LEGACY SENSORS GO WIRELESS WITH IEEE P1451.5

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ABSTRACT

The wireless sensor concept has been hindered in the past by the large number of components needed to add the wireless transceiver feature and the additional power consumption needed for that feature. This has been resolved by incorporating all the wireless components into a single, low power modular circuit. Intelligence is being added to legacy sensors to make them Institute of Electrical and Electronics Engineers (IEEE) 1451.4 compatible with an element called a Sensor Identification Transducer Electronic Data Sheet (SITEDS), which contains the Transducer Electronics Data Sheet (TEDS) for that sensor. All the sensor interface parameters are automatically configured by a module called the Universal Smart Transducer Interface Module (USTIM) using the TEDS input from the respective sensor's SITEDS. An IEEE P1451.5 compatible wireless interface can be incorporated into the SITEDS with the transceiver module giving the legacy sensor full wireless capability.

KEYWORDS

Smart transducers, IEEE 1451.4, IEEE 1451.5, Wireless, AATIS, data acquisition, SITEDS, USTIM and NCAP

INTRODUCTION

A system is being developed for Edwards AFB to give old sensors the same plug-and-play capability as the new 'smart' sensors. These smart sensors are being designed and developed according to the new IEEE 1451.3 and .4 standards and have the necessary information contained in their TEDS allowing them the same plug-and-play capability as the new sensors. The information needed to describe a particular sensor is located with each individual sensor, thus removing the need to program the main system with this information. The IEEE 1451.4 compliant SITEDS information is located with each sensor and will be available to the ground support equipment (GSE) when the particular sensor is inserted into the system. A device called a network-capable applications processor (NCAP) was developed to interface the USTIMs to the Advanced Airborne Test Instrumentation System (AATIS) party line bus. The legacy sensors with their associated SITEDS are connected to a USTIM, which resides on an NCAP-USTIM Party Line (NUPL) bus with other USTIMs. This bus is connected to the NCAP that, in turn interfaces to an external bus, such as the

AATIS party line bus. An IEEE P1451.5 compatible wireless interface could be incorporated into the SITEDS with the transceiver module giving the legacy sensor full wireless capability eliminating the need for the USTIM.

SENSOR IDENTIFICATION TEDS MODULE

In this system, the sensor/memory units are connected to a USTIM, which is essentially the same as the transducer bus interface module (TBIM) described in the IEEE 1451.3 standard. Since the USTIM is able to accommodate a changing number and variety of sensor/memory units, a complete TEDS, as described in the IEEE 1451.2-1997 standard, cannot be predetermined and stored in the memory module. In addition, data that are not incorporated into the TEDS descriptions in the IEEE 1451.2-1997 standard are required by the USTIM in order to properly configure the interface hardware to the sensor/memory unit.

In order to accommodate the unique requirements of the USTIM, a method of creating the overall TEDS and configuring its storage in the system had to be devised. With this method, all of the unique, sensor-specific information and portions of the transducer channel TEDS (including appropriate sub-TEDS for the transducer channel TEDS - such as the calibration TEDS) will be stored in the SITEDS. The rest of the TEDS will be stored in the USTIM. Further, portions of the TEDS will vary depending on the number and types of sensors that are connected to the USTIM. These portions of the TEDS will be dynamically created by the USTIM on power-up and in response to changes in the USTIM's sensor configuration.

THE IEEE 1451.4 SPECIFICATION STANDARD FOR SITEDS

The IEEE 1451.4 is a standard for adding sensor parameter information in a TEDS stored in an electrically erasable programmable read-only memory (EEPROM) that resides in the sensor. The IEEE 1451.4 smart TEDS sensors provide both an analog signal for traditional measurement, along with a serial digital link for accessing the TEDS information for plug-and-play operation.

The memory module that is connected to each legacy sensor will be contained in the SITEDS. The SITEDS will contain those portions of the channel TEDS that can be predetermined, regardless of the hardware and operation of the USTIM, as well as the sensor-specific data that are required by the USTIM or desired for possible use at the system level. The USTIM will use the SITEDS to create a complete transducer channel TEDS.

Some of the data fields contained in the SITEDS are shown in the examples in Table 1. The information required for the channel TEDS specified in the IEEE 1451.3 standard is shown in Table 2. Each octet listed in column 4 (table 2) is 8 bits long. The column specifying 'type' designates the data type. Unsigned 8-bit integers are designated by U8C for counting. An unsigned 16-bit integer is designated for counting by U16C and field length by U16L. An unsigned 32-bit integer is designated for counting by U32C and field length by U32L. The F32 designates a single precision real number and F64 a double precision number. A string is implemented with the eXtensible Markup Language (XML) controlled by the document W3C XML 1.0. Physical units are designated by 'Units' and are 10 octets long.

Table 1. Example Contents of the SITEDS for Two Sensors

	IEPE Accelerometer		Bridge (mV/V) Load Cell	
Basic TEDS	Manufacturer ID	34	Manufacturer ID	64
	Model ID	8113	Model ID	24
	Version Letter	A	Version Letter	C
	Serial Number	00461G	Serial Number	0003461
Standard and Extended TEDS	Calibration Date	June 14, 2002	Calibration Date	Dec 15, 2001
	Sensitivity @ Ref.	1.094E+03 mV/g	Measurement	± 100 lbf
	Reference Freq.	100.0 Hz	Electrical Output	± 3.01 mV/V
	Reference Temp.	23 °C	Bridge Impedance	350
	Measurement	± 50 g	Excitation, Nominal	10 VDC
	Electrical Output	± 5 V	Excitation, Min.	7 VDC
	Quality Factor	300 E-3	Excitation, Max.	18 VDC
	Temp. Coefficient	-0.48 % / °C	Response Time	5 ms
	Direction (x,y,z)	x		
User Data	Sensor Location	3A-p2	Sensor Location	R32-1
	Calibration Date	April 15, 2003	Cal. Record ID	543-01.23

Table 2. Contents of the Transducer Channel TEDS

Field	Description	Type	# octets
—	TEDS length	U32L	4
1	TEDS identifier	U8E	1
—	TransducerChannel related information	—	—
2	Calibration key	U8E	1
3	TransducerChannel type key	U8E	1
4	Physical units	UNITS	10
5	Design operational lower range limit	F32	4
6	Design operational upper range limit	F32	4
7	Worst-case uncertainty	F32	4
8	Self-test key	U8E	1
—	Data converter related information	—	—
9	Data model	U8E	1
10	Data model length	U8C	1
11	Model significant bits	U16C	2
12	Maximum data repetitions	U16C	2
13	Series origin	F32	4
14	Series increment	F32	4
15	Series units	UNITS	10
16	Maximum pre-trigger samples	U16C	2
—	Timing related information	—	—
17	TransducerChannel update time (t_u)	F32	4
18	TransducerChannel write setup time (t_{ws})	F32	4
19	TransducerChannel read setup time (t_{rs})	F32	4
20	TransducerChannel sampling period (t_{sp})	F32	4
21	TransducerChannel warm-up time	F32	4
22	TransducerChannel read delay time (t_{ch})	F32	4
23	TransducerChannel self-test time requirement	F32	4
—	Time of the sample information	—	—
24	Source for the time of sample	U8E	1
25	Incoming propagation delay through the data transport logic	F32	4
26	Outgoing propagation delay through the data transport logic	F32	4
27	Trigger-to-sample delay uncertainty	F32	4
—	Attributes	—	—
28	Sampling attribute	U8E	1
29	Buffered attribute	U8E	1
30	End-of-data-set operation attribute	U8E	1
31	Streaming attribute	U8E	1
32	Edge-to-report attribute	U8E	1
33	Actuator-halt attribute	U8E	1
—	Sensitivity	—	—
34	Sensitivity direction	F32	4
35	Direction angles	Two F32	8
—	Options	—	—
36	Event sensor options	U8E	1
—	Checksum	U16C	2

An EEPROM containing the transducer channel TEDS information, resides at the sensor instead of the USTIM, allowing the legacy sensors to become plug-and-play. The 24CXX family of EEPROMs is used since it offers a wider range of available memory and package sizes. For example, 128 x 8 bits of nonvolatile memory can be contained in a small 5-pin SOT-23 package. For many sensor types, this amount of memory may be sufficient for storing transducer channel TEDS information, provided calibration data are stored as coefficients as opposed to a large look-up table array.

Figure 1. SITEDS Adapter

To ensure a stable power source, a voltage regulator accompanies the memory device. The memory circuit could also tap the sensor excitation voltage. Since the memory is only accessed at power-up, the serial clock and data in-lines will be held in a DC state during normal operation. Hence, cross coupling of the digital to analog signals will not be an issue. Figure 1 shows a SITEDS module contained in snap-on housing for legacy sensors. A two-wire, I^2C bus is used to communicate with the USTIMs.

LEGACY SYSTEM UPGRADE TO IEEE 1451.3

A block diagram of the legacy system upgrade is shown in figure 2. These modules contain the intelligence and TEDS for each sensor. The modules are then connected together on their own 4-wire NUPL bus with other USTIMs, thus eliminating the need for the large cabling systems that are currently being used.

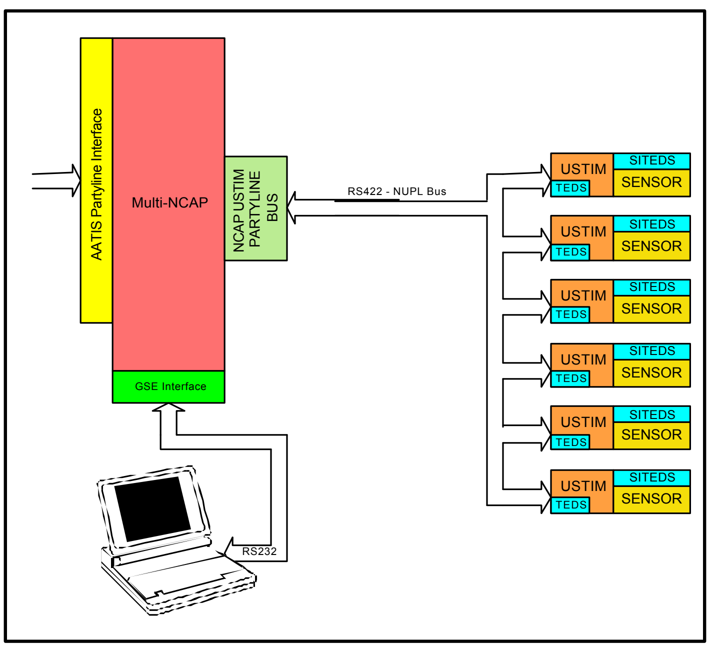

Figure 2. Multi-USTIM System Diagram with RF Interface

Changing to the information contained in the USTIM modules can be accomplished either through the main system, if allowed, or through a laptop computer or PDA. An IEEE 1451 TEDS can be loaded onto a USTIM through the GSE interface with a laptop computer during installation. An IEEE 1451.4 compliant TEDS associated with each legacy sensor will be located in the SITEDS. As previously mentioned, this module will be located next to the USTIM and plugged into the same connector as the sensor. A general purpose USTIM can be used with a variety of legacy sensors with no changes to its hard circuitry.

WIRELESS SENSOR UPGRADE

Circuits needed to allow wireless communication of modules on a bus have gotten smaller and power consumption has been reduced. This has produced the opportunity to add wireless connectivity to the sensors themselves. The IEEE has recognized this situation and is developing the IEEE 1451.5 specification to define Transducer Electronic Data Sheets (TEDS) based on the IEEE 1451 concept, and protocols to access TEDS and transducer data. It will adopt necessary wireless interfaces and protocols to facilitate the use of technically differentiated, existing wireless technology solutions. It will not specify transducer design, signal conditioning, wireless system physical design or use, or use of TEDS. An openly defined wireless transducer communication standard, that can accommodate various existing wireless technologies, will reduce risk for users, transducer manufacturers, and system integrators. It will enhance the acceptance of the wireless technology for transducer connectivity. The work for the wireless IEEE P1451.5 standard is leveraging other 1451 and 802 projects. This will include:

- Smart Transducer Object Model from 1451.1
- Basic TEDS Concept from 1451.2
- Synch and XML TEDS from 1451.3
- Compact TEDS and Transducer Interface from 1451.4
- Medium access and physical layer definitions from IEEE 802 family

Bringing legacy sensors up to the proposed IEEE P1451.5 standard will require some changes to the current system shown in figure 2. Each sensor will require a special SITEDS module to convert the sensor analog signal to digital and transmit the digital data and the TEDS information. The requirement to have USTIMs with multiple inputs is eliminated. A USTIM is still required for multiple sensors, but only one RF connection is needed. This will be a high-speed connection since many sensors must be multiplexed through the USTIM. The USTIM can now be made a part of the NCAP. This is shown in figure 3.

Current transducers used in an Instrumentation Support System (ISS) have no ability to be queried. The smart transducers described above can respond to queries with all the ‘vital statistics’ regarding their functionality – e.g., whether they are working, what their calibration information is, what their serial number is, or simply what they measure. This will allow an ISS to know exactly what is available on a test vehicle, which, in turn, would allow the coordination of the instrumentation setup and the ground station setup for a test to be significantly simplified. It would also be advantageous to generate simulated output and to auto-calibrate (change the calibration coefficients in real-time). This will allow full pre-test checkout and dynamic error correction, which, in turn, will decrease maintenance and increase quality. Handheld devices to allow reading and writing information to smart transducers are needed. Figure 4 shows a PDA displaying the contents of an accelerometer TEDS. Software that can do system-wide queries of status and configuration information will be needed. Wireless support GSE will be needed when data acquisition systems are installed on aircraft since wired connections such as those used in the existing NCAP for GSE may not be easily accessible.

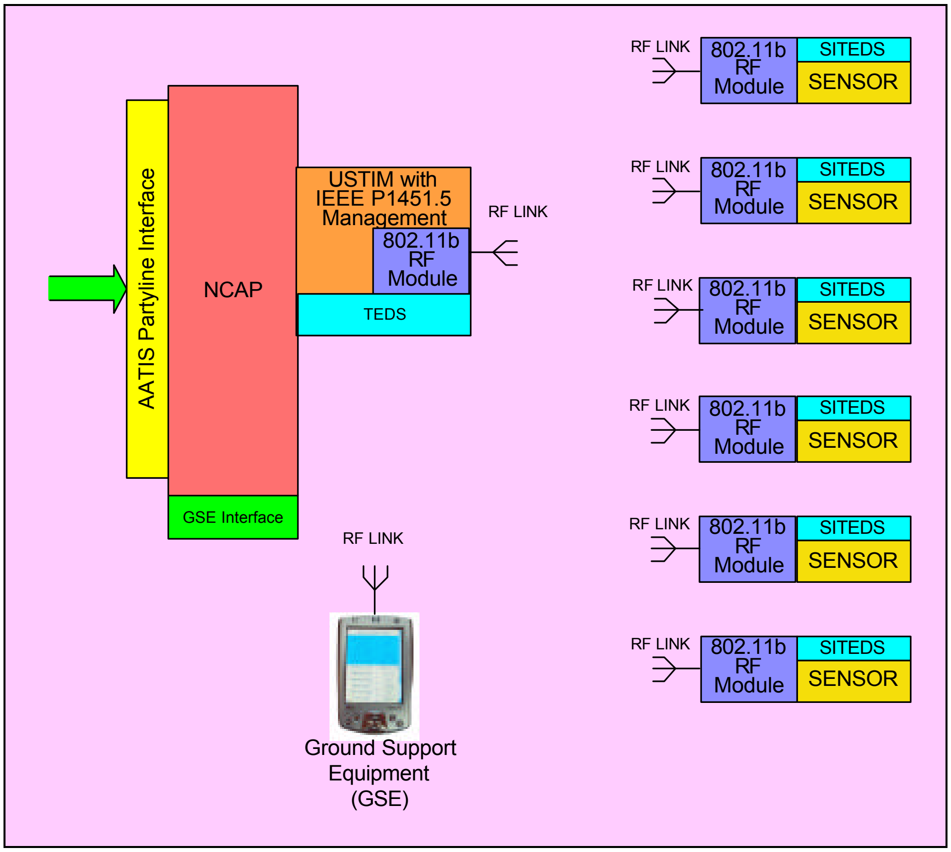

Figure 3. Wireless sensor bus with NCAP and USTIM combined

WIRELESS LAN NODE MEETING THE IEEE 802.11B SPECIFICATIONS

The wireless LAN node (WLN) module is a wireless local area network (WLAN) product based on the IEEE 802.11 standard and uses direct-sequence spread spectrum (DSSS) technology.
It is interoperable with PC-compatible WLANs and access points that conform to the 802.11b standard. The WLN module contains a media access controller (MAC), radio frequency (RF) transmitter and receiver section, and RF power amplifier. An external antenna is connected to the module to transmit and receive RF signals. A block diagram of the WLN module is shown in figure 5.

Figure 4. PDA displaying TEDS information

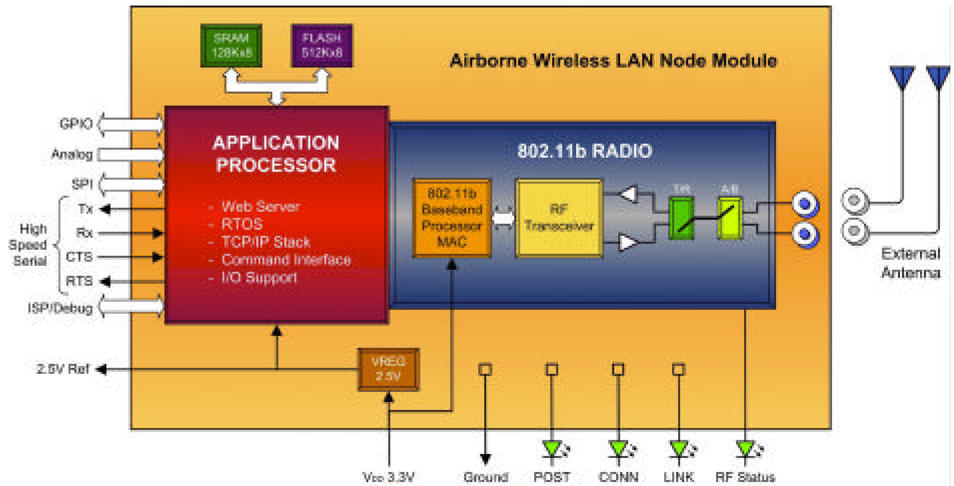

Figure 5. Wireless LAN module.

The physical wireless WLN module is shown in figure 6. Note the two antenna connectors on the top view of the module. These can be used for diversity antennas. The interface connector to the USTIM is shown in the bottom view. The WLN module size is 38 x 27 x 4.2 mm.

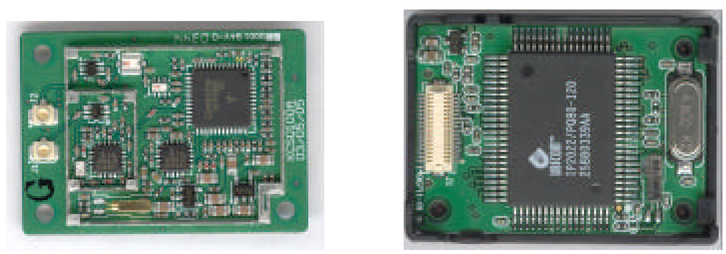

Figure 6. Wireless LAN Module Top   Bottom – Actual size

The wireless LAN module is contained in the USTIM-NCAP enclosure shown in figure 7. The antenna is connected to the USTIM-NCAP, shown in figure 7.

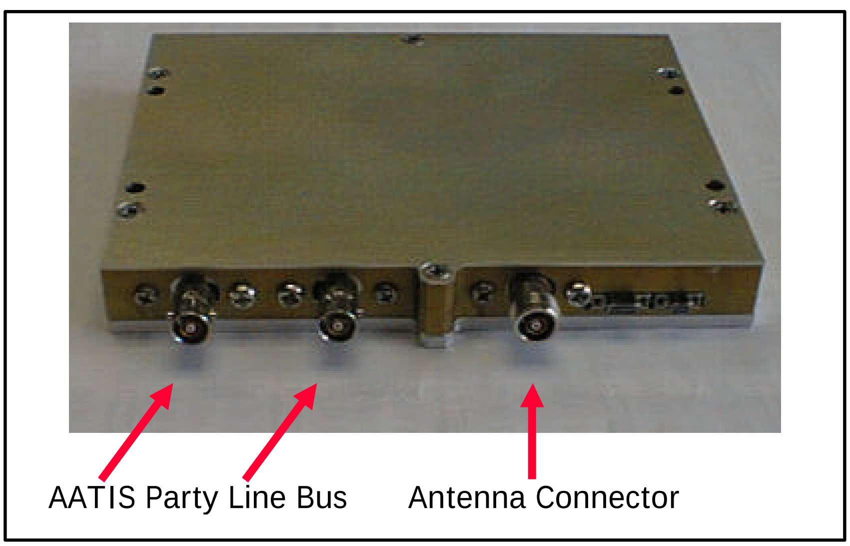

Figure 7. USTIM-NCAP with Wireless LAN Interface

Once the USTIM-NCAP is configured, the main system will be able to detect its addition to the system and automatically download all the information necessary to describe the sensors. Thus, no special software or hardware will be required for the legacy systems. A block diagram of the AATIS system and the sensors and their RF SITEDS is shown in figure 8. The USTIM connects the respective transducers directly to the System Control Unit's (SCU) party line bus through its integral NCAP as shown connected to the heavy black line in Figure 8. No additional interfaces are required since the GSE as well as the wireless smart sensors can use the RF interface. An in-circuit reprogrammable logic device is contained within the USTIM-NCAP that can be reconfigured with a laptop computer to accept other protocols.

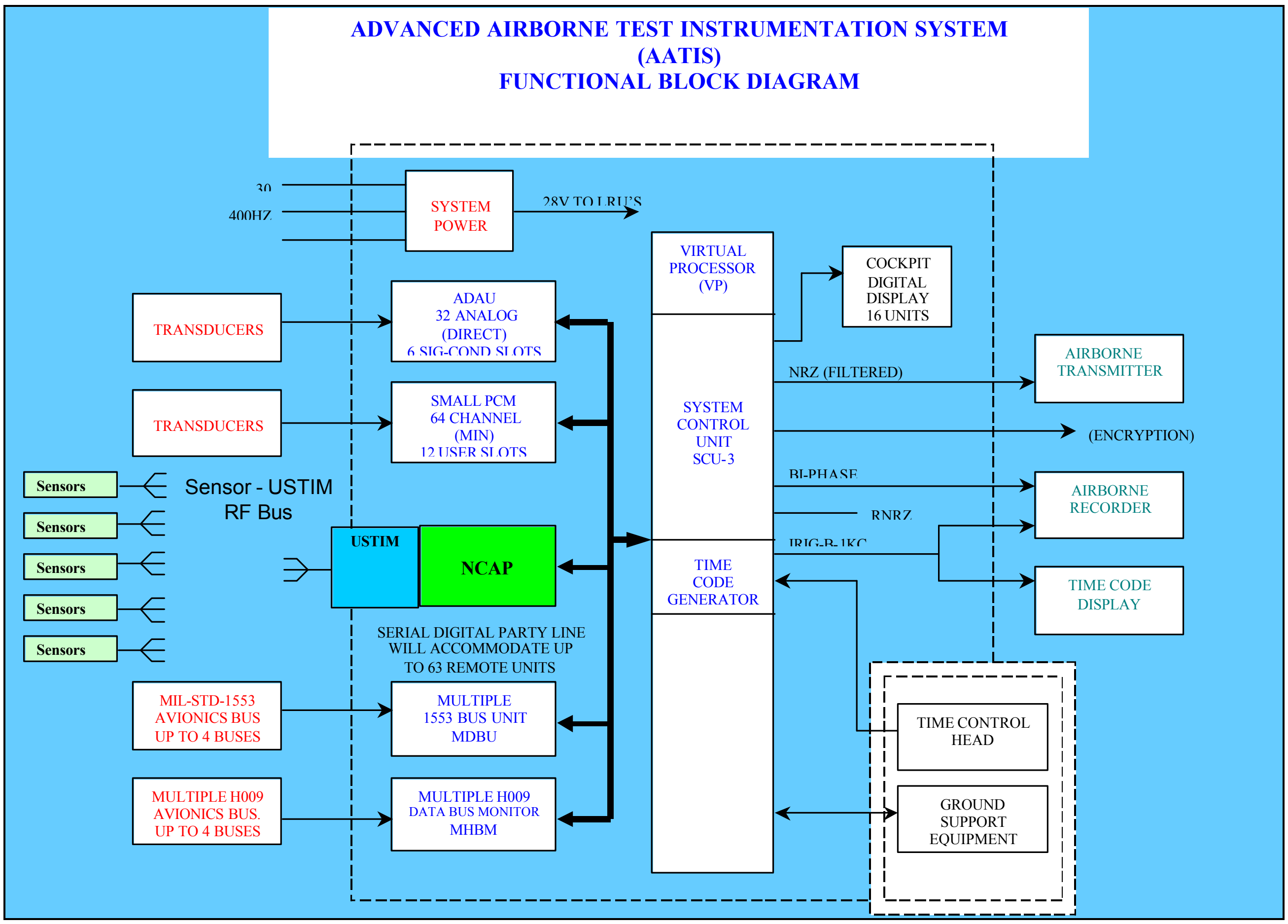

Figure 8. AATIS Block Diagram with Sensor RF Bus to USTIM – NCAP combined

CONCLUSION

The development of the NCAP, USTIM, and SITEDS has paved the way to reduced installation, maintenance, and configuration management for legacy systems such as the AATIS. With the incorporation of these innovations, cabling systems will also be greatly reduced. Adding wireless capability to legacy sensors meeting the proposed IEEE P1451.5 standard will reduce the amount of wiring even further. A wireless GSE PDA will be able to reconfigure and service the TEDS as well as perform other maintenance tasks over the same RF link as the smart sensors after the IEEE 1451 compatible test modules are imbedded in the aircraft.

ACKNOWLEDGMENT

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REFERENCES

1. IEEE Std 1451.1-1999, *IEEE Standard for a Smart Transducer Interface for Sensors and Actuators – Network Capable Application Processor (NCAP) Information Model.* Institute of Electrical and Electronics Engineers, New York City, New York, June 1999.

2. IEEE Std 1451.2-1997, *IEEE Standard for a Smart Transducer Interface for Sensors and Actuators - Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats.* Institute of Electrical and Electronics Engineers, New York City, New York, September 1997.

3. IEEE Std 1451.3, *Standard for A SMART TRANSDUCER for SENSORS and ACTUATORS – Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems.* Institute of Electrical and Electronic Engineers, March 31, 2004. (Final version recently approved and published.)

4. IEEE Std 1451.4, *Standard for a Smart Transducer Interface for Sensors and Actuators – Mixed-Mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats*. Institute of Electrical and Electronic Engineers, March 2001. (Final version recently approved, not yet published.)

5. IEEE Std P1451.5, *Draft Standard for A Smart Transducer Interface for Sensors and Actuators - Wireless Communication Protocols and Transducer Electronic Data Sheets (TEDS) Formats*, working group website - http://grouper.ieee.org/groups/1451/5/

6. IEEE Std 802.11b-1999, *(Supplement to ANSI/IEEE Std 802.11, 1999 Edition) Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band*. Institute of Electrical and Electronics Engineers, New York City, New York, September 1999.