# *The Elmer A. Sperry Award*


FOR ADVANCING THE ART OF TRANSPORTATION


# *The Elmer A. Sperry Award*

**The Elmer A. Sperry Award shall be given in recognition of a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea or air.**

**In the words of Edmondo Quattrocchi, sculptor of the Elmer A. Sperry Medal:**

***"This Sperry medal symbolizes the struggle of man's mind against the forces of nature. The horse represents the primitive state of uncontrolled power. This, as suggested by the clouds and celestial fragments, is essentially the same in all the elements. The Gyroscope, superimposed on these, represents the bringing of this power under control for man's purposes."***

*Presentation of*

# *The Elmer A. Sperry Award*

*For 2022*

**TO**

## ASAD M. MADNI

*in recognition of his leadership in the development and commercialization of the first solid state gyroscope and its subsequent integration into a complete automotive inertial measurement unit integrated circuit for stability control*

**BY**

**THE ELMER A. SPERRY BOARD OF AWARD**

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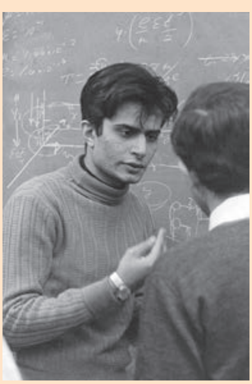
American Institute of Aeronautics and Astronautics
American Society of Civil Engineers

# *Asad M. Madni*

Dr. Asad M. Madni was President, Chief Operating Officer & Chief Technology Officer of BEI Technologies Inc. headquartered in California, from 1992 until the completion of its $600 million acquisition by Schneider Electric in 2006; and Chairman, President and Chief Executive Officer of Systron Donner Corporation (1975-1992). Under his leadership both Fortune 500 companies received international acclaim for their respective innovations in Aerospace and Defense (A&D), commercial aviation, homeland security, automotive and medical industries. He is currently Distinguished Adjunct Professor and Distinguished Scientist at the UCLA Electrical and Computer Engineering Department, Co-supervisor of the High Speed Electronics Laboratory, Faculty Fellow at the UCLA Institute for Transportation Studies and Faculty Fellow at the UCLA Connected Autonomous Electric Vehicle Consortium. Over 50 years, his contributions to U.S. economy, technical leadership, social wellbeing, environmental and homeland security are immeasurable.

He was born in Bombay (now Mumbai), India and after completing his General Certificate of Education through the University of Cambridge, he came to the United States to study electronics at RCA Institutes (previously Marconi Institute) in New York City, a school created in the early 1900s by Nobel Laureate Guglielmo Marconi to train wireless operators and technicians. After two years completing the electronics technology program at the RCA Institutes, Madni went on to the University of California, Los Angeles (UCLA), where he received B.S. & M.S. degrees in Electrical Sciences and Engineering. He received a Ph.D. in Engineering from California Coast University, and S.E. Senior Executive Program post graduate credential from the MIT Sloan School of Management. He is also a Chartered Engineer (CEng) and graduate of the Engineering Management Program at the California Institute of Technology, the Executive Institute and Director's College at Stanford University, and executive programs at Harvard University.  Dr. Madni has been awarded honorary doctorate degrees from Ryerson University, Technical University of Crete, California State University Northridge, Universiti Kebangsaan Malaysia, National Chiao Tung University, and Tufts University.



Asad Madni explains a problem in electronic ballistics to a classmate at the RCA Institutes in 1966 **[left]**.

In 1977, Madni **[seated, center]** discusses the communications-line analyzer he developed for the U.S. Navy.
Asad Madni

After two years teaching electronics engineering as a senior instructor at Pacific States University in Los Angeles and two years as a senior engineer in the design and development of computer peripherals at Pertec Corporation in Chatsworth, California, in 1975 he joined Systron Donner Corporation, where he served for 18 years in senior technical & executive positions, eventually as Chairman, President & CEO. Here, he made seminal and pioneering contributions in the development of Radio Frequency (RF) and Microwave Systems and Instrumentation which significantly enhanced the Combat Readiness of the US Navy and its allies, and which provided the Department of Defense (DOD) the ability, not possible with prior art, to simulate more threat representative ECM environments for current and future advanced warfare training.

Among his major contributions at Systron Donner were the development and commercialization of:

**1.** The world's first digital storage spectrum analyzer that replaced the bulky, unreliable, expensive, and scope limited, variable-persistence analog storage tube with the newly introduced semiconductor Random Access Memory based digital display. His patented innovations led to a revolution of features in spectrum analyzer capabilities and transformed the landscape of not only spectrum analysis but spawned a whole new era of low cost, highly powerful digital based instrumentation that established a multi-million-dollar market and the basis for powerful test and measurement capabilities that we enjoy today.

**2.** The world's first stand-alone system, the Transline Analyzer® (military version AN/PSM-40), capable of detecting the severities and locations of multiple faults in coaxial/waveguide transmission lines and antenna systems within inches and within minutes. This system, developed for the U.S. Navy under the Combat Readiness Electromagnetic Analysis and Measurement (CREAM) Program, became the basis for his doctoral research. Dr. Madni's patented correlation & interpolation techniques overcame limitations of time and frequency domain reflectometry and replaced nine instruments that took weeks to perform the measurements by highly trained personnel with much lower accuracy. It has long become standard test equipment for the US Navy while exponentially enhancing its combat readiness and of our allies that adopted it.

**3.** The world's first solid-state, miniaturized, microwave integrated circuit-based noise & deception jamming system used against Doppler radars in unmanned aerial targets, manned aircrafts and electronic countermeasures (ECM) pods. This revolutionary invention which replaced the bulky, expensive and unreliable traveling wave-tube amplifiers, provides the DOD with unprecedented ability to simulate realistic ECM threat environments for present and future advanced warfare training. This system is used by all three US military services and several allies and has become an invaluable tool for conducting system counter-countermeasures test, evaluation and operator training in an ECM environment. This system and the associated technology has had a profound impact on the performance, safety and well-being of the U.S. troops and its allies across the globe.

**4.** Advanced electronic warfare and solid-state radar systems for major A&D programs including for the defensive avionics for the B-1B Bomber, and the radar receiver for the C-130 Combat Talon II. His development of a High-Dynamic-Range Airborne Tracking and Fire Control Radar System dramatically upgraded the capabilities of the C-130 Combat Talon 2 after recognizing its terrain detection and avoidance limitations for advanced operations capabilities. With the increased system dynamic range and sensitivity developed by Dr. Madni and his team, the aircraft features terrain-following and terrain-avoidance radars capable of operations as low as 250 feet in adverse weather conditions and enables the aircrew to detect and avoid potential threats. If engaged, the system protects the aircraft from radar and infrared-guided threats. It has played a vital role in Air Force Special Operations Command (AFSOC) operations in Iraq, Afghanistan, Japan and Nepal.

Though his success moved him quickly into the management ranks, eventually climbing to chairman, president, and CEO of Systron Donner Corporation, former colleagues say he never entirely left the lab behind. His technical mark was on every project he became involved in, including the groundbreaking work that eventually led to the GyroChip®.

In 1990, he led the sale of the major assets of Systron Donner to BEI Electronics resulting in the establishment of BEI Technologies (NASDAQ: BEIQ) of which he was appointed President, Chief Operating Officer and Chief Technology Officer. Here, he led the development and commercialization of intelligent micro-sensors and systems for aerospace, military, commercial aviation, medical and transportation industries, including the Extremely Slow Motion Servo Control System for the Hubble Space Telescope's Star Selector which provided the Hubble with unprecedented pointing accuracy and stability, resulting in truly remarkable images that have enhanced our understanding of the universe; and the revolutionary MEMS GyroChip® technology which is used worldwide for Electronic Stability Control and Rollover Protection in passenger vehicles, thereby saving millions of lives every year. The sensing technologies that he developed are the fundamental building blocks that help make autonomous vehicles a reality.

The worldwide impact of his visionary leadership, and pioneering contributions to science, engineering and technology have been recognized with over 200 refereed publications, 69 issued or pending patents, and over 100 national and international honors and awards including: IEEE Medal of Honor (Institute's highest honor), RAE Prince Philip Medal (Academy's highest honor), ASME Soichiro Honda Medal, Ellis Island Medal of Honor, IEEE Frederik Philips Medal, IEEE Millennium Medal, IET J.J. Thomson Medal, IEE Achievement Medal, UCLA Professional Achievement Medal, TCI College Marconi Medal, UCSD Gordon Medal, World Automation Congress Medal of Honor and Lifetime Achievement Award, Tufts University School of Engineering Dean's Medal, Tau Beta Pi McDonald Mentor Medal and Distinguished Alumni Award, National Academy of Engineering Heritage Society Medal and Einstein Society Award, IEEE Sensors Council Sensor Systems/Networks Advanced Technical Achievement Award, IEEE AESS Industrial Innovation Award, IEEE AESS Pioneer Award, IEEE IMS Career Excellence Award, IEEE HKN Eminent Member Recognition, IEEE-HKN Vladimir Karapetoff Award, Mahatma Gandhi Pravasi Samman Medal, Hind Rattan ("Jewel of India") Medal, UCLA Engineering Alumnus of the Year Award, UCLA Engineering Lifetime Contribution Award, UCLA EE Distinguished Alumni Award, Engineers' Council Distinguished Engineering Achievement Award, LACES George Washington Engineer of the Year Award, Honorary Fellowship of the Royal Aeronautical Society, IEEE Heritage Circle Nikola Tesla Society Honored Philanthropist Award, Albert Nelson Marquis Lifetime Achievement Award, and USC Viterbi School of Engineering Dean's Faculty Award.


Asad Madni receives the 2022 IEEE Medal of Honor (Institute's highest honor)

He is an elected fellow of some of the world's most prestigious scientific and engineering academies and societies including, National Academy of Engineering, National Academy of Inventors, Royal Academy of Engineering, Canadian Academy of Engineering, European Academy of Sciences and Arts, New York Academy of Sciences, Washington Academy of Sciences, American Association for the Advancement of Science, Institute of Electrical and Electronics Engineers, Institution of Engineering and Technology, Institute of Electrical Engineers, American Institute of Aeronautics and Astronautics, SAE International, American Institute of Medical and Biological Engineering, Asia-Pacific Artificial Intelligence Association, Institute for the Advancement of Engineering and the Royal Aeronautical Society. He has also been awarded six honorary professorships. In 2019, IEEE HKN named its top award "The Asad M Madni Outstanding Technical Achievement and Excellence Award" to recognize and honor his nearly 50 years of technical and philanthropic accomplishments, and visionary leadership. In 2022, Tau Beta Pi, the Engineering Honor Society established a Distinguished Alumni Award & Student Scholarship in his honor.

Dr. Madni is not just a prominent and world-wide recognized innovator. He is a committed mentor to young professionals and a respected philanthropist. He has been a champion of diversity and inclusion (D&I) for underrepresented groups of individuals and equality for everyone for over 5 decades. His dedication to D&I is a synergistic part of his character that has always been fundamental in everything he does. He has shown us that recognizing and valuing the diversity and contributions of all voices is truly the only way to inspire innovation and make positive social impact.


Receiving AIAA Fellow Award from NASA Administrator Michael Griffin in 2013

Induction ceremony at the National Academy of Engineering in 2011


Induction ceremony at the National Academy of Inventors in 2015

Receiving the Royal Academy of Engineering's highest individual honor, the Prince Philip Gold Medal, from HRH Princess Royal Anne on November 8, 2022 at the historic Drapers Hall, London.

In the early 1990s, Systron Donner Inertial Division (SDID), a BEI Technologies company, celebrated 40 years of excellence in satisfying the inertial needs of A & D markets, primarily with a product line of high precision accelerometers for space, missile and aircraft applications. The Cold War had ended and forced a significant reduction in SDID's overall business as older product demand declined and business wasn't going to come back anytime soon. BEI needed to identify and capture new customers—and quickly. The company acquired a new Microelectromechanical Systems (MEMS) rate gyroscope technology concept based on a Coriolis force tuning fork, but the technology had yet to be commercialized for high volume production. The sensing element was a dual-ended vibrating tuning fork made out of monocrystalline piezoelectric quartz. The tines of the fork would be deflected by the Coriolis effect, the inertial force acting on an object as it resists being pulled from its plane of rotation. Because quartz has piezoelectric properties, changes in forces acting upon it cause changes in electric charge. These changes are processed in a silicon-based Application Specific Integrated Circuit (ASIC) which contains the electronics and signal processing to provide an output signal which is proportional to the angular rate of rotation as shown in Figure 1.

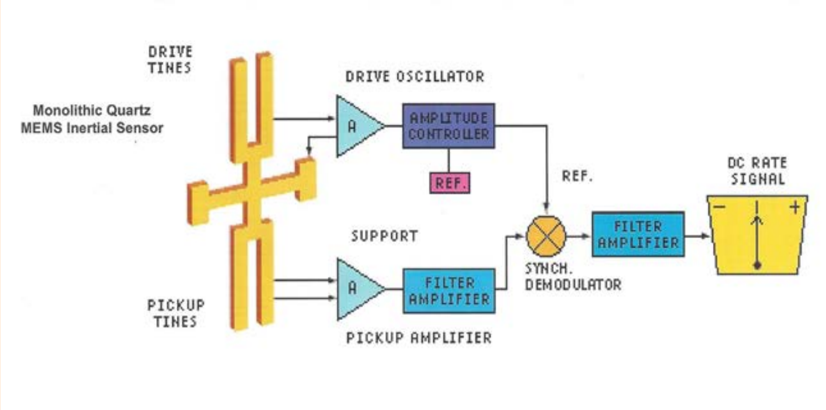



Figure 1. Classic QRS Block Diagram (Source: BEI Technologies Inc.)

The Quartz Rate Sensor (QRS) exhibited promise for manufacturing with high-volume methods, however, the low production volume demand before 1995 could not justify the capital expense to automate the low-volume, labor-intensive manufacturing methods. SDID clearly needed a growth strategy to take advantage of the promise of the QRS.

In the late 1980s, car companies had begun introducing basic traction-control systems in their high-end vehicles. These systems monitored steering-wheel position, throttle position, and individual wheel speeds, and could adjust engine speed and braking when they detected a problem, such as one wheel turning faster than another. They couldn't, however, detect when the direction of a car's turn on the road didn't match the turn of the steering wheel, a key indicator of an unstable skid that could turn into a rollover. The industry was aware this was a deficiency, and that rollover accidents were a significant cause of deaths from auto accidents. After performing an extensive market survey, automotive stability control systems were identified as a significant growth opportunity for an extremely low-cost solid-state rate gyroscope.

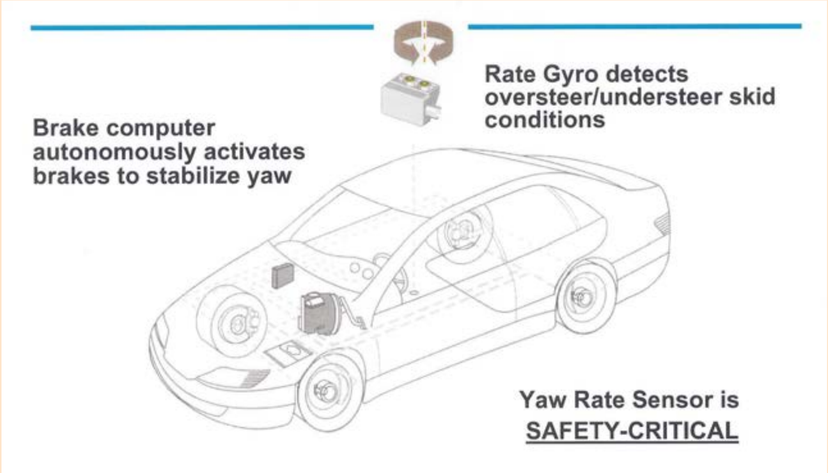



Figure 2. The YAW Rate Sensor Automotive Opportunity (Source: BEI Technologies Inc.)

Since gyroscopes had not previously been engineered and adapted to automotive service, this application represented a new challenging and emerging market. "Stability Control" (SC) systems measure the vehicle yawing (turning) rate and a brake computer compares it to the desired yaw rate from the driver steering wheel command. A skid condition is detected by an out-of-tolerance comparison in a software algorithm. This detection causes a momentary automatic application of either the left or right brake(s) to correct or "stabilize" the vehicle. SC systems enhance the safety of traditional Antilock Brake Systems (ABS) for a relatively small increase in cost. See Figure 2. The automotive application required a gyroscope with extreme reliability, medium performance, very low cost, built-in-test capability and high-volume manufacturability. Conceptually, the MEMS QRS could (and did) meet all these requirements.

Together Dr. Madni as President, COO, and CTO of BEI together with BEI Chairman Charles Crocker made the decision to convert BEI's SDID from being exclusively an aerospace and defense company and to begin concentrating on the automotive industry as well.

## *Inertial Measurement Units*

An inertial measurement unit (IMU) is a device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body. It works by detecting linear acceleration using one or more accelerometers and rotational rate using one or more gyroscopes, and sometimes magnetometers used to establish a heading reference. Typical configurations contain one accelerometer, gyro, and magnetometer per axis for each of the three principal axes: pitch, roll and yaw. See Figure 3.

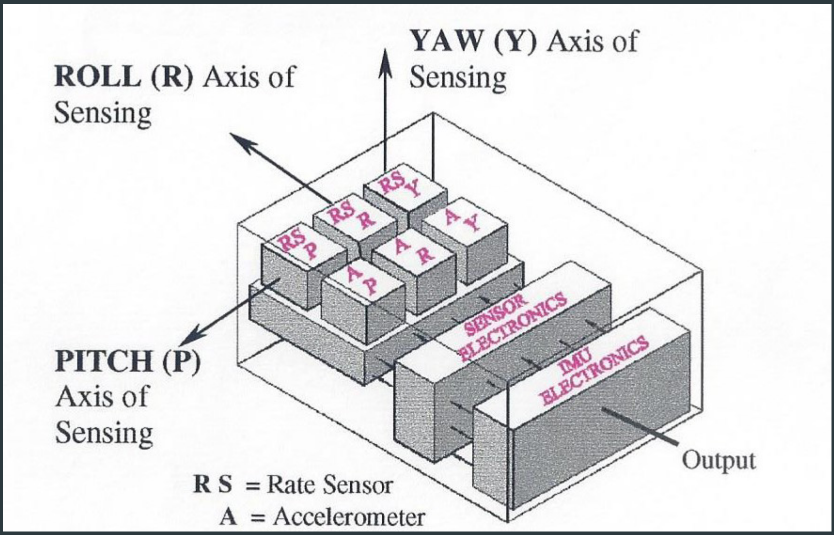



Figure 3. Inertial Measurement Unit (IMU) (Source: BEI Technologies Inc.)

In the early 1990s a typical IMU used mechanical gyroscopes for angular rate sensing. A package with three highly accurate spinning mass gyroscopes was about the size of a toaster oven and weighed about one kilogram. Versions that used ring-laser gyroscopes were slightly smaller. All high accuracy mechanical and laser gyros cost thousands of dollars at that time.

IMUs are typically used to maneuver aircraft (an attitude and heading reference system), including unmanned aerial vehicles (UAVs), among many others, and spacecraft, including satellites and landers. Recent developments allow for the production of IMU-enabled GPS devices. As an A&D contractor, SDID produced IMUs, based on its QRS technology, for specific applications.

## *Commercialization of the GyroChip®*

As with most modern products, underlying technical principles required discovery and implementation. The technologies individually matured over many years before being combined together to achieve higher level capability. The QRS was no exception. Over a century passed before the concept discovered by Coriolis in 1835 was utilized by the Sperry Company in the 1940s to develop a laboratory demonstration of a tuning fork rate gyro called the Sperry Gyrotron. While quartz is abundantly available in nature, the gyro tuning fork required its very pure form dictating commercial manufacture in highly controlled conditions.

The initial target was to match the performance of rate integrating-gyros, with improvements in size, reliability and price. With further maturation the QRS demonstrated capability for meeting tactical missile grade guidance and navigation requirements, and was qualified in missile, airborne and naval applications. Specifically, the QRS was installed on a major air-to-ground missile with over 30,000 gyros manufactured (Figure 4). It was also qualified and installed on the fleet of AV8-B aircraft. There were literally hundreds of other military applications including the Navy AN/WSC-6 Antenna Stabilization System which fielded QRSs for several years with excellent results and reliability; and the Multiple Launch Rocket System, Terminally Guided Weapon Program that successfully used QRSs to guide fully operational vehicles to direct hits on target.

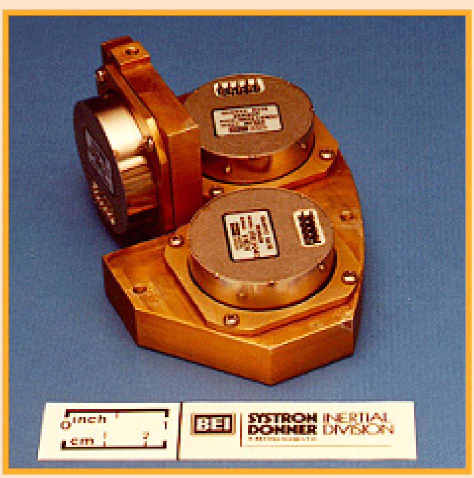



Figure 4. The First QRS Gyroscope Product. Missile Tri-Axis Cluster (Source: BEI Technologies, Inc.)

Mid-1900s produced high volume quartz manufacturing business based on quartz crystal oscillators and other telecom devices. Photolithography and micromachining techniques perfected in the 1970s by the semiconductor industry were adapted to quartz MEMS. Digital watch industry in the 1970s perfected extremely low-cost batch processing techniques for quartz tuning fork oscillators. Software development tools including Finite Element Analysis (FEA) made possible precision design of forks that avoided resonant modes over temperature. Signal conditioning circuits for the QRS were implemented in an ASIC. Technology convergence for the QRS is depicted in Figure 5.

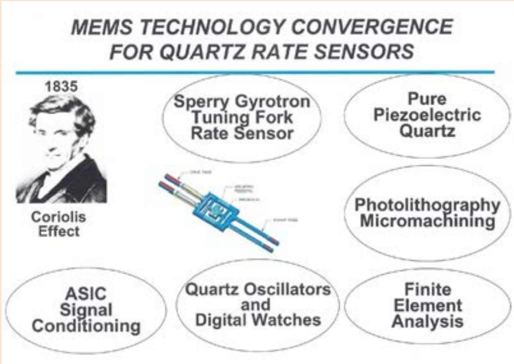



Figure 5. MEMS Technology Convergence for Quartz Rate Sensors. (Source: BEI Technologies Inc.)

Among the most formidable challenges that the company faced were the massive cultural and infrastructure changes that had to be made over the next five years to accommodate this new automotive and transportation business mentality, while not abandoning the existing A&D business. Several areas were impacted including: the quality system, Enterprise Resource Planning (ERP) computer system, Electronic Data Interchange (EDI) customer ordering, statistical process controls, factory automation, technology road-mapping techniques for continuous cost reduction, engineering design and validation techniques for lowest unit cost and development of a global supplier and customer base with businesses in USA, Europe and Japan. Strategic partnerships in all 3 market segments were developed, in order to maximize a solid customer base and mutually benefit the customer and SDID.

Manufacturing processes and techniques were re-designed for mass production primarily in fork fabrication and balancing, hermetic packaging, and final assembly, calibration and test. All labor-intensive processes were replaced by automation and proofing against human error. Continuous cost reductions were planned with 5-year Technology Roadmaps. Products achieved primary customer needs of performance specifications and continuous fault detection capabilities for safety-critical applications. A common quartz fabrication facility served both A&D and automotive product lines. These major changes together with leveraging A&D technology components into the automotive markets and similarly leveraging new technology components into the previous A&D markets allowed the company to ramp up production, shipping millions of units while continuing to serve the A&D market. Figures 6, 7 and 8 show the detail manufacturing sequence.

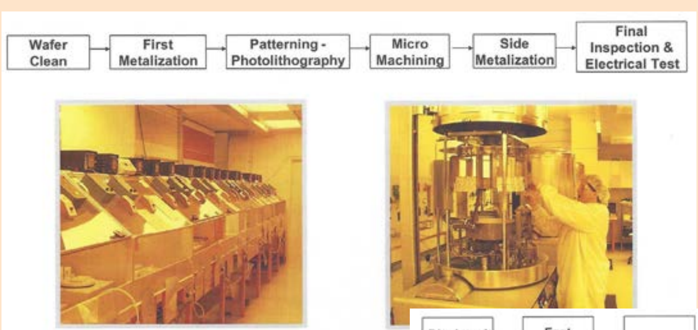



Figure 6. Quartz MEMS Production Fabrication Steps. (Source: BEI Technologies Inc.)

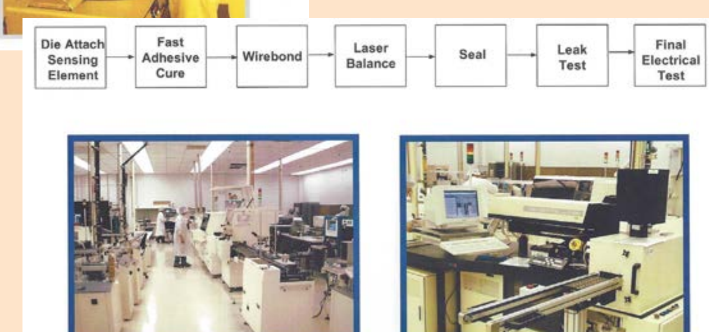



Figure 7. Nugget Subassembly Fabrication Steps. (Source: BEI Technologies Inc.)

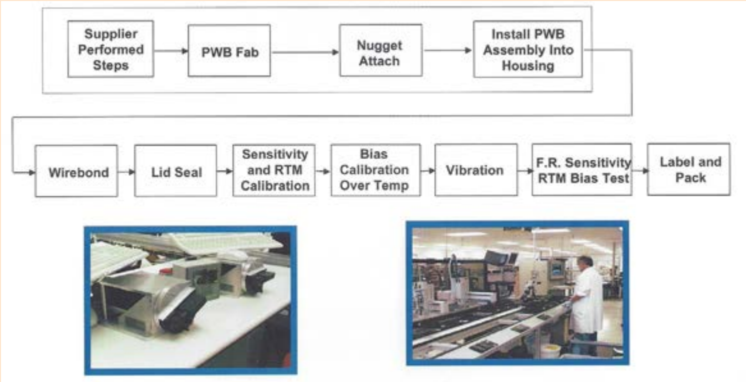



Figure 8. Final Assembly Fabrication Steps. (Source: BEI Technologies Inc.)

The MEMS QRS technology (now called the GyroChip®) had already met key A&D performance characteristics that were orders of magnitude better than the automotive application, including the critical performance parameter, offset bias over temperature. The automotive challenge hinged on reducing unit cost of the GyroChip® to "double-digit" dollar levels from the three and four-digit levels common to A&D products. The cost reduction occurred primarily through selective investments in automation, significant advances in design techniques, and mass production techniques.

The classic semiconductor industry technique of more chips per silicon wafer was embraced by progressively moving from one tuning fork per quartz wafer to 2, 4, 8, 16, and 56. All these designs utilized the same size wafer. See Figures 9 and 10. This batch manufacturing, together with laser trimming and electronically programming calibration techniques, dramatically reduced the cost per tuning fork. Performance degradation caused by fork size reduction in such mass-based sensors was not only significantly mitigated but the innovative ("Hammerhead") tuning fork designs actually improved the performance. Figures 11 and 12 provide a perspective on "Tine Motion" numbers based on angular rate input and underscore the challenge of detecting useable output signals. A special charge amplifier was designed to detect such challenging signal ratios. Figure 13 provides a comparison between the STD 4 and the STD 8 Hammerhead MEMS quartz tuning fork designs, and Figure 14 shows the FEA Stress Analysis comparison between the two designs.

In the Hammerhead design, the unusual masses at the end of the tapered tines add momentum, a key factor in generating more Coriolis force for a given length of fork. The masses also allow the fork frequency to be reduced, which would be excessively high with just tine tapering alone. All forks operate in the 10-17 kHz frequency region. Higher frequencies would require redesigned ASIC signal conditioning electronics with higher bandwidth amplifiers. The tapered tine/hammerhead design offers higher sensitivity with a smaller fork size, a result opposite to that expected with a fork size reduction. This improvement is the result of both better drive behavior, and enhanced pickup coupling. The drive system has a higher "Q", due to reduced tine displacement and improved charge coupling of the tines. This lowers impedance allowing for higher drive current levels from a given voltage source, and decreases zero rate offset bias. Finally, the tapered-tine-concept offers design control variables that include not only length and width (as with the square tine design), but also taper and hammerhead mass size. This additional design flexibility allows for more optimization of the overall structure, and eases (continues on pg. 14.)

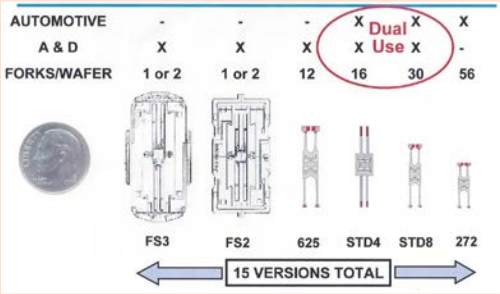



Figure 9. Fork Family Progression -- Moore's Law of Quartz. (Source: BEI Technologies Inc.)

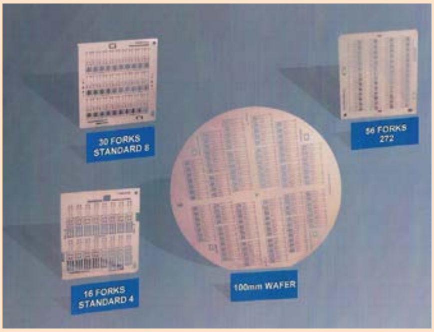
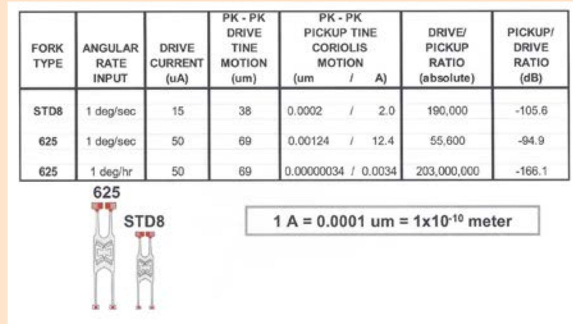



Figure 10. Tuning Fork Evolution--More Forks Per Wafer (Source: BEI Technologies, Inc.)



| FORK TYPE | ANGULAR RATE INPUT | DRIVE CURRENT (uA) | PK - PK DRIVE TINE MOTION (um) | PK - PK PICKUP TINE CORIOLIS MOTION (um / A) | DRIVE/ PICKUP RATIO (absolute) | PICKUP/ DRIVE RATIO (dB) |
|---|---|---|---|---|---|---|
| STD8 | 1 deg/sec | 15 | 38 | 0.0002 / 2.0 | 190,000 | -105.6 |
| 625 | 1 deg/sec | 50 | 69 | 0.00124 / 12.4 | 55,600 | -94.9 |
| 625 | 1 deg/hr | 50 | 69 | 0.00000034 / 0.0034 | 203,000,000 | -166.1 |



Figure 11. MEMS in Perspective—Some “Tine Motion” Numbers (Source: BEI Technologies, Inc.)

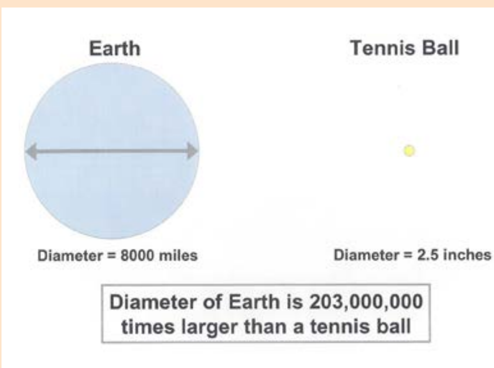



Figure 12. “Tine Motion” Perspective (Source: BEI Technologies, Inc.)


Figure 13 – Comparison between a STD 4 and STD 8 Hammerhead Quartz Tuning Fork (Source: BEI Technologies Inc.)

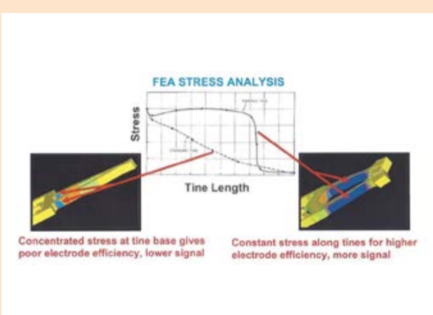



Figure 14. FEA Stress Analysis Comparison between a STD 4 and STD 8 Hammerhead Quartz Tuning Fork (Source: BEI Technologies Inc.)

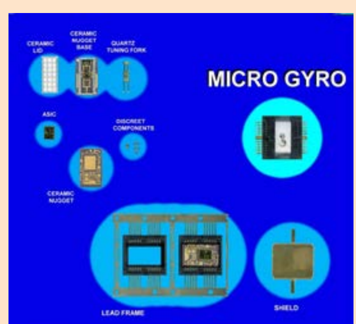



Figure 15. Production Details of the Micro Gyro (Source: BEI Technologies, Inc.)

(continued) challenges such as the pickup mode nodal line centering. It is also important to understand the fork balancing, which achieves several objectives. One of the most important is to reduce the quadrature error due to the imperfect match of either mass or stiffness of the two drive tines. The imperfection is attributed to the process variation in the quartz fork micromachining process. Quadrature appears as a Coriolis pickup motion in a zero angular rate environment. This error must ultimately be reduced by means that are cost-effective. By selectively removing more mass from one tine than the other in an automatic laser trimming operation, the quadrature error is reduced to an acceptable level in a matter of seconds. Figure 15 shows the production details of the Micro Gyro.

Another major hurdle was to implement Self-Monitoring for Safety Critical Systems. Rate gyroscope applications frequently occur in systems that create a dangerous situation if the gyro fails without the host system detecting that the rate-sensing device is providing faulty information. Automotive stability control brake systems generate direction-changing (yawing) brake commands independent of the driver. For this reason, this "safety system" may become an "unsafe system" if it erroneously activates the brakes. Unlike other limited self-tests, the BEI GyroChip® was embedded with a patented technique called Continuous Built-in-Test (CBIT), which can monitor end-to-end sensor and electronics health continuously during operation. CBIT is a major contributor to stability control brake system safety.

The first high-volume production of the GyroChip® Yaw Rate Sensor began in June 1996 for application in the Cadillac StabiliTrak™ brake system. An unexpected event happened in the Fall of 1997 when a Swedish automobile magazine editor swerved a test vehicle to simulate avoiding an elk crossing the road. The car rolled over. This created a firestorm of adverse publicity causing the manufacturer to commit to including stability control in all future vehicles. Other European car manufacturers seized on the opportunity to include stability in their vehicles as well. GyroChip® demand went up to 400,000 units during the first full year of production. By 2002 over 5 million units had been shipped. Following classic semiconductor techniques to package more chips per silicon wafer completely single chip IMUs were created, driving down the cost and power requirements. In 2005 the complete automotive IMU for stability control was packaged in a single chip. Under Dr. Madni's leadership BEI became the world's largest independent supplier of MEMS Yaw/Roll Stability Control (RSC) sensors for cars. Figure 16.

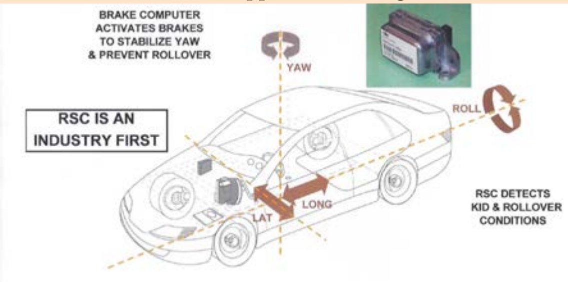



Figure 16. 4 DOF Vehicle Motion Sensed by RSC Sensor Cluster (Source: BEI Technologies, Inc.)

Using the success and knowledge gained through this low-cost manufacturing experience, SDID leveraged this engine of low cost, high-volume products back into the A&D market and made major inroads in the commercial aviation market. The Boeing 737 in the early and mid-'90s had been involved in a series of crashes and incidents that stemmed from unexpected rudder movement. Some of the failures were traced to the aircraft's power control unit, which incorporated yaw-damping technology. While the yaw sensors weren't specifically implicated, the company did need to redesign its Power Control Units (PCUs). Madni and BEI convinced Boeing to use BEI's quartz sensors in all of its 737s going forward, as well as retrofitting existing aircraft with the devices. Manufacturers of aircraft for private aviation soon embraced the sensor as well. And eventually the defense business came back. The STD 4 Fork model alone was used on 4,000,000 cars and 3000 737 aircraft (Figure 17).

The GyroChip® went on to became a foundational technology for A&D and commercial applications that included platform stabilization, attitude heading and reference systems, range instrumentation, air combat maneuvering, unmanned and remote piloted vehicles, helicopters, target drone navigation, aerial mapping and aerial imaging, airborne remote sensor positioning, vehicle dynamics testing, GPS augmentation instrumentation, short term navigation, and a host of other applications.

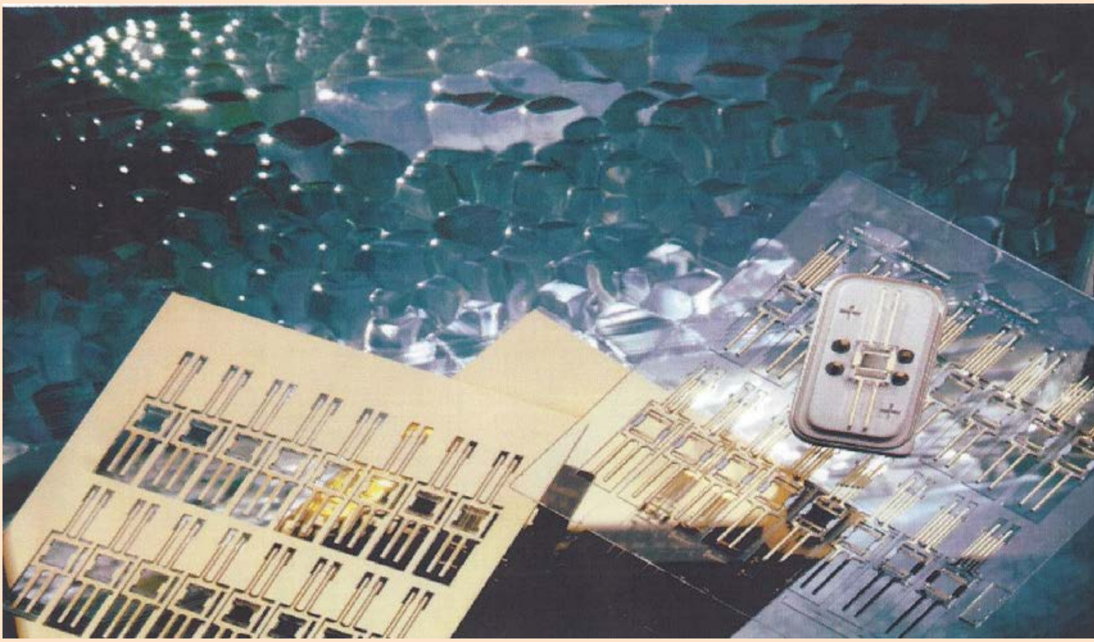
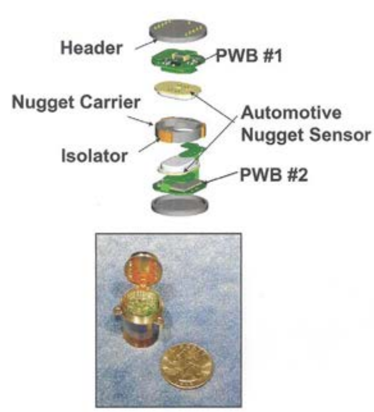


Figure 17. STD 4 Fork Commonality-- 4,000,000 cars and 3000 737 Aircraft (Source: BEI Technologies, Inc.)




**Performance Specifications**

| Parameter Specification | Summary |
|---|---|
| Standard Range | ±200°/sec |
| Output | ±2.0 Vdc (Analog DC Voltage) |
| Scale Factor Accuracy | ±1% Nominal |
| Bias Stability | Model to <0.1°/sec |
| Turn on Time | <1.0 sec |
| Random Noise | <.005°/sec/√Hz |
| Bandwidth (-3dB) | 100 Hz |
| Input Axis Alignment | <34 mrad uncompensated<br>Model 10 <1 mrad |
| Operating Temperature | -54°C to +85°C |
| Storage Temperature | -54°C to 125°C |
| Storage Life | 10 Years |
| Shock | 300 g's, ½ sine, 5msec |
| G-Sensitivity | .02°/sec/g |
| Weight | 20 grams |
| Input Voltage | + and –5.0 Vdc |
| Other ranges available | |

Figure 18. Quartz Dual Axis Rate Sensor (QDARS) (Source: BEI Technologies, Inc.)

Figure 18 shows QDARS, a miniature all-MEMS two-axis rate sensor designed for seeker stabilization applications. It was introduced in 2003.

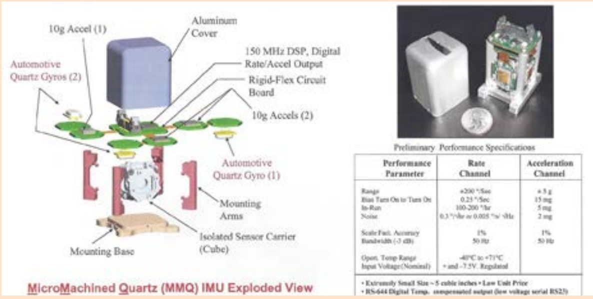



Figure 19. Automotive Gyros in a Low-Cost Aerospace IMU (Source: BEI Technologies, Inc.)

Figure 19 shows a Miniature MEMS Quartz IMU (MMQ-50), a very small, low-cost MEMS-based 6DOF IMU for low-cost aerospace applications. Digitally compensated output allows the MMQ to maintain high performance with gyro bias less than 0.25°/sec and accelerometer bias less than 15 mg. The low cost is achieved by leveraging high volume angular rate sensors used for automotive applications. Several million such nuggets were produced, and when applied to the MMQ, allow significant cost advantages. Other cost advantages were realized by utilizing SDID's Vibrating Quartz Accelerometers or a Silicon Designs Chip Accelerometer, and a military qualified ASIC for signal processing.

With further vertical integration, in partnership with Athena Technologies, the MEMS QRS became an enabling technology for advanced Inertial Navigation System (INS)/Global Positioning System (GPS) products, as shown in Figure 20.

By 2005, SDID had shipped in excess of 55 million MEMS GyroChips® worldwide, generating revenues in excess of $2 Billion. The technical and manufacturing innovations resulted in numerous sensors, actuators and control systems that are fundamental to autonomous vehicles, smart cities, and IoT, with a major economic, social-wellbeing and environmental impact on our nation.

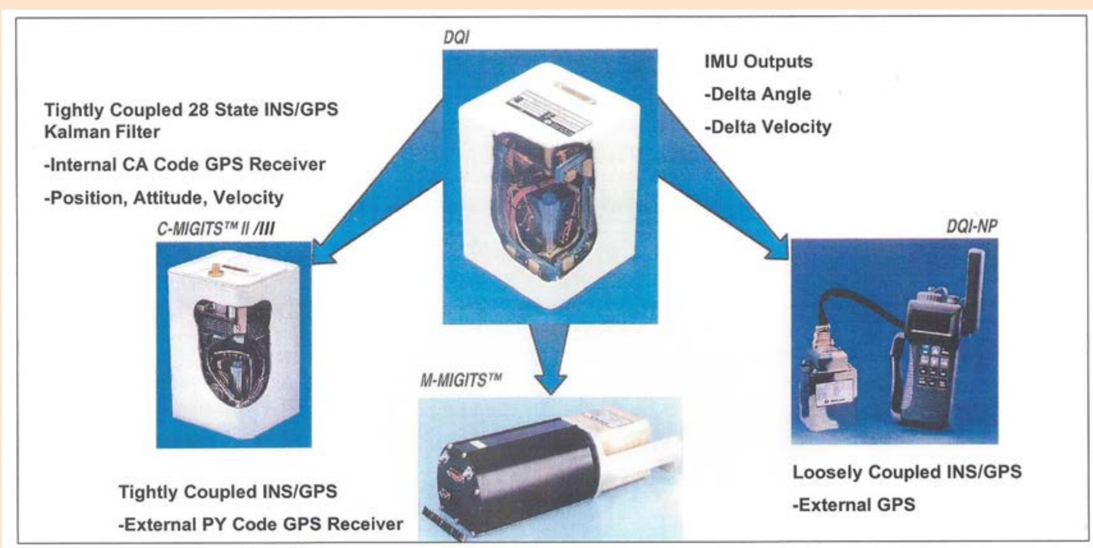



Figure 20. Inertial Navigation System (INS)/Global Positioning System (GPS) Products (Source: BEI Technologies, Inc.)

# *The Overall Achievement*

Dr. Madni led the first commercial development of a MEMS solid state gyroscope chip (GyroChip®) and ultimately the complete integration of an entire inertial measurement unit on a single chip, which revolutionized navigation and stability in aerospace, defense, and automotive systems. It combines an unconventional mono-crystalline, piezoelectric quartz tuning fork sensing element with surface mount packaging and a mixed-signal silicon ASIC. This opened the way to producing safer automobiles when combined with antilock braking systems to provide stability control. In addition, for land vehicles, an IMU can be integrated into GPS based automotive navigation systems or vehicle tracking systems, giving the system a dead reckoning capability and the ability to gather as much accurate data as possible about the vehicle's current speed, turn rate, heading, inclination and acceleration, in combination with the vehicle's wheel speed sensor output and, if available, reverse gear signal, for purposes such as better traffic collision analysis.

The GyroChip® applications range from satellites to airliners and cars. It is used in over 90 airborne platforms for guidance, navigation and control, including the ACE Pitch Stability Control of Boeing 777/stretch 777; as Yaw Damper for over 3000 Boeing 737s; in most business jets for attitude heading and reference; and for guidance, navigation & control in major missile, UAV, helicopter & space programs. It is also the foundational technology for Rockwell Collins' Pro-Line 21 & GHC-3000 avionics suites; inertial heading and reference for NASA's Mars rover "Sojourner"; inertial reference and stabilization for NASA's autonomous EVA robotic camera (AERCam) Sprint, a free flying 35 cm diameter sphere carrying TV cameras designed for use outside a spacecraft.; inertial reference in the SAFER (simplified aid for EVA rescue), an astronaut backpack designed for extra-vehicular activity on the STS-64 Space Shuttle/ Space Station Mission, intended to provide an astronaut who "falls off" the spacecraft with the means to get back; stabilization of numerous satellites including the UOSAT Microsatellite series; and ARCHER airborne Hyperspectral Imaging System used by Civil Air Patrol (CAP) in Search/Rescue and Disaster Management missions. It collects hyperspectral and high-resolution panchromatic data for real-time and post-flight processing and analysis and uses the GyroChip® IMU to pinpoint location of objects such as persons in need of assistance, fire hotspots or oil spills on lakes and rivers. It is deployed at all wings of the CAP.

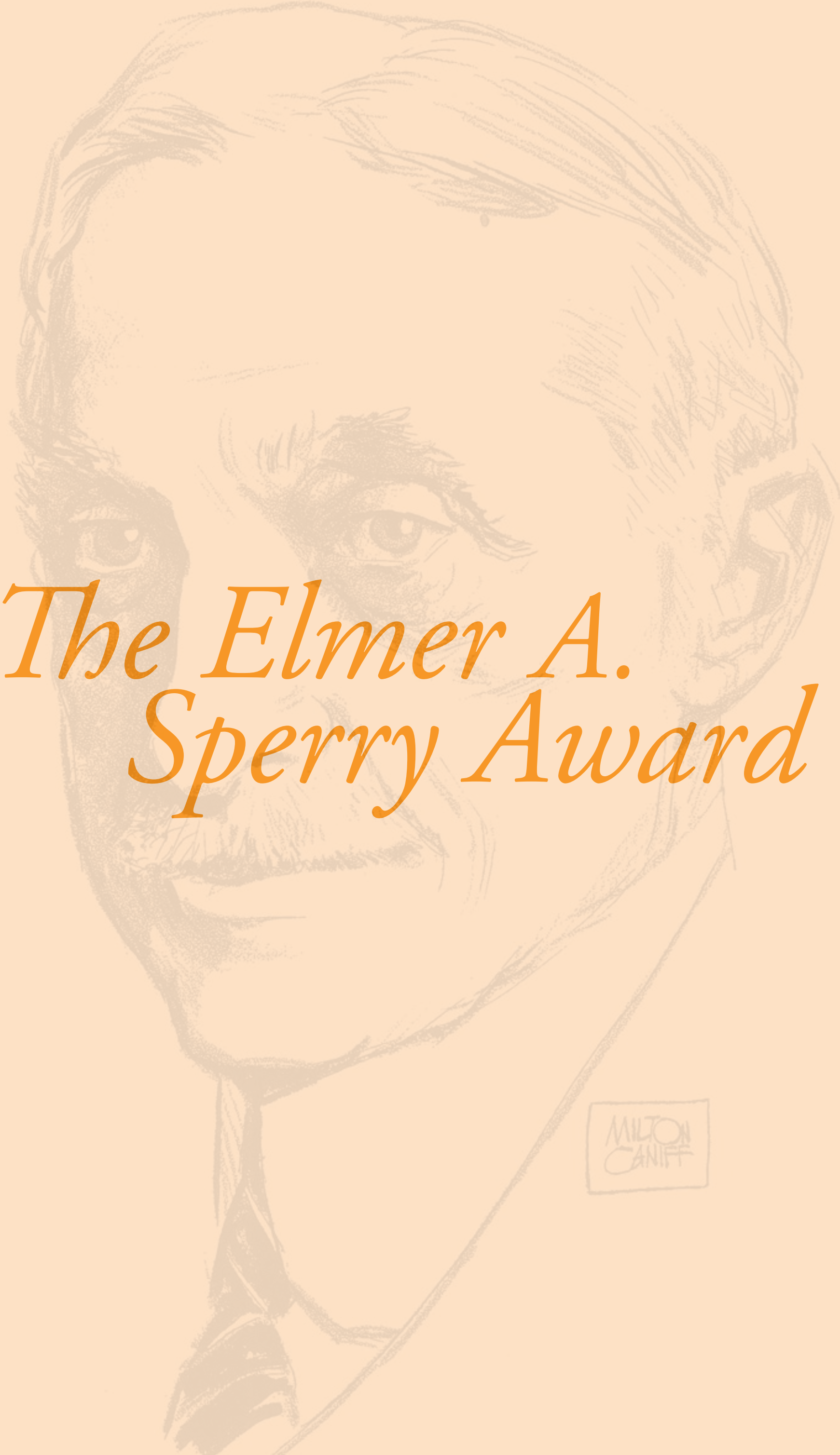
At the end of the cold war, Dr. Madni led the successful re-engineering of the company to address the automotive safety application. It is in use worldwide in over 80 models of passenger cars for automotive stability and rollover protection systems including, GM's StabiliTRAK System, Continental Teves's Electronic Stability Program, numerous models of GM, Renault, Nissan, Ford, VW, Hyundai, Daimler Chrysler, BMW, Honda, Toyota, Mitsubishi, Audi, Ssang Yong, etc. Over 55 million GyroChips® were produced; their use for stability augmentation in passenger cars has saved millions of lives around the globe and continues to enhance the safety of people and transportation systems daily. Electronic stability and roll-over prevention are of paramount importance to human safety which, thanks to the vision and technical capabilities of Dr. Madni, we all enjoy when driving a car or flying on an airplane.

Dr. Madni led the development of innovative MEMS accelerometers and pressure sensors, non-contact linear and angular position sensors and torque sensors, and embedded sensors/actuators that together with the GyroChip®, became the foundation of vehicle dynamic control and helped realize the dream of autonomous vehicles through capabilities such as: electronic stability control, rollover prevention, lane change assist, autonomous cruise control, navigation, drowsy-driver detection, drunk driver detection, child seat detection, memory seat sensing, self-maintenance and other key features.

At this point the story has been ongoing for over three decades. At the same time as often happens in microelectronics, greater and greater capability can be integrated onto a single chip. Almost all smartphones and tablets contain IMUs as orientation sensors. Fitness trackers, smart watches and other wearables can also include IMUs to measure motion, such as walking or running. IMUs also have the ability to determine developmental levels of individuals when in motion by identifying specificity and sensitivity of specific parameters associated with running. Some gaming systems such as the remote controls for the Nintendo Wii use IMUs to measure motion. Low-cost IMUs have enabled the proliferation of the consumer drone industry. They are also frequently used for sports technology (technique training), and animation applications. They are a competing technology for use in motion capture technology. And an IMU is at the heart of the balancing technology used in the Segway Personal Transporter.

Dr. Madni's visionary leadership and his seminal and pioneering technical contributions have written a major chapter in the history of gyroscopes and MEMS technology, with the invention of the GyroChip®. This inexpensive inertial-measurement sensor was the first such device to be incorporated into automobiles, enabling electronic stability-control (ESC) systems to detect skidding and operate the brakes to prevent rollover accidents. According to the U.S. National Highway Traffic Safety Administration, in the five-year period spanning 2011 to 2015, with ESCs being built into all new cars, the systems saved 7,000 lives in the United States alone. Today, electronic angular-rate sensors are in just about every vehicle—land, air, or sea. And Dr. Madni's effort to miniaturize them and reduce their cost blazed the trail.

# The Elmer A. Sperry Award



# *Elmer A. Sperry, 1860–1930*

After graduating from the Cortland, N.Y. Normal School in 1880, Sperry had an association with Professor Anthony at Cornell, where he helped wire its first generator. From that experience he conceived his initial invention, an improved electrical generator and arc light. He then opened an electric company in Chicago and continued on to invent major improvements in electric mining equipment, locomotives, streetcars and an electric automobile. He developed gyroscopic stabilizers for ships and aircraft, a successful marine gyro-compass and gyro-controlled steering and fire control systems used on Allied warships during World War I. Sperry also developed an aircraft searchlight and the world's first guided missile. His gyroscopic work resulted in the automatic pilot in 1930. The Elmer A. Sperry Award was established in 1955 to encourage progress in transportation engineering.

# The Elmer A. Sperry Award

To commemorate the life and achievements of Elmer Ambrose Sperry, whose genius and perseverance contributed so much to so many types of transportation, the Elmer A. Sperry Award was established by his daughter, Helen (Mrs. Robert Brooke Lea), and his son, Elmer A. Sperry, Jr., in January 1955, the year marking the 25th anniversary of their father's death. Additional gifts from interested individuals and corporations also contribute to the work of the board.

Elmer Sperry's inventions and his activities in many fields of engineering have benefited tremendously all forms of transportation. Land transportation has profited by his pioneer work with the storage battery, his development of one of the first electric automobiles (on which he introduced 4-wheel brakes and self-centering steering), his electric trolley car of improved design (features of its drive and electric braking system are still in use), and his rail flaw detector (which has added an important factor of safety to modern railroading). Sea transportation has been measurably advanced by his gyrocompass (which has freed humans from the uncertainties of the magnetic compass) and by such navigational aids as the course recorder and automatic steering for ships. Air transportation is indebted to him for the airplane gyro-pilot and the other air navigational instruments he and his son, Lawrence, developed together.

The donors of the Elmer A. Sperry Award have stated that its purpose is to encourage progress in the engineering of transportation. Initially, the donors specified that the award recipient should be chosen by a Board of Award representing the four engineering societies in which Elmer A. Sperry was most active:

**American Society of Mechanical Engineers** (of which he was the 48th president)
**American Institute of Electrical Engineers** (of which he was a founder member)
**Society of Automotive Engineers**
**Society of Naval Architects and Marine Engineers**

In 1960, the participating societies were augmented by the addition of the Institute of Aerospace Sciences. In 1962, upon merging with the Institute of Radio Engineers, the American Institute of Electrical Engineers became known as the Institute of Electrical and Electronics Engineers; and in 1963, the Institute of Aerospace Sciences, upon merger with the American Rocket Society, became the American Institute of Aeronautics and Astronautics. In 1990, the American Society of Civil Engineers became the sixth society to become a member of the Elmer A. Sperry Board of Award. In 2006, the Society of Automotive Engineers changed its name to SAE International.

Important discoveries and engineering advances are often the work of a group, and the donors have further specified that the Elmer A. Sperry Award honor the distinguished contributions of groups as well as individuals.

Since they are confident that future contributions will pave the way for changes in the art of transportation equal at least to those already achieved, the donors have requested that the board from time to time review past awards. This will enable the board in the future to be cognizant of new areas of achievement and to invite participation, if it seems desirable, of additional engineering groups representative of new aspects or modes of transportation.

# *The Sperry Secretariat*

The donors have placed the Elmer A. Sperry Award fund in the custody of the American Society of Mechanical Engineers. This organization is empowered to administer the fund, which has been placed in an interest bearing account whose earnings are used to cover the expenses of the board. A secretariat is administered by the ASME, which has generously donated the time of its staff to assist the Sperry Board in its work.

The Elmer A. Sperry Board of Award welcomes suggestions from the transportation industry and the engineering profession for candidates for consideration for this award.

# *Previous Elmer A. Sperry Awards*

***1955*** To ***William Francis Gibbs*** and his Associates for design of the S.S. United States.

***1956*** To ***Donald W. Douglas*** and his Associates for the DC series of air transport planes.

***1957*** To ***Harold L. Hamilton, Richard M. Dilworth*** and ***Eugene W. Kettering*** and Citation to their Associates for developing the diesel-electric locomotive.

***1958*** To ***Ferdinand Porsche*** (in memoriam) and ***Heinz Nordhoff*** and Citation to their Associates for development of the Volkswagen automobile.

***1959*** To ***Sir Geoffrey de Havilland, Major Frank B. Halford*** (in memoriam) and ***Charles C. Walker*** and Citation to their Associates for the first jet-powered passenger aircraft and engines.

***1960*** To ***Frederick Darcy Braddon*** and Citation to the Engineering Department of the Marine Division of the Sperry Gyroscope Company, for the three-axis gyroscopic navigational reference.

***1961*** To ***Robert Gilmore LeTourneau*** and Citation to the Research and Development Division, Firestone Tire and Rubber Company, for high speed, large capacity, earth moving equipment and giant size tires.

***1962*** To ***Lloyd J. Hibbard*** for applying the ignitron rectifier to railroad motive power.

***1963*** To ***Earl A. Thompson*** and Citations to ***Ralph F. Beck, William L. Carnegie, Walter B. Herndon, Oliver K. Kelley*** and ***Maurice S. Rosenberger*** for design and development of the first notably successful automatic automobile transmission.

***1964*** To ***Igor Sikorsky*** and ***Michael E. Gluhareff*** and Citation to the Engineering Department of the Sikorsky Aircraft Division, United Aircraft Corporation, for the invention and development of the high-lift helicopter leading to the Skycrane.

***1965*** To ***Maynard L. Pennell, Richard L. Rouzie, John E. Steiner, William H. Cook*** and ***Richard L. Loesch, Jr.*** and Citation to the Commercial Airplane Division, The Boeing Company, for the concept, design, development, production and practical application of the family of jet transports exemplified by the 707, 720 and 727.

***1966*** To ***Hideo Shima, Matsutaro Fuji*** and ***Shigenari Oishi*** and Citation to the Japanese National Railways for the design, development and construction of the New Tokaido Line with its many important advances in railroad transportation.

*1967* To ***Edward R. Dye*** (in memoriam), ***Hugh DeHaven,*** and ***Robert A. Wolf*** for their contribution to automotive occupant safety and Citation to the research engineers of Cornell Aeronautical Laboratory and the staff of the Crash Injury Research projects of the Cornell University Medical College.

*1968* To ***Christopher S. Cockerell*** and ***Richard Stanton-Jones*** and Citation to the men and women of the British Hovercraft Corporation for the design, construction and application of a family of commercially useful Hovercraft.

*1969* To ***Douglas C. MacMillan, M. Nielsen*** and ***Edward L. Teale, Jr.*** and Citations to ***Wilbert C. Gumprich*** and the organizations of George G. Sharp, Inc., Babcock and Wilcox Company, and the New York Shipbuilding Corporation for the design and construction of the N.S. Savannah, the first nuclear ship with reactor, to be operated for commercial purposes.

*1970* To ***Charles Stark Draper*** and Citations to the personnel of the MIT Instrumentation Laboratories, Delco Electronics Division, General Motors Corporation, and Aero Products Division, Litton Systems, for the successful application of inertial guidance systems to commercial air navigation.

*1971* To ***Sedgwick N. Wight*** (in memoriam) and ***George W. Baughman*** and Citations to ***William D. Hailes, Lloyd V. Lewis, Clarence S. Snavely, Herbert A. Wallace,*** and the employees of General Railway Signal Company, and the Signal & Communications Division, Westinghouse Air Brake Company, for development of Centralized Traffic Control on railways.

*1972* To ***Leonard S. Hobbs*** and ***Perry W. Pratt*** and the dedicated engineers of the Pratt & Whitney Aircraft Division of United Aircraft Corporation for the design and development of the JT-3 turbo jet engine.

*1975* To ***Jerome L. Goldman, Frank A. Nemec*** and ***James J. Henry*** and Citations to the naval architects and marine engineers of Friede and Goldman, Inc. and Alfred W. Schwendtner for revolutionizing marine cargo transport through the design and development of barge carrying cargo vessels.

*1977* To ***Clifford L. Eastburg*** and ***Harley J. Urbach*** and Citations to the Railroad Engineering Department of The Timken Company for the development, subsequent improvement, manufacture and application of tapered roller bearings for railroad and industrial uses.

*1978* To ***Robert Puiseux*** and Citations to the employees of the Manufacture Française des Pneumatiques Michelin for the development of the radial tire.

*1979* To ***Leslie J. Clark*** for his contributions to the conceptualization and initial development of the sea transport of liquefied natural gas.

*1980* To ***William M. Allen, Malcolm T. Stamper, Joseph F. Sutter*** and ***Everette L. Webb*** and Citations to the employees of Boeing Commercial Airplane Company for their leadership in the development, successful introduction & acceptance of wide-body jet aircraft for commercial service.

*1981* To ***Edward J. Wasp*** for his contributions toward the development and application of long distance pipeline slurry transport of coal and other finely divided solid materials.

*1982* To ***Jörg Brenneisen, Ehrhard Futterlieb, Joachim Körber, Edmund Müller, G. Reiner Nill, Manfred Schulz, Herbert Stemmler*** and ***Werner Teich*** for their contributions to the development and application of solid state adjustable frequency induction motor transmission to diesel and electric motor locomotives in heavy freight and passenger service.

*1983* To ***Sir George Edwards,*** OM, CBE, FRS; ***General Henri Ziegler,*** CBE, CVO, LM, CG; ***Sir Stanley Hooker,*** CBE, FRS (in memoriam); ***Sir Archibald Russell,*** CBE, FRS; and ***M. André Turcat***, L d'H, CG; commemorating their outstanding international contributions to the successful introduction and subsequent safe service of commercial supersonic aircraft exemplified by the Concorde.

*1984* To ***Frederick Aronowitz, Joseph E. Killpatrick, Warren M. Macek*** and ***Theodore J. Podgorski*** for the conception of the principles and development of a ring laser gyroscopic system incorporated in a new series of commercial jet liners and other vehicles.

*1985* To ***Richard K. Quinn, Carlton E. Tripp,*** and ***George H. Plude*** for the inclusion of numerous innovative design concepts and an unusual method of construction of the first 1,000-foot self-unloading Great Lakes vessel, the M/V Stewart J. Cort.

*1986* To ***George W. Jeffs, Dr. William R. Lucas, Dr. George E. Mueller, George F. Page, Robert F. Thompson*** and ***John F. Yardley*** for significant personal and technical contributions to the concept and achievement of a reusable Space Transportation System.

*1987* To ***Harry R. Wetenkamp*** for his contributions toward the development and application of curved plate railroad wheel designs.

*1988* To ***J. A. Pierce*** for his pioneering work & technical achievements that led to the establishment of the OMEGA Navigation System, the world's first ground-based global navigation system.

*1989* To ***Harold E. Froehlich, Charles B. Momsen, Jr.,*** and ***Allyn C. Vine*** for the invention, development and deployment of the deep-diving submarine, Alvin.

***1990*** To ***Claud M. Davis, Richard B. Hanrahan, John F. Keeley,*** and ***James H. Mollenauer*** for the conception, design, development and delivery of the Federal Aviation Administration enroute air traffic control system.

***1991*** To ***Malcom Purcell McLean*** for his pioneering work in revolutionizing cargo transportation through the introduction of intermodal containerization.

***1992*** To ***Daniel K. Ludwig*** (in memoriam) for the design, development and construction of the modern supertanker.

***1993*** To ***Heinz Leiber, Wolf-Dieter Jonner*** and ***Hans Jürgen Gerstenmeier*** and Citations to their colleagues in Robert Bosch GmbH for their conception, design and development of the Anti-lock Braking System for application in motor vehicles.

***1994*** To ***Russell G. Altherr*** for the conception, design and development of a slackfree connector for articulated railroad freight cars.

***1996*** To ***Thomas G. Butler*** (in memoriam) and ***Richard H. MacNeal*** for the development and mechanization of NASA Structural Analysis (NASTRAN) for widespread utilization as a working tool for finite element computation.

***1998*** To ***Bradford W. Parkinson*** for leading the concept development and early implementation of the Global Positioning System (GPS) as a breakthrough technology for the precise navigation and position determination of transportation vehicles.

***2000*** To those individuals who, working at the French National Railroad (SNCF) and ALSTOM between 1965 and 1981, played leading roles in conceiving and creating the initial TGV High Speed Rail System, which opened a new era in passenger rail transportation in France and beyond.

***2002*** To ***Raymond Pearlson*** for the invention, development and worldwide implementation of a new system for lifting ships out of the water for repair and for launching new ship construction. The simplicity of this concept has allowed both large and small nations to benefit by increasing the efficiency and reducing the cost of shipyard operations.

***2004*** To ***Josef Becker*** for the invention, development, and worldwide implementation of the Rudderpropeller, a combined propulsion and steering system, which converts engine power into optimum thrust. As the underwater components can be steered through 360 degrees, the full propulsive power can also be used for maneuvering and dynamic positioning of the ship.

**2005** To ***Victor Wouk*** for his visionary approach to developing gasoline engine-electric motor hybrid-drive systems for automobiles and his distinguished engineering achievements in the related technologies of small, lightweight, and highly efficient electric power supplies and batteries.

**2006** To ***Antony Jameson*** in recognition of his seminal and continuing contributions to the modern design of aircraft through his numerous algorithmic innovations and through the development of the FLO, SYN, and AIRPLANE series of computational fluid dynamics codes.

**2007** To ***Robert Cook, Pam Phillips, James White,*** and ***Peter Mahal*** for their seminal work and continuing contributions to aviation through the development of the Engineered Material Arresting System (EMAS) and its installation at many airports.

**2008** To ***Thomas P. Stafford, Glynn S. Lunney, Aleksei A. Leonov,*** and ***Konstantin D. Bushuyev*** as leaders of the Apollo-Soyuz mission and as representatives of the Apollo-Soyuz docking interface design team: in recognition of seminal work on spacecraft docking technology and international docking interface methodology.

**2009** To ***Boris Popov*** for the development of the ballistic parachute system allowing the safe descent of disabled aircraft.

**2010** To ***Takuma Yamaguchi*** for his invention of the ARTICOUPLE, a versatile scheme to connect tugs and barges to form an articulated tug and barge, AT/B, waterborne transportation system operational in rough seas. His initial design has led to the development of many different types of couplers that have resulted in the worldwide use of connected tug and barges for inland waterways, coastal waters and open ocean operation.

**2011** To ***Zigmund Bluvband*** and ***Herbert Hecht*** for development and implementation of novel methods and tools for the advancement of dependability and safety in transportation.

**2012** To ***John Ward Duckett*** for the development of the Quickchange Movable Barrier.

**2013** To ***C. Don Bateman*** for the development of the ground proximity warning system for aircraft.

**2014** To ***Bruce G. Collipp, Alden J. Laborde,*** and ***Alan C. McClure*** for the design and development of the semi-submersible platform.

**2015** To ***Michael K. Sinnett*** and the ***The Boeing Company 787-8 Development Team*** for pioneering engineering advances including lightweight composite wing and monolithic fuselage construction that have led to significant improvements in fuel efficiency, reduced carbon emission, reduced maintenance costs and increased passenger comfort.

*2016* To ***Harri Kulovaara*** for leadership in the engineering and design of the most advanced and trend setting cruise ships, ships that integrated "quantum jumps" in cruise ship safety, operational efficiency, features to suit passengers of "all ages," and diverse onboard activities. And, for being the driving force behind the Cruise Ship Safety Forum that brings together owners, builders and classification societies to ensure specific targeted areas of safety improvement are developed and implemented.

*2017* To ***Bruno Murari*** for his seminal work and leadership in the development of Power Integrated Circuits for the transportation industry.

*2018* To ***Panama Canal Authority*** for planning and successfully managing a program to undertake and complete a massive infrastructure project, he "Expansion of the Panama Canal" that required the integration of the most demanding multidisciplinary engineering endeavors.This expansion markedly enhances cargo trade and maritime transportation, with profound economic impacts on a worldwide scale.

*2019* To ***George A. (Sandy) Thomson*** in recognition of leading the innovation for water-lubricated main propulsion shaft bearings for marine transport through the application of polymeric compounds.

*2020* To ***Dominique Roddier, Christian Cermelli, and Alexia Aubault*** for the development of WindFloat, a floating foundation for offshore wind turbines.

*2021* To ***Michimasa Fujino*** in recognition of his singular achievement of research and development of new technologies for business aviation including the Over-the-Wing Engine Mount and Natural Laminar Flow airfoil, and the introduction to the market of commercial aircraft based on these technologies through the formation of HondaJet.

# *The 2022 Elmer A. Sperry Board of Award*

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*Joseph Englot*
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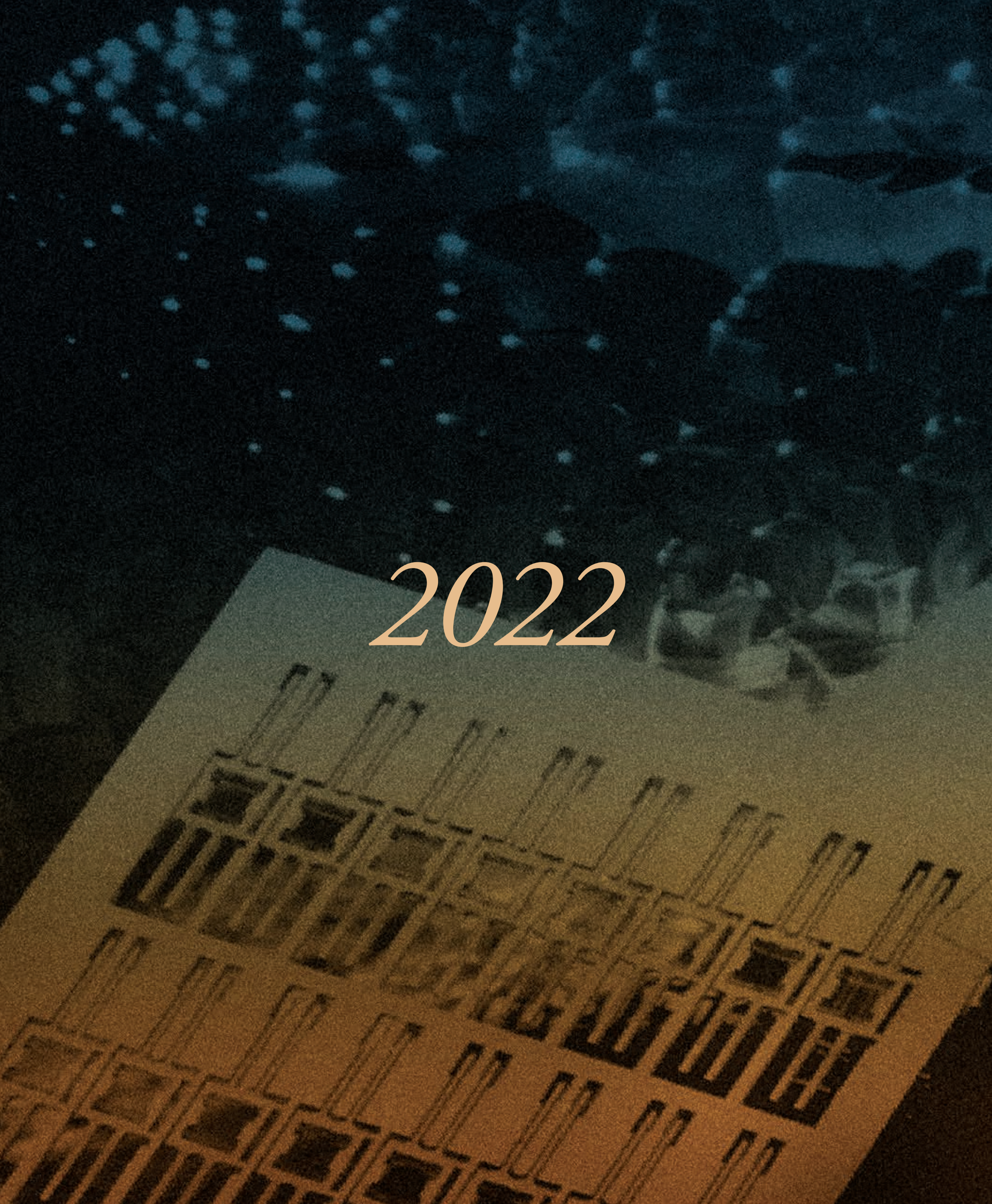
2022