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Ariane 5 Space Launcher Vehicle Equipment Bay Wireless Sensor Network Telemetry Subsystem with Smart Sensors

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Abstract:
In this work we show the design and implementation of an efficient telemetry subsystem for Wireless Sensor Networks inside the Vehicle Equipment Bay (VEB) of the ARIANE 5. The telemetry subsystem is utilizing infrared data communication and consists of various smart sensor chips such as temperature sensor, humidity sensor, visible light intensity sensor, infrared light sensor, acceleration sensor, air pressure sensor and 10 bit analog to digital (ADC) input for analog sensors. The heart of the telemetry subsystem is a microcontroller for controlling the smart sensors and power management. The Multi Layer Insulation (MLI) that covers part of the VEB and the strong requirements to minimize the electromagnetic interference inside the launcher made infrared data communication preferable over classical RF narrow band communication. Other factors like low complexity of the infrared system compared to UWB systems are also taken in consideration. The data received by an Access Point (AP) is processed before being forwarded to a Data Concentrator.

Key words: Smart Sensor, Avionic Gateway, Wireless Sensor Network, Infrared, Multi Layer Insulation, ARIANE 5 and Launcher.

I. Introduction

The main part of this work is done to be used by a project called Reliable Sensor Network (RSN) in the frame of European Agency's Program called Future Launchers Preparatory Program (FLPP) [1,7] that maintains long term independent access in space technology and increases European competitiveness in the worldwide space launcher market.

The telemetry subsystems is combined with wireless technologies such as Ultra-wide Band and Infrared. Commercial components are used in combination for the space electronics to build the subsystems. This is intended to shorten development time and cost which is the part of the progressive restructuring European launcher industries [2]. However radiation sensitivity has to be accessed for COTS components, depending on required reliability figures and expected radiation effects.

In order to miniaturize sensor system, some sensors are replaced with commercial components.

The usage of the sensors on the Ariane 5 are categorized as following: (1) to provide information about the behavior of the rocket when flying, (2) to identify anomalies in the operation when flying, (3) to secure the position of the rocket when flying, (4) to measure the characteristics of the rocket when flying, (5) to measure the levels of environment inside the fairing, and (6) to provide a coherence and standardization of the equipment [3].

The main focus of this work is developing a telemetry subsystem for application inside the Ariane 5 Vehicle Equipment Bay (VEB) [4] that houses a significant part of the vehicle avionics and is partly covered by Multi Layer Insulation MLI [5] (see fig. 1).

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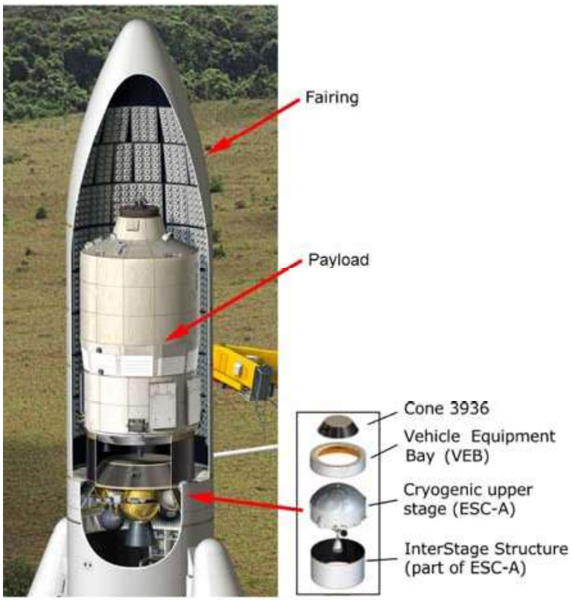

Fig. 1: The ARIANE 5 upper stage that mainly consists of Fairing, Payload and Vehicle Equipment Bay (VEB) [6].

The telemetry subsystem is developed as part of the Reliable Sensor Network (RSN) that consists of Avionic Network Gateway, Data Concentrator, Infrared Access Point, Infrared Sensor Network, Ultra-wide Band Access Point, UWB Sensor Network, Smart Sensors and some wired analog sensors as shown in figure 2 [7].

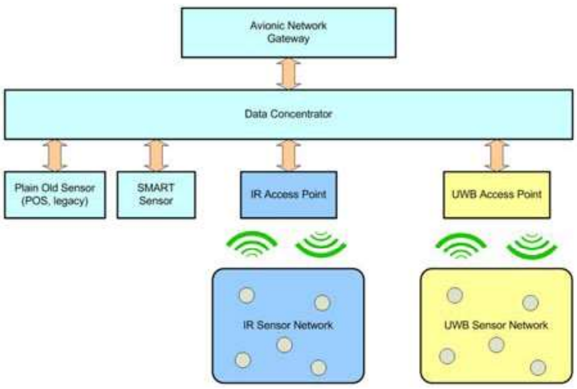

Fig. 2: The telemetry subsystems that are part of the Reliable Sensor Network within the VEB [7].

The main goal in this project is to achieve a reliable wireless sensor system design. As reference the following measurements have been foreseen:

- Air pressure /temperature measurement
- 3-axis Acceleration measurement
- Infrared/visible light intensity measurement
- Air humidity measurement

The architecture, hardware and measurement results are described as follow:

II. Sensor Node Description

The telemetry sub system consists of mainly Access Point and sensor nodes. In this section the sensor node will be described in more details started with its architecture, the smart sensors attached on it and at the end is its hardware description.

A. Sensor Node Architecture

The architecture of the telemetry subsystem on the wireless sensor node is described in figure 3.

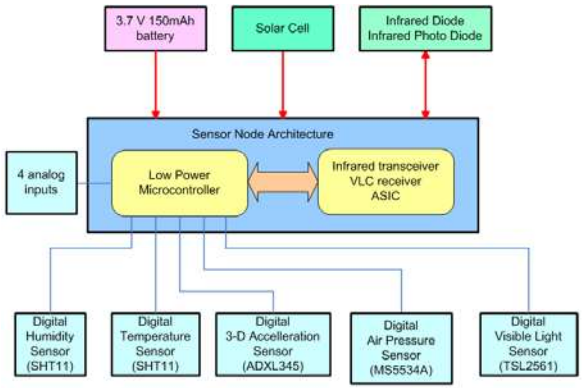

Fig. 3: Architecture of the sensor node.

The sensor node architecture consists of three main parts. The sensing part is built by a low power microcontroller connected with so called "smart" digital sensors. It also provides four analogue inputs to accommodate this kind of sensors as well. The transmission part is constructed with an self-designed ASIC, infrared transceiver and solar cell for Visible Light Communication (VLC)/energy harvesting. The power management part is supplied by a 3.7V/150mAh lithium battery and charged with a 6 V solar cell.

B. Smart Sensors Overview

There are four different kind of smart sensors tested to build the telemetry sensor node as shown in figure 4. They are a humidity and temperature sensor [8], an infrared and visible light sensor [9], a relative air pressure sensor [10] and a 3-axis accelerometer [11].

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Fig. 4: The smart sensors overview for building the telemetry subsystems on the wireless sensor node.

C. Sensor Node Hardware description

The realization of the sensor node architecture that is built with commercial components and a self designed ASIC is shown in figure 5. The infrared transceiver are placed surrounding the ASIC to increase the signal coverage and the smart sensors are located on the left and right side of the ASIC.

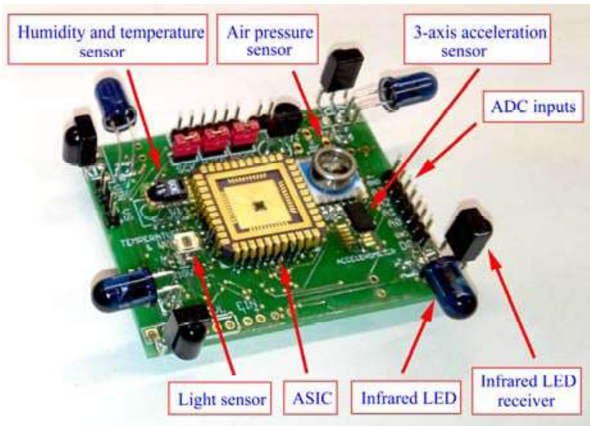

Fig. 5: The sensor node hardware description.

The casing for the sensor node that is designed with the solar cell holder is shown in figure 6. The solar cell is placed to face the incoming light that provides energy to charge the battery and carries information to initiate telemetry measurement on the sensor node.

III. Smart Sensor Measurement

The smart sensors are tested and measured to investigate their operational behaviour compared to the datasheet from the manufacturer. The discussion of the and measurement and results of each sensor are presented in the following sections.

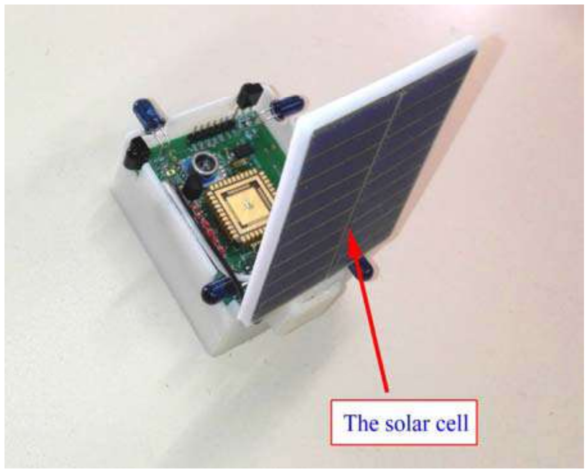

Fig. 6: The sensor node's casing with the solar cell installed.

A. Acceleration Sensor ADXL345

The 3-axis accelerometer has a maximum measurement range of ± 16 g. With only 40 µA current consumption and typical voltage supply of 3.3 V, it reaches a resolution of 4mg/LSB with 13-bits output data for each axis. The sensor measures static acceleration of gravity, dynamic acceleration from movement/shocks and is able to measure inclination changes up to 1° [11]. The time it takes to perform 3-axis measurement is about 1.61 ms as shown in the measurement, see figure 7.

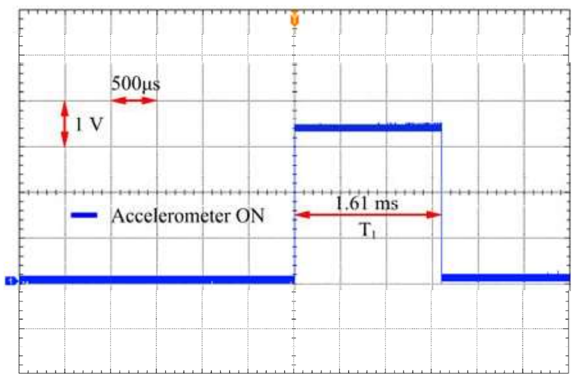

Fig. 7: The accelerometer sensor active period measurement.

In the so called the burst measurement mode the sensor takes 168 ms for 100 measurement samples. These samples are required for analysing the vibration / shock spectrum of events during flight. Figure 8 shows the active period measurement for 100 data samples.

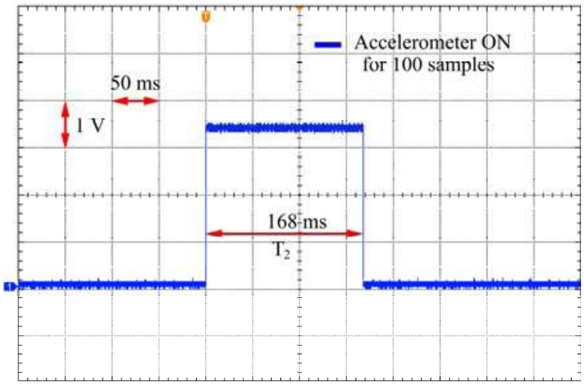

Fig. 8: The accelerometer sensor active period measurement for 100 data samples.

B. Light Sensor TSL2561

The TSL2561 converts light intensity to digital signal output providing the digital data stream via I^2C bus. The light sensor consists of a visible light 640 nm and a 940 nm infrared photo diode. The 16 bits data output of the sensor allows measurement up to 40,000 LUX. The current consumption during active mode is 0.6 mA with a typical voltage supply of 3.3 V [9]. During the mission, the infrared light sensor can be used to detect heat sources in the vacuum. The time it takes to perform light intensity measurement is about 32 ms as shown in the measurement, see figure 9.

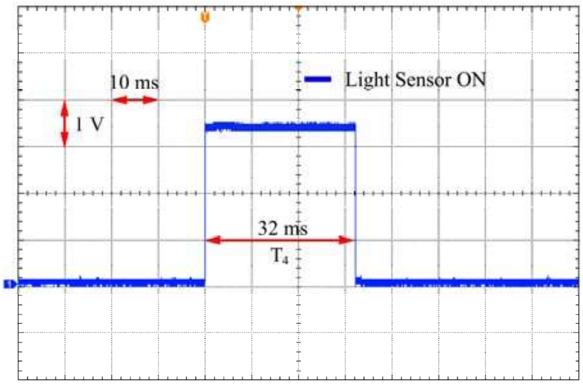

Fig. 9: The light sensor active period measurement.

C. Air Pressure Sensor MS5534A

The air pressure sensor MS5534A works with piezoresistive pressure sensing elements. The changes of the air pressure bends the membrane of the sensor, hence the values of the resistors on the membrane vary and can be measured by the electronic circuit embedded inside the sensor housing. The pressure range is 300 to 1100 mBar for this sensor. The current consumption during measurement is 1 mA at a typical supply voltage of 3.3 V. The relative air pressure sensor also incorporates a temperature sensor for linearity error correction. This correction increases the measurement accuracy to less than 1 mBar in the temperature range of 10°C to 60°C [10]. The time it takes to perform relative air pressure measurement is about 71.6 ms and is shown in the measurement, see figure 10.

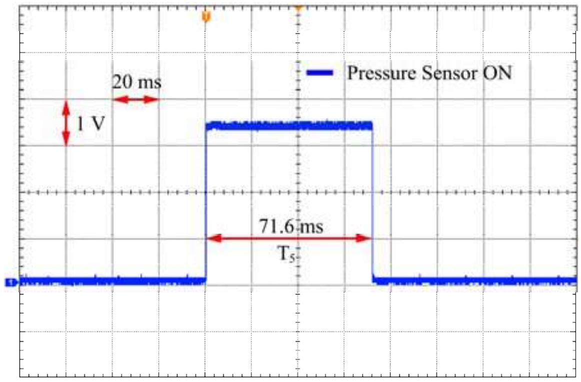

Fig. 10: The relative air pressure sensor active period measurement.

D. Humidity Sensor SHT11

The air humidity sensor SHT11 is using capacitive sensor elements for measuring the relative air humidity. A band-gap temperature sensor is embedded for a temperature compensation calculation process of the humidity data. The accuracy of the humidity measurement is ± 3%. Typical current consumption is 1 mA at 3.3 V [8]. The time it takes to perform relative humidity and temperature measurement is about 1.401 second as shown in the measurement, see figure 11.

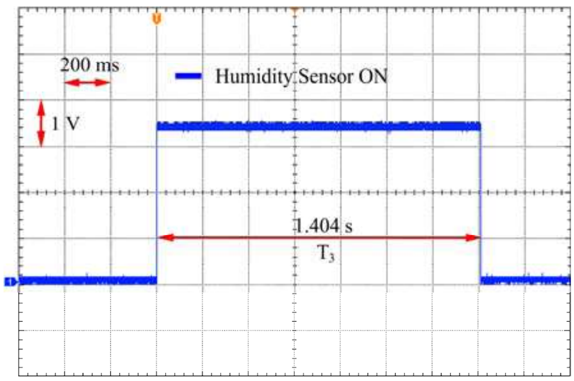

Fig. 11: The relative air humidity sensor active period measurement.

The measurement time up to 1.4 second is due to the internal measurement principle of the SHT11. The heater is turned on for the capacitive sensor calibration and it determines the humidity measurement time.

IV. Telemetry Measurement

The telemetry subsystem measurement requires Access Points that consist of Visible Light Communication LEDs and Infrared (IR) transceiver units. The description of the measurement is presented in the following section.

A. VLC and Infrared Access Point

The VLC consists of 3 high power LEDs and is controlled by a series of drivers to send the information to the solar cells of the sensor nodes. The IR transceiver at the Access Point then receives the measurement result transmitted by the sensor node. The Access Points are also able to communicate with the sensor node through infrared transmitter if the VLC is not available. Figure 12 shows the VLC and Infrared Access Point hardware.

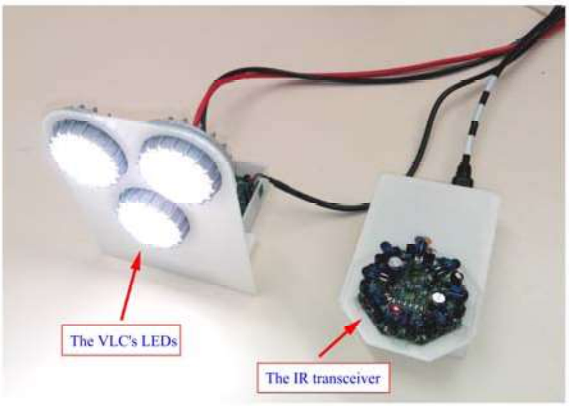

Fig. 12: The VLC and Infrared transceiver hardware.

B. Telemetry Subsystems Experiment with MLI

The telemetry subsystem experiment shown in figure 13 is utilizing the Multi Layer Insulation (MLI) to reflect the energy and information transmitted by the Access Point. The sensor node with its solar cell is placed facing a MLI surface that is covering on the experiment wall. A barrier is placed between the sensor node and the access point to prevent Line of Sight communication for the infrared and visible light.

The VLC is supplied with 0.13A and 21.7 V from a DC power supply. The goal of the experiment is to test the diffuse non line of sight visible/infrared propagation with the help of MLI reflection inside the Ariane 5 VEB [12].

The telemetry subsystem measurement sequence at the sensor node is shown in figure 14. The first sequence M_1 is to perform 3-axis acceleration measurement with 100 data samples. The second sequence M_2 is for measuring the infrared light and visible light intensity. The air pressure measurement with temperature compensation is done at M_3. The last sequence M_4 is performing a relative air humidity measurement. The total time it takes to perform the measurement cycle is 1.684 second.

The power consumption for M_1 is 132 µW, M_2 is 1.98 mW, $M_3 + M_4$ is 3.3 mW. The communication between the Sensor Node and Access Point is shown for the VLC and Infrared signal paths, see figure 13.

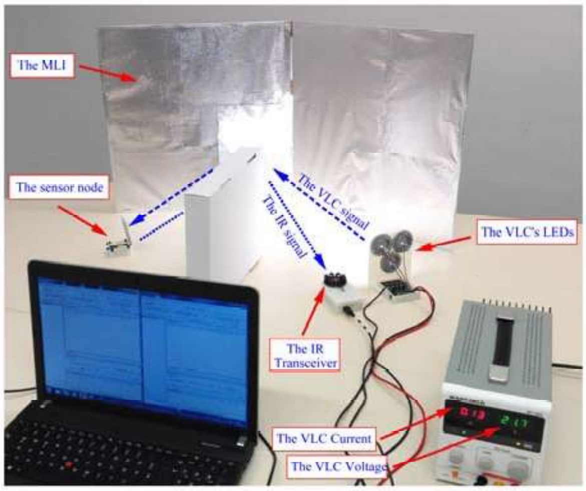

Fig. 13: The telemetry subsystems experiment setup with MLI.

The results from the measurement show that the Access Point VLC can manage to provide energy and send commands to activate the Sensor Node with the help of its solar cell. After receiving the commands the Sensor Node is able to complete the measurement sequences and send the measurement results back via infrared communication to the Access Point.

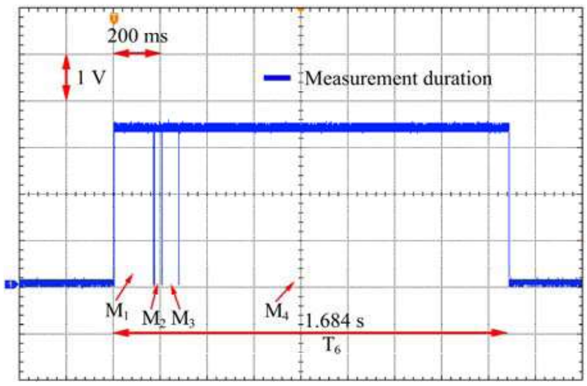

Fig. 14: The telemetry subsystems measurement sequences with the smart sensors.

V. Conclusion

The concept of telemetry subsystems with the smart sensors that is part of the Reliable Sensor Network in Ariane 5 VEB has been realized and investigated. The important results are:

- The smart sensors that measure five different physical quantities (temperature, humidity, light, pressure, acceleration) are successfully integrated in and tested within the Sensor Node.
- Each smart sensor with its required measurement period is verified by the measurement results. The 3-axis acceleration sensors requires the smallest amount of measurement time of 1.6 ms.
- The telemetry communication system can be operated in NLOS configuration using reflection at MLI for VLC and Infrared for the communication between access point and Sensor Node.
- The power consumption of maximum 3.3 mW for the sensor node measurement of all sensors is remarkable lower that the power consumption of the standalone analogue sensors used today.

Further development is planned for more compact Sensor Node size and measurement inside a flight representative VEB by the end of this year.

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