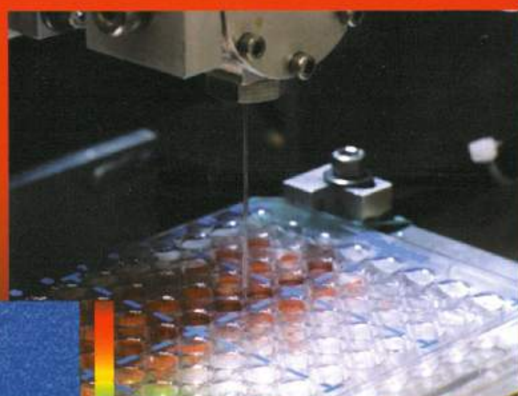
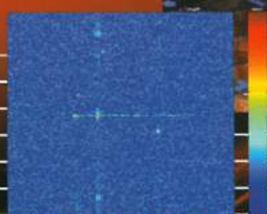
EEK 2001

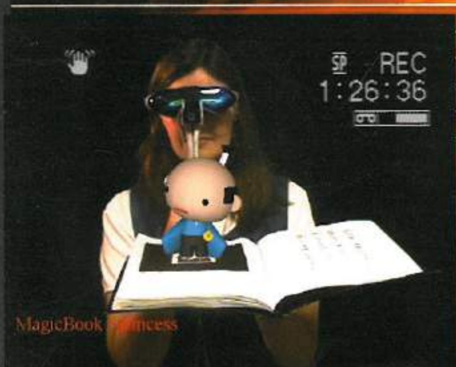
ANNUAL RESEARCH REVIEW

Electrical Engineering Kaleidoscope

A PUBLICATION OF THE ELECTRICAL ENGINEERING DEPARTMENT UNIVERSITY OF WASHINGTON







GENOMATION
The Machines Making It Possible

ON SPEAKING TERMS
Researchers Get People and Internet Talking

THE LONG HAUL:
Multistatic Passive Radar

FROM FANTASY TO REALITY
HITLab Puts "magic" in Magic Book

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EEK 2001

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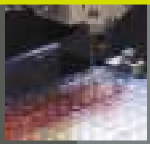

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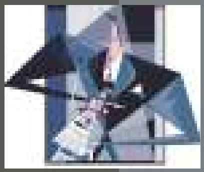

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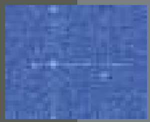

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THINGS THAT MAKE YOU GO EEK

Welcome to the inaugural edition of EEK—the *Electrical Engineering Kaleidoscope*, our answer to the conventional annual reports that most EE and ECE departments produce. Published annually by the University of Washington Department of Electrical Engineering, EEK includes standard annual report material, but mostly as "advertisements" amidst the articles. EEK magazine is intended to be interesting and informative, highlighting many exciting research and educational activities of our faculty, staff, and students. EEK is also an example of inter-departmental cooperation in the College of Engineering at the University of Washington. The editor-in-chief and author of most of the magazine's content is Mary Ann Krug, an M.S. candidate in the Department of Technical Communication. This publication is a part of her graduate work. My sincere thanks to her and to the Department of Technical Communication for their efforts in bringing this idea to fruition. Thanks also to our sponsors who have generously provided support to allow for the high production values of this document. Enjoy!

— Howard Chizeck,
Professor and Chair
Department of Electrical Engineering

This is the inaugural issue of EEK, an annual publication for friends of the UW EE Department. Letters to the editor are welcome. Please send to: eek@ee.washington.edu

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GENOMATION:

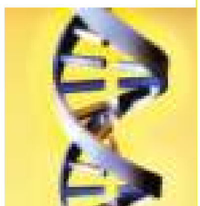
The Machines Making it Possible

M.A. Krug

Imagine wanting to conceive a child, but being afraid of passing on a genetic disease that runs in your family. What if you could give a blood sample to your doctor, and have your greatest fears dissipated or confirmed by the end of the day?

If Deirdre Meldrum and the Electrical Engineering Genomation Laboratory have their way, such scenarios will be a reality. Professor Meldrum oversees the development of ACAPELLA, which she describes as, "A general purpose chemistry analysis system. Our first application is for large scale DNA sequencing for the human genome project." The project is intensely multi-disciplinary, combining cutting edge research from engineering and molecular biology. The project involves four departments and industry partners Orca Photonics Systems, Inc. and Engineering Arts. Meldrum hopes one day automated sample preparation instruments and sequencers will be standard equipment in research laboratories and doctor's offices.

A high-resolution map is similar to what you get when you go to the automobile club and ask for a trip ticket: an actual map with your current and desired destination, detailing direction and exact distances of everything in between.



The next generation ACAPELLA-5K automated sample preparation instrument.

DNA sequencing is a multi-step, time consuming process. First, DNA samples must be extracted and purified from standard cell lines scientists have used for years (no specific individual or group is being sequenced). Next, molecular scissors called restriction enzymes cut the genomic DNA up into pieces tiny enough to work with. Many copies of the pieces are made, either by inserting them into single celled organisms and letting them grow (cloning), or by using enzymes that synthesize DNA (PCR amplification). When enough copies are made, samples are loaded into a gel and separated by an electric field. After separation, the exact order of the bases (sequence) can be read.

The Human Genome Project is currently undertaken by numerous entities, ranging from universities to private companies and institutes. Most have customized the process with a combination of manual and automated steps, depending on individual resources and sequencing needs. However, very few attempts have been made at reducing the fluid volumes of the molecular biology reactions.

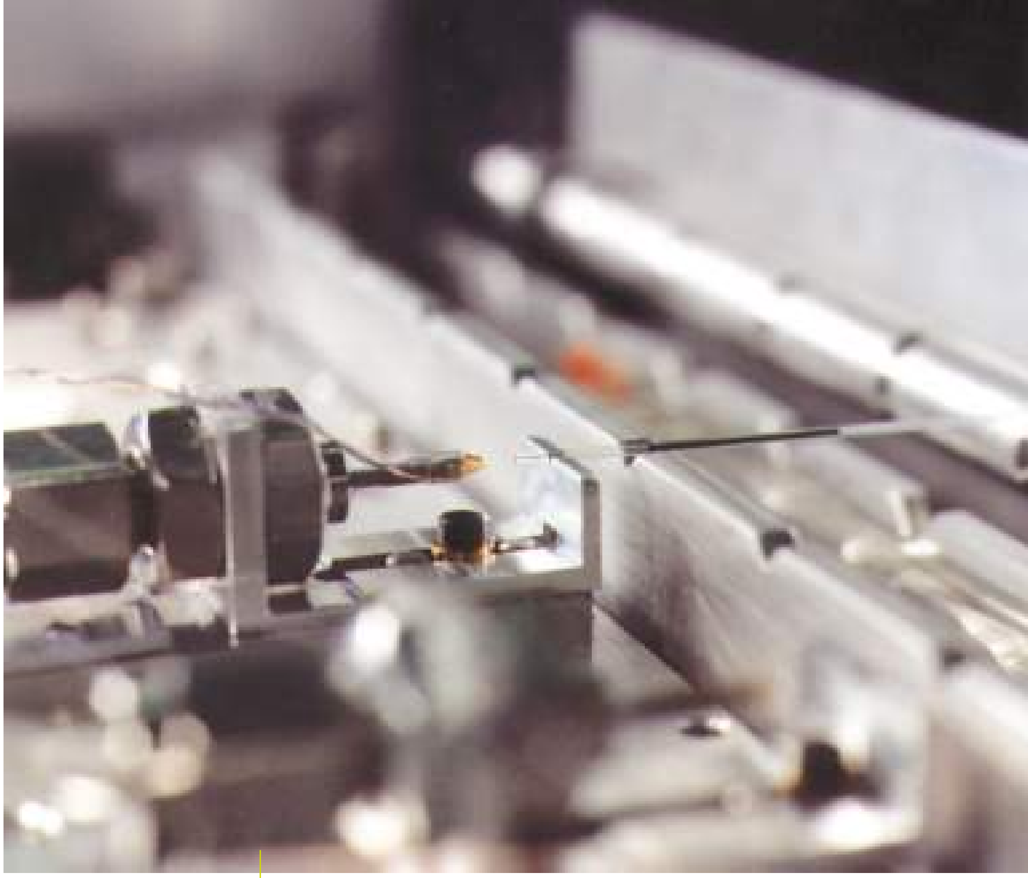
The idea to incorporate short capillary tubes or "microcaps" into the design was the contribution of Dr. Maynard Olson, Director of the UW Genome Center, and a big reason for ACAPELLAs early success. Capillary tubes resemble hollow glass toothpicks with fluid volumes on the order of a few microliters (millionths of a liter), and possess several advantages over standard microplates, used within current sample preparation instruments and commercial sequencers. The biggest advantage is that capillary tubes reduce the total volume of expensive reagents and precious samples required for the chemical reactions. This results in a reduction of material costs, as well as costs associated with preparation of DNA samples for sequencing. Another big advantage is the reduction of required reaction time: the reduced volume requires only 15 minutes thermal cycling time, as opposed to 1.5 hours for standard microplate volumes, which increases throughput dramatically.

The Human Genome Project began in 1990 with a 15-year project plan and a $3 billion dollar budget. Among its many objectives was mapping the human genome, estimated to contain 50,000-100,000 genes consisting of 3 billion base pairs. At the projects' inception, sequencing costs ranged from $2 to $5 per base. Put another way, that's $15 billion dollars to sequence the entire human genome, or 5 times the total initial budget. Wisely, project architects incorporated funding for lowering costs into the mission statement. Their initial goal was to bring costs down below a $1 per base pair. If that proved unfeasible within a certain time frame, the human genome project would be terminated. ACAPELLA-1K, the first prototype, processes 1000 2 micro-liter samples in an 8 hour day. ACAPELLA-5K, the next generation machine, will process 5000 2-microliter samples in an 8 hour day, at a projected cost of less than ten cents per base.

The June 2000 joint announcement by the NIH and Celera Genomics that a "draft" sequence of the human genome was completed did not diminish interest in capillary-based sequencing. Meldrum received an $8 million National Human Genome Institute Research Grant to proceed with ACAPELLA-5K, currently under development. Meldrum also received an additional $2 million from the NIH National Cancer Institute to develop a real-time quantitative thermal cycler module for ACAPELLA-5K. The thermal cycler will test for minimal residue disease such as cancer by detecting just a few molecules present in a patient sample. Meldrum's collaborator is Professor Daniel Sabath in the UW Department of Laboratory Medicine.

"Our instrument isn't used for large scale sequencing yet–we're trying to get it to a stage where it is." Meldrum explains.

The draft sequence Celera produced was generated by the "shotgun" approach. Scientists chopped up human chromo-

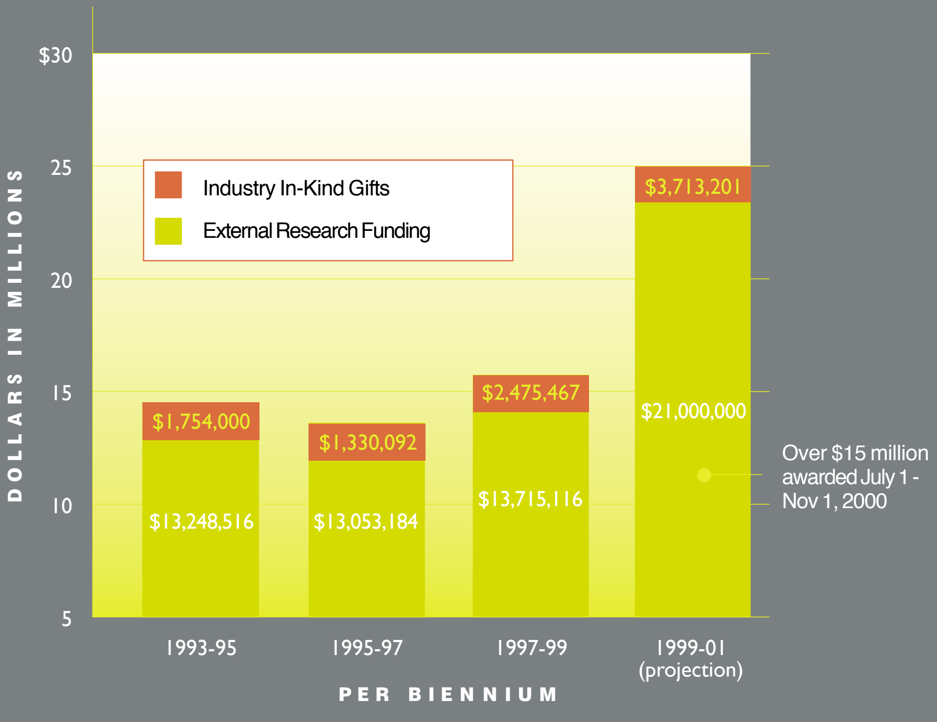


Pizoelectric actuator used to dispense biochemical reagents into "microcaps" on ACAPELLA-5K.

BIENNIAL EXTERNAL RESEARCH FUNDING

(July 1st to June 30th)

Externally funded research has grown from $13.5 million during the 1997-1999 biennium to an estimated $18-23 million during the 1999-2001 biennium. Currently, our annual research funding is approximately $11 million, and increasing. Approximately 50% of our funding comes from federal sources.



The high demand for electrical engineers and rapid changes in the field generate extraordinary challenges and opportunities for university research and education. The Electrical Engineering Department at the University of Washington is extremely well positioned to meet these challenges and to make significant contributions for positive change. Our department is in the midst of a period of dramatic growth and positive change. Since August 1998 we have grown through the addition of 13 outstanding new tenure track faculty and several research faculty. External research support for the department has increased from approximately $7 million per year to over $11 million per year. With this growth in research funding comes extraordinary new opportunities for our faculty and, most importantly, for our students. In early 2001, the old Electrical Engineering Building will be demolished, to make way for construction of a "Phase II" completion of our building. The new construction will house a large portion of the Computer Science and Engineering Department, as well as providing additional space for Electrical Engineering. We are aggressively recruiting the very best graduate students. We have an extraordinary range of new and growing research projects that provide outstanding opportunities for graduate education and professional growth. The department is in the midst of a comprehensive review and revision of our undergraduate and graduate curriculum. We are developing a new undergraduate program that takes full advantage of recent advances in knowledge about learning and innovations in instructional techniques. Our challenge is to deliver a solid theoretical background to our students that will effectively address topics with a long 'half life' (like electromagnetic and signal processing theory)—while simultaneously having our students learn the latest EE technology, techniques and applications (topics with a very short 'half-life'). Many of our faculty and students have volunteered their time to give technology presentations in local elementary schools, as part of our K-12 outreach effort. The department has developed courseware that is delivered by internet streaming. Our faculty and students have been very active in the development and transfer of intellectual property, and have participated in startup companies. The EE department is an engine of technological innovation for the Pacific Northwest and the nation. We are dedicated to maintaining an atmosphere of cooperation that nurtures high-quality research and education, and which develops outstanding undergraduate and graduate engineers.

somes into small pieces, then put them back together by sequencing only the ends of the pieces and matching them up. The DNA between each end remains unsequenced. This representation is one type of physical map.

Physical maps contain the location of non-inherited physical "landmarks" found in DNA sequences. In the "shotgun" approach, those landmarks are where the cuts were made in the chromosomes, and distances are measured in base pairs. Physical maps vary in degree of resolution. A high-resolution map is similar to what you get when you go to the automobile club and ask for a trip ticket: an actual map with your current and desired destination, detailing direction and exact distances of everything in between. A low resolution physical map resembles what you get when you ask a bystander on a street corner for directions: references to landmarks ("go down this street until you see a red sign") without exact distances and little or no information about what lies between.

"Some people think that once the human genome is sequenced, we're finished. Actually this is just the beginning of sequencing work that is needed to understand disease. The NIH is moving forward to finish the complete sequence, with an accuracy of 1 in 10,000 base pairs." Meldrum explains.

The EE Genomation Laboratory is moving forward as well. Alpha testing of ACAPELLA-5K will begin with the UW Genome Center in March 2001. Beta tests will begin June with the Washington University St. Louis Genome Sequencing Center and the MIT/Whitehead Institute Center for Genome Research.

Currently, only two human chromosomes have been completely sequenced. Add to that the fact that Celera only makes its data available to paying customers, and the incentive to continue the genome project cheaply and quickly, is stronger than ever.

Meanwhile, the current cost of sequencing is approximately fifty cents per base—and dropping. EEK2001

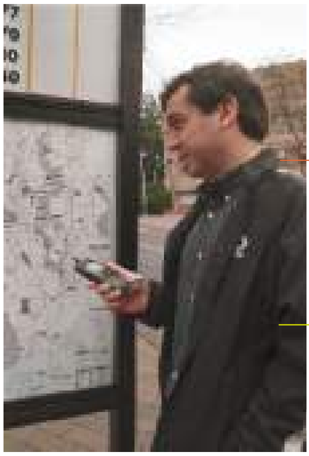
Laboratory website:

http://rcs.ee.washington.edu/GNL/Genomation. html

HELPING YOU GET HOME:

MyBus lets commuters locate buses with their cell phones

Rob Harrill



Stuart Maclean uses his cell phone to access MyBus and plan his commute.

UW News and Information

If you're a Puget Sound-area commuter wondering where your bus is, you're in luck – real-time information is now as close as the cell phone in your pocket.

Thanks to work by a group of University of Washington engineers, mass transit riders can keep tabs on nearly 1,000 King County Metro Transit buses with the punch of a few buttons. All they need is a cellular telephone that can access the World Wide Web.

The intent is to give commuters more flexibility and mobility in managing busy schedules around travel times, according to Stuart Maclean, research associate with the UW's Intelligent Transportation Systems (ITS) group. And the effort is garnering nationwide attention.

"I'm not aware of anyone else who is doing anything quite like this, and we're getting a lot of e-mail on it," Maclean said. "People are contacting us and telling us that they like what they see and want to replicate it for their cities."

The new application is the logical extension of an ITS project called "MyBus," which lists similar information on a conventional Web site. Riders can visit the site from their home or office computer to find out if their bus is running on time.

And therein lies the drawback to an otherwise popular service, according to Dan Dailey, electrical engineering research professor and ITS director.

"After all, where you really need this information is walking down the street to your stop, or while you're waiting for your bus," Dailey said. "The information is just not as useful on your computer or laptop."

Giving commuters cell-phone access to MyBus was relatively simple, Maclean said. Coding for the site was changed from HTML, the computer language commonly used on the Web, to WML, a language that allows access by Web phones, also known

"People are contacting us and telling us that they like what they see and want to replicate it for their cities."

as WAP-enabled phones. WAP is short for Wireless Application Protocol.

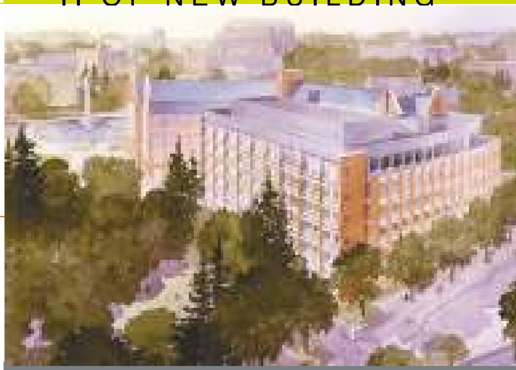
Callers can get bus information by pointing their phone browsers to the MyBus WAP site at http://www.mybus.org/wml/ and selecting MetroKC from the MyBus menu. They need to select a bus stop and enter the route number of their bus. The phone browser will then display real-time predictions of when the bus will leave the stop.

To make those predictions, MyBus taps into Metro's bus location system. An algorithm processes that information with data on how the buses have run in the past to predict the time the bus will be leaving the selected stop.

Response to the new application has been positive, Maclean said.

"There is a need – this is information that people really want," he said. "Research indicates that the most stressful aspect of riding the bus is wondering where your bus is. This can decrease that anxiety and hopefully help more people make good transportation choices." EEK2001

2001: OLD BUILDING DEMOLITION AND PHASE II OF NEW BUILDING



Good-bye to the old EE Building and hello to construction headaches! In 1902, the EE program began in Science Hall (renamed Parrington Hall in 1931). In 1910 we moved to Old Engineering Hall (Machinery Hall), built in 1908 for the Alaska-Yukon-Pacific Exposition. The Electrical Engineering Building (EEB) was built 1948-49. It reflects a European influence that followed World War II and was designed by Paul Thiry. On the first day of classes in the new building, the students met in Old Engineering Hall to pick up their chairs and carry them over to their new facility. The Fourth Floor of EEB was added in 1971. In February of 1998, the department moved most of its operations to the completed portion ('Phase I') of the new Electrical Engineering/Computer Science and Engineering Building. The newly designed Phase II construction will be integrated with Phase I, providing 75,000 square feet of new space for the CSE department plus 10,000 square feet of additional space for EE. Completion is scheduled for January 2003, with occupancy in March 2003.

THE SECRET LIFE OF THE ELECTRON

How does a microwave oven work? A cell phone? An AM radio? These questions and other mysteries of Electrical Engineering are being explored by over 40 freshmen during the Fall 2000 quarter, in the new introductory course "The Secret Life of the Electron." This "hands on" course is taught in modules by seven different EE faculty (Blake Hannaford, David Allstot, Deirdre Meldrum, Denise Wilson, Howard Chizeck, John Sahr and Jim Ritcey) and Teaching Assistants Joel Chenu and Joshua Olsen. The course, coordinated by Professor Hannaford, is designed for freshmen who are curious about the electronic technology that surrounds us. Many of the students who chose this course are considering majors in engineering, but some signed up just to increase their "technological literacy." During the Fall 2000 quarter the course has been organized around the theme of communication systems. Although the course is not required for any degree program, and is considered to be "challenging" by many students, it has been well-received. By popular demand, this class will be offered again.

Potato Power - potato as a battery, used to power a lightbulb.

NEW CURRICULUM

Targets Shortage of Hi-Tech Workers in Washington and Alaska

It's no secret that workers with high-tech skills are in short supply. Despite demands of an ever-expanding industry laden with generous employers, the shortage of hi-tech workers is projected to get worse.

According to the American Electronics Association (AEA), Washington Council, the state experienced a 59 percent increase in the number of high technology jobs from 1990-1997. During the same time the state's higher education system increased its production of technology and engineering graduates by only 3 percent. The shortage of high tech workers plays a huge role in local population growth, increases demands on local transportation and energy infrastructure, and poses further challenges to the natural environment.

A new project, co-directed by EE faculty members Mani Soma and Eve Riskin, attempts to directly address the shortage. Supported by the U.S. Department of Education Fund for the Improvement of Post-Secondary Education (FIPSE), the EE faculty will develop a hands-on, laboratory-driven Electrical Engineering 2-year curriculum. The curriculum targets students who cannot participate in a more traditional campus program.

The long-term objective is to establish a statewide network of regional engineering laboratories that will be accessible to students, as well as an Associate of Science degree granted by qualified community colleges. Partner institutions include Seattle Central Community College, Bellevue Community College, the University of Alaska-Fairbanks, the Washington State American Electronics Association, and Prentice Hall Publishers.

Specific goals include:

- Development of a laboratory-driven curriculum for four-year universities and community colleges that includes hands-on hardware-based laboratory experience. The curriculum may be delivered on-site (e.g., at a four-year university) or synchronously on-line (e.g., at a community college by a local instructor, using on-line materials). Topics of these courses include basic circuit theory and design, basic analog circuit design, basic digital and logic circuit design, and introductory signal-processing theory and circuits.
- Adaptation and enhancement of the laboratory-driven curriculum to target students in geographically remote communities without convenient physical access to nearby post-secondary educational institutions. This curriculum is delivered asynchronously on-line. These "at-home" students will do all their course work at home. The constraint in this instance is the lack of any laboratory facility at the student homes.
- Establish a laboratory-driven curriculum development methodology, common to two-year and four-year institutions, to provide hands-on laboratory experience at a reasonable cost.

This new program combines a project-driven curriculum development philosophy, the pervasive presence of PCs, and the

The long-term objective is to establish a statewide network of regional engineering laboratories that will be accessible to students, as well as an Associate of Science degree granted by qualified community colleges.

availability of low-cost instrumentation tool kits to create lower level EE courses that offer truly hands-on laboratory experience for distance learners. Laboratory instrumentation for the first two years of a traditional EE curriculum includes a multimeter for simple measurements, an oscilloscope for more complicated measurements, a DC power supply with several settings, and a waveform/ function generator. A personal lab kit, including all functions necessary for circuit design and test experiments (multimeter, oscilloscope, DC supplies, waveform generators), can be built on a board to plug directly into a PC or in a prototype unit connected to a PC. In conjunction with available low-cost PCs and software, this personal lab kit (costing less than $200 each) provides the full test, verification, and data analysis capabilities required in EE experiments for lower level classes.

The at-home format (asynchronous on-line) is a special component that targets students who must take classes at home and live in rural Washington and Alaska, where inclement weather and vast distances make access to the few available universities and community colleges impossible during much of the academic year.

This project will distribute materials via the UW Educational Outreach and EDGE programs, two established distance-learning organizations at the University of Washington. Textbooks and lab kits are will also be distributed by our partner Prentice Hall. EEK2001

K-12 PROGRAM TAKES RIGHT APPROACH TO LEFT-BRAIN DEVELOPMENT

"We can't be naïve. We can't expect students to come here and be good engineers if they haven't developed **the right skills.** Waiting until they get here is too late," says Prof. Denise Wilson, who oversees the K-12 program, which brings teaching materials she develops into local public schools for 6-week periods.

Prof. Wilson's involvement with curriculum development began during her graduate school days. Unlike other K-12 programs, her approach incorporates stages of development that take place through early years all the way through high school.

During kindergarten and up through 6th grade, children are extremely open to learning new things. Wilson uses **"sensing demonstrations"** to relate the familiar biology of the senses to artificial sensing systems. For example, Wilson uses the sense of smell to explain how a smoke alarm works, relates the sense of hearing to what a microphone does, and uses the eye as an analogy for a camera.

"By the time we hit middle school (7-9), learning for learning's sake ends—we are interested in learning things that will help us in our future, and things our peers are interested in." Wilson's middle school curriculum utilizes objects common such videogames to teach students how they detect the correct amount of change—just in case they ever want to build one someday.

"A lot of people complain about deficits that students have when they get to university. I don't see a lot of people doing anything about it. Teachers in public schools are overworked, underpaid and often have limited resources. Programs like these are in everyone's best interest."

ON SPEAKING TERMS:

Researchers Get People and Internet Talking

M.A. Krug

"Daddy, what's a keyboard?" is a question many of us might be asked someday.

An interdisciplinary group of researchers in the Electrical Engineering Department recently received a 5-year, $4 million grant from the National Science Foundation under the Information Technology Research Initiative (ITR). "These projects represent major innovations in information technology, rather than routine applications of existing technology," NSF director Rita Colwell explained in a press release announcing the awards. The EE department was among 62 out of 1,400 applicants to receive a portion of the $90 million NSF earmarked for the project.

"We're done pushing things together that are the same," explains Assoc. Professor Scott Hauck, who is involved with designing the actual chip itself. "In order for us to continue to follow Moore's Law, integrating very different types of pieces will be the next step."

"You can speak into it, and that [will] basically allow you to communicate with the Internet the way a keyboard does now," says Professor David Allstot, the Boeing-Egtvedt Chair and Principal Investigator on the ITR project.

The multi-disciplinary team from the EE department includes David Allstot, VLSI and Digital Systems; Jeff Bilmes, Signal and Image Processing; Scott Hauck, VLSI and Digital Systems; Hui Liu, Communications and Signal Processing; Sumit Roy, Communications and Networking; Carl Sechen, Circuits and Sensors; Richard Shi, VLSI and Digital Systems; and Mani Soma, Mixed Analog-Digital System Testing. Collaborators from outside the department include Chris Diorio, Neurally Inspired Computing, and Carl Ebeling, Architecture and Computer Aided Design of Digital Systems, who are both from the Computer Science and Engineering Department.

The team intends to design a wristwatch-sized device that takes in and processes voice commands prior to transmitting them over a wireless network where they are carried out. The device will utilize System-On-A-Chip (SOC) technology, similar to that found in devices commercially available now. Unlike today's technology, which contain chips with single types of circuits, this device will use a heterogeneous chip— one that contains analog, digital, and RF circuits. The analog circuits will take in voice commands and convert them into digital signals. The digital circuits will process the digitized signals using mathematical algorithms and transformations, and RF circuitry will encode the digital data and convert it into a form suitable for wireless transmission.

The chip design must be optimized at two levels: the device level and the chip level itself. At the device level digital, analog, and RF circuitry must be optimized for power dissipation and performance. Optimizing the design at the chip level involves finding the proper mix of digital circuits. The quest to find the right mix is one of the research objectives of the proposal.

"We're done pushing things together that are the same," explains Assoc. Professor Scott Hauck, who's involved with designing the actual chip itself. In order for us to continue to follow Moore's law, integrating very different types of pieces will be the next step."

Moore's law is a prediction made by Intel co-founder Gordon Moore in the 35th anniversary issue of Electronics in 1965. At that time, it stated that the complexity of Silicon Chips would double every year, and that by 1975 one chip would contain 65,000 transistors. The prediction proved to be uncannily accurate, and became known as Moore's Law in 1975. During that same year, Gordon Moore revised his prediction, stating that chip complexity would double at a rate of once every two years thereafter. In an interview published in *U.S. News and World Reports* (7/10/00), Mr. Moore stated that he believed his revised prediction would be valid for another 10 to 15 years.

Traditional digital circuits are hardwired—-software is used to program circuit blocks for a specific purpose, and once the circuitry is programmed its function remains fixed and unchanged. An example of such a hardwiring can be found in automobile cruise control systems: the chip is a generic piece of hardwire that performs a specialized function determined by the software that programmed it.

A second, and more dynamic type of digital circuit is known as the Field Programmable Gate Array (FPGA), a bright spot in the field of system integration. Unlike traditional digital circuits, which use software to fix the function of circuit blocks, software is

NEW COMPUTING LABS ADDED IN YEAR 2000

We have added three new computing labs in the year 2000...

Linux High-Throughput Computing Cluster (EE/CSE 365) is a result of donations from Intel Corporation (15 Pentium III 933 MHz computers) and the Student Technology Fee (13 PIII 600 MHz computers). This lab is a general purpose lab for students particularly targeting those students who need cycles for matlab computations and for program compilations. This lab is the first general purpose linux computing lab at the University of Washington and is uniquely clustered together to balance the cpu load and memory of the cluster. Automatic process division and migration occurs within nodes of the cluster.

VLSI Computing Lab (EE/CSE 361) is the result of donations worth $90,289 from Sun Microsystems. The donations include an Enterprise Server 450 with quad gigabit processors and 4GB of memory along with 20 Sun Rays as thin clients. This lab is primarily geared towards the students enrolled in VLSI courses to aid in simulations on applications such as cadence, synopsys, hspice and awaves. Students also remotely login to this server to run simulations using the linux lab cluster and the windows PCs. About 140 students are enrolled in VLSI courses for the fall quarter alone.

NT General Purpose Lab consists of 30 PIII 600MHz Kayaks that were donated by Hewlett Packard along with high speed network laser printers valued at $128,390. This is a general purpose Windows 2000 computing lab that will be used by about 700 undergraduate and graduate students.

These computing labs are also used for training purposes. One such training on august 24th involved the department organizing a UW workshop on computer security in the new High Throughput Linux Lab. This workshop was to help computer professionals at the University of Washington get hands-on training in internet security. Two EE computing interns, Alex & Sasha, were the guest hackers for this session while University Senior Security Expert Dave Dittrich helped with the hands-on training with the digital intrusion techniques. Another training session involved Howard Chizeck using the windows computing lab to demonstrate hands-on analytical simulations for the students in the course "The secret life of the electron".

We offer an ABET-accredited Bachelor of Science in Electrical Engineering. We also offer the Master of Science and Ph.D. degrees, with concentrations in:

- Electromagnetics
- Devices and MEMS
- Energy
- Control and Robotics
- VLSI and Digital Systems
- Communications and Wireless
- Signal and Image Processing
- Nanotechnology (story p. 13)

Our undergraduate program has approximately 500 juniors and seniors. Students usually join the EE major as juniors, although in 2000 we began to directly admit outstanding applicants to the major in the freshman year. Admission to the program is quite competitive; this year the average freshman/sophomore GPA of our new majors is approximately 3.6. The curriculum is ABET-accredited and combines strength in electrical engineering fundamentals with extensive laboratory experience and an environment that stresses leadership, teamwork, and creativity. The department has an undergraduate tutorial center to provide senior peer help for all undergraduate courses. The department has a focused program of ongoing improvement of undergraduate education. This includes curriculum revision for the core classes, new laboratories, and new courses ranging from consumer electronics to Intellectual Property Issues.

The UW Department of Electrical Engineering has approximately 270 graduate students. We graduate approximately 180 B.S., 20-25 Ph.D., and over 80 M.S.E.E. students per year. Our graduates are highly sought by industry and universities.

Financial support for graduate students includes approximately 35 Teaching Assistantships per quarter and approximately 130 Research Assistantships and Fellowships per year.

Weekly department social, as seen from above the Grand Atrium.

used to reprogram hardware to perform many different functions. This results in economies of scale: the chip requires less hardwired circuits, which make them smaller, and more power efficient.

FPGAs offer obvious and considerable advantages in low power, high-speed applications. Their versatility allows blocks of circuits to be shared for a variety of applications, providing practical solutions to real problems. A good analogy is a road that carries bicycle traffic 95% of the time, but must serve as a truck route during emergencies. Traditional digital circuits require dedicated resources that could accommodate the maximum load, but FPGAs allow resources to be borrowed for more intense applications (when the bike lane serves as a truck route) and then reallocated after the peak demand has been met (when the truck route reverts back to a bike path). The research team intends to use FPGAs not only to solve power and speed problems, but to cope with testing issues as well.

Defective chips are a reality of the manufacturing process, and companies must detect bad chips before they find their way into finished products. Analog, digital, and RF circuits require different testing protocols, and testing a mixed environment only adds to the complexity. Rather than inserting a dedicated test circuit into the chip, researchers intend to use FPGAs to test the many different circuit types within the chip, including the FPGAs themselves.

“You don’t go to the Fed Ex window to order a Big Mac,” observes Bilmes. “Why would you ask your toaster to withdraw $20?” Approximately one half of the chip will be used for speech processing.

A great source of novelty for the project comes from the incorporation of human voice as the interface between user and Internet. “What most people are currently doing— is to just transmit the voice signal itself to a central server for processing and recognition. The novel approach in this project is that everything will be done on chip, and that hardware features of the processor will be devoted to assist the speech recognition” says Asst. Prof. Jeff Bilmes who will be analyzing both existing and novel speech recognition algorithms, which will convert the users voice commands into digital form. It’s an important part of the project, because existing algorithms were developed with many different objectives, not necessarily minimizing power dissipation. Prof. Bilmes will need to modify or design new algorithms that meet the low power requirements of the device. Since the device must process speech in real time, he admits that it might need to be designed to recognize only a certain specific set of verbal commands.

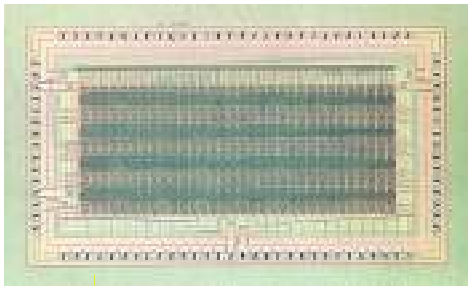


Photo: Thomas Fry

Photograph of an actual FPGA, custom designed to be integrated into a 32 bit microprocessor.

Such constraints lend themselves to asymmetric data transmission. The upstream link (user input to the Internet) powered by the device will travel much slower than the downstream link (data from the Internet to user). The benchmark for the downstream data link is set at 100 Mbs, which is based on current ethernet speeds.

"There's a lot of competition in this area. 100 Mbs is at least a factor of 2 above anything anyone else is doing now," according to Prof. Allstot who explained the benchmark was set that high to ensure the device would be state of the art five years from now.

According to Prof. Allstot, fabrication costs of such complicated chips will be in the range several hundred thousand dollars. Instead of fabricating the actual chips, the researchers intend to demonstrate their design concept at a functional level by the end of the five-year period. When asked if the timeline was exceedingly ambitious Allstot replied, "If the week has 80 hours instead of 40 in it, we've actually got closer to 10 years to complete the project."

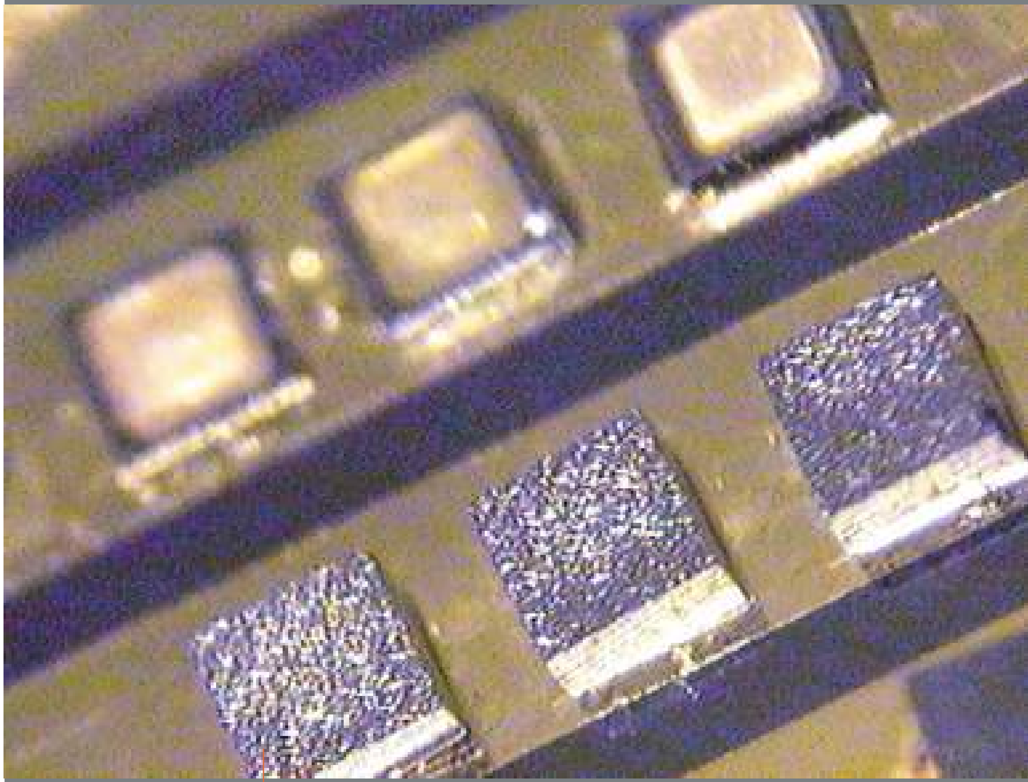
EEK2001

UW FIRST: PH.D. PROGRAM IN NANOTECHNOLOGY

The University of Washington is launching the nation's first doctoral degree program in nanotechnology. Nanotechnology involves the construction of extremely small machines and new materials by manipulating individual atoms or molecules. Nanotech devices are measured in the billionths of a meter. Nanotechnology is a developing field with profound implications for most fields of engineering.

The Electrical Engineering Department and eight other UW departments in science, engineering and medicine will take part. EE students will earn a PhD degree in Electrical Engineering and Nanotechnology (formal title of the degree is pending approval). Students will "rotate" through different research laboratories as a part of their training. Participating departments include biochemistry, bioengineering, chemistry, chemical engineering, electrical engineering, materials science and engineering, molecular biotechnology, physics, and physiology and biophysics.

The overall effort is being funded by a $2.7 million grant from the National Science Foundation's Integrative Graduate Education Research Training (IGERT) program. It is directed by Bioengineering professor Viola Vogel, director of the UW Center for Nanotechnology, which was established in 1997 with $2 million from a UW initiative designed to encourage interdisciplinary educational pursuits. Additional information can be found at http://www.nano.washington.edu/



Two sets of self-assembled microcomponents on a silicon substrate. This novel assembly technique can be used for integration of electronic, photonic, and microelectromechanical systems (MEMS) into complex future microsystems (Photo: Y. Hanein and X. Xiong).

By Tim Midgett

I write songs and play bass and guitar. My band, Silkworm, has been around for thirteen years. My bandmates and I record often, with eight albums and over a dozen shorter records to our credit. We play regularly throughout the U.S. and Europe in a wide variety of venues, from tiny clubs with little sound support to large venues with massive PA systems.

Rock music, more than any other kind of music, is capable of drastic timbral and dynamic range. My bandmates and I embrace rock's broad palette of sounds as readily as we embrace its limited harmonic vocabulary, and we are fairly obsessed with forging a sound that is as flexible and impactful as possible.

The quest for a flexible and impactful sound leads to a corresponding quest for expressive and responsive equipment. Give a musician reliable equipment capable of vibrant and appealing sound, and the musician will be more likely to produce bracing and fulfilling music. I continue to play and record music, I continue to learn about circuit design and the behavior of electricity, and I become more and more convinced that the effect of using the right tools is not ephemeral but quite quantifiable.

Quantifying the production of sound leads for me to an interest in quantifying sound specifically, and it is a relatively short leap from quantifying sound to quantifying high-frequency waves and the deep well of radar.

In his spare time, Tim Midgett is completing an undergraduate degree in electrical engineering.

THE LONG

"They hired me to get rid of me." John Sahr admits, grinning shamelessly at his early persistence.

Sahr, an associate professor of Electrical Engineering, studies the ionosphere. Ionospheric studies require radar systems, which provide information about distant objects using scattered radio waves.

When Sahr arrived, there were no other geophysicists, no established space science program, and no radar system in EE. His career demonstrates how collaborations between related disciplines can result in the development of novel technologies, as well as innovative uses for existing ones.

"I had no money for experiments [in the beginning]" Sahr explains. "In the early nineties, I was concerned about how to start some experimental research that didn't have large costs associated with it. If I tried to buy a conventional radar system, I knew it would cost a half million bucks—[Besides] transmitters are interesting, but scary."

Conventional radars consist of a transmitter and a receiver. The transmitter emits an electromagnetic signal into the atmosphere, similar to microwave radiation in ovens. Such high concentrations of radiation pose health risks, so the use of transmitters is highly regulated.

The receiver captures the scattered radio waves from the target being studied. After the signals are digitized and analyzed using computer algorithms, they can be used to study everything from weather patterns to air traffic.

"For geophysics applications, for atmospheric science, a really useful frequency range is around 100MHz– [But] you can't use that because it's full of FM Broadcast stations," Sahr explains.

Given the expense of transmitters, and the occupation of useful spectrum, I began to think of using the [existing] FM broadcasts themselves."

A radar system without a transmitter is like a car with a dead battery: if the engine won't start, it's useless. But if the car has a manual transmission and its parked on top of a hill– it can be started, and used, even without a working battery.

A passive radar system lacks a transmitter of its own. Instead, independent receivers pick up radio waves from transmitters sending signals for commercial radio or television broadcasts. If the signal is powerful enough, and transmitted at the right frequency, it can provide useful data.

It sounds simple enough, but in practice proves technically challenging. A passive radar system requires at least 2 receivers, positioned very far apart. In a sea of thousands of commercial

AUL:

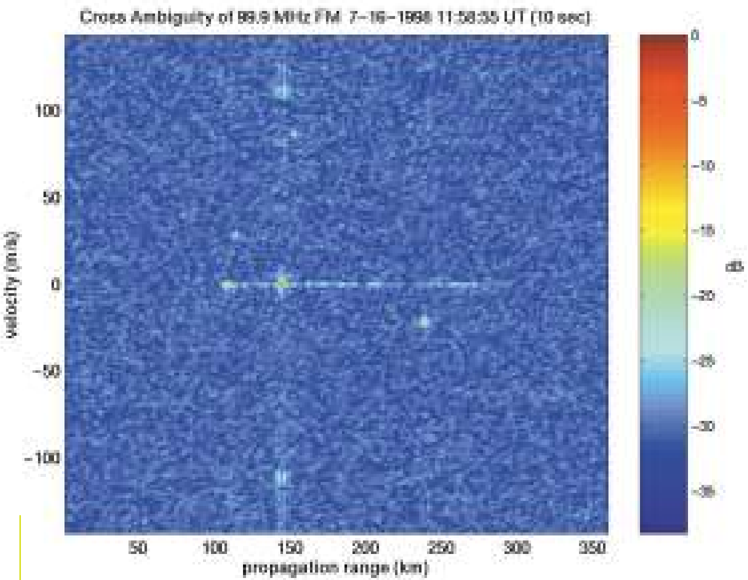
Multistatic Passive Radar

By M.A. Krug

"I had no money for experiments [in the beginning]," Sahr explains. "In the early nineties, I was concerned about how to start some experimental research that didn't have large costs associated with it. If I tried to buy a conventional radar system, I knew it would cost a half million bucks—[Besides] transmitters are interesting, but scary."

broadcasts, distance is a factor used to identify the desired signal. Since passive radars lack transmitter control, and commercial broadcasts are continuous, isolating the desired signal also requires receiving it at two different places, at the same frequency and time. Synchronization prior to global positioning systems was a monstrous task, and once a genuine barrier to passive radar systems.

Another technical hurdle with passive radars is managing the data. Each receiver generates data on the order of megabytes per second, which must then be transported to a single location for processing. Recent advances in the processing speed of personal computers and high speed internet connections provide feasible cost effective solutions.



Passive radar data, showing several targets visible in the radar field of view. The strongest single echo, the red dot in center, comes from Mt. Rainier. The other features on the horizontal line passing through that point are from other mountain peaks in the Cascades. The Doppler shifts at 120km, 160 km, and 240 km are aircraft.

A F.I.R.S.T. FOR RAINMAKER ONE

Sometimes doing your best is the only thing you can do. Occasionally, things end up better than expected.

Rainmaker One is a good example.

The remote controlled robot, designed by students from UW Engineering and Bellarme Preparatory High School, finished extremely well in both the Regional and National Robot Games Competition, sponsored by For Inspiration and Recognition of Science and Technology (FIRST) and NASA.

Under the guidance of EE Professor Alexander Mamishev and former Seattle Robotics Society President Kevin Ross, the Rainmaker One team won for "best offense", among the 42 teams at the regional competition in San Jose. A few short days later, the team finished in the top 10% at the national competition in Orlando, which hosted 280 teams. The finish was especially gratifying, because this was the first year the University of Washington sent a team to the competition.

"We were a rookie team competing with experienced professionals against some of the best talent in the country," team leader Kevin Ross commented. Both Mr. Ross and Prof. Mamishev agreed that the Rainmaker One team exceeded program goals in their first year of competition.

Support for the Rainmaker One Team included the UW Department of Electrical Engineering, the Mary Gates Scholarship Fund, Ford Motor Company, the Seattle Robotics Society, NASA-Ames Research Center, and the parents, students, and alumni of Bellarme Preparatory High School. Additional support came from the UW College of Engineering, the Computer Science and Engineering Department, the Mechanical Engineering Department, and the Minority Science and Engineering Program.

Pictured above: Rainmaker One preparing for competition.

UW DAWGSTAR: NEW ERA IN SATELLITES?

In the quest for things smaller and cheaper, the Air Force Research Laboratory (AFRL) and Defense Advanced Projects Agency (DARPA) are funding research for the design, construction, and eventual flight of a microsatellite array.

Traditional satellites are expensive, consisting of huge platforms mounted with large numbers of instruments. These satellites require large design, construction, and maintenance budgets. Nanosatellites, being much smaller provide a cheaper alternative for accommodating the ever-increasing demand for communication, defense, and intelligence. However, their limited energy supplies, combined with small communication and storage capacities, require frequent docking phases for recharging, data exchange, and reprogramming.

Electrical Engineering Professors Karl Bohringer, Bruce Darling, and adjunct faculty Mark Campbell from Aeronautics and Astronautics, are building a reliable docking system for UW DAWGSTAR using microactuators, which provide the mechanical force for very precise, tiny movements. The microactuators will create an active surface of microscopic cilia, capable of accomplishing positioning tasks with micrometer precision. When completed the device will connect spacecraft with the docking site on the satellite.

Sahr designed his system prior to these very recent advances in personal computer speed, global positioning systems, and high speed internet access.

He anticipated these advances almost 10 years before they became commercially available, and relied on them to make his radar a reality.

To do research, you need funding. To get funding, you need preliminary data to convince funding sources your idea will work.

"For the first year, I collaborated on some other projects. Then I did some back-of-the-envelope calculations. I did some mathematical simulations on a regular PC.

Finally, the Intel Paragon arrived in the department in early 1993. I was able to generate some preliminary data and use it [the Intel Paragon] as matching funds on an NSF grant."

This may seem like a major victory, but in the greater scheme of a university research career, it's more like winning a NFL preseason scrimmage: your potential is recognized, but you're still a long way from the superbowl.

This may seem like a major victory, but in the greater scheme of a university research career, it's more like winning a NFL preseason scrimmage: your potential is recognized, but you're still a long way from the Superbowl.

Sahr had enough money to fund full-time graduate students on the radar project—for awhile. An NSF grant typically runs for 3 years, while the average completion time for a Ph.D. is 6 years.

Sahr has gone without pay to keep his graduate students funded. He's done sideline projects to obtain funding, and he shifted students onto other projects to keep them funded.

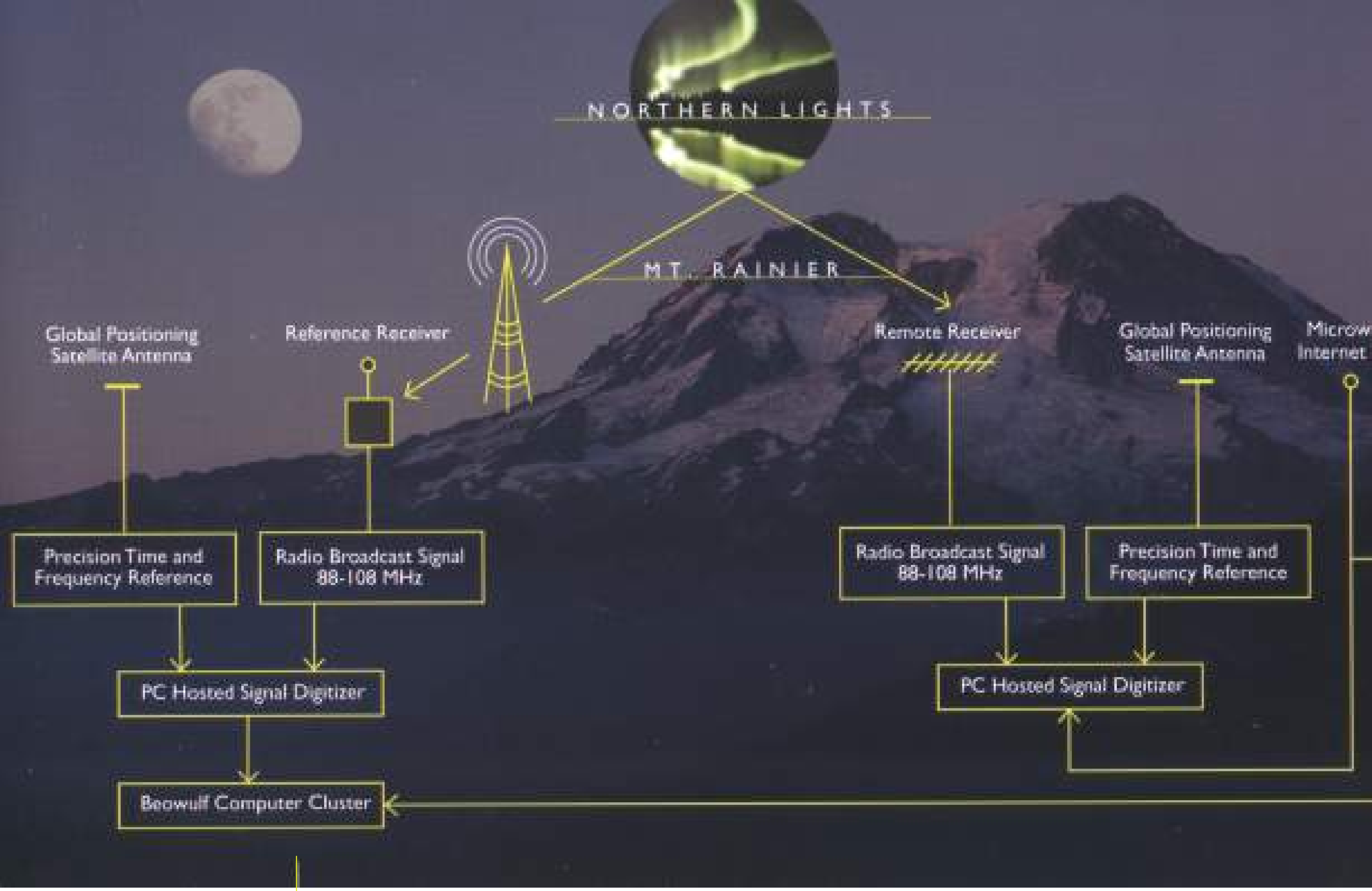
Sahr's and his group did all the work to complete the Manastash Ridge Radar System. They installed the distant remote receiver at the Manastash Ridge observatory. The reference receiver, which must be close to the local radio station transmitter, currently sits in Prof. Sahr's office.

The Manastash Ridge Passive Radar system isn't as versatile or complex as ones at top space science programs, like Cornell, where Sahr did his graduate training. It certainly doesn't have a dedicated full-time staff and operating budget.

It was a cosmic stroke of luck that the Aurora Borealis was far enough south that Sahr's group became the first ever to observe it with passive radar. He admits if he were purely interested in studying auroras, he should move his radar north into Canada.

Why doesn't he?

Because of what it has become – a wonderful teaching tool. Students working with Sahr sharpen their skills in systems engineering, signal processing, and computer programming in a real-world scenario: confronting technically challenging hurdles to produce valuable data.



Overview of Manastash Ridge Radar System — Two separate receivers, one located in the EE building, the other on Manastash Ridge, intercept commercial radio broadcasts from Seattle. A global positioning system (GPS) synchronizes the signals. The broadcast signal and GPS data are combined, digitized, and sent to the Beowulf computer cluster for analysis. Data from Manastash Ridge arrives at the Beowulf via a microwave internet link.

In the short term, passive radar systems may provide advanced weather warnings to rural areas, where expensive conventional radars are not an option. The same technology could be applied to airports.

Because passive radars use signal broadcast for commercial purposes, surveillance is very difficult to detect. A radar detector in your car is tuned to detect the special frequencies used for police radar. But suppose that instead of special radars, police could simply borrow ordinary broadcast signals. If all your detector "heard" was Howard Stern, you wouldn't suspect that your speed was being monitored... and you'd be stunned and confused when you were pulled over for speeding. Although using broadcasts to track speeders may not be feasible, it is desirable and possible to passively track aircraft. Lockheed Martin has developed such a system. Price? About seven figures.

In the long term, perhaps the most valuable impact will come in the form of inspiration. As innovators like John Sahr demonstrate passive radar viability, investigators in different fields have begun using other waveform sources as signals. Marine biologists at the Scripps Institute have used snapping shrimp and passing boat traffic as waveforms to illuminate underwater targets. It is well known among space scientists that some planets such as Jupiter have enormous and energetic ionospheres that emit powerful radio waves. Instead of positioning transmitters at distant stellar locations, someday we may be able to study signals from natural sources of radiation.

Who knows? And that is why research with no immediate commercial value needs to be done. EEK2001

FROM FANTASY TO REALITY:

HITLab puts “magic” in Magic Book

Ever wish you could fly?

The “Magic Book” project, currently underway in the Human Interface Technology Laboratory (HIT Lab), is a medium that makes the above scenario a virtual reality.

“Magic Book” looks exactly like an ordinary book, until the reader dons a head mounted display (HMD), and an extraordinary transformation takes place. Three-dimensional images emerge from the storybook pages. If the user physically moves the storybook, the 3-D images can be viewed at different angles. The reader can even become entirely immersed in the story, experiencing it through the eyes of the characters, called avatars in the virtual world.

“What we’ve done is create a continuum that people can move along, from the real world, to a combination of real and virtual, to an entirely immersive experience,” explains Mark Billinghurst, an EE research associate who initiated the “Magic Book” project.

Inset. A magic book character. Top. Augmented Reality. Users view virtual images, but can still interact with each other in the Real Environment.

If the user physically moves the storybook, the 3-D images can be viewed at different angles. The reader can even become entirely immersed in the story, experiencing it through the eyes of the characters, called avatars in the virtual world.

“Magic Book” is a demonstration of shared space–the merging of the physical and virtual worlds. Computer generated images (virtual images) are overlaid onto real ones, allowing humans to interact with each other and the virtual objects simultaneously.

How does it work?

The HMD viewer worn by users is attached to a color camera, an inertial tracker, and a computer. When the user views the images overlaid on the pages, the computer generates virtual images based on images it processes from the camera.

According to Billinghurst, “the key for this technology is the black square,” surrounding all the images in the storybook. The camera attached to the HMD uses the black square as a marker to position, orient, and select the correct virtual object for each part of the story.

By flipping a switch on the HMD, vision-tracking switches from computer vision to the inertial tracker, allowing the user to be immersed in the virtual world by becoming a character in the story. Users can move throughout the scene, and by pressing another button, they can actually fly through the virtual world in the direction they look; the harder they press the button, the faster they fly.

Because users can move seamlessly from the physical world to the virtual world, the technology can be used in a variety of settings, from entertainment purposes to educational applications. Anatomical texts might one day include a virtual model of the heart which would allow students to explore its function by becoming a blood corpuscle, while being able to ask students and professors questions at the same time.

“There are a lot of very innovative and useful things you can do with this,” Billinghurst said after “Magic Book” appeared in demonstrations of emerging technologies at the SIGGRAPH 2000 conference last summer. The conference was sponsored the Association for Computing Machinery, and over 50,000 participants from academia and industry gathered for the event.

The HITLAB would like to be contacted by people with application ideas and potential collaborators. Their web address is http//www.hitl.washington.edu. EEK2001

GETTING ZAPPED:

Professor Rich Christie Discusses Power Shortages in the Western U.S.

The roots of Electrical Engineering lie in the design of electric power generation, transmission and generation distribution systems. In the 1930's the department grew rapidly with the Grand Coulee Dam and the Pacific Northwest Hydropower. Suddenly, this aspect of EE is again very topical! Consider the following interview with Associate Professor Rich Christie:

EEK 2001: How has power engineering changed as a result of deregulation?

Pre-deregulation was about optimization. You had total control of the generators, and the goal was to set them to produce the most electricity at the lowest cost. Post-deregulation is about competition. Each generator makes its own decisions. For real-time markets like the California ISO you have to deliver the right amount of energy at the right time. This requires a roughly equal understanding of the technical needs of the power system and the economic consequences of technical decisions.

EEK 2001: What's causing high prices and power shortages in California?

The situation as I see it is due to the interaction between a generation capacity shortage and a competitive market.

Generation shortage, which is basically a lack of sufficient generation to supply the load, is a phenomenon that occurs in every power system occasionally. It can be caused by random events such as a generator breaking, weather, and economic conditions. This year has been a very dry one, both in the Northwest and in California. Enough rainfall would have prevented a lot of the problems we're seeing right now, or at least deferred them. There has also been a surprising load growth in California this past year–no one predicted it. The California economy is doing a lot better than anyone expected, and generally load follows the economy.

The $500 to $5000 per megawatt megawatt-hour prices we're seeing come from market conditions that are basically monopolistic. The load is so high that the generators know that what they have to sell will be bought–at any price. In a perfect market, when demand exceeds supply, prices go up, and there is never a monopoly. There are always new suppliers willing to sell as the price goes up.

EEK 2001: Aren't monopolies illegal?

No–the generators are doing what the rules tell them they can. There are some economists who believe generators are doing what they should do-set the price so high that it produces incentives for others people to enter the market and build more generation.

EEK 2001: Why aren't more generators being built?

One reason is that the citizenry of California have been extremely hostile to the construction of new power plants in their state. They don't want any new generation built, but they want cheap electricity. This is not a reasonable position.

Another is the political uncertainty caused by deregulation. In 1992 the National Energy Policy Act opened the door to deregulation, but without giving specifics. This law allowed for open access to transmission systems so that generators could sell electricity directly to load instead of to the utilities that those loads were located in. It also required transmission owners to move the electricity. In many cases before they had not been legally required to do so. This created a market, but one without any operating rules. This uncertainty inhibited investments. A generator is a 30-year investment of hundreds of millions of dollars. Before you invest that kind of money, you want to be sure that you'll be able to repay the loan with profits from the generator. In the United States, in California and in the Northwest, there's a great deal of uncertainty. Every time the state legislator or the Governor or the President announces a new approach to the crisis, more uncertainty is created, which continues to inhibit construction of new generation.

EEK 2001: How does this affect residents of Washington?

Washington is subject to deregulation under the 1992 National Energy Policy Act. The market created under the act is participated in by utilities in the state of Washington.

EEK 2001: Is that why Washington residents are experiencing large increases in the cost of power?

Seattle City Light (a branch of city government) normally has enough energy from water behind its dams to supply the city. The problem is there hasn't been a lot of rain recently in the Northwest. City Light does not have enough capacity to supply all the energy for Seattle, so they must purchase it– and essentially pay the same price that California pays.

EEK2001: Will the Northwest run out of power?

It's possible. Normally during winter months, we purchase electricity from California, and in the summer, California purchases from us. This winter California is purchasing from us. The summer will be challenging.

EEK 2001: Is there a technological solution to this problem?

The problem is political and economic. There is no fast, clean, cheap technological solution. EEK2001

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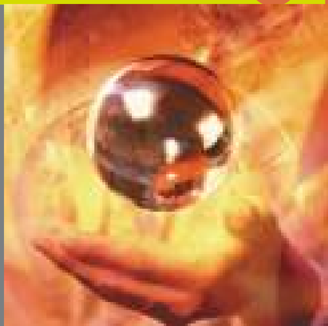
CRYSTAL BALL:



A Glimpse Beyond State-of-the-Art

By H. Chizeck

During the past century, Electrical Engineering has grown from its roots in motors and power, to encompass microchips, microwaves, optical switches, radar, ultrasound, autonomous robots and the recognition of human speech. Working at the macro scale of power grids and the micro scale of nanotechnology, electrical engineers have had an extraordinary impact on our lives. There are the obvious things like radio, microwave ovens, personal computers, satellite television, and video games. Less obvious are the electronics in our automobiles—on-board diagnostics, anti-lock braking and engine control. Aircraft are designed and flown electronically. We can spend money and trade stocks electronically, even when on a different continent. Magnetic resonance imaging, pacemakers, and instantaneous electronic access to patient medical and prescription records have all enhanced health care.

Where do we go from here? Foretelling the future is always risky. Consider the warning from the "inventor" of the geostationary orbit and science fiction author, Arthur C. Clarke (from *Profiles of the Future: An Inquiry into the Limits of the Possible*):

- Clarke's First Law: When a distinguished but elderly scientist states that something is possible he is almost certainly right. When he states that something is impossible, he is very probably wrong.
- Clarke's Second Law: The only way of discovering the limits of the possible is to venture a little way past them into the impossible.
- Clarke's Third Law: Any sufficiently advanced technology is indistinguishable from magic.

With this declaimer, here is what I see in my crystal ball.

The next phase of the Information Technology Revolution will exploit optical and wireless communication hardware to fundamentally change employment and entertainment for much of the population–like the telephone, radio, television and the personal computer have during the past decades. In the near future, if we choose, we may be in constant contact with anyone, anywhere, through highly personalized mobile devices that are attached to a global network. Early versions are already on the market, combining web browsing, paging, cellular phones and calendar management. Soon they may appear as watches or jewelry. Later, they will be embedded in our clothing, and eventually implanted within our bodies.

Since the Industrial Revolution, we have separated our homes from the places where we work, shop, are entertained, are educated, and receive medical care. Contemporary urban geography relies on transporting people to and from these activities. In the coming decade, the home will increasingly become the site for these activities. When we leave our houses we may stay connected to them electronically. The nature of transportation and the meaning of physical location will also change. Global Positioning Systems, already available as "smart" maps which show automotive travelers, boaters, and hikers their exact position and direction, will become move widely used. They will also enable individuals or governments to track the exact location of automobiles, valuable possessions, pets, children, medical patients, criminals or (more ominously), political opponents.

Enabling technologies will include new network architectures and secure communications protocols, advanced signal compression and processing, mass network-connected memories, and compact portable energy sources. Equally important will be the development of new interfaces between the physical world and electronic systems. These include sensors, transducers, actuators, and human-machine interfaces. We will talk with machines, as voice recognition provides hands-free interaction with computer appliances, lighting and transportation systems. "Virtual reality" projections and sound environments are beginning to be used to enhance computer games, music and video entertainment systems and are already tools for surgical instruction, pilot and astronaut training and human-assisted computer-aided design (of architecture and pharmaceutical molecules). Haptic interfaces that provide "touch" and "feel" are being developed for the remote operation of devices in hazardous or inaccessible environments or at different physical size scales (micro-assembly, microsurgery, macro-assembly of large structures). "Smart systems" will increasingly be used for automatic failure detection, self-diagnosis, maintenance and repair.

Microscopic machines, measured in atoms rather than millimeters, will revolutionize industry. Nanomachines may be injected into our bodies to diagnose and treat disease, destroying individual cancer cells while not harming healthy cells, cleaning arteries, repairing vital organs. Nanotech-based smart materials with embedded sensors, actuators, and intelligence fabricated at the molecular level will be able to give off warnings when they experience stress. For instance, automobile or aircraft parts could send out warnings (over the pervasive network) before failing.

In the rapidly developing field of genomics, EEs will be the toolmakers–making the equivalent of Levis(for these twenty-first century "gold miners," developing sensors, actuators, automated test devices and perhaps extending control, signal processing and coding theory to gene and protein expression. MEMS (microelectrico-mechanical systems) devices will provide platforms for nanotech components. Watch for genetic-based personal identification and medical diagnostic systems and, later on, combined electronic-biological devices that can control gene expression and protein synthesis in vivo.

Of course, all of this could be completely wrong. Consider how none of the science fiction literature before the early 1970's predicted personal computers. EEK2001