NASA/TM–2013-217997

Guidelines of the Design of Electropyrotechnic Firing Circuit for Unmanned Flight and Ground Test Projects

Guillermo A. Gonzalez, Melvin H. Lucy, and Jeffrey J. Massie
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May 2013

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Acknowledgments

The authors will like to knowledge Arthur T. Bradley, PhD for his guidance in the content and redaction of this technical memorandum.

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1. Introduction

The NASA Langley Research Center, Engineering Directorate, Electronic System Branch, is responsible for providing pyrotechnic support capabilities to Langley Research Center unmanned flight and ground test projects. These capabilities include device selection, procurement, testing, problem solving, firing system design, fabrication and testing; ground support equipment design, fabrication and testing; checkout procedures and procedure‟s training for pyro technicians.

2. Scope

The following technical memorandum will serve as a guideline for the design, fabrication and testing of electropyrotechnic firing systems. The guidelines will discuss the entire process beginning with the project scope‟s definition phase and ending with development and execution phases. In this document the following projects will be used as examples to illustrate the guidelines: F/A-18 A/E Drop Model Program, Inflatable Reentry Vehicle (IRVE), and Structural Passive Landing Attenuation for Survivability of Human-crew (SPLASH).

Figure 1: F/A-18 E/F Drop Model

Figure 2: Inflatable Reentry Experiment Vehicle Concept

Figure 3: SPLASH Test

3. Objectives

The primary objective of this technical memorandum is to capture the design phases, from concept to flight.

The secondary objective is to serve as a guideline for future electropyrotechnic firing circuit designers.

4. Definitions

The following definitions [1] are associated with current NASA Langley Research Center (LaRC) operations.

Arm / Disarm (A/D) Device	An electrically or mechanically actuated switch that can make or break one or more electroexplosive firing circuits. A/D devices do not physically interrupt the explosive train. There are A/D units which actually interrupt or block the explosive train, but are not currently used at NASA LaRC.
Arm Plug	A plug that makes the firing circuit continuous when inserted in a connector.
Bonding	The permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity and the capacity to conduct safely any current likely to be imposed. The purpose of the bonding is to establish an effective path for current that, in turn, facilitates the operation of the over current protective device.
Bridgewire	A resistive element within the electroexplosive device which is the final electrical element at the electrical/explosive interface.
Catastrophic Hazard	A hazard that has the potential for personnel fatality, loss of launch site facilities, or loss of reusable or manned launch vehicles.
Critical Hazard	A hazard that has the potential for personnel injury, damage to launch facilities, or damage to reusable or manned launch vehicles.
Duding	The process of permanently degrading an electroexplosive device to a state where it cannot perform

	its designated function.
Electroexplosive Device (EED)	The first device in an explosive train which is designed to transform an electrical stimulus into an explosive reaction. Detonators, electrical matches, squibs, exploding bridge wires (EBW) devices, NASA Standard Initiator (NSI), explosive bolts, cable cutters are examples of electroexplosive devices (EED). They are also known as pyros.
Electromagnetic Environment	The electromagnetic energy (radiated or conducted) to which the electroexplosive subsystem will be subjected.
Faraday Cage	Also called Faraday screen or Faraday shield. A network of parallel wires connected to a common conductor at one end to provide electrostatic shielding without affecting electromagnetic waves. The common conductor is usually grounded.
Firing Circuit	A circuit that is composed of the firing source circuit, the firing output circuit, the firing control circuit and the monitor circuit. (See Typical Firing Circuit Diagram, Figure 4)
Grounding [2]	The intentional connection of a current-carrying conductor to ground or other electrically conductive material likely to become energized to create a permanent, low impedance circuit capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point in the wiring system where ground fault may occur to the electrical supply source.
Maximum No-Fire Level	The maximum direct current (DC) or Radio frequency (RF) level at which an electroexplosive device shall not fire with a probability of 0.999 at confidence level of 95 percent.
Minimum All-Fire Level	The least DC current which causes initiation with a probability of 0.999 at a confidence level of 95 percent.
Monitor Circuit	Part of the electroexplosive subsystem which indicates the status of the firing circuit.
NASA Standard Initiator	A 2 pin electrically activated, hot-wire, electro-explosive device designed and initially qualified as the Single Bridgewire Apollo Standard Initiator (SBASI) to meet the requirements of the APOLLO LUNAR MISSION. It was subsequently adopted and standardized for use on the NASA Space Shuttle System, payloads and other NASA-sponsored programs as the NASA Standard Initiator (NSI) [3]. Its function is to translate an electrical stimulus into the production of flame, pressure, and hot particles to ignite or initiate a pyrotechnic action or train. It is used alone or incorporated into higher level devices in various systems associated with the spacecraft's mission. See Section 5.3.15 for more information.
Optical Coverage	The percentage of the surface area of the cable core insulation covered by a shield.
Safe and Arm Device	These devices provide for a) mechanical interruption (safe) or alignment (arm) of the explosive train, b) electrical interruption (safe) or connections (arm) of the firing circuits, and c) shorting and grounding of the EED

	leads in the safe mode. See Section 5.3.25 for examples.
Safe Plug	A plug that shorts EED pins together and connects to ground through a resistor which provides electromagnetic and electrostatic protection as appropriate. Safe plugs, by definition, are used in conjunction with Arm Plugs.
Safe/Arm Plug	Safe/Arm plug is a single plug which when installed works as an Arm plug and when removed, built-in features of the firing circuit perform the same function as a Safe plug.
Safety Device	A device which by interruption of the firing circuits or explosive train is intended to prevent the inadvertent ignition of any explosive device prior to its intended operation. The following are examples of safety devices: safe and arm devices, safe/arm plugs, arm/disarm devices, switches and relays.
Safety Shorting Plug	A single plug that when installed shorts all of the EED pins to prevent inadvert firing it.
Shielding Cap	A solid metal outer shell which makes electrical contact with the EED case in the same manner as the mating connector for the EED. It is attached during storage, handling, transporting, and installation.
Single Point Ground	A feature of a power distribution network wherein each conductively isolated segment (i.e., transformer-coupled or supplied from a separate source) of the distribution network has only one physical connection to ground. A 1MΩ resistor placed between a circuit segment and ground does not violate the single point ground concept.
Solid State Relay	A semiconductor device with isolated input and output which operates by means of electronic components and without moving parts. Its primary function is to open and close electrical circuits in response to electrical controlling signals to effect the operation of other devices in the same or other electrical circuits.
Static Bleed Resistor	Resistors which are placed between firing circuits and ground to prevent built-up of static electricity on circuits.
Switches and Relays	These devices open or close circuits when acted upon by external stimuli such as electrical signal, physical force, material proximity, etc. These devices are normally contained in safety devices, but may be used independently for making or breaking (interrupting) the firing circuit. Switches and relays may be electromechanical or solid state.

5. Design Approach

There are three phases in the design of electropyrotechnic firing circuits. Each phase should be completed before commencing the next. Phases I and II should not be omitted due to schedule constrains. Omitting Phases I and II will eventually result in cost overruns, schedule delay and a poor design.

5.1. Phase I – Scope of the Product

Phase I is an important phase of product development. When properly executed, it prevents cost and schedule overruns. During this phase, the designer must meet frequently with the Project Manager and Principal Engineer for the purpose of defining the project needs, goals and objectives. The project needs are associated with the Agency or Nation needs. The goals and objectives flow down from the needs, and are associated with what the product will do and how it will develop [4]. In addition, a high level operational concept and interfaces must be defined during this phase. For projects like the aircraft Drop Model Program and IRVE need to define, the needs, goals and objectives could also be found in the project‟s documentation. For other projects like SPLASH‟s need to define, the information could be obtained from the Principal Investigator and / or Project Manager. Also, during this phase, it is important to identify critical items, the quantity needed, and the product expected delivery date. Critical items example are the Electro Explosive Devices, materials, equipment and any other hardware needed for the completion of the project. The expected delivery date will help the designer with procurements strategy, design drawing release, fabrication, procedure writing, testing and end user‟s training. It is imperative that all requirements and other criteria be documented in an official project document to serve as reference point for the design.

5.1.1. Overall Operational Concept

The term operational concept is used to denote a high level description of the product‟s day of operations. The description is essential in the development of requirements. For example, in the case of SPLASH, the operational concept included the following:

- Hook up the test article to release cables, activate electropyrotechnic firing box and lift it to the drop altitude point.
- Sever capsule‟s pull back cables once it‟s reached a pre-determined drop point.
- Activate frangible bolts to release the capsule at pre-determined release point.
- Release capsule
- Deactivate electropyrotechnic firing box
- Recover the capsule.

A more elaborated and complex example of an overall operational concept is the aircraft Drop Model. The following was the operational concept:

- Attached aircraft drop model to the belly of the helicopter.
- Activate electropyrotechnic firing boxes
- Have the helicopter climb to release altitude point.

- Release the model from helicopter‟s Zero Impulse Bolt (ZIB) attachment point.
- Wait 10 seconds to arm model‟s electronics‟ power, and activate smoke generators.
- Fly the model remotely.
- Upon completion of test flight, deploy main parachute using a mortar.
- Upon water landing use Sea Water Release System (SEAWARS) switch to (a) Cut parachute lines, (b) activate flotation system and (c) Cut power in model.
- Recover the model.

5.1.2. Interface Definition

It is important to define early on, the external and internal interfaces of the end product. Identifying these interfaces will clarify the product scope [4]. All identified interfaces must be documented to prevent design oversights.

5.1.3. External Interface

Identifying external interfaces early helps to clarify the product scope, aid in risk assessment, reduce product development costs, and improve customer satisfaction [4]. The designer lead, must identify the end product needs, including power supplies, batteries, battery chargers/cyclers, electrical ground support equipment, data acquisition systems, transmitters, antennas, receivers, and any other electronic equipment / tools. Mechanical interfaces must be identified, as well. This includes, but is not limited to, enclosures, boxes, brackets, pull pins and/or safety shorting pins.

5.1.4. Internal Interface

As the design moves forward, internal Interfaces need to be identified. In order to avoid schedule delays, internal interfaces that require a lengthy procurement lead time must be identified early in the design phase. After initial discussions with the project, the designer must initiate the necessary hazards permit request to begin the process per NASA Langley Research Center Directive LPR 1710.7 Handling and use of Explosive.

5.2. Phase II - Requirements, Rationale, Verification and Traceability

Once the designer has identified the need, goals, objectives, concepts of operations, and interfaces, writing the requirements should begin. A well-defined requirement meets the following criteria: necessary, verifiable, and attainable (i.e. technical feasible, within cost and within schedule), and traceable to the goals and objectives of the project. The requirements control the product outcome. This phase should not be omitted in lieu of working on a design. Omitting this phase will lead to requirements creep, cost and schedule overruns.

5.3. Phase III – Design Definition

This phase should start once the requirements, interfaces and operational concepts are well defined and approved.

5.3.1. Firing Circuit Design Safety Requirements

Safety is the most critical consideration when designing a robust electropyrotechnic firing circuit. The firing circuits must meet the following safety requirements:

1. The firing circuit shall have a minimum of two safety inhibits to prevent premature or inadvertent firing.
2. The firing circuits shall have continuous, twisted, shielded wires from the firing circuit end to the ordnance mating connector. The shield shall have 360°shield[1] coverage at the ordnance mating connector.
3. The firing circuits shall have a single point ground.
4. The firing circuits shall have a 1 MΩ bleed resistor between firing return and structure.
5. The firing circuits shall have the correct electrical bond between metallic surfaces.

5.3.2. Other Safety Considerations

1. **Personnel handling pyro devices must be certified.**
2. **The use of the proper safety gear is required when handling the pyro devices.**
   - **This gear consists of safety glasses or face shield, electrostatic discharge (ESD) protective smock, and ground strap.**
3. **The personnel installing, handling, observing, walking around and/or inspecting the EED shall not carry pagers, badges, card keys, cell phones, or other transmitting devices.**
4. Pyrotechnic work activities require the presence of a minimum of two individuals: a pyro lead and a pyro technician.
5. The electronic equipment‟s calibration must be up to date.
6. Storage, assembly and test facilities building ground must be annually certified.
7. The electroexplosive devices (EED) storage cabinets must be grounded to building ground.
8. The operation should be properly safety placarded.

5.3.3. Electrical Ladder Diagram

An electrical ladder diagram is a power bus diagram that shows the connectivity between electronic components from the positive terminal to the return. Figure 4 shows an example of a simplified electrical ladder diagram from SPLASH. The diagram illustrates the main components of the pyrotechnic firing train connected from the power bus positive terminal to the power bus return terminal. The power bus positive terminal is drawn in the left side of the diagram, and the return terminal is in the far right of the diagram. The simplified diagram aids in following the firing train of the pyro device. When multiple EED are illustrated, one must follow the concept of operations in order to understand the sequential firing of each EED.

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[1] See Section 5.3.29 Shielding for more details

Figure 5 shows an example of a simplified ladder diagram with the ground support equipment components highlighted.

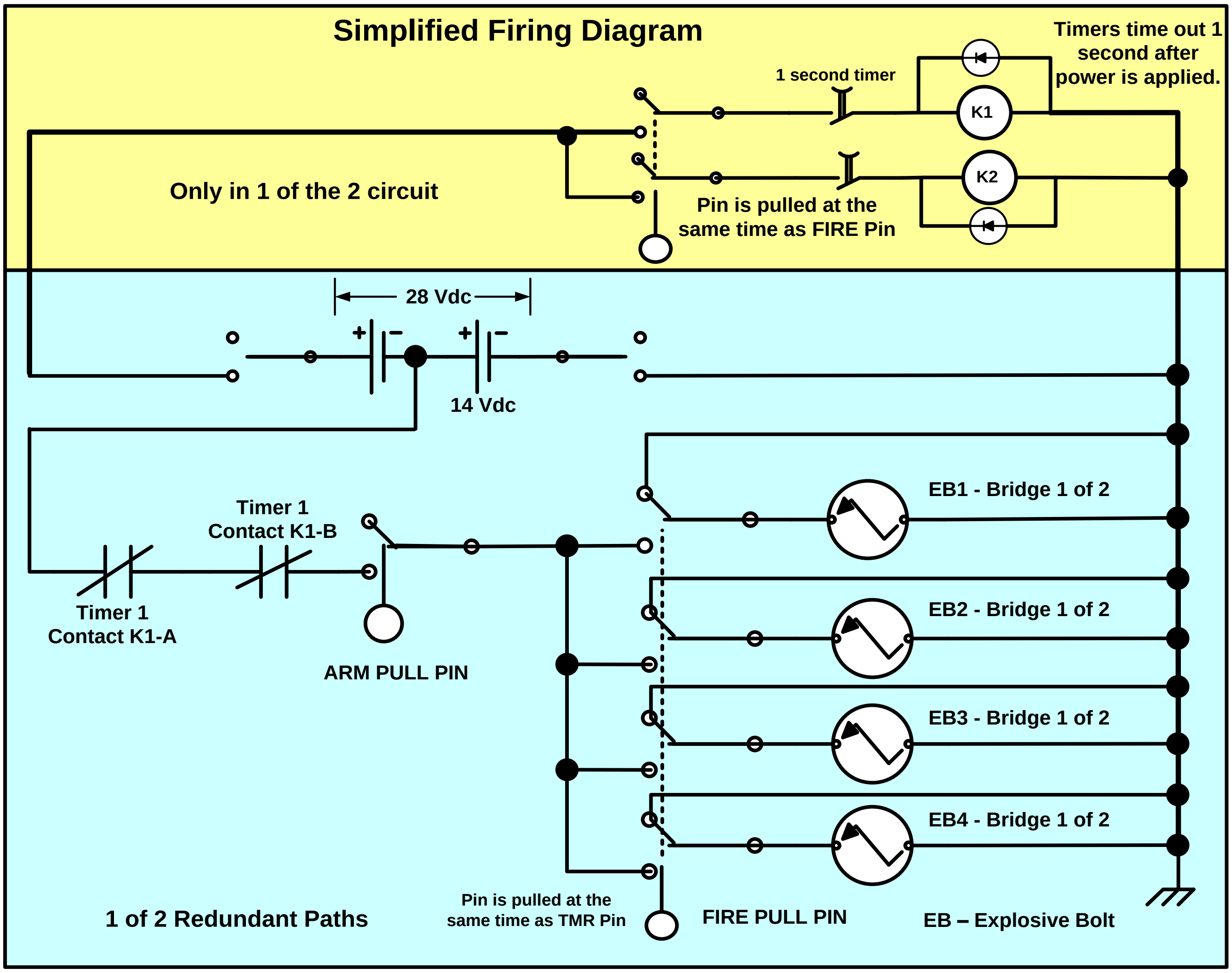

Figure 4: Simplified Electrical Ladder Diagram from SPLASH

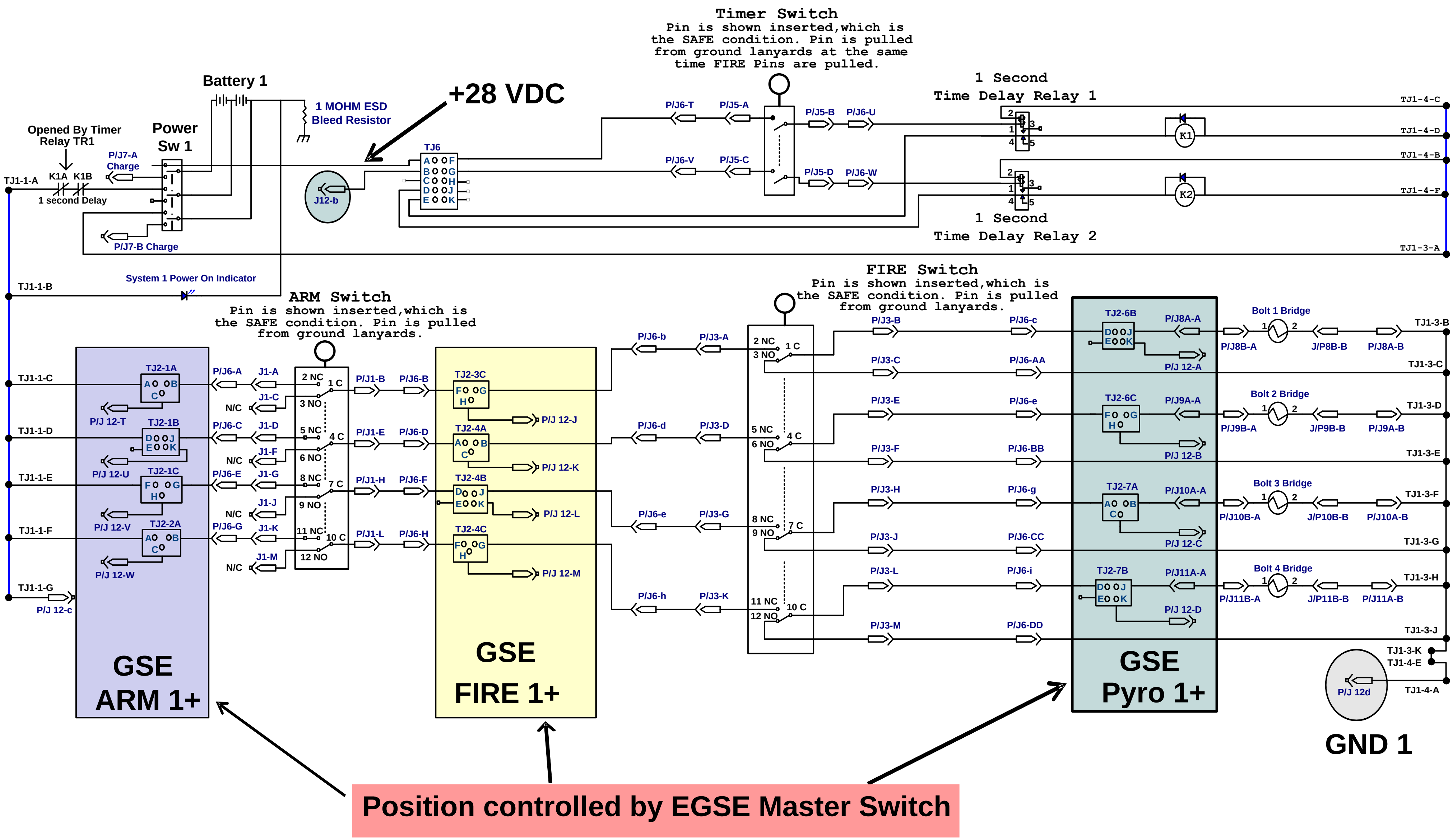

Figure 5: Simplified Ladder Diagram with GSE Markings from SPLASH

5.3.4. Electrical Ground Support Equipment

The design of the Electrical Ground Support Equipment (EGSE) must occur in parallel with the electropyrotechnic firing circuit design. The EGSE will prove to be very useful during ground checks and for troubleshooting purposes. The complexity of the EGSE will depend on the complexity of the design, the quantity of electro explosive devices (EED) needed for the completion of the mission, and the concept of operations. For example, the EGSE for the SPLASH (Figure 6) project is much simpler than the one for the Drop Model Program (see Figures 7 and 8). The EGSE typically performs the following checks: the firing sequence, EED firing test, multipoint checks for resistance, No-Voltage, Continuity, and signal detection.

Figure 6: SPLASH Ground Support Equipment

Figure 7 shows an example of the Drop Model Release EGSE release from the helicopter.

Figure 7: Zero Impulse Bolt EGSE

Figure 8 shows an example of the Drop Model EGSE for checkout of the model‟s pyrotechnic functions.

Figure 8: Drop Model Program EGSE Console

5.3.5. *Electroexplosives Checkout Equipment*

There are several instruments used for the checkout of EEDs and EED firing circuits. Among them are the Amptec 601ES Ordnance Meter (Figure 9), ALINCO Circuit Tester (Figure 10), blasting galvanometers (Figure 11) and pyrotechnic voltmeters (Figure 12).

Figure 9: Amptec 601ES Ordnance Meter

5.3.6. *ALINCO Igniter Tester*

The ALINCO Igniter Circuit Tester was developed by the Allegany Company in 1956, and it‟s currently manufactured by MB Electronics. The model that is used currently at NASA LaRC is a stable, precision instrument designed primarily for the preflight testing of EED bridgewires, specifically used for detecting open or short circuit conditions. The circuit of this instrument is a modified version of the well-known Wheat Stone Bridge. The Wheat Stone Bridge circuit assures the stability and reliability necessary when measuring EED bridgewires resistance.

Figure 10: ALINCO

5.3.7. Blasting Galvanometer

The blasting galvanometer (a.k.a blasting galvo) is used to indicate firing circuit continuity. It also measures the short circuit back through the EED firing circuit. The short enables the EED to remain in a safe configuration by keeping the bridgewire short circuited. Figure 11 shows a blasting galvanometer.

Figure 11: Blasting Galvanometer

5.3.8. Pyrotechnic Voltmeter

The pyrotechnic voltmeter is used to verify there is no AC or DC voltage on the EED firing circuit. This device shall not contain a battery to prevent accidental firing of the EED during checks. The voltmeter must have a label in the front indicating "*PYROTECHNIC USE ONLY*", and another in the battery compartment indicating "*DO NOT INSTALL A BATTERY*". Figure 12 shows a pyrotechnic voltmeter.

Figure 12: Pyrotechnic Voltmeter

5.3.9. Personal Protective Equipment (PPE)

EED and some electronics are designated as electrostatic discharge sensitive, as such; measures to protect personnel against inadvertent firing of the EEDs must take place. Any EED sensitive electronics must be labeled as such. Personal Protective Equipment (PPE) includes as a minimum: a „static dissipative" lab coat or smock, safety glasses or face shield and wrist straps. All PPE must be worn when handling and installing the electro-explosive devices (EED). The wrist strap shall be grounded to the test assembly. The test assembly must be grounded to a common, designated, certified ground system through these procedures. Personnel coming in contact with or within 3 feet of any test equipment must wear a wrist strap and lab coat. Wrist-straps must be checked with a qualified wrist strap tester prior to use. If wrist straps are removed, the check must be repeated. All individuals involved with any operation involving EED"s must be trained to the latest ESD Standard. Any test article consisting of two or more metal sections that are separated shall be bonded electrically with ground straps.

5.3.10. Test Facilities, Pyro Bunkers

The test and pyro bunker facilities must comply with NASA–STD-8719.12 Safety Standard for Explosives, Propellants, and Pyrotechnics and NASA NSS 1740.12 Explosive Safety Manual for Explosives, Propellants, and Pyrotechnics. The facilities usage includes EED storage, EED preparation, and installation into test devices. In the case of the SPLASH project, the facility was used to modify the dual bridge frangible bolts by attachment of an appropriate four pin connector, and to install the devices in the test article release mechanism. For the Drop Model Program, the same facility was used for parachute mortar preparation with the NSI installation, and for mortar testing.

5.3.11. Power

There are several methods to provide the firing energy required to fire electro explosive devices (EED). There are several alternatives for the firing of EEDs; (1) A capacitive discharge bank, or (2) a direct battery connection. The use of a capacitive discharge bank is more complex than using direct power from a battery. The pyrotechnic firing energy source must be supplied independent of the energy source used to power the electronics. The use of a separate battery pack is used to guarantee a fully charged pack to fire the EED.

For the Drop Model Program and SPLASH, nickel cadmium (NICADS) battery packs were used. There are other types of battery chemistry that could be used as well. These other sources, however, shall be capable of providing the instantaneous current spike needed to fire EEDs.

5.3.12. Mechanical Design

The mechanical design aspect for EED systems consists primarily of the EED support brackets, mortar, boxes to house the electronics firing circuit, its mounting brackets and pull pin assemblies. For the Drop Model program, a mortar assembly was designed and fabricated for the release of the main parachute. For SPLASH, a housing assembly was designed and fabricated to house the explosive bolts. The Drop Model Program also contained connector mounting brackets.

5.3.13. Analysis and Simulation

For unmanned testing, the analyses are simplistic in nature, and they consist of calculating the batteries capacities needed to meet requirements. With respect to simulation, one can simulate a day of operation by firing match squibs, NSI simulators, and fuses or by using light bulbs to simulate the EEDs. Figure 13 shows SPLASH NSI Simulator firing set up. In this set up, the OrCAD Software Version 16.0.0 p001 June 5, 2007 program was used to capture the firing signals.

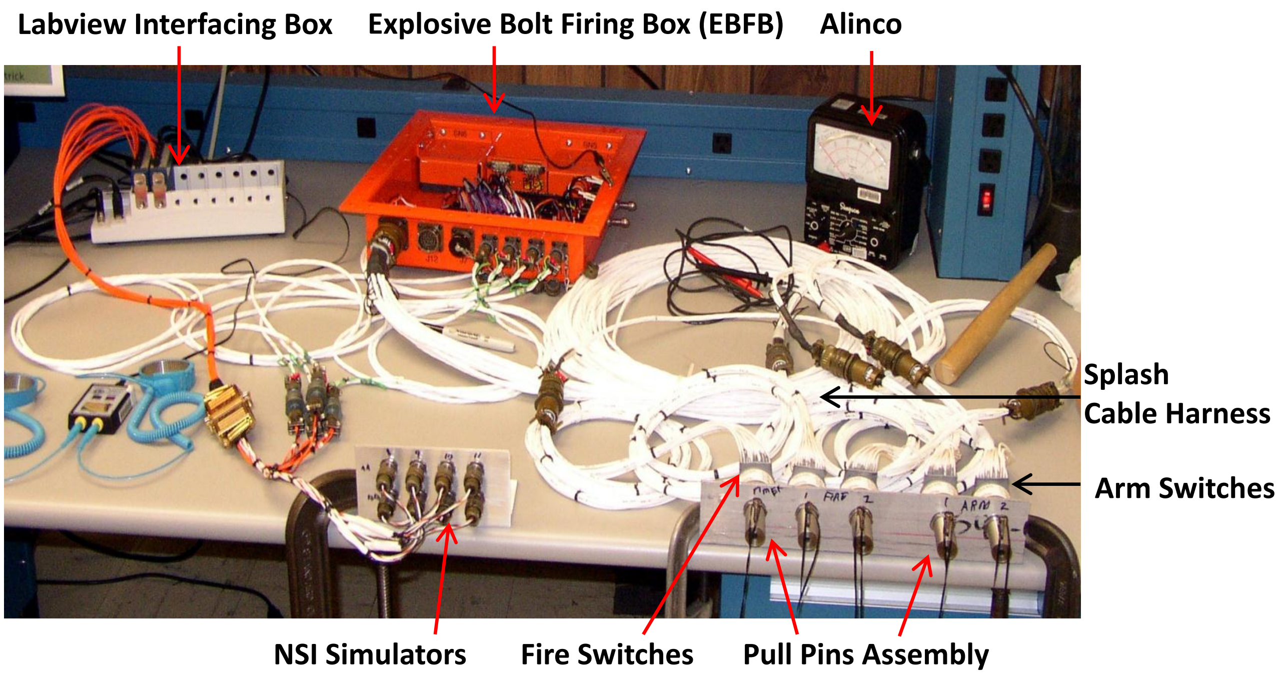

Figure 13: SPLASH NSI Simulator Firing Set Up

5.3.14. Electroexplosive Devices (EED)

The pyrotechnic devices or electro explosive devices (EED) are selected based on the project"s requirements and, are available from various military and space application vendors. Typical devices currently being used are Hollex Cable Cutters, NASA Standard Initiators (NSI) and frangible bolts. These devices incorporate bridgewires that are rated at 1 watt, 1 amp no fire in the initiator. Specifically, the initiator will not ignite when the bridgewire is subjected to a one ampere DC for five minutes or a DC power of one watt for five minutes, within the temperature range of -260°F to +300°F.

5.3.15. NASA Standard Initiators (NSI)

The NASA standard initiator, Type 1, NASA-JSC P/N SEB26100001, is a 2 pin electrically activated, hotwire, electroexplosive device designed and qualified initially as the Single Bridgewire Apollo Standard Initiator (SBASI) to meet the requirements of the APOLLO LUNAR

MISSION [3]. It was subsequently adopted and standardized for use on the NASA Space Shuttle System, payloads and other NASA-sponsored programs as the NASA Standard Initiator (NSI). Its function is to translate an electrical stimulus into the production of flame, pressure and hot particles to ignite or initiate a pyrotechnic action or train. It typically produces 900 psi in a 10 cc closed bomb. It is used alone or incorporated into higher level devices in various systems associated with the spacecraft's mission. It uses a fine particle zirconium fuel mixed with a fine particle potassium perchlorate oxidizer bound together with a viton rubber binder. It features Inconel alloy 718 body construction and hermetic sealing. The NSI can also be hermetically sealed (by welding) to the next component. Other features include high electrostatic sensitivity protection, internal construction designed for severe vibration protection, a high pressure ceramic header, a flush-mounted single stainless steel bridgewire, 1 amp - 1 watt, 5 minute no-fire protection and high and low (cryogenic) temperature performance. Figure 14 shows a picture of an expended NSI.

Figure 14: NASA Standard Initiator

5.3.16. Frangible Bolt

The frangible bolts are pyrotechnic devices having a 1 amp - 1 watt, 5 minute no-fire protection dual bridgewire device. Upon application of current, the bridge wire explosive prime charge is activated, and in turn, activates the main charge that generates a shock wave that exceeds the ultimate strength of the bolt at a predefined break line. For the SPLASH project we used Pacific Scientific P/N 92768 (See Figure 15) rated with an ultimate tensile of 35000 lbs.

Figure 15: Pacific Scientific P/N 92768 Frangible Bolt

5.3.17. Guillotine or Cable Cutter

A guillotine or cable cutter is used to sever cables, tubes and/or electrical wires. When severing electrical wires with a guillotine or cutter, the possibility of electrical shorting during or after operation or both should be considered, and appropriate circuit protection should be provided. Figure 16 illustrates the HOLEX model 5803 cable guillotine used in the SPLASH Project.

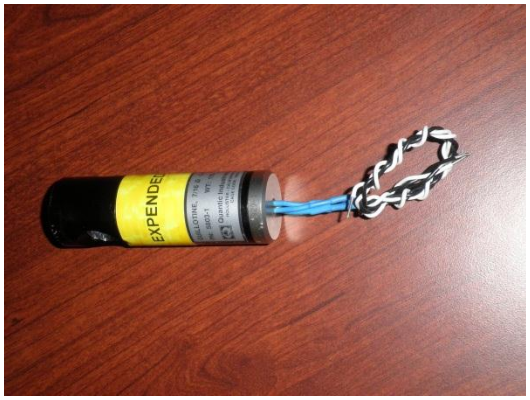

Figure 16: Holex Cable Guillotine

5.3.18. Smoke Generator

Pyro activated smoke generators are sometimes used as an observable signal tool. For the Aircraft Drop Model Program the generators were activated shortly after the model was released from the helicopter. The colored (white, orange, or purple) generated smoke provided a tracking visual to the ground crew. This bridge-wire equipped cartridge was activated with a 5 amps current for 2 milliseconds. When the cartridge was fired, an internal smoke package is initiated to begin ejecting orange smoke which appears 0.5 seconds after initiation and continues until the charge is exhausted.

5.3.19. Parachute Mortar

The parachute mortars are typically used for the deployment of parachutes. For the Drop Model Program, the parachute mortar was designed and tested by NASA Langley engineers. Upon command, the mortar released the parachute compartment hatch, which in turn released the drogue chute which extracted the main parachute. The design contained two (2) NASA Standard Initiators. The mortar circuit was also designed to deploy the chute 10-seconds after release should there be a detected failure of the model"s main internal power source.

5.3.20. Pyro Activated Valve

Pyro valves are critical for engine chill down in launch vehicle propulsion systems and are used for inflation systems. They operate when a firing current is received to either open or close the valve. The initiator ignites a booster charge located within the valve body, driving a cutter downward to either open or close the flow path. Figure 17 shows the pyro valve used for IRVE I project.

Figure 17: IRVE I Pacific Scientific Pyro Valve

5.3.21. Match Squib

The match squib is essentially a small bridgewire covered with a small amount of pyrotechnic material, and when excited with a 1 amp current, it will fire like a match but with minimum flame. The match squib is used in the firing train in lieu of the actual EED during outdoor or bunker functional tests. Figure 18 shows an example of a match squib.

Figure 18: Match Squib Sample

5.3.22. Zero Impulse Bolt (ZIB)

The Zero Impulse Bolt (ZIB) is a ball–lock release mechanism designed and qualified for use in the Minuteman Missile Program by the Air Force. The F/A-18E/F Drop Model Project adopted this release system in order to be able to carry/release larger, heavier models from under the belly of the UH-1H Helicopter that possessed tall landing gear. The ZIB is inserted into a collar that is mounted in the top of the model near its center of gravity. Prior to using the ZIB assembly, LaRC personnel successfully axial load tested it to 4500 lb., and the Air Force had tested it to 5690 lb. Figure 19 illustrate the ZIB interfaced between the F/A-18E/F Drop Model and the UH1 helicopter.

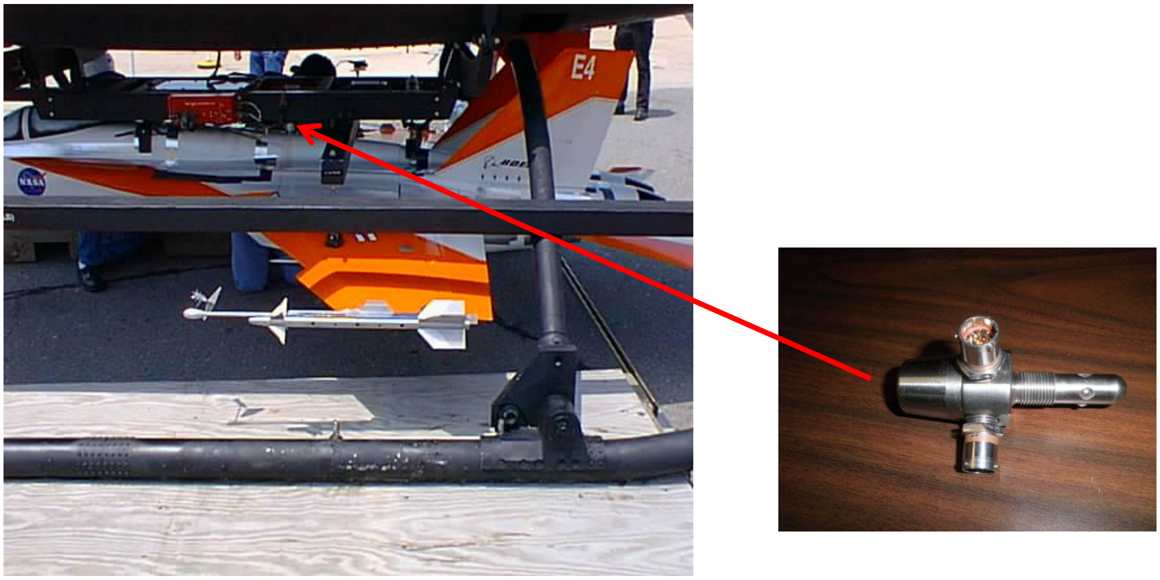

Figure 19: Zero Impulse Bolt / UH-1 Interface

5.3.23. Sea Water Activated Release System (SEAWARS)

The SEAWARS (Figure 20) was used in the Aircraft Drop Model Program. Upon water landing of the aircraft Drop Model, the SEAWARS (Figure 20) with internal battery and exposed switch contacts was activated via water emersion to complete the firing path to (a) Cut parachute lines, (b) activate flotation system and (c) Cut power in model.

Figure 20: SEAWARS

5.3.24. Detonator

A detonator is most commonly used for the detonation of high explosives. It uses filament wire, which is covered with a sensitive ignition mix or prime. The prime will not detonate but ignites a booster charge, which will transfer the deflagration (burning) to a detonation (shock wave advancing ahead of the burning front) which then detonates the main charge or load. The load is sized according to the type of work it needs to perform. This can vary from a simple pressed cylindrical form to a shape charge, which will direct the shock front. A shape charge will normally have an optimum distance from its target where the greatest shock is achieved due to overlapping shock waves. A detonator will be found in a high explosive train. Figure 21 shows an Ensign Bickford electric detonator.

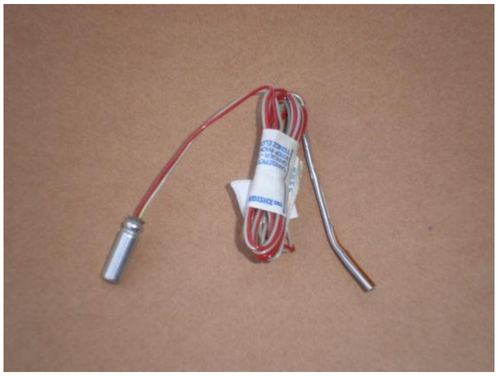

Figure 21: Ensign Bickford Electric Detonator

5.3.25. Safe and Arm Device

The safe and arm device is used to provide a path that can safe and/or arm the pyrotechnic firing train. This device is typically used in launch vehicles. For ground or unmanned testing, controllable relays can be used. Pyrotechnic firing circuits must be designed so circuits are not armed until necessary. Provisions must be made to disarm pyrotechnic devices promptly when no longer needed. Arm and fire must be separate functions that are separately controlled and displayed. Manual arm and fire switches must be physically separate and manned by trained personnel. Figure 22 illustrate a safe and arm device that was used as a developmental device for a future man-rated mission. The device could possibly be used for ground testing projects.

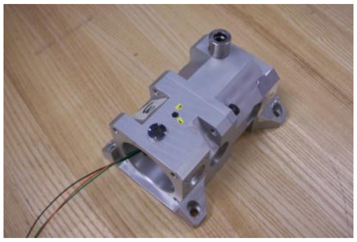

Figure 22: Launch Abort System Safe and Arm Device

5.3.26. Firing Circuit Component Selection

The firing circuit component selection is critical to prevent an overdesign situation. While meeting all of the safety requirements, the circuit components and design must be kept as simple as possible. Complex design will lead to complex verifications and checkouts.

5.3.27. Electrical and Electronics

For typical unmanned / ground projects, it is preferable to use electrical and electronic components that meet military specifications. These components are more reliable and robust than their commercial off the shelf (COTS) counterparts. COTS components are acceptable on a case by case basis. EEE parts far exceed the pedigree required; in addition, they are cost prohibitive for the typical ground test project.

5.3.28. Cables

Electrical cables may be fabricated such that several electroexplosive subsystem circuits are contained in a common shielded cable bundle, provided that shielding and isolation requirements are met. There shall be no splices used to join elements of ordnance cables. A connector shall be provided wherever mating or demating of a circuit is required. All cable runs shall be routed as close to a metal structure as feasible.

5.3.29. Shielding

- The firing circuit, including the EED[2], shall be completely shielded or shielded from the EED back to a point in the firing circuit at which isolators eliminate radio frequency (RF) entry into the shielded portion of the system. Isolators that provide an attenuation of 16.8 dB (regardless of source and load impedances) across all frequencies of the expected electromagnetic environment shall be considered acceptable. The adequacy of the RF protection provided by these isolators can be demonstrated by test or analysis for each specific usage (i.e., the necessary protection is dependent on the configuration of unshielded circuits connected at this point and the expected electromagnetic environment).
- Cable shielding shall provide a minimum of 85 percent optical coverage.
- With the exception of cable shielding, there shall be no gaps or discontinuities in the shielding, including the termination at the back faces of the connectors. Also, there shall be no apertures in any container which houses elements of the firing circuit.
- Shields terminated at a connector shall provide 360 degree continuous shield continuity without gaps.
- Shields shall not be used as intentional current-carrying conductors. Multiple point grounding of shields to structure is recommended.

[2] Some EEDs, for example cable cutters, do not come with twisted shielded wires. Twisting the device pigtail without adding shielding is acceptable for applications delineated in this document.

5.3.30. Crimping and Soldering

EED connections should be made using standard stranded wire techniques. Soldering is not acceptable because it could change the thermal characteristics of the ordnance.

5.3.31. Connectors

All connectors used with the electroexplosive devices shall:

- Be approved by the procuring activity
- Have a stainless steel shell or suitable electrically conductive finish
- Complete the shell-to-shell connection before the pins connect, and provide for 360 degree shield continuity.

5.3.32. Connector Pin Assignment

The circuit assignments and isolation of pins within any EES circuit connector shall be such that any single short circuit occurring as a result of a bent pin or contamination will not result in more than 50 milliamperes or one-tenth of the no-fire current, whichever is less, applied to any electroexplosive device. There shall be only one wire per pin. The use of a connector pin as a terminal or tie-point for multiple connections is prohibited. Any unused pins in the connectors should contain a blank insertion without electrical connections.

5.3.33. Insulation Resistance

All current carrying components and conductors shall be electrically insulated from each other and system ground. The insulation resistance between all insulated parts, at 500 Vdc, minimum, shall be greater than 2 megohms, after exposure to the environment specified herein. (For the NSI, the potential shall not exceed 250Vdc and only one 250Vdc test shall be permitted.)

5.3.34. Wiring

Individually shielded twisted pair of wiring shall be used throughout the firing train. Any grounding of the firing circuits shall be done at one point only. The return path, on all circuits, shall be selected to minimize voltage buildup and transients on the firing circuit return with respect to the single point ground. Ungrounded firing output circuits shall be connected to structure by a 1 MΩ static bleed resistor in the return line. Structural ground shall not be used as return for ordnance circuitry. The source circuits shall terminate in a connector with socket contacts. The design shall preclude sneak circuits and unintentional electrical paths. The return line shall not be connected directly to the vehicle structure and shall be isolated from vehicle direct current (dc) returns through a minimum of 100 kilohms resistance.

5.3.35. Wire Routing

The firing circuit wiring shall be routed separately (in separate trays or conduit) from all other current carrying circuits including electrical power, electrical control, RF transmission lines, and monitoring circuitry. Routing through a single multi-circuit connector does not satisfy this requirement.

5.3.36. Firing Leads

Initiator firing leads shall be configured to prevent incorrect installation.

5.3.37. Grounding

The topic of grounding [4] is a broad subject that deals with establishing a low-impedance reference for one or more electronic systems. For this technical memo, it is defined as a means of referencing electrical circuits to a well-bonded equipotential surface. The electrical circuits must have a single point ground reference.

5.3.38. Electrical Bonding

Electrically initiated pyrotechnic devices or those containing primary explosives shall be designed so that electrical resistance between the metal exterior of the device and the next adjoining device or contact surface, if mechanically joined, shall be 2.5 milliohms or less. Reefing line cutters are exempt from this requirement.

5.3.39. Batteries

The use of commercial off the shelf (COTS) batteries is acceptable as power source components for electronics and/or firing EEDs. Typical chemistry includes Lithium Ion, Lithium gel, Lithium Polymer, and Nickel Cadmium.

With respect to sizing the battery capacity, a good best practice is that it must meet the mission capacity requirement with at least 25% capacity margin.

Unless otherwise specified, typical EEDs are designed to withstand a constant, direct current firing pulse of up to 1 ampere and 1 watt power (minimum) for a period of 5 minutes (minimum) duration without initiation or deterioration of performance (i.e. duding).

Laboratory testing of the EED has shown that typical firing minimum conditions are: an all-fire bridgewire current level of 3.5 amps for 6 milliseconds; or an all-fire voltage level of 6.5 volts across the bridgewire for 6 milliseconds. Therefore, the EED firing battery must be sized accordingly.

5.3.40. Circuit Board and Cable Harness Manufacturing

For the manufacturing of harnesses, circuit boards, enclosures, and support brackets, the latest approved NASA Standards and best practices apply.

5.3.41. Procedures

The number of procedures needed for a successful test campaign is dependent on the design complexity. This should not be a deterrent from having a set of well written procedures. The procedure should be written clearly, and divided in sections. Each procedural step shall contain only one instructional step, written as a complete sentence. Having multiple instructions in one step produces a potential risk of missing a step during the execution of the procedure. Each line of the procedure should have a signoff check point at the end of the sentence. Also, each page of the procedure should have a set of signoff lines for the Operational Safety Supervisor (OSS) and the two pyrotechnic technicians who are running the procedure. Figure 23 shows a sample page of such a procedure.

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5.1.8 At the Bench Test Assembly make the following cable connections:

- 5.1.8.1 Arm Switch 1 Cable, P1 to J1 ________
- 5.1.8.2 Arm Switch 2 Cable, P2 to J2 ________
- 5.1.8.3 Fire Switch Cable 1, P3 to J3 ________
- 5.1.8.4 Fire Switch Cable 2, P4 to J4 ________
- 5.1.8.5 Timer Switch Cable, P5 to J5 ________

5.1.9 At the EBFB make the following connections:

- 5.1.9.1 Pull Pins Harness P6 to EBFB J6 ________
- 5.1.9.2 Explosive Bolt Cable, P8A to J8A ________
- 5.1.9.3 Verify that the EB P/J8B end has the EB Pyro Sim Plug inserted_______
- 5.1.9.4 Explosive Bolt Cable, P9A to J9A ________
- 5.1.9.5 Verify that the EB P/J9B end has the EB Pyro Sim Plug inserted_______
- 5.1.9.6 Explosive Bolt Cable, P10A to J10A ________
- 5.1.9.7 Verify that the EB P/J10B end has the EB Pyro Sim Plug inserted. ______
- 5.1.9.8 Explosive Bolt Cable, P11A to J11A ________
- 5.1.9.9 Verify that the EB P/J11B end has the EB Pyro Sim Plug inserted. ______
- 5.1.9.10 Verify that battery charging receptacle J7 contains the dust cap. _____
- 5.1.9.11 Remove dust cap from J12 and connect GSE cable P12. ________
- 5.1.9.12 At the GSE, connect P112 to J112. ________

Pyrotechnic Technician – Lead	Pyrotechnic Technician I	Operational Safety Supervisor	Date

Figure 23: Test Procedure Sample Page

There are several types of checkout procedures required during the build-up of a project. These include but are not limited to pyro assembly build-up, simulation test procedure, and / or test verification procedures.

5.3.42. Procedure Check Sequence

There is a sequence of procedural steps that must be followed to ensure that the firing circuits are safe both before and after installation of the EED. Prior to commencing the checkout procedure, the battery must be fully charged and tested with a 2 minute load test. This simple test will demonstrate that the energy source is capable of completing the upcoming test. The steps start with the verification that the electroexplosive checkout equipment has its calibration up to date followed by a confidence check of the ALINCO and blasting galvanometer. The subsequent steps are as follows: no-volts check, resistance measurement, functional check, post-functional no-volt checks, EED installation and EED firing path check.

The first no-volts check is done to make sure that there is no stray DC or AC voltage in the firing circuits. The resistance measurement is done to make sure that the firing path impedance has not changed. The measurement is compared against the baseline measurement that was taken after all harnesses and circuits have been fabricated. The functional check consists of a simulated firing sequence test. Fast blow fuses, circuit breakers, match squibs, NSI simulators, or light bulbs could be used in lieu of the EED. The purpose of the functional test is to make sure that the entire firing circuit is ready for the test. After completion of the functional test, a no-volts check followed by a resistance check must be repeated to make sure that the EED can be installed safely. After installing the EED, the firing path resistance must be measured to verify that a full path to the EED exists. In order to prevent an inadvertent firing, it is imperative to make the resistance measurement with the firing circuit power source disconnected. The resistance measurement will be compared against the baseline measurement.

5.3.43. RF Silence

Prior to the installation of EEDs, all types of RF transmission must be stopped. This includes walkie-talkies, cell phones, electronic badges, pagers, and PA systems. The rationale for having RF silence during the EED installation is to prevent misfiring due to unwanted signals.

5.3.44. Test Points

The firing circuit design should have test points. These test points are brought out through the electrical ground support equipment (EGSE) connector. The locations of the test points are strategically selected from the firing circuit path and include the positive and return power bus lines, Safe and Arm contacts, and the EED elements.

5.3.45. Verification

The requirements verification is typically done throughout the build-up phase of the project. The verification process starts with the Preliminary Design Review, and it is completed at the test “dress rehearsal”.

5.3.46. Day of Test Procedure

The Day of Test Procedure contains various phases, and it is typically controlled by the Test Director and a Master Test Procedure. For the EEDs, this procedure contains a wiring harness integrity check, no volts checks, firing circuit no-volts check, firing circuit resistance measurements, functional checks and EED installations, test sequence, and posttest operations.

5.3.47. Other Procedures and/or Documents

Throughout the life of the project, there is a possibility that build up procedures are required. For instance, in the case of SPLASH, a procedure was written for the installation of connectors to the frangible bolt bridge wires. Another procedure was written for the installation of the frangible bolts into the test article release mechanism, and installation of the final release assemblies into the test article.

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01- 05 - 2013	Technical Memorandum	

4. TITLE AND SUBTITLE
Guidelines of the Design of Electropyrotechnic Firing Circuit for Unmanned Flight and Ground Test Projects

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Gonzalez, Guillermo A.; Lucy, Melvin H.; Massie, Jeffrey J.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
747797.06.43.13.99.04

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-20244

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2013-217997

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 33
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The NASA Langley Research Center, Engineering Directorate, Electronic System Branch, is responsible for providing pyrotechnic support capabilities to Langley Research Center unmanned flight and ground test projects. These capabilities include device selection, procurement, testing, problem solving, firing system design, fabrication and testing; ground support equipment design, fabrication and testing; checkout procedures and procedure's training to pyro technicians. This technical memorandum will serve as a guideline for the design, fabrication and testing of electropyrotechnic firing systems. The guidelines will discuss the entire process beginning with requirements definition and ending with development and execution.

15. SUBJECT TERMS
Electroexplosive devices; Electropyrotechnics firing circuits; Pyrotechnics

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	36	(443) 757-5802