

# International Conference on Space Optics—ICSO 2008

Toulouse, France

14–17 October 2008

*Edited by Josiane Costeraste, Errico Armandillo, and Nikos Karafolas*



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International Conference on Space Optics — ICSO 2008, edited by Josiane Costeraste, Errico Armandillo, Nikos Karafolas, Proc. of SPIE Vol. 10566, 1056663 · © 2008 ESA and CNES  
CCC code: 0277-786X/17/\$18 · doi: 10.1117/12.2308283

## OPTOELECTRONIC LINK FOR OPTICAL SATELLITE HARNESSING SUBSTITUTION IN SPACE COMMUNICATIONS

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### 1. ABSTRACT

The current space harness has limitations associated with the use of copper cables in the intra-satellite networks: mass, volume and limited data rate for a given link distance. To overcome these limitations the space community has identified fibre optics as a desired solution for payload and potentially for platform applications. EADS CASA Espacio and DAS Photonics have already been working developing an optoelectronic conversion module to use fibre optic in control buses (MIL-STD-1553 and CAN BUS) and point-to-point links (SpaceWire, clocks, AOCS, TM/TC...) to serve as a drop-in replacement for present copper solutions. The mechanical design was done to fit conventional connectors plus backshell dimensions with similar mass. The use of optical fibre instead of copper allows for mass reduction of 25% in typical satellite. All of Engineering Model's (EM) employ 850 nm vertical cavity surface lasers, GaAs PIN photodiodes, radhard graded index multimode fibre (50/125 µm), space qualified optical and electrical connectors with all materials and processes suitable for space applications. All modules survived the test campaign without performance degradation or failures. Based on test results, the transceivers are promising candidates to substitute copper harness in the short term, for communication protocols used in satellites at low and medium data rates.

### 2. INTRODUCTION

Complexity and modularity of current onboard systems make necessary a big number of connections among them. These connections, which allow for data interchange among units, usually using massive shielded cables designed to withstand the harsh

conditions of space environment and thus adding a significant part to the total satellite mass.

The main advantages of optical fibre data links, when compared to traditional harnessing, are mass reduction and EMI immunity. These advantages are a great opportunity of optimise space harness from actual copper to fibre links, making an optical transceiver a real future alternative for satellite harness systems.

These advantages have raised the interest of the European Space Agency (ESA) and many system integrators for future satellite harnessing. The space community has identified fibre optics as a desired solution, for payload and potentially for platform applications and for the high bit-rate links a new standard, "SpaceFibre", extension of the "SpaceWire", is being developed making exclusive use of fibre optics. Similarly the use of optical fibre for the current standards such as Spacewire, CAN, 1553 or other links (TM/TC-Calibration, clock signals).



Fig. 1 SIOS

The proof-of-concept has already been demonstrated under the project "Sistema de Interconexiones Ópticas para Satélites" (SIOS) framed in the Spanish National Space Program. In this development performed by DAS

Photonics and EADS CASA Espacio under the frame of Spanish National Space Program, the possibility of replacing conventional harness by fibre optic has been investigated differently from SpaceFibre initiative, allowing for a reduction on satellite mass that can lead to lower the launch costs or increase the fuel charge to extend satellite's orbit life. Five EM's were developed under this phase and all of them passed successfully the pre-qualification campaign.

This paper includes the conclusions obtained during the first phase of the project with respect to design, tests and results.

### 3. REQUIREMENTS

The optronic conversion module is an optical harness cabling system, designed to substitute traditional copper wires used in satellite data buses and point-to-point signals with lightweight optical fibre and without impacting the terminal connectors of the equipments. Considering the variety of electrical interfaces used in intrasatellite connections, there is the possibility of creating different versions of the module adapted to a selection of connectors to allow the substitution of the most part of current links in an easy way.

Based on the experience from EADS CASA Espacio about the most common links currently being used, to optimise the performances of the modules it is recommendable to group the above links in these two categories, depending on the data rate:

- **Low speed (up to 10Mbps):** covers 1553 bus, CAN BUS (both up to 1Mbps). This also includes any other data signals or even clock links within this frequency range (up to 10 Mbps).
- **Medium speed (<500Mbps):** covers mostly SpaceWire data links, usually used up to 400Mbps.

The transceivers developed by DAS and CASA during 2007 were designed to be representative and compliant with low and medium data rates. These transceivers were divided on three SIOS for low data rate and two SIOS for medium data rate.

All transceivers developed by DAS and CASA surpassed all mechanical and environmental tests without any degradation on their performances.

Table 1 summarizes all tests submitted to the transceivers:

Table 1 Tests and levels submitted to SIOS transceivers

Test	Value
Sine vibration	5-16Hz 9mm 16-200Hz 6.4g(peak) Performed on three axes
Random vibration	23.76g Performed on three axes
Shock	1500 @ 10KHz Performed on three axes
Thermal vacuum	(-60,85)° @4E-5 mbar 8 cycles
Gamma radiation (TID)	150Krad @ 45 krad/h 150Krad @ 360 rad/h (1500Gy)
Proton radiation	60MeV Total dose 3E10 protons/cm2 Flux 5E7 protons/cm2/s

All transceivers were designed and manufactured with attending to outgassing maximum values tolerated for parts and materials and fully compliant with ESA authorised materials and radiation recommendations.

### 4. SIOS DESIGN

#### 4.1. Electrical design

First step was to search for qualified components to be used on the transceiver to achieve the best performance results in test plan. It was necessary to look for compact components to save in size and mass.

One of the main objectives was to use qualified parts and components but in a few devices this requirement was not compatible with low mass/size or qualified optronic devices. If to use qualified parts was not possible, the choice was based on COTS devices and parts with characteristics similar to qualified parts and components for outgassing requirements, temperature range, drifts, mechanical and radiation environment, etc. The transmitter uses a VCSEL @ 850nm as an emitter with a laser driver.

This driver will be optimized to bit rate and logical levels of the link to decrease power consumption and mass of the transceiver and allow the transceiver to be fully compliant with target protocol. Obviously, each different protocol application will need different laser driver, optimized to input/output values, bit rate and, in case of a bus, topology of the link. The driver is a commercial device working as a operational transconductance amplifier (OTA) that provides a bias current and modulation current to the VCSEL. This

driver performs the adaptation and conversion between electrical interface and optical one.

The receiver uses a photodiode with a TransImpedance Amplifier (TIA). This TIA drives to the limiting amplifier which translates the signal to CML data output. If another level is required, such as CMOS, it is mandatory to add another amplifier after the limiting amplifier, to translate the signal to the desired level.

These amplifiers must adapt the logical levels of the transceiver to the logical levels of the protocol target (LVDS for SpW, CMOS diff for 1553...). Here there is some margin to optimise power consumption if this amplifier chain is being substituted by only one amplifier adapted to target protocol and bit rate.

The transceiver architecture allows adding or subtracting channels and even combining different number of transmitters and receivers (2TX/2RX, 1TX/3RX, 5TX/3RX...) and allowing more integration capability inside each connector than only one type of link. Also it's possible to develop transceivers to work as signals repeaters.

Both VCSEL and Photodiode use encapsulate compatible with LC standard type in order to allow better and easy junction to the ferrule and optic fibre.



Fig. 2 VCSEL with LC encapsulate

#### 4.2. Power supply

As the module uses active devices in the optoelectronic design, it is necessary to supply them with the correct voltage and current.

All modules developed have power consumption below maximum requirements of the project for a future application as substitution of copper harness in intrasatellite communications.

To achieve an optimum improvement when comparing the traditional and optical approach for satellite harness, it is necessary to optimize consumption and module supply. The consumption may (and should) be minimised to lower the impact on satellite power consumption because of the inclusion of conversion modules. As an objective for new SIOS versions is to decrease power consumption of all modules below 500mW (100-150mA @ 3.3V).

With the above values, and based on the applicability of the modules, it can be stated that the consumption of all the optical harness must (and will) be below 5% of the total power of the satellite.

Various cases of real satellites have been analysed to confirm this estimation. In GAIA satellite, total mass saving for 50kg copper harness is around 20-25% with a power consumption of 2-3% over total GAIA power supply.

This estimation was done according to possible copper links candidates to be substituted in GAIA satellites (1553bus, SpaceWire and AOCS/clock signalling).

#### 4.3. Mechanical design and analysis

The mechanical design was done according to the specifications, to comply with the volume and mass constraints, as well as with thermo-mechanical and radiation requirements. With a robust mechanical design was possible to achieve a minimum mass and dimensions of the package. The mechanical design has several important aspects improving the final features of the transceiver, such as, metal walls between channels, countersunk slots to make possible to use countersunk screws to minimize package height.

The package has two parts (top and bottom), when the package is closed the PCB is fixed with the screws with minimum vibrations in the structure. One of the most important goals of the package is achieve a robust unit to assure that the internal vibrations do not crack the transceiver.

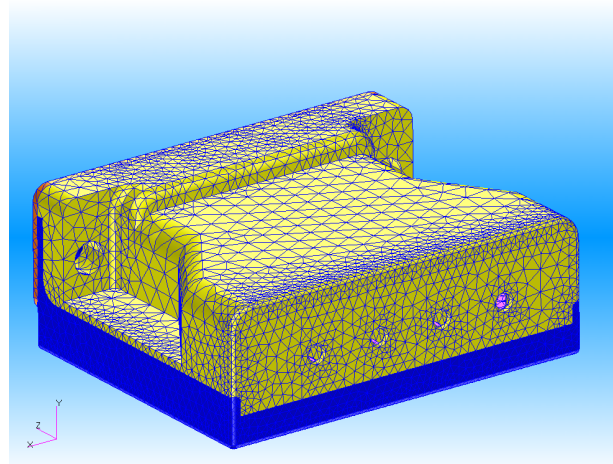


Fig. 3 FEM model of SIOS

The transceivers have dimensions of 30x35x15 mm and a mass below 35 grams (considering a transceiver with a DB15) without AVIM connectors. Fibre mass is on depending final length of each target link, used fibre has a mass below 2 g/m, SpaceWire cable has a typical mass of 80 g/m without connector and backshell.

A finite elements model (FEM) of the conversion module was generated and vibration, shock and thermoelastic simulations were performed using MD NASTRAN y MD PATRAN.

#### 4.4. Optical fibre and connectors

Optical fibre used in SIOS transceiver was RadHard Multimode type, under qualification approval of USA DSCC with good performances in radiation exposure environments.

In all SIOS, optical losses increment after irradiation with 150Krad and two dose rates of 50Krad/h and 360rad/h were less than 1 dB for typical copper wires length in satellite (5m).

Future developments based in SIOS will use a custom fibre length adapted to real satellite link between systems, e.g. SpaceWire links length in GAIA are below 3 meters.

Considering the variety of electrical interfaces used in intrasatellite connections is possible to create different versions of the module adapted to a selection of connectors to allow the substitution of the most part of current links in an easy way. SIOS was designed according a DB15 connector due that this type is one of most used in typical satellite harness. This DB15 connector allows the design of an optical transceiver with two full duplex channels in 2TX plus 2RX configuration.

### 5. QUALIFICATION TESTS

Five modules were manufactured, 4 of them with package and one without it. The one without package was intended to use it in the radiation test and verify how radiation could impair the optoelectronic performance. In that way was possible to check which components are more sensitive to radiation with a direct beam radiation. In case that any of devices as a result of direct exposition to radiation we would have all the information about maximum level of radiation absorbed by them in order to redesign the package thickness (if needed).

#### 5.1. Functional and visual tests

All devices were tested in a set of initial functional and visual tests. The main parameters, in terms of visual tests, to check were cleanliness, physical dimensions, mass, venting holes (to allow air exit in low pressure environments)... all of these parameters were according to design requirements.

For electrical tests, was mandatory to check if power consumption, BER, voltage levels were according to design requirements. All of them were according to requirements.

BER value was tested with a communications protocol emulated in two programmable devices (FPGA commercial). This test set-up generates a bit pattern and transmits it to each SIOS. Receiver checks if bit pattern received is different from bit pattern sent.

All transceivers surpassed BER test with BER values better than  $1E-12$  for typical link length in satellite harness.

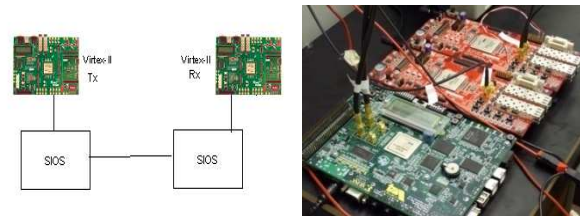


Fig. 4 Testbench for BER

#### 5.2. Sine and random vibration tests

All SIOS with aluminium package were submitted to a sine and random vibration tests. They were tested in three axes and with qualification values; 2 dB/octave for sine vibration test and 4 minutes for random vibration test.

All transceivers surpassed the vibration tests without any degradation performance.

#### 5.3. Shock test

One SIOS was submitted to shock test that consists in a metallic table with supporting foam below it. The table was hit by a metallic mass and with sensors to measure all acceleration in each axis. The transceiver was tested in three axes and surpassed the vibration test without any degradation performance or damage in any optical or electronic device inside the package.

Maximum shock value was 1991g @ 3200Hz.



#### 5.4. Thermal vacuum test

The transceivers were submitted to a thermal vacuum test between (-60, 85)°C ambient temperature with a low pressure of 1E-8 mbar. This test consisted on 8 cycles. The units were tested in operation and with a BER detector connected to each SIOS during all cycles. All transceivers surpassed the thermal vacuum test without any degradation performance and with no BER errors during all eight cycles.

#### 5.5. Gamma radiation test (TID)

This test was performed in two phases with different dose rate but identical total dose.

First test was performed with a total dose of 150Krad (1500 Gy) and flux of 50Krad/h. In this first radiation test, two units were introduced inside the radiation chamber, one with aluminium package and one without it. The reason to irradiate a transceiver without metallic protective package was to identify maximum allowable dose for all optronic devices inside SIOS. None of optronic devices enclosed in SIOS transceiver without package were damaged due to a irradiation of 150Krad. During the test power supply and BER were monitored to detect any variation in SIOS performance with an accumulate dose of gamma radiation. The duration of this test was 3 hours.

Both SIOS, with and without package, surpassed the TID at high flux without any degradation in their performance or BER value.



Fig. 5 Receptacle for Gamma radiation test

Second test was performed with a low flux radiation (360 rad/h). This phase had as objective to test all optronic devices in conditions with more similarities with space environment than a flux of 50Krad/h. Test conditions and measures (BER and power supply) were performed identical to first radiation test.

The duration of this test was of 17 days to guarantee 150Krad as total ionizing dose.

Both SIOS submitted to this second test surpassed it without any performance degradation.

#### 5.6. Proton radiation test

Proton radiation test was performed on a unique SIOS transceiver. During whole test the BER was monitored and an oscilloscope showed the sequence in its display. The test was recorded to check any variation on values. The SIOS transceiver submitted to radiation test surpassed successfully without any performance degradation.

Table 2 Proton radiation values

MeV	Dose (p/cm2)	Flux (p/cm2s)
60	$3.00 \cdot 10^{10}$	$5.00 \cdot 10^7$

### 6. CONCLUSIONS

Five breadboards have been manufactured and tested to prove the feasibility of the concept and adequacy to space environment. The configuration chosen for the prototype allows for two bi-directional communications per link, each link comprises two DB15 connectors (each containing 2 transmitters and 2 receivers) connected by a custom fibre length allowing differential input data signals to be transmitted over the desired length.

The optronic link system, as currently designed, can replace any direct data link (voltage signals). This gives it a direct application as a substitute for data and control buses as 1553, RS-422 and specific to some platforms similar to the ones mentioned, as Amazonas' LSSB (type 422) or OBDH (type 1553). Each of these buses can have typically 20 to 50 connectors depending on each satellite configuration.

It can also replace AOCS's bus and status/data transmissions, telemetry and tele-command between sensors and actuators of AOCS (gyroscopes, sun sensor, star tracker ...) and the CDMU or EIU. The same principle could apply to some telemetry and tele-command data between antennas and CDMU/EIU. It is also applicable to clock distribution from CDU to DCMU, transponders and VPU.

Another very interesting application is in harnesses needing high-speed signals now using SpaceWire, as

between CDMU, transponders, PDHU, VPU or EGSE. SpaceWire cabling for high speeds is usually heavy and needs EMC backshells thus resulting in significant mass per link.

Finally it is also directly applicable to substitute data cables from some sensors in scientific or earth observation payloads, its number very variable depending on each case.

Given that the harness topology for each satellite is different, as a function of the satellite's application and platform size, a real case has been studied to quantify the benefits of substituting present approaches for an optical one.

One real case based on GAIA harness, including as well payload 1553 and SpW links has been found a potential harness mass reduction of about 20-25% (for LISA estimations, total mass reduction is around 27%).

A 20-25% mass saving could be reasonably achieved in future commercial programmes based on this technology development.

Currently, four SIOS transceivers are going to be included in a set of experiments in AlphaSat (TDP8). The proposed experiment is the demonstration of a photonic data link whose bit error rate is constantly monitored and correlated with the radiation dose received and temperature to see the effect on the components (especially optoelectronics) and identify possible radiation-induced failures at lower rates than the ones used in the pre-qualification campaign.

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