The Changing Pattern
of
Ordnance Initiation

Wm. David Fahey
Robert M. Valenti
Ian Bell

Quantic Industries, Inc.
San Carlos and Hollister, Ca. USA

SAFE (Europe) SYMPOSIUM 2000 Deauville, France
March 28, 29, and 30, 2000

The Changing Pattern of Ordnance Initiation

Wm. David Fahey, (Dave.Fahey@QuanticIndustries.com
Robert M. Valenti (R.Valenti@QuanticIndustries.com
Ian Bell (ian.bell@dial.pipex.com)

Quantic Industries, Inc.
www.QuanticIndustries.com

San Carlos Facility
1010 Commercial St
San Carlos, Ca. USA 94070
1-650-595-1100 ph
1-650-592-4669 fax

Hollister Facility
2751 San Juan Rd.
Hollister, Ca. USA 95024
1-831-637-5851 ph
1-831-637-1013 fax

ABSTRACT

Ordnance Initiation has changed over time driven by improvements in the ordnance devices, in electronics systems and the development of new technologies. This paper discusses the recent history of electrical ordnance initiation and provides a high level comparison of devices and methods currently being used. The paper ends with a safety comparison of a typical current generation high voltage EBW system with a next generation laser diode system.

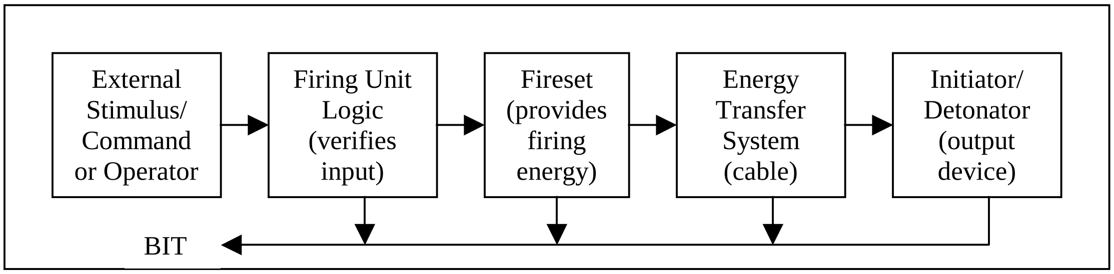
ORDNANCE IGNITION/INITIATION BACKGROUND

Electrically initiated ordnance devices are used daily to provide a desired outcome. Everyday examples well known to the public are starting the ordnance train that inflates an airbag or tightens a seatbelt in an automobile and lighting the engines of a rocket to put a satellite into space. In the near future, the market near you will be selling meat tenderized by the shock wave from a detonation.

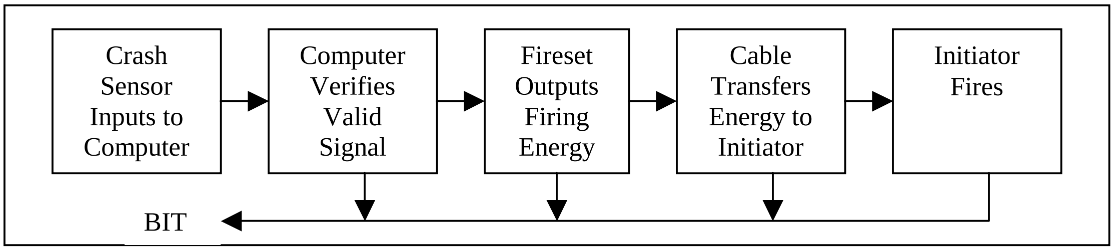
Each initiation application has different safety implications. Inadvertently inflating the driver's airbag on the Autobahn can have a dour effect on the driver. Similarly, inadvertent operation of the Destruct system on a $100,000,000 satellite launch can have negative side effects.

Development of cost effective and robust initiation systems that provide safe and cost effective initation well matched to the application is rapidly changing due to new developments and technology. This paper provides a high-level overview and comparison of the most commonly used initiation devices and initiation systems.

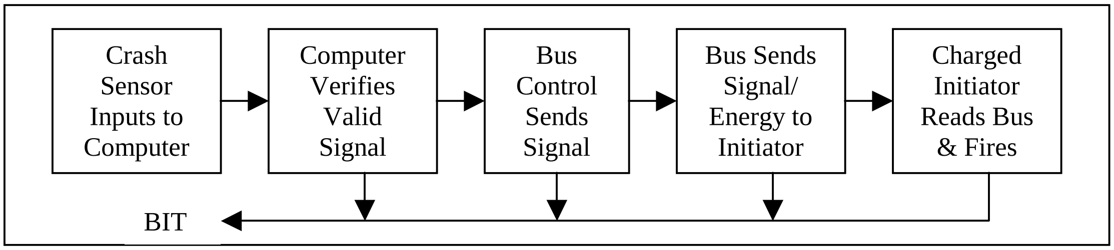
A conceptual block diagram of an electrical initiation system up to the initiator/detonator output device is shown below:



The initiation industry is expected to provide systems and devices that provide the highest possible reliability with the highest level of safety at the lowest possible cost. The automobile industry is a very good example of the level of ordnance initiation safety that can be provided in a reliable system at a low cost if extensive system engineering is provided and units are produced in high quantities. The above diagram represented for the current generation of automotive safety systems is shown below:



In this system the initiator is typically a 2 ohm, 200 ma to 400 ma/10 second no-fire device with a firing energy of 2 to 3 mj. The most often used military and Aerospace initiators in safety applications are 1 ohm, 1 amp no-fire for 5 minutes with a firing energy greater than 50 mj. The next generation of automotive systems that use smart initiators have only a slightly modified appearance but greatly modified performance.



In the above example the energy storage and ordnance initiation is provided in the smart initiator rather than partitioned between the fireset, harness and initiator. Many of the smart initiators will use Semiconductor Bridges (SCB's) as the initiating element in order to provide low energy ignition. Low energy ignition, e.g. 25 to 100 microjoules, allows the use of a small storage capacitor, e.g. 1 μf, and a lossy fireset that can be produced on a small ASIC die at low cost. 25 microjoules is approximately 1/100 of the previous automotive firing energy and approximately 1/2000 of the firing energy of currently used military devices.

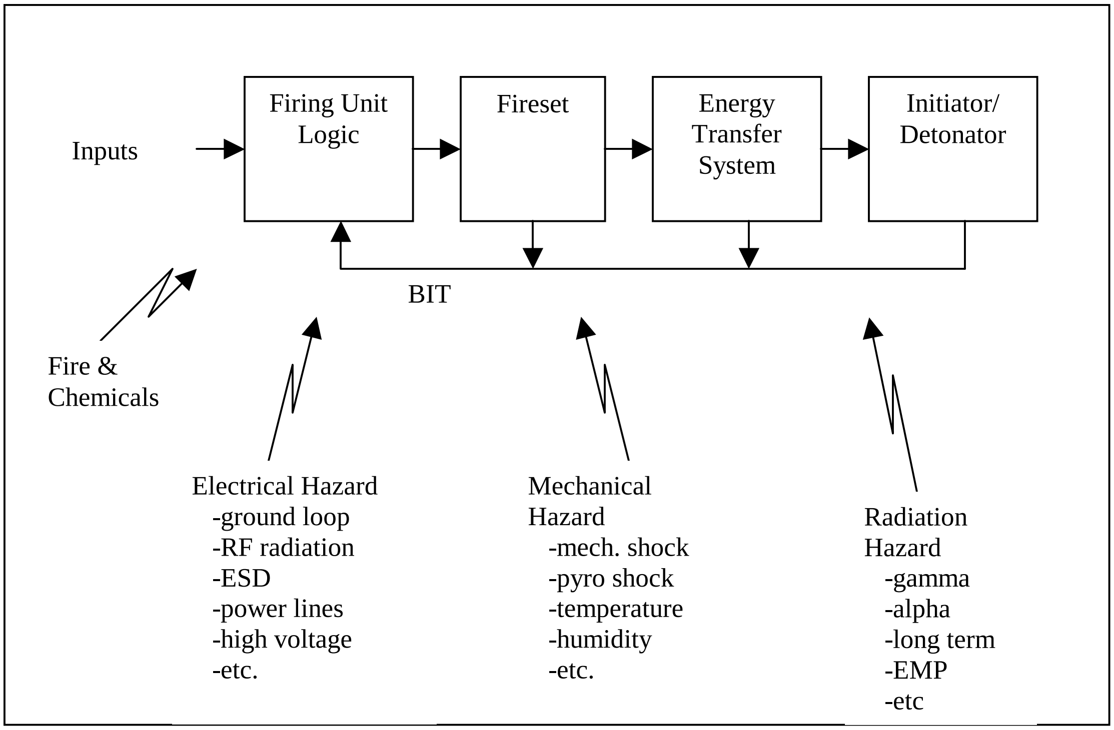
Generally everyone would agree that the safety and reliability of the ordnance initiation systems provided in today's vehicles is exemplary. Our purpose in providing the automotive examples is to show by example the safety and reliability that can be provided in a well engineered system that uses devices and material in-line that would be considered completely unacceptable in other applications. Using a low energy unprotected bridgewire device with Zirconium Potassium Perchlorate (ZPP) in-line would not be considered acceptable practice on many if not most military initiation systems. Use of initiators that fire with 25 microjoules of applied energy in-line is difficult to currently conceive of in most of today's safety critical aerospace and military applications.

The next generation of initiation systems will use the new technologies that allow additional system safety, flexibility and reliability to be provided at lower costs than previous systems. Low energy Semiconductor Bridges (SCB's) Systems with reactive outputs and Laser Diode systems that ignite via photons are examples of what will be used in the future.

INITIATION SYSTEM COMPARISON

James Diamond, in his Pulitzer Prize Winning 1997 book Guns, Germs and Steel, provides a short history of mankind for the last 13,000 years and refers to the first sentence in Tolstoy's novel Anna Karenina: "Happy families are all alike; every unhappy family is unhappy in its own way." Diamond interprets Tolstoy's sentence "in order to be happy, a marriage must succeed in many different respects: sexual attraction, agreement about money, child discipline, religion, in-laws, and other vital issues. Failure in any one of those essential respects can doom a marriage even if it has all of the other ingredients needed for happiness." The same can be said about cost effective, safe and reliable ordnance initiation systems. The ordnance initiation system must succeed in many different respects in order to meet this goal: DC voltage immunity, RF signal immunity, ESD immunity, mechanical shock and vibration immunity, high and low temperature exposure immunity, procurement cost, maintenance cost, functional reliability, flexibility, robustness, etc. Providing these attributes to produce a “happy” (safe and reliable plus cost effective) ordnance initiation system is the challenge.

Viewing an ordnance initiation system from an environmental exposure point of view provides the following exposure diagram:



The system must withstand all of the external environments without degradation in order to be safe and reliable. Multiple devices and systems have been developed over time to provide various levels of protection to these external environments. Table I provides an overview of different initiation devices and their intrinsic safety and performance. The use of these devices in a system must address these issues if a highly reliable, safe and robust system is to be provided. Table II provides a system comparison of electrical systems that operate the devices of Table I.

It is clear from Table I and II that a great many combinations and permutations exist. Table III outlines how each device of Table I provides its safety.

The system designer needs to understand the requirements of the system from a reliability and safety point of view in the presence of these environments and provide a system that provides the desired performance in the presence of these hazards. The trend today is to use advanced technologies with advanced safety features and enhanced reliability and flexibility to fulfill the safety applications as shown in Table IV.

This can best be seen by comparing two approaches to providing a highly safe initiation system. The first approach uses conventional EBW technology and fully complies with well proven safety criteria. The second approach uses new laser diode technology and provides a system that is more flexible and robust while also providing the same or a higher level of safety. The attached figure shows a block diagram comparison of both approaches:

The top half of the figure shows the conventional EBW approach while the bottom half shows a Laser Diode approach. Note that the External interface as indicated by the Ground/Missile Systems is identical between both approaches. The Firing Unit Logic is also identical.

Both the EBW and Laser Diode fireset use a complex interface to the Firing Unit Logic to ensure that the proper signals are present before the Fireset is energized or allowed to charge.

The EBW fireset is a high voltage unit that provides immunity by converting the input low voltage to a different form, i.e., high voltage, typically 3,000 volts. The system, once high voltage is stored on the firing capacitor, has a single point failure mechanism if the electronic switch used, e.g. a spark gap, is inadvertently triggered.

The Quantic Industries Laser Diode fireset provides immunity by first principles, i.e. enclosing the firing element and its drive within a Faraday cage. Thus, if a 400-volt power line inadvertently connects to the fireset, the laser diode will not fire because of the protection provided to the laser diode by the Faraday cage. Additionally the particular Faraday cage design used incorporates a Quantic Faraday Isolator, aka Radio Frequency Attenuating Coupler (RFAC), that does not pass EM signals to the firing element and provides protection against electronic signals including ground loops, RF, ESD and EMP. (It should be noted that a laser diode is more sensitive than a 1 amp/1 watt device and that the use of the patented Quantic Faraday Isolator provides a robust first principles method of allowing the many advantages of the laser diode to be used in a practical system. The Quantic Faraday Isolator has been tested and proven by MOD, U.S. Navy, Quantic and Quantic's customers. This general design approach is being used by Quantic on multiple new products, two of which use laser diodes.)

The ETS or Energy Transfer System in the EBW approach is typically a shielded high voltage cable. This cable usually has restriction on allowed length, and it necessary to provide sealed high voltage connectors particularly if the system is to be operated in low pressure regimes, e.g. above 2,500 meters. Safety in this element is provided by the cable shield and the unique signal required to fire the EBW.

The ETS in the Laser Diode System is fiber optic cable. Length is generally not an issue since the signal attenuation per unit length is very low. The number of connectors in line may be issue depending upon the system configuration since the attenuation per connector can be significant in some approaches. Safety in this element is provided by first principles and the transmission of the firing signal as photons rather than electrons. The fiber optic cable is not sensitive to electromagnetic phenomena such as ground loops, ESD, RF, EMP, etc

The initiated device, in this case a detonation output, for the EBW system is a EBW with the quasi secondary PETN used as the Deflagration to Detonation (DDT) element. The EBW provides a high level of safety by requiring a unique energy form in order to function. EBW's are generally considered mechanically insensitive but are difficult to seal for high altitude operation. PETN will ablate at relatively low temperatures and this can be an advantage or a disadvantage.

The initiated device for a detonating output Laser Diode System is a laser detonator that uses a DDT material. The material currently being used most often is BNCP. BNCP has been proven to provide reliable DDT over military environments via extensive testing. The Laser Initiator provides a very high level of safety since the ordnance is effectively sealed within a faraday cage. Laser Initiators are relatively temperature insensitive.

The two system approaches look very similar. The EBW approach is very mature but inflexible and relies on high voltage components, e.g. capacitors, switches, hermetic connectors, etc., whose long term availability is questionable. Additionally EBW systems have to deal with containing/isolating the high voltage before and during firing. This issue has caused many reliability problems in previous systems. Quantic's comparison of identical multiple output systems shows that EBW systems are approximately three (3) times larger and heavier and significantly more expensive than a laser diode system providing equivalent safety.

Laser Diode technology may not be appropriate if the ordnance output is required in less than a few milliseconds. The Quantic laser diode advantage is size, weight, flexibility and, in particular, built-in-test that can fully exercise the system plus eliminate the need for specialized high voltage components. These advantages as well as steadily decreasing laser diode pricing makes these systems the preferred choice for new systems where safety, reliability, flexibility size, weight, long term component availability and cost are critical.

The table on the following page summarizes this comparison:

EBW vs. Laser Diode System Comparison Table

Function	**EBW System**	**Diode Laser System**	**Note**
Ground Missile/System	Same	Same	Identical Interface
Firing Unit Logic	Same	Same	Conceptually Identical
Fireset Interface	Same	Same	Complex interface to Logic
Fireset Energy Form	High Voltage	Photons	
Single Point Firing Failure	Yes (spark gap)	No	
Fireset Robustness for Safety	High (High Voltage)	High (Faraday Cage and QFI)	
High Voltage Issues	Yes	No	
Energy Transfer System	Shielded High Voltage Cable	Fiber Optics	
Energy Transfer System Robustness	Limited	Large	
Output Device	EBW (Detonation)	Imitation or Detonation (DDT)	
Built-in-Test (BIT)	Limited	Extensive	Laser diode approach allows testing of components
Size/Weight		Approximately 1/3 of EBW in multiple output system	
System Complexity	High	Low	Low voltage laser diode approach is simple
System Cost (multi-channel)		Significantly lower	
System Reliability	High	Higher (simpler)	BIT improves edibility to
System Safety	High	Higher (fiber optics and laser initiator)	New technology allows increased safety

CONCLUSION

New technology, particularly SCB and Laser Diode, is allowing new cost effective approaches to provide initiation systems with high safety and reliability. The new and old technology has many factors that influence the final selection of a system approach that have been outlined in this paper. The authors view is that the trend for new systems is the use of SCB's where low energy is critical and laser diodes where safety plus size, weight and adaptability are critical. Quantic is designing these devices into new, advanced systems such as: Theater High Altitude Air Defense (THAAD) and National Missile Defense (NMD).

Table I
Electrical Initiation Device Comparisons (Typical)

Device/ Feature	**Bridgewire (hot wire) 1A/1W**	**EBW**	**EFI**	**Laser Initiator/ Detonator**	**General SCB with ESD Protection (1 a/ 1 w)**	**Junction SCB**	**Constant Current Reactive SCB (1 a/1 w-ESD)**
Radiated Energy Sensitivity	High	Low	Low	Not Sensitive to Radiated Energy	Med-High	Low	Med-High
Pin-to-Pin ESD Sensitivity 25 KV,5KΩ	Low	Low	Low	Not Sensitive to ESD	High	High	High
Pin-to-Pin ESD Sensitivity 25 KV, 150Ω	High	Medium?	Low?	Not Sensitive to ESD	Medium-High	Medium	Medium
Intrinsic Pin-to-Case ESD Sensitivity	Low to High	Low	Low	Not Sensitive to ESD	Low to High	Low to High	Low to High
Firing Voltage/ Current (typ)	5v/5a/10 ms	800v/ 1000a/ 500ns	2000v/ 2000a/ 50 ns	Photons	20v/10a/10µs	20v/10a/10µs	5v/1.5a/10µs
Firing Energy (typ)	250 mj	2000 mj	2000 mj	0.4 mj (photons)	5 mj	5 mj	5 mj
Function Time (typ)	10 ms	100 ns	10 ns	1 µs to 10 ms	10 µs	10 µs	10 µs

Table II
Electrical Initiation Device System Comparisons
(Typical)

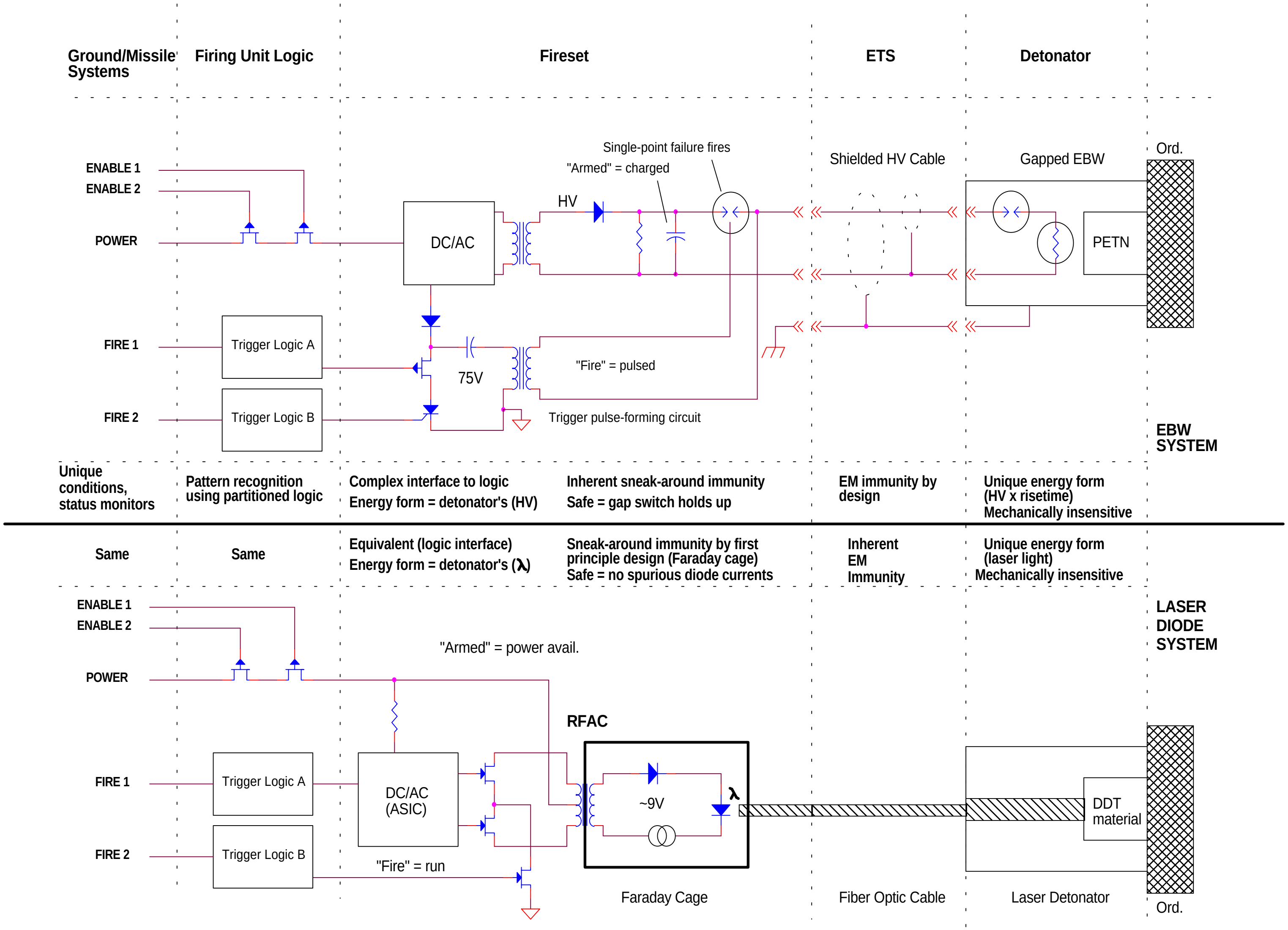
System/ Feature	Simple Hot Wire	Protected Hot Wire w BIT	Simple EBW/ EFI	Complex EBW/ EFI w BIT	Rod Laser w BIT	Simple Diode Laser	Protected Diode Laser w BIT	Simple SCB	Protected SCB w BIT
Radiated Energy Sensitivity (safety)	High	Low	Very Low	Very Low	Very Low	Medium	Very Low	High	Low
ESD Sensitivity (safety)	High	Low	Very Low	Very Low	Very Low	Medium	Very Low	High	Low
System Reliability	High	High via Redundancy	Low	High via Redundancy	Low	High	High	High	High
BIT Quality	Not provided	High	Not provided	Low	High	Not provided	High	Not Provided	High
System Safety	Low	Medium-High	Medium-High	Medium-High	High	Low	High	Low	Medium-High
System Complexity	Low	Medium	High	Very High	Very High	Low	Medium	Low	Medium
System Robustness	High	High	Low	Low	Low	High	High	High	High
System Operating Power	28 v/ 5 a/ 10 ms	28 v/ 5 a/ 10 ms	28 v/ 5 a/ 500 ms	28 v/ 5 a/ 500 ms	28 v/ 5 a/ 2000 ms	28 v/ 5 a/ 10 ms	28 v/ 5 a/ 10 ms	28 v/ 5 a/ 10 ms	28 v/ 5 a/ 10 ms
Function Time	<20 ms	<20 ms	<1 µs after armed	<1 µs after armed	<5 ms	<5 ms	<5 ms	<50 µs	<50 µs
Cable Length Sensitivity	Low	Low	High	High	Very Low	Very Low	Very Low	Low	Low
Component Long Term Avail.	High	High	Low?	Low?	Low?	High	High	High	High

Table III
Device Characteristics
(Typical)

	No-Fire Current	**Firing Current Signature**	**Ordnance Material**	**DC Blocking**	**RF Sensitivity**	**Low Current ESD Sensitivity**	**High Current ESD Sensitivity**
Bridgewire	1 a/ 5 min	5 a/ 10 ms	Pyrotechnic or Primary	No	High	Low	High
EBW Detonator	100’s of amps	Fast Rise Time with 100’s of amps required	Quasi Secondary (PETN)	No	Low	Low	Low?
EFI Detonator	100’s of amps	Very Fast Rise Time with 1000’s of amps required	Secondary	No	Low	Low	Low?
Laser Initiator Detonator	Photons	Photons	Pyrotechnic or Primary	Yes (Photons)	Not Sensitive	Not Sensitive to ESD	Not Sensitive to ESD
Generic SCB	1 a/ 5 min	10 a/ 5 µs	Fast Pyrotechnic or Primary	No	Low-Medium	High	High
Junction SCB	DC Blocking	Exceed Junction Threshold 6 to 500 volts	Fast Pyrotechnic or Primary	Yes	Not Sensitive	Medium	TBD
Next Generation SCB	DC Blocking	Exceed Junction Threshold (6 to 500 volts)	Secondary	Yes	Not Sensitive	Medium	Low

Table IV
Approach Selection Factors
(1=worst, 10=best)

Device/ Criteria	**Bridgewire (hot wire) 1A/1W System**	**EBW System**	**EFI System**	**Rod Laser System**	**Diode Laser System**	**SCB System**
Cost	10	3	2	1	7	10
Energy	5	3	2	1	8	10
Flexibility	7	3	1	4	10	7
Safety	1-7	8	9	10	10	1-9
Fast Initiation	1	9	10	5	4	8
Initiation Output	Yes	No	No	Yes	Yes	Yes
Detonation Output	Yes (DDT)	Yes	Yes	Yes (DDT)	Yes (DDT)	Yes (DDT) Direct Coming
System Weight	8	4	3	1	10	8
BIT Quality	5	3	1	10	10	5
Ruggedness	10	5	4	1	10	10
High Voltage Arcing Issue	No	Yes	Yes	Yes	No	No
Long Term Parts Avail.	High	?	?	?	High	High
Complexity	7-10	3	2	1	7-10	7-10
New Designs	Yes	Limited	Limited	Very Limited	Increasing	Increasing
Technology Advancing	Limited	No	Limited	Limited	Yes	Yes



Ground/Missile Systems	Firing Unit Logic	Fireset		ETS	Detonator	
Unique conditions, status monitors	Pattern recognition using partitioned logic	Complex interface to logic Energy form = detonator's (HV)	Inherent sneak-around immunity Safe = gap switch holds up	EM immunity by design	Unique energy form (HV x risetime) Mechanically insensitive	EBW SYSTEM
Same	Same	Equivalent (logic interface) Energy form = detonator's (λ)	Sneak-around immunity by first principle design (Faraday cage) Safe = no spurious diode currents	Inherent EM Immunity	Unique energy form (laser light) Mechanically insensitive	LASER DIODE SYSTEM

Safety Comparison - Laser Diode to EBW System