Development of an Electronic Time Delay (ETD) Cartridge for CAD/PAD Applications

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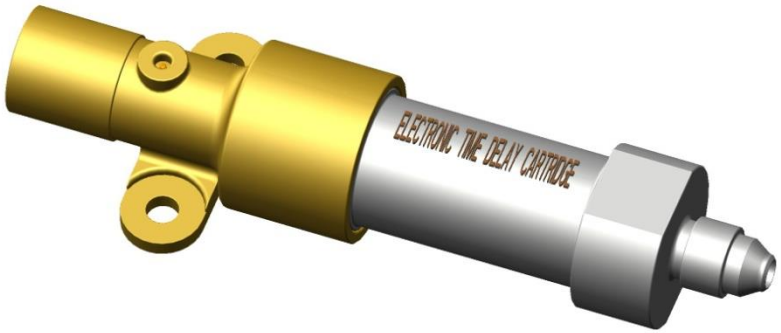

NSWC IHEODTD
CAD/PAD Technical
Exchange Workshop
May 2016

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Funding/Customer/Deliverables

Customer (NISE219 FY14/15):

- NISE 219 (Naval Innovative Science and Engineering) Program
- NSWC-IHEODTD

End User:

- USN/USMC and USAF

Deliverable:

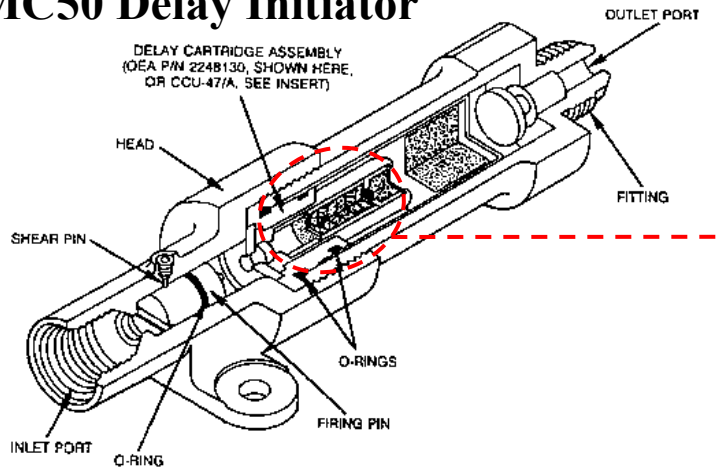
- Prototype Electronic Time Delay Cartridge Design

Project Completion:

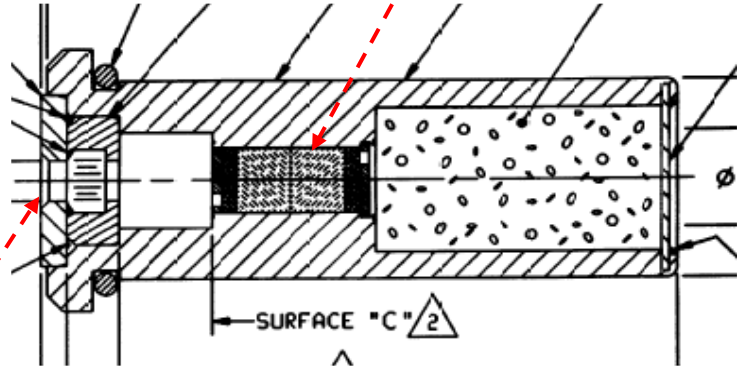
- New electronic time delay cartridge design supported by a series of functional tests

Background

MC50 Delay Initiator



Pressed Explosive Delay Column



Percussion Primer

CCU-47/A Delay Cartridge

"Pressed Column" Delay Cartridge Characteristics:

- Delay timing variability ±25%
- Difficult and expensive to manufacture
- Require aircraft change-out as often as every 24 months

Ejection Seat

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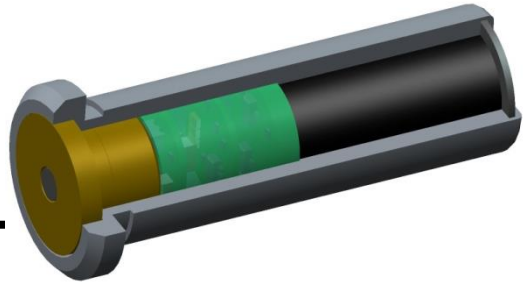
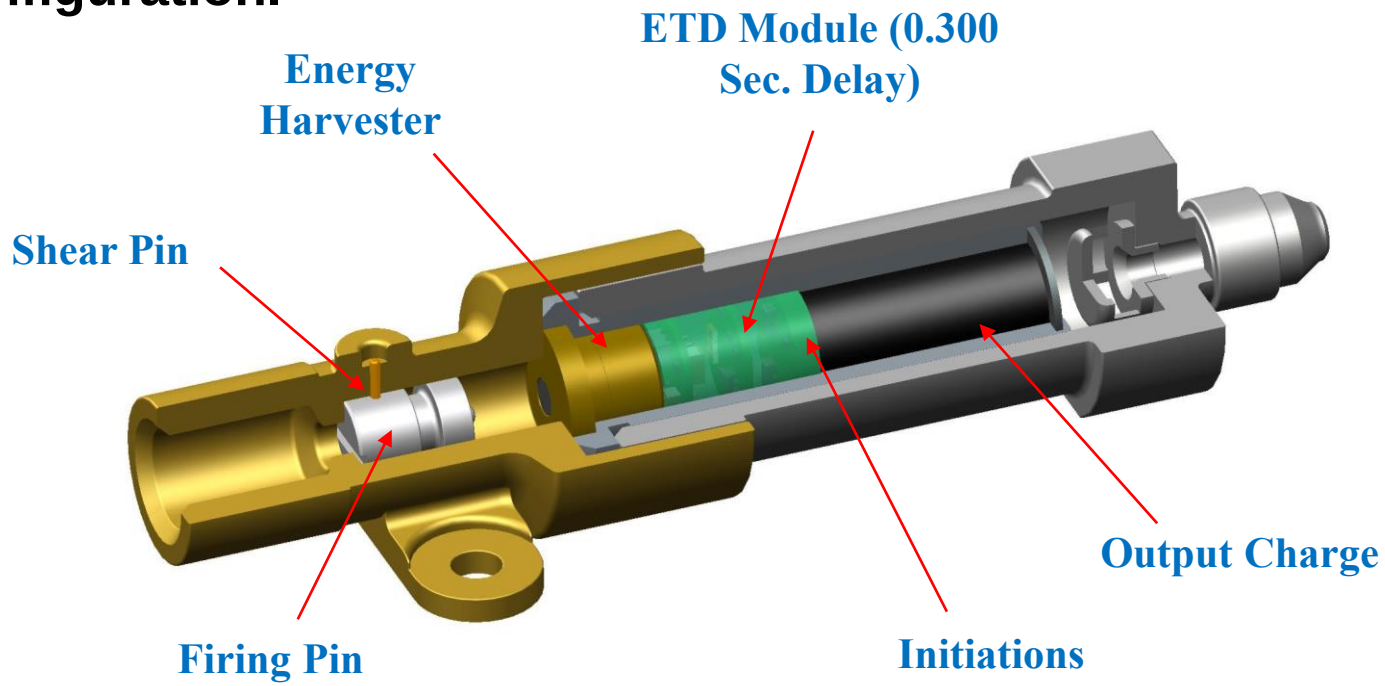
ETD Cartridge for CAD/PAD

- Direct replacement for legacy system (accepts same input and delivers same output)
- Eliminates percussion primer and pyrotechnic delay column
- Piezo-based energy-harvesting generation
- Re-programmable dual ETD Architecture
- Precise timing delay (3% variation)
- Same principle of operation (no training required)
- Operational temperature: -65F to +200F
- Improves CAD/PAD performance and reliability while reducing the cost and extending service life



Technical Objective

To replace the CCU-47/A Delay Cartridge (0.300 second delay), contained within the MC50 Delay Initiator housing, with an electronic time delay cartridge design capable of maintaining both the identical gas pressure input and output energetic material as the current configuration.



Electronic Time Delay Version of MC50 Delay Initiator

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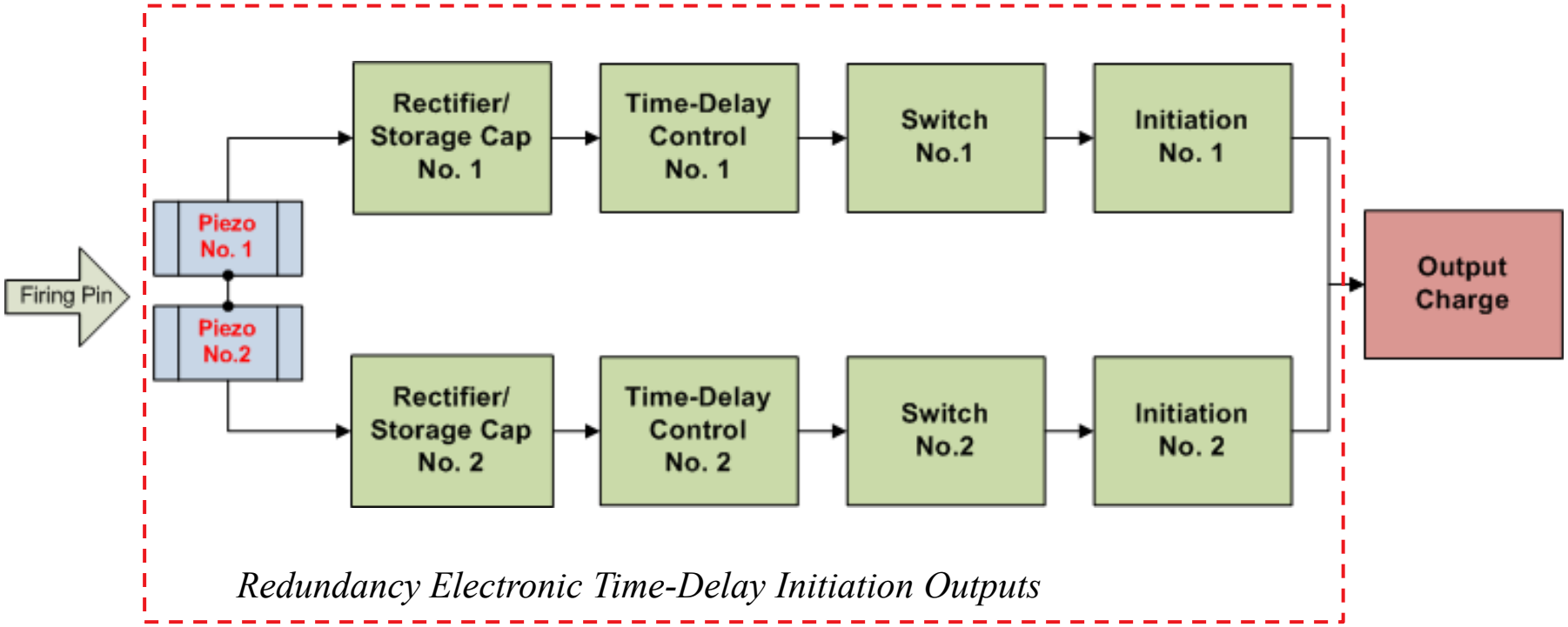
Technical Approach



Functional Block Diagram of the Electronic Time Delay Cartridge

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Approach Activities

Task 1: Piezo-based Energy-harvesting Generation (PEHG) Development

- Design and integrate PEHG for proposed cartridge design
- Manufacture a quantity of PEHG sub-components for functional testing
- Conduct functional tests (at temperature) on the PEHG sub-components
- Ensure proposed design is rugged to survive cartridge environments

Task 2: Development & Manufacture of Time Delay Circuits

- Complete detailed electronic circuit design
- Determine the most effective fabrication approach
- Fabricate a quantity of these electronic circuits and establish time delay parameters
- Conduct functional tests at temperature on the fabricated sub-components

Task 3: Develop bridgewire initiator, interface bet/ ETD circuitry and energetic materials

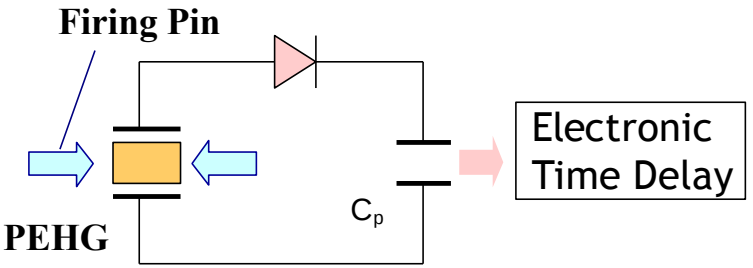
- Low-energy hot bridgewire initiation approach for energetic material output charge
- Manufacture a quantity of these sub-components for functional testing
- Conduct functional tests (at temperatures) on these sub-components
- Finalize the design of this energetic material initiation sub-component

Task 4: Freeze Electronic Time Delay (ETD) Cartridge Design

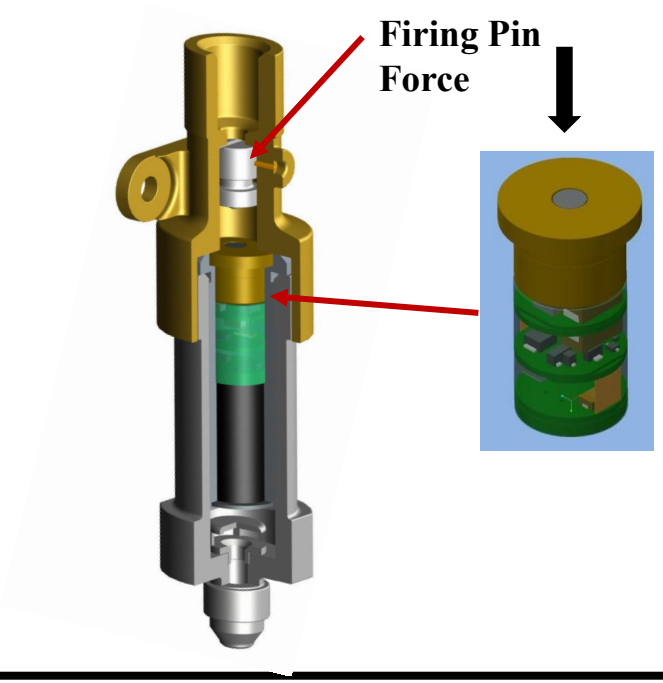
- Based on the engineering, analysis, and test data, prototype ETD cartridge design frozen
- Full-up propagation tests (-65F, 77F, and +200F)
- System integration laboratory demonstration

Advantages of Piezo-based Generators

- Piezo-based energy-harvesting generator (PEHG) are solid state devices that convert mechanical energy into electrical energy.
- When used as a PEHG, the piezoelectric element harvests the mechanical energy from the compressive forces generated from firing pin.
- This electrical energy can be then stored in a capacitor and used for powering the associated electronics of the CAD/PAD device.
- By using PEHGs, smart CAD/PAD devices can be built without the use of batteries.
- Less maintenance. A PEHG is a solid state ceramic component which does not change performance over 20-30 years. This means there is no requirement for frequent replacement of the energy source.
- High reliability. A PEHG will always perform as energy is generated during launch of firing pin.
- Very fast response. Piezoelectric devices are used in accelerometer and sensing systems due to their fast response. When designed as piezoelectric generators, they are capable of following the mechanical stress profile so as to generate the proportional electrical charge with very little delay. Response times of less than few micro-seconds are possible.
- Small. A PEHG may be smaller in size than a battery of same energy rating

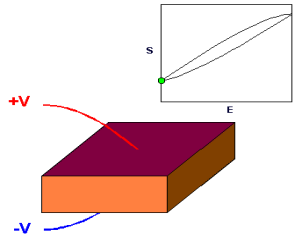


Principle of PEHG actuation with a storage capacitor



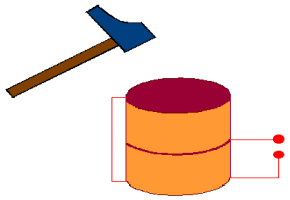
Piezoelectricity Basics

INVERSE PIEZOELECTRIC EFFECT



Electrical to Mechanical energy conversion

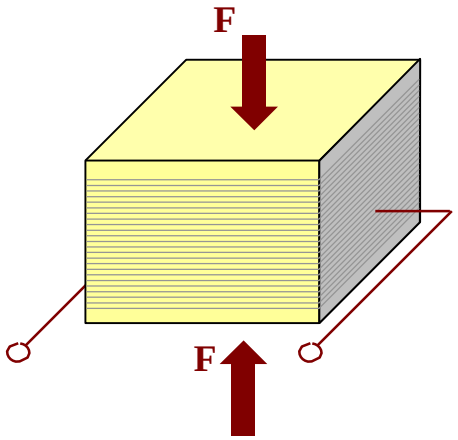
DIRECT PIEZOELECTRIC EFFECT



Mechanical to Electrical energy conversion

Piezo-based Energy-harvesting Generation Type

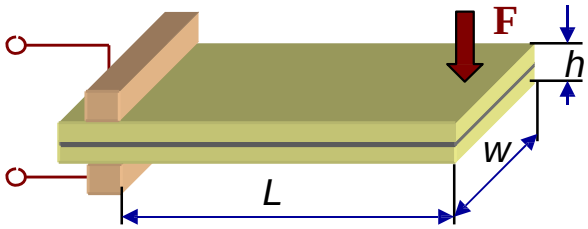
Longitudinal



High Forces

Small displacement

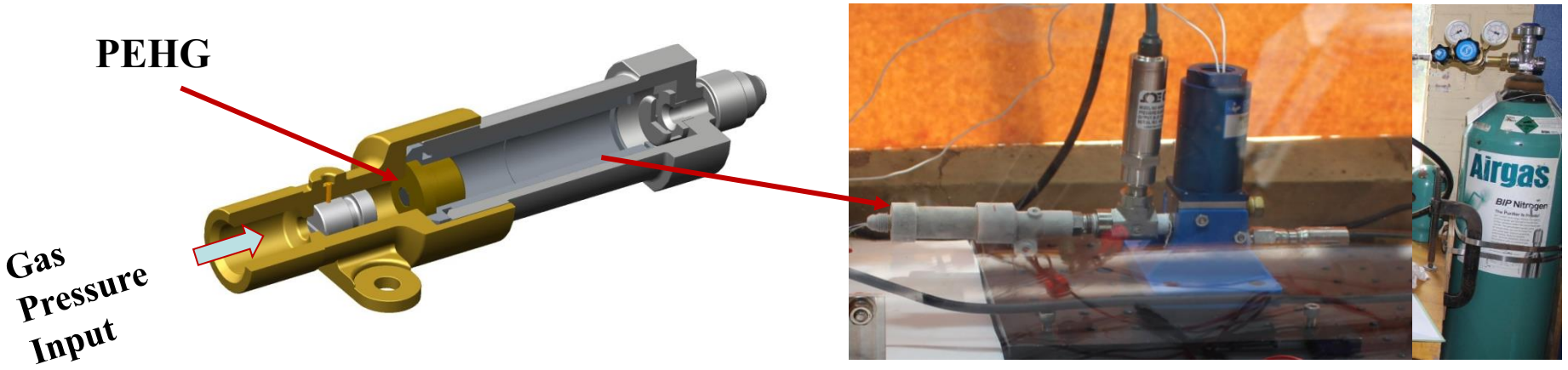
Bending type

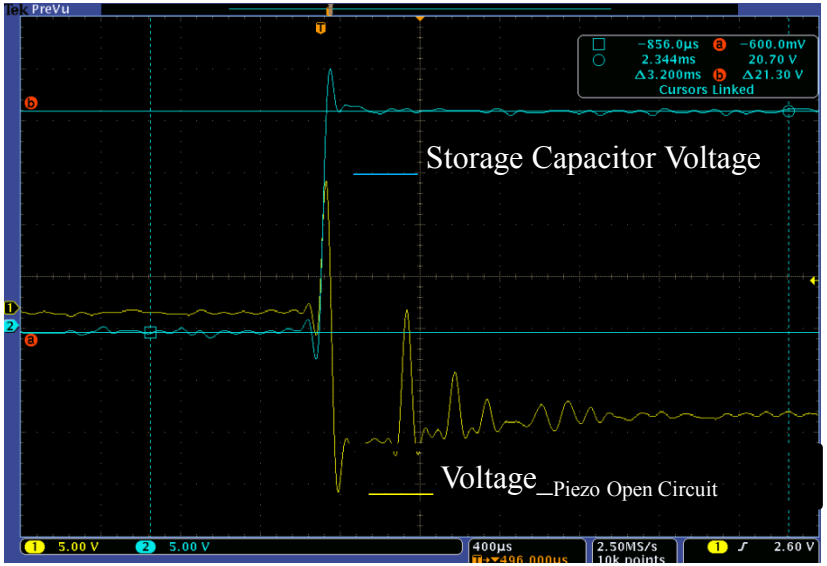


Low forces

Large displacement

Piezo-based Generator Testing





PEHG Generated Voltages

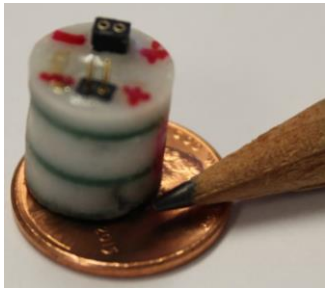
Test Summary of Piezo-based Energy-harvesting Generators Across Operational Temperatue, @ Min Pressure

PEHG No.	Ambient (77⁰ F)		Low (-71⁰ F)		High (206⁰ F)	
	Voltage (Vdc)	Energy (mJ)	Voltage (Vdc)	Energy (mJ)	Voltage (Vdc)	Energy (mJ)
1	21.2	1.806	20.7	1.714	20.2	1.639
2	20.6	1.708	21.1	1.781	20.6	1.697
3	20.5	1.688	22.3	1.989	20.2	1.632
4	20.9	1.748	21.7	1.884	20.2	1.632
5	21.5	1.85	21.7	1.884	21.6	1.866
6	21.3	1.821	21.7	1.884	19.4	1.505
7	20.2	1.632	21.1	1.781	19.4	1.505
8	21.8	1.901	21.3	1.817	21	1.764
9	20.7	1.714	-	-	21	1.764
10	21.3	1.819	-	-	20.2	1.64
Mean	21.00	1.77	21.45	1.84	20.38	1.66
STDEV	0.50	0.08	0.50	0.09	0.70	0.11

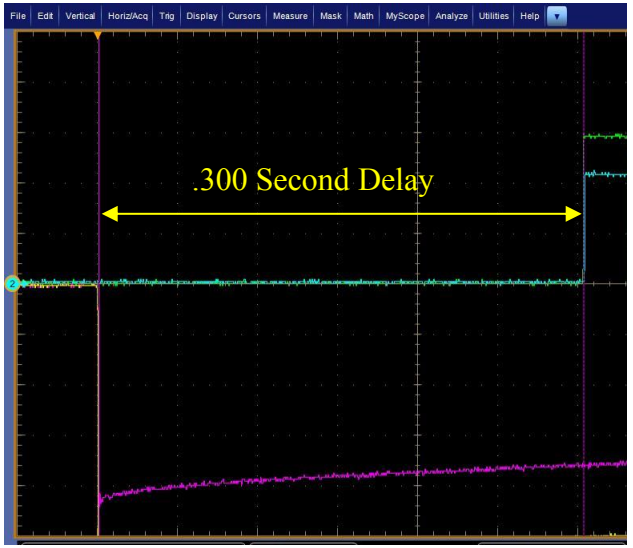
To power each electronic time delay plus initiation required only 0.9mJ.

Dual ETD Circuit Evaluation

- **Dual Electronic Time Delay circuit:**
  - **Re-programmable dual ETD architecture**
  - **Delay time can be easily changed to meet other applications requirements**
  - **Robust flex cable design**
  - **Simplifies high volume manufacturing**



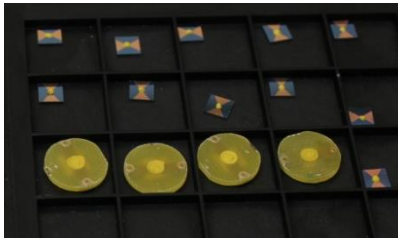
Lab Evaluation Result Summary		
Number of Dual ETD Circuit Tested	Temperature Tested	Mean ETD Recorded
(Unit)	(^{0}F)	(Second)
17	+77	0.299 (Ω=.01)
10	-70	0.297 (Ω=.07)
10	+200	0.290(Ω=.12)
Used General Purpose COTS electronic components.		



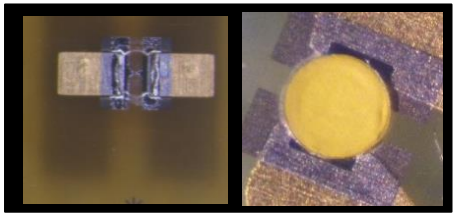
Sensitivity Test (Neyer) of the Initiators

NSWC-IHEODTD's low-energy initiator development testing for All-fire and No-fire voltage:

- **Initiator Type 1**
  - Bridgewire resistance: 3.2 – 3.6 ohms
  - Test sample size: 35 ea.
  - All-fire: 460 µJ
  - No-fire: 338 µJ



- **Initiator Type II**
  - Bridgewire resistance: 3.4 – 3.6 ohms
  - Test sample size: 23 ea.
  - All-fire: 230 µJ
  - No-fire: 85 µJ



- **Initiator Type III**
  - Bridgewire resistance: 4.9 – 5.1 ohms
  - Test sample size: 35 ea.
  - All-fire: 235 µJ
  - No-fire: 150 µJ

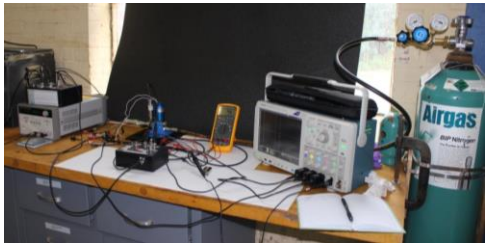
Quick Look (NDT) 6-foot Drop Testing

- **Six (6) foot drop testing consists of the power supply, ETD and inert low-energy bridgewire initiators. Five units dropped on a ½" steel plate at different impact orientations (Nose up, Nose down, 45-degree Nose up, 45-degree Nose down and Horizontal). Each unit is dropped only once.**

  - **✓All 5 units were opened and examined for damage, no damage to mechanical or electrical components. All 5 bridgewire initiators were intact.**

- **Following 6-foot drop test, 5 units were functional tested.**

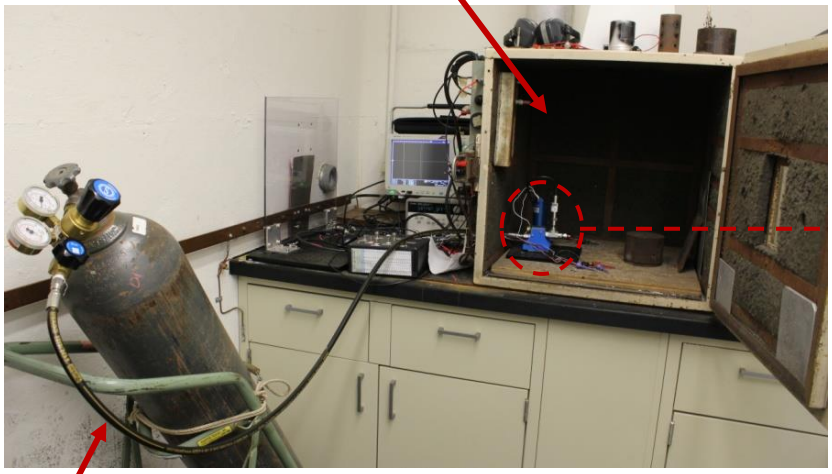
  - **✓ 5/5 units successfully functioned the initiator.**



Experimental Test Setup

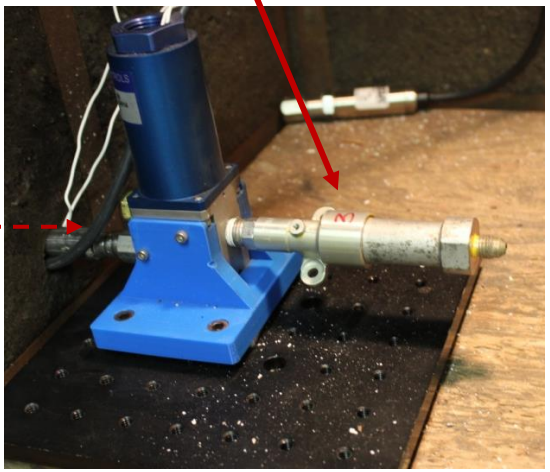
Hardware of the Electronic Time Delay Cartridge

Test Chamber



Input Gas Pressure

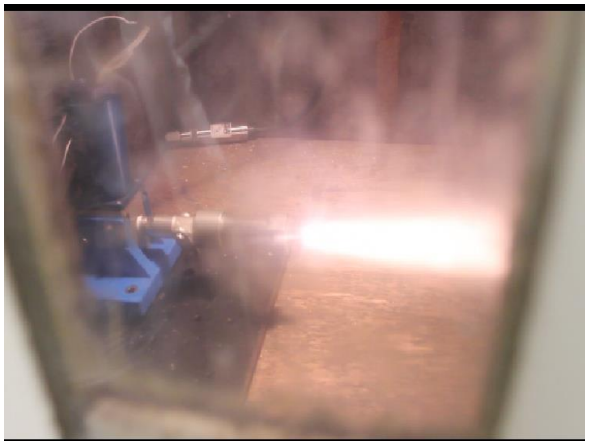
ETD assembled inside the MC50 housing assembly

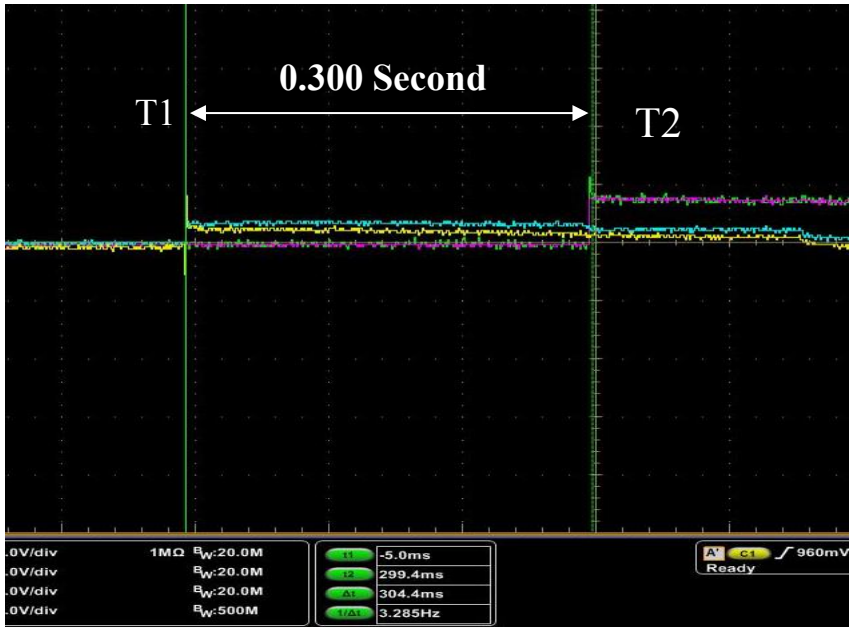


Experimental Test Results

30 units successfully tested across the operational temperatures.

- ✓ **Functioned off of a legacy energy input, and initiated the energetic materials.**
- ✓ **Achieved the desired delay (0.3s) and precision (<3%)**





Lab Integration Test Results

MC50 w/ ETD Cartridge (Live)*	Temperature Tested	Mean Timing-Delay Recorded
(Unit)	(^{0}F)	(Second)
13	+77	0.299
9	-70	0.297
8	+200	0.294

Total of sub/full assembly units
Objective: .300 second Delay

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Videos

Video 1

Video 2

Video 3

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Conclusions

- A prototype electronic time delay cartridge for CAD/PAD applications has been demonstrated.
- Cartridge is a drop-in replacement for legacy systems
- Powered via an internal energy harvester
- Replaces the pyrotechnic delay column with a digital time delay
- Exhibits tight timing tolerance (<3%)
- Design can readily be adapted to various time delay.

Questions???