Digital Integrated Pyrotechnic System

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Abstract

DASSAULT-Aviation in collaboration with the French Space Agency (CNES) and LAAS-CNRS have proposed a new pyrotechnic chain architecture suitable for the next launchers and aircrafts in replacement of classical pyrotechnic devices based on detonic order. It is based on smart and a safe safe and smart PyroMEMS interconnected and communicating via a digital bus. These safe and smart PyroMEMS also called Integrated Function Initiator (IFI) contain a Al/CuO nano-thermite microinitiator chip, a local energy storage device, a miniaturized safe and arm mechanical barrier, electrical protections, and a micro controller which enable the bidirectionnal communication between the bus and the IFI to control the operation and safety procedure. This work relies on both the knowledge of LAAS-CNRS in nano energetics and pyroMEMS integration as well as on DASSAULT-Aviation skills in pyrotechnics engineering. This paper presents the principle and conception of this digital integrated pyrotechnic system that could constitute a real breakthrough for next generation of embedded Pyrotechnical Systems.

1. Introduction

Pyrotechnic systems are key elements for Space launch vehicles and military aircrafts as they fulfill critical functions like engine starting, booster or canopy separation and distancing, seats ejections etc. Existing pyrotechnic devices are reliable and robust but also heavy, quite large and complex. Furthermore, their installation is relatively costly due to their hazardous characteristics. Importantly, they also have to be regularly replaced to ensure high reliability level requirements.

Space launcher calls on several pyrotechnic equipments for engine starting, stage separation and distancing, and self-destruction. Combat aircraft's ejection seats use the same technologies for canopy separation and distancing, and seats propulsion. Pyrotechnic equipments are indeed based on energetic materials (explosives, propellants...) to produce very strong and fast mechanical effects with small amount of embedded material.

Pyrotechnic equipments are connected together to form pyrotechnics chains, thus enabling the generation and the propagation of a pyrotechnic signal. A pyrotechnic chain consists in a succession of equipments distributed according to dedicated architectures, designed to be as safe and reliable as possible.

Ariane 5 pyrotechnic architecture has been standardised to be Fail Safe and Fail Operational and is composed of:

- Electro-detonators able to convert electric signal into shockwave (pyrotechnic signal)
- Motorized mechanical arming device that can interrupt the pyrotechnic signal
- Pyrolines and multi-ways relay for signal distribution and propagation
- Pyrotechnic time delays for sequecement
- Terminal function for pyro-mechanical conversion

To increase reliability, detonators, pyrolines and multi-ways relays are doubled and are geographically independent so that a unique event cannot lead to any dysfunctionning. A schematic view of the Ariane 5 architecture is given in figure 1.

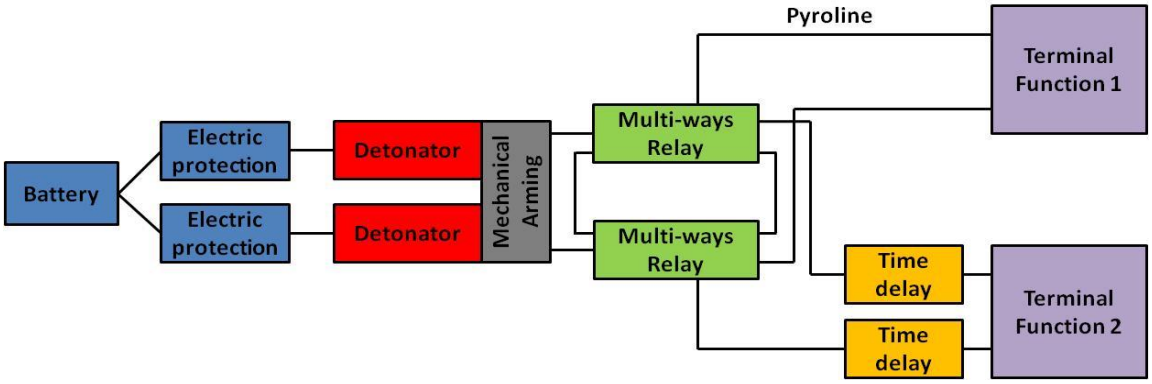

Figure 1: Ariane 5 Pyrotechnic Architecture

As this architecture is based on detonic transmission, generated by detonators and distributed through pyrolines, the Ariane 5 launcher embed several large and heavy pyrotechnic equipments. Owing to their hazardous nature (due to the presence of explosive material), pyrotechnic equipments are at the root of fabrication, transportation, storage and installation constraints, also responsible of expensive logistics. For instance, pyrolines cannot exceed 15 meters long; they need specific transportation and secured storage. During their installation on Space launcher, other activities on launch site are forbidden to reduce the impact of unexpected accident. Knowing that Ariane 5 contains 530 meter of pyrolines, it is easy to realize the impact of these constraints. Otherwise, this architecture is not testable as the only way to test equipment consists in firing it, leading to its destruction. System reliability also depends on fabrication quality and redundancy of equipments. Finally, detonators, pyrolines and relays are not compatible with the European regulation REACH on innocuousness of chemical products, as they integrate lead, lead salts, azides and dichromate. Combat aircrafts pyrotechnic architecture is close to Space launcher's one and encounters the same constraints. Given that aircrafts lifetime is more than 30 years, the pyrotechnic equipments have to be replaced regularly to ensure high reliability requirements.

To meet the need of next generation launchers and aircrafts, Dassault-Aviation in collaboration with the French Space Agency (CNES) and the LAAS-CNRS have proposed a new architecture based on advanced technological solutions in replacement of classical pyrotechnic architectures. The key elements are safe and smart miniaturized pyrotechnic initiators which are all interconnected through a digital bus. This architecture is therefore called Pyro-Numeric architecture.

2. The Pyro-numeric Architecture

The pyro-numeric architecture has been designed and patented by Dassault-Aviation in 2010. It lies in the use of digital bus for the command distribution instead of pyrotechnic communication solutions. Digital orders are transmitted through classical electric wires from the numerical bus to each smart initiator which are designed to receive, decode and interpret the digital messages. Smart initiators are directly settled on pyrotechnic terminal functions and keep the same mechanical interface as the European Standard Initiator actually used on ESA's launchers. This way, pyrolines, multi-ways relays and time delays are replaced by electric wire and digital clock.

Each smart initiator integrates 4 main integrated functions:

- The pyrotechnical initiator which is based on pyroMEMS [1-3] integrates a Al/CuO nano-thermite [4-6] in replacement of dangerous primers. Indeed, a thin layer of Al/CuO nanothermite is directly sputter deposited on a Platinum hotwire being realized on a Si chip [6]. This technology presents many assets as the fact that no dangerous primers are manipulated for the realisation of the pyrotechnical initiator and also the Al/CuO thermite does not impact the environment and is compatible with European regulation REACH.
- a local energy storage device for electro-pyrotechnic conversion called Energy Storage in schematic view of figure 2. Electrical energy is charged-up from the main launcher charge into the smart initiator

capacitor just before Space launcher lift-off or just before and during the combat aircraft flight. This solution permits to save batteries mass by optimization of electric power consumption, as energy has not to be delivered from battery in one go (for simultaneous initiators firing) but in a much longer time (for local storage charging).

- A miniaturized safe and arm mechanical barrier and electrical protections circuitry (called S&A in figure 2) to fulfil safety requirements.
- A micro controller which is in communication with the digital bus and also manages the safety procedure (arming & disarming procedure, self testing….). It is called Control Unit in figure 2.

The Safe and Smart initiator is also called Integrated Function Initiator, consequently noted IFI. A schematic view Pyrotechnic architecture is given in figure 2.

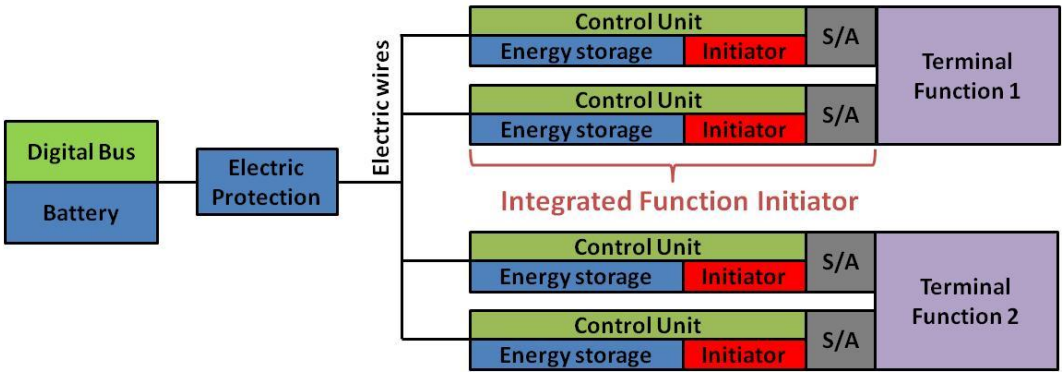

Figure 2: Pyro-numeric Architecture

3. Advantages Analysis

The pyro-numeric architecture advantages are numerous. First, as the communication is based on digital messages, the bidirectional communication is therefore possible unlike to pyrolines in which detonic signal can only go from detonator to terminal functions. System manager can thus gather information about the status and states of each IFI connected to the bus, like a simple question/answer dialog. For instance, the different IFI arming state can be checked anytimes, ensuring the safety and reliability of the overall system. We have already pointed out the replacement of old pyro-initiators integrating primers on metallic hotwire by a nanothermite based pyroMEMS. This provides many progresses in terms of safety, manufacturing costs since pyroMEMS is fabricated by collective processes), mass saving….

Overall, we have evaluated that the replacement of the current Ariane 5 architecture by the proposed and patented pyro-numeric architecture will lead to the following progresses:

- **Overall pyro chains mass saving** : mainly on pyrotechnic distribution subsystem and by the replacement of big and heavy batteries by miniaturized capacitor.
- **Overall system performances upgrading**: increasing accuracy in time delays and better firing synchronisation
- **Testability increase** since each part and function of the system cans be checked by the digital network Reduce transport, storage and installation constraints on leading to easier integration on launcher and aircrafts
- **Decrease the impact on human and environment** by the replacement of dangerous product containing Pb by friendly components as copper and aluminun. This will help for the REACH and ROHS regulations requirements.

3.1 Mass saving

On combat aircrafts, pyrotechnic system mass saving has been calculated to 50% of total mass, mainly on pyrolines and time delays. Regarding Space launchers, detailed value of mass saving are given in table 1.Pyro-numeric architecture save 141 kg compared to Ariane 5 one's, corresponding to 66% of total mass. Major mass saving is realized by replacing pyrolines, multi-ways relay and time delay by electric wires and digital clock. Battery mass

reduction is obtained by optimization of power consumption, also avoiding current overload for simultaneous firing of several initiators since they use local storage rather battery.

Table 1: Mass comparison between Ariane 5 and Pyro-numeric Arcitecture

	Ariane 5 (kg)	**Pyro-numeric (kg)**
Terminal functions	15	15
Distribution	118.5	37.5
Battery	80	20
Total	**213.5**	**72.5**

3.2 Costs

Pyro-numeric architecture permits the direct replacement of pyrolines, multi-ways, and time delays by electric wires and electronic functions. Knowing that the launch of 1g to Space costs 20€, the 141 kg mass reduction imply a 2.8M€ saving per launch. As they are replaced by electric wires, the transportation, storage and installation of pyrotechnic equipment (pyrolines, multi-ways relay and time delay) is no more necessary, leading to additional savings which have not been estimated for the moment.

3.3 Performances

Using the convenient numeric communication protocol, the synchronism between the initiators can be controlled with more accuracy. In the same order, the IFIs are able to perform the delay function, with much more accuracy (µs) than actual pyrotechnic delays. Due to the communication network, the testability can be centralized, based on answers/response dialogue with the control box.

3.4 Reliability

The objective of global reliability is the same than the actual one (i.e. European Standard Initiators), but the safety is increased by the presence of mechanical barrier included in each initiator. The bus redundancy provides a high reliability in the dialog between the control unit and the initiators. The terminal function ignition redundancy must provide the same reliability than by the past.

3.5 Operability / Integrability

The concept allows minimizing the pyrotechnic operations. These pyrotechnic operations are limiting, for safety reasons, the number of operators during the launcher integration and subsequently increase the cost and duration of final integration. The main integration work consists in integrating wirings in the launcher structure with no special safety rules required. The advantage is that a wiring can be checked after installation by opposition to pyrotechnic distribution chains.

3.6 Robustness

The pyro-numeric subsystem is not impacted by evolution of flight sequences, by the mean, it serves of interface between the main system (flight control) and the pyrotechnic terminal functions. It is easy to add or subtract some initiators because they are just connected in parallel on the pyro data bus. (This implies some wiring modifications on the launcher and some software modification on the main system).

3.7 Growth potential

For growing the capability of a launcher system in terms of point of initiation, due to the modularity of pyronumeric subsystem, there are two possibilities:

- Add initiators on an existing pyronumeric subsystem (i.e. connect initiator to an existing control box via an existing pyro data bus).
- Add a new pyronumeric subsystem by adding a new control box, pyro data bus, and initiators.

3.8 Payload service / Environment

As the concept replaces the actual full pyrotechnic components near the payload by a principally electrical transmission system, it minimizes the risk of pollution of the payload by leaks of residual pyrotechnic gazes and particles after ignition. To prevent any leak at the level of initiators by design the initiators are hermetic during all their life (before, during, and after firing).

3.9 Environmental impact

The concept proposed, is ROHS compliant with regard to the electronic components. The suppression of the Pyrolines, and manifold permits to have an order transmission system "lead free". With regard to the pyrotechnic ignition powder, REACH compliance is today fulfilled.

4. Conclusion

A new pyrotechnic architecture based on digital bus communication and integrating a miniaturized smart and safe initiators has been proposed, designed and is being developed in replacement to classical detonic transmission solution. This new architecture represents an important technological step compared to all detonic solutions and presents many advantages. They are based on the development of a safe and smart miniaturized pyrotechnic initiators which will be all interconnected through a digital bus. These safe and smart miniaturized pyrotechnic initiators also called Integrated Function Initiator (IFI) are pyroMEMS. They contain a Al/CuO nano-thermite based microinitiator, a local energy storage device, a miniaturized safe and arm mechanical barrier, electrical protections, and a micro controller which permit the bidirectionnal communication with the bus and also control the operation and safety procedure : arming & disarming procedure, self testing, firing order). This constitute an innovation in the field of pyrotechnical chain, especially for launcher but also for civil and defense applications (combat aircraft), since no more pyrotechnic equipments are required for the signal distribution : very sensible and dangerous pyrolines and multi-ways relay will be definitively removed. In consequence, the synchronisation (time delay) will be instantaneous since the signal spread through electric wires. We evaluated that the pyrotechnic system mass will be divided by 2 for combat aircrafts and 3 on Space launchers. Pyro-numeric architecture also permits important costs savings, due to mass reduction and pyrotechnic equipment replacement and should also make the fabrication, transportation, storage and installation easier. In terms of performances, pyro-numeric should give better accuracy, safety, reliability and flexibity than existing solution. A last important point to note is the use of non toxic materials for initiator.

Aknowledgment

This work was supported by French National Space Agency (CNES) and Dassault-Aviation and LAAS-CNRS. The authors would like to thank the French Technological Network namely RENATECH that has partially funded smart and safe initiator manufacturing.

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