

# **The Advanced Subminiature Telemetry System (ASMT): A Wireless, Network Based, Miniaturized Instrumentation System**

Steven A. Musteric<sup>1</sup>

*46th Test Systems Squadron, Eglin AFB, FL, 32542, USA*

Albert Berdugo<sup>2</sup>

*Teletronics Technology Corporation, Newtown, PA, 18940, USA*

[Abstract] The aircraft-store certification community and other tri-service test organizations have identified a need for a small inexpensive instrumentation/telemetry system that can be non-intrusively installed in a variety of configurations and locations on aircraft, stores, or other test articles without significantly impacting the performance of the system being tested. This paper provides an overview of a project managed by the 46<sup>th</sup> Test Wing at Eglin Air Force Base, Florida to develop a low cost, miniaturized instrumentation and telemetry system to meet this need. The principal focus of the Advanced Subminiature Telemetry (ASMT) project is development of a flexible and modular data acquisition and telemetry system that can be non-intrusively installed on a variety of test articles without permanent modifications, reducing dependence on expensive, uniquely instrumented test assets. Technology integration, risk reduction, and demonstration of ASMT prototype functional performance have been performed under a Central Test and Evaluation Investment Program (CTEIP) sponsored Test Technology Development and Demonstration (TTD&D) project. The telemetry approach utilizes modern commercial wireless design methods and technologies and available COTS components. The system concept introduces a number of advanced features into air-to-ground telemetry including an intelligent bi-directional link that provides real-time test control and the ability to react to adverse link conditions to minimize bit error rates. The two primary ASMT subsystems under development at this time are a wireless remote sensor network for data acquisition and a network controller. The system as a whole is to be compatible with existing and future test range infrastructures.

As a follow-on to the TTD&D effort, the 46<sup>th</sup> Test Systems Squadron at Eglin AFB has initiated the ASMT Initial Test Capability Project which will aim to enhance 46TW flight test instrumentation capabilities with emphasis on the aircraft flutter application. The goals of this project are to a) evaluate the functional performance of two sets of remote sensor installations (one external, one internal to the aircraft launchers), and b) compare transmitted data to the legacy wired flutter instrumentation source currently in use. In doing so, this project will be exercising a wireless sensor network which will use the Wireless Communications Standard for Wireless Personal Area Network<sup>TM</sup> (WPAN<sup>TM</sup>) IEEE 802.15 Working Group standard (commonly referred to as Bluetooth). There are numerous challenges associated with this approach including a) the ability to transmit bi-directional RF signals in the absence of line of sight, b) electromagnetic and RF interference, c) data accuracy, d) data timing and latency, and e) environmental considerations. These risk areas will be mitigated through a series of lab tests, environmental testing, and risk reduction ground tests. The 46<sup>th</sup> Test Systems Squadron will deliver a usable set of hardware and software to the flutter flight test community in 2007.

## **I. Introduction**

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<sup>1</sup> ASMT Project Manager, 46<sup>th</sup> Test Systems Squadron (46 TSSQ), 308 W. D Avenue, Eglin AFB, FL

<sup>2</sup> Vice President, Advanced Product Development, 15 Terry Drive, Newtown, PA, 18940

he ASMT project evolved in response to a long standing need in the aircraft-store certification community for a flexible, miniaturized instrumentation/telemetry system that could be installed non-intrusively on aircraft or stores to support quick reaction test requirements. Current instrumentation systems for supporting aircraft-store compatibility testing are expensive, can be bulky, and can sometimes require extensive modifications for different aircraft and/or weapon system configurations. As new requirements for aircraft-store certification emerge, flight test assets must often be modified. This can be costly, may require customized instrumentation, and may require significant aircraft downtime. Frequently, test schedules are delayed by the non-availability of properly configured test assets resulting in delays in delivery of enhanced combat capabilities to war fighters. Additionally, space for mounting conventional instrumentation packages is limited, especially in advanced fighter aircraft, unmanned platforms, and small weapons. Although the need for a miniature instrumentation system was initially driven by the aircraft-store certification community, the ASMT concept can provide the capability to satisfy a wide variety of tri-Service test and training test needs. The ASMT concept provides a unique capability to support operational testing since, in some cases, the complete instrumentation/telemetry system can be non-intrusively installed on inventory aircraft or weapons and easily removed after test completion with minimal impact on the operational configuration. The ASMT concept will provide a cost-effective test and evaluation capability that is not available today.

The ASMT system concept is shown in Figure 1. The remote sensors and network controller form a wireless sensor network. Note the bi-directional communication links within this network. Key features of the ASMT concept are: 1) non-intrusive installation of ASMT hardware, 2) The ability to remotely activate/deactivate and re-configure remote sensors, 3) The ability to interface with a larger network. The ASMT ground station consists of a base station connected to a control PC and local area network (LAN).

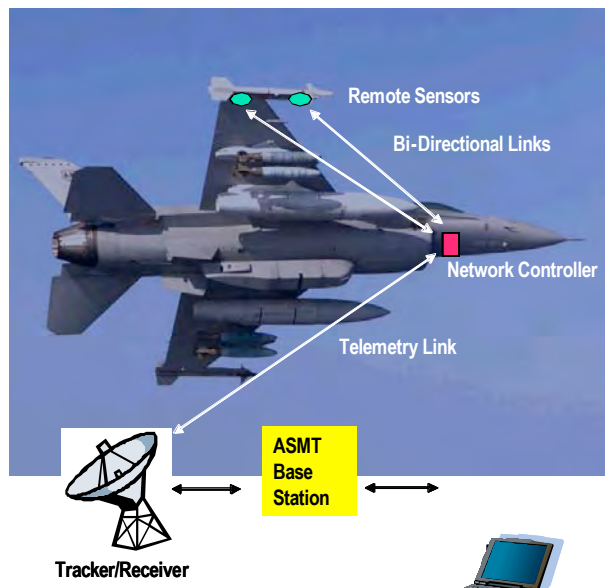


Figure 1. ASMT System Concept

## II. PROJECT DESCRIPTION AND GOALS

The design strategy for the ASMT concept includes a number of innovative approaches to minimize size and cost, maximize flexibility and utility, and provide spectral efficiency. These design innovations include:

- Maximum use of modern commercial wireless design methods and technologies;
- Use of commercial off-the shelf (COTS) components and generic computer and data storage systems to reduce cost and ensure availability;
- Modular design approach at all levels for maximum flexibility and growth potential;
- Transmit and receive capability on both ends of the link to provide real-time instrumentation control and intelligent link management from a ground base station;
- Error detection and retransmit capability to minimize bit error rates;

- Software control to allow convenient selection of key test parameters including resolution, sampling rate, and channel count;
- Capability for dynamic reconfiguration in real time during test missions;
- Flexible sensor interface capable of data acquisition from a variety of different sensor types.

### III. THE ASMT INITIAL TEST CAPABILITY PROJECT

The ASMT Initial Test Capability Project (ITC) seeks to develop an initial ASMT system that has the potential to support F-16 flutter flight test missions. To meet a goal of interoperability with future sensors, the Institute of Electrical and Electronics Engineers (IEEE) Standards Association standard IEEE 1451 Family of Smart Transducer Interface Standards and the IEEE Wireless Communications Standards for Wireless Personal Area Network™ (WPAN™) IEEE 802.15 Working Group standard (commonly referred to as Bluetooth) are to be utilized to the extent allowable with utilization of COTS equipment solutions.

**Test Objective:** Validate ASMT system performance by comparing ASMT measured flutter response data to data obtained by existing means on a flutter instrumented F-16 aircraft. Record and/or telemeter this data along with baseline flutter response data and aircraft parameters such as calibrated airspeed, Mach, altitude, etc. for real time comparison and post mission analysis.

**Desired outcome:** Enhance 46TW flutter instrumentation capability by providing a validated, non-intrusive instrumentation suite for non-flutter instrumented aircraft.

While the long range goal of the ASMT program is to independently telemeter data of interest to the ground via an integrated telemetry unit, this feature will not be exercised in the ITC project. Instead, the ASMT ITC project will make use of onboard data acquisition systems and current TM infrastructure.

#### A) 46TW NEED

Legacy wired flutter instrumentation systems found in F-16 flutter flight test aircraft at Eglin AFB are aging and becoming less reliable over time. For this reason, this project seeks to produce a leave-behind system which moves flutter flight testing into the realm of wireless network based instrumentation.

The current legacy system makes use of the Common Airborne Instrumentation System (CAIS) and associated wiring. The ASMT Initial Test Capability Project will use this system as a truth source when validating ASMT system performance.

#### B) ASMT INITIAL TEST CAPABILITY PROJECT – SYSTEM DESCRIPTION

The ASMT system to be tested under this project will be comprised of a set of wireless sensors and a network controller module. See Figure 2. The wireless sensors will be installed on FWD and AFT positions on LAU-129 launchers. These positions will allow for measurement of low frequency accelerations in the vertical, lateral, and horizontal axes. Wingtip missile launcher response measurements are labeled as “Group 1” parameters (highest priority). Inboard missile launcher responses are labeled as “Group 2” parameters (second in importance). The launchers will be mounted on F-16 stations 1 (or 9) and 2 (or 8). The wireless sensor incorporates transducers, signal conditioning, an acquisition controller, a processor, power (battery), a wireless radio, and an antenna into a sealed, aerodynamically shaped package. It is intended for external installation on the LAU-129 launcher via the use of an electro-cleavable adhesive. A second type of wireless sensor intended for installation internal to the LAU-129 is also being pursued under this project. This sensor will use available 28V DC power near the sensor unit location and will also use an external legacy transducer.

The wireless controller module is part of an on-board data system for controlling and collecting data from the wireless sensors. This unit identifies sensors in its network, facilitates the sensor calibration and programming process, and provides two way communication within its network. The controller module will be added to the aircraft data acquisition unit in a modular fashion.

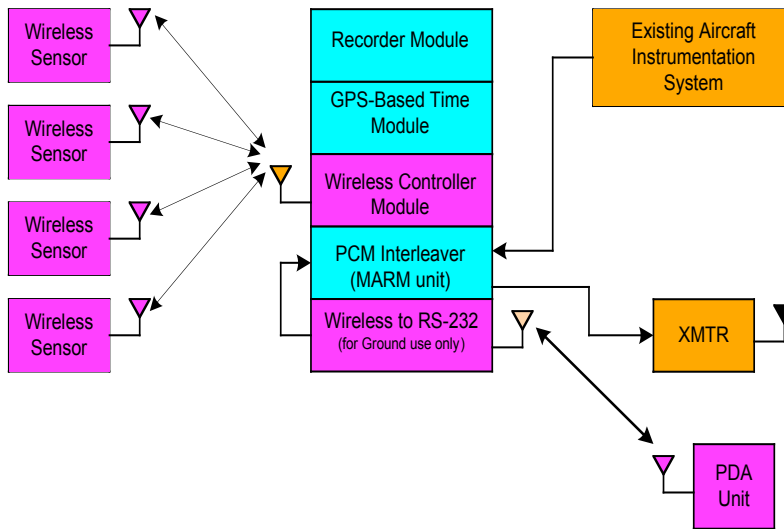
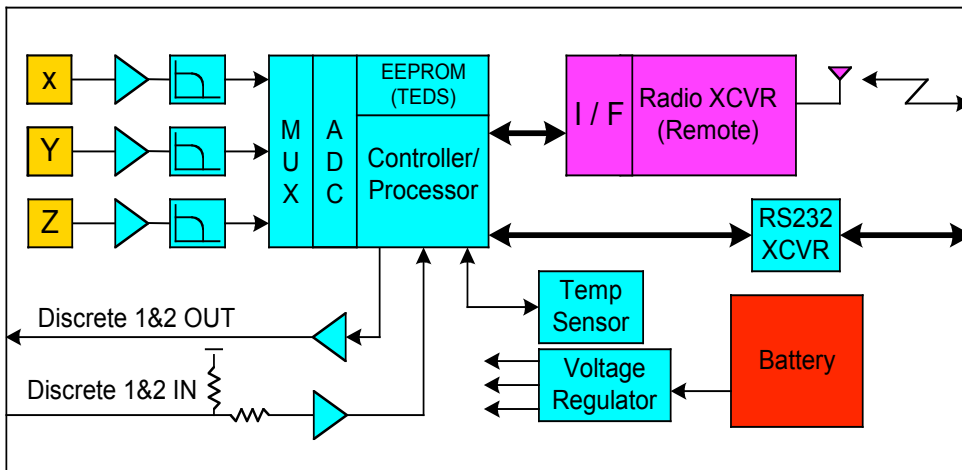


Figure 2. ASMT Initial Test Capability Project System Diagram

### C) SYSTEM COMPONENTS (DETAIL)

#### Remote Sensor Unit with Integrated Transducer and Battery (SWSC-103)

This wireless sensor is a stand-alone assembly intended for external installation on a test article via an electro-cleavable adhesive. In this project, the test article is a LAU-129 launcher. The SWSC-103 conditions one (1) triaxial accelerometer, digitizes, and encodes the data for wireless transmission to a collector node. The sensor node is processor based and allows user programmable control of sensor variables and data filtering. The sensor's programmable variables include channel sample rate, gain, offset, and digital IIR filter cutoff frequency characteristics. All calibration and signal conditioning will be preset within the unit. The sensor node is fully programmable via the wireless connection from the controller node. The unit operates from a single rechargeable internal battery for a duration of up to four hours. It includes an on-board non-volatile memory for storage of critical information such as module identifier, channel setup, transducer calibration data, etc. An IEEE 1451.0 "like" Transducer Electronic Data Sheet (TEDS) datasheet will be employed. See Figure 3.



**Figure 3. Block diagram for SWSC-103 Wireless Sensor**

The internal triaxial accelerometer is optimized for measuring low frequency vibration response. The sensor allows a programmable output sample rate of up to 200 samples/s and has a programmable filter whose  $-3\text{dB}$  frequency is automatically set to  $\frac{1}{4}$  of the sample rate (1.5 Hz to 50 Hz). The channel filter has a 6-pole Butterworth IIR characteristic. A 5-pole Butterworth filter with a  $-3\text{dB}$  frequency of 75 Hz precedes the A/D converter. This, along with the oversampling scheme of the A/D converter, prevents aliasing. The sensor unit includes a fourth channel to provide auxiliary data such as sensor temperature and/or the state of several digital I/O lines at programmable update rate. The discrete output signals represent the state of discrete input signals at the wireless controller unit. The sensor unit includes a digital signal controller capable of the following actions:

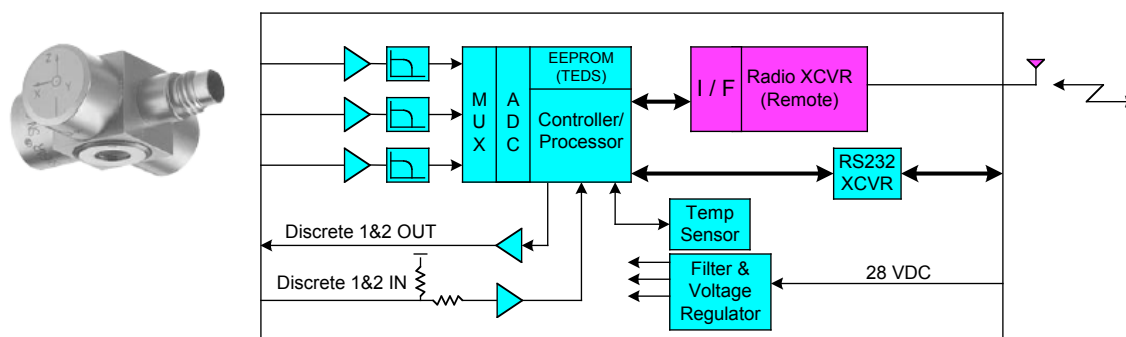
- Generation of a data sample rate clock
- Initiation of data sampling
- Control of the A/D converter and axis channel multiplexer
- Collection of axis channel data from the A/D converter
  - Collected at 400 to 800 samples per second per channel
- Implementation of an IIR filter algorithm with decimation to provide the required data output sample rate and frequency response
- Reception and correction of time information from the controller unit
  - Used to time tag outgoing sensor data
- Interface with the on-board wireless radio

Factors that influence selection of the digital signal controller include:

- Chip physical size
- Supply voltage flexibility
- Power consumption at various clock speeds
- DSP functionality (must be sufficient to maintain data flow)
- Processor instruction cycle time (must be low number of clock cycles, preferably 1)
- Useful on-board peripherals (UART, SPI, memory interface, etc.)

**Remote Sensor Unit with External Transducer (SWSC-103E)**

The second type of wireless sensor node under development under the ASMT initial Test Capability Project is described here. This unit will be installed internally in a LAU-129 missile launcher, has an external triaxial sensor requiring excitation power from the unit, uses 28 VDC power, and uses an external antenna. All other building blocks used in the unit with the internal transducer are used in this unit. The intended transducer for use with this unit is the Kistler triaxial piezo-electric accelerometer K-Shear® #8792 M 04. See Figure 4.



**Figure 4. Block Diagram for SWSC-103E Wireless Sensor**

**Wireless Controller Unit (MWTR-103)**

The wireless controller unit is installed as part of a data system such as the Teletronics MARM-2000 or MCDAU-2000 units. Its function is to receive wireless data from the sensors and to format the data in a fashion required by the host Data Acquisition Unit (“DAU”). The controller unit also sends control data and discrete channel data to the sensor units. The network controller implements command and control with the sensor units, uniquely addresses each sensor in its network, controls multiple sensors simultaneously, and provides access capability to the health status of each sensor unit in its network. In addition, the controller translates discrete inputs to the unit into discrete commands to the sensor units. On power up or as required, the controller programs the sensitivity and sample rate of the sensor channels. The frequency response of the sensor channels is automatically set to ¼ of the sample rate so in effect, it is also programmed by the controller. Periodically the sensor will append additional data to the accelerometer data. This data includes time tag, the state of the discrete sensor inputs, temperature within the sensor module enclosure as well as other required “housekeeping” signals. As required, the controller can send commands to each sensor under its control, instructing it to change the logic state of its discrete output lines and can also command the battery powered sensor to go into a “sleep” mode to conserve power. Figure 5 shows a block diagram for the wireless controller. A sensor unit is shown at left.

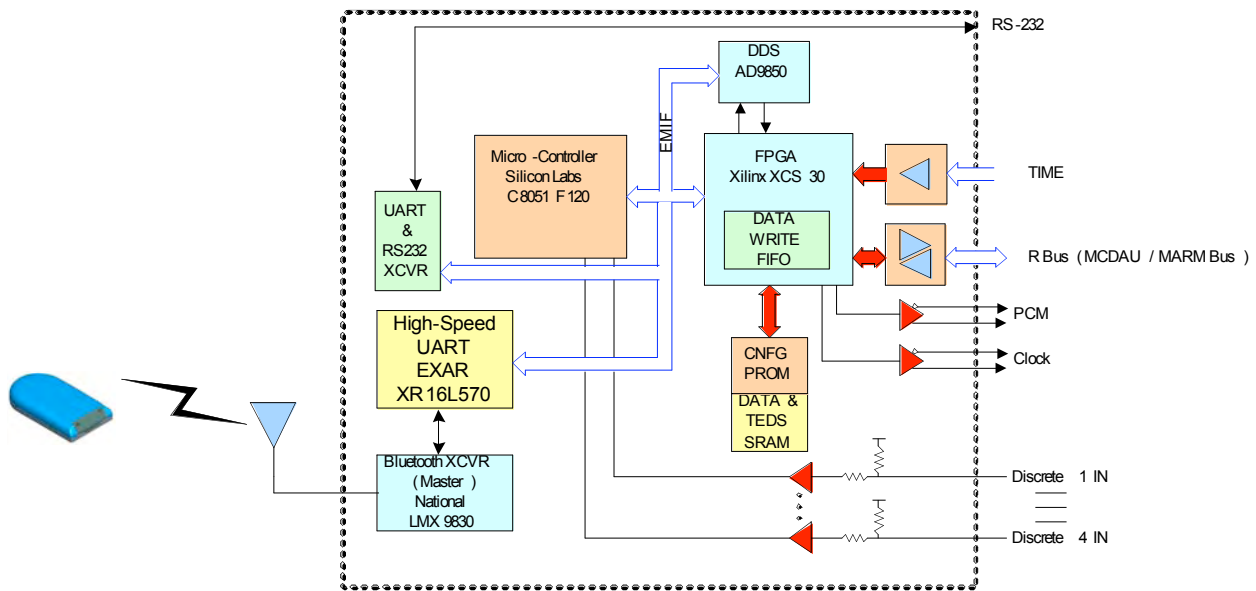


Figure 5. Block Diagram for MWTR-103 Wireless Controller

## D) MODIFICATIONS NEEDED TO SUPPORT THE ASMT INITIAL TEST CAPABILITY PROJECT

### LAU-129 Launcher Modifications

Two (2) LAU-129 launchers will be modified to incorporate the installation of the two types of remote sensors described above. Figure 6 shows proposed locations for the external installation. This installation will be accomplished through the use of an electro-cleavable adhesive. A second modification will involve the installation of a wireless sensor inside the LAU-129 (similar to AFT and FWD locations shown below). This installation will use aircraft power (28 VDC) for excitation of the transducer and will require the addition of an antenna external to the launcher. See Figure 7. It should be noted that this wireless sensor configuration differs from the externally mounted wireless sensor in that its transducer is not housed inside the sensor package but outside the package as shown in Figure 4.



**Figure 6. LAU-129 Launcher showing proposed ASMT Remote Sensor locations**

**Figure 7. LAU-129 Launcher showing location of internally mounted sensor package**

### **Aircraft Modification**

In order for the remote sensors and network controller to establish and maintain communication with each other, at least one antenna will be required on the surface of the test aircraft. Although not a “non-intrusive” solution in the classical sense, this aircraft modification is minor as is the installation of the network controller into an existing data acquisition unit within the test aircraft.

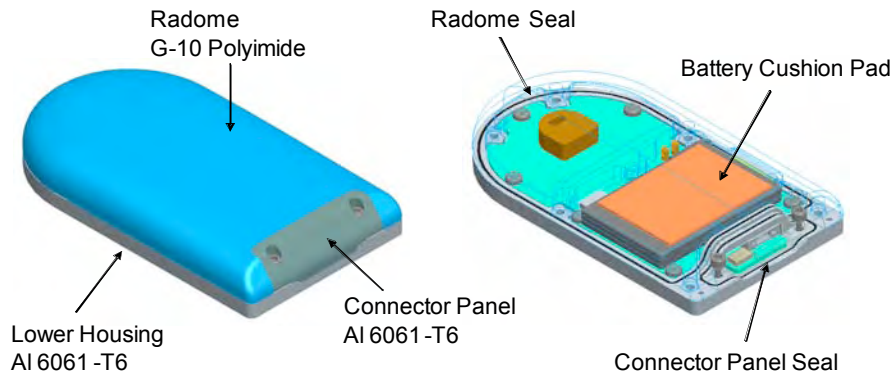
### **E) DESIGN CHALLENGES**

The following represent some of the key design challenges for the ASMT Initial Test Capability Project:

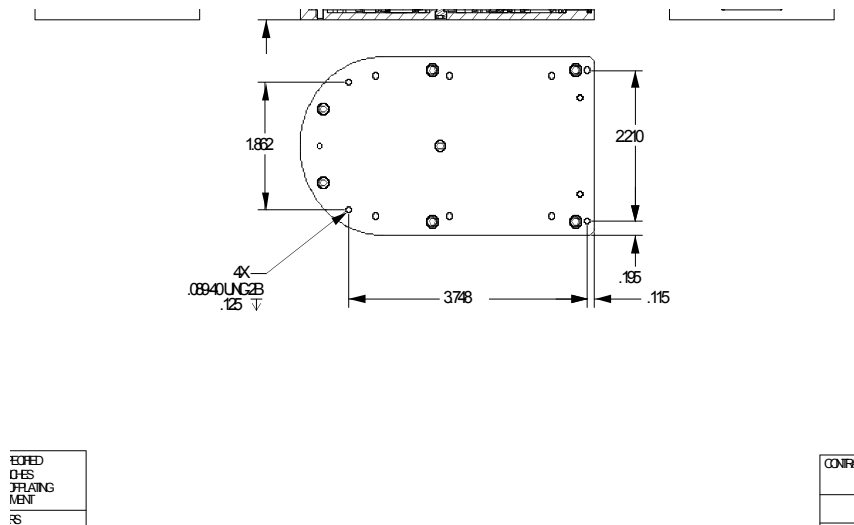
- Remote Sensor Packaging (SWSC-103)
- Battery Selection (SWSC-103)
- Radio and Antenna Selection (SWSC-103)
- Frequency Study

### **Remote Sensor Packaging (SWSC-103)**

The size and shape of the SWSC-103 unit are a function of the components contained within. Envelope drivers are the battery, the antenna, conditioning circuitry, and lower housing. Figure 8 shows two views of this sensor package.



**Figure 8. SWSC-103 Wireless Sensor**



**Figure 9. SWSC-103 Dimensions**

Figure 9 shows the dimensions of the SWSC-103 sensor unit. The size (4.625”L x 2.6”W x 0.69”H) and weight of this package (7 oz.) were determined to be acceptable for this test program. However, future applications will require further miniaturization of sensor packages to minimize aerodynamic effects.

**Battery Selection (SWSC-103)**

The power source of the SWSC-103 wireless sensor must be self-contained and capable of sufficient energy storage to provide at least four (4) hours of continuous operation. Energy storage capacity of 1.0 to 1.5 Watt-hours will be required. The battery must be lightweight and consume as little of the available sensor volume as possible. In addition, it must be able to supply short pulse currents of several 10s of milliamperes. The required operating temperature range is -40°C to +70°C.

Candidate battery chemistries were Lithium Manganese Dioxide (LiMnO<sub>2</sub>), Lithium Thionyl Chloride (LiSOCl<sub>2</sub>), and Lithium Ion. Lithium batteries are lightweight and have very high energy densities for their size. Because any Lithium cell used to power the wireless sensor will be small, the amount of Lithium present will be insufficient to pose any explosion or fire risk, should the battery housing become damaged. The LiMnO<sub>2</sub> and LiSOCl<sub>2</sub> batteries are primary (replaceable) cells. Secondary (rechargeable) chemistries were also considered. Candidate Lithium-Ion (Li-Ion) cells were tested at -40°C and +70°C with positive results. The Lithium-Ion cell was subsequently selected.

The rechargeable cell was selected primarily for ease of use. The battery can be recharged by applying +5VDC through a connector that is accessed via a removable cover. The charging circuitry is contained within the SWSC-103 sensor module to eliminate the need for an external charging unit and to prevent access to the battery terminals. This eliminates the possibility of damaging the unit by inadvertently applying a direct short circuit across the battery terminals. The use of a secondary cell will also lower overall maintenance costs and simplifies the mechanical design of the package as the need to replace the battery while the unit is installed on the aircraft is eliminated.

### **Radio and Antenna Selections**

Bluetooth (IEEE-802.15.1) and Zigbee (IEEE-802.15.4) were considered to be candidate technologies for wireless communication in this project. Each has desirable attributes. Both operate in approximately the same frequency range. Bluetooth ranges from 2.4 – 2.483 GHz with 79, 1 MHz wide RF channels (generally, 2.408 – 2.480 GHz is the operating range), transmitting up to 1Mbps (Bluetooth 2.0) or up to 2 to 3 Mbps for Bluetooth 2.0 + EDR (Enhanced Data Rate). Zigbee based systems are configured to operate at 2.4 GHz (with data rates up to 250 kbps), or alternatively at 915 MHz (with data rates up to 40 kbps), or 868 MHz (with data rates up to 20 kbps).

In terms of power consumption and device size, Zigbee and the latest version of Bluetooth (2.0) are comparable. The power requirement of Bluetooth 2.0 devices is half that of previous versions.

Zigbee devices are specified to operate over distances of up to 100 meters as are Bluetooth class 1 devices. Bluetooth class 2 devices are specified for distances up to 10 meters. Both wireless communication systems have their own security protocols. Zigbee security is defined by a 128 AES plus application layer security; Bluetooth security uses 64 and 128 bit encryption. The different security systems must be evaluated in the aircraft environment. One advantage of Zigbee devices is their connection time. Zigbee can join existing networks in less than 30ms, whereas, Bluetooth 2.0 devices require approximately 3-5 seconds.

Zigbee has the unique ability to receive information from a device outside the network, even if this receiver is not the principal controller, and then forward the information (without reading the data it is transmitting). The device simply looks at the destination and sends the data on to the controller. This capability may be useful in situations where a direct line of sight between an outlying sensor and controller is not possible.

The wireless sensor intended for external installation using electro-cleavable adhesive will employ an internal surface-mount antenna as part of the main PC board. This antenna is omni-directional and lies wholly within the sensor enclosure, greatly simplifying sensor mounting. However, signal strength of the RF link becomes a consideration in sensor placement along with the optimal position for measuring vibrations.

The wireless sensor intended for installation internal to the LAU-129 launcher will require an externally mounted antenna. This arrangement clearly requires a more intrusive installation but may provide greater flexibility in sensor placement. External antennas are connected to the sensor via a coaxial cable link that should be kept as short as possible to minimize RF signal attenuation. The choice of coaxial cable material is based on a trade-off between thinner cables that can be more easily routed and heavier cables that will introduce less RF attenuation per foot of travel. An external antenna need not be omni-directional. A properly oriented directional antenna can significantly improve the robustness of the RF data link.

Ultimately, Bluetooth was chosen because the devices were available with lower power requirements (class 2 devices) that still met the minimum distance requirement of 10 meters line of sight. Bluetooth also offers higher data transmission rates of 1 Mbps currently and up to 2 or 3 Mbps as the Enhanced Data Rate versions come to market (no suitable EDR devices were available at the time the current devices were selected). The lower power consumption is important for the external, battery powered unit and is being used in all modules for commonality and to reduce both non-recurring and recurring costs.

The antenna recommended for mounting on the aircraft is a horizontally polarized blade antenna. This could be mounted anywhere on the circumference of the fuselage and still radiate successfully to the wing (top or bottom mount would have the advantage of reaching both wings simultaneously). An added advantage of horizontal polarization is there will be additional rejection of the signal from the high power, vertically polarized telemetry antenna.

### **RF Frequency Study/Selection**

Tests will be conducted in order to better understand the capabilities and challenges associated with the use of COTS wireless transceivers in aircraft data telemetry applications. Concerns involve both the potential of wireless devices to interfere with other aircraft electronic systems and conversely, the potential for aircraft electronics to corrupt wireless telemetry data. For example, aircraft S band transmitters operate from 2.2 – 2.4 GHz while Bluetooth devices operate between 2.4 – 2.483 GHz. Sharing of this frequency band may lead to serious loss of Bluetooth data due to receiver saturation whenever the aircraft S band transmitter is in operation. This concern illustrates why wireless data telemetry testing within the vicinity of the aircraft is necessary to understand the limitations of the technology.

Line of sight is another issue in wireless technology. When implementing a low power wireless data link from one part of the aircraft to another, it is highly desirable to have an uninterrupted line of sight from transmitter to receiver. When this is not possible, the quality of the data link may suffer. For this reason, other wireless COTS technologies such as Zigbee are being studied as possible alternatives to Bluetooth for providing accurate data transmission without the benefit of a line of sight radio link.

### **F) GROUND/FLIGHT TESTS**

A series of ground and flight tests will be conducted under this project. These include:

- Laboratory testing of Bluetooth devices
  - Open field testing of the horizontally polarized blade antenna has yielded successful data transfer at distances up to 90 feet. Further tests were conducted at a distance of 30 feet with steel and aluminum obstructions. Successful data transmission was maintained.
  - Additional testing was performed with an S-Band transmitter having a measured power output of eight Watts into a vertically polarized antenna. The Bluetooth devices maintained successful communication with transmitting antenna at a distance of 5 feet from the Bluetooth transmitting antenna. The Bluetooth receive antenna was located at a distance of eight feet from the Bluetooth transmitter.
  - This preliminary ground test data provides a measure of confidence that the system will work well in the intended aircraft environment.
- Evaluation of Bluetooth RF connectivity on a test aircraft
- MIL-STD-810 environmental tests to evaluate electro-cleavable adhesive bond strength and survivability of ASMT system components
- EMC/EMI ground tests
- Captive flights on test aircraft to evaluate adhesive bond strength
- Flutter flight tests – it is these missions where ASMT measured response data will be directly compared to that measured by the legacy wired system.

Data collected by the ASMT system will be telemetered to the ground using conventional methods. Flutter flight test engineers will have the ability to view and compare ASMT data to legacy wired F-16 flutter data real time or on a post mission basis. This comparison will be a key indicator as to the data quality provided by the ASMT system. The goal of the ASMT Initial Test Capability Project is to deliver a proven, reliable wireless, network based instrumentation system which supports F-16 flutter flight testing within the 46<sup>th</sup> Test Wing.

## **IV. FUTURE APPLICATIONS**

The long range goal of the ASMT project is to develop a family of non-intrusive wireless sensors for a wide variety of test and training applications. One of these applications is store separation/store Time, Space, and Position Information (TSPI). Sensors developed for this application must be extremely small, aerodynamically packaged, and lightweight. The communication protocol, power source, frequency band selection, and controller module design are some of the areas that merit careful study for this application. Requirements definition is underway. Potential users include weapon development programs, operational testers, the training community, the aircraft-store certification community, or other scenarios where TSPI is required. Other applications and sensor types include, but are not limited to, high frequency vibration for instrumentation of stores, pressure sensors (surface measurements), and acoustics (weapons bays).

As depicted in Figure 1, the ASMT concept includes a base station which interfaces with a personal computer. Future ASMT work will strive to include this component so as to exercise key attributes of the system such as sensor re-configuration, and changing resolution and/or sample rate. The ASMT project keeps pace with the Integrated Network Enhanced Telemetry (iNET) project and will work within established guidelines when considering methodologies for the bi-directional air-to-ground telemetry link segment of the system. It is also possible that the iNET project would provide the network to accomplish this link. The ASMT project may serve as a demonstration platform for the vehicular network component of iNET.

## V. CONCLUSIONS

The potential applications for the ASMT system are numerous and varied. The test article or item to be instrumented is not limited to aircraft or stores. In fact, the test item can be anything where the measurement and transmission of one or more physical phenomena are of interest. Major challenges include miniaturization of hardware, particularly the remote sensors, power, and selection of the appropriate communication protocol and operating frequency. There have been a host of advances in these areas in recent years. The ASMT project hopes to leverage these advances and integrate the latest COTS hardware into an affordable system. Another set of challenges revolves around the telemetry link. As discussed in this paper, one of the key features of the ASMT system is the ability to re-configure the sensors via uplink messages. This can be done either through the development of unique ASMT subsystems or by relying on the iNET project to provide a network by which to exercise this feature.

The ASMT concept offers a much needed alternative to the test and training communities for the rapid, non-intrusive instrumentation of a wide variety of test articles.

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