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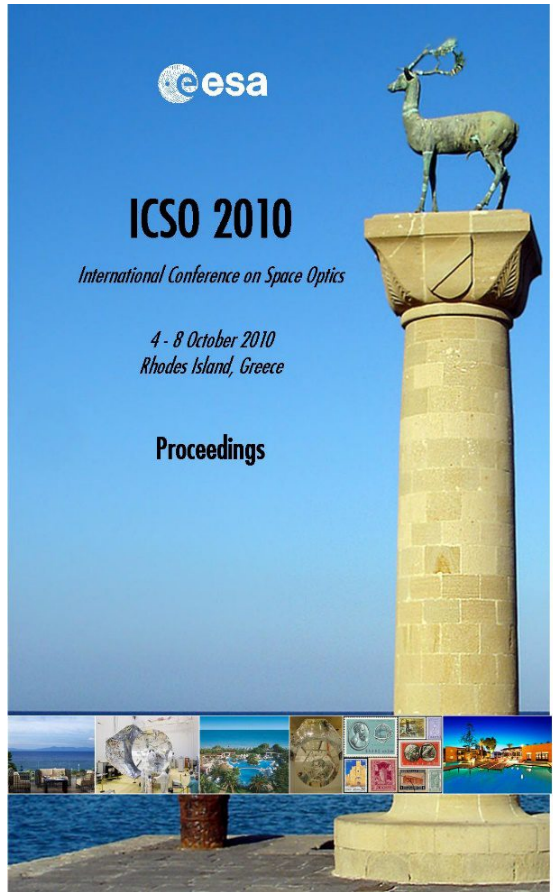

Opto-pyrotechnics for space applications

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OPTO-PYROTECHNICS FOR SPACE APPLICATIONS

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I. OPTO-PYROTECHNICS BACKGROUND

Pyrotechnics is in widespread use in both launchers and satellites. The devices are relatively simple, light and compact and provide near-instantaneous response with very little input energy.

Several examples of Pyrotechnics functions can be found on Ariane 5, where pyrotechnics are used to ignite engines such as the main engine, boosters and distancing rockets. Pyrotechnics are also used for stage and payload separation, cutting of the DAAV/DAAR stays, valve opening, passivation and, if required, neutralisation of the launcher.

In current launcher implementations the pyrotechnic chain is ignited by applying an electrical current. The squib provides a mechanical shock that is relayed through explosive pyrolines to the function location. In Opto-Pyrotechnics systems, intense laser pulses distributed via optical fibres initiate the Laser Initiated Devices (LID).

On each Ariane 5, there are several tens of pyro-functions and several hundred meters of pyrolines. Although the system has been proven to be both reliable and safe, there are some disadvantages: It is difficult to verify the integrity of the pyrolines, synchronisation is challenging and lead used to protect the pyrolines is highly polluting.

Opto-Pyrotechnics, i.e., initiation by laser pulses, 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 Opto-Pyrotechnics will offer significant cost reductions related installation and procurement.

Opto-Pyrotechnics has been demonstrated in satellites such as Demeter[2] and it has been utilised in the Sea Launch[1] launchers. It has yet to be demonstrated on a European launcher.

II. SYSTEM OVERVIEW

Although Opto-Pyrotechnics is suitable both for Launchers and for Satellites, we will here concentrate on the architecture investigated for launchers.

Laser pulses are provided by a Laser Firing Unit (LFU), which contains control logic, laser drivers and the laser diodes. The LFU interfaces with the control system of the launchers and produces laser pulses that are relayed through an Optical Safety Barrier (OSB) to the detonators. As in the current Ariane 5 Pyrotechnic system, redundancy is implemented: there is nominal and redundant LFU, OSB, and LID as illustrated in Fig. 1.

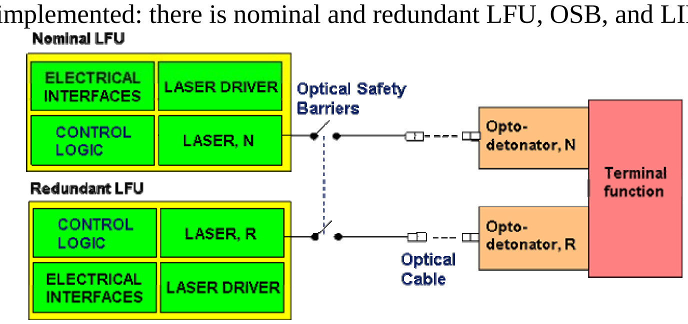

Fig. 1. Opto-Pyrotechnics system architecture

In the chosen implementation, one laser is used for each LID. Although it is possible to use couplers to distribute light from one laser to several detonators, such a system would be less flexible and offer only minor advantages with respect to recurrent cost.

III. BREADBOARDING

An ESA Technology Research Programme contract was awarded in 2007 to KDA and Astrium for the development of a breadboard demonstrator. External to this programme, KDA developed an Optical Safety Barrier. In addition to demonstrating compatibility of components and technologies, the breadboard demonstrated the system functions:

- Communication, in this case RS422 was enabled through an FPGA implementation
- Implementation of safety barriers, two of different nature.
- Creation of light by driving a laser diode
- Relay of light through optical harness, representative in the number of connectors and length of cables.
- Delivery of light to inert detonators, demonstrating the mechanical interface.

As can be seen in Fig.2, two safety barriers were implemented. In addition to KDA's proprietary OSB, a mechanical relay was introduced as an electrical safety barrier. The safety barriers were commanded and monitored through separate Safe/Arm panels. Their status was also relayed separately to the Control Electronics, which transmitted the safety barrier status through the RS422 interface. Firing commands were also transmitted to the Control Electronics through this interface.

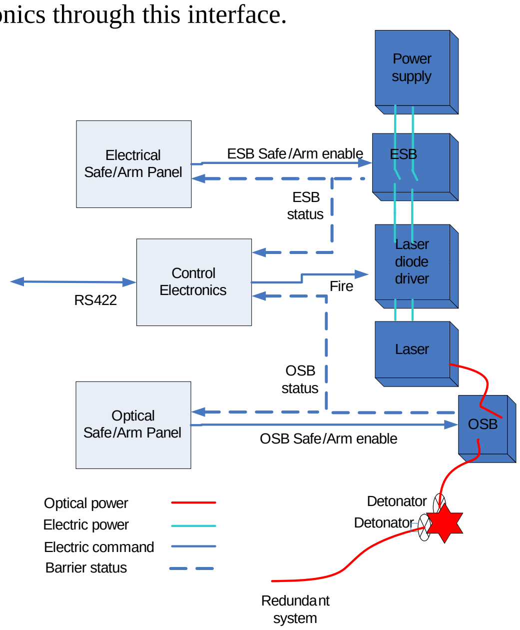

Fig.2. Opto-Pyrotechnics safety architecture

After function testing, the Opto-Pyrotechnics breadboard was operated with inert detonators under representative vibration and thermal conditions. These tests demonstrated technology feasibility. The tests also helped establish the Technology Readiness Level (TRL)[3] of several components (see Section IV).

IV. TECHNOLOGY STATUS

KDA has conducted extensive component investigations in cooperation with ESA, CNES and Astrium through the ARTA and TRP programmes and with internal funding.

Component technology is a prime challenge for Opto-Pyrotechnics on launchers. Although both lasers and optical components are currently used in space, there is little experience with these components operating in a launch environment. Also, several of the requirements are application specific. In the case of optical harness components, multi-channel cables and connectors (also with lanyard release) are required for efficient integration on the launcher.

With the exception of the OSB, where KDA has engineered a prototype, the focus has been on investigating feasibility and establishing the potential of components available primarily from European suppliers. Components are ranked according to their TRL level as defined by Mankins [3]. An overview is found in Tab. 1, with the TRL of the best component of each element. Please note, however, that the tests conducted did not include all environmental parameters, of which pyro-shock is the most important –this may lead to reassessments of components with TRL 5. TRL 6 requires verification on system or sub-system level. Work still has to be conducted on multi-fibre cable assemblies and harness strain relief (we hence assigned TRL 3).

Tab. 1. TRL level of different components

Opto-pyro element	TRL	Status
Optical Safety Barrier (OSB)	4	Prototype has been tested in a relevant environment.
Couplers	4	Temperature dependent split ratios
Multi-fibre cable assembly	3	Work not started
Single fibre cable with single channel termination	5	Fibre optic cables have been demonstrated in space.
Multipin Connectors	5	Passed mechanical and thermal tests, but some issues with reliability
Single pin connectors	5	Passed mechanical and thermal tests
Harness Strain relief	3	Work not started
Lasers	4	Some performance issues at low temperature.
Electronic components	8	No new electronic components are required

Tests have focussed on the optical harness components in particular since it is exposed to the harshest environment, being routed across the launcher. Connectors and cables were tested under thermal and vibration environments, sometimes in a test chamber with the capability to test both simultaneously. Fig. 4 shows the light transmitted through a multipin connector under random vibration testing with 54g R.M.S. and frequencies from 20 Hz to 2000Hz. Eight connector pin pairs were connected in series (in the same connector). The loss was hence approximately 0.2dB per pass through the connector. The losses were largely unaffected by the vibration environment (started at 0.5 minutes). The connector was vibrated along the connector axis (vertical) and perpendicular to the connector axis (horizontal).

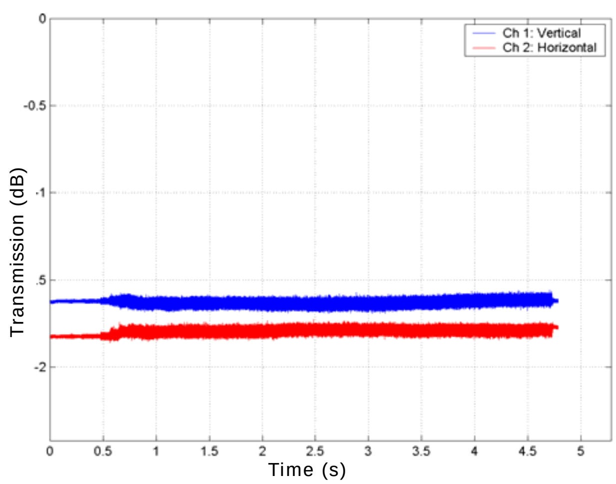

Fig. 4. Opto-Pyrotechnics connector test

KDA also investigated the performance of single emitter laser diodes from a European manufacturer under both thermal and mechanical environments. Fig. 5 shows the laser output power at high (85˚C) and low (-85˚C) temperatures. The observed changes in output power are acceptable for the system as long as they remain predictable. The drop in laser power at high temperature is caused by the reduced efficiency of the laser itself. At low temperature it may be related to the coupling of light into the fibre pigtail, stresses in the pigtail or absorption in trapped package condensation.

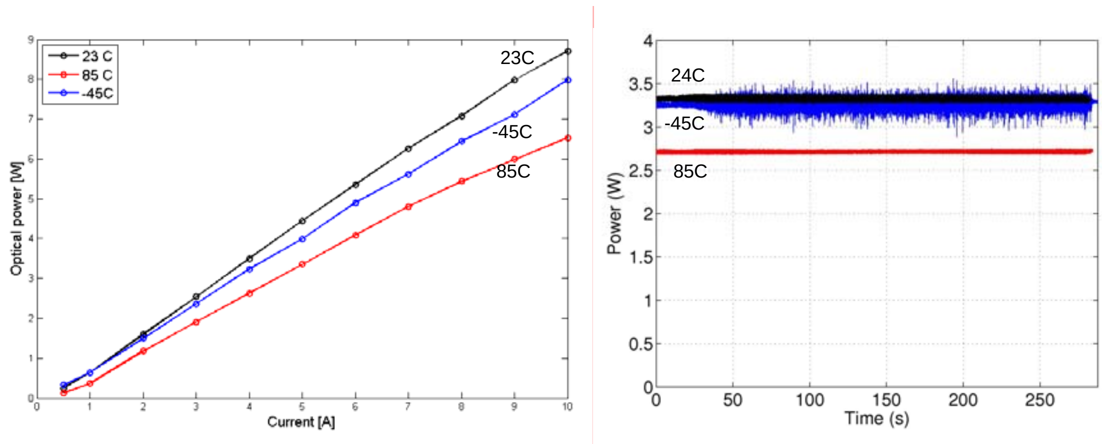

Fig. 5. Emitted laser power (power vs. current on the left; at 4A drive current and vibration on the right)

Vibration testing was conducted with 4A drive current. The output power during vibration testing is shown on the right in Fig. 5, where the laser output at three temperatures and for the three vibration axes (22.5g R.M.S. 20-2000Hz) has been superimposed on the same graph (the dependency on the axes was relatively small in this experiment). The effect of vibration was the highest at low temperatures (-45C), but this was more than compensated by the enhanced efficiency of the laser at low temperatures as compared to high temperatures (85C). Vibration losses were negligible at high temperature.

Couplers were tested under previous programmes. Although they are mechanically strong, we have found that their split ratios are strongly dependent on the temperature. This is particularly true for 99/1 splitters where the 1% branch can change by several percent (of the input energy) as the temperature changes.

V. NEXT STEPS

KDA is currently preparing the next development step for Opto-Pyrotechnics under Astrium prime contractorship. The intention is to produce an Engineering Qualification Model (EQM) to conform to launcher representative requirements. The EQM will be representative in form, fit and function and it will include the development of appropriate Ground Support Equipment (GSE) that will verify both the laser output and the integrity of the optical harness. Built-In tests will be used to verify the electronics. Component TRL will be raised through targeted developments up to level 6.

In a later step it is foreseen that the opto-pyrotechnics chain is subject to full environmental testing at system level. In order to demonstrate Integration Readiness Level (IRL) [4]; Assembly, Integration and Testing (AIT) processes for use on the launcher will be established and verified by Astrium on a launcher mock-up.

VI. CONCLUSIONS

Opto-pyrotechnics is currently developing to become a mature alternative to traditional pyrotechnics, compared to which it can offer significant advantages, in particular with respect to safety and testability. The technology can potentially be used on both launchers and satellites.

VII. ACKNOWLEDGEMENTS

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