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Electrical and Computer Engineering Research Report 2008

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A satellite view of Earth from space, showing a large portion of the Western Hemisphere. The image is dominated by dark blue oceans and lighter blue/white landmasses. The curvature of the Earth is visible at the top. The text 'ECE' is overlaid in the top left corner.

ECE

ELECTRICAL AND COMPUTER ENGINEERING
RESEARCH REPORT 2008

MICHIGAN
TECHNOLOGICAL
UNIVERSITY





GREETINGS FROM MICHIGAN'S UPPER PENINSULA

IT IS MY PLEASURE TO PRESENT the research activity in the Department of Electrical and Computer Engineering at Michigan Tech. This is my first opportunity to do so, having just arrived in September to take up the position of Department Chair. In getting to know my new academic home, both during the interview process and in the last few months, I have been deeply impressed by the breadth and the quality of the technical work done in the department. I hope to convey a little of my enthusiasm for that work in these pages.

Michigan Tech has a rich history and a well-deserved reputation for providing one of the best undergraduate educational programs in the Midwest. More recently, the College of Engineering has made a firm commitment to grow the size and stature of its research activity. The ECE department stands with the College in that commitment, and has seen an eight-fold increase in the number of the PhD students and a six-fold increase in annual research expenditures just since 2000.

The ECE department has active research and teaching programs going on in four broad technical areas: 1) power and energy, 2) signals and systems, 3) computer engineering, and 4) electrophysics. Much of the research is carried out in two centers that call the department home, the Center for Integrated Systems in Sensing, Imaging, and Communication (CISSIC) and the Power and Energy Research Center (PERC). Some of our most exciting work is affiliated with the interdisciplinary Multi-Scale Technologies Institute (MuSTI). In this report one can see projects led by some of our newest faculty members, and by our more senior faculty as well.

All of our investigators consider the broader impact of their work, both at Michigan Tech and elsewhere. There are ample opportunities for undergraduates to get involved in the research described here, through Senior Design, Enterprise, or independent directed study experiences. The Enterprise program, unique in the nation, gives undergraduate students the opportunity to develop entrepreneurial organizations on campus that can serve as vehicles for design experiences at all levels. The ECE department is home to four Enterprises, including the brand-new Automotive Computing Enterprise which is described here.

This report summarizes and highlights work done during the 2007–2008 academic year—work that was ongoing before I arrived on campus. I am looking forward to seeing more innovations from the talented ECE team, being a part of that activity, and describing it in more reports like this one in the years to come.

Dan Fuhrmann
Professor and Chair
fuhrmann@mtu.edu

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ECE

ABOUT THE DEPARTMENT

Established in 1928 as the Department of Electrical Engineering, the ECE department at Michigan Tech is among the world's leaders in providing quality education and research. As of September 2008 we have twenty-one full-time faculty members, three lecturers and instructors, 635 undergraduates and 135 graduate students, including forty-eight PhD students. We are housed on six floors of the Electrical Energy Resources Center (EERC) building at the very center of Michigan Tech's campus in Houghton. We offer programs leading to the degrees Bachelor of Science in Electrical Engineering (BSEE), Bachelor of Science in Computer Engineering (BScPE), Master of Science in Electrical Engineering (MSEE), and the Doctor of Philosophy (PhD) in Electrical Engineering. New MS and PhD programs in Computer Engineering have been proposed and are in the university and state approval process. There is a plan in place to grow the department to twenty-six full-time faculty members over the next three years, to support the expected growth in research activity.

OUR FACULTY

The faculty in the Department of Electrical and Computer Engineering are leaders in their respective fields and are committed to developing the next generation of technological leaders through undergraduate and graduate education. Several faculty members are recognized as Fellows in the Institute for Electrical and Electronic Engineers (IEEE), the Society of Photo-Optical Instrumentation Engineering (SPIE), the Optical Society of America (OSA), and the Society for Women Engineers (SWE). A number have written popular textbooks, and others hold prominent editorial positions for archival journals such as the *IEEE Transactions on Signal Processing*, *IET Communications*, and *Applied Optics*.

TENURE-TRACK FACULTY

ASHOK K. AMBARDAR

PHD, UNIVERSITY OF WYOMING

PAUL L. BERGSTROM

PHD, UNIVERSITY OF MICHIGAN

LEONARD J. BOHMANN

PHD, UNIVERSITY OF WISCONSIN

JEFFREY B. BURL

PHD, UNIVERSITY OF CALIFORNIA, IRVINE

Bo CHEN

PHD, UNIVERSITY OF CALIFORNIA

CHUNXIAO (TRICIA) CHIGAN

PHD, STATE UNIVERSITY OF NEW YORK—STONY BROOK

ASHOK K. GOEL

PHD, JOHNS HOPKINS UNIVERSITY

DANIEL R. FUHRMANN

PHD, PRINCETON UNIVERSITY

SHIYAN HU

PHD, TEXAS A&M UNIVERSITY

ROGER M. KIECKHAFFER

PHD, CORNELL UNIVERSITY

ANAND K. KULKARNI

PHD, UNIVERSITY OF NEBRASKA

JOHN LUKOWSKI

MS, MICHIGAN TECHNOLOGICAL UNIVERSITY

CHRISTOPHER T. MIDDLEBROOK

PHD, UNIVERSITY OF CENTRAL FLORIDA

PIYUSH MISHRA

PHD, POLYTECHNIC UNIVERSITY

BRUCE A. MORK

PHD, NORTH DAKOTA STATE UNIVERSITY

WARREN F. PERGER

PHD, COLORADO STATE UNIVERSITY

MICHAEL C. ROGGEMANN

PHD, AIR FORCE INSTITUTE OF TECHNOLOGY

TIMOTHY J. SCHULZ

PHD, WASHINGTON UNIVERSITY

MARTHA E. SLOAN

PHD, STANFORD UNIVERSITY

JINDONG TAN

PHD, MICHIGAN STATE UNIVERSITY

ZHI (GERRY) TIAN

PHD, GEORGE MASON UNIVERSITY

WAYNE W. WEAVER

PHD, UNIVERSITY OF ILLINOIS

DENNIS O. WIITANEN

PHD, UNIVERSITY OF MISSOURI-ROLLA

SEYED (REZA) ZEKAVAT

PHD, COLORADO STATE UNIVERSITY

ZHIJUN (ZACH) ZHAO

PHD, UNIVERSITY OF ILLINOIS

RECENT PHD GRADUATES

HUI TONG

A joint data rate-error rate analysis in correlated space-time wireless channels

JAFAR POURROSTAM

Direction-of-arrival estimation for periodic-sense, high-resolution and low complexity applications

GRANT SOEHNEL

Phase correction techniques for severe turbulence conditions

PRASANJIT S. KARRE

Fabrication and characterization of room temperature operating single electron transistors using focused ion beam technologies

ARANGGAN VENKATARATNAM

Design and simulation of logic circuits using single electron transistors

HUAMING LI

ECG signal processing for long-term healthcare monitoring in body sensor networks

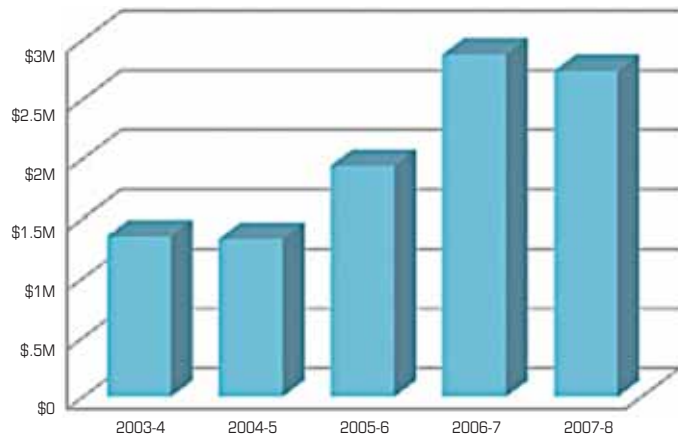
XIAONING SHAN

Frequency time domain system identification and its application to gasoline engine air fuel ratio calibration

TONGQUAN WEI

Energy efficient fault-tolerance schemes for multi-core hard real-time systems

RESEARCH EXPENDITURES



RESEARCH SUPPORT

The ECE department has high-impact research programs in the broad areas of sensing and imaging, wireless communication, communication networks, electric power and energy, and solid-state electronics. Our programs have been supported by several government and private agencies and corporations, including the National Science Foundation, the Michigan Initiative for Innovation and Entrepreneurship (MIIE), Boston Scientific Corporation, General Dynamics Land Systems, Minnesota Power Company, American Electric Power, Consumers Energy, the US Army Research Office, the US Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency (DARPA). External funding for our programs has grown by a factor of nearly eight over the past six years.

EXPLAINING EXPLOSIONS

CREATING THE TOOLS TO UNDERSTAND MATERIALS SCIENCE

FOR THE PAST SEVEN YEARS, Professor Warren Perger has been collaborating with researchers at Washington State University and MIT in an Office of Naval Research grant to understand how deformations in crystals ultimately lead to the initiation



▲ Warren Perger

of a shock and, consequently, a detonation. Researchers at Washington State are performing IR, Raman, and optical absorption studies of energetic crystals, MIT is performing femto-second resolution experiments of the shock to detonation transition, and Perger is computing theoretical predictions for these phenomena.

In other words, Perger is trying to find out why bombs blow up. It's more than an interesting theoretical question. If we understood the fundamental nature of explosive materials, life might be a lot safer for those who handle or are exposed to explosives, such as America's soldiers.

For instance, it's conceivable that one could work out a way to find an improvised explosive device and detonate it from a safe distance. "We'd really like to be able to say, 'Ah ha! There's an IED behind that door,'" said Perger, who is a professor of both physics, and electrical and computer engineering.

Perger hopes to figure out what happens in the trillionth of a second after an energetic material is subjected to impact and subsequently detonated. The team is also trying to uncover ways to detect explosives remotely.

Their work is being funded by a \$3 million grant from the Department of Defense Multidisciplinary University Research Initiative, part of a massive effort by the military to better understand energetic materials and use that knowledge to better defend against the type of warfare now being waged in Iraq.

Over the last seven years, the scientists have been investigating how some very energetic materials respond to pressure. "That's what happens when you hit it with a hammer or detonate it with a blasting cap," Perger explains. "We are interested in what happens during the initiation phase," the material's first response before detonation.

Explosives are metastable materials, meaning they aren't

perfectly stable. They are made up of stack upon stack of molecular crystals, like those in a chunk of rock salt but more complex. When you send a shock through a material in a metastable state, the crystals are squeezed together and the bonds between them break down and release energy—sometimes lots of energy.

What sets off any given explosive can be quirky. Some can be detonated from any direction. Some can be detonated with lasers. One particularly dangerous material, PETN, is made up of a very complicated crystalline lattice. "It has a weird property—you can hit it in one direction and it's stable, but will easily detonate if you hit it from another," Perger said.

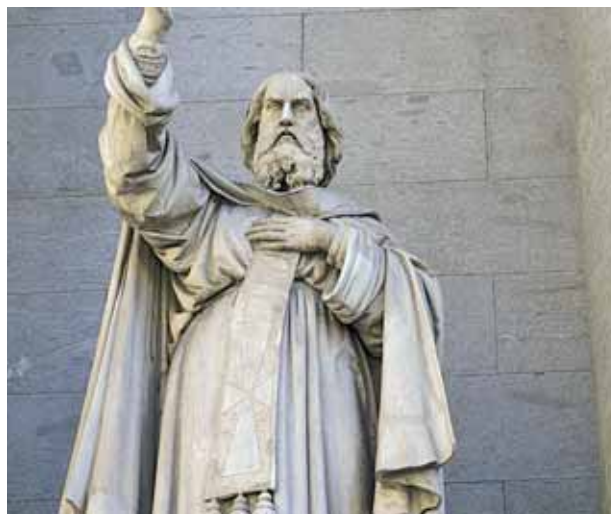
His mathematical models have made some remarkably accurate predictions.

Perger works only in unclassified areas. "I want to work in the light of day, with unrestricted publishing of my work. It's important to tell the world what you do. What I do is so basic," he says.

Perger was first recruited to Michigan Tech by ECE Professor Barry Kunz, who was involved in the research. When Kunz passed away in 2001, Perger continued on with the work.

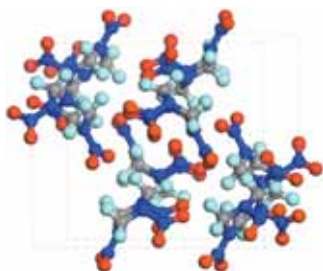
"Barry was a wonderful mentor. At first I wasn't sure how I could follow in his footsteps. He'd been working on this project for ten years. But I thought I'd try it for one year, to see how it went," Perger recalls.

He started by making calculations to determine material safety and longevity on a quantum mechanical level. "It's a calculation of Raman and infrared vibration frequencies. When



you start squeezing a system, those frequencies shift. The goal is to obtain information on how those crystals respond under pressure. It's also important to know why a material has particular properties in the first place," Perger explains.

To obtain that information, Perger realized that he needed to get inside a working group of software developers capable of doing the computation. Only a few such groups in the world are able to calculate the properties of crystals. One lab team at the University of Turin, in Italy, had created a software program able to predict the stability, storage and fundamental science behind mechanical deformation of energetic substances.



Cyclotrimethylene trinitramine, an orthorhombic structure with 168 atoms per unit cell.

In 2003, Perger spent a few weeks working with the Italian group. "I'm a firm believer—if you really want to understand something, you must become a part of it. It's especially important in science. As a result, you can predict the science with new ability. Otherwise it's frustrating to be on the outside looking in," he says.

Five years later, Perger is now one of the coauthors of the software, entitled CRYSTAL, and an adjunct faculty member at the University of Turin. "Roberto Dovesi, the lead researcher, is always encouraging and cooperative. Torino has become a second home to me. The borderless relationship is outstanding. We want this to be academic exchange and accessible to all," he adds. "It's a narrow field. The group has managed to stay small and nimble."

Perger is the only American on the research team at present. There is a researcher from Mexico, two from the United Kingdom, several Italians, and a Frenchman. Perger now speaks Italian, as well.

CRYSTAL software calculates the mechanical stiffness of a wide range of materials. "It is predictive materials science at a computational level," notes Perger. His work with CRYSTAL will soon be tapped at Michigan Tech. "It's a way to bring something really state of the art to campus—a platform to perform calculations routinely with little effort."

In another project, Perger is developing yet another computational method of understanding materials. To check the validity of his calculations, Perger analyzes bulk properties that are commonly measured, and measures his own calculations against those. "So far so good," he says. "We are lock step with our new method in terms of what's been published thus far. "

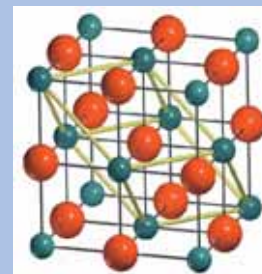
The focus is on the math behind it. "It's more of a numerical issue than a physics issue. There's also an art to it—picking and choosing what's important about a certain material. The path for carrying out the calculation depends on the material itself."

Utilizing the table of crystallography, Perger determines the "space group" or what structure it forms. "Right now we are working with large crystals. More important, though, are nano-applications," he notes.

"When it comes to atomic physics and condensed bulk matter, the in-between is a difficult no-man's land, but a challenge," he says. "It's not a world of pristine atoms and lattices. There are some great discoveries to come. We must first understand the bulk. If we can reproduce the bulk state, then we can go smaller, to nanoscale."

Right now Perger has a collection of analyzed materials—"not infinity, not a huge collection, not one, but some." One particular goal: a quasi lattice. "I'd like to take the science we've learned from bulk and keep dialing it down."

The CRYSTAL program was jointly developed by the Theoretical Chemistry Group at the University of Turin and the Computational Materials Science group in the Central Laboratory of the



Research Councils—one of seven national research councils in the UK. The program computes the electronic structure of periodic materials within Hartree Fock, density functional or various hybrid approximations. The Bloch functions of the periodic systems are expanded as linear combinations of atom-centered Gaussian functions. Powerful screening techniques are used to exploit real space locality. The code may be used to perform consistent studies of the physical, electronic and magnetic structure of molecules, polymers, surfaces and crystalline solids.

The general philosophy is to make the software developed available to the scientific community by periodically publishing well-tested and documented versions of the codes. For more information online, go to www.crystal.unito.it.

MICROGRIDS

THE FUTURE OF ALTERNATIVE ENERGY

"MICROGRIDS—POWER SUPPLIES FOR A COMMUNITY—are a good way to facilitate alternative energy," says Assistant Professor Wayne Weaver. "Microgrid technology will enable the future of reliable, distributed, efficient, and renewable energy



▲ Wayne Weaver

resources. The main challenge is keeping it stable. Right now microgrids are fragile."

The microgrid is a small, local interconnection of power sources and loads that may or may not have a connection to the larger electric utility system. A localized system, it leverages renewable energy resources like photovoltaics, fuel cells, batteries, and electric vehicles.

One key feature, a controllable utility connection, allows the microgrid to sell power back to the utility. That same connection can also be severed in order to preserve the stability of the local system, or to operate autonomously for extended periods of time.

Weaver, who researches power electronics, utility interfaces and microgrids, joined the faculty of the ECE department in January 2008. He holds PhD and MS degrees in Electrical Engineering from the University of Illinois at Urbana-Champaign. He is a licensed engineer in the state of Illinois.

After earning BS degrees in both Electrical Engineering and Mechanical Engineering from Kettering University, Weaver began his career as a research and design engineer at Caterpillar Inc., in Peoria, Illinois, where he worked in both the Cat Electronics and Technical Services divisions.

While in graduate school Weaver worked as a researcher for the US Army Corps of Engineers in Champaign, Illinois. He conducted research on microgrids, as well as distributed and renewable energy resources for military installations and forward base camps.

"Distributed and renewable energy technologies in military microgrids are a high priority not only because they are environmentally friendly," he notes. "They enhance energy security and saves lives by reducing the need for fuel convoys through hostile theaters of operation."

According to Weaver, some of the main challenges to be addressed with microgrids are utility connection and metering,

power source development and optimization, as well as control and coordination of energy resources. He recently started the Microgrid Research Initiative, which is affiliated with PERC—the Power and Energy Research Center at Michigan Tech. "We're working to address those problems in cooperation with the power industry," he says.

How long until the everyday person is tapped into a microgrid? "It ought to be five to ten years at least before actual implementation and broad impact. That's the nature of research—long range vision," he says, adding: "We're typically looking five, ten, twenty years out."

In addition, Weaver is researching ways to improve the utility grid. One of his goals is to create flexible AC transmission switches to alter the grid. Other areas of interest include power electronics, motors and microprocessors. "Microprocessors could be smaller and more powerful, and far more energy efficient than they are now," he says. "Server farms are becoming so dense and big. They have a hard time getting enough energy in, and wasted heat out. Every conversion step loses energy, which converts to heat." Weaver is



investigating methods to maximize the power density of server equipment while minimizing the generated heat.

Last summer Weaver mentored a Delta Community College student, Jesse Carmona, in conjunction with MICUP: Michigan College and University Partnerships. The program helps community college students transfer to a four-year institution through a six-week summer program that provides support for a positive and smooth transition. Carmona plans to transfer to Michigan Tech to study power electronics. "He is bright and inquisitive, with a lot of potential," says Weaver.

TWO-DIMENSIONAL ISI CHANNELS CALCULATING THE BOUNDARIES

MODERN TELECOMMUNICATION SYSTEMS have experienced rapid growth and evolution. Underlying the development and understanding of these systems is a common theoretical framework.

That framework is the mathematical discipline of information theory established by Claude Shannon in 1948. Traditionally, problems in communication systems are mostly one-dimensional in nature. Information theory has been largely



▲ Zach Zhao

directed toward the study of one-dimensional communication channels and waveforms, and how to demodulate those waveforms in noise.

However, new problems that are two-dimensional and even three-dimensional in nature have arisen in important applications.

Many of these problems are beyond the scope of the classical one-dimensional

information theory, and they form a new fertile and challenging area with strong connections to deep problems in both physics and mathematics.

Assistant Professor Zhijun (Zach) Zhao hopes to advance two-dimensional information theory. He is attempting to solve important two-dimensional communication problems, specifically detection and channel coding/decoding for two-dimensional intersymbol interference (ISI) channels.

Zhao hails from Beijing, China. He joined the ECE department in 2006, coming to Michigan Tech from the University of Illinois at Urbana-Champaign. He holds a PhD in Electrical Engineering from the University of Illinois at Urbana-Champaign, as well as a PhD in Solid Mechanics from Tsinghua University.

"ISI is a big problem that has been plaguing engineers since the telegraph age, especially for the past half century or more," notes Zhao. "We know the loose bounds. But we don't know the closer bounds yet. Two-dimensional information transmission has both theoretical and practical importance," he adds. "With today's digital communications, just about any channel will become an ISI channel when the data rate is high."

Zhao hopes to determine how large the capacity is for a given channel. His approach is to design and analyze new two-dimensional detection algorithms of low complexity and

high error performance. He works on pure theory, as well as simulations and math, including developing algorithms for ISI channel detection and coding.

One example of two-dimensional ISI: optical data storage. In current systems, data is put onto tracks. A guard space separates the adjacent tracks. "Just imagine an eight-lane highway," Zhao explains. "You don't want cars veering into each other's lane. The same goes for data. It needs to stay on its track. But what we don't know right now is how much room there needs to be between those tracks.

"Also, as we place tracks closer together, how much will the capacity increase? Then, once we have that knowledge, how do we use it in order to get the performance the information theory promises?"

This kind of channel appears quite often in wireless communications. "In fact, it is one of the core fundamental problems of communications research," says Zhao.

Only a handful research groups worldwide are working on the problem. "Different people try to solve it in different ways. But in a theoretical sense, everyone is looking at the same framework."

Zhao's approach is to look at the problem by relaxing or modifying the exact formulation to design lower complexity algorithms that achieve near optimal performance. "Then, during iterations, we tighten it up, applying constraints little by little," he adds.

"It's a hard problem, which is exciting for me. I admit it's not for everyone. It could take a year to solve, or it could take a lifetime."

The problem is also present in math (Markov Fields) and physics (Ising problem). "When advancements are made, they will be utilized broadly," Zhao notes. "We see the links. One possible direction of research is to study those problems, then go back and solve ours, or vice-versa."

Zhao is working on several areas of research at Michigan Tech, including communications, signal processing, and information theory and coding.



ISI-corrupted and noise-contaminated channel output

TRANSFORMING TRANSFORMERS IMPROVING WIND ENERGY CONVERSION

ELECTRICAL ENGINEERING PROFESSOR Bruce Mork is working to develop improved computer modeling tools for high-voltage power transformers—an aging and vulnerable part of the power infrastructure.

Mork and his research team have spent the past few years developing advanced computer simulation models as part of a transformer performance project funded by a large European research consortium.

Initially a three-year endeavor, the project has been extended another two years. The consortium consists of the Research Council of Norway, ABB (Sweden's GE), EDF (Electricity de France, the French national power company), and several European corporations including Statnett, Statkraft, and Nynas Naphtenics. Michigan Tech and the Norwegian Electric Power Research Institute are conducting the research.

Transformers convert electrical energy between voltage levels and also electrically isolate the input and output. "Transformer technology is a proven technology with recent development related to advanced magnetic materials and

dielectrics," notes Mork.

A transformer works traditionally with 50 or 60 Hz and sinusoidal voltages and currents, with efficiency in the range of 98 percent and above.

"There is a huge need for simulation tools which correctly predict transformer behaviors. Since 'what if' scenarios cannot be tested on the actual system without risking damage and

blackout, simulation tools are vital," Mork explains. "Our goal is to extend their operational life, as well as delay or avoid unexpected failure."

Another project seeks to improve wind energy conversion



using high-frequency transformation and DC collection. The focus area involves individual wind generators in larger wind farms including offshore applications. The work is founded on an international cooperation between the Norwegian University of Science and Technology (NTNU) in Trondheim—known for its excellence in power electronics and power transformer research—and Michigan Tech, with international expertise in transformer modeling and power system protection.

Researchers will explore the combined use of a wind farm HVDC series collector and a high frequency energy conversion system. To facilitate wind power integration, they will try placing a lightweight, high frequency converter-transformer device



Front view of a windmill rotor hub, with nacelle behind

in the windmill nacelle—which sits on top of the tower. The nacelle includes the gearbox, main and small shafts, generator and brake, with a cover that protects the components within.

Generally, in a wind power system there are combinations of power electronic solutions for converting energy from the wind generator and transformers, stepping up the voltage, and supplying the connecting grid.

"In order to reduce weight, size, and cost of the power converter in a wind turbine, a high frequency transformer could be the solution," says Mork. "It would work in combination with new converter types and an efficient HVDC approach, where wind generators are connected in series."

This first requires fundamental research on the behavior of the transformer at frequencies in the range of 500 Hz to 10 kHz. "Transformers at 400 Hz are used today in ships and airplanes to save space and weight, but to go above 1 kHz requires new solutions both regarding core material and handling of capacitive effects," he adds.

POWER AND ENERGY RESEARCH CENTER (PERC)



Drs. Bruce Mork, Leonard Bohmann and Wayne Weaver, with twelve of their graduate student researchers

PERC is a cross-disciplinary organization focusing on electrical energy, energy conversion, and related technologies and issues.

Federal funding has come from the National Science Foundation and the Department of Energy.

The Center recently welcomed two new industrial partners: Lawrence Livermore National Labs, and Schweitzer Engineering Laboratories, Inc. Other partners include Consumers Energy, American Electric Power, and ITCTransmission.

Wayne Weaver, assistant professor of electrical engineering, recently joined the PERC research team. Weaver came to Michigan Tech in January 2008 from University of Illinois at Urbana-Champaign (see page eight). He will head up PERC's microgrid research initiative.

Other news at PERC:

- New labs in power system protection (relaying), power electronics, and motor drives
- Ongoing research collaboration with Norway
- Four additional online electric power courses and two new power systems certificate programs (more info at www.ece.mtu.edu/RemoteMSEE)
- Renewable energy research initiatives in photovoltaics, windpower, and microgrids

For more information about PERC, check out www.ece.mtu.edu/perc

LASER COMMUNICATIONS EXTENDING USE AND RANGE

IT IS NOT ALWAYS POSSIBLE to run wires, fiber optics, or cable. If your setting is inaccessible—atop a mountain, out on a drillings rig, or at a remote international weather station, for instance—and you need to transmit photos, videos, or other large data files, you're mostly out of luck.



▲ Mike Roggeman

Laser communications, essentially wireless connections capable of transmitting bandwidth-intensive imagery through the atmosphere, could soon change all that.

Professor Mike Roggeman is investigating how turbulent outdoor conditions affect the real-world performance of laser communications. His goal is extend their range and understand their performance in any kind of weather. Michigan Tech's north woods location on Lake Superior is uniquely suited to the job. "We've got it all here—remote locations, blizzards, thunderstorms, heat waves," he notes.

Roggeman and his research team, including Assistant Professor Zhijun (Zach) Zhao, have developed a laser communications testbed to evaluate adaptive optics algorithms, installing it atop an eight-story building in the nearby city of Hancock. The system directs a laser beam 3.2 km to a receiver located on the roof of the Dow Building on the Michigan Tech campus. They will spend the next few years monitoring atmospheric turbulence, scattering, and weather to understand how such factors fluctuate in the real world.

"Free space laser communications systems send lasers through air. The problem is, it's not really free space—we have air, not a vacuum," notes Zhao. Atmosphere changes and turbulence can make the laser beam wander.

The result is channel fading, sometimes deep channel fading. "If it goes down too low, the communication link could be broken. We're looking at how to solve this problem and make laser communications more stable and reliable—and achieve the highest possible channel capacity," he adds.

The team uses adaptive optics (AO) on the transmitter in order to steer and focus the laser beam on the receiver aperture. "AO is one way of combating the fading problem. We control micromirror arrays so we can compensate for the wandering beam and broadening," Zhao explains. The result is less fluctuation, which reduces fading. Another benefit has been increased received average optical signal power.

"You can use coding techniques to achieve higher capacity and more reliable communications," says Zhao "We use AO devices (hardware) and coding (software). Neither will solve such a complex problem alone, so we combine them to determine how much of each to use."

For coding, the team also looks at theoretical improvements. They are looking at soft decoding and iterative coding techniques for the free space optical communications channel.

Their web-based interface also allows researchers around the country to plan and execute experiments remotely, and obtain data for their own uses.



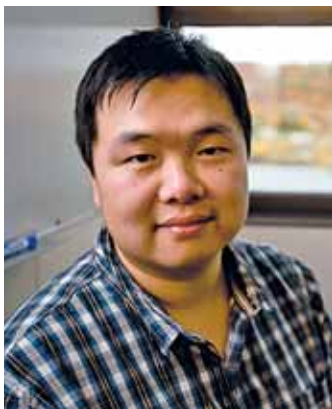
An image of the target taken via telescope from about 3km. Image analysis provides some characterizations of turbulence over the long path.

VLSI CIRCUIT DESIGN

PUSHING THE BOUNDARIES WITH DISCRETE MATH

AS VLSI TECHNOLOGY ENTERS THE NANOSCALE regime, chip design becomes increasingly difficult.

"Progress in this area faces several limiting factors: the fundamental interconnect limit, variational effect, and lithography-related manufacturability," explains Assistant Professor Shiyan Hu. "These emerging issues for next generation integrated circuit designs require ultra-fast and high-quality



▲ Shiyan Hu

solutions. Advanced algorithms for large scale optimizations need to be used and invented." Hu seeks to address these difficult design automation problems through his research on the computer-aided design of nanoscale circuits and combinatorial optimizations.

Hu joined the faculty of the ECE department this past fall. He comes to Michigan Tech from Texas A&M University, where he earned a PhD in Computer Engineering. In 2007, he spent seven months at the IBM Austin Research Lab working on the company's chip physical layout design flow. Some of his work, such as slew buffering, has been utilized in IBM chip design flow. The collaboration with IBM continues.

"Since childhood I've been very intuitive. I've always loved discrete mathematics. The problems are very easy to describe, but very hard to solve," notes Hu. "Right now I am more or less a mathematician, working with combinatorial optimization theory. But there's always an element of engineering. There's got to be a balance between the practical and the pioneering aspects of the work. I am continually looking for the potential applications of profound theory."

Even so, some of Hu's work is purely theoretical. "Most engineers don't think about discrete math all that much when it comes to VLSI circuit design. My goal is to get it to run fast and still get good quality," he says.

VLSI is the process of creating integrated circuits by combining thousands of transistor-based circuits into a single chip. VLSI began in the 1970s when complex semiconductor

and communication technologies were being developed. For instance, the microprocessor chip is a VLSI circuit. As chips have increased in complexity into the billions of transistors, VLSI technology is approaching its limits.

"In order to tackle the fundamental physical limits of CMOS transistors, the world needs innovative devices," notes Hu. "The utilization of these devices certainly requires the corresponding new design techniques. There is an especially pressing need for high-performance computer-aided design techniques that address nanoscale circuit design challenges. If there's no existing approach, we'll create a brand-new one."

His recent research is focused on designing ultra-fast algorithmic techniques for large-scale design optimization problems. His goal: to devise innovative, ultra-fast, provable algorithms in timing optimizations on VLSI interconnect including buffer insertion, layer assignment and nontree-based routing. Another area of effort is novel combinatorial robust optimization techniques on manufacturability-driven VLSI detailed placement. Hu is also involved in simultaneous logic and clock optimization using robust mathematical programming techniques to address the IC variability subject to power constraints. Another innovation is twisted differential line structures in VLSI low-power high-speed bus design. Last but not least, Hu has developed a novel gate sizing approach integrating mathematical programming and dynamic programming techniques.

Hu has published over forty journal and conference papers including those in *IEEE Transactions on CAD*, *IEEE Transactions on VLSI*, *DAC* and *ICCAD*. Hu's research has been cited by numerous research groups, including the University of Michigan, University of Texas at Austin, Northwestern University, University of California San Diego, University of Wisconsin at Madison, the University of Waterloo, and ETH Zurich—as well as leading chip-makers IBM and Intel.

"There are three important elements that make life good—challenge, freedom, and students," he says. "Here at Michigan Tech I've got flexibility. I feel free to choose highly challenging projects. I can join the pioneering work with the practical," he adds.

"I also chose Houghton because Texas was too hot—it was 105–110° F eight to ten months out of the year!" According to Hu, the weather in Houghton is just fine, despite the snowy winters. "Here you just need to wear more. It's a great place to do the research."

MATT WOLFE AWARD WINNER MANORANJAN ACHARYA

DOCTORAL STUDENT MANORANJAN ACHARYA received the Matt Wolfe Award as the Outstanding Graduate Research Assistant for the 2007/2008 academic year. He was presented with a plaque and a cash award of \$500.

Acharya is from the remote town of Athgarh in eastern India. He completed his BS degree in electrical engineering in 2002 at Berhampur University, in Orissa, India. After that he joined a power distribution company (BESCOM) in Bangalore, as a technical manager. He arrived at Michigan Tech in the fall of 2005.



▲ **Manoranjan Acharya**

Associate Professor Paul L. Bergstrom and others to develop room temperature operating single electron transistors by focused ion beam (FIB) processing. Bergstrom's team has demonstrated the first operating SET of any kind accomplished with focused ion beam technology, the second demonstration of room temperature SET behavior in the US and sixth in the world.

"Manoranjan's contributions toward our understanding of both the fabrication technologies and the mechanisms of room temperature behavior for our SET devices has been outstanding," says Bergstrom. "He has followed on the excellent work of Dr. P. Santosh K. Karre, another Matt Wolfe Award winning doctoral student, who initiated the technological development on the room temperature SET at Michigan Tech. Manoranjan has significantly contributed toward our expanded understanding of these devices and technologies. He has developed the smallest linewidth reported by FIB etching for these devices at 17nm, and has been instrumental in developing a more complex two dimensional conduction model to explain the device behavior at room temperature. He has been a very productive scholar, an independent researcher, and a pleasure to work with. He will be missed but will represent our group very well in his new role at Intel Corporation."

"Achieving repeatability in the FIB based process flow has been a challenge," adds Acharya. "We are among the few

groups who have achieved a sub-20nm line width nano-gap using FIB etching. However, in order to obtain the repeatability in such low dimension range, we had to make a lot effort to optimize the process."

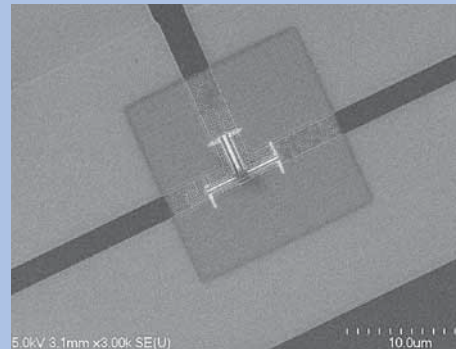
The most interesting aspect of the work? "Comparing the data obtained and analyzing it theoretically," he says. "It is fascinating to see how device behavior can be improved by optimizing the structural parameters."

Apart from studying, Acharya loves to play piano and harmonica. He will complete his PhD in January 2009.

Matt Wolfe, a 1992 BSEE graduate and master's candidate in electrical engineering, was tragically killed in an automobile accident during his second year of graduate study.

SINGLE ELECTRON TRANSISTORS (SET)

Paul L. Bergstrom leads the team that is developing technologies and device physics for charge- and non-charge-based nanoelectronic devices, including the SET. In addition to Matt Wolfe Award winner Manoranjan Acharya, two other current doctoral students, Daw Don Cheam and Madhusudan Savaikar are engaged in the work along with Bergstrom. P. Santosh K. Karre, Bergstrom's former student, led off the work well using FIB for SET devices, and is now working on sub 32nm FET technologies for Intel Corporation.



A sub 20nm single electron transistor, located at the center of three T-shaped electrodes

DYNAMIC SPECTRUM ALLOCATIONS

THE FUTURE OF COGNITIVE RADIO

COGNITIVE RADIO (CR) IS INCREASINGLY recognized as an emerging disruptive technology for alleviating today's spectrum scarcity problem.

Associate Professor Zhi (Gerry) Tian is working to solve that scarcity problem with a new paradigm of CR networks. "CR communications and networking hold great potential to drastically enhance spectrum utilization efficiency," says Tian.

Radio frequency (RF) spectrum is an increasingly valuable resource tightly regulated by governments—the US and UK governments raised \$17 billion and \$22.5 billion respectively in their auctions of third-generation mobile phone licenses.

"On the other hand, radio access technologies are currently built on fixed spectrum allocation, which causes severe spectrum underutilization when dedicated spectrum is idle," notes



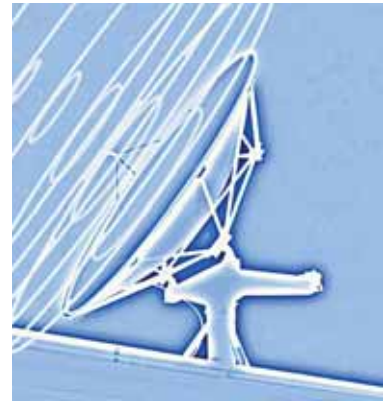
▲ Zhi (Gerry) Tian

Tian. For instance, one recent study showed the average spectrum occupancy of all bands from 30MHz to 3GHz measured in New York City was just 13 percent during a peak period. "The imbalance between spectrum scarcity and spectrum underutilization is especially undesirable today, when significant amount of radio spectrum is needed to provide ubiquitous wireless high-speed connectivity," she adds. "Dynamic spectrum allocation, in which network users opportunistically gain wireless access to frequency bands without causing harmful interference to incumbent users, could be the answer."

The emerging paradigm of Dynamic Spectrum Access (DSA) shows promise to alleviate today's spectrum scarcity problems by ushering in new forms of spectrum-agile cognitive networks. Key to this paradigm are cognitive radios that are aware of the radio frequency environment and can dynamically program radio parameters to efficiently utilize vacant spectrum without causing harmful interference to authorized users.

The Federal Communications Commission recently released a Report and Order to usher in a pilot program for open spectrum access.

But CR research today is still at a conceptual stage. "While a key hindrance in programmable radio design has been the front-end circuit interface, the emerging open access paradigm brings up new technical challenges," says Tian.



"It's important to dynamically manage network resources in the presence of harsh time-varying wireless environments, but it is crucial."

Tian seeks to advance the fundamental research on core CR issues at the physical layer. She is systematically investigating algorithms for efficient spectrum management in CR networks. She is conducting fundamental research to cope with major hurdles in spectrum sensing, programmable radio platform and adaptive dynamic spectrum allocation. And, by exploring compressive sampling, she hopes to develop effective signal processing techniques that exploit various elements of sparsity inherent to CR networks.

"All these indispensable elements of cognitive radio can be integrated to develop a generalized signal design framework, which will lead to intelligent and agile radio cognition at tractable complexity."

Tian uses analyses, simulations and network testing to fully optimize system design.

In collaboration with ECE Associate Professor Chunxia (Tricia) Chigan, Tian will build a software-based simulator for CR network performance evaluation, which will be disseminated as shareware to the public.

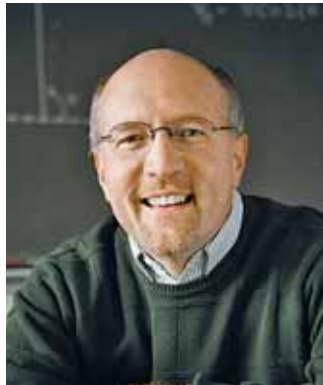
"Development of the open spectrum paradigm will lead to unprecedented network capacity, allowing a multitude of new CR wireless transceivers with Quality of Service (QoS) guarantees," notes Tian. Devices include wireless sensors and RFID chipsets for monitoring and tracking applications, as well as wireless telemedicine radios for remote healthcare and emergency response—"all of which will certainly have an impact on our quality of life."

OUR NEW CHAIR

DANIEL R. FUHRMANN

DANIEL R. FUHRMANN ACCEPTED a three-year appointment as the chair of the Department of Electrical and Computer Engineering, beginning September 1, 2008.

Fuhrmann comes to Michigan Tech from Washington University in St. Louis, Missouri, where he was a faculty mem-



ber in the Department of Electrical Engineering (now Electrical and Systems Engineering) for the last 24 years. He was also a research associate in the Biomedical Computer Laboratory and the Genome Sequencing Center, both part of the university's School of Medicine.

In addition, he was an ASEE Summer Faculty Fellow at both the Naval Underwater Systems Laboratory and the Air Force Research Laboratory and a Fulbright Scholar at the National University of La Plata in Argentina.

Fuhrmann's research and teaching interests are in statistical signal and image processing and related topics. The author of more than 100 technical papers, he is best known for his contributions in array signal processing, including structured covariance estimation, array calibration, remote sensing, subspace tracking and space-time adaptive processing, all areas that involve processing data from multiple-sensor systems.

His experience with the mathematical modeling and statistical methodology that are central to his research interests also served him well when he developed software that made possible the first automated analysis of electrophoretic gel images collected in DNA fingerprinting.

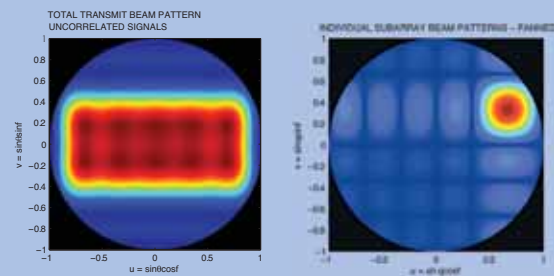
An Eta Kappa Nu Outstanding Professor award recipient, Fuhrmann has taught undergraduate and graduate courses in introductory electrical and computer engineering, communication theory, signal processing, probability and stochastic processes, and statistical signal processing. He is a Senior Member of the IEEE, and in 2006 he was a distinguished lecturer at the IEEE Workshop on Sensor Array and Multichannel Processing. Fuhrmann has been an associate editor for the IEEE Transactions on Signal Processing, technical program chairman for the 1998 IEEE Workshop on Statistical

Signal and Array Processing, publications chair for the 2002 Workshop on Genomics, Signal Processing, and Statistics, and general chairman for the 2003 IEEE Workshop on Statistical Signal Processing. He has been a consultant for MIT Lincoln Laboratory and for local industry in St. Louis.

He received his BS in Electrical Engineering from Washington University in 1979, his MSE from Princeton University in 1982 and his PhD in Electrical Engineering and Computer Science from Princeton in 1984.

Professor Fuhrmann is married and has three children. His hobbies include music (he is an accomplished jazz and salsa pianist), hiking, and bicycling. In Houghton he sees no choice but to develop an interest in winter sports.

NEXT GENERATION RADAR



Fuhrmann brings to Michigan Tech active research programs in adaptive sensing and multiple-input multiple-output (MIMO) radar systems, with funding from the Office of Naval Research and the Air Force Research Laboratory.

"One feature of radar is that it allows the user to gather a lot of information buried in the signals that come back. That is a basic principle," he explains. "But here's what's new—people are adding more and more levels of complexity to the transmitted signal in order to get more and more info in return.

"We are basically shining a very intelligent flashlight, which sends energy where you want it to go, and not where you don't," adds Fuhrmann. "With new radar systems, multiple signals work together, cooperating, synchronized, all seeing reflections from the other flashlight signals."



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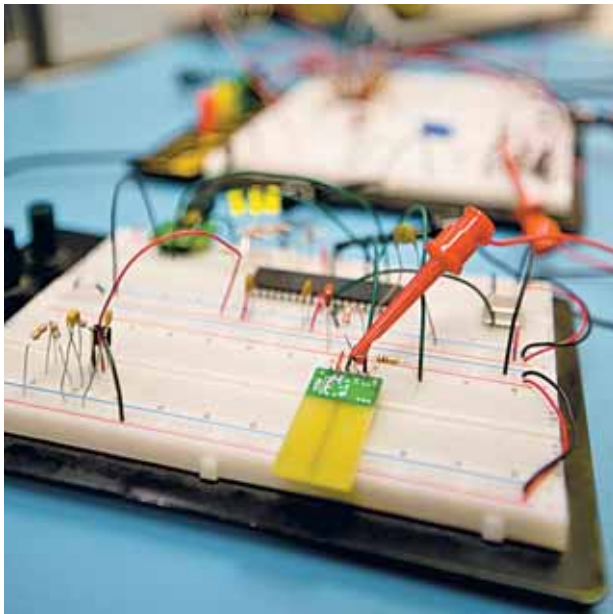
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WIRELESS COMMUNICATIONS ENTERPRISE (WCE) WIRELESS EEG

THE WCE TEAM IS DEVELOPING a wireless EEG (electroencephalogram) machine for use with children.

"Right now, EEG involves the placement of approximately thirty electrodes on the skull, connected to a base station with wires," explains electrical engineering student Richard Preena, WCE operations officer. "The current setup, combined with the duration of the testing, is often frightening to children."

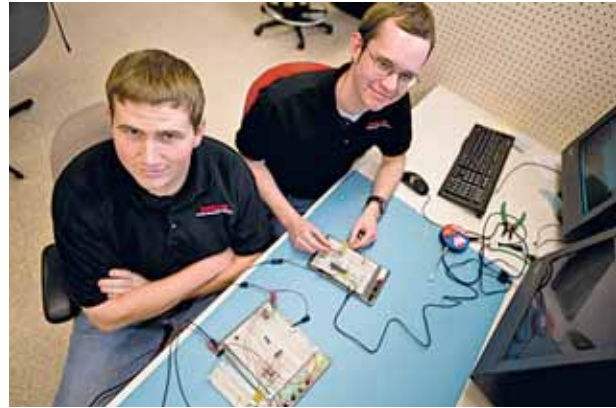
WCE will integrate twenty-one sensors to form a functional unit. Individual wireless sensors will connect to a base station for display of the data.



The team has determined the best use of a "floating" ground, along with ultra-small wireless microcontrollers, DSP (digital signal processing) filter design, and signals on the microvolt level.

"The most challenging aspect of this project has been transmitting, receiving and regenerating the digital signal without error," notes Preena.

The team is also developing software to display EEG test results, using DirectX for the graphical portion. Once the functional unit is complete, they will perform the first phase of human testing on WCE team member volunteers.



The project sponsor, Mr. Patrick Eddy, has ties to Spectrum Health. "The idea came about as a result Mr. Eddy's own experience working with children," adds Preena.

WCE creates wireless, optical, and biomedical solutions. The enterprise operates as a virtual company with students holding leadership positions at the project and executive level, with as many as twelve different teams working during a semester. Team sponsors include Boston Scientific, Roehl Transport, Mr. Patrick Eddy, and the Chrysler Foundation.

AUTOMOTIVE COMPUTING ENTERPRISE (ACE) CARPUTERS

ACE IS A NEWLY FORMED ENTERPRISE team, which aims to simplify human-automobile interaction through hardware and software development and integration.

ACE is using a 2007 Chevrolet Suburban donated by GM for development and prototyping. "Our fundamental goal is to develop a strong and expandable base that future ACE students

can use to access information from the vehicle, but easily incorporate other personal electronics (PDAs, iPods, cellphones etc.) into the main vehicle console," explains electrical



engineering student Matt Rose. "We also want to create user interfaces quickly so as to not hinder the development process," he adds.

Rose, together with fellow student, Max Leason, founded the ACE team. They discovered during their freshman year that both were interested in cars and the computer systems that govern so much of their behavior today.

GM provided not only the Suburban, valued at more than \$30,000, but also an additional \$20,000 in start-up funding



and regular access to the advice of two Michigan Tech alumni, Will Poirer and Chris Winegarden, computer systems engineers at GM.

ACE's enterprising students work in two teams. One has embedded an ITX PC in the Suburban which is connected to the truck's on-board CAN network. "Using software that the team has developed, you can interface with most functions of the vehicle—from door lock actuators to engine sensor outputs," notes Rose. Students are also developing integrated CAN enabled modules to add custom functionality to the truck.

The second team is working to design and implement a customizable LCD graphical interface to replace the current vehicle instrument cluster. The design is based on a simple Intel notebook platform with a 15.4" LCD panel.

"Ultimately, the user will be able to select the gauge type, style, size, color and position for comfort and personal expression, says Rose.

"We're mapping out as many vehicle functions as possible so that future software developers for ACE will be limited only by their imaginations."

BLUE MARBLE SECURITY

PROJECT ROACH

MANY LIVES HAVE BEEN LOST in past and current military conflicts due to bad intelligence or lack of visual identification of one's surroundings. Blue Marble Security's latest invention, the Remote Optical Advanced Camouflaged Hound (ROACH) is a surveillance device that will aid in the inspection of environmental surroundings when additional support is limited or nonexistent.

"When it is complete, the ROACH will be a remote-controlled drone small enough to fit into a backpack and simple enough to deploy in seconds," explains electrical engineering student Paul Bauman, Blue Marble Security project engineer.

The Roach will be equipped with environmental sensors and wireless video transmission. It will utilize radio communication technologies, high tech composite materials, and servo motor drives.

The largest obstacle for the team thus far has been size versus cost. "In order to get the small size that we want, the cost goes up exponentially," he notes. "As of this moment, though, we have found a delicate balance."



Project ROACH is in search of a sponsor. "We are looking for funds, which would enable us to reach the small size that was originally conceived for the project," says Bauman.

Blue Marble Security is a virtual company/Enterprise team focused on securing the future through thoughtful use of technology. The team has eleven projects under way in areas of security, the environment, and industrial process control. Sponsors include General Dynamics Land Systems, Superior Diesel, General Motors Foundation, and Mr. Aaron Ellison.

**INTEGRATED
MICROSYSTEMS
ENTERPRISE (IME)
ROADBED ASSESSMENT
TRANSMITTER**

"IME IS INVOLVED IN SEVERAL CHALLENGING projects," says electrical engineering student Justin Ayers, who serves as president and chief executive officer of the team.

Under development is the Roadbed Assessment Transmitter (RAT), a wireless device that can be implanted into asphalt



and concrete roadbeds in order to transmit valuable data to road workers. "Sensors will collect pressure, temperature and moisture content—all of which are important in the pavement industry," Ayers explains.

IME's RAT engineers are also using a CC1110 development kit to read temperatures from an external sensor, as well as transmit temperature data wirelessly between development kits, design a prototype circuit board, and create a rudimentary wireless protocol for transmitting/receiving temperature data.

In another project, IME formed a joint team with the Blue Marble Security Enterprise to work on a motion sickness test for General Dynamics Land Systems. Participants rode in the M113 Armored Personnel Carrier, and tests were conducted to determine their level of motion sickness. Statistical analysis will be run on the data.

IME investigates and applies microsystem technologies to real-world engineered systems. Sponsors include General Motors Foundation, Chrysler, 3M, American Axle and Manufacturing, Cummins, Inc., Trijicon, Inc., V.I.O Inc., General Dynamics Land Systems, and Alcoa, Inc.



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