Qualification of a Networked Pyrotechnic Initiation System for the CST-100 Starliner Spacecraft

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Abstract

Ensign-Bickford Aerospace & Defense (EBAD) Company has more than 60 years of continuous innovation in the field of space components and subsystems. While EBAD first developed linear expolosive technologies such as Linear Shaped Charge for separation events on missile and manned space platforms, we have added newer technologies such as Non-Explosively Actuated (NEA) mechanisms made by our NEA Electronics and TiNi Aerospace subsidiaries for separation events on spacecraft launched in the last 15 years. The traditional method of pyrotechnic initiation on manned and Mars exploration platforms involve large batteries supplying high current pulses (greater than 5 amps) via heavy gauge wires to NASA or ESA Standard Initiators for U.S. and European-based platforms. EBAD developed a smart, networked initiation system several years ago as a means to simplify the complexity and lower the weight of the pyrotechnic initiation system. We recently completed qualification of this initiation system for Boeing's CST-100 Starliner spacecraft developed for NASA's Commercial Crew Development program and believe this technology has benefit to newer space platforms.

Introduction

Satellite and spacecraft platforms employ many "one-shot" devices and mechanisms for payload, communication, propulsion, and power systems. These mechanisms are used for solar array and antenna deployment, separation events, propulsion and instrument boom deployment, propulsion isolation valve actuation, and battery cell isolation switch activation. Critical timing of these events are magnified on manned and exploration platforms, where fast-acting pyrotechnic events are employed to assure achievement of millisecond timing and simultaneity of multiple events, especially during events for safe landing on Earth, Mars, or other space bodies.

The number of "one shot" events on manned and exploration platforms can range from more than fifty to greater than one hundred. This is also the case for many large geosynchronous satellite platforms and satellite constellation dispensing systems, where the number of "one shot" mechanisms can easily be greater than fifty. The tax on the power systems and weight / complexity of cable harnessing consume valuable resources that could be used for additional payload capability.

EBAD developed a smart networked initiation system several years ago as a means to simplify the complexity and lower the weight of the pyrotechnic initiation system. We recently completed qualification of this initiation system for Boeing's CST-100 Starliner spacecraft developed for NASA's Commercial Crew Development program. This system saved significant mass from the mission by simplifying the one-shot cable harnesses, and by lowering the peak power load required during pyrotechnic initiation. This paper discusses the networked initiation technology, the qualification effort for CST-100, and application for future satellite and spacecraft platforms, including future use with many non-pyrotechnic actuated devices.

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Smart Initiation System Background

EBAD's Smart Initiation architecture moves the ordnance initiation electronics typically found in a centralized firing controller to a within the initiator metallic housing. This creates a more efficient architecture as the firing circuitry is less than 25 mm (1 inch) away from the bridge element and one-shot events are commanded to actuate via a data bus rather than using point-to-point wiring. The initiation architecture consists of a small Initiation Controller (IC) capable of controlling more than 120 Smart Initiators (SI); the system elements are shown in Figure 1. Implementation of an architecture like this has resulted in a dramatic reduction in the size, weight, and power needed for firing of ordnance events on a missile and space platforms. EBAD also has a Smart Detonator (SD) configuration for applications where a detonation input is required.

Figure 1. Smart Initiation System Elements.
Left to Right: Initiation Controller (IC) & Cable Harness, Smart Initiators (SI)

<u>Initiation Controller (IC) Functional Characteristics</u>

The Initiation Controller (IC) provides the interface between the host vehicles' electrical/data interfaces and provides digital commands to Smart Initiators (SI) to perform arming, firing, and Built-In-Test functions. Commands are based on signals from the ground system or host vehicle and execute discrete commands and/or trigger a predetermined sequence of events. The IC does not change based on the number of SIs but rather on the mission profile and mission needs. The IC is a low-power electronics unit drawing less than 100 mA of quiescent current.

<u>Smart Initiator (SI) Functional Characteristics</u>

The Smart Initiator (SI) contains the arming and firing functions that are typically contained in a centralized firing controller. Each SI contains a unique address and is commanded to arm and fire by receiving digital commands over a data bus from the Initiation Controller (IC); it contains electronic safety interlocks that preclude inadvertent firing, provides Arming and Firing functions when commanded, and has extensive Built-In-Test capability. Initiator functional and safety characteristics are accomplished by having the proper physical, electrical, pyrotechnic, and software/firmware features in the SI. The SI provides a NASA Standard Initiator equivalent pyrotechnic (pressure-time/caloric) output.[1]

<u>Key Technologies for Size and Power Reduction</u>

Two technological advances enabled the successful development and fielding of a smart initiation system. The first is the availability of small, low cost, reliable microelectronics that allows the integration of SI circuitry into a very small package. The second is the availably of a low-energy Semiconductor Bridge (SCB) element for initiation of pyrotechnic materials. The primary advantage of a SCB firing element is that it requires $1/100^{th}$ the firing energy over conventional Hot Bridgewire (HBW) elements, enabling use of a small, capacitive discharge firing circuit. The SI trickle charges its firing capacitor during arming, drawing less than 10 mA during arming/firing versus a typical 5-A current draw for a NASA Standard Initiator or equivalent initiator. This is particularly important for systems where multiple events are required to be actuated simultaneously.

SCB Initiation Element Characteristics

Our SI design utilizes a Semiconductor Bridge (SCB) firing element manufactured by our SCB Technologies division in Albuquerque, NM. SCB technology was originally developed by Sandia National Labs in the mid-1980s as a low-energy replacement for HBW and Exploding Bridgewire devices. EBAD manufactures more than 10,000 SCB based initiation devices each year used in aerospace and industrial initiation applications.

SCB firing elements offer a significant reduction in the all-fire energy over conventional HBW devices, while meeting 1.0 A/1.0 W no-fire performance. The low-energy all-fire level of an SCB device is a direct result of the much smaller mass of a semiconductor bridge as compared to a typical HBW initiator. The all-fire energy for a typical SCB device is 200 microjoules, whereas the corresponding all-fire energy of an HBW initiator is greater than 25 millijoules. While the all-fire energy is low, the application of a short-duration, high-current pulse allows a SCB element to rapidly change from solid to plasma state in tens of microseconds, providing a convective heat transfer into the surrounding pyrotechnic material.[2]

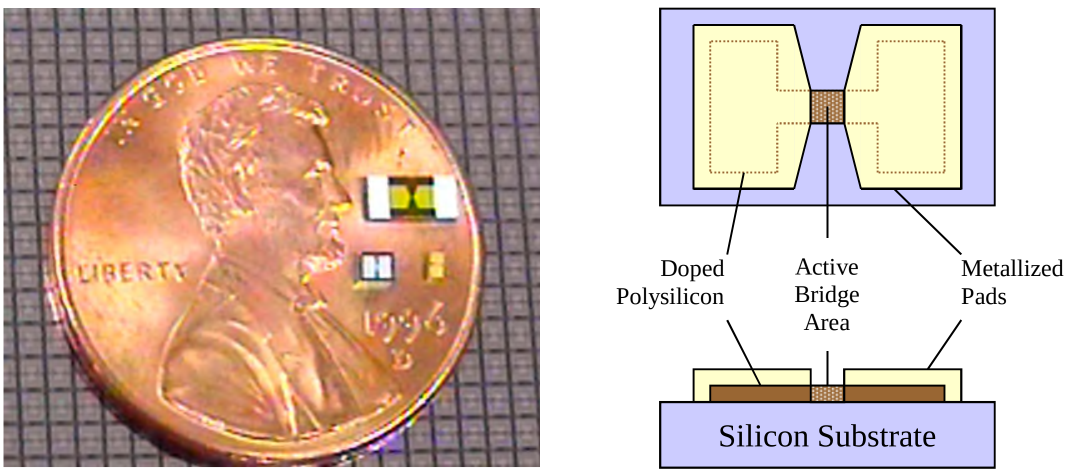

Figure 2. Semiconductor Bridge Construction

Smart Initiator Environmental Testing

Prior to application on the CST-100 program, EBAD successfully tested our SI to the following environments. This provided confidence that our SI could hold up to the rigors demanded by a manned spacecraft environmental qualification test program.

- Thermal Cycling: -54°C to 71°C
- Random Vibration: 111 grms, 180 sec/axis
- Pyrotechnic Shock: 14,000g peak
- EMI: CE102, CS101, CS106, CS116, RE102, RS103, TT101
- Ionizing Radiation: To 8.00E+7 Protons/cm^2-sec flux, 5.39 kRadSi total dose

Prior Applications

Prior to CST-100, EBAD had significant test and fielding experience of our smart initiation system, having produced nearly 6000 smart initiators. Most of the applications were for tactical systems, so our SI had a Technology Readiness Level of 7 for manned space environments prior to our CST-100 qualification effort. Prior papers described our technology being applied to derivative systems: an RF safe Mobility Unit[3] and a tactical missile divert and attitude control system[4]. Both applications demonstrated the technology could be configured to the custom application needs of divergent systems, and could be readily scaled up to relatively high production volumes.

Application to CST-100 Starliner

EBAD's Smart Initiation System was adopted for use on the CST-100 Starliner spacecraft for NASA's Commercial Crew Program. The benefit to the spacecraft was estimated savings of several hundred pounds in cabling, firing electronics, and pyrotechnic batteries over a traditional initiation system using heritage manned space HBW initiators. Our experience is that there are very few options on manned and exploration spacecraft that can offer mass savings of this magnitude.

<u>Radiation Environments</u>
Prior to selection for the CST-100 platform, our Smart Initiator (SI) electronics were subjected to radiation equivalent of 10X the estimated maximum mission life and worked flawlessly. Subsequently, EBAD has implemented a Radiation Lot Acceptance Test (RLAT) screening process on EEE parts used in our design to assure proper parts operation during radiation environments. Our design architecture has inherent immunity to Single Event Upset since initiators remain in a powered-off configuration until immediately prior to actuation when they enter a rapid Arm-Fire sequence. This sequence take place in less than several seconds, so probability to upset is minimized.

<u>Devices Initiated</u>
Our Smart Initiators (SI) and Smart Detonators (SD) were used to initiate many unique devices used on the CST-100 platform including separation nuts and bolts, cutters, frangible joints, and many other devices. While the photographs shown in Figure 3 are not necessarily the exact devices, they offer a good representation of the devices actuated on CST-100. EBAD provides the majority of the initiators, detonators, and pyrotechnically actuated devices used on CST-100 and other current manned platforms in the U.S.

Figure 3. Types of Devices Initiated by Smart Initiators
Left to Right: Separation Nuts, Separation Bolts, Cutters, Frangible Joints

<u>Environmental Validation and Qualification</u>
EBAD successfully completed an extensive validation and qualification test program for the CST-100 platform. Testing was first done at the SI and SD level, and subsequently at the device level, joining the SI and SDs to end effectors such as separation nuts. The total validation and qualification effort involved more than 700 Smart Initiators and Detonators. The environments were roughly within prior test levels. Some issues arose from self-induced shock, where there were high shock levels observed during actuation of the various devices used on the spacecraft to redundant initiators. While there were a few bumps during the test program, EBAD was able to fix these issues and successfully completed its qualification effort in 2017.

Application to Future Platforms

With the successful qualification for the CST-100 platform, this technology is being adopted on other platforms within the space community. One of the applications is coupling this technology with a non-explosive Split Spool Release Device (SSRD) offered by our NEA Electronics subsidiary. NEA SSRDs are widely used in the space industry for solar array, antenna reflector, payload release, and spacecraft separation and are well known for high preload capability while offering low shock separation. The weight and mass benefits can be similar for systems that use various one-shot technologies, although they were very pronounced for the CST-100 application due to the large number of pyrotechnic devices employed during the launch and subsequent re-entry events.

Figure 4. Example of an NEA SSRD Device

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