

Mems Before And After 2025: From Application Requirements And Theoretical Aspects To Practical Design Approach

Lake Como School of Advanced Studies - May 29, 2023

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MEMS BEFORE AND AFTER 2025: FROM APPLICATION REQUIREMENTS AND THEORETICAL ASPECTS TO PRACTICAL DESIGN APPROACH

Villa Grumello, Como, Italy
May 29th, 2023 – June 1st, 2023

Microelectromechanical systems (MEMS) have been one of the most revolutionary technologies for the first two decades of the XXI century. Throughout twenty years, they quickly led first to an unprecedented miniaturization of sensors of various physical quantities (motion, magnetic field, sonic and ultrasonic waves...) and then to the introduction of microscale actuators (mirrors, lenses, speakers). Even more remarkable is their key enabling role towards artificial intelligence systems, robotics, autonomous mobility, remote patient monitoring, virtual reality... which indicates that their development in the next three decades, until 2050, will be even faster, with growing performance and applications.

These peculiar systems are often a delicate equilibrium between various physical domains, intuitively including micromechanics, electrics and electronics, but also involving fluidics, acoustics and thermodynamics. Their development thus requires cross fertilization of scientific knowledge in different engineering, physics mathematics and informatics sciences.

The goal of the Summer School is to provide the fundamentals of their working principle, with advanced description of a few case studies. Starting from the underlying theoretical bases, key fabrication processes and innovative technologies will be described, with an outlook to future developments. Afterwards, advanced electromechanical and electronics design for accelerometers, gyroscopes, micromirrors and microspeakers will be discussed, including innovative working principles which are under research all over the world. The importance of advanced multi-physics modeling will be presented to students with examples belonging to different physical domains. Finally, taking the advantage of having several MEMS companies in the Lombardia region, an industrial perspective towards the next-generation MEMS era will show the students the paths and the opportunities which are opening up in this exciting field.



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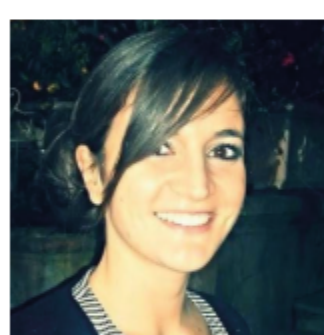
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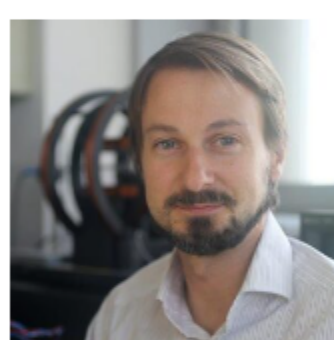


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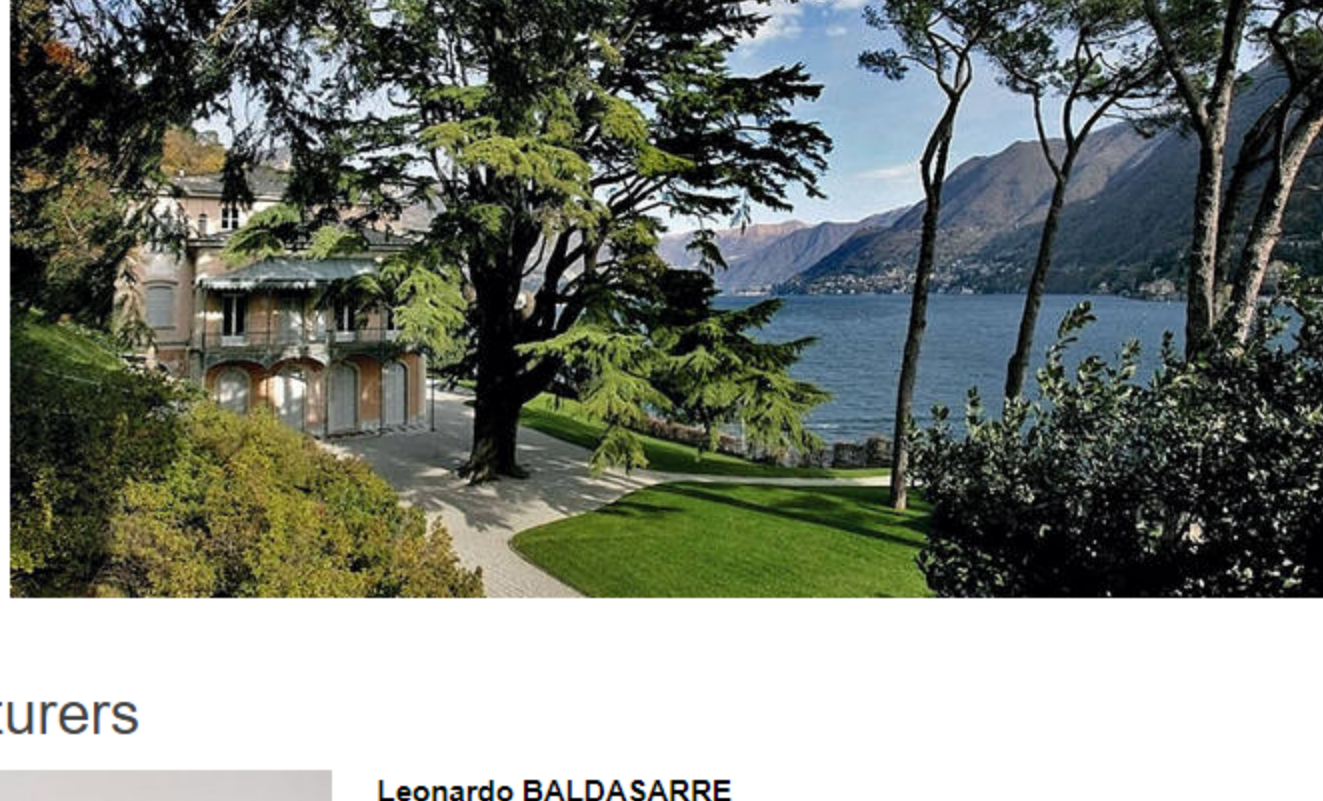


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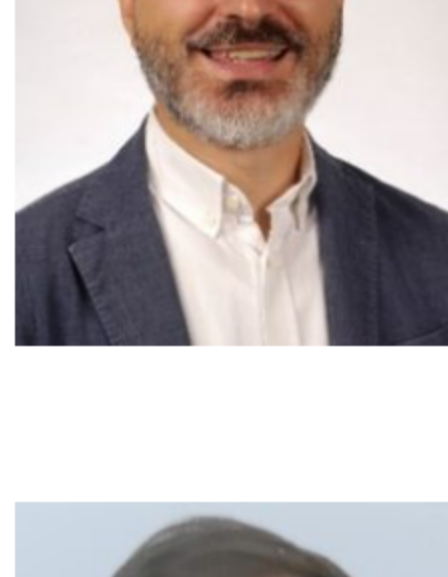
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Lecturers



Leonardo BALDASARRE

received his BS, MS and PhD from Politecnico di Milano in structural engineering in 2005, 2007 and 2011 respectively. His initial research activity is focused on finite element modeling of MEMS Multiphysics and stiction. In his early industrial career, he joined STMicroelectronics in 2011 and InvenSense in 2013 as MEMS Designer working on inertial sensors. He then worked on the development of the ultrasonic fingerprint sensor and on the founding technology of pMUT platforms. Since 2022 Leonardo is Director of Advanced Technology leading the development of new technologies and applications based on pMUT. Leonardo is the author of more than 10 patents and several articles in the MEMS field.



Roberto CARMINATI

received the M.Sc. degree in physics from the University of Pavia, Pavia, Italy, in 2011. During his M.Sc. studies, he worked on the optical characterization of nonlinear materials for telecommunications and holography. He is currently a MEMS Design Manager in the MEMS R&D Group of STMicroelectronics, Cornaredo, Italy, where he is working on the development and industrialization of MEMS micromirror devices and other MEMS actuators. He has applied for more than 30 patents in the MEMS research field.



Claudia COMI

is full Professor of Solid and Structural Mechanics at the Department of Civil and Environmental Engineering of Politecnico di Milano, Italy. C. Comi has authored and co-authored more than 170 scientific publications in various fields of solid and structural mechanics and 5 patents on microsystems. Her main research interests concern theoretical and computational mechanics of materials and structures. Her research activities focus on damage and quasi-brittle fracture modelling, on instability and bifurcation phenomena and nonlocal models for elastoplastic and damaging one-phase and multi-phase materials, including functionally graded materials. Her more recent research is devoted to modelling of auxetic and locally resonant metamaterials, and to design and reliability of microsystems.



Alberto CORIGLIANO

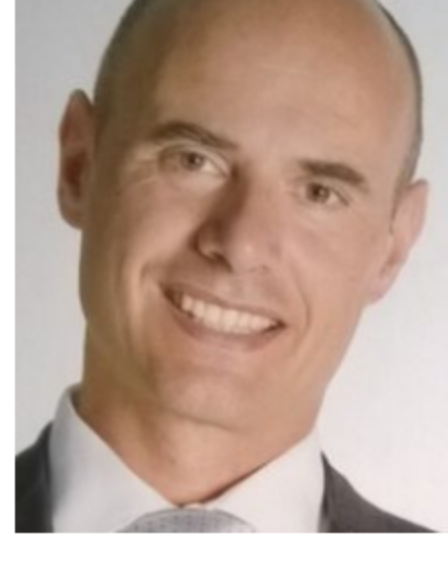
is full professor of Solids and Structural Mechanics with the Department of Civil and Environmental Engineering of Politecnico di Milano, Italy. Is member of the technical committee of Eurosime, Associate Editor of the European J. of Mechanics A/Solids, of Advanced Modelling and Simulation in Engineering Sciences and of Frontiers in Materials – Mechanics of materials. He was president of the 25th International Congress of Theoretical and Applied Mechanics (ICTAM2020+1-Virtual) and is member of the Executive Committee of the Congress Committee of IUTAM. In 2006 won the Bruno Finzi prize for Rational Mechanics of the "Istituto Lombardo Accademia di Scienze e Lettere", in July 2015 was appointed Euromech Fellow by the European Mechanics Society, in July 2018 was elected member of the "Istituto Lombardo Accademia di Scienze

e Lettere". Is (co) author of more than 330 papers, 13 patents, 2 books, 4739 citations and h-index 37 (Scopus, February 17th, 2023).



Vittorio FERRARI

is a professor of Electronics at the University of Brescia, Italy, where he is active in scientific research and application-oriented industrial projects on sensors, microsystems, and electronics for measuring instrumentation. His research interests are in piezoelectric transducers, acoustic-wave and resonant sensors, energy harvesting for sensors and microsystems, electromechanical and piezoelectric MEMS, and sensor electronics. He holds a MSC-equivalent in Physics and a PhD in Electronic Instrumentation. In 1994, he was at HP Labs, Palo Alto, CA, USA. In 2013, he has collaborated with CERN, Switzerland, on electronics for particle detectors. In 2017, he has been a visiting professor at the Institut Polytechnique de Grenoble, France. He is IEEE senior member, affiliated with Italian INFN and CNR. Since 1990, he has been involved in national, EU and international academic research projects and training networks and in industrial collaborations. He has been project evaluator for national and international organizations, member of the scientific advisory board for one Austrian research institute, member of the program committee and chair in international conferences including Eurosensors 2014. He serves in the editorial boards of Sensors, Micro, and Frontiers of Micro- and Nanoelectromechanical Systems. He is author of more than 250 publications, books, chapters, keynote/invited talks, editor of journal special issues, and co-inventor in 8 patents.



Attilio FRANGI

received the M.Sc. degree in aeronautical engineering and the Ph.D. degree in structural engineering from the Politecnico di Milano, Italy, in 1994 and 1998, respectively. From 2001 to 2014 he was an Associate Professor at the Department of Mechanics, Ecole Polytechnique, France. He is currently a Full Professor with the DICA Department, Politecnico di Milano. He has authored over 150 publications on themes of computational mechanics with a special focus on the simulation of multiphysics phenomena for microsystems.



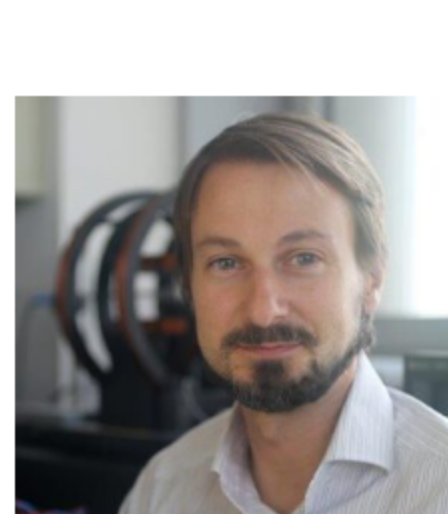
Paolo FRIGERIO

received his M.Sc. in Electronics Engineering and his Ph.D. in Information Technology from Politecnico di Milano, Italy, in 2018 and 2022, respectively. He joined the department of Electronics, Information Technology and Bioengineering as an Assistant Professor (RTDa) in 2022. During his Master Thesis he worked on the implementation of an integrated low-power oscillator for a temperature-compensated MEMS-based Real-Time Clock. His current research activity is centered on MEMS resonators, inertial sensors and micro-mirrors, with a focus on the design of electronic actuators, controllers and on transducers reliability.



Giorgio GOBAT

started his PhD in 2018 after his master's degree in Structural Engineering at Politecnico di Milano. During his PhD, he developed simulation tools and reduced-order modelling strategies. He gained expertise in the field of micro-electro-mechanical systems (MEMS) modelling thanks to the collaboration between Politecnico di Milano and STMicroelectronics. During his PhD visiting period at the ENSTA ParisTech in France, he developed the skills needed to build analytical solutions for nonlinear dynamic systems and he transposed them to MEMS applications. The complexity of the response given by these systems, when pushed to the limit for better performances led his research towards the study of nonlinear dynamics and chaos. From the end of his PhD up to now, as a junior researcher (RtdA), he worked on data-driven methods and deep-Learning in simulations for MEMS applications.



Giacomo LANGFELDER

(Member, IEEE) received the Ph.D. degree in information technology from Politecnico di Milano, Italy, in 2009. He is currently an Associate Professor of MEMS and Microsensors and of Electronics Fundamentals with Politecnico di Milano. He is the author of about 200 publications and has applied for more than 20 patents. His research interests include sensors, actuators, and related electronics. He has been a member of the TPC of various IEEE conferences since 2016 and the TPC Chair of the IEEE Inertial Conference in 2018 and 2022.



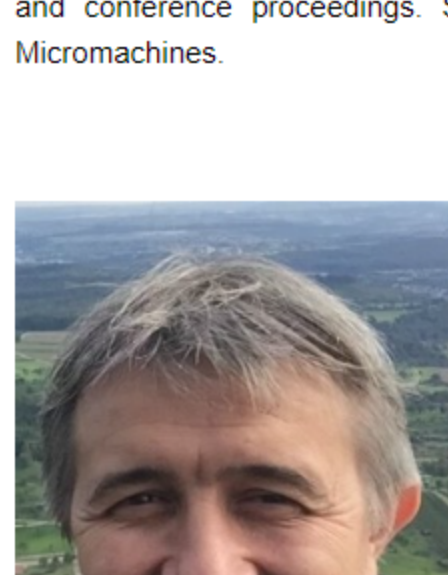
Stefano MARIANI

received an M.S. degree (cum laude) in civil engineering in 1995, and a Ph.D. degree in structural engineering in 1999. He is currently an Associate Professor at the Department of Civil and Environmental Engineering of Politecnico di Milano. He was a research scholar at the Danish Technical University, an adjunct professor at Penn State University, and a visiting professor at the Polytechnic Institute of New York University. He is a member of the Editorial Boards of Algorithms, International Journal on Advances in Systems and Measurements, Inventions, Machines, Micro and Nanosystems, Micromachines, and Sensors. He has been a recipient of the Associazione Carlo Maddalena Prize for graduate students (1996), and of the Fondazione Conflonieri Prize for PhD students (2000).



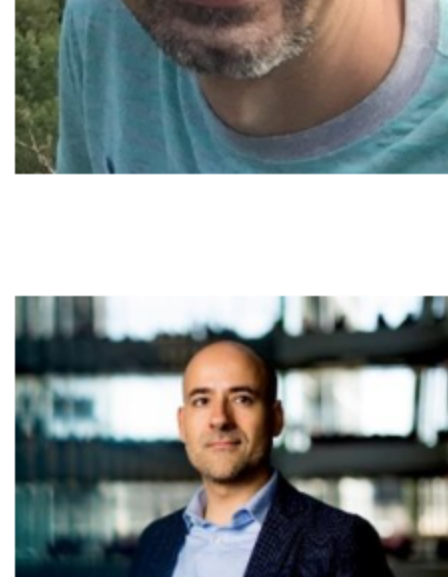
Sabina MERLO

received in 1987 the master's degree and in 1991 the Ph.D. degree, both in electronic engineering, from the University of Pavia. She also received the M.S.E. degree in bioengineering from the University of Washington, Seattle, USA, in 1989, thanks to a Rotary Foundation Graduate Scholarship. Assistant Professor since 1993 and Associate Professor since 2001, she is Full Professor of Electrical and electronic measurements since 2018 at the Department of Electrical, Computer and Biomedical Engineering, University of Pavia. Her research interests include optical testing of MEMS/MOEMS and microfluidic devices, interferometry, optical chemical sensing and other photonic applications. She has collaborated with STMicroelectronics on MEMS/MOEMS since the very beginning of the company activity in this field (2000). She holds four patents and is the author of more than 150 publications in journals, books, and conference proceedings. She is an Associate Editor of IEEE/ASME JMEMS, MDPI Sensors and MDPI Micromachines.



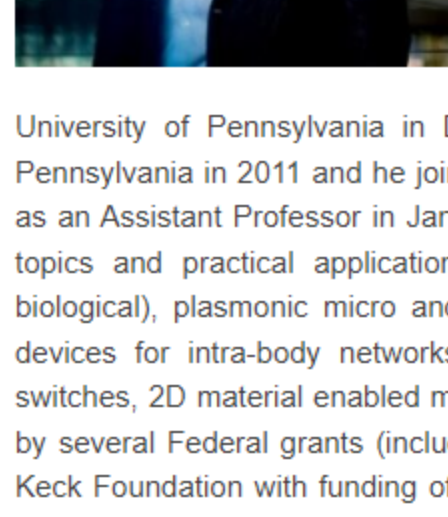
Dusan RADOVIC

Electrical engineer with Dipl.-Ing. degree from the School of Electrical Engineering in Belgrade, Serbia in 1999. Since 2012 he works at Bosch Sensortec as sensor expert in the development of inertial sensors as BMI160, BMI260 to name a few. His expertise and interests cover areas of testing automation, sensor prototyping and applications.



Matteo RINALDI

is a Professor in the Electrical and Computer Engineering department at Northeastern University and the Director of the *Kostas Nanotechnology Laboratory* and the Director of *Northeastern SMART* a university research center that, by fostering partnership between university, industry and government stakeholders, focuses on the discovery, pilot manufacturing and rapid transition of new micro and nano systems technologies that are foundational for emerging paradigms like zero-power sensing, 5G/6G communications, artificial intelligence, quantum information science and nanomedicine. Dr. Rinaldi received his Ph.D. degree in Electrical and Systems Engineering from the University of Pennsylvania in December 2010. He worked as a Postdoctoral Researcher at the University of Pennsylvania in 2011 and he joined the Electrical and Computer Engineering department at Northeastern University as an Assistant Professor in January 2012. Dr. Rinaldi's group has been actively working on experimental research topics and practical applications to ultra-low power MEMS/NEMS sensors (infrared, magnetic, chemical and biological), intra-body micro and nano electromechanical devices, medical micro systems and implantable micro devices for trans-body networks, reconfigurable radio frequency devices and systems, phase change material switches, 2D material enabled micro and nano-mechanical devices. The research in Dr. Rinaldi's group is supported by several Federal grants (including DARPA, ARPA-E, NSF, DHS), the Bill and Melinda Gates Foundation and the Keck Foundation with funding of \$30+M since 2012. Dr. Rinaldi has co-authored more than 200 publications in the aforementioned research areas and also holds 15 patents and more than 10 device patent applications in the field of MEMS/NEMS. Dr. Rinaldi was the recipient of the IEEE Sensors Council Early Career Award in 2015, the NSF CAREER Award in 2014 and the DARPA Young Faculty Award class of 2012. He received the Best Student Paper Award at the 2009, 2011, 2015 (with his student), 2017 (with his student) and 2020 (with his student) IEEE International Frequency Control Symposiums; the Outstanding Paper Award at the 18th International Conference on Solid-State Sensors, Actuators and Microsystems, Transducers 2015 (with his student) and the Outstanding Paper Award at the 32nd IEEE International Conference on Micro Electro Mechanical Systems, MEMS 2019 (with his student). Prof. Rinaldi is the co-founder and CEO of *Zepsor Technologies*, a start-up company that aims to bring to market zero standby power wireless sensors for various internet of things applications including human presence detection, distributed wireless fire monitoring systems, battery-less infrared sensor tags for occupancy sensing and distributed wireless monitoring systems of plant health parameters for digital agriculture. Prof. Rinaldi is also the owner of *Smart MicroTech Consulting LLC*, a company that routinely provides consulting services to government agencies, large companies and startups in the broad areas of Micro and Nano Technologies, Internet of Things, Wireless Communication devices and systems, Broad Frequency Devices and Systems and Sensors.



Philippe ROBERT

is business development manager and senior expert at CEA-Leti for MEMS sensors and actuators activities. After serving various positions in the sensor industry, he joined CEA-Leti in 2001 as project manager for RF-MEMS research and was promoted to Manager of the MEMS Sensors Laboratory from 2003 to 2013, and Head of the Microsystems Department from 2013 to 2019. He holds a PhD in Electrical Engineering and a M.Sc. degree in Optical Electronic from Grenoble-INP.



Andrei SHKEL

has been on faculty at the University of California, Irvine since 2000. From 2009 to 2013, he served as a Program Manager at DARPA, where he initiated and managed an investment portfolio in microtechnology technology development. His research interests are reflected in over 300 publications, 42 patents, and 3 books. Dr. Shkel has been on a number of editorial boards and he is currently serving as the Editor-in-Chief of IEEE Sensors Letters. Dr. Shkel is the Fellow of NAI, Fellow of IEEE, and Past President of the IEEE Sensors Council. He has been awarded in 2013 the Office of the Secretary of Defense Medal for Exceptional Public Service. He received his Diploma with excellence (1991) in Mechanics and Mathematics from Moscow State University, Ph.D. degree (1997) in Mechanical Engineering from the University of Wisconsin at Madison and completed his postdoc (1999) at BSAC of UC Berkeley.



Valentina ZEGA

received the Ph.D. degree in structural, seismic, and geotechnical engineering from Politecnico di Milano in 2017. She is currently an Assistant Professor with the Department of Civil and Environmental Engineering, Politecnico di Milano. She has co-authored around 40 papers in international journals and has applied for 8 patents. Her research interests include the mechanical design and optimization of MEMS devices and metamaterials and the numerical modeling of their linear and nonlinear dynamic response. In 2018 she received the Arnaldo Rancati award from Istituto Lombardo Accademia di Scienze e Lettere, Milano for an unpublished work to the advantage of the aeronautics or technical industry in general. Since 2019, she has been a TPC Member of IEEE MEMS and IEEE EFTF-IFCS conferences.

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