Defence Science Journal, Vol. 63, No. 2, March 2013, pp. 186-191, DOI: 10.14429/dsj.63.4262

REVIEW PAPER

Wireless Data Acquisition System for Launch Vehicles

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ABSTRACT

Present launch vehicle integration architecture for avionics uses wired link to transfer data between various sub-systems. Depending on system criticality and complexity, MIL1553 and RS485 are the common protocols that are adopted. These buses have their inherent complexity and failure issues due to harness defects or under adverse flight environments. To mitigate this problem, a prototype wireless, data acquisition system for telemetry applications has been developed and demonstrated. The wireless system simplifies the integration, while reducing weight and costs. Commercial applications of wireless systems are widespread. Few systems have recently been developed for complex and critical environments. Efforts have been underway to make such architectures operational in promising application scenarios. This paper discusses the system concept for adapting a wireless system to the existing bus topology. The protocol involved and the internal implementation of the different modules are described. The test results are presented; some of the issues faced are discussed and the; future course of action is identified.

Keywords: Wireless, data acquisition, RF, bus controller, remote terminal, separation events, launch vehicle, radio frequency

NOMENCLATURE

WDAU-M	Wireless data acquisition unit-master
WDAU-S	Wireless data acquisition unit-slave
BC	Bus controller
RT	Remote terminal
RF	Radio frequency
ADC	Analog to digital convertor
CRC	Cyclic redundancy check
RE	Radiated emission
FEC	Forward error correction

1. INTRODUCTION

Data bus wiring harness between packages is a significant contribution by avionics towards payload integration complexity and weight. Wiring is prone to harness defects and failures in adverse environmental conditions. It is a point of failure in daisy chain implementation of multi-drop bus schemes. Buses like RS485 require specific bus termination for proper impedance matching of the bus.

A wireless interface between the different data acquisition modules eliminates the bus wiring; it does not require bus termination as required by certain bus topologies; it reduces overall weight. For an inter-stage communication, a wireless scheme eliminates the need for connectors and their subsequent disconnection on stage separation. Even after stage separation, it allows acquisition of parameters like strain measurements and pressure monitoring for retro-rocket firing. For manned missions, a wireless data acquisition system would monitor the astronaut's health parameters while also allowing for crew mobility within the crew module or during extra-vehicular activities. It has application on ground-based test-stands, simplifying the electrical integration for the complex instrumentation involved.

2. EXISTING APPLICATIONS

Literature survey indicates that wireless systems have been flown in experimental nano-satellite modules[1]. RFID is used for inventory management on the International Space Station (ISS)[2]. On-board WiFi was provided on the ISS for wireless data connectivity for astronauts on their PDAs. Temperature and strain data on the space shuttle were also monitored by wireless modules[3].

Commercial applications are numerous - the omnipresent mobile phones, wireless keyboard and mouse, wireless dongles for internet connectivity, keyless car-entry, cordless telephones, wireless door bells, wireless sensor networks; the list is endless. Any launch vehicle system requires ruggedness in aspects of redundancy, security, interference immunity, error handling and recovery, packaging and environmental protection. RF systems are now available with high data-rates and improved ranges, while implementing enhanced error detection mechanisms for received data payloads, making the implementation of a wireless scheme feasible.

3. GENERALISED BLOCK DIAGRAM

The present implementation looks to realise the wireless system as an add-on, data acquisition scheme that operates in tandem with the existing wired scheme, which is similar

Received 10 September 2012, revised 08 February 2013, online published 23 March 2013

to MIL-1553 interface. The proposed system implements a bus controller (BC) that communicates with multiple remote terminals (RTs). One RT is made as a wireless data acquisition unit - master (WDAU-M) terminal that interfaces with multiple wireless data acquisition unit - slaves (WDAU-S). For the wireless network, the master assumes the role of the BC (Secondary), while the slaves act as RTs (Secondary). The master–slave configuration applies to both the primary and the secondary phases, with the WDAU-M acting as a buffer between the two phases. The WDAU-M module is itself an RT in the wired domain.

The rest of the primary RTs function as data acquisition unit for multiple sense channels. Since the WDAU-Ss have a similar data acquisition role as the other RTs, they are to replace the RTs in a phased manner, till the BC can communicate wirelessly, when no more wired link will be necessary. Figure 1 shows generalised block diagram of a wireless data acquisition system.

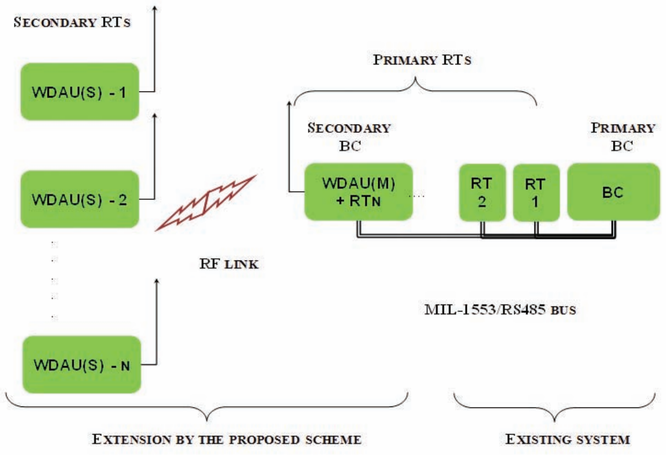

Figure 1. Generalised block diagram of a wireless data acquisition system.

4. ADVANTAGES OF THE PROPOSED SYSTEM

The wireless scheme gives the advantage of reduction in harnessing compared to the present wired scheme - this can be a major savings in the upper stages of the launch vehicle. While 1553 protocol enforces a data-rate of 1 Mbps, it also has a limitation of 31 RTs on the bus. 256 devices can be addressed using the proposed scheme and can be scaled with increased byte allocation for the address field. Presently, stage separation events are monitored till within a few milliseconds after separation using a detachable lanyard. The method is primitive as well as highly susceptible to failure. A clean separation monitoring mechanism is feasible with the proposed scheme. The trade-offs here are the reduced data rate, change in communication mechanism to packet data transfers and an overall increase in RF signals onboard. Yet, the reduction in harnessing translates into simplified integration, reduced weight and costs.

5. PROTOCOL IMPLEMENTATION

Various implementation protocols have been worked out as below.

a. *Real time transmission of data:* The WDAU-M, at pre-defined intervals, interrogates the slave and collects and stores the data. The primary BC interrogates the WDAU-M at regular intervals, the latter responds with the latest available data. The acquisition by the primary BC from the WDAU-M and the acquisition by the WDAU-M from WDAU-S run independent of each other. To ensure that repetition of transmission of data doesn't occur, time-stamping or data ID is used. Figure 1 shows real time transmission of data.

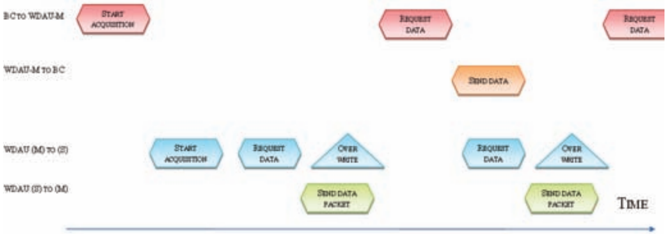

Figure 2. Real time transmission of data.

b. *Storage and delayed mode of transmission:* The WDAU-M, at pre-defined intervals, interrogates the slave and collects and stores the data with time-stamp. The primary BC interrogates the WDAU-M in delayed mode, the latter responds with the time-stamped data. This protocol may be suitable for transmission of data from separated stages. Figure 1 shows delayed data transmission for data acquisition in separation events.

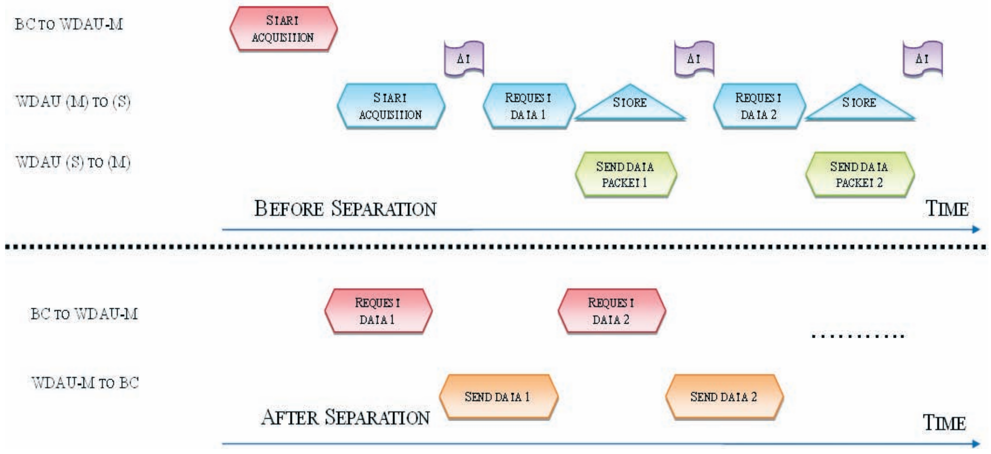

Figure 3. Delayed data transmission for data acquisition in separation events.

c. *Interoperability:* To allow interoperability between different wireless slaves, the WDAU-M communicates with multiple WDAU-Ss using a common frame format. For ease of implementation, all devices communicate over a common, RF frequency. Time-Division Multiplexing is adopted for interrogating the WDAU-Ss. Currently, interoperability among systems, running at different frequencies and different protocols, is not envisaged. Yet, the wireless module is made re-configurable for frequency and protocol. So it should be possible to dynamically program the system for a different configuration to interface with a different telemetry chain and is left for future work.

6. INTERNAL IMPLEMENTATION SCHEME FOR WDAU-SLAVE

The sensors that need to be monitored are connected to the WDAU-Slave. A simple, low-pass, resistor-capacitor filter forms the front-end electronics. 24-bit, ΣΔ ADC is used for each channel to be monitored. A microcontroller interfaces to the ADCs and the RF transceiver. A low dropout regulator is used to regulate the voltage to the ICs within the package. A checkout interface is provided for lab-level testing and verification. Figure 4 shows internal implementation of WDAU-Slave.

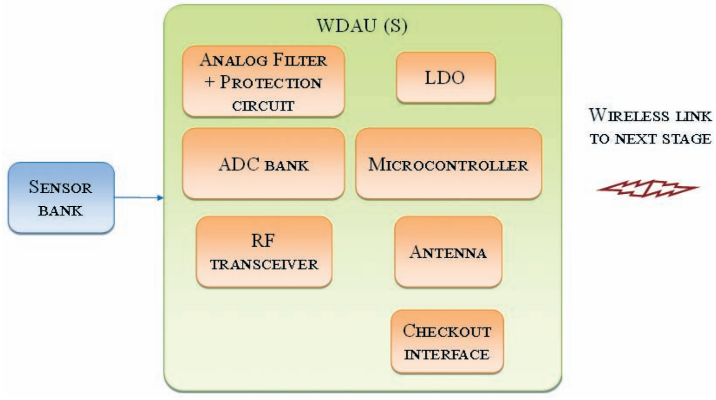

Figure 4. Internal implementation of WDAU-Slave.

7. INTERNAL IMPLEMENTATION SCHEME FOR WDAU-MASTER

The implementation of the RF and power systems remains similar to the WDAU-Slave. The Master module effectively acts as a relay, sending data logged from the slaves to the Bus Controller. The collation of data from the slaves can run independent from the wired protocol. The wired link to the BC can be implemented by an RS485/MIL-1553 interface. SRAM/EEPROM provides data storage for the delayed telemetry option. Figure 5 shows internal implementation of WDAU-master.

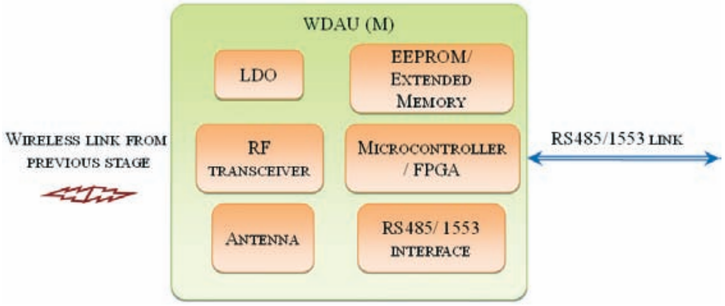

Figure 5. Internal implementation of WDAU-Master.

8. AVAILABLE WIRELESS SPECTRA AND PROTOCOLS

Frequency choices are limited to spectra allocated to license-free operation. These include frequencies in and around 13.56 MHz, 40 MHz, 433 MHz, 868 MHz, 915 MHz, 2.4 GHz, and 5.8 GHz. The sub-1 GHz ranges are preferred for applications that require longer range and lower power. Figure 6 shows unlicensed frequency band.

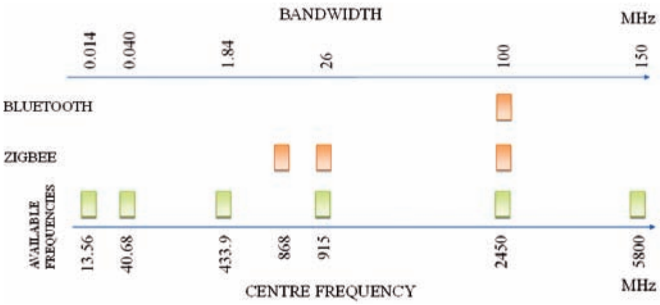

Figure 6. Unlicensed frequency band.

Different RF protocols are currently available for commercial applications – each having its niche market. Zigbee/ IEEE 802.15.4 are suited for low data-rate applications. The maximum data rate achievable is 250 kbps at 2.4 GHz with an address space for 2^{16} devices. RFID is well suited for short range, low power system like inventory management. Bluetooth has gained widespread acceptance in short range applications like communication among desktop peripherals with speeds of 1Mbps at 2.4 GHz. It can address a maximum of 7 devices. While WiFi can attain greater range, they have significant power at their disposal as these devices are powered from the mains. These protocols have significant overheads and the actual, transmitted data payload is small; each system has its advantages and trade-offs. The proposed system is built for our specific application, which requires high speeds, long ranges, low power and minimum overheads.

9. PARAMETER SELECTION

Interference with other onboard, radio frequencies: RF interference is a major concern in the selection of frequency. The selected frequency should neither affect the tele-command and telemetry frequency, nor should it be affected by them. Additional, interference from inter-modulation products are to be taken care of. If f_1 and f_2 are the two frequencies, then interference is expected to occur if :

$$f = nf_1 \pm mf_2 \quad (1)$$

And f is a multiple of f_1 or f_2, and where n and m are integers. The frequency is chosen so that sufficient skew is available.

Our frequency is chosen such that the pass-band of the low noise amplifier of the susceptible RF system lies outside the frequencies of our interest as per the above equation.

- *On-air-data rate:* This is the speed at which the transmission occurs. With a faster speed, more data can be transmitted; it also reduces the limitation on the number of wireless nodes due to mismatch in data-rate skew with the main bus.
- *Packet overhead:* Packet overheads arise due to the implementation of synchronization patterns for frame recognition, error control and security. Bytes of data are dedicated for each of these functions and are appended before and after the data to form the packet overhead. With minimum packet-overhead, the communication is faster and the transmitter can then be powered down to save energy.
- *Operating frequency:* Typical applications for devices in the 2.4 GHz range are wireless PC peripherals like mouse, keyboard and remote controls. Sub 1 GHz devices are recommended for Wireless sensor networks, Industrial monitoring and control to take advantage of their longer range while 2.4 GHz devices have the advantage of achieving faster on-air, data rates. Since increase in range and data rate involves an increase in power, trade-off is involved in the choice of frequency.
- *Antenna size:* Higher frequencies require smaller antennae and hence smaller footprint.

Link budget calculations

Power (transmitter) + Gain (Transmitter) + Gain (Receiver) = Sensitivity (receiver) + Path Loss + Fade Margin

For a patch antenna, a conservative gain of 0dBm is assumed.

$$Path - Loss = 20*\log\left(\frac{4\pi D}{\lambda}\right) = 20*\log\left(\frac{4\pi Df}{c}\right) \quad (2)$$

D = distance in metres, λ = wavelength, f = Frequency of operation, C = velocity of light.

Computation for path-loss is carried out at different frequencies that do not interfere with on-board frequencies. For 900 MHz and specification of 200 m, path loss works out to ~78 dB.

10. PACKAGE SPECIFICATIONS

System sizing as shown in Table 1 is made for a 16-channel, wireless data acquisition system (excluding antenna). For standardisation purposes, the dimensions are approximated to the closest standard dimension commonly used for other packages.

While a major portion of the Slave module is taken up by the front-end analog electronics, the Master module has to accommodate the components for the interface to the wired, master bus.

Table 1. System sizing

	WDAU-Slave	WDAU-Master
Power requirements	5 V, 200 mA (nominal)	5 V, 300 mA (nominal)
Size	255 * 221 * 36.5 mm	255 * 221 * 36.5 mm
Weight	1 kg	1 kg

11. ANTENNA DESIGN

A rough estimate is made for dimensions of the antenna is shown in Table 2. All dimensions are in centimetres.

Table 2. Dimensions of different antenna configurations for different RF transceivers

Freq (MHz)	915	2450
Monopole	16.4	6.1
Patch	10.1 * 5.0 * 4.4	3.8 * 1.9 * 1.7

12. COMMUNICATION PROTOCOL

The system implements a packet data transfer. Each packet is composed of 8 bytes of bit synchronizer, 4 bytes for byte synchronization, 1 byte for packet length check, 1 byte for address check and 2 bytes for CRC check which form the overhead. The size of each field is re-configurable, to allow for different packet sizes. The data field ranges from 2 bytes to 64 bytes. Larger data fields would be preferable to compensate for the overheads. All slaves are pre-programmed to a common packet structure. Figure 7 shows packet structure of the system.

Figure 7. Packet structure.

The communication protocol implemented is application specific and is either of those described is ealier section. Each WDAU-S has a minor frame table which determines the interrogation rate for the group of sensors in its control. This ensures that the sensors connected to a WDAU-S are polled as per the desired operational rate. The WDAU-M, as the secondary BC, interrogates WDAU-Ss for data. Since the wireless communication involves packet data, addresses are not assigned to a single sensor but to a group of data which may involve multiple sensors at different data rates. On an address match, the WDAU-S offloads the relevant group of sensor data in the packet format. The WDAU-M then buffers the data from the WDAU-Ss into its memory, to match the major frame format table for the vehicle.

For the primary network, each sensor channel is provided a unique address. All RTs are, by default, in the listening mode. The BC sends out the address of the sense channel, whose data it requires, and then itself goes into listening mode. All RTs check for address match and only the RT whose address matches (whether the particular sense channel is in its acquisition subset), responds. After completion of response, the responding RT goes back into listening mode. Individual channel address for a sensor channel that is connected to a WDAU-S is available only to the WDAU-M. When asked for by the primary BC, the WDAU-M responds with the latest data that is available with it for that particular channel. The WDAU-S implementation thus remains opaque to the primary BC and vice-versa. The WDAU-M matches the speed of the 1553 bus on one end and that of the wireless network on the other. Since, the actual sampling rate and hence the bandwidth requirement for each sensor will be less than a few kilo-Hertz, this discrepancy in the data-rates are acceptable upto a finite number of sensors. When this limit is attained, the skew in speeds will need to be addressed.

13. IMPLEMENTATION

A 5-channel, data acquisition system is realized as a prototype. To simplify the system, the WDAU-M was made to interface directly to a PC, which acted as the primary BC. To aid in error control, the following features are used:

- CRC-16 computation and check
- Address check
- Packet length check
- Received Signal Strength Indicator check

14. TEST RESULTS

- The package was subjected to EMI tests. Its radiated emission test (RE02) is within the MIL-STD-461C at tele-command and telemetry frequencies. Figure 8 shows results of radiated emission test.
- It provides 200 m (line of sight) range with 10 dBm output power. Receiver sensitivity was -90 dBm.
- The system is characterized with sensors. Prime contribution to error in the data received at the WDAU-M is from sensor inaccuracies. Figure 9 shows results of output and corresponding error for a sensor channel.

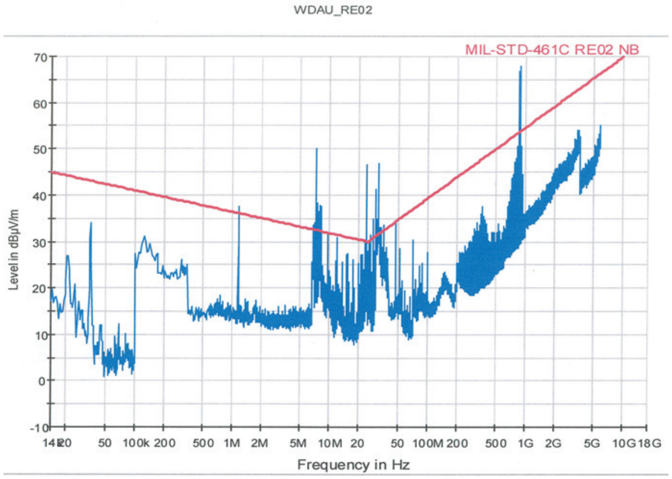

Figure 8. Radiated emission test.

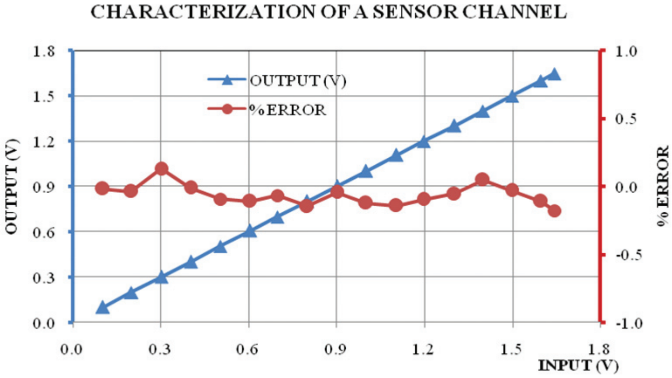

Figure 9. Output and corresponding error for a sensor channel.

- Similar characterisation was carried out for the remaining channels. The responses were as expected.
- Three slaves were realized and assigned different addresses, to validate interference issues. With unique addresses assigned to each device, all slaves responded appropriately when interrogated by the master.

15. DISCUSSION

- The RE test showed higher emissions at 32 MHz and below. 32 MHz is the crystal oscillator frequency. These emissions can be reduced by a better PCB layout. Currently, a simple, double-sided board is implemented. Routing the clock signal between ground lines and providing ground planes will reduce this noise. Also, the RF system is very close to the analog and digital circuitry. Implementation of the RF system as a separate card and shielding using a metallic chassis with dedicated slot for the RF system will localize the card-level RF noise. This will improve the overall noise performance of the system.
- Since the RF system is operating at 10 dBm transmit power, care is taken to maintain minimum distance between different devices to avoid receiver saturation.
- The system is susceptible to radiated frequencies that satisfy Eqn (2) but immune to corruption at other frequencies.
- The range test was limited by interfering civil structures and vegetation. A longer range may be achievable with the existing system, if the interfering structures are absent.

16. FUTURE WORK

Currently all devices (master or slave) are made to operate at the same frequency. To have increased reliability in communication and reduced problems of interference, such as line-holding by a single device, the WDAU-M may be made to hop between the different frequencies that the WDAU-Ss are programmed to. Sufficient channel spacing is then required to prevent RF interference. Additional timing is necessary for the RF channel of the WDAU-M to switch and settle at each different frequency.

To provide for redundant data acquisition, two RF channels are planned per WDAU-S. If same frequency is planned for both primary and redundant channels, then all the channels should have different addresses and their interrogation is to be spaced out in time. If the redundant RF channels operate at a different frequency, then this restriction is reduced.

The present system implements a minimalistic error detection scheme. Implementation of error correction schemes like FEC with interleaving will improve the packet error rate. The extension of the WDAU-M to interface through a MIL1553/RS485 bus to a bus controller will implement the complete system. Operation in crowded environments is a major challenge for the successful implementation of this system. System level tests are planned to validate performance in the integrated environment.

17. CONCLUSION

The realized system is a proof-of-concept for the implementation of a wireless data acquisition system for launch vehicle applications. Work is currently underway for the implementation of the system for launch vehicle applications.

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