IEEE SPECTRUM

FOR THE TECHNOLOGY INSIDER | 04.14

CELLULAR TELEPHONY MUST DIE!
Steve Perlman says he's got a better idea
P. 11

AN IMPLANTABLE OPTICAL SENSOR
This microlab will get under your skin
P. 38

THE MAN WHO MADE THE CRYOTRON
How Dudley Buck's invention lives on
P. 44

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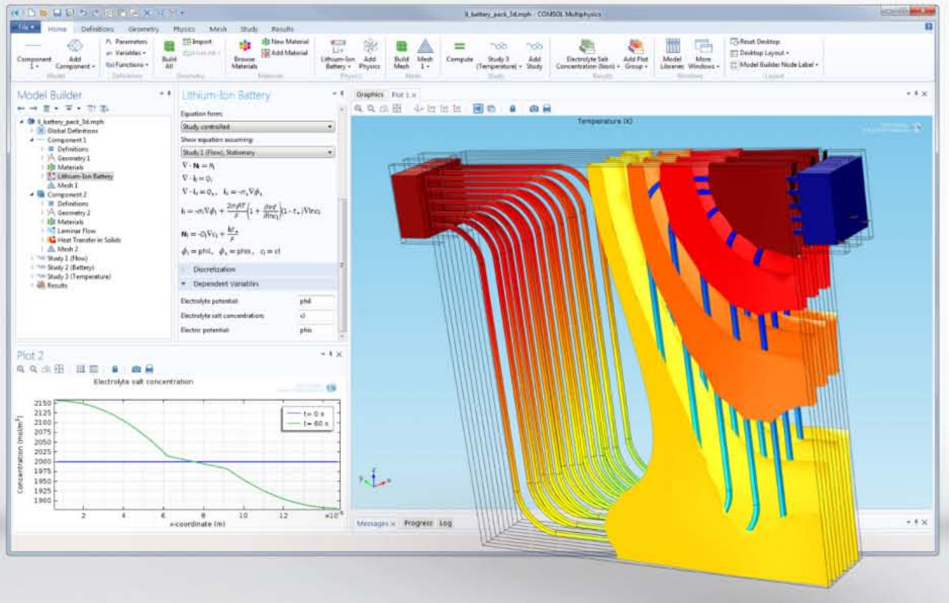
LI-ION BATTERY PACK: Temperature field in a battery pack. The model includes a high-fidelity electrochemical model of the batteries coupled to a thermal analysis for the batteries and the components in the battery pack, and the fluid flow in the cooling channels.



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On the Cover **Illustration for *IEEE Spectrum* by Chris LaBrooy**

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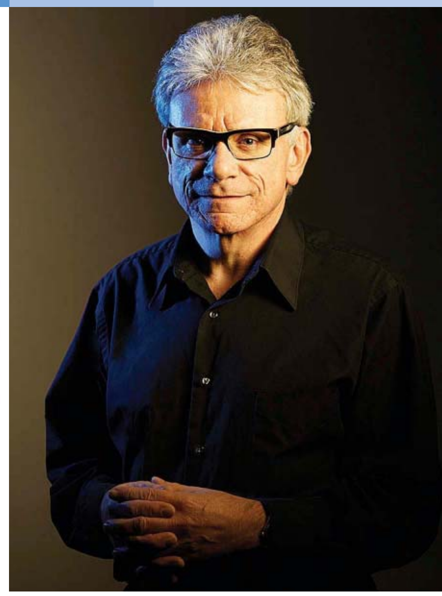

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- **AUTONOMOUS CARS** Three IEEE Fellows pioneered the technology that will pave the way for cars that drive themselves.

FROM LEFT: ARTEMIS NETWORKS; GABRIELA HASBUN; BMW

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BACK STORY_

It's a Tough Job, but Someone Has to Do It

ON A FAIRLY REGULAR BASIS, it's really fun to be Lawrence Ulrich. Here you see him draped on a newly released Porsche 918 Spyder at a Formula One test track in Spain, where he put the "carbon-fiber phantasm" through its paces. But he's writing for *IEEE Spectrum*'s annual Top Ten Tech Cars, where the point is neither speed nor swoopy lines but technology.

Not that there's anything wrong with speed and swoop, of course. But in this case, the technology really is stunning. The Spyder is a plug-in hybrid–a half-gasoline, half-electric chimera that can go many miles on battery power alone, emitting hardly more carbon than a Toyota Prius and getting the kind of mileage that a family breadwinner could love. But in this Porsche, that eco-friendliness is paired with unparalleled ferocity. Think tiger in house-cat clothing.

After the test, Ulrich took the Spyder to Valencia, alongside Timo Glück, a renowned Porsche factory driver, who was behind the wheel of a Porsche 911 Turbo. There they each drove onto a walkway over water, near the science museum and the magnificent Queen Sofia Palace of the Arts. "It's incredibly dramatic modern architecture, but the Porsche's own take on the arts-and-sciences theme managed to upstage it," Ulrich says. "Crowds of people stopped taking pictures of the complex and crowded around our convoy of Porsches instead." And what did he think of the car? In one word, "fantabulous." ■

CITING ARTICLES IN IEEE SPECTRUM *IEEE Spectrum* publishes an international and a North American edition, as indicated at the bottom of each page. 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, Dataflow is in *IEEE Spectrum*, Vol. 51, no. 4 (INT), April 2014, p. 64, or in *IEEE Spectrum*, Vol. 51, no. 4 (NA), April 2014, p. 76.

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Richard Barnes & Brian Rosen

Barnes [left], a security engineer at Mozilla, and Rosen, a systems architect at Neustar, both work on technical standards for emergency 911 systems. In "911 for the 21st Century" [p. 50], they describe a global effort to redesign such systems to handle cellphones and voice-over-Internet Protocol telephony. Barnes once used a cellphone to dial 112 (the European emergency number) to summon an ambulance for a fallen colleague—at a Next Generation 112 conference. Fortunately, the ambulance found him, Barnes recalls, but only after being given directions over the phone.

Jacques Albert

Albert heads the Advanced Photonic Components group at Carleton University in Ottawa, Canada. He is captivated by the elegant way that physical models can find "simplicity in things that are apparently complex." As an engineer of fiber optic devices, he strives for simplicity in his designs. "I look at those complex devices and tell myself, 'There has to be a better way.' " He describes one solution in "A Lab on Fiber" [p. 38].

James Archer

In his work for Anatomy Blue, medical illustrator Archer endeavors to evoke an emotional response. To do that, he employs cinematic techniques to give his images a sense of intimacy and realism. In his illustrations for "A Lab on Fiber" [p. 38], he used shallow depth of field, lighting, and lens distortion. "We're all accustomed to seeing those elements in photos," Archer says. "It brings a sense of authenticity to the image. People begin to question, is it real?"

David C. Brock

Brock is a senior research fellow at the Chemical Heritage Foundation's Center for Contemporary History and Policy. While writing *Makers of the Microchip: A Documentary History of Fairchild Semiconductor* (MIT Press, 2010), he learned of efforts to build briefcase-size superconducting computers during the 1950s. "I asked my history-of-technology friends, and nobody had ever heard about it," says Brock, who recounts this curious historical episode in "Dudley Buck and the Computer That Never Was" [p. 44].

Susan Karlin

Karlin covers the nexus of science, technology, and entertainment from Los Angeles. A frequent contributor to *IEEE Spectrum*, as well as *Fast Company* and NPR affiliate KCRW, she has written for *Forbes*, *Wired*, *Scientific American*, and *Discover*. This month, she profiles Dolby Labs engineer Patrick Griffis [p. 21], who is championing Dolby's attempt to introduce a potentially disruptive video technology. To succeed, Griffis will need to get people all along the entire production pipeline to buy in. He faces a "daunting task," says Karlin.

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PHOTO-ILLUSTRATIONS BY **Gluekit**


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THE TEAM that brings you *The Institute* every month includes [from left] Senior Editorial Assistant Amanda Davis, Editor in Chief Kathy Kowalenko Pretz, and Associate Editor Monica Rozenfeld.

The Birth of *The Institute*

News for members grew from a few pages in *IEEE Spectrum* into a full-fledged publication

TO THRIVE, A MAGAZINE has to publish articles of intense interest to its readers. The alternative is irrelevance, followed by extinction. But is there anything else a magazine should do?

Well, if you're talking about a magazine published by an association, you might reasonably expect it to dispense news about the association–important decisions by its governing boards, election results, recent achievements of its high-flying members, a calendar of upcoming conferences, perhaps a column written by its top officer.

And so it was with *IEEE Spectrum*, from its very first issue in January 1964. A column called "News of the IEEE" (and later "Inside IEEE") dispensed just such information. But the two missions never coexisted comfortably. *Spectrum* was never a typical association magazine. To begin with, it competed for advertising with several hard-charging commercial magazines with big staffs, international bureaus, and powerful publishers. And for most advertisers, an association publication isn't the first choice to get their message across.

So when *Spectrum's* new editor, Donald Christiansen, came on board in 1972, he found it awkward to have IEEE's flagship magazine trying to serve two masters: those who wanted to read about technology and those who were interested in how the society was being governed.

"Ideally, those two should not be attempted in a single publication," he says. "First, it discourages advertising. Second, the governance issues are of little or no interest to a significant number of readers, and of course, of great importance to others."

It took Christiansen a few years to convince IEEE's Board of Directors that a separate publication was needed. He gained some traction from developments within IEEE. In 1972, IEEE members voted to change the organization's constitution to broaden the scope from that of a strictly technical society to one involved in professional issues as well. Back then those topics included wage busting, unionizing, licensing, and working conditions.

The question was, how should *Spectrum* cover such topics? "Because of the controversial nature of professional issues at the time, many of us feared that including such material within the covers of *Spectrum* would have a significantly adverse effect on advertising revenue," wrote Jerome J. Suran, an IEEE officer who would become the organization's president in 1979. That comment is an excerpt from a letter Suran wrote in 1985.

In the letter, Suran went on to describe major debates within the IEEE Publication Services and Products Board and the IEEE Board of Directors about the new publication's mission. Eventually, the boards approved Christiansen's and Suran's plan to spin off a newspaper to cover professional and IEEE news. The boards also resolved to give the editorial staff the responsibility to report independently on professional issues in a balanced and timely way, and to reserve space in the new publication for IEEE leaders to communicate their views and decisions to the members.

IEEE SPECTRUM 1964 / 2014

Christiansen, with support from Suran, took steps to launch the separate publication. In December 1976 a four-page insert called *The Institute* was introduced. It

Editor's note: In this 50th anniversary year of IEEE Spectrum, *we are using each month's Spectral Lines column to recount some pivotal moments of the magazine's history. Here we describe the origins of* Spectrum's *companion publication of IEEE news,* The Institute.

PHOTOGRAPH BY Randi Klett

included two subsections: "Inside IEEE" and "IEEE People." It was printed on heavier paper than *Spectrum*, signaling to members that changes were afoot. In April 1977, the IEEE Board of Directors finally passed a motion that *The Institute* "be published separately for six months, beginning in July 1977 as a non-archival, fast-reading and fast-responding newspaper at a regular frequency."

Expecting to get a new publication off the ground in three months proved to be overly ambitious. An extra month was needed. Under its first editor, Ellis Rubinstein, the inaugural issue was published in August 1977. It carried the tagline "A news supplement to *IEEE Spectrum*" and was mailed only to members in North America. It was published as a monthly in 1978 and was eventually mailed to all members worldwide.

It stayed a monthly until 2003, when for budgetary reasons the IEEE Board of Directors reduced the number of print issues to four per year. At the same time, though, the publication's online presence was expanded. A bimonthly electronic newsletter, *The Institute Alert*, was also launched; it is sent to all members who have shared an e-mail address, giving them a quick summary of the latest online coverage.

Over the past decade *The Institute* has expanded into a set of multimedia outlets that include videos, blogs, social media sites, a PDF digital edition for computers or mobile devices, and a mobile edition for smartphones and tablets.

Visionary though he was, Suran didn't foresee that splendid evolution. But he did predict that we would stumble occasionally. "At times the editorial staff will err, either by a bad judgment call or by excessive zeal in responding to the initial charge of the Board that they try to stir reader interest," wrote Suran in that 1985 letter.

As the longest-serving editor of *The Institute*, I have indeed made a few calls I regret. But my staff and I are committed to stirring reader interest by constantly looking for new ways to showcase IEEE and the work of its members.

—KATHY KOWALENKO PRETZ,
Editor in Chief, *The Institute*

NEWS

8: NUMBER OF HD VIDEOS SIMULTANEOUSLY STREAMED TO 8 SMARTPHONES USING JUST 5 MHz OF SPECTRUM

ARTEMIS NETWORKS

5G SERVICE ON YOUR 4G PHONE?

Start-up Artemis Networks aims to boost wireless data capacity with its pCell technology. But experts are skeptical

"This is going to change everything," said Steve Perlman in a New York City hotel room in February, two days before revealing that his new start-up, Artemis Networks, plans to commercialize its pCell wireless technology. "We can deliver in 2014 all the goals of 5G on 4G phones," he said, including more network capacity and faster, more reliable connections.

Many wireless experts aren't convinced. "This is a promising technology, but some of the claims seem too good to be true," says Lingjia Liu of the University of Kansas, in Lawrence.

Based in San Francisco, Artemis is pitching pCell as a radical change to the way wireless networks operate. The company aims to replace today's congested cellular systems with an entirely new architecture that combines signals from many distributed transmitters to create a tiny pocket of reception, or "personal cell," around every wireless device. With enough transmitters, each centimeter-wide pCell could use the full bandwidth of spectrum available to the network, making its capacity "effectively unlimited," says serial entrepreneur Perlman, Artemis's CEO.

THE ANTI-CELL: Artemis Networks' pWave radio access points transmit data to multiple wireless devices at once using the same slice of spectrum.

IEEE SPECTRUM | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

"If they've done what they say they've done, it's an absolutely remarkable achievement," says Giuseppe Caire, a multiple-antenna systems expert at the University of Southern California, in Los Angeles.

That's a big "if." Artemis has made public few details behind the technology, and many experts doubt that pCell can live up to the company's claims. "Everyone is thinking, 'Is this just smoke and mirrors? Is it a repositioning of existing tech? Or is it something radically new?' " says Peter Jarich, a vice president at market intelligence firm Current Analysis, in Washington, D.C.

Perlman's nine-person team began filing patents on the technology behind pCell a decade ago, calling it DIDO, for distributed input, distributed output. Most wireless researchers refer to this kind of approach as distributed (or coordinated) multiuser multiple input, multiple output (MU-MIMO).

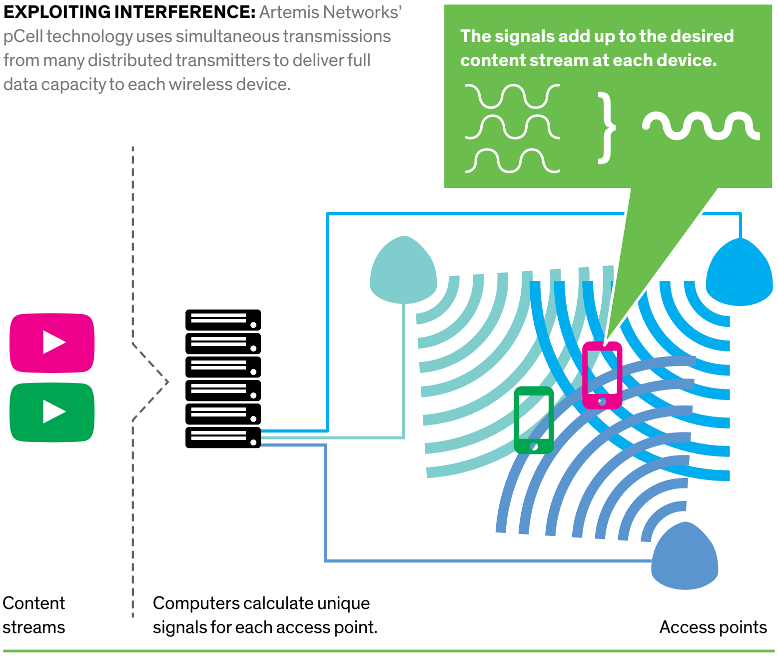
Regardless of its name, Perlman believes his technology is key to solving the wireless industry's biggest problem: the exponential growth in data traffic. "For operators, it's the best of times and the worst of times," he says." People want more data, but the operators "don't have the physical capability to deliver it."

It isn't for a lack of ideas. Engineers are pursuing plenty of them, including small cells, millimeter-wave spectrum, beam forming, and advanced cell coordination. The LTE-Advanced standard, for example, already supports simultaneous connections to multiple base stations.

But Perlman thinks that many of these fixes are just clever kludges for an outdated system. The real bottleneck, he argues, is the fundamental design of the cellular network. "There is no solution if you stick with cells," he says.

What's wrong with cells? In a word, interference. Base stations and wireless devices must carefully coordinate their transmission power and spectrum use so that they don't jam one another's signals. This ability to divide spectrum resources among many users has been at the heart of cellular systems since they emerged in the 1980s. It's also the reason why data rates tend to plummet when many users try to use the same cells or roam between them. Although a 20-megahertz-wide 4G LTE channel can theoretically support about 75 megabits per second, the average throughput to a single user is typically only a fraction of that.

EXPLOITING INTERFERENCE: Artemis Networks' pCell technology uses simultaneous transmissions from many distributed transmitters to deliver full data capacity to each wireless device.



Artemis's pCell technology turns traditional cellular architecture on its head by exploiting interference rather than trying to avoid it. To deploy such a system, an operator would first need a data center connected by fiber or wireless line-of-sight links to radio transmitters distributed near its customers. Roughly the size of hatboxes, these access points would be unlike ordinary cellular base stations. "They're dumb devices," Perlman says, adding that they would serve merely as waypoints for relaying and coordinating transmissions.

To deliver data to a wireless device such as a smartphone, the data center would first fetch it from the content provider. But rather than transmit the stream through a single transmitter, as in a traditional cellular system, the data servers would send signals simultaneously through all of the access points in your phone's range–as many as dozens at a time, Perlman says.

Of course, if every transmitter broadcast the same signal, it would drown out other phones trying to connect to the network. So instead, the data center would use the positions of the access points and the channel characteristics of the system, such as reflection and fading, to calculate a unique waveform for each access point. Although indecipherable when they left the transmitters, these waveforms would add up differently at each phone to form a signal that delivers the desired data.

As each phone moved about, and as other devices connected to or dropped off the network, the data center would continuously recalculate new waveforms so that every user maintained a good connection. To upload data, the process would happen in reverse: Each phone would transmit simultaneously to a cluster of access points, and the data center would resolve the individual signals mathematically, using the differences in channel characteristics. "There's no handoffs, and no one has to take turns," Perlman says. "You could literally light up a whole city using all the same spectrum."

In theory, every pCell antenna adds another full channel of bandwidth to the network. For example, if your network uses a 20-Mhz-wide channel capable of delivering 70 Mb/s, deploying 10 antennas would increase the total capacity to 700 Mb/s. If there are more users than antennas, they would share the 10 available channels in time or frequency.

ILLUSTRATION BY Erik Vrielink

Perlman has claimed that pCell technology could eventually increase the capacity of today's cellular networks as much as a thousandfold. But experts say that any performance gains will be limited by the processing capability at the data center and the speed and reliability of links to the access points. "You should be able to collect channel information, compute the signals, and send them back to the transmitters in less then 10 milliseconds," USC's Caire says. "According to our simulations, we see gains of about a factor of 10 for realistic scenarios. Much more than that, I'm skeptical."

At Columbia University in New York City, Perlman demonstrated pCell technology communicating with 4G LTE phones and other devices. Compatibility with LTE would allow users to roam seamlessly between the two networks without having to buy new handsets. Artemis's engineers achieved this feat by simulating LTE base stations in software, using these virtual radios to inform the waveform calculations. However, MU-MIMO experts argue that such compatibility will be much more difficult to maintain in real-world environments.

Artemis is manufacturing pCell access points with small-cell provider PureWave Networks and is planning for large-scale trials in San Francisco. The company expects commercial rollouts by the end of 2014.

Wireless experts say that Artemis has yet to prove it can overcome several difficult obstacles, including the large-scale coordination of transmissions from many access points and the integration of pCell clusters into existing cellular networks. "These are rigorous engineering challenges," says Zhouyue "Jerry" Pi, a senior director of Samsung Research America in Dallas. "It's not easy to make this kind of distributed MIMO work and create benefits."

Still, some experts concede that technologies like pCell would make sense in congested hot spots such as airports, sports stadiums, and city centers—places where operators are already investing in dense clusters of small cells and where users don't move around much. "But is it really going to revolutionize the data capacity of the whole world?" Pi asks. "I doubt that." —ARIEL BLEICHER

NEWS

SATELLITES AND SIMULATIONS TRACK MISSING METHANE

Europe is spending €45 million to correctly gauge emissions of the greenhouse gas

Methane emissions from oil and gas extraction, herding livestock, and other human activities in the United States are likely 25 to 75 percent higher than the U.S. Environmental Protection Agency currently recognizes, according to a meta-analysis of methane emissions research published recently in *Science*. While experts in remote sensing debate the merits of this and other recent challenges to the EPA's numbers, definitive answers are already on order via a high-precision Earth observation satellite to be launched next year.

The intensifying methane emissions debate has profound implications for climate and energy policy. Natural gas consumption is rising, and methane's global warming impact is more than 30 times as much as that of carbon dioxide, molecule for molecule, and second only to carbon dioxide's in today's net climate impact.

Greenhouse gas inventories such as the EPA's quantify emissions from the bottom up. They assume a leakage rate for each known source type and add up the sources. The EPA's figures are being challenged by studies employing top-down methods, which use "inverse modeling" to transform point measurements of atmospheric methane into emissions estimates. Models of airflow are used to predict where measured methane is coming from and how fast it is flowing.

Conclusions from the meta-analysis research, led by Stanford University energy resources expert Adam Brandt, track closely the results of the most recent and most comprehensive measurement-based estimate of nationwide methane emissions. The latter, published in November in the *Proceedings of the National Academy of Sciences* by a multi-institution team of U.S.-based scientists, relies on more than 12 000 air samples collected from towers across the United States and flights by research planes

DO YOU SMELL SOMETHING?
A satellite might determine whether cattle or oil and gas wells are the bigger climate culprits.

ISTOCKPHOTO

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

in 2007 and 2008. Anna Michalak, one of the study's authors and an expert in remote sensing and inverse modeling who also happens to be at Stanford, says the team's national methane estimate is accurate to within 10 percent and shows that EPA's inventories have some holes.

"The total from our atmospheric measurements does not equal the sum of the parts counted in the inventories. We need to look at whether there are line items that are underestimated by the inventories, or missing entirely," says Michalak.

A regional estimate by the authors of the *PNAS* report for the heavily drilled south-central U.S. states, meanwhile, points to oil and gas operations as a likely undercounted methane source. Accounting methods comparable to those used in the EPA's inventories (which do not break down emissions by region) yield methane estimates of 3 million metric tons of carbon per year, only about a third of what Michalak and her colleagues found. The report's authors conclude that the region's oil and gas fields leak five to seven times as much methane as the EPA inventories capture.

Natural Resources Defense Council staff scientist Vignesh Gowrishankar says those higher leakage rates—at least 7.5 percent of gas production instead of the 1.5 percent assumed by the EPA—would make electricity generated from natural gas more carbon intensive than coal-fired power. The EPA says it is paying attention. In January, EPA administrator Gina McCarthy told a U.S. Senate panel that the EPA was working with other agencies to "assess emissions data" for methane and "address data gaps."

Higher leakage rates would make natural gas more carbon intensive than coal

Not all experts are buying the latest figures, however. Harvard University environmental engineer Daniel Jacob says the latest inverse modeling study did not include enough data to reliably model emissions nationwide. And Jacob says they conflict with findings from top-down estimates that he and his colleagues assembled from two months of satellite-based measurements from 2004 before the premature failure of a methane detector on Europe's Envisat satellite. (The satellite itself operated from 2002 to 2012, five years longer than it was engineered for.) Their study affirms the EPA's national estimate and attributes larger-than-expected emissions in the south-central U.S. primarily to livestock.

Where Michalak and Jacob do concur is on what they call an approaching revolution in top-down predictions due to satellite observation. For methane, the revolution kicks off with the €45 million (US $62 million) Tropospheric Ozone Monitoring Instrument (Tropomi), which the European Space Agency plans to launch next year on board the Sentinel-5 Precursor satellite. Like its predecessor on Envisat, Tropomi measures sunlight reflected off Earth and detects absorption of telltale wavelengths to measure atmospheric levels of methane and other gases.

But Tropomi is at least 10 times as sensitive as the Envisat instrument, according to Johan de Vries, Tropomi's instrument scientist at Dutch Space, the satellite's manufacturer. And its resolution is higher too, promising daily measures for the entire globe at 7 by 7 kilometers. "It will mean that you can see sources of methane on the subcity level," says de Vries.

The data, predicts de Vries, will have political and commercial implications as top-down measurements shift the balance of responsibility for methane emissions from one state or economic sector to another.

He anticipates another round of reassessment as top-down measurement of CO_2 improves. But that will take more work, because CO_2's absorption signal is harder to isolate than methane's from the signals of other gases. "CO_2 measurements are at least five years behind," says de Vries.

—PETER FAIRLEY

CLOCKWISE FROM TOP LEFT: PLANETIQ; URTHECAST; NASA; SKYBOX IMAGING; DAURIA AEROSPACE

5 EARTH-IMAGING START-UPS COMING TO A SKY NEAR YOU

A tech boom in cheap, tiny, yet surprisingly able satellites

Words like "provocative" and "disruptive" are rarely applied to the staid world of satellite imaging. But that's exactly the kind of talk the industry is generating, with the launches of more than two dozen Earth-imaging satellites in the last few months and more planned by year's end.

Those spacecraft, far smaller and cheaper than traditional satellites, are being lofted not by the usual aerospace players but by venture-capital-funded start-ups. In many cases they'll orbit in large constellations capable of revisiting sites several times a day. Though their per-pixel resolution won't compete with that of satellites from market leader Digital Globe, they'll provide fresher data at a lower price.

The press has made much of start-up Skybox Imaging's projected ability to count all the cars in every Walmart parking lot in the United States on Black Friday. Other uses


UrtheCast


Skybox Imaging


Planet Labs

include assessing storm damage, monitoring crop health, and tracking human-rights abuses.

Pete Klupar, former director of engineering at NASA's Ames Research Center, notes how Skybox and Planet Labs creatively scavenge components from other industries. "They're using IMUs [inertial measurement units] from video games, radio components from cellphones, processors meant for automobiles and medical devices, reaction wheels meant for dental tools, cameras intended for professional photography and the movies," he says. "They're taking the fruits of the commercial world's labor and applying them to space."

To be sure, offering images on the cheap isn't enough to make a business. "Images are just raw data," says Tim Brown, a satellite imaging expert at Globalsecurity.org. Equally important, he says, are "reliability, accuracy, how much tinkering of pixels do I have to do, how user friendly is the interface."

Right now, there are two dozen nonmilitary Earth-imaging spacecraft, notes Alex Herz, CEO of Orbit Logic, which makes mission-planning software for satellites. (To find out when one of them is passing overhead, try the company's SpyMeSat app.) "Five years from now, there might be 200 or more up there," he says.

"The things you'll be able to do with satellite images will grow exponentially," Brown predicts. "Pretty soon, you'll have a world where pretty much nothing goes undetected."
—JEAN KUMAGAI

Who, where: SKYBOX IMAGING, Mountain View, Calif.

What: High spatial- and temporal-resolution Earth imaging (including high-definition video) at a competitive price.

How: A planned 24-satellite constellation within the next five years, starting with SkySat-1 (launched November 2013), SkySat-2 (launching mid-2014), and SkySat-3 (launching late 2014); six more are set to launch in late 2015. According to Skybox, each satellite costs less than US $20 million to put into space, with a planned life span of 6-plus years. SkySat-1's 0.9-meter-per-pixel resolution is the best to date among all the start-ups' offerings, although still lower than established operator Digital Globe's spacecraft. A full constellation will enable revisits of any spot on Earth up to four times daily.

Verdict so far: "I'm most impressed with Skybox's high-resolution video. It's almost mind-blowing to think of what you could do with that information." —PETER WEGNER, *director of advanced concepts at the Space Dynamics Laboratory*

Who, where: PLANET LABS, San Francisco

What: Medium-resolution "whole Earth" imaging with unprecedented frequency for both commercial and humanitarian ends.

How: Large constellations of nanosatellites ("flocks of doves," in the company's parlance) based on CubeSat architecture that will fly in a low Earth orbit of about 400 kilometers. At press time, Planet Labs was in the process of releasing 28 satellites from the International Space Station, following the successful launch of four test doves last year. Each 10- by 10- by 30-centimeter dove weighs just 5 kilograms, has an image resolution of 3 to 5 meters, and is built to be expendable: According to Planet Labs, up to 20 percent of its satellites can fail without affecting operations.

Verdict so far: "There's definitely a niche where temporal resolution is more important than spatial resolution." —CHARLES FINLEY, *spacecraft lead in the Department of Defense's Operationally Responsive Space Office*

Who, where: URTHECAST, Vancouver, B.C., Canada

What: 24/7 high-definition video of Earth for monitoring the environment, humanitarian relief, social events, agricultural land, and such.

How: Two high-definition video cameras (1-meter and 6-meter resolution) installed on the Russian portion of the International Space Station, passed their initial functional tests in mid-February. Being on the space station means the UrtheCast cameras have a constant ground link, so they can be "retasked" on the fly. Small satellites, by contrast, have fewer opportunities to link up with ground stations, so they typically experience a delay in receiving new instructions to reposition their imagers.

Verdict so far: "It's a great idea. It's surprising that NASA did not think of this years ago." —ALEX HERZ, *CEO of Orbit Logic*

Who, where: PLANETiQ, Bethesda, Md.

What: Atmospheric imaging for weather forecasts, climate modeling, and space weather prediction using a sounding technique known as GPS-radio occultation.

How: A planned constellation of 12 to 24 small satellites; no launch date. The company says its network could help fill a looming gap in U.S. weather-data collecting that could start as early as this year and last 17 to 53 months. It would be cheaper to build and operate than the government's own weather systems.

Verdict so far: PlanetiQ could face some competition from GeoOptics, another start-up aiming to do the same basic thing, using the same basic technique.

Who, where: DAURIA AEROSPACE, Munich

What: Small, low-cost satellites built on contract for Earth observation, communication, and navigation.

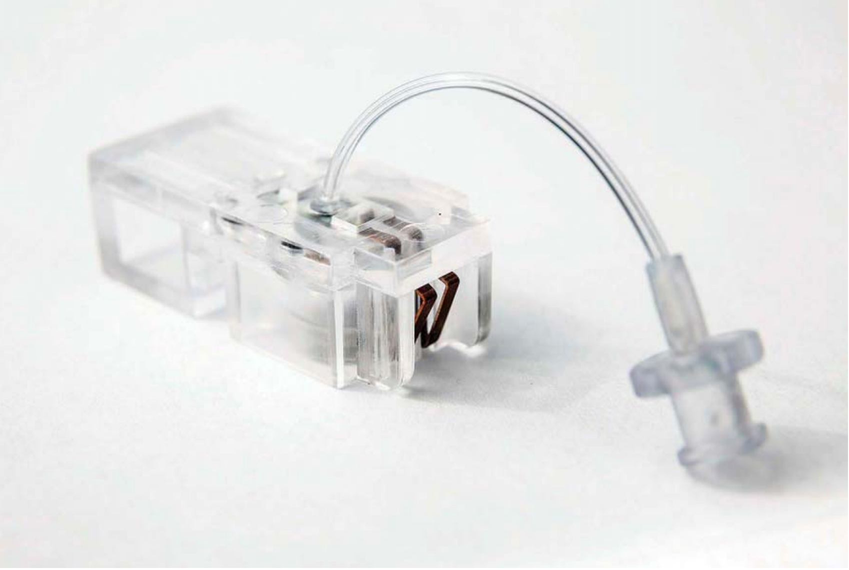
How: The German-Russian-U.S. start-up (sometimes called Russia's first private space firm) is designing and building satellites for government and corporate customers, including NASA, the European Space Agency, and the Russian space agency, Roscosmos. Dauria also plans to launch four of its own satellites: Sagitta and Perseus this year, and Pyxis and Auriga sometime between 2015 and 2017.

Verdict so far: "Rather than pursuing new market segments or novel hardware like some others are doing, Dauria's plan is to sell to [the U.S. agencies] NOAA, NASA, and to European governments." —PETE KLUPAR, *former director of engineering, NASA Ames Research Center*

For more Earth-imaging start-ups, see http://spectrum.ieee.org/satellites0414

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

NEWS



SUPERBUG SUPERSLEUTH: F Cubed's chip uses an electric field to tease out the presence of a MRSA bacterium's DNA.

BIOCHIP VS. SUPERBUG

A lab-on-a-chip could quickly tell if an infection is the dreaded antibiotic-resistant MRSA

It's an irony of our time that checking into a hospital can kill you, thanks to several antibiotic-resistant superbugs that have found niches in health-care facilities. Now, to combat the menace of one particularly lethal strain of bacteria, doctors at four hospitals in the United States are trying out a speedy method to identify patients who have MRSA (methicillin-resistant *Staphylococcus aureus*).

Using a lab-on-a-chip technology from a start-up called F Cubed, physicians should be able to diagnose MRSA within an hour, and without leaving the emergency room. F Cubed hopes that this year's clinical trial will lead to a commercial device.

MRSA infections start on the skin or in a wound, but they can spread through the bloodstream to cause life-threatening illnesses like pneumonia and sepsis. The U.S. Centers for Disease Control recently estimated that more than 80 000 people got invasive MRSA infections in 2011, and more than 11 000 of those patients died. Most of those serious infections, says the CDC, occurred during or soon after inpatient medical care.

Les Ivie, president and CEO of F Cubed, which is in South Bend, Ind., says that despite the pressing need, doctors lack a quick and easy test to diagnose MRSA. The fastest lab tests today take many hours, and they're so expensive that physicians rarely opt for them. "If you were to check into a hospital with a suspected infection, typically they would do a plate culture to grow bacteria, and that takes three to four days," he says. "The problem is that if you have a MRSA infection, you may not have three to four days before it gets into your bloodstream."

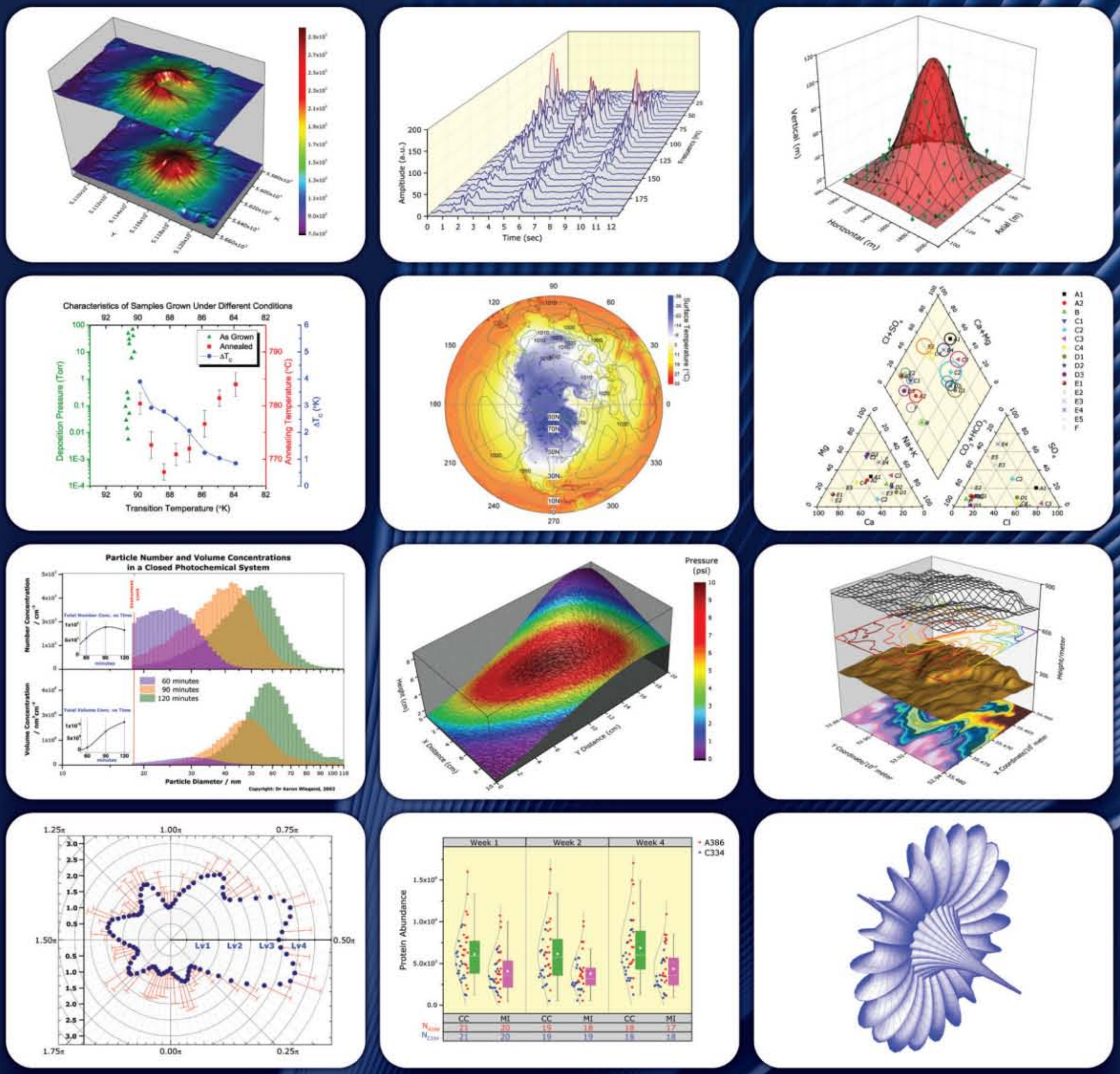
The heart of the F Cubed system is a disposable biochip measuring 7 by 14 millimeters, which snaps into a molded plastic panel that handles the sample flow and waste. The biochip is based on research by Hsueh-Chia Chang, director of the Center for Microfluidics and Medical Diagnostics at the University of Notre Dame, in Indiana. The plastic panel is inside a suitcaselike container along with the components that manage the rest of the testing process, from sample preparation to the final readout.

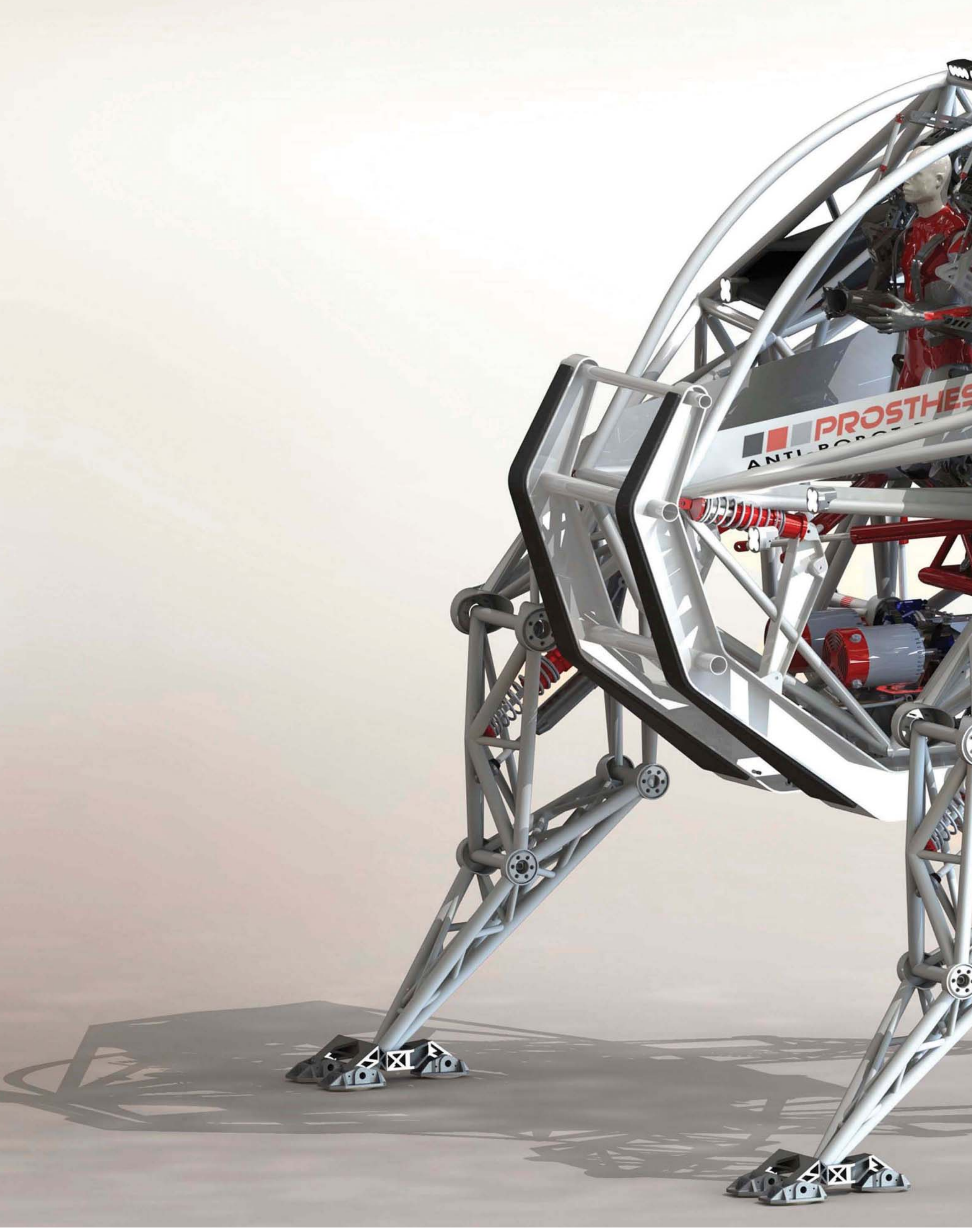
The device first isolates the DNA in a pus sample from a wound and breaks apart the DNA's double helix structure into two single strands. Then a pump sends that DNA through the chip's nanofluidic channel, where minuscule probes hold single strands of DNA unique to the MRSA bacterium. Electrode microarrays on the sides of the chip create an electric field throughout the channel. If MRSA is present in the patient's body, the DNA in the sample will bind to the complementary DNA on the probes, changing the conductivity of the system. If the biochip detects that change, that means the MRSA bug is present in the sample.

Ivie says this system is cheap to manufacture because, unlike many other genetics-based tests, it doesn't use any fluorescence or optics. "All we are doing is measuring electrical changes, which is very simple to do," he says. Another advantage, Ivie says, is ease of use. Other lab tests require technicians to isolate the DNA of just one species in the sample and are vulnerable to contamination, but the F Cubed system works even if the DNA of multiple microbe species is in the mix; the biochip will register the MRSA bacterium's DNA if it's present, and the rest will just wash through the channel and out of the chip. "Our process could be done by a physician in an emergency room, in the back of a truck, or in the middle of the desert," Ivie says. "It does not have to be clean."

This technology could be a great boon in emergency rooms, says Richard Wenzel, a physician at the Virginia Commonwealth University and an expert on MRSA prevention and treatment in hospitals. "If the patient has actual pus somewhere and you could know within an hour whether this really is MRSA and should be treated appropriately, that would be very useful," he says. However, Wenzel says, because of increased vigilance by hospital staff, few MRSA patients go untreated today. "What we're doing now is just treating all skin and soft tissue infections like MRSA, because in 70 to 75 percent of the cases that's what they turn out to be," he says. "That would be the caveat to saying this diagnostic tool is a major breakthrough."
—ELIZA STRICKLAND

PETER RINGENBERG


Characteristics of Samples Grown Under Different Conditions
Particle Number and Volume Concentrations in a Closed Photochemical System
Pressure (psi)
Protein Abundance



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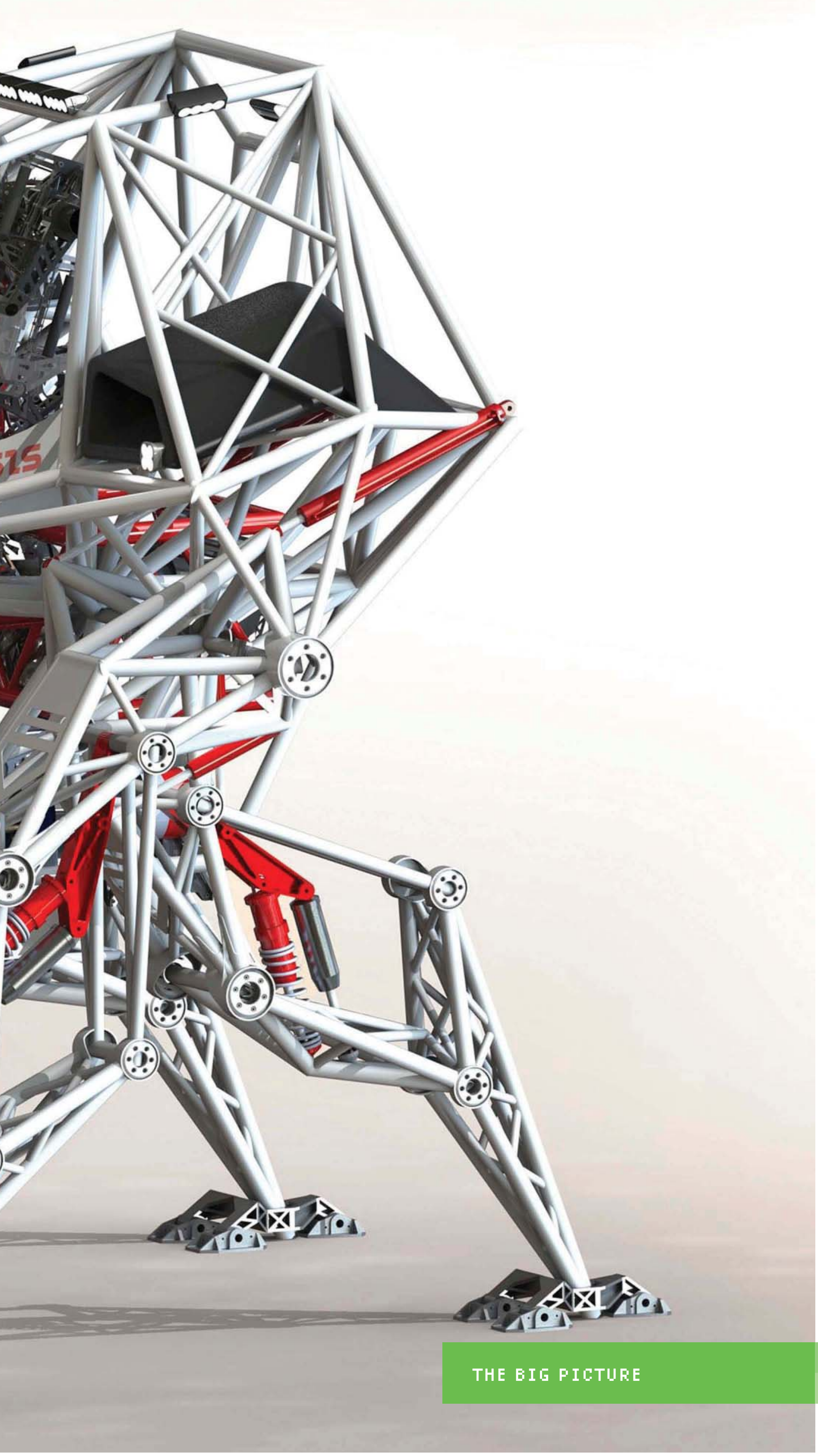


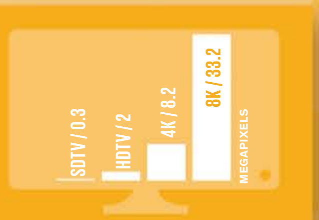
I AM THE MACHINE

COUNTLESS KIDS have daydreamed about putting on an exoskeleton that provides superhuman strength and protection from bad guys. But as this illustration shows, Jonathan Tippett, an artist and mechanical engineer, is bringing his childhood vision to life. Tippett, assisted by a team of volunteers, has designed a mock-up of Prosthesis, the Anti-Robot, which he says is the world's first human-piloted racing robot. The 5-meter-tall aluminum quadruped's limbs mirror the movement of its pilot's arms and legs. An electrical system that draws power from a bank of lithium-ion batteries delivers up to 230 kilowatts to hydraulic pumps that amplify the force exerted by the pilot by up to 100 times. This will allow the human who controls the 3500-kilogram machine to make it gallop at speeds approaching 30 kilometers per hour.

THE BIG PICTURE NEWS

ILLUSTRATION BY Rex Features/AP Photo

RESOURCES



INCREASES IN TV RESOLUTION ARE PLACING HIGHER AND HIGHER DEMANDS ON NETWORKS AND STORAGE.

RESOURCES_PROFILE

PATRICK GRIFFIS
HE'S LEADING DOLBY'S CHARGE TO REDEFINE DISPLAY TECHNOLOGY

It's hard enough to come up with groundbreaking technology. But what happens when implementing that technology requires changes to an entire industry? That's the challenge that Patrick Griffis faces at Dolby Laboratories, as a new system from the company aims to revamp how video is captured, processed, and displayed. ● Called Dolby Vision and unveiled at the Consumer Electronics Show this past January, the system is actually a suite of technologies that promises greater brightness, contrast, and color range. "It's not just another knob on a TV," says Griffis, who is Dolby's executive director of technology strategy. "It's a fundamental rethinking of the content creation, packaging, and delivery systems." ● Convincing all the players who will have to buy in for Dolby Vision to succeed is where Griffis comes into play. Six years ago, he joined Dolby to help guide its technology into the marketplace. A longtime IEEE member and former president of the IEEE Consumer Electronics Society, Griffis has tackled TV audio design, digital broadcast standards, and digital TV strategy at RCA, Panasonic, and Microsoft. "My job has been to target upcoming technologies impacting the company, determine how to deal with them, investigate partnerships, represent our technology in standards efforts, and, finally, explain the technology," he says.

PHOTOGRAPH BY Gabriela Hasbun

Consequently, Griffis often finds himself expounding why he thinks it's time to move beyond current cinematic and broadcast standards, which had their genesis in 20th-century film and cathode-ray-tube technology.

"It all starts with making a better pixel," says Griffis. Standard displays have pixels that are encoded with 8 bits each for red, green, and blue, allowing 256 steps in intensity for each primary color. Dolby Vision pixels start at 12 bits per primary color (enabling 4096 steps) and can go up to 16 bits (providing 65 536 steps). With these pixels, Dolby created a research monitor that can display images with roughly 80 times the cinematic standard in peak brightness—4000 candelas per square meter, or nits, instead of the standard 48. The standard today is 48 cd/m^2 because in the early days of film "the brightest lightbulb you could put in a projector without melting the film resulted in 48 nits on the screen," says Griffis.

Such legacy standards, from those for how movies are shot to the way they're distributed on DVD and Blu-ray discs or (increasingly) by Internet-based video services, are why Griffis has spent a lot of time working with companies through the entire movie and TV ecosystem. "A lot of partnerships were involved," he says. "We weren't working in a vacuum."

Some of those partnerships are further along than others. TV manufacturers Sharp, TCL Multimedia, and Vizio have developed their own prototype sets—also shown at CES—that can display Dolby Vision. Amazon, Microsoft, Netflix, and Vudu hope to deliver entertainment using the new technology once Dolby Vision–enabled sets and Dolby Vision–mastered content are in place.

Griffis earned a bachelor's in electrical engineering from Tufts University in 1974 and a master's in EE from Purdue University in 1981. He's particularly attracted to the job of wrangling technology partnerships, he says, because "it's using my engineering skills in a different way—understanding how technology trends are affecting business."

"I love working on technologies that make a difference for the consumer, in a role where my personal contributions make it happen," says Griffis. And he encourages other engineers to join in the creative and technological renaissance he feels is in the offing: "Entertainment is benefitting from advancements across the board in computing, displays, signal processing, and delivery, among others," he says. "It's a great time to be a technologist in this arena. A revolution is in the making that will be driven by technology and realized by the artists who master the new tools."

But Griffis accepts that it's going to take a while for his work with Dolby to bear fruit. "It's taken 100 years to get to where we are today. You're not going to change the ecosystem overnight."

—SUSAN KARLIN

THE WHOLE PICTURE: As shown in these simulated images, Dolby's new technology captures and displays more information per pixel [left] than current systems [right].

DOLBY VISION SIMULATION: ROBIN ATKINS AND SUZANNE FARRELL

RESOURCES_REVIEW

MUSHROOM CLOUD MEMORIES
LAS VEGAS'S NATIONAL ATOMIC TESTING MUSEUM IS A SHRINE TO COLD WAR INGENUITY

A FEW MINUTES FROM THE GAUDY ENERGY OF THE LAS VEGAS STRIP IS A quiet museum dedicated to an age when nuclear fireballs lit up the Nevada desert like second suns. Starting in 1951, more than 1000 atomic devices were detonated at what is now called the Nevada National Security Site, about 100 kilometers north of Las Vegas. Detonations went underground in 1963 and were suspended completely in 1992. The National Atomic Testing Museum (NATM) chronicles the history of the period, as well as some of the work at the site that continues to this day. ● While many visitors will be drawn to the museum by the dark glamour of the atomic age, the museum is in truth a celebration of test and measurement engineering. For obvious reasons, minimal details are given regarding the nuclear bombs at the heart of the tests. So the focus is squarely on the equipment used to capture the nuances of the highly energetic yet incredibly brief operating lives of these devices.

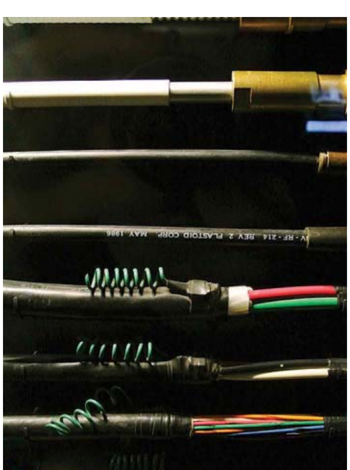
The museum displays many photographs and movies taken during the iconic atmospheric testing days, when Las Vegas hotels and casinos would run buses for tourists out to viewing sites. But for me the most interesting period followed the move to underground testing.

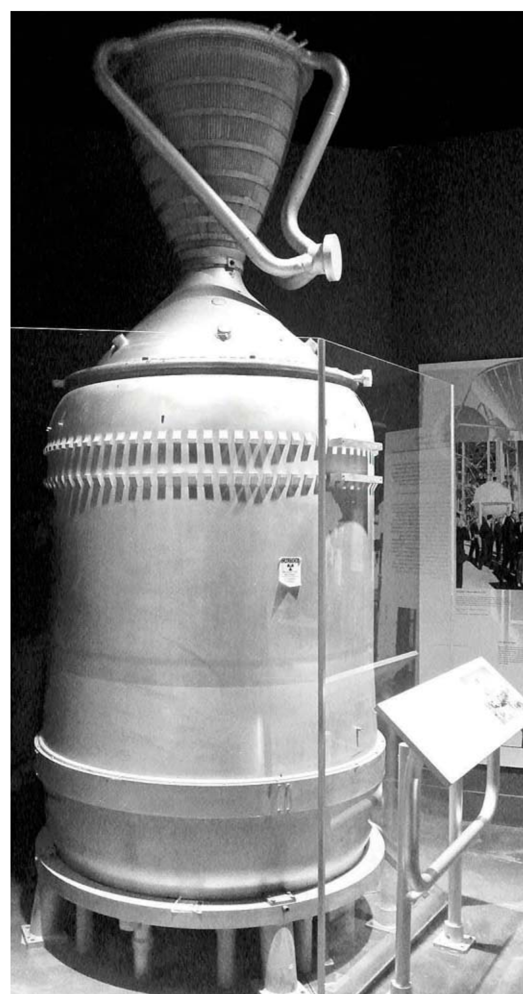
Researchers initially feared that the shift underground from the typical arrangement of placing a bomb on a tower would diminish the value of the tests, but in fact the result was higher quality data. All sorts of testing equipment and ancillary experiments (such as directing beams of radiation from the blast onto targets of various materials) could be set up much closer to the detonation epicenter. Of course, a big challenge for engineers was to make critical measurements and communicate the results in the scant fractions of a second before their underground equipment was vaporized. The exhibition halls are filled with ingenious solutions.

One fascinating exhibit is devoted to the development of nuclear rocket technology. Such rockets can deliver tremendous performance compared to that of chemical rockets. A test stand was built at the Nevada site, but a lack of funding post-Apollo led to the program's cancellation in 1973. Nonetheless, NASA judged that the Nevada testing had sufficiently proved the technology for nuclear stages to pop up in Mars exploration plans for decades.

Some missteps in the desert are featured, such as the accidental release of a huge cloud

COLD WAR RELICS: The AIR-2 Genie, a nuclear missile for air-to-air combat [top], and radiation warning tape issued to civil defense organizations [bottom].





MEASURING THE BOMB: Nevada's test site was host to many iconic nuclear detonations such as 1953's Grable explosion [above] before testing moved underground. Capturing data from exploding nuclear bombs often required sending information via cables [left] designed for high-speed transmission before sensing equipment was destroyed. Cables were often bound together into large bundles; a cross section of one bundle on display at the National Atomic Testing Museum is about 30 centimeters across [top]. Not every test involved weaponry. The test site also housed trials of nuclear rocket engine designs [right].

PREVIOUS PAGE: STEPHEN CASS (2); THIS PAGE, CLOCKWISE FROM TOP: STEPHEN CASS (3); U.S. DEPARTMENT OF ENERGY of radioactive dust and gas during the 1970 Baneberry test. There's also space set aside for a display on Native American artifacts and beliefs, acknowledging that an ancestral homeland is now one of the most dangerously contaminated places on Earth.

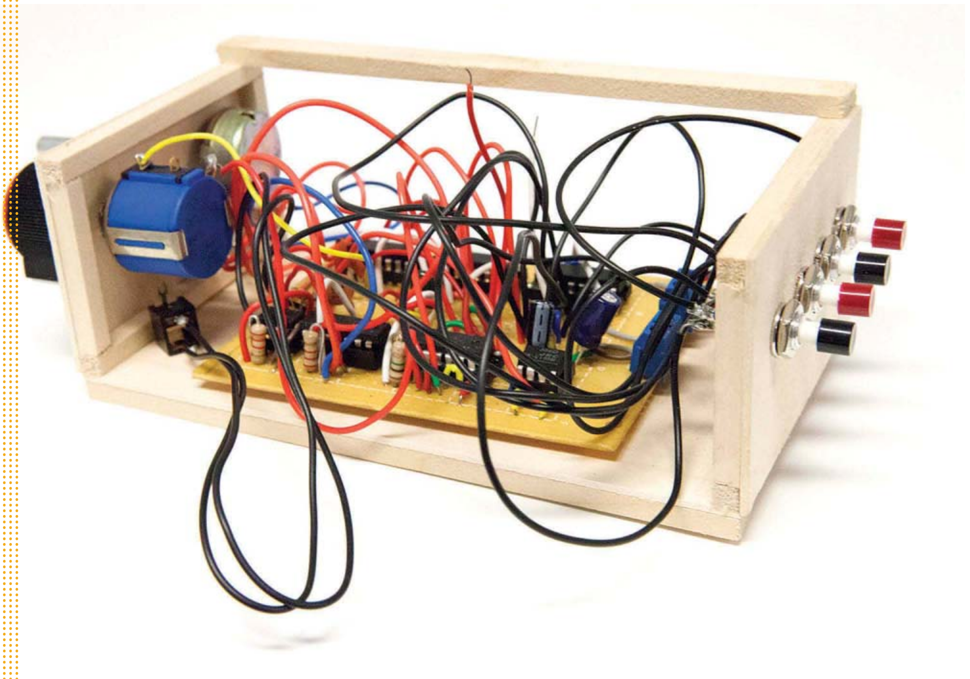
A temporary exhibition on Area 51 is also currently running. This seems to be the product of two distinct groups: one composed of those wanting to commemorate the difficult and often dangerous secret work done during the Cold War at facilities like Area 51 (also known as Groom Lake), the other composed of UFO-as-alien-visitor conspiracy types. Despite the frequent "Myth or Reality?" cautionary signs posted about, the UFO believers appear to have gotten the upper hand—but not the last laugh. On exiting the exhibition, via a dark corridor, visitors see a UFO-shaped group of lights floating above the corridor's end, which resolve themselves into a pattern draped over a model of the SR-71 reconnaissance plane, flight-tested at Area 51 in the 1960s.

Finally, I usually wouldn't bother mentioning a science and technology museum's gift shop, since they are generally full of run-of-the-mill T-shirts with the local logo, along with a generic assortment of educational toys and novelties. But the NATM shop has a couple of items you're unlikely to find anywhere else, including snow globes with little mushroom clouds inside and hand-painted shot glasses. Each of these glasses pictures the result of a specific Nevada nuclear test. I chose one that depicted the 1953 Grable test, the only time an atomic bomb was delivered via artillery shell. —**STEPHEN CASS**

A version of this article ran online in February.

RANDI KLETT

STORE BITS IN THIN AIR
BUILD AN ACOUSTIC DELAY-LINE MEMORY FROM AN EDUCATIONAL KIT



SPAGHETTI JUNCTION: This 4-bit memory uses a speaker and microphone [not shown]. The buttons on the right invert individual bits.

Recently, I moved from Boston to New York City, which necessitated a purge in order to fit into our inevitably smaller apartment. One of the things I tossed out was an old Electronics Learning Lab from RadioShack, which consisted of a breadboard surrounded by commonly used electronic components such as potentiometers, buttons, and LEDs. "You can throw this out," I thought. "What are the odds you're ever going to need it again?" The glow of decluttering lasted until I saw a project by Joseph Allen, who used the Electronics Learning Lab to re-create an acoustic version of an ancient form of computer memory: the delay line.

Before the proliferation of ferrite-core memories, which permitted random-access, multikilobyte memories, delay lines were a popular memory technology. In the classic example, sonic pulses, representing bits, were introduced at one end of a long tube of mercury by a transducer. The pulses would travel the length of the tube and be picked up by another transducer. These pulses would then be fed back into the starting end of the tube to create a loop. The longer the tube, the greater the number of bits that could be stored.

Allen told *IEEE Spectrum* he was inspired to revisit delay memory after seeing a Victor 1400 electronic calculator in a vintage shop. A marvel of mid-1960s solid-state engineering, the Victor 1400 used a magnetorestrictive delay-line loop in its arithmetic processing unit. "And I thought I could probably make one of these," says Allen.

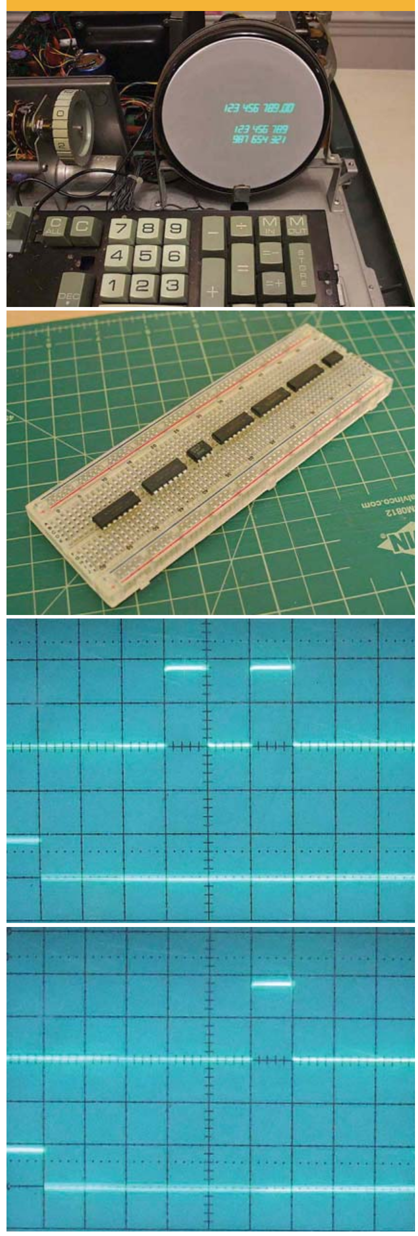
Allen's implementation uses the same principle as mercury delay-line memory, except that the medium used to support the sonic pulses is air, not mercury. A loudspeaker emits a series of chirps, with the presence of a chirp indicating a 1. The chirps travel through air until they are picked up by a microphone. A chain of amplifiers turns the chirps back into digital pulses, and they are fed back into the speaker. Some flip-flops and a synchronized counter allow individual bits to be inverted by pressing a button that corresponds to each bit; the entire system can hold 4 bits (a quantity also known as a nybble). To view the memory requires an oscilloscope tapped into the circuit at two points, one to provide a synchronizing trigger signal and the other to read out the actual bits.

Fortunately, although I had thrown out the actual Electronics Learning Lab, I had kept the assortment of integrated circuits that came with it. This collection includes chips from the 4000 series, which is a menagerie of logic chips such as flip-flops, XOR gates, and pulse counters. The acoustic delay-line circuit uses seven chips: TL272, LM339, and LM386 op-amps; a 4001 quad NOR gate; a 4013 dual flip-flop; a 4070 quad XOR gate; and a 4017 decade counter. Two potentiometers set the threshold for passing audio signals picked up by the microphone back into the circuit and the frequency at which the circuit operates.

Having discarded the kit's breadboard, I built the circuit using a regular breadboard, dipping into my own supply of components such as buttons to replace those built into the kit. For a microphone, I used a RadioShack monodynamic microphone and ran about 7 meters of hookup wire to drive a speaker: Because the circuit relies on there being a detectable delay between when a pulse of sound leaves the speaker and when it is picked up by the microphone, the further apart they can be placed, the better.

While the functional arrangement of Allen's circuit is pretty straightforward, the physical layout is a different story. Gates on the same chip are often interconnected, and two of the ICs are used simultaneously in completely different parts of the circuit.

SYNTHESIZING STORAGE



JOSEPH ALLEN'S INSPIRATION was a 1960s calculator that used delay-line memory [top]. His acoustic delay line uses a collection of amplifier and logic chips [second from top]. An oscilloscope displays the bits 0011 flowing through the delay line [second from bottom] and the result of inverting a bit [bottom].

FROM TOP: JOSEPH ALLEN; STEPHEN CASS; JOSEPH ALLEN (2)

I soon had wiring spaghetti all over my breadboard and realized, to my dismay, that I had become utterly spoiled by modern microcontrollers like the Arduino and the Basic Stamp. These let you do all the messy logic in software, with a rich collection of plug-and-play daughterboards and modules for popular hardware functions such as sensing or powering motors. But here I was back to the fiddly and error-prone business of creating hardwired logic, gate by gate.

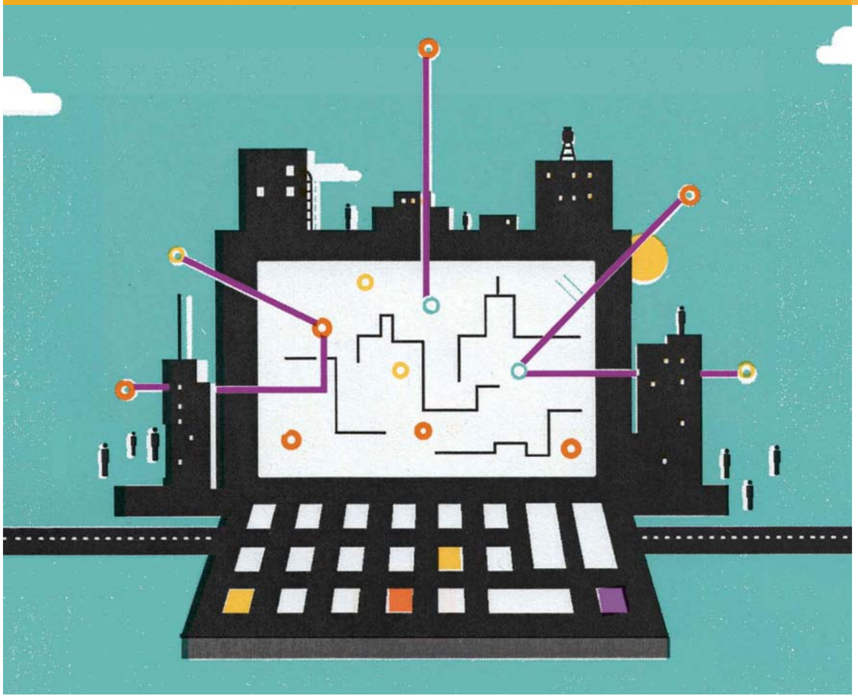
Debugging the circuit raised another problem: noise. I should have paid more attention to the fact that in the video on his blog, Allen demonstrates his circuit in his basement. An acoustic delay-line memory, by its very nature, emits a clicking noise loud enough to be picked up across a fair distance when it's working right and an irritating buzz when it's not. Not wishing to drive my new neighbors (or myself) to distraction, especially late at night, I limited the operation of the circuit to a minute or so at a time. This made hunting down wiring mistakes difficult, especially when, say, I pressed a button to invert a bit and it worked a jumper loose.

In the end, I decided to break with habit and solder the circuit together on perfboard before getting it to work on the breadboard. Wiring the circuit as carefully as I could, I finally turned it on at an hour during the weekend when a little extra noise might be forgiven. I was able to reliably modulate the audible signal passing over the delay line as I pressed the various bit-controlling buttons. I could see bits flitting across the oscilloscope display, but I wasn't quite able to get the nice sharp readout of a frame of 4 bits that Allen has been able to demonstrate, so we've used Allen's pictures here to demonstrate the output. Nonetheless, as soon as I can purchase a pair of earplugs and get some more free time on a weekend, I intend to use a few of the other leftover chips from the Electronics Learning Lab and see if I can add a built-in display for the memory, eliminating the need for the oscilloscope.

—STEPHEN CASS

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

TECHNICALLY SPEAKING_BY PAUL McFEDRIES — OPINION



THE CITY AS SYSTEM

As in all Utopias, the right to have plans of any significance belonged only to the planner in charge. —Jane Jacobs, *The Death and Life of Great American Cities* (1961)

IN A PREVIOUS COLUMN, I ran through some words and phrases associated with *urban computing*, where the city is a computer, the streetscape is the interface, you are the cursor, and your smartphone is the input device. This is the user-based, bottom-up version of the city-as-computer idea, but there's also a top-down version, which is systems-based. It looks at urban systems such as transit, garbage, and water and wonders whether the city could be more efficient and better organized if these systems were "smart." That is, if we applied principles of information technology and connectivity to the various processes that make up the urban infrastructure, we would end up with a **smart city**. • The need for more urban smarts seems obvious: Cities have finite (and shrinking) budgets, and the resources that make a city run—including water, energy, clean air, and land—are precious. So the move from the current urban environment to the **digital city** includes upgrading components and retrofitting so-called **smart technologies**. For example, many urban homes have had their gas and electrical meters upgraded to **smart meters** that enable not only remote monitoring and reading but also **smart pricing** (or **time-of-use pricing**), where costs rise or fall depending on whether usage is on- or off-peak. On a larger scale, these newfangled meters are part of the **smart grid**, which uses real-time data and analytics to match energy production with demand, monitor equipment, and control supply. • Big data plays a big part in **smart urbanism** because city managers are starting to create a **networked city** that deploys digital sensors and other electronic infrastructure. These generate massive amounts of information not only on energy use but also on traffic, transit, and other **civic data**. The goal is the **real-time city**, which enables planners and administrators to make decisions and implement policies based on current data and trends. Call it **city 2.0**.

Eventually (so the blue-sky thinking of your average **civic hacker** goes), these sensors, monitoring devices, and other elements of urban technological infrastructure will cover almost every available public surface. The result will be the **ubiquitous city** (often shortened to **u-city**), where every urban system and resource will make its data available for monitoring, analysis, and control. This **transphysical city** will enable new services to be implemented seamlessly over the network or via the **g-cloud** (government cloud), a computing model sometimes called **city-as-a-service**.

The ultimate smart city is one that's built from the ground up with **civic tech** goals in mind. The forerunner here is the Garden City model proposed in the late 19th century by Englishman Ebenezer Howard, which features parks, retail, residences, and industry organized in concentric circles. The modern equivalent of a built-from-scratch smart city is called a **cyburg**, and examples include Songdo in South Korea, Masdar City in the United Arab Emirates, and the proposed, pedestrian-only Great City in China. These cities are planned for efficiency and are wired for data and services—**cityware**—all controlled by an **urban operating system**. Citizen access to these services is networked and ubiquitous, thanks to the implementation of civic tech.

The problem with these **soft cities** (or **e-cities**) is that, like Howard's Garden City, the benefits accrue only if the whole thing remains under the strict control of an overarching authority that dictates things such as land use and density. But, as urban critics such as Lewis Mumford, Jane Jacobs, and more recently Richard Sennett have pointed out, a city is almost by definition an organic entity that constantly changes and evolves. To define this aspect of urbanism as a bug that must be fixed strikes at the soul of the city, because it sees commercial and individual freedom as the problem, not the solution. And if the increasing ubiquity of networked monitoring devices—particularly CCTV cameras—is combined with databases and software that enable easy searching and analysis, then the time of the **superpanopticon** is nigh. That kind of city doesn't sound very smart to me. ■

ILLUSTRATION BY Oliver Munday

TOP 10 TECH

PRICE (EST.): US $60 000
POWER PLANT: 100 kW (134 hp) hydrogen fuel cell, hybrid electric drive
OVERALL FUEL ECONOMY (EST.): energy equivalent of 3.35 L/100 km (70 mpge)

THE AUTOMAKERS OF THE WORLD are tearing the veil off their latest techno marvels, and this year their hottest offering is the automated car. ● No sooner did Nissan introduce the world's first steer-by-wire car—the Infiniti Q50 highlighted in our 2013 Top Tech Cars—than Nissan chief Carlos Ghosn pledged to bring a self-driving car to showrooms by 2020. ● As our 2014 top-tech selections show, cars are adding cameras, radar, lasers, sonar, and GPS to serve and protect drivers and passengers, with the ultimate goal of rendering human drivers superfluous. In August, Mercedes's self-driving S500 Intelligent Drive prototype—just a bit more advanced than the showroom S-Class reviewed below—drove itself 100 kilometers (62 miles), from Mannheim to Pforzheim. That trip followed the route that Bertha Benz, wife of company founder Carl Benz, completed in 1888, after pilfering his Patent Motor Car from the factory to go on a joyride with their two sons. Like today's tech visionaries, Bertha hoped to prove a point to skeptics and even to her husband: This invention had a future. ● Automated cars promise safer highways, better use of time and energy, and cleaner air in exchange for surrendering the occasional pleasures of controlling a fine machine. Whether that bargain strikes you as fantastic or Faustian depends on your temperament. Ghosn, for one, envisions senior citizens extending their driving years and teenagers starting younger. Other backers envision intelligent transportation pods that never crash, eliminating the need for air bags and other safety gear. Even driving enthusiasts might be happy to sit back and text during a slog through traffic. ● Nevertheless, we realize that many drivers aren't quite ready for retirement. So we've also chosen hands-on pleasures, such as an overachieving Japanese small car and a German plug-in that's likely the world's most advanced sports car. —LAWRENCE ULRICH

Toyota FCV CONCEPT

FUEL CELLS: NOT DEAD YET

QUIXOTIC OR NOT, the dream of hydrogen fuel cells as the ultimate clean-energy solution continues to fascinate automakers. Toyota has worked on the idea for more than 20 years, and it is now pledging that something very like the FCV will reach small numbers of customers in Europe, Japan, and the United States by 2015. (Daimler, Ford, Honda, Hyundai, and Renault also have fuel-cell models in the works.) ● The company says the FCV's power density of 3 kilowatts per liter is a record for a fuel cell. That's twice the density of Toyota's 2008 hydrogen concept, which is why although it's markedly smaller and lighter, it produces at least 100 kilowatts (134 horsepower). And did we mention that all it emits is water vapor? Bob Carter, Toyota's senior vice president of automotive operations, says the company has slashed fuel-cell and hydrogen-tank costs by 95 percent in just five years.

The oddly styled, nostril-flaring FCV uses the Prius's familiar Hybrid Synergy Drive, which gets the car to 100 kilometers per hour (or 62 miles per hour) in a workmanlike 10 seconds. Unlike electric vehicles, the Toyota can refill in roughly 3 minutes; also unlike them, it can cover well over 300 miles on its dual tanks of compressed hydrogen. The near-nonexistent fueling network remains a huge obstacle, yet California has pledged US $200 million to begin developing up to 48 hydrogen stations by 2016. "Stay tuned," Carter says, "because this infrastructure thing is going to happen." If you say so, Bob. ■

ALL PHOTOS PROVIDED BY MANUFACTURERS

Mercedes S-CLASS

ALMOST A ROBOTIC CHAUFFEUR

AS THE WORLD'S MOST POPULAR vehicular status symbol, the S-Class is the fallback for everyone from royals to Russian oligarchs, with plenty of doctors, financiers, and celebrities in between. ● But to ensure that the S-Class remains a hands-down choice, Mercedes is trying a hands-off approach: The S-Class convincingly shows that the automated car has hopped most of the technical hurdles. The steeper barriers will be posed by laws, safety regulations, and highway infrastructure. Only California, Florida, Michigan, Nevada, and Washington, D.C., sanction self-driving cars, and Europe currently allows only "corrective steering functions," rather than full autosteering, at speeds above 10 kilometers per hour (6.2 miles per hour).

The new Mercedes has plenty of firsts. Drivers can select a scent to waft through the cabin—the sweet smell of success, no doubt. Air bags in the rear seat-cushion bottoms ensure that a reclining passenger won't slide beneath the shoulder belt during a collision. All the light comes from 500-odd LEDs, making this the first modern car without a single incandescent bulb.

Semiautonomous driving is provided by "sensor fusion." An array of two dozen sensors integrates stereoscopic 3-D cameras with near- and far-infrared cameras, ultrasonic sensors, and short-, mid-, and long-range radar, wrapping the Benz in a 360-degree cocoon of sensory awareness. The whole shebang is tied to an antilock brake, stability control, power train, and electric steering system.

Setting out from Manhattan in the S550, I satisfied myself with a few 4.8-second 0–100 km/h runs—with me steering and controlling the car's silken 335-kilowatt (449-horsepower) Biturbo V-8. Then I switched on Benz's Distronic adaptive cruise control. The windshield-mounted cameras,

PRICE: US $93 825
POWER PLANT: 335 kW (449 hp) 4.6-L Biturbo V-8
OVERALL FUEL ECONOMY: 11.8 L/100 km (20 mpg)

FORD C-MAX SOLAR ENERGI

A car that moves itself to track the sun

ADD TO THE cars that drive or park themselves a car that suns itself actively—it doesn't just sit there but, like a true sun worshipper, changes its position throughout the day to max out the rays.

A concept version of Ford's existing plug-in hybrid, C-Max, the Solar Energi packs about 1400 square centimeters (1.5 square feet) of cells on its roof. Still, it generates 350 watts at most, which would be enough to drive just a kilometer and a half for every hour spent in the sun. So to boost that range, Ford designed a separate canopy containing Fresnel lenses that magnify sunlight by a factor of eight. You park the C-Max under the canopy and it moves itself to keep the light focused on the solar cells, inching forward or back along an east-west coordinate as the day wears on.

Ford says that the C-Max can soak up enough light in 6 to 8 hours to pack 8 kilowatt-hours into its lithium-ion battery. That's enough to cover 21 miles, meaning a worker could, um, tan the Ford during the day, drive home courtesy of Sol, and plug into a charging outlet at night. ■

PRICE: Not for public sale POWER TRAIN: 2.0-L four-cylinder with electric motor; 140 kW (188 hp) total power OVERALL FUEL ECONOMY (EST.): 5.5 L/100 km (43 mpg) on gasoline; energy equivalent of 2.35 L/100 km (100 mpge) on battery

scanning a 45-degree field of view, are the heart of the Intelligent Drive system, complemented by radar that tracks the car ahead and the one ahead of that. The Mercedes faithfully paced traffic, smoothly braking and accelerating on its own, allowing me to drive for miles without touching the pedals. On rural two-lane roads north of New York City, the camera scanned for oncoming cars, vibrating the steering wheel when I strayed from the lane, then applying brakes to the appropriate wheels to pop the Mercedes back onto the proper path.

And on gently curving highways, the cameras and radar actually command the steering wheel to keep the Benz centered in its lane. It's an assistant rather than a full-on robot: If I took my hands off the wheel for more than 10 seconds, the display would tell me to put them back on again.

The Mercedes also scans for cross traffic and pedestrians. It can automatically prevent a collision at speeds up to 50 km/h and mitigate the damage at up to 74 km/h if the driver fails to act. I resisted the temptation to test this capability on unsuspecting New York taxicabs and jaywalkers, but I did get a demonstration at a German test facility. It works.

Sensors at the rear scan for potential collisions, firing seat-belt pretensioners if necessary, closing windows and sunroof, and applying brakes to keep the Benz from being driven into cars or intersections ahead. At night, the heat-seeking Night View camera system identifies moving impediments—including humans and some large animals.

The car also oversees the all-too-human species at the wheel: Attention Assist monitors roughly 75 parameters—including the driver's steering and control inputs—to spot a sleepy driver and even guide him or her to the nearest exit or rest stop. Magic Body Control, the world's first camera-based suspension, spots speed bumps and pavement imperfections, adjusting air springs to glide over obstacles.

Right now, these wonders can be enjoyed only by the few: S-Class households earn an average of US $371 000 a year. Yet similar tech is already trickling down: Mercedes's driver-assistance technology is already a $2800 option on the more affordable E-Class, and it will migrate to the entry-priced 2015 C-Class, this fall. And such preternatural abilities are rapidly filtering into mass-market cars, like the Mazda3. ■

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

Porsche 918 SPYDER

SETTING A RECORD PACE WITH PLUG-IN POWER

PLUG-IN HYBRIDS ARE ON A FAST TRACK, and the Porsche 918 Spyder is the proof. In our testing, Porsche's carbon-fiber phantasm conquered a Spanish Formula One test track like a machine from a more-advanced planet. Porsche says that this performance—including a 6-minute, 57-second trip around Germany's Nürburgring circuit, better than any other production car in history—could not have been achieved without electricity.

The Spyder gets its oomph from a 4.6-liter, 453-kilowatt (608-horsepower), 9150-rpm V-8 descended from the RS Spyder racer. That midmounted engine mates with Porsche's seven-speed PDK transmission and a 116-kW (156-hp) electric motor at the rear axle. Front wheels get a 96-kW (129-hp) jolt from yet another electric motor. At full charge, the all-wheel-drive system amasses 661 kW (887 horses) and 1280 newton meters (944 foot-pounds) of torque.

And what a charge it is, in both senses: The Porsche reaches 100 kilometers per hour (62 miles per hour) in 2.6 seconds, 200 km/h in 7.2 seconds, and 300 km/h in 19.9 seconds. Peak velocity is 344 km/h. Drivers can dial up five operating modes, from virtuous to vanquishing. The default electric-only mode pushes the Spyder for about 18 miles on its 6.7-kilowatt-hour battery while still allowing the car to travel at up to 150 km/h. Diverting engine power, the Porsche can recharge that battery on the fly in about 15 minutes, or in as little as 25 minutes on its home station.

Under Europe's forgiving way of calculating energy equivalences, Porsche claims up to 3 liters per 100 kilometers (78 miles per gallon), with Prius-like emissions as low as 72 grams of CO_2 per kilometer. Based on our test drive, reality should be closer to 9.4 L/100 km (25 mpg), still efficient by supercar standards, or the energy equivalent to 3.1 L/100 km on just the battery.

Electricity also plays a key role in braking: The Spyder's motors alone deliver enough reverse torque for purely electric stops at up to half a *g*—as much total deceleration as a typical sedan could muster a decade ago—while recuperating up to 230 kW for the battery pack. When I needed to press harder, as at the end of repeated 281-km/h (170-mph) straightaways, the ceramic-composite brakes reeled in the roadster with heroic force.

Tech aside, the Porsche is glorious to drive. On the Circuit Ricardo Tormo in Spain, I chased an ex–Formula One driver, the irrepressible Timo Glück, who drove ahead of me in a Porsche 911 Turbo S (with a mere 418 kW, or 560 hp). As Glück began sliding through turns, pushing the Turbo S to its limits, I was forced to slow down and wait patiently—as if the Spyder were taking a walk in the park—to allow Glück to maintain the lead.

What kind of car lets an amateur keep pace with a professional racer? A Porsche, one that proves that electrification isn't the death of fast cars but their salvation. ■

PRICE: US $845 000
POWER PLANT: 453 kW (608 hp) 4.6-L V-8 with dual electric motors; 661 kW (887 hp) total power
OVERALL FUEL ECONOMY (EST.): 9.4 L/100 km (25 mpg) on gasoline; energy equivalent of 3.13 L/100 km (75 mpge) on battery

VOLVO V60 PLUG-IN HYBRID

The world's first diesel plug-in

PLUG-IN CARS, HYBRIDS, and diesels are the triple threat of fuel economy. Now, Volvo has combined all three technologies in one wagon: The seductively curvy V60 is the world's first plug-in diesel hybrid, and it sets a new standard for frugality among family haulers.

An electric motor rated at 51 kilowatts (68 horsepower) drives the rear axle, juiced by an 11.2 kilowatt-hour lithium-ion battery nestled below the floor. That lets the Volvo cover 50 kilometers on electricity alone. Pop the V60 into Hybrid mode and a 160 kW five-cylinder diesel drives the front wheels, either separately or in tandem with electrically powered rear wheels. Add it up and you're looking at a wild wagon that dashes to 100 kilometers per hour (62 miles per hour) in 6.1 seconds, with a 230-km/h (143-mph) top speed. Yet in hybrid mode, the Volvo is rated for just 48 grams of CO_2 per kilometer. Under Europe's divorced-from-reality fuel-economy ratings, that equates to about 1.8 liters per 100 kilometers (130 miles per gallon). But in the real world there's little doubt the Volvo can manage 4.7 or even 3.9 L/100 km.

The Save mode lets the driver conserve battery power for when it matters most, as in driving through urban centers that charge entry fees to internal combustion cars. The safety-first Volvo also heralds the automated era: A radar- and camera-based system can automatically stop the V60 for pedestrians, cars, or cyclists. U.S. buyers will see a plug-in gasoline hybrid version, likely in 2014. Either way, the V60 is a car that even wagon-averse Americans could love. ■

PRICE (EST.): US $60 000 POWER PLANT: 51 kW (68 hp) electric motor with 2.4-L 160 kW (215 hp) five-cylinder diesel OVERALL FUEL ECONOMY (EST.): 5.9 L/100 km (40 mpg) on gasoline; energy equivalent of 3.12 L/100 km (75 mpge) on battery

Mazda3

AUTOMOTIVE AUTOMATION FOR THE MASSES

THE TINIEST COMPANIES are often the most willing to innovate: The alternative is to be crushed by the big boys. Mazda is a case in point. ● Among the first new cars Mazda developed without resources from Ford, its former part owner, the Mazda3 declares the company's independence in trumpet-sounding techno fashion. It blends Asian ingenuity and European styling and performance into a zesty dish that seems poised to set a new global standard for small cars. ● Mazda's Skyactiv technology suite kicks off with a chassis that's 30 percent stiffer and roughly 45 kilograms (100 pounds) lighter than that of the 2012. Two different four-cylinder engines are available, and both are high compression and direct injection. For sedan versions, the standard 2-liter, 116-kilowatt (155-horsepower) achieves 5.7 liters per 100 kilometers (41 miles per gallon) on the highway; even the muscular 137 kW (184 hp) 2.5-L manages 6.0 L/100 km. ● The available six-speed manual transmission is the most satisfying stick this side of a Porsche. A novel six-speed automatic transmission marries the best functions of conventional automatics and the dual-clutch units found in luxury models: It combines a fluid-driven torque converter for smooth starts and shifts below 8 kilometers per hour (5 miles per hour), then switches to a locking clutch for sporty gear changes and fuel savings. Fuel conservation continues with i-Eloop, a regenerative braking system that ditches a storage battery for a lighter capacitor to help power electrical systems.

In the surprisingly luxurious cabin, the 3 debuts Mazda Connect, a distraction-limiting human-machine interface that includes a slick main screen and head-up display. It also features upgradable smartphone apps that pair with the car's onboard system. Integrated into the system is Harman's Aha infotainment platform, which accesses more than 40 000 cloud-based presets, including Internet radio, audiobooks, and Facebook and Twitter feeds.

The Mazda also highlights the speedy trickle-down—more like a waterfall—of first-gen automation to mainstream cars. Radar- and camera-based systems provide adaptive cruise control and automated high beams, along with lane-departure, blind-spot, and rear-cross-traffic monitors.

Did we mention that the Mazda is a feisty joy to drive? The zoom-zoom lives on in an affordable Mazda that looks like a high-style Alfa Romeo and drives like a slick Euro car. ■

PRICE: US $17 740
POWER PLANT: 116 kW (155 hp) 2.0-L four-cylinder or 137 kW (184 hp) 2.5-L four-cylinder
OVERALL FUEL ECONOMY: 7.1 L/100 km (33 mpg)

CADILLAC CTS

Not your father's land yacht

THERE IS A long history of American carmakers trying—and usually failing—to beat German sports sedans. But Cadillac triumphs with the CTS's superlative chassis, steering, and suspension, which make a BMW 5-Series or an Audi A6 feel tame in comparison.

Once notorious for lumbering land yachts, Caddy applied a ruthless gram-by-gram strategy to trim weight. The doors, hood, subframe, brake calipers, front suspension, and bumper beam are all aluminum. The engine mounts are *not* aluminum—too heavy. The new magnesium mounts weigh 680 grams less than the old aluminum ones. Despite being larger, the base CTS weighs 113 kilograms (250 pounds) less than its predecessor, a lightest-in-class 1655 kg.

A trio of engine options starts with a 204-kilowatt (272-horsepower), 2.0-liter turbo four and peaks with a real beauty: the vSport edition's 313 kW twin-turbo V-6—the most powerful V-6 in GM history. The combination of two fast-acting turbos and very short paths for both exhaust gases and compressed air dramatically reduces "turbo lag"—the time it takes the engine to respond when you step on the accelerator. It also produces 583 newton meters of torque, 176 Nm more than the BMW's turbo V-6.

PRICE: US $51 925 POWER PLANT: 313 kW (420 hp) 3.6-L twin-turbo V-6
OVERALL FUEL ECONOMY: 13 L/100 km (18 mpg)

The vSport girds its loins with an electronic limited-slip differential, a quicker steering ratio, 20 percent stiffer springs, larger antiroll bars (to keep the car level in a turn), and the aggressive Track mode for stability control. So equipped, the vSport charges from 0 to 60 miles per hour (97 kilometers per hour) in 4.6 seconds, achieves 0.97 *g* of tire grip on a skid pad, and halts from 113 km/h in 45 meters. Those are numbers you'd associate with a two-seat sports car, not a roomy midsize luxury sedan.

The Cadillac drives with bank-vault solidity and smoothness, with available all-wheel-drive and a cabin rich in tech and trims such as carbon fiber, aluminum, or burl walnut. In tandem with its smaller ATS sibling, the CTS is good enough to impress even the Germans. ■

BMW i3

A CARBON-FIBER, ELECTRIC-DRIVE BIMMER

FOLLOWING A LUKEWARM reception for the Nissan Leaf and Chevy Volt, the BMW i3 is the latest test case: Are people ready to spend extra money to drive an electric? The fruit of massive BMW investment in sustainable transportation and designed for future megacities, the four-seat i3 packs efficiency and a charming personality into a toylike yet ultrasturdy shape.

The aluminum Drive module mates with a lightweight carbon-fiber passenger cell for a mere 1200-kilogram (2634-pound) curb weight. That's 320 kg lighter than the Leaf, despite the i3's 230-kg load of batteries, with a capacity of 22 kilowatt-hours. The electric motor delivers 125 kilowatts (168 horsepower) and a stout 250 newton meters of torque, which together with a seamless single-speed transmission send the rear-drive BMW from 0 to 100 kilometers per hour (62 miles per hour) in 7.2 seconds. It tops out at 150 km/h and covers 130 to 160 km on a charge, or 200 km in frugal Eco Pro Plus mode. An optional 650-cc, two-cylinder gasoline engine extends that range to 300 km.

A low center of gravity and sophisticated suspension—this is a BMW, after all—create a surprisingly fun-to-drive runabout. A 9.8-meter turning circle helps the i3 shred city traffic and negotiate tight spots. On sale already in Europe, the BMW will come to the U.S. and Japanese markets later this year. ■

CHEVROLET CORVETTE STINGRAY

A featherweight muscle car

MOST SUPERCARS HAVE certain things in common, starting with carbon-fiber panels, an aluminum chassis, and an active suspension. But the all-new Corvette offers all of those things, along with a sticker price that starts at US $54 000. This seventh-generation 'Vette puts the long-dormant Stingray name on a ferociously modern sports car. Even the car's most ardent fans back in the swinging '60s couldn't imagine a Corvette getting to 60 miles per hour (97 kilometers per hour) in 3.8 seconds, with a top speed beyond 190 mph, and the ability to pull nearly 1.1 *g* in lateral acceleration.

The roof and hood are carbon-fiber-reinforced polymer; other panels mix such fiber into a hybrid composite. Beneath that skin lies a 60-percent-stiffer chassis made of

PRICE: US $53 995 **POWER PLANT:** 343 kW (460 hp) 6.2-L V-8
OVERALL FUEL ECONOMY: 11.2 L/100 km (21 mpg)

PRICE: US $42 275
POWER PLANT: 125 kW (168 hp) electric motor; optional 25-kW (34 hp) 650-cc two-cylinder
OVERALL FUEL ECONOMY (EST.): 5.9 L/100 km (40 mpg) on gasoline; energy equivalent of 2.14 L/100 km (110 mpge) on battery

extruded, hydroformed aluminum.

The 6.2-liter, direct-injected V-8 cranks up 343 kilowatts (460 horsepower) when equipped with the dual-mode exhaust system. And like the Corvette engines of the 1960s, it has valve pushrods and just two valves per cylinder. Europhiles can scoff, but the fact is that the Chevy's ever-evolving small block is 10 centimeters shorter and 18 kilograms lighter than BMW's 4.4-L twin-turbo V-8.

The V-8 can run on four cylinders in Eco mode, lifting fuel economy on the highway to an impressive 7.8 liters per 100 kilometers (30 miles per gallon) with the manual transmission. That nifty stick has seven speeds—just like on the Porsche 911. Flick the shifter and a patented sensor anticipates gear changes, automatically goosing the throttle to match engine revs like a track racer. Powerful Brembo brakes, in conjunction with heroic Michelin Pilot Sport Cup tires, halt the Corvette in as short a distance as you'd get from a Porsche 911.

The interior, long a Corvette sore spot, gets welcome upgrades in design and craftsmanship. Body-hugging seats with magnesium frames replace the unsupportive chairs of old. A built-in lap timer helps turn the Stingray into a real-life video game. And Performance Traction Management features a dizzying range of settings for the engine, suspension, traction, and stability systems, including racetrack modes that sharply boost performance without eliminating the safety net. There's even a tire-temperature algorithm that expands the performance envelope.

And don't forget the third generation of the Corvette's groundbreaking Magnetic Ride Control, the magnetic-fluid-based adjustable suspension that's also being used by Ferrari and Audi.

The result is a Corvette whose stellar performance is easy to love, on road or track. When I took it out on a test track in western Michigan, the Corvette tore around like an attack dog, but it never threatened to bite its master. And if technology is a wonderful thing, affordable technology is better: The Stingray's style and performance can be had for about half the price of a comparably equipped Porsche 911 S. ■

HONDA ACCORD HYBRID

At last, a Honda hybrid that really saves on fuel

HONDA BUILT ITS reputation around small cars with small engines. But Honda's attempts at gasoline-electric hybrids—which included the first in the United States, the two-seat Insight of 1999—have often been half-baked technical curiosities that got disappointing mileage.

Honda's Accord Hybrid should help demolish that reputation. It uses a technically ingenious hybrid system to turn in a class-topping city mileage rating of 5.6 liters per 100 kilometers (50 miles per gallon).

A pair of electric motors and a complex nest of shafts, gears, and oil pumps replace a conventional transmission. They're linked to a 2.0-liter gasoline engine that runs on the Atkinson cycle, which saves fuel via lower compression and precise valve control. The main drive motor sends 306 newton meters (226 foot-pounds) of torque to the front wheels, for a 7.1-second sprint to 60 miles per hour (or 7.3 seconds to 100 kilometers per hour).

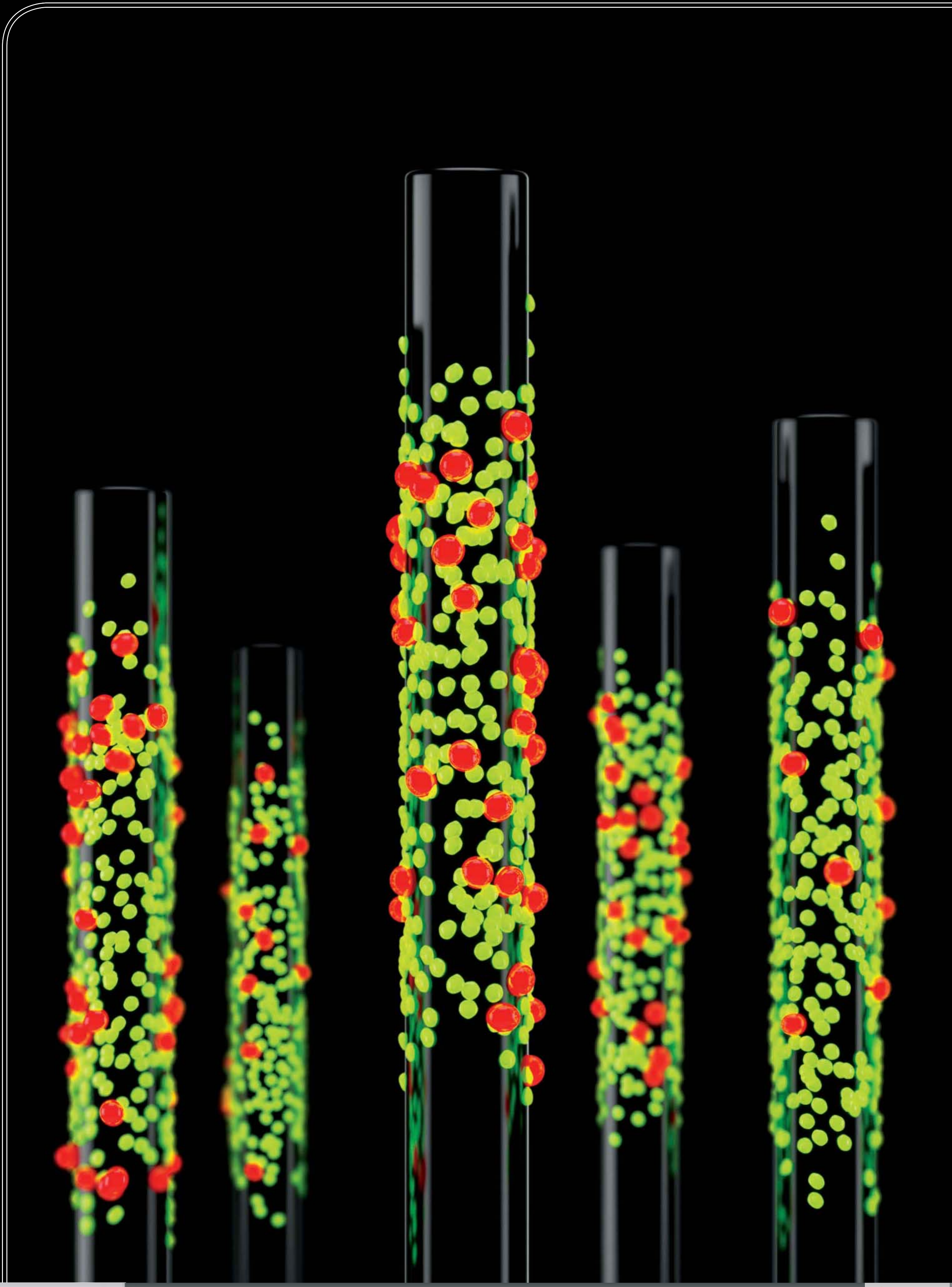
As in the Chevy Volt, the 105-kilowatt (141 horsepower) gasoline engine is used mainly to generate electricity. That's where the second electric motor (or "motor generator") comes in. It spins on the engine's crankshaft to convert gasoline energy into electrons, which can either charge the battery or power the drive motor. Only at highway speeds does the engine physically propel the wheels via a direct drive that connects the engine via a single fixed gear.

The Accord's regenerative brakes apply stronger-than-average electrical resistance from the motor to provide robust stopping power, maximizing the energy that's recaptured. You have to push hard and long on the pedal to bring the conventional mechanical brakes into play. The push-button Battery mode further boosts energy regeneration, producing faster stops the second you take your foot off the gas. That's useful in city or stop-and-go driving, allowing the "one pedal" driving that electric vehicle fans love.

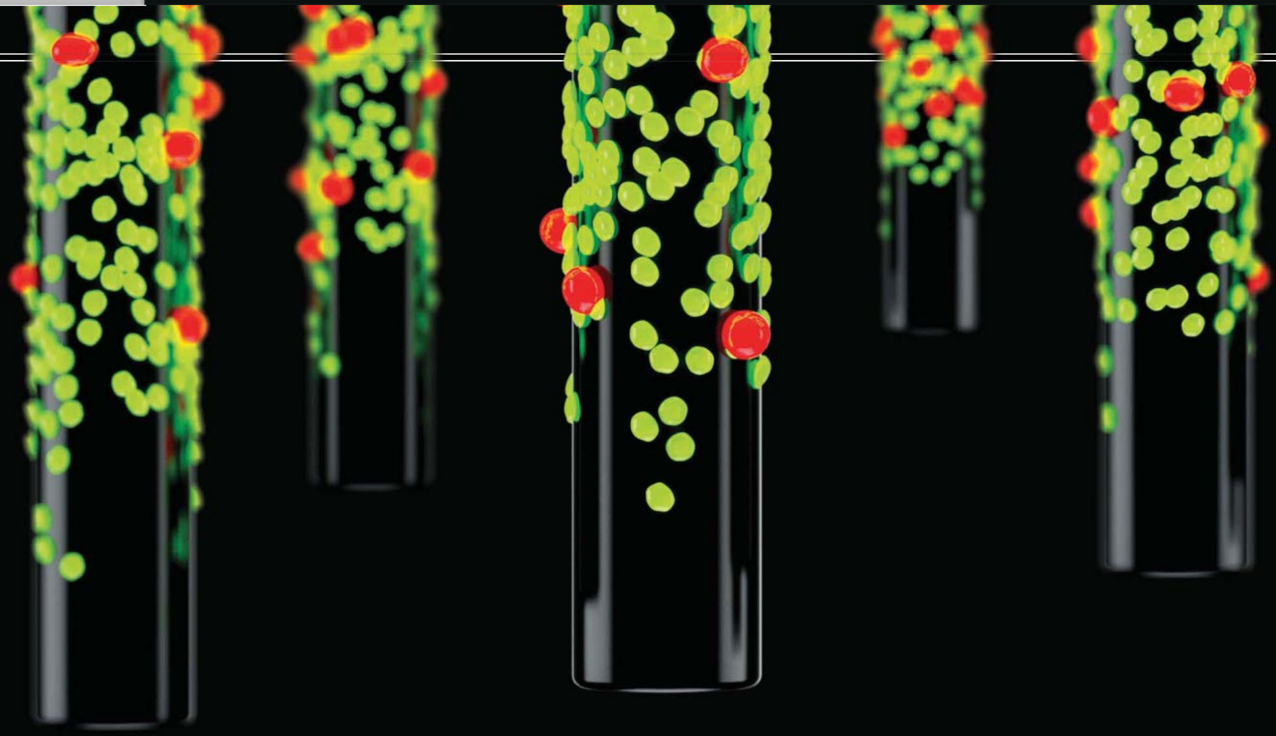
As with the best modern hybrids, including the Ford Fusion, there is absolutely no mistaking the Honda for an overgrown golf cart. Handoffs between electric and gasoline power are quiet and seamless, although the Hybrid doesn't feel quite as athletic as a standard Accord, in part due to its low-friction, fuel-saving tires.

Even so, this hybrid, like the Fusion, doesn't live up to its knockout mileage ratings. Driving carefully, I coaxed 5.9 to 5.4 L/100 km (40 to 43 mpg) from the Honda. That's still terrific mileage in a powerful midsize sedan, enough to save Americans $650 to $850 a year in fuel in comparison with conventional four- and six-cylinder Accords, respectively. Considering the Hybrid's roughly $3400 price premium over the four-cylinder model, your takeaway may hinge on a question: Do you see its hybrid tank as half empty, or half full? ■

PRICE: US $29 945 **POWER PLANT:** 124 kW (166 hp) electric motor with 2.0-L 105 kW (141 hp) four-cylinder engine
OVERALL FUEL ECONOMY: 5.0 L/100 km (47 mpg)



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



A Lab ON FIBER

Tiny chemical sensors could use light to monitor the environment and hunt for disease

By JACQUES ALBERT

Illustrations by JAMES ARCHER

THINK BACK TO THE LAST TIME YOU GOT A BLOOD TEST. Maybe you had your cholesterol checked or got screened for infections, heart disease, stroke risk, thyroid troubles, or osteoporosis. Easy, right? A nurse simply drew your blood and shipped the vials to a lab. But behind the scenes, the process gets more complex. Today's laboratory technologies require rooms full of temperature-controlled chemicals, analytical machines worth hundreds of thousands of dollars, and trained technicians to run them. That's why it probably took days, maybe even a week or two, to get your results. And depending on the tests, a panel of them could easily have set you back several hundred dollars. • Such expenses are a major reason that health-care costs are rising around the world. In rural communities or developing countries, the situation may be much worse than inconvenient. Patients may travel hours or days just to reach a clinic and often don't make it back to collect the results. Many of them can't afford tests for such life-threatening diseases as malaria and tuberculosis.

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

To help solve these problems, we need better laboratory instruments. They should be cheap and portable so that they can be distributed to remote clinics, village doctors, battlefields, disaster zones, and patients' homes. They should be easy to use so that nurses, hospice workers, soldiers, and even patients themselves can administer tests with minimal training. Finally, these tools should provide results quickly and reliably so that patients don't have to wait or worry.

Imagine an entire laboratory that fits inside a case the size of a tablet computer. The lab would include an instrument for reading out results and an array of attachable microsize probes for detecting molecules in a fluid sample, such as blood or saliva. Each probe could be used to diagnose one of many different diseases and health conditions and could be replaced for just a few cents.

This scenario is by no means a pipe dream. The key to achieving it will be optical glass fibers—more or less the same as the ones that already span the globe, ferrying voluminous streams of data and voice traffic at unmatchable speeds. Their tiny diameter, dirt-cheap cost, and huge information-carrying capacity make these fibers ideal platforms for inexpensive, high-quality chemical sensors.

We call this technology a lab on fiber. Beyond being an affordable alternative to a traditional laboratory, it could take on tasks not possible now. For instance, it could be snaked inside industrial machines to ensure product quality and test for leaks. It could monitor waterways and waste systems, survey the oceans, or warn against chemical warfare. One day, maybe as soon as a decade from now, it could be injected into humans to look for disease or study the metabolism of drugs inside the body.

RESEARCHERS FIRST BEGAN IMAGINING WAYS TO BUILD low-cost mobile laboratories in the late 1960s. Around that time, engineers had figured out how to pack thousands—and eventually billions—of transistors onto a single chip the size of a thumbnail, paving the way for powerful microprocessors and dense, fast memory. And as microelectromechanical systems advanced, biomedical investigators began using these technologies to build compact arrays of chemical sensors on a single silicon chip.

Such a system, known as a lab on a chip, varies widely in design and complexity. A typical setup includes miniature pumps and valves that guide a small liquid sample—a drop of blood, say—through microchannels to various detection stations. At these sites, target molecules in the blood—such as glucose or viral antibodies—react with other chemicals on the chip, changing the voltage across electrodes or varying the current flowing through a conductor. The chip amplifies these signals, digitizes and analyzes them, and then sends the results through wires or a radio channel to a handheld display. The whole process takes no more than 20 minutes.

Lab-on-a-chip sensors are ideal for use in rural clinics or at a patient's bedside. But their widespread use for other tasks has long been stalled by seemingly insurmountable obstacles. For example, in wet environments—such as inside the body or outdoors—a chip's metal conductors easily corrode or short, making the sensor unreliable. Many chips also contain materials such as arsenic that are toxic to humans. Their biggest drawback, though, is size. Today's power sources, processors, and transmitters take up at least a few square centimeters—too big to squeeze through blood vessels.

To overcome many of these problems, some researchers are seeking to replace a chip's electronic circuits with optical ones. By using light rather than current to read chemical reactions, a photonic chip works reliably in aqueous solutions, is immune to electromagnetic radiation, tolerates a wide range of temperatures, and poses fewer risks to biological tissues.

And light has another important advantage. Electronics relay information using only one measurable parameter, the magnitude of a current or voltage. Optical devices similarly encode data by varying the intensity, or amplitude, of a light wave. But light can also be divided into many wavelengths, or colors, providing multiple delivery channels. This ability to multiplex data vastly increases a circuit's information capacity, which could make photonic lab-on-a-chip sensors orders of magnitude more sensitive than electronic ones.

Yet despite its many desirable qualities, a photonic lab on a chip still presents some significant challenges. Like electronic chips, optical systems are far too large to fit in the body. And in at least one respect, the problem is even worse. Light waves can't be squeezed into spaces much narrower than their wavelengths. So photonic chips, which use near-infrared wavelengths of around 1 micrometer, are much larger than their electronic cousins, whose ICs can have features smaller than 30 nanometers.

Photonic lab-on-a-chip sensors are also expensive to make, because they require complex arrangements of lenses and mirrors to shape light beams and direct the waves to chemical-detection stations. Photonic ICs built on silicon substrates, for example, which are used in telecommunications equipment today, cost several hundred dollars apiece. Meanwhile, you can buy an electronic chip for pennies.

So how do we take advantage of light's wonderful properties without the drawbacks? We build our lab not on a silicon photonic chip but on a glass fiber.

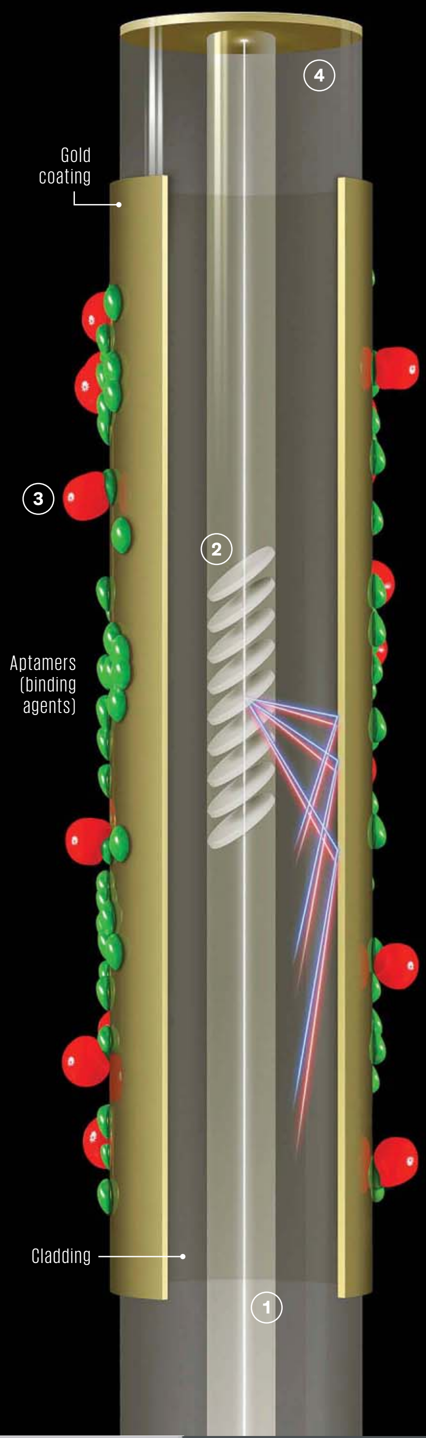
EVER SINCE OPTICAL FIBERS BECAME CHEAP and abundant in the 1980s, researchers have experimented with all sorts of ways to build lab-on-fiber sensors. Now, several groups around the world are homing in on the best materials and assembly methods for manufacturing robust systems cheaply and on a large scale.

For instance, my group at Carleton University, in Ottawa, Canada, and our collaborators, including engineers at the Université de Mons, in Belgium, and Jinan University, in China, are developing a lab on fiber that is simple to make and yet can provide extremely precise measurements. We begin the fabrication process

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

DIAGNOSIS by Light

A lab on fiber uses near-infrared frequencies to detect precise concentrations of chemicals or biological molecules in a solution. Here's how it works.

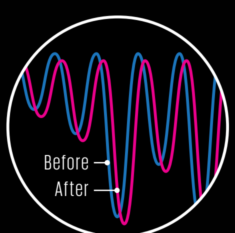


1 **A laser transmits light into the fiber's CORE.**

2 **A TILTED GRATING reflects certain wavelengths known as resonances out of the core. These resonances depend on the properties of the grating and the fiber's surface.**

3 **When TARGET MOLECULES bind to receptors on the surface of the fiber, they shift the wavelength and intensity of the resonances.**

4 **A GOLD MIRROR on the tip of the fiber reflects the light remaining in the core back to a spectrometer at the opposite end.**



The spectrometer detects changes in the returning light, revealing the concentration of target molecules.

with a standard telecom fiber, which costs next to nothing.

This hair-thin glass fiber consists of an inner core and outer cladding encased in a protective polymer jacket. While the cladding is made of pure silica, the core is laced with tiny amounts of germanium oxide, which raises its refractive index, a measure of the speed of light in a material. If light traveling through the core strikes the cladding within a certain critical angle, the slight difference in refractive indices between the two layers causes the beam to bend back into the core—a property called total internal reflection. In this way, light can ping-pong down a fiber's core for up to several kilometers. The ability to carry light over long distances with very little loss could allow fiber labs to be inserted into water supply networks, lowered into the ocean, or strung throughout hospitals.

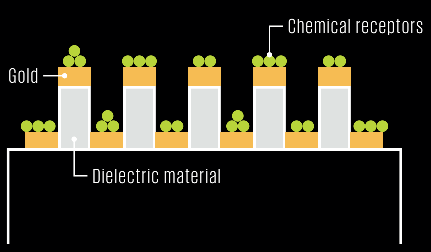
To transform our inert fiber into a chemical sensor, we must first choose where to put the detection site. Some groups are investigating designs that place this probe on a fiber's tip or inside tiny air tunnels in the cladding of an experimental type of fiber called a microstructured optical fiber [see sidebar, "Where to Put the Probe?"]. We have found, though, that the simplest—and therefore cheapest—approach is to use a short segment of a fiber's outer surface, around 1 to 10 millimeters long.

We coat this probe with a chemical compound, called a reagent, that will interact with whatever target molecules we want to measure, such as blood enzymes or food additives. There are many different compounds that can serve as reagents and many ways to attach them to a fiber. One of the most promising processes that we are developing takes two steps. First we cover the surface of the probe with a thin layer of metal using standard deposition techniques such as sputtering, evaporation, or electroless plating. Then we dip the probe into a salt bath filled with synthetic molecules called aptamers, which bind to the surface coating, forming the reagent.

Chemical supply companies can make a huge variety of aptamers that each bind to a different target molecule, including vari-

Where to Put *THE PROBE?*

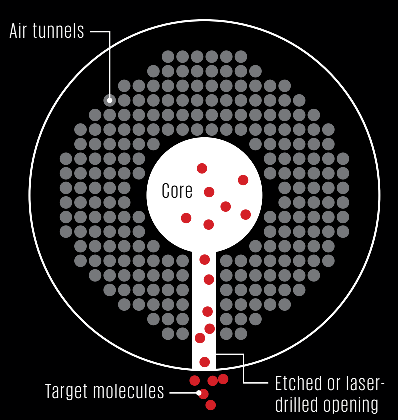
One of the best ways to make a lab on fiber is to build the chemical detector, or probe, on the outer surface of an optical fiber [see illustration, "Diagnosis by Light"]. But that's not the only approach. Here are two leading alternatives.



On the Tip

Gold nanostructures deposited on the tip of a standard optical fiber reflect light back to a detector at the opposite end. When target molecules attach to chemical receptors on this coating, they thicken it, changing the properties of the reflected light.

INVESTIGATORS INCLUDE ANDREA CUSANO AT THE UNIVERSITY OF SANNIO, IN ITALY.



Inside the Fiber

Researchers start with a "microstructured optical fiber," which guides light using air tunnels that surround a hollow or solid glass core. After filling the core or other holes with a gas or liquid sample, they determine its chemical properties by analyzing the spectral fingerprint of the light that emerges at the fiber's end.

INVESTIGATORS INCLUDE PHILIP RUSSELL AT THE MAX PLANCK INSTITUTE FOR THE SCIENCE OF LIGHT, IN GERMANY, AND OLE BANG AT THE TECHNICAL UNIVERSITY OF DENMARK.

ous proteins, toxins, and even whole bacteria. So it's possible to make fiber probes that can test for just about any chemical or biological substance. We can repurpose a used probe by stripping the original aptamers in a chemical wash and attaching new ones.

Now that our fiber lab has the ability to capture molecules, we need a way to count them. To perform this task, we use light. We connect a micro light source, such as a laser diode, to one end of the fiber, which naturally guides the light through the core to our chemical probe. We cap the opposite end of the fiber with a gold mirror so that we can analyze the returning waves with a commercial spectrometer.

But this uniform reflection won't tell us anything about changes occurring at the probe, such as molecules attaching to its aptamers. In order for us to observe these events, the light must be able to interact with the probe's outer surface, where these aptamers reside. So we must somehow force the light to leave the core.

Many early solutions involved removing part of a fiber's cladding, through polishing or chemical etching, to expose the light to the outside world. But such alterations weaken the fiber and are difficult to do precisely, which increases the cost of the sensor.

In our lab, we instead build what's known as a tilted grating inside the core of our probe. It is essentially a permanent hologram, which we create by exposing the fiber to intense ultraviolet laser light for just a couple of minutes before adding the metal coating and reagent. First we dissolve the plastic buffer around the probe, making it transparent to UV light. We shine the UV light through a grooved glass plate, called a phase mask, which splits it into two beams. Then we place the fiber behind the mask, where these beams interfere with one another, creating a periodic radiation pattern: intervals of high exposure separated by intervals of no exposure. The radiation breaks some of the electronic bonds in the fiber core, increasing its refractive index in the same pattern as the interfering light, like an image being formed on a photographic film. Each rise in the core's refractive index is called a fringe, and together they make up the grating.

The disklike fringes act like tiny imperfect mirrors: Each reflects a small amount of light traveling through the probe. If we build the grating so that its fringes align straight up and down inside the core, they will reflect this light back toward its source. But remember, we want the grating to redirect the light through the cladding to the fiber's surface. So we simply tilt the fiber as it's being irradiated with the UV light, forming a tilted grating.

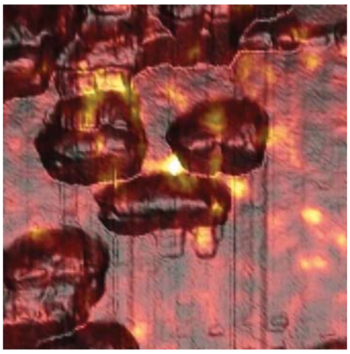
It's important to note that a grating doesn't reflect *all* light out of the core. Rather, it targets only certain wavelengths known as resonances, which depend on the distance between fringes and the refractive properties of the fiber. As these resonances leave the core, they bounce off the fiber's surface and propagate backward through the cladding. They travel only a couple of centimeters at most before being fully absorbed by the fiber's plastic covering. So by analyzing the entire spectrum of light that reflects off the gold mirror and returns to the spectrometer through the core, we can identify these escaped resonances and how much of this light was lost.

Now we're ready to put our probe to work. When we dip it in a test solution, such as human blood, any target molecules that are present–traces of pharmaceutical drugs, for example–will bind to the aptamers on the probe's surface, altering the way it reflects and absorbs light. This small physical transformation tweaks the color or intensity of the resonances leaving the core. Then by analyzing the characteristics and magnitude of these changes, we can determine the concentration of molecules reacting with our probe.

SO HOW SENSITIVE IS OUR LITTLE FIBER LABORATORY? THAT depends on the material we use to attach the molecule-catching aptamers to a probe's surface. You may recall that we first coat the fiber with metal before attaching the aptamers. Remarkably, we have found that this metal layer can increase the sensitivity of our lab by as many as four orders of magnitude.

The explanation involves some rather bizarre physics. The thickness of our coating is typically between 10 and 100 nm, as little as 1/100th the length of the resonant light waves that reach it. If the coating were made of almost any other material, a lot of this light would pass by without being affected by changes at the coating's surface, such as from target molecules attaching to the aptamers. That's because these wavelengths are so much larger than the width of the coating. We might say that the light fails to notice the chemical changes.

But our metal coating has unique properties that force more light to interact with it. Because metal is conductive, its surface electrons oscillate in the presence of an electromagnetic field, such as that produced by a light wave. Under the right conditions, having to do with the wavelength and angle of the light and the material properties of the coating, the oscillations of electrons belonging to nanoparticles in the metal will resonate with the oscillations of the electromagnetic field. These electron resonances are called localized surface plasmons. Like sound vibrations amplified by the air inside a guitar, they absorb energy from the light wave inducing the field, creating hot spots of electromagnetic energy that can extend as far as several hundred nanometers beyond the metal surface. Because plasmons take up so much more space than the nanoparticles they surround, a light wave is far more likely to "see" the molecular events that affect them.



A CRUCIAL COATING: Metal nanocages [brown] deposited on the surface of a fiber probe induce hot spots of electromagnetic energy [yellow] in this composite image. This layer increases the sensitivity of a lab on fiber by as many as four orders of magnitude.

MITCHELL ROBSON AND ANATOLI IANOUL/CARLETON UNIVERSITY

In one experiment, for example, we demonstrated that an uncoated fiber probe could detect 20 micrograms of a common protein, called biotin, per liter of test solution. A gold-coated probe, however, could detect concentrations as small as 2 nanograms per liter, which translates to roughly a pinch of table salt in a 25-meter swimming pool. (We use gold because it's chemically inert, so it's considered safe to use inside the body and won't degrade over time.)

Due to its small size and extraordinary sensitivity, a lab on fiber could take on many diverse roles. As reported in a 2012 paper in the journal *Small*, for instance, researchers led by Jeroen Lammertyn at Katholieke Universiteit Leuven, in Belgium, used a gold-coated probe to detect the smallest possible variations in snippets of DNA. The results suggest that this inexpensive tool could one day provide quick and accurate genetic screening for complex conditions such as cystic fibrosis, cancers, and certain infections.

More recently, our group demonstrated that a lab on fiber can also be used to monitor living cells. For this experiment, we submerged a probe in a culture of skin cells, which attached themselves to it. When we fed the cells nutrients, they grew, increasing the density of the fiber's surface and thereby altering the patterns of light arriving at our spectrometer. Conversely, when we exposed the cells to toxins, they died and detached from the probe, decreasing its surface density and resulting in differences in the spectrogram. Scientists may find lab-on-fiber sensors particularly favorable for studying living tissues because they are too small to affect the cells' behavior.

Ultimately, we aim to develop a lab on fiber that can be inserted directly into humans to monitor biological changes happening in real time. We are currently planning experiments–first in test tubes and eventually in animals–to see if a fiber probe can detect metastasized cancer cells in the bloodstream. We hope to shed light (literally) on the process by which these cells invade other organs. We also hope that this work will help develop new cancer-screening technologies that are less invasive than current tools such as biopsies. For instance, a doctor could insert a fiber probe into a blood vessel using a hypodermic needle. The procedure would be no more painful than a flu shot.

It will probably be at least five years before lab-on-fiber instruments are ready for commercial use. For example, a remaining major challenge is figuring out how to toughen the surface coating on the probes so that they can be stored for several months without becoming unstable and thereby losing their ability to bind with target molecules.

Nevertheless, lab-on-fiber technology is tantalizingly close to being able to compete in cost and performance with today's diagnostic tools for many applications. One of the first might very well be a blood test: Imagine turning on your home lab kit, pricking your finger, and blotting the blood on an array of fiber probes. In just a few minutes, the machine would automatically e-mail the results to your doctor, who could get back to you within hours if there was a problem. Meanwhile, you could get on with the rest of your day. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/labonfiber0414

In the 1950s, this MIT graduate student convinced engineers to build computers using superconducting magnetic switches instead of tubes or transistors

Dudley Buck

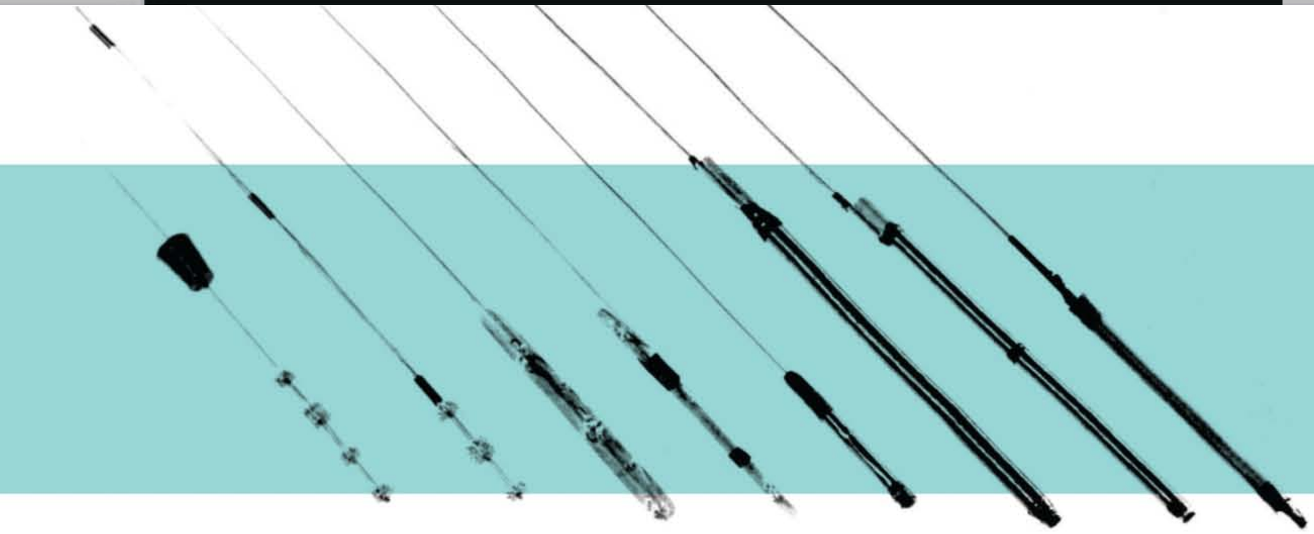
and the Computer That Never Was

By DAVID C. BROCK

Immediately following the Second World War, electrical engineers grappled with a fundamental but open question: How should electronic digital computers be built? What kind of switch would serve best for logic circuits? And what should be used for main memory?

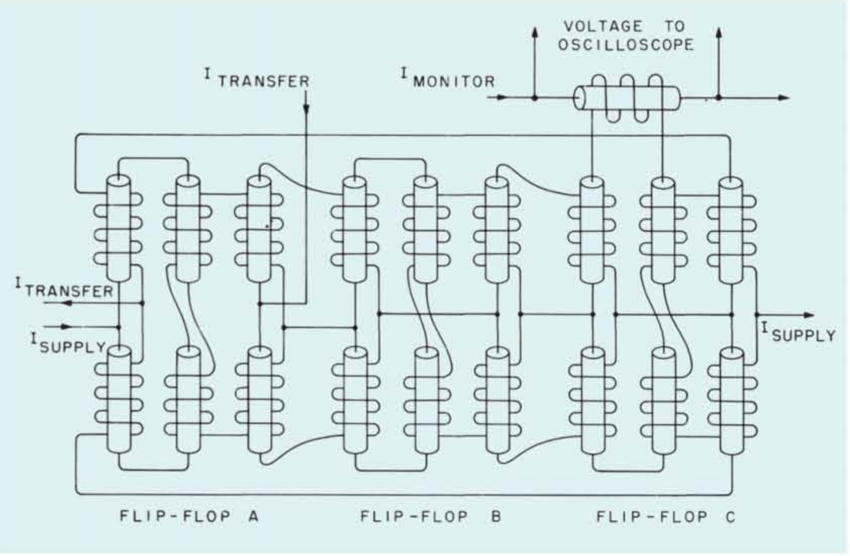
They quickly settled on the speedy vacuum tube, among several options, for the basic logic switch, with each machine requiring thousands of them. (The transistor wasn't yet a serious candidate, having just emerged from Bell Telephone Laboratories.) The options for main memory in the earliest systems were also diverse: specialized cathode-ray tubes, mercury-filled pipes, and spinning drums covered with magnetic paint. But in the early 1950s, the technical community began to converge on another memory technology–magnetic cores. These small rings of ferromagnetic material each held a single bit of data when magnetized in one direction or the other.

Through the mid-1950s, "big iron" mainframes containing vacuum-tube logic and magnetic-core memory dominated the budding world of electronic digital computers. In time, tubes gave way to transistors, and discrete transistors to silicon integrated circuits, for both logic and main memory. But this progression was not inevitable. In the 1950s and early 1960s groups of engineers actively explored radically different paths for the digital computer.



MADE BY HAND: Buck [right] fashioned many prototypes, including a multivibrator circuit [close-up, above], the schematic for which reveals 19 individual cryotrons [below]. With this technology, he anticipated, engineers could construct a bread-box-size computer as powerful as MIT's Whirlwind [far right].

One of the most original of these explorers was Dudley Allen Buck, who worked at MIT from 1950 until his sudden death in 1959 at age 32. Buck made important early contributions to the development of microcircuitry–the pursuit of highly miniaturized circuits fabricated as integral wholes rather than from discrete components wired together. What's more, Buck invented the "cryotron," a superconducting switch he hoped would become the fundamental building block for future digital computers. Inspired by Buck's vision, GE, IBM, RCA, and the U.S. military all mounted major cryotron-research programs in the late 1950s and early 1960s before shifting their focus to silicon microchips for computer logic and memory.



Buck's vision outlived him. It survives even today: The cryotron is at the root of efforts at IBM and elsewhere to make superconducting quantum bits–qubits–in pursuit of quantum computing.

Despite the decades of work that it sparked, Buck and his cryotron have faded from memory. Most electrical engineers today know nothing about this technology. So let me offer here a sketch of Buck's work and his now-forgotten cryotron computer.

AFTER GRADUATING from the University of Washington in 1948 with a bachelor's degree in electrical engineering, Dudley Buck joined the Navy's cryptologic organization in Washington, D.C., where he worked with early digital computers. In 1950, he moved to MIT and began graduate studies in electrical engineering under physicist Arthur von Hippel. Buck also became a research assistant on MIT's pioneering Whirlwind computer, a behemoth intended for military use.

Jay Last, who was a fellow graduate student with Buck at MIT and who later led the team that created the first planar silicon integrated circuit at Fairchild Semiconductor, recalls him as being both a "great visionary" and a "good person…close to obnoxiously good." A clue as to why Last got this impression can be found in a letter that Buck wrote in 1954, when he was just 27: "I have a foster son, aged 17 who has been with me for 4 years, have been a Scoutmaster for 6 years, and I am a lay speaker in the Methodist Church, where I occasionally fill the Sunday morning pulpit. I enjoy working with the human values as well as the engineering values."

Despite the many commitments of a rich personal life, Buck poured enormous energy into his research at MIT. Early on, as part of the Whirlwind effort, he investigated various materials for making magnetic cores. He also searched for materials with dramatic physical properties that could be useful as the basis for improved switches from which to make advanced digital computers.

In 1952, Buck's attention alighted on the chemical element bismuth, which exhibits strong magnetoresistance: Its electrical

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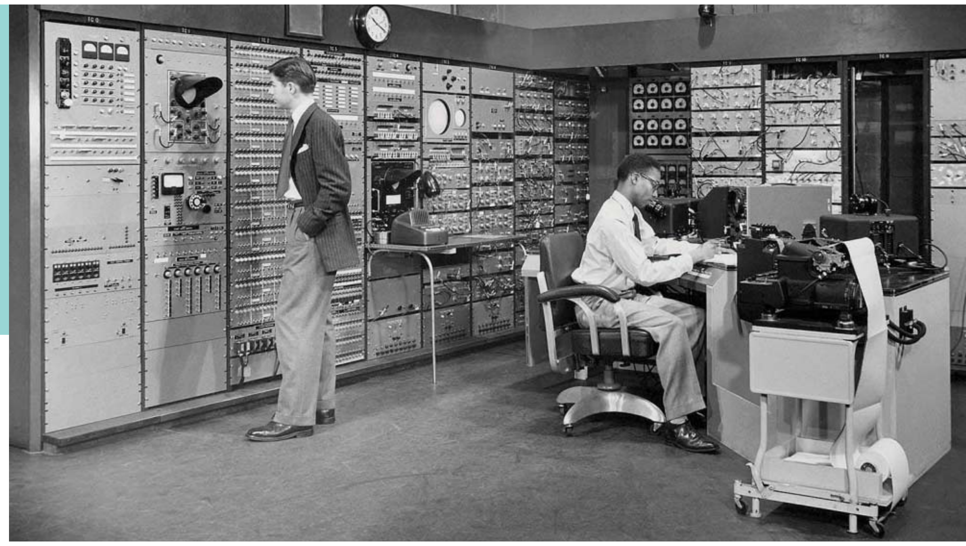


MIT MUSEUM (2)

resistivity rises dramatically in response to an applied magnetic field, especially at low temperatures. At the boiling point of liquid helium (4.2 kelvins), the electrical resistance of bismuth varies by a factor of tens of millions with the application of a strong magnetic field. Buck thought this behavior could be useful for building computers. A relatively small current in a control wire, and the magnetic field it produces, could bring about an enormous change in the resistivity of a piece of bismuth, abruptly halting or allowing current to travel through it. He would have an electronic switch.

By 1954, Buck began to focus on an even more extreme quirk of electromagnetism found at the low temperatures of liquid helium: superconductivity. The phenomenon, while peculiar, was well established. Since the early 20th century, physicists had known that when cooled to temperatures around the boiling point of liquid helium, various metals lose their electrical resistance *entirely*.

Superconductivity also has a magnetic aspect, known as the Meissner effect. A piece of superconducting material excludes magnetic fields—but only up to a point. If a sufficiently large magnetic field is applied, the material is driven, nearly instantaneously, into the resistive state. If the magnetic field is removed, the material returns to the superconducting state.

Buck saw in this phenomenon the possibility for a new, singular building block for electronic digital computers: a magnetically controlled, superconductive switch. He thought it might beat both tubes and cores. A superconductive switch could be very small and fast and consume very little power.

Buck dubbed his invention the cryotron, using a futuristic, quintessentially 1950s evocation of *cryo* (Greek for "icy cold") in a play on the word *electronics*. But he didn't just conceive and name it. He immediately built and tested dozens of prototypes.

Buck's first cryotrons were fantastically simple. They involved nothing more than a short length of tantalum wire around which he wound some copper wire in a tight helix. He then attached electrical leads to both ends of the tantalum and copper wires, so that the cryotron could be dipped into a container of liquid helium while still connected to external circuitry.

By sending a current through the copper helix, thereby creating a magnetic field, Buck could drive the tantalum wire from superconductivity to resistivity. What's more, his prototypes showed gain. That is, a small current in the copper winding could control a much larger current in the tantalum wire. Like triode vacuum tubes and transistors, Buck's cryotron could act as a digital computer's logic switch.

Buck was seized by the promise of his new superconducting device. He imagined making large arrays of cryotrons using the printed-circuitry techniques that he had contemplated in his master's thesis. From these, or even from his wire-wound cryotrons, Buck believed an all-cryotron digital computer could be built, with cryotrons serving for logic and memory alike. But he was concerned about the switching speed of his prototypes, which were disappointingly slow—barely better than electromechanical relays.

In a quest for better performance, Buck tried many different materials. A combination of lead wound with niobium, for instance, offered a switching time of 5 microseconds—not bad, but still much slower than the speediest transistors of the era, which switched 100 times as fast. But Buck believed that by reducing their physical dimensions, he could build cryotrons that matched even the best transistors.

In the meanwhile, wiring together several of his hand-wound cryotrons, Buck successfully fabricated a logic gate, a flip-flop, and a fan-out amplifier. He thus created all the basic circuits required for digital computer memory and logic using cryotrons alone. The all-cryotron superconducting computer was not an idle dream.

AT THIS POINT, Buck's research program, and his ambitions for it, expanded dramatically. He believed that by using microminiaturization techniques he'd be able to fashion a computer containing tens of thousands of cryotrons. Buck's computer would have roughly the computing power of Whirlwind, which at the time was among the world's most advanced digital computers, but it required many rooms packed full of electronic equipment and consumed 150 kilowatts of electricity.

Division 6 - Lincoln Laboratory
Massachusetts Institute of Technology
Lexington 73, Massachusetts

SUBJECT: THE CRYOTRON — A SUPERCONDUCTIVE COMPUTER COMPONENT

To: David R. Brown

From: Dudley A. Buck

Date: August 22, 1955

Approval: Torben Meisling
Torben H. Meisling

Abstract: The study of nonlinearities in nature suitable for computer use has led to the cryotron, a device based on the destruction of superconductivity by a magnetic field. The cryotron, in its simplest form, consists of a straight piece of wire about one inch long with a single-layer control winding wound over it. Current in the control winding creates a magnetic field which causes the central wire to change from its superconducting state to its normal state. The device has current gain, that is, a small current can control a larger current and it has power gain so that cryotrons can be interconnected in logical networks as active elements. The device is also small, light, easily fabricated, and dissipates very little power.

1. The Cryotron Principle

Before describing the cryotron as a circuit element and potential computer component, the basic physical phenomena underlying its operation will be described.

BETTER THAN TUBES: This 1955 report, published in 1956, informed the computer-engineering community of Buck's new magnetic switching element.

The 28-year-old engineer was in essence proposing to squeeze Whirlwind down to the size of a radio set, submerge it in a tub of liquid helium, and run it using no more power than what a Christmas-tree bulb consumes. His vision was audacious, but his arguments, enthusiasm, and results convinced his colleagues that the cryotron had merit.

Cryotron research now became Buck's official job at MIT's Lincoln Laboratory. While he continued to work on smaller, faster, lower-power cryotrons, he simultaneously began a project to create a large computer memory, for which the slow switching speeds of existing cryotrons would not matter.

Buck proposed using 75 000 cryotrons to form what is known today as a content-addressable memory. Buck himself would come to refer to it as a "recognition unit." That's because each of the many memory locations was simultaneously checked to see whether it contained a desired piece of information.

Such a memory had particular advantages for cryptanalysis, in which the identification of patterns is often paramount. I suspect that Buck's motivation for building it stemmed from his earlier work on code-breaking machines for the Navy and from his ongoing consulting work while at MIT for the newly minted National Security Agency (NSA). In any event, his all-cryotron recognition unit would be only about as large as a briefcase, and yet at 3.2 kilobytes, it would roughly match the main magnetic-core memory of Whirlwind.

As Buck prepared a patent application on the cryotron in mid-1955, news of his effort to build a content-addressable memory percolated through U.S. cryptological and computing circles, generating considerable interest. In July of that year, John McPherson, an IBM vice president who was a leader in the firm's efforts in electronic computing, wrote to Buck, explaining that William Friedman, the chief cryptologist of the NSA, was "very interested" in Buck's superconducting computer components.

Buck filed his patent application just days after receiving McPherson's letter. The patent, for a "Magnetically Controlled Gating Element," contained broad claims for the cryotron and its use in computers.

At this point, Buck's cryotron research expanded beyond MIT, albeit just down Memorial Drive. He signed a consulting agreement on cryotron technology with the contract-research firm Arthur D. Little. Named after its MIT chemist founder, A.D. Little was adjacent to the MIT campus and in the 1950s had become a leading producer of cryostats for the production of liquid helium. With NSA sponsorship, Buck and researchers at A.D. Little began development of Buck's cryotron recognition unit, starting with a smaller proof-of-concept memory array.

Through the rest of 1955, Buck's personal cryotron research at MIT focused on creating miniature cryotrons, and even integrated cryotron arrays, using evaporated thin films. Instead of winding small wires about one another, he wanted to evaporate metal through a mask, like a stencil, onto a substrate to create a patterned thin film of superconducting material. Atop this film, he would evaporate the control wiring through another mask. He would thus be able to print cryotrons, arrays of them.

In preparation, Buck tested a variety of films made of alloys of lead, bismuth, strontium, indium, and other elements. During these experiments, he produced a 100-nanometer-thick film of a lead-bismuth-strontium alloy that could switch between superconducting and resistive states in 0.1 microsecond–a tenth the speed of the fastest transistor at the time. Buck also designed a wide range of binary circuits that could be constructed solely from cryotrons, including flip-flops, gates, multivibrators, adders, and accumulators.

With his patent filed and significant research completed, Buck was ready to announce the cryotron to the world. He submitted a paper titled "The Cryotron–A Superconductive Computer Component" to the Institute of Radio Engineers, one of IEEE's predecessor organizations, in November 1955. In the paper, Buck detailed the wire-wound cryotron and a range of basic digital circuits that could be made with it, stressing the implications for this superconductive device in computing. "The cryotron in its present state of development... can be used as an active element in logical circuits," Buck wrote. He did not restrain himself from sharing his conviction that, in the near term, "a large-scale digital computer can be made to occupy one cubic foot.... The power required by such a machine extrapolates to about one-half watt."

Buck's discussion of switching speeds in this paper was, in contrast, coy: "The device is at present somewhat faster than electromechanical relays, but far slower than vacuum tubes and transistors. A program is under way to increase the speed." Although he had already tested thin-film cryotrons that could come close to the fastest transistors, Buck kept news of this development and the ongoing | CONTINUED ON PAGE 57

MIT

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

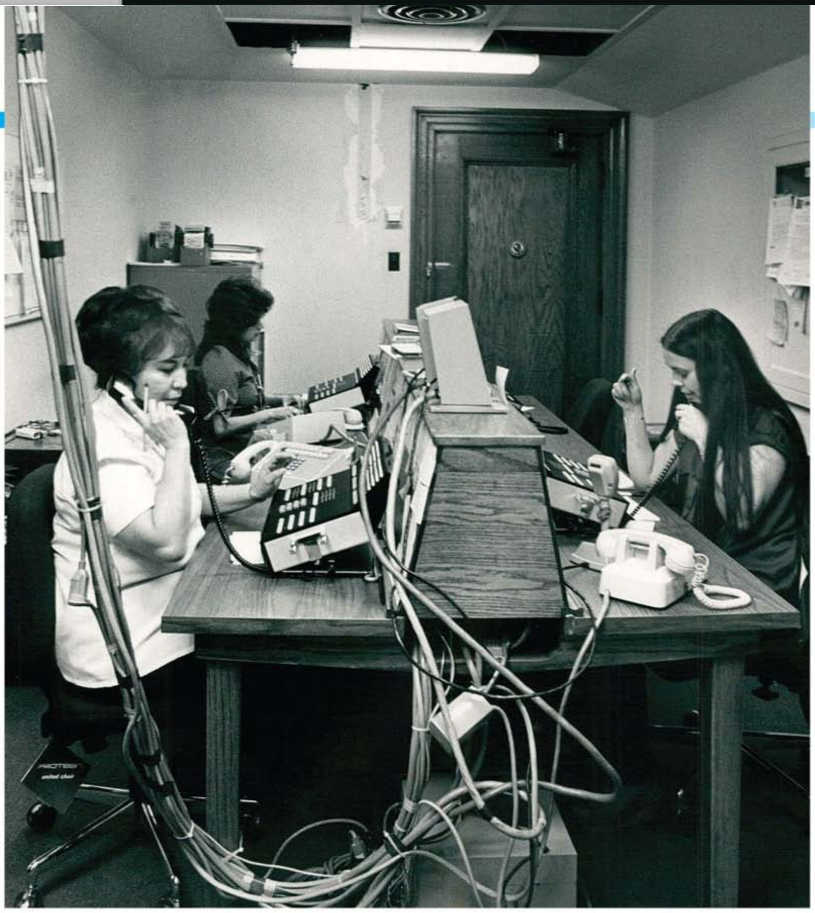
911 FOR THE 21ST CENTURY

Here's how to make emergency services work with wireless and Internet distress calls

By Richard Barnes & Brian Rosen

NO MATTER HOW SMART YOUR PHONE MAY BE, your Mayday call likely relies on an ancient 2400-baud modem to tell emergency responders what they most need to know—your location. And as phone technology advances, the problem is getting worse. • An elementary school in Illinois found this out the hard way when a school official called 911 to report that two kindergartners had wandered off. The call went to an emergency communications center in Canada, delaying the response by several minutes. The children were eventually found, but the delay could have made a deadly difference in other circumstances. • Engineers have installed a patchwork of updates to try to keep pace with calling technology, but they've reached their limit. It's time to rebuild the system from the ground up—and that's exactly what's happening in the United States and in many other places around the world. • Governments, network operators, and technology developers are building emergency

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



IN THE '80s: Operators in a Denver emergency communications center answer calls in 1984.

calling systems based on the Internet Protocol. These systems will route emergency calls in an entirely new way, expand the service to include video and text, and reduce the cost of operations. This modernization is happening in a consistent way everywhere, which means that emergency calling will work for users who take their devices with them as they travel. And by creating a global market for emergency response equipment, standardization is lowering the cost of the systems.

In the United States, where the emergency number is 911, the National Emergency Number Association is leading the effort with its NG911 project; the European Emergency Number Association is leading a corresponding NG112 effort. National regulators and local standards organizations in South America and Asia are interested but not as far along.

To understand the benefits such systems can provide, it helps to take a look back at how we arrived at the hodgepodge we have today. We'll use the U.S. 911 system as an example.

The 911 service originated in the 1960s, when most phones were connected to the telephone network by copper wires and were installed and served by the same company–AT&T. There were relatively few phone lines, so it was easy for an emergency call taker to look up a number in a book to find the correlated street address. Each local telephone exchange had a set of lines connecting it to an emergency communications center, officially called a Public Safety Answering Point, where call takers routed each call to the dispatcher for the appropriate response agency: fire, ambulance, or police.

In the original system, all 911 calls arriving at a telephone exchange would go to the same place. A telephone exchange that received a call to the number 911 would automatically route it to the connected emergency communications center. But because emergency services were provided by local governments whose jurisdictions often did not coincide with areas covered by the centers, emergency responders had to cobble together cooperation agreements between emergency services agencies to reroute calls properly.

A MORE ORGANIZED and reliable fix came in the 1980s, in the form of Enhanced 911, or E911, which is still in use today. This standard employs an automated digital information service that makes it unnecessary to look in directories for numbers and makes it possible for telephone exchanges to route different calls to different emergency communications centers.

With E911, instead of going to a directly connected emergency communications center, calls to 911 go to a designated telephone switch called a selective router. Each selective router serves a number of telephone exchanges and directly connects to the centers in the region. The selective router has a database with an entry for each telephone number that specifies which center should receive the call. This extra intelligence allows the selective router to connect a call to the proper center based on the caller's actual location, not just the exchange the caller is connected to.

When the call reaches the correct emergency communications center, the computer there queries an off-site database, using a 2400-baud modem. This database lists the street address for each telephone number, the name of the subscriber, the identity of the carrier serving the subscriber, and the class of service–for example, residential, business, or pay phone.

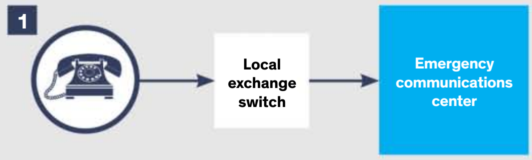
Just as emergency responders got used to getting all this information, however, the appearance of mobile phones plunged them back into darkness. Mobile phones violate all the assumptions about the wired phones on which E911 relies. For one thing, mobile phone users roam the world, so a caller's phone number no longer reliably indicates the caller's location or the appropriate set of responders. Mobile phone users were shocked to discover that unless they could verbally tell emergency call takers where they were, a 911 call often led to a lengthy delay while responders searched for the person needing help.

It's not only the routing problem that made it hard to connect mobile phone calls to the system: The means of describing the location was also at fault. Until the early 21st century, emergency communications centers found callers by street address; they didn't have a way to handle the latitude and longitude coordinates they received from mobile networks. It's better today: Only a few percent of emergency communications centers still can't map a caller's location with that information. Still, some methods for locating wireless callers can get responders to

PREVIOUS PAGES, LEFT: NICOLE BENGIVENO/THE NEW YORK TIMES/REDUX; RIGHT: EDWARD MCCAIN/GETTY IMAGES; THIS PAGE: DAVE BURESH/THE DENVER POST/GETTY IMAGES

EVOLUTION OF 911

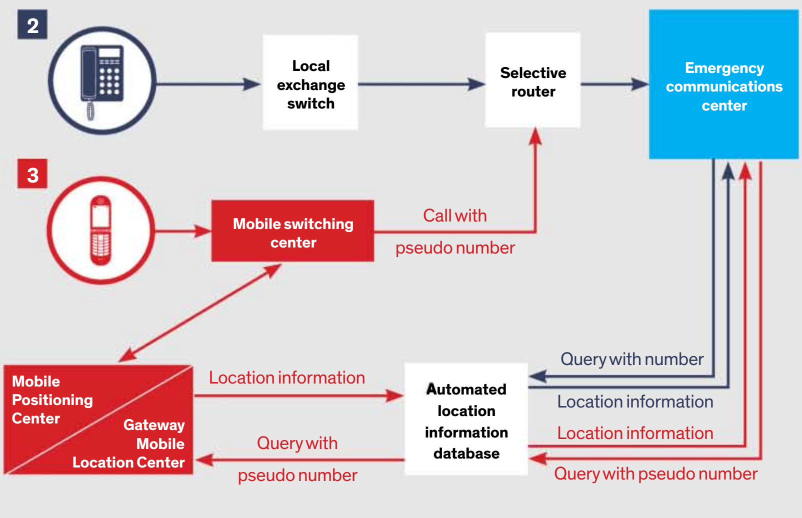
1 **BASIC 911** In the United States started in the 1960s. Emergency calls went directly from the telephone exchange to an emergency communications center, where call takers looked in paper directories to determine the associated phone number. Areas served by telephone exchanges and emergency communications centers didn't overlap perfectly.

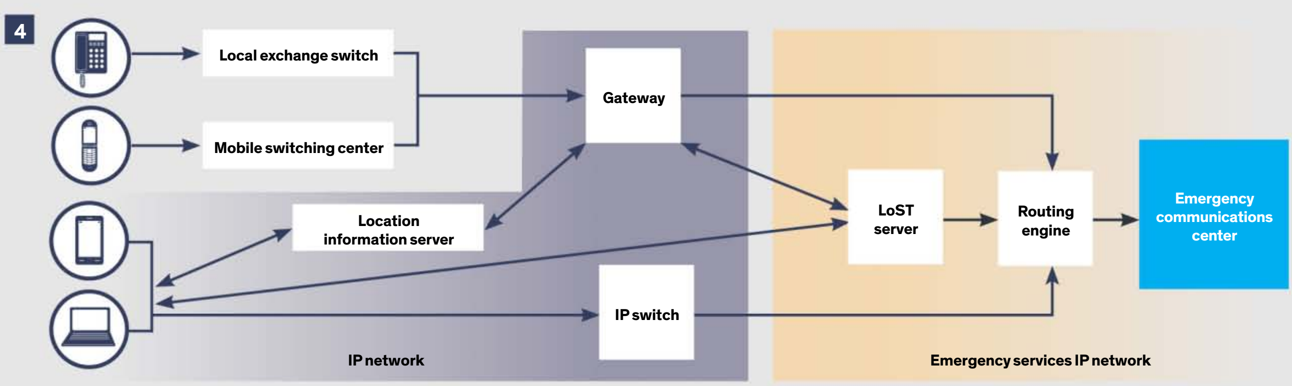


2 **ENHANCED 911** services began in the 1980s. They send calls to a special router that directs them to the correct communications center. This solved the problem of mismatches between areas covered by exchanges and areas covered by communications centers. E911 also looks up address information automatically.

3 **E911 ADAPTED** to include cellular calls in the 1990s. Such calls go first to a Mobile Positioning Center or Gateway Mobile Location Center, which determines the caller's location using GPS or triangulation. The center obtains a pseudo phone number that enables the router to direct the call to the correct emergency communications center. The center queries the automated location database to get the location information for responders.

4 **THE NEXT-GENERATION 911** system uses the Internet Protocol to direct emergency calls, including the new Location-to-Service Translation (LoST) protocol. Mobile phones and Internet calling services get location information from the access network. Calls from landlines are converted at a gateway to use the same protocol as for Internet calls.





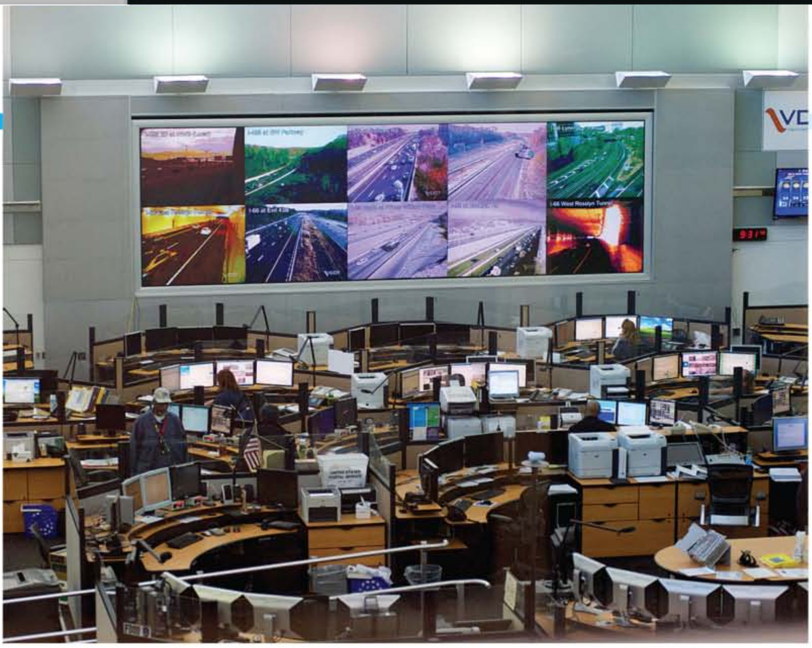
only within 100 meters of the caller; known addresses associated with wired phones are obviously better than that. And when the network has to rely on information from cell towers, it can sometimes locate the caller to only within a few kilometers.

UPGRADING E911 TO support mobile phones requires that each mobile phone company operate a new type of information service, usually called a Mobile Positioning Center or Gateway Mobile Location Center. These services make the location information databases used by emergency responders more dynamic. Instead of storing a fixed location for each phone number, the systems query the network or the device in real time.

It works like this: The switching center for the mobile network connects to a selective router that deliberately lies about the caller's number in order to get the location to come out right. It provides a pseudo number from a set of numbers appropriate for the geographic area around the caller's current location. That way the call goes to the right responders.

At the emergency communications center, the database flags the call as coming from a pseudo number and identifies the Mobile Positioning Center or Gateway Mobile Location Center that assigned it. The system then sends the query along to the correct positioning center or location center, which tries to figure out the cellphone's location by collecting its GPS coordinates or calculating its location by comparing the strength of the signals coming from several points–that is, by triangulation. If the system can't do that, say, because the GPS signals are blocked, or too few towers are able to measure signals from the phone to provide coordinates for triangulation, it instead sends the street address of the cell tower. That, however, may not be particularly useful, because the caller could be several kilometers away.

ILLUSTRATION BY Erik Vrielink



911 TODAY: Operators at the Department of Public Communications in Fairfax, Va., answer emergency calls in 2012.

THE WASHINGTON POST/GETTY IMAGES

Outside of the United States, caller information systems vary dramatically. In Japan, callers can request that their locations be suppressed for privacy reasons. In some countries, like Austria, the phone companies can locate callers, but call takers at communications centers might have to make a special phone call or send a fax to get the information. Many countries in the European Union can identify only the serving cell tower, although very recent EU regulations will force operators of mobile systems to upgrade to more accurate location determination systems. And in some parts of the world, emergency calls are still simply normal calls to the local police station.

AROUND THE YEAR 2000, most emergency communications systems were able to locate mobile callers reasonably well; then voice over IP (VoIP) technology, introduced by companies such as Vonage and Skype, set them a giant step back. A VoIP service knows only callers' IP addresses, not their locations. And regulators didn't initially require VoIP services to support emergency calling.

But regulatory pressure eventually forced emergency authorities and VoIP companies to hack VoIP 911 calls into the E911 system. They followed the approach used for mobile phones: A VoIP Positioning Center for a VoIP provider, like a Mobile Positioning Center for a cell-service provider, creates a pseudo number with corresponding location information. However, the only location a VoIP number has is one that the user has manually registered. So if a user takes a Vonage device from New York to Seattle and forgets to update its registered location, 911 calls will still go to New York. And people do forget. In some cases, American callers in the United Kingdom have reached U.S. emergency communications centers because they had brought their devices abroad.

The fixes that allow emergency dispatch systems to get some kind of location information from mobile and Internet calls can still cause delays. For mobile calls in the United States, about one call in a thousand suffers from these delays. For Internet calls, the rate is at least several percentage points, possibly much higher. If you're in that unfortunate fraction, the 20 extra minutes it takes to find you can be huge.

But this is the best that today's 911 system can do. And as bad as that system is at extending location services to mobile phones and Internet phones, it is worse still at accommodating even newer services like text, video, social networking, and Web-based calling.

The circuit-based nature of the 911 system also makes it easy to knock an emergency communications center off-line. Because the number of physical lines that go into a center is typically small, it can take only a few calls to overwhelm many of today's centers. Because there is no automatic way to reroute calls to other centers, an attacker with a few phones can deny emergency services to an entire area.

THE ONLY WAY to fix this mess is to replace the whole system and start with a clean slate. And that's what's happening, with a redesign of emergency calling known in the United States as Next Generation 911 (NG911) and in Europe as NG112.

The core of NG911 is the Emergency Services IP Network, or ESInet. This network uses the standard Session Initiation Protocol, common in VoIP services and 4G mobile networks, to define the data messages that must be sent to begin and end calls, along with data to initiate other calling features, like Caller ID and call forwarding.

Because the dialing string that starts an emergency call, like 911, varies by country, the Internet Engineering Task Force, which develops standards for the Internet, has defined a standard emergency marking that goes in the message that starts the call. The marking can be recognized by all systems in the call path, even those outside of the country in which the call is being made. It therefore doesn't matter whether 911, 112, or some other series of local emergency digits were actually dialed.

Remember that E911 was designed around wire-line networks, and mobile and VoIP callers had to be adapted to fit into the wire-line model. NG911 reverses that approach—VoIP and 4G mobile calls go straight through, and it's the wire-line and older wireless calls that have to adapt. A gateway converts them so that they can use the Session Initiation Protocol.

This reversal simplifies the path of VoIP and 4G calls, but a fundamental challenge for VoIP calls remains. Delivering a VoIP call requires two types of networks, each of which is missing a key piece of information needed to route an emergency call. The first type of network is an "origination network," which delivers the call over the Internet—think Skype or Vonage. An origination network "knows" that it's delivering an emergency call but doesn't know where the caller is, only the caller's IP address. The second type of network is an "access network," which routes IP packets over wires or antennas—think Comcast or Verizon. The access network usually knows where the caller is, but it can't tell that there's an emergency because emergency-call packets look the same as any other packets. In fact, because many calls are encrypted to protect the user's privacy, the origination network may not even know that the packets are part of a call at all (as opposed to, say, Web browsing or online gaming packets).

So there's a need for some entity involved in an emergency call to contact the access network and fetch the caller's location. The calling device itself is in the best position to do this. Because it is connected to both the access network and the origination network, it can query the access network to get its own location and then send that location data through the origination network to the emergency communications center as part of the data that signals the start of a call.

THAT'S HOW THE NG911 system figures out where a caller is. The next step is to route the call.

The calling device or the origination network obtains the caller's location from the access network and sends it to a local server based on the Location-to-Service Translation (LoST) protocol, defined by the Internet Engineering Task Force in 2008. The LoST servers have maps of emergency communications center coverage areas. These LoST servers provide a much more flexible routing system than the selective routers they replace. That greater flexibility translates into increased reliability as well. If a given center is overloaded, the LoST servers can steer new calls away, to a backup center. In extreme emergencies that overwhelm huge regions–say, a hurricane–LoST can route calls anywhere in the country. The call taker in a distant center can see the same map that a local call taker would see and dispatch the call the same way the local center would.

With this new system, in which every call–landline, mobile, or Internet–travels through the network according to the Internet Protocol, calls can contain any mix of voice, video, and text media as long as the calling device supports it. These rich media can allow a call taker to better assess an emergency situation through photos or video. The new standards also allow emergency communications centers to get previously unavailable information, like device-specific data (such as the status of a rollover sensor from an in-car calling system like OnStar). The NG911 design includes extensive support for persons with disabilities, including the ability to establish a three-way call, for example, that includes a deaf caller, the call taker, and a sign-language interpreter.

The NG911 system will eventually be able to transmit medical history data to emergency medical technicians or even to specially trained call takers who coach callers in first aid. It will allow emergency communications centers to tap into information about buildings, such as floor plans, elevator status, and storage sites of hazardous materials. It will be able to notify parents if their children call 911, or add parents to the call.

NG911 also includes mechanisms to ensure the security and resiliency of emergency services. Because NG911 operates over an IP network, designers of emergency networks can build upon the comprehensive Internet security tools that already exist. Even if a disaster or a deliberate attack should over-

load an emergency communications center, with NG911 other centers can step in to help.

MOST OF THESE benefits, however, lie in the future. A few states have installed NG911 systems that use IP networks and the NG911 call-routing mechanisms, but these systems have enabled just a few of the new features that NG911 provides, mainly more flexible routing of calls. Systems that are capable of taking advantage of more new features should be available within the next year or two.

The technical challenges of migrating to NG911 are daunting: Because emergency communications centers, calling networks, and IP networks will all be making upgrades independently, as their schedules and funding allow, it will be necessary to operate legacy and next-generation services side by side for several years to come.

There are also legal and financial challenges. The regulations that have governed emergency calling for the past several years are largely predicated on the idea that telephone companies, not Internet companies, are the entities that connect emergency calls. So it is likely that many regulations or statutes, across many jurisdictions, will have to be adapted. It's not always clear which service providers should have to support emergency calling; while with hindsight, it's obvious now that mobile and VoIP services must do this, it wasn't so obvious when those services began. It's important to balance the need for emergency communications with the need to keep Internet communications technologies flexible and open to innovation.

Now that text-to-911 is coming, should stand-alone messaging systems like Facebook's or Google's be required to support emergency messaging? When you can click to dial a video connection through an app like Skype or even a browser, should these services be required to support emergency calling? Regulators do not require Internet service providers to provide emergency services with the locations of their customers, but they will need to in order to allow many Internet applications to provide emergency communications. Will a hotel that operates a Wi-Fi network also be required to run a location server?

The initial wave of NG911 upgrades currently in progress will be largely invisible to the consumer. The upgrades focus on creating the emergency services network, installing the servers that route the calls, and connecting the emergency communications centers.

Once most 911 calls travel over the Internet, consumers will begin to see visible changes. They'll be able to add pictures or video to their emergency calls. They'll be able to request that they be added to an emergency call when a child or elderly parent calls 911. When physical wires no longer limit the routing of emergency calls, emergency responders will be able to create far more efficient, reliable, and adaptable systems for use in disaster response.

And if the standard is widely adopted around the world, as we anticipate it will be, we will have a single, uniform way of placing an emergency call. All these benefits mean that more lives will be saved. And that, of course, is the point of emergency services. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/emergency0414

Dudley Buck

CONTINUED FROM PAGE 48 | work on the cryotron recognition unit to himself.

By the time Buck's article appeared in the *Proceedings of the IRE* (April 1956), he was regularly creating and testing thin-film cryotrons. The work at A.D. Little on the proof-of-concept cryotron memory unit was under way, and NSA engineer Albert Slade had begun his own investigations of cryotron circuitry with advice from Buck.

Around this time, Buck submitted to von Hippel his ideas for a doctoral thesis. The outline came as no surprise: Buck would investigate evaporated thin films of superconducting materials and study ways of controlling their thickness and geometry to create fast-switching cryotrons. Von Hippel signed off on the proposal, which promised to yield exciting results promptly.

UNTIL HIS DEATH IN 1959, Buck was at the center of expanding and intensifying efforts to develop integrated cryotron microcircuits. Albert Slade, for example, moved from the NSA to A.D. Little to work on the cryotron recognition unit. Another NSA researcher, Horace Tharp Mann, began studying evaporated thin-film cryotrons in consultation with Buck. In 1957, IBM and RCA each initiated their own NSA-funded programs to develop high-speed thin-film cryotron circuitry. General Electric added to the momentum with a self-funded program of cryotron research. Buck, still the MIT graduate student, now had some stiff competition.

In characteristic fashion, Buck responded by setting even higher goals for his research. He did that in a collaboration with Kenneth R. Shoulders, who, like Buck, was a member of von Hippel's MIT laboratory. Shoulders was actively pursuing a different innovation: using electron beams to "micro-machine," or etch, extremely small microcircuits. This approach, later dubbed electron-beam lithography, has become indispensable in making silicon microchips. In the mid-1950s, Shoulders was aiming to construct electronic devices with features as small as 100 nm–smaller than a virus and orders of magnitude smaller than anything anyone had ever attempted to make. Shoulders's ambitions aligned precisely with Buck's desire to increase the speed of cryotrons through miniaturization and to create large-scale integrated arrays of them.

In their work together, Shoulders explored various ways of manipulating electron beams while Buck evaluated a wide variety of superconducting alloys and the resist materials for electron-beam etching. The pair worked together until the middle of 1958, when Buck earned a doctorate and a position as an assistant professor in MIT's department of electrical engineering and Shoulders left MIT for the Stanford Research Institute in Menlo Park, Calif.

As a capstone to their collaboration, Buck and Shoulders presented a paper titled "An Approach to Microminiature Printed Systems" to the Eastern Joint Computer Conference in December 1958. This paper expressed their now-shared conviction in the future of massively integrated microcircuitry. "The day is rapidly drawing near when digital computers will no longer be made by assembling thousands of individually manufactured parts into plug-in assemblies," they wrote. "Instead, an entire computer or a very large part of a computer probably will be made in a single process."

Five months after presenting this paper, Buck died suddenly. The last entry in his lab notebook, dated 18 May 1959, describes his effort to deposit a film of the element boron. Stricken in the following days by respiratory distress, Buck perished on 21 May. Not one month had passed since his 32nd birthday.

Although his death was attributed at the time to viral pneumonia, I believe that his deposition experiments may have been to blame. Buck's work of 18 May involved two substances that require the utmost care. His source of boron was boron trichloride gas, and the process for depositing the boron film generates hydrogen chloride gas. Exposure to either gas, to say nothing of their combination, can cause fatal pulmonary edema to develop, with symptoms similar to pneumonia. And while he had taken courses in the subject at MIT, Buck was not a chemist. He may not have appreciated the danger or have had sufficient bench experience to safely contend with these gases. In any event, for his colleagues, Buck's death was a tragedy.

CRYOTRON RESEARCH did not end with Buck. Strong efforts to build cryotron computers continued into the 1960s. Mann, who had worked on thin-film cryotrons at the NSA, moved to TRW's Space Technology Laboratories in Los Angeles in the late 1950s. There, he pursued electron-beam lithography to make thin-film cryotrons until 1966. And researchers at A.D. Little continued to develop cryotron memory arrays in an effort to build Buck's recognition unit.

Meanwhile, GE, IBM, and RCA developed thin-film cryotron microcircuitry, particularly for memory, through the early 1960s. By 1961, GE researchers had produced a working integrated shift register made with thin-film cryotrons, matching the complexity of silicon integrated circuits at the time. Within two years, GE's cryotron microcircuitry had *surpassed* silicon microchips in its level of integration. Researchers there even fabricated an experimental working computer from three arrays of integrated cryotrons.

Despite all these efforts, the rapid development of silicon microchips—in particular their ability to lower the cost of electronics—during the 1960s eclipsed the advances in cryotrons, leading to digital computers dominated by silicon logic and magnetic-core memory. By the mid-1960s, most cryotron researchers abandoned the superconducting switch, shifting their attention to silicon.

Some persisted, however. Their attention focused on special cryotrons that exhibited a quantum-mechanical phenomenon called the Josephson effect. In the early 1970s, IBM researchers created modified cryotrons known as Josephson junctions. These were at the center of a huge effort at IBM to build superconducting computers, which lasted into the 1980s. And Josephson junctions continue to be a mainstay of quantum-computing research at IBM and elsewhere.

So Buck's cryotron never really disappeared. It has survived, in different forms and under different names, in the long shadow of the silicon microchip. We can only wonder what more Buck might have explored had he lived longer. ■

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

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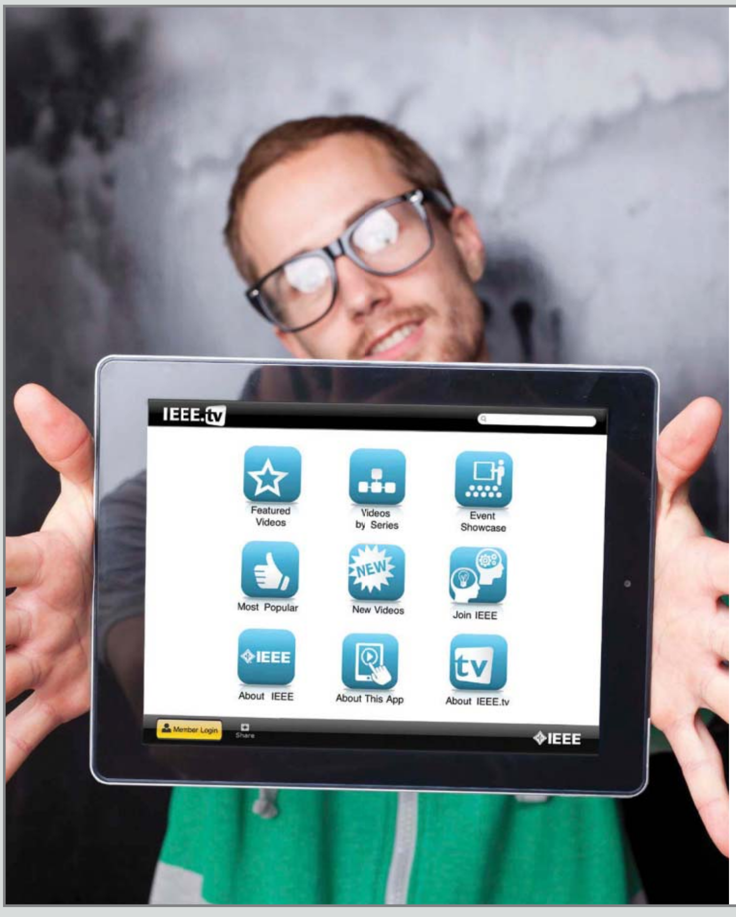

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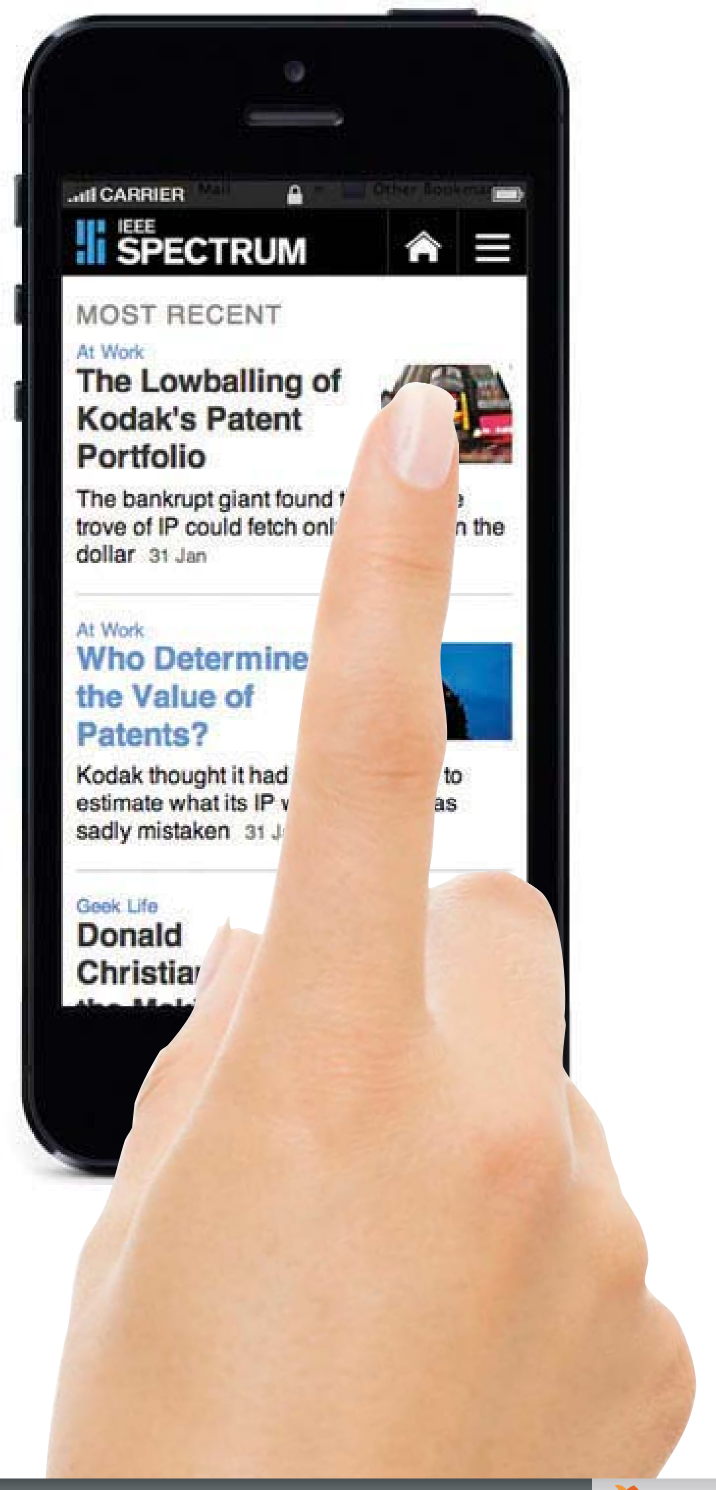
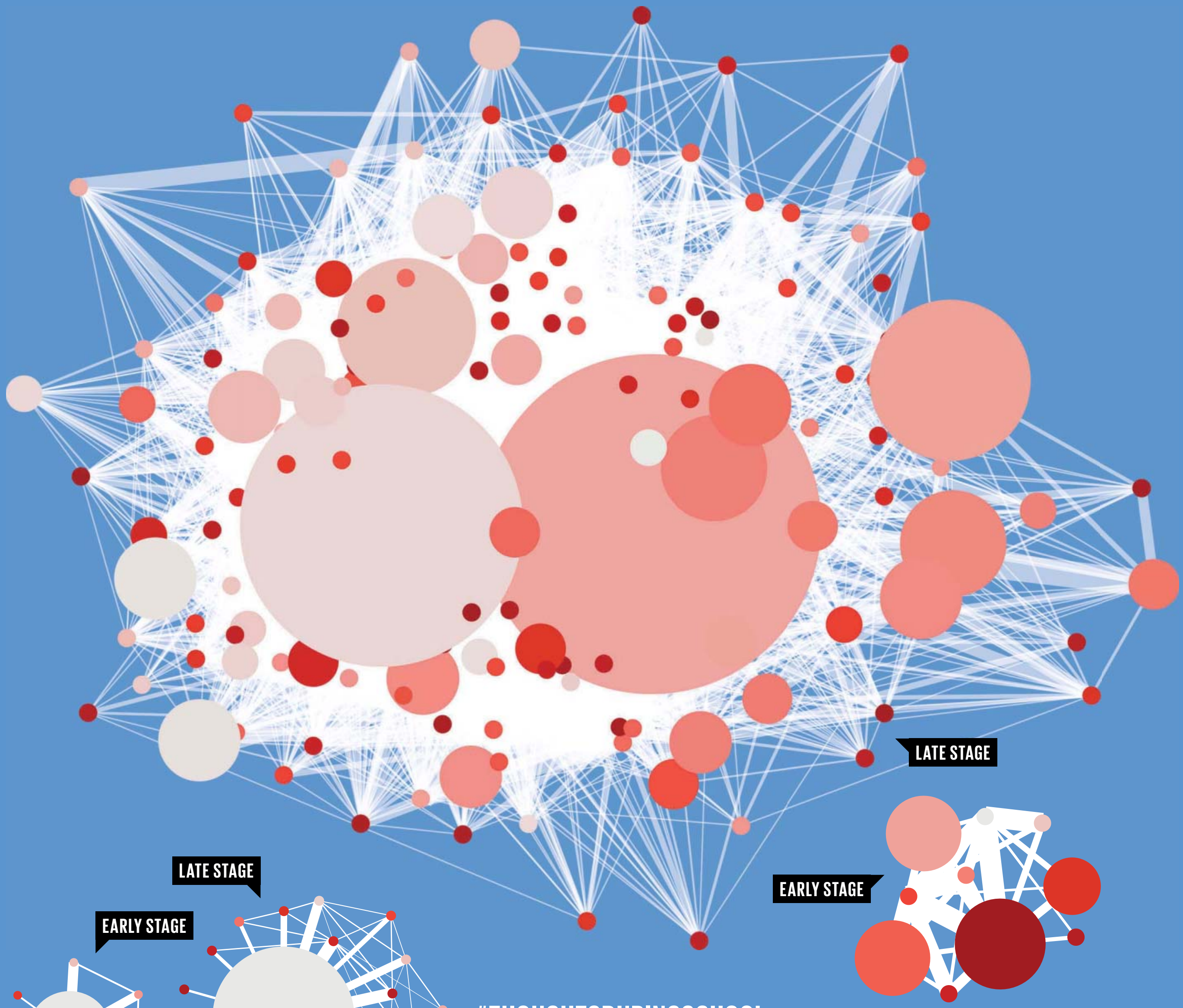
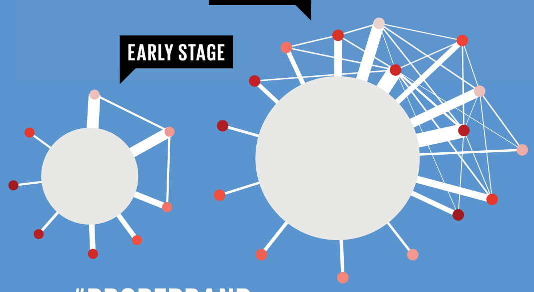


DATAFLOW_

FORECASTING VIRALITY
THE STRUCTURE OF EARLY SHARING IS A PREDICTOR

Memes, like Rickrolling or LOLcats, are the invasive species of social network ecosystems such as Facebook and Twitter. "Viral hashtags are so interesting that even at first sight, you just start to use them," says Yong-Yeol Ahn, assistant professor at Indiana University's School of Informatics and Computing. Ahn and his coauthors have isolated the network properties of memes and turned them into a forecasting tool, enabling the prediction of which Twitter hashtags will go viral nearly two out of three times based on how the hashtag is shared in its early stages. Ahn says later this spring they'll be publishing follow-up research that looks at predicting just how big a splash a viral meme will make. —MARK ANDERSON





#PROPERBAND

Ahn's group considered more than 10 million different Twitter hashtags generated during March and April 2012. #ProperBand was a nonviral example, never spreading beyond one degree of separation from the original community of users that created it.

#THOUGHTSDURINGSCHOOL

By contrast, #ThoughtsDuringSchool started in one community and, even in its early stages, rapidly spread to other communities, some distantly connected to the hashtag's original source. This is a hallmark of virality, Ahn says. By the end of the rapid diffusion of #ThoughtsDuringSchool, it's nearly impossible to discern which community originated the hashtag. But the cross-community behavior it displayed at its outset is still in evidence. Forecasting virality, then, is about identifying cross-community connectivity at its earliest stages and then betting that a given meme will keep behaving the same way, just on a larger scale.

Circles represent communities—densely connected groups of users. Circle size represents the number of tweets with a given hashtag made per community. The color indicates when in the hashtag's life span the most tweeting occurred in a community (darker is newer).

SOURCE: "VIRAL PREDICTION AND COMMUNITY STRUCTURE IN SOCIAL NETWORKS," LILIAN WENG, FILIPPO MENCZER, AND YONG-YEOL AHN, *SCIENTIFIC REPORTS*

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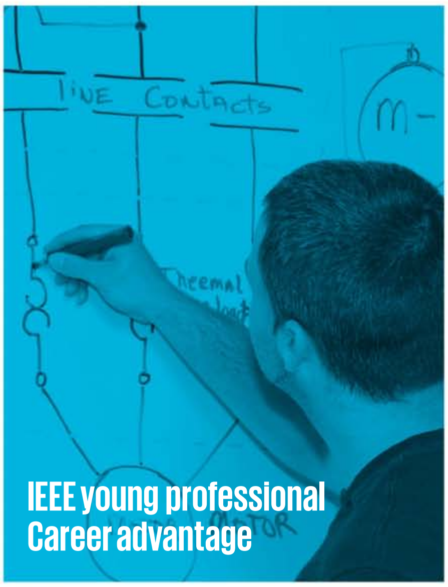

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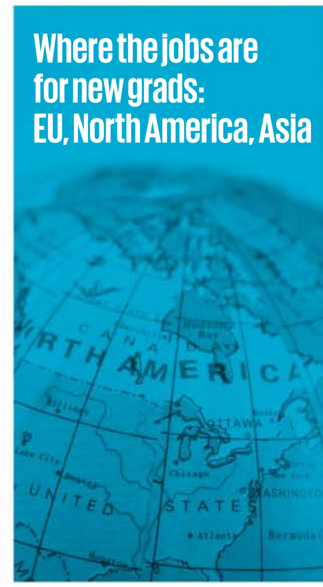

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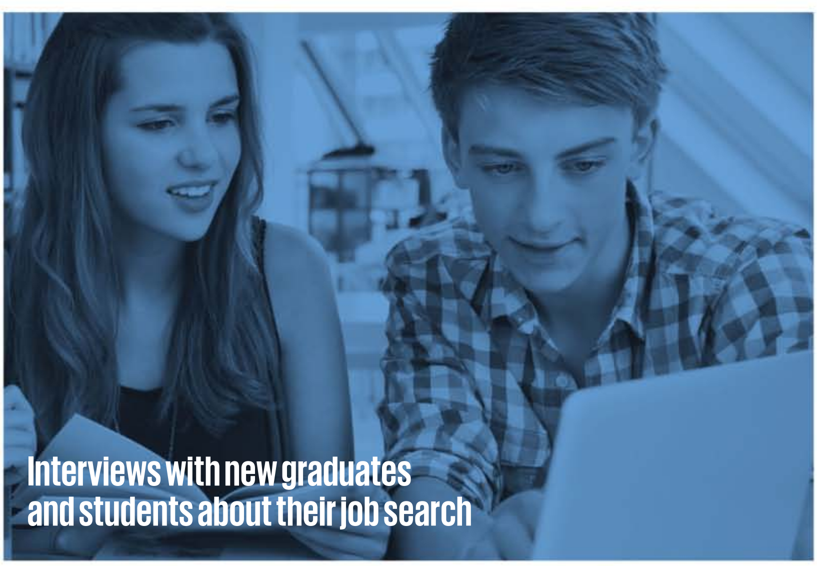

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IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

SUMMER INTERNSHIPS A LAUNCHPAD TO GREAT CAREERS

By Anant Baijal

There is no more exciting way to spend your summer than to develop yourself professionally while also exploring interests and learning new things. Yes, summer internships can help you gain experience, travel to new places, and meet like-minded individuals. They also look impressive on your résumé. Summer internships can be academic: You can work in a research lab or an institution on a challenging research project. Or they can be something totally offbeat: You may want to try your hand at politics by organizing campaigns, write for a magazine or news daily, learn about operations research at an airport, or even join an entertainment theme park and combine learning with fun. You may also choose to take part in summer schools, which are organized worldwide in a variety of subjects.

The first step is to secure an internship, but many students are unaware of summer openings. The best thing to do is to talk to others and find out where they pursued their internships; some may even directly recommend you. Moreover, your professors should be a great help, for they have connections. Also, don't feel shy about contacting your relatives, friends, and friends of friends—it is time to use your resources productively.

While applying for an internship, keep in mind that there are thousands of applicants and that your application needs to be different. It will not suffice to brag about your high grades or mention that you are hardworking and possess out-of-the-box-thinking. You need to show them that you have these qualities through examples and through your previous work.

Once you have secured an internship, use your time judiciously. Understand the work culture and make connections. For those of you working on research projects, try to figure out an improvised technique or develop a new method, and publish your results in reputable journals or international conferences—this will greatly help toward your future admission to universities and also give you an edge during job interviews.

Applying for an international summer internship adds a lot more excitement. You get to see a new country, work on some of the most advanced technologies, and make friends from around the world—plus you learn to be independent and self-reliant. Having a global outlook and the experience of working in multicultural environments helps you emerge as a leader. Prospective employers may seek referrals from the organization at which you interned, so it is essential that you take your internship seriously.

Prospective employers may seek referrals from the organization at which you interned, so it is essential that you take your internship seriously.

I feel fortunate in having interned in some of the best research environments—one at Indian Institute of Technology Delhi, another at Ryerson University, Toronto, and a five-month stint at IIT Bombay. I would like to share a few things that these internships taught me. The internship coordinator at IIT Delhi highlighted the importance of ethical work, and he gave me a very meaningful lesson: "Recommendation letters are not something to be asked for; they are something to be earned."

At Ryerson, I learned that international collaborations can work wonders—we were about 10 people, representing more than six nationalities, working together on interesting research that involved assisting the hard-of-hearing and deaf community to "feel" music through vibrations of the audio coils embedded in a unique chair that is known as the Emoti-Chair. Although my background is electrical engineering, at IIT Bombay I worked on optimizing aircraft surface movement on airports with an aim to reduce the overall delay while taxiing. This internship taught me that tackling multiple disciplines can broaden your horizons while also increasing the number of career domains that you can target.

All my internships have helped me build myself professionally and identify my strengths and weaknesses, and they have given me an opportunity to meet some of the smartest students and most brilliant mentors from around the world. They proved to be a launchpad to my career in research.

It's time that you beat the heat and embark on the coolest summer ever. Still, it is advisable to plan, search, and apply starting now. Get ready for the launch into your future. ■

BE THERE OR BE SQUARE
THE IMPORTANCE OF LINKEDIN FOR THE ENTRY-LEVEL ENGINEER
By Elizabeth Lions

It's surprising to me how many college students are not on LinkedIn, yet they will chew up time on Facebook and Twitter. Speaking to an engineering audience at the University of Texas, I asked them if they had heard of LinkedIn. Not one hand went up.

The easiest way I can describe LinkedIn is that it is the who's who of corporate America. We don't chat or make comments about photos or posts on LinkedIn; rather, it's an electronic business card. Years ago we had the old-fashioned Rolodex. Today we have LinkedIn, where anyone can find anyone in the professional world. It's a place to tout your professional prowess by showing your work history, your awards, where you went to school, and—if you are lucky—testimonials from others about how reputable you are at your profession.

For college students, having a profile is critical, and I'll tell you why. It's who is on LinkedIn that matters, and the fact that they have the decision-making power to hire a new grad or an entry-level engineer who just needs a break in a tough post-recession economy. It's a place to be found—by the right audience.

IS THERE ANYBODY OUT THERE?

LinkedIn now has **200** million users.

2 new users join every second.

64% of users are in the United States.

2.7 million business pages are available.

1.5 million groups are on LinkedIn.

The standard user is male, between the ages of **25** and **57** years old.

Industries with the highest concentration are high-tech (**14.3%**), finance (**12.4%**), and manufacturing (**10.1%**).

39% of users are managers, directors, owners, chief officers, or vice presidents.

Furthermore, LinkedIn is a hot spot for recruiters, HR, and hiring managers if they are having a tough time finding an engineer with 0 to 3 years of experience. Believe it or not, this is a tough demographic to find. For managers, LinkedIn is often a safer bet than the traditional college fairs because a manager can read the profile, see a professional head shot, and get some sense of activities outside of work or college grade average.

A CALL TO ACTION FROM HR

8.4% of users paid for their LinkedIn membership, allowing them to reach outside of their network—to find you.

47% of users spend **0 to 2** hours a week looking at LinkedIn profiles.

26% of users spend **3 to 6** hours a week looking at LinkedIn profiles.

Top features of LinkedIn are joining groups, searching for people, finding people you may know, and seeing who has viewed your profile.

So with all the hype about social media, we have to ask the question: Does time spent on a social media platform like LinkedIn actually help anyone? Does it lead to a job?

38.3% of users said it helped them uncover potential job opportunities.

76.9% of users said it allowed them to research people and companies.

68.6% of users said it helped them reconnect with old business contacts.

49.9% of users said it helped them build new networking relationships.

44.5% of users said it helped increase networking effectiveness.

DOS AND DON'TS OF PROFILES

Getting started with LinkedIn for the young professional isn't difficult. Most engineers tell me they are concerned their profile will be too short and not draw in other members to connect with them. Not true. All you need is a professional head shot and a summary of your degree and interests. The head shot and picture you add is critical. This is LinkedIn with a corporate image. Don't post pictures of yourself at the beach. Save that photo for Facebook. Remember that an employer may be perusing your profile and will judge your appearance.

Definitely add awards or honors that you earned while in school, as they make you stand out. Internships or anything that is work-related as a stepping stone should be included. Employers like hiring someone who has some work experience, even if the experience is scant.

Engineers often do small side projects that are of interest to them from a technological perspective. Building your friend's website or creating a new application is a gold star on LinkedIn.

For the new grad, the data is pretty clear. You've got to get off the sidelines in order to get into the game. LinkedIn is the social media hangout to be a part of if you are starting your career. ■

U.S. TECH JOBS DEMAND SEEN FOR HIGHLY FOCUSED SKILL SETS

By Ron Schneiderman

The headline reads "Skills trump credentials." And not just any skills.

Businesses, government agencies, and even academia are having problems finding job applicants with the right "talent," as most HR specialists often refer to it, to meet their engineering requirements.

Cybersecurity, robotics, IT, software engineering, mobile application developers, and big data top the list of most-in-demand skills. Smart grid expertise also is high.

Top candidates for current and future jobs will be measured by capabilities and competencies in millions of high-growth, high-paying job postings, according to a white paper commissioned by Microsoft and released by IDC. "IT skills are important, but soft skills, while not evaluated in school, are fundamental to every job students are pursuing today and in the future," says Anthony Salcito, vice president of world public sector education at Microsoft.

Unemployment rates for graduates in computer science with work experience are well below the national average, but people with big data skills are very much in demand by just about any organization that collects and uses lots of data. And applicants don't need a degree in computer science or math to get the job. With utilities increasing their investment in smart grid programs, *FierceSmartGrid* reports that 48 percent of all respondents to its survey expect smart grid hiring to increase. (One popular job site lists 290 jobs for "smart grid engineers," covering a variety of EE skill sets.) Job postings for robotics skills have also been in the thousands.

With defense budgets in decline, Lockheed Martin plans huge layoffs over the next few years, but some defense contractors have more jobs than applicants. Modus Operandi, a small defense software company in Florida, says it is having serious problems filling several software engineering jobs because it can't get U.S. citizens who can write Java, a requirement for the job. Another company, Intelligent Software Solutions, a Colorado Springs-based defense software company, says it has dozens of software engineering job openings and is having trouble filling them. Its solution: open a new office in Denver to expand its search. But it's still struggling to fill its openings.

Most large companies and government agencies are aggressively recruiting computer security talent. The Pentagon alone says it expects to hire more than 4000 specialists in this area between 2014 and 2016. "Do I look if somebody has a CISSP [Certified Information Systems Security Professional] or a law degree?" Mostly, no, said Philip Reitinger, chief information security officer for Sony Corp. and a former director of the National Cyber Security Center at the U.S. Department of Homeland Security, said at a conference on homeland security in Washington, D.C. Reitinger says he wouldn't undercut credentials, but what he looks for when hiring is reputation and technical knowledge. Ronald Layton, deputy chief information officer at the U.S. Secret Service, agrees. Attend hacker conferences, he said, "and you're likely to find people you want to hire."

A study by the U.S. Bureau of Labor Statistics reports a general consensus that "despite a large pool of available workers, the skills mismatch prevents staffing firms from fully meeting client demand." In certain markets, wages are rising in response to this problem. Simply put, there aren't nearly enough software engineers graduating with the skills that employers want.

As for university graduates, engineering and computer science (and business) majors ranked at the top of the most-in-demand list for the class of 2013 in the United States in a report by the National Association of Colleges and Employers (NACE). Computer engineers rank second in average starting salary (US$70 300) among technical majors, behind petroleum engineers. Electrical/electronics and communications engineering was seventh ($62 500).

In Canada, layoffs began at BlackBerry in October 2013, but Motorola and other mobile companies expanding into the area were quick to pick up some of the troubled smartphone maker's tech people. Recruiting was reportedly also high at the Canadian Wireless Trade Show in Toronto in late 2013. ■

ASIA-PACIFIC STILL HIRING

By Ron Schneiderman

The hiring of EEs and other technical professionals continues at a healthy pace in the Asia-Pacific region.

Tech transfer zones are being established in China to attract domestic and offshore companies. The China International Technology Transfer Center, established in 2012, has attracted 49 high-tech companies from abroad, including the United States, United Kingdom, and Canada.

Global Foundries, which opened a sales office in Shanghai years ago, has expanded its services in the city to enhance its presence in China with expanded technical services for its semiconductor foundry.

Intel has been on a hiring spree over the past few years, and has announced plans to add at least 60 engineers across several regions experienced in cloud computing, user interface design, and security. In one of its most recent job notices, Intel listed 865 job openings globally, including 42 engineering positions in China (specific requirement examples include Android software system engineers, wireless app engineers, and camera software engineers) and additional positions in Taiwan, Malaysia, and Japan.

Seoul-based SK Hynix Inc., the second biggest producer of dynamic RAM (DRAM) chips after Samsung, has established an R&D center in Taiwan to focus on advancing its competence in the development of high-value NAND Flash memory products. With the new facility, located in Hsinchu, Gi Hyun Bae, the head of the company's solution development division, says it expects to "secure a pool of superior human resources" to staff its expanded tech support for Chinese and Taiwanese clients.

Qualcomm announced more than a year ago that it planned to establish an IC design and engineering R&D center in Singapore. More recent plans call for hiring engineers throughout the region, including Beijing, Shanghai, and across Taiwan, South Korea, and India.

At last count, there were 360 job openings for EEs in Malaysia, but most of the activity was in IT positions, with 1600 available slots.

Infosys Ltd. said in October 2013 that it was cutting its R&D arm, Infosys Labs, and moving these employees to billable projects on the IT service side. The plan was to reduce the R&D staff by 30 percent over time. However, IT growth in India is projected to increase 12 to 14 percent this fiscal year in dollar terms, and hiring of IT personnel this year countrywide is projected at 180 000. Priyanka Waghre of Infosys's corporate marketing staff says, "With so many engineers being produced each year, perhaps we will need to look at re-skilling some of our talent, introduce new courses, and broaden existing academic disciplines to ensure that the talent we are grooming today in our universities can meet the needs of the dynamically changing industry."

India's National Association of Software and Services Companies (NASSCOM) and its member companies are doing just that, with a plan to standardize the process of hiring and training talent in the country's IT and business process management (BPM) sector. The government of India has set a target of "skilling" 500 million people by 2022 and says this is just the starting point for developing the skills needed for jobs that will grow its IT industry and the country's exports. (The Indian IT-BPM industry currently employs about 3 million people directly and about 9 million indirectly.) As part of this effort, the NASSCOM Engineering Council has sponsored a study that will help identify gaps between industry requirements and academic results. Several global companies with major operations in India have contributed to the development of the program. The objective of the program, according to NASSCOM officials, is to streamline the hiring as well as training processes to facilitate job readiness of university graduates.

NASSCOM also said it has moved into the second phase of its 10 000 start-ups program with an in-residence mentoring program that calls for collaborating with successful entrepreneurial tech companies. ■

EEs IN EUROPE SHORTAGES AND SKILL GAPS

By Ron Schneiderman

Despite shortages of EEs across much of Europe, U.K.-based Cambridge Consultants, which designs products for other companies, says it plans to more than double its 400-plus workforce with new hires in the United Kingdom and United States over the next four years and expand into Asia. In March 2013, the company decided it would create 50 new jobs by year's end. By November, it had increased its number of new hires to 70. "Business was growing faster than we had projected," said Mark Fowler, commercial director of the company's wireless division.

"We expected to grow the [wireless] team more than 20 percent in 2013, and we're going to do it again in 2014. We're looking for people with skills in detailed analog and RF electronics, DSP [digital signal processing], software, software test, and program and project management." Much of the company's success is from new design assignments from Asia, which has led to its opening a new office in Singapore.

Despite Cambridge Consultants' success, the U.K. is reporting engineering shortages. A report by the Royal Academy of Engineering identifies current and future shortages in engineering and mathematics and falling enrollments across many engineering subjects in U.K. universities, including electrical and electronic engineering. Huawei, the giant Chinese telecom company, may pick up some of the slack as it plans to invest $200 million in a new R&D center in the U.K.—part of a wider $2 billion investment in the country as it expands its operations in Europe. It's not clear where Huawei plans to find the people to staff its new operations. The company currently employs more than 80 engineers in its U.K. R&D facility in Ipswich and expects to boost the U.K. R&D staff to 300 by 2017, mostly with specialists in software development, device design, and optoelectronics. Huawei also says it will create at least 5000 new jobs in Europe over the next few years to help it better tap into European telecom markets. The company says Europe offers more growth potential than the United States, where it is considered a security threat to U.S. businesses.

Germany continues to report huge shortages of qualified graduate engineers, with 12 700 current vacancies for EEs, according to the Association of German Engineers. "That equals on average 3.5 vacancies per unemployed electrical engineer," says the association's Dr. Ina Kayser. Part of the problem is Germany's aging population at the same time that the number of graduating engineers is in decline, making it difficult to replace those who retire. Another issue is that graduates aren't necessarily immediately available to the German labor market; many continue their studies in graduate school or seek employment in non-engineering disciplines. In an attempt to fill gaps, some companies are recruiting engineers from other European Union countries.

Eurostat, the EU's statistical body, says computers, electronics, and optical products constitute almost 48 percent of high-tech manufacturing in the EU. But needed skills are hard to find throughout most of the EU. A report by the European Commission on the European strategy for micro- and nanoelectronics components and systems indicates that these sectors account for about 200 000 direct and more than 1 million indirect jobs—and the demand for these skills is increasing. "Similar to the whole ICT [information communication technology] sector, micro- and nanoelectronics is suffering from an increasing skills gap and a mismatch between supply and demand in skills," the report states. It says the commission will continue to promote digital competencies for the industry through its e-Skills initiative and has launched a Grand Coalition for ICT Skills and Jobs program for micro- and nanoelectronics jobs. The commission is also organizing an EU Skills Panorama, with updated forecasts of skills supply and labor market needs up to the year 2020. ■

HOW TO STAND OUT IN YOUR JOB SEARCH

By Steven Cherry

Few things have changed as much as looking for a job. In a way, it's all Google's fault. We've gone from an information-scarce world, in which the hardest thing was finding jobs you might be right for, to an information-rich world, in which the hardest thing is standing out from the hordes of people who might also be right.

And yet there are people who seem to thrive in the new employment marketplace. We've all seen them—the ones who land great job after great job. And we see the ones, sometimes the same ones, who rise through the corporate hierarchy as if their careers were filled with helium. Once we get over the intense pangs of envy these overachievers engender deep within our breasts, the natural thought is, How do I become one of them?

I said it's all Google's fault, so it's only fair that the answer lies over at the Googleplex as well. My guest today is Mike Junge. He's Google's senior recruiter and the author of a new book (published in February 2012) entitled *Purple Squirrel: Stand Out, Land Interviews, and Master the Modern Job Market*. He joins us by phone from his office in Mountain View, California, where it's 8 a.m. there. Mike, good morning, and welcome to the podcast.

MIKE JUNGE: Morning, Steven. Thanks so much for having me this morning.

STEVEN CHERRY: Mike, let's start with the title. Who were the purple squirrels?

MIKE JUNGE: Yeah, so that's an interesting question in itself. So "purple squirrel" is a phrase that we use in the recruiting industry, almost like someone would say "running on a wild goose chase." It's a way that we describe hard-to-find talent. So when clients turn us on to a search that's particularly challenging, we say that they're having a search for purple squirrels.

STEVEN CHERRY: So companies write ads for purple squirrels because they're dizzy with the idea that a million job seekers are going to see their job listing?

MIKE JUNGE: You know, I think it's an excellent question as well. I think people are always looking to get as much out of each hire as they can. And writing complex job specs gives you a higher probability of coming up with that one candidate that brings a little bit something more to the equation.

STEVEN CHERRY: So if an employer does get, you know, hundreds and hundreds of résumés nowadays, from the job seeker's point of view, what's the best strategy to get noticed?

MIKE JUNGE: Well, I think the phrase "get noticed" is really a big part of the equation. From my personal perspective, and speaking as an individual, I think it's far better to actually be found as a job seeker than to be

This interview was recorded 22 February 2012. Audio engineer: Francesco Ferorelli

IEEE SPECTRUM | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

good at applying. Even as companies are accepting lots and lots of applications, almost always they're also proactively searching for talent. And being effective at both—being able to stand out as an applicant and attract the attention of the people who are out hunting for talent—I think that balance is really where the magic starts to happen.

STEVEN CHERRY: So are there any strategies for that?

MIKE JUNGE: Yeah, a big piece of it is understanding the marketplace which you work in. So you set the context really nicely, in that there's enormous amounts of information available these days. You have to go to the strategies for how would you find any kind of information. If you were to go to your search, your favorite search engine—or let's just say your favorite search engine—and you wanted to find information, what would you do? You'd type in a search string. You'd come up with some sort of query that's designed to bring back specifically relevant results. The same thing is happening when people are looking for talent. They're looking for specific words, phrases, ideas to show up in a résumé that lets them know that they're on the right track. So when you build your résumé, it's really useful to know what those words and phrases are. And I think a great place to start is by reading lots of job descriptions, not just to find out if you want to apply to the jobs but also to get a real sense of what your market is looking for. What is it that you've done that other people are searching for, and how do they describe, and what phrases did they use to capture the essence of what it is that you've done? And the more that you can build them into a résumé, the more likely you are to catch the attention of the people reading résumés and looking for talent.

STEVEN CHERRY: Yeah, your book devotes a fair amount of time to the sort of new world of résumés. And one thing that caught my eye is the résumé starts to look a little bit like, I don't know, a magazine article, where, you know, all of the really important information is right at the top.

MIKE JUNGE: Yeah, so because there's so much information available, you've got a really limited window of opportunity to catch the attention of a résumé reader. If, me personally, if I click on a résumé and I don't see content almost immediately—you know, within the first half page to a page—that seems appropriate and relevant to a particular, the particular search that I'm working on, I'm probably going to be on to the next résumé before I ever get to Page 2. And I think that's a commonality across the industry. There's so much information available that you have a really, you have to use that finite window of opportunity to catch the attention of someone reading.

STEVEN CHERRY: Your book mentions hybrid titles. What are they?

MIKE JUNGE: That's a great question. So hybrid titles...so where this starts, really, is companies have unique naming conventions. Everyone talks about similar types of work in somewhat different ways. So you can go into one company and it's a systems engineer, and another it's a software engineer, and another it's an engineer four, and another it's a database engineer. So a hybrid title allows you to use the title that's given. So your company calls you whatever they call you—let's just say sales, sales engineer, sales specialist. But what you're really doing is engineering and building applications for, let's say, Windows databases, SQL Server. A hybrid title would allow you to say, you know, sales engineer, and then throw a slash or a parenthesis, and then SQL Server database engineering. And because that, the tag, the second part of the phrase is more specific and relevant to the people hunting for talent, there's a good chance that it'll capture a broader audience.

> I think a great place to start is by reading lots of job descriptions, not just to find out if you want to apply to the jobs but also to get a real sense of what your market is looking for.

STEVEN CHERRY: And you actually recommend tailoring the résumé to a specific job that you're applying for.

MIKE JUNGE: Yeah, to some extent, yes. Most certainly. Particularly after someone's been in the industry for a period of time. You gain so many skills and experiences. You work on a variety of projects. Capturing all of that and presenting it precisely in a single-version document is really challenging. In fact, I'm not even sure it's possible.

STEVEN CHERRY: In the book you talk about making yourself visible on social networks. Is LinkedIn the most important for a job seeker, or are there others that are more important?

MIKE JUNGE: From my personal perspective, absolutely. I think it's really starting to gain—LinkedIn specifically is starting to gain a lot of traction as a dominant recruiting source in the industry. The others, I think, have really interesting potential. Particularly as the ability to build out robust profiles, and companies attempt more and more to engage with their, you know, with job applicants through social media, the opportunities for that being a viable medium are going to continue to expand, but as of right now, I would say LinkedIn is the most valuable place to invest energy as a job seeker.

STEVEN CHERRY: So once you do get noticed, the next hurdle is generally the interview.

MIKE JUNGE: Yeah, I think preparation is absolutely key. And I tend to break preparation into a couple of key components. The first and maybe the most important is really to own your own background. By that I mean being able to speak intelligently

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

and articulately about everything you've done as a professional. Particularly the things that are recent, but you should be able to dive into any project or initiative that you've been a part of and talk clearly and specifically about what you've done, the role you've played, how you did it, why you did it, what the outcome was, what you learned. And be able to do that on the fly, without a lot of umms and and hmms and hesitations. That can be a process in itself. So I really strongly recommend that people take the time to dig into their own backgrounds.

STEVEN CHERRY: You have a really cool story in the book about a guy who was maybe the most prepared you'd ever seen, and he walked into the interview with a portfolio book. And you know, I think about that as something that, you know, art, you know, graphic designers bring a portfolio, sometimes even a journalist will bring in a book of clips, but I don't think of an engineer as having a portfolio.

MIKE JUNGE: Yeah, well, I found it to be really an–it was remarkably impressive, partly because he tailored what he showed me in his portfolio specifically to my interests at that particular time. An engineer–there's so many things that an engineer can put into a portfolio. And it depends a lot on what type of engineering it is. And there's, the world is pretty broad. But you know, it can be code if it's software, it can be a finished product if it's hardware or mechanical, it can be snapshots throughout the process. It can be personal projects that you've done in your own time, just demonstrating how you go through your process. It can be any of a hundred things. Personally, when I, in building a portfolio, I really recommend people build it almost the way that they would go about achieving their normal, day-to-day job. So if it's starting with requirements, what is the goal or the expectation, and then how do you document, how do you break that down into smaller tidbits, and then showing the work, so that you can, at any stage of the process, demonstrate what you've done and how you've done it, in a tangible, meaningful way.

> The first and maybe the most important [thing] is really to own your own background. By that I mean being able to speak intelligently and articulately about everything you've done as a professional.

STEVEN CHERRY: Mike, Google is famous for interviewers asking strange questions in an interview: What's the angle on the hands on a clock at 3:15, or how many piano tuners are there in the world? But it seems like a lot of companies are doing this nowadays. Do you have any advice for handling those kinds of questions?

MIKE JUNGE: Yes. I mean, actually, it's one of my favorite things that I see people doing is trying to figure out some key skill related to the particular job, and test or evaluate that skill in an interview context. As a salesperson, that could be actually mocking a sales call or going out on a sales call. As an engineer, that may be demonstrating the ability to evaluate and break down and solve a problem.

STEVEN CHERRY: Yeah, and I guess what interviewers really want to hear is how you talk through the problem more than any actual solution.

MIKE JUNGE: Yeah, oftentimes they really want to see your mind at work.

STEVEN CHERRY: So once you have a job, sometimes you want to move up in the same company, and a portion of your book is devoted to that as well.

MIKE JUNGE: Yeah, so that's what I call getting on the fast track, or being a fast-track professional. Most top performers find ways to make a difference, not just in the way that they want to make a difference but in the way that other people want them to make a difference. They find out what's important to their customers or their bosses, and then they figure out how to deliver to that. I think it's one of the real secrets to success is figuring out how to deliver what other people are looking for. And to do so effectively.

STEVEN CHERRY: I gather that your understanding of hiring, a hiring manager is that he's looking for specific skills but also specific attitudes: basically a devotion to the job, the ability to do hard work, things like that. And you can do that in your current job and make yourself stand out.

MIKE JUNGE: Absolutely. Yeah, I mean, the more you approach your day job with a great attitude, looking for ways to make a difference, looking for ways to be helpful, looking to be someone that others want to work with–I talk about that a little bit in the book as well–is being someone that others want to work with. That creates, that opens all kinds of doors. The cool projects go to the people that others like working with–and the ones that are talented–but being someone that others can work with and enjoy working with goes a pretty long way as well.

STEVEN CHERRY: You mention a fast track, and your book chapters often end with something you call fast-track challenges. In fact, the book is really pretty clearly structured. Tell us about the fast-track challenges.

MIKE JUNGE: So those are simple exercises that are designed to take the concepts of the book and put them into practice. So that it's not just theoretical, it's something that you do. And they're all simple–simple things that have been proven to work in the real world. And I think it's one of the things that really makes the book valuable.

STEVEN CHERRY: You know, you're the third book author we've had in about three months, and partly that's a coincidence, and partly it's because I think an author interview can be more interesting than a book review. But at any rate, I'm going to ask you a question that, as it came up with the other two authors. One of them was self-published, and the other one went the sort of traditional publisher route, you know, even though he gave the manuscript to the publisher at the same time as his wife got pregnant, and the baby won that race by a wide margin.

MIKE JUNGE: Yeah. The self-publishing world is really agile. Pretty fantastic the, you know, the barriers to entry, and the speed and effectiveness at which you can bring new information and material to the market is pretty extraordinary.

STEVEN CHERRY: You not only went the e-book route, you went directly with Amazon, I guess.

MIKE JUNGE: I did. I think–so there's advantages to both. I think the traditional pub-lishing world, you know, the distribution, and if you want the book on bookshelves, I think that's probably the clear winner. If timing and speed and control over your own work are significantly important to you, then, you know, the self-publishing route really opens a lot of doors and creates a lot of options that didn't used to exist for authors.

STEVEN CHERRY: Very good. Well, we'll... Thanks for writing the book, and thanks for joining us today.

MIKE JUNGE: Thanks so much for having me. I really enjoyed talking with you.

STEVEN CHERRY: We've been speaking with Mike Junge, Google's senior recruiter and the author of a new book entitled *Purple Squirrel*, about mastering the modern job market. For *IEEE Spectrum's* "Techwise Conversations," I'm Steven Cherry.

ANNOUNCER: "Techwise Conversations" is sponsored by National Instruments. ■

THE JOB HUNT
MAKE IT YOUR OWN
By Prachi Patel

Two years ago, Leo Szeto didn't think he'd be using his robotics skills to give people the time of their lives at Disney theme parks. Szeto is a ride controls engineer at Walt Disney Imagineering, the inventive force behind Disney entertainment venues. Dream jobs like this don't open up every day.

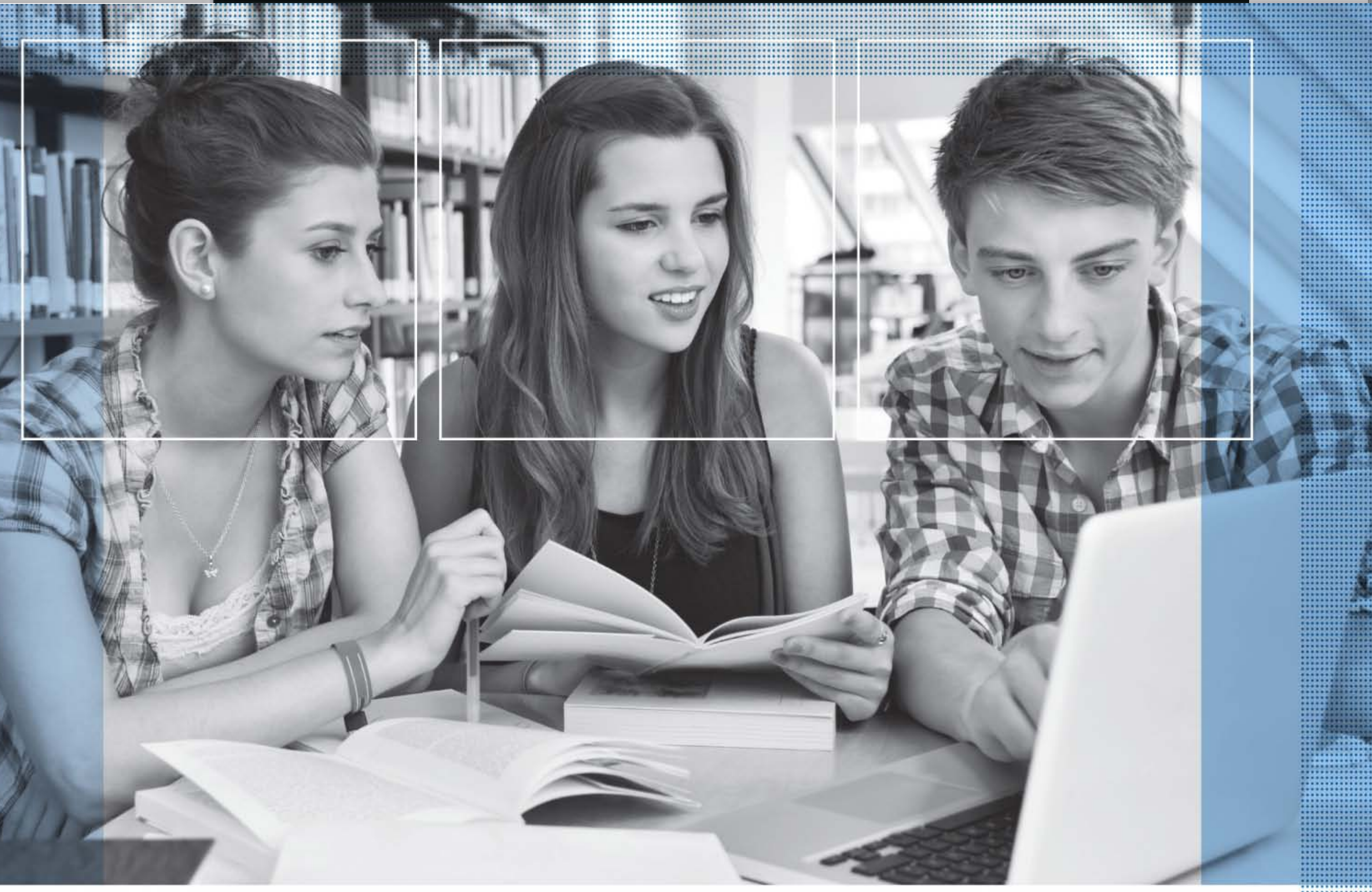
That's why his job-hunting strategy was helpful. "There isn't really a right time to look for a job," he says. "The key is to grab opportunities when they present themselves."

This one came during Szeto's senior year, when he was chair of the IEEE student chapter at University of California, Los Angeles. Being an Imagineer wasn't on his radar, but when a past chapter chair working at Disney contacted him seeking an intern, he jumped at the chance. The internship soon turned into a job.

Looking for a job can be stressful as you finish your course work or thesis. While attending career fairs and scouring employment websites, smart strategies and networking really tip the scale. And IEEE ties can play a vital role.

All the internships that pad Szeto's résumé came via IEEE connections, he says. Plus, his always-on-the-lookout approach led to a smooth job search. "I didn't have that 'Okay, now I need to look for a job' moment," he says. "I'd been looking ever since I started junior year, so it was a very fluid process."

Social and IEEE networks were crucial for Jill Madison, a systems engineer at Pacific Northwest National Laboratory who started as an intern in 2010



Looking for a job can be stressful as you finish your course work or thesis. While attending career fairs and scouring employment websites, smart strategies and networking really tip the scale. And IEEE ties can play a vital role.

during her sophomore year at Washington State University. Madison came to EE after a degree in music. A family friend who worked at PNNL alerted her to an internship that would use her talents.

A year later, Madison became student representative for the university's IEEE chapter. Through IEEE's new Volunteer Leadership Training Program, she was put in touch with a mentor who happened to work at PNNL. "This mentor relationship has allowed me to figure out how to navigate my career at the lab because there are so many options," she says. "The combination of a good internship and the IEEE network really allowed me to find a job that I love."

Madison is now a member of the IEEE Young Professionals Program (formerly GOLD), which allows her to broaden her horizons by "meeting so many people doing so many different cool things," she says. "It exposes you to everything you can do with an EE degree."

Ankit More, a research scientist at Intel who earned his Ph.D. in electrical and computer engineering in 2013 from Drexel University, in Philadelphia, found job leads by tapping his friends to find contacts at semiconductor companies and by forging connections at IEEE conferences and career fairs. He says attending IEEE events has been one of the best ways to network. Someone from Intel approached More after he presented his research at a conference last year. "We struck up a conversation," he said, "and he asked me to send him a résumé."

Meanwhile, Isuru Daulagala, who will finish his bachelor's degree in electrical and computer engineering from Drexel in June 2014, is using the university's job database instead of big job websites. He wants to focus on small hardware companies. He gets as much company information and as many employee reviews as he can before applying for a job. "I am selective in what I want to do," he says. "I seek out current or former employees so I can know firsthand what it's like to work for a company and what I will be doing."

An information session hosted by Drexel's IEEE student chapter introduced him to Micron Technology, a small memory device company. After a six-month internship, he was offered a full-time position, which he hasn't accepted yet. He wants to keep his options open, and is applying to graduate school to cover all bases.

Many graduates are now paying it back by assisting new job hunters. Szeto, who is moving to China next year to help finish Shanghai Disneyland, sends employment news to UCLA's IEEE student chapter. And, he says, "this year I hired two new interns through the chapter." ■

MUCH TO-DO ABOUT NOTHING

PLENTY OF WORK FOR THE COLLEGE GRAD IN ENGINEERING

By Elizabeth Lions

There was much to-do in the news about college graduates and their lack of job opportunities in 2013. Many reported that employers are simply not ready to hire grads and are adhering to tight post-recession budgets. Employers argue that hiring a senior engineer is better than an entry-level candidate, saying they need someone who can hit the ground running with little training.

However, *Spectrum's* findings showed that plenty of companies did hire in 2013, and we asked employers where they found talent and how the year's hiring plans worked out for them.

Companies reported that they were finding talent by engaging with universities through events organized by the university career offices. Mariya Kirillovykh, program manager of Intel's Europe College Program, commented, "We regularly hold Intel-exclusive events, including Tech Talks and Intel Open Days, either in the offices of the company or on campus. Moreover, students have a chance to interact directly with senior Intel managers and engineers and get to know the details about working at the company firsthand."

To attract talent, Intel uses social media, which includes international and local networks. Through its efforts, more than 800 students in 2013 were hired for internships in Europe. Countries where Intel has the most traction include Germany, Ireland, Poland, Russia, and the United Kingdom. The engineering career path at Intel can take students and graduates from product development to component design to process improvement engineering. At Intel in Europe and America, there are opportunities for college grads in networking, wireless communications, Flash memory, chip sets, motherboards, open source development, performance optimization, quality assurance, and software architecture. For a college grad, the sky is the limit in terms of career mapping.

In the United States, Timothy O'Conner from the electronics engineering senior staff of Lockheed Martin Aeronautics said

Lockheed Martin hired 450 college grads this year. "New hires selected were electrical engineers, computer science, and mechanical engineers. Talent was found through job fairs, word of mouth through college alumni and virtual job fairs."

All companies interviewed said they put college grad candidates through a series of intense technical interviews. Each candidate hired was then given a rigorous training program. After training is completed, engineers are expected to become a full part of the team working on the specific challenges on a project. Overall the success of the hire was based on the depth of training provided. William Robson, a Microsoft consultant, stated, "By choosing wisely and then spending the time to train properly, the system, which was originally fraught with poor choices and lack of productivity, began to crank out qualified, productive employees within two months' time of graduation day."

One-on-one mentoring was also an important factor for new hires. Another employer explained that new grads do well as long as the what, when, why, and how are clear in advance–as long as this doesn't require them to go past using a basic search engine, that is. Their tool kit and their whole sense of searching are limited, so you need to say to them, "Use these kinds of tools to look for these kinds of things, and when you find a possible answer, you need to evaluate it using this criteria." You really have to lay it all out there so it's more test-like. If you can circumscribe the request, the better and better they do.

On the flip side, how does a winning company find good college grads? What is important to them?

ConnectEDU is a job board that connects college grads with entry-level positions within companies. In 2013 it conducted a survey of 10 000 students across the United States. The top three factors millennial candidates care about in jobs are career advancement opportunities (23 percent); having interesting, challenging work (23 percent); and salary (15 percent). Smart companies market these attributes in job descriptions and when engaging with entry-level candidates, and they see the results in terms of strong candidate flow.

The top three factors millennial candidates care about in jobs are

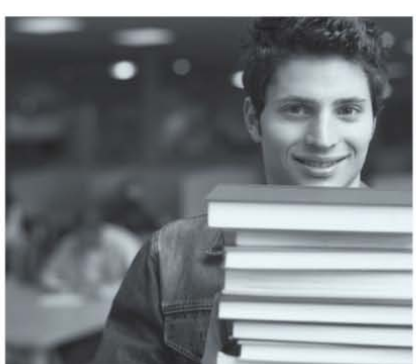
23% career advancement opportunities

23% having interesting, challenging work

15% salary

Interestingly enough, 86.7 percent of millennial candidates apply directly through a company website. Smart companies make a point to invest in talent communities and employer branding to better attract talent and hold their attention.

Attracting, selecting, training, and retaining have never been as important in corporate America as they are today. As we find the Great Recession in our rearview mirror, companies are staffing up with college grads with the promise of a new technological future that only the millennium generation can drive. ■



WHAT HAPPENS WHEN GEN Y ENTERS THE GLOBAL JOB MARKET?

By Nannette Ripmeester

There is a lot said about Generation Y. And as with every generation, comments have not always been positive. Gen Y has been described by some as a group of overqualified yet under-experienced individuals who are willing to work in teams whilst keen to make their own mark.

However, you'll also find counterarguments about this generation being self-aware and highly qualified, with a global outlook and a working knowledge of current technology. We take it for granted that IEEE members are high achievers, with a global mind-set and the ability to work in a diverse team.

GET OUT OF THAT CULTURAL COMFORT ZONE

Due to the economic crisis, finding work has become paramount to the minds of Generation Y. More than ever before, the mismatch between the number of applicants and the number of jobs has underlined current changes in the labor market, where new growth markets may offer previously nonexistent career opportunities. Hence graduates are encouraged to expand their horizons and step out of their cultural comfort zone.

Looking for a job outside your home country requires several key skills. A good first step is realizing that finding a job nowadays comes down to persistence, preparation… and a bit of luck. Make sure you understand what you have to offer. What sets you apart from other recent graduates? The most challenging part is "translating" your experiences into skills a recruiter is keen to hire. If the ad asks for an independent work attitude, make sure your CV shows you possess that skill, by giving examples to illustrate your level of coping skills and your tolerance for uncertainty.

CULTURAL DIFFERENCES IN JOB HUNTING

Your next step to career success is being internationally minded. Prepare yourself for different job markets and understand how you can fit into the international workplace. Be aware that job hunting in Asia differs from job hunting in Europe or the United States. In Asia many organizations use online application forms asking about your parents and their background. Do not dismiss those questions as irrelevant, but try to understand the cultural differences that cause this other way of looking at a potential new colleague. Whereas it is common to use action verbs and strong words underlining achievement in an American résumé, in Europe the term "résumé" is replaced by "CV," and too much performance-based wording is seen as bragging and will not gain you any points.

STAND OUT FROM THE CROWD

It helps to understand that employers are keen to get to know you as a person before deciding to hire you. Simply having high grades is no longer the master key to any job; your extracurricular activities and experiences can be just as important. Try to understand what this organization requires and how you may be able to fill that gap. Perhaps you've been busy working the internship route or involved with charity work recently. If something can make you stand out as an individual, there is a good chance it can make you stand out as a job candidate.

Decision making is a crucial component for Gen Y. With seemingly limitless options, selecting one seems almost like a burden rather than a luxury. If you can opt for one particular career goal and follow up on it, though you will already be ahead of many people in your situation. Constructing a basic plan around this goal and starting some fact-finding will set you in good stead.

With so many countries and cultures to choose from, one may worry about getting the basics right: How is applying for a job in the U.K. different from, say, Singapore? Each culture is different, and that includes their job-hunting and recruitment principles. So make sure you prepare yourself thoroughly for the path you are intending to travel, understand what sets you apart from others, and be able to translate this into terminology that a recruiter understands. ■

SHINING A SPOTLIGHT ON FEMALE ENGINEERS IEEE WOMEN IN ENGINEERING AIMS TO RAISE AWARENESS AND CLOSE THE GENDER GAP

By Kathy Pretz

Did you know that the person widely recognized as the first computer programmer was a woman?

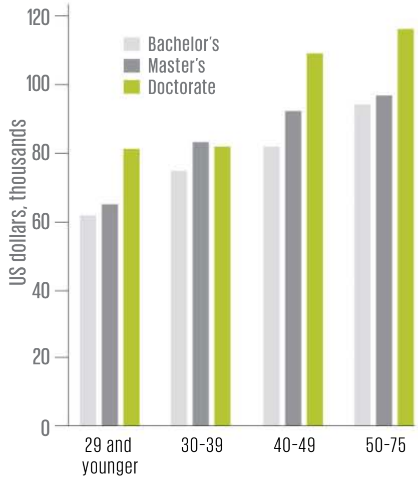
Ada Lovelace was known for her work on Charles Babbage's early mechanical general-purpose computer, the Analytical Engine. Her notes on it include what is now recognized as the first computer algorithm.

And another woman, Grace Hopper, developed the concept of a compiler in the late 1940s and early 1950s while working at Remington Rand, which became part of Sperry Rand Corp. in 1955.

Despite their technical achievements through the years, however, women represent only about 10 percent of engineers in the workplace—a figure that has held steady for years.

IEEE Women in Engineering (http://www.ieee.org/wie), which celebrates its 20th anniversary in 2014, is working hard to increase that percentage and bring greater public awareness of women's contributions. It now has more than 15 000 members, one third of them men.

Median annual salary for full-time employed female electrical engineers by highest degree and age (2010)



Source: National Science Foundation

WIE offers a number of services and programs. These include live online chats, an app for tablets that spotlights the work of several women who are IEEE members, videos of its activities, an international leadership conference, several awards and scholarships, and more. The group also has an active social media presence, with more than 73 000 Facebook followers at http://www.facebook.com/ieeewomeninengineering.

"These efforts support WIE's core mission of recognizing outstanding achievements and providing a vibrant, engaged community for women in IEEE," says Nita Patel, chair of the 2013 IEEE WIE Committee.

GREATER VISIBILITY

To spotlight the work of female engineers, WIE has a visibility campaign with the catchphrase "I Change the World. I Am an Engineer." The campaign features online chats with prominent WIE members as well as posters highlighting successful women engineers who are IEEE members. The posters are hung at engineering schools as well as in preuniversity classrooms.

It also holds monthly online chats with viewers of the live video streaming website UStream, available on YouTube or the WIE website. WIE members speak about a variety of topics.

And WIE has been spreading the word about female engineers' accomplishments through the "I Change the World. I Am an Engineer" app. Available for Android and Apple tablets, it features profiles of more than 80 women. Each profile includes a biography, information about the engineer's career, and a photo. An e-book version, featuring interactive PDFs, is also available on the WIE website.

PARNERSHIPS

To build support for women in science, technology, engineering, and mathematics (STEM) fields, WIE will hold the IEEE Women in Engineering International Leadership Conference (http://ieee-wie-ilc.org) from 1 to 3 May, in San Francisco. There will be more than 50 speakers.

According to Patel, the vision for the conference is a mini-M.B.A. for women in technology to help them advance their careers and develop leadership skills. The conference theme is "Lead Beyond: Developing Inspirational Women Who Change the World." Four tracks are planned: empowerment (skills to help women advance in their careers), inspiration (presentations/skills to inspire women to achieve their goals), enjoyment (work/life balance, reducing stress, enjoying life), and engagement (hands-on skills development workshops).

SCHOLARSHIPS AND AWARDS

WIE teamed up with TechSearch International, a licensing and consulting firm in Austin, Texas, to offer an annual US $2500 scholarship to a female college engineering student. The IEEE Frances B. Hugle Engineering Scholarship was developed with TechSearch's founder, Jan Vardaman. Hugle, a pioneer in the invention of tape-automated bonding, which is used in the manufacture of ICs, held 16 electronics patents. WIE also awards a scholarship to a female IEEE student member in her third year of undergraduate study at an accredited university or college in the United States.

To mark its 20th anniversary, WIE is also launching two awards, the IEEE Women in Engineering Inspiring Member of the Year and the IEEE Women in Engineering Student Member of the Year. ■

Learn more by visiting the WIE website at http://www.ieee.org/wie.

"WE DO WORK AT NSA THAT CAN'T BE DONE ANYWHERE ELSE."

BEHIND THE SCENES AT NSA

MARCUS BAYNES, Position: Analyst/Computer Scientist. **Education:** MIT, Mathematics, 2000; Master's in Electrical & Computer Engineering, Johns Hopkins University, 2007.

WHEN MARCUS BAYNES ENTERED the National Security Agency as a college intern, he never expected to stay longer than the four years that a special scholarship had required, planning instead to gain experience at NSA while focusing on other career goals. His mind quickly changed once he started working at the agency – he fell in love with its mission and relaxed atmosphere, as well as the exciting challenges he faced at work, and realized it was the perfect place for him.

Are there any misconceptions or myths about the agency? Were your own perceptions correct?
I try to dispel myths that are put forth in movies: We're not spying on Americans or walking around with guns, for example. That's just not who we are. I also had some misconceptions about working for the government. Before I started, I thought everyone was going to be nerdy and uptight, coming to work in suits all of the time. In reality, the people here are really cool and diverse. There are people who wear suits, but there are also people with blue hair who wear T-shirts to work every day. I wasn't expecting such a fun and relaxed environment.

Can you talk about the mission of NSA? How does it feel knowing the work you do helps achieve this mission?
Our mission has two sides to it, the offensive and the defensive. We try to uncover foreign adversaries' data and figure out what they're doing to disguise it. And we also come up with ways to protect our own data. Innovation plays a huge role; NSA is on the cutting edge of technology. It's awesome to be a part of a larger mission that's serving Americans, saving lives and protecting our troops around the world.

What's the work environment like at NSA?
The work is demanding and important, but we have a lot of fun doing it. There is a huge emphasis on work/ life balance. I love the fact that once I go home, I don't take my work home with me – I can't take it home with me, because it's classified – and I can spend time with my family.

How does NSA foster an inclusive environment?
There is an incredibly wide range of people who work here, so anyone will fit in one way or another. I've never found race, gender, disability or anything like that to be any kind of hindrance. People don't even see those things as defining characteristics, because everyone knows we're all working for the same cause. We're prepared to work together to serve our country.

What excites you about working for NSA? What are some challenges you face?
The work we do is really cool, and it's work that you can't do anywhere else. That's exciting to me. The main challenge is that, since our work is so important, the job can be pretty demanding. As a team leader, I have to juggle a lot of projects and figure out the most efficient way to get the job done. It's not easy, but it keeps me challenged and allows me to grow.

What are the opportunities for advancement within the agency?
There are opportunities to further your education – I was able to get my master's degree while working at the agency. There are also plenty of resources available to help you grow, learn and rise up in the organization or move into different areas. The possibilities are endless.

NATIONAL SECURITY AGENCY

www.NSA.gov

The National Security Agency (NSA) secures the nation's vital networks and critical information while exploiting those of foreign adversaries. The mission never sleeps. As technology evolves, so do America's cyber vulnerabilities. NSA needs a wide range of talented professionals to help us outthink, outwork and defeat adversaries' new ideas.

Number of employees: Approximately 30,000

Employees profile: NSA is looking for talent in fields such as comp. sci., engineering, cybersecurity, math, intel analysis, foreign language and business admin.

Ways in: Apply for a full-time position or one of NSA's many student programs at www.NSA.gov/Careers. U.S. citizenship and a security clearance are required.

Contact: Contact NSA at 1-866-NSA-HIRE or visit www.NSA.gov/Careers.

ONCE UPON A TIME ... For 60 years, NSA has protected national security information and systems. We give the nation a decisive edge to make information and IT an asset for America and a liability for its adversaries. The American people have placed great trust in us, and we strive at all times to be deserving of that trust. Remarkable people with remarkable skills form the heart of the National Security Agency.

WHY I CHOSE AN INDUSTRY JOB

By Bonnie Cheng

By my senior year of school, I found myself attracted to an array of postgraduate options. The thought of entering academia was compelling, but so was the prospect of entering the workforce. It took a few years of weighing the options before I decided to enter the workforce.

During my undergrad at the University of Kentucky, I had the opportunity to work as both a student technician for the Center for Nanoscale Science and Engineering (CeNSE) and a business research intern for the Kentucky Science and Technology Corporation (KSTC). Between these two experiences, I discovered what it was like to work in a research environment as well as a more typical office environment.

I ultimately decided to pursue a career in industry, realizing that this fit best with my personality and goals. I am currently a graduate electrical engineer for Arup, a buildings design and engineering firm. My time here has been spent applying much of the knowledge I gained from school, but I've also been able to broaden my knowledge outside of electrical engineering.

Arup is a multidisciplinary firm, well known for its collaborative working process. In order to provide the holistic designs that we do, I continually work with mechanical, structural, plumbing, and fire engineers, as well as others in the design and construction industry. Catching these glimpses into others' work is incredibly interesting to me and has been the biggest advantage of my time here. I have always enjoyed this type of constant learning environment, and I am driven by the excitement of learning and applying new skills.

My experiences at CeNSE and KSTC helped guide my decision to pursue an industry job. I would encourage current students to take advantage of any similar opportunities and experience both academia and industry before graduation. I believe it is vital to understand the risks and rewards of each path before deciding which to choose. ■

WHY I CHOSE GRADUATE SCHOOL

By Joshua Shank

After four years of undergraduate education, I decided to pursue a graduate degree so that I could specialize as a microelectronics engineer and choose my own projects in the future. During my undergraduate years at the University of Kentucky, I worked both as a student researcher developing nano-scale solar cells and as a co-op engineer with the United States Air Force. After comparing these two experiences, I opted to continue as an academic researcher.

During my three semesters with the Air Force, I worked on several engineering analysis and design projects. I experienced what it is like to work in an office, although it was admittedly not a typical office environment, and what it is like to have projects assigned to me whether I found them interesting or not.

As an undergraduate researcher, I was given the freedom to choose my own projects and pursue problems that I found interesting. In addition, I was constantly learning how to use new tools, such as a scanning electron microscope, and learning new ways to think about complex problems.It was largely due to this freedom and constant pursuit of knowledge that I decided to pursue a Ph.D. at Georgia Tech.

Upon arriving at Georgia Tech, I intended to continue my research in solar technology. However, I quickly encountered a new area of electrical engineering and am now a researcher in the field of neuromorphic computing. In this field we develop analog circuits, devices, and materials in order to build computers that act like the human brain. These circuits will serve as extraordinarily low-power microcontrollers and will likely improve direct human-machine interfaces. It may even be possible someday to build robots of human complexity.

For this research, I constantly work on the boundaries of electrical engineering, physics, and neurobiology. I am always learning about new discoveries within these fields, discovering materials and devices that have never been seen before, and contributing to the development of a technology that may someday change the world. This is why I chose to go to graduate school. ■

IEEE YOUNG PROFESSIONALS CAREER ADVANTAGE

INSPIRING, ENERGIZING, EMPOWERING, AND ENGAGING EARLY-CAREER MEMBERS

By Lisa Delventhal and Rory McCorkle

IEEE Young Professionals is an expanding community focused on the early-career needs of members who are within 15 years of having earned their first professional degree. The goal of this community is to help young professionals evaluate and achieve their career goals, polish their professional image, and create the building blocks of a lifelong and diverse professional network.

These goals are realized through an international committee representing all IEEE Regions, chaired this year by Timothy Wong of Australia. Tim's team encourages tens of thousands of young professionals to connect to their local affinity groups, to industry, to academia, and to one another. "Your introduction to IEEE Young Professionals often begins while you are a student in one of the over 2 000 world-wide IEEE student branches, but your campus or club experience of IEEE is really just the beginning," says Wong.

"The camaraderie of IEEE Young Professionals is a really important feature," he continues. "Members go back to graduate school, land and change jobs, start businesses and families, and move to new cities–sometimes moving across the world. You can count on IEEE being your professional home during these life and career changes. Wherever you go, you'll find IEEE and its members."

TEN WAYS YOU CAN TAP INTO IEEE'S CAREER ADVANTAGE:

1. The IEEE Community: IEEE is a network of more than 400 000 engineering and technology professionals from all over the world.

2. Maintain Your Technical Edge: As you enter and grow within the workforce, IEEE can be a great source of technical knowledge. Get access to IEEE technical publications like *Potentials* and *Spectrum*, join its 45 technical societies and councils, and more.

3. Find a Mentor: IEEE MentorCentre is a member benefit enabling you to find another IEEE member who can assist you in your career and technical development.

4. Develop Your Résumé and Prepare for Interviews: IEEE ResumeLab helps you develop your résumé or CV using predesigned templates, examples of different formats, and assistance in embedding keywords that will increase your ranking in database searches and online recruiting tools. In addition, more than 900 mock interview questions are provided. The software enables you to record your responses and improve your performance.

5. Opportunities to Win Awards and Recognition for Your Work: Get published in the Young Professionals blog, *Potentials* Magazine, or technical articles accessible through the powerful digital library IEEE *Xplore*. Win scholarships and awards for outstanding technical skills or contributions to the organization and the engineering profession.

6. Participate in the Young Professionals Webinar Series: IEEE Young Professionals develops and produces an annual series of career development and technical webinars produced by IEEE Young Professionals for IEEE Young Professionals.

7. Advance to Senior Member: Advancing your member grade can bring added peer recognition to your accomplishments. IEEE Young Professionals supports you as you amass experience and qualifications in IEEE-designated fields, and interface with the world's leading technologists.

8. Contribute, Collaborate, and Volunteer: Use IEEE collaboration tools to manage projects, chair committees, engage in humanitarian initiatives, and work side by side with an international cadre of volunteer members. Each of these will help you hone technical, leadership, and entrepreneurial skills that will make your career and your life more rewarding.

9. Sign In to Find or Post Jobs and Access Opportunities: The IEEE job site (http://careers.ieee.org) is a searchable database, while myIEEE (http://ieee.org/myIEEE) is a personalized gateway to IEEE membership.

10. Benefits of Higher-Grade Membership: There are more than 100 products and services offered to help you succeed. These range from insurance, software, and equipment discounts to continuing education credentials. Check out the Benefits Navigator at http://www.ieee.org/benefits. ■

Questions?
See http://www.young-professionals.ieee.org or email your inquiries to young-professionals@ieee.org.