IEEE

INERTIAL 2023

The 10th IEEE International Symposium on Inertial Sensors & Systems

Kaua'i, Hawaii | March 28-31, 2023

INERTIAL 2023 SYMPOSIUM PROGRAM

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Welcome Message

Dear Colleagues and Friends,

We welcome you to the beautiful island of Kaua'i to present, exhibit, and participate in the 10th IEEE International Symposium on Inertial Sensors and Systems (Inertial'23)!

This year's event continues our established tradition, started in 2014 in Laguna Beach, CA, USA of informal international meetings discussing the latest developments of modern inertial sensors and emerging applications enabled by inertial sensors. In addition, this year you will find that we are including new initiatives and implementing sustainable practices.

The IEEE Inertial is sponsored by the IEEE Sensors Council and is the only IEEE event exclusively dedicated to inertial sensors and systems technology. The adoption and application of this technology is growing fast, with the global inertial sensors and systems market expected to increase by approximately 50% over the next 5 years.

Our symposium offers a rare opportunity to meet and network with leaders in the field of inertial sensors and systems in the relaxed tone of this focused international technical gathering. We hope the atmosphere, as well as the breadth and depth of research topics combined with the quality of invited and contributed technical presentations will continue to make the IEEE Inertial a 'must attend' event for you every year.

The IEEE Inertial has established itself as the premier forum for reporting the latest research, development, and commercialization results in modern inertial sensors technology. You will hear from world experts on the latest in materials and micro-fabrication processes, atomic and quantum innovations, novel designs, new physical principles, increased performance, and a growing number of new applications and business opportunities.

The technical program covers three and a half days of technical presentations. By design, this is a single-track symposium with high quality oral and poster presentations as well as exhibitions. Each presentation was carefully reviewed and selected by our Technical Program Committee (TPC), after a careful evaluation by at least three independent reviewers – the technical experts in the field. The TPC was led by Ron Polcawich (Chair) and Joan Giner (Vice Chair). Max Perez coordinated with our 7 distinguished invited and keynote speakers who will participate throughout the meeting. The program will begin on Tuesday with three tutorials offered in the areas of (i) inertial and imaging sensor fusion, (ii) ultracold atoms and quantum inertial sensors, and (iii) photonic inertial sensors. The tutorials are organized and chaired by Sunil Bhave.

The Digest of Technical Papers for the 2023 IEEE Inertial Sensors contains up to four-page versions of the standard technical papers and abbreviated two-page Late News presentations, all provided to attendees in an electronic form. Most (but not all) presented papers will be available in the IEEE Xplore after the symposium. Our distinguished exhibitors and patrons will be involved throughout the symposium hosting events and available for discussions. Please be sure to visit their exhibitor booths and talk with them throughout the meeting to learn about their products, solutions, and career opportunities.

Welcome Message (continued)

Continuing the long-standing IEEE Inertial tradition, the Technical Program Committee will select one Best Student Paper (as well as first and second runner up papers). The results will be announced on Thursday ahead of the gala Lū'au. Good luck to all presenting students! In addition to the student awards we are also kicking off a new year long inertial application innovation competition coordinated by Clark Taylor and David Woodburn. There will also be career/hiring events hosted by Bosch & Northrop.

During this year's meeting, in addition to celebrating the 10th edition of INERTIAL, we are celebrating the 25th anniversary of the IEEE Sensors Council other components throughout the event. Sensors Council has chosen sustainability as the theme for 2023 and Inertial is going all in. You will notice significantly less paper and disposable materials at this year's event and I hope you join us on Saturday morning for a beach cleanup where we can all give a little back to this beautiful island.

The Inertial Symposium would not exist without the industry base in which so many of us work. To recognize the contributions of the inertial industry we will be holding a special appreciation reception on Wednesday during the poster session.

Our special thanks go out to all who have contributed to make this symposium a reality: the Oversight Committee, the Technical Program Committee, and many experts who contributed their time to evaluate submissions. We thank the IEEE Sensors Council for sponsoring the 2023 IEEE Inertial as well as our generous Patrons and Exhibitors. Many thanks to Caroline Kravec, and the entire staff at Conference Catalysts, LLC for administrative support.

Finally, thank you speakers, presenters, and attendees for making the 2023 IEEE Inertial Symposium such a unique event. We hope that you find the INERTIAL'23 Symposium professionally stimulating and enjoyable, and of course, we are looking forward to seeing you back next year for the INERTIAL'24 (Location to be disclosed on Thursday).

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General Co-Chair
IEEE INERTIAL 2023

Kari Moran
General Co-Chair
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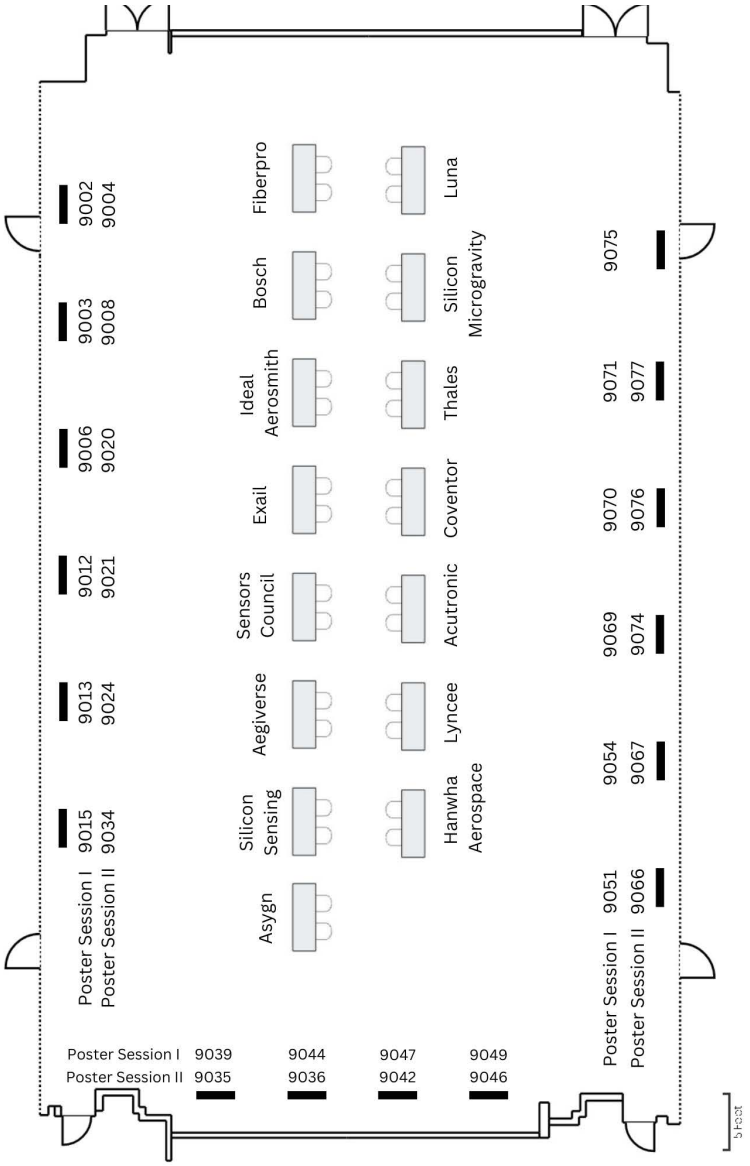

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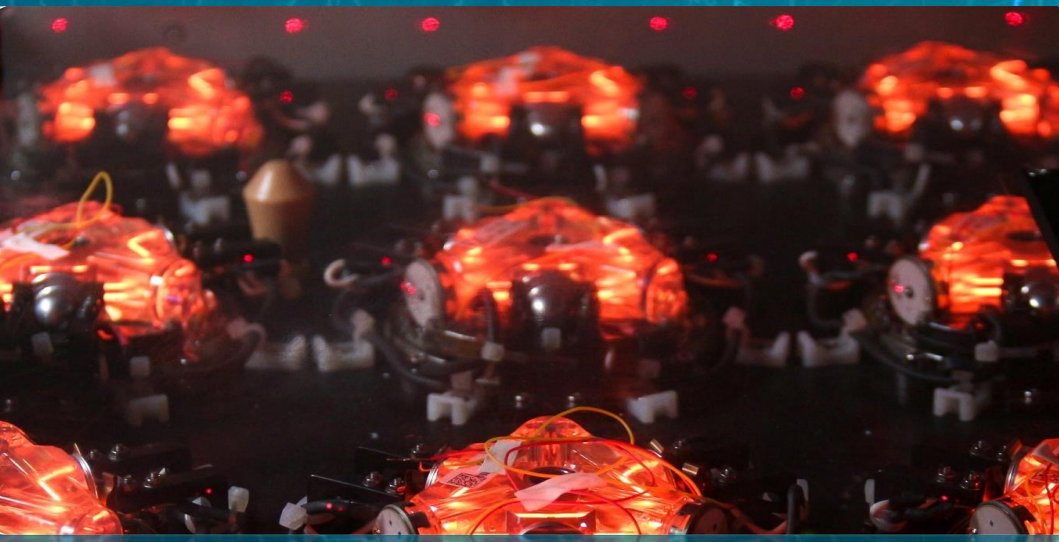

Technology People Vision

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Tuesday, March 28th | 08:40 - 10:40 HST

Inertial and Imaging Sensor Fusion for Autonomous Vehicles

Room: Kona (Salon 1)
Instructor: Igor Prikhodko, *Analog Devices, USA*

Abstract: Today the emerging field of autonomous driving demands accurate positioning and trustworthy self-localization methods which requires new technologies and hardware. The common approach is to fuse all available information sources: GPS, IMU equipped with the tri-axial gyroscope and accelerometer, odometer, and perception sensors (camera, lidar, radar). This tutorial will discuss trade-offs between inertial-based (IMU) and perception-based sensors for Autonomous Vehicles (Avs) requiring 10 cm positional accuracy 100% of the time without using GPS. The perception sensors provide centimeter accuracy but require powerful graphical processors to perform feature recognition. In contrast to perception sensors, IMUs allow for navigation completely independent of external references (e.g. satellites, road markers, geomaps, databases) and immunity to weather conditions. MEMS IMUs are attractive due to the SWaP-C metric, but only suitable for short-term inertial dead-reckoning because of positional error growth with time. The long-term navigation using MEMS, however, is possible when aided using perception sensors available in AV for correction of IMU drift. This tutorial will present various approach to solve vehicle localization problem by using MEMS IMU aided with Visual Odometry. The trade-offs between 1) Wheel Odometry, 2) Camera Odometry, 3) Lidar Odometry, and 4) Radar Odometry will be covered in detail. Visual Odometry in autonomous vehicles works by exploiting geometrical consistency of surrounding stationary objects to determine its track in 3D. VO implications for correcting IMU drift as well as 3D map generation will be discussed during tutorial. Finally, this tutorial will address hardware and primarily software challenges associated with developing an ambitious navigation system fusing all available input sensors (IMU, camera, lidar, wheel speed) to obtain an accurate vehicle position on the map without GPS.

Tuesday, March 28th | 11:10 – 13:10 HST

Ultracold Atoms and Quantum Inertial Sensors for the Masses

Room: Kona (Salon 1)
Instructor: Noah Fitch, *ColdQuanta, USA*

Abstract: Interferometry based on quantum systems, e.g. ultracold atoms, offers unprecedented sensitivity and performance when compared to classical inertial sensors. Such systems also commonly feature absolute measurements as their transduced signals are functions of their perfectly reproducible internal structure and the fundamental constants of nature. Choices of the internal quantum states, and procedures used to manipulate them, can make these systems highly sensitive to, or immune to, signals of interest.

Despite significant promise and effort over the past decades, practical deployment of quantum sensors in harsh real-world environments remains a challenge. One barrier is the required expertise, cost, and access to suitable quantum systems for development of devices. Infleqtion/ColdQuanta's Albert project seeks to remove this barrier, by making ultracold quantum matter available both on the cloud or delivered as turn-key systems customized for target applications. Access to this advanced hardware also comes with easy-to-use abstractions and interfaces, providing tools for both experts and quantum novices alike. Albert makes the development of quantum sensors more accessible than ever before and facilitates exploration of both established and emerging interferometric techniques.

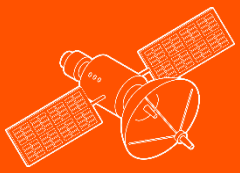
In this tutorial, I will introduce methods for creating ultracold quantum matter, how that matter can be used as an interferometer for inertial sensing, and how these methods are or will be implemented and accessed on Albert. I will discuss both traditional light-pulse (Raman, Bragg) atom interferometry as well as emerging approaches based on so-called "atomtronic" and "shaken lattice" methodologies, which provide a pathway to higher precision and compact sensor packaging.

Tuesday, March 28th | 14:30 – 16:30 HST

Photonic Inertial Sensors with Nano-Opotmechanical Displacement Readout

Room: Kona (Salon 1)
Instructor: Matt Eichenfield, *Associate Professor and SPIE Endowed Chair in Optical Sciences, University of Arizona Distinguished Faculty Joint Appointee, Sandia National Laboratories, USA*

Abstract: MEMS accelerometers and gyroscopes typically use an electrical displacement readout mechanism, such as a capacitor gap between the proof mass and frame or piezoelectric/piezoresistive readout of tether strain. Optical readout for accelerometers have up until recently relied on bouncing a laser off the surface of the proof mass a single time. However, advancements in on-chip photonics and nano-optomechanics over the past ~15 years have enabled MEMS accelerometers to take advantage of on-chip displacement readout mechanisms that leverage long waveguide paths and high-Q cavities that are exquisitely sensitive to mechanical displacement and strain, achieving displacement sensitivities that are not attainable for typical electrical readout schemes. In this tutorial, I will present the fundamentals of optomechanical inertial sensors so that the attendee can understand the mechanisms that underlie the displacement sensing, fundamental noise sources, and packaging requirements/challenges.



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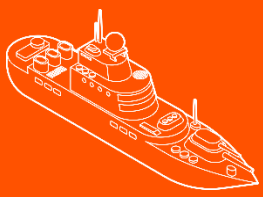

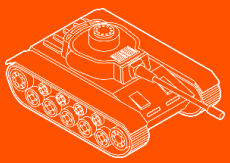

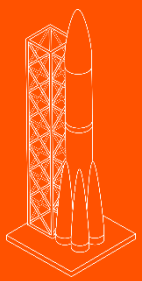

Wednesday, March 29th | 08:40 - 09:25 HST

Inertial sensing with Bose-Einstein condensates

Room: Kona (Salon 1)
Instructor: Sven Abend, *Leibniz Univ. Hannover, Germany*

Abstract: Ultra-cold quantum gases promise to boost the sensitivity and accuracy of inertial matter-wave interferometers. Benefiting from the low expansion energies, novel methods to coherently manipulate the atomic ensembles with high efficiencies, such as twin-lattice interferometry, allow to create interferometers featuring (i) large space-time areas, (ii) discrimination of accelerations and rotations as well as (iii) Sagnac interferometers performing multiple loops. As the sensitivity of these devices increases with the time spent by the atoms in the interferometer, sensors operated in space may reach even higher precision. We take benefit of various microgravity platforms such as the Bremen drop tower, the Einstein elevator in Hannover, sounding rockets and the international space station to advance the necessary methods for space-borne inertial sensing.

Thursday, March 30th | 08:35 - 09:15 HST

Inertial Sensors and Sensor Fusion for Robust Location Applications

Room: Kona (Salon 1)
Instructor: Ken Davis, *Qualcomm Technologies Incorporated, USA*

Abstract: Demand for location aware platforms has given rise to increasingly sophisticated location aware platforms that can require centimeter accuracy in challenging environments. A strategy to meet these opportunities is to employ a variety of sensors and signals and play to their strengths utilizing machine learning situational awareness models. This presentation will provide an overview of how inertial sensors and sensor fusion techniques are applied to extended reality, automotive, and interplanetary use cases.

Friday, March 31st | 08:35 - 09:15 HST

Narrow Linewidth Atomic Clock Transitions for Inertial Sensing and Fundamental Physics

Room: Kona (Salon 1)
Instructor: Jason Hogan, *Stanford University, USA*

Abstract: I will describe a new approach to inertial sensing using atom interferometry that takes advantage of the narrow linewidth transitions used by the best atomic clocks in the world. These hybrid “clock” atom interferometers offer a number of advantages, including the possibility of substantially improved sensitivity using enhanced matter wave optics that increase the enclosed space-time area of the interferometer. In particular, I will show results demonstrating large momentum transfer (LMT) atom optics that achieve a record-setting momentum separation between the interferometer arms of over 400 ħk. Unlike previous work in LMT enhancement, clock atom interferometry supports the use of comparatively ‘hot’ atoms, substantially reducing the complexity of atom cooling requirements for an applied sensor. Clock atom interferometry also has broad potential applications in fundamental physics experiments which I will describe, and is central to the MAGIS-100 experiment, a 100-meter-tall atomic sensor under construction at Fermilab that will probe for ultra-light dark matter candidates and will serve as a prototype for a future gravitational wave detector.use cases.

Invited Speakers

Wednesday, March 29th | Atomic Sensors

Quantum Sensors for Inertial Navigation

Room: Kona (Salon 1)
Instructor: Joseph Cotter, *Imperial College London, UK*

Abstract: Satellite navigation systems cannot be relied on underground or underwater, they are vulnerable to local weather conditions, and can be spoofed or blocked. To overcome some of these vulnerabilities the Imperial team are developing inertial sensor technologies that harnesses quantum physics to deliver measurements of acceleration and rotation with extremely low scale factor and bias drift. I will present recent results from our multi-axis laboratory sensor that can measure accelerations and rotations in a single unit. I will also introduce our new transportable quantum inertial sensor that is currently undergoing moving platform field trials.

Wednesday, March 29th | Piezoelectric Sensors

PinPoint® Thin Film PZT MEMS Gyroscope

Room: Kona (Salon 1)
Instructor: Mark Marshall, *Silicon Sensing Systems, Ltd.*

Abstract: A brief description of the PinPoint® PZT Coriolis Vibratory Gyro inertial sensing performance, construction and mode of operation, including key properties and characteristics of the PZT film used as both gyro actuator and transducer.

Friday, March 31th | Final Session of Contributed Talks

Photonic Integrated Circuits for Cavity Optomechanical Inertial Sensors: From the Classical to Quantum Regime

Room: Kona (Salon 1)
Instructor: Dr Ying Lia Li (Lia), *CEO of Zero Point Motion, UK*

Abstract: High-volume low-cost optical devices can be realised through scalable photonic integrated circuits (PICs) to create optical analogues of existing technologies that benefit from increased signal-to-noise readout and the coherence of lasers. Zero Point Motion reports on progress in developing chipscale optical inertial sensors, where an optical resonance is highly sensitive to the mechanical response of inertial test-masses. When optimised, these so-called cavity optomechanical systems can reach displacement sensitivities at 10^(-18)m/Hz^(1/2), with paths towards quantum sensing where the mechanical test-mass is cooled to a macroscopic quantum ground state. Our core mission is first commercialising classical sensors with 100x lower noise floor than existing automotive accelerometers and gyroscopes, exploiting the PIC supply chain to mass-produce photonics chips with integrated lasers and detectors, and combining these semiconductor fabrication steps with existing MEMS processes to create released test-mass structures.

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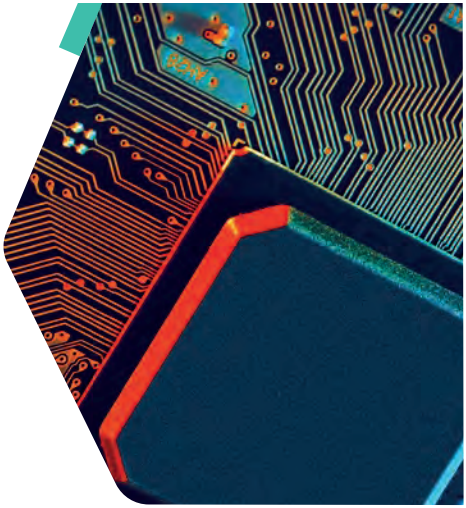
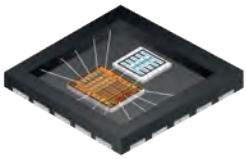


AS40XX

Integrated circuits for inertial sensors

AS4001



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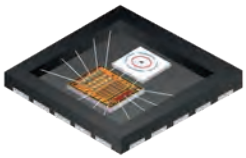
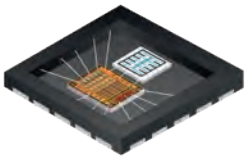


Suited to 1-DOF gyros
2-DOF or differential accels, and more.

5 DACs - 2 Charge Amplifier + ADC - 1 Temperature Sensor - SPI / I2C - RISC V

AS40XX



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Program at a Glance

Time (HST)	TUESDAY, MARCH 28
8:30-8:40	**Opening Remarks** Room: Kona (Salon 1)
8:40-10:40	**Inertial and Imaging Sensor Fusion for Autonomous Vehicles** Room: Kona (Salon 1)
10:40-11:10	**Coffee Break/ Exhibits** Room: Kauai Court
11:10-13:10	**Ultracold Atoms and Quantum Inertial Sensors for the Masses** Room: Kona (Salon 1)
13:10-14:30	**Lunch** Room: Kauai Court
13:10-17:10	**Sensors Standards Workshop** Room: Ko'olau (Salon 3)
14:30- 16:30	**Photonic Inertial Sensors with Nano-Opotmechanical Displacement Readout** Room: Kauai Court
16:30-16:35	**Closing Remarks** Room: Kauai Court
18:00-20:00	**Ideal Aerosmith Welcome Reception** Room: Kauai Court and Gardens

Time (HST)	WEDNESDAY, MARCH 29
8:20-8:40	**Opening Remarks** Room: Kona (Salon 1)
8:40-9:25	**Keynote: Inertial sensing with Bose-Einstein condensates** Room: Kona (Salon 1)
9:25-10:45	**Atomic Sensors** Room: Kona (Salon 1)
10:45-11:10	**Exhibitor Lightning Round** Room: Kona (Salon 1)
11:10-11:35	**Coffee Break/ Exhibits** Room: Kauai Court
11:35-12:40	**Gyroscopes** Room: Kona (Salon 1)
12:40-14:05	**IAI Lunch** Room: Kauai Court
14:05-15:35	**Piezoelectric Sensors Session** Room: Kona (Salon 1)
15:35-15:40	**Competition Announcement** Room: Kona (Salon 1)
15:40-16:05	**Poster Lightning Round** Room: Kona (Salon 1)
16:05-17:35	**Poster Session I** Room: Kauai Court
17:35-17:45	**Student Competition Informative Session** Room: Kona (Salon 1)
17:35-18:35	**Open Poster Session Sponsor Appreciation** Room: Kauai Court
18:00-19:00	**Bosch Career Event** Room: Puna Court

Time (HST)	THURSDAY, MARCH 30
7:30-8:30	**Northrop Grumman Recruitment Breakfast** Room: Puna AB
8:35-9:15	**Keynote: Inertial Sensors and Sensor Fusion for Robust Location Applications** Room: Kona (Salon 1)
9:15-10:35	**Inertial Sensors** Room: Kona (Salon 1)
10:35-11:00	**Coffee Break/ Exhibits** Room: Kauai Court
11:00-12:25	**Measurment Systems and Error Minimization** Room: Kona (Salon 1)
12:25-13:55	**Lunch** Room: Kauai Court
13:55-15:45	**Compensation Techniques** Room: Kona (Salon 1)
15:45-16:25	**Poster & Live Demo Lightning Round** Room: Kona (Salon 1)
16:25-18:00	**Poster Session II** Room: Kauai Court
18:00-18:45	**Fehlerkultur, INERTIAL 2024 & Awards** Room: Kona (Salon 1)
18:45-20:45	**Luau Dinner** Room: Lu'au Gardens

Time (HST)	FRIDAY, MARCH 31
7:30-8:30	**WiSe Breakfast** Room: Puna AB
8:35-9:15	**Keynote: Narrow Linewidth Atomic Clock Transitions for Inertial Sensing and Fundamental Physics** Room: Kona (Salon 1)
9:15-10:15	**Final Session** Room: Kona (Salon 1)
10:15-10:40	**Coffee Break/ Exhibits** Room: Kauai Court
10:40-12:15	**Late News** Room: Kona (Salon 1)
12:15-12:20	**Closing Remarks** Room: Kona (Salon 1)

Time (HST)	SATURDAY, APRIL 1
8:00-11:30	Beach Clean Up

Invented for life

BOSCH

All times appear in Hawaiian Standard Time (HST) GMT-10

07:30 - 08:30
Tutorial Registration
Room: Kona (Salon 1)

08:30 - 08:40
Opening Remarks
Room: Kona (Salon 1)

08:40 – 10:40
Tutorial: Inertial and Imaging Sensor Fusion for Autonomous Vehicles
Igor Prikhodko, *Analog Devices, USA*
Room: Kona (Salon 1)
Session Chair(s): Sunil Bhave, *Purdue University, USA*

10:40 – 11:10
Coffee Break
Room: Kauai Court

11:10 – 13:10
Tutorial: Ultracold Atoms and Quantum Inertial Sensors for the Masses
Noah Fitch, *ColdQuanta, USA*
Room: Kona (Salon 1)
Session Chair(s): Sunil Bhave, *Purdue University, USA*

13:10 – 14:30
Lunch
Room: Kauai Court

13:10 – 17:10
Sensors Standards Workshop
Room: Ko'olau (Salon 3)

14:30 – 16:30
Tutorial: Photonic Inertial Sensors with Nano-Opotmechanical Displacement Readout
Matt Eichenfield, University of Arizona, USA
Room: Kona (Salon 1)
Session Chair(s): Sunil Bhave, *Purdue University, USA*

16:30 – 16:35
Closing Remarks
Room: Kona (Salon 1)

18:00 – 20:00
Ideal Aerosmith Welcome Reception
Room: Kauai Court and Gardens
All attendees are invited to the Welcome Reception for drinks and light hors d'oeuvres.

07:20 - 08:20
Registration
Room: Kona (Salon 1)

08:20 – 8:30
Opening Remarks
Room: Kona (Salon 1)
Session Chair(s): Michael Larsen, *Northrop Grumman*
Kari Moran, *Naval Information Warfare Center Pacific*

08:30 – 8:40
Session: Sensors Council 25th Anniversary Introduction
Room: Kona (Salon 1)
Session Chair(s): Ravinder Dahiya, *Sensors Council President*

08:40 – 09:25
Keynote: Inertial Sensing with Bose-Einstein Condensates
Sven Abend
Room: Kona (Salon 1)
Session Chair(s): Tobias Hiller, *Robert Bosch GmbH*

09:25 – 10:45
Session: Atomic Sensors
Room: Kona (Salon 1)
Session Chair(s): Tobias Hiller, *Robert Bosch GmbH*

9:25
9073: Membrane-Based Optomechanical Accelerometry
Mitul Dey Chowdhury, Aman Agrawal, Dalziel Wilson
University of Arizona, United States

9:45
9060: ORIENTATION-INDEPENDENT, Atomic Magnetometer for MAGNETIC-Aided Inertial Navigation
Justin Brown{2}, Joshua Abney{2}, Michal Cwik{2}, Daniel Richardson{1}, Jonathan Jeffrey{1}, John Shields{1}, Robert Wyllie{1}
{1}Georgia Tech Research Institute, United States; {2}Physical Sciences Inc., United States

10:05
9033: Development of a STRAP-DOWN, Absolute Atomic Gravimeter for MAP-Matching Navigation
Jonathan Kohler, Artyom Vitouchkine, Akash Rakholia, Christopher Corder, Arman Cingoz, Martin Boyd, Andrew Dowd, Gunnar Skulason, Matthew Cashen
Vector Atomic, United States

10:25
INVITED: Quantum Sensors for Inertial Navigation
Joseph Cotter
Imperial College London, UK

10:45 – 11:10
Exhibitor Lightning Round
Room: Kona (Salon 1)
Session Chair(s): Ohad Zohar, *MEMS Technology Center, Rafael Advanced Defense Systems*

11:10 – 11:35
Coffee Break/Exhibits
Room: Kauai Court

11:35 – 12:40
Session: MEMS Gyroscopes
Room: Kona (Salon 1)
Session Chair(s): Paola Carulli, *ST Micro*

11:35
9079: A High-Performance Resonant MEMS Accelerometer with a Residual Bias Error of 30 Âµg and Scale Factor Repeatability of 2 ppm
Lokesh Gurung{1}, Theo Miani{1}, Guillermo Sobreviela-Falces{1}, Douglas Young{1}, Colin Baker{1}, Ashwin Seshia{2}
{1}Silicon Microgravity, United Kingdom; {2}University of Cambridge, United Kingdom

11:55
9045: A Navigation Grade, Software Defined Gyroscope and Extensions for Generic Vibratory Inertial Sensors
David Hayner, Dorian Challoner
Coherent Sensors, Inc., United States

12:15
9043: A New Design of Mode-Matched (100) Silicon Ring Gyroscope with Chamfered Rectangle Springs Immune to Fabrication Error
Shuya Okayama, Amit Banerjee, Jun Hirotani, Toshiyuki Tsuchiya
Kyoto University, Japan

12:40 – 14:05
IAI Lunch
Room: Kauai Court

14:05 – 15:35
Session: Piezoelectric Sensors
Room: Kona (Salon 1)
Session Chair(s): Ryan Knight, *DEVCOM-ARL*

14:05
INVITED: PinPoint® Thin Film PZT MEMS Gyroscope
Mark Marshall, Eric Whitley
Silicon Sensing Systems, Ltd., United Kingdom

14:25
9058: A Low-Voltage Wideband AlN-on-Si Gyroscope with Sub 10-DPH Bias Instability Mode Matched Using Laser Trimming
Zhenming Liu{1}, Haoran Wen{3}, Farrokh Ayazi{2}
{1}Georgia Institute of Technology, United States; {2}Georgia Institute of Technology and StethX Microsystems Inc, United States; {3}StethX Microsystems Inc, United States

14:45
9068: A Centrally-Anchored High-Q Tunable Piezoelectric MEMS Resonators for Wide Temperature Range RTC
Yaoyao Long{1}, Zhenming Liu{1}, Charlotte Wehner{1}, Farrokh Ayazi{2}
{1}Georgia Institute of Technology, United States; {2}Georgia Institute of Technology and StethX Microsystems Inc, United States

15:05
9018: Laser Induced Chemical Etching of Quartz for MEMS Sensors Fabrication
Marina Sirota{1}, Neta Melech{2}, Boris Lipavsky{1}, Omer Halevy{2}, Slava Krylov{2}, David Nuttman{1}
{1}Israel Aerospace Industries, Israel; {2}Tel-Aviv University, Israel

15:35 – 15:40
Competition Announcement
Room: Kona (Salon 1)
Session Chair(s): Michael Larsen, *Northrop Grumman*

15:40 – 16:05
Poster Lightning Round I
Room: Kona (Salon 1)
Session Chair(s): Giacomo Langfelder, *Politecnico di Milano*

16:05 – 17:35
Poster Session I
Room: Kauai Court
Session Chair(s): Giacomo Langfelder, *Politecnico di Milano*

9002: Practical Approaches to Allan Deviation Analysis of Low-Cost MEMS Inertial Sensors
Tobias Hiller{2}, Miloš Vujadinović{2}, Lukas Blocher{2}, Wolfram Mayer{1}, Dušan Radović{1}, Thorsten Balslink{2}, Thomas Northemann{2}, Alexander Buhmann{2}
{1}Bosch Sensortec GmbH, Germany; {2}Robert Bosch GmbH, Germany

9003: Compensation of Non-Orthogonality Changes in Low-Cost MEMS Gyroscopes Across Soldering, Temperature and Lifetime
Tobias Hiller{2}, Patrick Tritschler{1}, Lukas Blocher{2}, Wolfram Mayer{1}, Miloš Vujadinović{2}, Thorsten Balslink{2}, Martin Schöfthaler{1}, Thomas Northemann{2}
{1}Bosch Sensortec GmbH, Germany; {2}Robert Bosch GmbH, Germany

9006: Modeling and Experimental Analysis of Low-Cost MEMS Gyroscopes Under PCB Bending Stress
Wolfram Mayer{1}, Alexandra Küster{1}, Patrick Tritschler{1}, Tobias Hiller{3}, Dušan Radović{1}, Andre Zimmermann{2}
{1}Bosch Sensortec GmbH, Germany; {2}Institute for Micro Integration, The University of Stuttgart, Germany; {3}Robert Bosch GmbH, Germany

9012: Quantifying IMU Forward Models
Michael R. Walker II, David Olson, Jason Bingham
Sandia National Laboratories, United States

9013: Three Axis Rate Table Forward Model
Jason Bingham, Michael R. Walker II, David Olson
Sandia National Laboratories, United States

9015: Reducing Thermo-Elastic Damping of MEMS Resonators Using a Virtual Spring
Chen Tang{2}, Zhiheng Wu{2}, Martin Heller{1}, Daisuke Nishinohara{1}, Toma Fujita{1}, Tamio Ikehashi{2}
{1}Rohm Co., Ltd., Japan; {2}Waseda University, Japan

9039: Combined Rotation and Magnetic Field Sensor Based on Lissajous FM Technique
Takashiro Tsukamoto, Shuji Tanaka
Tohoku University, Japan

9044: Locomotive Syndrome Assessment in Older Adults Using a Single Inertial Measurement Unit
Iman Hosseini{1}, Maryam Ghahramani{2}
{1}Australian National University, Australia; {2}University of Canberra, Australia

9047: Dynamical Encircling of a Lock-In Area with a Combination of Fast and Slow Dithering in a Ring Laser Gyroscope
Woo-Seok Choi, Jun-Eon An, Cheon-Joong Kim, Kyu-Min Shim
Agency for Defense Development, Korea

9049: Impact of Amplitude and Demodulation Errors on the Nonlinear Frequency Modulated Gyroscope
Andrew Sabater
Naval Information Warfare Center Pacific, United States

9051: Analysis and Compensation of Phase Error for the Butterfly Gyroscope
Zhanqiang Hou, Yunbin Kuang, Dingbang Xiao, Xuezhong Wu
National University of Defense Technology, China

9054: A Digital Twin to Model the Impact of Etch Profile on MEMS Gyroscope Performance
Christopher Welham{1}, Arnaud Parent{4}, Bryan Helmer{2}, Eran Valfer{2}, Tommi Piirainen{3}, Mikko Partanen{3}, Matti Liukku{3}
{1}Coventor, A Lam Research Company, France; {2}Lam Research, Israel; {2}Lam Research, Italy; {3}Murata Electronics Oy, Finland; {4}oventor, A Lam Research Company, France

9069: Large Amplitude Linear Drive Quadruple Mass Gyroscope
Ryan R. Knight{2}, Christopher Scheri{3}, Jeffrey S. Pulskamp{2}, Ryan Q. Rudy{1}, Don L. DeVoe{4}
{1}Army Research Laboratory, United States; {2}DEVCOM Army Research Laboratory, United States; {3}Oak Ridge Associated Universities, United States; {4}University of Maryland, College Park, United States

9070: c-Axis Parallel ZnO Piezoelectric Multilayer for BAW Gyroscope Applications
Ayaka Hanai, Shinya Kudo, Kohei Ekida, Junjun Jia, Takahiko Yanagitani
Waseda University, Japan

9071: Shear Mode Bulk Acoustic Wave Type Gyroscope Based on c-Axis Tilted ScAlN Piezoelectric Films
Momoka Matsumura, Yuna Koike, Ryo Seki, Takahiko Yanagitani
Waseda University, Japan

9075: Analysis of Charge Accumulation Effect in Microshell Resonator Gyroscope
Ming Ze Gao, Dingbang Xiao, Sheng Yu, Jun Feng, Jiangkun Sun, Yongmeng Zhang
National University of Defense Technology, China

17:35 – 17:45
Student Competition Planning Session
Room: Kona (Salon 1)
Session Chair(s): Michael Larsen, *Northrop Grumman*

17:35 – 18:35
Open Poster/ Sponsor Appreciation Reception
Room: Kauai Court

18:00 – 19:00
Consumer Sensor Development #LikeABosch: Markets, Products, Career Insights
Room: Puna Court

07:30 - 08:35
Registration
Room: Kona (Salon 1)

07:30 – 08:30
Northrop Grumman Recruitment Breakfast
Room: Puna AB

08:35 – 09:15
Keynote: Inertial Sensors and Sensor Fusion for Robust Location Applications
Ken Davis, *Qualcomm Technologies Incorporated, USA*
Room: Kona (Salon 1)
Session Chair(s): Johannes Classen, *Bosch*

09:15 – 10:35
Session: Inertial Navigation Sensors
Room: Kona (Salon 1)
Session Chair(s): Johannes Classen, *Bosch*

9:15
9072: "Sugar-Cube": Pedestrian Hardware Platform That Fits in the Sole of a Shoe
Austin Parrish{1}, Chi-Shih Jao{2}, Danmeng Wang{1}, Andrei Shkel{1}
{1}University of California Irvine, MicroSystems Lab – MEMS, United States; {2}University of California, Irvine, United States

9:35
9025: Prio-IMU: Prioritizable IMU Array for Enhancing Foot-Mounted Inertial Navigation Accuracy
Chi-Shih Jao{2}, Danmeng Wang{1}, Andrei Shkel{1}
{1}University of California Irvine, MicroSystems Lab – MEMS, United States; {2}University of California, Irvine, United States

9:55
9028: Searching for the Origin of Zero-Rate Offset and Scale-Factor Drift in NEMS-Based Nav-Grade Gyroscope
Andrea Buffoli{2}, Pietro Segala{2}, Marco Gadola{2}, Thierry Verdot{1}, Philippe Robert{1}, Giacomo Langfelder{2}
{1}CEA-Leti, France; {2}Politecnico di Milano, Italy

10:15
9016: Sensor Individual Non-Orthogonality Correction in Low-Cost MEMS Gyroscopes Using Neural Networks
Patrick Tritschler{1}, Tobias Hiller{3}, Torsten Ohms{1}, Wolfram Mayer{1}, Andre Zimmermann{2}
{1}Bosch Sensortec GmbH, Germany; {2}Institute for Micro Integration, The University of Stuttgart, Germany; {3}Robert Bosch GmbH, Germany

10:35 – 11:00
Coffee Break/ Exhibits
Room: Kauai Court

11:00 – 12:25
Session: Measurment Systems and Error Minimization
Room: Kona (Salon 1)
Session Chair(s): Eugene Hwang, *SpaceX*

11:00
9023: Optimization of Localization Error in Multi-Agent Systems Through Cooperative Positioning: Autonomous Navigation in Partially Denied GNSS Environments
Shahram Shahkar, Khashayar Khorasani
Concordia University, Canada

11:20
9032: An Autonomous North Alignment Method for Motion Simulators
Bernard Vau, Mehdi Bussutil, Nicolas Bernard
iXblue, France

11:40
9010: A New High-G Measurement System for Severe Perforation Tests
Maylis Lavayssière{1}, Jérôme Willemin{2}, Aurélien Hottelet{1}, Nicolas Stephanopoli{1}, Clément Grein{1}, Clément Garaffa{2}, Esteban Cabanillas{2}, Prince-Arnaud Ramahefa{2}, Stéphane Driussi{2}, Martin Gauroy{2}, Justin Boussac{2}, Stephan Louwers{1}
{1}CEA DAM Gramat, France; {2}Université Grenoble Alpes, CEA-Leti, France

12:00
9057: Low Frequency Inertial Sensing
Andrea Nelson, Adam Hines, Guillermo Valdes, Jose Sanjuan, Felipe Guzman
Texas A&M University, United States

12:25 – 13:55
Lunch
Room: Kauai Court

14:00 – 15:45
Session: Compensation Techniques
Room: Kona (Salon 1)
Session Chair(s): Diego Serrano, *Panasonic*

14:00
9009: Modeling of Phase Noise in Mode-Split Open-Loop MEMS Gyroscopes Miloš Vujadinović{2}, Tobias Hiller{2}, Lukas Blocher{2}, Dušan Radović{1}, Thorsten Balslink{2}, Thomas Northemann{2}, Bhaskar Choubey{3}
{1}Bosch Sensortec GmbH, Germany; {2}Robert Bosch GmbH, Germany; {3}University of Siegen, Germany

14:20
9041: Dynamic Quality Factor Equalization for Improved Bias Stability in Mode-Matched Gyroscopes
Ryan Rudy{1}, Ryan R. Knight{1}, Carl Hauser{2}, Jeffrey S. Pulskamp{1}
{1}DEVCOM Army Research Laboratory, United States; {2}Oak Ridge Associated Universities, United States

14:40
9048: Quadrature Compensation and Demodulation Phase Reference Selection for FM Accelerometers
Andrew Sabater
Naval Information Warfare Center Pacific, United States

15:00
9026: Towards a Better Understanding of Offset Changes Across Temperature in Mode-Split Open-Loop MEMS Gyroscopes
Miloš Vujadinović{1}, Tobias Hiller{1}, Lukas Blocher{1}, Thomas Northemann{1}, Bhaskar Choubey{2}
{1}Robert Bosch GmbH, Germany; {2}University of Siegen, Germany

15:20
9040: Virtually Rotated Multiple Mass Resonator Enabled by Electrostatic Frequency and Q-Factor Tuning
Jianlin Chen{2}, Takashiro Tsukamoto{2}, Giacomo Langfelder{1}, Shuji Tanaka{2}
{1}Politecnico di Milano, Italy; {2}Tohoku University, Japan

15:45 – 16:25
Poster Lightning Round II
Room: Kona (Salon 1)
Session Chair(s): Ryan Rudy, *U.S. Army Research Laboratory*

16:25 – 18:00
Poster Session II
Room: Kauai Court
Session Chair(s): Ryan Rudy, *U.S. Army Research Laboratory*

9004: Highly Accurate Inertial Navigation That Compensates for the Earth's Rotation and Sensor Bias Using Non-Holonomic Constraints
Masato Kimishima, Tsutomu Sawada, Akihiro Sonoura, Toru Amano, Hiroyuki Kamata, Kosei Yamashita
Sony Group Corporation, Japan

9008: Scale Factor Instability Noise in Mode-Split Open-Loop MEMS Gyroscopes
Miloš Vujadinović{2}, Tobias Hiller{2}, Lukas Blocher{2}, Thorsten Balslink{2}, Dušan Radović{1}, Thomas Northemann{2}, Alexander Buhmann{2}, Bhaskar Choubey{3}
{1}Bosch Sensortec GmbH, Germany; {2}Robert Bosch GmbH, Germany; {3}University of Siegen, Germany

9020: Development of Inertial Acceleration Measurement Device with Zero-Compliance Mechanism
Takeshi Mizuno, Yuji Ishino, Masaya Takasaki
Saitama University, Japan

9021: 71 kHz Frequency Modulated PiezoMEMS Gyroscope
Antti Ontronen{1}, Ville Kaajakari{1}, Konsta Wjuga{1}, Akiko Uno{2}, Seiji Umezawa{2}, Yasuhiro Aida{2}
{1}Murata Electronics Oy, Finland; {2}Murata Manufacturing Co., Japan

9024: Detection and Identification of GNSS Spoofing Cyber-Attacks for Naval Marine Vessels
Mahdi Taheri, Mohammad Reza Nematollahi, Khashayar Khorasani
Concordia University, Canada

9034: MEMS Directional Underwater Acoustic Sensor Operating in Near Neutral Buoyancy Configuration
Justin Ivancic, Jeffrey Catterlin, Gamani Karunasiri, Fabio Alves
Naval Postgraduate School, United States

9035: Efficient Online Compression for MEMS Based BCG Wearable Sensors on ULP FPGA
Ulf Kulau, Abdelrahman Ahmed
Hamburg University of Technology, Germany

9036: Manufacture of Hemi-Spherical Resonators Using Printable Fused Silica Glass
Yahya Atwa, Hamza Shakeel
Queen's University Belfast, United Kingdom

9042: Efficient Quadrature Suppression for Improved Performance of a MEMS Vibratory Gyroscope
Roman Forke{1}, Alexey Shaporin{1}, Sebastian Weidlich{3}, Daniel Bülz{1}, Karla Hiller{2}, Harald Kuhn{2}
{1}Fraunhofer ENAS, Germany; {2}Fraunhofer ENAS and Technische Universität Chemnitz, Germany; {3}Technische Universität Chemnitz, Germany

9046: Improvement of Scale Factor Nonlinearity Over Temperature Variations by Real-Time Phase Compensation
Yunbin Kuang, Zhanqiang Hou, Gao Liu, Dingbang Xiao, Xuezhong Wu
National University of Defense Technology, China

9066: Verifying IMU Suitability for Recognition of Freshwater Mussel Behaviors
William Jackson, Alan Marchiori, Stewart Thomas, Elizabeth Capaldi, Sean Reese Bucknell University, United States

9067: Study of IMU Mounting Position for ZUPT-Aided INS in the Case of Firefighter Crawling
Austin Parrish{1}, Chi-Shih Jao{2}, Danmeng Wang{1}, Andrei Shkel{1}
{1}University of California Irvine, MicroSystems Lab – MEMS, United States; {2}University of California, Irvine, United States

9074: 780 nm narrow-Linewidth Laser by self-Injection Locking a low-Cost Fabry-Perot Laser to an Integrated Si3N4 145 Million Q Resonator
Andrei Isichenko, Nitesh Chauhan, Kaikai Liu, Mark Harrington, Daniel Blumenthal
University of California, Santa Barbara, United States

9076: A Fast Start Method for Whole-Angle Micro-Shell Resonator Gyroscope Sheng Yu, Xuezhong Wu, Yongmeng Zhang, Jiangkun Sun, Dingbang Xiao
National University of Defense Technology, China

9077: Non-Destructive Characterization of High Aspect-Ratio Structures Using 3D X-Ray Microscopy
Ester Lomeli Bentley, Sahana Prabhu, Sajal Singh, Jae Yoong Cho, Khalil Najafi University of Michigan, Ann Arbor, United States

18:00 – 18:20
Session: Fehlerkultur
Room: Kona (Salon 1)
Session Chair(s): Doug Meyer, *Northrop Grumman*

18:00
9029: Bandwidth vs ZRO Stability Trade-Off in Lissajous Frequency Modulated MEMS Gyroscopes
Marco Bestetti{1}, Christian Padovani{1}, Andrea Bonfanti{1}, Giorgio Mussi{1}, Gabriele Gattere{2}, Giacomo Langfelder{1}
{1}Politecnico di Milano, Italy; {2}STMicroelectronics, Italy

18:20 – 18:45
Session: INERTIAL 2024 & Awards
Room: Kona (Salon 1)
Session Chair(s): Takashiro Tsukamoto, *Tohoku University*
Joan Giner, *Bosch Sensortec*
Michael Larsen, *Northrop Grumman*
Kari Moran, *Naval Information Warfare Center Pacific*
Ron Polcawich, *U.S. Army Research Laboratory*

18:45 – 20:45
Banquet Luau
Room: Luau Gardens

07:30 – 08:35
Registration
Room: Kona (Salon 1)

07:30 – 08:30
WiSe Breakfast
Room: Puna AB

08:35 – 09:15
Keynote: Narrow Linewidth Atomic Clock Transitions for Inertial Sensing and Fundamental Physics
Jason Hogan, *Stanford University, USA*
Room: Kona (Salon 1)
Session Chair(s): Susannah Jones, *DSTL*

09:15 – 10:15
Session: Final Session of Contributed Talks
Room: Kona (Salon 1)
Session Chair(s): Susannah Jones, *DSTL*

9:15
9059: UMEMS: A Robust Technology Platform for Quality Automotive Inertial Sensor Manufacturing
Lianjun Liu, Matthieu Lagouge, Bob Steimle, Aaron Geisberger, John McKillop, Dave Monk
NXP Semiconductors, Canada; NXP Semiconductors, United States

9:35
9063: Out of Plane Double Differential Quadrature Compensation Electrodes with ThELMA-Double Technology
Patrick Fedeli, Luca Giuseppe Falorni, Gianfranco Javier Yallico Sanchez, Manuel Riani, Gabriele Gattere
STMicroelectronics, Italy

9:55
INVITED: Photonic Integrated Circuits for Cavity Optomechanical Inertial Sensors: From the Classical to Quantum Regime
Dr Ying Lia Li (Lia)
Zero Point Motion, UK

10:15 – 10:40
Coffee Break/Exhibits
Room: Kauai Court

10:40 – 12:25
Session: Late News
Room: Kona (Salon 1)
Session Chair(s): Jae Yoon Cho, *Enertia*

10:40
9090: Dual-Species Diamond NMR Gyroscope
Andrey Jarmola{3}, Sean Lourette{3}, Victor Acosta{4}, Glen Birdwell{1}, Peter BluÌˆmler{2}, Dmitry Budker{2}, Tony Ivanov{1}, Vladimir Malinovsky{1}
{1}DEVCOM Army Research Laboratory, United States; {2}Johannes Gutenberg-UniversitÃ¤t Mainz, Germany; {3}University of California, Berkeley, United States; {4}University of New Mexico, United States

11:00
9086: Simulation of Anchor Loss in MEMS Resonators Using Perfectly Matched Layers
Daniel Schiwietz{2}, Laukik Rajnish More{1}, Eva Maria Weig{3}, Peter Degenfeld-Schonburg{1}
{1}Robert Bosch GmbH, Germany; {2}Robert Bosch GmbH and Technical University of Munich, Germany; {3}Technische UniversitÃ¤t MÃ¼nchen, Germany

11:20
9089: Gold Single-Axis Differential Capacitive MEMS Accelerometer with Proof-Mass Position Control Electrode Fabricated by Post-CMOS Technology
Akira Onishi, Kisuke Miyado, Devi Srujana Tenneti, Katsuyuki Machida, Parthojit Chakraborty, Masato Sone, Yoshihiro Miyake, Hiroyuki Ito
Tokyo Institute of Technology, Japan

11:40
9088: Indirect Excitation of micro-HRG Using Segmented Piezoelectric ALD PHT Actuator
Danmeng Wang{2}, Nicholas Strnad{1}, Yusheng Wang{2}, Austin Parrish{2}, Robert Benoit{1}, Ryan R. Knight{1}, Andrei Shkel{2}
{1}DEVCOM Army Research Laboratory, United States; {2}University of California Irvine, MicroSystems Lab – MEMS, United States

12:00
9085: An Inverted Pendulum Model of Walking for Predicting Navigation Uncertainty of Pedestrian in Case of Foot-Mounted Inertial Sensors
Chi-Shih Jao{2}, Eudald Sangenis{2}, Paula Simo{2}, Alexandra Voloshina{2}, Andrei Shkel{1}
{1}University of California Irvine, MicroSystems Lab – MEMS, United States; {2}University of California, Irvine, United States

12:25 – 12:30
Closing Remarks
Room: Kona (Salon 1)
Session Chair(s): Michael Larsen, *Northrop Grumman*
Kari Moran, *Naval Information Warfare Center Pacific*

8:00 – 11:30
Beach Clean Up
Room: Royal Sonesta Lobby