Laboratory for Electromagnetic and Electronic Systems

The Laboratory for Electromagnetic and Electronic Systems (LEES) is engaged in applying a broad range of advanced technologies to increase the efficiency of electric energy production, distribution, conversion, utilization, and storage. It performs research in electromechanics from the nanoscopic to the macroscopic levels. Electric energy and electromechanics are defined broadly to include power systems design, monitoring, and operation; electrical energy storage; automatic control; power electronics; high-voltage engineering; and conventional, continuum, and biological electromechanics. In recent years, the laboratory has extended its expertise in controlling and monitoring complex electrical distribution networks to the area of controlling and monitoring complex patient monitoring systems such as in a hospital intensive care unit—a new area of research that offers considerable promise and has recently brought in funding from the National Institutes of Health.

LEES also maintains and operates a 3.5-MeV Van de Graaff electron accelerator, which has been used for cancer therapy and to develop hip replacement materials and is now used for cargo inspection research through nuclear resonance (funded by Homeland Security through Passport Corporation) for basic studies of conduction in insulators (funded by Toshiba) and for radiation testing of commercial satellites.

Much of the work of the laboratory is experimental, and industrial sponsorship represents a large fraction of its support. The laboratory's professional staff consists of eight faculty members from the Department of Electrical Engineering and Computer Science (EECS), one principal research engineer, two principal research scientists, two postdoctoral associates, and approximately 50 graduate students. The laboratory faculty and most of the staff are heavily involved in teaching and course development, including outreach through freshman seminars and women's and minority programs, and two of the faculty are involved in managing the EECS VI-A Internship Program. Faculty from the Departments of Mechanical Engineering, Chemical Engineering, Materials Science and Engineering, Physics, and Architecture are collaborators in many of the laboratory's programs, and there are extensive joint activities with the Microsystems Technology Laboratory (MTL), the Gas Turbine Laboratory, the Materials Processing Center, the Research Laboratory for Electronics, and the Harvard–MIT Division of Health Sciences and Technology (HST). Every term, undergraduate students in LEES carry out a substantial number of Undergraduate Research Opportunities Program and senior projects.

Automotive Consortium

The MIT/Industry Consortium on Advanced Automotive Electrical/Electronic Components and Systems, managed within LEES by director Thomas Keim and business manager Gary DesGrosseilliers, continues to provide a venue for automotive companies and suppliers from around the world to come together and discuss innovations in the use of electric power in automobiles. Last fall, the Consortium co-organized a meeting on automotive power electronics with the Société des Ingénieurs de l'Automobile, and in June it organized and conducted a Consortium meeting in

Shanghai. The Consortium inspired and funded several of the research projects in the following pages.

Research Emphasis

The LEES research emphasis has broadened from traditional applications of electrical power and energy and now includes several exciting nontraditional and cross-disciplinary areas that show great promise. In particular, many of the projects described here relate to the pressing topic of increased efficiency in generating and storing electrical power.

Representative LEES energy-related projects

1. Nanotube-enhanced ultracapacitor (synthetic battery) for portable electrical energy storage
2. High-efficiency thermophotovoltaic energy conversion using photonics (heat to electricity)
3. Miniature gas turbine generators (in conjunction with digital avionics systems)
4. Scavenging (reclaiming) vibrational energy
5. High-frequency (lightweight) DC-DC conversion
6. High-efficiency windmill generator and ship propulsion
7. Electromagnetically actuated valves for internal combustion engines
8. High-efficiency automobile alternator
9. Designing and monitoring high-efficiency buildings (in conjunction with Architecture)
10. Nanofluids for efficient cooling and improved electrical breakdown characteristics in high-voltage electrical transformers
11. Research on breakdown mechanisms in high-voltage electrical insulators
12. Leadership of international automobile consortium on improved automobile performance through electronics.

Research Projects

High-Efficiency Automotive Alternators

Professor David Perreault has proposed, implemented, and patented the combination of an automotive alternator with a boost-mode rectifier in place of the standard diode rectifier. Several important advantages result, including both a large increase in the output capability of the alternator, when averaged over a drive cycle, and a substantial increase in efficiency. The increase in output makes it possible to make the overall vehicle more efficient by reducing the empty vehicle mass-to-payload ratio. The increase in alternator efficiency reduces fuel consumption directly.

Electromagnetic Engine Valves

Electromagnetic engine valves offer a substantial increase in fuel economy by allowing easy and flexible implementation of the ability to vary valve lift height, lift duration, and lift timing in response to changes in the engine operating condition. LEES has invented a system that provides inherent soft landing of the valve on the seat and also at its rest position at the open end of the stroke and has developed a custom-designed electromagnetic actuator providing an especially high torque-to-inertia ratio and low electrical loss. This year the staff includes professors John Kassakian and David Perreault, Dr. Thomas Keim, and graduate student Yihui Qiu.

Electrochemical Modeling of Battery Dynamics

Graduate student James Geraci completed and defended his thesis in June. His work demonstrated practical and effective numerical techniques for overcoming the substantial numerical difficulties arising from finite-difference solution of the electrochemical differential equations describing the dynamics of charging and discharging lead-acid batteries. He identified and articulated how the complexity of the structure of physical battery electrodes places practical limits on the accuracy of this method of analysis. This work also included a substantial contribution to the use of multicore digital computers in solving sets of equations of this general structure.

Interfacing Renewable Energy Sources with Electric Power Systems

With support from the MIT–Portugal program and the Masdar Institute of Science and Technology (Abu Dhabi), professor James Kirtley is working with two Masdar faculty members (Dr. Hatem Zeineldin and Dr. Scott Kennedy), one postdoc (Dr. Mirjana Marden), and three graduate students (Kevin Brokish, Jiankang Wang, and Olivia Leiterman) to develop ways renewable energy sources (such as wind and solar) could interface with electric power systems. We are considering a number of issues in this general area, including microgrids (an area of particular interest to our opposite numbers at the University of Porto, Portugal), load-responsive controls including FAPERs (frequency adaptive power energy regulators, an idea proposed about three decades ago by LEES' Fred Schweppe), real-time pricing in a deregulated environment and as it might be affected by nondispatchable generation such as wind, and operational details of distributed generation such as islanding detection.

Load Losses in Induction Motors

Professor James Kirtley is working with PhD student Steve Englebretson to better understand stray load losses in induction motors with cast rotor cages. Professor Kirtley will deliver a paper to this year's International Council on Large Electric Systems meeting in Paris, and Mr. Englebretson will present this work to the International Conference on Electric Machines in Vilamoura, Portugal.

Naval Combat Ship Power Systems

As part of the Electric Ship Research and Development Consortium, Professor Kirtley is helping to develop an architectural model for the power system on a modern naval combat ship. In this work, he is collaborating with professor Chryssostomos Chryssostomidis of the Mechanical Engineering Department.

Wind Turbine Generator

Professor Kirtley built an experimental generator intended as a prototype for wind energy, also adaptable to large adjustable-speed motors, particularly ship propulsion.

Very High Frequency Electronic Power Conversion

Increasing the switching frequency of power electronics is a principal means for improving size and transient performance and for achieving higher degrees of integration. Professor David Perreault and doctoral students Yehui Han, Anthony Sagneri, and Jackie Hu have continued the development of power conversion circuits that operate at very high frequencies (30–300 MHz), two orders of magnitude higher than conventional designs. Efforts by the group in this area have received multiple honors this year, including two prestigious Institute of Electrical and Electronics Engineers (IEEE) best paper awards.

High-Efficiency Power Converters

Professor Perreault and doctoral student Brandon Pierquet are working to develop single-phase utility-interface power converters that operate at ultrahigh efficiencies (>97%). Such designs could greatly reduce power supply losses in a tremendous range of electronic equipment. Most recently, work has commenced under a contract with Enphase Energy to develop designs optimized to interface low-voltage solar panels to the grid at ultrahigh efficiency.

Ultraminiature Low-Voltage Power Regulation and Distribution

The ongoing proliferation of electronic systems operating at very low voltages (~1 V) under precisely controlled conditions represents a challenge for both power regulation and distribution. This has created a need for ultraminiature power supplies capable of providing substantial voltage transformation along with high-bandwidth regulation. Professor David Perreault and doctoral students David Giuliano and Robert Pilawa have been developing new two-stage architectures for low-voltage power conversion. The technology under development enables unprecedented degrees of miniaturization and power density and a high degree of integration. This work has resulted in one provisional patent filing and one conference publication this year.

FITMOS Vertical Power Transistors for Automotive Applications

Professor Perreault and graduate student Wei Li have been exploring the modeling and application of a new class of vertical power transistor—FITMOS—under contract from the Toyota Motor Corporation. The work focuses on identifying and quantifying the circuit-level performance advantages that can be gained by using these devices and on finding the best means of applying them to improve automotive power converters.

Demand-Side Energy Management for High-Efficiency Lighting Systems

With support from the MIT Energy Initiative and the National Science Foundation (NSF), professor Steven Leeb and graduate students John Cooley, Al Avestruz, and Amy Englehart developed and demonstrated hardware building blocks of a new autonomous demand-side energy management system for electric discharge lighting. This work builds on our effort to develop proximity sensing of people using electric field disturbances surrounding fluorescent lamps. We developed power electronics for new autodimming ballasts that detect occupants and automatically adjust their own brightness levels. All the electronics fit inside a standard ballast box with the intent of creating a drop-in replacement for standard ballasts. A patent was filed for this technology.

Noninvasive Monitoring Technology for Electrical System Fault Detection

With support from the Office of Naval Research through the Electric Ship Research and Development Consortium program, and with additional support from the Grainger Foundation, professor Steven Leeb is leading a team of graduate students and US Navy officers in implementing new condition-based maintenance systems for US Navy and Coast Guard ships using nonintrusive monitoring technology. During the past year, we have conducted the first field test of a fully autonomous monitoring system on the United States Coastguard Charter Escanaba, a 270-foot cutter stationed in Boston. The system correctly identified pathological operating conditions in real-time during an under way mission. Expanded testing and development with other applications, including energy conservation experiments on land-based utilities, are under way. Other uses of this technology involve localizing shorts in an automobile chassis (support from Granger and Ford), detecting faults in air-handling systems [National Aeronautics and space Administration (NASA) and NSF] (air conditioning alone accounts for a substantial portion of the total energy consumed by an average building in the United States), detecting faults in underwater autonomous vehicles (MIT SeaGrant), and detecting faults in satellites (NASA).

Micro Gas Turbine Project

The MIT micro gas turbine engine project seeks to replace batteries by using tiny gas-turbine generators that can be fabricated using microelectromechanical system (MEMS) technologies. As part of this project, professor Jeffrey H. Lang, in collaboration with professor Zoltan Spakovszky of the Aeronautics and Astronautics Department and colleagues at the Georgia Institute of Technology, has completed the redesign of the MEMS generator and successfully implemented a fully integrated version that projects to generate more than 10 watts of electrical power from a 0.5-cm^3 package.

Micro Electrical Relay Development

Professor Jeffrey Lang, in collaboration with professor Alexander Slocum of the Mechanical Engineering Department, has fabricated and demonstrated MEMS relays that are capable of hot-switching electric power at voltages up to one kilovolt. Their goal is to improve the current handling capability of these relays so that electric power can be hot-switched at currents up to 10 amperes. Such relays could find use in residential and light industrial applications.

Micro Energy Harvesters

Professor Lang is involved in several projects that focus on harvesting energy from ambient vibration. One representative project done in collaboration with principal research engineer David Otten is a component of the multiuniversity Cyborg Moth Project funded by the Defense Advanced Research Projects Agency. This system involves everything from micropower radio communications to nervous system interconnections.

MEMS Pressure Sensor Arrays

Professor Lang, in collaboration with professors Michael Triantafyllou and Franz Hover of the Mechanical Engineering Department, has begun developing MEMS pressure sensor arrays, and the corresponding signal processing, for use in underwater obstacle avoidance and navigation. The passive sensor arrays are biologically inspired as they mimic the lateral-line organ of fish and consume very little power, making them ideal for underwater autonomous vehicles.

Stress-Induced Conduction in Insulators

Dr. Chathan Cooke, working with industry for electric power apparatus, has applied ultrasonic diagnostics to quantify space charges and internal stresses in high-voltage epoxy dielectrics. The purpose of this effort is to improve the long-term reliability of materials used in electric power systems and other high-voltage applications.

High-Voltage Electron Beam Facility

Dr. Cooke and the late Mr. Kenneth Wright have been improving the instrumentation and performance of the 3.5-MeV electron beam facility at LEES. The facility has been used for a variety of measurements including the processing of silicon wafers for improved radio-frequency windows, the production of gamma rays for the stimulation of nuclear fluorescence radiation for cargo inspection, charge implantation studies, and polymer processing for biocompatible materials, especially joint replacement studies with Massachusetts General Hospital in Boston. A recent project, being worked on by MIT Physics professor William Bertozzi with funding from Homeland Security, uses a nuclear resonance technology first demonstrated at this facility in the 1960s to provide cargo inspection for container ships.

Thermophotovoltaic Projects

Devices that statically convert heat into electricity are highly desirable, but low efficiency and high costs have hindered widespread and large-scale use. Professor John Kassakian, principal research engineer Dr. Thomas Keim, postdoctoral research associate Dr. Ivan Celanovic, and doctoral student Natalija Jovanovic (who received her PhD in June) have continued the experimental and theoretical investigation of advanced spectral control components—based on photonic crystal devices. The Thermophotovoltaic (TPV) group's mission is to demonstrate that viable, high-performance and low-cost static energy-generation devices and systems are achievable. By combining our knowledge and experience in fields as diverse as photonic crystals, micro- and nanofabrication, microscale heat transfer, semiconductor devices, power electronics, and system design optimization, we have embarked on the quest for new and ultraefficient ways to generate and convert static energy.

Our current projects demonstrate the highly cross-disciplinary and collaborative nature of our work that ranges from theoretical investigations and modeling, device fabrication, and characterization all the way to system design and implementation. We are currently working on three research projects:

- Portable TPV power generator
- Modeling, characterizing, and packaging low-bandgap GaInAsSb photovoltaic diodes
- Quasi-coherent narrow-band thermal radiation: theory and applications.

Portable Thermophotovoltaic Power Generator

Under the support of the MIT Institute for Soldier Nanotechnologies, we are developing the first-of-a-kind 20-W propane-fueled portable TPV power generator, which will demonstrate five times the energy density of the best rechargeable batteries on the market (TPV power generation is a static power conversion system that generates electricity from radiant heat). One key innovation is the design and optimization of photonic crystal materials with a photonic bandgap optimally tuned to the electronic bandgap of a low-bandgap III–V photovoltaic diode. This approach maximizes the overall radiant heat into electricity conversion efficiency.

Modeling and Packaging Low-Bandgap GaInAsSb Photovoltaic Diodes

Jointly with the Lincoln Laboratory, we are developing packaging techniques for 0.5-eV bandgap GaInAsSb photovoltaic diodes that they developed and fabricated in previous programs. Our initial effort has resulted in packaged photovoltaic diode cells with a measured efficiency of 29%.

Quasi-Coherent Narrow-Band Thermal Radiation: Theory and Applications

Resonant thermal emission is a highly anomalous phenomenon in which certain materials can exhibit quasi-coherent (spatial and/or temporal) thermal radiation properties. We conceived and demonstrated two types of resonant thermal emission sources, in collaboration with professors John Joannopoulos and Marin Soljacic of the Physics Department, based on new photonic crystal structures. These structures can be used to efficiently convert heat into other useful forms of energy including electrical, optical, and further. Our initial theoretical findings suggest that resonant thermal emission devices can be used to achieve heat-to-electricity conversion efficiencies approaching Carnot efficiency, the upper limit on the heat engine conversion efficiency.

Nanotube-Enhanced Ultracapacitors for Improved Electrical Energy Storage

The goal of this project, conducted by professors Joel Schindall and John Kassakian and graduate students Riccardo Signorelli and Daniel Ku, is to develop a practical electrical energy storage device that combines the long life and rapid charge–discharge capability of a capacitor with the much higher energy storage capacity of a rechargeable battery. We believe this goal can be achieved by increasing the energy storage capacity of a commercial electrical energy storage device called a double layer capacitor or ultracapacitor by replacing the activated carbon electrode coating with an array of vertically aligned nanotubes.

The predicted performance of the nanotube-enhanced ultracapacitor is significantly higher (30 to 60 Wh/kg) because of its improved electrical characteristics and because the diameter and spacing of the nanotubes are matched to the dimensions of the electrolyte ions, in contrast to the irregular pores exhibited by activated carbon. Calculations indicated that this structure could achieve an energy storage density approaching that of a lithium battery, while providing significantly higher power, faster recharge, and almost unlimited lifetime.

We have successfully fabricated electrode material using a reactor designed and assembled in our laboratory, we have assembled working test cells, and we are working to improve the storage density. Professor Donald Sadoway from Materials Science and Engineering has recently joined this project, and professor Mildred Dresselhaus is assisting as well. Ongoing funding for this activity is being provided by the Ford–MIT Alliance and MIT Energy Initiative seed funding.

Fault-Tolerant Systems

Under funding from the Draper Laboratory, professor Joel Schindall and postdoctoral researcher Dr. Alejandro Domínguez-García continued their work on the design of ultrareliable embedded electronic systems and controls for safety-critical/fault-tolerant applications used in aircraft, aerospace, tactical, automotive, and power systems. Dr. Domínguez-García left the laboratory in June to become an assistant professor in the power electronics group at the University of Illinois, Urbana.

Commonality Analysis of Guidance Navigation and Control Architecture for Space Systems

Dr. (now professor) Domínguez-García also worked with professors Edward Crawley and Steven Hall from the Aeronautics and Astronautics Department and NASA Engineering Safety Center to study the potential for developing common architectures for guidance navigation and control systems of different space applications, both human-rated and robotic.

Streamer Propagation and Electrical Breakdown in Nanofluids

An electrical, fluid dynamic, and thermal multiphysics model of streamer initiation and transport that leads to electrical breakdown in transformer oil and in nanoparticle suspensions in transformer oil has been developed by professor Marcus Zahn and graduate student George Hwang, with funding from ABB. The analysis has explained and verified counterintuitive ABB measurements of higher positive voltage breakdown levels with slower positive streamer velocities for nanoparticle suspensions than that of pure transformer oil.

Ferrofluid Dynamics in Time-Varying Magnetic Field

With funding from the Binational Science Foundation, Professor Zahn has investigated microfluidic and nanofluidic pumping of magnetic and dielectric nanoparticle and microparticle suspensions in host liquids, driven by a combination of DC, alternating, and rotating magnetic or electric fields. This has application to fluid transport and thermal heat pipes in terrestrial and space applications, selective absorption of particles, biomedical applications such as cancer and other therapies, hyperthermia treatment, and magnetic resonance imaging (MRI) contrast enhancement. June 2008 PhD graduate

Padraig Cantillon-Murphy's thesis focused on MRI applications of magnetic fluid, PhD graduate student Shahriar Khushrushahi contributed to magnetic fluid pumping, and PhD graduate student Hsin-Fu Huang is working on increased microfluidic flow velocities due to dielectric particle rotation in dielectric fluid/particle suspensions known as electrorotation or the Quincke effect.

Dielectrometry Measurements of Moisture Diffusion and Temperature Dynamics in Oil-Impregnated Paper-Insulated Electric Power Cables

Paper-insulated lead-covered (PILC) cables have played an important role in underground power distribution for a hundred years. Replacing aged PILC cables before failure due to temperature and moisture is critical to managing power distribution. With recent funding from the Electric Power Research Institute, we are utilizing interdigital dielectrometry sensors excited by a wide range of frequencies, along with an advanced theoretical model, to detect the degrading effects of moisture and changes in temperature. Extensions of this technique might apply to a wide range of detection devices, ranging from subsurface corrosion to an airport security mat to detect dangerous materials without the need for passengers to take off their shoes.

Stochastic Network Models

Professor George Verghese's group continues to develop and study stochastic network models in a variety of dynamic settings ranging from synchronization and desynchronization of networked oscillators (as in the case of generators in a power network), to propagation of infection-like processes on networks, to the collective behavior of stochastic automata at the nodes of a network interacting with the automata at neighboring nodes. The three doctoral students currently working in this area, Laura Zager, Victor Preciado, and Bill Richoux, have been supported by fellowships (NSF, La Caixia, Martin, and others) and have served as teaching assistants in EECS.

Integrating Data, Models, and Reasoning in Critical Care

Professor George Verghese's group is pursuing one of the core research thrusts of an NIH-sponsored bioengineering research partnership directed by professor Roger Mark in HST. The partnership combines the resources of a powerful interdisciplinary team from academia (MIT), industry (Philips Healthcare and Philips Research North America), and clinical medicine (Beth Israel Deaconess Medical Center) to develop and evaluate advanced monitoring systems for patients in intensive care units. The aim is to develop intensive care unit monitoring approaches and systems that will improve the efficiency, accuracy, and timeliness of clinical decision making in intensive care. Professor Verghese's group, which includes postdoctoral associate Dr. Thomas Heldt (who obtained his PhD in Professor Mark's laboratory), focuses on questions of model-based estimation of clinically meaningful variables from available data streams, along with the associated signal processing challenges. The use of electrical circuit analogies for hemodynamic behavior is especially fruitful, given the intimate understanding electrical engineers have for circuit behavior (including nonlinearities, periodicities, and disparate timescales). The project is nearing the end of its first five-year term, but a competitive five-year renewal proposal has been selected for funding, after excellent reviews.

Cerebral Hemodynamics

Neonatal Neurodevelopment

Extremely preterm neonates (infants born at less than 26 weeks of gestational age) often suffer from severe cognitive and neurological impairments that seem to be caused by a hemorrhagic or a hypoxic insult to the brain during the first few days of life. Despite extensive risk-factor analyses, the clinician's ability to identify infants at risk of developing neurodevelopmental deficits is quite poor. This nascent collaboration between professor George Verghese's group at MIT (again with Dr. Thomas Heldt as a key participant) and Dr. Adre Du Plessis's group at Boston Children's Hospital aims to elucidate the relation between cerebral hemodynamics and the occurrence of neonatal brain injury, with the ultimate goal of developing an early warning system to alert neonatologists of impending cerebrovascular crises.

Intracranial Pressure and Cerebrovascular Autoregulation

A similar collaboration in the setting of adult patients with conditions such as stroke and traumatic brain injury is developing with Dr. Vera Novak at the Gerontology Lab in Beth Israel Deaconess Medical Center. Both the physiology and the measurement modalities in this case are different from the case of neonates, but the two efforts complement each other well.

Micropower Medical Technology Platform for Wearable Monitoring

This collaboration between researchers from Texas Instruments and MIT's MTL, and involving Professor Verghese's group in LEES, aims to develop a wearable chip platform that enables the robust acquisition and processing of a wide variety of biomedical signals indicative of human health. Funding from Texas Instruments to MTL over a 2.5-year period is anticipated to start shortly.

Stochastic Chemical Kinetics

Beginning with the doctoral thesis of Dr. Carlos Gomez Uribe (recently completed under the joint supervision of professor George Verghese and professor Leonid Mirny in HST), Professor Verghese has initiated work in LEES in the area of stochastic chemical kinetics. The aim is to track the dynamics of chemical reactions that involve low molecule numbers or low volumes, as arise in intracellular processes or potentially in nanoscale energy devices. The ongoing master's thesis of Paul Azunre focuses on developing tools for linearization, numerical computation, and stability analysis of model free kinetics models. All this work has been supported by a Merck Fellowship to Carlos Gomez and a gift in support of Professor Verghese's work in this area.

Approaches to Physically Based Multimodel Reduction

A recurring theme in the model-based research done by Professor Verghese's group is the challenge of carrying out systematic model reduction on large and elaborate physically based (or physiologically based) models, as arise in power systems, biomedical settings, and biochemical networks. The task is to preserve the hard-won physical insights that underlie the detailed models, while reducing these models to meaningful, interpretable lower-order or lower-complexity models that are better suited to identification, inference, reasoning, and/or control with the limited data that can be obtained in operational settings. We are working up a research proposal focused on developing fundamental methodology for such physically based multimodel reduction.

Educational Initiatives

Physics of Energy

Professors Steven Leeb, James Kirtley, and Leslie Norford have been teaching interlocking freshman seminars. With support from the d'Arbeloff Foundation, we have developed teaching material for these seminars. The idea is to involve students in experimentally-based learning about energy, including power density, energy density, and efficiency. Examples of the sorts of experiments the students do include the following:

- Measuring the power consumption of an electric go-kart and figuring out its range with a battery of a certain weight and energy storage capability
- Building a shake flashlight, including optimizing the induction coil for the application
- Building a small power plant, fired by alcohol gel fuel, using a sterling cycle engine and a permanent magnet generator and estimating its efficiency
- Making a very simple (paper clip) motor, competing with the other students for the highest rotational speed using a given terminal voltage
- Building a robot for environmental sensing
- Our overall objective is to get students thinking about energy and issues associated with it: generation, storage, and consumption.

Honors and Awards

Professor James L. Kirtley Jr. was inducted into the National Academy of Engineering.

Professor Dave Perreault received an IEEE Power Electronics Society Transactions Prize Paper Award (for the paper "Resistance Compression Networks For Radio-Frequency Power Conversion") and the IEEE Power Electronics Society PESC Conference Prize Paper Award (for the paper "A Very High Frequency DC-DC Converter Based on the Class Phi-2 Resonant Inverter").

Joel Schindall
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Bernard Gordon Professor of Electrical Engineering and Computer Science

More information about the Laboratory for Electromagnetic and Electronic Systems can be found at http://lees.mit.edu/lees/.