Low Cost, High G, High Accuracy, Micro Electro-Mechanical Systems (MEMS), Inertial Measurements Unit (IMU) Program

Albert Warnasch
U.S. Army TACOM-ARDEC
ATTN: AMSTA-AR-FS
BLDG 94
Picatinny Arsenal, NJ 07806-5000
Phone: 973-724-7282
FAX: 973-724-4135

Dr. Albert Killen
U.S. AMCOM AMRDEC
ATTN: AMSAM-RD-MG-SD
Building 5400
Redstone Arsenal, AL 35898-5270
DSN: 645-8171
Phone: 256-955-8171

Precision Guided Munitions (PGMs) are critical to the Maneuver Battalion Commander's success on the future, rapidly deployed, battlefields. These PGMs will provide an increase in lethality, significantly improve survivability, reduce collateral damage, minimize non-combatant casualties, and decrease the logistics burden or increase the number of kills from the standard logistics load. PGMs all require inertial measurement sensors embodied in an IMU. Up to now they have been large, expensive, and could not readily survive the high G launch environments. MEMS technology provides inherent cost savings and size reduction and is ideal for application to navigation and control systems for small missiles and munitions. Using MEMS technology, gyroscopes, accelerometers and control electronics can readily be integrated to form a tightly packaged, low-cost, extremely small, high performance IMU suitable for munition, missile, and personnel guidance as well as other applications. This paper will describe the current Army development underway and it's partnering with industry to achieve the needed requirements. The Program goal is to survive a 20,000g gun launch and meet a 1°/hr, ½ millig performance capability. The MEMS IMUs will significantly reduce the cost of precision-delivered missiles & munitions, as well as expand precision delivery capability to artillery ammunitions, and thus reduce the number of required rounds by more than 30% while meeting roughly 90% of the tactical weapons fleet navigational requirements.

For the Army's and Navy's guided munitions and missile war-fighting concepts to be successful, they require improvements in Fire Support (FS) capabilities for both close range and over-the-horizon missions. Many DoD Programs are currently striving to meet this need. A goal for all DoD Programs is to provide a low-cost, highly accurate, near term solution. All extended range munitions require an inertial navigation system to achieve required delivery accuracy. A critical component of this system is the IMU. Today, the IMU is costly; it cannot survive the high-G setback acceleration experienced by projectiles; it cannot provide tactical accuracies; and it cannot be produced in quantity. Accordingly, the Army is focusing on development of a common MEMS configured IMU product that meets the requirements of 90% of all DoD guided tactical weapons.

This High-G, High Accuracy IMU PROGRAM was specifically designed to capitalize on and develop technologies for high quality, affordable fabrication of MEMS-based IMUs in order to directly address the Army's concern over the high cost of traditional IMU systems, such as spinning mass, ring laser, and fiber optic gyroscope-based systems. Although the specific application requirement varies among gun-fired munitions, which need high-G capability, and missiles, which need high accuracy, the same processing and manufacturing technologies are necessary for high yield, low-cost MEMS devices for both weapon systems. The program will be absolutely essential in transitioning the recent promising developments in processing, manufacturing, packaging, modeling, and analysis technologies to the missile and munitions system developers. The performance advantages of MEMS devices (e.g., light weight, low power, small volume) are numerous. Ensuring the cost effective production of MEMS-based IMUs will be very important for significant implementation in future DoD systems. Processing and manufacturing contribute greatly to the total delivered cost of MEMS device. Design is the first variable with a significant impact on affordability. It has been shown that over 60% of the life cycle cost is already built in by low rate initial production (LRIP). Both trial and error and past experience in design and processing are typically costly and become even more costly with complex geometries and evolving design criteria. Accordingly, this program emphasizes designing for manufacturability from the first phase through the entire Program. This program has, as a primary objective, a cumulative cost reduction of 75% compared to current conventional IMUs.

The first objective of this Program is to design, develop and produce an IMU that will survive launch accelerations of > 20,000 Gs, have an accuracy of < 0.5 deg/hr over the launch environment, have a volume of < 2 cubic inches, and meet the Government cost expectation for the IMU of < $1200. This goal will evolve through the three Program phases. The design and manufacturing technologies concurrently developed and pursued in Phases 1 and 2 shall directly evolve into the ultimate Phase 3 IMU product. The second objective is to design, develop and produce an IMU deeply coupled or deeply integrated (DI) within a Selective Availability and Anti-Spoofing Module (SAASM) Global Positioning System (GPS) military receiver with anti-jam (AJ) capability. The resultant DI Guidance and Navigation Unit (GNU) will be executed as an option to the basic three-phase Program. Figure 1 summarizes High-G MEMs IMU Program features.

In addition to the baseline IMU and DI-GNU design and development, a major concurrent effort is required in the areas of production processes, manufacturability and manufacturing technology (MANTECH). Here, the general areas of interest are efforts to minimize the major manufacturing cost drivers. These include but are not limited to: electronic integration; process consolidation and automation; wafer level processes; sensor, package and IMU sensor alignment; packaging enhancements and automation; automation of in-process and final testing; and innovative business planning. Other areas of interest include but are not limited to: development or refinement of manufacturing processes to reduce the cost of IMUs; management tools/techniques to determine the effectiveness of current cost drivers; development of cost reduction/yield improvement efforts; fabrication of test hardware; and execution of a Design of Experiment (DoE) plan(s).

A manufacturing goal of this program is to develop multiple production sources for the MEMS IMU that will reduce costs through Economy of Scale (EoS). A second manufacturing goal of this program is to develop multiple production sources for the DI-GNU that will reduce costs through EoS.

Phase 1 of this program will develop and manufacture prototype MEMS IMUs with < 75 deg/hr required accuracy over the launch environment, > 10,000 Gs survivability in < 8 cubic inches. The contractors will determine the initial manufacturing and process improvements and develop and/or enhance the equipment/processes to improve MEMS IMU manufacturability and testing to reduce cost. Phase 1 is an 18-month effort that delivers 8 pre-production units to the Government for test and evaluation. Phase 2 of this Program will develop and manufacture prototype MEMS IMUs with < 10 deg/hr desired (< 20 deg/hr required) accuracy over the launch environment, > 20,000 Gs survivability in < 4 cubic inches. Phase 2 is an 18-month effort that delivers 12 pre-production units to the Government for test and evaluation. Phase 3 of this Program will develop and manufacture prototype MEMS IMUs with < 0.5 deg/hr desired (< 1.0 deg/hr required) accuracy over the launch environment, > 20,000 Gs survivability in < 2 cubic inches. Phase 3 is a 24-month effort that delivers 72 pre-production units to the Government for test and evaluation. The Government's cost expectation for the IMU in production quantities is < $1200.