

2016 IEEE International Symposium on Inertial Sensors and Systems

**Laguna Beach, California, USA
22-25 February 2016**



**IEEE Catalog Number: CFP16YAL-POD
ISBN: 978-1-4673-6940-4**

**Copyright © 2016 by the Institute of Electrical and Electronic Engineers, Inc
All Rights Reserved**

Copyright and Reprint Permissions: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limit of U.S. copyright law for private use of patrons those articles in this volume that carry a code at the bottom of the first page, provided the per-copy fee indicated in the code is paid through Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923.

For other copying, reprint or republication permission, write to IEEE Copyrights Manager, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854. All rights reserved.

******This publication is a representation of what appears in the IEEE Digital Libraries. Some format issues inherent in the e-media version may also appear in this print version.***

IEEE Catalog Number:	CFP16YAL-POD
ISBN (Print-On-Demand):	978-1-4673-6940-4
ISBN (Online):	978-1-4673-6939-8

Additional Copies of This Publication Are Available From:

Curran Associates, Inc
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: (845) 758-0400
Fax: (845) 758-2633
E-mail: curran@proceedings.com
Web: www.proceedings.com

CURRAN ASSOCIATES INC.
proceedings
.com

Table of Contents

Wednesday, February 24	vi
Thursday, February 25	ix
Welcome Message	x
IEEE Inertial Sensors & Systems Symposium 2016 Organizers	xi
Patrons & Exhibitors	xiii
Tutorials	xiv
Invited Speakers	xvi

Tuesday, February 23

09:00 - 09:30

A1L-A: Invited Talk

Room: Sand Dollar

Session Chair: Andrei Shkel (University of California, Irvine, USA)

**PRECISE ROBUST INERTIAL GUIDANCE FOR MUNITIONS:
NAVIGATING IN A GPS-FREE WORLD.....** *Not available at time of production*

Robert Lutwak
DARPA, USA

09:30 - 10:30

A2L-A: Rate Integrating Gyroscopes

Room: Sand Dollar

Session Chair: Alexander Trusov (Northrop Grumman, USA)

Co-Chair: Doruk Senkal (University of California, Irvine, USA)

HRG BY SAGEM: FROM LABORATORY TO MASS PRODUCTION 1

Alain Jeanroy, Gilles Grosset, Jean-Claude Goudon, Fabrice Delhaye
Sagem, France

OVERCOMING LIMITATIONS OF RATE INTEGRATING GYROSCOPES BY VIRTUAL ROTATION 5

Igor Prikhodko, Jeffrey Gregory, Dmitry Bugrov, Michael Judy
Analog Devices, United States

A NEW ELECTRONIC FEEDBACK COMPENSATION METHOD FOR RATE INTEGRATING GYROSCOPES..... 9

Parsa Taheri-Tehrani², A. Dorian Challoner¹, Oleg Izyumin³, Bernhard Boser³, David A. Horsley²
¹Inertialwave Inc., United States; ²University of California, Davis, United States; ³University of California, Berkeley, United States

11:00 - 12:00

A3L-A: Sensor Phenomena and Modeling

Room: Sand Dollar

Session Chair: Olivier Le Traon (ONERA, France)

Co-Chair: Kari Moran (Systems Planning Corporation, USA)

NUMERICAL PREDICTION OF STRESS EVOLUTION DURING BLOWTORCH REFLOW OF FUSED SILICA MICRO-SHELL RESONATORS 13

Behrouz Shiari, Tal Nagourney, Ali Darvishian, Jae Yoong Cho, Khalil Najafi
University of Michigan, United States

A SEMI-ANALYTICAL METHOD FOR CALCULATING RESONATOR ENERGY LOSS INTO PLATE SUBSTRATES 17

Christoph Schaal, Ajit Mal, Robert M'Closkey
University of California, Los Angeles, United States

CORRELATION OF FREQUENCY, TEMPERATURE, AND BIAS STABILITY OF A SI RING GYRO 21

Randall Kubena², Richard Joyce², Anthony Challoner³
¹*Boeing Research and Technology, United States;* ²*HRL Laboratories, United States;* ³*InertialWave, United States*

13:30 - 14:30

A4L-A: Sensor Systems

Room: Sand Dollar

Session Chair: Ryan Supino (Honeywell, USA)

Co-Chair: Adam Schofield (CERDEC US Army, USA)

ANALYSIS OF GYROCOMPASSING THROUGH MINIATURIZED MEMS BASED ON PIEZORESISTIVE SENSING 25

Stefano Dellea², Federico Giacci², Antonio Longoni², Giacomo Langfelder², Patrice Rey¹, Philippe Robert¹
¹*CEA-Leti, France;* ²*Politecnico di Milano, Italy*

MHRG: MINIATURE CVG WITH BEYOND NAVIGATION GRADE PERFORMANCE AND REAL TIME SELF-CALIBRATION 29

A.A. Trusov, M. R. Phillips, A. Bettadapura, G. Atikyan, G. H. McCammon, J. M. Pavell, Y. A. Choi, D. K. Sakaida, D. M. Rozelle, A. D. Meyer
Northrop Grumman Systems Corporation, United States

TEMPERATURE COMPENSATION OF CAPACITIVE MEMS ACCELEROMETER BY USING MEMS OSCILLATOR 33

Talha Kose¹, Kivanc Azgin¹, Tayfun Akin²
¹*METU-MEMS Research and Application Center, Turkey;* ²*Dept. of Electrical and Electronics Engineering, Middle East Technical University, Turkey*

15:30 - 17:00

A5P-B: Sensors Phenomena and Sensor Systems

Room: Sand Dollar Patio

Session Chair: Michael Larsen (Northrop Grumman, USA)

Co-Chair: David Johnson (Draper Laboratory, USA)

HIGH-PRECISION FIBER OPTICAL GYRO WITH EXTENDED DYNAMICAL RANGE Not available at time of production

Yury Korkishko², Viacheslav Fedorov², Victor Prilutskii², Vladimir Ponomarev¹, Ivan Morev¹, Dmitry Obukhovich², Sergey Kostritskii², Igor Fedorov¹, Alexander Zuev²
¹*Optolink, Russia;* ²*Optolink and FOS, Russia*

FIBER OPTIC GYRO FOR SPACE APPLICATIONS: RESULTS OF R&D AND FLIGHT TESTS.....	37
Yu.N. Korkishko ¹ , V.A. Fedorov ¹ , V.E. Prilutskiy ¹ , V.G. Ponomarev ¹ , I.V. Morev ¹ , D.V. Obukhovich ¹ , S.M. Kostritskii ¹ , A.I. Zuev ¹ , V.K. Varnakov ¹ , A.V. Belashenko ¹ , E.N. Yakimov ² , G.V. Titov ² , A.V. Ovchinnikov ² , I.B. Abdul'minov ² , S.V. Latyntsev ²	
¹ Optolink RPC LLC, Russia; ² JSC Academician M.F. Reshetnev Information Satellite Systems, Russia	
MEASURING THE SPIN POLARIZATION OF ALKALI-METAL ATOMS USING NUCLEAR MAGNETIC RESONANCE FREQUENCY SHIFTS OF NOBLE GASES	Not available at time of production
Xiaohu Liu, Hui Luo, Tianliang Qu, Kaiyong Yang, Zhiguo Wang, Zhichao Ding National University of Defense Technology, China	
INNOVATION OF FLAT GYRO: CENTER SUPPORT QUADRUPLE MASS GYROSCOPE.....	42
Bin Zhou, Tian Zhang, Peng Yin, Zhiyong Chen, Mingliang Song, Rong Zhang Tsinghua University, China	
A LOW POWER MEMS-ASIC SILICON RESONANT ACCELEROMETER WITH SUB-UG BIAS INSTABILITY AND ±30G FULL-SCALE	46
Jian Zhao, Guoming Xia, Yang Zhao, Anping Qiu, Yan Su Nanjing University of Science and Technology, China	
ANALYSIS OF THE DYNAMICS OF A PERTURBED RING.....	50
Amir Behbahani, Robert M'Closkey University of California, Los Angeles, United States	
THE MECHANICAL SENSITIVITY OPTIMIZATION OF A DISK RESONATOR GYROSCOPE WITH MUTATIVE RING THICKNESS	54
Xin Zhou, Qingsong Li, Dingbang Xiao, Zhanqiang Hou, Zhihua Chen, Yulie Wu, Xuezhong Wu National University of Defense Technology, China	
AN IMPROVED DUAL-MASS DECOUPLED MICRO-GYROSCOPE FOR THE NON-IDEAL DECOUPLED ERROR SUPPRESSION.....	58
Bo Yang, Di Hu, Yunpeng Deng, Xingjun Wang Southeast University, China	
INTRINSIC DISSIPATION IN A SILICON NANO-RESONATOR WITH SURFACE ROUGHNESS.....	Not available at time of production
Behrouz Shiari ² , Khalil Najafi ¹	
¹ University of Michigan, United States; ² University of Michigan, United States	

Wednesday, February 24

09:30 - 10:30

B2L-A: Inertial Measurement Units

Room: Sand Dollar

Session Chair: Diego Serrano (Qualtre, USA)

Co-Chair: Jenna Chan (Systems Planning Corporation, USA)

HIGH-PERFORMANCE 6-AXIS MEMS INERTIAL SENSOR BASED ON THROUGH-SILICON VIA TECHNOLOGY..... 62

Cenk Acar

Fairchild Semiconductor, United States

THRU-WAFER INTERCONNECTS FOR DOUBLE-SIDED (TWIDS) FABRICATION OF MEMS 66

Alexandra Efimovskaya, Yu-Wei Lin, Andrei Shkel

University of California, Irvine, United States

A TRI-FOLD INERTIAL MEASUREMENT UNIT FABRICATED WITH A BATCH 3-D ASSEMBLY PROCESS..... 70

Weibin Zhu, Casey Wallace, Navid Yazdi

Evgia Systems Inc., United States

11:00 - 12:00

B3P-B: Emerging Sensors and Applications

Room: Sand Dollar Patio

Session Chair: Randall Jaffe (L3-Com, USA)

Co-Chair: Alexander Trusov (Northrop Grumman)

DEVELOPMENT OF A HIGHLY ACCURATE AND LOW COST MEASUREMENT DEVICE FOR FIELD OPERATIONAL TESTS..... 74

Johannes Masino², Michael Frey², Frank Gauterin², Rajat Sharma¹

¹*Birla Institute of Technology and Science, India;* ²*Karlsruhe Institute of Technology, Germany*

MICRO SHELL RESONATOR WITH T-SHAPE MASSES FOR IMPROVING OUT-OF-PLANE ELECTROSTATIC TRANSDUCTION EFFICIENCY 78

Wei Li, Kun Lu, Dingbang Xiao, Zhanqiang Hou, Yan Shi, Xuezhong Wu, Yulie Wu

College of Mechatronics Engineering and Automation, National University of Defense Technology, China

VERTICAL SIGNAL FEEDTHROUGH FOR SANDWICH DEVICES BASED ON ANODIC BONDING AND AFTER LASER TRIMMING..... 81

Xinghua Wang, Qiang Xu, Dingbang Xiao, Zhanqiang Hou, Zhihua Chen, Xuezhong Wu

National University of Defense Technology, China

PARAMETRIC DRIVE MEMS RESONATOR WITH CLOSED-LOOP VIBRATION CONTROL AT AMBIENT PRESSURE..... 85

Mingliang Song, Bin Zhou, Zhiyong Chen, Hongbo Wang, Tian Zhang, Rong Zhang

Tsinghua University, China

WHISPERING GALLERY MODE OPTICAL GYROSCOPE 89

Wei Liang, Vladimir Ilchenko, Danny Eliyahu, Elijah Dale, Anatoliy Savchenkov, Andrey Matsko, Lute Maleki

OEwaves Inc., United States

ORIENTATION AND INERTIA SENSORY FEEDBACK FEASIBILITY USING SPINNING MAGNETIC NANOPARTICLES	93
Brian Krug, Johnson Asumadu <i>Western Michigan University, United States</i>	
DUAL MODE RESONANT CAPACITIVE MEMS ACCELEROMETER.....	97
Fatemeh Edalatfar, Sadegh Hajhashemi, Bahareh Yaghootkar, Behraad Bahreyni <i>Simon Fraser University, Canada</i>	
STUDY ON SURFACE ROUGHNESS IMPROVEMENT OF FUSED QUARTZ AFTER THERMAL AND CHEMICAL POST-PROCESSING	101
Yusheng Wang, Andrei Shkel <i>University of California, Irvine, United States</i>	
AN OPTOMECHANICAL ACCELEROMETER WITH A HIGH-FINESSE HEMISPHERICAL OPTICAL CAVITY.....	105
Yiliang Bao, Felipe Guzmán Cervantes, Arvind Balijepalli, John Lawall, Jacob Taylor, Thomas LeBrun, Jason Gorman <i>National Institute of Standards and Technology, United States</i>	
BISTABLE FORCE/ACCELERATION SENSOR BASED ON PULL-IN VOLTAGE MONITORING.....	109
Erez Benjamin, Stella Lulinski, Slava Krylov <i>Tel Aviv University, Israel</i>	
SIMULATIONS AND EXPERIMENTS OF LOW-FREQUENCY SPECTRUM OF HEMISPHERICAL RESONATOR GYROSCOPE	113
Sergii Sarapuloff, Huinam Rhee, Taras Bondarenko <i>Sunchon National University of Korea, Republic of Korea</i>	
SUB-DEGREE PER HOUR SPLIT MODE TUNING FORK GYROSCOPE	115
Yang Zhao, An Ping Qiu, Qin Shi, Guo Ming Xia <i>Nanjing University of Science and Technology, China</i>	
SILICON VIBRATING BEAM ACCELEROMETER WITH PPM GRADE SCALE FACTOR STABILITY AND TENS-PPM GRADE FULL-RANGE NONLINEARITY.....	117
Guoming Xia, Yang Zhao, Jian Zhao, Qin Shi, Anping Qiu <i>Nanjing University of Science & Technology, China</i>	
FAST AND RELIABLE CLOSED-LOOP WAFER-LEVEL MEASUREMENT OF GYROSCOPES DRIVE QUALITY FACTOR	119
Giacomo Langfelder ² , Mattia Vandi ² , Nicola Aresi ¹ , Tommaso Frizzi ¹ ¹ ITmems s.r.l., Italy; ² Politecnico di Milano, Italy	
14:30 - 15:30	
B4L-A: Precision Accelerometers	
Room: Sand Dollar	
Session Chair: Ryan Lu (SPAWAR Systems Center Pacific, USA)	
Co-Chair: Igor Prikhodko (Analog Devices, USA)	
HIGH ASPECT-RATIO LOW-NOISE MULTI-AXIS ACCELEROMETERS MADE FROM THICK SILICON.....	121
Yemin Tang, Khalil Najafi <i>University of Michigan, Ann Arbor, United States</i>	

A CMOS-COMPATIBLE OSCILLATION-MODE OPTOMECHANICAL DC ACCELEROMETER AT 730-NG/HZ^{1/2} RESOLUTION.....	125
Jaime Flor Flores ⁴ , Yongjun Huang ⁴ , Ying Li ¹ , Di Wang ¹ , Noam Goldberg ¹ , Jingjun Zheng ¹ , Mingbin Yu ² , Ming Lu ⁵ , M. Kutzer ³ , Daniel Rogers ³ , Dim-Lee Kwong ² , Layne Churchill ³ , Chee Wei Wong ⁴	
¹ Columbia University, United States; ² Institute of Microelectronics A*STAR, Singapore; ³ Johns Hopkins Applied Physics Laboratory, United States; ⁴ University of California, Los Angeles, United States; ⁵ Brookhaven National Laboratory, United States	
 16:00 - 17:00	
B5L-A: Advanced Analysis, Test, and Evaluation	
Room: Sand Dollar	
Session Chair: Joan Giner (Hitachi CTI, Japan)	
Co-Chair: Giacomo Langfelder (Politecnico di Milano, Italy)	
 ON-CHIP STRESS COMPENSATION ON THE ZRO OF A MODE MATCHED MEMS GYROSCOPE	128
Erdinc Tatar, Tamal Mukherjee, Gary Fedder	
<i>Carnegie Mellon University, United States</i>	
 NOISE ANALYSIS IN OPTOMECHANICAL INERTIAL SENSORS.....	132
Jonathan Yiho Lee, Qiang Lin	
<i>University of Rochester, United States</i>	
 PERFORMANCE CHARACTERIZATION OF THE HOLLOMAN 120" RADIUS CENTRIFUGE.....	136
Mike Hooser ² , Reese Sturdevant ¹ , Isaac Nacita ¹	
¹ 746 Test Squadron, Holloman, AFB United States; ² ALS, Holloman AFB, United States	

Thursday, February 25

09:00 - 09:30

C1L-A: Invited Talk - Chip-Scale Atomic Devices

Room: Sand Dollar

Session Chair: Andrei Shkel (University of California, Irvine)

CHIP-SCALE ATOMIC DEVICES: FROM CLOCKS TO BRAIN IMAGING AND BEYOND.....

Not available at time of production

John Kitching

National Institute of Standards and Technology, United States

09:30 - 10:45

Late News

Room: Sand Dollar

Session Chair: Andrei Shkel (University of California, Irvine)

DYNAMIC HYSTERESIS CALIBRATION ALGORITHM FOR INERTIAL GRADE ACCELEROMETERS

140

Arazi Yaakov, Gruver José Luis

Israel Aerospace Industries, Israel

VACUUM SEALED AND GETTER ACTIVATED MEMS QUAD MASS GYROSCOPE DEMONSTRATING BETTER THAN 1.2 MILLION QUALITY FACTOR

142

Sina Askari, Mohammad H. Asadian, Kasra Kakavand, Andrei Shkel

University of California, Irvine, United States

IN-RUN SCALE FACTOR AND DRIFT CALIBRATION OF MEMS GYROSCOPES WITH REJECTION OF ACCELERATION SENSITIVITIES.....

144

Sachin Nadig, Visarute Pinrod, Serhan Ardanuç, Amit Lal

Cornell University, United States

SQUEEZING ANGLE RANDOM WALK.....

146

Erdal Yilmaz

Cornell University, United States

A MEMS INERTIA SENSOR WITH BROWNIAN NOISE OF BELOW 50 NG/ $\sqrt{\text{HZ}}$ BY MULTI-LAYER METAL TECHNOLOGY

148

Daisuke Yamane³, Toshifumi Konishi¹, Hiroshi Toshiyoshi², Kazuya Masu³, Katsuyuki Machida¹

¹NTT Advanced Technology Corporation, Japan; ²The University of Tokyo, Japan; ³Tokyo Institute of Technology, Japan

AUTHOR INDEX

150