

A Modular Approach to Hardened Subminiature Telemetry and Sensor System (HSTSS) Development

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ABSTRACT

In the past, typical telemetry systems for munitions and small missiles have often comprised adaptations of monolithic components originally conceived for aircraft or large missile applications. Programs have developed expensive monolithic systems to meet the needs of specific programs, but they often require extensive redesign for use by other potential users. The tri-service HSTSS Integrated Product Team (IPT) determined that a monolithic “one size fits all” approach has technical and fiscal risks. Thus, a modular approach to system development has been adopted. The HSTSS IPT is flight qualifying commercial microelectronic products designed for environments similar to that of munition interiors, and is developing microelectronic components required to complete a subminiature system. HSTSS components can then be integrated to support the form factor and measurement needs of any given user. In addition to offering a flexible system to the user, the HSTSS lends itself to upgradability (modernization through spares).

KEY WORDS

HSTSS, module, component, flexible system, chipsets, MEMS, DAC, S-Band transmitter, MCM

INTRODUCTION

Government munition developers and test ranges require on-board instrumentation systems to gather data, ascertain, and verify munition performance characteristics. In the past, few options were available to determine the internal characteristics of a weapon system under test, and the resulting failure analysis was often a random, trial and error process.

HSTSS is to provide telemetry capability in the harsh space-limited environments encountered within munitions, and is intended for use in artillery, direct fire, medium caliber and small missile programs. The system provides test data that has been unavailable or difficult to attain due to the inability of technologies to fit, survive, and operate within functioning test articles. HSTSS is a tri-service program that has fostered and promoted partnering between the US Government, Contractors and Foreign Military Test Activities.

Installed on weapon systems under test, HSTSS component suites will comprise rugged, modular, subminiature instrumentation system components to acquire flight performance and system status data, and telemeter the data to a ground receiver station in support of range test and evaluation activities. HSTSS components may be integrated to support the form factor and measurement needs of any given user. While offering a flexible system to the user, the HSTSS can be upgraded, and thus will avoid obsolescence. System components are currently being developed and validated for use in HSTSS systems. The tri-service HSTSS IPT has determined that a monolithic “one size fits all” approach has technical and fiscal risks. Thus, a modular approach to system development has been adopted. The HSTSS IPT is flight qualifying commercial microelectronic products designed for environments similar to that of munition interiors, and is developing microelectronic components required to complete a subminiature system.

DETERMINING AND MEETING USER NEEDS

There are multiple HSTSS IPTs with crossed membership chartered with the task of successful communication between user and developer. The tri-service user community supported by HSTSS is broad and dynamic, requiring a variety of measurement system capabilities. For example, indirect fire munitions (U.S. Navy & U.S. Army) may incur launch shocks of 30,000 g's and spin up to 350 rps, followed by a non-dynamic trajectory. Small missiles (U.S. Air Force & U.S. Navy) may spin at 40 rps and incur shocks of over a hundred g's, with a flight pattern that is dynamic, with substantial vibrations. Direct fire kinetic energy munitions (U.S. Army) can incur launch setback shock of 100,000 g's. In order to assure user needs are determined and understood a multi-service IPT was formed with user representatives as members. This IPT meets semi-annually, with additional meetings on an as-needed basis to update requirements, and to assure the program is on

track to meet user requirements. In order to assure needs are met, Working IPTs including user representatives and development contractors meet continually (i.e. bi-weekly teleconferences) during the development and validation processes. Throughout development and maturation of the HSTSS program, tri-service representation has continued, and user involvement is prevalent within HSTSS IPT's to maintain accurate and complete requirements from which HSTSS is designed.

MODULAR APPROACH, A STRATEGY FOR SUCCESS

During 1998, the HSTSS integrated product team embraced an "open architecture" philosophy resulting in a modular, interoperable system that will obviate the need for many independent instrumentation developments. The fiscal year 1998 transmitter chipset and the data acquisition chipset (DAC) contract awards were based on this philosophy. HSTSS components and modules are flexible and programmable, and are designed for incorporation into a myriad of platforms. Component architecture leverages advances in microelectronics technology to provide on-board instrumentation that will survive and operate in the harsh environments weapon systems experience during launch, flight and impact. Telemetry transmitter chipsets, data acquisition chipsets, sensors, and batteries will be integrated to accommodate applications in the direct fire, indirect fire and small missile system mission areas.

The modular design approach supports users with varying challenges by offering flexibility to support unique form factors and performance requirements. Devices will be available in various packaging schemes, such that they can be used where space is very limited, as stand-alone systems, incorporated into a module, or integrated into weapon system electronics:

- Die level integration for users with very limited space and MCM processing capability.
- Chip level integration for users with somewhat limited space and capability to build chip level electronics systems.
- Module level integration for users who desire functional LRU level modules.
- System level integration, for programs requiring many identical complete HSTSS instrumentation systems.

In addition to meeting various user integration requirements, a modular ("open architecture") approach encourages longevity for the useful life of HSTSS and reduces program risks. To avoid obsolescence and employ the latest available technologies, HSTSS may be updated through a program of "modernization through spares". Interface requirements between modules are being considered and standardized to the extent

practicable. Also, programmable aspects of system allow leeway for evolution of user requirements.

HSTSS DEVELOPED PRODUCTS

HSTSS development efforts have concentrated on advancement of the state of the art for subminiature components and modules unique to the T&E community. As new devices become commercially available, the user market is expected to expand. Survival of these components (e.g. integrated circuits) in a high-g environment leads to employment of some basic design principles: small size, low mass, small wires and connectors, plastic parts, and provision of support to physical structures.

DATA ACQUISITION CHIPSETS (DAC)

Systems and Processes Engineering Corporation (SPEC), in Austin, Texas is under contract to develop HSTSS Data Acquisition Chipsets (DACs).

The DACs will acquire input data from various sensors and devices, and process the signals (formatting and encoding) for output to the HSTSS transmitter. There are four configurations being designed to meet a broad range of user requirements: (1) the 4 Channel PCM DAC; (2) the Programmable Pulse Code Modulation (PCM) DAC; (3) the Frequency Division Multiplexer (FDM) DAC; and (4) the DAC delay/repeater. The four different DAC functionalities are required due to the differences in mission requirements and physical space available for electronics installation within unique munition geometries.

TRANSMITTER

M/A-COM, Lowell MA has been contracted to develop a set of integrated circuits comprising a S-Band transmitter. This transmitter design utilizes technologies prevalent in the cellular telephone industry. A modular approach to transmitter design allows interchangeable power amplifiers for varying user requirements. HSTSS is intended to operate at various Department of Defense Test and Training Ranges. DOD test centers and ranges operate under the guidelines of the Range Commanders Council Telemetry Standards - IRIG Standard 106-96 to a maximum extent. The HSTSS concept of operations is to use existing telemetry ground stations located at these DOD ranges.

CRYSTAL OSCILLATOR

Due to requirements of the transmitter and DAC to operate with an accurate clock source, HSTSS has contracted with STATEK, Orange, CA to develop a crystal oscillator capable of surviving 100,000 g's and providing a of 20 MHz clock with 20 ppm stability.

LEVERAGING COMMERCIAL DEVELOPMENTS

To encourage and aid product improvement, HSTSS has tested Commercial Off The Shelf (COTS) components and provided test results to the manufacturer. Thereby, the manufacturer attains information useful for product improvements and increase potential sales. As a low cost, modular solution to the need for rugged subminiature sensors, various COTS devices have been examined for use in HSTSS. In some cases identified products require no modifications to support munitions tests. For example, MEMS accelerometers developed for crash testing of automobiles have far exceeded the manufacturer specifications for shock tolerance. They are capable of surviving shock levels experienced in munition launches, and have flown in test firings with successful measurement results.

BATTERIES

Advances in battery technology have allowed efficiency to increase dramatically with regard to packaging and energy density. Thin, lightweight, physically flexible batteries may be shaped to practically any form required. The batteries tested have been primary lithium manganese dioxide batteries, designed for ballistic telemetry applications under a contract between HSTSS and Ultralife Batteries, Inc. Through concurrent engineering processes between WMRD, ARL and Ultralife Inc., prototype batteries have survived required shock, spin, and accelerations while providing constant rates of discharge required for this application. Cells tested in a Thin Cell™ format have demonstrated the capability to provide constant rate discharge while surviving 100,000 g forces in 3 axes. Commercial cylindrical Ultralife Li/MnO₂ cells are capable of surviving 20,000 g forces and spin rates of 300 Hz.

Global Positioning System (GPS)

Several organizations, including HSTSS and the Joint Advanced Missile Instrumentation (JAMI) program are involved in testing GPS systems for use in missiles and munitions. HSTSS is investigating benefits of translator vs. receiver technologies and their applications to high shock environments. HSTSS will be testing GPS chipsets, studying functionality and survivability of commercial technologies in missile and munition operational environments.

ACCELEROMETERS

Currently, there are commercially available accelerometers designed to survive and measure linear accelerations encountered in munition testing. The U.S. Army routinely uses these devices, such as those made by Endevco Inc. with excellent results.

Commercial Microelectromechanical (MEMs) accelerometers utilized by the automobile industry may offer significant advantages in cost, size, weight, and power requirements for use in munitions testing. At the U.S. Army Research Laboratory (ARL), in Aberdeen MD,

tests were conducted to characterize inexpensive commercially available MEMS accelerometers.

Initial tests identified devices that exceeded the manufacturer specifications for shock tolerance to the degree necessary for use in munition testing. Analog Devices engaged in an iterative process to determine internal performance and failure modes of their commercial accelerometers when subjected to high shock. ARL performed shock tests on Analog Devices' ADXL50 and ADXL05 accelerometers, and delivered them to Analog Devices for analysis.

SPIN SENSORS

A spin rate sensor measures rotational velocity/position (providing one pulse per revolution as output), and has successfully flown on a 155 mm projectile by the WMRD/ARL. The SCSA50 is a miniature Giant MagnetoResistance Ratio (GMR) sensor, made by Sensor Applications, Waterford Connecticut. When the sensitive axis is in line with the earth's magnetic field, the sensor output is a specific voltage. Output may be digital or analog, and cycles with each revolution. Ground and flight testing of this device has yielded favorable results. The frequency range of this sensor is 60 Hz to 1000 Hz. Lower bandwidth sensors are needed and under development by Sensor Applications.

ANGULAR RATE SENSORS

Magnetohydrodynamic (MHD) technology, developed by ATA Sensors was employed as part of an IMU developed by HSTSS IPT members in support of ATIRCM to fly on small missiles. The MHD sensor measures angular vibrations from millidegrees/second to kilodegrees/second in the frequency band from 0.1 Hz to over 1,000 Hz.

Microelectromechanical (MEM) angular rate sensors are under development through DARPA efforts. Various companies are developing potentially inexpensive micro-miniature, angular rate sensors for use in the automotive industry. These developments are expected to meet HSTSS needs

SYSTEM ASSEMBLY & PROTOTYPING

PACKAGING

A primary requirement of HSTSS is the miniaturization of electronics packaging. To improve the overall performance and reliability of electrical systems, and to reduce volume and weight, high integration density must be realized on the board or substrate level. A Multichip Module (MCM) allows a completely integrated electronic system with complex functionality, using bare (unpackaged) ICs to achieve a very high integration density.

Programmable MCM technologies have been under evaluation at the Army Research Laboratory (ARL). The Microelectronics and Computer technology Corporation (MCC) programmable MCM technology uses a generic thin film substrate, upon which custom circuitry is etched with a laser. Die are then attached using standard wire bonding techniques. The Naval Air Warfare Center Weapons Division, Instrumentation Development Branch (NAWCWPNS) performed electrical testing of the MCC MCM. Laboratory testing at ARL has shown survivability of the MCC MCM bare substrate in excess of 30,000 g's.

Currently, research is being performed to develop methods of "chip piling" where bare die are physically attached. Also, methods of stacking and electrically connecting separate MCM boards is under investigation.

SYSTEM PROTOTYPING

As HSTSS developments mature, and technologies are validated for fielding, prototype systems are being designed and assembled for use in existing test programs. Current users of HSTSS technologies include SADARM, MLRS, Crusader, and ATIRCM. The prototype DAC module being designed and manufactured will support 2.75-inch missile applications. This device will provide analog and digital data acquisition and PCM formatting in a much smaller form factor than is currently available, allowing more space for other missile components, such as a GPS receiver or translator.

The U.S. Army Research Laboratory (ARL) in Aberdeen MD will lead the integration of HSTSS devices into prototype systems. ARL possesses testing capabilities relative to shock, spin, and vibration required for validating HSTSS components. System analysis and modeling is performed early in the prototyping process, and components are selected. Mechanical and electrical system design then take place. Air gun testing and flight simulations are then performed to validate the prototype system prior to flight tests.

CONCLUSIONS

For continued development and success of the U.S. smart weapons arsenal, development costs must be reduced and risks must be mitigated. HSTSS goals include provision of previously unavailable measurement capability to the user community at very low cost. To accomplish this, HSTSS will leverage from commercial developments, fostering modifications required for adaptation to HSTSS requirements, and develop the remaining system components. Users of HSTSS vary in their requirements, such that a single "one size fits all" system is inappropriate. Therefore, a modular approach to HSTSS development will provide the flexibility to instrument many varying configurations.

To ensure HSTSS fully supports the user community, their involvement has been encouraged since the beginning of the program, during the collection of requirements (technical, fiscal, and schedule). User involvement will continue as HSTSS components are validated as systems.