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J. Rivas

J. Martinez-Oter

I. Arruego

A. Martin-Ortega

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OWLS AS PLATFORM TECHNOLOGY IN OPTOS SATELLITE

J. Rivas. [1], J. Martinez-Oter[1], I. Arruego[1], A. Martin-Ortega[1], J. R de Mingo[1], J.J. Jimenez[1], B. Martin[1].

[1]*Instituto Nacional de Técnica Aeroespacial (INTA), Spain*
rivasaj@inta.es

I. INTRODUCTION

Optical Wireless Links for intra-Satellite communications (OWLS) [1] was proposed by Instituto Nacional de Tecnica Aeroespacial (INTA) in 1999 [2] [3] [4] and was developed during the last years. Several ground and in-orbit demonstrations were made to test and validate new technologies and concepts, for example, network architectures and communication protocols. These demonstrations included optical wireless schemes based on Controller Area Network (CAN) bus [5]. This standard is integrated in many commercial microcontrollers or as Intellectual Property (IP) Cores in Field Programmable Gate Arrays (FPGAs). INTA developed a pico-satellite called OPTOS [6] based on a completely wireless network by means of OWLS-CAN. The wireless network consists of highly integrated optical ports employed as the main TM/TC bus for the satellite. This OWLS port was called On-Board Communication (OBCOM). Smart, compact, low cost and low-power optical transceivers were manufactured as complete components that include, inside a 25x14x14 mm^3 metallic housing the complete optical emitter, receiver, and a reduced CAN IP-Core embedded inside a low power Complex Programmable Logic Device (CPLD).

Section II of this paper summarises the OWLS-CAN ground and in-orbit demonstrations developed by INTA. Section III briefly describes OPTOS satellite. Section IV presents the Distributed On-board Computer. OBCOM module features, as well as their electronic components based on Radiation-Hardened (Rad-Hard) and Commercial Off-The-Shelf (COTS) qualified for Space, are described in Section V. Section VI describes optical configuration and electrical power budget of the OBCOM modules. Finally, section VII summarizes the conclusions of this work.

II. OWLS-CAN SPACE APPLICATIONS

OWLS technology has been developed by INTA since the end of the 90's. It was proposed as a solution for interconnections between future micro/nano devices [2]. OWLS aims at the suppression of data harness and connectors inside a space system. Some benefits in weight reduction are related to launch costs and fuel requirements along with the growing in miniaturization of equipments and platforms [4]. The CAN bus was selected due to its inherent Multi-Master nature and star topology. As the standard does not define a specific physical layer, the optical physical layer is a very adequate solution, where the light is dominant over no-light (recessive). OWLS-CAN was successfully used in-orbit in FOTON-M3 mission [7], as well as in European Space Agency (ESA) OWLS Technology Research Programme with a Venus Express Mock-up [8]. However, those in-orbit and ground demonstrators had an experimental approach. In order to turn OWLS into a realistic platform technology, an application as On-Board Communication sub-system in a real spacecraft was required. OPTOS was built with this goal.

III. OPTOS: A NEW LIGHT IN THE SPACE

OPTOS satellite was conceived as an in-orbit test bed for different technologies and micro-systems. It is based on the triple configuration of the popular Cube-Sat developed in 1999 by CalPoly and Stanford University [9]. It was launched by INTA in November 2013 and makes intensive use of optical wireless links, being an all-optical satellite. There are no data wires and all the units are communicated through a Wireless-CAN (diffused in all satellite cavity through a channel of 40x20x178 mm^3, see Fig. 1), working on 950 nm at 125 kbps. The OPTOS computer is a distributed architecture where all terminals are connected by the OWLS-CAN bus [10].

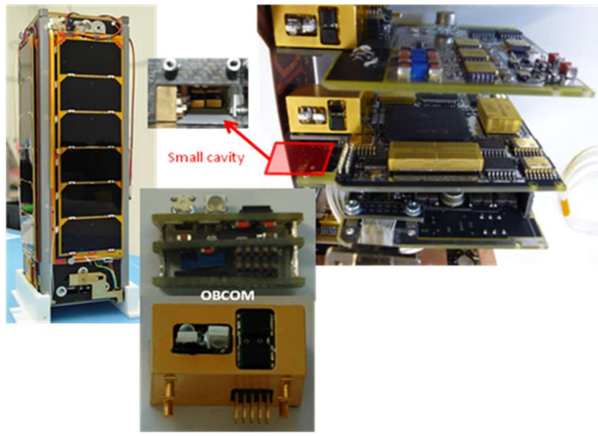

Fig. 1. View of the OPTOS satellite, distributed architecture, optical diffuse cavity and a complete OBCOM module.

IV. DISTRIBUTED ON-BOARD COMPUTER

The concept that was applied as a solution for the OPTOS computer is a design that presents a data handling architecture with distributed intelligence inside the spacecraft. Every subsystem and payload incorporate a small computer called Distributed OBC Terminal (DOT) based on low-size, low-power and programmable logic implemented in a Xilinx CoolRunner™-II CPLD [11] [12]. It acts as a controller of the associated unit (a sensor, an experiment or an actuator), also collecting and digitizing data from it when required. Besides, there is a more complex computer (Enhanced Processing Hardware - EPH -) implemented on a Xilinx QPro Virtex-II FPGA [13] with enhanced capabilities devoted to the communications with ground. All those computers (eight in total) perform the whole Data Handling and Control of the satellite, and communicate among themselves through the Wireless-CAN. Some tasks are shared, such as time distribution, housekeeping telemetry acquisition, or time-tagged command execution. In order to access to the optical medium, each unit DOT or EPH, was connected to an OBCOM terminal.

V. OBCOM: OPTICAL MODULE DESCRIPTION

The OBCOM is an optical wireless port that was manufactured as a three-level stack of small PCB's of 23x12 mm^2 packaged in their own metal case (25x14x14 mm^3). They incorporate through-hole pins for connections, thus resulting in a complete component from the user point of view. OBCOMs include not only the electrical-optical-electrical transceiver (transmission is included), but also a 256-Macrocell CoolRunner™-II CPLD [14] from Xilinx [15]. In this case, a reduced CAN IP-core was developed for it. To achieve this reduced volume, the module also relays an OPA354 commercial Operational Amplifier (OpAmp). Next subsections described the used opto-electronic components as well as the IP-Core.

A. Emission module

Small and simple electronics are used to implement the driver circuit given that the data rates being used are not very high, and the thermal-stability requirements are not strong. The driver circuit has a medium to high-speed Cutoff-Active switching transistor (Rad-Hard) connected to one or two LEDs (Osram SFH4248). This LED was tested to characterize Displacement Damage (DD) [16]. To reduce the peak currents an R-C low filter power input is used. This is charged while there is no transmission, providing approximately 3mA of peak current. When a transmission occurs the LED current reaches values greater than 35 mA during at least six consecutive pulses.

B. Reception module

According to the constraints of volume and power, a reduced/simplified receiver was designed. The reception chain stars with one or two photodiodes (Vishay TEMD5110), where a Direct Current Block (DC-Block) cancels the ambient-light photocurrent in the first stage to avoid its saturation [17], [18]. A standard Transimpedance Amplifier (TIA) follows, that converts the AC photocurrent in a voltage pulse. As OpAmp of the TIA, OPA354 of Texas Instrument was used. It was tested by INTA for Total Ionizing Dose (TID) (Fig. 2) and protons. This OpAmp is optimized for operation on single supply and has a SOT-23 package (3x3 mm^2). To work with symmetric range of ±2.5 V, a virtual ground of 2.5 V was provided by mean of a divider resistor from +5 V power supply.

C. Logic module

A Xilinx XC2C256 CoolRunner™-II CPLD also tested by INTA for TID (Fig. 2) and protons [12], was selected as logic module, where the reduced IP-CAN Core called RED-CAN was implemented. It was fit in a CP 132 CoolRunner™-II 256-macrocell with a resource optimization of 83% Macrocells, 88% PTerms, 54% Registers, and 80% Function Block, and 9 input and output signals: two signals are interfaces with the emission and reception module, and seven with the DOT. The main characteristics of REDCAN are the following:

- Elimination of extended frame (CAN 2.0B specification).
- Reduction of data field from 8 bytes to 3 bytes (CAN 2.0A specification).
- Fix the numbers of time quantum (TQ) for each one of the four segments within the nominal bit rate:
    - Synchronization: 1TQ.
    - Propagation: 1TQ.
    - Phase segment 1: 3TQ.
    - Phase segment 2: 3TQ.
- Keep the error detection mechanism with a reduce fault confinement implementation.
- Perform an On-Off Keying (OOK), with Return-to-Zero (RZ) coding with a data rate of 125kbps and 25% of duty cycle. '0's are signalled.

VI. OPTICAL AND ELECTRICAL POWER BUDGET

As is mentioned in Section IV, there are nine OBCOMs in total, but one of them was only used in the AIT phase as a spy of the OWLS-CAN bus. Fig. 3 shows the OBCOM distribution. In order to solve the saturation of the receiver when multiple transmitting occurs, a RZ-0.25 coding was implemented, and different configurations of LEDs and photodiodes were selected. Fig. 4 shows all OBCOM modules (left) and four wave-forms of TIA output (right) when an Active Error Flag (AEF) is received. The red bracket contains the reception when four units transmit an AEF at the same time. The green bracket contains the reception in the four units when the fifth unit transmits an AEF (blue bracket).

Every OBCOM module provides a sensitivity better than 750 nW/cm^2. The electrical power consumption of reception module is 81 mW (TIA + CA + CPLD), whereas the electrical/optical peak power during the transmission of a '0' (the signalled symbol) goes from 13 / 22 mW to 50 / 75 mW depending on which OBCOM.

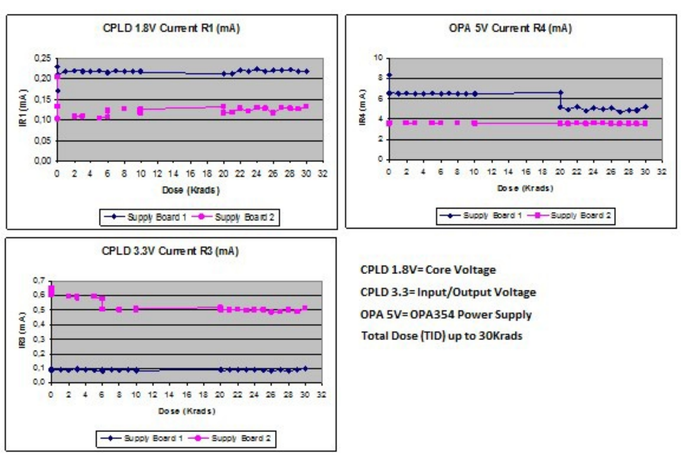

Fig. 1. TID up to 30Krads of XC2C256 CoolRunner™-II CPLD and OPA354.

Fig. 3. OBCOM distribution in OPTOS satellite.

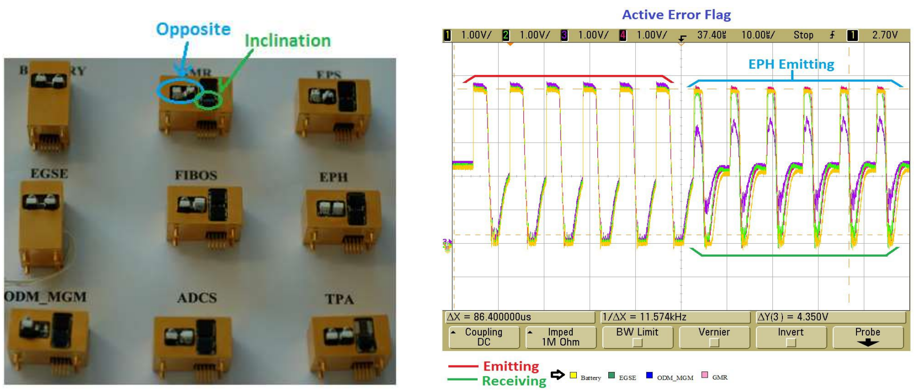

Fig. 4. Left, all OBCOM modules. Right, AEF detected in the TIAs.

VII. CONCLUSIONS

OWLS technology provides reduced volume, low cost (due to use of qualified COTS), and very low power consumption to on-board communications.

OPTOS on-board communications through OWLS-OBCOMs have successfully demonstrated their capabilities and reliability during the last three years of mission. This step has increased OWLS to a Technology Readiness Level (TRL) 8, qualifying it to safely use in satellite sub-systems.

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