THE IMPACT OF EMERGING MEMS-BASED MICROSYSTEMS ON US DEFENSE APPLICATIONS

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ABSTRACT

This paper examines the impact of inserting Micro-Electro-Mechanical Systems (MEMS) into US defense applications. As specific examples, the impacts of micro Inertial Measurement Units (IMUs), radio frequency MEMS (RF MEMS), and Micro-Opto-Electro-Mechanical Systems (MOEMS) to provide integrated intelligence, communication, and control to the defense infrastructure with increased affordability, functionality, and performance are highlighted.

INTRODUCTION

In the post-cold war environment, a key mission of our defense is to combat emerging threats (e.g., threats from biological and chemical attacks). In such a climate, the insertion of innovative technologies that integrates sensing, communication, actuation, and control functions into our defense infrastructure (e.g., using smart weapons) will be key to meeting this defense obligation in the 21st century. The rapidly emerging field of MEMS shows special promise of being a technology capable of providing those functions [1].

An outgrowth of the electronic integrated circuit (IC) industry, MEMS are micron-sized systems that incorporates mechanical components that perform sensing and actuation functions with traditional microelectronics-based data processing and control systems. This results in system's whose "attributes" include the abilities to sense their surroundings, process the information gathered from this environment, compute a course of action, and thus intelligently responding to the stimuli from their environment. MEMS devices are usually batch fabricated using standard silicon IC processing tools and techniques, and thus, they yield systems which are low cost, lightweight, small, low power, and reliable. These attributes allow MEMS to be used in defense applications where they would provide low cost, high-end functionality, intelligence, communication, and control to our defense infrastructure.

This paper provides an overview of the impact of inserting MEMS technologies into US defense applications. As specific examples, the impacts of micro IMUs, RF MEMS, and MOEMS are highlighted.

GENERAL IMPACT OF MEMS ON DEFENSE APPPLICATIONS

In general, MEMS are batch fabricated using equipment, processes, and facilities matching those of existing silicon IC manufacturers. This facilitates large volume production of completely self-assembled MEMS-based systems. The combination of leveraging the existing IC infrastructure and exploiting large volume production leads to low manufacturing costs typical of those achieved by manufacturers of silicon ICs. This will lead to significant reductions defense procurement costs especially in cases where defense systems they are expected to be deployed in significant numbers.

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Furthermore, by reducing the number of assembled components in a system and eliminating the bond wires connecting electrical to mechanical components, surface micromachining of MEMS devices provides significantly improved systems reliability.

The fact that MEMS-based systems are lightweight will translate to decreases in military deployment payloads and increases in mobility for military personnel and platforms. Similarly, their small size means that many of these devices can be integrated to increase the level of system intelligence available to military personnel and platforms. Also, the fact that MEMS-based systems are low-power means that personnel and systems incorporating these devices will be able to operate for extended mission periods without power re-supply. Finally, since MEMS-based systems are reliable, the likelihood that system failures would degrade the military's ability to perform its mission will be reduced.

The aforementioned discussion of the attributes of MEMS indicate the impact of their insertion into defense applications will include the delivery of low-cost, high-end functionality, intelligence, flexibility, and mobility to our defense infrastructure.

SPECIFIC APPLICATIONS AND THEIR IMPACTS

In recent years, MEMS have enabled the commercial development of MEMS-based accelerometers for automotive applications and digital mirror devices (DMD) for projection displays [1]. With the continued maturation of MEMS, one area where MEMS will play a vital role in defense applications is for inertial measurements. The insertion of very small, lightweight, low cost, MEMS-based IMUs will enable the proliferation of GPS-aided systems for application in smart, precision-guided munitions and personal navigation gear where they would provide precision strike capabilities. For example, UC Berkeley and Sandia National Laboratories (SNL) have demonstrated the first 6-axis micro-IMU prototype [2] fabricated in Sandia's Integrated MEMS (IMEMS) technology. The system shown in Figure 1 consists of two vibratory gyroscopes (XY-axis and Z–axis gyros) and a force-feedback 3-axis accelerometer monolithically integrated with the controlling electronics on the same chip. This early IMU prototype provides the technology foundation for the development of small, lightweight, and inexpensive micro-IMUs for future defense applications.

The impact of the insertion of MEMS-based IMUs into defense applications is expected to translate directly into increased tactical and strategic advantages to our military through precision strike capabilities and extend the operational performance range for our defense platforms.

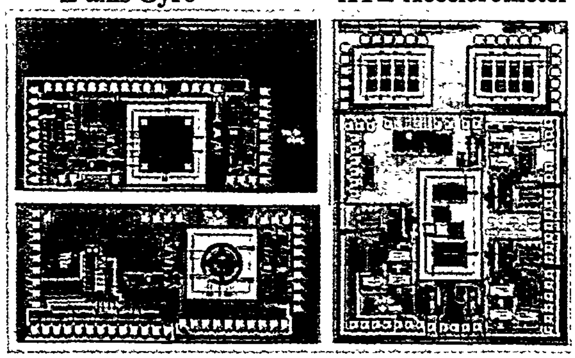

Figure 1. Monolithically integrated 6-axis IMU

Another area where MEMS can play a vital role in defense applications is RF signal processing. Today, researchers have produced many RF MEMS components such as micro-RF oscillators and switches [3]. These miniaturized components require low power for operation, have extremely high quality factors (Q), exhibit high phase stability, and show lower insertion loss than their existing bulky, off chip counterparts (e.g., ceramic based SAW filters) used in current communication systems. In addition, since RF MEMS components are silicon-based, most components can be monolithically integrated on a single chip. For example, at SNL, collaboration with the researchers at BSAC has demonstrated a stable, low noise, 1MHz oscillator prototype [4]. The device shown in Figure 2 consists of a vibrating tuning fork in a positive feedback loop with a transimpedance amplifier. The 300-micron by300-micron device is monolithically integrated with the controlling electronics on a single chip. As another example, researchers at the University of Michigan [3] have proposed the novel wireless architecture shown in Figure 3 where the typical bulky off-chip components are replaced with on-chip MEMS components. Such endeavors are leading to the ultimate miniaturization of communication systems. These RF MEMS devices can be integrated into defense applications where there is a need for small, mobile, low-power, wireless communication networks and radar. For example, they could be used to replace bulky radar antennae used on military aircraft with small, phase-array systems , as "wrist-watch-type" micro-radios to be used by troops for secure wireless communication, or as sensors for monitoring the deployment of military resources in the battlefield.

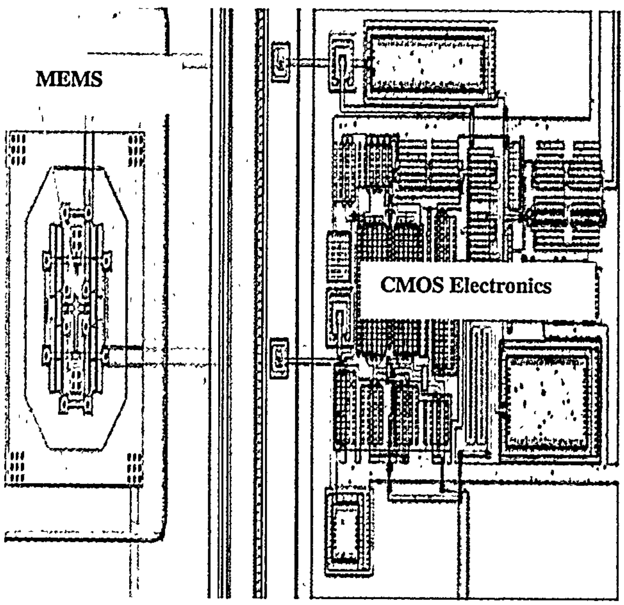

Figure 2. 1 MHz Oscillator

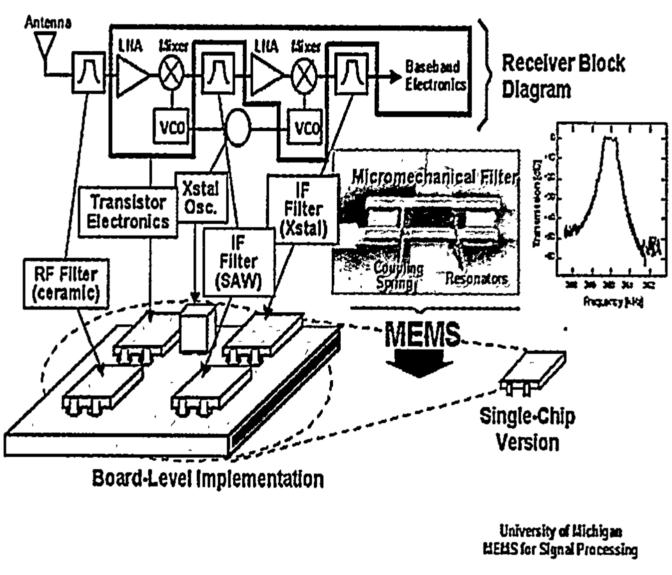

Figure 3. Novel MEMS wireless architecture.

The impact of such RF MEMS-based systems on defense will be the provision of operational superiority and mobile communication and control over military assets through integrated information flow to and from the battlefield.

The final class of MEMS based systems that will be discussed for insertion into defense applications is MOEMS. MOEMS are optical devices (e.g., micro-mirrors) used for the generation, manipulation, guidance, and detection of light for information processing. Defense applications areas for MOEMS include surveillance, systems safety, data storage, and optical communication. As an example, at SNL, researchers have built a prototype microscopic safety device, pictured in Figure 4 in the SUMMIT technology [1].

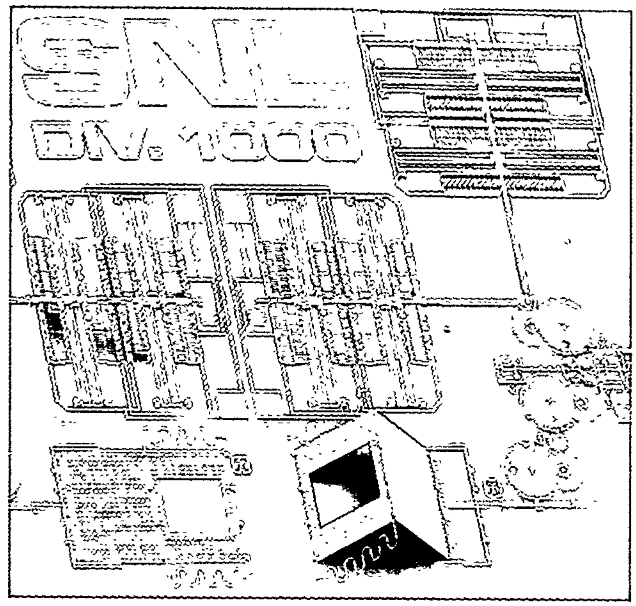

Figure 4. MOEM safety system

This system utilizes a micro-mechanical pin-in-maze discrininator assembly to prevent positioning an optical shutter until a specific sequence of events occurs. The unlocking sequence consists of first entering a multi-bit code to properly guide a pin through a maze. If the wrong sequence is entered, an anti-reverse mechanism will cause the system to be safely locked. With the correct code, the maze is successfully traversed and two interlocking gears are coupled which then power a gear train that positions two mirrors. The mirrors pass an optical signal to electrical circuitry that then activates the system.

The insertion of MOEMS into defense applications is expected provide enhanced levels of surveillance capability, safety, and security to our defense infrastructure.

SUMMARY AND CONCLUSIONS

This paper discussed the impact of inserting MEMS technologies into US defense applications. As specific examples, the impact of micro IMUs, RF MEMS, and MOEMS were highlighted.

The discussion revealed that the primary impact of the insertion of MEMS technologies into US defense systems will be the provision of low cost, high-end functionality, intelligence, mobility, and control to our defense infrastructure. For example, inserting MEMS-based IMUs into defense applications is expected increase tactical and strategic advantages to our military through precision strike capabilities and extend the operational performance of defense platforms. Similarly, RF MEMS systems will provide operational superiority through flexible, mobile communication command and control of military assets. Finally, MOEMS are expected to provide enhanced levels of surveillance capabilities, safety, and security to our defense infrastructure. These capabilities are clear indicators that MEMS will be, increasingly, a product differentiator in meeting our defense mission in the 21st century.

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