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FIBER OPTIC SENSING FOR TELECOMMUNICATION SATELLITES

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ABSTRACT

Modern telecommunication satellites can benefit from the features of fiber optic sensing wrt to mass savings, improved performance and lower costs. Within the course of a technology study, launched by the European Space Agency, a fiber optic sensing system has been designed and is to be tested on representative mockups of satellite sectors and environment.

Keywords: Space, satellite telecommunication, fiber optic sensing, ARTES

1. INTRODUCTION

Modern telecommunication satellites have extensive monitoring requirements for control and housekeeping. From up to 2000 sensor inputs 20-25% is used for temperature sensing. Current trends in telecommunication satellite design such as increased throughput, higher payload mass, extended operation will further increase the sensing requirement. Any technology that can extend the lifetime of the satellite, or increase the mass and power ratio of Payload/Total spacecraft allowing more useful payload to be served by a spacecraft which is there only to support the payload would be of great interest.. Fiber Optic Sensors (FOS) represent such a technological option and in addition provide EMI-free operation which in certain applications can be critical.

The potentials of FOS are investigated in the context of the FOSAT (Fiber Optic Sensing for Telecommunication Satellites) project, launched by the European Space Agency (ESA) in the ARTES 5 program. A thorough review of applications has been performed and a fiber optic sensing system using a single interrogator to address hundreds of sensors has been designed and is to be tested in representative mockups of various sectors of a typical satellite. The selected applications to be demonstrated include FOS installed in a reflector, a structural panel and a fuel tank mockup and are to be tested under representative environmental loads including vacuum and vibration.

2. IDENTIFICATION OF FO SENSING APPLICATIONS

FO sensors can either be applied as a replacement of an existing sensor/system or as new instrumentation. New instrumentation in this context means a "new" specific monitoring task which has not yet been realized due to technical and/or commercial reasons. Following this baseline, the study has started with the definition of monitoring requirements based on the following study logic:

- Identification of satellite monitoring requirements tasks on subsystem level and for each relevant life cycle
- Trade off of existing sensing technologies for the monitoring tasks
- Identification of main drivers to adopt FOS in replacing of existing solutions or in providing new instrumentation (less mass, improved monitoring performance) in selected applications

The study used as a reference current satellite platforms such as "Eurostar" series Geosynchronous Telecommunications satellite shown in Figure 1 and the "Galileo" Medium Earth Orbit satellite for Global Positioning and Navigation. It encompassed all major subsystems such as structure, propulsion, thermal, solar arrays, reflectors, payloads and considers the monitoring requirements throughout the satellite lifetime of a typical duration of 15-20 years.

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The important characteristics required by a sensing system like the FOS are the ability to measure multiple parameters (temperature, strain, pressure) to provide extensive multiplexing of tens of sensing elements per fiber, have a single interrogation unit in the spacecraft

Fig. 1. Picture of Inmarsat 4 & Intelsat X satellite based on the Eurostar 3000 platform

addressing up to 500 sensors and be easily handled in the spacecraft integration and assembly. Any technology offering these advantages would then be assessed on whether it offers the potential to be space qualified.

The FO technology trade off has been divided into the sensing elements, sensing network and interrogation unit. Physical measurands such as temperature can be acquired with different sensing concepts, e.g. Fiber Bragg Gratings (FBG) and Fabry Perot measuring spectral shift or Microbend measuring amplitude shift. The study revealed several potential of FO sensing, some examples are listed below:

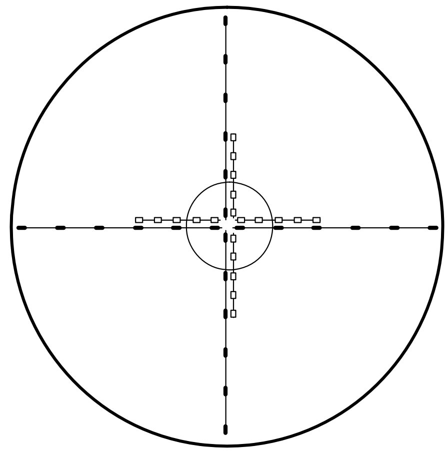
- Thermal mapping: reduction of mass, assembly/integration due to embedding in an early assembly stage, high number of sensors
- Strain and vibration monitoring: of interest for design verification during ground testing, launch and orbit, FO sensing offers this monitoring tasks with a negligible mass increase
- Daisy chain link between different type of sensors reduces interface, harness and mass.

Based on the results of the study, a number of applications has been selected and FOS based monitoring solutions have been elaborated for each application.

3. SELECTED APPLICATIONS OF FOS IN SATELLITES

3.1 Antenna Reflector Demonstrator

Reflectors are currently not instrumented for deformation control. However, the increase of transmission performance imposed higher technical requirements for stability, pointing and size while the low mass requirements remain. To date no data of in-orbit deformations are available.



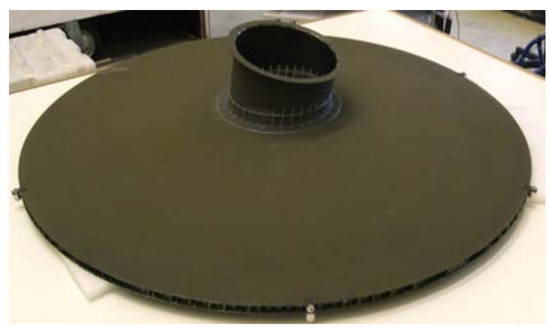


Fig. 2. Strain (rectangles) and temperature sensor distribution on face and rear sheet (left) and picture of final reflector

This data could be used to lower margins or to increase pointing performance. The designer recommends a tight sensor grid network with strain and temperature sensors. During launch dynamic loads and eventually acoustic emissions could be measured. In orbit only the quasi-static deformations are of interest. A thermal and mechanical load analysis has been performed in order to identify the critical monitoring requirements of the reflector and to identify the most appropriate positions to apply FO sensors. A temperature and strain sensor network composed of FBGs will be embedded in a Ø120 cm reflector as illustrated in the following figure. Face and rear sides of the reflector shall be instrumented with FO sensors. The embedding concept and the integration process must verify that the surface of the reflector face sheet is not impacted by the embedded fibers. The reflector shall be thermal cycled in vacuum and subjected to vibration loads to determine the Eigenfrequencies.

3.2 Satellite Structural Panel

Apart from equipment accommodation standard S/C panels also provide thermal monitoring and control for the attached equipment, mostly electrical boxes. By embedding FO temperature sensors inside those panels, usually honeycomb with thin metal face sheets, the thermal control could be optimized and the harness for additional temperature sensors reduced. Furthermore, assembly time could be reduced by the integration of the FOS sensors during the panel manufacturing. A smart panel mockup shall be realized which consists of the panel itself and a dummy payload box for heat injection. Next figure illustrates the smart panel function in a 3 D sketch.

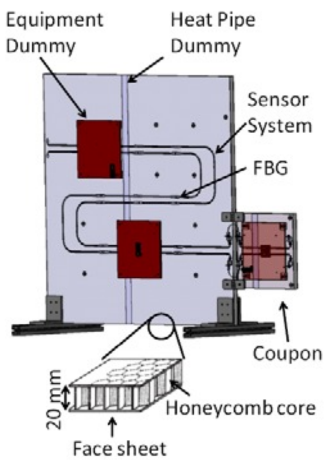


Fig. 3. Satellite Structural Panel demonstrator with attached test coupon (3D-model including fiber optic sensor systems

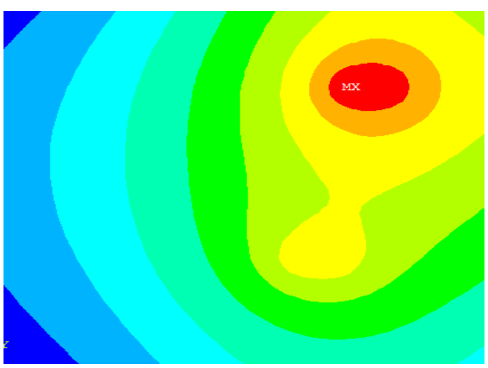


Fig. 4. Simulation of a hot spot

The Smart Panel Demonstrator shall show the feasibility of an integrated temperature sensor network using fiber optic sensors for the hot spot detection in satellite panels. The Smart Panel shall be representative for telecommunication satellites. The operating environment shall be a temperature of -20°C to 50°C and vacuum conditions. The sensor system shall ensure the location of a hot spot defined by the provided equipment dummies. A spatial resolution of around 5% and a temperature resolution of around 1°C are aspired.

Fig. 5. Smart Panel Test coupon for verification of MAIT, functional and environmental testing

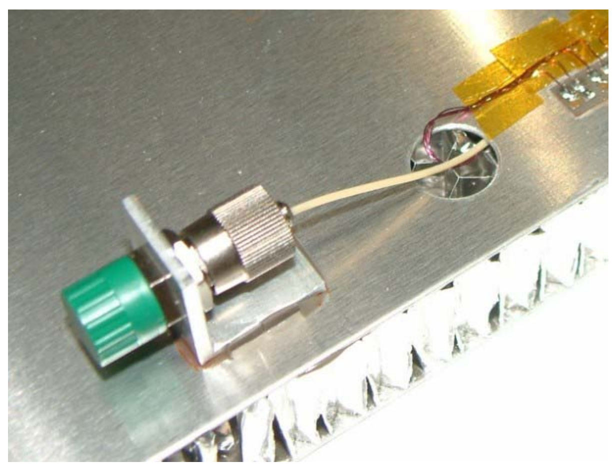


Fig. 6. Sensor fiber interface and FO connector

The sensor system shall be integrated in the Smart Panel. Connectors shall be routed to the inner and outer side of the panel. The connection feasibility to other components shall be demonstrated with a test coupon. Furthermore the sensor system shall survive launching loads. This will be verified by means of a test coupon, which is representative in terms of all FO-sensor relevant behavior. This leads to a better qualification of FO-sensor hardware. Higher loads and temperatures can be applied without reaching the limits induced by the smart panel structure.

3.3 Fuel tank

A further interesting application of FO sensing are propellant tanks. During operation the pressure of the tank could be determined by FOS strain sensors by the overall stress distribution. The strain sensor could also be used to monitor the tank integrity during manufacturing, testing and launch. Currently tank fill level is determined based on the heat capacity of the remaining propellant. The tank including the propellant is heated up and then the thermal flow is determined. Based on the thermal flow, the tank fill level is determined. This method is not very accurate, in particular for the "last drop". For deorbiting of the satellite, a specific amount of propellant is needed (approx 6 kg). With a more precise tank fill level sensor, the required propellant margins could be lowered and thus the satellite remains longer in operation. As mockup a scaled ATV watertank from the company MAN Technologie will be used. The tank consists of a metal liner and a composite layer wrapped around with embedded FOS sensors (Figure 7).

The tank is equipped with two types of FO pressure sensing, a grid of embedded FBG inside of the composite wrap and an external FO pressure sensor installed in a bypass configuration. Additionally, external FO temperature sensors are mount in form of a spiral at the lower bulkhead.

Fig. 7. Satellite Fuel Tank demonstrator

Fig. 8. Spiral mounting of the external FO temperature sensor grid

3.4 Interrogator

The technology trade offs concerning FO sensors and FO network have derived the requirements for the FO interrogator. All components are heavily cross-linked and changes along the measurement chain, e.g. introduction of other sensing concepts or introduction of different sample rate have a severe impact on the interrogator design. A trade-off between several demodulation concepts for FO sensing has been carried out wrt to the interrogator requirements. The manifold criteria and associated technical solutions increased the complexity of this trade-off considerably. A spectrometer setup with a 2D CMOS detector with a 800 nm working wavelength has finally be selected based on the following rationale

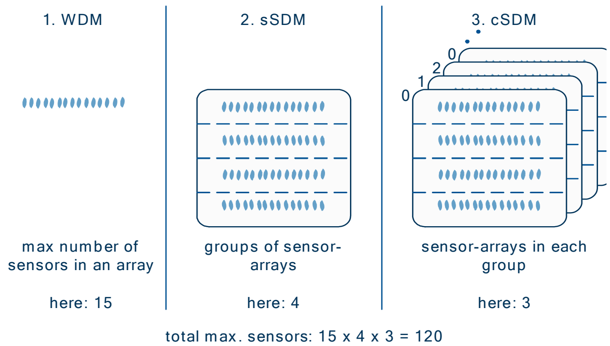


Fig. 9. Combination of spatial and wavelength division multiplexing

- High number of sensors by an appropriate combination of WDM, synchronous Spatial Division Monitoring (SDM) and consecutive SDM (refer to next figure), for standard ops mode with a sample rate < 1 Hz
- Feasibility to readout single arrays with high frequency (> 500 Hz) by SW switch of detector readout for advisory monitoring, e.g. during launch
- Readout of spectral and intensity based sensors (FBG, FP, microbend)
- Feasibility of a compact single unit (mass 1 kg, dimension 50 x 200 x 200 mm³)
- Life-time 15 years in space

A decisive argument in favour of the CMOS spectrometer was the availability of space qualified components for the optoelectronic system of the interrogator. The selected CMOS image sensor STAR-1000 with 1024 x 1024 pixels is currently used for star sensors. Figure 5 illustrates the IU principle based on combining Wavelength and Spatial Division Multiplexing. The IU would be a usual PCB card in the on board computer for spacecraft housekeeping. As such the acceptable dimensions for a FO interrogator are 50 x 200 x 200 (see Figure 6). While the mass should be less than 1 kg.

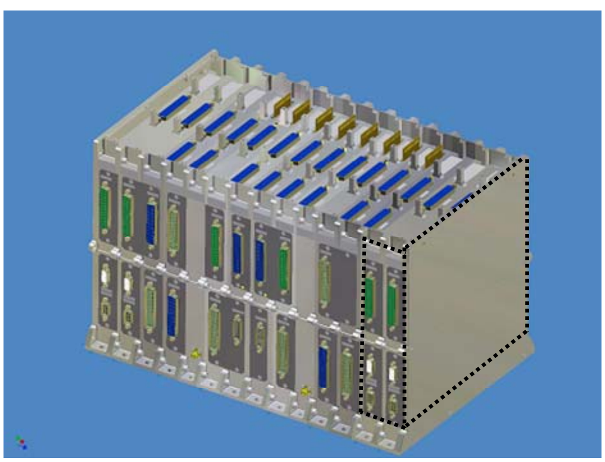


Fig. 10. Potential position of Interrogator Unit in a standard On-Board Computer (OBC) from Astrium

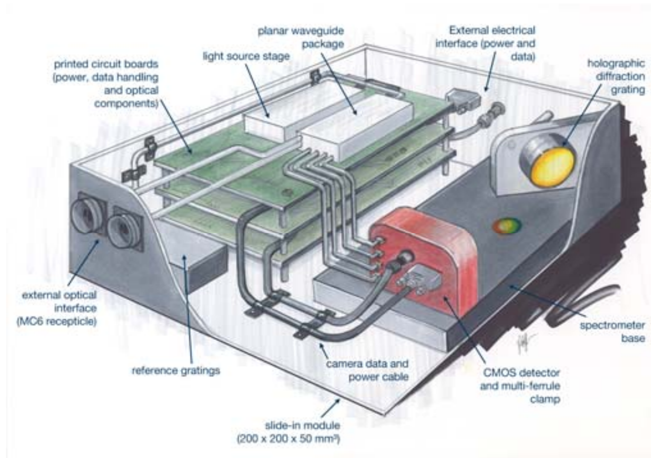


Fig. 11. 3D sketch of the Interrogation Unit

4. CONCLUSION

The study which is composed of system and technology activities has revealed potential applications for fiber optic sensing on satellite system. Benefits are lower mass, less integration, more sensors, improved functions, etc. Most interrogator components are space qualified, e.g. such as light sources and detectors. The fiber sensor itself have a lower maturity due to the low level of experiences. The FO sensors have to been seen as a complementary sensing system which provides specific benefits. With further investigation and maturity increase, the application of FO technologies, either for telecommunication, sensing or both will became a standard technology for future satellite systems.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] E. J. Friebele, C.G. Askins, G.A. Miller, J.R. Peele and L.R. Wasserman, “Optical Fiber Sensors for Spacecraft: Applications and Challenges”, Photonics for Space Environments IX, Proc. SPIE 5554, 120-131 (2004).

[2] I. Mckenzie and N. Karafolas, “Fiber Optic Sensors in Space Structures: The experience of the European Space Agency”, Invited Paper in 17th Optical Fiber Sensors, Bruges, Belgium (2005).

[3] S. Kabashima, T. Ozaki and N. Takeda, ”Structural health monitoring using FBG sensor in space environment”, Smart Structure and Materials 2001, Proc. SPIE 4332, 78-87 (2001).

[4] D. Estublier, G. Saccoccia and J. Gonzalez del Almo “Electric Propulsion on SMART-1”, ESA Bulletin 129, pp. 14-27 (2007). http://www.esa.int/SPECIALS/ESA_Publications/SEMAMLN0LYE_0.html

[5] S. McCulloch, R.R.J. Maier and G. Bumell, “Fiber Optic Sensors optical measurement techniques”, Discovery Mag. 7, 28-41 (2003)