Techniccal Paper
International Journal of Aerospace System Engineering
Vol.9, No.2, pp.1-9 (2022)

ISSN 2383-4986
EISSN 2508-7169
http://dx.doi.org/10.20910/IJASE.2022.9.2.1

Hot Firing Test of a Quadrature NEA SSD9103S1 Configuration

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Abstract

The NEA release mechanism is used to provide restraint and release functions with low shock for critical deployment operations on solar arrays after launch. The GK3 solar array consists of 2 wings and 6 hold down points per panel. The NEA SSD9103S1 is a part of the GK3 solar array hold-down and release mechanism. Each NEA unit is equipped with two Z-diodes which provide power to a NEA unit connected in series after actuation of the fuse wire. This paper presents the hot firing test results of a quadrature NEA SSD9103S1 configuration. One output powers a maximum of 4 NEA SSD9103S1 units simultaneously. The necessary actuation pulse duration has been determined to meet margin requirement for thermal energy of minimum 4. Actuation thermal energy difference is about 6.6% between each half of two fired serial NEAs. Thermal energy margin at worst case is minimum 5.9 in case of an actuation pulse duration of 500 ms. Two series Zener impedance depend on current applied has been characterized by an additional actuation after all fuse wires are open circuit. Total number of actuation commands to the GK3 NEA unit reduce drastically from 24 in case of single NEA configuration down to 8 in case of parallel and quadrature NEA configurations. It can be accommodated by the existing HP2U Pyro design without any impact.

Key Words : Non-Explosive Actuator, Split Spool Device, NEA SSD9103S1, Hot Firing Test, Quadrature Configuration, Thermal Energy Margin

1. Introduction

The NEA(Non-Explosive Actuator) release mechanism is used to provide restraint and release functions for critical deployment operations on S/C(spacecraft) such as SA(Solar Array)s, antennas, radiators and payloads after launch[1]. The NEA is an electrically initiated HDRM(Hold-Down and Release Mechanism) that has the ability to carry a very high tensile preload until commanded to release, with the additional advantage of very low output shock[2]. The NEA has been used for many different S/C HD(Hold-Down) applications over the years[2]. The spool assembly of the NEAs used in electro-mechanical structural separation devices increases the durability and reliability of repeatable operation of the NEAs, shortens the assembling and production process of the spool assemblies, and reduces material and manufacturing costs of the NEAs[3].

The NEA SSD(Split Spool Device)9103S1 Low Shock Release Unit is a part of the GK3(GEO-KOMPSAT-3) SA HDRM. Its purpose is to keep the stowed SA HD points during launch and to release the

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Received: Jun. 24, 2022 Revised: Nov. 01, 2022 Accepted: Nov. 24, 2022
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SA deployment after launch. The NEA unit provides the following properties:

- A safe and fast release process in order to achieve an instantaneous release of multiple HD points.
- A low release shock in order to minimize the impact on adjacent electronic equipment.
- Non-pyrotechnic actuation for safety reasons and to prevent release of debris. Note: The term "pyrotechnics" shortened to "pyros" in the aerospace field was first used during the Mercury program for explosive and propellant-actuated devices[4].
- Easy refurbishment to allow multiple actuations (for on-ground tests) at low costs.
- Compliance to mechanical and electrical loads and I/F(interface) requirements.

The NEA SSD9103S1 units in both quadrature and parallel configurations can reduce the number of channels required for actuation. Two release units can be electrically connected in series if required. For that purpose, the main and redundant circuit of the NEA unit are equipped with a Z(Zener)-diode which is connected in parallel to the "fuse" or "bridge" or "link" wire. The wire is caused to break as a result of the receipt of the electrical signal. Series and parallel associations are done thanks to a "regulator" compatibility in pyrotechnic converter by an electronic current limited voltage regulator in each pyrotechnic board. One output powers a maximum of 4 devices simultaneously. Both quadrature and parallel configurations do not include two devices (primary & redundant) from the same release unit. The GK3 SA consists of 2 wings and 6 HD points per panel. If GK3 used NEA units in single release configuration only, a total of 24 actuation commands would be necessary (i.e. 6 HDs x 2 wings x 2 primary & redundant). It would impact the existing HP2U(Heater, Pyro and Pulse Unit) Pyro design. The required number of Pyro boards would have to be increased from existing 2 to 4.

First of all, this paper presents the hot firing test results performed on ETB(Electrical Test Bed) at ambient condition of a quadrature NEA SSD9103S1 configuration to reduce the number of required actuation commands. The second, starting from measurements made on the hot firing test, the necessary actuation pulse duration has been determined to meet margin requirement for thermal energy of minimum 4. Finally, two series Zener impedance in each half depend on current applied has been characterized to understand the effect of Zener impedance by an additional actuation after all fuse wires are open circuit.

2. Solar Array and HDRM Configuration

2.1. GK3 Solar Array Configuration

The GK3 SA configurations are shown in Fig. 1 at transfer orbit and on-station. The transfer orbit phase goes from the S/C-launcher separation to the geostationary orbit. This includes SA partially deploy the outer panel and hold the outer panel at 90° (Fig. 1 (a)). The attitude in this phase will be changing, but most of the time it will be with the -Z vector pointing to the Sun. The on-station phase is the final geostationary orbit in nominal attitude (i.e. S/C pointing to the Earth for mission and SA rotates once a day). The SA wings are fully deployed and locked to form a straight SA wing on-station phase (Fig. 1 (b)). The panels and the yoke of each wing are fixed in stowed configuration during launch by 6 HDRM units. The partial deployment is initiated by the actuation of the 5 primary HD points (1, 2, 3, 5 and 6) while the inner panel stack (inboard panel and yoke) is still kept stowed at the S/C sidewall by one secondary HD point (4). The full deployment of the SA wing is released by the actuation of the secondary HD unit (4). The jump out occurs and then the full deployment will be continued by the actuation of the MGU(Motor Gear Unit) in order to control the deployment speed at a very slow level.

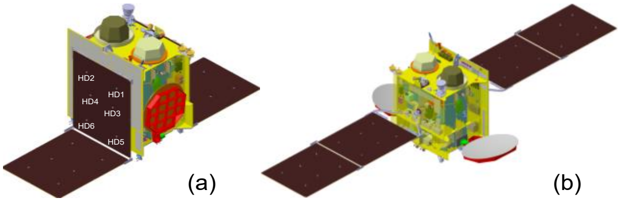


Fig. 1 GK3 solar array configurations (a) at transfer orbit and (b) on-station

2.2. NEA SSD Description

The NEA is based on a split spool principle as shown in Fig. 2[5]. The restraint wire is held in place by redundant electrical fuse wires (Fig. 2 (a))[5]. Actuation of either circuit allows release[5]. When sufficient electrical current is applied, the restraint wire unwinds allowing the spool halves to separate

(Fig. 2 (b)) releasing the rod and the associated preload (Fig. 2 (c))[5]. The preload is released slowly to minimize the release of strain energy and therefore minimizing shock.

A plot of the strain energy release is shown in Fig. 3 (a) which is provided by NEA Electronics for a SSD9101B[6]. The nominal values are not corresponding to the GK3´s use but the principle characteristics are similar with the SSD9103S1. The NEA actuation time is the time from application of current to the start of the release rod exiting from the NEA (i.e., preload drop to zero)[2,7]. This actuation time can be split into two independent segments (1. fuse-wire burn-time, 2. pre-load drop time) per Fig. 3 (b)[2,7].

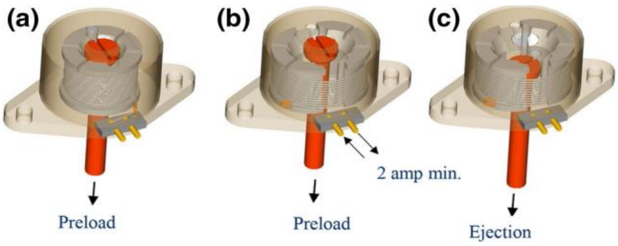


Fig. 2 NEA operational principle[5]: (a), preload reacting against split spool, (b) fuse wire initiation and (c) releasing the rod

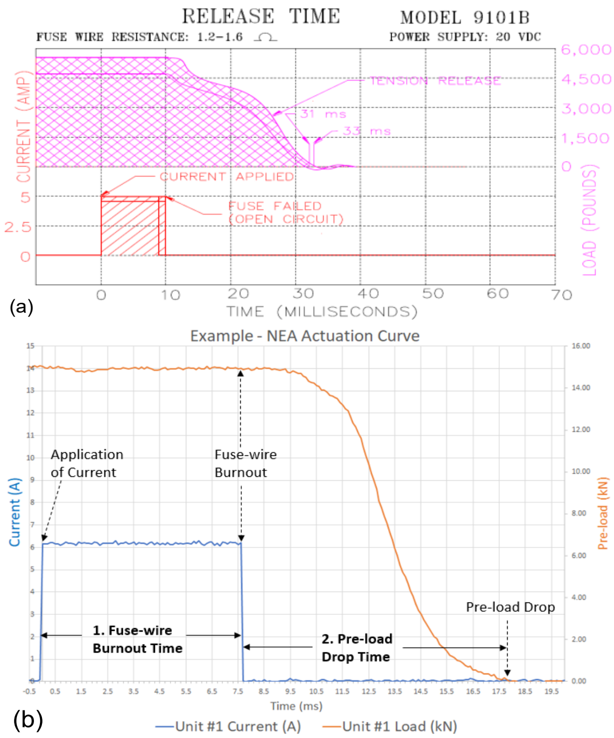
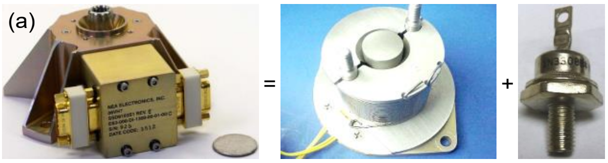


Fig. 3 (a) NEA strain energy release[6] and (b) typical NEA actuation curve[2,7]

2.3. GK3 HDRM Configuration

The NEA SSD9103S1 acts as a HDRM for the GK3 SA and is an electrically initiated, one-shot release mechanism. It is produced by NEA Electronics Inc. (now Ensign-Bickford Aerospace & Defense Company) and shown in Fig. 4. The model 9103S1 is based upon the existing design of 9103[8], only the housing is adapted to carry the structural loads and to contain 1N3308B[9] Z-diode. The mechanical interior of model 9103S1 is identical to 9103. A 9103S1 release unit has two fully redundant electrical actuators (fuses)[10,11]. Each fuse of 9103S1 is individually electrically wired[10,11]. Each actuator (fuse) has a separate I/F connector. The stainless steel 304 wire works perfect for bridge wire applications[12]. Stainless steel has a higher tensile strength and can handle greater loads[10,11]. The stainless steel fuse wire, about 0.1 mm diameter[10], is sufficient to retain the bending of the spiral spring[13], with a safety factor of 8. For release the fuse wire is electrically heated up until breakage temperature (about 1400 °C[14-18]). Then its tensile strength drops drastically. Nominal actuation requires only one fuse breakage. The 9103S1 fuse wire electrical resistance is 1.00 Ω to 2.70 Ω. A Z-diode is connected directly onto the fuse wire and used to close the electrical circuit of an actuated unit (melted fuse wire).



NEA 9103S1 = the existing NEA 9103 + the housing adapted to carry the structural loads and to contain 1N3308B Zener diode.

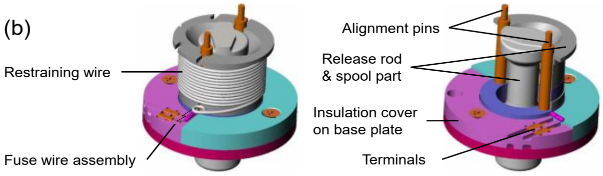
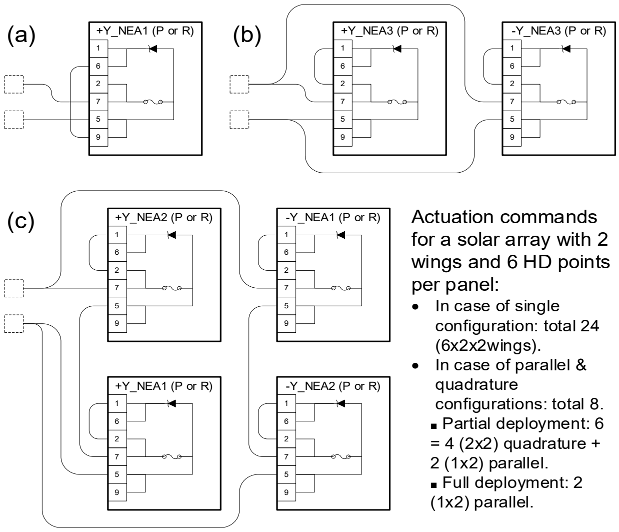


Fig. 4 NEA SSD9103S1 (a) photo and (b) internal main components

The high power 50 W Z-diode 1N3308B is EEE(Electrical, Electronic and Electromechanical) standard component, minimum operating voltage of 10 V_{DC} – 0.5 V_{DC}, nominal Zener Voltage of 9.1 V at test current (I_{ZT} = 1370 mA), maximum Zener dynamic impedance (Z_Z) of 0.5 Ω (Z_{ZT}) at test current (I_{ZT}) and 70 Ω (Z_{ZK}) at knee current (I_{ZK} = 5 mA), and maximum

DC Zener current (I_{ZM}) of 4.8 A[9]. The power dissipation of 1N3308B is compatible with 3 A for 30 seconds. The 9103S1 qualified temperature range is -95 °C to +120 °C. The 9103S1 unit is easily refurbished and can be reused. Refurbishment of the unit is achieved by replacing the restraining wire and fuse wire assemblies after actuation and can be done numerous times to allow for ground test[19].



Actuation commands for a solar array with 2 wings and 6 HD points per panel:

- In case of single configuration: total 24 (6x2x2wings).
- In case of parallel & quadrature configurations: total 8.
  - ▪ Partial deployment: 6 = 4 (2x2) quadrature + 2 (1x2) parallel.
  - ▪ Full deployment: 2 (1x2) parallel.

Fig. 5 NEA SSD9103S1 (a) single, (b) parallel and (c) quadrature configurations

Different possible 9103S1 configurations are shown in Fig. 5. Each electrical I/F uses a pyrotechnic line, from HP2U Pyro, with actuation current of 6 A ±1 A. The 9103S1 devices are redundant which gives a total number of 24 actuation commands in case of single configuration. Pyrotechnic lines with 9103S1 can be grouped by 2 (parallel; Fig. 5(b)) or 4 (quadrature; Fig. 5(c)) per channel. Series and parallel associations are done thanks to the "regulator" (Fig. 7) compatibility. One output powers a maximum of 4 devices simultaneously. These do not include two actuators (primary & redundant) from the same release unit. In the quadrature configuration the Z-diodes provide power to release unit connected in series. After actuation of the fuse wire (open circuit) the Z-diode closes the electrical circuit in reverse mode. For the GK3 SA, total number of actuation commands can be reduced drastically to 8 (6 for partial deployment and 2 for full deployment) in case of parallel and quadrature configurations. The pyrotechnic converter design (Fig. 7) is compatible with each of the following two configurations with same arrangement for primary and redundant lines:

- 4 fuse wires in quadrature configuration (fuses of 4 different HD points), or
- 2 fuse wires in parallel configuration (fuses of 2 different HD points).
- Note: For the actuation of a single configuration, the Z-diode is not required and has not to be used by bypass (simple means to contact pins 6 & 9 in Fig. 5 (a) at S/C harness side). For the actuation of a parallel configuration, the Z-diode is not required but used for an identical connector I/F with quadrature configuration.

3. Pyrotechnic Firing Circuit Description

The fundamental requirement of the pyrotechnically energized function is that it must occur reliably when correct commanded at correct time and must not occur under any other circumstances[20]. Much more severe safety requirements apply for firing of the pyrotechnic[20]. Three inhibiting switches are required to isolate the initiator until firing is imminent, and afterwards to prevent a drain on the power supply system due to a short circuit to ground potential, which frequently occurs in initiators[20].

Acceptance All-Fire current is 3.5 A for the NSI(NASA Standard Initiator)-type EED(Electro Explosive Device)[18]. The engineer may then place an additional margin on both the current ***level*** and the ***time*** the current[21]. System All-Fire current levels of 5.0 A to 7.0 A is commonly used[18]. At constant firing current of 3.5 A, the standard deviation is relatively large but it reduces to a less extent at 5.0 A as one often observed in test firing[18]. Thus, an adequate margin for system reliability is ensured[21].

The command chains of the GK3 pyrotechnic firing circuit is shown in Fig. 6 for the primary board only[22]. The pyrotechnic firing circuit is qualified already at the GK2 program. Each pyrotechnic board includes a reliable pyrotechnic converter and a switch network[22]. The architecture of switch network is based on group allocation and 4 serial safety barriers (a pre-arm, group arm and fire switches, and a pyrotechnic converter)[22]. The EED channels (13 primary and 13 redundant) are dedicated to standard pyrotechnic devices[22]. The Kevlar channels (7 primary and 7 redundant) are dedicated to Kevlar cutters or more generally to heating devices for release mechanism[22]. The SA release devices and MGU motors are actuated by the Kevlar channels[22].

A reliable pyrotechnic converter consists of a "regulator" and a "breaker" as shown in Fig. 7[22]. The current limit amplifier and the voltage sensing error amplifier in regulator are tied at the PWM(Pulse Width Modulation) comparator input with a priority for current detection[22]. The pyrotechnic converter controls the voltage and current levels seen by switches whatever failures[22]. The breaker protects output overcurrent and overvoltage[22].

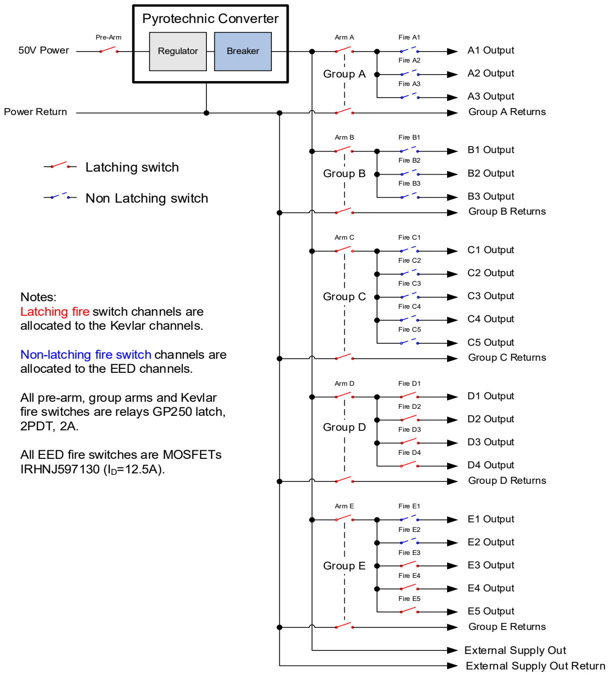


Fig. 6 Command chains of pyrotechnic firing circuit[22]

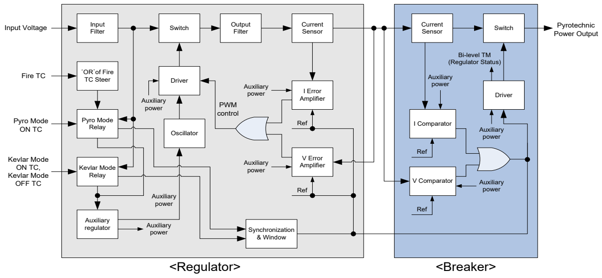


Fig. 7 Block diagram of pyrotechnic converter consists of a regulator and a breaker[22]

Table 1 shows output characteristics of pyrotechnic converter[22]. The pyrotechnic converter automatically operates a current limit of 6 A or a voltage regulation of 21 V with priority of current limit[22]. The pyrotechnic converter operates a current limit when the equivalent impedance including S/C harness and initiator or actuator device is ≤3.5 Ω (i.e. 21 V / 6 A), and a voltage regulation when the equivalent impedance is >3.5 Ω. The pyrotechnic converter operates two modes, EED and Kevlar, implemented in hardware and can't be changed between two modes[22]. Output pulse duration is fixed to 35 ms by hardware for the EED channel, and can be adjustable through 100 ms steps from external commands for the Kevlar channel[22]. The pyrotechnic converter protects nominal output overcurrent of 7.5 A and overvoltage of 27.5 V[22].

Table 1 Output characteristics of pyrotechnic converter[22]

Current limit	6 A ±1 A
Voltage regulation	21 V ±1 V
Pulse duration	EED channel: Fixed to 35 ms ±3 ms, Kevlar channel: adjustable through 100 ms steps.
Priority (current limit vs. voltage regulation)	Current limit
Overcurrent protection	Set to 7.5 A nominal
Overvoltage protection	Set to 27.5 V nominal

4. Hot Firing Test

4.1. Test Set-up

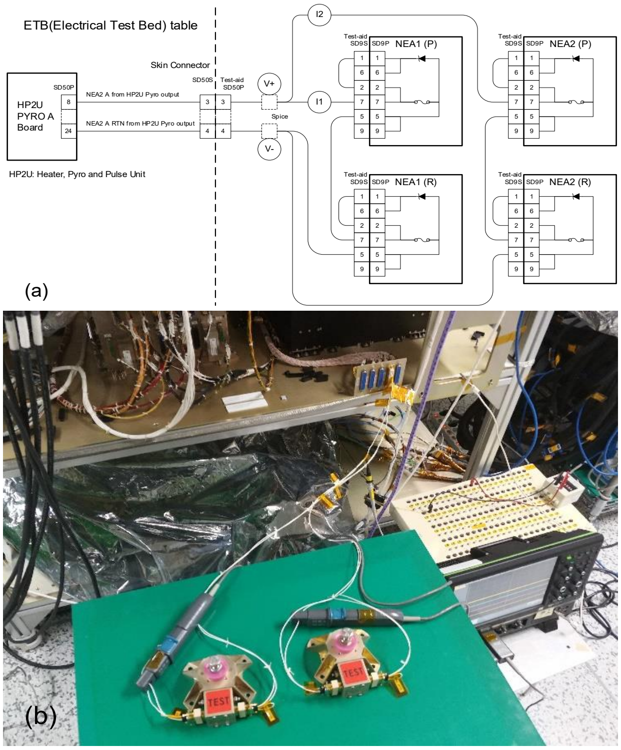


Fig. 8 Hot firing test set-up (a) diagram and (b) photo

Hot firing test performed only a quadrature NEA configuration, which is worst case, due to available test NEAs are limited. Hot firing test set-up of a quadrature NEA9103S1 configuration is shown in Fig. 8. To minimize the number of NEA units to test, a quadrature NEA configuration consists of two actuators in each half from the same release unit(test NEA1 P-R and test NEA2 P-R respectively). Two devices (primary & redundant) from the same release unit in each half are used for test purpose only. In flight configuration, a quadrature NEA configuration shall not include two actuators from the same release unit. A quadrature NEA is configured exterior ETB table by a test-aid cable. All NEA release units are operated simultaneously by one power output from HP2U Pyro. A common voltage (V) is measured on just exterior ETB table and two currents (I_1 and I_2) are measured in each half cables as shown in Fig. 8 (a). Measuring equipments used to hot firing test are an oscilloscope (Lecroy 6054, 500 MHz BW(bandwidth)), a voltage probe (Lecroy AP016, 100 MHz BW) and two current probes (Lecroy AP015, 50 MHz BW).

4.2. Hot Firing Test Results

Hot firing test results are shown in Fig. 9 and summarized in Table 2. Two measured currents are added (I_1 + I_2) in Fig. 9 (a). The equivalent resistance for exterior ETB table as shown in Fig. 9 (b) is calculated as Eq. (1).

$$Z_1 \,//\, Z_2 = \left(\frac{V}{I_1}\right) // \left(\frac{V}{I_2}\right) \qquad (1)$$

where $Z_{1/2}$ are impedances calculated in each half of two serial NEAs, V is a common voltage measured (Fig. 8 (a) and $I_{1/2}$ are currents measured in each half cables (Fig. 8 (a).

At 0 ms, HP2U Pyro converter starts CC(Constant Current) supply of about 6.1 A. Before any NEA fuse has blown up, current of each half is almost the same and voltage increases by taking a positive TCR(Temperature Coefficient of Resistivity) both the harness cable material and the NEA fuse wire material. The impedance rise with temperature at actuation was characterized to voltage increase (Fig. 9 (b)) under an electrical CC.

At 25.82 ms, the first NEA fuse has blown up and the current of I_2 decreases due to effect of the Z-diode impedance, which will be discussed later in paragraph 4.4. It flows as a consequence that the current of I_1 increases due to the HP2U Pyro converter control with CC about 6.1 A.

At 27.46 ms, the current of I_2 increases due to the Z-diode impedance connected to the first NEA fuse blown up is low driven into its reverse breakdown avalanche mode of operation. As a consequence, the current of I_1 decreases by the HP2U Pyro converter control with CC. After the first NEA fuse has blown up, both current difference of each half and voltage increase by two effects (1. Z-diode impedance connected to the first NEA fuse blown up, 2. NEA fuse impedances not yet blown up).

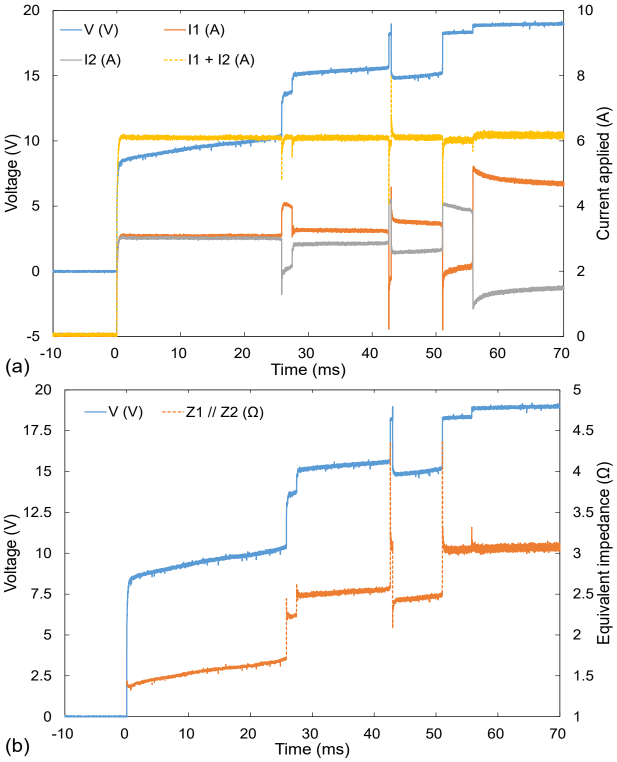


Fig. 9 Hot firing test results: (a) voltage and current applied, (b) voltage and equivalent impedance

Table 2 Hot firing test results summary

Time [ms]	Firing No.	Pyro converter*	Energy [A^2sec]	Event Description
0	-	CC	-	Current supply start.
25.82	1	CC	0.234 (other half)	First NEA fired. The Zener impedance is high.
27.46	-	CC	-	The Zener impedance of first NEA fired is low.
42.62	2	CV	0.431 (one half)	Second NEA fired. Pyro converter changed to CV control.
42.98	-	CC	-	Pyro converter recovered to CC control.
51.03	3	CC	0.531 (one half)	Third NEA fired. Pyro converter changed to CC control immediately.
55.77	4	CC	0.498 (other half)	Fourth NEA fired.

* CC: Constant Current, CV: Constant Voltage

At 42.62 ms, the second NEA fuse has blown up and the current of I_1 decreases due to effect of the Z-diode impedance with high. HP2U Pyro converter changed to CV(Constant Voltage) control from CC due to equivalent resistance (Fig. 9 (b)) >3.5 Ω. During the second NEA fuse blown up transient, the voltage recorded to 18.2 V. Other voltage drop will be about 2.8 V (i.e. 21 V - 18.2 V) on the interior ETB cable. During the transient, total current is slightly lower than 6.1 A.

At 42.98 ms, HP2U Pyro converter recovered to CC control from CV due to equivalent resistance (Fig. 9 (b)) ≤3.5 Ω by the Z-diode impedance connected to the second NEA fuse blown up is low driven into its reverse breakdown avalanche mode of operation. Voltage decreased shortly and then total current remains about 6.1 A. HP2U Pyro converter with CV control stay on about 360 μs (42.62 ms to 42.98 ms).

At 51.03 ms, the third NEA fuse has blown up and the current of I_1 decreases. Although the equivalent resistance momentarily changed to >3.5 Ω, HP2U Pyro converter changed to CC control immediately due to its switching frequency of 100 kHz.

At 55.77 ms, the fourth NEA fuse has blown up and the current of I_2 decreases. After all NEA fuses have blown up the voltage is clamped to average 19.0 V by two series Z-diodes driven into its reverse breakdown avalanche mode of operation. HP2U Pyro converter stayed on CC control due to equivalent resistance (Fig. 9 (b)) ≤3.5 Ω.

4.3. Determination of Actuation Pulse Duration

Thermal energy (I^2t) integration calculated of each half during the hot firing test is shown in Fig. 10. Two calculated thermal energies are added (E_1 + E_2) in Fig. 10. The actuation thermal energy, at ambient condition, to fire two series NEAs of each half is about:

- One half (current I_1 in Fig. 9 (a)): 0.431 A^2sec (firing no. 2 at 42.62 ms), **0.531 A^2sec** (firing no. 3 at 51.03 ms).
- The other half (current I_2 in Fig. 9 (a)): 0.234 A^2sec (firing no. 1 at 25.82 ms), **0.498 A^2sec** (firing no. 4 at 55.77 ms).
- Note: Actuation thermal energy (E_1 + E_2) is 1.03 A^2sec up to all fuse wires have blown up.

Actuation thermal energy difference (0.531 A^2sec versus 0.498 A^2sec) is about 6.6% between each half to fire two serial NEAs. The value of 6.6% shows a good balance in terms of the fuse wire resistances and the mechanical loads of NEA.

The pyrotechnic subsystem requires minimum thermal energy margin of 4 at ambient condition. The thermal energy margin may be >2 at worst case cold temperature if thermal energy margin is minimum 4 at ambient condition. The worst case minimum current supply from HP2U output to a half of quadrature NEA configuration is 2.5 A (i.e. half of 5 A from a current limit characteristic of 6 A ±1 A). Hence, the actuation pulse duration of 500 ms from HP2U output can meet margin requirement for thermal energy of minimum 4: margin of **5.9** (3.125 A^2sec / 0.531 A^2sec) at one half and 6.3 (3.125 A^2sec / 0.498 A^2sec) at the other half respectively for the supply energy of 3.125 A^2sec ($(2.5\ A)^2 * 500$ ms) from HP2U output.

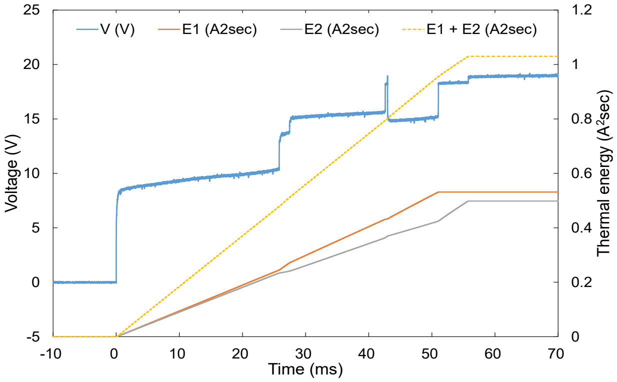


Fig. 10 Hot firing test voltage and thermal energy

4.4. Zener Impedance Measurement

A Z-diode is operated in reverse bias for nominal voltage regulation[23]. When sufficient reverse voltage is applied (cathode end biased positively), the Zener is driven into its reverse breakdown avalanche mode of operation[23]. The initial transition into avalanche breakdown is called the "knee" region of the Zener[23]. Typically, the Zener dynamic impedance (Z_Z) decreases with increasing Zener current on a log-log scale plot[24]. This is applicable only for operating currents in the linear operating region[24]. In the knee region, the breakdown or avalanche current does not increase suddenly, but consists of a series of smoothly rising currents versus voltage increments each with a sudden break point[25]. The Zener impedance always decreases as current increases, although at very high currents (usually beyond I_Z max) the impedance will approach a constant[25]. In contrast, the Zener impedance decreases very rapidly with increasing current in the knee region[25]. Between two points (I_{ZT} and I_{ZK}) a plot of impedance versus current on a log-log scale is close to a straight line[25].

All fuse wires are open circuit after hot firing test. One output powers once again to a quadrature NEA9103S1 configuration to check Zener impedance of each half depend on current applied and understand the effect of Zener impedance. The Zener impedance measured in each half during HP2U Pyro converter operation is shown in Fig. 11 with a linear-linear and a log-log scales. Each half resistance is calculated using a common voltage (V) and currents (I_1 and I_2) measured in each half cables. And then Zener impedance in each half is sorted in ascending order to the current applied to each half. The Zener impedance of each half on a linear-linear scale plot (Fig. 10 (a)) is high and low when Zener current applied is less than (non-conducting region, between 0 V and V_Z) and greater than (Zener control region, $\geq V_Z$) the knee region respectively. The Zener impedance of each half on a log-log scale plot (Fig. 10 (b)) decreases close to a straight line with increasing Zener current. After all fuse wires are open circuit through hot firing test, two series Z-diode impedances in each half depend on current applied have equivalent characteristics.

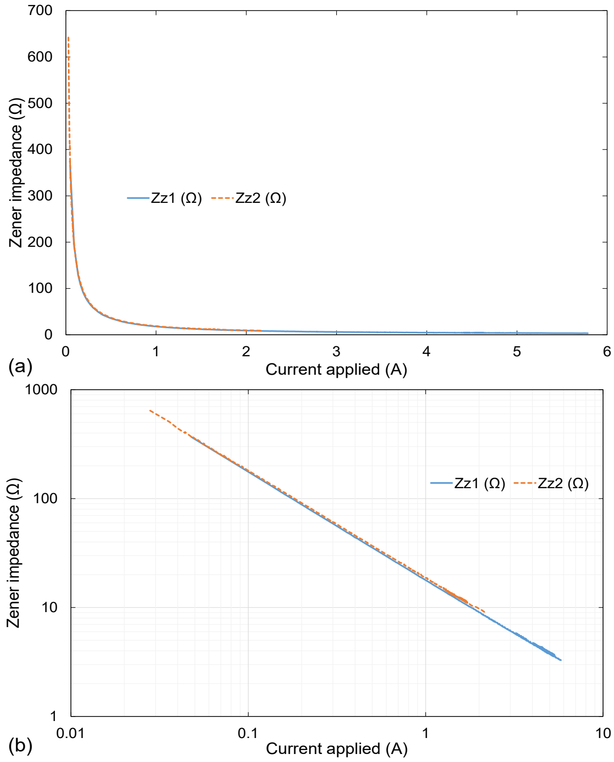


Fig. 11 Zener impedance of each half depend on current applied in (a) linear-linear and (b) log-log scales

5. Conclusions

The hot firing test of a quadrature NEA SSD9103S1 configuration has been performed on ETB at ambient condition. The hot firing test shows successful and all useful data has gathered. The hot firing test results are summarized:

- One output from HP2U Pyro powers a maximum of 4 NEA SSD9103S1 units simultaneously.
- Actuation thermal energy difference, I^2t integration, is about 6.6% between each half of two fired NEAs in series. The value of 6.6% shows a good balance in terms of the fuse wire resistances and the mechanical loads of the units.
- Thermal energy, I^2t, margin at a worst case minimum current supply of 2.5 A (i.e. half of 5 A from HP2U output current limit characteristic of 6 A ±1 A) for a half of a quadrature NEA configuration is minimum 5.9 in case of an actuation pulse duration of 500 ms.
- After all fuse wires are open circuit through hot firing test, the impedance depending on current of two Z-diodes in series in each half has equivalent characteristics.

The GK3 SA consists of 2 wings and 6 HD points per panel. In case of single NEA configuration, total number of actuation commands are 24 (12 primary and 12 redundant) and it impacts the existing HP2U Pyro design (7 primary and 7 redundant in Kevlar channel). In case of parallel and quadrature configurations, total number of actuation commands reduce drastically to 8 (4 primary and 4 redundant) and it can be accommodated by the existing HP2U Pyro design without any impact. Actuation pulse of minimum 500 ms will be used to release the GK3 NEA units in both quadrature and parallel configurations.

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