



# BSAC News

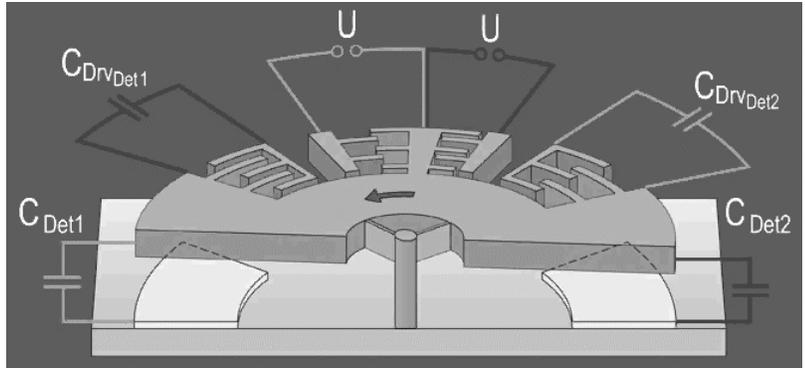
AN NSF INDUSTRY / UNIVERSITY COOPERATIVE RESEARCH CENTER  
UNIVERSITY OF CALIFORNIA BERKELEY & UNIVERSITY OF CALIFORNIA DAVIS  
FOUNDED IN 1986

## THE "E" IN MEMS

by George Landsburg

Micro Electro Mechanical Systems (MEMS) can be tough taskmasters, and as BSAC Director and Professor Bernhard Boser approaches his latest electronic design challenge, he recognizes it well; it is a recurring theme. The sensed electrical output from a MEMS device can be incredibly small, on the order of microvolts, while electrostatic actuator drive requirements can be 50 volts or more. It gives so little, but needs so much. These are not problems for standard cell or compiled silicon solutions.

MEMS transducer deflections can be on the order of Angstroms, and the resulting differential changes in capacitance, the most commonly sensed variable, are often fractions of an attoFarad ( $10^{-18}F$ ). The electronic signatures of different types of proteins may demand even more challenging sensitivity. Circuit capacitances several orders of magnitude larger than the sensed variable are



*MEMS Capacitances for Comb-Drive Rotational Actuation (C<sub>Drv</sub>) and Detection (C<sub>Det</sub>). Parasitic capacitances (not shown) reduce sensitivity of position detection. (courtesy Bosch)*

often encountered when coupling a MEMS sensor to even a single IC transistor. Fortunately, Professor Boser is no stranger to this challenging problem: interfaces to innovative transducers are a continuing part of his pioneering work in high-resolution Analog-to-Digital converters and analog sensing circuits. His previous work in signal conditioning mixed-signal IC's applies, and his students are now applying these principles to the even more extreme MEMS environment.

His position of Editor-in-Chief of the IEEE Solid State Circuits Journal is testament to the experience he brings.

### Sensing Changes in Capacitance

Whether dealing with the interleaved fingers of an accelerometer or gyroscope, the coupling component of a resonant strain gauge, or the membrane of a cell, capacitance is a *natural* signal parameter of MEMS, he explains. The physical forces or biological properties

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## A PEEK INTO MEMS TECHNOLOGY IN HONG KONG

### BSAC Hosts Visiting Professor Yitshak Zohar

During October and November 2002, Mechanical Engineering Professor Yitshak Zohar of the Hong Kong University of Science and Technology (HKUST) was a campus guest of BSAC Director and Professor Liwei Lin. Shortly after his arrival, Professor Zohar was a guest speaker at the BSAC lunch seminar at which he introduced the BSAC researchers to MEMS topics being studied in the micro-systems program at HKUST.

HKUST has a well-equipped microfabrication facility within which experimental devices and structures are fabricated and packaged, and provided to various laboratories. An impressive scope of materials and micro-systems work underway in multiple Hong Kong universiti-

*Continued on page 3*

## EXECUTIVE DIRECTOR PERSPECTIVE

### From the desk of John Huggins

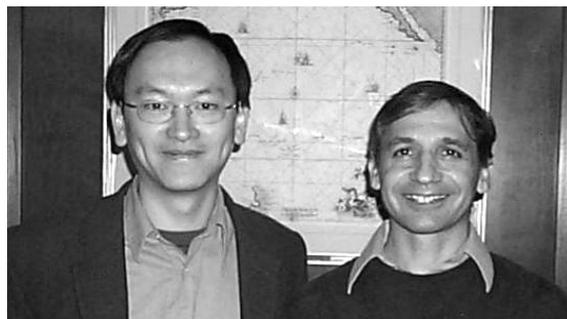
#### It's about the people.

The articles in this issue of the BSAC Newsletter are tilted toward recognition of accomplishments of a representative few. We touch not only on achievements but also on the energy and work ethic which we see in exceptional people. These are recurring virtues to those attracted here and contagious virtues to those working and studying here. So the story is about more than accomplishments. It's about the people. Having said that, the same "drive" results in people moving, if temporarily, for other challenges and risks. Victor Faessel, a valued Grant Administrator, and my executive assistant, is moving his family to Japan in February, to complete his Doctoral thesis in comparative linguistics. Sayonara, Victor! Professor Pister's new challenge, *Dust, Inc.*, is covered on page 2.

#### It's also about the web site.

At the last IAB I committed to work on our communications vehicles, including our web site. The commitment was to make it better if not prettier. Two minutes into a web search, we don't care much about pretty. However, it will, by the time you read this, have a minor cosmetic facelift. By better we mean more valuable for access to the work and results of the Center, especially for the members and Graduate Student Researchers. So the effort is going into adding content and navigational convenience and maintainability. As members

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*Professor Liwei Lin and Professor Yitshak Zohar*



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## BSAC-INSPIRED SMART DUST START-UP

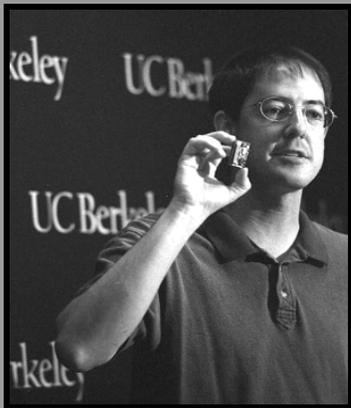
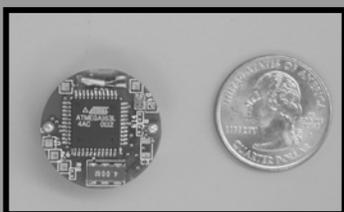


Photo by Noah Berger

Eighteen commercial start-up ventures have been inspired and enabled by research at BSAC. The latest in this legacy is a company formed to commercialize wireless networks of communicating, self-discovering motes. These motes have been termed "Smart Dust" (because of their extreme miniaturization goals) by UC Berkeley Professor and BSAC Director Kristofer Pister.

The venture has taken the name *Dust, Inc.* with facilities in nearby Emeryville, CA. Several recent UC Berkeley graduates will form the nucleus of the technical team with Pister, who will serve as CEO while taking a leave from teaching at UC Berkeley. *Dust, Inc.* is in the capital formation phase while work continues on launch of their first product, code-named "Blue". What could the code color for the second product be? Hint: Go Bears! Pister has likened this capital formation phase to "life in a centrifuge".

You will continue to see him periodically in his UC Berkeley office while leading and advising his UCB graduate students. And he will continue to serve as a BSAC Director. When, after getting the new company on track, he returns full time to his Berkeley/BSAC academic life, you can expect him to create exciting new research in his primary area of interest, micro-robotics. Between cycles in the centrifuge, he has already begun thinking about that.



Sensor Node  
(Smart Dust Mote)

# THE NEW STRUCTURE OF IAB MEETINGS

## IAB Spring 2003 Adds Technical Directions Session and a Third Day

At the Fall 2002 BSAC Research Review & Industrial Advisory Board (IAB) meeting, the Industrial Membership requested the addition of a technical session on the afternoon of the day preceding the general research review. The goal of this session would be to put into better perspective the directions and context for the multiple BSAC research projects, and to allow more dialogue with members on these directions.

So, our Spring 2003 Research Review & IAB meeting will begin a day early, on the afternoon of Monday, March 10, with a session for Industrial Members and Directors, at which the trends of our technologies and thrusts of BSAC will be presented by BSAC Faculty Directors. A dinner on the first evening with member companies and Directors will facilitate additional opportunities for informal contact. A special industry keynote speaker for the first evening will be announced. The second and third days will be organized as in the past, with a full day of intensive research review at which all 90+ projects are summarized in plenary session, with poster sessions to allow discussions between members, invitees, and individual researchers. The 700 page IAB Proceedings with research summaries, updates, and poster information for all projects will be distributed. Dinner on the second evening with all members, GSRs, NSF personnel, and Directors concludes the Research Review portions of the meeting. As in the past, the third morning will comprise the closed Industrial Advisory Board meeting attended by representatives of each member company (two votes per company) and the NSF Evaluator, followed by a feedback session to the Center Directors.

### Register for IAB Spring 2003 in January on the BSAC website at

<http://www-bsac.eecs.berkeley.edu>

There you will find reservation forms, directions, maps, hotel suggestions, and as the IAB approaches, a more detailed agenda. Abstracts and the Executive Director's State of the Center report will be emailed to all members in advance.

### PRELIMINARY IAB AGENDA

#### Monday, March 10, 2003

(UCB, Barrows Hall 7<sup>th</sup> floor, Lipman Room)  
*Industrial Members, Directors, and NSF Personnel*

12 PM	Registration Opens
2 PM	Technical Directions Sessions
6 PM	Informal Mixer
7 PM	Members Dinner with Invited Keynote Speaker

#### Tuesday, March 11, 2003

(UCB, Bechtel Engineering Center)  
*Industrial Members, Directors, NSF Personnel, Graduate Student & Post-Doctoral Researchers, Affiliated Faculty, and Invitees*

7:30 AM	Registration and Continental Buffet
8:30 AM	First Morning Technical Session
10 AM	Morning Poster Session
11 AM	Second Morning Technical Session
12 PM	Light Lunch
1:30 PM	First Afternoon Technical Session
3 PM	Afternoon Poster Session
4 PM	Second Afternoon Technical Session
5:45 PM	Wine Tasting and Mixer

(UCB, The Faculty Club)

*Industrial Members, Directors, NSF Personnel, and Graduate Student & Post-Doctoral Researchers*  
7 PM Spring 2003 BSAC Dinner & Awards

#### Wednesday, March 12, 2003

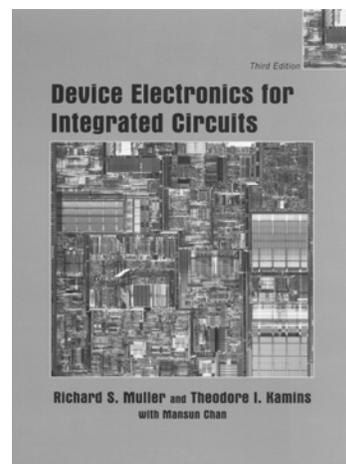
(UCB, Bechtel Engineering Center)  
*Point of Contacts (2 from each Industrial Member), Directors, and NSF Personnel*

8 AM	Coffee/ Tea and Pastries
8:30 AM	Level of Interest Feedback Evaluation (LIFE forms) on Research Presentations
9:30 AM	Closed Industrial Member/ NSF meeting (no BSAC personnel)
10:30 AM	Industrial Member/NSF Report to BSAC Directors and Discussion
11:30 AM	Spring 2003 IAB Meeting Adjourns

## NEW EDITION OF AN INFLUENTIAL BERKELEY TEXTBOOK

He has been called "a founding father of MEMS" in the trade press. Corporate researchers ask for his autograph at BSAC meetings. Professor Richard Muller, while flattered, focuses instead on making new contributions to technology, science, and education. He is Editor-in-Chief of the IEEE/ASME Journal of MEMS (JMMS). He continues to advise his Berkeley BSAC doctoral students, to publish widely, and to push into new technologies. And he continues to advance and inspire the education of undergraduate engineering students through his writings.

In October 2002, Muller received the first copy of his 3<sup>rd</sup> edition of the seminal textbook, Device Electronics for Integrated Circuits, which he co-authors with Theodore Kamins of HP Labs and Mansun



Chan of HKUST.

The text deals primarily with the physics of semiconductor devices. Basic physics, unlike programming languages, network protocols, or politics, is not so likely to change, is

not so subjective. But the dominant manifestations of technologies do change. The new edition reflects these changes mainly in treatments of highly scaled MOSFET designs. New examples in the book illustrate the escalating multidisciplinary impacts of electronics to "mechanics, optics, chemical, and biological integrated systems where techniques, paradigms, materials, and processes developed for ICs are being extended to MEMS."

In the past 25 years, more than 50,000 science and engineering students have learned semiconductor electronics from the first three foreign-language translations and even unauthorized printings. Now, a new generation of engineers and scientists has the opportunity to learn from Muller, Kamins, and Chan.

# INDUSTRY ACCOLADES FOR BSAC DIRECTORS

Small Times Magazine 2002

## Professor Luke P. Lee Researcher of the Year Finalist

Selection for this level of recognition in a "hot spot" of technology research, at such a relatively early phase in his career, bodes extremely well for Bioengineering Assistant Professor and BSAC Director Luke Lee – and for BSAC members and researchers! His research in BioMEMS will significantly impact not only engineering fields, but scientific and medical disciplines as well.



"Lee is developing a miniaturized microscope that could allow physicians and biologists to observe living cells and their components. His research at the University of California, Berkeley, focuses on 'BioPOEMS,' or Bio Polymer-Opto-Electro-Mechanical Systems. An assistant professor of bioengineering and a director in BSAC, Lee reported this year that he and his research team devised a MEMS-based scanner array that produced 2-D images of a cell wall as effectively as a traditional confocal microscope.

"His goal is to provide 3-D images with a technology that could fit on a ballpoint pen tip for use in endoscopes, for instance. That would allow physicians to investigate what appear to be abnormal cells."

## Professor Roger T. Howe Innovator of the Year Finalist



Perhaps this is just another exhibit in the growing body of evidence of Professor Roger Howe's status as contending "superstar" in the MEMS world, but his natural leadership skills are proving as strong as his technical and management aptitudes. We're sure there's a lot more to come!

"Howe has had a lot of good ideas in the 20+ years he's been tinkering with MEMS, materials and micromachining processes. But he not only has good ideas, he also shares them with students, colleagues and as a consultant.

"An engineering professor at the University of California, Berkeley, and a director of BSAC, he's made microresonators, micromirrors, microsensors and microactuators; experimented with less traditional materials such as silicon carbide and polysilicon coatings; and developed microassembly techniques. He's published a textbook and numerous reports on MEMS advancements worldwide. In 1998, he shared the IEEE's Cleo Brunetti Award 'for leadership and pioneering contributions to the field of microelectromechanical systems'."

Excerpts used with permission of Small Times Magazine, [www.smalltimes.com](http://www.smalltimes.com).



## MEMS IN HONG KONG

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es includes the Chinese University of Hong Kong (integrated rotational micro-sensors with vibrationally-powered RF transmission), the University of Hong Kong (semiconducting ceramic thin-films for photo, thermal, and humidity sensors); Hong Kong Polytechnic University (ultrasonic transducers and thin film materials including copolymers); and City University of Hong Kong (magnetron-sputtered and pulsed-laser deposited Shaped Memory Alloy SMA thin films for micro-pumps and micro-valves).

Professor Zohar's micro-systems group at HKUST, like BSAC, is exploring alternatives to overcome some of the limitations of "classical" silicon/polysilicon processing for highly integrated MEMS-CMOS systems. Examples include germanium (Ge), metal-induced laterally crystallized (MLC) polycrystalline silicon, and titanium-nickel shaped memory alloys (SMA).

Of interest to the BioMEMS and microfluidics BSAC researchers is HKUST's work on fluid mechanics and heat transfer mechanisms in microchannels. Prof. Zohar has reported that forced convection liquid flow in microfluidic channels

could be different from that of macro-systems. The observed onset of liquid-to-vapor phase change at critical heat flux (CHF) conditions, in forced-convection micro-systems, occurs without the expected pre-CHF bubble-induced (boiling plateau) flow. Another on-going effort to generate complex liquid flows in microchannels, utilizing patterned surface charge, has many potential applications in biotechnology.

Professor Yitshak Zohar can be reached at [mezohar@ust.hk](mailto:mezohar@ust.hk)

Professor Liwei Lin can be reached at [lwlin@me.berkeley.edu](mailto:lwlin@me.berkeley.edu)

## EXECUTIVE DIRECTOR

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of our formal research consortium, you are probably now getting automatically generated notifications and abstracts of pending new BSAC publications for your internal review and comment, a couple of months before they are presented externally. Full pdf versions are available on the site following publication. (Of course, you've been hearing about these projects for a couple years

before they are actually published.)

By mid-January, you will be able to access (and hopefully, find) organized "public abstracts" for all 92+ projects. These are Spartan abstracts by intent, so as to not preclude future patent or publication rights. We plan to make substantially more on-line content available to members and researchers. Shortly after the next IAB in March 2003, you will have on-line access to full abstracts, recent (6-month old) research sum-

maries, and possibly poster material, while preserving all IP and publication rights. To do this, we will have to document and enforce a more rigorous web authentication and access system with, for example, individual non-obvious passwords for members and researchers. We will measure, preserve, and extend the important and popular *existing* content. We hope you will find the content well worth the security features – and the wait.

JMH

## SUMMER 2003 MEMS SHORT COURSES

Five courses on MEMS are being organized as part of the fourth annual session of the Berkeley Summer Engineering Institute, a summer series of University Extension courses. All courses will be given in June 2003 on dates that will not conflict with the biennial Transducers Conference to be held in Boston, June 8-12. Many BSAC Directors will act as faculty for these courses, joined by colleagues who are, in many cases, BSAC alumni or postdoctoral researchers.

### DISCOUNTED TUITION JUST FOR BSAC!

BSAC members who make a non-binding early reservation on our BSAC website before the next IAB on March 10-12, 2003 will receive discounted tuition!

Questions can be directed to Ms. Joan Shao, UC Berkeley Extension at: [jvs@unx.berkeley.edu](mailto:jvs@unx.berkeley.edu).

### PRELIMINARY SCHEDULE

#### June 16-18, 2003 FUNDAMENTALS OF MEMS

Liwei Lin, Richard S. Muller, Norman C. Tien, and Kirt Williams

#### June 19-20, 2003 DESIGN OF MEMS

Albert Pisano, Liwei Lin

#### June 23-24, 2003 BIOMEMS

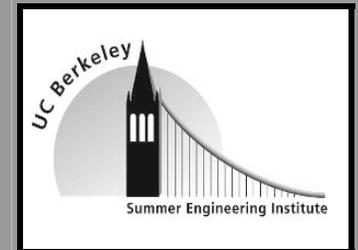
Dorian Liepmann, Luke Lee

#### June 23-24, 2003 OPTICAL MEMS IN COMMUNICATIONS & SENSING

Norman C. Tien, Olav Solgaard

#### June 25-26, 2003 PRACTICAL MICROSYSTEMS FOR BIOCHEMICAL ANALYSIS

Joseph Shoeniger, Anup K. Singh, Ernest Hasselbrink, and Bill Flounders



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## THE "E" IN MEMS

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### Sensing Changes in Capacitance

that change MEMS differential capacitances are typically of low frequency, dc to a few kHz. They are usually sensed by applying a higher frequency MHz range electrical signal to the MEMS capacitors. The sense signal is then amplified, filtered, detected, and quantified by use of established techniques from the signal processing world, such as:

- ✦ Use of modulation, double correlated sampling or chopper stabilization, to translate (in frequency) the narrowband sense signal well above dc circuit offsets and beyond 1/f noise characteristic of CMOS pre-amps
- ✦ Application of feedback around the electronics and the sensor to:
  - improve accuracy by having a well-controlled feedback network determine the response
  - restore the MEMS transducer to its most linear position of mechanical rest (electrostatic force feedback)
  - flatten the frequency response by reducing the effect of the MEMS self-resonance (especially in gyros)

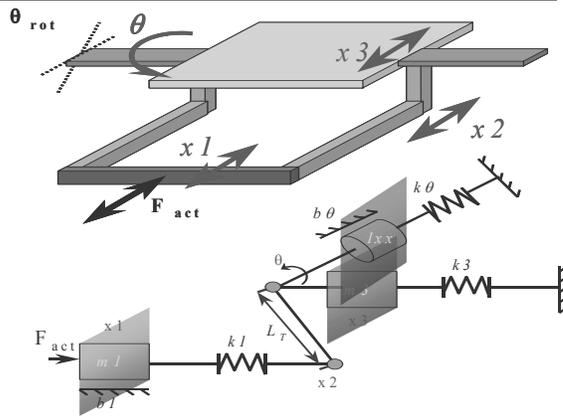
One promising approach of one Boser student "builds in" the basic structure of a sigma-delta converter to the mechanical-electronic loop, creating a new closed-loop sense architecture for micromachined gyroscopes.

### Sensing Frequency

As an option to direct measurement of capacitance, an inductor may be combined with a MEMS capacitor to create circuit whose resonance depends on the sense variable which can then be detected with a frequency-sensitive detector. Phase locked loop and frequency counters are common IC building blocks that can be applied to MEMS. Calibration cycles can tune up MEMS for maximum sensitivity and linearity, and built-in test modes can detect faults on the production floor.

### MEMS-Electronics System Design

How does one go about synthesizing and evaluating a MEMS electro-mechanical design? First, Boser suggests, think about some basic tradeoffs in the MEMS structure to maximize for example the available signal-to-parasitic ratio. Increasing the size of the transducer may be a poor strategy if the accompanying parasitics increase proportionately. Whatever design solution is proposed exposes another major challenge: modeling the composite structure. Because of the diversity of MEMS, from strain gauges and resonators to organic molecules, no general-purpose turnkey MEMS-modeling tool exists (yet). Much of the design phase is still hand-crafted modeling, heuristics, and insight borne of experience. The designer must ensure all the parameters and states affecting the performance and stability of the system are included, be they desired or parasitic, and the composite system model must converge. In short, there is no escaping an understanding of the multidisciplinary system and modeling problems confronted in MEMS. For the moment, the designer must select tools separately and combine them or use them iteratively, to accurately describe his system. Hope may be on the way. A lumped spring-mass abstraction model (such as that shown in the figure) may yield reasonable simulation accuracy without decompositions of elements into piecewise linear models. Kris Pister, a number of his students, and a Computer Science team from UC Berkeley has hopes of creating the equivalent of SPICE (the ubiquitous UC Berkeley lumped-model electronic circuit simulator) through development of "Sugar", a direct lumped model, mechanical simulator.



Lumped Spring-Mass Abstraction of MEMS Actuated Mirror

And to help develop electrical models for physical entities, Boser and his colleagues have access to other top rank BSAC faculty and affiliated faculty from *mechanical and electrical engineering, bioengineering, computer science, materials science*, and other UC Berkeley and UC Davis faculty with whom to collaborate and brainstorm. It would be hard to assemble so rich an environment anywhere else.

### Single- or Multi-Substrate?

Complete integration of MEMS-electronics systems are sometimes possible. Isolation trenches for MEMS structures in composite MEMS-CMOS processes are in use, allowing single-die solutions at the cost of process complexity (and yield). Roger Howe, Tsu-Jae King, and affiliated faculty at UC Berkeley are developing and championing a different approach with Silicon-Germanium processes which can be fabricated on top of (after completion of) conventional CMOS processing.

But while such single-substrate systems appear outwardly attractive from the signal routing and overall size perspectives, the economics are complex. Adding MEMS processing steps to those for standard IC's may result in a more costly system. Boser states, "Integration will be driven by economics." Today, multi-die approaches with simpler processes but more complex interconnect and packaging, are the only feasible solutions for some MEMS projects.

### A Good Time to be a Mixed-Signal Designer

The benefits of applying the wealth of established IC signal processing techniques are being borne out in multiple BSAC programs. BSAC teams have constructed gyroscopes incorporating electrostatic force feedback and modulation to detect Coriolis torque deflections of under an Angstrom. Resonant sensors detect fractional microstrains in steel bearings. Electronic-magnetic biological diagnostic sensors promise to unlock more information about cell chemistry, such as differences between normal and malignant cells, and detection of specific proteins in a solution.

Each new MEMS structure and application will present new design parameters for the interface electronics, but Boser has yet to encounter an instance not addressable in some way by extending and improving established art. This continuing work ensures there will be ongoing improvements in the mixed-signal IC techniques applicable to MEMS and to interfaces for NanoTechnology structures. "The E in MEMS" illustrates that it is, indeed, a good time to be a Mixed-Signal IC Designer.



Bernhard E. Boser

George Landsburg is a semiconductor design management specialist. He can be reached at [george\\_landsburg@hotmail.com](mailto:george_landsburg@hotmail.com).

## DEGREES EARNED

### Hongrui Jiang, PhD

UC Davis  
On-chip Micromachined RF Transformers and Variable Capacitors  
Currently Assistant Professor, University of Wisconsin, Madison

### Uma Krishnamoorthy, PhD

UC Davis  
Currently Post-Doctoral Researcher, Stanford University

### Kebin Li, PhD

UC Davis  
Currently Post-Doctoral Researcher, UC Davis with Professor Jonathan Heritage

### Patrick Riehl, PhD

UC Berkeley  
Microsystems for Electrostatic Sensing  
Degree Conferral January 2003

### Kyutae Yoo, PhD

UC Davis  
Biomimetic Directional Microphone Diagrams  
Currently Researcher with Samsung, Korea



## MAJOR MEMS UPCOMING CONFERENCES

### IEEE MEMS 2003

January 20-23, 2003  
Kyoto, Japan

BSAC will be presenting nine papers.

<http://mems.kaist.ac.kr/mems2003>

### TRANSDUCERS 2003

June 8-12, 2003  
Boston, MA

G. Benjamin Hocker  
General Conference Chair

Roger T. Howe  
Technical Program Chair

[www.transducers03.org](http://www.transducers03.org)

