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OPTICAL PYROTECHNOLOGY FOR LAUNCHERS AND SATELLITES

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I. INTRODUCTION

Pyrotechnics components and subsystems are employed for ignition, valve operation, separation systems and many other functions on both launchers and satellites. Other technologies exist, for example thermal or magnetically driven initiators and electric initiators. The choice of technology is mainly driven by application, cost and the environmental requirements to be met, such as shock and thermal requirements. The bulk of the initiator functions on board, including neutralization, are driven by the pyrotechnic chain.

In optical pyrotechnics a light pulse, generated by a laser, initiates the pyro function. This has several advantages

- No primary explosives are required. Use of comparably insensitive secondary explosives increases safety
- Reduced total mass
- Possible new functionality (built-in system test/verification)
- Low current requirements
- Potential for better safety (immunity to EMI and ESD)
- It is estimated that optical pyrotechnics will offer significant cost reductions related installation and procurement.

Kongsberg Defence & Aerospace (KDA) has been working on optical pyrotechnics for launchers since 2001; in various projects with the European Space Agency (ESA), the French Space Agency (CNES), Norwegian Space Centre (NSC) and Airbus D&A. Recently, KDA started working on an ARTES project where the use of optical pyrotechnics onboard satellites shall be evaluated.

During an ESA Technology Research Programme (TRP) in 2007, a breadboard of the optical pyrotechnic system was developed and tested [1]. The current program builds on the knowledge gathered from the TRP, such as main system design. The tests performed during the TRP had high focus on components, in order to evaluate and raise their maturity.

In 2012 development activities were continued under the Future Launcher Preparatory Programme (FLPP) step 2 awarded by ESA. The development activities were continued into FLPP step 3 in 2014 with the aim of developing a fully functional technology demonstrator at qualification maturity level within the scope of the FLPP program.

II. SYSTEM DESCRIPTION – LAUNCHERS

An important aspect of any pyro system is to maintain a high level of safety; during manufacturing, integration and testing. Safety considerations impose three physical barriers of different nature to make the pyro ignition inoperative until an arm command is sent.

The optical pyrotechnic system on launchers will consist of several building blocks distributed throughout over the launcher to provide the required functions. The main building blocks are (see Fig. 1):

- Laser Firing Unit (LFU)
- Optical Harness (OH)
- Optical Safety Barrier (OSB)
- LID (Laser Initiated Device)

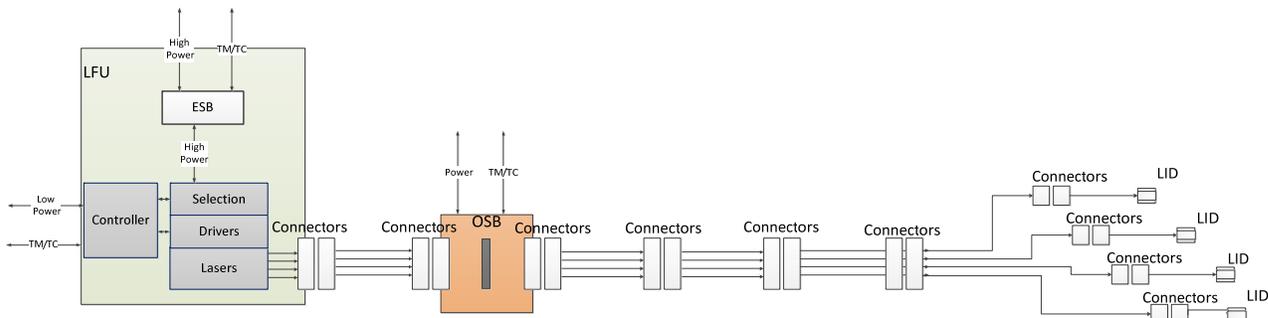


Fig. 1. System Architecture Block Diagram

The LFU shall provide:

- An electrical safety barrier
- Light pulses to the LID
- Methods for verifying the various parts of the LFU during production, integration and launch.

The LFU contains a controller circuit, a low power supply and the lasers with their individual drive circuits. The dimensioning of the LFU has not been fixed yet. Currently, the design objective is to have a 40 channel LFU with a total mass of less than 5 kg.

For the launcher application, the LFU shall be capable of firing 16 lasers simultaneously, leading to a total current of more than 350 A being drawn from the high power supply.

The number of channels, the mass limitation and the current consumptions constitutes important design drivers for the LFU.

From the LFU, the OH relays light to the OSB (see Fig. 2). The OSB acts as the ultimate safety barrier downstream of the LFU. Its main function is to stop inadvertent light pulses and to relay firing pulses when commanded and to do this with high intrinsic safety and reliability. In addition, it shall provide visual and electrical indication of its status, i.e. armed or safe. The barrier is commanded by ground, and features connection inhibitor mechanism to avoid inadvertent connection of a downstream optical harness when the OSB is armed.

The final component of an optical pyrotechnics system is the LID. It is a pyrotechnic device giving pyrotechnic function upon receiving a high power laser pulse. The amount of light required by the optical pyro system is determined by the LID and its temperature dependence.

As a part of the step 2.1, a breadboard of the OSB has been built and tested mechanically. The OSB differs significantly from the one built and tested parallel to the TRP in 2007, although consisting of the same principal elements. The updated design and development of the OSB is partly to provide a unit with a more modular design to better adapt to future system needs. KDA has chosen an OSB concept employing a mechanical shutter inserted in a section where the optical beams are collimated and in free space. This design meets the requirements of less than -60 dB optical crosstalk and will also survive continuous firing of lasers when in SAFE state.

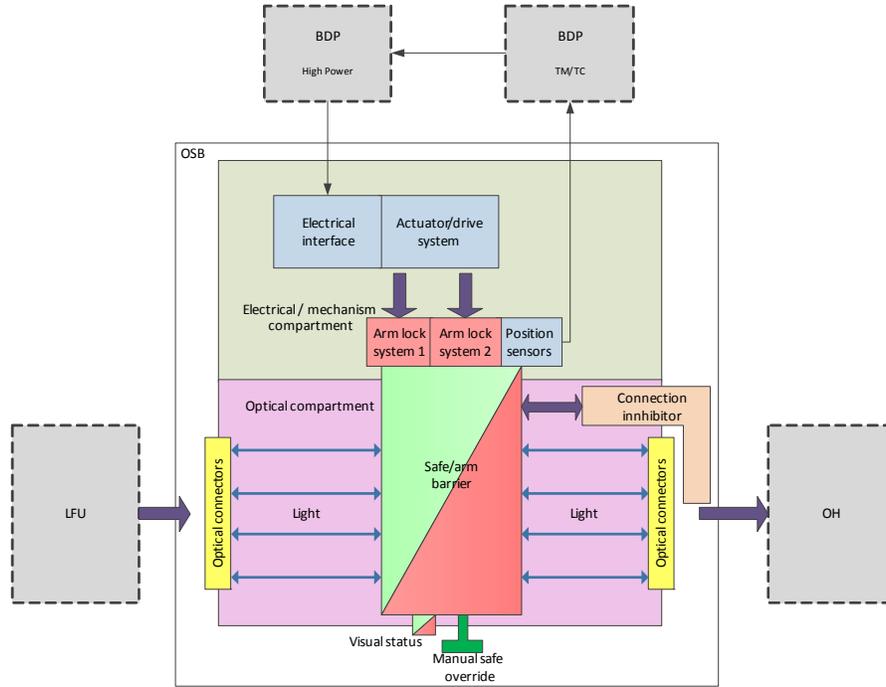


Fig. 2. Optical Safety Barrier Block Diagram

III. TESTING AND VERIFICATION

Vibration testing was conducted with two channels monitored to verify optical performance in addition to the status signals. The sine vibration levels used are those specified for Ariane 5, and thus relevant for future launchers as well. As can be seen in Fig. 3, the optical signals are continuous throughout the testing. The artifacts shown on both the signals through the OSB and the laser monitor signals are EMC-related.

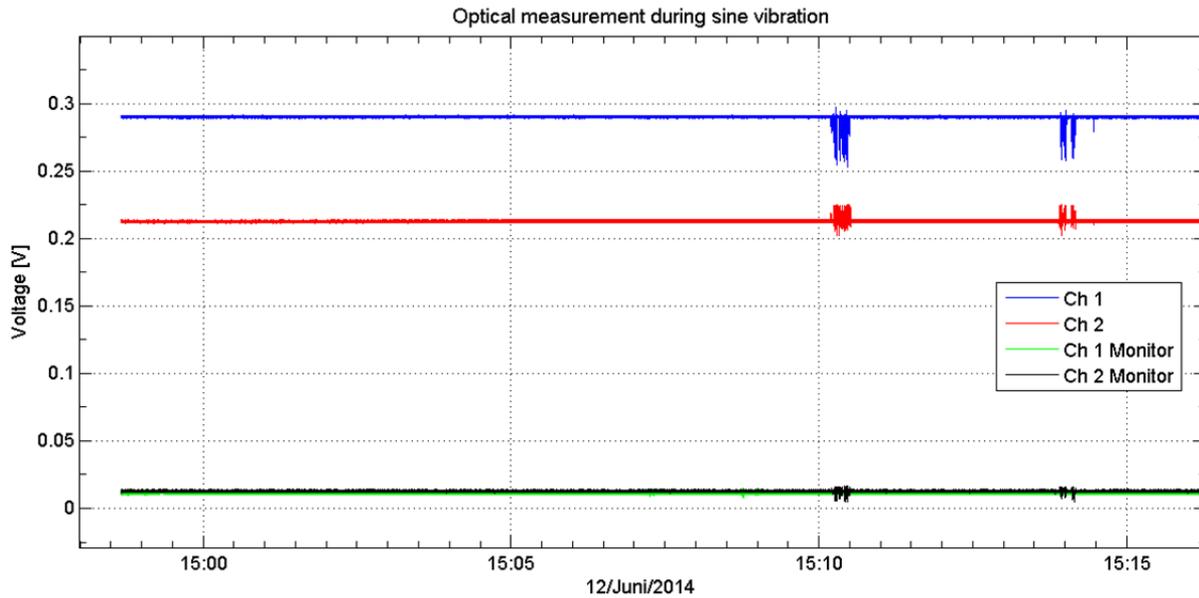


Fig. 3. Vibration test of the Optical Safety Barrier. Artifacts at 15:10:30 and 15:14 are EMC-related as they appear on both channels and monitor measurements.

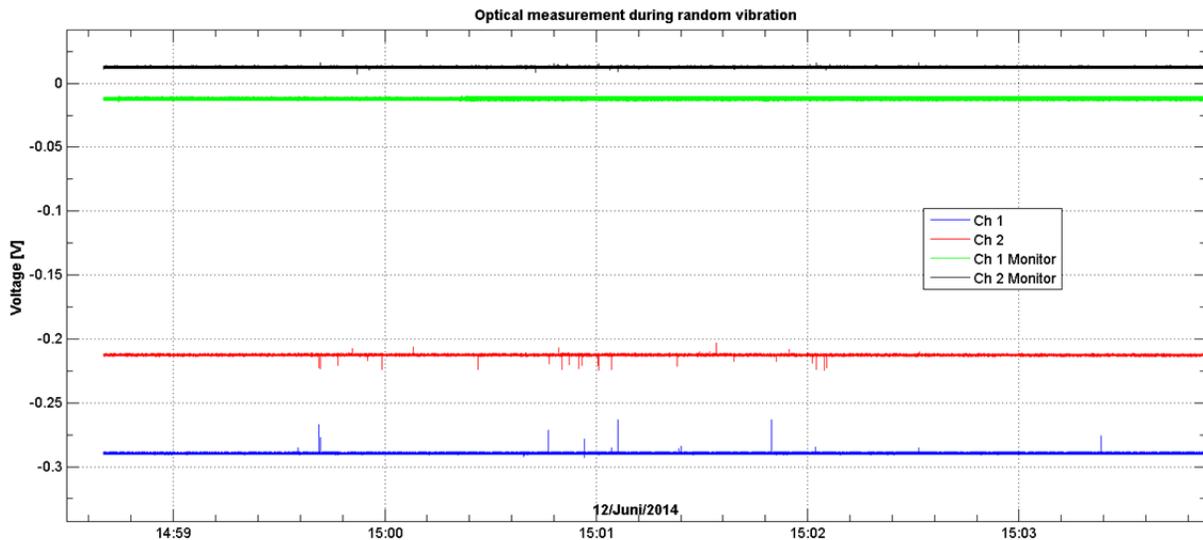


Fig. 4. Vibration test of the Optical Safety Barrier.

The following functional tests were carried out in which the OSB performed as expected:

- High power light block
- High power light transmission
- Actuator and gear performance
- Manual disarming

In addition to the testing activities carried out on the OSB, a laser driver breadboard (part of the LFU) has been built and is being tested at the time of writing. The laser driver is the most important part of the optical pyrotechnic system main function "Provide light" and contains the firing lasers themselves.

IV. SYSTEM DESCRIPTION – SATELLITES

For a satellite based application, the optical pyro system may be divided into three main components:

- Controller Unit
- Optical Harness (OH)
- Laser Initiated Device (LID)

The *Controller Unit's* main function is to provide light with a specified power to a specified channel when receiving commands from the On-Board Computer (OBC). It is responsible for converting electrical power into optical power, and acts as the "intelligent" part of an optical pyrotechnic system. The main design drivers are low mass, low power consumption, high reliability and safety. Built-in functions will allow for verification of the electrical system, and may also be employed for the optical system to give a higher level of reliability. To comply with safety requirements, several safety barriers are needed. These may be implemented both as logical electronic barriers, and as optical barriers downstream of the laser diodes.

The light signals are relayed from the Controller Unit to terminal functions distributed across the satellite using an *Optical Harness*. The optical harness will consist of optical fiber, cabling, backshells and connectors. As for launcher applications, the optical harness acts as one of the strongest advantages of optical pyrotechnics over conventional pyrotechnics. The optical harness is ESD/EMI immune, and lighter, and will in require a simpler MAIT approach.

Reliability is an important design driver for both satellite and launcher applications. The design is directed by very stringent reliability requirements. There will be a hot redundant pyro system on the satellite system side, since the number of safety barriers required is expected to reduce the reliability of each system.

Among the system architectures considered for satellite applications, two are relatively straight-forward and given in Fig. 5 and Fig. 6. The selection of system architecture depends heavily on the maturity of components

available. Additionally, the MAIT effort must be considered to ensure that the architecture chosen gives the best level of functional testing and increases the reliability of the system. The option using an internal OTDR (Optical Time Domain Reflectometer) offers built in testing which will make it possible to detect faults after launch.

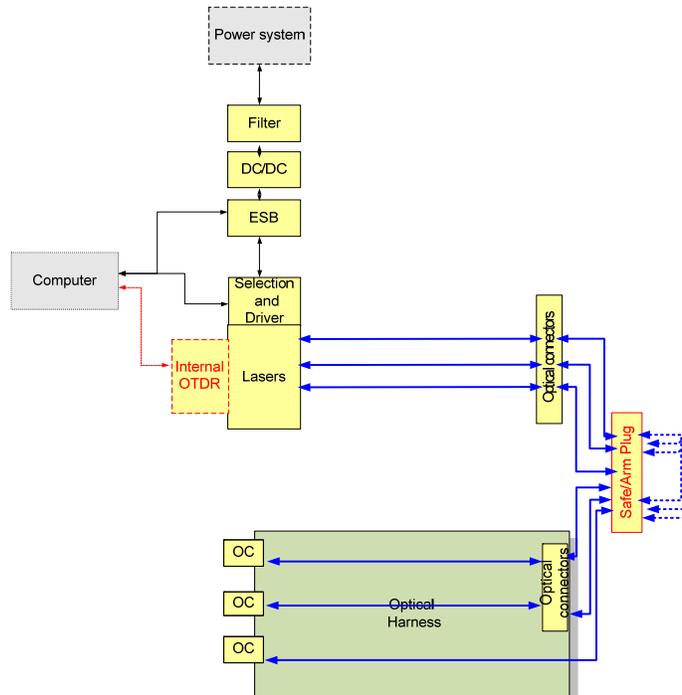


Fig. 5. System Architecture with optional Internal OTDR and Safe/Arm Plug

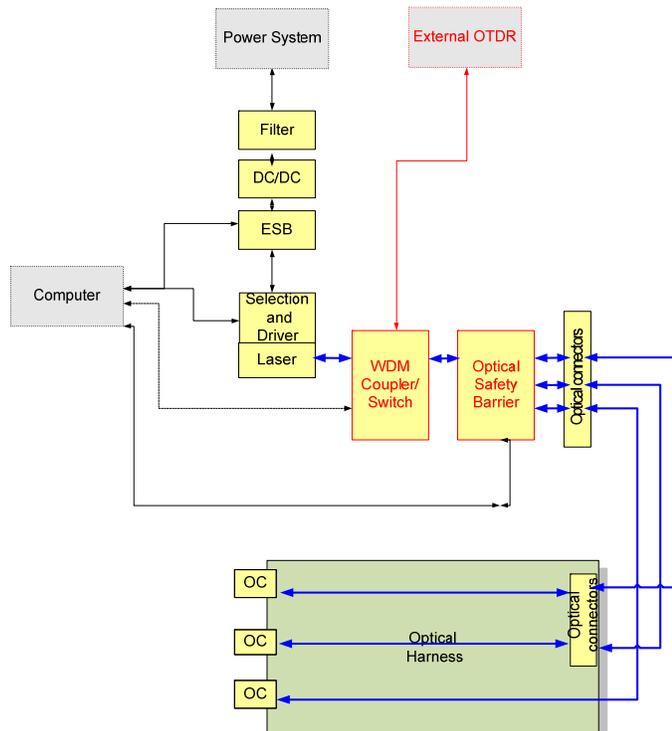


Fig. 6. System Architecture 2 with internal Optical Safety Barrier and external OTDR

V. COMPARISON OF SYSTEMS

The main functions of the optical pyro systems are the same for launchers and satellites; *become safe* or *contribute light*. Many of the same components and technologies may be used, and the two programs could benefit from close cooperation.

An optical pyro system on a satellite will have less stringent environmental requirements when compared with a launcher. The biggest differences may be in the temperature ranges, where each satellite has different sets of temperatures it must comply to.

Main differences:

- The optical pyro system on a satellite is not operational during launch.
 - Satellite operational conditions are much harsher than launch conditions, and eases qualification effort.
 - Components that are too sensitive for launcher applications may be used for satellites and simplify system design or add enhanced features.
 - There is a lower chance of catastrophic failure incidents with satellites and the safety requirements may be relaxed.
- The optical harness in a satellite is shorter than in the case of a launcher.
 - Lower optical losses for a satellite optical pyro system.
 - Fewer connectors are needed which also gives lower losses.
- Timing is less critical on satellites than on launchers.
 - May give simpler electrical design.
- Mass is more critical for satellites than it is for launchers. Key design drivers therefore are simplicity and mass efficiency.

VI. WAY FORWARD

A. Optical Pyrotechnics on Launchers

During the next two years, KDA will develop, manufacture and test Equipments to a Technology Readiness Level (TRL)[2] of 6. Following the results of these tests and during the development of the Equipment, and analyses of the design, a dependability and safety study will be carried out. The safety study is of particular attention as pyrotechnic accidents may lead to catastrophic incidents. KDA has extensive knowledge in safety related systems from our long background in defence technologies.

The tests to be performed on the Engineering Qualification Model (EQM) are:

- Full mechanical tests (vibration, shock, pyroshock)
- Thermal tests (thermal shock, dry cold, dry heat)
- Thermal vacuum tests
- Full functional tests
- Integration tests

The Assembly, Integration and Test design will play an important part in reducing overall cost for the optical pyrotechnic system when compared with the conventional pyrotechnic system. The system demonstration aims to demonstrate an Integration Readiness Level (IRL) of 2.

At this stage, the architecture of Next Generation Launcher is not known, and the focus is to design Equipments to be scalable with respect to number of channels and modular to ensure that the system design will meet any requirements regarding centralized/distributed architecture.

B. Optical Pyrotechnics on Satellites

KDA will, with support from Airbus Defence & Space, design and develop a breadboard of an optical pyro system for use on a specific telecommunication satellite platform. The purpose is to prove a TRL of 4 as well as determine a way forward to further qualify the system for use on satellites. It is expected to show a significant reduction of power needs and mass, as well as recurrent cost. Additionally, an AIT approach will be presented which aims to simplify existing procedures and reduce the overall MAIT cost.

The work is divided into two phases; phase one focuses on conventional pyrotechnics and optical pyrotechnics system studies to prepare for a trade-off between the two technologies. A reference satellite platform will be used as baseline for the trade-off, where high level requirements will be considered. Following this trade-off,

phase two will commence with the design of a breadboard of the optical pyrotechnic system. The breadboard will be tested rigorously in the critical environments, as well as functional tests to demonstrate the technical feasibility.

VII. ACKNOWLEDGEMENTS

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