SUBMINIATURE TELEMETRY FOR MULTIPLE MUNITION (TECHNOLOGY TRANSITION)

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ABSTRACT

The Instrumentation Technology Branch of Wright Laboratory Armament Directorate (WL/MNSI), has successfully completed an Exploratory Development (6.2) program to develop Subminiature Telemetry (SMT). SMT is a flexible, programmable telemeter with self calibration, power control and Direct Sequence Spread Spectrum modulation. The development program successfully demonstrated the ability of the SMT system to collect up to 64 analog and/or 128 digital discrete signals with programmable gain, bandwidth and offset. The program demonstrated a spread spectrum multiple-access technique that allows for simultaneous transmission and receipt of up to 96 different telemetry units within a 100 MHz telemetry band. WL/MNSI is conducting an Advanced Technology Development (6.3) program to continue development in this area. An air-worthy 4 channel spread spectrum demodulator was developed to support the SMT program but it is too costly for ground applications. The goals of this effort are to reduce the demodulator cost by a factor of 10 while increasing the capability for simultaneously processing data from 24 telemetry units and to support the first Technology Transition Plan (TTP) between WL/MN and the Air Force Development Test Center (AFDTC). The TTP will facilitate the transition of SMT spread spectrum technology to AFDTC for mission support over the next three years.

KEY WORDS

Spread spectrum, Multiple access telemetry, CDMA, Subminiature telemetry

INTRODUCTION

This paper summarizes the progress made by the Wright Laboratory Armament Directorate Instrumentation Technology Branch in developing spread spectrum subminiature telemetry technology and discusses the on-going, associated cost reduction and technology transition efforts.

TECHNOLOGY NEED

A need exists for the capability to obtain telemetry (TM) data from all guided and/or fuzed conventional weapons during all phases of flight testing. The rapid advancement of weapon systems with on-board processors and complex guidance and fusing systems requires that internal electrical signals and waveforms be acquired for performance evaluation. There have been many efforts to develop systems that can track small weapons to help verify system performance, however, tracking provides only a limited amount of position data and does not provide any data on internal system performance and aimpoint. Effective test and evaluation of these weapons requires precise knowledge of these internal signal levels during actual mission conditions. Test programs are greatly enhanced when signals are provided without removal of the warhead or any significant modification to the weapon itself. [1]

SMT INSTRUMENTATION

To help satisfy DOD telemetry needs, the Subminiature Instrumentation program at Wright Laboratory Armament Directorate was formed to develop the technologies necessary to permit an instrumentation capability for current and future weapon systems stressing rapid development and installation, low cost, and extremely small size (Reference 1). Highly integrated microelectronics technologies have been applied to the problem to provide a miniaturized system applicable to many different weapon test requirements. SMT will permit weapon systems to be quickly instrumented for test and evaluation, at low cost, and with minimum test item modification.

LIMITED TEST RESOURCES

Current TM instrumentation systems are often costly, bulky, require extensive modification to aircraft and/or munitions and are limited to single data stream operation (reception of only one telemetry unit per frequency channel, with typically 2 MHz between each channel). Once operational, they do not accommodate installation of additional data sources. Multiple TM requirements can only be met with separate systems for each TM stream. The associated cost is often prohibitive. Test range schedules and costs are also impacted by the need for multiple frequency band allocations. The spread spectrum method developed under the Subminiature Telemetry program allows simultaneous transmission from multiple transmitters within the 100 MHZ "S" band (2.3-2.4 GHz), thus allowing the collection of critical performance data from many items under test at the same time. Spectral efficiency is critical considering a recent trend to reallocate what had traditionally been DOD

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[1] WL/MNSI FY96 Technical Program Description (TPD) for SMT Spread Spectrum Demodulator, 15 December 1994.

spectrum to commercial users, the ever increasing number of users and their increasing requirements for precision and information rates. In this light, one objective of the SMT program is to maximize the number of users on a range while minimizing the interference between them. [2]

SCOPE

WL/MNSI continues to pursue SMT exploratory development efforts where areas for improvement were identified and now form the basis of the new objective, to mature this technology into a usable form. As described in the most recent WL/MNSI TPD for Range Instrumentation, these efforts include: 1) Improvements in the subminiature telemetry chip-set, substrates/packaging, and product support 2) Studies in spectrally efficient modulation and coding methods 3) Development of a Telemetry Instrumentation Development System (TIDS) and 4) Studies in Instrumentation Signal Processing Techniques (ISPT). The goal is that through enhancements to the prototype chip-sets, substrates /packages and product support equipment, this technology will become affordable in lower volumes, more reliable, and easier to use. [2] This paper, however, will focus only on the current Advanced Technology Development program regarding the multiple access telemetry demodulator development/cost reduction efforts and the process used in transitioning SMT technology from WL/MNSI to AFDTC.

SUBMINIATURE TELEMETRY(SMT) DEVELOPMENT

WL/MNSI successfully completed a program to develop subminiature telemetry instrumentation for rapid, low cost execution of developmental weapons tests, aircraft weapon compatibility assessment, and operational validation of inventory weapons.

PREVIOUS ACCOMPLISHMENTS

A contract was awarded in November 1989 to develop breadboard level designs of a flexible, programmable telemeter with self calibration, power control and a spread spectrum modulation technique (for multi-munition test scenarios). The resulting breadboards successfully demonstrated the ability of the system to collect analog and/or discrete signals with programmable gain, bandwidth and offset. They demonstrated a spread spectrum multi-access technique that would greatly simplify the simultaneous collection of data from multiple munitions. Contract options were awarded in 3Q91 to miniaturize the product. Four ASIC's were developed and fabricated to jointly achieve all the breadboard functions. The die were mounted bare onto 2 multi-chip module (green tape) substrates resulting in a 2"x2"x0.2" self-

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[2] WL/MNSI FY96 Technical Program Description (TPD) for Range Instrumentation, 15 December 1994.

contained, programmable product. Construction of 8 prototypes was completed 3Q93. All 8 were successfully tested in flight and laboratory tests during FY94. These ASICS, which can be assembled into modules, allow quick design changes to meet a broad range of weapons test applications. [2]

USERS

Sensor Fused Weapon (SFW), Boosted Kinetic Energy Penetrator (BKEP), SEEK EAGLE Store Certification Program, and the Army SADARM programs served as "model" programs for SMT requirements development. The AMRAAM WRTTM program used SMT technology in their telemetry design. In 1993, the AGM-130 Program Office funded WL/MNSI to develop 10 prototype telemeters for their improved air-to-ground missile using this technology. WL/MNSI is currently delivering these kits. Two similar prototypes have also been developed for Ballistic Missile Defense Organization (BMDO) applications. In addition, the Joint Direct Attack Munition (JDAM) contractors are evaluating the AGM-130 telemeters for their application. Potential future users of SMT include the ARMY Walter Reid (for medical use), NAVY NRAD (for marine mammal training), AGM-65 telemetry system upgrade, Wind Corrected Munitions Dispenser system and SEEK EAGLE Store Certification.

SMT SYSTEM DESCRIPTION

A number of tasks and trades were necessary to achieve a general SMT system architecture and component specification. The primary efforts were link design, waveform design, power/system control, system partitioning, and packaging/interfacing. For details of the work performed and the resulting SMT system architecture, see the referenced reports (Reference 1, Reference 2). The SMT system concept requires two levels of multiplexing (Reference 1). The first level is multiplexing data channels, or measurands, within a single munition. For low to moderate level analog signal bandwidths (typically less than 200 kHz for most TM systems), a Pulse Code Modulation (PCM) serial data format was chosen due to its extreme accuracy, robustness, and convenience. The second level of multiplexing deals with transmitting and receiving data from multiple munitions. Frequency Division Multiple Access (FDMA) is the most compatible with Inter-Range Instrumentation Group (IRIG) standards, however, it requires one RF receiver per transmitter (e.g., 96 transmitters require 96 receivers). Code Division Multiple Access (CDMA) multiple access transmits multiple data streams on a single frequency, differentiating them by spread spectrum codes unique to each munition. A Direct Sequence (DS) CDMA system directly modulates the data stream with a (PN) code. A CDMA-DS/FDMA “hybrid” approach was chosen for a large number of simultaneous operators. As shown in Fig. 1., this approach uses 4 center frequencies on which up to 24 munitions may transmit per frequency, each using CDMA.

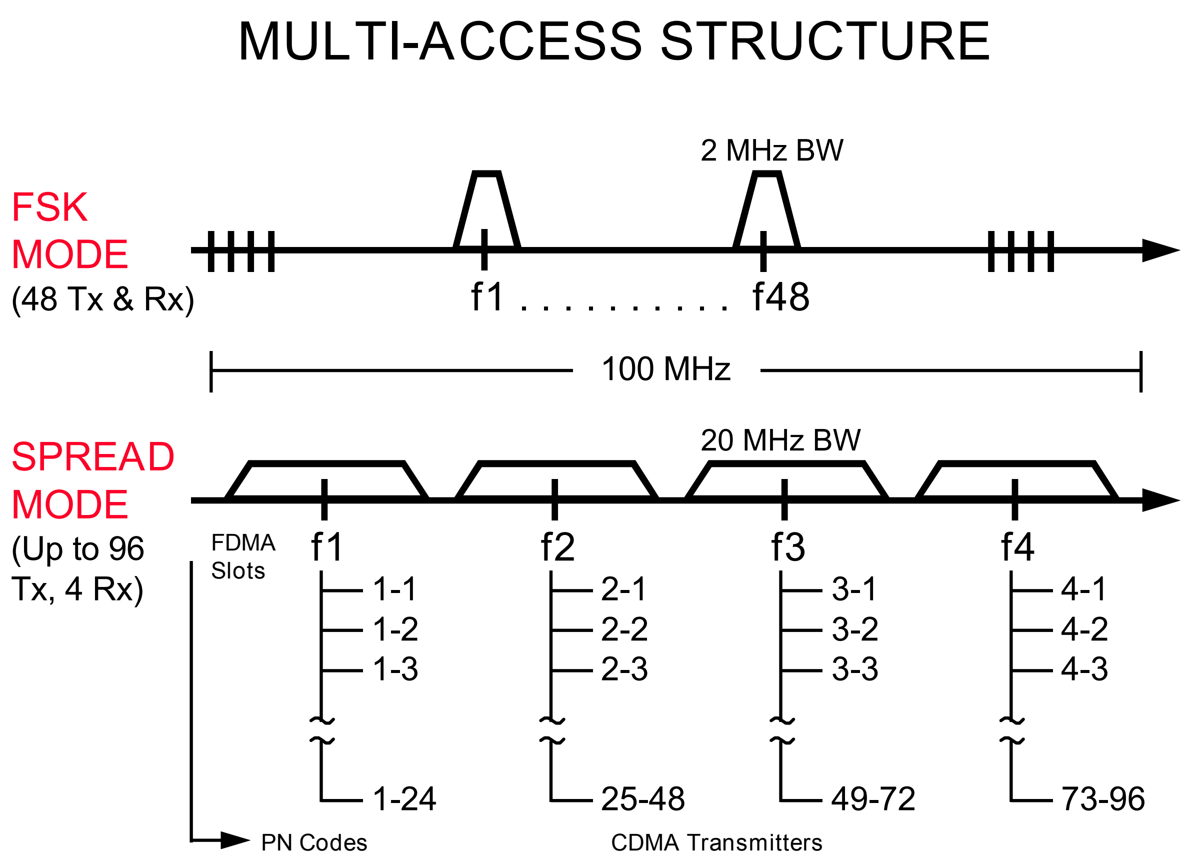

Figure 1. SMT Multi-Access Structure.

RF modulation techniques best suited for a particular multi-access technique were studied under the basic SMT effort. The existing SMT chip-set uses one of two RF modulations. For an FDMA application, Frequency Shift Keying (FSK) performs best, whereas for the CDMA/FDMA system, Differential Phase Shift Keying of an Off-set Quadrature direct spread signal (using a nonmaximal Gold code) works best. Henceforth, the FDMA approach using FSK modulation will be referred to as "FSK mode", and the CDMA/FDMA approach will be called Spread mode (Reference 1). FSK is used with or without convolutional encoding and O-QPSK is used with convolutional encoding, block interleaving, and direct sequence spread spectrum modulation.

The FSK mode of operation is chosen for a single or very low number of simultaneous operators. Spread mode is chosen when a large number of transmitters must be accessed simultaneously. In either case, analog, discrete, and digital data are commutated into a single PCM serial data stream of variable, selectable bit rates and frame structures. The SMT signal path, waveform design and spreading stage (with Gold code sequence) are described in detail in the referenced report (Reference 1).

The spread spectrum technique requires transmission and receipt of telemetry units using a receiver along with a demodulator. In Spread mode a standard (off-the-shelf) wideband telemetry receiver is used. A 70 MHz Intermediate Frequency (IF) and Local Oscillator (LO) are routed from the receiver to a downconverter that separates the signal into its compound, quadrature components. A 4 channel spread spectrum Airborne Receiver Demodulator Unit (ARDU) was developed and tested to support the SMT program but it is too costly for ground applications. The receiver system is partitioned into four major areas, two of which are existing ground station systems (Reference 1). The remaining two, the downconverter/quantizer and Digital Signal Processor, are structured as appliqué modules that are easily inserted into the existing signal path. In such a case, up to four receivers, downconverters, DSP module banks and decommutators would be required.

ADVANCED TECHNOLOGY DEVELOPMENT PROGRAM

The SMT for Multiple Munitions program builds on the results of the SMT effort. The objective of this effort is to develop, fabricate and test low cost Multiple Access Telemetry Demodulators (MATDs) for use in simultaneously processing data from up to 24 spread mode telemetry units (Integrated Telemetry Packages - ITPs). The program will include, as a key element, a design to cost effort aimed at minimizing costs of the demodulator.

APPROACH

The major limitation of the current SMT product is the high cost of the spread spectrum demodulator for use by Department of Defense test ranges. The goals of this effort are to reduce the demodulator cost by a factor of 10 while increasing the capability for simultaneously processing data from 12 to 24 ITPs per demodulator. Currently the only existing compatible demodulator for the ITP is the ARDU. This demodulator was designed and built for a specific military aircraft pod application. Therefore, although the ARDU was the best design for the application in which it was required, it is too expensive for ground range sites or for commercial applications. Low cost will facilitate commercial use of the SMT and dramatically reduce the cost to military users. This program will provide a new capability to the DoD test community, since this program will support simultaneous flight testing of multiple live submunitions. Reception of multiple channels on the same frequency greatly reduces mission costs while reducing range scheduling conflicts (only one telemetry frequency to schedule).

A functionality comparison of the MATD and the ARDU is presented in Table 1. One MATD control processor 4 channel demodulator card will replace 4 demodulator cards in the ARDU. The ARDU also required a LO 70 MHz local oscillator and a 256 MHz input clock reference that the MATD will generate. The MATD configuration will allow for an off-the-shelf wide-band receiver to be used in place of the RF Converter.

TABLE 3. COST REDUCTION AREAS/TRADE STUDIES (HARRIS CORPORATION)

Make use of existing commercial downconverters (From high-production markets, such as GPS and cellular phones)
Use single-ended outputs rather than differential reduced driving requirements from 12 to 6 boards (1 channel per board to 4 channels per board) - also reduces the number of final filters and bus drivers
Adapt commercial control processor to MATD (One third of the cost and eliminates an extra processor bus)
Combine/repackage several complex demodulator circuits/PROMS into two gate arrays (started under Harris Corp. IR&D)
Use commercial Viterbi Decoder chip in place of existing Military part
Repackage/less power required for MATD Timing and Control gate (less gates required)
Surface-mount devices to minimize card size and production costs
Investigate using one high-speed analog-to-digital (A/D) converter to drive all four channels on each Demodulator card.
Implement the functionality for more than one demodulator channel in one gate array.
Use double-sided printed wiring boards to reduce the number of Demodulator cards.
Investigate the relaxation of performance parameters such as chip rate, phase increment resolution, and deinterleaver functions.
Investigate implementing, in hardware, the tracking functions currently performed in software, and the use of one processor to control more than four channels.
Investigate using a matched filter architecture.
Investigate using commercially available despread/demodulator chip sets.

This program complements advanced technology development (6.3) laboratory funding with OSD funding. The OSD funding is provided by the Central Test & Evaluation Investment Program (CTEIP), Test Technology Development & Demonstration (TTD&D) with dual use emphasis. The effort will involve trade studies, a redesign of the demodulator circuitry for lower cost (structured design to cost program), increasing ITP power, remote on/off ITP capability and technology demonstration at AFDTC. A 24 month contract will be awarded to accomplish these tasks. This contract effort will improve on that design using Application Specific Integrated Circuit (ASIC) technology to dramatically lower the cost while maintaining a capability for growth and expansion to demodulate additional transmitters. Prototypes will be developed and flight test data will be collected and processed to verify system performance for support of up to 24 transmitters. The output of this program will be a build-to set of specifications and drawings, along with several prototype units and associated test assets. [3]

Design to Unit Production Cost Program (DTUPC)

The MATD program includes as a basic element a DTUPC program. The initial DTUPC activities will focus on identifying cost drivers and potential risk area. This program ensures that cost is addressed on a continuous basis as part of the system development. Realistic but rigorous cost goals are established at the system level and these are then flowed down to every individual supporting the tasks. Progress against these goals will be briefed regularly. As development continues, efforts will focus on identifying areas requiring corrective action because of excessive costs. Cost reduction techniques will be applied to such areas to keep costs within acceptable tolerances. DTUPC objectives, expressed in constant dollars, will be established early in the program. Additional guidance for a formal DTUPC program can be found in MIL-STD-337.

ITP Design Modification, Fabrication, Assembly, and Test

Twenty-six (26) Spread Spectrum ITPs will also be delivered to WL/MNSI under the contract to allow realistic demonstrations/testing of the MATD. To provide extended range and save on battery life, some features will be added or changed from the basic SMT design. The ITP design will be changed to incorporate the ability to remotely command the ITP "ON" or "OFF"; to increase RF output power for greater range (CDMA mode); and to provide two RF connectors on the side of the module to permit external antenna connection.

Test and evaluation of prototype systems will be performed in existing Directorate facilities and on existing AFDTC ranges by WL/MNSI. The AFDTC B-4 telemetry range, B-70 air delivery range, and water ranges will be used to test ITPs with the Shelter DU.

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[3] WL/MNSI FY96 Technical Program Description (TPD) for SMT Spread Spectrum Demodulator, 15 December 1994.

A single dedicated flight is planned to demonstrate that the SMT system meets/exceeds transition criteria relative to airborne requirements. The Demonstration will consist of one 200 milliwatt ITP mounted on each wingtip of a previously instrumented F-16. Each ITP will transmit accelerometer data to the Shelter DU in the GI Pod carried on a chase aircraft. In addition, during the mission an MK-82 bomb (modified with an ITP interfaced to an omni antenna) will be released and also transmit data (before, during, and after separation) to both the chase aircraft pod and the Shelter DU. All data will be retransmitted from the GI pod to a ground station and monitored real time. The SMT transmitted/received data will be compared to data transmitter/received in parallel by existing telemetry system(s) as a verification of data fidelity.

The ground demonstration will involve mounting at least six and up to 12 ITPs on tanks, trucks and other available vehicles and transmitting from all simultaneously to the Shelter DU. The data to be transmitted is to be determined and will necessarily depend upon vehicle selection and data available from each vehicle.

TECHNOLOGY TRANSITION

Technology Transition (T2) can be defined as the movement of technology from the Laboratory to another acquisition agency or AFMC Center. Technology Transfer is the process by which knowledge, capabilities, information and ideas that are developed under federal Research and Development (R&D) funding can fulfill public or private-sector, non-military needs. [4] The goal of this effort is to transition SMT technology to AFDTC, however, WL/MNSI is always considering opportunities for technology transfer to state and local governments and private industry (to the extent it is not detrimental to the Laboratory's mission). The pursuit of commercial applications for this technology will help increase MATD production quantities which will, in turn, reduce the cost for military applications.

Commercial/Dual Use Strategy

The strategy for transfer of this technology for non-defense use is to perform the proposed system enhancements and cost reduction necessary to support a dual-use market. Having a low cost receiver dramatically increases the possible dual use applications of the SMT technology. There are many potential commercial applications for transmitting volumes of data from several units at the same time on the same frequency. Environmental monitoring, manufacturing process control, sports events and patient monitoring in the medical field are just a few. Other possible

[4] Wright Laboratory Armament Directorate Project Managers' Guide, Research and Development, 31 January 1994.

consumer markets include automobile transponding devices, such as toll booth systems or on-board navigation systems, remote sensing for pipelines and oil/gas well systems, earthquake monitoring, factory remote data collection, and a host of other applications. The commercial applications for this technology can greatly reduce the cost for military applications.

SUMMARY

The subminiature telemetry for multiple munitions program will provide extremely small, low cost, rapidly installable, and easily configured TM capabilities for any test application. When this technology is transistioned to AFDTC as a schedulable resource over the next three years, the ability to support multiple telemetry transmitters will be a reality. Only four frequencies will need to be scheduled for 96 transmitters. This will be a great advantage for missions supporting flutter analysis, multiple munitions testing, and submunition development and testing. The Advanced Technology Development (6.3) program to continue development in this area and reduce the demodulator cost will implement performance/component trade studies and a formal DTUPC program to dramatically reduce the demodulator cost. The first Technology Transition Plan (TTP) between WL/MN and the AFDTC has been signed and we have achieved significant accomplishments in the completion of the Integrated Technology Transition Process. The stage is set for a successful transition of SMT spread spectrum technology to AFDTC for mission support (another “Team Eglin “ success).

REFERENCES

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