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RANdOM NOISE

Modern security depends on numbers that are *really* random, and new chips are harnessing the mysterious phenomenon of atomic vibrations to churn them out

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back story

Snowbound

Electrical engineering can take you to some far-flung work sites. Just ask David Braaten and Prasad Gogineni, two of the authors of this month's feature "Beneath the Ice Sheets." In it, Braaten (an atmospheric scientist), Gogineni, and John Paden (both electrical engineers) explain how they are using a new kind of ice-penetrating radar to study the slowly melting Greenland ice sheet.

They've also taken their radar to the other end of the world: The photo above shows Braaten [left] and Gogineni arriving at McMurdo Station in Antarctica aboard a C-17 transport plane. How do you train for such work? "Once I had to walk around with a bucket on my head to simulate being blinded in a blizzard," says Gogineni.

Coping with blizzards is indeed part of the job. Five years ago, Braaten and Gogineni almost got stuck at a science camp on the West Antarctic Ice Sheet when a heavy snow accumulation put the camp's runway out of commission. But on the day they were to depart, someone at the camp suffered a medical emergency. Officials decided to evacuate the stricken man, which meant that Braaten and Gogineni were unexpectedly offered a ride out on a Lockheed LC-130 that had been flown in with a medic aboard.

Strapped into the plane's narrow jump seats, though, they soon went from feeling relief to anxiety. The newly fallen snow on the ice runway dragged on the plane's skis and made it difficult to attain takeoff speed—the pilot tried four times to no avail. At one point, the plane's front ski got completely stuck, and a crew member had to dig it out.

"Before the fifth try, the plane's loadmaster asked all of us to sit near the rear cargo door to help lift the plane's front ski during the next takeoff run," recalls Braaten. That did the trick. The medical evacuee soon got the care he needed, and these researchers had a workday they wouldn't soon forget. ❑

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ROBERT W. LUCKY reflects this month [p. 25] on the various models of research funding in the past century, a subject on which he is particularly well informed. Lucky, an IEEE Fellow and holder of 11 patents, worked for many years at Bell Labs before becoming vice president for applied research at Telcordia Technologies, in Piscataway, N.J. He retired in 2002, but he can't stop thinking about ways to make the current century equally progressive.

SWAPNAJIT MITRA works on input/output chip protocols as senior manager of hardware engineering at PLX Technology, in Sunnyvale, Calif. In The Data [p. 56], he reports the results of tests he ran on how the most popular search engines try to anticipate what information you're seeking, even as you type in your query. He is amazed that while one search engine predicts you want to find a flash-in-the-pan singer, another is sure you're searching for a multiplayer fantasy game.

SIMON C. PAGE, who created the colorful illustrations for "The Terahertz Frontier" [p. 38], first caught the design bug while drafting presentations as an analyst for a real estate finance firm. He started doing graphics just for fun, and some of his art, including a series of posters about the International Year of Astronomy in 2009, drew attention—and ultimately patrons. Page, based in London, says his slogan is "Good design excites."

GREG TAYLOR and **GEORGE COX** have over half a century of combined experience as Intel architects. Helping to develop a hardware random-number generator, which they describe in "Digital Randomness" [p. 26], was their first collaboration. Cox believes this work could make a fundamental computing problem—the need for a dependable source of truly random numbers—"just go away." Taylor has helped design 10 generations of microprocessors and traces his interest in digital logic to his father, who worked on the first commercial computer produced in the United States.

MICHAEL C. WANKE and **MARK LEE** write about creating the first terahertz IC in "The Terahertz Frontier" [p. 38]. Wanke is a principal member of technical staff at Sandia National Laboratories, in Albuquerque. Lee, formerly of Sandia, is a physics professor at the University of Texas, Dallas. They met at Bell Laboratories more than 10 years ago, where Wanke worked on terahertz photonic devices and Lee focused on terahertz electronics. "It wasn't until we started working at Sandia that we realized we could blend the two approaches to make an integrated circuit," Wanke says.

THOMAS WIEGAND and **GARY J. SULLIVAN** became coleaders in 2000 of the International Telecommunication Union group that developed the H.264/MPEG-4 Advanced Video Coding standard, which they describe in "The Picturephone Is Here. Really" [p. 44]. Wiegand, a professor at the Technical University of Berlin and head of the image processing department of the Fraunhofer Institute for Telecommunications, got into video telephony in the late 1990s, when data rates were still measured in kilobits. Sullivan, a principal software development engineer at Microsoft, began working on video telephony 20 years ago at PictureTel Corp.

FROM TOP: STEPHEN LACKO; SWAPNAJIT MITRA; SIMON C. PAGE

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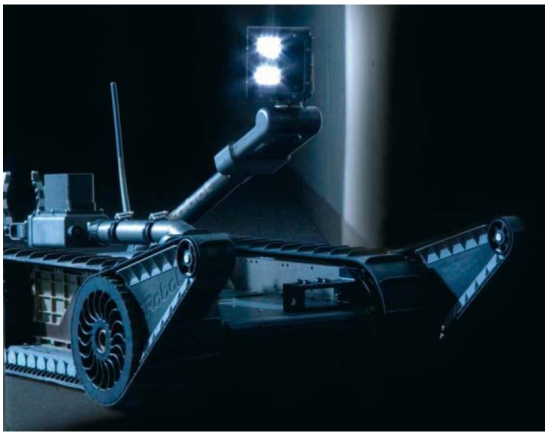

9/11 and the Rise of Robots

iRobot's 510 PackBot, a tactical mobile robot used by military troops, bomb squads, hazmat teams, and first responders.

SEPTEMBER 11 had quite a different meaning for me before it became 9/11. It's my birthday. And early on that cool blue morning I took my daily run from our Chelsea apartment down the West Side Highway past the World Trade Center to South Ferry and back. I never thought much about the Twin Towers then, except sometimes to remember the convoluted history of how they got built in the first place, or to feel their overwhelming presence in what was then a low-rise part of Manhattan as I breezed past, with no sense of how gigantic their absence might become.

At work later that morning, when the news came in, we first thought "accident." After all, in 1945 a B-25 bomber had crashed into the 79th floor of New York City's Empire State Building. But how could this be on such an acutely clear day? Now, 10 years later, when almost any disaster is tinged with the possibility of terrorism, it's hard to remember a time when these thoughts were not second nature.

Before anyone knew there would be no one to rescue, people from around the United States, and around the world, flocked to the city to help. Among the would-be rescuers who came that day and the ones that followed were robots. They were driven to the scene by engineers and technologists from places like iRobot Corp. and Foster-Miller in the Boston area, and from Robin Murphy's brand-new Center for Robotic-Assisted Search and Rescue, then at the University of South Florida, in Tampa, and now at Texas A&M University.

While they saved no one, these robots were able to traverse some of the vast debris field, going where humans and dogs dared not, demonstrating indisputably that they weren't toys or expensive curiosities but viable machines capable of standing in for humans in dangerous situations. As Murphy has noted, before 9/11 the idea that intelligent robots could help save lives at disaster sites was dismissed as science fiction. But not after.

To be fair, the artificial-intelligence community and the military were skeptical for good reason. While serious work on robot development had picked up in the 1990s, the problems facing robot builders were intractable and expensive: Computer vision was still slow and unreliable; robotic control, remote or autonomous, was tenuous. Sensor-based navigation was demonstrable but fragile. Materials and motor technologies were rudimentary, and sensors weren't small enough or smart enough.

But since 9/11, work and progress in all these areas have accelerated dramatically. Now robots are everywhere, and the demand for more is tremendous. The U.S. military, for one, has seized upon the development of ground robots to detect improvised explosive devices and drones to fly reconnaissance missions, as our August story "Autonomous Robots in the Fog of War" makes clear.

Robots have been used in the aftermath of many subsequent disasters—hurricanes, building collapses and, most recently, in the nuclear plant meltdown at Fukushima. They are showing up in civilian sectors beyond manufacturing, in health care and medicine. And self-driving vehicles have completed successful urban and long-distance challenges that were unapproachable 10 years ago.

These robots are saving lives, time, and money. They do things humans can't or don't want to do. But the social and political implications of robotic applications haven't begun to play out. Will we use them productively—or destructively? Or as with so many of our other technological innovations, will we do both?

To get a sense of the dizzying pace of robotic development, visit Senior Associate Editor Erico Guizzo's Automaton blog on our website. In July he had an excellent interview with John Dulchinos, president and CEO of Adept Technology, the largest U.S. industrial robotics company.

According to Guizzo, Dulchinos believes that "robotics is going to be one of the transformative technologies of the 21st century." Global sales of industrial robots represent only a US $5 billion market today, Dulchinos says, but according to some estimates it will grow to $100 billion by 2020. He envisions domestic robots helping us at home and factory robots that won't displace humans but rather work alongside them—and alongside one another.

Let's work to make his conviction and optimism carry the day, so that the robotic technology spurred by 9/11 is put to uses more fruitful than lethal, and some good can come from so much misery. —SUSAN HASSLER

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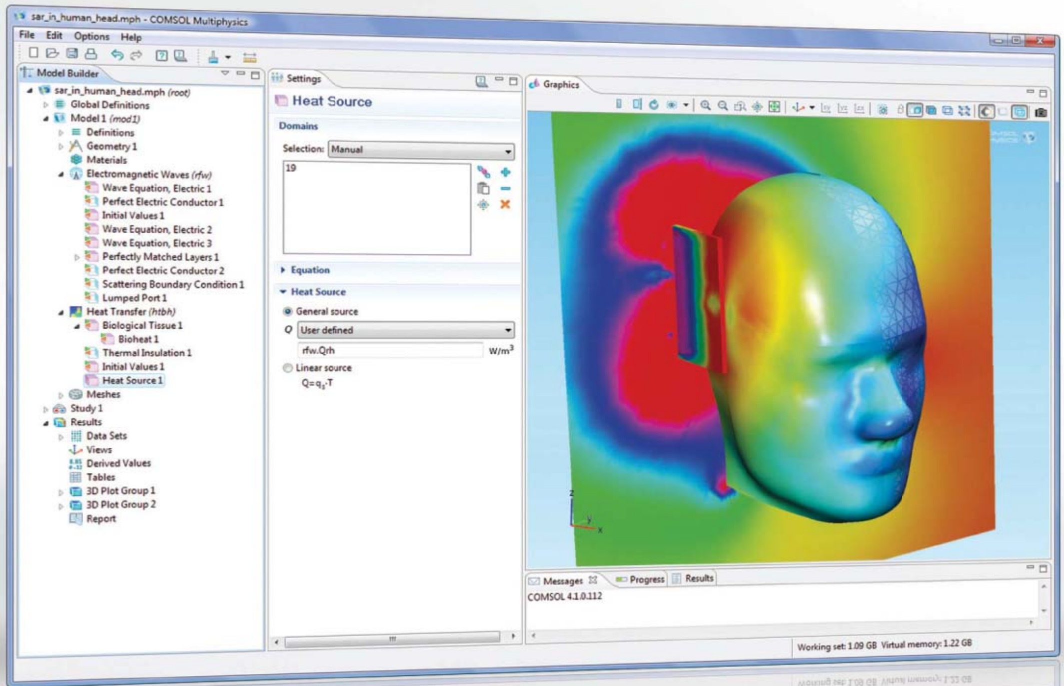

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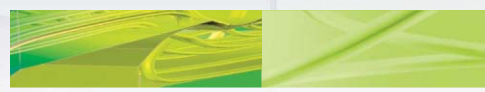

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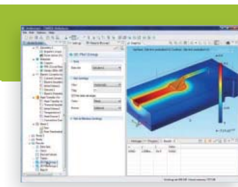

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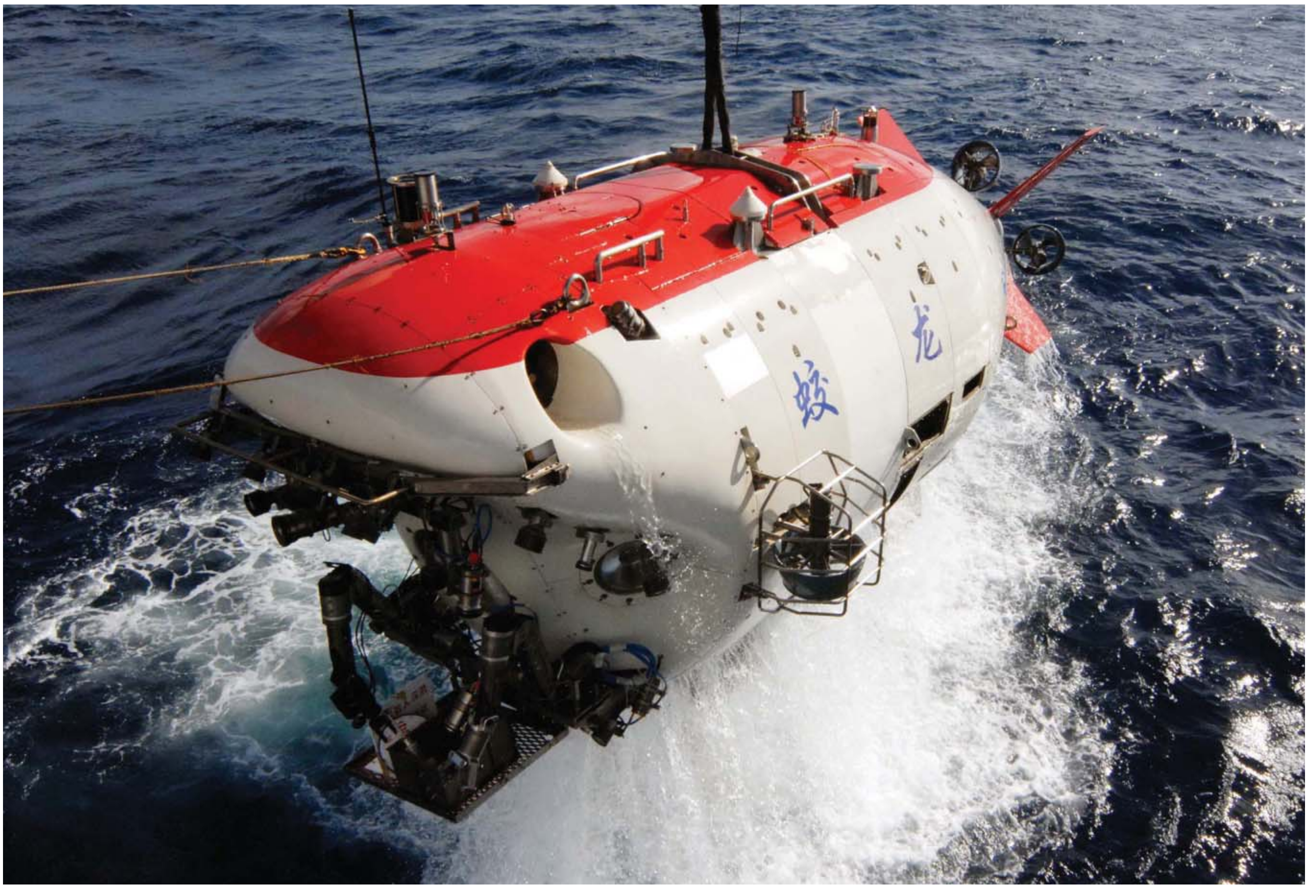


China's Research Sub Dives Deep

The country's first manned science sub goes for global bragging rights

When a team of Chinese engineers set out to build the deepest-diving submersible in the world, they had never laid eyes on a manned deep-sea vehicle. "We had only read some reference papers that had pictures; there was no chance for us to see a real manned submersible," says Cui Weicheng, deputy director of the China Ship Scientific Research Center and project manager for the new sub. "We were starting from the very beginning."

This past July, after 11 years of cautious labor, Cui and his team watched their submersible plunge beneath the Pacific waves, bringing three crew members to the ocean floor 5057 meters below. The *Jiaolong*, named after a mythical sea dragon, is not the deepest-diving manned submersible yet: That distinction still belongs to Japan's *Shinkai 6500*. But if the Chinese sub successfully dives to 7000 meters next year, as planned, it will take the top honor.

The *Jiaolong* dropped to the bottom of the northeast Pacific Ocean in a region where China has been granted mineral exploration rights by the International Seabed Authority. Unlike the venerable 47-year-old U.S. submersible *Alvin*, the Chinese sub is intended to earn its keep not only by conducting fundamental scientific research but also by scouting for precious metals and minerals on the seafloor.

This emphasis on an undersea vehicle's utility is a new thing in China. Several months ago, in the glossy marble headquarters of the research center, in Wuxi,

DEEP DOWN: The *Jiaolong* went down 5057 meters in the northeastern Pacific in July. Its designers are hoping to set a 7000-meter record.
PHOTO: CHINAFOTOPRESS/GETTY IMAGES

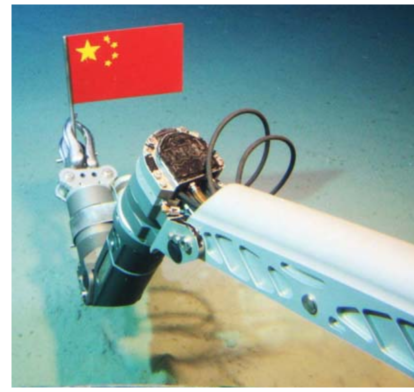
update

Cui explained the difficult history of China's undersea-vehicle program. In the 1980s and 1990s the researchers built both remotely operated and autonomous underwater vehicles capable of reaching depths of up to 6000 meters. But, Cui notes ruefully, those vehicles were never put into operation. "In China, in the past, there was government funding to develop the technology," he says, "but there was no actual requirement for use." After these vehicles successfully completed their sea trials, they were stowed in warehouses.

For the *Jiaolong*, the researchers vowed, it would be different. In 2000 they submitted the proposal for a 7000-meter manned submersible to the China Ocean Mineral Resources R&D Association, a government agency. They also won government support for a new national organization modeled on the Woods Hole Oceanographic Institution, in Massachusetts. In this model, the national government provides most of the funding for a vehicle's operation, and scientists submit research proposals to gain time on the sub. Construction of the new Chinese institution, the National Deep Sea Center, began on the Shandong peninsula this year.

Despite having no experience in manned submersibles, the researchers began in 2002 to design a world-beating vehicle that could withstand pressures of 71 megapascals, or about 700 times atmospheric pressure. They took a slow and steady approach. When, after two years of sketching and planning, they had a preliminary design, they built a full-scale mock-up out of wood and steel to make sure all the planned components would actually fit together.

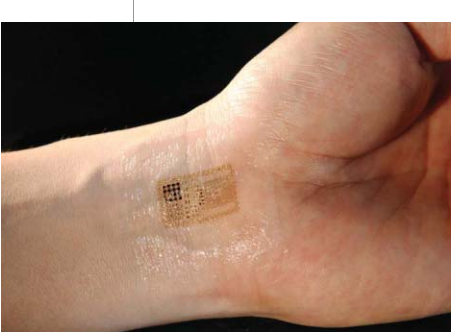
The first sea trials of the *Jiaolong* didn't take place until the summer of 2009, after years of testing the sub and its components in pressure vessels and water tanks. This first 1000-meter dive had an ominous start: The mother ship had to take shelter in a harbor while a typhoon roared by. But Cui was determined to push the trial through and insisted on heading back to sea despite the high waves. "We had a group of the engineers who were prepared to dive, but some of them had fear, and some got seasick," Cui remembers with a laugh. "In order to release their fear, I decided to dive—to show the confidence of the designer!"



FLAG DAY: In a July 2010 dive, *Jiaolong* stuck a Chinese flag 3759 meters under the sea.
PHOTO: XINHUA NEWS AGENCY/EYEVINE/REDUX

If the *Jiaolong* proves itself at the 7000-meter dive next year, it will be ready to begin its work in earnest. But its primary task, mineral exploration, can best be accomplished if it is working in cooperation with unmanned vehicles, says Susan Humphris, who's leading an upgrade to *Alvin* at Woods Hole. "You could have an AUV [autonomous underwater vehicle] that surveys a large part of the ocean floor, and you could then home in on specific sites where the submersible can dive and take samples," she says. In fact, Cui has plans that include several unmanned vehicles as well as a new manned sub, both rated for 4500 meters. These vehicles can be the workhorses of the underwater fleet, Cui says, while the *Jiaolong* can take on more challenging missions at greater depths.

When this high-tech fleet is in operation, the science can really start. "The Chinese government's mission is to push forward the technology," says Cui. It's his mission to keep that technology out of the warehouses, and in the sea. —Eliza Strickland



JOHN ROGERS

Tattoo You

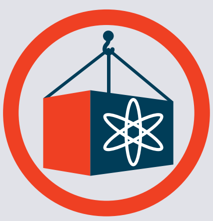
Scientists and engineers in China, Singapore, and the United States have developed a temporary tattoo-like electronic device capable of sensing electrical signals such as brain waves and muscle activity and then transmitting the data. To make the epidermal electronics, they used techniques pioneered at the University of Illinois, Urbana-Champaign, that allow the printing of inorganic semiconductors and metal interconnects on stretchable surfaces. The patch sticks to the skin for up to 24 hours, even without glue, and it draws all its power from a mix of induction and small embedded solar cells.

US $232 246 Amount fetched at auction for the property of Unabomber Ted Kaczynski, who terrorized technologists and others between 1978 and 1995. The money went to his victims and their families.

How 5 Technologies Fared After 9/11

Developed, deployed, and sometimes demoted

THE TERRORIST attacks of 11 September 2001 sparked a security mania in the United States that included a brassbound push for new surveillance technology—one that 10 years later has had mixed results. Radiation monitors for incoming cargo have been deployed en masse, but their utility remains dubious. Other technologies—such as the airline passenger imagers used by the Transportation Security Administration (TSA)—seem to work and have proliferated but leave some people feeling creeped out. Below, we compare five technologies pre-9/11 and today. —RITCHIE S. KING

TECHNOLOGY		PRE-9/11	NOW
	**ADVANCED IMAGING**	Advanced imaging technology was **not used** to screen people prior to 9/11.	The first advanced passenger scanners in the United States—using X-ray backscatter or millimeter wave radiation—were installed in 2007. There are now a total of **488 machines at 78 U.S. airports**. The revealing images the machines produce have raised privacy concerns.
	**CARGO CONTAINER RADIATION SCANNING**	In 2003, there was only **one radiation scanner** at a U.S. seaport and none along the U.S.-Mexico border. But 63 percent of the cargo entering the United States through Canada was scanned.	**All cargo** entering the United States overland is scanned, as is 99 percent entering by sea. Existing scanners, however, have been fraught with **high false-positive rates**, and in July, the United States announced it is killing a program to develop next-generation scanners owing to operational problems.
	**BIOLOGICAL WEAPONS DETECTION**	The only reliable portable bioweapons detectors were **large mobile labs**; the U.S. Army's was housed in a Humvee and operated by four technicians.	The Bio-Seeq Plus, from Smiths Detection, of Watford, England, can detect anthrax, plague, and other agents, **weighs 3 kilograms**, and provides results in a little over an hour. However, handheld detectors still aren't reliable enough to justify public health measures, such as quarantining.
	**FACE RECOGNITION**	In 2000, **a few early commercial incarnations** of face recognition were tested. Their accuracy in identifying a face faltered when the subject's distance from the camera or facial expression varied or when the lighting changed.	Engineers and computer scientists made a **20-fold improvement in accuracy** between 2000 and 2006. Today, Facebook, Apple's iPhoto, and Google's Picasa all have facial-recognition capabilities. In August, a German official asked Facebook to disable the feature, claiming that it violated European privacy laws.
	**EXPLOSIVES DETECTION**	In 2002, airline passengers and cargo were **rarely swabbed** for explosives (those swabs were run through chemical-trace detectors). **No explosive-trace-detection portal machines were used**. Called puffers, these machines puff air at a passenger and sniff for explosives and other chemical contraband.	Since 9/11, **1200 explosive-trace detectors** have been installed to screen airline baggage. At their peak, there were also **94 puffers in 37 U.S. airports**, but the TSA started phasing them out in 2008 because of high maintenance costs.

ILLUSTRATIONS: ANDERS WENNGREN

SOURCE: U.S. DEPARTMENT OF HOMELAND SECURITY

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X7 Severity of the most powerful solar flare since 2006. Space weather scientists warned power and communications companies to be prepared for disruptive space weather a few days before the 9 August flare.

update

WARM WHITE: Analysts and the industry are putting out mixed signals on how hot the market for OLED lighting will be. *PHOTO: PHILIPS*

Expectations Dim for OLED Lighting

High costs could keep the LED's carbon-based cousin off the shelf

A NEW REPORT suggests that organic light-emitting diodes, or OLEDs, won't come anywhere close to replacing conventional illuminators like incandescent and compact fluorescent lightbulbs in the foreseeable future. The analysis, conducted by Lux Research, a technology consultancy based in Boston, is marked by an extremely bleak projection of the worldwide OLED lighting market in 2020—a mere US $58 million in annual sales.

But experts from industry and academia and even other independent analysts aren't nearly so pessimistic, with one annual sales projection in the billions of dollars. Which future for OLED lighting comes to pass will depend on how much technology developed for OLED displays proves transferable to the lighting world.

Like conventional, inorganic LEDs, an OLED is an assembly of semiconductor sandwiched between two electrodes. Voltage at the positive electrode yanks resident electrons out of the inner semiconductor layers, leaving vacancies, or holes, while the negative electrode pushes new electrons in. When electrons meet holes, photons are emitted.

But OLEDs have carbon-based semiconductors, and when it comes to producing white light, the organic and inorganic varieties do it differently. Ordinary white LEDs are actually blue diodes shining through a yellow phosphor. OLEDs create white by combining red, green, and blue semiconductor films—either stacked on top of each other or laid down in thin, alternating stripes.

Proponents of OLEDs tout the quality of light they produce and the fact that they can be molded into any shape, two characteristics that also distinguish them from LEDs. OLEDs could also, in theory, save more than 90 percent of the energy that's currently used to power incandescents and consume less than half the electricity needed by compact fluorescents. Because of this potential, the U.S. Department of Energy has invested about $40 million in OLED lighting research.

But right now, because OLEDs are still a new technology, they're less efficient than compact fluorescent bulbs, and they're incredibly expensive: An OLED panel that produces slightly less light than a one-dollar 75-watt incandescent bulb costs $2560.

Jonathan Melnick, an analyst at Lux and the author of the damning report, claims that OLED lights will remain expensive and therefore obscure. "It's hard to see people adopting such an expensive lighting source without a compelling reason to do so," Melnick says. According to his report, the small future OLED market will be limited to designer applications—chic-looking lamps in swanky bars and upscale hotels—that take advantage of OLEDs' flexibility.

news brief

Runway Radar
The fatal crash of a Concorde supersonic jet in 2000 is probably the most famous instance of a flight problem caused by debris on the runway. Today, airport staff hunt for debris by driving up and down the runway, but researchers in Germany have come up with a better solution. It is an automated network of cameras and sensors sensitive enough to find a screw on the runway but smart enough to know how big an object has to be to threaten airplanes.

FRAUNHOFER FHR

But others see a brighter future for the technology.

"The progress in OLED lighting has been spectacular in the recent past, and I don't see why it won't continue," says Stephen Forrest, a materials scientist at the University of Michigan who has made fundamental OLED developments. And a projection by NanoMarkets, a market research firm, pegs OLED lighting sales at more than $10 billion in 2018, over 100 times as much as the Lux estimate.

The difference in outlook arises from different perceptions about the relationship between OLEDs used for lighting and OLEDs used for displays—a fledgling technology that brought in over $700 million in sales in 2009. OLED displays can be made extremely thin and flexible and have better contrast than LCDs.

If the market for OLED displays really takes off, it will help drive down the cost of OLED lights, because the techniques used to fabricate displays and lights are "very similar," according to Janice Mahon, vice president of technology commercialization at Universal Display Corp., an OLED development company in Ewing, N.J. But Lux's Melnick says the similarities are limited: "The principles of technology are the same, but there isn't a huge materials overlap."

The truth lies somewhere in between, according to Lisa Pattison, an analyst at Solid State Lighting Services, which advises the Department of Energy. Because they require individually controllable pixels, "displays are more complicated to manufacture," she says.

When displays are fabricated—today on 1.3- by 1.5-meter sheets of glass, processed one at a time—pixels are created by stenciling red, green, and blue OLEDs onto a backplane of circuitry. OLED light panels don't require the backplane, and the color patterning—stacks or stripes—is much simpler.

But lights have more stringent performance requirements than displays. Lights spend more time powered on than the screens of televisions, computers, and mobile devices, so they'll have to deliver on their promise of high efficiency and have a longer life span. (Today, an OLED panel lasts about 8000 hours, compared to 1000 for cheap incandescents, 12 000 for compact fluorescents, and 25 000 to 50 000 for LEDs.)

In spite of these differences, Pattison agrees with Universal Display's Mahon. "There are enough similarities that advances in one can help the other," Pattison says. For one, developments in solution printing, where the semiconductors are printed onto the electrode with an inkjet printer, would benefit both. Printing could lower manufacturing costs by allowing lights to be produced cheaply on rolls of plastic or larger sheets of glass.

"There's a lot of potential for cost to go down and performance to go up," Pattison says. "OLEDs will be a part of the lighting future."

—Ritchie S. King

Germany Faces a Shortage of Engineers

Even loosening immigration won't fill the gap, say experts

SOLAR SOLO: Germany's growing energy industry is one reason the country is short on engineers.
PHOTO: PATRICK PLEUL/AFP/GETTY IMAGES

Germany needs to address the growing number of job openings for engineers if it hopes to keep its mighty manufacturing machine roaring ahead. In June, the Association of German Engineers (VDI) reported that there were 76 400 vacant engineering jobs, an all-time high.

A strong economy is one reason for the shortage of engineers. But a declining population—at 1.38 children per mother, Germany has the lowest birth rate in Europe—and a steadily rising demand for transportation and energy technology are also contributing to the problem.

"Demand for engineers will continue to grow as we move toward an all-electric society," says Michael Schanz, head of engineering education at the Association for Electrical, Electronic & Information Technologies (VDE), referring to the growing use of plug-in hybrid cars and electric vehicles. "More companies will simply need more engineers."

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update

news brief

Motion Capture in Reverse

Engineers at Carnegie Mellon University and Disney Research, both in Pittsburgh, have turned the traditional motion-capture method on its head. Instead of pointing multiple cameras at an actor to follow his movements, the engineers strapped the cameras to the actor's body. A technique called structure from motion uses the camera's images to figure out how the actor is moving. Although this method can't capture images as well as Hollywood techniques can, it can record movements outside the studio that would be difficult if not impossible otherwise.

VDE estimates a shortage of 6000 electrical and electronic engineers in 2011, up from 3000 last year and 1000 the year before, when the global economic and financial crisis slammed Germany. The country has some 170 000 EEs today. VDI, which calculates its figures differently, reported 18 000 open EE positions in June, up from 11 000 a year ago.

Policymakers in Berlin have responded to the shortage of skilled workers with a number of measures, including changes in immigration rules that allow German companies to hire engineers from other countries, including those outside the European Union. Among the measures: The annual salary that companies must pay foreigners has been lowered from €66 000 (US $95 000) to €40 000, which is roughly the starting salary of an engineering graduate in Germany. The government is also sponsoring programs to attract engineers from Spain, Greece, and other European countries suffering from high unemployment.

To make it easy for engineers to move around Europe, engineering associations and other groups across Europe are working with the European Commission (the executive arm of the European Union) to launch the new Engineering Card. The card, which German engineers can apply for now and other countries are planning to offer, provides standardized information about the engineer's qualifications and skills for greater transparency.

Lars Funk, head of the profession and society division at VDI, welcomes these measures by the German government and the EU, but he doesn't believe they will solve the country's engineering shortage. "We don't expect many engineers will come, because among other reasons, there is a shortage of engineers across Europe," says Funk. "What we really need to do is educate more engineers."

The number of engineering students in Germany is growing slightly. Around 40 000 will graduate this year (up about 5000 from five years ago), 9000 of whom are in electrical and electronic engineering. With the aim of increasing those numbers, the German engineering associations are spearheading several promotional initiatives targeting young students and are also lobbying lawmakers to establish a nationwide educational policy for teaching technology in primary and secondary schools.

But if getting young people into engineering is one challenge, keeping them there is another. The dropout rate among electrical engineering students in Germany is 50 percent, according to Schanz. "There is much more potential to increase the number of engineers by investing in dropouts rather than trying to attract young people who are less interested in engineering," he says. The dropout problem, he adds, is often linked to math, which isn't taught sufficiently in many primary and secondary schools and tends to dominate the first year of studies at most engineering schools.

Some universities have responded by offering greater support during the first year of study, providing math refresher courses and mentoring programs. Some are also involving students directly in hands-on projects to show them how math skills can help them construct models and solve problems.

"Math is really an issue and a big reason why lots of first-year engineering students quit," says Robin Goebel, a student at the Technical University Berlin. "But you need to box your way through—it's fundamental to engineering."

Another challenge is attracting more women to engineering. Germany today has around a million engineers, 13 percent of whom are women, up from around 10 percent a decade ago, according to VDI. Of the 384 000 students currently studying engineering in Germany, 79 000 are female, says the organization. (VDE estimates there are 85 000 women engineers out of 700 000 engineers.)

While the engineering associations have initiated various programs to encourage female students to study engineering, they admit that it's tough going. "Many girls are more interested in helping people and society and don't see this possibility in engineering," Schanz says. "It will remain very hard to attract women to engineering—much harder than reducing the dropout rate."

But for those young men and women who master the math and are interested in engineering, the doors to a promising career are wide open in Germany. "One of my professors told me that no student will leave the engineering department without a job," says Goebel, who is specializing in environmental technology and renewable-energy systems. "That's certainly encouraging." —John Blau

A version of this article appeared online in August 2011.

CARNEGIE MELLON UNIVERSITY/DISNEY RESEARCH

FRIEDEMANN VOGEL/GETTY IMAGES

Will Soccer-Ball Tracking Ever Reach Its Goal?

Goal-line technologies advance but might not score an invitation to the 2014 World Cup

THIS MONTH, the Fédération Internationale de Football Association (FIFA) is set to take yet another look at technology meant to eliminate the possibility of human error in the most fundamental aspect of a match—determining when a goal has been scored. Nine companies met the 1 June deadline to register for the tryout, but a federation spokesman would not reveal the names of the firms. The federation, the governing body for football (or soccer), says the winner will be announced sometime in 2012.

"If it's proved to be accurate and affordable, it's possible that the international board will adopt this technology during the 2014 World Cup," says FIFA president Sepp Blatter.

Déjà vu, anyone? FIFA was expected to adopt goal-line technology after a round of tests in 2008. But it unexpectedly reversed course, with Blatter saying that he wanted football to "keep its human face." But FIFA officials had a change of heart after referees blew several calls at the 2010 World Cup. During a match between England and Germany, a goal was not counted despite TV replays that showed the ball crossing the goal line before bouncing back.

With the specter of the 2010 tournament in the background, FIFA has assigned the task of assessing goal-line systems to the Swiss Federal Laboratories for Materials Science and Technology, in Zurich. FIFA expects the systems to recognize 100 percent of free shots on goal, and to transmit within 1 second a vibrated and visual indication of a scored goal to a special watch worn by the referee.

Only a few companies showcasing their wares during the preliminary round of testing in December will be invited back for a second, more stringent judging, between March and June 2012. The results of both assessment stages will be unveiled by next September.

Though FIFA is being tight-lipped about who is participating in the testing, the lineup reportedly includes several names that have been associated with FIFA's on-again, off-again courtship of goal-line technology since it began in earnest in 2005.

Among them is HawkEye Innovations, in Winchester, England, whose eponymous system uses a half dozen high-speed cameras to track the ball in flight. The system is best known as the brains behind line calls in grand slam tennis tournaments such as Wimbledon, where it has a margin of error of 3.6 millimeters (the company says the margin of error is the same for soccer). HawkEye's accuracy is enhanced by software that can find the ball even if only 25 percent of it is visible, and it predicts the trajectory even if several of the cameras' views are obscured, say the system's creators.

Another perennial candidate is a partnership between French transponder maker Chronelec and Swiss high-end watchmaker Tag Heuer. The group has created a ball with a transponder suspended at its center. When the ball crosses the plane of a goal that has been wired to emit a small magnetic field, the transponder radios encrypted data to a remote decoder. The group's decoder provides an update every 0.0001 second on whether the transponder has crossed the goal, a rate so high that the ball would have to be traveling 500 kilometers per hour to evade detection.

Also in the running is a German pair, Cairos Technologies and sporting goods and apparel maker Adidas. When the call for electronic goal-line technology began in 2005, the Cairos-Adidas group stepped forward with ambitious technology featuring small transponders inside the ball and on players' shin pads that would indicate goals and offsides. The system could deduce the ball's location by calculating how long it took signals from each of several receivers on the edges of the playing field to reach the transponder inside the ball and return. As a bonus, team coaches would also have access to data regarding each player's movements.

But in 2008, the German firms began hawking a system similar to the one presented by Tag Heuer–Chronelec. The difference between the two systems is where the wires lie. Instead of wiring the frame of the goal and the ground beneath the goal line, the Cairos-Adidas group uses a series of thin cables installed underneath the penalty area (the rectangle in front of the goal) and behind the goal line to generate two distinct magnetic fields.

The companies are reluctant to talk about their technologies or to discuss FIFA's ever-changing stance on goal-line technology, for fear of offending the governing body and torpedoing their chances. "There are many stories I could tell you, but I'm not sure what I'm able to say," says one company spokesman. So it's hard to predict whether electronic goal-line technology will make it onto the playing field in time to help World Cup referees in 2014. —WILLIE D. JONES

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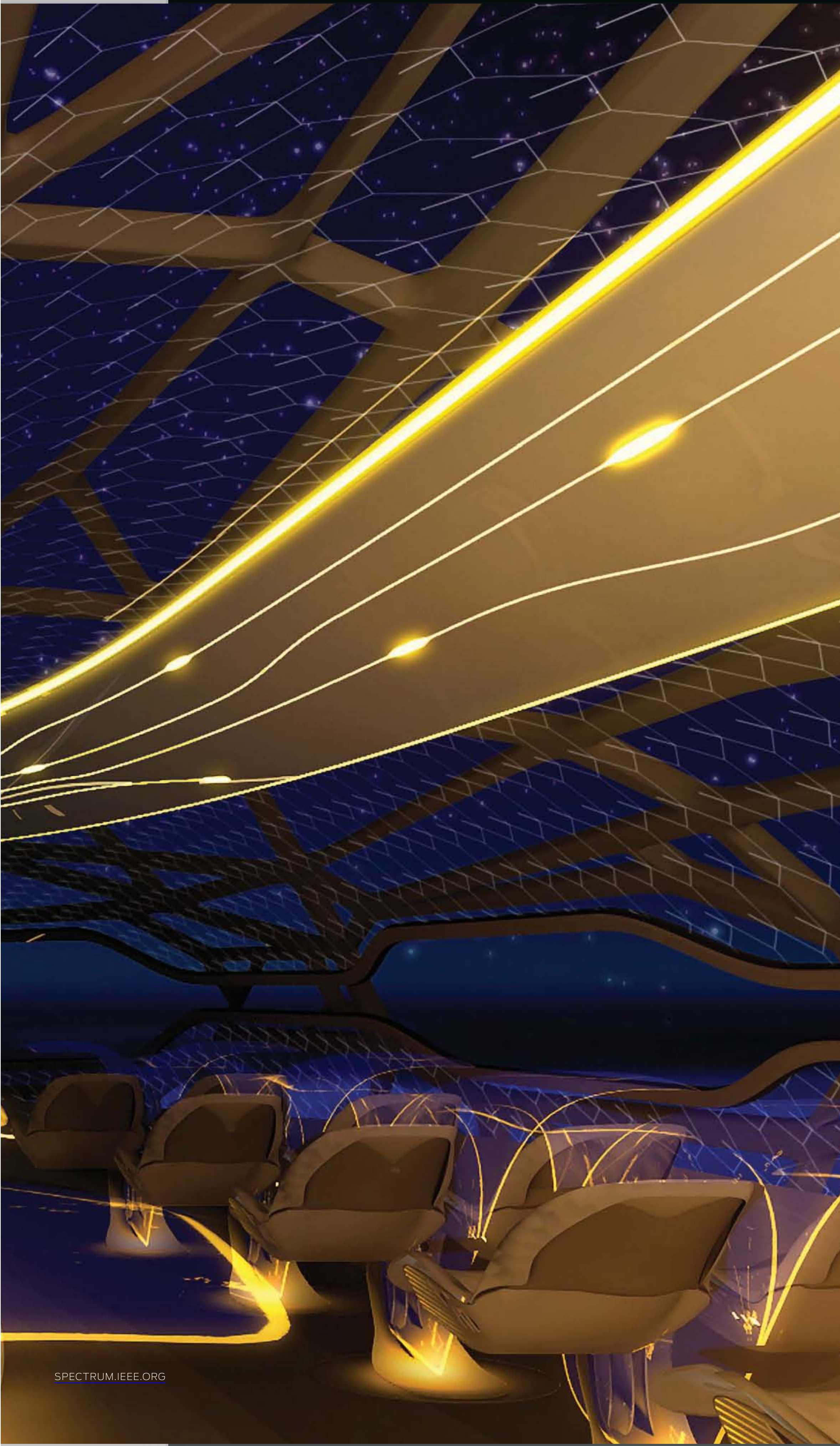

the big picture

FUTURE FLIGHT

Humans have always envied birds' ability to soar through the air. In 2050, airplanes with fuselages that replicate the structure of bird bones will change the way we fly, says aircraft maker Airbus. In one vision of this future, in-flight entertainment could cover all of the lightweight cabin's walls. Or, as shown in this rendering, the walls could be made transparent to give passengers a truly bird's-eye view of the nighttime sky. And instead of first class, business, or coach, travelers will be given a choice of seats based on whether they desire a revitalizing spa experience, need to stay connected via holographics and remote telepresence, or want to play interactive games such as virtual golf.

ILLUSTRATION: AIRBUS/GETTY IMAGES

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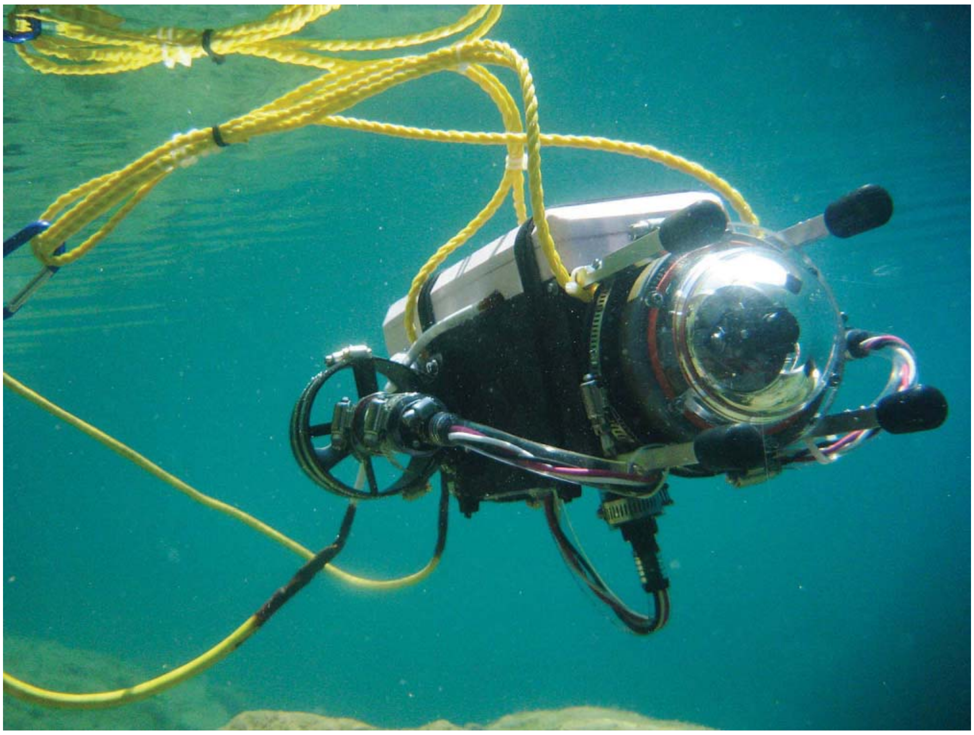
hands on



BUILD YOUR OWN ROBOSUB

With a remotely operated underwater vehicle, you can explore the depths without getting wet

LAST YEAR at about this time, crews in the Gulf of Mexico were working feverishly to bring BP's blown-out oil well under control. Some of the more spectacular parts of that effort, as you may recall, involved the use of remotely operated vehicles, or ROVs. Perhaps you had the same thought as I did—that it would be cool to build one.

To be sure, no garage-workbench hacker is going to build an undersea robot that operates a diamond saw or wrestles with a stuck blowout preventer. But those vehicles also monitored events on the seafloor and streamed some amazing video to the Web in real time. A small inspection-class unit—one that carries just a video camera around underwater—ought to be within the grasp of an avid DIYer.

A quick search of the Web revealed no shortage of home-built ROVs. There are even competitions, such as the one for students that the Marine Advanced Technology Education Center in Monterey, Calif., has been running for 10 years. In a similar vein, MIT's Sea Perch program trains teachers (who in turn train their students) to build a simple ROV as an educational exercise.

With all that going on, I thought it was high time for me to get my feet wet—again. As it happens, I've some background in this sort of thing, having worked briefly building underwater instruments at Columbia University's Lamont-Doherty Earth Observatory, just north of New York City.

I even built an ROV for fun in the late 1990s. Its underwater thrusters, like the ones employed by most DIYers today, used DC motors mounted in watertight housings. Flexible shaft seals prevented water from getting to the innards of the motors. It used trolling motors, the kind you see pushing small fishing boats around. Submersible bilge pumps are another popular solution.

The great thing about bilge-pump motors is that they are dirt cheap—perfect if all you want is something that can swim around at shallow depths. At greater depths, though, the pressure will cause the flexible seals to close down around the spinning shaft, sapping power and heating the seal. Ultimately, the seal fails and the motor floods.

I wanted my next-generation ROV to be able to go deep, so I took a different approach this time, which was to fill the motors with oil. Shaft seals are still required to keep the oil on the inside separated from the water on the outside. But the two sides of the seal are always at the same pressure, so the motors should be able to operate at any depth.

The wrinkle here is that brushed DC motors don't like to run in oil—the brushes foul. So I used brushless DC motors, which are electronically commutated and will spin as happily in oil as they do in air. These days such brushless motors and their controllers can be had for very little, because they are widely used in radio-controlled model cars and airplanes.

I wanted my ROV to be as small as possible—my first ROV was so big and heavy it was hard to lift—so the new model would need only small motors. I selected the HXT 2835 (US $20 each from HobbyKing.com). Their controllers (HK-30A, also from HobbyKing.com) are also surprisingly inexpensive, only $15. In fact, the tiny shaft seals (from McMaster-Carr) cost nearly as much as the controllers.

To hold each motor and to shield the attached prop, I used a 90-millimeter-diameter plastic shroud designed for an electric-ducted fan, the sort that powers some model airplanes ($2 from BP Hobbies). They aren't shaped like real Kort nozzles—the kind you might see on the U.S. Navy's *Alvin* or other submersibles—but they look the part. I cut down the propellers from some model-airplane props I had on hand. A small aluminum disk placed on the business end of the motor holds the shaft seal in place. Some vinyl tubing, a few stainless-steel hose clamps, and a plastic hose fitting from the local home center completed the unit, bringing the cost of each to about $70, which is astonishingly little for an underwater thruster that could, in principle, operate at the bottom of the Mariana Trench.

The rest of my ROV can't go anywhere near that deep, of course. But I expect it would have no trouble diving down as much as 60 meters or so. That's because I made its two hefty pressure housings from 10-centimeter-diameter polyvinyl chloride end caps ($17 each from a local plumbing supplier) intended for 3-inch schedule-80 pipe.

The rear pressure housing contains the three motor controllers, which just barely fit. The front housing was also stuffed rather full with a Panasonic GP-CX161 video camera (only $24 from CCTVohio.com, unfortunately now discontinued), a radio-control servo (a $3 no-name model) to tilt the camera up and down, a 0- to 100-psi pressure sensor to gauge depth (which I scored for just $28 on eBay), an HMC6352 digital compass ($35 from Sparkfun Electronics) to determine heading, and an Arduino Pro Mini microcontroller ($19, also from Sparkfun) to serve as the ROV's brain. Were I to do this again, I'd probably use 4- or 5-inch PVC end caps to make fitting everything in easier.

The tether connecting the ROV with the surface is split into two parts: a power cable and a data cable, both bright yellow because it looks so spiffy in the water. I strapped on short lengths of foam pipe insulation attached at intervals; a neutrally buoyant tether would have been great, but pricey.

ROV HACKING: The front pressure housing uses an acrylic dome (1). Epoxy-filled plumbing fittings allow wiring to pass into the rear pressure housing (2). Both housings fit between aluminum rails (3). Exposed electrical connections are covered with Scotchkote (4). The thruster motors and the tubing containing their leads are filled with mineral oil (5). Tests reveal the amount of flotation needed for neutral buoyancy (6).
PHOTOS: DAVID SCHNEIDER

The cheapest power cable I could find to send 12 volts DC down to the ROV was a 30-meter outdoor extension cord ($39 on eBay). To reduce resistance, I wired two of its three 14-gauge conductors together. The 30-meter CAT5e data cable (another eBay bargain, $10) contains four twisted pairs of conductors. One pair carries a salvaged RC transmitter's pulse-position-modulated control signals from the surface down to the ROV. Another pair carries heading and depth values up to the surface at 9600 baud, where they are read by a second Arduino microcontroller, which displays the data on a serial-enabled LCD screen (Sparkfun, $25). The control signals and data telemetry pass through Maxim 490 line driver/receiver chips at both ends, which will allow the ROV to operate with a much longer data cable if desired. A third twisted pair conveys the video signal up to the surface, with video baluns ($20 each from Svideo.com) at each end to make that work properly.

Although I tried to design this little ROV to be easy to build, making the end caps for the two pressure housings watertight took some machining on a lathe. For the rear housing, I used aluminum, which acts as a heat sink for the three motor controllers mounted behind it. The front pressure housing includes a ¼-inch-thick (6-mm) acrylic dome ($30

hands on

from EZ Tops World Wide) that allows the camera to tilt up and down without introducing optical distortion. The dome also looks slick. But I had to machine an acrylic disk and attach it to the back of the dome so that it could be fitted with an O-ring (about $1 from McMaster-Carr). The machined aluminum cap on the rear housing is similarly outfitted with an O-ring for a high-pressure seal.

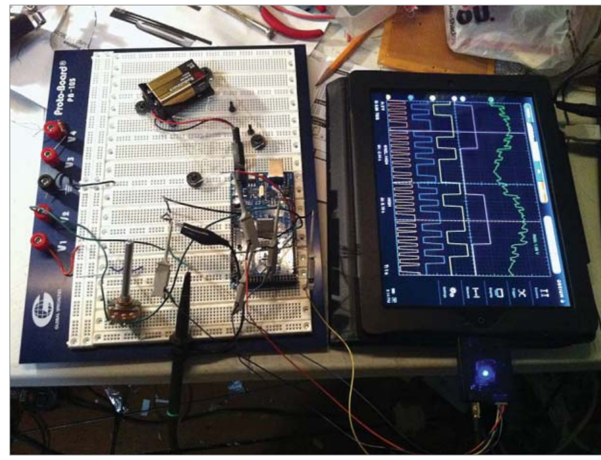
One particular challenge is making the many electrical connections that pass through the two PVC housings—you really don't want those to leak under pressure. Were money no object, I'd buy fittings designed for this purpose from Sea Con or a similar company. Money was an object, however, so I made my own bulkhead connectors, using plastic pipe fittings, copper wire, and epoxy. I tested one of these creations under pressure using a short length of water-filled steel pipe and a bicycle pump, and it seemed to work just fine. I covered these and all other wiring splices exposed to water with a generous amount of 3M's Scotchkote Electrical Coating—an important trick I learned at Lamont-Doherty.

I tested my ROV at a flooded quarry that local scuba divers frequent, where the water was crystal clear. All systems worked pretty much as intended. The little sub went up and down briskly when I operated the vertical thruster, and it proved very responsive in the horizontal plane, too.

At some point, I'd like to take this little ROV out for some wreck diving in the ocean off my home state of North Carolina, a goal that drove many of my design decisions. Some fascinating sites, including the remains of *U-352*, a German submarine that was depth-charged in 1942, are located not far away. Sure, you can visit that wreck, which lies in about 30 meters of water, by donning conventional scuba gear. But that requires no motors, no batteries, no cables, no video camera, no electronics, no microcontrollers, and no programming. Where's the fun in that? —David Schneider

SEE TRIAL: Testing was done in a flooded quarry [top]. Video frames from the ROV [middle and bottom] show the local fauna. More video is available online.

PHOTOS: DAVID SCHNEIDER



JAMES TURNER

Scoping Out My iPad—Oscilloscoping, That Is

To build an inexpensive touch-screen oscilloscope, start with an iPad

It is a truth universally acknowledged that an engineer in possession of a good fortune must be in want of an oscilloscope. You can get low-end oscilloscopes for less than US $500, but they're heavy and cumbersome, and usually offer a minimum of functions, all accessed from knobs and switches.

Luckily, a new option has emerged for the scope-hungry hacker: the Oscium iMSO-104. For a mere $300, you can get this four-channel digital, one-channel analog touch-screen oscilloscope with some advanced trigger functions, handy calculations such as the signal root mean square or duty cycle, and the means to capture screen shots with the press of a button. Best of all, it weighs a scant few ounces and fits in your pocket with enough room to spare for an iPhone. The catch is that you'll also need that iPhone—or an iPad or iPod Touch—to use it.

But the software is free at the app store. Once it's downloaded to your iOS device, plug the iMSO-104 into the docking connector on the bottom and you're ready to capture data. Although it will work with the iPhone and iPod Touch, to truly enjoy the experience, an iPad is the way to go. Everything is controlled by touch. You can change the analog scale or time scale with a simple pinch of the finger and drag cursors and analog triggers around to measure the distance between two peaks or a voltage drop. You can trigger on an analog voltage level or use the digital probes and trigger on a rising or falling edge—or combine two digital signals with an "and" or "or."

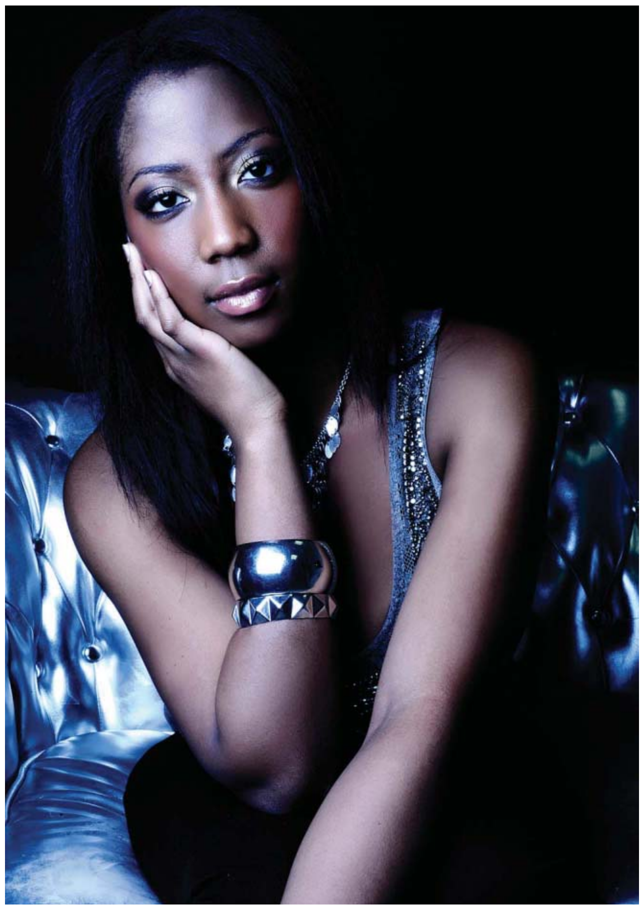
I've been using logic analyzers and oscilloscopes on and off for 30 years. In terms of sheer ease of use, this is the best I've ever gotten my hands on (pun intended). But that's not to say there aren't a few caveats. For one thing, it's a 5-megahertz scope, so you won't be going out and taking test readings on microwave transmission signals with it. It is also somewhat limited in the analog voltage it can handle, maxing out at 40 volts in 10x mode and at 13 V in 1x. But within those restrictions, it's a great value and a joy to use.

So the next time you're hanging around the hackerspace and someone whines about not having an oscilloscope, whip out your iPad and iMSO-104 and give him an eyeful of signal. —*James Turner*

profile

DIGITAL DIVA

Chip-failure analyst by day, chanteuse by night. Meet Obehi Ibhanesebhor



OBEHI

By day, Obehi Ibhanesebhor, 24, is a bespectacled engineer in a lab coat with her hair pulled back and minimal makeup. By night—*vavoom*!—the diva comes out. Big hair, flashy makeup, dress slit up to there—and sparkles.

"You gotta have sparkles!" she exclaims with a laugh.

As if Obehi—she goes by her first name as a performer—didn't stand out simply for apparently being Scotland's sole Nigerian-born R&B singer, she's also a working electrical engineer. Specifically, she troubleshoots audio microchips for Wolfson Microelectronics, a design company in Edinburgh. "When they fail, it's my job to find out why—like "CSI" for chips," she says.

So do the two careers conflict? "It's a different frame of mind," she says. "Engineering is very black and white—either something works or it doesn't. Music allows me to get out of that box. I have the technical brain, but I have the creative thing in me, too. At work, I'm rocking the nerdy chic. When I'm onstage, that's me where I should be. It's a weird double life."

During her off hours, Obehi studies voice, cranks out songs on her laptop and keyboard, rehearses, records, and plays gigs as far away as London, a 5-hour train ride south. She records musical ideas throughout the day on her phone and MP3 player, fleshes them out in rough demos on her laptop and keyboards (using Samplitude Music Studio 15 software), then books a producer and studio time for a more polished product, which she distributes on her own record label, GNI Records. She has several songs on iTunes and debuted a new single and her first video in July. She takes no vacations and pours all of her savings—some £4000 (US $6600) last year alone—into her singing. "I look at it as an investment rather than a hobby," she says. "But sometimes I don't think I sleep."

Obehi moved with her parents and five sisters to Glasgow at age 8. She returned to Nigeria with her mother at 12, when her parents divorced, but she came back to Scotland in 2004 to study electrical engineering at the University of Edinburgh, graduating in 2008.

Obehi comes by her science honestly: Dad is a neonatal physician and Mom is a geologist. As a child, Obehi spent a lot of time taking apart appliances and trying to put them back together—but mainly breaking them. "It was pointless for my parents to hide the screwdrivers—I'd just use a bread knife," she says.

The music comes from her mother. From her, Obehi learned piano and began writing songs at 12. "But my parents weren't up for the singing as a career," she says. "So I made a pact. I should study science as a backup, but as soon as I graduated, I could do what I wanted."

Obehi was a nervous wreck the first time she performed. "I stood there clutching the mic and shaking in my boots. I couldn't wait for it to be over!" she says, laughing. "Now I'm like, 'We're done already?' "

Her challenges these days have more to do with navigating the music business, whether it's promoting an R&B sound in a region rife with guys with guitars or avoiding the sharks who come at her with dodgy promises of fame and fortune. "I'm now looking for a full-time publicist and manager," she says. "I'm a member of the musician's union, which offers free legal advice. They've saved me numerous times from signing very bad contracts."

As for engineering, she says, "Now my mom is my biggest cheerleader. I'm glad she made me have this pact. Going to university and having this double life has taught me discipline. Nothing worth having is easy."

—Susan Karlin

careers

WHERE THE JOBS ARE: SOFTWARE ENGINEERING

Mobile apps and cloud computing are driving demand for new engineering grads

DAVID PAUL MORRIS/BLOOMBERG/GETTY IMAGES

THE WORST of the recession is behind us. While the job outlook for electrical and computer engineers was not dire last year, the uptick in the economy brings even happier tidings for the class of 2011. Everyone—from Microsoft and Google to small start-ups—seems to be looking for talented programmers and developers.

Grads with software skills have particularly bright prospects. We can credit the proliferation of social media and new devices, says Forrest Shull, a senior scientist at the Fraunhofer Center for Experimental Software Engineering, one of several U.S. arms of the giant German research organization.

"Over the last two years or so, cloud computing and mobile applications are the two paradigms that have increased demand for software engineers," says Shull. "We really like walking around everywhere now with our smartphones, tablets, and other gadgets."

A December 2010 report by the London-based Centre for Economics and Business Research estimated that cloud computing could add 2.4 million jobs in Europe's biggest economies by 2015.

As another hopeful sign, recruiters are back on campus this year. Scott Midkiff, head of the electrical and computer engineering department at Virginia Tech, in Blacksburg, says they "are reappearing with significant hiring goals," particularly in the areas of defense, energy, consulting, banking and finance, and computing. Notable as well is the increased presence of information and communications technology companies, which had drastically reduced their hiring after the telecom and dot-com busts.

Beverly Principal, assistant director of employment services at Stanford, is seeing the same thing. "On-campus recruiting was higher this year, especially for students focused in computer science, hardware, software, and programming," she says.

The National Association of Colleges and Employers, in Bethlehem, Pa., expects hiring of new grads to be up 19 percent. Computer science, electrical engineering, and computer engineering are among the top 10 degrees on employers' most-wanted lists. Those three degrees are also in the top five of the association's list of the 10 top-paid degrees—a list that consists entirely of technology majors. Of the three, computer science grads are making the most—slightly more than US $63 000 on average. While overall offers to engineering grads have stayed roughly the same as last year, EEs saw the biggest jump (4.4 percent) to reach $61 690.

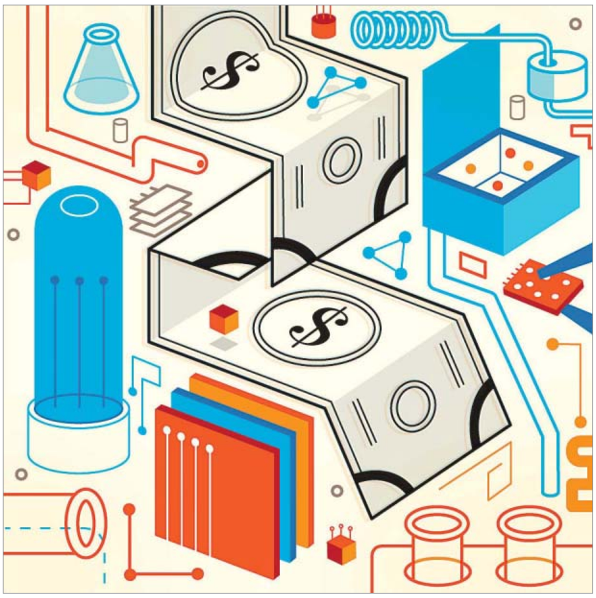
Software engineering, a field that has been strong for a while, was voted the best job for 2011 by career guidance website CareerCast. Software engineers earned the most after chemical engineers in 2009, according to the U.S. Bureau of Labor Statistics. They are also some of the most employed—their unemployment rate was 4.6 percent compared with 5.4 for EEs in 2010.

Four social networking companies—Facebook, Google, Twitter, and online gaming company Zynga—are expected to create around 10 000 jobs, a good portion of which will be for software engineers. However, talented engineers of all stripes are wanted, says Facebook representative Slater Tow. "We're primarily looking for what people have done, what they've built. This is more important to us than just academic credentials."

Tech bigwigs such as Dell, Hewlett-Packard, Lockheed Martin, and Microsoft are also hiring, as are smaller companies, including Agilent, Altera, Analog Devices, and Applied Materials.

Many new jobs are overseas, even as powerhouse manufacturers Nokia and Panasonic cut thousands of jobs. Google is planning to make more than 1000 new hires in Europe, at least half of which will require engineering and computer science credentials, and the company is posting hundreds of jobs across the Asia-Pacific region. Siemens and Microsoft are recruiting in Europe, while Microsoft is hiring in the Asia-Pacific (mainly China, India, Malaysia, and Singapore), looking particularly for cloud technology skills. Software and IT jobs remain plentiful in India and China.

In the United States, entrepreneurship has been on an upswing since the current recession began. Kerri Boivin, director of the engineering career resource center at the University of Michigan, in Ann Arbor, says, "We are seeing more students becoming entrepreneurs [and] have seen a significant increase in start-ups posting jobs." —PRACHI PATEL reflections BY ROBERT W. LUCKY


HARRY CAMPBELL

Adventures in Research Funding

How do you fund a bunch of researchers, given that little of their work will be readily marketable and the real breakthroughs will often benefit your competitors more than yourself?

Through the years, different funding models have come and gone. At the end of the 19th century there was what I'll call the Marconi model. Marconi was an amateur tinkerer when he invented radio. He went on to become a legendary entrepreneur, creating a number of companies to implement his invention. Benz, Birdseye, Sikorsky...a lot of innovators started companies on the Marconi model. Sadly, it doesn't work very well today. Amateurs have been outclassed, and teams have mostly replaced individuals.

While Marconi was tinkering with radio in Italy, Thomas Edison was using the profits from his inventions to build the first stand-alone industrial research laboratory, in West Orange, N.J. It became self-sufficient through the selling and licensing of its patents. You can still visit that lab to see the apparatus, beakers, and jars of chemicals redolent with the smells of yesteryear. But like those old artifacts, the Edison model of funding research has been put on the shelf. Most organizations that tried that approach have been forced to augment their income in other ways.

Next came the "Bell Labs model" of great industrial research labs that were contained within and funded by the profits of large corporations. Unfortunately, most of them—at companies like IBM, Xerox, HP, and Intel—have now disappeared altogether or devoted themselves to directed development instead of research. Senior management has become skeptical about the return on investment of long-term research, especially when competitors without research divisions seem to thrive regardless.

Along came World War II with a new model for research. An unprecedented burst of technical innovation gave us radar, computing, electromechanical cryptography, and the Manhattan Project—an existence proof of what can be done when everyone works extremely hard for a common goal under an existential threat. Shortly thereafter, the Cold War promoted some of the same government focus on research funding. But, as aerospace expert Norman Augustine has observed, it often takes longer today to get approval for a project than it did to fight the entire world war.

This led to the "Internet model," a wonderful example of government/industry cooperation. Research was funded and managed by government and conducted all over academia and industry in a shared environment. I often think that the Internet could not have come to its present form without the government acting as a central funder and gatekeeper. (The evolution of GPS had some of these same characteristics.) Unfortunately, like the others, this model appears to be broken today. The Defense Advanced Research Projects Agency, which led the Internet project, now focuses almost exclusively on military applications.

Recent history has also brought us the "MCC model" (for the Microelectronics and Computer Technology Corp.)—a research lab funded as a consortium of member companies. On paper this looks like a great idea—sharing expenses, risks, and rewards across a number of institutions. In practice, however, it has fallen apart beneath the quibbles and competing objectives of its members.

The newest model, the Silicon Valley phenomenon—a lethal mix of a great research university, empowered graduates, and hungry venture capitalists—has been extremely successful, although largely by capitalizing on existing research. All over the world, cities and states have tried to duplicate Silicon Valley, and although a few have been quite successful, none has neared the output of the original. I've sometimes felt that there must be some special innovation-inducing elixir in the air out there.

Today fundamental research in technology is almost the sole province of academia and is almost exclusively paid for by government. As my short history is meant to illustrate, the funding models have changed over the years. They all worked for a while, and then they didn't. Perhaps it's all a cycle that will repeat, and today there is some young Marconi in his or her basement, experimenting with communication via quantum entanglement. But maybe not. ❑

A NEW RANDOM-NUMBER GENERATOR USES DIGITAL CIRCUITS TO STUMP THE SMARTEST HACKERS

By Greg Taylor & George Cox

Imagine that it's 1995 and you're about to make your very first online purchase. You open your Netscape browser, sipping coffee as the home page slowly loads. You then navigate to Amazon.com, a new online bookstore your friend told you about. As you proceed to make your purchase and enter your payment information, the address your browser points to changes from one starting with "http" to one that begins with "https." That signals that your computer has established an encrypted connection with Amazon's server. This allows you to send credit card information to the server without worrying that an identity thief will intercept the transmission.

Unfortunately, your first online transaction was doomed from the start: It will soon be discovered that the supposedly secure transfer protocol your browser just followed wasn't very secure after all.

The problem was that the secret keys Netscape was using weren't random enough. They were strings of only 40 bits, meaning there were around a trillion possible number combinations. That may seem like a lot, but hackers were able to break these codes, even with mid-1990s computer speeds, in about 30 hours. The nominally random number Netscape used to form a secret key was based on just three values—time of day, process identification number, and parent-process identification number—all of them predictable. This allowed the attackers to reduce the number of keys that they needed to try, and to find the right one much sooner than Netscape had anticipated.

Netscape's programmers would have loved to use a completely random number to form the encryption key, but they had a hard time figuring out how to come up with one. That's because digital computers are always in well-defined states, which change only when the programs they are running tell them to change. The best you can often do with a computer is to simulate randomness, generating what are called pseudorandom numbers by using some sort of mathematical procedure. A set of such numbers may at first glance look perfectly random, but somebody else using the same procedure could easily generate exactly the same set of numbers, which often makes them a poor choice for encryption.

Researchers have managed to devise pseudorandom-number generators that are considered cryptographically secure. But you must still start them off using a special seed value; otherwise, they'll always generate the same list of numbers. And for that seed, you really want something that's impossible to predict.

Fortunately, it's not hard to harvest truly unpredictable randomness by tapping the chaotic universe that surrounds a computer's orderly, deterministic world of 1s and 0s. But how exactly do you do that?

For several years, you could find an online source of random numbers, called Lavarand. It got its numbers from the pictures a computer took of the waxy blobs churning away inside lava lamps. More sophisticated hardware-based systems use quantum-mechanical phenomena, such as photons striking a half-silvered mirror, as a basis for generating random numbers. You can even get an ordinary unassisted computer to produce random numbers based on erratic events taking place within its own mundane hardware—the precise timing of keystrokes, for example. But to get many of these numbers, you'd need to hammer away at a lot of keys.

A WHOLE LOT OF LAVA Lavarand was developed in 1996 to generate randomness from lava lamps. Over a million people grabbed numbers from the Lavarand website.

We and our colleagues at Intel think this should be easier. That's why for more than a decade now, many of our company's chip sets have included an analog, hardware-based random-number generator. The problem is that its analog circuitry squanders power. Also, it's hard to keep that analog circuitry working properly as we improve our fabrication processes. That's why we have now developed a new and entirely digital system that allows a microprocessor to produce a copious stream of random values without those difficulties. Soon it will be coming to a processor near you.

INTEL'S FIRST ATTEMPT to help an average computer produce better random numbers came in 1999, when the company introduced the Firmware Hub chip-set component. The random-number generator in that chip is a ring-oscillator-based analog design that works by taking some of the thermal noise that's present in all resistors, amplifying it, then using the resulting jittery signal to change the period of a relatively slow-running clock. On each of the erratic ticks of that slow clock, the chip then samples the output of a second, fast-running clock, which cycles back and forth quite regularly between its two possible binary states: 0 and 1. That erratic sampling then produces a random sequence of 1s and 0s.

The rub here is that the analog circuitry needed to amplify thermal noise consumes lots of power—and that circuitry operates whether or not the computer actually needs random numbers for what it's doing at the time. Those analog circuits are also a nuisance when it comes time to improve the manufacturing technology used to make the processor. Every few years, chipmakers modify their fabrication lines to produce integrated circuits at a finer scale, allowing them to pack more transistors into the same area. Making these shifts is pretty straightforward for CMOS digital circuitry, but each new generation of analog circuitry requires careful reevaluation and testing—a major headache.

That's why in 2008 Intel set out to make a random-number generator that uses only digital hardware. Intel researchers based in Hillsboro, Ore., and at the company's Bangalore Design Lab in India started by tackling a key part of the problem—how to make a random source of bits without using analog circuitry.

PREVIOUS PAGES: TYPOGRAPHY, CARL DeTORRES; THIS PAGE: ISTOCK.COM

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Ironically, the solution this team came up with breaks a cardinal rule of digital design: that a circuit should be in a well-defined state, outputting only logical 0s or logical 1s. A digital circuit element can, of course, spend short periods switching between these two possible states. But it should never remain teetering, uncertain of which way to go. That would introduce delays and could even produce system failures.

But in this random-bit generator, teetering is a feature, not a bug. The design includes a pair of inverters, circuit elements whose single output is the opposite of its single input. We connect the output of one inverter to the other inverter's input. If the first inverter's output is 0, so is the input to the second inverter, whose output is then 1. Or if the first inverter's output is 1, the second inverter's output will be 0.

This random-bit source adds two rather oddly placed transistors to this two-inverter circuit. Switching those transistors on forces the inputs and outputs of both inverters to the logical 1 state. The inverters have to be modified slightly to take this sort of abuse, but that's easy enough to do.

Interesting things can now happen when the added transistors are turned off. The two-inverter circuit doesn't like having all its inputs and outputs in the same state: It wants the output of one inverter to be 0 and the other 1. But which inverter should output which?

There are two possibilities, and for the briefest of moments, the circuit hovers between them. In a perfect world, it might linger like that forever. But in reality, even a small amount of thermal noise—random atomic vibrations—within the circuitry will send it racing toward one of its two stable states. It's the physically random properties of the thermal noise that determine the outcome of this otherwise indecisive circuit.

In this way, our simple digital circuit can easily harvest some of the ubiquitous randomness of nature. All we need to do is to connect those two extra transistors to a clock that regularly turns both of them on and off. Every time the clock cycles, the circuit generates one random bit.

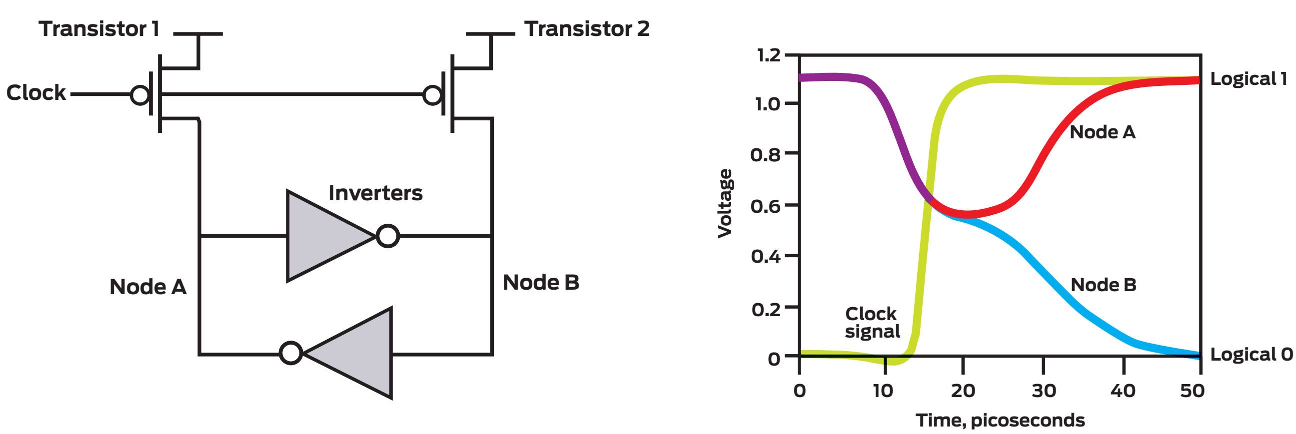
This digitized approach to random-bit generation would work fine if all inverter circuits were absolutely identical. But the messiness of the physical world never really allows that. In reality, no two inverters are exactly the same. Having subtle differences in the speed or strength of their responses might seem like a mild offense, but in this application, such differences could easily compromise the randomness we were trying to extract from the circuit.

To keep the inverters in balance, we built a feedback loop into the new hardware. The circuitry in that loop performs some targeted fiddling until the two possible output values, 0 and 1, each occur roughly half the time. This helps our design satisfy one of the rules for statistical randomness: In a long stream of numbers, there should be roughly the same number of all possible digits. By adjusting the internal workings of each inverter on the fly, we can defend against the predictability that cryptologists so dread.

IN PARALLEL WITH RESEARCH EFFORTS to refine a consistent digital source of random bits, other Intel engineers began developing the additional logic needed to deliver those bits effectively in a product. You might think that a processor could simply collect the output bits from basic random-number-generator hardware, feed them to an application, and call it a day. But the truth is that those bits aren't as random as you'd want them to be. The raw bit stream coming out of basic hardware, no matter how good, can have bias and correlation.

Our goal was to build a system that delivers random numbers compliant with and certified to meet common cryptographic standards, such as those set by the National Institute of Standards and Technology. To guarantee the quality of our random numbers, we designed a three-stage process—which uses digital circuitry, a conditioner, and a pseudorandom-number generator—now known by the code name Bull Mountain.

Our previous analog random-number generator was able to produce only a few hundred kilobits of random numbers a second, whereas our new generator spins them out at a rate of around 3 gigabits per second. It starts by collecting the mostly random output of the two inverters 512 bits at a time. Further circuitry then breaks each package of 512 bits into a pair of 256-bit numbers. Of course, if the original 512 bits aren't completely random, those 256-bit numbers won't be completely random either. But they can *Continued on page 49*



UNCERTAIN CIRCUITS: When transistor 1 and transistor 2 are switched on, a coupled pair of inverters force Node A and Node B into the same state [left]. When the clock pulse rises [yellow, right], these transistors are turned off. Initially the output of both inverters falls into an indeterminate state, but random thermal noise within the inverters soon jostles one node into the logical 1 state and the other goes to logical 0.

Beneath the Ice Sheets

Scientists can now probe polar ice sheets better than ever using synthetic-aperture radar

BY JOHN PADEN, DAVID BRAATEN & PRASAD GOGINENI

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UNDER WING: The authors' airborne radar flew over Greenland's Jakobshavn glacier.
PHOTO: CAMERON LEWIS/CRESIS

It's rare that an academic researcher gets to experience the life of a stunt pilot,

but we found ourselves in more or less that position this past May, as we flew over the ice-covered fjords of southeast Greenland. It was exhilarating—and a little scary. We were riding in one of NASA's research aircraft, a P-3 Orion turboprop, on which we had installed a special kind of radar for probing glacial ice. Although our equipment can work at higher altitudes, other science instruments needed to be flown low, over terrain so rugged that at times we came within a mere 30 meters of the ridges—near misses that our downward-looking radar measured for us while we peered out the window holding our breath.

Crisscrossing over this vast expanse of whiteness by air, you can easily forget that Greenland's huge endowment of ice is slowly disappearing. The eight-times-larger Antarctic ice sheet appears to be shrinking, too, particularly around the periphery. These two areas hold 99 percent of the land-based ice on Earth, and as it melts, the water that runs off flows into the oceans, adding to their rising level. Meanwhile, most mountain glaciers, which contain the remaining 1 percent of the ice perched on land, are also retreating, further compounding an increasingly urgent problem. If sea level goes up by a meter over the next several decades, as many scientists suspect will happen, it will disrupt the lives of countless people around the world.

PREVIOUS PAGES: ERIC RIGNOT/JPL/NASA

Will sea level really rise a meter? Or could it go even higher? And if so, how fast? Although the computer models of the ocean and atmosphere are good enough to gauge how much temperatures will likely climb over the next century, current ice-sheet models leave much room for improvement. In particular, they don't account for many of the factors that are causing ice sheets to thin and sea level to rise.

One of the main problems is that these models lack important details about what's going on where the ice meets the bedrock—whether the bottom of a particular locale is flat or sloping, whether there is liquid water lubricating the contact, that sort of thing. Those details in turn determine how quickly the ice will flow toward the sea.

The best way to get that information is by sending radio waves into the ice and examining the echoes. This can be done with downward-looking radar equipment that's either towed over the ice or flown in aircraft, like the P-3 that carried us over Greenland.

The idea of using airborne and surface-based radar equipment to investigate polar ice sheets isn't new. In fact, it's many decades old. But we're trying to bring such radars into the 21st century—a century that's desperately in need of the insights that better radar surveys of these great accumulations of ice can provide.

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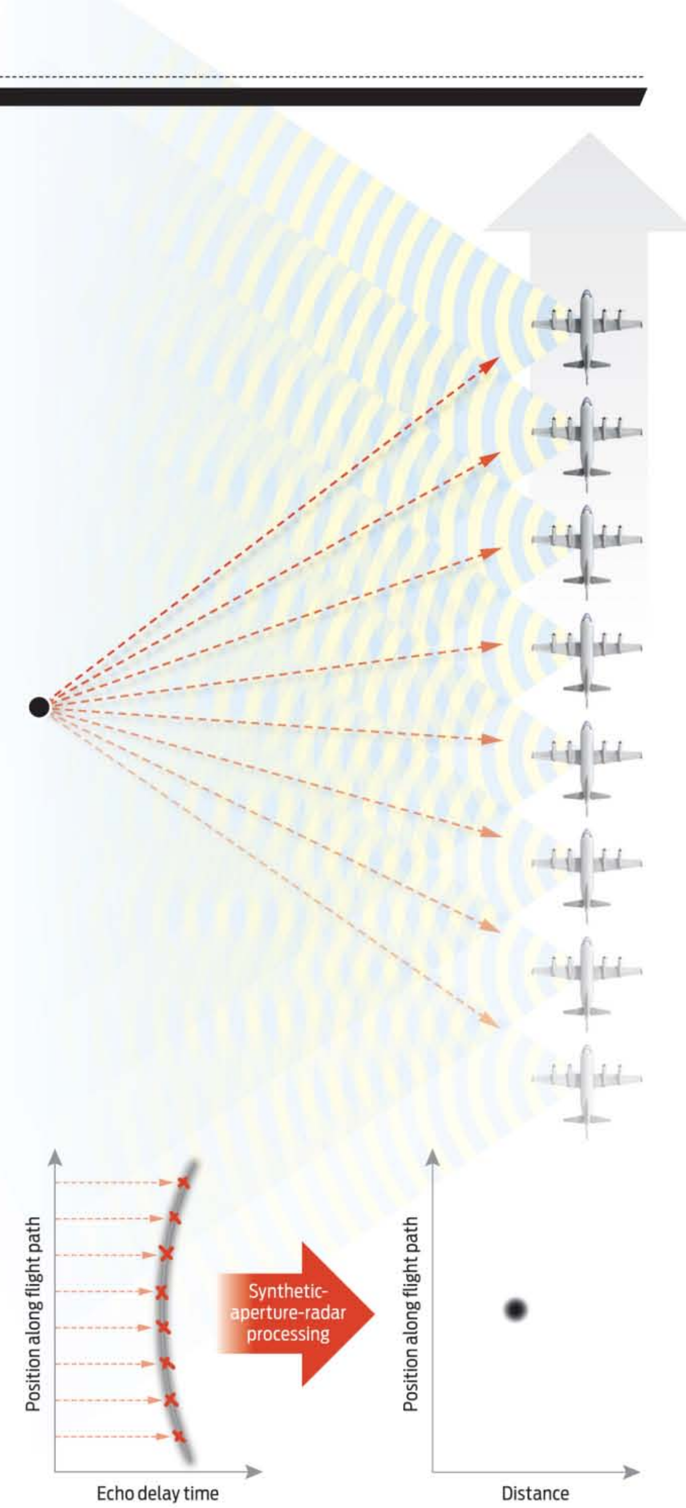
THE FIRST INKLING that radio might be useful for investigating ice sheets came during the 1930s, when the men working at the Little America base in Antarctica realized that snow and ice are transparent to radio waves. But it wasn't until the late 1950s, after pilots reported that their radar altimeters were useless over ice, that electronics technician Amory Waite Jr. and others figured out how to use radar altimeters to measure the thickness of polar ice.

Over the next few decades, researchers from Canada, Denmark, the Soviet Union, the United Kingdom, and the United States devised various surface-based and airborne radars for probing ice. This equipment not only allowed scientists to map the bedrock hidden far below the thick ice sheets of Greenland and Antarctica, it also revealed internal layering within the ice, which can arise from the presence of air bubbles, density changes, liquid water, and even ancient dustings of the former ice surface with volcanic ash.

But such radars suffer from a fundamental problem: They can't detect the direction from which the radar echoes emerge. Such systems assume that the radio waves travel vertically downward and their echoes come straight back up. Accordingly, the time delay between the emitted radar pulse and its echo is supposed to indicate the depth of whatever surface is causing the reflection, say, the rock on which the ice sits.

The radio waves aren't only transmitted straight down, however, because the antennas used for probing ice can't provide the needed directionality. For an antenna to be direc-



SYNTHETIC MAGIC

Consider a plane using radar to scan to one side, where a single reflective object is located [top]. When that object first comes within range, the radar echo's delay time is relatively large. It reaches a minimum when the plane is abreast of the object and increases thereafter. Plotting those raw results gives a hyperbolic curve [left]. Synthetic-aperture-radar processing collapses this hyperbola to a single point at the position of the reflective object [right]. *ILLUSTRATION: EMILY COOPER*

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tional, it has to be many times the size of the wavelength it transmits or receives. These ice radars typically operate at frequencies between a few tens and a few hundreds of megahertz, corresponding to wavelengths that range from about 1 to 10 meters. A few go as low as 1 megahertz (a wavelength of 300 meters). For any of these radars, you'd need an enormous antenna to obtain a narrow vertical beam. But toting around an antenna the size of a football field or larger just wouldn't work—the antennas must be much smaller to be practical. So these ice radars invariably receive some echoes coming in from odd angles, which tend to confuse the interpretation of the results. This difficulty is especially troublesome in places where the bedrock is very uneven or where the ice surface is especially rough.

Another shortcoming of the simple radio echo-sounding systems that continue to be widely used is that, even where the bedrock topography is obligingly gentle, these radars can tell you only what's directly below your feet. So to map out a large area, you'd need to make measurements over a lot of closely spaced tracks, as though you were mowing some huge white lawn. Otherwise, you couldn't be sure you weren't missing some significant feature located between adjacent passes of your equipment.

Our group at the University of Kansas's Center for Remote Sensing of Ice Sheets, in collaboration with others at the Byrd Polar Research Center at Ohio State University and the Center for Ice and Climate at the University of Copenhagen, has devised a way around these limitations: using signal-processing tricks from the world of synthetic-aperture radar, a common technique for mapping the surface of the Earth and other planets.

We aren't the first to apply synthetic-aperture radar to glacial ice. Researchers at other institutions tried this approach in the 1980s with limited success, and even members of our own team attempted to assemble a synthetic-aperture radar for ice studies in the 1990s. But the electronics and computing power available then weren't up to the job—one that turns out to be much harder than operating a synthetic-aperture radar over other sorts of terrain. To understand why that is, you need to know a little about how synthetic-aperture radar works.

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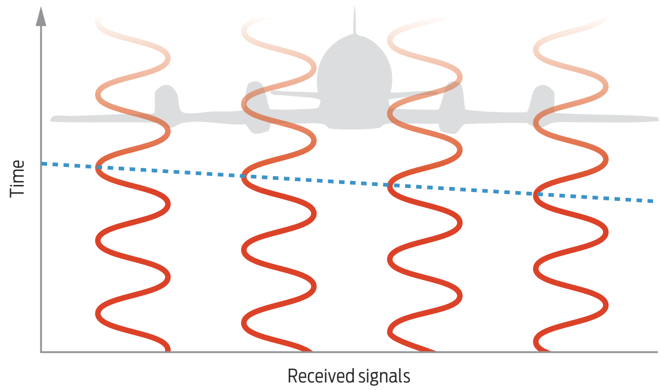
MOST SYNTHETIC-APERTURE radars are side-looking systems. The antenna could, for example, be pointed out the door of a plane, which would then fly to one side of the area on the ground that the operator wanted to scan. If the surface were perfectly smooth—say, an expanse of still water—the only radar return you'd get would be from directly below, where the radio waves hit straight on and bounce straight back. The radio waves striking the water's surface off to the side would just reflect away from the plane.

But the surface you're scanning is rarely perfectly flat. So you'll also receive radar echoes from objects located off to the side—buildings, mountains, whatever. Because the antenna is moving (and the stuff on the ground isn't), your results will match what you'd get if you'd made the measurements all at once with a very long antenna array. That is, the forward motion allows you to synthesize a long array, hence the name synthetic-aperture radar. To turn the many measurements into a well-formed image of the scene, however, you need to do some serious number crunching. The complexities of the required mathematical operations can be a little daunting, but the basic principles really aren't that difficult to understand.

Imagine you are surveying a patch of ground with a side-looking airborne radar, and there's just one object nearby that reflects radio waves—say, a metal flagpole. Imagine further that you're doing this in total darkness, so you can't see the pole. As your plane comes within radar range of the pole, you will start to receive reflected radio echoes from it. But the pole is still a long way ahead of you, so there will be a relatively long delay between the radar pulses sent out and the returned reflections. As the plane continues on, that delay will diminish, reaching a minimum when you come abreast of the pole. From there on out, the delay will increase.

Now, imagine that you're using a pencil and paper to plot those received signals as a function of the echoes'



A NEW ANGLE ON ICE RADAR

An array of radar antennas [opposite page, orange] can be used to map out a wide swath of glacial ice. If a reflective object isn't directly beneath the array, points of the same phase in the received signals [dotted line] will be shifted in time across the array. Such phase shifts can be used to determine the echoes' angle of arrival. *ILLUSTRATIONS: EMILY COOPER*

delay and position along your flight path, putting a mark wherever there is a radar return. At the start, the only echo you get from that lonely pole has a long delay, which gradually diminishes, reaches some minimum value, and then increases. So your sequence of plot marks will form a curved line (a hyperbola). If you then scan a few different flagpoles with radar, you'll quickly come to recognize the characteristic curved line that each one creates. So when you next see a line with that distinctive hyperbolic curvature on your hand-drawn radar plot, you'll say, "Oh, we must have passed another pole." You'll know that it was located directly to the side of your flight path at the point where the echo delay reached a minimum. Its distance from the flight path is also easy to work out from the delay time. Assuming you know where your plane flew, you can now pinpoint the position of the pole precisely.

The data processing that's done for synthetic-aperture radar collapses the radio echoes that give rise to those curved lines into distinct points on a map. This is, of course, impossibly difficult to do by hand when there are many hundreds or thousands of objects creating a hodgepodge of radar reflections all at once, but an appropriately programmed computer can handle the required computations easily enough.

Our ice-penetrating radar differs from conventional synthetic-aperture radar in a key respect: Those systems look mostly sideways, whereas ours looks mostly down. And looking down, it turns out, is considerably harder. The reason is easy to see if we go back to our thought experiment.

Suppose your plane is flying high above an ice sheet with a single flagpole planted in the snow along its flight path. The minimum echo delay will come when the plane is right above the pole. But the delay won't be all that much longer if the pole is located a little off to one side, because the distance between the plane and the pole won't be that different. From the curved line you draw, you'll still be able to figure out when the plane overflew the pole, but the sideways distance between the pole and the flight path will be impossible to determine precisely. The geometry of a down-looking radar makes that too tough to do using only the echo delay. That's why we had to adopt an entirely different method to give our ice radar good resolution in the sideways direction.

What we really needed to know, and what normal synthetic-aperture radar doesn't measure, is what direction the radio echoes were coming from. With that information, and with the usual measurements of the echo delay, we'd then be able to work out how far off to the side a reflective object is.

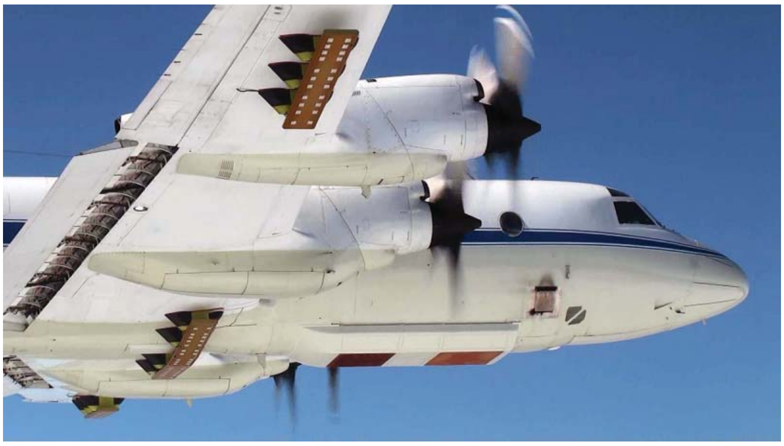
Fortunately, it's possible to get this directional determination: You just need to use several radar antennas arrayed along a line that's perpendicular to the path you're following. That way, echoes coming in from one flank at an angle arrive at the antennas on one side slightly before they hit those on the opposite side. And by adding the appropriate time lags to the signals from the different antennas, you can make the array sensitive to waves arriving from particular angles.

This is standard practice in many radar systems, ones that use what are called phased arrays. They allow you to scan the sky in different directions without having to physically rotate the antenna. The challenge for us was that, given the limited size of the arrays we could fit on a surface sled or under the wing of a plane, standard array-steering techniques couldn't provide as much angular resolution as we wanted.

To overcome that hurdle, we used a special signal-classification algorithm that was developed in the 1980s, which has proved very powerful for estimating the direction of arrival of various kinds of waves. We also needed to apply a correction that most people working with radar never have to worry about—for the bending of the radio waves as they pass through the ice. It took us a couple of years to work out the kinks in the hardware and the data processing, but eventually we had an impressive ground-based system assembled.

Our first opportunity to use that equipment came in 2005, at the U.S. National Science Foundation's Summit Greenland Observatory—also known as Summit Camp—in central Greenland. Two deep ice cores were drilled there in the 1990s (one by U.S. researchers, the other by Europeans) in an effort to obtain a detailed record of past changes in Earth's climate—a record that would go back more than 100 000 years. Ice cores can provide this history because they preserve various kinds of evidence of climate conditions during the ancient past, when the snow that formed the ice first fell.

One of the two cores drilled at Summit Camp showed particularly dramatic changes in composition in the 300 meters recovered from nearest the bedrock. Some climatologists interpreted that as evidence of ancient episodes of sud-



ARRAY OPTIONS: The multiple antennas required by the new system may be either mounted under an aircraft [top] or pulled on a sled by a tracked vehicle [bottom].

PHOTOS: TOP, RICK HALE/CRESIS; BOTTOM, CRESIS

den climate change. But the other deep ice core, drilled just 30 kilometers away, had no such pattern at its base.

One explanation offered at the time was that the gradual flow of ice over uneven bedrock had caused the folding of internal layers, confusing the climate record. But for many years it was hard to know for certain whether this was the case. With our new radar, however, we were able to survey a swath of ice a few kilometers wide in a single pass, so it was relatively easy to map out the bedrock in a large area around the sites where the two ice cores were drilled. Our results showed definitively that the bedrock there is indeed quite rugged, with a deep channel adjacent to the site of the coring that suggested those ancient episodes of sudden climate change. Had the original researchers known that the bedrock there was so irregular, they would no doubt have drilled somewhere else.

• • •

THE RADAR EQUIPMENT we've constructed for seeing through ice is helping to tackle another major challenge in radio glaciology: sounding and imaging the margins of ice sheets. Those margins are difficult to survey because they have relatively warm ice near the bottom and lots of deep cracks on top. Also, some of the surface ice melts during the summer. The warm ice and liquid water attenuate radio waves, severely weakening the radar returns from the ice bed. Worse, the subtle radar echoes from the bed are often masked by strong waves bouncing back at odd angles from the rough spots on the surface. This isn't usually a problem when surveying the cold interior of an ice sheet, because the surface of the ice is so smooth it acts like a mirror, reflecting radio waves away from the radar equipment.

These effects explain why prior radar surveys of many of the fast-flowing glaciers at the margins of Greenland's ice sheet were unsuccessful. But our synthetic-aperture ice radar's ability to discriminate the incoming direction of the echoes allowed it to do much better. In 2006 we were able to map for the first time the bedrock at a particularly challenging locale, the roughly 3-km-thick Jakobshavn glacier. This glacier flows down to the sea on the west coast, where it produces about 10 percent of the icebergs coming from Greenland and drains about 7 percent of the Greenland ice sheet. For reasons that aren't entirely clear, this giant glacier sped up considerably, starting in the late 1990s. Just before then it was moving about 7 km per year, whereas currently it's flowing at almost twice that rate. We are now well positioned to examine other fast-moving glaciers, which should help improve computer models of the dynamic processes that take place in these rapidly evolving masses of ice.

Such computer models are becoming increasingly important. For years now, scientists have been observing worrisome changes in the polar ice sheets. Will they stabilize, or will future transformations dwarf those already seen? Answering that question requires good models, which in turn demand detailed measurements of these ice sheets. And, right now at least, there is no better way to do that than using the advanced radar system we've developed. We just wish NASA's P-3 pilots would fly a little higher. ❏

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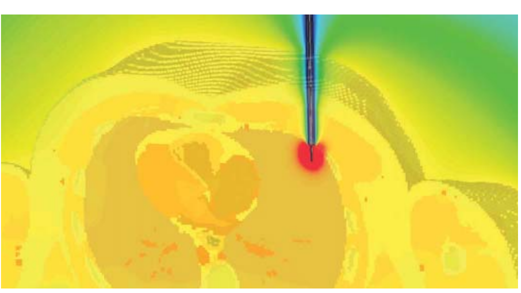

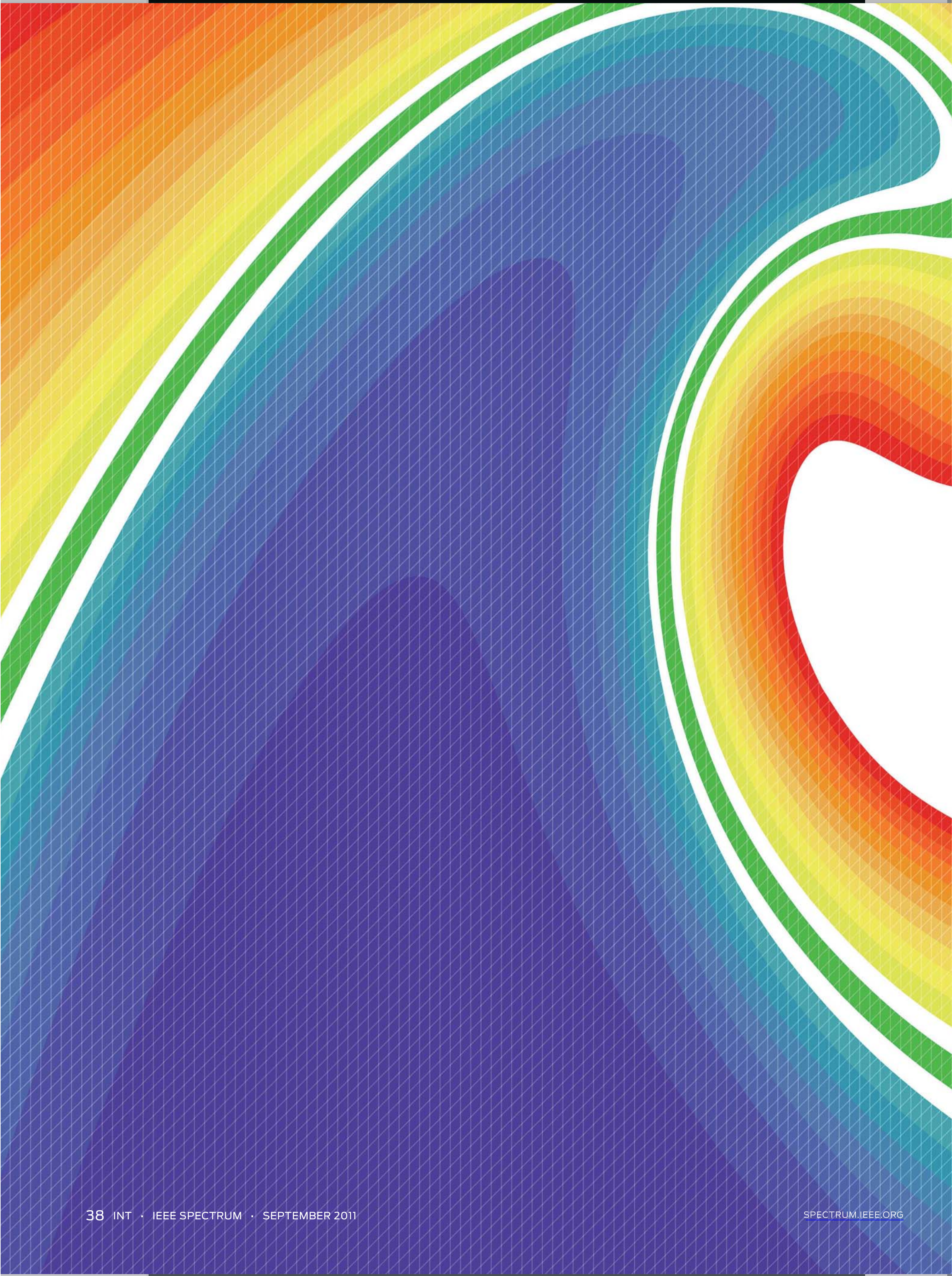

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THE TERAHERTZ FRONTIER

Bringing new devices to a long-ignored electromagnetic band

IF WE CREDIT THE INTEGRATED CIRCUIT with one thing, it should be the taming of the electromagnetic spectrum. If you want to create or capture visible photons, there are plenty of compact devices to choose from, incorporating everything from miniature photodiodes and lasers to LEDs and slim charge-coupled devices. And if you want to pick up or send a radio signal, there are a staggering number of receivers, transmitters, and antennas to suit your needs.

¶ But the IC hasn't conquered every bit of the spectrum, and one region stands out: the terahertz frontier, a range that extends from the highest frequency radio waves to the lowest frequency infrared light. Over the decades, engineers have made many attempts to create compact, solid-state devices that can harness it, but terahertz radiation has proven particularly tricky to use.

BY MICHAEL C. WANKE & MARK LEE

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WHY DOES IT MATTER? For one thing, terahertz radiation has a lot of promise for noninvasive imaging in industry, medicine, and security. Unlike X-rays, terahertz waves are too low in energy to knock electrons off atoms, which could damage living tissue. And because of their shorter wavelength, they can produce pictures that are far sharper than those made with microwaves, the current safe imaging alternative.

Terahertz waves also occupy a unique window of the electromagnetic spectrum where a large number of molecules emit and absorb radiation. The signals produced when a molecule jumps among rotational modes form a unique and highly distinctive chemical fingerprint. If we can devise compact, easy-to-manufacture terahertz spectrometers that can detect these fingerprints, we could, for example, use them to identify the constituents in a patient's breath or flag a potentially dangerous substance.

For a long time, these sorts of applications were out of reach. Until recently the only sources capable of creating significant power in the terahertz range have been custom-built, temperamental affairs that take up entire optical tables, are difficult to transport and calibrate, and can cost hundreds of thousands of dollars.

But recent research has shown that miniature sources can be just as powerful. And we've used these sources to make the first integrated devices that can simultaneously emit and detect terahertz radiation. These devices are proof that terahertz signals can be handled in a small, portable, mass-producible package. For the first time, we can begin to imagine a bright future for terahertz technology, one full of innovation.

THE INTEGRATED CIRCUIT MAY BE MORE than 50 years old, but constructing one that can operate at terahertz frequencies isn't trivial. It might not be immediately apparent why that's the case. After all, electromagnetic radiation, whether it's migrating through a transistor channel or emanating from a distant quasar, comes down to a single process: the propagation of electric and magnetic fields.

But materials aren't insensitive to frequency—even a factor-of-10 increase can have a big impact on device performance. As a result, over the years integrated circuit devices have essentially bifurcated. Low-frequency waves are the domain of solid-state electronics, where semiconductor transistors govern everything from wall currents oscillating at a lazy 60 hertz to radar and satellite communications that extend up to about a hundred gigahertz. Jumping up a factor of 1000 in frequency beyond the radio realm requires solid-state photonics, where semiconductor-based LEDs, lasers, and waveguides are used to create and manipulate near-infrared, visible, and ultraviolet light.

These two areas—the worlds of electronics and photonics—have given rise to a seemingly infinite array of products that have woven themselves into the fabric of modern life. But the terahertz realm, which spans the in-between range from a few hundred gigahertz to about 30 terahertz, hasn't proven so easy to exploit.

To make something as simple as a terahertz transceiver, a device that's capable of both emitting and detecting terahertz radiation, you might think that a few adjustments to a conventional electronic or photonic trans-

PREVIOUS PAGES: SIMON C. PAGE

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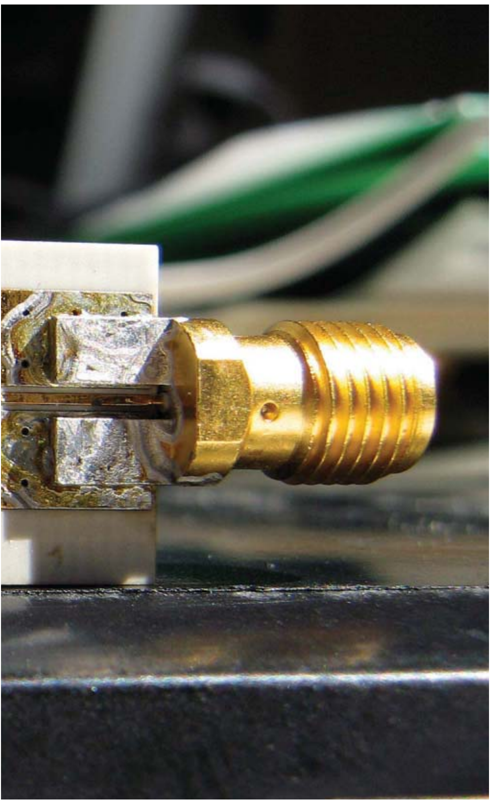
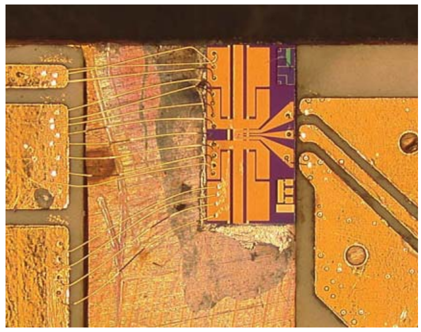
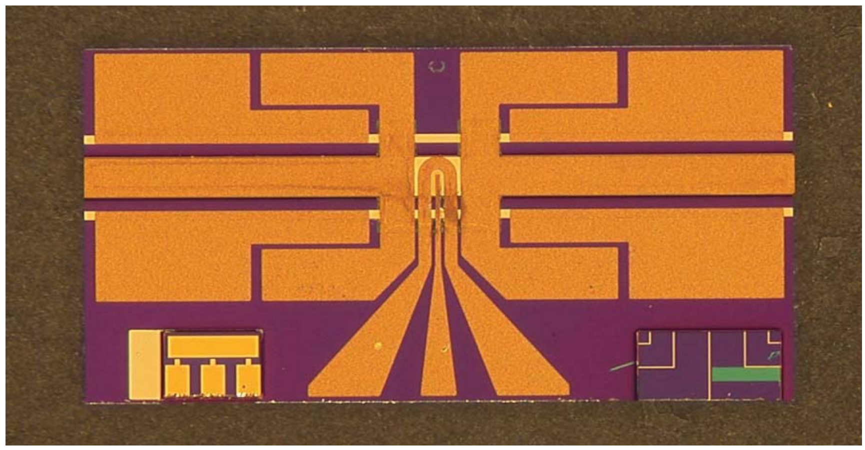
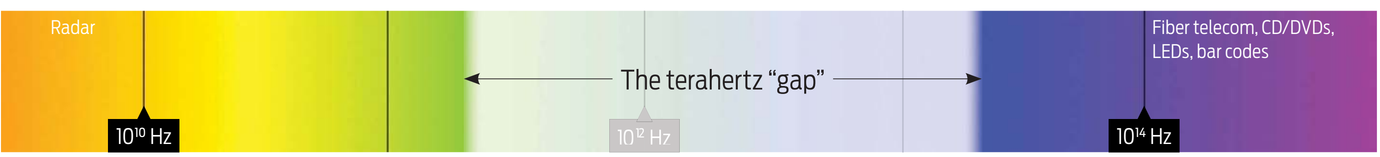




MICROWAVE OUT

The terahertz transceiver [below] uses a horizontal laser to pump the diode at its center. Waveguides [left] carry the transceiver's signals, which are at microwave frequencies, off the chip. The entire device [opposite page] is mounted on a copper plate so it can be cooled. A coaxial connector carries signals off the chip.





PHOTOS: SANDIA NATIONAL LABORATORIES

ceiver would do. But neither technology is really suitable for the task.

For example, if you try to adjust a radio transceiver so that it operates at terahertz frequencies, you'll quickly encounter fundamental physical limitations. The rapidly flipping voltage of a high-frequency alternating current can have strong electromagnetic effects on the transistors in a transceiver, giving rise to parasitic resistances and capacitances that take power away from the devices. More fundamentally, there is a speed limit on how fast electrons can move. Beyond a few tenths of a terahertz, the frequency of oscillations becomes so high that an electron can't cross a transistor channel from the source to the drain before the voltage flips its polarity, forcing the electron to reverse direction and causing transistor power to drop precipitously.

Approaching the terahertz frontier from the photonic end is no picnic either. To produce light from an LED or a semiconducting laser, you need a way to excite electrons so that they can then relax back to a particular lower energy state and emit photons. This mechanism is used to make visible and infrared light. Producing lower-frequency radiation in the terahertz range should be even easier. You need only supply electrons with a tiny energy kick, just 0.004 electron volt, less than 1 percent of what's needed to create visible light.

But it turns out there are a number of problems with this approach. For one, there's a dearth of practical materials with such a small bandgap. Another problem is that the small energy jump is, in fact, too small: The average room-temperature electron gets thermal kicks from its environment that are easily six times as big as the terahertz gap. These thermal kicks let electrons jump easily from one energy level to another, and they make it very difficult to corral enough electrons into the energy state needed to make usable light. The thermal energy problem lessens if you lower the temperature, but it doesn't go away. Even when an LED is cooled, you'll find that the device's power drops rapidly when the frequency is lowered beyond a few tens of terahertz.

CLEARLY, CREATING A TRANSCEIVER THAT can operate at terahertz frequencies requires a different approach. And in 2005, at Sandia National Laboratories in Albuquerque, we set about figuring out what that approach might be. Our aim was to create the terahertz analogue of an almost ubiquitous radio device: the heterodyne transceiver. The device needs two ingredients to operate: a local, stable source of electromagnetic waves with a well-defined frequency, and a mixing device that can combine incoming radiation with the light produced by this local source. The mixer in a heterodyne transceiver creates a new signal with a frequency equal to the difference in frequency between the two radiation sources. This property is ideal for terahertz detection: Heterodyne devices produce output signals with microwave frequencies, which, unlike terahertz radiation, can be handled easily by existing high-performance signal-processing electronics.

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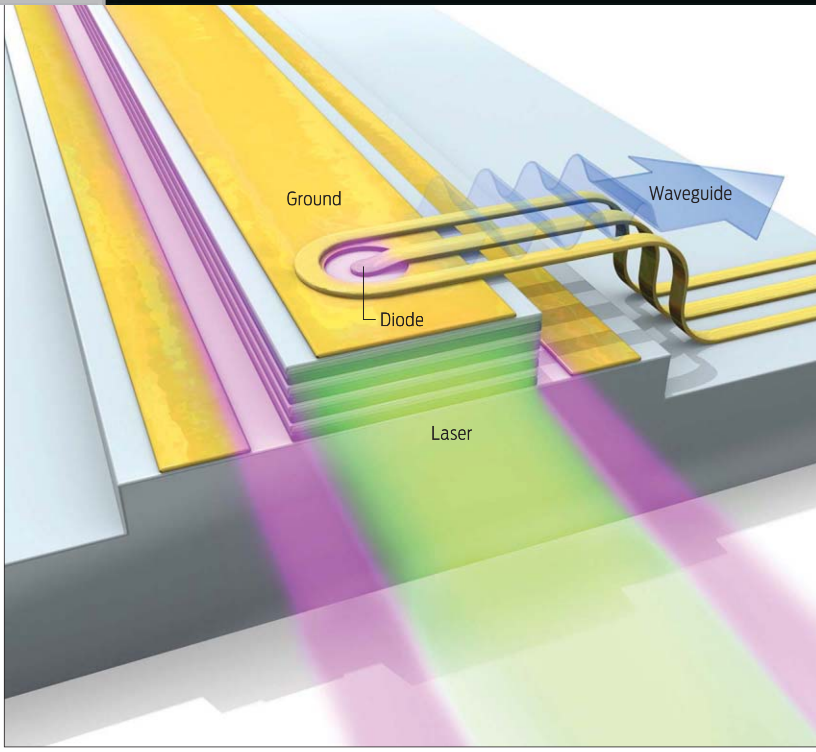

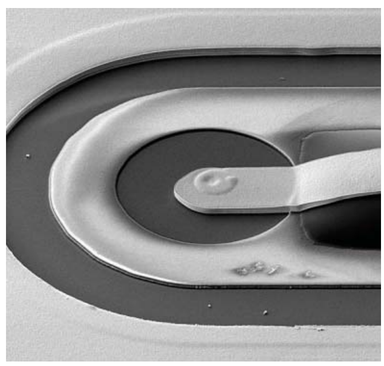

DIRECT CONNECTION

Part of the transceiver's diode, which acts as a terahertz detector, is built into a hole in the top layer of a quantum cascade laser. The terahertz radiation inside the laser is used to pump the diode directly, eliminating the need for mirrors and lenses.

ILLUSTRATION: EMILY COOPER; IMAGE: SANDIA NATIONAL LABORATORIES

Convenient compact mixers that operate in the terahertz range have been around for many years in the form of Schottky diodes, simple devices made of metal and semiconducting material. These diodes have performed admirably as radio telescope detectors as well as in balloon-borne and satellite monitors of Earth's upper atmosphere.

But practical terahertz sources capable of powering these diode mixers have lagged behind. For decades, creating radiation above 1 THz involved zapping a tube of gas or vacuum with a laser or a beam of electrons. These sources have big footprints, and the light they produce must run a gantlet of carefully aligned mirrors and lenses. Portability is a difficult and expensive option.

Fortunately, an alternative terahertz source, one that can be mass-produced and requires just a few millimeters of real estate on a chip, is beginning to reach maturity. The technology got its start in the early 1990s, when two Bell Laboratories physicists, Federico Capasso and Jérôme Faist, found a way to circumvent the natural limitations of semiconductor materials. They discovered that they could create a powerful and tunable source of infrared radiation by alternating layers of semiconducting materials with large and small bandgap energies. Electrons are confined to the small bandgap layers, and when a voltage is applied, they can be encouraged to drop in energy and release a photon. As an electron tunnels through the many-layered device, it can make hundreds of identical energy-drop transitions, creating a cascade that generates additional light with each drop. The team called its device a quantum cascade laser (QCL).

The original QCLs were not true terahertz devices; they operated at mid-infrared frequencies, from 30 to 80 THz. But in 2002, a team of researchers at the University of Pisa and the University of Cambridge unveiled a QCL that worked well down to 4.4 THz. This new device was capable of generating milliwatts of power, putting it close to the power output of the awkward tabletop sources.

The new QCL was a tour de force in precision engineering. The device boasted electron energy levels that were separated by one-tenth the energy of those in previous lasers. Constructing those levels required nearly atom-level control over semiconductor layer thicknesses—and the ability to maintain this control while growing many hundreds of layers in a process that could last more than 20 hours.

WITH THE ADVENT OF THIS COMPACT terahertz source, we now had both of the ingredients we needed to construct miniature terahertz transceivers. But when we began working on such devices in 2005, we soon realized that the most obvious design—laying out a QCL and a Schottky diode mixer side by side on a chip—was not only inelegant but also fraught with problems.

A key issue was funneling the radiation from a QCL into the diode mixer. QCLs emit terahertz radiation over rather wide angles—30 degrees or more, depending on the type of waveguide that's used. Only a small fraction of this light can be beamed into a diode.

So instead of setting up the QCL and the Schottky diode in separate areas on the chip, we tried stacking them. Both the top electrical contact layer of a QCL and the cathode of a high-frequency Schottky diode are made of the same material: a heavily doped layer of the semiconductor gallium arsenide (GaAs). In principle, the two devices could share a common monolithic GaAs layer, sort of like conjoined twins.

Integrating the two devices let us deliver power from the local source to the mixer without any mirrors, lenses, or waveguides. The strategy—which effectively immersed the diode in the QCL's internal radiation—also allowed us to take advantage of a little-used property of lasers. Most of the light produced is reflected back into the interior, so the radiation inside a laser cavity is significantly stronger than what emerges. For QCLs, the interior power is up to 20 times as high as the output. Merging the diode with the QCL let us access this intense internal field. Then the entire output power of the QCL could be dedicated to transmitting terahertz radiation.

To combine the devices, we needed to create an opening in the top of the QCL for the diode's anode. Early on, we worried that the hole would disrupt the lasing process. Happily, by making the opening as small as possible, we were able to minimize any effects on the device.

But creating this monolithic design came with other hurdles. Although the QCL and the Schottky diode each use a layer of GaAs, the devices have quite different doping requirements. In the end, we devised a double layer containing two different doped regions, but some performance concessions were unavoidable.

Proving we had a working transceiver required three basic tests. The first was to show that the QCL coupled to the diode. For that, we designed our QCL to emit radiation at multiple, equally spaced frequencies centered around 2.8 THz and separated by 13 gigahertz. When we read off the output signal from the diode, we found a signal of 13 GHz, showing that the diode was directly coupling to the internal electromagnetic field in the QCL.

To prove the device could detect outside signals, we then shone 2.841143-THz light from a standard tabletop molecular gas laser onto the transceiver. Measuring the voltage changes on the diode's anode, we found several signals, all with frequencies that matched the difference between the frequency of this external light and the modes of the QCL.

Finally, to justify calling the device a true transceiver we needed to show that the device could simultaneously send out terahertz light and detect what came back. We did this by placing a mirror on the vibrating surface of a stereo speaker. When light from the QCL bounced off this moving mirror, its frequency shifted. We found that the frequency difference between the QCL's light and the reflected light immediately appeared in the output signal from the diode.

All told, our first working circuit—including the circuit board with the necessary electrical connectors but excluding the cryostat needed to cool the QCL—measured 2 square centimeters and weighed 14 grams. It's not the smallest integrated circuit, but it is a far cry from tube-based systems, which can easily occupy a square meter of space and weigh dozens of kilograms.

BUT THERE ARE STILL A FEW PRACTICAL problems that will have to be overcome before these transceivers can be fabricated in bulk and placed in imagers and detectors. One key limitation is that terahertz QCLs need to be cooled to cryogenic temperatures to generate significant amounts of power. But the QCL community has greatly improved the cooling requirements. While the first devices needed to be chilled to within a few degrees of absolute zero, in the last few years basic terahertz QCLs developed at MIT and Sandia have run at 186 kelvins. That is still quite cold—almost 100 °C colder than the freezing point of water—but it is getting close to the point where thermoelectric coolers can be used to refrigerate the devices. And we expect operating temperatures to continue to improve.

Another hurdle is sensitivity. State-of-the-art tabletop detectors are a few thousand times as sensitive as these first integrated terahertz transceivers. But we haven't yet tried to optimize the performance of these proof-of-concept devices, and we expect there are ways to improve their sensitivity. Adding an antenna to a diode, for example, could help boost the strength of incoming signals. Embedding the diode more deeply in the top of the QCL could also improve sensitivity by delivering higher power to the device, which should make it easier to mix the QCL's light with external signals.

Of course, terahertz detectors will have their limits. The same property that makes terahertz radiation ideal for chemical identification also makes it difficult to detect, even across fairly short distances. Many molecules, including water vapor, readily absorb the light. Even the most sensitive terahertz detector likely won't be able to pick up low-altitude terahertz waves that originate more than a few hundred meters away.

So are integrated circuits based on QCLs the path toward filling in the terahertz technology gap? As with any field of active research, there is no general agreement on the best way forward.

QCLs have now been shown to emit light down to frequencies of 1.2 THz. And QCL output is now on a par with the power of traditional tube sources. The miniature lasers have even been shown to be effective sources for imaging devices, producing video-quality scans at rates of up to 30 frames per second.

Even so, researchers are aggressively pursuing other ways of producing and detecting terahertz radiation. Like QCLs, these alternative sources also employ techniques that go well beyond straightforward extrapolations of transistor or LED technologies. Some groups are using infrared lasers to trigger devices that can generate picosecond-long pulses that emit a broad range of terahertz radiation. Others are experimenting with more exotic technologies, including superconducting circuits and ways to convert the infrared light emitted by diode lasers down to terahertz frequencies.

In the future, these techniques could have advantages over the QCL-based approach. Because it emits light at a single well-defined frequency, a QCL-based heterodyne transceiver will work best when you know the specific frequency you're hoping to detect. It won't be well suited for broad-spectrum applications, such as identifying an unknown material, where the peaks and troughs in its spectrum will be at unknown frequencies. Other techniques offer very broad frequency coverage, although they do so at the expense of power and brightness. In the end, we may see multiple technologies settle the terahertz frontier. ❏

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The Picturephone Is Here. Really.

THANKS TO THE POWER AND CONNECTIVITY OF TODAY'S MOBILE DEVICES, COMPUTERS, AND TELEVISIONS, VIDEO TELEPHONY WILL SOON BE EVERYWHERE

By Thomas Wiegand & Gary J. Sullivan

In the annals of technologies with long gestation periods, few can match video telephony. *Punch's Almanack* published a cartoon illustrating the concept way back in 1878. Then, throughout the next century, the idea resurfaced repeatedly in science-fiction comics, motion pictures, pulp stories, and novels. In the animated TV series "The Jetsons," starting in 1962, George's boss, Mr. Spacely, regularly appeared on a display screen to show George the latest sprocket design. In a memorable scene from the 1968 movie *2001: A Space Odyssey*, a weary space traveler videophones his daughter from a space station orbiting Earth.

Around the same time, videophones began showing up in the real world. AT&T announced its Picturephone service in 1964; the company even installed a Picturephone booth at New York City's Grand Central Terminal. But at US $16 per 3 minutes of jerky images, the service never caught on.

Nevertheless, as with flying cars and jet packs, there is something about video telephony that people just can't let go of. And unlike flying cars and jet packs, a videophone is something you almost certainly have access to already, in the form of your computer, your smartphone, and almost every gizmo that communicates. The biggest computer firms have embraced the trend: Microsoft is now buying Skype for $8.5 billion to further strengthen the video telephony capabilities already built into Windows, Office Live Meeting, and a number of other products. Apple's got FaceTime, and Google has begun rolling out multiuser video chat in its emerging Google+ social network.

With the exception of road warriors checking in with their kids at home, however, for most of us video telephony still isn't a part of our daily lives. But allow us to go out on a limb: It will be, and within just a couple of years.

The rap on video telephony is that people just didn't want it in their homes. They didn't want people seeing them bleary eyed and mussed in the morning (or any other time, for that matter). Nor did they want their callers seeing that they were flipping through mail or making a grocery list while chatting on the phone.

So equipment manufacturers turned to the corporate world, introducing pricey videoconferencing systems designed to replace on-site meetings and reduce travel costs. While many companies invested in the technology in the 1990s, it typically gathered dust, unused. It looked as though people didn't want it anywhere.

Call us eternal optimists, but we believe that this conventional wisdom is wrong. For one thing, the vast majority of personal telephone calls occur between spouses or close relations: parents and children, siblings, and so on. These people have already seen each other bleary eyed and mussed (and would probably overlook a little grocery-list making or other multitasking). We think the main reason people haven't embraced video telephony is that it has been clunky, owing to

PHOTOS: DAN SAELINGER; STYLIST: WENDY SCHELAH/HALLEY RESOURCES

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technical obstacles that prevented it from being done well. But most of all, videophone equipment was considered too expensive for most people for their private use.

One by one, those obstacles—hardware, networking, compression—have fallen away. And the final roadblock—standardization and interoperability—is teetering.

Let's start with hardware. Video telephony isn't all that complicated. It needs four basic things: a microphone and a camera to capture sounds and images, and a loudspeaker and a monitor screen to re-create them.

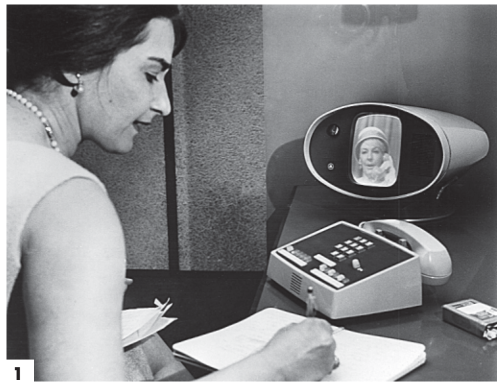
The call, of course, also needs a network to connect across. And there's one more basic requirement: a system to compress the data. The signals captured by the microphones and cameras contain more information than can be sent across the available communications networks, wired or wireless—and more than is necessary for an adequate video call. So the final piece of the videophone tech puzzle is a means for compression. On the sending end, a microprocessor and its software act as an encoder, compressing the signal—that is, reducing the number of bits that represent the video and audio data so they can be sent in real time over the available connection, be it wired or wireless. Of course, what gets encoded on one end must be decoded on the other; on the receiving end the microprocessor reassembles the audio and video from the bits. The compression system eliminates a vast amount of data, because today's communications networks, even broadband ones, don't have nearly enough throughput to send all the data created by the cameras and microphones.

For example, one form of high-definition video has a resolution of 1280 by 720 pixels at a rate of 60 frames per second; uncompressed, that flows at about 660 megabits per second. Even if the resolution and frame rate were each cut by half, reducing the data flow to 165 Mb/s, that speed is still way beyond the capabilities of today's typical broadband networks, which operate at a tenth of that rate at best. So compression is essential. The algorithms used to encode the signals typically reduce the data by a factor of 250 to 1000.

Years ago, hardware that could run the compression algorithms fast enough to encode and decode good-quality video and audio signals in real time cost a lot. And in those days, the algorithms themselves weren't very efficient, imposing an even higher burden on the processors. To make it work at all required dedicated digital-signal-processing hardware. The costs of that hardware and the need for high-speed network connections relegated video telephony to corporate conference rooms through the 1990s. There, groups of people could share a video camera and a screen connected to a similarly equipped remote conference room over expensive connections. And even so, the systems could send images with only limited resolution, about a quarter that of a standard-definition television picture, which itself is less than half the resolution of a high-definition television picture.

The cost and quality problems got even worse if the meeting called for participants at more than two locations to join. Then an expensive multipoint control unit (MCU) entered the mix, first to convert the variety of encoded data into a single package, and then to convert that package into all the formats needed for each participant's receiving hardware. This transcoding at the MCU not only degraded the image quality of the video but also created lags in the video stream, making communication unnatural and awkward.

Video Telephony Through the Ages



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1 In 1965, the Bell System heavily promoted its new Picturephone service; this photo was published in the *New York Post*. **2** In the 1990s, business users were the target market for video telephony. Here, Intel marketing manager Jeff Abbate demonstrates a videophone at the company's Hillsboro, Ore., campus in 1997. **3** When Skype introduced a free and easy-to-use form of computer-to-computer video communications, it found a host of uses outside the business environment. Here, a user in Hong Kong takes a Mandarin lesson from a teacher on Hainan Island. **4** Today, Apple promotes FaceTime as a way to make an emotional connection with friends and family. **5** In 1991, users of business videoconferencing systems, like the US $40 000 PictureTel Model 200 shown here, had to gather around the conferencing hardware to communicate. **6** Robotic telepresence systems like the VGo let the remote user navigate outside the conference room.

CLOCKWISE FROM TOP RIGHT: DAVID PAUL MORRIS/BLOOMBERG/GETTY IMAGES; RICHARD A. BROOKS/AFP/GETTY IMAGES; JOHN GRESS/AP PHOTO; ABC PHOTO ARCHIVES/GETTY IMAGES

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TOP: RICHARD HOWARD/TIME LIFE PICTURES/GETTY IMAGES; BOTTOM: VGO

The technology got a lot better, and a lot cheaper, around the turn of the millennium. Cellphones and laptops became enormously popular, with screens and cameras and vast processing power built into every unit. And when that occurred, video telephony became simply a software problem. Around the same time, Internet-style, packet-switched communications continued to replace traditional circuit-switched networks on the telephone system; this simplified the compression problem, because packet-switched networks typically make more throughput available to the average user, enough to pass along video images of at least a tolerable quality.

The rise of the portables flooded the market with relatively cheap flat-panel displays and cameras, lower-cost microphones, and chips fast enough to process audio and video. Today's smartphones, for example, have screen resolutions about as high as yesterday's standard-definition televisions.

Compression technology has also improved significantly in recent years. The main players here—the Visual Coding Experts Group (VCEG) of the International Telecommunication Union and the Moving Picture Experts Group (MPEG) of the International Organization for Standardization—cooperatively brought out a new compression standard under the name H.264/MPEG-4 Advanced Video Coding (AVC) to supplant the H.263, MPEG-4 Part 2, and MPEG-2 video-compression standards of the 1990s. (The alphabet soup of acronyms comes from the fact that there are two different standards organizations involved and that the video standards are subsets of larger sets of audio and video standards.)

The new standard reduced the bit rate for the same video quality to at least half that of its predecessors. For example, it takes HD video with a resolution of 1280 by 720 from a raw data rate of 660 Mb/s down to 2 Mb/s or less. That means clearer, smoother video images, video calls across standard Internet connections, and the ability to connect with multiple people simultaneously. Already, about a billion devices, including iPods, mobile phones, and other consumer devices, use the new standard to display broadcast TV, Blu-ray movies, Windows Media or QuickTime files, and YouTube videos.

Problem solved? Not quite. H.264/MPEG-4 AVC, even though it was originally intended for video telephony as well as for consumer devices, isn't quite good enough. Problem No. 1: It is simply a video-encoding format. It does not cover any of the other aspects of telephony, such as audio coding and all the protocols that define, for example, how the system tells the receiving equipment that it's getting a video call. Those protocols involve a vast array of different specifications.

Problem No. 2: Even in the area of video coding, this format is limited. For example, if even one or a few packets are dropped during a transmission—pretty common in today's networks—the result may be catastrophic. The image the user sees is completely garbled. It might look something like a wet painting that has been wiped by a hand. Or if software masks the smearing, the video instead freezes in not just one but multiple frames. These distortions can last a half second or more, and a half second seems quite long to a viewer.

Removing redundancies from video images is good for compression but bad for robustness. To understand the problem, consider Short Message Service texting: People use abbreviations and other conventions to remove superfluous characters. However, even one or two typos in one of these cryptic SMSs can alter its meaning or render the entire message incomprehensible. The upshot is that encoding and decoding technology needs to be more forgiving when data drops out of the transmission.

Problem No. 3: lack of interoperability. Skype, for example, uses a proprietary video-compression system; it was already out in beta when the earliest draft of the new standard was published. Apple, Google, and Microsoft all start with one established coding scheme or another—Apple's FaceTime uses H.264/MPEG-4 AVC, Google+ uses another alteration called scalable video coding (more on that later), and some Microsoft products are currently based on a third standard called VC-1—and then add their own nonstandard technologies for the system negotiation and transport protocols. Today, these systems can't talk to each other, although you can get a Skype app that runs on the iPhone. So at least for now, if you have any hopes of using video telephony regularly, you'll have to plan your calls carefully. If you're using an iPhone, you'll likely use FaceTime to call other iPhone users. But if you want to make a video call to an Android user, you'd likely text the person and suggest your friend open up a Skype app, switch yourself from FaceTime to Skype, and then make the call.

Your phone will not figure all this out automatically. But help is on its way. The companies that manufacture communications gear are trying to hash out their differences under the auspices of a burgeoning alliance called the Unified Communications Interoperability Forum, which was founded by HP, LifeSize, Microsoft, and Polycom. Their plan is to work with standards organizations, companies, and government regulators until the currently disparate technologies evolve into products that can seamlessly communicate.

Along with better interoperability, making video calls as common as text messages will require something else: the ability to talk to at least a small group of people at the same time. People take this for granted in the voice realm—consider the success of three-way calling and conference-calling services. To date, though, having more than two people participate in one video call strains existing video-telephony systems, creating unacceptable delays. Mixing people communicating using high quality Ethernet connections in an office, say, with participants using a hotel's strained wireless network means that everyone on the call must suffer the low resolution or jerkiness of the hotel user's connection; the lowest common denominator typically prevails. The same thing happens when some participants are using devices that are "smarter" than other devices in the same call: a high-powered laptop versus a low-end phone, for example.

So one item on the wish list is the ability to see different callers in a group at different resolutions, rather than just at the worst one. Another is more flexibility in these multiperson calls—the ability to make the video image of one participant larger on your screen than others, for example, without requiring each device to open up a separate connection to every other device, which dramatically multiplies the demands on throughput and processing.

POST YOUR COMMENTS *online at* http://spectrum.ieee.org/videophone0911

Toward that end, VCEG, MPEG, and the Unified Communications Interoperability Forum have been working on the interoperability issue. VCEG and MPEG have jointly developed a new standard technology, scalable video coding, or SVC, publishing it in November 2007. The SVC design is an extension of the H.264/MPEG-4 AVC standard, not an entirely new scheme, so it is relatively easy for people who use the base standard to enhance their products to also support SVC.

SVC specifies what a bit stream has to look like to be read by all devices following the standard, and how the decoder of those devices translates that bit stream into images. The SVC technology gives the devices that use it all sorts of options in terms of video quality, including different resolutions and frame rates, by allocating one section of the bit stream to the lowest-quality options—sort of like a short text message summarizing a longer message. Devices having minimal processing power or communicating over low bandwidth can grab this small set of bits and ignore the rest. More sophisticated devices with faster network connections can also pay attention to bits that enhance quality, using these to display smoother, higher-resolution images. As in the text message analogy, the bits are adding details to the basic information that's in the short text message; however, the recipient can get the gist of the message without those details.

There is a small price to pay for breaking up the video signal in this way. Were the system to select a level of video quality and encode it separately, it might use about 10 percent fewer bits than it takes to use SVC—that is, including all the possible levels of video quality in the transmission and letting the receiving hardware do the selection. However, the 10 percent overhead is worth it, because SVC can make multiple video quality options available at once. This enables true device interoperability—people at big-screen computers using blazingly fast connections can participate in a video call involving someone using a smartphone in a hotel room without giving up the large HD images of the rest of the callers.

With SVC, users can also selectively size the video images on their receiving devices, choosing to see coworkers as smaller images and saving bandwidth to make the boss bigger and clearer—or the other way around.

The SVC approach also makes it easier to guard against those transmission errors that cause the annoying video glitches, because it doesn't take a lot of extra data to protect the small subset of data that encodes the lowest-quality images. Using the SMS example, the system could easily make sure that the SMS summarizing the larger text arrives error free, by transmitting another copy of the original summary or by supplementing it with a mathematical check of its accuracy. This would be harder to do for the larger message. In video telephony, protecting the "summary" means that receivers will almost always be able to display at least this most basic video image, no matter how bad the Internet connection; instead of smears and freezes, network glitches will only mean the image resolution will drop briefly, a far less vexing effect.

Companies that make corporate videoconferencing equipment have quickly embraced SVC. Vidyo pioneered some of the first SVC-based systems before it was fully clear to many in the industry that SVC could be especially useful in this application; that company and its partners, including Google, Hitachi, Ricoh, and others, have since adopted SVC technology in a number of products. Vidyo's implementation of SVC is also behind Hangouts, the multipoint video-chat system in Google+. Other companies, including Microsoft, Polycom, and Radvision, have also introduced videoconferencing systems based on SVC or announced plans to do so.

If companies that make consumer devices follow these business-equipment manufacturers, soon every device will indeed be able to talk to every other device. That could possibly happen in two or three years.

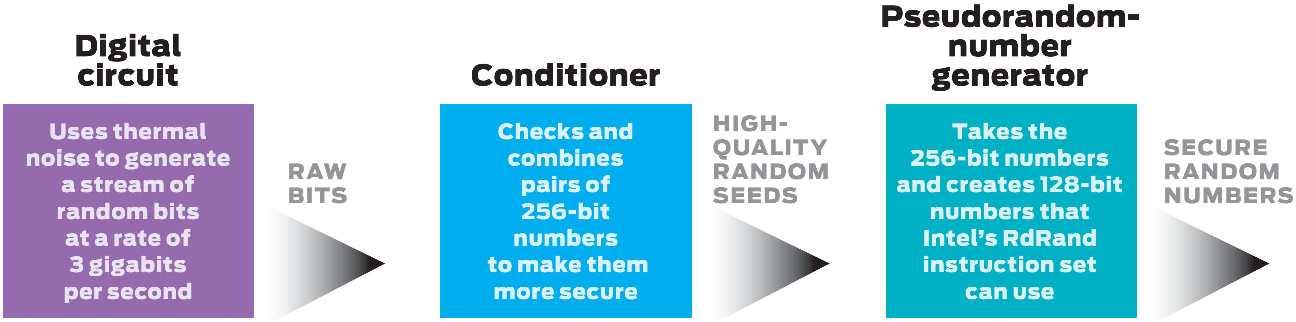
The use of video telephony on mobile gadgets does face other obstacles besides standardization, like ambient noise, poor lighting, battery drain, and strained cellular network capabilities. And, to be realistic, when you're in a crowded and noisy place, you're unlikely to find a phone's video feature useful. However, when you're in a coffee shop or a hotel room, video capabilities can significantly add to a conversation. This is even more the case with the larger tablets, which with scalable technology will be able to take advantage of more features than smartphones can—such as higher resolutions or making several people visible—even on the same call.

And the initial awkwardness felt by video callers in a public place will quickly fade. When the telephone came into the home more than a century ago, people feared everyone would be able to listen in on their private conversations; today, people chatter on cellphones in public with abandon. Indeed, people may soon forget that phones were once meant to be listened to, not watched.

By the way, "The Jetsons" was set in 2062. We're way ahead of them. ❑

Digital Randomness

Continued from page 29



THREE-LAYER NUMBERS: Intel's Bull Mountain random-number generator prevents bias and correlation with a three-step process. First, a digital circuit generates a stream of raw random bits. Next, a conditioner generates healthy random seeds. Third, a pseudorandom-number generator readies the numbers for use in software.

be mathematically combined or conditioned in such a way as to produce a 256-bit number that's closer to that ideal.

You can see this better with a simple illustration. Suppose for a moment that the random-bit generator spits out just 8 bits at a time, which is to say that it provides a stream of binary numbers that range in value from 0 to 255. Suppose further that those 8-bit numbers aren't completely random. Imagine, for example, that some subtle flaw in the circuitry tends to suppress values at the high end of the range. On casual examination, the random-number stream looks good, but if you plot millions of values, you'll notice that the high numbers come up a little less frequently than the low numbers.

One possible fix for that is simple: Always take two of these 8-bit values, multiply them together, and then throw out the upper 8 bits of the resultant 16-bit number. Such a procedure would largely eliminate the bias.

Bull Mountain doesn't work with 8-bit numbers: It works, as we said, with 256-bit numbers. And it doesn't just multiply two together—it does a more sophisticated cryptographic combination. But the basic idea is the same. You can think

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of this conditioning step as concentrating whatever degree of randomness the two-inverter circuit can provide.

We really like to sleep well at night, so we've built in additional circuitry that tests to make sure that the concentrating machinery is always working with bit streams that aren't too biased. If it detects a biased output, we tag it as unhealthy and refine it to meet our standards. This way, only healthy pairs of bit streams are combined.

Guaranteed randomness isn't all that useful if the random values aren't produced and vetted quickly enough to meet demand. While the hardware's circuitry generates random numbers from thermal noise much more quickly than its predecessors, it's still not fast enough for some of today's computing requirements. To allow Bull Mountain to spew out random numbers as quickly as software pseudorandom-number generators, and also maintain the high quality of the random numbers, we add yet another level of circuitry. It uses the 256-bit random numbers to seed a cryptographically secure pseudorandom-number generator that creates 128-bit numbers. From one 256-bit seed, the pseudorandom-number generator can spit out many pseudorandom numbers. With those seeds coming at a rate of 3 gigahertz, a healthy supply of these secret codes quickly builds up.

A new instruction, called RdRand, provides a way for software that needs random numbers to request them from the hardware that's producing them. Built for Intel's 64-bit microprocessors, RdRand is the key to using Bull Mountain. It retrieves a 16-, 32-, or 64-bit random value and makes it available in a software-accessible register. The RdRand instruction has been public for about a year, and the first Intel processor to provide it is known as Ivy Bridge. The new chip set performs 37 percent faster than its predecessor, and its smallest features have been reduced from roughly 32 nanometers to about 22. The overall increase in efficiency easily accommodates the demands of our random-number generator.

POST YOUR COMMENTS *online at* http://spectrum.ieee.org/random0911

WHILE LAVA LAMPS MIGHT LOOK COOL, they don't go with every decor. We think our approach to random-number generation, on the other hand, will be the most versatile of its kind, able to work across the range of Intel silicon products.

As we mentioned, the timing of keystrokes has provided a convenient source of randomness for seeding random-number generators in the past. So have mouse movements and even the time it takes a disk drive to find some of the information stored on it. But such events don't always give you enough random bits, and to some extent the bits you get are predictable. Worse, because we now live in a world of servers with solid-state drives and virtualized workloads, these sources of physical randomness just aren't available to a lot of computers. Those machines need to be able to get random numbers from something other than random events taking place on the periphery. Bull Mountain provides a solution.

So if you're a programmer, get ready for a prolific source of randomness to be put at your fingertips. And even if you don't want to part with a pseudorandom-number generator you've grown to love—whether for cryptography, scientific computing, even gaming—you'll now have Bull Mountain to produce the seeds for it. We expect to see those seeds scattered widely, with all sorts of wonderful software growing and blossoming as a result. ❑

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EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Micronanotechnology

at the Ecole Polytechnique Fédérale de Lausanne (EPFL)

The Institute of Microengineering (IMT) within the School of Engineering at EPFL is seeking for its Neuchatel site, a **tenured associate or full professor** in the area of **micronanotechnology.** This new position is aimed at reinforcing the leading position of the Swiss watchmaking industry by giving it the means to further improve its competitiveness and to continue innovation.

The mission of the chair and its objectives are:

- to develop novel fabrication technologies at the micro- and nano-scale that benefit watchmaking applications, micro- and nano-machining, micro-assembly, and efficient and environmentally-friendly fabrication processes,
- to lead research into new technologies, concepts and high-performance materials for the watch industry, and means to integrate these results,
- to train researchers and scientists to the forefront of these innovative technologies.

This will be accomplished by:

- an internationally recognized fundamental research program that will deepen our understanding of fabrication processes that utilize novel materials,
- an applied research program aimed at innovative developments that bring a positive impact on performance and quality of watches of highest quality: new functionalities, improved accuracy, cost reduction and a lower environmental footprint,
- continuous education, seminars and conferences for the watchmaking industry, with a communication strategy aimed at researchers and professionals in the field.

The Neuchâtel site of IMT-EPFL offers a particularly advantageous position for this chair by virtue of its central location in the Jura Arc, home to many of the key watchmaking companies, and of its historically very strong links to the diverse and well-established local high-technology industry. This new chair will enable a closer collaboration and coordinated strategy between academic research and the private sector.

As a faculty member of the School of Engineering, the successful candidate will be expected to initiate independent, creative research programs and participate in undergraduate and graduate teaching. Internationally competitive salaries, start-up resources and benefits are offered.

The EPFL is a dynamically growing and well-funded institution fostering excellence and diversity. It has a highly international campus at an exceptionally attractive location boasting first-class infrastructure. As a technical university covering computer and communication sciences, engineering, environment, basic and life sciences, management of technology and financial engineering, EPFL offers a fertile environment for research cooperation between different disciplines. The EPFL environment is multi-lingual and multi-cultural, with English often serving as a common interface.

Applications should include a curriculum vitae with a list of publications, a concise statement of research and teaching interests, and the names of at least five referees. Applications should be uploaded in PDF format to the recruitment web site: **micronano-search11.epfl.ch**

Formal evaluation of candidates will begin on **15 January 2012** and will continue until the position is filled.

Enquiries can be addressed to:
Prof. Nico de Rooij
Search Chairman
e-mail: **micronano-search@epfl.ch**

For additional information on EPFL, please consult the web sites: **www.epfl.ch, sti.epfl.ch** and **imt.epfl.ch.**

EPFL is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

UCL

UCL Department of Electronic and Electrical Engineering

Lecturer/Senior Lecturer in Electronic Engineering

Salary range from Grade 7 £35,557 - £38,594 per annum/Grade 8 £39,668 - £46,822 per annum for Lecturer and Grade 9 £50,902 - £55,362 per annum for Senior Lecturer (inclusive of London Allowance).

The Department of Electronic and Electrical Engineering at UCL is recognised as one of the leading Departments for research in its subject area, worldwide. The Department has an extensive teaching programme both at undergraduate (BEng and MEng) and Masters level. Postgraduates substantially outnumber undergraduates in the Department. Further information about the Department can be found at www.ee.ucl.ac.uk.

The Department now wishes to make an appointment at Lecturer or Senior Lecturer level, it is initially for a fixed term of four years to cover the appointment of one of our staff to a Royal Society University Research Fellowship.

We particularly seek candidates with research experience in communications networks systems and circuits, whose research is either within or complementary to our existing programme.

Applicants should have a record of carrying out internationally leading research, together with demonstrated ability in obtaining the support necessary for work at the highest international level, and an outstanding publications record. The ability to inspire students and research staff to achieve their full potential is also of great importance to us.

For further details about the vacancy and how to apply online please go to http://www.ucl.ac.uk/hr/jobs/ and search for reference 1196726.

If you experience any problems please contact Vicky Coombes (v.coombes@ee.ucl.ac.uk) quoting reference 1196726, please **do not** send CV's direct. Informal enquiries can be made to Professor Izzat Darwazeh (i.darwazeh@ee.ucl.ac.uk).

Closing date: Friday 30th September at 5pm.

We particularly welcome female applicants and those from an ethnic minority, as they are under-represented within University College London at this level.

UCL Taking Action for Equality

LCN
LONDON CENTRE FOR NANOTECHNOLOGY

UCL

London Centre for Nanotechnology and the
Department of Electronic and Electrical Engineering

Academic Position in Nanoelectronics/Nanophotonics

University College London (UCL) wishes to appoint an outstanding, self motivated individual who will exploit the potential of nanotechnology for electronics and/or photonics. The appointment will be at Lecturer/Senior Lecturer, Reader or Professor level and will be a joint appointment between the London Centre for Nanotechnology (LCN) and the Department of Electronic and Electrical Engineering (EEE).

The London Centre for Nanotechnology (LCN) (www.london-nano.com) is an interdisciplinary and multi-faculty research centre that has recently been established on the UCL and Imperial College London campuses. It draws together researchers from the fields of physical sciences and engineering with those from the life sciences and medicine. The post-holder will be expected to provide intellectual leadership and conduct a world-class research programme in her/his area of research.

The post-holder will additionally contribute to the teaching programme in the Department of Electronic and Electrical Engineering (www.ee.ucl.ac.uk) and perform the normal administrative duties expected of a member of academic staff, as required by the LCN Director and the Head of the Department of Electronic and Electrical Engineering.

Informal enquiries can be made to Professor Gabriel Aeppli at the LCN (email: lcn-administrator@ucl.ac.uk) and Professor Alwyn Seeds in the Department of Electronic and Electrical Engineering (a.seeds@ee.ucl.ac.uk). Further particulars can be found on the LCN and EEE websites listed above.

Closing date: 30th September 2011.

We particularly welcome female applicants and those from an ethnic minority, as they are under-represented within UCL at these levels. This is in line with section 48 of the Sex Discrimination Act and section 38 of the Race Relations Act.

Applications for the post at Lecturer/Senior Lecturer level should be made via the following link, the advert reference is 1197795. http://www.ucl.ac.uk/hr/jobs

Applications for the post at Reader/Professor level should be made via the following link, the advert reference is 1197826. http://www.ucl.ac.uk/hr/jobs

UCL Taking Action for Equality

IEEE Global History Network
www.ieeeghn.org

IEEE

Technische Universität Berlin

Technische Universität Berlin - School IV (Electrical Engineering and Computer Science), Department of Energy and Automation Technology invites applications for the position of

University Professor - salary grade W 3

for the chair "Electric Energy Storage Engineering" to assign.

Reference Number: IV-5 (closing date for applications 18.10.2011)

Job Description:

The applicant is to represent the area in research and education. He/she must have distinguished expertise in one or more of the following areas:

- Electrochemical energy storage
- Control of energy storage systems
- Reliability and durability of storage systems
- Electronic circuits in batteries
- Product development of battery technology

Requirements:

Applicants must fulfill the formal requirements of Berlin's University Law (§100 Berliner Hochschulgesetz). Candidates are expected to demonstrate excellent research and teaching skills. He/she must have comprehensive knowledge and experience within the field of the professorship. A multi-year professional experience in industry or in the context of a professorship with focus areas as listed above is desired. Collaboration with national and international organizations, collaboration skills as well as a proven track record in the acquisition of funding are wellregarded.

The candidate is expected to participate in the core education of electrical and electronic engineering. A spirit of cooperation with other areas, in particular within the energy strategic area of TU Berlin, is considered as important.

To ensure equal opportunities between men and women, applications from women with the respective qualifications are explicitly desired. Handicapped applicants with the same qualifications are preferred.

Please send your **written** application with the **job reference number** until 18.10.2011, with the appropriate documentation to the Präsidenten der Technischen Universität Berlin, **Fakultät IV, Inst. für Energie- und Automatisierungstechnik, Sekr. FR 5-1, Franklinstr. 28-29, 10587 Berlin.**

Please send only copies and not original documents, as they will not be returned.

The vacancy is also available in the internet at **http://www.personalabteilung.tu-berlin.de/menue/jobs/**.

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AHMEDABAD UNIVERSITY

School of Information and Communication Technology

Ahmedabad University-AU
A State Private University, Gujarat, India
ict.ahduni.edu.in

AU is in the process of establishing a new School of ICT by July 2012. School of ICT, AU invites applications for faculty positions at the level of Director, Professors, and Associate/Assistant Professors. Academicians committed to teaching and research, excited by institution building are invited to participate in our vision to establish a leading new School of ICT.

The school aims to redefine ICT education -where high powered technological innovations will complement sustainable growth in various sectors such as healthcare, energy, finance. To build a high quality research driven academic program (B Tech, M Tech and PhD), the school will leverage its multi-disciplinary position as one of the four schools planned under the umbrella of Institute of Science and Technology, AU: Engineering, Life sciences, Physical sciences & ICT. AU is also engaged in developing a network cluster with leading institutes in a variety of disciplines.

Candidates, from any branch of ICT or related cross disciplinary fields such as computer science electrical engineering, bioinformatics, and humanities may apply. For all positions, a PhD in related field, significant demonstrated research record commensurate with the level of the position being applied for are required. Being a State University (privately funded) we offer more attractive remuneration package as compared to other institutions in the country. Faculty will be encouraged and supported to establish research labs and get involved in institution building, innovate, teach, consult and conduct collaborative research.

Applications should consist of a cover letter, CV, a research statement, names and contact information of at least 3 references, and URLs' /Pdf of at least 3-5 papers. Submit CV and queries to: **ict@ahduni.edu.in**

NSF-Funded Doctoral Student Opening In Wound Image Analysis

The ECE Dept. at WPI has an opening for a doctoral student (ECE or CS) to develop Android smart phone image analysis algorithms to quantify the healing progress of foot ulcers, funded by a 4 year NSF grant.

The image analysis tools will process a sequence of color wound images, track boundaries of a diabetic wound and segment the wound into tissue categories. Strong image analysis and mathematics skills, experience in Matlab, C and C++ and Java programming, good technical writing and oral communication abilities are desired.

Contact Peder C. Pedersen, Professor of ECE, (***pedersen@ece.wpi.edu***) for details. Additional information re graduate studies in ECE at WPI, see: ***http://www.wpi.edu/academics/ece/gradprograms.html***.

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

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

1. Electrical Power Systems

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

2. Electronic Circuits, Devices and Technologies

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

3. Communication Systems

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

4. Software Systems

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

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

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

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

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

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

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

UNIVERSITY OF TORONTO
The Edward S. Rogers Sr. Department of Electrical & Computer Engineering
10 King's College Road
Toronto, Ontario, Canada M5S 3G4

the data

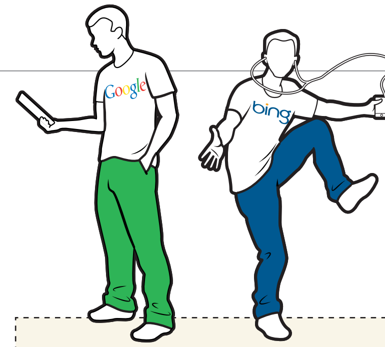
Search Engine ABCs

START TYPING in a browser's search box and the search engine races to complete your query. It's a great feature that can save you a lot of time.

The guessing begins the moment you type the first letter, with results that can be surprisingly accurate or amusingly off base. Search engine providers don't reveal their algorithms, but the theory is that they base their guesses on what other people in the same geographic area have searched for when they type the same initial letter.

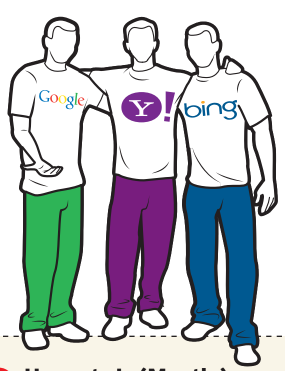
But even within regions, what most people are searching for depends on what search engine they use. The two leaders, Google and Microsoft's Bing, which jointly cover most of the search market, differ. But together they offer a snapshot of the world's 536.6 million English-language-using Internet searchers. Here are the top search guesses from one-letter tests I did in the San Francisco Bay Area in mid-May.

—*Swapnajit Mitra*



I ***I* Before *A*:** While Apple is never suggested for *A*, each search engine features an Apple product for *I*.

A **Brands and More Brands:** Out of 26 letters, 21 (81 percent) of Google's suggestions are names of organizations and products. Bing's suggestions for brand names totaled even higher—about 92 percent (24 letters).

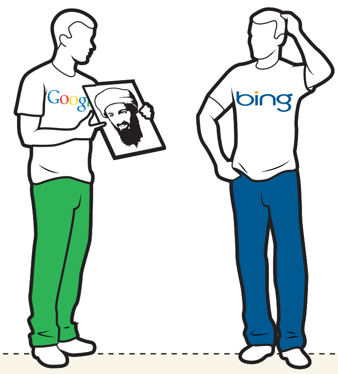


Y **Honesty Is (Mostly) the Best Policy:** Bing, not surprisingly, selects Microsoft's Hotmail for *H* and Google picks Google for *G*. But Bing's *O* is Orkut—a Google product. Google returns the compliment with Xbox for *X*. Things get even more interesting at the letter *Y*—Google chooses Yahoo instead of its own YouTube. Do people really search for Yahoo on Google?

Search Engines Fill in the Blank

	GOOGLE	BING
A	Amazon	AOL
B	Bank of America	Bank of America
C	Craigslist	Craigslist
D	DMV	dictionary
E	ESPN	e (the numerical constant)
F	Facebook	Facebook
G	Google	Google
H	Hulu	Hotmail
I	iPad	iTunes
J	JetBlue	JC Penney
K	Kaiser	Kohl's
L	Lowe's	Lowe's
M	Mapquest	mySpace
N	Netflix	Netflix
O	Osama bin Laden	Orkut
P	Pandora	Pandora
Q	quotes	QVC
R	Rebecca Black	RuneScape
S	Southwest	Southwest Airlines
T	Target	Target
U	United	USPS
V	Virgin America	Verizon Wireless
W	weather	www.facebook.com
X	Xbox	Xbox
Y	Yahoo	Yahoo
Z	Zillow	Zillow

Top one-letter search-engine guesses, San Francisco Bay Area, May 2011



O **No One Here:** Search engines don't seem to like people very much. Google's list shows only two, known mostly for their notoriety. Recently Osama bin Laden and musical flash in the pan Rebecca Black shared this rare honor (and she was gone by July). Bing's list is person-free.

Z **Location, Location, Location:** Checking out real estate values on Zillow is a San Francisco Bay Area obsession; when this test was run on the East Coast in July, shoe site Zappos.com edged Zillow out in Google search results.

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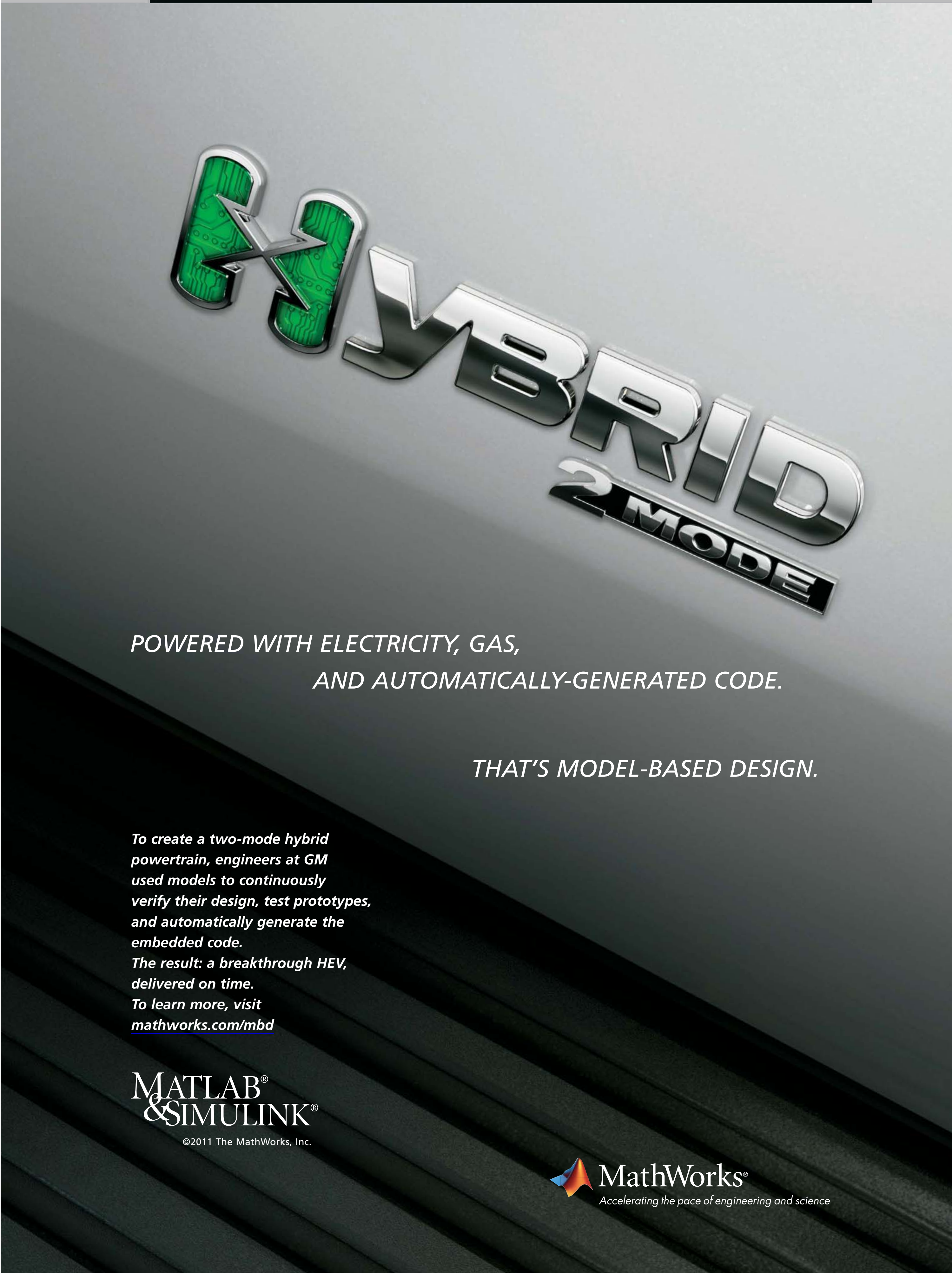
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