Posiva's top concern. At each new depth, geologists extract slim rock cores in search of telltale "structures"—the fractures and crevices that determine how water moves in rock. So far, Onkalo appears to have uncharacteristically few structures, which explains why the tunnel is only damp and muddy rather than flooded with a torrent of water escaping from its high-pressure home in the rock.

Water is the one agent that could seriously threaten Posiva's design. What the company has bet on is a nested system of what it calls engineered barriers, which are enveloped by the natural barrier of gneiss bedrock. The first engineered container for the radioactive refuse is the copper burial cask, within which sits an iron insert. Each canister will then be buried in specially dug holes in the underground tunnel network and surrounded by a special clay—the second engineered barrier—through which water can slowly diffuse, but not flow. A century from now, after Finland's last planned reactor has long been closed and its fuel has cooled, the tunnel's empty spaces will be filled back up with rubble and clay, the final safeguard. A concrete slab will cover the entrance and, the designers hope, deter future adventurers.

In the nightmare scenario, water would somehow manage to reach the canisters, carrying with it bacteria that burrow through the clay and erode the metal containers. The fuel rods would become exposed to the clay, and the water would carry harmful radionuclides from the fuel back to the surface.

So far, though, the drillers haven't struck any major fractures through which water might travel. So the work goes on. In three shifts, crews are working around the clock to deepen Onkalo. An arm of a drilling machine bores a hundred holes across the tunnel face, deposits dynamite into them, and the workers blast out a new layer of rubble. Then they clear the rubble and do it again. When they've finished, the diggers will have excavated a total of 7 kilometers of tunnels, shafts, and underground alleyways. The canisters will be deposited in neat rows of hollowed rock branching off the main tunnel, like the prongs of a TV antenna.

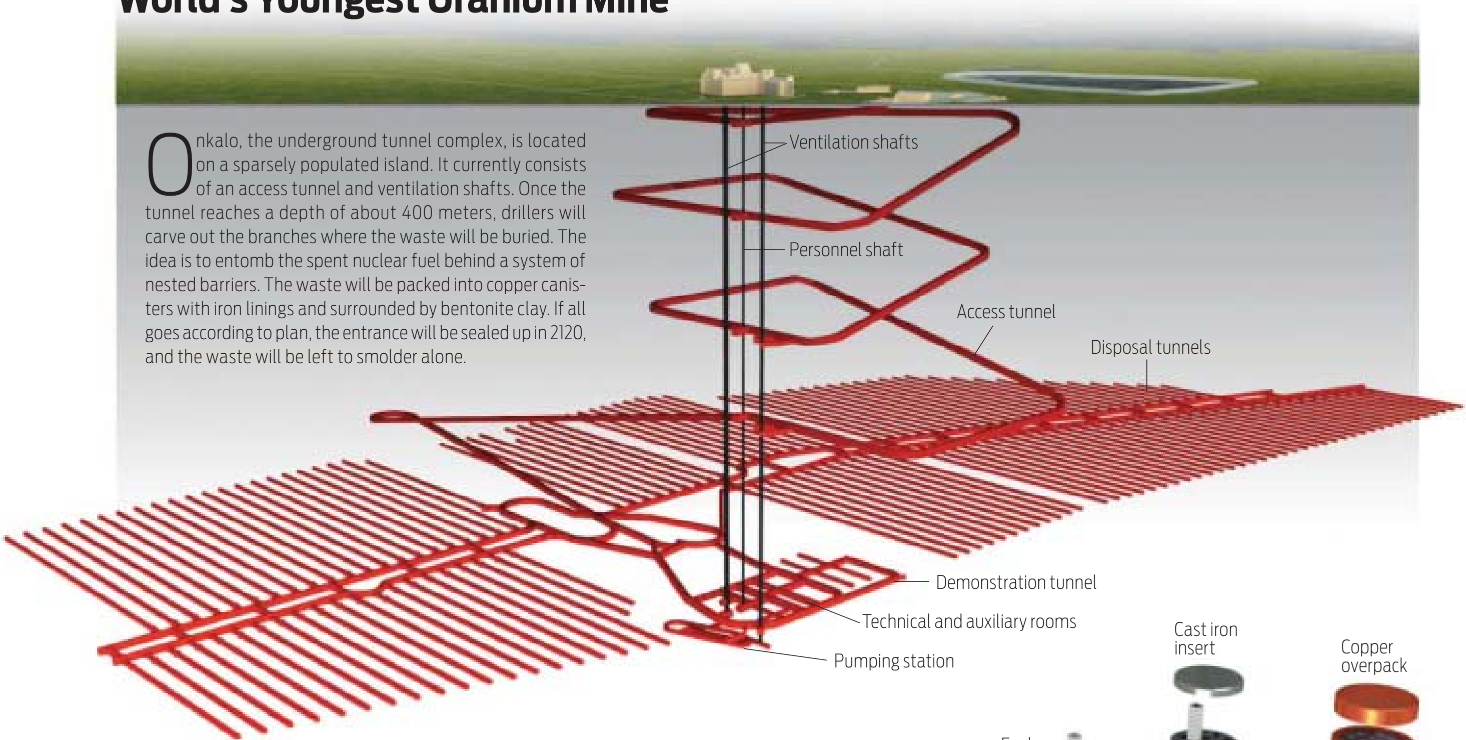
Down in the tunnel-in-progress, the enveloping hum of the invisible machines grows louder and more insistent. Then straight ahead, two specks of light appear. "Ah, we have to pull aside," says Lehesvuori. "Another jumbo." The growl becomes deafening as the giant red vehicle inches past, and then, gradually, the lights disappear and it's back to black. The machine's rumble fades to a distant murmur, and Lehesvuori pulls away from the wall to drive deeper into the nuclear void.

FINLAND MIGHT seem like an odd place to find cutting-edge nuclear waste technology. The country isn't accumulating waste on a scale anywhere near that of other nuclear nations, such as France, Japan, the United Kingdom, and the United States. Nonetheless, Finland's four reactors account for one-quarter of the country's electricity production, making them the single largest contributor to Finland's energy mix.

The origins of the Finnish nuclear program, in the 1970s, help to explain the country's interest in disposal. In 1979, a reactor at the Three Mile Island plant, in Pennsylvania, experienced a partial core meltdown, forcing Finnish officials to take a harder look at their own fledgling nuclear effort. They'd been exporting their waste to the Soviet Union, but the Finns soon concluded that an environmental disaster was probably brewing on the other side of their shared border. So in 1983, the Finnish parliament mandated that the country's two nuclear power plant companies set aside funds and begin planning immediately for disposal to begin in 40 years.

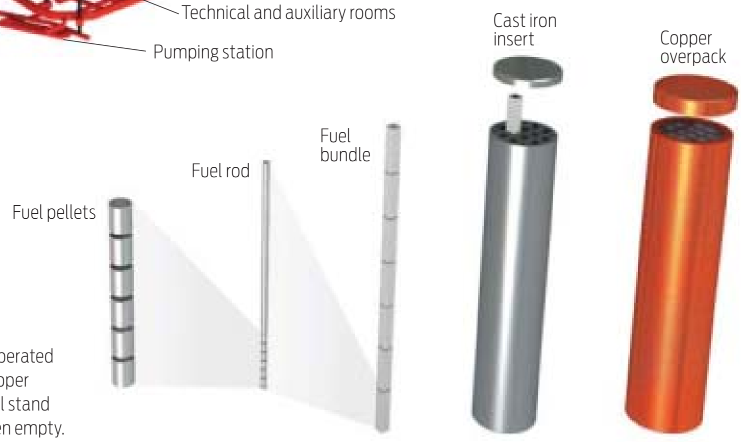
The first challenge for Posiva was to locate a spot where no one would ever be likely to dig a deep hole. Then they had to figure out how to make and seal a container so perfectly that

World's Youngest Uranium Mine



Onkalo, the underground tunnel complex, is located on a sparsely populated island. It currently consists of an access tunnel and ventilation shafts. Once the tunnel reaches a depth of about 400 meters, drillers will carve out the branches where the waste will be buried. The idea is to entomb the spent nuclear fuel behind a system of nested barriers. The waste will be packed into copper canisters with iron linings and surrounded by bentonite clay. If all goes according to plan, the entrance will be sealed up in 2120, and the waste will be left to smolder alone.

A SPACE FOR WASTE: The network of passages may extend over as much as 190 hectares of rock. If Finland decides to build two new nuclear reactors, the projected amount of spent fuel will include 12 000 tons of uranium.



PACKING UP PELLETS: The spent nuclear fuel will arrive at a remotely operated processing plant above Onkalo, where the fuel bundles will be inserted into copper canisters with cast-iron linings. Depending on the type of fuel, the canisters will stand between 3.6 and 5.2 meters tall and weigh between 16 and 26 metric tons when empty.

URANIUM'S CRYPT: The disposal holes will be 6 to 8 meters deep and will either branch vertically [shown here] or horizontally off the tunnel. Rings of clay will surround the canisters. In the presence of water, the clay will swell, forming a tighter seal in the hole and slowing the water's migration. The tunnels will later be filled up with a mix of clay and the excavated rubble.

ILLUSTRATION: JOHN MACNEILL; PHOTO: SANDRA UPSON

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

the weld would maintain its integrity through the next ice age, which might come as soon as 20 000 years from now.

"We needed a place that was very boring," explains Johanna Hansen, Posiva's research and development director. Rather than putting up elaborate signage to communicate with their far-future descendants, Hansen and her colleagues are betting that humanity will simply never want to dig here. They'd scanned the entire country for spots with no valuable metal deposits. They'd sampled groundwater all over Finland in search of the most saline, inhospitable locations. Pristine Olkiluoto passed muster. Olkiluoto's residents, who were

PILLARS OF FAITH: Johanna Hansen, the research and development director, stands between a 1-meter-wide copper canister and its iron interior, which Posiva says can withstand earthquakes and advancing glaciers.

already sharing their island with two nuclear power plants—and were acutely aware of its lack of resources—welcomed the possibility of well-paying jobs for a century to come.

Their confidence that the project will be safe and well managed is unusual and not strongly supported by the historical record of government handling of other forms of high-level nuclear waste. In the Soviet Union, old nuclear submarines were simply abandoned along with their reactors and spent fuel in the Arctic Ocean. In the United States, at the decommissioned military reactor complex in Hanford, Wash., an estimated 1.67 trillion liters of low-level radioactive waste and more than 3 million liters of high-level waste have contaminated the soil and groundwater, and the radionuclides continue to leach into the nearby Columbia River. Unsettling lapses have also occurred at facilities in Sellafield in Wales, at Savannah River in South Carolina, and at La Hague in northern France.

But in recent years, other than a couple of relatively small incidents in France, nuclear waste management has had a pretty good run. "The nuclear industry has an almost exemplary record in managing its material," says Fergus Gibb, a professor of geochemistry at the University of Sheffield, in England. But, he cautions, "If there are instances of bad management, you probably don't get to hear about them."

To hedge against any gaps in their scholarship, a dramatic change in climate, or a total failure of design, Scandinavian engineers have agreed on what they insist is the most foolproof facility design possible. Mainly, they've agreed to mimic nature whenever they can. As Posiva's communications manager, Timo Seppälä, puts it, "This is a design that forgives our mistakes."

Starting in 2020, the fuel bundles will be hauled out from their temporary storage in pools near the reactors at Olkiluoto and Loviisa, Finland's two nuclear power plant complexes. The fuel rods may be a half-century old by the time they reach the facility, after four years in a reactor and as many as 40 years in a pool. During its time underwater, the fuel's radiation will have dropped to about 1 percent of what it was when it was first put in the pool.

Special transfer casks will deliver the bundles, still submerged in water, to the repository. The casks will slide off a truck bed into an encapsulation plant, and the doors to a fuel-handling cell will clamp shut, sealing the 1-meter-thick walls from the outside world. The room will be kept just under atmospheric pressure. That way, if a seal breaks, air will tend to rush in rather than out.

The outer lid of the transfer casks will slide open, and then the most dangerous part will begin. The fuel bundles will still be extremely radioactive, and they will be exposed to air for the first time since leaving the reactor core. With operators watching a video feed from radiation-tolerant cameras and through thick, lead-crystal windows, a remotely controlled arm will lift the fuel bundles out of the casks. A single bundle contains about 100 hollow zirconium rods, each as thick as a finger and filled with uranium pellets.

First, the bundles must dry. A cask of 12 fuel bundles could emit about 2 kilowatts of heat, so the smoldering rods tend to dry themselves pretty fast, according to Petteri Vuorio, the design engineer in charge of the encapsulation plant. But for final disposal, even a minuscule amount of water would be anathema. "This is the only place in the world where you have to worry about drying fuel bundles," he says. So Posiva's engineers have designed drying stations that will hold the fuel under a vacuum, lowering the pressure on the rods so that the water can boil off at about room temperature.

Once the bundles dry, a machine will select an assortment of varying ages and radioactivity levels to insert into the canisters. Including older fuel with more recent bundles will help ensure that the canisters won't accidentally cause the water in the bedrock to boil. Each canister consists of an iron tube that sits snugly inside a copper shell. Here, the Finns draw inspiration from their geology. Copper exists naturally in the bedrock here, which means it has withstood millions of years without suffering anything worse than turning green. In the nuclear fuel industry, that's as good an existence proof as any.

Then it'll be time to seal the canisters. The 5-meter-long cylinders will move on a track that guides them through the facility, allowing them to swivel and turn to meet each station. Each canister will rotate precisely on its track as high-velocity electrons weld the lid to the top of the canister without weakening the surrounding material. "It is quite demanding to have so much accuracy so that the weld is perfect," says Vuorio. He says his engineers are still working out the details of how to lift and rotate the untouchable, bulky 26-metric-ton canisters during the

The Atomic Age's Long Tail

2012
Finnish government votes on activating the repository.

2020
First batches of waste enter the complex.

2120
Final waste canisters are deposited; tunnels are backfilled.

22 000
Earliest projection for Finland's next ice age.

26 122
Plutonium-239 reaches its half-life.

2.3 million years
Cesium-135 reaches its half-life.

15.7 million years
Iodine-129 reaches its half-life.

4.46 billion years
Uranium-238 reaches its half-life.

welding. All in all, they'll need to create and package about 3000 canisters as flawlessly as possible.

The canister will then roll to the next station, where X-ray beams will search out flaws in the welding, and ultrasonic and eddy-current inspection systems will analyze the surface for tiny aberrations. In eddy-current testing, a coil carrying alternating current generates a magnetic field when brought close to the copper. The field induces eddies of current whose flows change in the presence of surface imperfections. If a canister passes the tests, it will glide into an elevator at one end of the building that will carry it down a shaft, straight into the repository.

As much as 12 000 metric tons of uranium—alongside the other isotopes and zirconium rods—may eventually find their way into Onkalo. The facility will pack away at least 27 000 fuel bundles, and more may follow from Finland's projected nuclear power production through 2080.

After the canisters are deposited, stacks of bentonite clay blocks will be dropped in to encircle each canister like pineapple rings, to fill in the gaps between the wall of a hole and the copper. Should water approach, the bentonite would swell, forming an even tighter envelope around the rock and the canisters. Any water would diffuse very slowly through the sludgy gray clay to the copper and the fuel pellets inside. "We're talking millions of years for water to get through clay," says Michael Apted, an executive consultant for Monitor Scientific, in Denver, and chairman of an advisory group to Finland's nuclear safety authority, STUK. Bentonite also holds up well over time: In Hungary, coal miners stumbled on 8-million-year-old wooden tree trunks buried in a clay shell.

Once the canisters are in place, the tunnels will be filled with a blend of more bentonite and excavated rock. "We know that the bedrock is 1.8 billion years old and hasn't changed since it was created," says Hansen. "We must try to maintain the bedrock as it was, so that the conditions return to how they were before we started disposal." Now, however, the bedrock will contain the highest local concentration of uranium in the world, and the new geology must hold strong for a period of time that's almost absurdly beyond human reckoning.

But in repository design, everything is relative. A thousand centuries may seem like a long time, but for nuclear waste it's just the beginning. Spent nuclear fuel is mostly uranium-238, with a half-life of 4.46 billion years. The longer the half-life of the isotope, the less radioactivity it emits—but that's not the full story. Some harmful isotopes are less likely to attach themselves to clay or rock, and therefore they are more likely to move around. "In terms of the stuff that could make it out in hundreds of thousands of years, iodine-129 and cesium-135 would be on the list," says John Kessler, a spent-fuel-management expert at the Electric Power Research Institute, in Charlotte, N.C. "But over a million years, the uncertainties are pretty big."

The next logical question might be whether all this potency might in fact be useful. In other words, should we regard spent nuclear fuel as an incorrigible health hazard or as a potential resource? Not everyone sees spent fuel as waste—the UK, France, and now Japan, for example, reprocess much of their waste into usable fuel, at considerable cost.

Technical breakthroughs may end up driving down the cost of reprocessing the spent fuel, in which the uranium and plutonium are separated from the remaining waste and potentially reused. "It becomes an economic competition between mining and drilling technology and the technology of reprocessing to see who is going to drive the cost down," says Charles Forsberg, a research scientist at MIT and the executive director of the MIT Nuclear Fuel Cycle Project.

Hans Forsström, the director of the Nuclear Fuel Cycle and Waste Technology Division at the International Atomic Energy Agency, doesn't see it that way. He argues instead that building repositories is a question of public acceptance, not a question of money. By Forsström's estimate, the cost of spent nuclear fuel disposal is between 10 and 20 percent of the cost of producing the electricity, which he thinks is not all that much. "There's this intergenerational responsibility, that those who profited from using the waste should take care of the waste," Forsström says.

Finland has made its commitment. It's not a country prone to fads or rapid change. Down the road from Onkalo, the town of Rauma is a 500-year-old testament to Finnish impassivity. This UNESCO world heritage site is a cobblestone wonderland of wooden houses gussied up with lacy trim. While most of the world's 15th-century towns burned to the ground long ago, this one still provides homes and shelter for businesses.

Here, though, 500 years is hardly a heartbeat. In as little as 20 000 years, Finland may enter an ice age, and advancing ice sheets kilometers thick could carve out the rock and force more water into its fractured depths. The liquid may then diffuse through the bentonite barrier, eat through the copper, and carry off still-hot radionuclides. No one can be sure.

But maybe nobody will be here to care. In 1000, 10 000, or 100 000 years, it might not be unreasonable to think our descendants will have abandoned this toxic land for a cozier alternative, on space pods or newly colonized planets. Where once there were humans, now hermaphroditic fish and finned flamingos may slither through our poisonous landscapes. Or perhaps evolution's charge will have delivered beings who are healthier, cuter, and more intelligent than the ones designing today's disposal systems. Or evolution may go in the opposite direction and cockroaches will reign supreme, just as we always suspected they might.

Then perhaps, as one epoch slides into the next, whoever remains will come to Onkalo to study, with great curiosity, their distant ancestors' struggle with the dark side of Earth's bounty. ❑

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

MECHANICAL RADIO

Future wireless designs will replace electronics with precision mechanical components

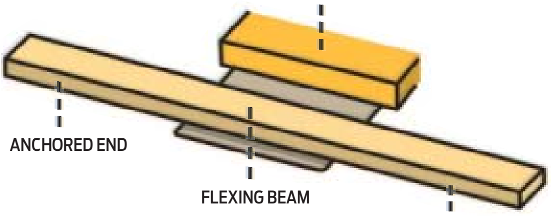
BY CLARK T.-C. NGUYEN

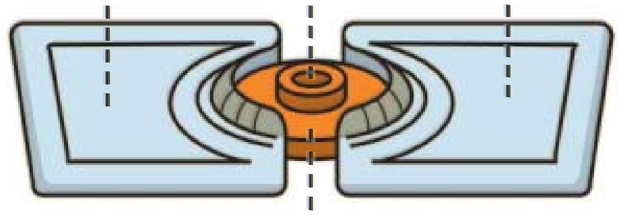
WE DO LOVE our cellphones. And we hate them, too, of course—when they drop a call, go dead in the middle of a conversation, or simply fail to work in another country. Soon we'll probably be complaining about other things—perhaps that our handsets can't receive satellite TV broadcasts or last more than a week on a single charge.

HARRY CAMPBELL

BEAM

Micromechanical resonators are often fabricated from silicon, using techniques similar to those employed in making microelectronic circuits. Perhaps the simplest resonator that can be made this way is a beam fixed at both ends and excited using an electrode placed under the freely suspended middle portion. Oscillatory signals applied to this electrode induce vibrations in the beam.





DISK

Disk-shaped resonators supported in the middle and surrounded by input and output electrodes can have resonant frequencies in the gigahertz range without being awkwardly small. That's because such disks vibrate inward and outward around their central axes in a motion reminiscent of breathing. Resonant frequencies can be higher still if the disk is made of diamond rather than silicon.

You might guess that better microelectronics will soon provide higher data rates, lower power consumption, and greater flexibility in the types of communication that our handsets can manage. To some extent, that's true. But transistor advances alone will probably not be enough. The Moore's Law world of regularly doubling transistor densities has brought us cheap PCs that outperform the multimillion-dollar mainframes of 30 years ago, but those incredible shrinking transistors might not do much to eliminate dropped calls. In this respect, the most significant improvements may, in fact, come from what seems a bizarre source: better *mechanical* components.

The idea of adding a bunch of moving parts to a radio handset conjures up images of cellphones outfitted steampunk style with brass levers and steel gears. This, of course, is not what I mean. Rather, I'm suggesting that tomorrow's designs will benefit from advances in the kinds of mechanical devices already found in cellphones and other wireless equipment. If you don't believe your phone contains such things, open up the back and take a look. You'll see a battery and integrated circuits—and also such things as thin-film bulk acoustic resonators (FBARs), surface acoustic-wave resonators, and quartz crystals. These components, which convert electrical signals to mechanical displacements, do the work that electronics struggle with—for example, selecting a narrow band of radio frequencies and removing interfering signals from all the energy captured by the antenna, and synthesizing extremely stable oscillating waveforms, which are needed to process the incoming radio-frequency signals.

This vision of wireless gear evolving to include more and better mechanical devices of this sort is very different from the approach some radio engineers are now pursuing. They seek to eliminate analog filters and use digital circuits to handle everything—interfering signals and all—using software to do all the filtering. The problem with building such a fully software-defined radio is that the ultrafast analog-to-digital converters that could deal with interfering signals in such a setup are not yet available. Worse, when they do become available, they will probably use too much power to be practical for battery-powered handsets.

Doing more of a radio receiver's up-front work mechanically has many advantages over relying solely on electronics and software. For example, it eases the demands on the electronics used for further signal processing—the additional filtering, analog-to-digital conversion, and so forth—and that in turn saves on the power consumed in that circuitry. This strategy would allow a portable radio receiver to monitor a wide swath of the spectrum at all times without swiftly burning through its batteries. That will be important in the much-anticipated world of cognitive radio, in which our handsets become agile enough to exploit frequencies that are fair game only when a higher-priority user hasn't claimed them.

It's likely that better mechanical components, and the cognitive-radio techniques they enable, will usher in the next wave of mobile telephony by giving our cellphones access to much more spectrum. These phones will operate in multiple bands, provide greater data throughput, and minimize if not eliminate the need for wireless providers to drop our calls because traffic exceeds capacity. Consumers will love the result, even if they don't know anything about the high-tech mechanics that may soon make it possible.

HOW CAN mechanical devices outperform electronic ones? One reason is that they generally consume no battery power. Another has to do with the quality factor of the resonating components, a quantity that physicists and engineers denote with the letter *Q*. The higher the *Q*, the more selective the resonator will be in responding only to a narrow range of frequencies.

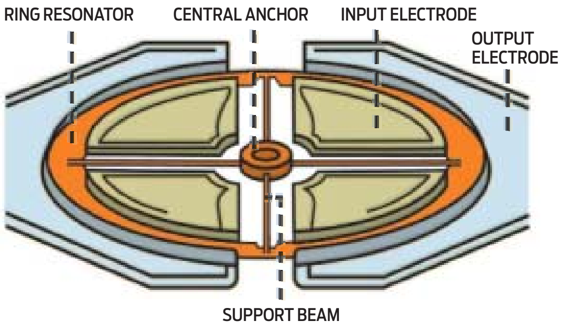
Like any good radio receiver, the one in a cellphone requires resonators with *Q*s greater than 1000. Resonant electrical circuits, typically built with capacitors and inductors, have great difficulty achieving values that high. Indeed, the inductors in conventional integrated circuits are dismal, generally yielding circuits with *Q*s of less than 10. Vibrating mechanical resonators, on the other hand, can easily provide values in the required range.

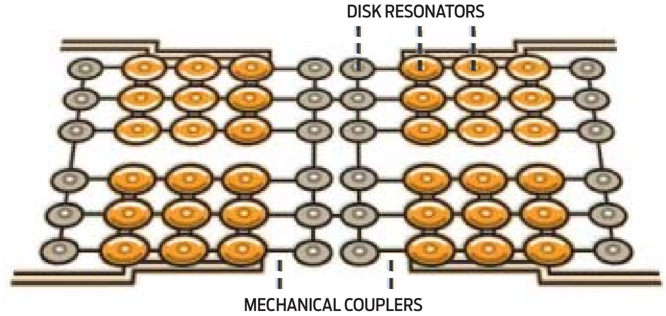
Unfortunately, the need for such resonators makes handsets more costly to manufacture. If tomorrow's cellphones were to use many more of these mechanical components, the expense of including them could well dominate the cost of handsets. And the large sizes typical of these mechanical components could be a problem, too, although some are already quite small. Makers of FBARs, for example, use micromachining to con-

HARRY CAMPBELL (4)

RING

A **ring-shaped resonator** is supported by a central hub and spokes, much like a bicycle tire. The ring expands and contracts in width while keeping its overall diameter constant. One advantage of this geometry is that the designer can decrease the impedance of the device (by increasing the area adjacent to the surrounding electrodes) without altering the resonant frequency.





ARRAY

Another strategy to reduce impedance is to **gang together many individual disk resonators,** forming a single micromechanical circuit. The links between adjacent disk elements are mechanical rather than electronic. Such arrays are more compact than the equivalent ring resonators, so disk arrays are the better choice when space is at a premium.

struct on-chip gigahertz-frequency resonators with dimensions of about 200 micrometers.

But small size is not the only requirement. Consumers will soon demand handsets that can handle all their wireless communication needs—Wi-Fi, Bluetooth, hookups with wireless sensor networks, cellular calls, broadcast television, even satellite links. And to do all that practically, designers will be compelled to put resonators of many different frequencies on a single chip. Unfortunately, the frequency of an FBAR resonator is set by the thickness of its constituent film, which means, for example, that 20 different deposition procedures would be needed to fabricate 20 different filters on the same chip. Doing so would likely end up being more expensive than just buying 20 individual FBAR devices.

Here's where the latest wizardry of microelectromechanical systems (MEMS) can save the day. A single layer of silicon, for example, can provide many different resonant frequencies if it is patterned so that parts vibrate from side to side, in directions parallel to the plane of the device. The designer just needs to create features with the correct lateral dimensions.

Easier said than done, of course. To get a sense of the challenge, consider a more familiar object whose lateral dimensions govern its resonance frequency: a steel guitar string, which spans about 64 centimeters. If tuned to middle A, it will have a fundamental resonance frequency of 110 hertz. The act of plucking a guitar string is capable of exciting any frequency, but this string will mechanically select just the one A note—and will do so with a *Q* of about 350. (That, by the way, is 50 times as good as a typical on-chip electrical circuit made of inductors and capacitors.)

Selecting a particular frequency is exactly what the filters of a radio do. Of course, they oscillate much faster than a guitar string vibrates, commonly hundreds of millions of times a second. To achieve such rates, you'd have to shrink a guitar string down to less than 10 µm and construct it out of a stiffer material, such as silicon. The result would be a tiny, flexible beam. You couldn't pluck such an object with a pick, of course, but you could easily excite it with an electric field. Such a micromechanical oscillator can be made to resonate with *Q*s in excess of 10 000.

As you might guess, shrinking things by another factor of 10 yields resonant frequencies in the gigahertz range, which are needed to reach the higher bands used for wireless communications today. However, as with nanometer-size electronics, some thorny engineering issues arise with mechanical resonators this small. For one, it's hard to control the resonance frequency precisely when the dimensions are so tiny. And even if you could do that consistently, you'd probably find that what you'd built couldn't handle much power.

Fortunately, there are ways to achieve gigahertz-range resonant frequencies without having to reduce dimensions to nanometer scale. For example, my colleagues and I at the University of California, Berkeley, have fabricated some very useful gigahertz-frequency MEMS devices that measure several micrometers across. They can be tuned to the desired frequency relatively easily and are large enough to handle the power levels found in receiving circuitry. We've made them by fashioning the moving parts in the shape of thin disks, which resonate by expanding and contracting radially ever so slightly, rather than flexing like a beam.

If you make such a disk out of diamond instead of silicon, it will be stiffer and will consequently resonate at frequencies that can easily exceed 1 gigahertz. And if you arrange things so that this disk is supported only at its center—a point that doesn't move during the in-and-out oscillation—using a slender stem of silicon, the quality factor for this resonator can be stunningly high. We've built ones that measure 10 µm across, run at 1.5 GHz, and have *Q*s of more than 10 000—even higher when the air between the disk and the surrounding electrodes is removed. Versions of such disks running at 500 megahertz give *Q*s greater than 50 000.

This approach not only achieves the kinds of frequencies you'd want without having to build nanoscale objects, it also eliminates the need to use a vacuum to achieve high *Q*, reducing manufacturing costs. And because the resonant frequency of such a disk is roughly inversely proportional to its radius, even higher frequencies—such as Wi-Fi's 2.4-GHz, 3.6-GHz, and 5-GHz bands—with similar *Q*s should be possible simply by reducing the size.

But there's a limit to how much you can shrink things before the complications of working at the nanoscale start to emerge. Thankfully, we've discovered ways to dodge this problem. And happily enough, they don't require the use of diamond, which can be expensive to manufacture. In fact, all-silicon resonators can perform just as well, if not better, when constructed with somewhat more complicated geometries.

My colleagues and I have had success, for example, with resonators that take the form of a ring attached to a central support with four spokes. The ring expands and contracts in width while its average diameter remains fixed. (Imagine a bicycle wheel with just its rubber tire expanding and contracting slightly.) Our resonators can vibrate in this way at very high frequencies and, if properly designed, without losing much energy through their "spokes."

We have constructed one such ring that resonates at 1.46 GHz and has a *Q* of 15 248, the current world record for an on-chip resonator operating above 1 GHz at room temperature. In a cellphone, that would translate into a filter with a pass band about 100 kilohertz wide—much more selective than the 35-MHz filters now found in cellphones. Indeed, it's narrow enough to remove all interfering signals and pass just a single communications channel. Because the processing circuitry that follows wouldn't have to deal with large-amplitude interfering signals, it could operate at lower power levels. And this basic design should work for much higher frequencies as well.

Ring resonators have other advantages too. Unlike what happens with a disk, it's easy for the designer to specify the electrical impedance of the device without changing its resonant frequency. This then allows the impedance to be matched to the circuits attached to the resonator, which is important for the same reason that it's important between, say, a stereo amplifier and its speakers: Without a good impedance match, power isn't transferred efficiently.

As nice as rings are, it might, in fact, be advantageous to gang several disks together in a mechanical circuit. A set of such disks will accomplish the necessary impedance matching and be physically smaller than an equivalent ring resonator. So a disk array may be a better choice when space is at a premium.

Some researchers, including Albert P. Pisano, my colleague at Berkeley, and Gianluca Piazza, of the University of Pennsylvania, are looking at another way to achieve the desired impedance and to handle high power levels. They are using piezoelectric MEMS resonators similar to FBARs, but with frequencies that can be controlled by adjusting certain lateral dimensions. The devices they've built should be sufficient even for the kinds of power levels found in transmitter circuitry, which are always much higher than what's encountered on the receiving end. The problem with piezoelectric resonators is that their *Q* values have so far been limited to about 3000.

In addition to working with disks and rings, I and other researchers around the world have experimented with MEMS resonators of other types: beams, squares, and combinations of these shapes. Lots of geometries are possible, of course, and no one will be surprised if something entirely new eventually proves even more capable than anything that's been built so far.

Some component vendors—for example, SiTime Corp. of Sunnyvale, Calif., and Discera, a company I founded in 2001, based in San Jose, Calif.—are currently marketing MEMS resonators for use in precision oscillators. These add to the growing number of applications where MEMS devices are turning up: principally in accelerometers, pressure sensors, gyroscopes, ultrasonic transducers, and microphones. The FBAR filters found in today's cellphones are also MEMS devices, albeit ones with lower *Q* values. I expect to see companies gearing up to apply more advanced MEMS technology to the construction of high-*Q* filters.

SUFFICE IT to say that oscillators built with these mechanical resonators are far superior to their electrical counterparts. But these are not the only virtues of this technology. The best thing about these mechanical marvels is that they can do much more than just oscillate. If you're clever, you can transform a MEMS resonator into a complete radio receiver stage—one that can take an incoming RF signal and amplify it, down-convert its frequency, and filter the result—all with just one minuscule, passive mechanical device. This may seem like magic, so let me explain in more detail how this micromechanical prestidigitation works.

Whether built as a disk, a ring, or something else entirely, the vibrating mechanical part of these new MEMS resonators isn't placed in physical contact with its input or output terminals. Rather, it's coupled to the input and output signals by means of an electric charge placed on it. Because of the force between electric charges, the moving piece begins vibrating when an oscillating electrical signal is applied to the nearby input electrode. And similarly, the vibration of the electrically charged resonator induces an oscillatory signal on the adjacent output electrode.

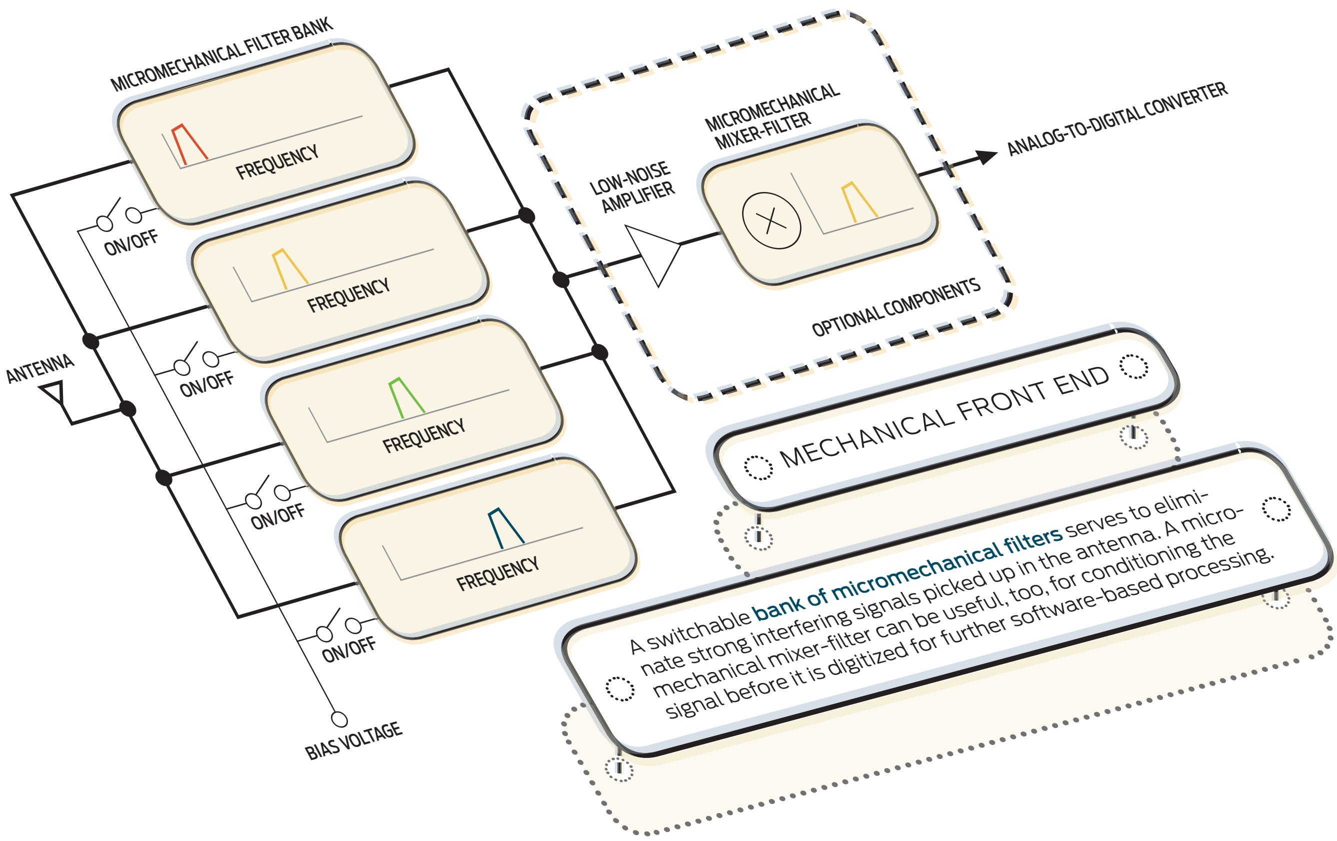
To generate the required electric charge, you simply apply a bias voltage using a third terminal attached to the oscillating part of the resonator. Setting that bias voltage to zero turns the resonator off, effectively opening a switch between the input and output terminals. (That's better than putting a transistorized switch in the signal path—which is what you'd have to do with an electrical filter—because such switches degrade the signal.)

The bias voltage can, in fact, do more than just turn the resonator on or off: It can also amplify the incoming signal, down-convert its frequency, and filter it, as I mentioned. The trick is to apply an *oscillating* bias instead of a DC voltage.

If you think about what happens when the bias voltage varies with time, the magic begins to make sense. When the bias voltage is close to zero, the output will of course be very muted. When the bias is significant, the output will be large if the input is large and small if the input is small. In other words, by changing the bias, you can modulate whatever signal you apply to the input.

You could, for example, use this mechanism to shift your voice up to radio frequencies by attaching an RF oscillator to the input and using the voice signal to adjust the bias voltage. A MEMS resonator can be used equally well to shift frequencies in the other direction and down-convert the RF picked up on a radio's antenna: Just direct the captured RF to the input electrode of the resonator and hook up a suitable RF oscillator to the bias terminal. The MEMS device will automatically filter the output, too, passing only signals that are close to its resonant frequency. If the down-converted and filtered output of the resonator is too weak, increase the amplitude of the oscillating bias voltage; if it's too strong, use a smaller bias. As you can see, it's easy to control the operation of such an all-in-one MEMS radio stage.

JUST AS integrated circuits overtook discrete transistors decades ago, collections of MEMS devices—integrated micromechanical circuits—may eventually become common in wireless handsets. Designers could, for example, combine a large number of MEMS resonators to create a bank of elements each capable of selecting a single communications channel instead of a broad band containing a confusion of signals picked up by



the antenna. Providing a radio with filters that could separate out hundreds or even thousands of individual channels has been unthinkable before now. With MEMS, such separation becomes possible.

This strategy is very different from what goes on in the front end of a typical radio set, which uses tunable electronic circuitry to select which of the many frequencies captured by the antenna is sent on to subsequent amplifying and processing stages. It's also different from what's proposed for software-defined radios, which is to separate the signals on different channels computationally.

Doing channel selection mechanically would, like the computational approach, allow a smart radio receiver to monitor many different channels simultaneously, allowing it to identify in real time which slices of spectrum are free. The advantage of doing this with a bank of MEMS resonators is that they would draw very little power while doing their job, whereas the purely computational approach, even when it becomes feasible, seems destined to leave our handsets too often with dead batteries.

Using MEMS devices to replace typical front-end radio circuitry is very much still in the active research phase, but virtually all the handset makers are funding work in this area, as is the Defense Advanced Research Projects Agency. So some very sophisticated mechanical radio stages will very likely make the leap from lab bench to marketplace within the next few years.

These complex micromechanical devices will not only be integrated together; they'll most likely be put on the very same chip with electronic circuitry. This combination is possible because the fabrication processes used to create these tiny moving parts—depositing various materials in thin layers and patterning them in complex ways—is so similar to what's done in making complementary metal-oxide semiconductor (CMOS) circuits.

For example, Analog Devices, in Norwood, Mass., currently makes MEMS accelerometers and gyroscopes with mechanical and electronic components together on the same chip. This is awkward to do, though. The problem is that the construction of MEMS components requires high temperatures that would damage the copper or aluminum traces used in the electronics. So you have to lay down the mechanical parts first before putting down metal. Because most foundries won't work with wafers that are anything but pristine silicon, this arrangement prevents MEMS-device manufacturers from outsourcing the construction of the electronics and taking advantage of industry-wide advances in CMOS fabrication.

Analog Devices mixes MEMS and CMOS fabrication on a single wafer, first doing some of the steps needed for the transistors, then some for the MEMS, then returning to the transistors, and so forth. It would be better to arrange things so that all the CMOS circuitry is created first with the MEMS on top. Some researchers have done that by bonding a MEMS device to a CMOS chip using tiny wires. My colleagues and I have lately been exploring a different strategy: building the resonators out of metal, which can be laid down at temperatures low enough to avoid ruining the underlying electronics.

Whatever system eventually wins out, it's a good bet that the highly integrated chips that go into radios will slowly evolve from purely electronic devices into ones that are a complex mixture of electronic and mechanical components. The handset you carry a few years from now might not look very different from the one you have at the moment, but if you're technically savvy, you'll appreciate that it performs much better, thanks to internal mechanical parts. If you appreciate that fact enough, you might even be tempted to dress up your cellphone on the outside with a few brass levers or steel gears. ❏

POWERLESS IN GAZA

A 15-YEAR-OLD POWER PLANT HAS SURVIVED BOMBINGS, EMBARGOES, AND BLOCKADES. WILL IT EVER FULFILL ITS MISSION TO BRING ELECTRICITY TO PALESTINE?

by SHARON WEINBERGER

IN NOVEMBER OF 2008, the backup batteries unexpectedly failed at a power plant in the Gaza Strip. Almost anywhere else, the incident would have been a blip, forgotten a week later. But this is Gaza—blockaded by Israel and Egypt and cut off from the Palestinian National Authority in the West Bank. It's a place where more than a million and a half people inhabit a strip of land not even one-third the size of the city of Los Angeles...

...and where there is only *one* power plant.

WITHIN DAYS, THE PLANT'S desperate engineers came up with a novel solution: They hooked up 170 twelve-volt car batteries to restart the plant's turbines. To everyone's amazement, including the engineers themselves, the impromptu kludge actually worked. "It was an abnormal situation," notes Rafiq Maliha, one of the plant's managers, who holds a Ph.D. in mechanical engineering.

Triumphs, even small ones, are uncommon these days in Gaza, which has endured a devastating run of strife, death, and dysfunction. A three-week war that began in late December 2008 killed 1660 Palestinians and 13 Israelis and left 4000 homes and 80 government buildings wrecked or seriously damaged. Since 2007, Gaza's 360 square kilometers have been controlled by Hamas, a militant Islamic group that much of the world, including the European Union and the United States, regards as a terrorist organization.

Conceived in 1994 during a short-lived interlude of relative tranquility that began after the Oslo Accords, the Gaza power plant, which operates under the official name of the Gaza Power Generating Co., was part of a larger blueprint to lessen Palestinian dependence on Israel for such basic municipal services as electricity, education, and security. But today, with the other parts of the blueprint long abandoned, the plant's 100 or so engineers are reduced to operating the 140-megawatt plant in ways its designers never anticipated.

Some days, notes Maliha, the power plant doesn't even have the fuel needed to provide transportation for its employees, a nightmare for a facility that requires 24-hour support. Other days, something as simple as a faulty temperature sensor can shut down operations, because the plant has no easy way to obtain a new one. "We managed to survive up till now, but things are becoming more difficult," says Maliha. "We try to manage with temporary solutions, but then the temporary becomes permanent, and suddenly you have a complete failure."

Like the territory itself, Gaza's electrical system—and its lone power plant—seems stuck in a kind of chaotic limbo. Life for a plant engineer here is a daily struggle to keep the operation running amid chronic shortages of fuel, spare parts, expertise, and basic building materials. Somehow, this solitary power plant wheezes on. This is what engineering looks like at the edge, where engineers keep the lights on amid bombings, embargoes, intrigue, and instability in one of the world's longest-simmering combat zones.

POWER PLANT: Gaza's only power plant shut down for lack of fuel after Israel tightened a blockade in early 2008.
PHOTO: MAHMUD HAMS/AFP/GETTY IMAGES

YOU APPROACH THE POWER PLANT in central Gaza on a dirt road in an area that seems to lack any modern infrastructure. Today, on a weekday afternoon in early June, the facility looks all but deserted. A cat is asleep in the guard station. A sign near the entrance to the plant, advertising the number of days with no accidents, hasn't been updated since 2008. Maliha, who greets a visitor, looks exhausted. He's been involved with the plant since its inception and is accustomed to patiently explaining its difficulties to visitors. An alarm goes off somewhere in the plant as he is speaking, and he doesn't even pause.

With its four 24-MW diesel-fueled combustion turbines and two 22-MW steam units, this plant was the longtime dream of Palestinians who wanted to wean Gaza of its total dependence on Israel for power. "This plant was supposed to cover demand for the whole Gaza Strip," Maliha explains. But today, only half those turbines are working, and the plant is producing only about 60 out of a potential 140 MW.

The US $140 million project was troubled from the start. Construction had been under way for barely a year when the second Palestinian uprising, or intifada, began in 2000. Worsening relations between Israel and the Palestinian National Authority made any projects more difficult to complete, not to mention risky for private investors. Nor did the situation get any better when the plant began operating in 2002, shortly after one of the initial investors, the notorious U.S.-based energy firm Enron, collapsed.

Today one of the biggest problems is getting enough fuel. It's one of the many problems you encounter running a power plant in a war zone. Since 2007, Israel has restricted the amount of fuel it rations to Gaza, leaving the plant to operate at only partial capacity.

PREVIOUS PAGES: LEFT: ADEL HANA/AP PHOTO; RIGHT: MOHAMMED ABED/AFP/GETTY IMAGES

At one point in 2007, the European Union, which pays for the fuel brought into Gaza, cut off the supply because it was concerned Hamas was skimming money. Deliveries soon resumed, and the plant continues to get the rationed fuel. Under the original blueprint, the plant would have been fueled by natural gas, but today it is still dependent on liquid diesel fuel. "Everything here is temporary," Maliha says with a wry laugh. He estimates that the plant, which receives about 2.2 million liters of rationed diesel fuel per week, needs over twice that amount, about 4.9 million liters, to operate at full capacity. Without fuel, the power plant stops, and when the power plant stops, things start to break. "Fuel tanks without fuel become rusty, and they're destroyed," Maliha says. The storage tanks grow rusty, the rust contaminates the fuel, and the contaminated fuel damages the equipment. Then the turbines shut down, leading to more failures when engineers try to start them up again.

GAZA APPEARS TO CARVE a rectangular, 41-km chunk out of Israel, its width ranging between 6 km at its narrowest and 12 km at its widest, at the Egyptian border. The 1967 Arab-Israeli War left the strip under Israeli control, which remained the status quo until 2005, when Israel unilaterally pulled its military forces out of the Gaza Strip. Palestinians could then move about freely within Gaza, but Israel's disengagement, and the subsequent political ascendancy of Hamas within Gaza, led to the present situation, in which Gaza is effectively in international limbo and its residents cut off from the world.

THE GAZA POWER STRIP

Gaza's power plant was supposed to lessen the territory's dependence on Israel. But after seven years, the plant provides only 25 percent of what Gaza needs to survive.

1993 The Oslo Accords give Palestinians greater authority over municipal services like the electricity grid.

1994 The Gaza power plant is commissioned as part of a larger blueprint to lessen dependence on Israel.

1999 Construction begins on the US $140 million project. Total demand to be met: 244 megawatts.

2002 The plant begins initial operations; Enron, a major U.S.-based investor, collapses.

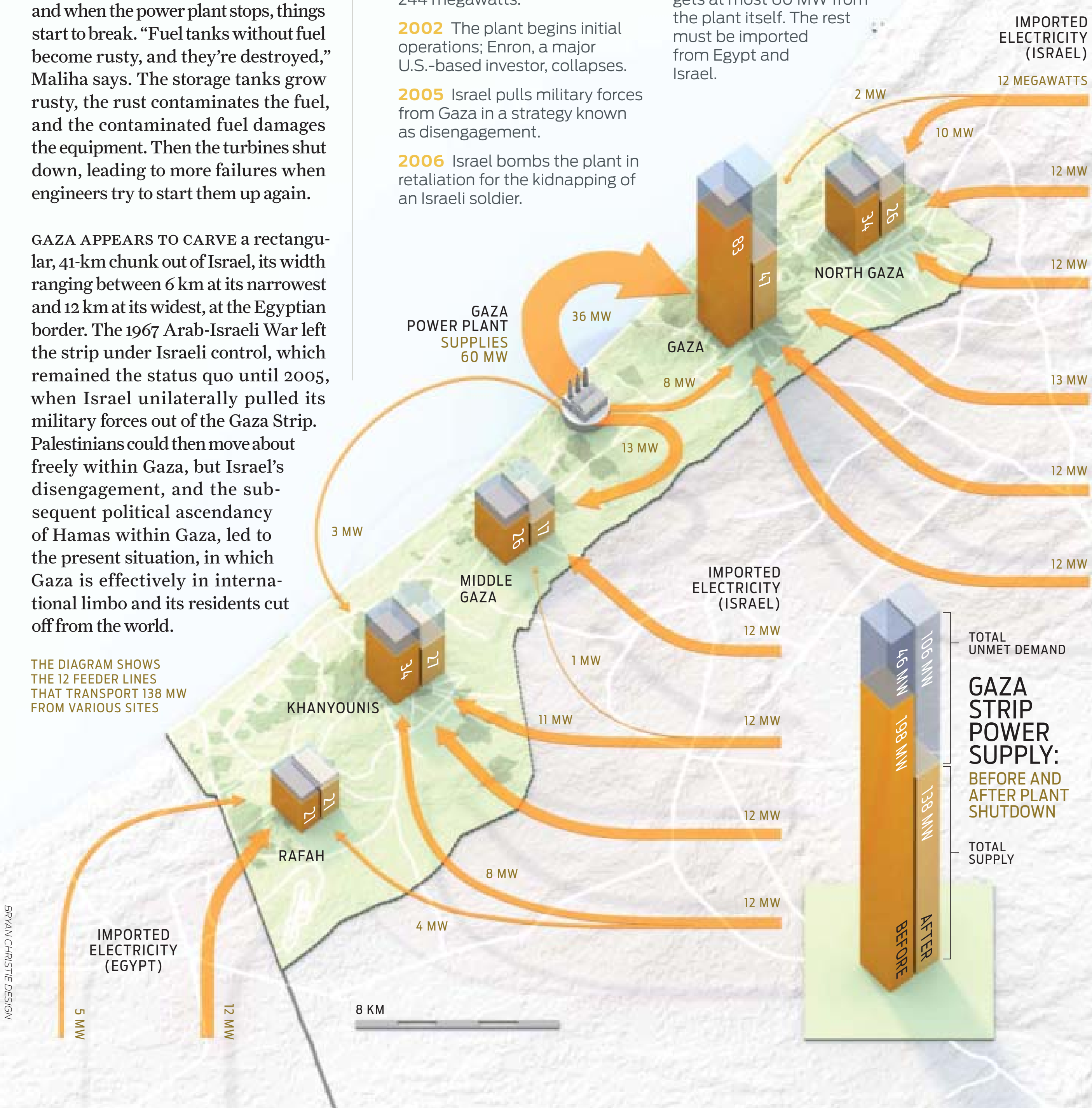
2005 Israel pulls military forces from Gaza in a strategy known as disengagement.

2006 Israel bombs the plant in retaliation for the kidnapping of an Israeli soldier.

2007 Israel begins rationing fuel to 2.2 million liters per week. The plant needs 4.9 million liters per week to meet demand.

DECEMBER 2008 Fuel cutoffs in the wake of Israel's military strikes damage the plant's transformers, and the plant shuts down completely.

2009 Even when the power plant is online, Gaza only gets at most 60 MW from the plant itself. The rest must be imported from Egypt and Israel.



UNDER EMBARGO: Gaza's sole power plant [far left] struggles to operate under heavy fuel rationing; Palestinians wait at the last gas station in the Gaza Strip that still has fuel [above]; plant workers douse a generator following an Israeli air strike [left]; and a transformer is damaged as a result of the latest strikes [right].

PHOTOS, FROM LEFT: MEHDI FEDOUACH/AFP/GETTY IMAGES; LAURA LEON/POLARIS (2); GAZA ELECTRICITY DISTRIBUTION CO.

The region's airspace, borders, and coastline continue to be under Israeli control. But other than allowing for basic humanitarian aid, Israel neither officially acknowledges any legal responsibility for Gaza nor recognizes the territory as an independent state.

During the 40-year occupation, Israel provided Gaza with electricity. However, the 1993 Oslo Accords—the first real milestone in attempts to solve the Palestinian-Israeli conflict—gave the Palestinians greater authority over municipal services like the electricity grid. The Palestinian National Authority dreamed of building its own power plant in Gaza. But those ambitious plans to take control came at a time when the population was soaring, greatly increasing pressure on the grid.

Gaza's total demand, according to estimates by the Gaza Electricity Distribution Co. (GEDCo), is 244 MW. But even when the power plant is up and running, Gaza gets at most only 198 MW. The power plant—when it's working—contributes about 60 MW; 121 MW are brought in from Israel (but only if all 10 feeding lines are in good order), and Egypt powers the southern Gaza city of Rafah with another 17 MW. So the deficit, under the best of circumstances, is 18 percent. Adding to the complexity, the "grid" is not actually integrated, meaning that power from Egypt, Israel, and the power plant can't be diverted within Gaza to make up for losses in another part. That means, for example, if the power plant stops working, electricity from Egypt can't be rerouted to Gaza City.

If anything, it's remarkable that Gaza's grid isn't in worse shape. In 2006, Hamas won the parliamentary elections in Gaza, and after a series of violent clashes with Fatah (its main political rival), took over control of the government and security forces. Israel bombed the power plant in late 2006, destroying six transformers and halting operations; the bombing was in retaliation for Hamas's June kidnapping of Israeli soldier Gilad Shalit (Shalit is believed to be alive and in captivity somewhere in Gaza). The Palestinian National Authority protested the bombing of a civilian power plant, while the Israeli military described the strike as a military blow aimed at Hamas. The bombing left thousands of Gazans in the dark and pushed the sewage and water systems, which rely on electricity, to the brink of collapse.

The power plant sputtered back to life in 2007; it was partially insured by the Overseas Private Investment Corp., an agency of the U.S. government, Israel's staunchest ally. But the plant had barely been resuscitated when another setback hit. Israel, declaring Hamas a "hostile entity," sharply curtailed electricity and fuel supplies to Gaza, setting off the first of what would be periodic energy crises that continue to this day.

The most recent war, which began on 27 December 2008, brought yet another catastrophe to Gaza. Israel launched Operation Cast Lead, a three-week military offensive retaliating against Hamas for a series of rocket attacks that fell on civilian areas in southern Israel. The military operations, which combined strikes from the air and sea with a ground assault, damaged transformers and several of the transmission lines that brought power from Israel. Gaza also lost a line from Egypt during the offensive. Lacking fuel, the power plant shut down completely. Vast swaths of Gaza were left once again to fend for themselves in massive blackouts.

The Israeli offensive also knocked out three of the four remaining lines from Israel to the Gaza Governorate. So for the first two weeks of the war, most residents of Gaza City, Gaza's main population center, lived in darkness. By the time Israeli forces withdrew in late January 2009, GEDCo reckoned that 40 percent of the population was entirely without electricity, while the other 60 percent were getting only intermittent power. In all, GEDCo estimates that the military operations caused some $10 million in damages to its systems.

EVEN IN WARTIME, LIFE GOES ON. GEDCo still has to deal with everyday issues, like ensuring that customers pay for their electricity use. That's no small feat in a region where 80 percent of the population lives below the poverty line: GEDCo estimates that it manages to collect only about 25 percent of what it is owed by its customers.

The company's Web site proclaims that "paying the bill is a religious obligation." Every day in Gaza, GEDCo's collectors fan out over the territory with sheets of paper identifying delinquent customers. If the customer refuses to pay or agree to a payment plan, the technician will often immediately climb a pole and physically disconnect the cables. Some of the disconnected customers attempt to reconnect the line themselves or hire someone else to do it. In that case, GEDCo takes drastic action, and the phrase "cutting the power" becomes more than a figure of speech, as this reporter saw on a sunny afternoon in late May.

Perched atop a wooden pole on a Gaza City street lined with buildings still pockmarked by mortars from Israel's recent military incursion, a maintenance worker at first glance appeared to be repairing a power line leading to a two-story building. But a split second later, the line dangled free—the building's connection to the Gaza grid had just been severed.

Unlike GEDCo, a public utility, the power plant is a commercial operation that must produce and sell electricity to stay in business. The Gaza power plant has been operating at only partial capacity—today mostly because of the blockade. For the moment, only four of the plant's six turbines are running. At one point, the power plant's managers had hoped to add an additional six turbines to the facility, bringing total generation up to 280 MW. But now, because some of the plant's transformers were damaged during the war, it cannot handle full output from even the working turbines. Siemens, the turbines' manufacturer, sends its technicians to work at the plant, but only if the power plant pays a private security company to protect them.

Rebuilding after the most recent war, with key parts unavailable or in very short supply, demanded resourcefulness. GEDCo had to erect wooden poles to replace damaged medium-voltage steel poles. But even if GEDCo could get steel poles, it couldn't obtain the concrete needed to set the poles, because as part of the economic blockade, Israel does not allow any concrete into Gaza, making it an especially prized commodity.

Major Guy Inbar, a spokesman for the Israeli defense ministry's Coordinator of Government Activities in the Territories, which is responsible for Gaza issues, says Israel has not received any applications for cement or steel poles from the Palestinian power authority. And while some equipment was approved for the power plant, Inbar says, some other items were denied for what Israel determined were security concerns. Inbar acknowledges that the long list of needed items must be reviewed individually, which makes for a long wait.

The blockade has also led to shortages of certain wires and cables, so GEDCo has had to use whatever it has on hand. In many cases the cable sizes are inadequate for the loads, leading to excessive heat and high resistive losses. Lines that should be replaced are left in place with splices and connectors. Transformers are routinely overloaded, admits Suheil Skeik, GEDCo's general manager. "We risk them by overloading, but we have no other way," he says.

For the power plant, the inability to get parts and supplies has been particularly challenging. Israel's offensive has been over for nearly a year, but the power plant must still clear every spare part with Israeli authorities, a system that Maliha insists is unworkable. Sometimes the plant gets approval; sometimes it doesn't. "If you are running a power plant, you need a continuous flow of spare parts and consumables," he notes.

SKEIK'S RADICAL SOLUTION is to eliminate Israel from the energy equation. Fueling the plant, he explains, means relying on Israel. But without energy and fuel from Israel, what is the future of the grid? "We look to Egypt as our solution," he maintains. But it's hard to see how that would work, because Egypt also cooperates in the Gaza blockade. For several years, there have been plans to put in place ten 22-kilovolt feeder lines to increase the electricity supply from Egypt; but the project, which was to be funded by the Islamic Development Bank, has been put on hold practically from the day it was first proposed in 2003.

Israel continues to insist that the weekly fuel ration is enough. That fuel enables the plant to produce about 65 MW, according to Israel's estimates; Inbar insists that this is "the needed amount for the humanitarian needs of the civil population." Assuming the situation remains stable, Israel will provide "enough power supply for the humanitarian needs of the people of Gaza." Israeli spokesman Inbar did not say how Israel determines the amount required for these needs.

The Palestinians see Israel's actions differently. "The Israelis want everything closed down: electricity, materials, everything," says Skeik.

One thing is certain: The power situation, like the political situation, has reached a seemingly insurmountable impasse. "It was the first of its kind in the Palestinian National Authority," recalls Maliha of the power plant's construction. "It was promising because at the beginning, there was talk about regional power sharing between different countries." Now, he says, all those dreams have evaporated. There are currently no plans for expansion.

Asked about the future, Maliha responds with an answer typical in Gaza these days. "You cannot make a plan; there is no plan," he says. "You live for the day." ❑

GO BIG OR GO HOME

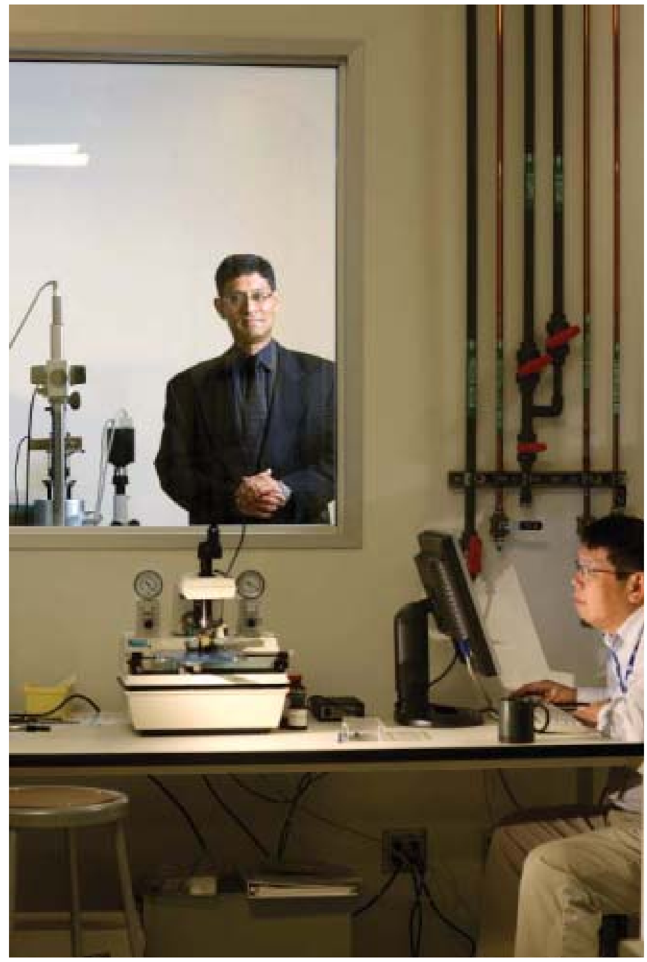
Prith Banerjee made a reputation in academic research by taking risks and swinging for the fences.

Now he's taken that philosophy to the renowned HP Labs

by Tekla S. Perry


Berkeley Farms

Some baseball players are known for being consistent, if not flashy, hitters. They get on base and keep the game going. Then there are the sluggers, who bring the crowd roaring to its feet every time they step up to bat. You know they're going for that home run.



When Prithviraj Banerjee arrived at HP Laboratories, in Palo Alto, Calif., as the organization's new director in August 2007, he was intent on pushing the researchers to swing big. HP Labs, a sprawling enterprise with some 500 researchers spread over seven locations worldwide, is the company's advanced research arm, spending about US $150 million annually. The first commercially available LED, the pocket scientific calculator, thermal inkjet printing, and reduced-instruction-set computer architecture were all born in the labs. The labs got the company into digital printing, and HP is counting on those researchers for future wins.

In recent years, company executives had grown concerned that the labs had lost their focus. When Banerjee arrived, there were 150 projects under way, most of them involving just a couple of researchers and having no overarching goal. He didn't know yet which ones had home-run potential; he just knew he had to focus on those that did and forget about the rest.

And he had to move fast. Since his arrival he has flattened out the labs' hierarchy, restructuring the organization into 23 laboratories, each with a leader and a single research focus. He asked researchers and lab directors to come up with 20 "big bet" projects that would advance the state of the art of technology and have a significant impact on HP's businesses now and in the future.

This bold strategy didn't immediately win everyone over. Under Banerjee many longtime employees were forced to set aside projects they had spent years on. Many people wondered why he had been tapped for the job at all.

HP has a history of promoting its management from within. Not only had Banerjee never worked for Hewlett-Packard, he had never worked for any large corporation. He'd spent nearly his entire career in academia, with a brief detour to start a software company. Banerjee was the ultimate outsider.

A year into his tenure at HP, Banerjee has won over some skeptics. Crawford Del Prete, executive vice president of worldwide research at International Data Corp., a market research and analysis firm, says that Banerjee has "brought a level of focus to HP Labs that before didn't exist. I see a number of focused teams working away, and far more cooperation between product groups and labs than I ever saw before."

And even his critics can't question Banerjee's energy, dedication, or passion. Whether those qualities and the changes he's set in motion will be enough to put the labs in a position to score big for HP is not clear.

OF COURSE, Silicon Valley is a culture of outsiders, drawn from all over the world and all walks of life, united by their common passion for technology. In that sense, Banerjee fit right in. Born in Sudan, he spent much of his childhood in the Himalayan foothills of Bhutan, to this day one of the most isolated nations in the world. The nearest school was a 2-hour hike through steep hills, so Prith studied at home. In his middle school years, the family settled in Calcutta, where Banerjee began more formal schooling. He was always tinkering with electronics, and in high school he won the top prize at a national science fair with a widget that measured

THIS PAGE AND PREVIOUS: TIMOTHY ARCHIBALD the flow of water in a pipe using an external transducer. From an early age, he also liked to be in charge. His older brother, Sanjay, remembers 8-year-old Prith once shoving his father onto a train, impatient with his father's extended farewells.

Prith entered the India Institute of Technology, in Kharagpur, as an electronics engineering major in 1976 and then went on to the University of Illinois at Urbana-Champaign for a Ph.D., where he focused on fault tolerance for multiprocessor computers. After getting his doctorate in 1984, Banerjee entered a booming job market, with more than a dozen job offers from the likes of Bell Labs, IBM Research, Carnegie Mellon University, and the University of Michigan. He chose to stay at Urbana but changed his research thrust to parallel algorithms for computer-aided design. Within eight years he was a full professor.

In 1994 Banerjee got his first taste of management. At the time, the university housed one of four national supercomputing centers. The College of Engineering wanted a graduate program to take advantage of this resource. Two early attempts had failed. Banerjee wanted to take another crack at it. He rallied support among students and faculty and within two years had 10 departments involved, 100 graduate students signed up, and several million in grant money committed.

"I learned in doing this," he says, "how to build support for an idea from the bottom up, because if it comes from the top down, people in the academic world will hate it." Even as he nurtured consensus, Banerjee didn't hesitate to step in at key moments and take charge. He was passionate about seeing the project through. In fact, "passionate" is typically the first word that comes to people's minds when describing Banerjee. In recent years, he says, he has tried to moderate his more passionate moments, at the urging of his wife. "She thinks I sometimes come off as a dictator," he says with a chuckle.

Banerjee left the University of Illinois in 1996 to take on a new challenge at Northwestern University, in Evanston, Ill. At the time, Northwestern's graduate engineering program ranked so low, Banerjee recalls, "it wasn't even on my radar. But the undergraduate school was fantastic."

As a newcomer, he didn't feel he had the knowledge or the right to simply make sweeping changes. Instead, he began holding regular meetings with faculty members to hammer out a strategic plan. "It was the first time I tried doing strategic planning," Banerjee says, "so it was not a very well-thought-out thing." He learned that Northwestern professors tended to work alone. "They'd go off and do something with one or two graduate students, and no one would bother them." Having autonomy was great for the researchers, but their results hardly made a ripple. An important idea emerged: To make an impact, the department needed to do a few big collaborative projects instead of lots of individual ones. Banerjee also began recruiting star faculty from other universities.

"It was a fun time," he says. "We had all these top people coming in, we got five large DARPA grants, and our [graduate engineering] ranking, according to *U.S. News & World Report*, moved up to 15th or 16th." (Currently it ranks 21st.)

Banerjee was directly involved in one of the Defense Advanced Research Projects Agency efforts, the creation of a software tool that would greatly simplify chip design. It would take a file created using the popular Matlab design software and spit out the corresponding design. Without such a tool, design engineers had to manually convert the Matlab chip simulation into the hardware design. Banerjee, working with another faculty member and two graduate students, developed a prototype and demonstrated it to DARPA. He called the effort MATCH (for MATlab Compiler for Heterogeneous computing systems).

It was 1999, and "everybody and his dog were doing a dot-com," he recalls. "I thought, 'I have a real technology, I should be able to do something.' "

STARTING A COMPANY was something Banerjee knew nothing about. But after a childhood spent educating himself, his first impulse was to hit the books. He spent six months studying and then wrote his business plan. He sent it out to a long list of venture capitalists, and he quickly got an offer of $2 million from an East Coast firm. The venture capitalist told Banerjee to start hiring people, lease an office, and buy computers, because the money was on its way. Banerjee did all that and also retained a Chicago lawyer to represent the company. Toward the end of 2000, he booked a ticket for the day after Thanksgiving so that he could fly East and sign the paperwork.

The day *before* Thanksgiving, the firm pulled out of the deal. The dot-com bubble had burst. And Banerjee had just committed $200 000 that he didn't have.

After spending what he recalls as the worst Thanksgiving in his life, he decided to go ahead with his start-up anyway. He took out a second mortgage to pay the bills and began shopping the product around to customers, who told him it was a good idea but off target. The MATCH prototype supported a type of field-programmable gate array used in defense but not in commercial applications. Banerjee and his team started modifying the prototype. He also began making regular trips to Silicon Valley to talk to companies that might be interested in buying MATCH if it ever got to market.

If he was worried, he didn't show it. Says David Zaretsky, then a graduate student at Northwestern who worked on the start-up, "You couldn't tell that anything was bothering him. He remained cool and calm."

Finally, in February 2001, Banerjee got an order from a customer that promised to pay $2 million over three years. With that in hand, he was able to attract a new venture capitalist to fund the company, which he named AccelChip. He took a one-year leave from Northwestern to get the company off the ground. The AccelChip Compiler came out in 2002; early customers included Elixent, Motorola, and Quicklogic. Four years later, Xilinx purchased AccelChip for an undisclosed amount rumored to be around $21 million, most of which went to investors.

Banerjee returned to Northwestern in September 2002, although he continued to serve as AccelChip's chief scientist until the Xilinx buyout. Straddling business and academia is common for professors in Silicon Valley; it wasn't in Chicago. "I was the guinea pig," Banerjee says. Since then another 9 or 10 engineering professors at Northwestern have followed in his footsteps.

By 2004, Banerjee was restless and began applying for engineering dean positions. Three schools made offers: Iowa State University, Johns Hopkins University, and the University of Illinois at Chicago (UIC). He accepted the job at Johns Hopkins, but his family balked at moving during his son's high school years. Banerjee instead went to UIC, another school without a top-ranked engineering program.

Again, Banerjee got his faculty to work on a strategic plan. For many of them, it was an eye-opener. "Most colleges have strategic plans that are 5 or 10 pages long," says Peter Nelson, who was a department chair at UIC under Banerjee and is now dean. "Prith locked 20 or 25 of us into a room for a few hours a day, several days a week, and we came up with a 256-page detailed plan."

Banerjee again pushed the ideas of doing small numbers of large-scale research projects. Meanwhile, he was getting calls from other universities. In 2007, with his son out of high school, Banerjee began to consider the offers seriously. "I wanted to move up the academic ladder," he says. He was thinking provost, maybe even president.

Then in November 2006 he got a call from a search firm hired to identify candidates to take over HP Labs. The headhunter knew Banerjee was looking at academic posts but asked if he'd consider the HP job. "Absolutely not," Banerjee replied.

The recruiter persisted. He flew out to Chicago, and once there he asked Banerjee to meet him at the airport. Banerjee said he'd give him an hour.

"I'm not interested," he said after hearing the pitch. "I am going to academia. My dream is to be a college president."

Perhaps he wasn't interested, but the headhunter badgered him into agreeing to come to Silicon Valley for one more meeting—with Shane Robison, HP's chief strategy and technology officer.

Robison says he was looking for someone with academic credentials, start-up experience, and "a fresh perspective." Banerjee had all those qualifications—but so did a number of other candidates. The CTO scheduled just an hour with Banerjee at Hobee's, a popular brunch spot in a strip mall across from Stanford University. "Two and a half hours later I had to finally break off to go to another appointment," Robison recalls. "He was that interesting."

When Banerjee returned to Chicago, he asked his wife, Swati: What if he got an offer from HP—would she move to California? To his surprise, Swati was ecstatic. She had always dreamed of living in California, she told him.

Still on the fence himself, Banerjee then called his brother. Sanjay was happy with an academic career himself—he's at the University of Texas at Austin. But just after grad school, he'd spent a few years in Texas Instruments' corporate laboratories and felt his brother might thrive in such an environment.

"The HP job was an absolute godsend," Sanjay says. "Of course, it was financially lucrative, but more, it's the kind of position in which you can do something real. In academia, without the market push, we publish paper after paper. In corporate R&D, you can do cutting-edge research that influences society."

ON 1 AUGUST 2007, Banerjee started work. As he'd done at Northwestern and UIC, he started with developing a strategic plan. But this time the discussions, which involved 80 people from the labs and 40 from HP's business units, bogged down. "The process drove me and the entire organization crazy. Mark Hurd [HP's CEO] told me I was wasting too much time," Banerjee says.

Meanwhile, much of the research ground to a halt. Banerjee had expected as much. "I told Mark and Shane that for a transformation the size of which I'm trying to accomplish, we had to stop and really think about what we should be doing," Banerjee says.

After two months of back-and-forth during which little was settled, Banerjee stepped in and announced his vision, which included sweeping away layers of hierarchy. Under the director were four centers, under the centers were 12 labs, under the labs were 24 departments, under these 24 departments were a total of some 150 projects. Banerjee envisioned a flatter, more focused organizational chart with 20 projects at most. He didn't call for layoffs. (By the time Banerjee started, the labs were already smaller than they had been in the past, with about half the number of researchers as there had been in 2000.)

Distinguished Technologist Parthasarathy Ranganathan, who worked as part of the planning group, said the labs' previous philosophy was to "let a thousand flowers bloom. But Prith said, 'My garden doesn't have room for all these roses,' and once we got the sense of what kinds of flowers he liked, we started pruning."

The final list of laboratories came to 23; the structure went into effect in December 2007. Bob Tarjan, one of the researchers, wrote what he called a stable-marriage algorithm to match lab directors and researchers, who had ranked their preferences. By 15 March 2008, the new labs were in place, but with only general missions. Projects were to be selected from researchers' proposals by a review board that included representatives from the business units as well as the labs; each year 20 percent of the projects would be replaced by new ideas.

To observers, this move optimized the research structure to focus on existing businesses and was not that shocking. Lab operations, points out a former researcher, have always been cyclical. "Sometimes," he recalls, "Hewlett and Packard would tell us to focus on supporting the businesses, that HP had enough on its plate and wasn't looking for new lightbulbs. Other times they would look to the labs for new footprints."

Banerjee thought it a fine plan. Many of the researchers, though, hated it. In principle, most were willing to give up their individual projects and focus on a smaller number of large projects. But in practice, there were a few pet projects and research paths they were loath to see go.

He realized that the researchers wanted greater autonomy. Google, he recalled, lets its researchers spend 20 percent of their time on whatever they want. He decided to follow suit, and in addition he permitted 20 percent of the people in each lab group—6 out of a typical lab's 30—to work full-time on whatever they wanted. (Interestingly, it was HP founder William Hewlett who was an early champion of this type of policy. He called his plan "schedule-free Fridays.")

By October 2008 the review board had selected its list of projects. Banerjee had been looking for about 20 big bets; what he got were 22 large projects and 40 medium ones. Some were entirely new, and some encapsulated projects that had been canceled. "We came a long way, but we were not quite there," he says. Now, a year later, after some more judicious trimming, the projects number 21.

Banerjee explains: "It's as if we are in an auto company, and we have efforts of tire research, body research, and so on. I'm asking people to focus on the vision. What is the car you are trying to build? A fast car? A fuel-efficient car? I don't know. They can tell me what they want. I just want them to focus."

For the first time in a long time, the labs have that focus, says analyst Rob Enderle, of the Enderle Group. He gives Banerjee an A– for his work so far. "He's made a difference. He got costs under control; he got the labs focused. The groups I've met with seem to have a higher morale than before; they know that no ax is going to fall soon. He isn't going to get a higher grade with me until we see products in the market, but that takes time."

Banerjee's radical restructuring may have been tumultuous, but the labs needed it, says HP CTO Robison. "The most effective way was to do it quickly. A big bang approach."

It's too soon to tell if Banerjee's big bang approach will pay off—advanced research organizations measure their results in decades, not months. But Banerjee is confident. "I am going for the big bet, the home runs," he says. "There is a huge risk, but I just keep swinging—boom, boom. A few of them will make it." ❑

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

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

KUWAIT UNIVERSITY

COLLEGE OF ENGINEERING AND PETROLEUM • KUWAIT

The Department of Electrical Engineering at the College of Engineering and Petroleum at Kuwait University invites applications for a faculty position at the rank of Associate or Full Professor, starting from September, 2010 in the following area: Power Systems with High Voltage.

Required Qualifications:
A Ph.D. degree in the area of specialization from a reputable university in the area of specialization is required. The applicant's GPA in the first university degree should be 3 points out of 4 or the equivalent. Research experience and a strong publication record in refereed international journals are also required. Also required is a full command of teaching in English with demonstrated evidence of quality teaching as well as university teaching experience in the specified field. The successful candidates are expected to teach undergraduate and graduate courses, conduct scholarly research, supervise graduate students and carry out some administrative duties.

To apply send by mail or courier within six weeks of the date of announcement, a complete application form with required documents as stated in the form as well as a detailed CV, a copy of the passport and three recommendation letters. All applications should be sent to the following address:

Administration for Academic Staff
Academic Staff Department
Kuwait University
P.O. Box 5969
Safat 13060
State of Kuwait
Tel: 00965-24844189
Fax: 00965-24849562
For application forms refer to the website: **http://www.kuniv.edu/forms.php**

For further inquires: College of Engineering and Petroleum, Kuwait University
Phone: +965-498-7029 Fax: +965-481-7451

Faculty Position in **Mechatronic Systems Engineering**

School of Engineering Science
Simon Fraser University

NOUS SOMMES PRETS

The School of Engineering Sciences at Simon Fraser University is seeking outstanding candidates for tenure track position at the rank of Assistant Professor for its program in Mechatronic Systems Engineering (MSE). The area of specific interest is **Power Electronics with Applications to Clean Energy Systems** including hydrogen technology, fuel cell, microturbines, wind, solar, biomechanical energy conversion, energy harvesting, and hybrid energy source systems, energy storage systems, DSP-based power electronics, motor and adjustable speed drives, development of novel power converters and control strategies, electric machines and actuators, electric and hybrid vehicles. Individuals with an undergraduate and a doctoral degree in Electrical Engineering or a closely related area with a demonstrated potential for scholarly and funded research in the aforementioned research areas, as well as a commitment to undergraduate/graduate teaching are encouraged to apply. Finally, registration or eligibility to register as a Professional Engineer in the Province of British Columbia is required. This normally requires an undergraduate engineering degree from a reputable university.

The School of Engineering Science has a strong commitment to high quality research and offers an excellent research environment. Initial research support will be provided to the successful applicants for establishing their research program. The University has consistently been placed at or near the top of the Maclean Magazine's national ranking. SFU Surrey campus offers brand new state-of-the-art facilities in a central location with easy access to metropolitan Vancouver. All qualified candidates are encouraged to apply; however Canadians and permanent residents will be given priority. The University is committed to employment equity and welcomes applications from all qualified women and men, including visible minorities, Aboriginal people, and persons with disabilities. Applications will be accepted until the position is filled. Position is subject to final budgetary approval by the University. Further, under the authority of the University Act personal information that is required by the University for Academic Appointment Competitions will be collected. For further details see:

http://www.sfu.ca/vpacademic/Faculty_Openings/Collection_Notice.html

To apply, send curriculum vitae, evidence of research productivity (including selected reprints) and the names, addresses, and phone numbers of four referees to:

Dr. Mehrdad Saif, Professor & Director
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby B.C. V5A 1S6 Canada
email: saif@ensc.sfu.ca

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

Endowed Professorships and Faculty Positions in **Energy and Health**

Michigan Technological University announces two Strategic Faculty Hiring Initiatives (SFHIs) that will add up to ten tenure-track positions, including at least one endowed professorship, over the next two years. SFHIs are ongoing commitments to substantially expand Michigan Tech's faculty resources in targeted strategic areas of multidisciplinary research and inquiry.

Michigan Tech seeks to attract exceptional candidates whose interests and capabilities match the two initiatives. Energy SFHI candidates should possess interest and capabilities which can strategically bridge existing strengths and expand research in Next Generation Energy Systems.

For the Health SFHI, the focus areas include biochemistry, bioengineering, bioethics, biomaterials, biomechanics, human factors, medical informatics, cell biology, physiology, and statistical genetics.

Details about the two SFHIs and application instructions are available at ***www.mtu.edu/sfhi***. More general information on Michigan Technological University is available at ***www.mtu.edu***.

Michigan Tech is an internationally renowned doctoral research university located in Michigan's scenic Upper Peninsula, on the south shore of Lake Superior. Houghton provides a unique setting where natural beauty, culture, education, and a diversity of residents from around the world come together to share a superb living and learning experience.

Michigan Tech is an ADVANCE institution, one of a limited number of universities in receipt of NSF funds in support of our commitment to increase diversity and the participation and advancement of women in STEM.

MichiganTech
Create the Future

Michigan Technological University is an equal opportunity, affirmative action employer/educational institution. Applications from women and minorities are encouraged.

UNIVERSITY OF NOTRE DAME

Open Faculty Positions in Electrical Engineering

The University of Notre Dame invites applications and nominations for open tenured or tenure-track faculty positions in the Department of Electrical Engineering.

As many as four new hires will be made, and candidates at all levels – from assistant professor to full professor with an endowed chair – are encouraged to apply. Senior-level appointments will require an outstanding record of achievement and international stature. Recent (or imminent) doctoral graduates with demonstrated research prowess and exceptional promise are encouraged to apply for junior-level positions. All technical areas will be considered, but areas of particular interest include these:

- **electronic materials;**
- **electronic and photonic devices;**
- **nano- and nano-bio electronics;**
- **communications and networking;**
- **signal processing;**
- **control systems.**

Notre Dame's Stinson-Remick Hall of Engineering is scheduled to open in January 2010, and it will contain state-of-the-art facilities for device fabrication and semiconductor material processing.

All positions require a Ph.D. in electrical engineering or related area. Those interested can apply on-line at **http://ee.nd.edu/apply** or by sending a cover letter, curriculum vitae, and two-page statement of research and teaching interests to: Prof. Tom Fuja, Chair – Department of Electrical Engineering, 275 Fitzpatrick Hall, University of Notre Dame, Notre Dame, IN 46556.

The University of Notre Dame is an equal opportunity employer. We particularly invite applications from women and members of groups that are under-represented in science and engineering.

TEXAS A&M UNIVERSITY 1876

Texas A&M University at Qatar

(TAMUQ) is a branch campus of Texas A&M University (TAMU) at College Station, Texas. TAMUQ began teaching undergraduate students in chemical, electrical, mechanical, and petroleum engineering in the Fall of 2003 and started conferring degrees in December 2007. The coursework undertaken by the students is materially identical to the programs offered at the TAMU main campus and the program is ABET accredited. The TAMUQ campus is situated within a new building and is part of Education City, Doha, Qatar, a consortium of educational and research institutions hosted by the Qatar Foundation (QF) for Education, Science and Community Development.

The electrical and computer engineering (ECE) department at TAMUQ currently offers BS degrees in Electrical Engineering but a graduate program in electrical engineering is currently awaiting approval. All formal instruction is given in English. More information about the ECE program at TAMUQ can be found at

http://ecen.qatar.tamu.edu/.

The ECE department at TAMUQ invites applications for faculty positions at all ranks with research and teaching specializations in the following areas:

Telecommunication Networks
Power Systems
Electronics & Electromagnetics

Applicants must have a Ph.D. or equivalent degree, or completion of all requirements by date of hire. For senior positions, applicants should have a proven record of scholarly contributions and a proven ability to attract research funding. For junior positions, candidates should have demonstrated potential for quality teaching and research.

Starting rank and salary will depend on qualifications and experience. The appointment also includes the following benefits: Fully furnished housing; coverage of local tuition fees for school-age dependent children; annual home leave allowance for family members; air tickets to Doha on appointment; and local transportation allowance. Fringe benefits include health and medical insurance as well as an enrollment in a retirement plan. Initial appointment will normally be on a two-year contract, with subsequent contracts being longer term. Re-appointment will be subject to mutual agreement.

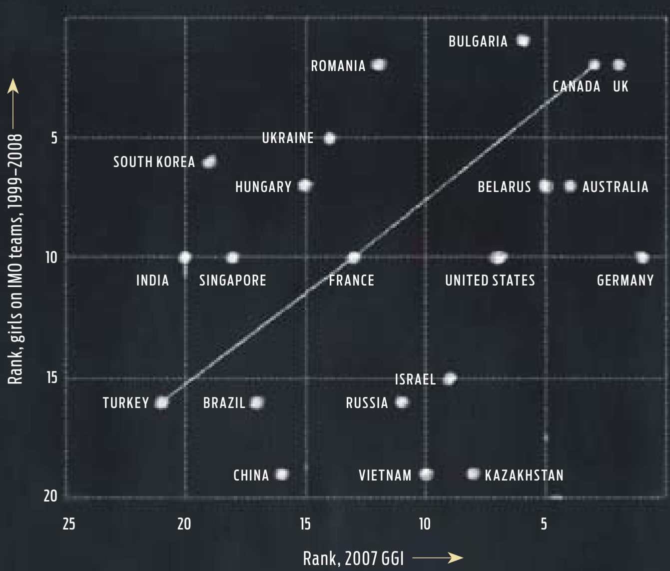
Applications, including full curriculum vitae with a list of publications, a statement of teaching, a statement of research and the names, addresses (regular mail and E-mail), of three references should be sent to in a single PDF file electronically to **TAMUQ-Search@ECE.tamu.edu**, or in hard copy to:

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

Texas A&M University at Qatar is an equal opportunity/affirmative action employer and actively seeks the candidacy of women and minorities. The deadline for applications is February 15, 2010 but applicants will be considered until the positions are filled.

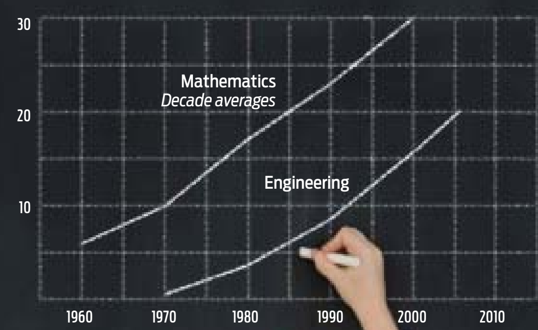
the data

TIMES TABLES: The strongest International Mathematical Olympiad (IMO) countries tend to have the highest percentage of girls on their teams and also have the lowest overall gender gaps, as measured by the World Economic Forum's 2007 Gender Gap Index (GGI).



PERCENTAGE OF U.S. Ph.D.s AWARDED TO WOMEN

Sources: "Gender, Culture and Mathematics Performance," Proceedings of the National Academy of Sciences, 2 June 2009. Mathematics data points are averages of their respective decades; National Science Foundation, "S&E Degrees: 1966–2006," October 2008.



Sources: World Economic Forum; "Gender, Culture and Mathematics Performance," Proceedings of the National Academy of Sciences, 2 June 2009.

Math and Gender

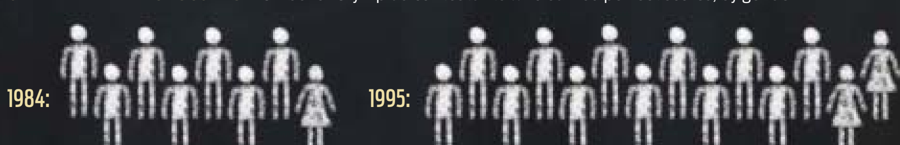
In 1874, the University of Berlin refused to grant a doctorate to the Russian mathematical genius Sofya Vasilyevna Kovalevskaya, who turned around and got one at the rival University of Göttingen; even so, she had to emigrate to Sweden to find a teaching job. Eight years later in the United States, Johns Hopkins University refused to grant Christine Ladd-Franklin a Ph.D., although she'd done her dissertation under the famous logician Charles Sanders Peirce. The school simply did not grant degrees to women.

Today men still dominate mathematics, but there is reason to believe that things are changing. One strand of evidence comes from a study at the University of Wisconsin, published in the *Proceedings of the National Academy of Sciences*, which finds that the overall progress of women in society is a surprisingly good indicator of their performance at the highest math levels.

The World Economic Forum's Gender Gap Index measures inequality between men and women with regard to salaries, politics, education, and health. The Wisconsin study looked at the 2007 index and noted that higher-ranking countries have had more girls on their International Mathematical Olympiad teams in the past two decades. The 2009 index shows a similar correlation.

Girls are starting to perform just as well as boys on standardized math tests [see "Math Quiz: Why Do Men Predominate?" elsewhere in this issue]. The percentage of math Ph.D.s awarded to women has jumped to 30 percent since the 1960s. That's more than can be said for engineering, which is still a male stronghold. —*Prachi Patel*

OLYMPIAD PERFECT SCORES Number of Olympiad contestants who earned perfect scores, by gender



PRIMARY PICTURE/ISTOCKPHOTO

The MathWorks

Accelerating the pace of engineering and science

Puhutko MATLABia?

Over one million people around the world speak MATLAB. Engineers and scientists in every field from aerospace and semiconductors to biotech, financial services, and earth and ocean sciences use it to express their ideas. Do you speak MATLAB?

Image of the Antenna Galaxies processed in MATLAB with the ADRIC galaxy matching program. Provided by Dr. Marianne Doyle, Univ. of Queensland.

Programs available at mathworks.com/ltc

MATLAB®

The language of technical computing