MiniBRAGG

Miniaturized Acquisition Unit for Fiber Bragg Grating Sensor Based In-flight Applications

State of the art – Background

Fiber Bragg Grating (FBG) technology is a promising alternative to conventional sensing on aeronautic environments due to its low weight, high multiplexing capabilities, EMI immunity and electrical passive nature. Nevertheless, state of the art equipment for data acquisition of FBG sensors still lacks the required performance for in-flight use, especially in critical non-cabin areas. Available units are large, have quite restricted operation temperature ranges, and either have sampling rates under the requested value or have a limited operation bandwidth limiting the number of addressable sensors. These units have also not being designed for the harsh environments encounter in-flight, especially regarding vibration, temperature, humidity and EMC requirements.
It is thus necessary to develop an FBG interrogation equipment than can cope with the requirements to be used in a broad range of locations within the aircraft, which involves both functional (operational bandwidth, number of channels, sampling rate, accuracy,..), mechanical (size) and environmental (temperature, vibration, EMC, air and liquid tightness) improvements.

Objectives

The aim of the MiniBRAGG project has been to develop, test and manufacture a miniaturized acquisition unit for Fiber Bragg Grating optical sensors to be remotely used for strain, pressure and temperature measurements in-flight monitoring applications.
The MiniBRAGG equipment required features are:

- Simultaneous acquisition of 8 optical channels
- Wide bandwidth wavelength > 100 nm
- Over 2000 samples per second
- High spatial resolution accuracy (2pm = picometer)
- Dimensions less than: 250mm x 120mm x 75mm
- Power consumption: <50W
- Use in A/C harsh environment and DO160 compliant
- Operating Temperature: -55°C to 105°C
- ATEX compliant (EU guidelines for Atmosphere Explosibles)
- Data output: Ethernet output
- Able to address a chain of sensors on a same fibre of such physical quantities:
  - Temperature (Range from -60°C to 300°C; Range from: 0°C to 700°C),
  - Pressure (0 to 1.5 bar; Accuracy < 1mbar; Temperature compensated between -50°C to +80°C),
  - Strain (Range: +/- 2500 µstrains with a 20 µstrain accuracy; Range: +/- 6000 µstrain with a 100µstrain accuracy; Both temperature compensate)

Based on this set of initial requirements, the development has been based up-on FiberSensing's proprietary tunable laser technology (BraggMETER) that enables multi-channel parallel acquisition over broadband tunability (100nm). This enables large sensor count to be addressed in a single compact instrument. BraggMETER platform processing core is fully implemented in low-level electronics (microprocessors and FPGAs) that ensure high reliability, while reducing power consumption. The platform integrates an ultra-stable multi-line reference that ensures high accuracy over the full tuning range.

Description of work

The base BraggMETER platform relies in high speed analog to digital converters that restrict the maximum acquisition rate to 500S/s. Within the MiniBRAGG project the acquisition electronics have been redesigned using high-speed comparators to increase the acquisition rate to 2048S/s, while maintaining the spectral resolution (±2pm) and reducing the power consumption. The instrument architecture integrates: the tunable laser module scanning 100nm at 2048S/s; the optoelectronic module that incorporates 8 independent photodetection blocks with digital gain control to ensure more than 20dB of dynamic range; and, the processing module with digitalization based on multi-level high speed comparators, fast accurate spectral peak detection processing based on FPGAs and microprocessor for sensor calibration and interface through Ethernet. All these features have been integrated into a compact equipment, that has been tested following DO160 specifications. TRL-6 will be formally achieved after the test in flight to be performed with Airbus beyond the project in 2017..

The project execution has been divided into five phases:

1. Definition of Specifications and prerequisites in accordance with Airbus, acting as Topic Manager
2. Feasibility demonstration
3. Alfa prototype implementation and testing
4. Beta prototype implementation and testing
5. Final product implementation

In addition to the technical development, additional work has been devoted to dissemination and exploitation activities and to the project management itself.

Definition of Specifications and prerequisites in accordance with Airbus, acting as Topic Manager

The first phase of the project involved the close collaboration between FiberSensing and Airbus to define the final requisites for the equipment.
In addition to the requisites from the call, Airbus requested the inclusion of the following additional features:

- Internal and external data logging capability
- IENA protocol communication
- Selectable digital filtering and sampling rate
- Synchronization (PTP) and two different timestamping modes
- Sensor data network configuration trough XML files
- Individual sensor engineering unit conversion using 4^{th} order polynomial
- Graphical User Interface (GUI)

Since the main objective of the project has been to develop a useful product for the aeronautic industry, when incompatibilities were found among the different requirements, decisions as to which requirement to prioritize were taken in accordance with Airbus.
In particular, some of the additional requested features implied the use of devices (memories, high-end processing modules,…) rated for 85ºC, so a compromise was taken at this first stage as to sacrifice the initial temperature range on the call.

Feasibility demonstration
An initial mockup has been designed and tested to demonstrate the following features:

- Evaluation functional board, providing 2048S/s data acquisition over 60nm (100nm target for the final implementation, requiring minor modifications on the mockup platform) tuning range and resolution below 2pm.
- Full mechanical virtual prototype with target dimensions. A key aspect of the mechanical implementation was not only to comply with the required dimensions, but to also guarantee useful handling of connectors selected by Airbus. A mechanical mock-up was assembled with the selected connectors to assess connector handling complexity.
- Implementation of a optoelectronic board mockup for assessment of the optoelectronic component cooling using TEC elements. This test already provided indications that the required heatsink to achieve 105ºC would be too high to fit the required dimensions.

Alfa prototype implementation and testing

The first fully operational prototype was designed and assembled during this phase.
The following successful tests were performed on the alfa:

- Wavelength measurements: 2048S/s, 100nm, 8 channels, ±3.2pm accuracy and 1.2pm resolution
- Sensor acquisition with multiple sensors on a fiber and 4th order polynomial calibration
- Equipment configuration trough XML file
- Start sequence: the equipment automatically enters operational mode on unit power ON, based on the last downloaded XML configuration
- Power supply requirements
- Power consumption
- Optical power (towards ATEX)
- PTP synchronization
- Memory data recording (internal and external)
- Mechanical dimensions and marking
- Partial demonstration of GUI performance
- Environmental:
    - RF susceptibility and EM environment (Figure 1)
    - Altitude/pressure (Figure 2)
    - Relative humidity (Figure 3)

Additional test were performed that were either unsuccessful or not fully compliant with requirements:

- Digital filtering. Digital filters were not correctly implemented
- Vibration. An optoelectronic component was broken during sinusoidal testing due to high stress on the connection pins cause by the component assembly method.
- Temperature. Although the initial 105ºC had already been discarded at this stage (as a trade-off with additional equipment functionalities such as internal data recording, IENA communication,…), major design and testing efforts were oriented to maximizing the upper temperature operation. Two main approaches were analysed: passive heat dissipation, optimizing component heat

transfer to case and heatsink, and active cooling (TEC) of the critical components. Also different heatsinks were tested at this stage. Testing concluded that the use of TEC elements provided a reduction on the temperature of the critical OE components, but in turn heated up the processing platform (also limited to 85ºC), so a passive approach was finally selected to be implemented on the beta prototype.

Beta prototype implementation and testing

In this phase a second prototype was designed and implemented with the following modifications provided based on the alfa testing results:

- Since the passive thermal approach had finally been selected, mechanical adaptations were provided to improve thermal contact on critical components to the case and heatsink.
- Also the mechanical assembly of the vibration damaged component was modified.
- Corrections on the electronic boards
- Correction of several software bugs
- Improvement of the startup sequence to reduce equipment startup time.
- Correction of digital filtering implementation
- Additional features added on the GUI
- IENA communication implemented

Tests that had either not been performed on the alfa of that had failed were re-conducted, mainly vibration testing (Figure 4), digital filtering operation and testing of the new GUI features (Figure 5), and IENA communication.
Further thermal testing was performed on the beta to assess final temperature limits: -35 to 78ºC have been set as operation range for the developed equipment (Figure 6). Still, the negative range testing was limited just by the available thermal chamber, and further testing is expected following the project conclusion to assess the minimum operating temperature.

Final product implementation

The final equipment developed within MiniBRAGG project will be further tested and developed, in collaboration with Airbus, in order to reach a maturity of TRL6.

Results

The main result of the MiniBRAGG project has been a fully functional FBG interrogation equipment, fulfilling almost all initial requirements. The equipment also provides additional features, regarding communication, control and data processing and recording. The equipment is DO160 and ATX compliant.

a) Timeline & main milestones

The project started in 1st July 2014 and finished in 31st October 2016.
Main milestones within the project have been:

- Specifications agreed upon with the Topic Manager.
- Feasibility demonstration of proposed architecture.
- Functional alpha prototype and prototype testing results assessing its performance
- Beta prototype available for in-flight tests
- Functional final product available

b) Environmental benefits

The MiniBRAGG product design considered quantity and types of materials used in the manufacturing process, operation efficiency for low power consumption, and designing for better end of life recyclability:
•The enclosure is manufactured of aluminium fully recyclable.
•Power-efficient components were selected for low power consumption.
•The adoption of the RoHS directive on the restriction of the use of hazardous substances in electrical and electronic equipment and of the EU regulation on conflict minerals were considered in the development phase.
The MiniBRAGG equipment is a low consumption (<20W) equipment capable of simultaneously interrogating 160 sensors. Those 160 can be multiplexed over 8 fiber optic cables, greatly reducing cabling weight and thus contributing to the achievement of lightweight aircrafts. Furthermore, the employment of lightweight composite materials requires the improvement of monitoring systems to assess structural integrity of the parts, and thus the employment of FBG sensors interrogated by this compact and low consumption equipment will provide relevant environmental benefits while ensuring structural integrity of these new aircrafts.

c) Dissemination / exploitation of results

Activities and results of the MiniBRAGG project have been **disseminated** in the following forums, mainly targeting the industrial sector:

- **ENOVA PARIS 2015**. 22nd and 24th September 2015 at Porte de Versailles, Paris. ENOVA PARIS joins together start-ups, businesses, technology developers, digital stakeholders, research laboratories, designers and entrepreneurs to explore new usages and services, creating the perfect climate for doing business, co-building an innovative and competitive industrial project and launching cross-disciplinary initiatives. The fair included the 4th Congress on Fibre Optic Applications, dedicated to fiber optic sensors and sensor networks, fiber optics in operator networks and buildings, and applications for new fiber optics and upstream technology. A presentation was provided on "Capteurs fibre optiques de Bragg dans les applications aerospatiale" (September 22nd at 15h30), including the information on the MiniBRAGG project.

- **WESTERN REGIONAL STRAIN GAGE COMMITTEE**. 2015 Fall Test and Measurement Conference—September 14 -16, 2015, Savannah. The Western Regional Strain Gage Committee (WRSGC) is a Technical Division of the National Society for Experimental Mechanics (SEM). The purpose of the committee is to promote a free interchange that explores all the aspects of strain measurements. The Western Regional Strain Gage Committee (WRSGC) consists of members from companies and government agencies mostly in the Western United States. Members include Major Aircraft Companies, National Laboratories, Propulsion Engine Manufacturers, Government Facilities, Aerospace Research and Development firms and strain gage, transducers and instrumentation manufacturers. Organizations from other regions are also members.
  On the fall meeting 2015 a presentation was provided by Bernd Guenther (HBM) on “Manufacturing and Reliability Evaluation of Embedded Fiber Bragg Gratings in Composite Materials”, presenting results from previous CleanSky project (RemFOS) and incorporating the MiniBRAGG results achieved up to that point. Also a presentation on the MiniBRAGG results was provided on the WESTERN REGIONAL STRAIN GAGE COMMITTEE 2016 Fall Test and Measurement Conference—September 12 -14, 2016, Seattle.

- The project has been included on **FiberSensing’s web page** (http://www.fibersensing.com/rd/projects/ongoing/view/minibragg).

Regarding **exploitation**, the MiniBRAGG project results will have commercial application for HBM FiberSensing, after further development and maturation of the technology as planned in collaboration with Airbus. ,
The exploitation plan is focused on two aspects:

- aeronautic market: Commercialization of the final equipment in the aeronautic market within the next 3 years.
- other markets: Integration of some of the features developed on the MiniBRAGG in the commercial HBM equipment for other markets. In particular, the following aspects will be further exploited as part of the company’s general portfolio:
  - Integration of the developed 2048S/s platform in general purpose HBM FiberSensing equipment for dynamic measurements. Current dynamic platforms at HBM FiberSensing provide 500S/s acquisition rates, so a new generation of dynamic interrogators is to be launched, running at 2048S/s.
  - PTP synchronization to become standard in HBM units
  - Integrated OETL board in opposition to actual individual boards for the laser and the detection block (size reduction).

d) Communication

The following **communication** activities have been carried out as part of the project communication plan

- **Open webinar on “Optical measurement solutions for the aerospace industry”,** performed on 25/02/16, the webinar was part of the HBM series of webinars on their different measurement solutions. The webinar had over 50 attendees both from the industry and academia.
- The project has been included as part of the **general company presentation**. As such, visibility on the project is given on a large number of events and client and partner meetings, in which the overall company capabilities are presented.
- Presentation of the project outcomes and the final instrument capabilities to Airbus personnel, on December 12th 2016. This presentation is especially relevant since the equipment has been designed following Airbus specifications.

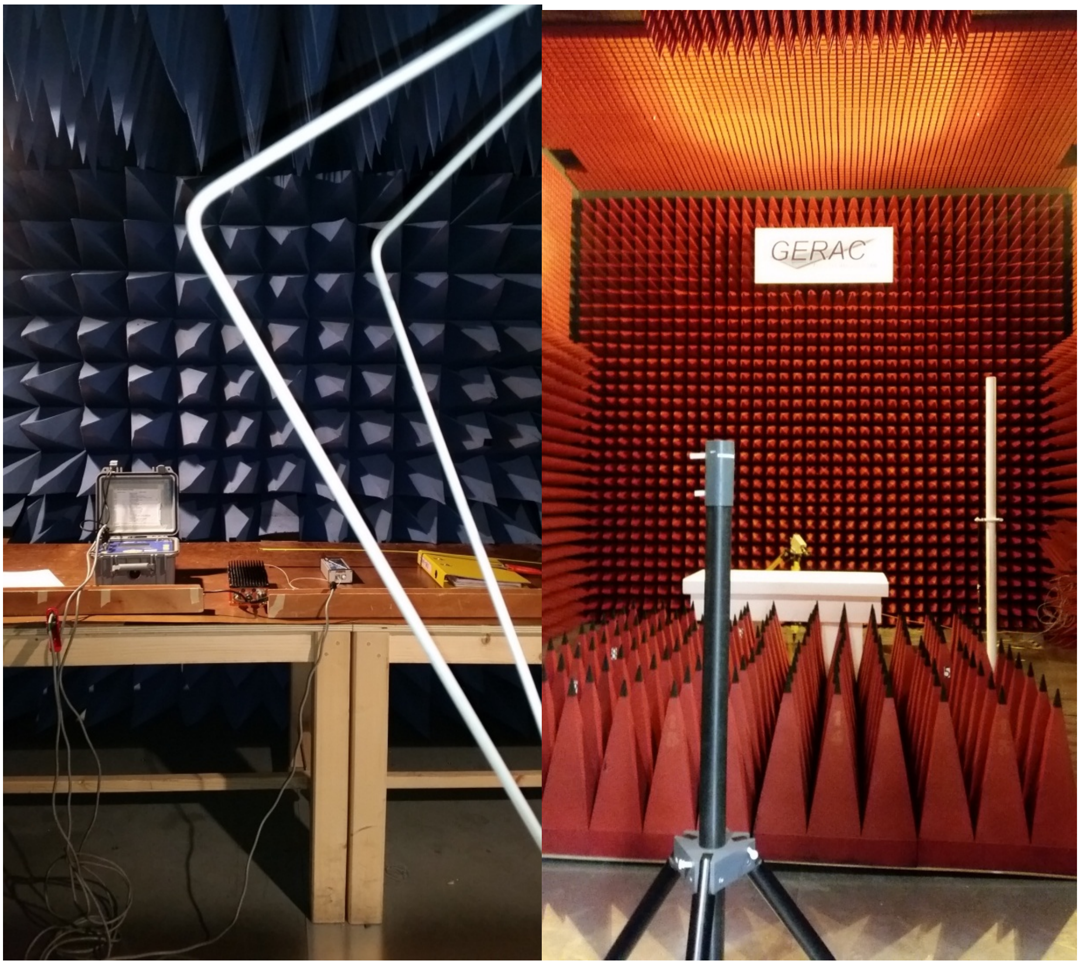


Figure 1: Equipment RF /EMC testing

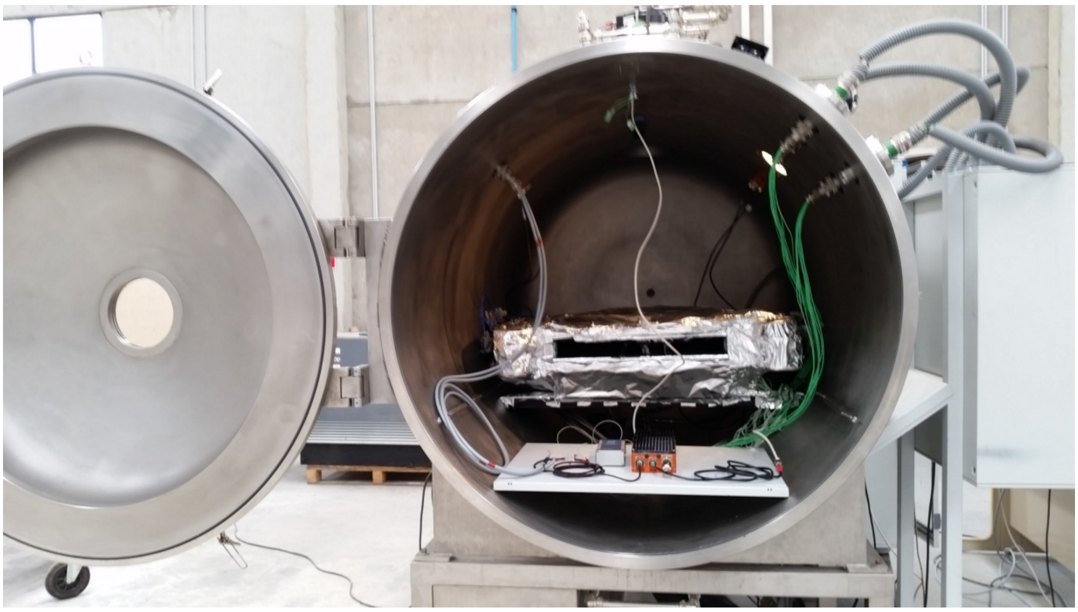
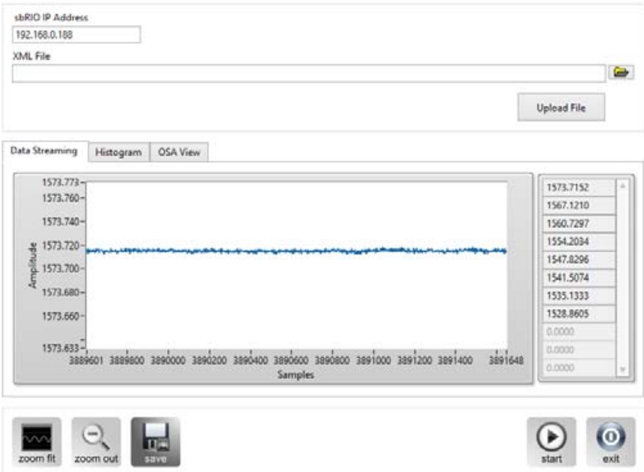


Figure 2: Equipment altitude/pressure testing

Figure 3: Equipment immediately after chamber removal during humidity test



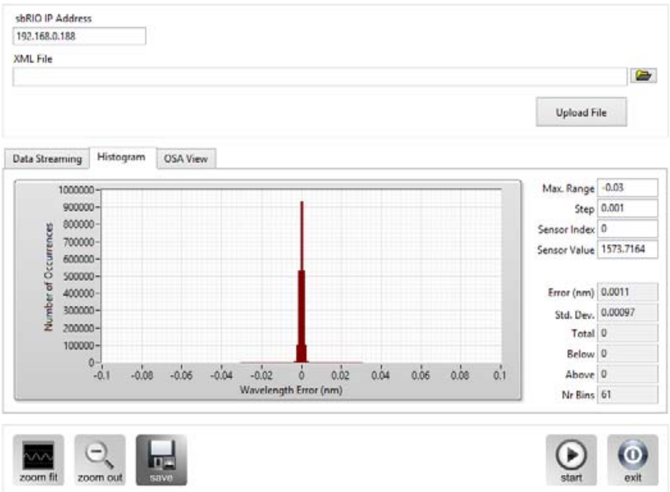


Figure 4: Equipment during vibration testing. The lower figures show the measurements taken on a sensor at 1573.716nm (measurement standard deviation under 1pm)

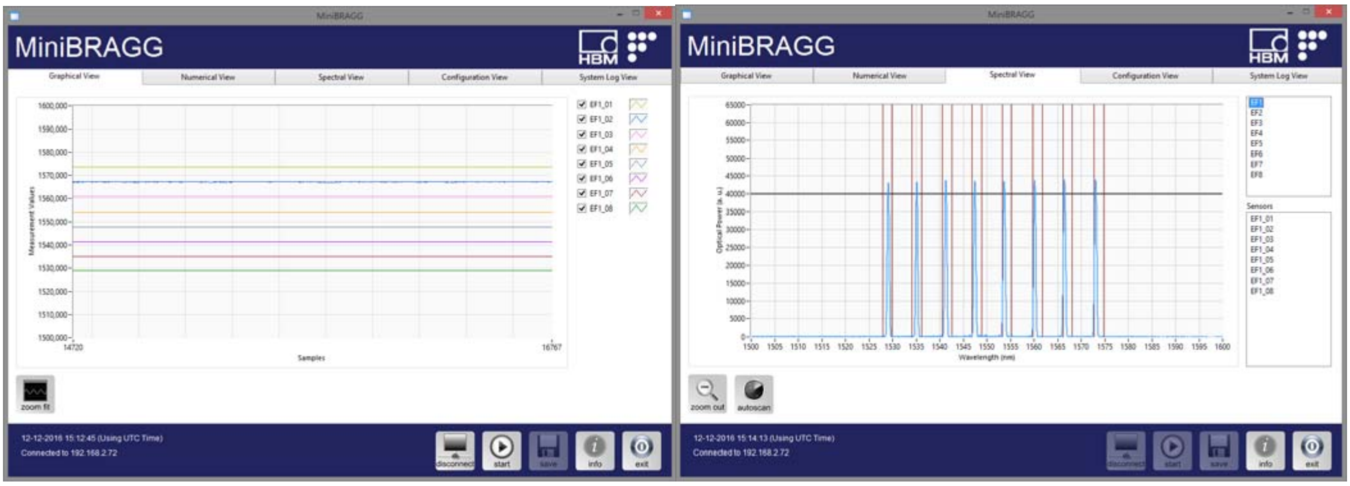


Figure 5: Graphical User Interface. Equipment measuring 8 sensors on channel 1

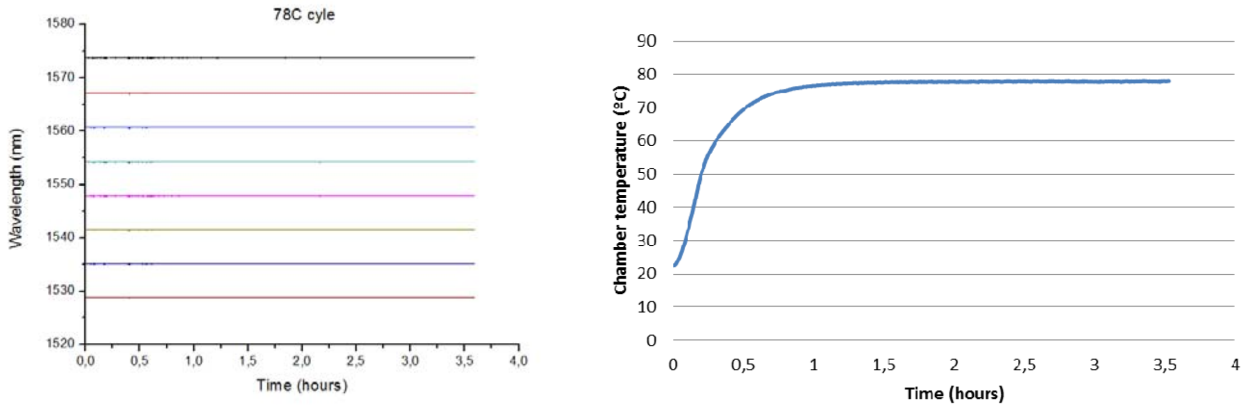


Figure 6: Top: Equipment getting ready for thermal testing (thermistor leads for internal thermal mapping can be seen on the right). Bottom: 8 sensors recorded with standard deviation under 6.5pm (left) during 78ºC cycle (right)

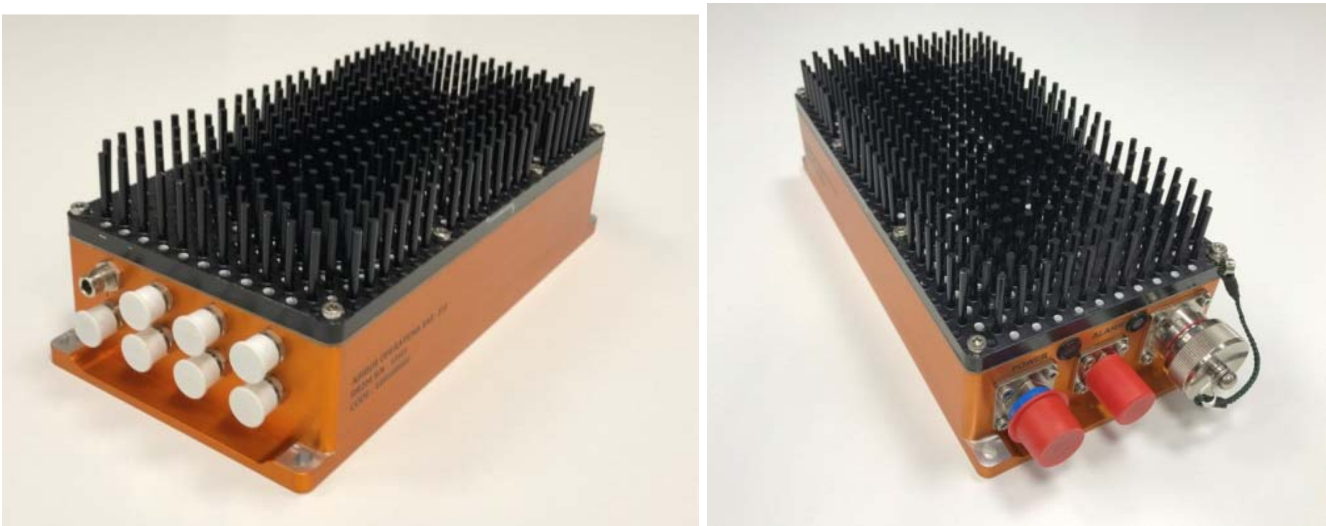


Figure 7: Final serial product

Project Summary

Acronym:	MiniBRAGG
Name of proposal:	Miniaturized Acquisition Unit for Fiber Bragg Grating Sensor Based In-flight Applications
Involved ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement:	641558
Instrument:	Clean Sky
Total Cost:	532.111,10€
Clean Sky contribution:	264.600,00€
Call:	JTI-CS-2013-03-SFWA-03-019
Starting date:	01/07/2014
Ending date:	31/10/2016
Duration:	28 months
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