REXUS/BEXUS

EXPERIMENT PROPOSAL FORM.

Your text should be intelligible to scientists of various fields and engineers with a general scientific background. Before you submit your proposal, please ensure that you have read the **REXUS/BEXUS Technical Overviews**. You can also refer to the **REXUS/BEXUS User Manuals** for more detailed information. The forms and the documents are available at www.rexusbexus.net. To submit your proposal to DLR, please sent the **Letter of Intent** for registration and the filled-in application form electronically before their deadlines to rexusbexus@dlr.de

Team/Short experiment name	**FOVS**
Full experiment title	Fiber-Optic Vibration Sensing Experiment

☒ **REXUS** ☐ **BEXUS**

- ☒ spinning with 4 Hz
- ☒ despun with Yo-Yo to about 0.08 Hz

Science & Organisation

Team Information	
Student team leader:	Max Rößner, Technische Universität München Degree in Electrical Engineering, Enrolled as Ph.D. student since 2010
Contact information of team leader:	Max Rößner, [redacted] m.roessner@tum.de, +49-89-289-23349, [redacted]
Members of your team:	[redacted] Technische Universität München Master of Photonics degree, PhD student in the field of fiber optics since 2010 **Ongoing university-internal promotion of the project aims for attracting additional students.**

What is the scientific and / or technical objective of your experiment?	**<u>Motivation</u>** There are emerging technologies for launch vehicles demanding advanced sensory solutions. Particularly, the concept of active vibration damping in launchers calls for the capability to sense entire fields of vibrational stress throughout the structure. Furthermore, the SOMID project (Rexus 11/12) demonstrated the usage of solid-borne sound measurements to independently deduce information on mechanical actuators. Thus, there is demand for a vibration measurement system that allows for monitoring of vibration throughout the structure. **<u>Challenge</u>** The state-of-the-art approach for vibration measurements is the usage of electrical sensors. Unfortunately, the wires connected to electrical sensors (at least two per sensor, often more) and the cable shielding can quickly add up to a heavy mass contribution, what is to be avoided in a launcher. For this reason, establishing a sensor network for vibration measurement in a launcher can be problematic when electrical sensors are to be applied. Furthermore, a large network of electrical sensors inside a rocket is susceptible to electromagnetic interference due to the long cable lengths involved. In addition, safety and reliability issues (flammable propellants etc.) pose additional requirements. From an engineering perspective, it would, thus, be beneficial to have a sensing system that combines the following properties: • Low mass, low volume. • Possibility to cascade multiple sensors along a single connecting wire. • Insusceptible to electromagnetic interference, not causing electromagnetic interference. • Minimal mechanical and thermal influence to the structure or device under test. • Operational under very high and very low temperatures.

Solution Approach

An emerging class of sensors that has the potential to combine several beneficial aspects in this context are fiber-optic sensors. Fiber-optic sensors make use of the propagation properties of light inside an optical glass fiber to deduce information on various physical quantities. Due to the absence of electrical wires or electricity and due to the properties of glass, the above-mentioned issues associated with electrical sensors are solved.

Due to their advantages, fiber-optic sensors are increasingly popular in application on ground, such as in monitoring concrete structures in civil engineering. The proposed Rexus experiment aims for a demonstration of this technology in the challenging and highly dynamic environment of a rocket vehicle.

The most versatile fiber-optic sensor is the fiber Bragg grating (FBG). An FBG is made of a periodic perturbation of the refractive index of the core of an optical fiber along its axis. Every single perturbation causes a small amount of light being scattered back. If the light's wavelength happens to match the grating pitch Λ, the backscattered light is superimposed in-phase and, consequently, constructive interference occurs. Such a fiber Bragg grating can be seen as a filter that reflects light around a particular wavelength, called the Bragg Wavelength λ_B, and that is transparent to other wavelengths (refer to figure 1 below).

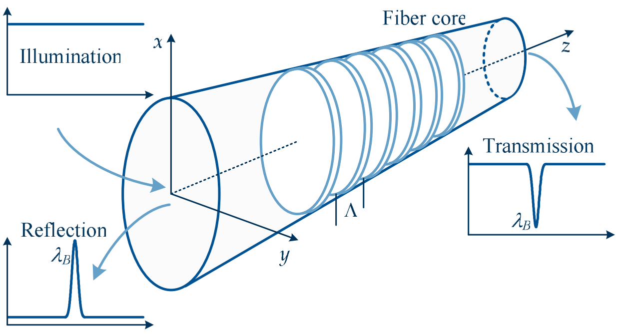

Figure 1: Schematic visualisation of a fiber Bragg grating

The Bragg wavelength can be modelled as $\lambda_B = 2 \cdot n_{eff} \cdot \Lambda$. Both the effective refractive index n_{eff} of the fiber and the grating pitch Λ depend on mechanical strain exerted on the grating as well as on the grating's temperature. In this way, mechanical forces and temperatures can be quantified by measuring the wavelength at which the FBG reflects light (or by measuring at which wavelength the FBG does not transmit light). This is an entirely optical way of performing the measurement; no electricity is involved up to now.

The absence of electricity at the point of measurement guarantees that no electromagnetic interference occurs. The low mass and low volume of an FBG-based sensor cause little thermal or mechanical interference with the unit under test.

The low mass and low volume of an FBG-based sensor also allow for easy accommodation of a number of sensors even under the stringent mass and volume requirements of a launcher. Last but not least, it is possible to cascade multiple FBGs along a single fiber. In this concept, each FBG operates around an individual Bragg wavelength. By wavelength division multiplexing, each sensor can be individually queried using a designated wavelength range.

In this way, FBG sensors can pave the way for highly advanced sensory solutions on board of commercial launchers, such as the Ariane. This can be of benefit for increased situational awareness during launch and for emerging technologies such as active vibration damping. As an additional advantage, an FBG-based measurement system can be used as an overlay system that compliments established and proven techniques (such as electrical sensing) without causing problems of mutual interference.

Usage scenarios

Summarizing, a few examples are provided in which FBG-based measurement systems could provide advantages in a launch vehicle context. These concepts will not be included in the proposed Rexus experiment but are presented here to demonstrate some applications in which a distributed fiber-optic measurement system can offer benefits in a large-scale satellite launcher, such as the Ariane.

Integration of a fiber-optic vibration measurement network in a launcher is performed in order…

- …to increase the situational awareness of the launch control engineers;
- …to prove or disprove that product assurance limitations in vibrational acceleration were met;
- …to capture comprehensive data on the vibration throughout the structure (“vibration map”), as required for active vibration damping;
- …to identify structural defects by observing the vibration modes, thereby detecting structural failures before they become apparent otherwise. Particularly useful for the time frame between liquid rocket engine ignition and solid rocket booster ignition, as even launch abort is possible;

- …to measure and to triangulate (using multiple sensors) the source of a vibration pattern, independently proving or disproving the correct activity of actuators such as valves, pumps or motors (extension of the concept of the SOMID experiment previously flown on Rexus).

Heritage

In an already completed research project called SMAFO, the Institute of Measurement Systems and Sensor Technology (MST) of Technische Universität München, which hosts the present Rexus proposed experiment, developed fundamentals required for a fiber-optic sensor system in a launcher.

Particularly, for any vibration measurement system it is crucial that some way of anti-aliasing is implemented. The frequency at which the vibration sensors (regardless of whether these are electrical or optical sensors) are sampled has to be greater than twice the maximum vibration frequency that is measured by the sensors (plus some safety margin to account e.g. for imperfect low-pass filters). Otherwise, aliasing would occur, what would mean that frequencies higher than half the sampling rate would appear as lower frequencies in the measurement result. Usually, low-pass filters with an appropriately selected cut-off frequency are used for this purpose. In the SMAFO project, a measurement concept was developed that allows for reliable low-pass anti-aliasing filtering in the context of fiber-optic measurement systems. SMAFO consisted of lab experiments; no flight test had been carried out. A derived and simplified, yet representative system (still featuring the anti-aliasing property) is planned for the proposed FOVS experiment on Rexus.

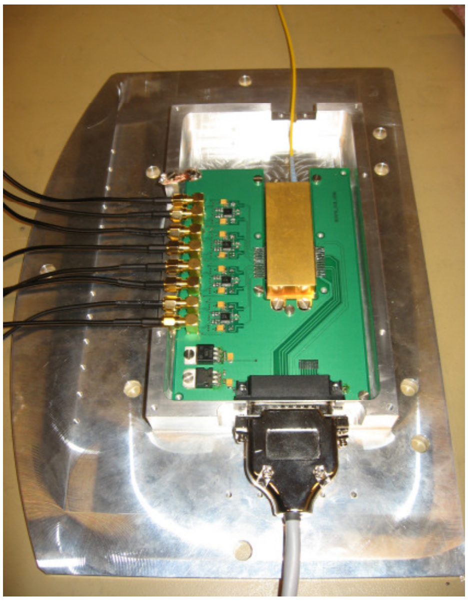

Figure 2: Photo of the SMAFO demonstration unit.

Furthermore, a fiber-optic acceleration sensor was developed. It is based on a small test mass held in place by a thin metal foil inside a cylindrical housing. A fiber Bragg grating is mounted to the test mass and to the housing. According to acceleration acting on the test mass, strain to the fiber Bragg grating results. This causes the Bragg wavelength to shift accordingly.

It is made sure by the thermal mass of the aluminum housing that the temperature inside the sensor changes slowly compared to changes caused by vibration. In this way, influences to the sensor resulting from temperature changes can be filtered out by appropriate signal processing.
DC accelerations cannot be measured with thermal compensation, but this is outside the scope of the FOVS experiment.

Alternatively, a commercially available fiber-optic acceleration sensor might be used.

Figure 3: Photo of the fiber-optic accelerations sensor. The diameter of the aluminum tube is 11 mm. The cable that leaves the senor is an optical fiber, not a copper wire.

A fiber-optic light source intended for spaceborne applications was developed by the team leader of the proposed Rexus experiment (figure 4). It is based on amplified spontaneous emission in the core of an Erbium-doped fiber. Using a pump laser at approx. 980 nm, the Erbium atoms in the fiber are driven into electron inversion. Electron inversion enables stimulated emission of photons. If an electron spontaneously relaxes, it causes a photon being emitted. This single photon in turn causes an avalanche of addition photons by stimulated emission. In contrast to a laser, the emission is broadband due to the intentional lack of a resonator cavity. The light source was implemented in a way hardened to vibration and extreme temperatures, which was also tested. The work was awarded the Pierre Contensou Medal at the International Astronautical Conference 2010 and is planned to be used as light source for FOVS.

Literature

This paragraph gives a short overview of related publications.

An FBG-based fiber-optic measurement system was tested on board the experimental X-38 re-entry vehicle. 12 fiber sensors were illuminated by a superluminescent diode and queried by a spectrometer. The sample rate was limited to 1 Hz due to limitations in spectrometer performance and data handling. Vibration measurements are, obviously, not possible in this way. (Ecke, W. et al.: “Fibre optic sensor network for spacecraft health monitoring”, Measurement Science and Technology, Volume 12, 2001.)

A FBG measurement system was also implemented for a cryogenic liquid hydrogen tank of an experimental reusable rocket by the Japan Aerospace Exploration Agency. Fiber Bragg gratings were applied to monitor the material strain resulting from pressurisation of the tank. The illumination system based on LEDs does not allow for high intensities coupled into the measurement fiber, however. Anyway, the system was neither intended nor used for vibration measurements. (Mizutani, T. et al.: “On-board Strain Measurement of a Cryogenic Composite Tank Mounted on a Reusable Rocket using FBG Sensors”, Structural Health Monitoring, Volume 5, Number 3, 2006.)

The FOSAT project aimed to demonstrate advanced multiplexing techniques to enable monitoring of several hundred fiber bragg gratings jointly. The system concentrated on temperature measurements. Hence, it relied on a spectrometer not suited to operate at sampling frequencies high enough for vibration measurements. (Hoffmann, L. et al.: “Fiber-Optic Measurement System for Temperature Monitoring of Telecommunication Satellites”, International Conference on Space Optics, 2008.)

The SMAFO project, the predecessor of the proposed FOVS experiment, demonstrated anti-aliasing features in FBG-based measurement systems for launchers. The feasibility of the underlying concepts was proven in lab setups, but SMAFO never made it on a test flight. (Plattner, M. et al: “Development of Fiber Optic Sensing Interrogators for Launchers”, International Conference on Space Optics, 2010; Yasukazu, S. et al.: “Fast Optical Wavelength Interrogator Employing Arrayed Waveguide Grating for Distributed Fiber Bragg Grating Sensors”, Journal of Lightwave Technology, Volume 21, Number 1, 2003.)

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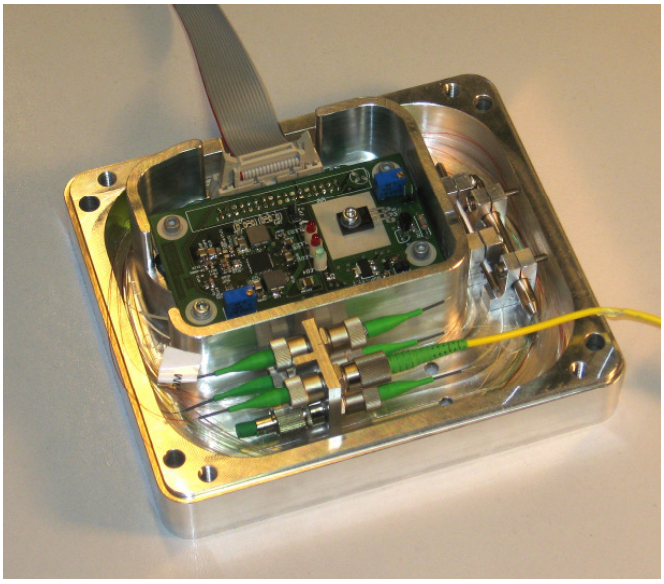
<tr><td></td><td>

Figure 4: Photo of the space-hardened amplified spontaneous emission light source. The volume can be further reduced by using fiber splices instead of the bulky fiber-optic connectors that consume almost half the available space in this device.

<u>Research Question</u>

The experiment aims for a demonstration of a fiber-optic vibration measurement system, intended for structural and actuator monitoring, in an actual flight, to prove (or disprove) its benefits compared to electrical sensing in the launcher environment.</td></tr>
<tr><td>Why do you need a rocket?</td><td>As described, the concept has already been tested in a lab experiment. There has never been an in-flight verification, however. It is the purpose of the proposed experiment to challenge the concept in a real-world environment.</td></tr>
<tr><td>Where did you get the idea from?</td><td>The proposed experiment is inspired from the SMAFO experiment described above. Furthermore, the team leader was awarded the Pierre Contensou Medal of the International Astronautical Federation for his diploma thesis on “Development and Implementation of a Broadband Light Source for Fiber Optic Measurement Systems in Space Applications”.

The team leader is aware of the Rexus program due to his long-time involvement in ESA’s educational missions, particularly the European Student Moon Orbiter mission.</td></tr>
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Describe your experiment

Figure 5 below illustrates the basic concept of the experiment. A light source generates broadband light in the 1550 nm band. This light is fed to the FBG acceleration sensor using an optical circulator. The reflected light around the Bragg wavelength is coupled out using the optical circulator and fed to a directional fiber coupler which splits the light. One output of the coupler is connected to an optical filter that has a monotonic filter curve. This means that the light intensity at the filter output is a function of the wavelength. The photodiode behind the filter measures the intensity. The wavelength can, thus, be deduced by measuring the photo current (which is proportional to the intensity). To cancel out any intensity fluctuation of the light source, a second photodiode, without the filter, is used as a reference. This principle is referred to as "edge-filter interrogation", as the edge of the filter curve is used to measure the wavelength at which the FBG reflects light.

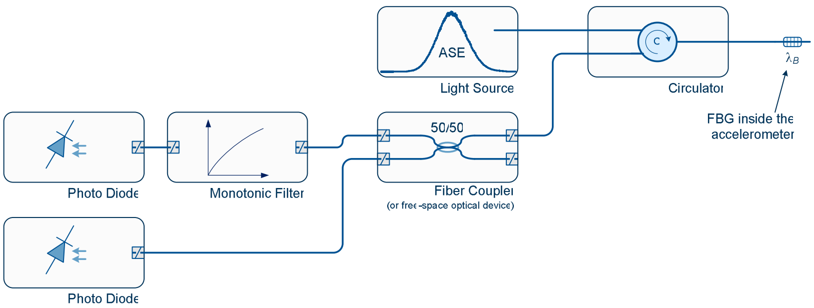


Figure 5: Basic concept of the FOVS system

The system is representative for possible future large-scale fiber-optic measurement systems in commercial satellite launchers. For a future large-scale system, one can easily scale up the FOVS system proposed for the Rexus flight. This may be achieved by cascading multiple FBG accelerometer sensors along a single measurement fiber, each sensor operating around a different wavelength in an individually assigned wavelength band of typically 10 nm bandwidth. To decompose those wavelength-multiplexed signals into individual values, one can, for example, use a system as outlined in figure 6. Bandpass filters are used to cut a designated wavelength band out of the wavelength-multiplexed data. Each bandpass filter is assigned to an individual FBG sensor. (The cascade of bandpass filters can either be built by discrete components, as shown in figure 6, or can be built into a joint device, a so-called arrayed waveguide grating, which is a standard component in fiber-optic communication lines.) One can easily see that there is a close similarity to the FOVS system, hence the FOVS system is representative for a future large-scale system on a commercial launcher like the Vega or the Ariane.

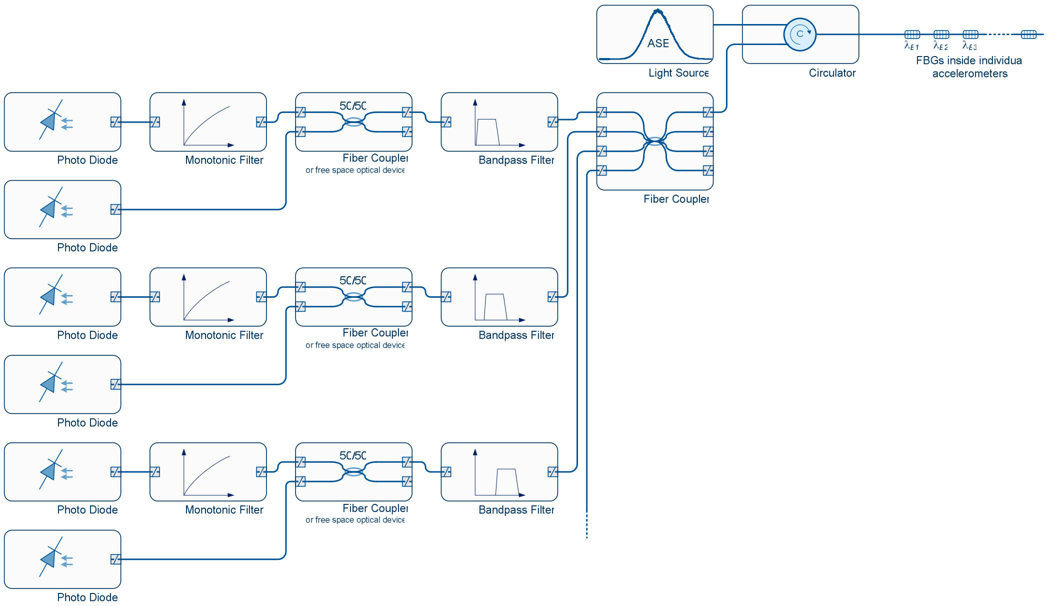


Figure 6: Evolved concept for a future large-scale system featuring wavelength-division multiplex

Which data do you want to measure?	The system measures vibration data using a fiber-optic accelerometer. The photo currents of the photodiodes shown in figure 5 are amplified and low-pass-filtered. **This filtering ensures anti-aliasing capability, which is crucial for meaningful vibration data. This feature, to the best knowledge of the proposers of this experiment, has not yet been applied in any flight experiment before in the context of fiber-optic measurement systems.** To verify the correctness of the data, a usual, state-of-the-art electrical accelerometer will be flown as well in immediate vicinity of the optical accelerometer. (A more detailed evaluation will reveal whether the accelerometer data of Rexus's service module can be used instead. However, this is not probable as the data of the two accelerometers, hence their location and sampling rate, have to be comparable to produce meaningful, i.e. comparable, results.) Furthermore, general housekeeping data, such as temperatures, will be measured to put the scientific data into an overall context.

How do you want to take measure-ments?

Figure 5 has shown the basic idea of the FOVS experiment. Figure 7 combines this with the block diagram of the light source. It is crucial that the light source generates light in a broad band and with a low degree of polarisation to prevent disturbing birefringence effects. As described above, a specialized light source to accomplish that is already developed. A laser having a wavelength of approximately 980 nm is used to illuminate an Erbium-doped fiber. As the name suggests, an Erbium-doped fiber contains a small amount of Erbium atoms. Electrons in the shell of the Erbium atoms are excited to a higher energy level, causing electron inversion. Hence, stimulated emission can occur. An electron spontaneously relaxing causes an avalanche of addition photons by stimulated emission. As the polarisation direction of every initial photon is selected arbitrarily, the collectivity of the emitted photons follows no particular polarisation. This is referred to as “Amplified Spontaneous Emission Light Source (ASE)”.

The generated broadband light, which is in the wavelength band of 1510 nm to 1610 nm, is coupled out of the light source by a wavelength demultiplexer (WDM), sent to a circulator and further on to the FBG inside the fiber-optic accelerometer. The FBG reflects light at a distinct spectral peak around its Bragg wavelength, which is coupled out by an optical circulator. This spectral peak is fed to a directional fiber coupler which splits the light. One output of the coupler is connected to the optical edge filter to determine the wavelength. To cancel out any intensity fluctuation of the light source, a second photodiode, without the filter, is used as a reference.

For calibration of the system while it is still in the lab, the directional fiber coupler is used to insert light of known wavelengths directly to the edge-filtered diode and to the reference diode.

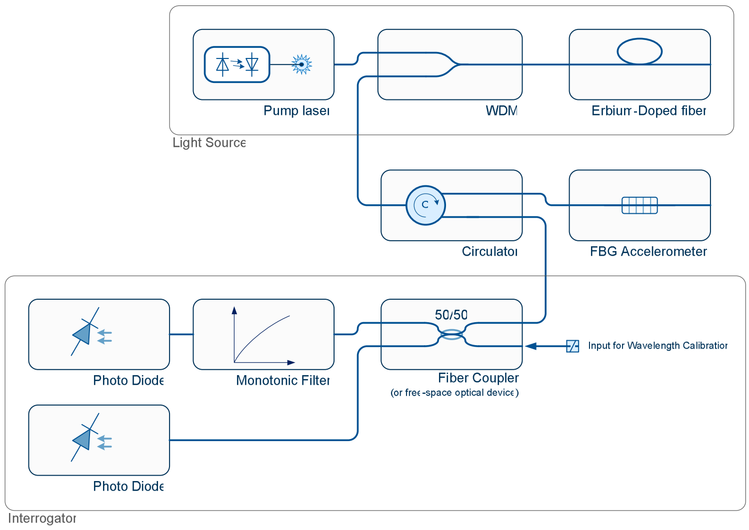


Figure 7: Entire optical system of the FOVS experiment

Figure 8 shows the electrical sub-system of the proposed FOVS experiment. One can see a concise separation into three functional groups, each featuring an individual microcontroller, individual low-pass filters and individual memory card for data storage. This is done to ease parallel development and to exclude mutual dependencies of the systems. Obviously, design re-use between the systems is possible. In figure 8, from top to bottom, the systems for general housekeeping data, optical acceleration sensor handling, and electrical sensor handling are shown.

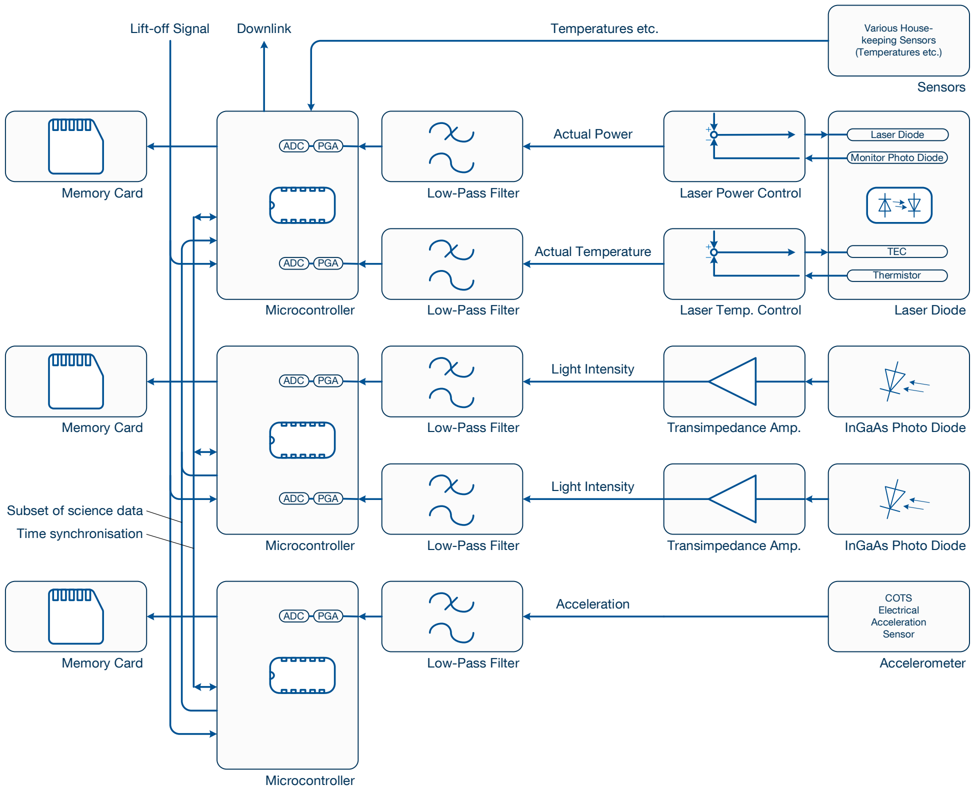


Figure 8: Electrical block diagram of FOVS

The sub-system shown in the top part of figure 8 is responsible for general housekeeping data. Most importantly, the output power of the 980 nm pump laser and its temperature are measured. A low-pass filter is used to further limit noise. The internal programmable gain amplifiers (PGA) and analog-to-digital converters (ADC) of a microcontroller are used to convert the data to the digital domain. The measured values are stored on a memory card, e.g. an SD card, and also sent to Rexus's service module for downlink. Auxiliary sensors such as temperature sensors etc. are treated in the same way.

A separate microcontroller is used to handle the data of the optical vibration sensor. The photo currents of the two photodiodes are amplified using transimpedance amplifiers. The resulting voltages are low-pass-filtered, which is crucial for anti-aliasing and which, besides, limits noise. The data is stored on a memory card. A subset of the data can be forwarded to the housekeeping microcontroller for downlink.

	Yet a separate microcontroller (plus memory card) is used to measure and store the acceleration data of the electrical acceleration sensor used as a reference. All microcontrollers are connected to a time synchronisation line. In this way, the data is stored with common time tags. The microcontrollers are also connected to the Lift-Off Signal of Rexus to provide the time of lift-off. Thus, all data time tags can be evaluated relative to the time of lift-off. Not shown in the figure are opto couplers to provide galvanic separation, and the power supply system.
Describe the process flow of your experiment.	The process flow is easy: The microcontrollers begin to capture and store data immediately after powering up. To account for launch delays that might occur, they begin to overwrite the oldest data once the memory cards are full. They are switched off shortly before or shortly after landing.
What do you plan to do with your data after the flight?	The data of the optical acceleration sensor will be compared to the data of the electrical acceleration sensor. This will prove (or disprove) that the data of the optical sensor is identical to that of the electrical sensor. Thus, it is proven or disproven that the upcoming fiber-optic measurement technique can be used as a replacement of the electrical sensors that are common today, with the additional benefits of fiber optics outlined above.

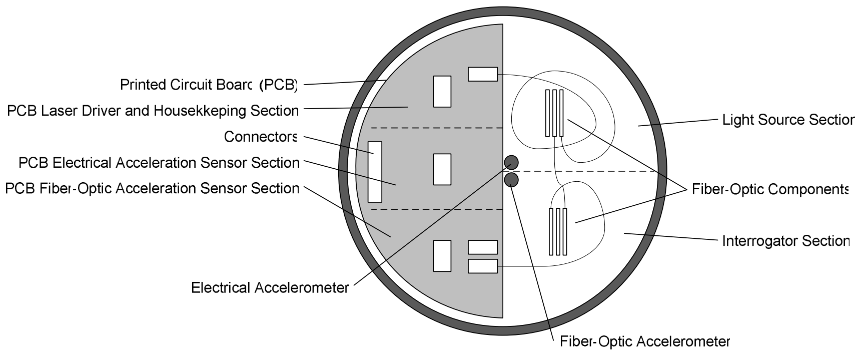
Organisation of your project	In addition to the core team as indicated in the sections “team leader” and “members of your team” above, additional students will work on the project, either in their spare time or in the framework of Bachelor’s and Master’s theses, lab courses, etc. The overall organisation of these tasks will be coordinated by the persons indicated above. Outreach work will be conducted by those persons as well with the support of the faculty’s and the university’s corporate communication offices. It should be noted in this context that all key techniques required for the FOVS experiment are readily available, either at the Institute for Measurement Systems and Sensor Technology that hosts the FOVS experiment, or as commercial products. The work to develop the experiment thus concentrates on the delta development required for the Rexus conditions. A basic requirements management system is planned to be established for coordination of the individual project contributions and to keep in line with the Rexus-implied and experiment-implied requirements.
Are you supported by institutes and/or senior scientists?	The experiment is hosted at the Institute for Measurement Systems and Sensor Technology (MST) of Technische Universität München. Supporting professor: Prof. Dr.-Ing. habil. Dr. h.c. Alexander W. Koch. Additional support by the university’s astronautics institute, please see below.

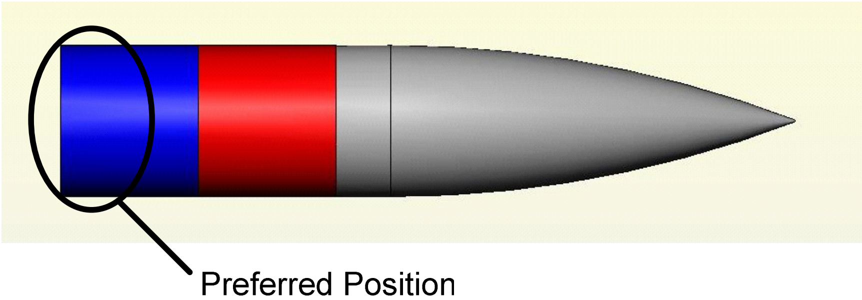
Do you have access to a workshop or a laboratory that meets the fabrication and testing needs of your experiment?	The FOVS experiment team has access to the fiber-optic lab at MST. This laboratory features all equipment needed to develop and assemble the experiment. There is also comprehensive equipment for electronics development. Furthermore, the team can give mechanical drawings to the institute's workshop to have the parts manufactured by professional staff and state-of-the-art machinery. For flight qualification testing, please refer to the section "Who else will support you?" below.
Do you have all the material and equipment which is needed for your experiment? If not, how do you plan to obtain it?	The above-mentioned labs provide the required equipment. Material expenses are covered by money sourced from tuition fees, see below.
How do you plan to finance your expenses?	The experiment team applied at the university for funding from tuition fee funds. This application was accepted. The expected material expenses are covered in this way. Costs of the MST Institute's mechanical workshop staff are covered by the Institute. For testing and qualification of the experiment, see below.
Who else will support you (sponsors, others)?	For flight qualification tests (vibration, thermal), the team was offered support by [redacted], which is a company specialized in conducting [redacted] Provided that the experiment results are shared in return, [redacted] can also provide technical guidance concerning these qualification tests. Costs actually incurred by the tests are to be covered by the project, however. The astronautics institute of the university (Lehrstuhl für Raumfahrttechnik, LRT) has a considerable heritage of Rexus experiments. Support was promised from this side as well, particularly as university-internal review instance and for the usage of environmental test equipment (thermal-vacuum, etc). fos4x GmbH, which is a Munich-based company specialized in fiber-optic measurement systems on wind energy turbines, agreed in supporting the experiment as well.

Outreach Programme	
Describe your outreach programme for before, during and after the REXUS/BEXUS flight campaign.	The following ways of conducting an outreach programme are planned: • For the general public: A blog-style webpage will be implemented. The domain FOVS.de already is registered by the experiment team. Furthermore, the project will be presented as part of open house days the university regularly arranges as information event e.g. for pupils interested in studying an engineering discipline. In addition,

	the corporate communication offices of the university and of the faculty will issue press releases etc. • For the scientific community: The project will result in scientific publications and presentations, such as at conferences and in scientific journals. Furthermore, the project will be presented in the framework of the Munich SPIE student chapter. (SPIE: International Society for Optical Engineering, formerly Society of Photographic Instrumentation Engineers).

Experimental Set-up & Technical Information

Mechanics	
Describe your experimental set-up.	 Figure 9: Floor plan of the mechanical set-up of FOVS. Figure 9 above illustrates the preliminary mechanical set-up There is a printed circuit board (PCB) that is divided into three parts. These three parts correspond to the three microprocessor stages described above. The PCB is expected to consume about half the available area. The other half is dedicated to the fiber-optic parts. This area again is divided in two sections, one for the light source and one for the interrogator. These two sections are neighbouring the corresponding section on the printed circuit board. The accelerometers are mounted in close proximity to each other in the middle of the experiment module. This allows for easy access both by cables from the PCB section and by fibers from the optical section. One can note that components are not stacked on top of each other, allowing for easy access during assembly.
Estimate the dimensions and the mass of your experiment (kg and m).	Mass: Approx. 0.8 kg excluding the cylindrical experiment module structure. Dimension: A standardized Rexus cylindrical experiment module of 0.12 m height (0.09 m usable interior height) is considered sufficient, as illustrated in figure 9 above. The height of the experiment itself is planed to be less than 0.08 m, including the support structure.

Indicate the preferred position of your experiment:	Indicated below is the preferred position of the experiment. To measure vibrations, the preferred experiment position is in the vicinity of the propulsion stage and the service module where those vibrations are generated. This is only the preferred position, however. The possible position of the experiment is anywhere in the rocket provided that the volume constraints are met. 

Electrics / Electronics	
Will you need the 28 Vdc power supply from the REXUS service system or power from the BEXUS gondola respectively?	Yes. The 28 Vdc power supply from the service system will be used to generate the experiment power supply using DC/DC converters.
Will you need (additional) batteries? What do you need for charging?	No additional batteries needed.
Estimate the electrical consumption of your experiment (Ah or Wh).	The primary energy load will be the laser. In addition to the semiconductor laser itself, the laser enclosure also has a small solid-state thermo-electric cooling element. Together, this consumes approx. 7 W under worst-case conditions (usually less). 4 W is assumed as average consumption. The remaining electronics consists of semiconductor devices with less consumption. The estimated overall consumption is, thus, about 7 W. To include some extra safety margin, 10 W is assumed. Assuming that the experiment is switched on the entire flight of roughly 9 min, that corresponds to 1,5 Wh of electricity consumed from the Rexus service system. (Time on the launch pad not included in this estimation.)
Do you use any equipment with high inrush currents? If so estimate the current (A).	No.
Do you need auxiliary power? Do you need a separate umbilical?	No auxilinary power, no separate umbilical.

Use of uplink and downlink:	The available downlink capacity is insufficient to transmit the measured data entirely. Instead, the scientific data will be stored on board on a solid state memory. The available downlink capacity will be used to transmit experiment housekeeping data and a subset of scientific data. No uplink needed during flight. For ground testing, a connection to the experiment is established by a standard RS-232 line for data transmission and by a JTAG interface for firmware updates and for debugging. If required by standard Rexus operations procedures, the experiment can also be equipped with the ability to use Rexus's Electrical Ground Support Equipment to talk to the experiment.
REXUS Only: Do you need to use the REXUS TV Channel?	No.
Provide an event timeline, including the experiment actions during flight, such as timer or telecommand events.	Upon powering the experiment (well before the launch, rocket still on the launch pad), the experiment will immediately begin to store the experiment data. To acount for possible launch delays, the experiment will overwrite the oldest data when the memory is full. The system will be switched off shortly before or shortly after landing. Certain subsets of data will be transmitted using the downlink. The transmission of this data can be triggered by a time-tagged cue.

Environmental Questions & Safety Issues	
Does the experiment use wireless devices?	No.
Does the experiment create any disturbing magnetic or electrical fields?	The experiment contains an infrared light source. Strictly speaking, light is electromagnetic radiation. However, infrared light is not a source of disturbing magnetic or electric fields or of other electromagnetic interference issues.
Do you expect to use high voltages in any part of your experiment?	No.
Does your experiment eject anything from the rocket?	No.
Is the experiment sensitive to light?	No.
Is the experiment sensitive to vibrations?	It is the very purpose of the experiment to be sensitive to vibrations.

Does the experiment generate vibrations?	No.
Will you use any flammable, explosive, radioactive, corrosive, magnetic or organic products?	No.
Will you use a laser?	Yes. There is a fiber-coupled laser of approx 250 mW optical output power. For generating infrared, invisible light, the laser is rated Class 3. However, the laser is fiber-coupled. The laser light is confined to the core of an optical fiber and does not propagate freely in the experiment. Therefore, it is not an eye hazard. It has to be switched off, however, when fibers are disconnected during assembly on ground. Fiber terminations will be covered appropriately to absorb any light leaving the fiber. The works on the experiment are supervised by a trained laser safety officer (*Laserschutzbeauftragter*) at the Institute for Measurement Systems and Sensor Technology and all participants are obliged to attend a laser safety instruction once a year. If safety restrictions (e.g. by Esrange) call for a less powerful laser, this can be implemented, but the signal-to-noise ratio of the optical measurements will suffer accordingly.
Is your experiment airtight? Are parts of your experiment airtight?	Laser diodes in so-called butterfly packages, as they will be used in the experiment, often are packaged air-tight. A test was already conducted in a vacuum chamber that confirms that the enclosure can withstand the pressure. Anyway, it is possible to drill an exhaust hole into the package and there are also packages that readily feature an exhaust hole.
Are there any hot parts (> 60℃)?	No. There will be only modest heat-up of electronic components below the 60℃ threshold.
Are there any moving parts? Are the moving parts reachable?	No moving parts except for the small test masses inside the accelerometers. No maintenance of these parts required.
Do you need any pressure systems from Eurolaunch before launch?	No.
Is there any aspect in your experiment which you believe may be viewed as a safety risk by others (regardless of whether you will mitigate this risk in your design)?	The presence of invisible infrared light requires eye safety measures. However, as described above, the light is confined to the fiber and does not propagate freely in the experiment. The used laser does not pose any risk to the skin. If radiation leaves the fiber for some reason, it is not collimated and thus is spread over an increased area, lowering the energy density (proportional to the distance squared).