DUAL TELEMETRY SYSTEM PROVIDES COMPREHENSIVE TEST STRATEGY

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ABSTRACT

The Army's continuing effort to develop self-guided, anti-tank weapon systems has been fueled by successful development of an earlier generation of smart weapons. These self-guided systems, also labeled "brilliant weapons," will present a natural progression to "smart" weapons development and testing.

What has been critical to the success of these smart weapons development programs has been an end-to-end testability provided by on-board telemetry methods. The end-to-end test procedures can be efficiently performed in a static laboratory environment where space is available. On board the smart weapon, end-to-end testability is less feasible due to space and bandwidth limitations.

The STAFF XM943 projectile development program makes use of a dual telemetry link to transmit an array of measurements which characterize the performance of the projectile in and end-to-end fashion. The dual telemetry systems provide analog measurement capability to evaluate system component-level functions and digital measurement capability to evaluate a system processor which lends itself to computer processing. The digital data is intrinsic to smart weapon systems since they typically employ embedded microprocessors for projectile system control. The STAFF XM943 electronic system is controlled by a TMS320C30 microprocessor.

The dual telemetry system employs a traditional FM/FM technique for monitoring a number of analog functions and a "quasi-traditional" PCM/FM scheme for digital transmission.

This paper discusses the implementation of this dual telemetry approach for the XM943 Projectile System.

INTRODUCTION

The Smart Target Activated, Fire and Forget (STAFF), XM943 projectile, nearing the completion of its development testing phase, is a 120mm tank round which provides a high probability of single shot kill by top attack of tank armor. The STAFF, XM943 projectile uses a downward pointing millimeter wave sensor to scan the ground for flight orientation. A forward-looking millimeter wave radar is used to detect armored vehicles on the ground or helicopters in flight.

The heart of this weapon systems is an on-board digital processor which provides decision-making capabilities in response to sensors designed to provide ranging, tracking, scanning, fuzing and aeroballistic measurements from a smart weapon in flight. Once a target is detected, it is validated by a digital processor which gives a command to a torque control system which causes the projectile's warhead to roll toward the target, and fires the mechanism.

As indicated previously, the XM943 uses a TMS320C30 digital processor to control the projectile electronic system. As an aid in the development of the STAFF system, a dual telemetry system is used to monitor an array of measurements which characterize the performance of the projectile in an end-to-end fashion. That is, signals are measured at their points of origin in the system as well as at their control outputs to determine the proper operation of the systems comprising the STAFF projectile.

An ideal telemeter for a smart weapon system must have the capability to transmit signals which represent hundreds of measurements from sensor inputs (and redundant monitors for sensors), sensor outputs, processor outputs, internal algorithms, and control system outputs to characterize the flight performance of the smart system. Using traditional telemetry methods, this would require prohibitive use of space and power for analog systems or equipment-intensive, complex digital coding for traditional PCM systems. However, the end-to-end test capability is necessary for smart weapon development. The end-to-end testing method is a comprehensive test strategy which includes a validation of the total round performance using test equipment. From this viewpoint comprehensive testing is possible in the laboratory setting, but is not generally feasible in the field test setting for these smart rounds.

The STAFF projectile utilizes an analog telemetry system to transmit signals which are monitored for shape to determine the functional condition of the front end sensors. The analog system is generally reserved for this type of data. A digital telemeter is used in a PCM/FM format to monitor signals that are digital in nature in the system. In systems with a digital processor, pre-conditioned digital signals are used for data communications. The dual system is used as an alternative to "burdening" either the analog or the digital system with signals that may require extensive overhead to process outside of their natural environments. The ensuing discussion is on the STAFF, XM943 telemetry test systems.

The STAFF XM943 projectile is shown in figure 1. This configuration utilizes an analog telemetry system in place of the warhead system and a digital telemetry system that is destroyed in test at warhead detonation. The analog telemeter employs 12 Constant Bandwidth, IRIG standard oscillators in a traditional Frequency Division Multiplex (FDM) configured in the arrangement shown below in figure 2. The subcarrier frequencies are recorded in Table 1.

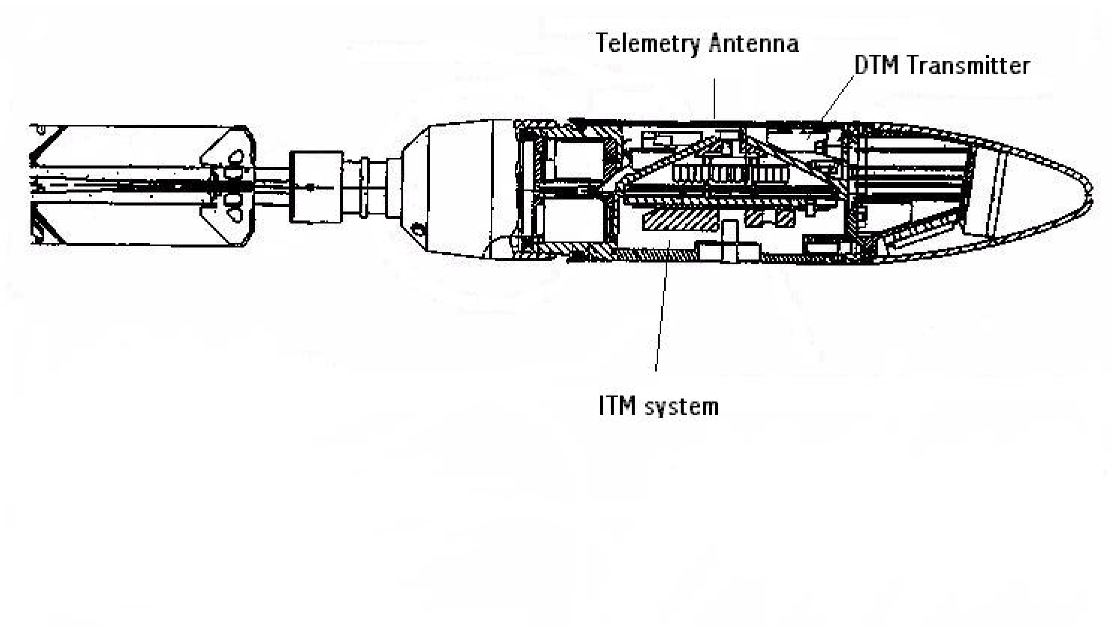

Figure 1. XM943 STAFF Projectile

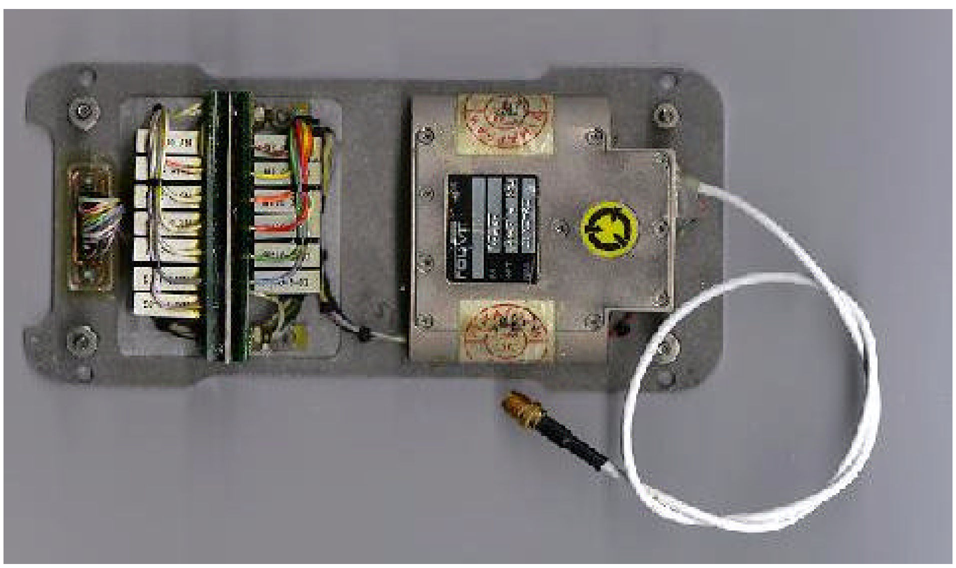

Figure 2. Independent Telemetry System (ITM)

The transmission bandwidth for the above system is 4 MHz. The system is designed to meet a minimum signal-to-noise output from the FM demodulators of 40dB.

The STAFF analog system provides continuous measurement of outputs from a thermal battery, power signal conditioning boards, an angular rate sensor, a millimeter wave sensor, a roll control system, a safe arming system, and a warhead release actuator. These shall hereafter be referred to as the subsystems of the XM943 projectile. The analog telemeter also monitors the “health status” of a digital processor which integrates all of the subsystems and is responsible for the dynamic control of the XM943.

TABLE 1

Channel	Frequency, Subcarrier	Frequency, Data	Modulation Index
CHAN1	1024+/- 128 KHz	25 KHz	5.12
CHAN2	512 +/- 64 KHz	15 KHz	4.26
CHAN3	256 +/- 32 KHz	12 KHz	2.67
CHAN4	144 +/- 4 KHz	1.6KHz	2.50
CHAN5	128 +/- 4 KHz	1.0KHz	4.00
CHAN6	112 +/- 4 KHz	1.0KHz	4.00
CHAN7	96 +/- 4 KHz	1.0KHz	4.00
CHAN8	80 +/- 4 KHz	1.6KHz	2.50
CHAN9	64 +/- 4 KHz	1.0KHz	4.00
CHAN10	48 +/- 4 KHz	1.0KHz	4.00
CHAN11	32 +/- 4 KHz	1.0KHz	4.00
CHAN12	16 +/- 4 KHz	1.0KHz	4.00

The analog telemeter is functionally modular by design including a battery section (or module) of Nickel Cadmium cells to supply 28 Volts DC to the analog telemeter and to the signal conditioning electronics. These three modules are interconnected by microminiature connectors and encapsulated in rigid epoxy potting for gun hardness.

The second section is the analog signal conditioning section. This provides voltage amplification, filtering, and bandwidth limiting, DC offsetting, noise suppression, voltage regulation, and voltage division which are essential functions for typical analog telemetry designs. Due to the complexity of the XM943 control environment, over 30 signals are necessary to determine the complete operational performance of the STAFF subsystems. For this, the STAFF analog telemeter also requires additional signal conditioning functions. The benefit of using an analog telemeter to monitor the output of these subsystems is that the signal characteristics are preserved during the projectile operation and the raw signal can be analyzed either in real-time or during post-evaluation procedures. In this way, analog telemetry serves as a useful diagnostic tool.

The additional signal conditioning includes analog multiplexers and programmable devices in the signal conditioning module to reduce the hardware count in the telemetry electronics. Each subcarrier oscillator is modulated by a single signal but the signal can, by sampling, represent up to 8 individual signals. This technique embeds a time division multiplex within a frequency division multiplex. The disadvantage of using analog multiplexing schemes is that the signal characteristics are preserved only to an extent limited by the mux (multiplexer) sampling rate. The signals multiplexed in the STAFF system are predominantly regulator voltages or pulse event functions of which the signal characteristic is not critical.

INDEPENDENT BATTERY SOURCE

Since the STAFF projectile is powered by a thermal battery, it was necessary to power the analog telemetry independently from the other subsystems. The 28VDC required to operate the analog telemetry is derived from this independent module previously identified. This independence from the other STAFF components is the reason for the analog telemetry nomenclature “Independent Telemeter,” (ITM).

The digital telemetry system is the second part of the XM943 composite telemetry system. It is used in a tactical configuration, as part of the XM943 integrated subsytems Therefore, it derives power directly from the STAFF thermal battery due to its tactical configuration. It is then dependent upon the XM943 system power to operate - hence its nomenclature, “Dependent Telemeter,” (DTM).

DIGITAL TELEMETRY

The XM943 uses a true-FM, modified, video transmitter to send data from the TMS320C30 digital processor serial port to the telemetry receiving station in an IRIG standard BIΦ–M, PCM format. While the processor could be used to implement the digital encoding, the choice was made to develop an external ASIC to interface with the C30’s serial port and format the data. This approach saves on the processing overhead for functions that are external to the basic performance of the XM943 system (i.e. telemetry).

The external ASIC performs 3 basic functions:

(a) Collection of data words from the C30 serial interface into a FIFO (first-in/first out) memory / shift register.
(b) Insertion of IRIG standard synchronization word into serial data stream
(c) Implementing a BI -M algorithm to encode the data for transmission

The FIFO is used to buffer the flow of asynchronous data as received from the digital processor interface. The resultant serial digital stream is 6.3 Mbps BI -M coded The transmitter is a 0.5Watt , FM, phase locked loop device operating at S-band. In order to meet the transmission bandwidth requirement for 6.3 Mbps bi-phase, the transmitter has a frequency response from 20Hz to 12 MHz. Crystal stability is achieved by a 16MHz reference oscillator that is divided down to drive the phase detector along with the divided output from an S-Band VCO. The capture time (phase lock acquisition) is under 50 ms after acquisition of power. In conjunction with a wideband FM receiver, the maximum 20KHz incidental FM specification makes the transmitter useful during gun shock to collect preshock data.

The FM transmitter incorporates a premodulation filter at the front end to accommodate the 6.3Mbit TTL level and remain within the IRIG spurious response and bandwidth requirement specified in the Frequency Management Plan. Other digital front end techniques typically include pulse shaping but is unnecessary in the STAFF DTM due to the quality of the interface between the digital processor and the DTM on the XM943. The ITM utilizes the same transmitter as the DTM digital telemeter excluding the digital front end. Additionally, it is packaged into a lower profile package. The DTM telemetry stream is organized into 16 bit words that represent the status of the control systems within the XM943 in response to the subsystem input signals. The DTM transmitter is shown in figure 3.

DUAL TELEMETRY ANTENNA

The ITM analog telemeter and the DTM digital telemeter are both operated into a dual antenna assembly which consists of a printed circuit board with two series-fed arrays, one at 2235.5 MHz (DTM) and the other at 2254.5MHz (ITM). The antenna is bonded to a partial section of the XM943 into a recessed top cover which houses the liner and warhead mechanisms. The two series-fed arrays are terminated with a resistor into a quarter-wave stub with sufficient isolation between bands. The antenna is called an “end-fire” radiator with most of the pattern gain directed towards the rear of the projectile for the field set up. The antenna offers a 6dBiL gain over the conical plane 60-70 degrees and is used in the field testing. Two receiving antennas in the field setup have gains of 26dBi (Dish) and 15 dBi (helical) with beamwidths of 10 and 30 degrees respectively in order to support testing over a 4 Kilometer range for the STAFF projectile with sufficient margin.

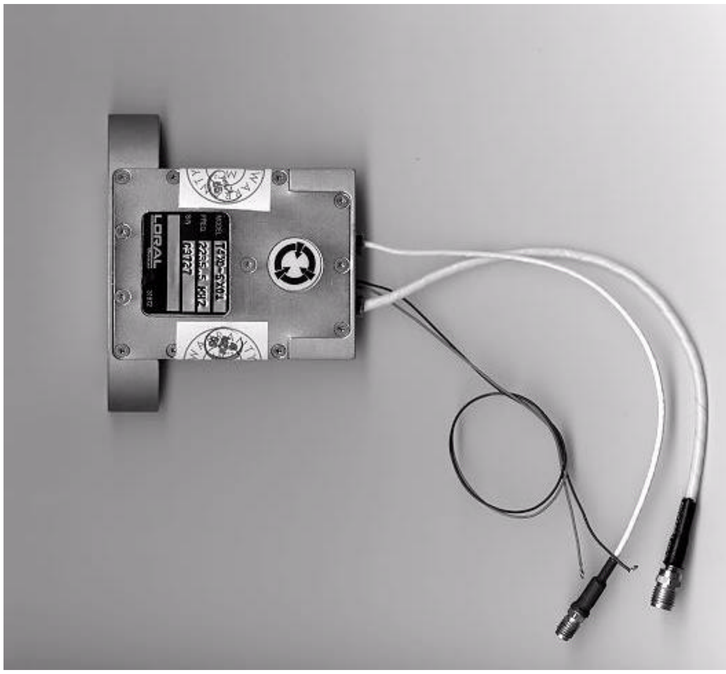

Figure 3. DTM - digital telemetry system

The dual antenna assembly is configured in a uniquely compact form factor to complete the telemetry components that comprise the XM943 test strategy.

In the laboratory, the telemetry supports the testing of the integrated system in a hardware integration setup referred to as a “hardware-in-the-loop” test facility. The hardware-in-the-loop is constructed to test the dynamic response of the projectile control systems with stimuli to the various subsystems and demonstrate the mission sequence on a spin fixture. This setup gives comprehensive test capability to the XM943 in a laboratory environment.

The mission sequence is initiated and telemetry data is collected over hardwire in the laboratory to confirm the operation of each subsystem. During the laboratory test, changes can be made to the operational algorithms via software modifications and each subsystem can be studied for responses to various stimuli under temperature extremes.

It is this level of testability that is defined as comprehensive because the tester has the capability to study the input/output (transfer function) of individual components and characterize their interface into the microcontroller for the system. This is a test level typically associated with bench methods, but is achieved through the telemetry link. It is possible then to capture this level of testability in the field, taking the “lab to the field.” A type of reverse test engineering is applied in the comprehensive test plan due to the creation of laboratory capabilities in the STAFF projectile. Typically, the laboratory is designed to duplicate the actual test environment as closely as possible.

CONCLUSION

Classic telemetry system organization falls into two approaches: FDM and TDM. Utilizing the analog (FDM) telemeter in harmony with the digital (TDM) telemeter, combines the total or comprehensive capability for telemetry measurement within a system and gives the system this level of testability.

There were two main objectives to meet for "comprehensive-testability" for the STAFF projectile:

I. System performance testing and evaluation
II. Replication of system functions for post-test study.

In scoring Army weapon programs, the system development phase leads to performance evaluation. The performance of the STAFF round is mainly evaluated from the DTM telemetry data. The DTM data set includes:

a. verification of system operation through signals such as: Mission status signals
b. validation of processor operation through system initialization
c. status of subsystem operation during the control event cycle
d. subsystem outputs during the operational modes in test.

In scoring the performance of smart weapon systems such as the XM943, it is useful to have the comprehensive 2-Layered test approach. Traditional methods of testing have been designed to learn more about system functions and malfunctions solely from hardware recovery and failure analysis studies. While this cannot be eliminated as a standard practice, it is often unreliable in circumstances when hardware recovery is unfeasible. Smarter weapons demand smarter testing strategies.

Smart weapons are built around microprocessor control and programmability. In a comprehensive test strategy, the telemetry must not only be the object to achieve testing, but it must be subject to testability as well. Within the scope of these digital processors is an inherent capability for signal generation and for implementing algorithms to test bit errors and this represents the core of validation testing for the dual telemetry links as well.

First generation test strategies for the XM943 smart weapon system utilized one half of the telemetry capability by employing analog telemetry in the subsystems level test phase and eliminated the digital telemetry approach to study the processor responses. The second generation combined the two systems to integrate the functions and study the complete system response. The next generation of testing on such smart weapon systems must include programmability within the subsystems themselves, including telemetry. "Smart transducers" will be the link that ties in missing functions from the model for comprehensive testability established in this paper. Allowing the sensors to see the flight conditions and interfacing their responses into a composite telemetry system will carry the capability for simulation out to the field test site and give the tester immediate access to expected mission profiles in a pre-test, near actual flight environment. These results can be overlaid onto the actual test results for immediate determination of performance and for a more complete study in post test analysis.

While the direction has been to pack more measurement capability into more compact volumes, care must be taken to retain technologies which provide the most intuitive, and comprehensive picture of system performance. The integration of analog and digital telemetry approaches give the tester that ability for total test.

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