As chair of electrical and computer engineering, I’m proud of how our department leads the nation in research, education and technology innovation that addresses critical global challenges. For example, we are creating contact lenses so advanced, they could eliminate the need for reading glasses by refocusing themselves on the fly; miniature microwave antennas that mimic insect auditory systems and thus are smaller than what theory says is possible; and discovering and quantifying the basis of human consciousness.

We are innovating the computer and network architectures of tomorrow that will provide more performance and greater mobility while consuming less energy. We are national leaders in researching fusion energy, advanced power electronics and an electrical power grid compatible with alternative energy sources, solving the challenge of generating and distributing sustainable electric power for all.

We have exceptional teachers who are developing and using cutting-edge instructional methods and facilities to ensure every student learns successfully. This includes providing 24/7 access to notes and lectures online, developing new learning spaces and methods that individualize the instruction to each student’s learning needs, and providing every student with electronic laboratory measurement systems light enough to be carried alongside a laptop computer.

And we are blessed to do all this in a fantastic environment: at a university that leads the nation for spontaneous and successful interdisciplinary collaboration, on a campus known for its beautiful, lake-surrounded environment, and in a city that is annually ranked in the top-25 places to live.

On Wisconsin!
On the cover:
One of the many images of bee wings from a database that powers a machine vision algorithm that can identify a bee’s species using the shape and number of cells in its wings. Professor Bill Sethares *(below, left)* and graduate students Chris Hall, Chuck Hatt, and Mark Lenz *(below, right)* developed the algorithm and hope to have a web-based version of the tool in 2012.
How to ID a bee

It’s a vanishing act that has puzzled everyone from top entomologists to characters on the popular British sci-fi series *Doctor Who*. What’s happening to the honeybees? Every year, colony collapse disorder decimates the European honeybee population in the United States—and the disappearance of these key pollinators has serious implications for growers who depend on honeybees to pollinate their crops.

In Wisconsin, European honeybees are only one of about 600 different bee species. And the important question many not be *where* the missing bees are—but rather, *which* bees are still here, and *what* are they doing, says UW-Madison entomologist Claudio Gratton. “What we want to know is how this diversity of bees is affecting pollination in Wisconsin crops,” he says.

But the big bottleneck in that endeavor starts with the people who can ID bees: There are fewer than a half-dozen people in North America who have the expertise to classify multitudes of bee specimens, and the turnaround time for a submitted sample can be as long as a year.
Gratton thought that there had to be a more efficient way to do things, so he contacted Professor Bill Sethares to ask if he could create a system for digital taxonomy, possibly even an iPhone application, that could quickly and accurately identify bee species from images of their intricately veined wings. “Bees have wings that look like a series of membranes arranged in a pattern,” says Sethares.

He and graduate students Chris Hall, Mark Lenz and Chuck Hatt developed an algorithm that can learn to recognize those patterns and identify a bee species based on a database of images from Gratton’s research lab. To increase both the number of images and the diversity of species that could be identified, graduate student Mark Lenz is building a website through which users can contribute to their own photos of bee wings—thus providing a larger pool of photos for testing the algorithm. He hopes to launch the website in summer 2012.

With some improvements to the image-processing and learning algorithms, Lenz also is optimistic the iPhone app will become a reality. “At that point, if a smartphone has a camera of high enough quality, we should be able to create an app for schoolchildren,” he says.

Gratton and his team are willing to be patient because the potential of an easy-to-use app could pay enormous dividends—both for research purposes and as a way involve the public in what they do.

“How many eyes can you get looking for things for you? You end up seeing a lot of things that a professional entomologist might not see—because we just can’t be everywhere,” Gratton says.
Back in the 1960s, there were curious Wisconsin engineers—and there was then-UW-Madison University Industry Research Program Associate Director Don Novotny. “Generally, companies had an engineer tasked with seeing the future,” says the professor emeritus. “I would set up visits for them to come to UW-Madison and talk to four or five different faculty members in the areas they were interested in.”

The Wisconsin Idea—the university principle of knowledge and technology transfer for the good of all—inspired Novotny as he, then-new faculty member Tom Lipo and colleagues founded the Wisconsin Electric Machines and Power Electronics Consortium, or WEMPEC, in 1981. In exchange for student and faculty support, member companies received access to WEMPEC research with industrial applications.

With the support of more than 80 corporate sponsors, eight faculty members, around 60 graduate students, and international scholars work together at WEMPEC to research and develop the newest technologies in power electronics, actuators, sensors, drives, motion control, and drive applications.

While the consortium’s research areas and number of member companies have grown considerably in the last 31 years, WEMPEC still is all about the Wisconsin Idea, says Professor Giri Venkataramanan. “What sparked the idea was this drive to know what the community needed and being responsive to that,” he says.

**WEMPEC: Taking the Wisconsin Idea global**

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Often, what Wisconsin companies need is a test bed for new, unproven technologies that could be important for the future of power engineering. For example, 12 years ago, the word “microgrid” was virtually unknown. Venkataramanan and Professor Emeritus Robert Lasseter initially used it in a proposal for research into using a self-contained power grid connected both to on-site renewable energy sources and to the regional power grid to create highly reliable power systems. WEMPEC resources enabled them to make the idea work in the lab with actual hardware.

Seeing the potential for national power infrastructure improvement, WEMPEC industry partners collaborated on microgrid research and helped pursue federal research dollars to build and implement larger projects across the country—including at the Santa Rita jail in Alameda County near San Francisco, and the McGuire Air Force Base Medical Clinic in central New Jersey.

Now, WEMPEC researchers have multiple microgrid projects in the works, including one with United Technologies Research Center of East Hartford, Connecticut. “They’re implementing this microgrid to demonstrate among their own engineers that this technology needs to be a part of their portfolio,” says Venkataramanan.

As a result, an idea that began as a speculative project in a WEMPEC lab could end up inside a high-tech skyscraper lighting the evening skyline of Abu Dhabi.

Some of the most globally applicable ideas aren’t the most technologically complex. Graduate student Pedro Melendez’s cheaper, more efficient wind turbine design exemplifies how a basic idea can take flight from the WEMPEC lab into the real world. “We developed a turbine blade constructed out of a PVC pipe,” says Melendez. “You can carve all three blades out of one pipe, which is much less expensive than the traditional wood design.”

The project earned Melendez an invitation to Zambia in June 2012 to implement his design as part of an ongoing outreach program through Seattle University in Washington.

Ideas like this can and do have global impact—and with the help of faculty, staff, students and industry partners, the WEMPEC of today is producing research that could be significant all over the world from Madison to Zambia. “It was the intent in the beginning for WEMPEC to be a resource for primarily Wisconsin companies,” says Novotny. “But as member companies started to come from all over the country—and then the world—we realized this is one big worldwide group.”
Self-focusing contact lenses? ... We’ll see!

Professor Hongrui Jiang asks a simple question: Why does presbyopia, the natural aging process that stiffens the lens and reduces the eye’s ability to focus, need to be treated with reading glasses or bulky bifocal lenses?

Instead, Jiang aims to design a pair of contact lenses that could change its focal length automatically, easing eye strain and providing both near and far vision within the same lens. “This is how cameras work,” says Jiang. “You try to focus on something, and then you change the focal length of the lens system, resulting in a sharper image. So why can’t we put a camera lens in our eye?”

The answer is decidedly more complicated than jamming a Canon lens into each eye, but Jiang’s expertise in microelectromechanical systems and micro-optical imaging is helping him work toward a design for a self-focusing contact lens. The National Institutes for Health awarded Jiang a five-year, $2.25 million New Innovator Award in 2011 to support prototype development.

The design will employ a liquid lens that can change shape to adapt its focal length, with a control circuit small and flexible enough to be situated on a contact lens without being noticed by the wearer.

To power the device, Jiang may harvest solar or electromagnetic waves. And, of course, the lens must be safe and comfortable to wear.

Although there are several hurdles to overcome, Jiang feels the technology has the potential to improve millions of lives. “There are going to be some challenges. Some I can foresee, and we have ideas of how overcome them,” says Jiang. “But we’ll bump into some that we can’t foresee, and try to come up with a solution.”
Network of neurons: A dynamic model of brain activity

Looking at a tangled mass of network cables plugged into a crowded router doesn’t yield much insight into the network traffic that runs through the hardware. Similarly, Lynn H. Matthias Professor Barry Van Veen says that looking at the three pounds of interwoven neurons that make up the hardware of the human brain doesn’t give the complete picture of the brain activity that supports human cognition and consciousness.

Working with multiple collaborators, Van Veen has applied signal analysis techniques to the electric or magnetic fields measured noninvasively at the scalp through electroencephalography (EEG) or magnetoencephalography (MEG) to develop methods for identifying network models of brain function—essentially, traffic patterns of neural activity present in the human brain. “It’s analogous to coming up with a new microscope,” says Van Veen.

Having a reliable traffic map of normal brain function provides a baseline for comparison for understanding how different disorders, substances and devices affect the brain. “Now that we’ve got the tool ready, the opportunities to try it out on scientifically interesting questions are really blossoming,” says Van Veen.

For instance, network models may provide a better blueprint for how medical devices can interface with the brain. Van Veen recently began working with Biomedical Engineering Associate Professor Justin Williams to apply his work toward making better brain-machine interfaces.

But the implications of network models go beyond engineering questions. The effect of alcohol on the brain just begs for network analysis, according to Van Veen. The network model could allow researchers to see precisely which parts of the brain are altered by alcohol consumption. It could provide insight into how short-term memory works, help explain the effects of schizophrenia and monitor treatment, help measure the depth and effectiveness of different types of anesthesia, and even help give insight into the brain activity that precludes—or prevents—a miraculous recovery from a coma. “We’re developing this tool as a significant improvement over what people have had access to before,” says Van Veen. “The possibilities for using it to study different aspects of brain function are nearly unlimited.”

Van Veen models the EEG sensor net used to noninvasively plot the network of activity in the brain.
Fast, flexible electronics for the next generation of gadgetry

This year’s thin, powerful smartphone quickly becomes yesterday’s underperforming battery hog in today’s consumer electronics market. The demand for smaller devices with more features and increased battery life seems insatiable—and Professor Zhenqiang (Jack) Ma is keeping up with that pace, working tirelessly to improve the technology that could power the next generation of mobile electronics.

Ma’s work centers on fast, flexible electronics—circuits that can bend to any shape without sacrificing performance. He’s been refining techniques for designing chips on silicon nanomembranes, developing faster methods of “carving” circuitry into these thin, stretched layers of insulated silicon using patterned adhesive membranes to pull off layers of insulation. “They use a single crystal material, which offers a much higher speed than can be realized using other materials,” says Ma, of his devices. “So far, we have gotten as high as 12 gigahertz (GHz).”

A typical smartphone runs at around 2 GHz, but the benefit of integrating fast, flexible electronics into future...

Wedging wireless broadband between TV signals

The demand for faster, more mobile Internet access for smartphones, tablets and laptops does more than strain the available space we have in our pockets and bags. There’s a finite amount of wireless spectrum available to those gadgets as well.

However, in November 2008, FCC changed its regulation to allow unlicensed devices to use TV “whitespace” spectrum—unused frequencies primarily designated for television broadcasts—as long as they do not interfere with incumbent TV broadcasts and other licensed users such as wireless microphones.

Researchers—including Professor Parmesh Ramanathan—now are looking for the best way to utilize whitespace to increase the data rates of wireless communication.

The 180 megahertz television band offers the best potential for improved wireless communication, since it provides nearly five times the bandwidth of conventional WiFi, with increased range to boot. “TV signals propagate through walls and so on much better than other bands,” says Ramanathan. “The higher the frequency, the less they propagate.”
Wedging wireless broadband between TV signals requires two things—reliable sensing to determine which parts of the airwaves are not being used at any given time, and spectrum-agile radios inside of devices that can reliably determine and switch to the clearest parts of the band for wireless communication.

Ramanathan and Associate Professor Suman Banerjee are refining that radio technology. They pair signal sensing with precise and easy-to-tune software radios as they work toward networks that eventually could provide higher speeds to more users over wider geographical regions than traditional wireless networks could ever provide. “Eventually, people will be replacing traditional WiFi with these kinds of radios,” says Ramanathan.

He believes technology that makes more innovative use of spectra is the future of wireless communications. “This is part of a change of how spectrum is going to work,” says Ramanathan.

Better technology for sensing spectrum use will enable licensed spectrum owners buy and sell them in short time scales.

For instance, consider the frequent dropped calls that occur when a football stadium is full of texting, tweeting fans. Ramanathan suggests that someday, cellular service providers could lease extra spectrum to improve communication during game day, invisibly adapting their network to better handle the influx of mobile device use. Moreover, police and security organizations could lease that same spectrum once the game is over, giving them more reliable communications among officers on the ground should an emergency occur.

Until the hardware catches up to the regulatory possibilities, these are all hypothetical scenarios. “Now that the FCC allows for these types of things, it becomes mostly a technological challenge to find the right solutions,” says Ramanathan.

But tapping into unused spectrum requires two things—reliable sensing to determine which parts of the airwaves are not being used at any given time, and spectrum-agile radios inside of devices that can reliably determine and switch to the clearest parts of the band for wireless communication.

Ramanathan suggests that someday, the flexibility of these chips gives them much wider applications than better versions of the tech we already have; they’re well suited for everything from small-scale wireless communications to more comfortable, reliable biomedical devices.

“Because they are flexible, you can put them anywhere you want—on your skin, your clothes, wherever,” says Ma. “The applications are very, very broad.”

Smartphone designs isn’t just about increases in speed. Huge improvements in battery life are possible, as well.

“You take a 12 GHz flexible transistor and run it at 2 GHz, and a 3 GHz rigid transistor and run it at 2 GHz. The power consumption will be one or two orders lower for the flexible chip,” says Ma.

Jack Ma, with a flexible transistor.
A lab bench packed with expensive oscilloscopes and function generators serves a seasoned electrical engineer well, but all that equipment might be overkill for students learning the basics of electricity. Having only a limited number of lab benches means that students don’t get a lot of time to learn the ins and outs of circuitry at their own pace.

Seeing an opportunity to improve the lab experience for his introductory courses, Associate Faculty Associate Mark Allie has moved his electronics lab courses ECE 270 and ECE 271 from traditional lab work to Mobile Studio, a portable lab kit that, paired with a laptop, can simulate all the equipment his students need for basic experiments with current, voltage and frequency. “The experiments have been modified so that students can do everything with just the Mobile Studio board, with minor exceptions,” says Allie. “We’re reinforcing concepts from lecture, so we can easily cover the material with a USB-based device.”

The idea originated with Rensselaer Polytechnic Institute Professor and ECE alumnus Ken Connor, who developed the hardware and software through a grant from the National Science Foundation as a means of simplifying hands-on learning of electrical principles. Rensselaer first implemented the kits in electrical engineering courses in 2007; embracing their success, the electrical and computer engineering department at UW-Madison funded a pilot in 2011 to test the concept in two lab courses. Mobile Studio lab kits will be added to a third course in fall 2012.

It’s not precisely the same as working with the real thing, but it’s a good primer for what to expect from a professional lab bench setup. “The interface even looks like the real equipment when you see it on screen,” says Allie. The portability of Mobile Studio lab kits means that courses are more flexible—they can be run anywhere that students can set up a laptop, including a lecture hall.

The kits have an enormous advantage for budget-minded students: cost. They can own a Mobile Studio lab kit for $99. “You could buy this equipment two years ago for $500 or so. Now, it costs less than a textbook,” says Allie.

Best of all, students can take the kits home if they like, giving them more time to master the basics or just simply experiment. “A lot of students use it on their own time, just because they’re interested,” says Allie.
At two UW-Madison libraries, newly remodeled instructional spaces ripe with technological upgrades are helping turn the 1,000-year-old, lecture-based, “one-size-fits-all” instructional model upside down. Together known as the Wisconsin Collaboratory for Enhanced Learning Center (WisCEL, pronounced “whistle”), these new instructional areas also increase daytime use of College Library and Wendt Commons—the engineering library—where students study primarily at night.

Instead of row after row of books, there are a variety of flexible, multi-use, technology-rich spaces, including classrooms and areas for small-group discussion, tutoring and peer-to-peer learning. WisCEL enables faculty and staff instructors to educate large groups of students—but in ways that foster student participation and allow instructors to spend more time interacting with their students.

For example, students could prepare for class by reading the text or viewing a video lecture. In class, they might use video monitors to discuss the material in small groups while the instructor circulates—then complete a quiz, homework assignment or practice test using special web-based software that provides them immediate feedback.

A primary WisCEL objective is success for all students, says ECE department chair John Booske, who spearheaded the initiative. “We aim to provide a personalized learning experience, even while teaching large numbers of students,” he says. “In part, we are teaching students how to think. Ultimately, we hope our efforts will help them develop as confident, independent, lifelong learners.”
Nader Behdad: Projecting the future of antenna technology

Recognized for his innovative approaches to antenna research and design, Assistant Professor Nader Behdad has received numerous accolades for his research efforts in the last year. His paper, “Insect-inspired miniaturized antenna arrays with super-resolving capabilities,” which posits that the limitations of electrically small antennas can be overcome by looking to insect antennae for inspiration, was one of the most widely read research articles among members of the Institute of Defense and Government Advancement (IDGA) in 2011. The IEEE Antennas and Propagation Society named that same paper as the recipient of its 2012 Piergiorgio L.E. Uslenghi Letters Prize Paper Award.

Behdad will further his research with highly compact broadband antennas thanks to a three-year, $510,000 research award through the Office of Naval Research’s Young Investigator program. Behdad will be exploring ways to swap the lengthy antennas currently used on Navy vehicles for a more compact and conformal multi-mode radiator design. Rather than fighting the laws of physics and trying to lower the operating frequency of a single dipole antenna, Behdad’s concept involves tuning multiple parts of the antenna structure to radiate at different frequencies, using synthetic “metamaterials” to shape their radiation patterns so that they won’t interfere with one another.

More efficient antennas will prepare Navy vehicles for the increased communications demands of the future, but more importantly, eliminating the large antennas from their communications equipment could also make U.S. soldiers safer. “If you have a huge antenna sticking out of a soldier, it paints a pretty big target on them as they walk in the street,” says Behdad.
AWARDS

Grainger Professor of Power Electronics and Electrical Machines Tom Jahns and Consolidated Papers Professor of Controls Engineering Bob Lorenz received the two top awards from the IEEE Industry Application Society.

Jahns received the 2011 Outstanding Achievement Award, recognizing his outstanding contribution and technical developments in the application of electricity to industry.

Lorenz received the 2011 Distinguished Service Award, recognizing his dedication and exceptional service to the IEEE Industry Application Society.

Assistant Professor Nam Sung Kim received an IBM Faculty Award for 2011. The honor is a cash award meant to both foster collaboration between academic and IBM R&D and to support curriculum that enriches disciplines of interest to IBM. The company selected Kim based on his research exploring near-threshold voltage computing, which he plans to build upon using the award.

Professor Zhenqiang (Jack) Ma has received the H.I. Romnes Faculty Fellowship, a UW-Madison honor funded by the Wisconsin Alumni Research Foundation. The fellowship recognizes outstanding research and provides career support for tenure-track faculty. Ma is only the 12th engineering faculty member to receive the award since the award’s inception in 1985.

A paper on airborne light detection and ranging (LIDAR) for airport construction authored by McFarland-Bascom Professor Robert Nowak and National Oceanic and Atmospheric Administration Scientist Chris Parrish received two awards from the American Society of Photogrammetry and Remote Sensing in 2012: The 2012 Talbert Abrams Award and the third-place 2012 ERDAS Award for Best Scientific Paper in Remote Sensing. The paper tackles a civil engineering problem—inaccurate mapping data for future airport construction sites—and applies modern filtering techniques Novak developed to better use LIDAR data in construction planning.

In addition, the IEEE Signal Processing Society awarded Nowak, Industrial and Systems Engineering and Computer Sciences Professor Stephen J. Wright and Instituto Superior Técnico Electrical and Computer Engineering Professor Mário A.T. Figueiredo with a best paper award for their paper, “Sparse reconstruction by separable approximation.”

FELLOWSHIPS & HONORS

- Professor B. Ross Barmish, International Federation of Automatic Control (IFAC) fellow
- Duane H. and Dorothy M. Bluemke Professor John Booske, American Physical Society fellow
- Professor Hongrui Jiang, editorial board for the IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)
- Professor Akbar Sayeed, IEEE fellow
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