ENABLING THE NEXT GENERATION OF MEMS TECHNOLOGY

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HISTORICAL PERSPECTIVE

As the fourth decade of MEMS research and development begins, a few important questions become of interest namely where are the technology transition opportunities, what lessons can be learned from previous R&D investments, and what are the new areas of research investment. Over the years, DARPA has invested in MEMS technology at the exploration phase of the technology and more recently into application specific areas where MEMS technology was explored as a possible solution. A review of the lessons learned from these investments and how they have and are impacting current DARPA programs will be discussed as a gauge of where the new investment opportunities may push the technology.

The early days of the MEMS investments focused on novel fabrication processes with a focus on novel sensor and actuator modalities. This transitioned into programs with specific device as well as system metrics but still plenty of investment in novel processes. Then, there was a shift toward more system driven performance metrics combined with a reduction in the generic investing in MEMS for the sake of MEMS. To address a growing gap in the fundamental challenges affecting several MEMS technologies, a joint government and industry collaboration was explored through the N/MEMS S&T Fundamentals Program to tackle the most pressing of these fundamental challenges. Currently, we are back to a more system driven program model where we can take advantage of the previous investments and strategically invest in foundational research in targeted areas of interest.

CURRENT INVESTMENTS

Recent and current areas of investment in MEMS technology have been in adaptable RF technologies, GPS denied position navigation and timing, and low power sensors. The initial investments across a broad area of technologies have resulted in highlighted successes that include phase change materials and switches, inertial sensors, low power thermal imaging, and lithium niobate based components for low power RF receivers to name a few. Within the Adaptable RF Technology (ART) program portfolio, several programs were able to leverage earlier investments in resistive phase change materials [1, 2] to realize high performance RF switches [3, 4]. Through continued investment as part of the RF FPGA program, these switches are making their way into commercial production.

With the challenges of maintaining assured and trusted position, navigation, and timing (PNT) of elevated importance across the Department of Defense, DARPA has continued its investments in advanced inertial sensors. The most recent program, Precise Robust Inertial Guidance for Munitions (PRIGM), is a broad attempt looking at novel and foundational technologies as well as maturing previous investments to get miniature navigation grade inertial measurement units (IMUs) into the DoD by early 2020.

PRIGM comprises two focus areas: development of a navigation-grade inertial measurement unit (NGIMU) based on micro-electromechanical systems (MEMS) platforms, and basic research of advanced inertial micro sensor (AIMS) technologies for future gun-hard, high-bandwidth, high-dynamic-range, GPS-free navigation.

The PRIGM:NGIMU focus area will develop a MEMS-based navigation-grade IMU that has a mechanical/electronic interface

compatible with drop-in replacement for existing tactical-grade IMUs on legacy DoD platforms. The results from Phase 1 of this effort have shown individual accelerometers exceeding the navigation grade specifications with the individual gyroscope performance close to meeting the targeted navigation grade specifications. The early and continued engagement of the DoD Service Labs has been essential in evaluating the early performance, providing guidance and technical feedback for surviving the harsh munitions environments, and to facilitate rapid transition of NGIMU technology.

PRIGM:AIMS is a basic research program exploring alternative technologies and modalities for inertial sensing, including photonic and MEMS-photonic integration, as well as novel architectures and materials systems. The principal objective of PRIGM:AIMS is to identify promising candidate technologies for further development as high-performance inertial sensors for long-duration missions and deployment in extreme environments. Examples from the current program include investments in MEMS fabricated glass structures [5], a “no proof mass” accelerometer using atomic layer deposited materials as both heaters and thermometers as a thermal bubble inspired accelerometer [6], surface acoustic wave gyroscope [7], and micromachined photonic based gyroscopes [8, 9].

The Signal Processing at RF (SPAR) program aims to mitigate both externally generated and self-generated interfering signals (from transmitters within a shared network or RF systems on a common platform, for example) of known and unknown characteristics. SPAR’s engineering challenges center on designing, building and demonstrating RF signal-processing components that can remove in-band interferers from the desired receive signal at the RF front end—that is, before the signals reach the receiver electronics, while maintaining the required low noise figure and high linearity required to operate directly at the antenna. SPAR is pursuing both micromechanical and integrated circuit based approaches to realize miniature correlator and circulator components for in-band interference suppression. Microacoustic correlators [10] being developed under the program have the advantages of high linearity (IIP3 > 30 dBm) and ease of synchronization but have more limited coding flexibility (4 vs. 1000’s of codes), bandwidth (25 MHz vs > 100 MHz) and processing gain (12 dB vs 27 dB) when compared to the integrated circuit based efforts. Similar benefits to mechanical approaches, especially high linearity, are seen for the micromechanical based circulator efforts. All told, SPAR aims to enhance radio and radar operation in increasingly congested and contested RF environments through innovation of a new class of low loss RF signal processing components.

Microsystem investments have long been a core component reflecting the DoD’s desire to reduce the size, weight and power of sensing, processing, and communications systems. The Near Zero Power RF and Sensor Operations (N-ZERO) program is pursuing a revolutionary leap in the sensing and processing that can be achieved over long durations (i.e. many years) from a miniature battery or without a battery at all. The program is developing the technological foundations for persistent, event-driven sensing capabilities in which sensors can remain dormant, with near-zero power consumption, until awakened by an external trigger or stimulus. To break the paradigm of using active power to sense

infrequent, high-consequence events, N-ZERO is developing a class of sensors that exploit the energy in the signal signature itself to detect and discriminate the events of interest while rejecting noise and interference. The N-ZERO program has had numerous successes across several technology areas. Focusing on the MEMS related technologies, the successes include the ability to detect, process and classify IR [11], acoustic [12] and inertial [13] spectral signatures while in some cases consuming zero stand-by power. The ability to sense and process information over long durations in a miniature, inexpensive form factor is critical for future internet-of-things (IoT) applications in industrial and infrastructure health monitoring, agriculture and security.

NEXT GENERATION OF MEMS

Before discussing what may be next for MEMS technology, it is worthwhile looking inward at some of the most recent hard lessons that have been learned. One of the key challenges that has arisen with several of the current programs is how to innovate faster within very custom fabrication processes that are sensitive to process stability and reproducibility. Compared to the integrated circuit community, where design innovations can occur twice or three plus times a year, the MEMS designer is generally getting one design cycle per year. Furthermore, the extremely custom processes that are being utilized have risks associated with single equipment, personnel, or facility failures. Additionally, these unique processes generally are not considering the requirements of transitioning from a university or small R&D facility to a more production proven facility and its processing constraints.

Related to this challenge, the questions being pondered now are the following: How can the MEMS community innovate faster with higher levels of integration and tighter control on our fabrication processes? Can the MEMS community leverage the way that the solid state electronics community innovates within the semiconductor and integrated circuit industry? Is there a path to leveraging or accessing the production proven processes currently supplying commercial MEMS devices and components? Can higher levels of device yields, reproducibility, and integration enable novel arrayed device architectures? What is the best model for handling and enabling access to intellectual property and process design kits for the MEMS community? The answer to these questions will begin to shape a path forward to ultimately realize a more flexible, rapidly innovative MEMS community capable of addressing technology gaps with a faster time to market and product insertion.

In addition, there is a continued interest in exploring those foundational technologies that can provide groundbreaking solutions for national security. Whether new material breakthroughs, innovation in material processing and patterning techniques, novel design architectures, or innovative integration strategies, there will be continued interest especially if it pushes the art of the possible and further ensures the leading edge of technology for national security.

WORD COUNT: 1435

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