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The Journal of Space Safety Engineering (JSSE) provides an authoritative source of information in the field of space safety design, research and development. It serves applied scientists, engineers, policy makers and safety advocates with a platform to develop, promote and coordinate the science, technology and practice of space safety. JSSE seeks to establish channels of communication between industry, academy and government in the field of space safety and sustainability.

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ABSTRACT

The Redesign of pyro train seems to be mandatory for next generation of European launchers, in order to be compliant with new requirements coming from:

- European community: health regulations, REACH and RoHs requirements …
- Agencies and customers: Cost reduction, Mass improvement, obsolescence risks reduction, robust design and versatility for any mission…
- Prime contractors: Safety improvements for pyro supply chain and AIT teams, explosive trains monitoring, dual components …
- Pyro Industries: «continuous» manufacturing to guarantee knowledge and competencies for the whole life of launcher manufacturing

Maturation and developments done since 1970 concerning Optic, optronique and explosive systems highlighted great opportunities to merge these so matured technologies into opto-pyrotechnic system. But at this moment the energy ratio of such optic emitters was too low, to be applied into a launch vehicle.

Since a decade great effort had been done by industries to provide more and more powerful laser emitters such as laser diodes for main data transmissions applications and strong needs rising from Industries, Aeronautics, Medicine, nuclear research

The maturity of powerful and miniaturized optic components becoming COTS at the beginning of year 2000 accelerate their integration into new field such as aircraft data transmission applications. In addition the very good REX acquired through end users operations (civil and military fields), allow aircraft companies to spread this optic technology into more and more safety functions.

The heritages coming from telecom and aircraft industries allow to set up and spread new type of portative monitoring tools to check any optical harness, detecting in a safe way any failure transmission and localize with a cm class accuracy any weak connection.

The maturity level of optronique and the robustness demonstrated within a large range of applications give confidence to space engineers for analyzing its implementation into space systems, with a guarantee of long term technologies availability.

The ability of optical fibre to transfer high amount of energy given by a very small laser diode, allow pyro designers to implement this technology into the first element of the pyro train: the initiator.

This main evolution highlights several improvements on launcher pyro trains, increasing mainly their safety levels.

The safety advantages given by Opto-pyro are addressing several fields such as:
- Ground aspect during preparations and operations
- Functional aspects
- Industrial and Prime concerns

AIRBUS Defence & Space through ASTRIUM-ST and Aerospatiale studies has been actively involved into Opto-pyro activities for a long time. The amount of Opto-pyro demonstration and justification has been accelerated since 2010 thanks to a special AIRBUS-DS R&T effort, focusing on TRL, IRL and MRL.

Step by step, AIRBUS-DS manage to set up Opto-pyro train maturation from TRL4-IRL1, based on demonstrators and representative demonstrations of launcher configuration. These on going demonstrations will lead to a TRL6-IRL3 level in 2014.

The higher safety level demonstrated by Opto-pyro train compared to the electro-pyro safety trains used on current space systems, allow implementing this new Opto-pyro technology on any new safety systems to be developed.
1. INTRODUCTION

Since the beginning of space conquest, Pyrotechnic trains have been the key elements of space systems from launchers to satellites and spacecraft.
By housing energetical materials into specifics pyrotechnical devices, engineers managed to faced the problem of launchers critical phases.
For the whole mission, starting with on ground launcher ignition to the end of mission stage passivation, and for each critical transient phase, current launchers commonly used pyrotechnics solutions to operate safely, in a very short time these difficult sequences: pyrotechnic remain the only technology able to perform launchers key functions

**Why Pyrotechnics on space systems**

The main advantages of these pyro trains is sum up in its small size equipments offering the high energy expected in the smallest volume and lowest mass, when activated over the safety level.
The pyro equipments designed and developed for space since the sixties have been, within the fifty passed years, safety improved, performance increased and suited for each new space system architecture, on the basis of the same original product principle.
AIRBUS Defence and Space by leading the prime contractor function, deliver to its customer an Ariane 5 launcher customized to each specific mission required, on quality and on time.
This Prime role leads AIRBUS Defence & Space to provide for each space systems under its responsibility the appropriate architecture with dedicated and selected pyro functions.
By this way and since the last fifth decade, zero Pyrotechnical accident occurred on its space systems.
However, these systems are very complex with a design oriented on the main mission, and specifically compliant with regulations of their local launch port.

Specificity is also linked to their one shot mission without any major failure.

Their level of complexity is emphased with level of requirements concerning mission reliability, health regulations and safety regulation for their local launch port.
That range of requirements makes the difference between performances of pyro devices available for current launchers over the world.

Main disadvantages linked to space systems activities have to be targeted:
- No important manufacturing ratio regarding the quantity of space systems launched, and the amount of pyro devices for one space system
- Very low commonalities between products/functions/programs
- No re-use
- Low duality
- A geographical return activities oriented, that very often lead to design One Function / One Equipment concept
Other difficulties for space systems operations are directly driven by pyrotechnic trains:

- Most of pyrotechnic trains are critical functions inducing catastrophic events in case of premature firing
- Pyro train design, constrained by local safety regulations
- The low electrical power available (low ratio Power/mass) lead Initiation train to generally use “Middle Energy” electric devices using Hot wire initiators loaded with sensitive primary explosives to be secured by heavy process to withstand possible and hazardous environmental levels
- One shot character
- Device acceptance often need specific non destructive process analysis for device health monitoring in order to achieve reliability demonstration
- Poor maintainability performances
- Small budget and not enough manufacturing volume lead to mono source suppliers
- Non continuously manufacturing lead to organize specific manufacturing batches
- Small amounts of very specialized components
- Need several pyro equipments to set up a train
- Pyro train routed on very long distance regarding launcher architecture
- Without any monitoring possibility for pyro trains, heavy pyro process are required to maintain a successful AIT,
- Heavy training of pyro AIT team needed to maintain safety and quality levels avoiding any “accustom” effects
- Several local health regulations leading more or less to friendly green energetical materials

These constraints don’t allow a unique and universal pyro design for a same function.

Despite these elements, the current pyrotechnic systems got the advantages to:

- Be the unique solution for the time functioning required during flight mission
- Perfectly operate under space environments since the last fifty years!

For the next space system generation, perenity and obsolescence risk reduction targeted, will lead to re-analyze available pyro solutions to comply with:

- New market expectations,
- Customers and prime requirements,
- Health and environmental regulations,

Any new space systems requirements will be focusing on ambitious requirements based on:

- Cost reduction (from hardware to AIT & Operations) to stay on market price (Most available components are produced for the industrial and commercial markets),
- RAMS improvement and more particularly Safety level, Maintainability,…
- Performances
- Mass and volume reduction,
- Environmental regulations,
- Design robustness to be manufactured during next 30 years of operations,
- Upgradeability
- …

Within a launcher budget, one can be aware that pyrotechnic initiation systems are not the main drivers for improvements:

- Mass launcher contribution ≈ 0.2%
- Cost launcher contribution ≈ 2%

However, any RAMS improvements concerning availability, maintainability or safety of launcher pyro trains could relax current strong constraints such as safety concerns induced by the pyro network (pyro devices and electro-pyro initiators) spread all over the launcher stages, and needed for its whole life cycle. The pyro safety constraints have to be set up for each pyro technology, and customized for main operations such as: transportation, storage, AIT, team training. This is one of the main drivers able to reduce process constraints such as AIT organization and duration …
2. FOCUSING ON OPTO-PYRO TECHNOLOGY

For next generation of Space systems, innovative pyrotechnologies have been analyzed for initiation train, regarding their ability to input the cut through needed to comply with ambitious requirements and bring improvements such as RAMS.

The Opto-pyro technology appears as the good candidate offering the best compromise for launcher pyro initiation functions, regarding improvement given at operation cost, safety and AIT level. The other solutions analyzed don’t demonstrate enough maturity and safety levels for short term applications.

At AIRBUS side, first Opto-pyro studies began in the 80’s with an Aerospatiale (AIRBUS DS) - GIAT (NEXTER) shared team for developing an optical initiator. These studies highlighted great advantages of opto-pyro as well at train level than system aspects. However at this moment this technology was not applicable on a space system because of great impacts in terms of mass and volume: laser source not enough miniaturized, important power budget required for their functioning leading to oversized battery. Within years 2000, the very fast improvements of electronic processes supported by a large deployment of electronic devices rise miniaturized laser source such as laser diode and small batteries, which allow boosting optical technologies and industries related: data transmission, medicine, industries (welding, cutting ...).

At this moment the technology maturity required for space systems, came from these new fields:

- Heritage of Optical data transmission / Telecom applications
- Important Market of Optical COTS supported by new Optical applications (industries, medicine, ...)
- Miniaturization of Optical sources in High Power Laser Diodes
- Availability of High power Laser diode with Safe threshold current
- New batteries technologies improving ratio Energy/mass
- Optical power transmission by fibre networks
- Progressive introduction of optics fibre into airplanes replacing electric copper cables, to improve mass ratio

⇒ OPTO-PYRO raised again great interests but not as a new technology but as an innovation based on strong & matured technologies such as: Optronique, Optic and pyrotechnic. Implementation of their important heritages lead to opto-pyro technology

By analyzing results from several programs supporting Opto-pyro, it appeared that within activities and justifications acquired during a decade, Opto-pyro technology is transferable on any safety architecture for space systems. The last system analysis phase concerning use of opto-pyrotechnic in avionics systems doesn’t raise any show stopper. In order to prepare decision making for next generation of space systems, a maturation phase up to TRL6 – IRL2, was planed. After a first selection phase of partners, Airbus Defence & Space set up an opto-pyro roadmap for achieving maturation demonstration at end of 2014.
First principle was to design an opto-pyro train, totally interchangeable with existing pyro terminal functions, on an existing space launcher. The study case was conducted on the A5 heavy launcher, due to the amount of pyro functions to be fulfilled. The second step was to adjust the opto-pyro train design in order to be implemented on the current avionic architecture with minimum impacts and with respect with safety requirements.
The scheme here under illustrate the fully interchange-ability of opto-pyro train between the unchanged electric train upstream, and the non modified pyro terminal functions downstream. Between the two vertical red lines, the opto pyro train is compared with the current electro-pyro one.

Fulfilling the FS/FS criterion, safety requirements demands three independent barriers on any Electro-pyro-technic train, whatever the life phases (storage, integration, stand-by, tests...).

The Opto-pyro safety approach is also based on:

- Different nature of safety barrier avoiding any common failure mode,
- 3 interceptions for the pyro fire signal for safety allocation:

For opto-pyro systems, the first two safety Barriers are electric (Electrical Safety Barriers: ① & ②) and, the ultimate one is Opto-mechanic (Optical Safety Barrier: ③). In case of Electro-pyro systems the architecture of safety barriers is the same, but with a Pyro-mechanic barrier for the ultimate one.

The other safety principle requiring a technological and topological segregation between energies: functional one segregated from pyro activation, to have an intrinsically safe architecture and to avoid any risk of spreading a failure, is also fully respected with the opto-pyro architecture.

Due to the low sensibility of the optical harness and opto-pyro initiator (high energy initiator) vs accidental/hazardous environments, the last safety barrier: OSB is located as close as possible, and downstream to the electro-optical converter (Firing Unit), considering that the laser diode could be the weak component of the train, able to input a premature firing. On going studies will status about this hypothesis.

As the safety barrier is located as close as the laser firing unit, this safety equipment can be centralized and shared for all the optic orders addressing terminal functions (except for neutralization trains which remain distributed in each stage).

The main philosophy for the ultimate safety barrier dedicated to an opto-pyro train can be described as:

**OPTO-PYROTECHNIC train**

**Ultimate safety Barrier Localization**

- **A Localization** (Mechanical Barrier) : required if:
  - opto-pyro initiator, pyro charge sensitivity level of are lower than referenced High Explosive
  - opto-pyro initiator not withstand environmental affects or ingress

- **B Localization** (Optical Barrier) : required if optical harness or connectors can gather and transmit any optical signals able to fire opto-pyro initiator, under environmental affects or ingress

- **C Localization** (Optical Barrier) : required if Laser diode can output any optical signal able to fire Opto-initiator under environmental or electric affects or ingress (laser diode threshold current)

- **D Localization** (Electrical Barrier) : Possible if sensitivity level of Laser diode is acceptable regarding previous requirements

Ultimate safety Barrier position will be fixed by sensitivity of Opto-pyro components and devices used in the train

**Figure 9**

Note that the case of a mechanical barrier required in A position is destructive regarding any pyro train. For this reason the first activities was targeted on opto-initiator consolidation.
3. PRESENTATION OF THE SAFETY APPROACH FOR THE OPTO-PYRO TRAIN

Following the first positive result of AIRBUS DS system analysis concerning the implementation of Opto-pyro trains on launcher avionic system, the second step was dedicated to technical specifications consolidation with a special focus on Safety, Performances and Operation improvements requirements. A validation process of technical specifications was set up with a dedicated task force including several experts (RAMS, Safeguard, mechanisms, mechanical, Electrical and Pyrotechnic design offices …). Then a consultation had been open through strong companies acknowledged in the fields of Electronics, Optronique, Optics and pyrotechnics. The dual applications targeted by AIRBUS DS, lead to select companies from France or Europe, able to deliver ITAR Free products compliant with technical specifications.

In addition, without any R&T budget coming from agencies research program, it was decided at AIRBUS-DS R&T office to support this strategic Opto-pyro end of maturation activities, from existing TRL3/4 to TRL6, through common activities co-funded by AIRBUS DS & partner interested in, with short terms shared interests.

Note that in parallel European space agency conduct also Opto-pyro maturation activities with one European partner KDA (Norway) through Future Launcher Preparatory Program (FLPP), with a set of AIRBUS DS technical specification for targeting an Opto-pyro train for an Ariane launcher.

The opto-pyro equipments development process was always focusing on safety aspects, and started by the two safety key elements of the train: the Opto-initiator and the ultimate barrier.

The amount and barriers position are driven by:
• Local safeguard regulation specifications,
• Lessons learned by Prime from its Launcher activities (at system and AIT levels)

4. OPTICAL INITIATORS: LID (LASER INITIATED DEVICE)

The initiation principle chosen for this opto-initiator is based on the conversion of optical power delivered through an optical fiber into thermal effect to react the first stage (safety pyro charge) of the initiator. Then the additional pyro charge (second stage of initiator) selected for the application needed: squib, igniter or detonator will convert the first pyro reaction into the output selected.

In order to manage an affordable optical power budget for the whole train, the optical requirement for LID initiation is in the range of 0.8W- 1.5W. In addition it is required to design an optical module of initiator able to be selective between the dedicated fire wavelength and the one for monitoring. This optical module will be operating with low optical power at 20dB below the firing power.

![Figure 10](Image)

By selecting appropriate pyro charges, insensitive against launcher environments (normal, abnormal and hazardous), an opto-initiator had been set up.

The design of this optical initiator is based on:

• An AIRBUS DS technical specification, allowing the implementation of that opto-initiator on existing space systems
• A safety concept for detonators, develop and patented by French-German institute: ISL
• A dedicated safety optical wavelength for monitoring set up by SOURIAU into the optical module of initiator
• A dedicated fire wavelength for fire set up into the optical fibre (Harness and initiator optical module): an optical fibre manufactured and customized by DRAKA compliant with Airbus technical specifications,
• Safety and low sensitivity pyro charges designed, customized and manufactured by NEXTER,
• Pyro charges sensitivity levels tested and certified by French DoD central laboratory
• A safety pig-tailed opto-initiator design by NEXTER with integration of several stages (optics-safety-pyro), compliant with technical requirements
• Performance tests to demonstrate the fully functions required, and safety tests for demonstration of non initiation conducted by NEXTER & ISL.
The safety pyro charge has been designed for insensitivity towards environments and for an initiation capability limited to a high optical power: kW/cm² on a dedicated IR wavelength.

From mechanical aspects, the opto-pyro initiator is based on a robust and very simple design with a very few parts comparing to hot wire initiators. This contributes to increase its reliability, performances and low cost.

Note that for safety systems such as specific ones for space system, a low cost solution is not a cheap one. A low cost solution shall remain compliant with safety principle and reduce the amount of costly equipments by using COTS, heritage of other technology fields and applications, …

Another safety principle introduced in the opto-detonators is a sterilization effects when submitted to hot temperatures: the pyro charges have been selected regarding their sensitivity levels, performances and also thermal decomposition vs possible flight and accidental environments: in case of rising high temperature higher than 200°C the detonating stage (second stage) will decompose without any detonating reaction before first stage reaction (= 400°C) → that not allow any initiation of Pyro terminal functions and avoid any catastrophic effects

Figure 11

Figure 12

Figure 13
After setting up all fire and no fire levels for this opto-initiator, safety test have been conducted in order to check its robustness against accidental and hazardous environments:

- No degradation of No Fire level under hot temperature
- No degradation of No Fire level under long stay in hot temperature
- No Fire during and after fall down tests
- No Fire during and after impact tests
- No Fire during and after crushing tests

Tests conducted were successful.

By comparison with classical hot wire initiator currently used on space systems (electro-pyro technology), the opto-pyro initiators brings several safety advantages by avoiding any Initiator premature functioning from electrical disturbance:

- No more electrical continuity between energy source and energetic material (no pin, no wire), avoiding all type of electrical accident due to electrical discharges (ESD, electrical sparks, arcing …), Immunity to electromagnetic interferences (EMI on electric conductors induce current, cross-talk…), hazardous current (vagabond current, …), lighting,
- Initiation only possible with a dedicated signal (to be created in wavelength, power, and shape) not available in normal environments
- Any gap on the optical path (disconnection, breaks, …) lead to a safety level, without any possibilities of firing the LID: 3dB of losses for any gap of 240 μm

As a conclusion for opto-initiator:

- **Opto-pyro Devices are proven to be less sensitive than Terminal Functions (and current items used on electro-pyro train such as Pyro transfer lines)**
- **Not any safety blocking point for considering a translation of ultimate safety barrier from A position to another one upstream the Initiator.**

5. OPTICAL HARNESS (OH)

At beginning of year 2000 main achievement through telecom application and optical networks maturity demonstration, lead aeronautic industries to implement optical harness on board (vs electrical ones), highlighting great advantages:

- Compactness & Mass saving with optical cable: Electrical copper quadax = 40 g/m, Optical fibre with 1.8 mm jacket = 4 g/m.
- Small dimensions of optical cable: Optical fibre is only 250 μm diameter and 1.8mm with its outer jacket.
- Easier routing for Optical cable
- ESD, EMI and lightning insensitivity:
- Optical harness deployment on Aircraft:
  - Increase of optical connectors amount on aircrafts (Boeing, Airbus, …) = 4 times more within 5 past years
  - Increase of optical cable length on aircrafts (Boeing, Airbus, …) = 3 Km/plane with almost 300 links

The functioning principle of an optic fibre is to transmit a light wave signal through a physical pipe used as wave guide. This wave guide allow the transmission of reflected light thanks to two specific elements made with the same material, but with different refraction indexes in order to allow reflection and gives the best ratio for optical output:

- The core
- The cladding

![Figure 14](image)

As a conclusion for opto-initiator:

- **Opto-pyro Devices are proven to be less sensitive than Terminal Functions (and current items used on electro-pyro train such as Pyro transfer lines)**
- **Not any safety blocking point for considering a translation of ultimate safety barrier from A position to another one upstream the Initiator.**

The optical cable is composed with several parts dedicated for optical transmission, and for fibre protection. Each of these technical parts contributes to the whole performance of the assembly, and shall be chosen regarding environmental conditions to be used.
The optical harness gathered the several optical cables to allow their best protection for routing inside the host vehicle, and got optical connectors at each ends to be connected to optical equipments.

A selection of COTS already used in Aeronautics (AIRBUS, BOEING…) or Telecom data transfers (from ground to submarine routing) has been tested in labs in order to select best compromise between existing heritages (optical standard parts already qualified through aeronautic applications …), performances, costs, peren-ity…and space systems requirements.

A technical specification for optical harness was submitted to R&T partners selected: DRAKA-SOURIAU, in order to manufacture prototypes, tests them and analyses their compliances to requirements. Optical harness (OH) requirements have taken into account the AIT lessons learned from electrical harness and pyro transfer lines of current space systems. OH has been design in a robust way from existing cots and process already qualified, coming from industry and Aeronautic.

Several optical cables have been designed in order to fulfill all the harness needs for launcher stages. These cables have been manufactured with qualified existing process used for aeronautic cable. Optical cable designed are now available to set up architecture of opto-pyro trains:
- 24 path optical harness
- Distribution fixture from 24 path to 3 x 8 paths
- 8 path optical harness
- Simplex harness for endings

At first, preliminary environmental lab tests (thermal, mechanical …) on cable parts allow selecting the best candidates. Additional mechanical test have been conducted on cable and harness assemblies with the selected items, following European norms EN 3745 applied for Aircraft cable to check:
- Cold-bend test
- Cut-through test
- Cable tensile strength
- Impact resistance
- Flexure endurance
- Bending test
- Torsion test
- Crush resistance test
- Resistance to fluids

Special conditions are required for transmitting an optical signal without losses:
- Clean interface between contacts
- Polished contacts without any cracks or defects
- Optical ends in contact to avoid any major optical losses
- Contacts aligned between emitter and receiver, without angular of parallel defects

In case of not respect of these conditions the system remain safe because of no optical transmission.
6. OPTICAL ENVIRONMENT CONDITIONS AND EFFECTS ON OPTICAL HARNESS (OH) TRANSMISSION

Ability to collect an optical signal into an optical cable depends on multiple conditions:

**Optical Emitter:**
- Type of Optical source
- Size of Optical source
- Power and frequency
- Emission spectrum
- Shape of optical source
- Scattering, attenuation, environment absorption...

**Optical Receiver:**
- Nature of optical protection on the receiver: existing cables, mated connector, connector damaged or not, contact damaged or not
- Distance of optical source from receiver (chromatic dispersion, environment absorption...)
- Type of optical fibre (50, 62.5, type of coating)
- Numeric aperture of the optical fibre (angular losses)
- Size of optical contact and diameter of optical fibre (geometric losses)
- Reflection of optical fibre (Fresnel losses)

**In these conditions:** Important optical losses induced in the transmitted signal.

Figure 19

Special conditions are required for transmitting an optical signal without losses:
- Clean interface between contacts

![Light Transmitted](Image)

**Polished contacts without any cracks or defects**

**Optical ends in contact to avoid any major optical losses**

**Contacts aligned between emitter and receiver, without angular of parallel defects**

![In case of not respect of these conditions the system remain safe because of no optical transmission](Image)

For analyzing the possible influence of optical environments, a preliminary list of critical environments for pyro equipments on space systems is set up in order to focus optical environments to be characterized:

### Possible Environments for the Space systems Pyro trains

**Optical Transmitters susceptibility** (Optical Harness, Connectors, Optical Initiators ...)

**Ground natural environment:**
- Inspection and checking lights / AIT phases
- Natural Light ambient & environments (Integration buildings & Launch pad)
- focalized lights
- Light effects coming from other processes
- Chemical environments

**Commands & activations:**
- Electrical
- Mechanical
- Optical
- Electro-magnetical

**Flight environments:**
- Lights environments (propulsion, pyro firing, ...)
- Thermal environments
- Electrical environments
- Electromagnetic environments
- Radiations

**Abnormal, accidental & malevolent environments:**
- Lightning
- Explosions
- Impacts (bullet, ...)
- Fire (from cryo, propellant, AIT vehicle, building, Forest, ...)
- Electrical arcing

![Figure 21](Image)
A characterization phase of maximal optical power available with existing optical sources meet in a space system environments (Ariane 5 launcher environment) determine maximal values and associated wavelength which could be collected by opto-pyro train and transmitted through the optical harness to the opto-initiator:

Optical sources from natural environments and accidental situations during launcher life cycle

- Lights from AIT buildings
- Welding means
- Sparks from millstone
- Blow torch
- Laser pointer (powerful source : 1500mW (forbidden))
- Flash bulb from camera
- Solid rocket motor plume (heavy IR generation)
- Fuel fire
- Sun (focalized with magnification)
- Moon
- Lightning

- Spatial distribution determination and measurement of lighting level (W/m²)
  between 180 et 11000nm
- Level calculated by numerical tools
- Bibliographic references

Figure 22

By inputting optical power transmitted by environment emitters on the optical train, for appropriate distance (and for optimistic configuration regarding numerical aperture of Optical fibre), the comparison of the No-Fire opto-initiator level to the optical power received will conclude about any risks of premature firing under environments.

This analyze conclude about safety margins remaining between maximal source effects and no fire level of:
- 20dB for all normal and accidental environments
- A safety factor more than 6 for abnormal environment (Sun focalized with a magnification x 20 in the axis of optical fibre (very low probability for occurrence)

As a conclusion for Optical Harness (HO):

- Optical Cables cannot capture and drive any amount of Spurious Light liable to fire the Opto pyro Devices
- Not any safety blocking point for moving the ultimate safety Barrier from B position to another one upstream the optical harness close to the Laser Diode which could becomes the source of danger

7. OPTICAL SAFETY BARRIER (OSB)

The Optical interception principle chosen for this Optical safety Barrier is based on the same principle than current Safe and Arm Device used on space system for the safety of electro-pyro trains: the principle is a physical interception of the signal.

An optical Safety Barrier technical specification was submitted by AIRBUS-DS to its R&T partner: SOURIAU in order to manufacture prototypes and analyses their compliances to requirements.

The Optical Safety Barrier requirements have taken into account the AIT lessons learned from electro-pyro trains of current space systems, such as:

- Status (Armed/disarmed) of Optical Safety Barrier is transmitted to ground system by electrical sensor,
- Direct visual information is given to the AIT operator by a colored indicator on OSB (Red/Armed; Green/Disarmed).
- OSB got a safety system which forbids any connection in armed position, to avoid any cata-
strophic accident during last connection of the harness bringing optical power from LFU (Laser Firing Unit),

- For emergency situation one can manually disarmed the OSB.

Considering that the safety barrier can be located up-stream from optical harness (demonstration given here under), it will be located as close as the LFU. That allow to get a centralize architecture, with few safety barrier able to cut simultaneously a great amount of orders (more than 70 orders). But for Neutralization train OSB will be decentralized in each stage with dedicated configuration. OSB have been design in a robust way from existing cots and process coming from space systems (Electrical parts: sensor, actuator; design philosophy…) and Aeronautics (optical parts: connectors …). The same type of optical fibre than for OH has been selected for OSB.

Test already conducted highlighted compliances to requirements:

- No Cross talks
- No optical transmission in disarmed position
- Very low optical losses when transmitting in armed position
- No thermal effects
- Possible manual disarming
- Robustness to optical power (twice maximal power value tested)
- Very short time for arming-disarming
- …

The OSB design could be adjusted to the amount of optical orders needed.
The two specimens here after are designed for interrupting 72 and 48 optical orders simultaneously:

![OSB 72 Paths](Figure 23)

In addition presentation meetings were organized by AIRBUS with safety and safeguard authorities from Space activities (Kourou safeguard authorities) and Defence activities (French DoD) to describe:

- Methodology about Safety Barriers,
- Justifications already acquired,
in order to gather advices and recommendations concern-
ing implementation and operations of opto-pyro on space systems.

No show stopper was addressed by civilian and Defence safety regulations.

To conclude about the safety barrier (OSB) design selected:

- Optical Safety Barrier allow the interception of high power optical orders (more than 25W)
- OSB design can be adjusted to the amount of optical path to be intercepted (from 1 to 96)
- OSB cannot capture and drive any amount of Spurious Light liable to fire the Opto pyro Devices (same demonstration than for Optical Harness)

8. LASER FIRING UNIT (LFU)

The Laser Firing Unit principle is to remain in a safety position (no optical emission) without any command orders. When command orders are received LFU has to address the specific Pyro function(s) selected, and finally fired with the dedicated power Laser diode to input the right optical power into the selected optical train.

The LFU shall be suited to the launcher avionic system type:

- Centralized with LFU functions implemented on electronic card of Integrated Modular Avionic (IMA),
- Decentralized with a self standing equipment LFU to be integrated on launcher stage.

The LFU will integrate the Electro-Optic converters based on Laser diodes and drivers. For current LFU designs, optical switches allowing several optical addressing from a same laser diode are not been taken into account due to their maturity levels and low robustness margin under critical environments.
The current LFU design is based on one diode for one pyro initiation.
The optical power of laser diode is increasing every year with important gaps, and offers now very good COTS suitable for LFU needs. This market supported by industries and telecom needs is now delivering a range of laser diode up to 80W.
First investigation on laser diode COTS lead to select a few ones regarding their results under environmental tests.
A second selection phase with Destructive physical analysis (DPA) leads to select final candidates. Investigations have now to be achieved concerning Laser diode failure modes and ability to spontaneously emit a spurious light.
Expert people are quite agreeing to not consider this case
as a probable one, but for safety reasons this topic remain under studies to conclude. In case of safety behaviour of Laser diodes, it could be analyzed a possible translation of the ultimate safety Barrier from C positions to D one upstream the Laser Diode. In this case the replacement of current optical safety Barrier by an Electro-Mechanical Barrier could be analyzed on a safety point of view.

9. TESTS METHODS FOR MONITORING OPTO-PYRO TRAIN

Several methods are daily used for monitoring and checking process of optical train on Aeronautic industries. These matured methods are fully applicable and compliant with safety requirements for an Opto-pyro train such as:

Opto-Pyro Train Demonstrator on A5 skirt panel

Figure 24

10. CONCLUSION

Taking advantage of the high Safety level of Opto-pyro-technic Devices and new possibilities offered by Optic systems, it is possible to design new Opto-pyrotechnic architectures that fulfil the Safety « root » requirements (and especially FS/FS criterion), meeting the spirit of Safety Regulations

Thanks to a special R&T effort: Opto-pyro is now compliant with ambitious requirements for next generation systems:

- Technology Maturity: TRL 5 (TRL6 in first quarter 2015)
- Safety improvements
- Compliant with safety regulations
- Operation Cost improvements
- Mass saving
- Fully interchangeable with existing systems (Functional performances demonstrated)

Opto-pyro is suitable to any systems with high safety level (from air to space systems)

First implementation of Opto-pyro technologies on space systems have recently been presented to customers for next generation of systems.
Progress in space safety lies in the acceptance of safety design and engineering as an integral part of the design and implementation process for new space systems. Safety must be seen as the principle design driver of utmost importance from the outset of the design process, which is only achieved through a culture change that moves all stakeholders toward front-end loaded safety concepts. Superb quality information for engineers, programme managers, suppliers and aerospace technologists.

Space Safety Regulations and Standards is the definitive book on regulatory initiatives involving space safety new space safety standards, and safety related to new space technologies under development. More than 30 world experts come together in this book to share their detailed knowledge of regulatory and standard making processes in the area, combining otherwise disparate information into one essential reference and providing case studies to illustrate applications throughout space programs internationally.

Safety Design for Space Operations provides the practical how-to guidance and knowledge base needed to facilitate effective launch-site and operations safety in line with current regulations. With information on space operations safety design currently disparate and difficult to find in one place, this unique reference brings together essential material on: Best design practices, Advanced analysis methods, Implementation of safe operation procedures, Safety considerations relating to the general public and the environment in addition to personnel and asset protection, in launch operations.