NDIA

61ST ANNUAL FUZE CONFERENCE

FUZING SOLUTIONS - A GLOBAL PERSPECTIVE

May 15 – 17, 2018

San Diego Marriott Mission Valley

San Diego, CA

NDIA.org/Fuze18

WELCOME TO THE 61ST ANNUAL FUZE CONFERENCE

On behalf of the NDIA Fuze Conference Steering Committee Members and the NDIA, I would like to welcome you to the 61st Annual NDIA Fuze Conference. This international conference brings together the work of the top professionals in the fuzing industry from government, private industry, and academia; and provides an opportunity for the exchange of the latest research and development on fuzing, with the common goal of improving safety for the warfighter. While the history of fuzing dates back several hundred years, and the advances in technology have been significant over that time, many challenges remain. Through the continuing, passionate work of the authors, presenters, sponsors, and attendees at this conference and across our worldwide defense industry, these challenges will be overcome, resulting in safer, more reliable fuzes being fielded to our warfighters.

Roy K. Streetz
Vice President Advanced Electronic Systems
Excelitas Technologies Corporation

SCHEDULE AT A GLANCE

TUESDAY, MAY 15

Registration & Opening Reception
Rio Vista Grand Foyer
4:00 – 6:00 pm

WEDNESDAY, MAY 16

Registration
Rio Vista Grand Foyer
7:00 am – 5:20 pm

Continental Breakfast
Rio Vista Grand Foyer
7:00 – 8:00 am

General Session & Keynote Speaker
Rio Vista Grand Ballroom, Salons A-E
8:00 – 8:45 am

Lunch
West Lawn
12:00 – 1:00 pm

Concurrent Sessions
Salons F - H & Salons A - D
1:00 – 5:20 pm

Grand Reception
Rio Vista Pavilion
5:30 – 7:00 pm

THURSDAY, MAY 17

Registration
Rio Vista Grand Foyer
7:00 am – 12:00 pm

Continental Breakfast
Rio Vista Grand Foyer
7:00 – 8:00 am

Concurrent Sessions
Salons F - H & Salons A - D
8:00 am – 12:00 pm

Lunch
West Lawn
12:00 – 1:00 pm

Concurrent Sessions
Salons F-H & Salons A - D
1:00 – 5:20 pm

Conference Adjourns
5:20 pm

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WHO WE ARE

The National Defense Industrial Association is the trusted leader in defense and national security associations. As a 501(c)(3) corporate and individual membership association, NDIA engages thoughtful and innovative leaders to exchange ideas, information, and capabilities that lead to the development of the best policies, practices, products, and technologies to ensure the safety and security of our nation. NDIA's membership embodies the full spectrum of corporate, government, academic, and individual stakeholders who form a vigorous, responsive, and collaborative community in support of defense and national security. For more information, visit **NDIA.org**

LEADERSHIP AND COMMITTEES

Timothy Bagniefski
Munitions Division Chair

Roy Streetz
Fuze Committee Chair

Melissa Hobbs-Hendrickson
Insensitive Munitions and Energetic Materials Committee Chair

FUZE MUNITIONS

MISSION

The purpose of the Fuze Section shall be to promote an open exchange of technical information among government and industry technical personnel, and to identify and address changes in standards, guidance, policy, and organizational functions that impact the development, production, and performance of fuzes.

EVENT INFORMATION

LOCATION

San Diego Marriott Mission Valley
8757 Rio San Diego Drive
San Diego, CA 92108

EVENT WEBSITE

NDIA.org/Fuze18

WI-FI

Network: Marriott_Conference | Password: fuze18

EVENT CONTACT

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Meredith Mangas
Associate Director, Meetings
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PLANNING COMMITTEE

Roy Streetz
Event Chair

Nassir Alaboud
Ray Ash
Ed Cooper
Chris DeWitt
Mark Etheridge
Frank Fairchild
Lawrence Fan
Doug Harms
Thomas Harward
Robert Herlein
Bruce Hornberger
William Konick
Bill Kurtz
Homesh
Lalbahadur
David Lawson
Homesh
Lalbahadur
David Lawson
Byron Lee
Telly Manolatos
Bob Metz
Barry Neyer
Eric Roach
Perry Salyers
James Sharp
Don Shutt
Martin Tanenhaus

ATTIRE

Business casual for civilians and uniform of the day for military personnel.

ATTENDEE ROSTER, SURVEY, AND PROCEEDINGS

A list of attendees (name and organization only), presentation proceedings, and conference survey will be emailed to you after the conference. NDIA would appreciate your time in completing the survey to help make our event even more successful in the future.

SPEAKER GIFTS

In lieu of speaker gifts, a donation is being made to the Fisher House Foundation.

HARASSMENT STATEMENT

NDIA is committed to providing a professional environment free from physical, psychological and verbal harassment. NDIA will not tolerate harassment of any kind, including but not limited to harassment based on ethnicity, religion, disability, physical appearance, gender, or sexual orientation. This policy applies to all participants and attendees at NDIA conferences, meetings and events. Harassment includes offensive gestures and verbal comments, deliberate intimidation, stalking, following, inappropriate photography and recording, sustained disruption of talks or other events, inappropriate physical contact, and unwelcome attention. Participants requested to cease harassing behavior are expected to comply immediately, and failure will serve as grounds for revoking access to the NDIA event.

AGENDA

TUESDAY, MAY 15

4:00 – 6:00 pm

REGISTRATION

RIO VISTA GRAND FOYER

Sponsored By L3 Defense Electronic Systems

4:00 – 6:00 pm

OPENING RECEPTION

RIO VISTA GRAND FOYER

Sponsored By L3 Defense Electronic Systems

WEDNESDAY, MAY 16

7:00 am – 5:20 pm

REGISTRATION

RIO VISTA GRAND FOYER

Sponsored By L3 Defense Electronic Systems

7:00 – 8:00 am

CONTINENTAL BREAKFAST

RIO VISTA GRAND FOYER

Sponsored By PCB Piezotronics, Inc.

SESSION 1 – WELCOME, ADMIN REMARKS & KEYNOTE ADDRESS

RIO VISTA GRAND BALLROOM, SALONS A - E

8:00 – 8:05 am

INTRODUCTION & ADMIN REMARKS

RIO VISTA GRAND BALLROOM, SALONS A - E

Roy Streetz
NDIA Fuze Committee Chair, Excelitas Technologies Corp.

8:05 – 8:15 am

NDIA OPENING REMARKS

RIO VISTA GRAND BALLROOM, SALONS A - E

CAPT Frank Michael, USN (Ret)
Senior Vice President, Programs and Membership, NDIA

8:15 – 8:45 am

KEYNOTE ADDRESS

RIO VISTA GRAND BALLROOM, SALONS A - E

SESSION 2 – U.S. GOVERNMENT SCIENCE, TECHNOLOGY & ACQUISITION

RIO VISTA GRAND BALLROOM, SALONS A - E

Don Shutt
Orbital ATK, Session Chair

Roy Streetz
Excelitas Technologies Corp., Session Assistant

8:45 – 9:10 am

ARMY S&T STRATEGY

RIO VISTA GRAND BALLROOM, SALONS A - E

Shannon Haataja
U.S. Army RDECOM AMRDEC

9:10 – 9:30 am

ARMY S&T STRATEGY

RIO VISTA GRAND BALLROOM, SALONS A - E

Charles Robinson
Mechanical Engineer, U.S. Army RDECOM AMRDEC

9:30 – 10:00 am

NAVY S&T STRATEGY

RIO VISTA GRAND BALLROOM, SALONS A - E

Brandon Stewart
Safe/Arm Development Branch Head, USN NAWCWD China Lake

10:00 – 10:30 am

NETWORKING BREAK

RIO VISTA GRAND FOYER

Sponsored By Pacific Scientific Energetic Materials Company

10:30 – 11:00 am

AIR FORCE S&T STRATEGY

RIO VISTA GRAND BALLROOM, SALONS A - E

George Jolly
Technical Advisor, Air Force Research Library/RWMF

11:00 – 11:20 am

OSD PERSPECTIVE/FUZE IPT

RIO VISTA GRAND BALLROOM, SALONS A - E

Lawrence Fan
JFTP Manager, Naval Surface Warfare Center - Indian Head Division

11:20 – 11:50 am

JOINT FUZE TECHNOLOGY PROGRAM (JFTP)

RIO VISTA GRAND BALLROOM, SALONS A - E

Lawrence Fan
JFTP Manager, Naval Surface Warfare Center - Indian Head Division

12:00 – 1:00 pm

LUNCH
WEST LAWN

Sponsored By Excelitas Technologies Corp.

CONCURRENT BREAKOUT SESSIONS

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RIO VISTA GRAND BALLROOM, SALONS F - H

Homesh Lalbahadur
U.S. Army ARDEC
Session Chair

Bob Metz
PCB Piezotronics, Inc.
Session Assistant

SESSION 3B – CLOSED SESSIONS
RIO VISTA GRAND BALLROOM, SALONS A - D

Robert Hertlein
L3 Defense Electronic Systems
Session Chair

James Sharp
Naval Surface Warfare Center - Dahlgren Division
Session Assistant

1:00 – 1:20 pm

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L3 Defense Electronic Systems

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20326

Sandy Risha
ARDEC Fuze Division

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U.S. Army AMRDEC

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20433

Kevin Cochran
Naval Surface Warfare Center - Indian Head Division

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Max Perrin
JUNGHANS Defence

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20428

Patrick DeLuca
U.S. Army ARDEC

2:00 – 2:20 pm

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Chase Whitman
EnerSys Advanced Systems

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20352

Hung-Sheng Chern
L3 Defense Electronic Systems

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20296

John Geaney
ARDEC Fuze Division

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Jason Koonts
Naval Surface Warfare Center - Dahlgren Division

Jim Ring
Orbital ATK

2:40 – 3:00 pm

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Christian Euba
TDW / MBDA

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Wayne Steege
Orbital ATK

3:00 – 3:20 pm

NETWORKING BREAK
RIO VISTA GRAND FOYER

Sponsored By Pacific Scientific Energetic Materials Company

CONCURRENT BREAKOUT SESSIONS

Continued

SESSION 3A – OPEN SESSIONS
RIO VISTA GRAND BALLROOM, SALONS F - H

Homesh Lalbahadur
U.S. Army ARDEC
Session Chair

Bob Metz
PCB Piezotronics, Inc.
Session Assistant

SESSION 3B – CLOSED SESSIONS
RIO VISTA GRAND BALLROOM, SALONS A - D

Robert Hertlein
L3 Defense Electronic Systems
Session Chair

James Sharp
Naval Surface Warfare Center - Dahlgren Division
Session Assistant

3:20 – 3:40 pm

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Dr. Dan Peairs
L3 Defense Electronic Systems

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Ezra Chen
Naval Surface Warfare Center - Indian Head Division

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Curtis McKinion
Air Force Research Laboratory

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GRAND RECEPTION

RIO VISTA PAVILION

Sponsored By Orbital ATK

THURSDAY, MAY 17

7:00 am – 12:00 pm

REGISTRATION

RIO VISTA GRAND FOYER

Sponsored By L3 Defense Electronic Systems

7:00 – 8:00 am

CONTINENTAL BREAKFAST

RIO VISTA GRAND FOYER

CONCURRENT BREAKOUT SESSIONS

	SESSION 4A – OPEN SESSIONS	SESSION 4B – CLOSED SESSIONS
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	Nassir Alaboud Lockheed Martin *Session Chair*	**Bob Metz** PCB Piezotronics, Inc. *Session Chair*
	Lawrence Fan Naval Surface Warfare Center - Indian Head Division *Session Assistant*	**Mark Etheridge** U.S. Army AMRDEC *Session Assistant*
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Diehl & Eagle Picher GmbH

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U.S. Army AMRDEC

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Dr. Vasant Joshi
Naval Surface Warfare Center - Indian Head Division

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20346

Dr. Aisha Haynes
U.S. Army ARDEC

10:00 – 10:20 am

NETWORKING BREAK
RIO VISTA GRAND FOYER

Sponsored By Kaman Fuzing & Precision Products

CONCURRENT BREAKOUT SESSIONS

Continued

SESSION 4A – OPEN SESSIONS
RIO VISTA GRAND BALLROOM, SALONS F - H

Nassir Alaboud
Lockheed Martin
Session Chair

Lawrence Fan
Naval Surface Warfare Center - Indian Head Division
Session Assistant

SESSION 4B – CLOSED SESSIONS
RIO VISTA GRAND BALLROOM, SALONS A - D

Bob Metz
PCB Piezotronics, Inc.
Session Chair

Mark Etheridge
U.S. Army AMRDEC
Session Assistant

10:20 – 10:40 am

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Roketsan Missile Industries, Inc.

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Air Force Research Laboratory

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ASELSAN Inc.

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Lei Zheng
U.S. Army ARDEC

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U.S. Army ARDEC

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Sarah Steffen
Orbital ATK

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Fraunhofer Ernst-Mach-Institut (EMI)

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Tim Hoang
Naval Surface Warfare Center - Indian Head Division

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LUNCH
WEST LAWN

CONCURRENT BREAKOUT SESSIONS

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RIO VISTA GRAND BALLROOM, SALONS F - H

Perry Salyers
L3 Defense Electronic Systems
Session Chair

David Lawson
L3 Defense Electronic Systems
Session Assistant

SESSION 5B – CLOSED SESSIONS
RIO VISTA GRAND BALLROOM, SALONS A - D

Byron Lee
Orbital ATK
Session Chair

Frank Fairchild
Air Force Research Library
Session Assistant

1:00 – 1:20 pm

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Charles Romaniello III
Picatinny Arsenal

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Dr. Nate Sanchez
Los Alamos National Laboratory

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Nathan Millard
L3 Defense Electronic Systems

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20380

Jerome Norris
Sandia National Laboratories

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Yao Wang
Institute of Chemical Materials

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Alexander Neeb
U.S. Army Fuze Division

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Wanjun Wang
Institute of Chemical Materials

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Alexander Neeb
U.S. Army Fuze Division

2:20 – 2:40 pm

Statistics for One Shot Devices

Dr. Barry Neyer
Excelitas Technologies Corp.

Defining Structural Dynamic Environments for Penetrator Fuzes
20361

Alma Oliphant
Applied Research Associates, Inc.

2:40 – 3:00 pm

Statistics for One Shot Devices

Dr. Barry Neyer
Excelitas Technologies Corp.

Development of Setback Locks for High Reliability
20297

John Geaney
ARDEC Fuze Division

3:00 – 3:20 pm

NETWORKING BREAK
RIO VISTA GRAND FOYER

Sponsored By Kaman Fuzing & Precision Products

CONCURRENT BREAKOUT SESSIONS

Continued

	SESSION 5A – OPEN SESSIONS RIO VISTA GRAND BALLROOM, SALONS F - H	SESSION 5B – CLOSED SESSIONS RIO VISTA GRAND BALLROOM, SALONS A - D
	Perry Salyers L3 Defense Electronic Systems *Session Chair*	**Byron Lee** Orbital ATK *Session Chair*
	David Lawson L3 Defense Electronic Systems *Session Assistant*	**Frank Fairchild** Air Force Research Library *Session Assistant*
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5:00 – 5:20 pm

Take the Fuze Safety Design Quiz, Part I **Session 5B Complete**

Homesh Lalbahadur
U.S. Army ARDEC

5:20 pm

ADJOURN

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L3 Defense Electronic Systems

L3 DEFENSE ELECTRONIC SYSTEMS

OPENING RECEPTION & REGISTRATION SPONSOR

L3 Defense Electronic Systems (L3 DES), a division of L3 Technologies, Inc., provides precision electronic components, subsystems, and systems for the Department of Defense and international allies. L3 DES specializes in the design and manufacture of build to print and modernized fuze solutions, ignition safety devices, proximity sensors, inertial measurement and GPS navigation systems, assured position, navigation, and timing (A-PNT) capabilities, aerospace status indicators, and intelligence management systems. As a trusted partner, you can count on L3 DES to deliver quality products and develop superior solutions that enhance capabilities and provide overmatch superiority to the warfighter.

Headquartered near Cincinnati, Ohio, L3 DES' primary manufacturing facility was specifically designed and constructed for the manufacture of fuzing and ordnance systems and precision electronic components. With additional locations in Anaheim, CA, Budd Lake, NJ, and San Diego, CA, L3 DES has strategically located its resources, including program management, engineering, and quality assurance, at each site to ensure complete adherence to programmatic and technical requirements, enabling process efficiencies.

Dedicated to continuous improvement, L3 DES operates a quality management system certified to AS9100D and ISO 9001:2015 standards. With highly flexible manufacturing operations, L3 DES can accommodate a variety of products, with run rates that can exceed 40,000 units per month down to individual production units for development efforts. L3 DES also has on-site inspection and test capabilities to perform all required environmental test procedures.

At L3 DES, customer focus is a key element of who we are and how we operate. Our customers are the foundation of our success and we are committed to establishing long-term relationships and ensuring collaboration throughout the product lifecycle.

L3 DES is committed to supporting the warfighter. We will continue to innovate and develop unique solutions by leveraging our valued workforce. To learn more, please visit www.L3T.com or call 513-943-2000.

ORBITAL ATK

GRAND RECEPTION SPONSOR

Orbital ATK is an industry-leading developer and manufacturer of defense and aerospace components and armament systems. Among our extensive portfolio of highly engineered products are some of the most technologically advanced intelligent fuzes available today, including the hard and deeply buried target defeat FMU-167/B void sensing penetrating bomb fuze, the FMU-139D/B all-electronic general purpose bomb fuze, the Multi-Function Fuze (MFF) for the 5 Inch 54 naval surface deck gun, and the Precision Guidance Kit (PGK) field artillery fuze for the U.S. Department of Defense and allies. In addition to munitions fuzing, Orbital ATK designs and produces proximity height of burst sensors for direct attack munitions, as well as rocket motor Ignition Safety Devices (ISD) and Flight Termination Systems (FTS) for the missile community.

For more information about these and other fuzes offered by Orbital ATK, visit us at www.OrbitalATK.com.

EXCELITAS TECHNOLOGIES CORP.

WEDNESDAY LUNCH SPONSOR

Excelitas Technologies Corp. is a global technology leader focused on delivering innovative, high-performance, market-driven photonic solutions to meet the lighting, detection, and optical technology needs of global customers.

Excelitas Technologies is a supplier of energetic safety systems for initiation, actuation, and detonation applications. Our scientific and engineering personnel have spent many years developing a fundamental understanding of all aspects of energetic device performance and testing. Knowledge of the basic properties of these devices allows the performance of Excelitas' products to exceed typical aerospace and defense requirements and makes them the energetic safety systems of choice for many defense and aerospace systems.

Leader in providing innovative defense and aerospace solutions, Excelitas Technologies is committed to enabling our customers' success in their end-markets. Excelitas Technologies has approximately 6,000 employees in North America, Europe, and Asia; serving customers across the world. Connect with Excelitas on Facebook, LinkedIn, and Twitter.

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CONFERENCE PROGRAM SPONSOR

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TABLE TOP INFORMATION

DISPLAY HOURS

TUESDAY, MAY 15
4:00 – 6:00 pm

WEDNESDAY, MAY 16
7:00 am – 7:00 pm

THURSDAY, MAY 17
7:00 am – 3:30 pm

TABLE TOP DISPLAYS

Chem Processing, Inc.

Diehl & Eagle Picher GmbH

EnerSys Advanced System

Excelitas Technologies Corp.

Gowanda Components Grou

HT MicroAnalytical, Inc.

Knowles-Novacap

L3 Defense Electronic Systems

Meggitt Sensing Systems

NASCENTechnology Manfacturing, Inc.

Orbital ATK

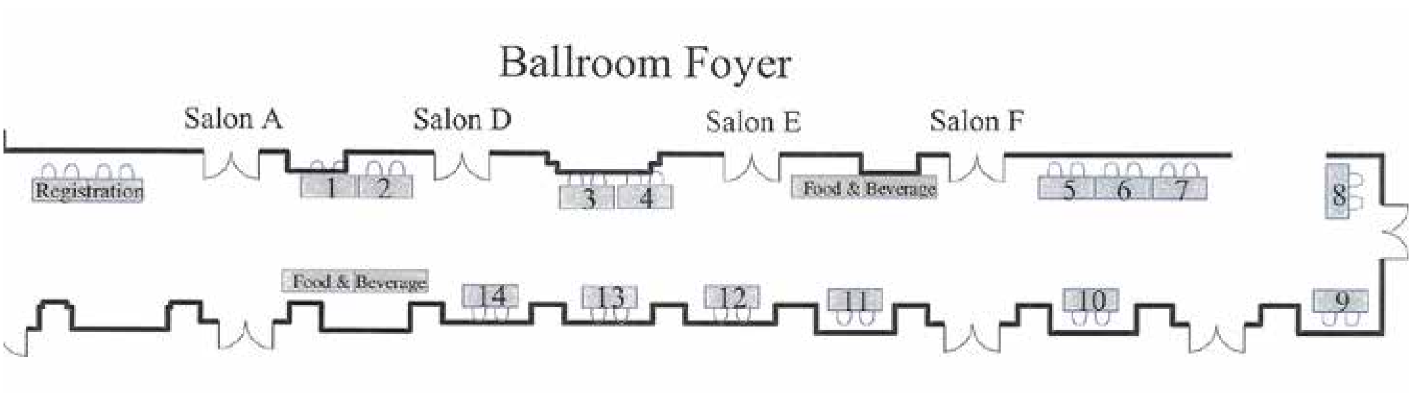
PCB Piezotronics, Inc.

Presidio Components, Inc.

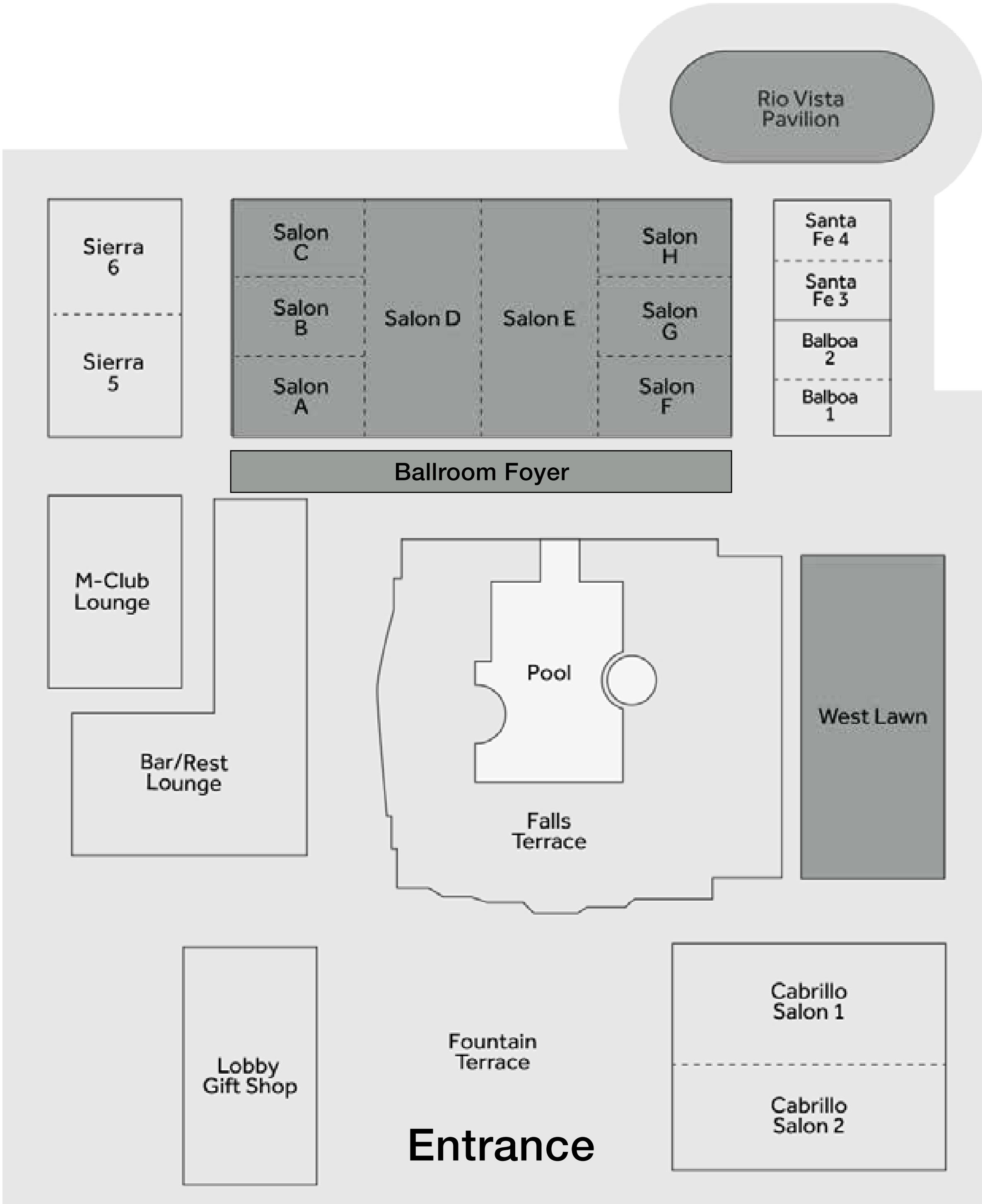
Teledyne e2v

Thiot Ingenieriee

MAP



VENUE MAP


Rio Vista
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Ballroom Foyer
M-Club
Lounge
Bar/Rest
Lounge
Pool
Falls
Terrace
West Lawn
Lobby
Gift Shop
Fountain
Terrace
Entrance
Cabrillo
Salon 1
Cabrillo
Salon 2

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Orbital ATK

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MTS SYSTEMS CORPORATION

PRESIDIO

SAVE THE DATE

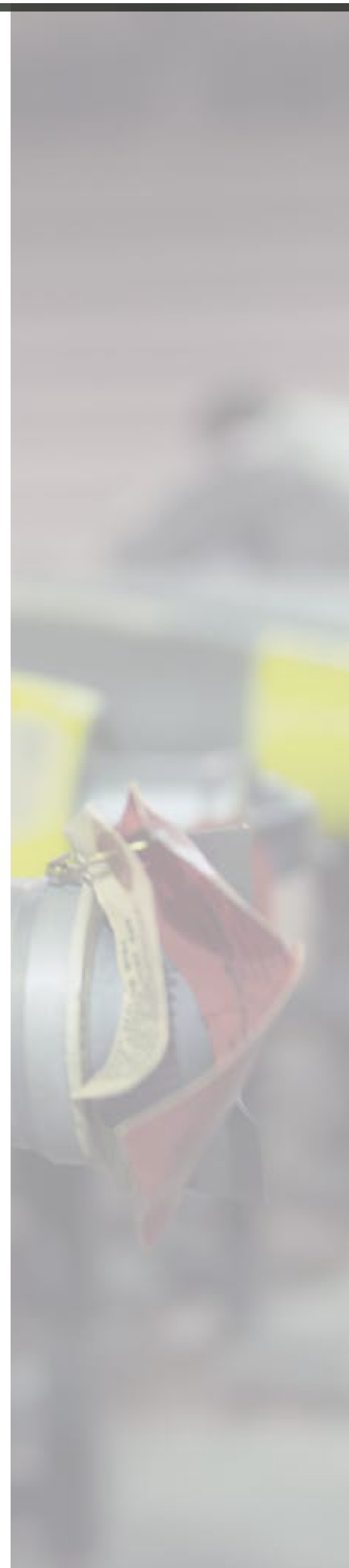
2018 INTERNATIONAL EXPLOSIVES SAFETY SYMPOSIUM & EXPOSITION

August 6 – 9, 2018

Sheraton San Diego Hotel & Marina

San Diego, CA

NDIA.org/Events



Unmanned System Safety Precepts

NDIA 2018 Fuze Conference

Presenter:
Jeffrey Fornoff, US Army

UxS Safety IPT Objectives

- ✓ **Updated 2007 Guide and Developed New Precepts**
  - ✓ **Filled critical gaps in AI, Autonomy, V&V**
  - – Subsequent to the 2007 UMS Safety Guide, the DoD perspective on autonomy evolved
  - – 2016 study by the Defense Science Board titled, “The Role of Autonomy in DoD Systems,” highlights need for a dynamic approach to evolving DoD policy regarding autonomous systems
- ✓ **Interfacing with Services**
  - – DOA – integrate Networked Munitions Requirements
  - – DON – interface with DASN UxS & RDT&E
  - – DAF – interface with USAF Safety Directorate
- ✓ **Collaborating with stakeholders**
  - – Collaborating with DOS [*the UN CCW LAWS talks*] and Defense Science Board
  - – Ensure unique interests, capabilities, and concerns are shared, leveraged, and addressed
  - – Integrate other Federal Agencies with similar interests
- – **Institutionalize UxS Safety Guidance**

<u>Guide sets threshold of rules of behavior that manage programmatic, design & operational characteristics aligning associated requirements</u>.

Programmatic Safety Precept (PSP) = Program management principles that help insure safety is adequately addressed throughout the lifecycle process.

Operational Safety Precept (OSP) = A safety precept directed at system operation setting operational rules to be adhered to. These safety precepts may generate the need for DSPs.

Design Safety Precept (DSP) = Design guidance that facilitates safety of the system and minimizes hazards. Safety design precepts are intended to influence, but not dictate, solutions.

UxS Safety Challenges

Critical Gaps

[*no meaningful safety guidance or policy in place*]:

1. Diverging & Missing Definitions
2. Authorized Entity Controls
3. Flexible Autonomy
4. Fail Safe Autonomy
5. Autonomous Function V&V
6. Artificial Intelligence (AI)

- **Highly Complex & Evolving Technologies**
  - Understanding technological complexities associated with Gap areas and their relationship to safety
- **Unmanned Systems (UxS's) cross many boundaries**
  - Cross Service and Cross Agencies - all Department of Defense (DoD) services and operational domains
  - Research & Development and S&T organizations
  - Various Federal Agencies & Industry e.g., DOT, NGA, DOE, DHS, USCG, etc.
- **AI technology advancing faster than expected and with less safety assurance**
- **UxS Lexicon**
  - Taxonomy gap bigger / more central than expected
  - To ensure guidance is effective terminology, lexicon, and definitions must align
    - New and unique terms evolve as a result of on-going scientific research and engineering
- **AI risk mitigation methodologies and techniques are at best immature**
  - E.g., V&V; Probabilistic software analytics; code level analysis techniques; etc.
  - Difficulties exacerbated in a Rapid Acquisition environment

Key Autonomy Safety Focus Points

- **Achieving Safety with Autonomy**
  - When tasks are assigned, the assigner bounds the assignment when issuing the task, and checks the bounds when the plan is generated
  - When autonomous functions are operating in a semi-autonomous mode, the human does the bounds checking
- **Bounding Autonomous Functionality**
  - Once the human is out of the loop (fully autonomous), deterministic bounded software becomes a real-time validator of the autonomous function or a notification for a human that an autonomous activity is taking place
  - Without separate deterministic bounding software, hazards may increase and trust may decrease when novel solutions are offered by the autonomous functions
- **Managed Machine Learning & Learning Mode**
  - A side effect of machine learning is the potential to execute unsafe decisions
  - The use of machine learning is expected to increase
  - Managed machine learning, or the concept of "Learning mode", provides a tool to enable or disable machine learning and a mitigation to associated potential risk
- **Flexible Autonomy**
  - Flexible autonomy allows, without reprogramming, rapid safe reconfiguration of the system based on validation results, field experience with the system, changing mission parameters or rules of engagement, DoD policy.
  - It allows people to rapidly grant the system more autonomy as trust is developed. It also allows people to rapidly revoke autonomy where trust has been compromised.

Safety Issues with UxS

- **Autonomous UxSs inherently introduce potential mishap risk to humans for many different reasons, ranging from unpredictable movements, to loss of absolute control, to potential failures in both hardware and software.**
- **Weaponized UxSs present even more significant and complex dangers to humans.**
- **Typical safety concerns for military UxSs, that apply across semi-autonomous, supervised, and fully autonomous UxSs include:**
  - Loss of control over the UxS
  - Loss of communications with the UxS
  - Loss of UxS ownership (lost out of range or to the enemy)
  - Loss of control of UxS weapons
  - Unsafe UxS returns to base
  - UxS in indeterminate or erroneous state
  - Knowing when an UxS potentially is in an unsafe state
  - Unexpected human interaction with the UxS
  - Inadvertent firing of UxS weapons
  - Erroneous firing of UxS weapons
  - Erroneous target discrimination
  - Enemy jamming or taking control of UxS

Unmanned System Safety Guide

- The purpose of this guide is to aid the PM’s team, the operational commander, and the systems engineer in recognizing and mitigating system hazards unique to partially or fully autonomous design capabilities.
- It augments the tasks within MIL-STD-882 with additional details to address UxSs and the incorporation of greater levels of autonomy and machine learning.
- Autonomous capabilities create unique safety challenges beyond those addressed in other safety guidance.
- This guide lists safety precepts that must be followed in order to address safety with respect to programmatic, operational, and design considerations

Safety Precepts

- **Programmatic**
  - directed specifically at program management. These principles and guidance are designed to ensure safety is adequately addressed throughout the UxS lifecycle process.
- **Operational**
  - directed specifically at system operation. These precepts contribute to operational rules that must be adhered to during system operation.
- **Design**
  - provide detailed and specific guidance to address safety issues associated with UxSs.

Programmatic Safety Precepts

- **PSP-1**
  - Establish and maintain a Systems Safety Program (SSP) in accordance with MIL-STD-882 (current version) for all life cycle phases.
- **PSP-2**
  - Establish consistent and comprehensive safety precepts across all UxS programs under their cognizance to ensure:
    - Mishap risk is identified, assessed, mitigated, and accepted
    - Each system can be safely used in a combined and joint environment
    - That all safety regulations, laws, and requirements are assessed and addressed
- **PSP-3**
  - Ensure that off-the-shelf items (e.g., COTS, GOTS, NDI), re-use items, original use items, design changes, technology refresh, and technology upgrades (hardware and software) are assessed for safety, within the system.
- **PSP-4**
  - Ensure compliance to and deviation from the UxS safety precepts are addressed during program reviews such as System Safety Working Groups (SSWG), System Readiness Reviews (SRR), Preliminary Design Reviews (PDR), & Critical Design Reviews (CDR) and Internal Program Office Reviews (IPR).

Programmatic Safety Precepts

- **PSP-5**
  - Ensure the UxS complies with current safety policy, standards, and design requirements.
- **PSP-6**
  - Ensure that the UxS, by design, does not allow subversion of human command or control of the UxS.
- **PSP-7**
  - Ensure that safety significant functions and components of an UxS are not compromised when utilizing flexible autonomy where capabilities or functions can be added, removed, enabled or disabled.
- **PSP-8**
  - Prioritize personnel safety in unmanned systems intended to team with or operate alongside manned systems.
- **PSP-9**
  - Ensure authorized & secure control (integrity) between platform and controller to minimize potential UxS mishaps and unauthorized Command and Control (C2).
- **PSP-10**
  - Ensure that software systems which exhibit non-deterministic behavior are analyzed to determine safe employment and are in compliance with current policy.

Operational Safety Precepts

- **OSP-1**
  - The control entity of the UxS should have adequate mission information to support safe operations.
- **OSP-2**
  - The UxS shall be considered unsafe until a safe state can be verified.
- **OSP-3**
  - The control entity of the UxS shall verify the state of the UxS to ensure a known and intended state prior to performing any operations or tasks.
- **OSP-4**
  - The UxS weapons should be loaded and/or energized as late as possible in the operational sequence.
- **OSP-5**
  - Only authorized, qualified and trained personnel using approved procedures shall operate or maintain the UxS.
- **OSP-6**
  - Ensure the system provides operator awareness when non-deterministic or autonomous behaviors are utilized in the various phases of the mission.

Operational Safety Precepts

- **OSP-7**
  - The operator should establish alternative recovery points prior to or during mission operations.
- **OSP-8**
  - Weapon should only be fired / released with human consent, or control entity consent in conjunction with preconfigured criteria established by the operator.
- **OSP-9**
  - When the operator is aware the UxS is exhibiting undesired or unsafe behavior, the operator shall take full control of the UxS. [manual override]
- **OSP-10**
  - The operator must have the ability to abort/terminate/kill the mission of the UxS. [Terminate system]
- **OSP-11**
  - During mission operations the operator shall enable or disable learning mode to avoid hazardous or unsafe conditions. [learning mode]
- **OSP-12**
  - The control entity must maintain positive and active control of the UxS when any transfer of control has been initiated.

Design Safety Precepts

- **DSP-1**
  - The UxS shall be designed to minimize the mishap risk during all life cycle phases.
- **DSP-2**
  - The UxS shall be designed to only fulfill valid commands from the control entity.
- **DSP-3**
  - The UxS shall be designed to provide means for C2 to support safe operations.
- **DSP-4**
  - The UxS shall be designed to prevent unintended fire and/or release of lethal and non-lethal weapon systems, or any other form of hazardous energy.
- **DSP-5**
  - The UxS shall be designed to prevent release and/or firing of weapons into the UxS structure itself or other friendly UxS/weapons.
- **DSP-6**
  - The UxS shall be designed to safely initialize in the intended state, safely and verifiably change modes and states, and prevent hazardous system mode combinations or transitions.
- **DSP-7**
  - The UxS shall be designed to be able to abort operations and should return to a safe state.

Design Safety Precepts

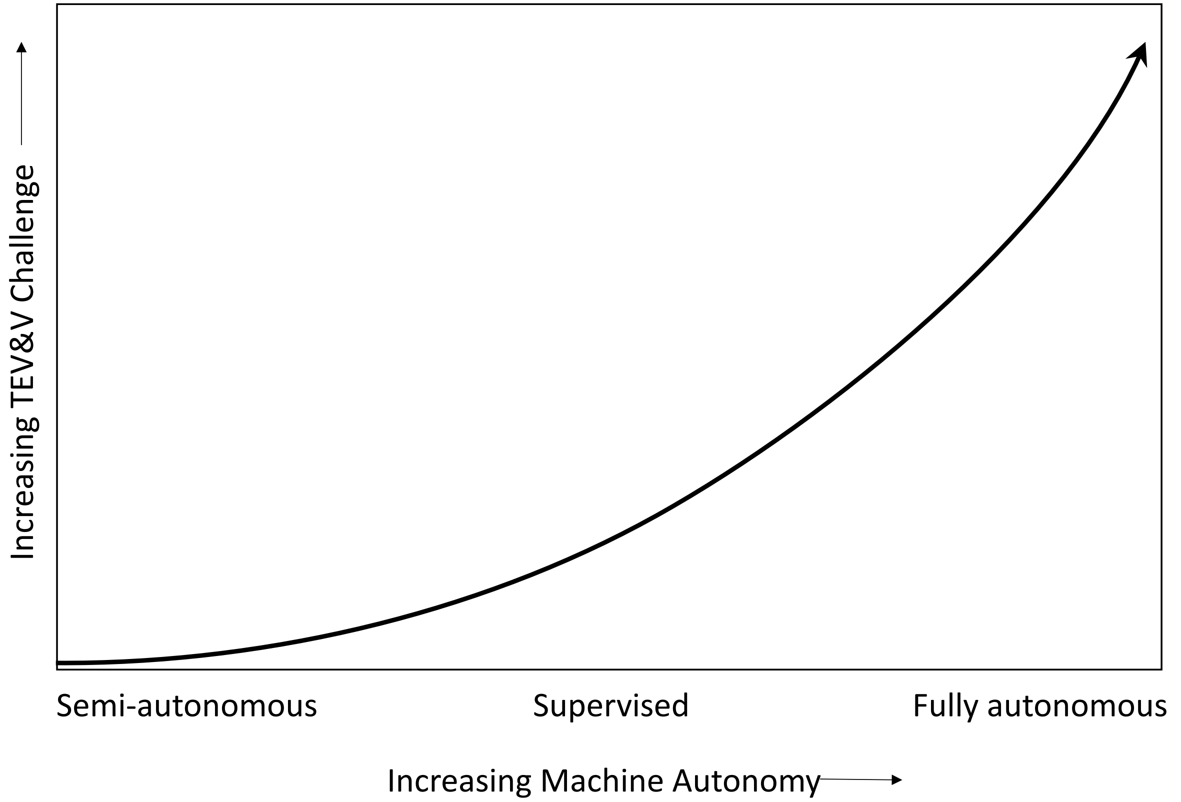
- **DSP-8**
  - Non-deterministic software, as well as safety critical software, shall be physically and functionally partitioned.
- **DSP-9**
  - The UxS shall be designed to minimize single-point, common mode or common cause failures, that result in high and/or serious risks.
- **DSP-10**
  - The UxS shall be designed to mitigate the releasing or firing on a friendly or wrong target group selection.
- **DSP-11**
  - The UxS shall be designed to transition to a pre-configured safe state and mode in the event of safety critical failure.
- **DSP-12**
  - The UxS shall be designed for safe recovery if recovery is intended.
- **DSP-13**
  - Use of the UxS newly learned behavior should not impact the UxS' safety functionality until the newly learned behavior has been validated.

Design Safety Precepts

- **DSP-14**
  - Autonomy shall only select and engage targets that have been pre-defined by the human.
- **DSP-15**
  - Common user controls and display status should be utilized for functions such as: Manual Override (OSP-9), Terminate Mission (OSP-10), and Learning Mode (OSP-11).

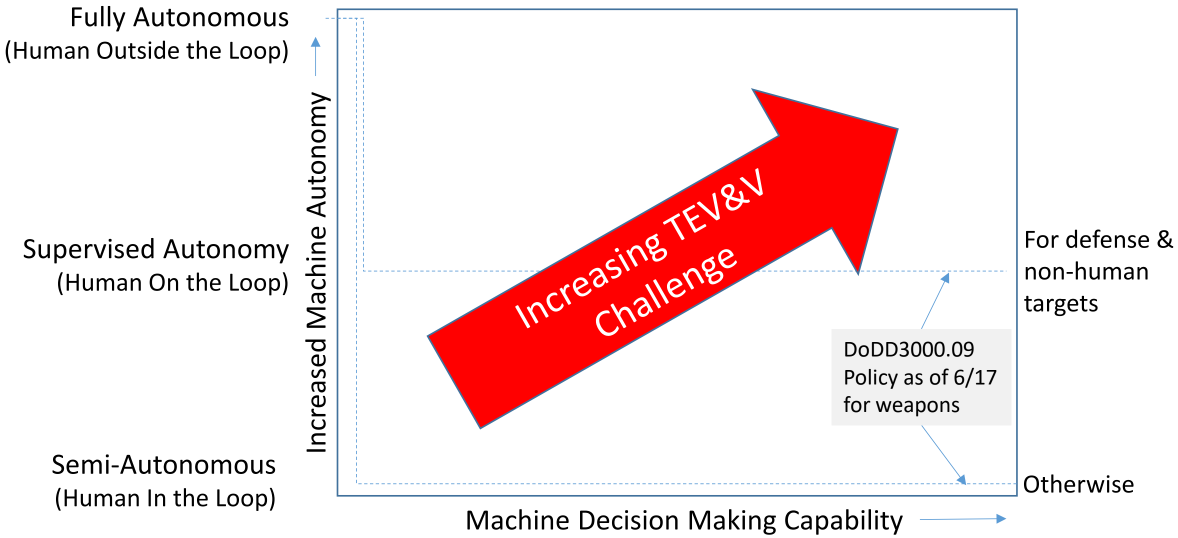
TEV&V Challenges

- The relative magnitude of the challenge as a function the extent of autonomy in the system has been estimated as being exponential due to state-space explosion and increasing lines of software



TEV&V Challenges

- The challenge to make the system capable and safe while meeting policy and passing the TEV&V portion of the acquisition process increases both as the machines decision making capabilities increase and as the degree of autonomy that it is provided increase.



	Automatic	Automated	Autonomy	
			Behavioral	Cognitive
V&V	Verifiable	Technically Verifiable	Non-Verifiable	TBD
Sample Technology	Data Processing	Expert System	Machine Learning	TBD
Complexity	Simple	Complex	Highly Complex	TBD
Outputs	Deterministic		Probabilistic	TBD



A Study on New-type High-Overload Loading Technology Based on Stress Wave Propagation under the Impact of Air Explosion

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1. Introduction

2. Outline of the Method

3. Experiment and Discussion

4. Finite Element Simulation

5. Future work

6. Acknowledgement

1. Introduction
2. Outline of the Method
3. Experiment and Discussion
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5. Future work
6. Acknowledgement

1. Introduction

- High overload in penetrating will lead to failure of projectile-born devices, such as fuze, detonator, and other electron device.
- In order to reinforce the projectile-born devices, it is necessary to study the failure mechanism caused by high overload during penetrating.
- Numerical simulation is unusable in most cases because of the structural complexity of the devices.
- Existing experiment method, such as Split Hopkinson Bar, Light-Gas Gun, Machete Hammer, etc. is limited because the peak magnitude and duration of the acceleration is insufficient compared with that in real penetrating.
- A new-type indoor method for high overload loading is proposed in this presentation, which is characterized by high peak acceleration, long duration, high efficiency and low cost.

1. Introduction

2. Outline of the Method

3. Experiment

4. Result and Discussion

5. Future work

6. Acknowledgement

2. Outline of the method

- The proposed method is based on a viewpoint that devices failure during penetrating is due to the stress wave propagation.
- In case of structure impact by high pressure and high velocity explosion product, the propagation of stress wave in the structure is similar to that in penetrating.
- Cylindrical LLM-105 explosive is used. A specific structure containing a sample is impact by the explosion product in this presentation.

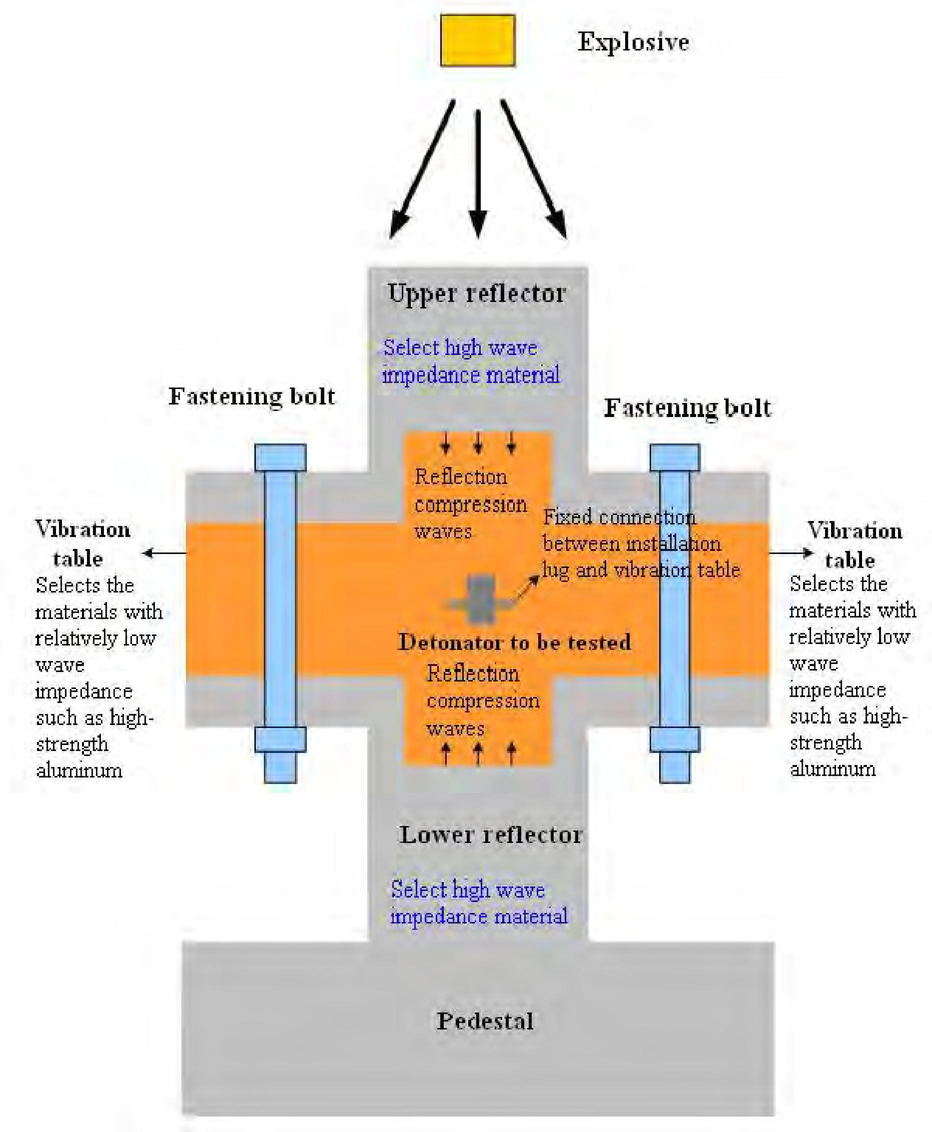

Fig.1 Schematic of the proposed method

3. Experiment and Discussion

- The experiments were conducted indoor. A structure as shown in Fig.1 was impact by explosion product. Φ40mm×23mm LLM-105 explosive was used and initiated by a 8# detonator.
- The explosive was 500m, 400mm and 300mm away from the structure, respectively. An acceleration sensor was fixed by two M2 bolts inside the structure, as shown in Fig.3.
- No plastic deformation happens in the structure, so it can be reused for many times.

Fig.2 Experiments arrangement

✓ Bottom of the sensor was lef t blanket, in order to protect th e sensor from the impact of str ess wave.

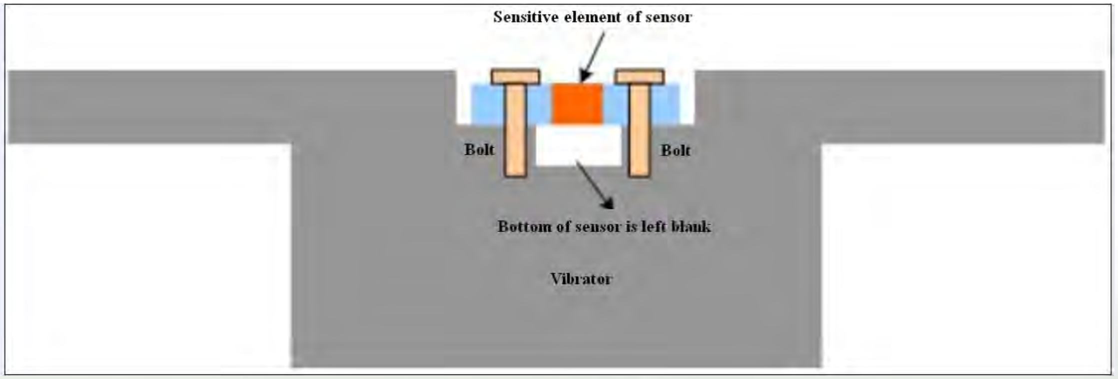

Fig.3 Schematic of the installation of the sensor

3. Experiment and Discussion

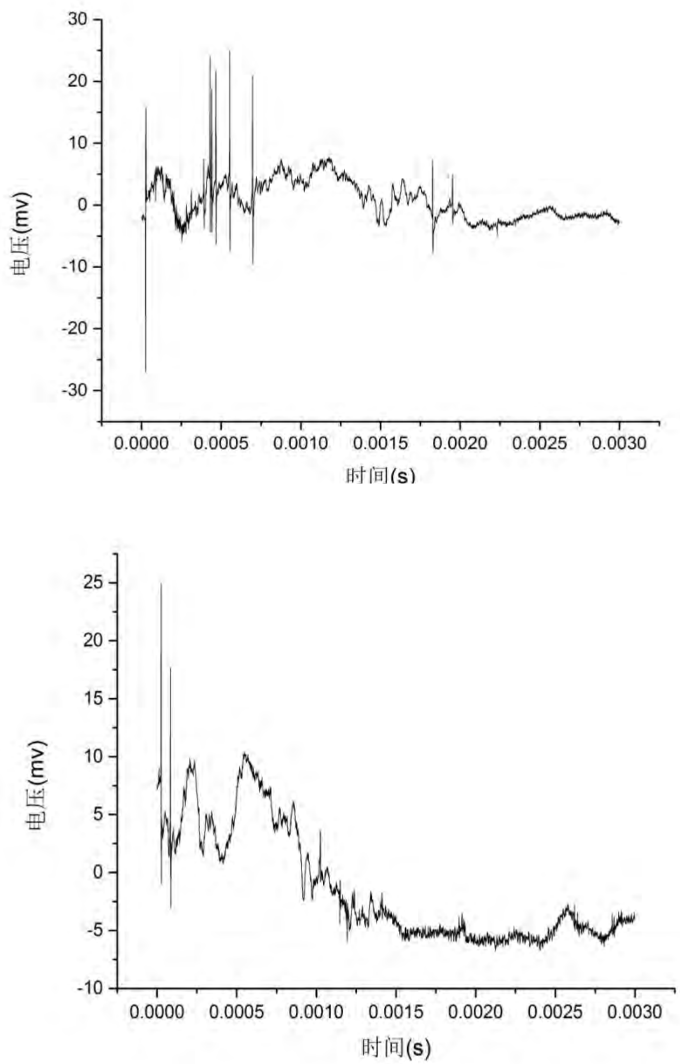

Fig.4 Typical Voltage Signal in Experiment

- Typical voltage signal from experiment is shown in Fig.4. The voltage signal can be translated into acceleration if the sensitivity of the sensor is given.
- In the case of explosive 400mm away from the structure, the peak acceleration was 33000g, while the duration is 1.5ms.
- The peak acceleration could be even higher if the distance between the explosive and the structure was shorten.
- The overload level in real penetrating could be achieved without difficulty by changing the distance between the explosive and the structure, or the size of the explosive.

4. Finite Element Simulation

- In order to reveal the mechanism of the acceleration history, a finite element simulation with LS-DYNA code was conducted.
- From the simulation, we can conclude that both the shock wave in air and the explosion product contribute to the acceleration.
- It is clear that the stress wave reflection at the material interface will influence the acceleration history.

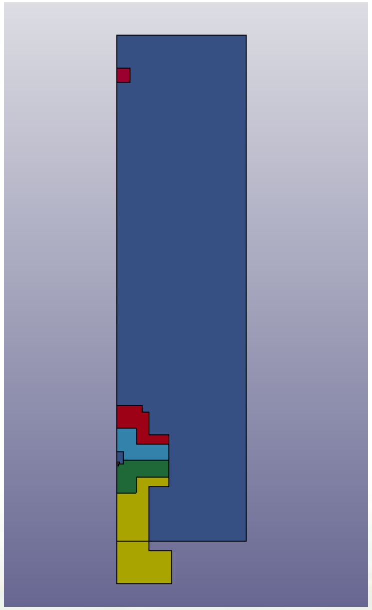

Fig.5 Simulation Model

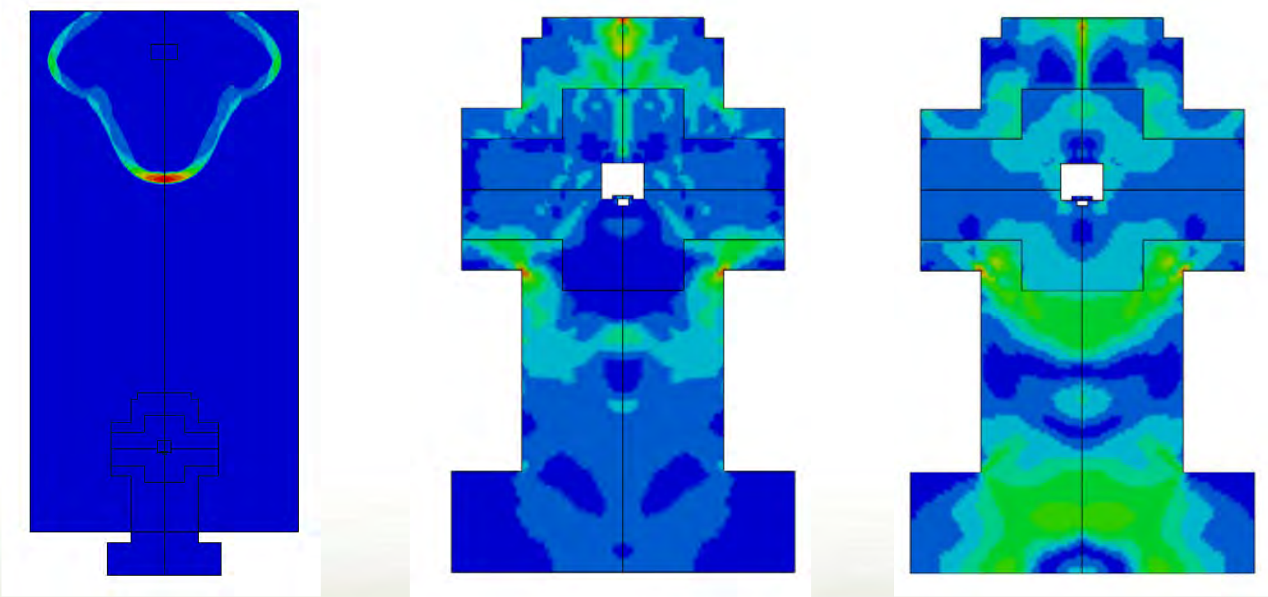

Fig.6 Stress wave propagation in the structure

1. Introduction

2. Outline of the Method

3. Experiment and Discussion

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5. Future work

6. Acknowledgement

5. Future Work

The future work will be focused on the following 3 directions:

- More accurate simulation will be conducted, in order to give more insight into the relation between the stress wave propagation and the acceleration;
- By designing the structure carefully, the acceleration history will be controlled.
- The application of the proposed method: such as evaluating the anti-overload performance of electronic devices, studying the failure mode of the projectile-born devices during penetrating, reinforcing the projectile-born devices.

1. Introduction

2. Outline of the Method

3. Experiment and Discussion

4. Finite Element Simulation

5. Future work

6. Acknowledgement

6. Acknowledgement

化工材料研究所

EFIs集成设计开发团队

Team of Integrated EFI System

让交流融合思想，用集成汇聚力量！

The presented work is supported by Mingshui Zhu, Qiubo Fu, Fan Lei from Team of Integrated EFI System, Institute of Chemistry Material, CAEP.

Thanks for your attention!

Any question is welcome!

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ASELSAN is a Turkish Armed Forces Foundation company.

DEVELOPMENT OF LOW ENERGY ELECTRIC INITIATOR

61st Annual Fuze Conference
May 15th, 2018

Berkay AKYAPI & Cemil YILMAZ
ASELSAN

- Electric Initiator Usage
- Comparison
- Components
- Characteristics
- Qualification Tests
- Conclusion and Future Work

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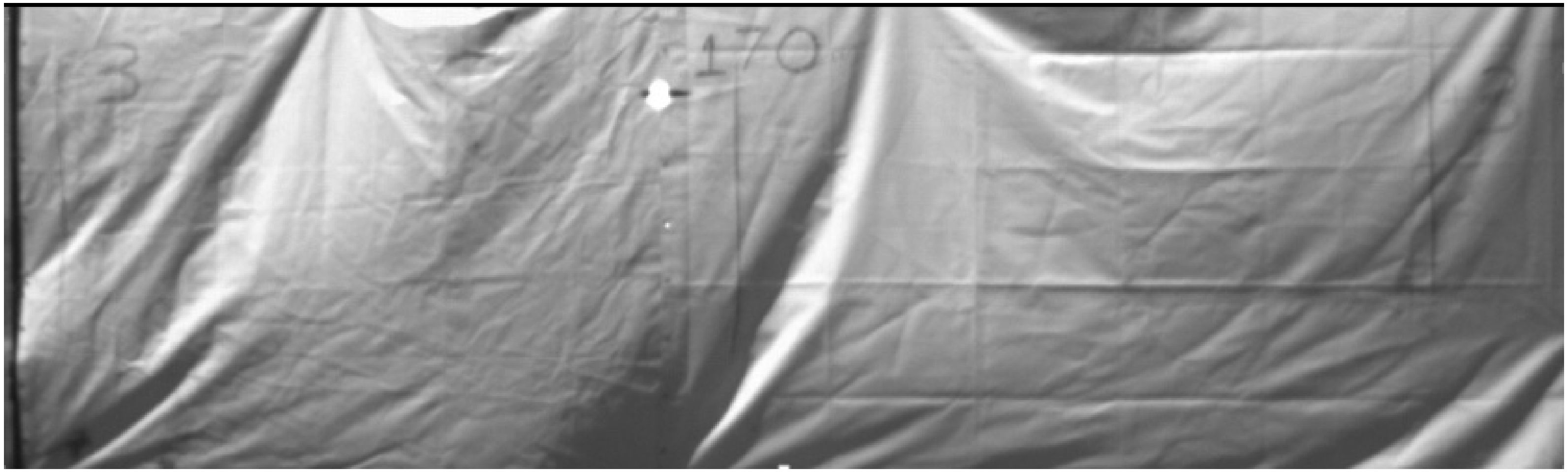
- One of the most important requirements for an ammunition is its explosion in the specified time and reliability. The unit that initiates the reaction is called Electric Initiator.
  - Initiation of energetic explosive mixture by use of electro thermal heat obtained through thin film chip.
  - Starting element of the explosive train.
  - Accuracy, low energy, short function time



ASELSAN's 35 mm Air Burst Ammunition's explosive chain reaction

Electric Initiator Usage

MILITARY APPLICATIONS

- Smart munitions,
- Ejection systems,
- Pyro components,
- Missiles

[1]

[3]

[2]

ASELSAN's 40 mm High Velocity Smart Grenade

ASELSAN's 35 mm Air Burst Ammunition

CIVIL APPLICATIONS

- Automotive safety (airbags, seat belts)
- Space applications (separators, explosive bolts)
- Mining (rock extraction)
- Industry (demolitions)

[2]

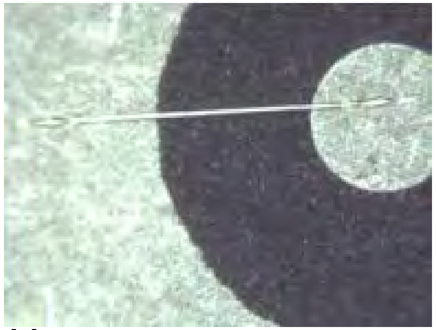
[2]

[4]

[5]

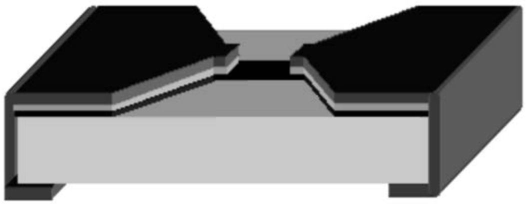
- Classic technology uses bridge wire instead of thin film initiator chip.
- This low cost initiators are produced since many years.
- Bridge wire initiators have many types and different sizes.
- But these products have disadvantages
    - Limited all-fire values, to obtain low energy initiators it has to use ultra fine(<10 micron) bridge wire
    - Difficult welding process and controlling resistance value
    - Not suitable for high shock, vibration and spin applications, e.g. smart munitions


[6]


[2]

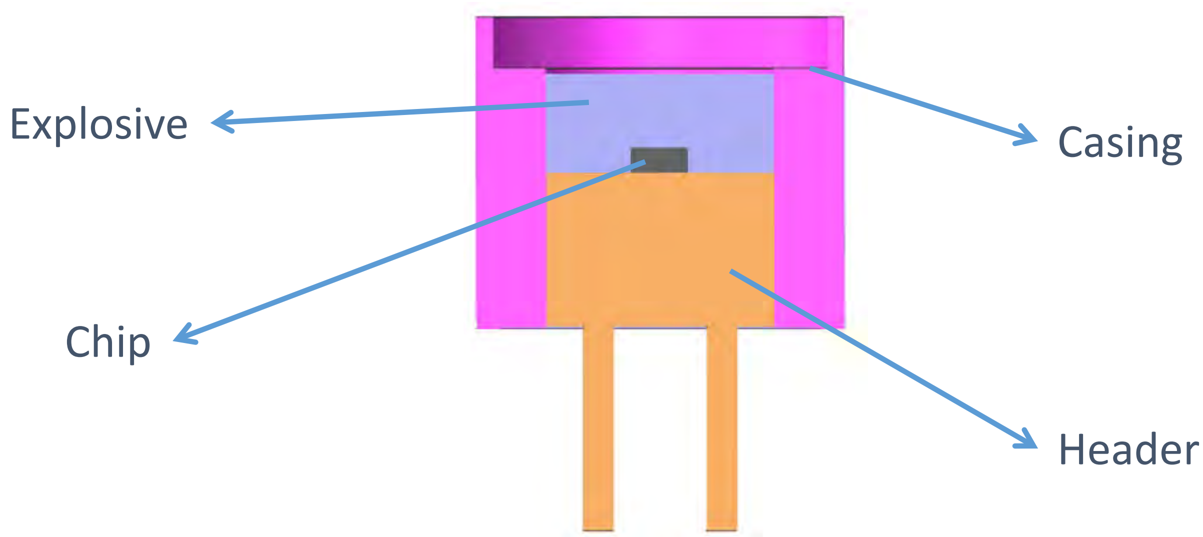
New technology uses thin film initiator chip to activate energetic materials.

Advantages	Disadvantages
Low firing energy	Cost
Low firing time	Need ESD filters
High [no fire/all fire] ratio	Need specific headers for soldering or bonding
Easy manufacturing, using automatic reflow-machines	Standart surface month resistors can be difficult for tiny initiators
Almost constant resistance value	
Withstands difficult environmental conditions	
Suitable for high accelarations and spin rates	



Electric Initiators are mainly composed of

- Glass to Metal Seal Header
- Thin Film Initiator Chip
- Explosive Mixture
- Casing



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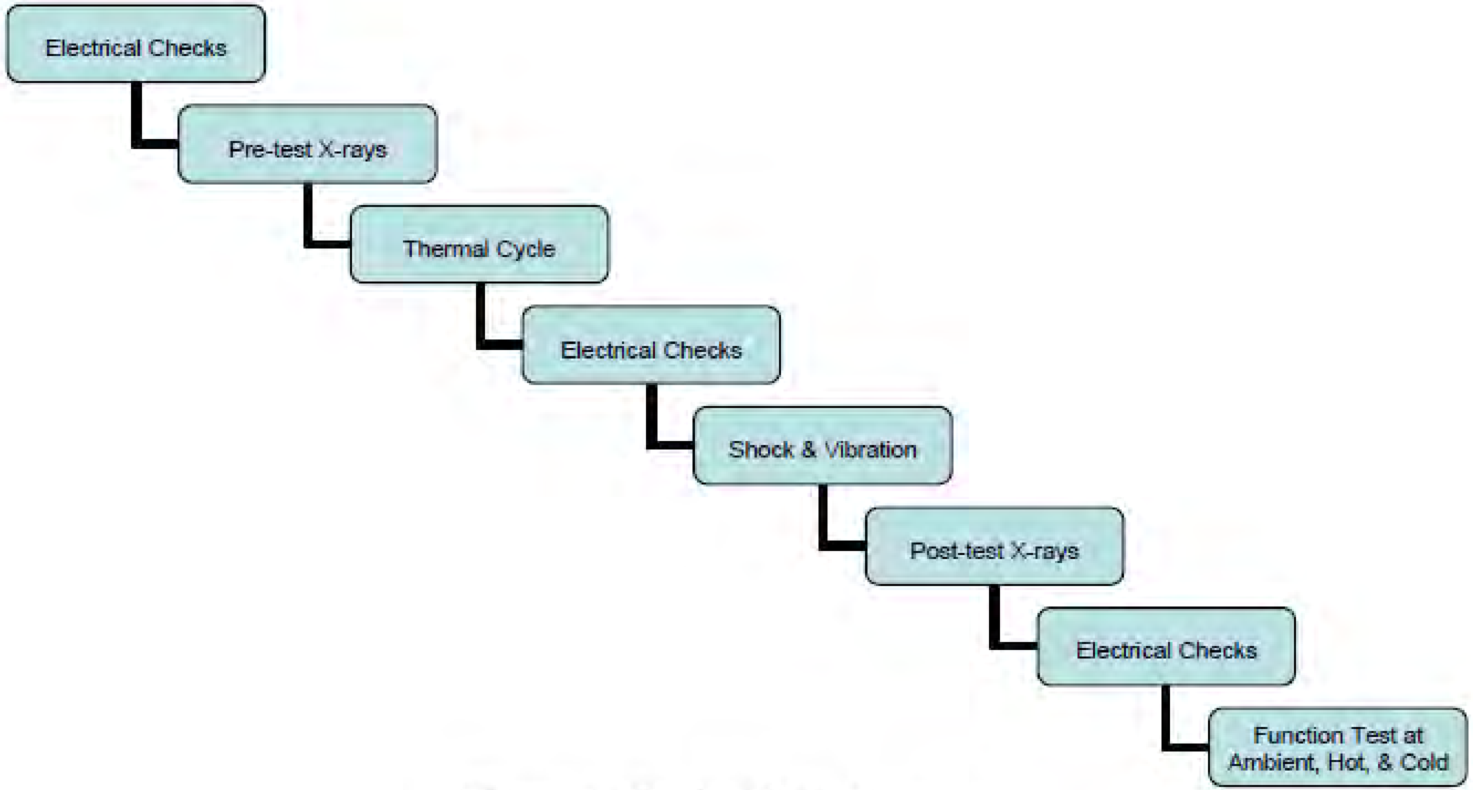

Figure 1. Typical Test Sequence.

[7]

Engineering Design Tests, were performed by the reference of MIL-DTL-23659F.

But we modified some of test routes.

Omit some of them and increase/decrease some test numbers according to our requirements.

TABLE 1: ENGINEERING DESIGN TEST SCHEDULE

TEST	REF. PARA	NUMBER OF INITIATORS (GROUPS)																					TOTAL
		50	6	6	20	20	20	20	20	20	20	20	2	2	2	2	2	2	2	2	2	176	416
Dielectric Withstanding Voltage	4.4.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Radiographic Inspection	4.1.2.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Leakage	4.1.2.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Bridge Circuit Resistance	4.4.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Static Discharge	4.4.3.2	X																					50
Bridge Circuit Resistance	4.4.2	X																					50
Stray Voltage	4.4.3.3	X																					50
Bridge Circuit Resistance	4.4.2	X																					50
Power Current or Stimulus 70° F	4.4.3.1 or 4.4.5.1	X																					50
Resistance	4.4.2	X																					50
Forty Foot Drop	4.6.1		X																				6
Six Foot Drop	4.6.2			X																			6
Shock	4.6.3				X								X	X	X	X	X	X	X	X	X		38
Vibration	4.6.4					X							X	X	X	X	X	X	X	X	X		38
Temperature-Shock/Humidity/ Altitude	4.6.5						X																20
Cook-Off	4.6.6.1							X															20
High Temperature Exposure	4.6.6.2								X														20
Salt Fog Test	4.6.7									X													20
Radiographic Inspection	4.1.2.2			X	X	X	X						X	X	X	X	X	X	X	X	X		84
Bridge Circuit Resistance	4.4.2			X	X	X	X		X	X			X	X	X	X	X	X	X	X	X		124
Leakage	4.1.2.3			X	X	X	X						X	X	X	X	X	X	X	X	X		84
Static Discharge	4.4.3.2			X	X	X	X		X	X			X	X	X	X	X	X	X	X	X		124
Bridge Circuit Resistance	4.4.2			X	X	X	X		X	X			X	X	X	X	X	X	X	X	X		124
Power Current or Stimulus 70° F	4.4.3.1 or 4.4.5.1			X	X	X	X			X			X	X	X	X	X	X	X	X	X		104
Power Current or Parmeters 225° F	4.4.3.1 or 4.4.5.1								X		X												40
Bridge Circuit Resistance	4.4.2			X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X		144
Min. 50 Milli sec. All-Fire 70° F	4.4.4	X		X	X	X				X			X			X			X			X	298
Min. 50 Milli sec. All-Fire -80° F	4.4.6						X					X		X			X			X			46
Min. 50 Milli sec. All-Fire 225° F	4.7								X		X				X			X			X		46

[8]

Engineering
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requirement

TABLE 1: ENGINEERING DESIGN TEST SCHEDULE

TESTS	23659F REFERANCE	TEST ROUTES A	B	C	D	E	F	G	H	I	J	K	L	M	N	TOTAL
		50	10	10	20	20	20	20	20	20	20	10	10	10	176	416
Radiografic Inspection	4.1.2.2	50	10	10	20	20	20	20	20	20	20	10	10	10	176	416
Bridge Circuit Resistance	4.4.2	50	10	10	20	20	20	20	20	20	20	10	10	10	176	416
Power Current or Stimulus 70° F	4.4.3.1 4.4.5.1	50														50
Bridge Circuit Resistance	4.4.2	50														50
Forty Foot Drop (12 m)	4.6.1		10													10
Siz Foot Drop (1,5 m)	4.6.2			10												10
Shock	4.6.3				20							10	10	10		50
Vibration	4.6.4					20						10	10	10		50
Temperature/Shock/Humidity/Altitude	4.6.5						20									20
Cook-off	4.6.6.1							20								20
High Temperature Exposure	4.6.6.2								20							20
Radiografic Inspection	4.1.2.2			10	20	20	20					10	10	10		100
Bridge Circuit Resistance	4.4.2			10	20	20	20		20			10	10	10		120
Power Current or Stimulus 70° F	4.4.3.1 4.4.5.1			10	20	20	20					10	10	10		100
Power Current or Stimulus 225° F	4.4.3.1 4.4.5.1								20	20						40
Bridge Circuit Resistance	4.4.2			10	20	20	20		20	20		10	10	10		140
Min 50 ms all fire (70°F)	4.4.4	50		10	20	20						10			176	286
Min 50 ms all fire (-80°F)	4.4.6						20				20		10			50
Min 50 ms all fire (225°F)	4.7								20	20				10		50

[8]

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Functional tests were done at factory level. During all-fire tests we double checked the explosion time with oscilloscope and fast-cam.

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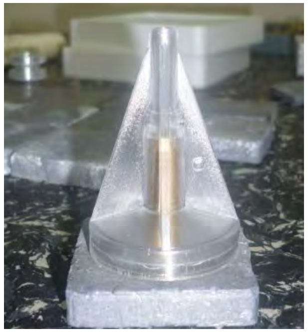
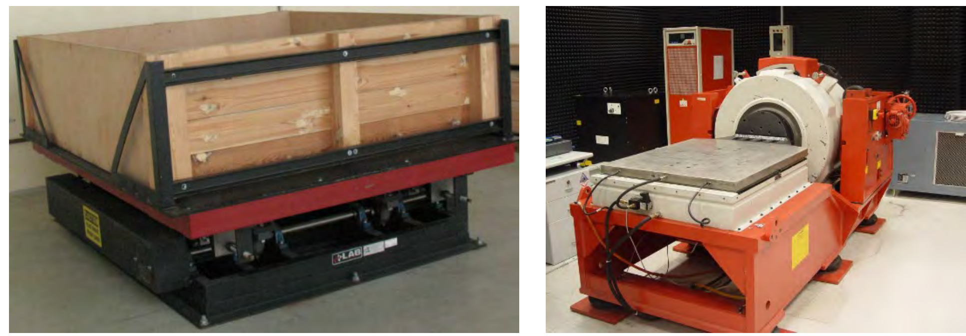
Activation of explosive train tests: Initiation of Safe and Arm

Dent in block tests

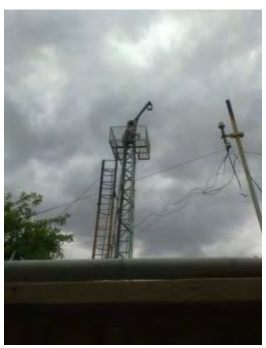


Series of environmental tests were done according to MIL-DTL-23659, STANAG 4157 and AOP-20.

Temperature and humidity cabinets



Vibration and Shock Tests

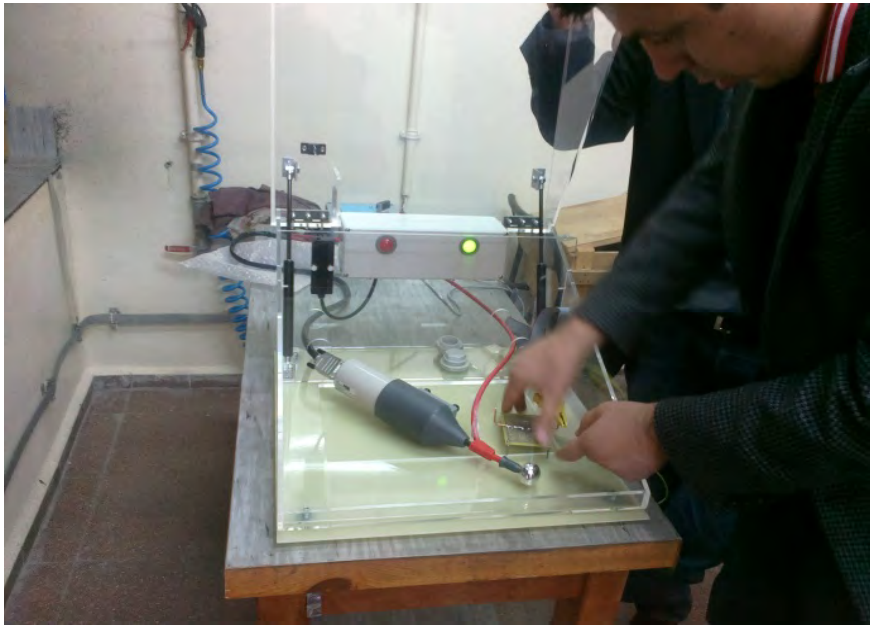


12m Drop Test

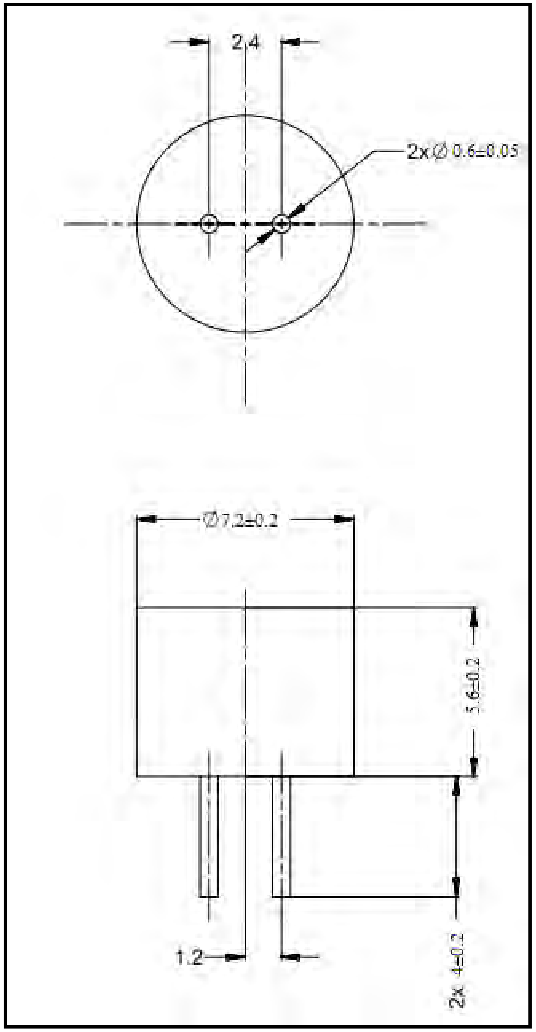
Jolt Test

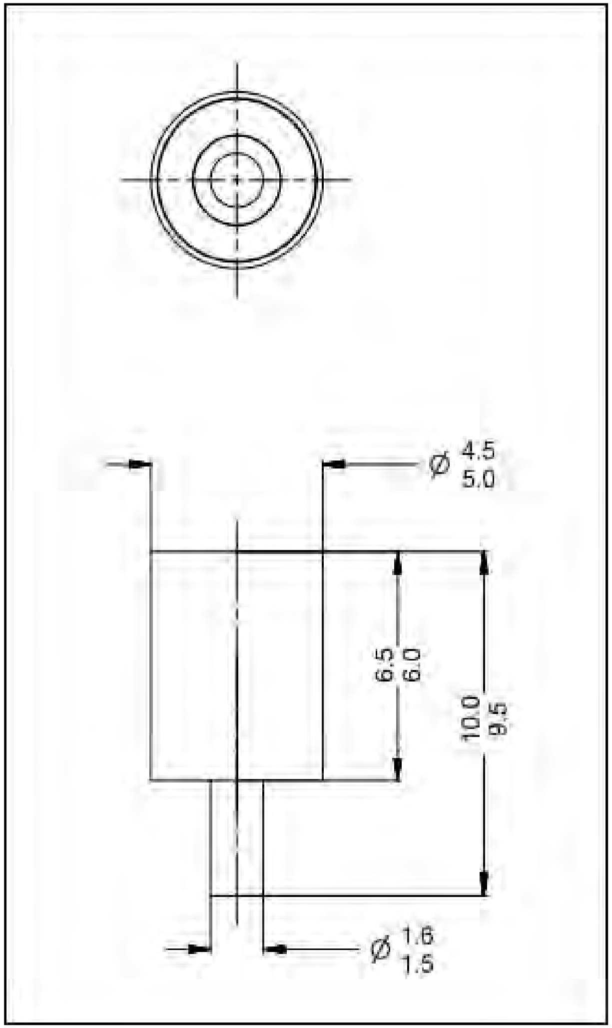
Jumble Test

- Electrostatic Discharge(ESD) tests were done.
- >10kV tested.



	Initiator 1	Initiator 2
All-Fire:	700 mA	350 mA
No-Fire (5 minutes):	450 mA	150 mA
Ignition time (max):	150 microseconds	100 microseconds
Firing Energy:	< 1 mJ	< 1 mJ
Resistance:	2.5-3.5 ohm	4-5 ohm
	~7 mm diameter	~5 mm diameter
	~10 mm length	~10 mm length
Dimensions:	double pins	single pin
Operation Temprature:	-54 +71 °C	-54 +71 °C
Service Life:	> 15 years	> 15 years
Explosive Amount:	< 100 miligrams of primary explosive	< 100 mg of primary explosive
Qualification Standard:	MIL-DTL-23659	MIL-DTL-23659





Note: The dimensions provided can be customized.

Conclusion and Future Work

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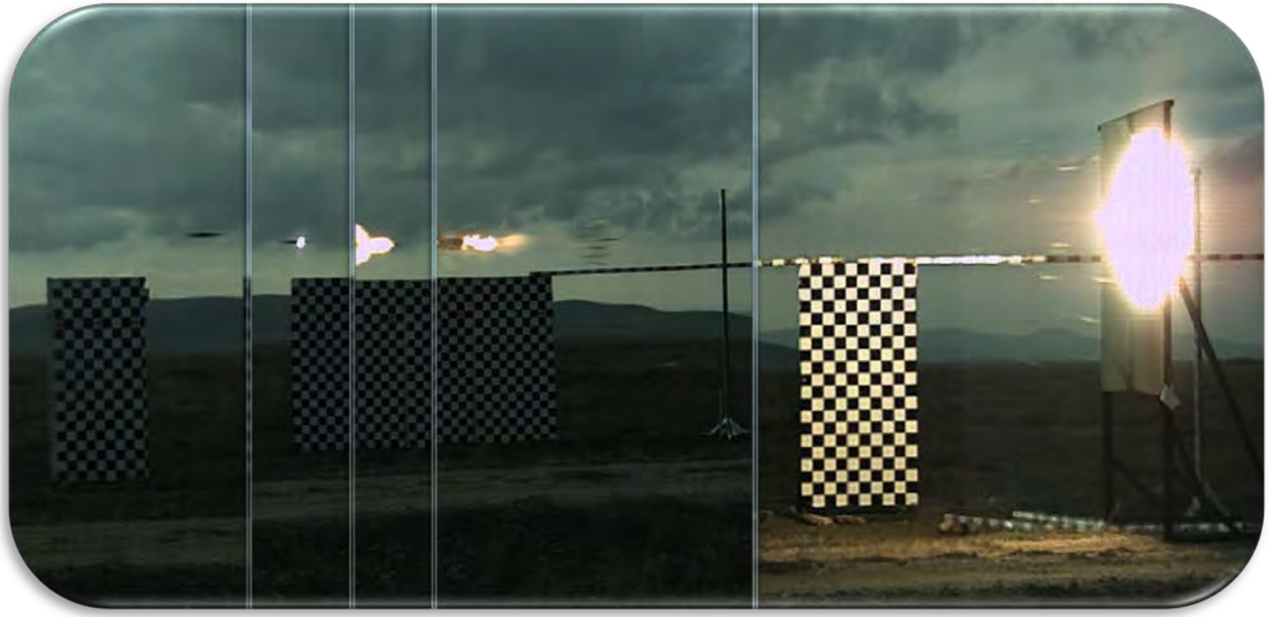
- Low Energy Thin Film Electric Initiators are developed, qualified and field-proven
- Thin Film Electric Initiators have many advantages compared to bridge wire initiators.
- The developed Electric Initiator, which is very fast and requires low energy, meets the design and performance requirements to be used in various kind of fuzes of smart munitions.



Development studies and qualification tests were conducted together with MKEK.

THANK YOU FOR YOUR ATTENTION!

QUESTIONS?

aselsan

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[1]-https://www.popularmechanics.com/military/aviation/a26193/how-pilots-eject-from-fighter-jet/ *18.04.2018*

[2]- Vishay-Sfernice Thin Film, EPIC presentation

[3]- https://psemc.com/products/pyrotechnic-cutter/ *18.04.2018*

[4]- https://www.fool.com.au/2017/12/20/205m-acquisition-boosts-orica-ltds-share-price-growth-potential/ *18.04.2018*

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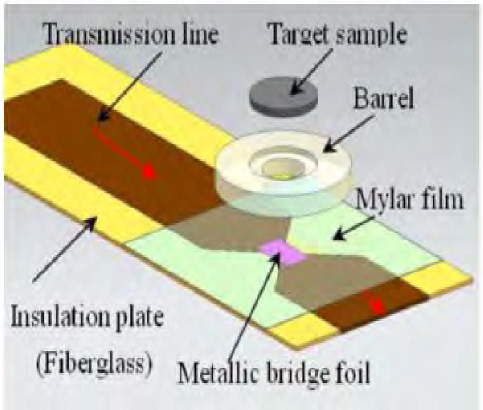
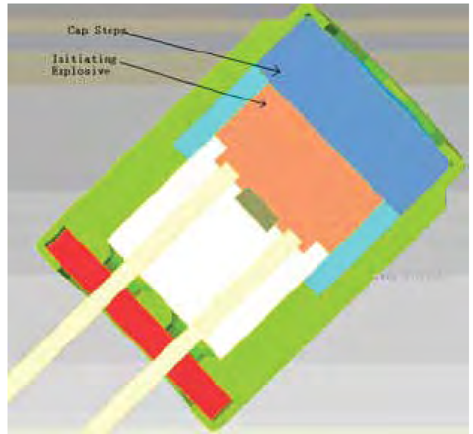
[7]- US Army Developmental Test Command Test Operations Procedure 5-2-522 Performance Testing Of Explosive Components , *20.11.2007*

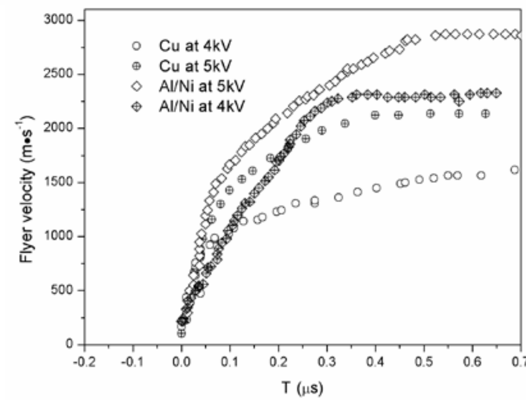
[8]- MIL-DTL-23659F

ICM

Institute of Chemical Materials







Reactive Materials for electrical initiators

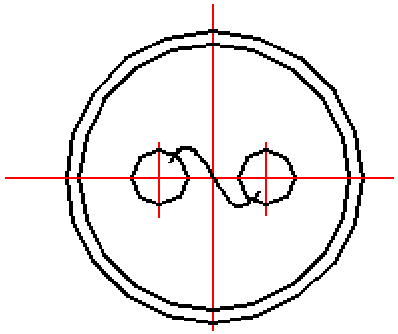
WANG YAO

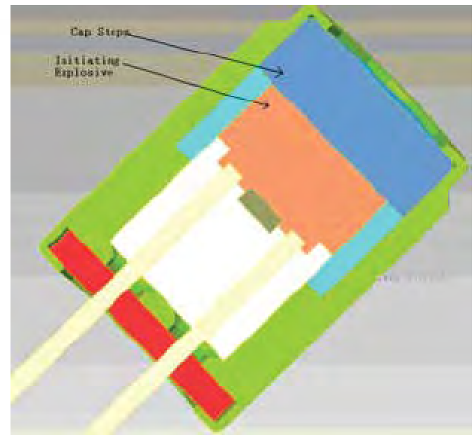
Email: wangyaocindi@caep.cn

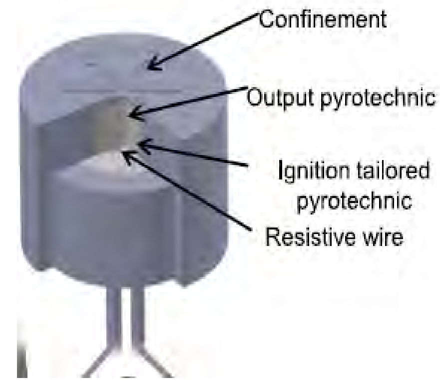
Electrical initiators

- ignition：

Resistance wire
Resistance bridge
SCB
Exploding wire

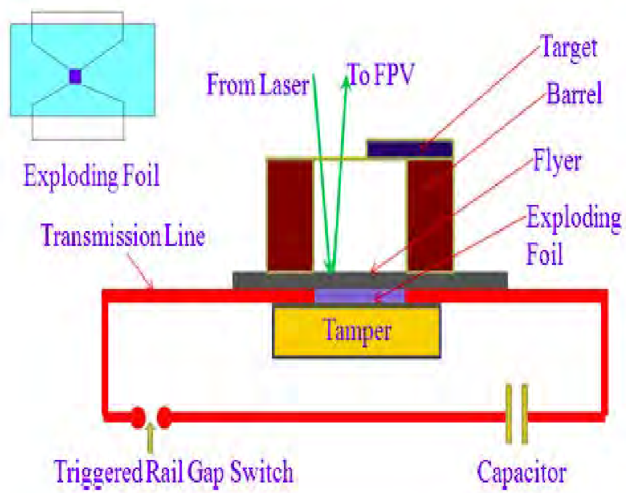


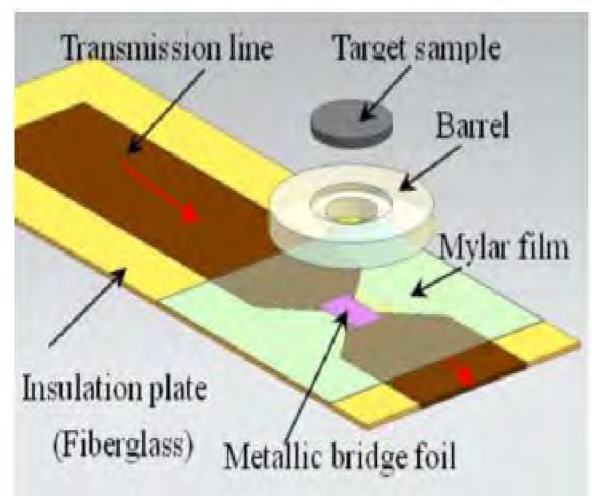




- Explosion:

Exploding foil





Reactive Materials

SAND98-1176C
To be presented at the 24th International Pyrotechnics Seminar, Monterey, CA, July 1998

THEORETICAL ENERGY RELEASE OF THERMITES, INTERMETALLICS, AND COMBUSTIBLE METALS†

S. H. Fischer and M. C. Grubelich
Sandia National Laboratories
Albuquerque, NM 87185-1453

reactants		adiabatic reaction temperature (K)		state of products		gas production		heat of reaction	
constituents	ρ_{TMD}, g/cm^3	w/o phase changes	w/ phase changes	state of oxide	state of metal	moles gas per 100 g	g of gas per g	-Q, cal/g	-Q, cal/cm^3
$2Al + 3Cu_2O$	5.280	4132	2843	liquid	l-g	0.1221	0.0776	575.5	3039
$2Al + 3NiO$	5.214	3968	3187	liquid	l-g	0.0108	0.0063	822.3	4288
$Be + CuO$	5.119	3761	2820	s-l	liquid	0.0000	0.0000	1221	6249
$2Al + 3CuO$	5.109	5718	2843	liquid	l-g	0.5400	0.3431	974.1	4976
$2Al + 3CoO$	5.077	3392	3201	liquid	l-g	0.0430	0.0254	824.7	4187
$3Ti + 2Fe_2O_3$	5.010	3358	2614	liquid	liquid	0.0000	0.0000	612.0	3066
$Ti + Fe_3O_4$	4.974	3113	2334	liquid	liquid	0.0000	0.0000	563.0	2800
$3Ti + 2Cr_2O_3$	4.959	1814	1814	solid	solid	0.0000	0.0000	296.2	1469

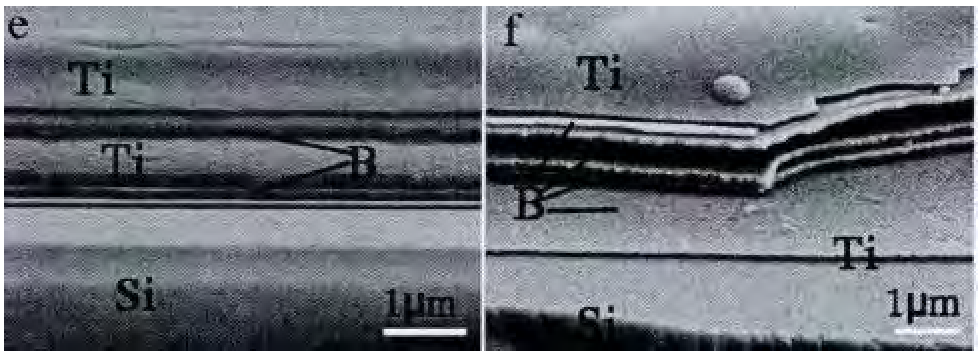
reactants		adiabatic reaction temperature (K)		state of intermetallic product	gas production		heat of reaction	
constituents	ρ_{TMD}, g/cm^3	w/o phase changes	w/ phase changes		moles gas per 100 g	g of gas per g	-Q, cal/g	-Q, cal/cm^3
Al + 2B	2.607	2251	>1252	l-g	0 - 2.1	0 - 1	742	1940
4Al + 3C	2.574	1673	1673	solid	0.0	0.0	371	965
2Al + Ca	2.051	2836	1738	liquid	0.0	0.0	558	1140
4Al + Ca	2.248	1880	>972	s-l	0.0	0.0	348	782
4Al + Ce	4.095	1173	1173	solid	0.0	0.0	126	458
Al + Co	5.171	2195	>1912	s-l	0.0	0.0	307	1590
4Al + Co	3.581	*	*	*	*	*	231	637
5Al + 2Co	3.999	1755	>1452	s-l	0.0	0.0	277	1110
3Al + Cr	3.568	793	793	solid	0.0	0.0	120	430
Al + Cu	5.294	935	935	solid	0.0	0.0	108	573
Al + Fe	4.844	1423	1423	solid	0.0	0.0	211	1020
3Al + Fe	3.688	1407	1407	solid	0.0	0.0	278	1020
4Al + La	3.946	1495	*	s-l	0.0	0.0	166	780
Al + Li	1.476	1160	>972	s-l	0.0	0.0	345	509
Al + Mn	4.676	803	803	solid	0.0	0.0	124	586
Al + Ni	5.165	2362	>1910	s-l	0.0	0.0	330	1710

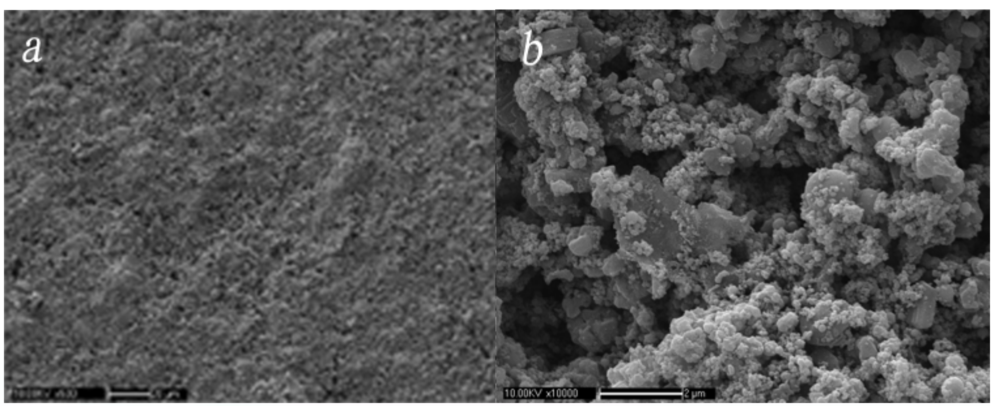
- Al + CuO: ΔH = 974.1 cal/g;
- Al + Ni: ΔH = 330 cal/g;
- B + Ti: ΔH = 1320 cal/g;

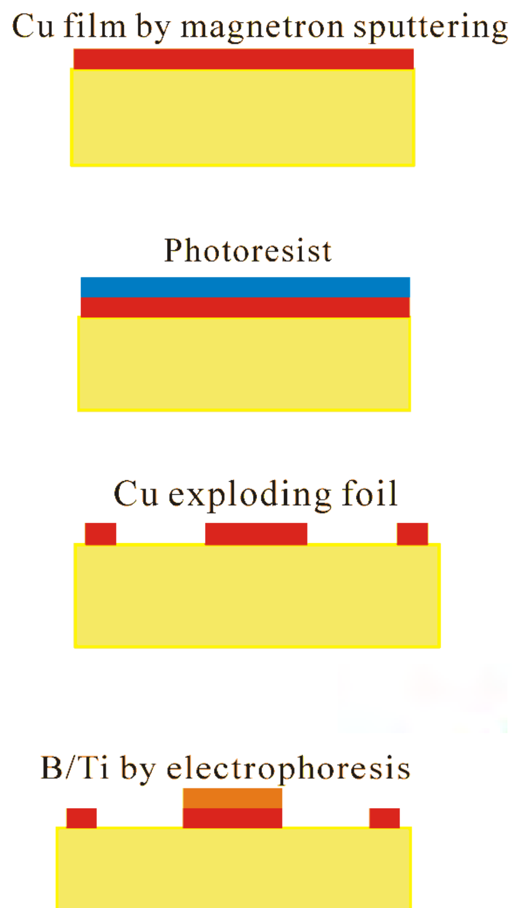
Reactive Materials for Ignition

1 B/Ti reactive materials

Thickness:3-4μm Bilayer:Ti(230nm) Bi(250nm)

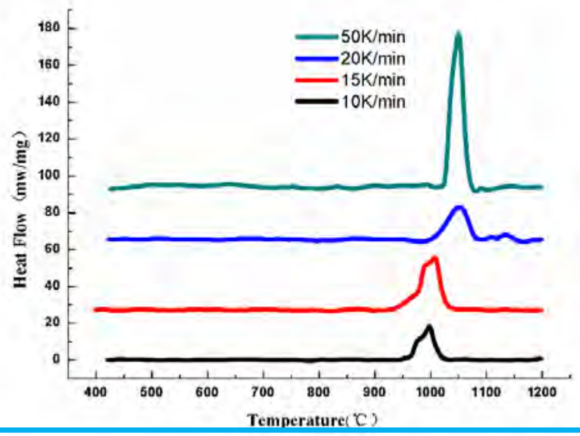




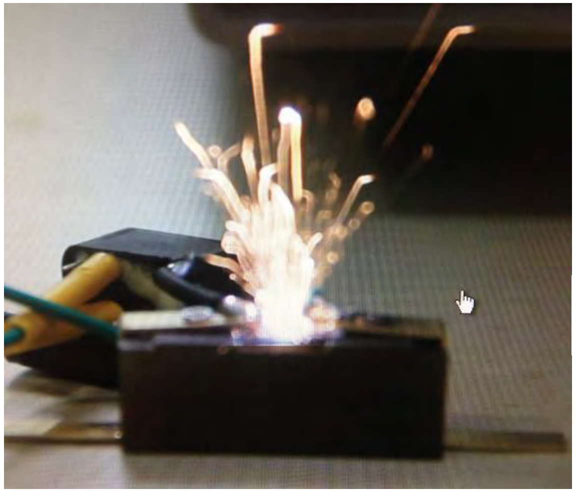


Reactive Materials for Ignition

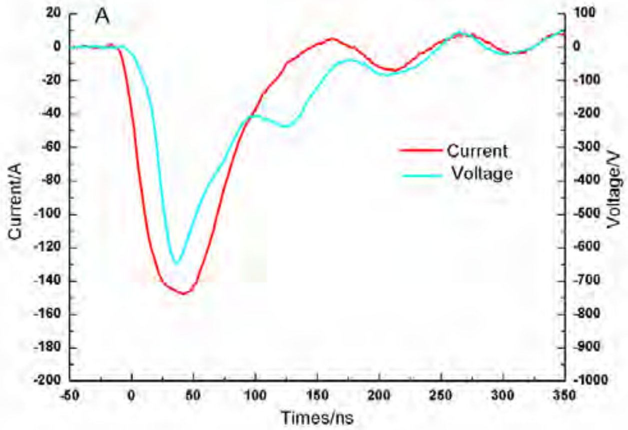
The exothermic reaction of B/Ti energetic materials :



- ✓ Single exothermic reaction;
- ✓ Onset temperature is 976℃ to 1023℃ (< B 2076 ℃and Ti 1678 ℃);
- ✓ Reaction heat was 1259J/g (<5517J/g).

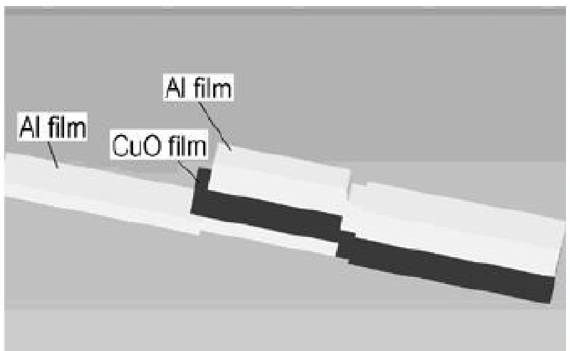


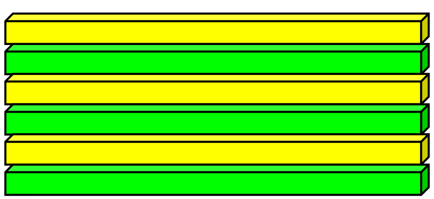
- ✓ Output energy:1.43mJ;
- ✓ Energy transformation efficiency: 71.5%;
- ✓ The height of flame can be reach to several millimeter.

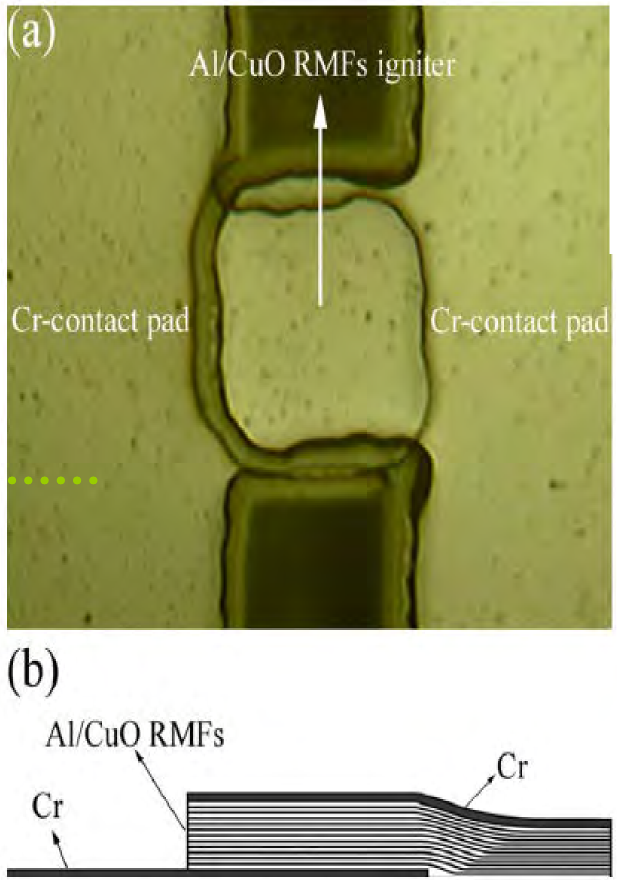


Reactive Materials for Ignition

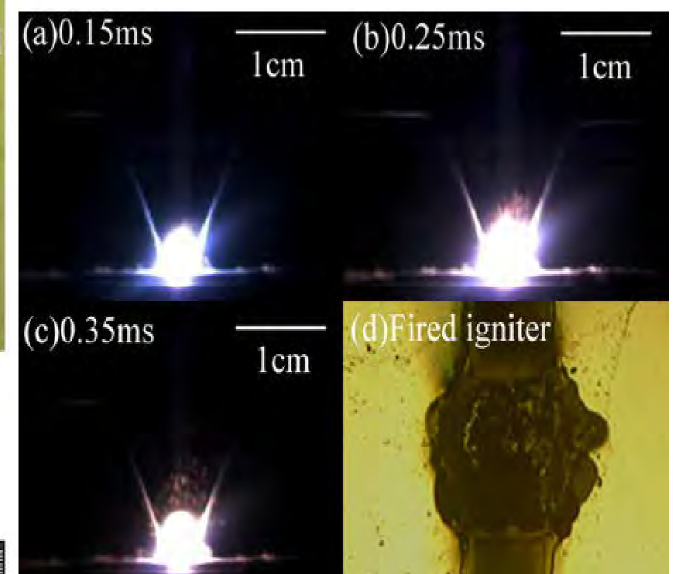
2 Al/CuO multilayers







the igniter. The ignition delay time and total released energy of the igniter discharged in 40 V are 0.7 ms and 482.34 mJ, respectively. For one igniter, the energy released by chemical reactions is accounted for 21% of the total energy, which can be improved by adjusting the deposition conditions of Al/CuO RMFs and by tuning the Al deposition to reach a stoichiometric reaction. Furthermore, the explosion temperature could keep an approximately constant value of 3500 °C for 1.4 ms.



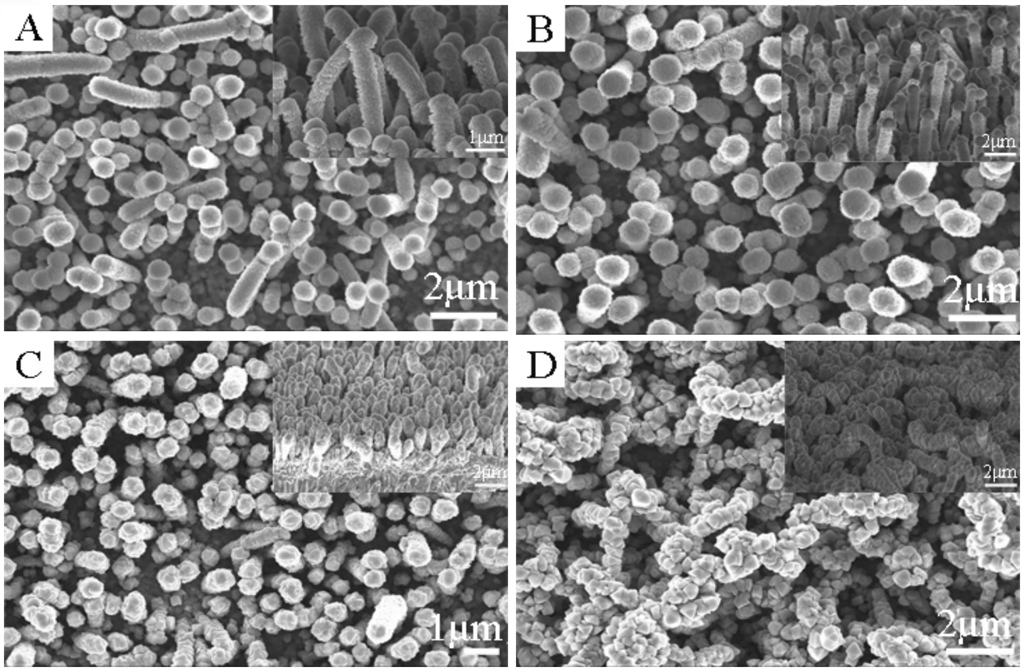
Reactive Materials for Ignition

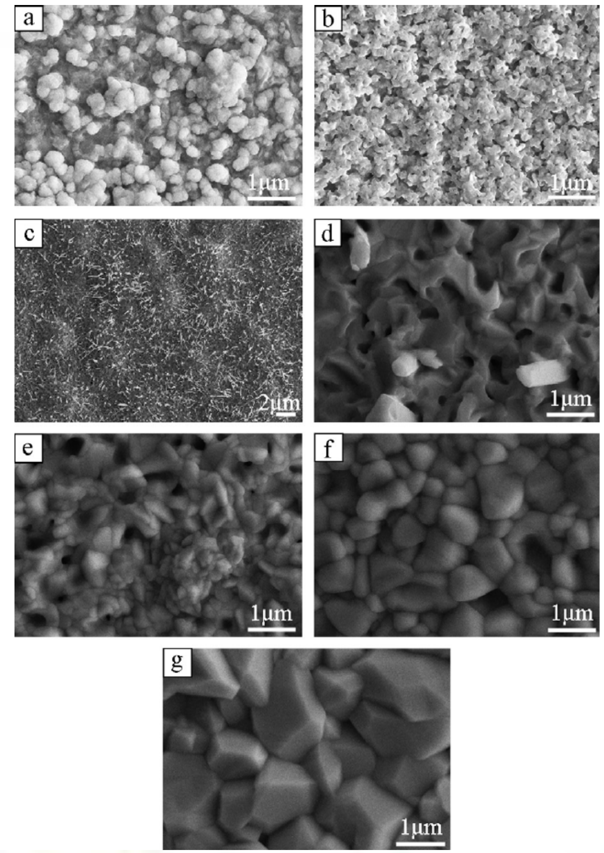
2 Al/CuO nanowires

1) Al/CuO nanowires grown from Cu thin film deposited onto silicon substrate.
2) The copper film is deposited byelectro beam Evaporation.
3) The CuO nanowires is synthesized by annealing copper film.
4) The formation of Al_2O_3 would consume Al nanoparticles which reduce the heat reation.
5) The reaction between fuel and oxidizer should destroy Al_2O_3 which has high melting temperature.

Processing	t_p/°C	Q/（J·g^{-1}）	Al/CuO摩尔比
Ultrasonic wave	549. 5	473. 2	2：3
Sol-gel approaches	561. 2	574. 9	2：3
Core-shell	500	1085	-

The core-shell structure



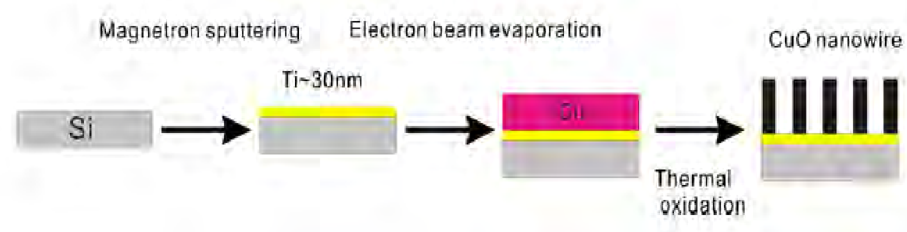


1) The annealing temperature: 400℃

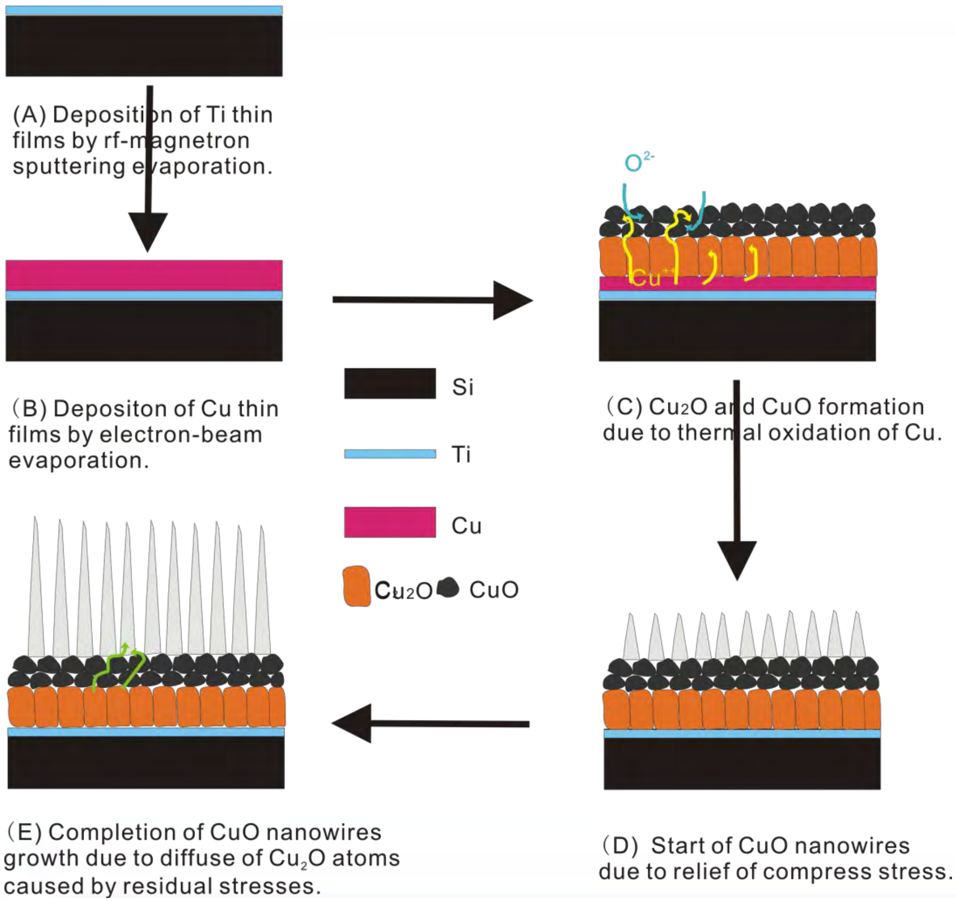
2) The film thickness: 1μm

3) The electron-beam evaporation: 0.15A

4) The annealing time: 4h



The growth mechanism



The CuO growth mechanism:

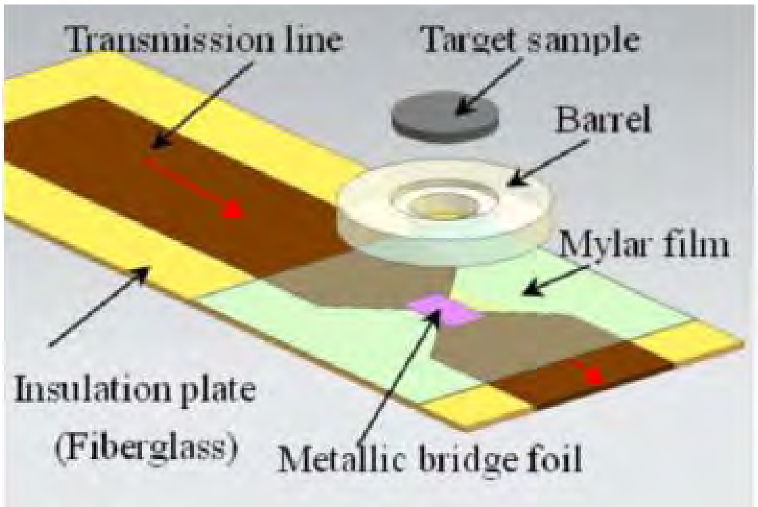
1) Accumulation stress;

2) The appearance of apophysis;

3) The nucleation with apophysis;

4) The growth of nanowires

Reactive Materials for Exploding foil initiator (EFIs)-Al/CuO



Influence of Al/CuO reactive multilayer films additives on exploding foil initiator

Xiang Zhou, Ruiqi Shen, Yinghua Ye, Peng Zhu, Yan Hu, and Lizhi Wu
School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, China

(Received 19 June 2011; accepted 12 September 2011; published online 3 November 2011)

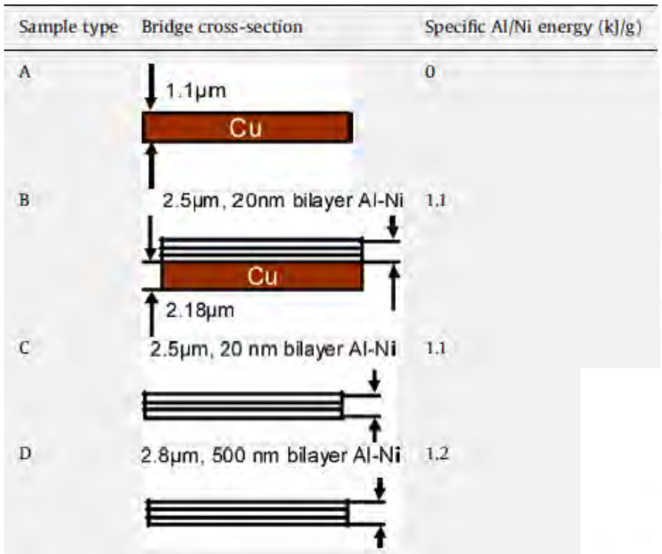
An investigation on the influence of Al/CuO reactive multilayer films (RMFs) additives on exploding foil initiator was performed in this paper. Cu film and Cu/Al/CuO RMFs were produced by using standard microsystem technology and RF magnetron sputtering technology, respectively. Scanning electron microscopy characterization revealed the distinct layer structure of the as-deposited Al/CuO RMFs. Differential scanning calorimetry was employed to ascertain the amount of heat released in the thermite reaction between Al films and CuO films, which was found to be 2024 J/g. Electrical explosion tests showed that 600 V was the most matching voltage for our set of apparatus. The explosion process of two types of films was observed by high speed camera and revealed that compared with Cu film, an extra distinct combustion phenomenon was detected with large numbers of product particles fiercely ejected to a distance of about six millimeters for Cu/Al/CuO RMFs. By using the atomic emission spectroscopy double line technique, the reaction temperature was determined to be about 6000–7000 K and 8000–9000 K for Cu film and Cu/Al/CuO RMFs, respectively. The piezoelectricity of polyvinylidene fluoride film was employed to measure the average velocity of the slapper accelerated by the explosion of the films. The average velocities of the slappers were calculated to be 381 m/s and 326 m/s for Cu film and Cu/Al/CuO RMFs, respectively, and some probable reasons were discussed with a few suggestions put forward for further work. © *2011 American Institute of Physics.* [doi:10.1063/1.3658617]

Traditonal metallic materials : Copper aluminum, gold and so on

Al/CuO multilayer: did not improve flyer velocity

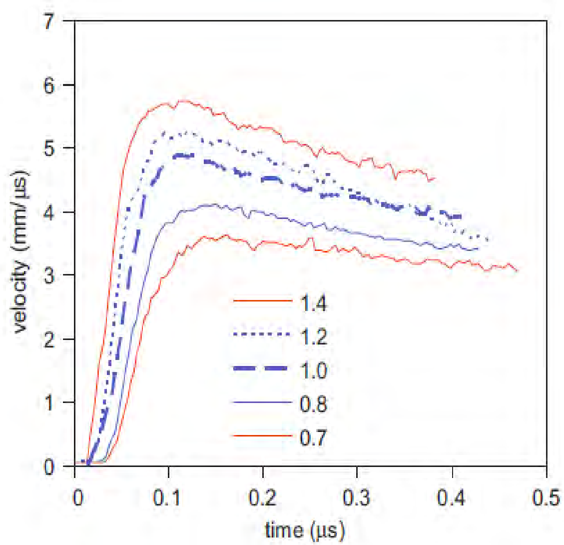
Disadvantage: low power transduction efficiency

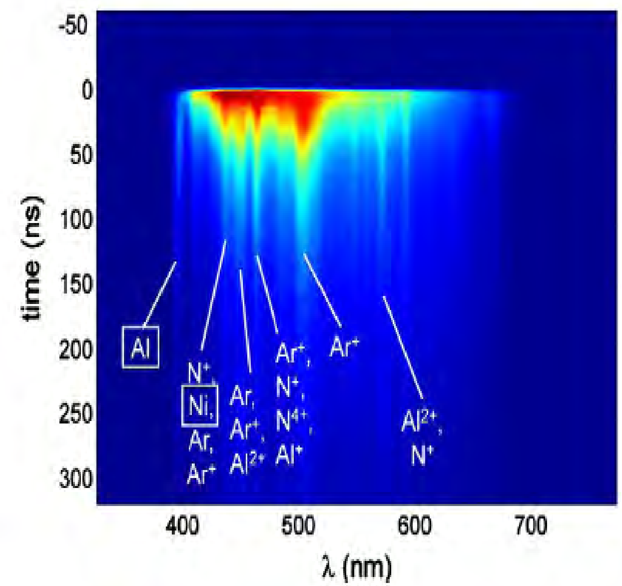
Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni



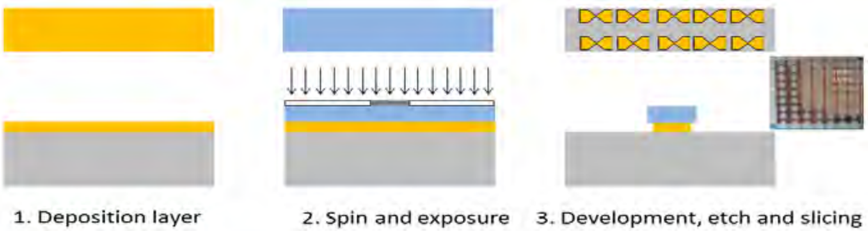
Sample type	Bridge cross-section	Specific Al/Ni energy (kJ/g)
A	1.1μm Cu	0
B	2.5μm, 20nm bilayer Al-Ni; Cu; 2.18μm	1.1
C	2.5μm, 20 nm bilayer Al-Ni	1.1
D	2.8μm, 500 nm bilayer Al-Ni	1.2

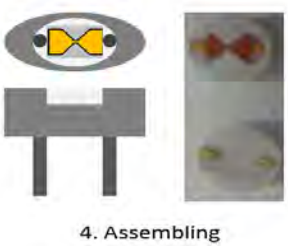
application of a large electrical current. We observed flyer plate velocities in the 2–6 km/s range, corresponding to 4–36 kJ/g in terms of specific kinetic energy. Several samples containing Ni/Al films with different bilayer thicknesses were tested, and many produced additional kinetic energy in the 1.1–2.3 kJ/g range, as would be expected from the Ni–Al intermetallic reaction. These results provide evidence that nanoscale Ni/Al layers reacted in the timescale necessary to contribute to device output.





Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni



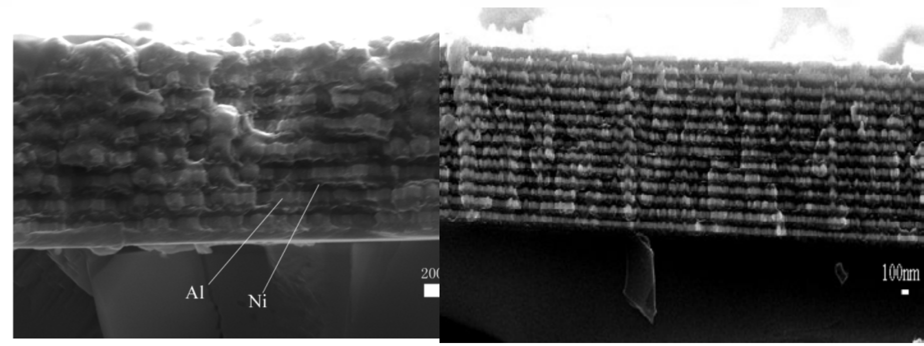


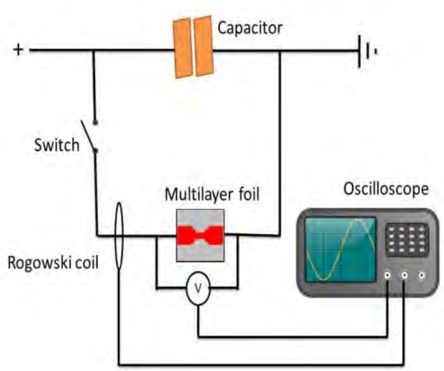
- **Sample:**

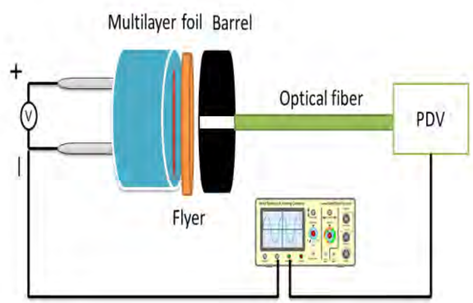
Al/Ni
Cu

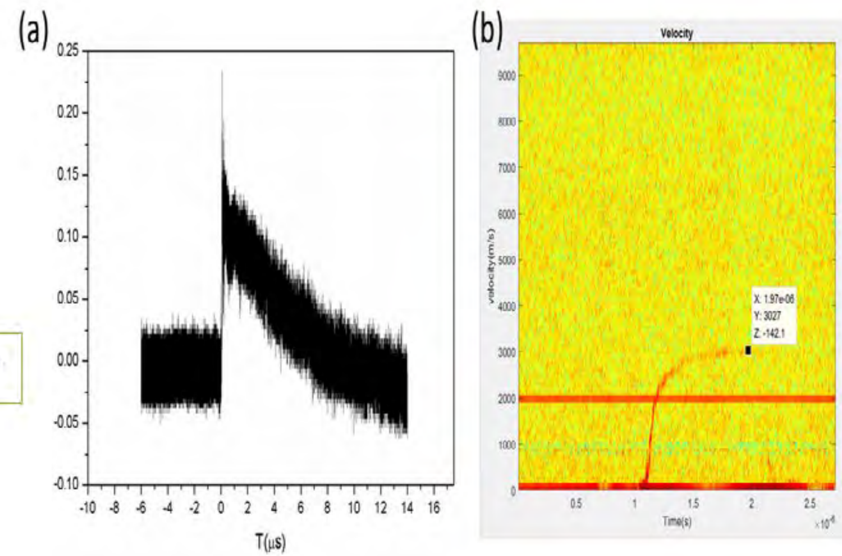
- **Measure method:**

PDV
U/I









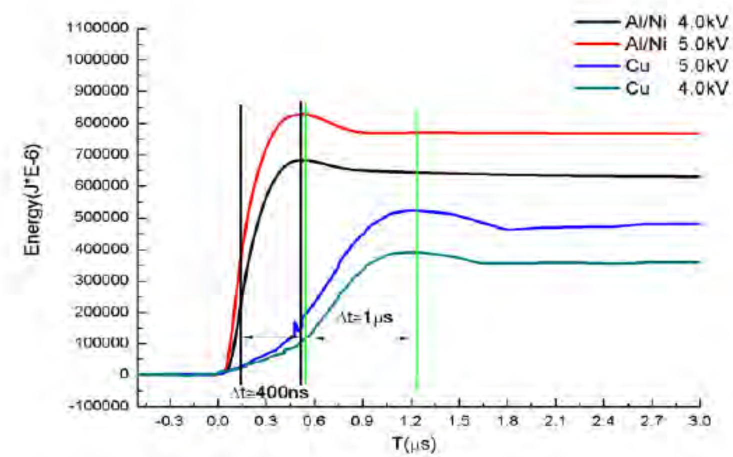
Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni

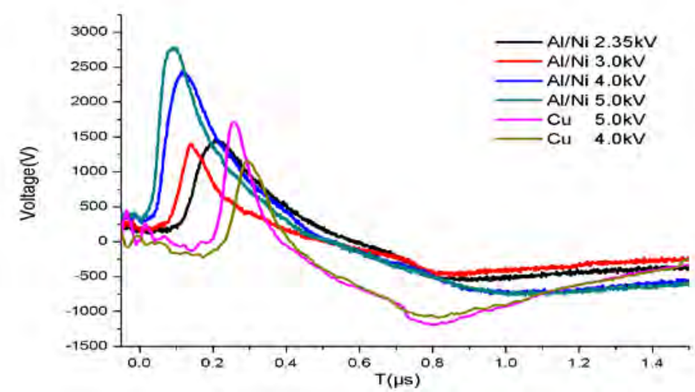
Fig. 5 (a): Current histories for Al/Ni and Cu film, (b): Voltage histories for Al/Ni and Cu film

Table.1 Results of exploding foil

No.	Material	Resistance of foil mΩ	Input voltage V	Peak voltage V	Time of peak voltage ns	peak current A	Time of peak current ns	Peak energy mJ	Maximum energy mJ	Input energy mJ	Energy efficiency	△t ns
1	Al/Ni	110	2350	1456	204	1203	201	110	340	610	18%	337
2	Al/Ni	104	3000	1500	140	1395	239	66	300	990	6.7%	346
3	Al/Ni	105	4000	2416	120	1498	261	170	650	1760	9.7%	366
4	Al/Ni	103	5000	2768	103	1760	273	240	780	2750	8.7%	376
5	Cu	26.2	5000	1717	260	3014	240	160	690	2750	5.8%	1245
6	Cu	26.5	4000	1157	275	2489	235	45	470	1760	2.6%	1180

△t: The time of maximum energy minus time of peak voltage



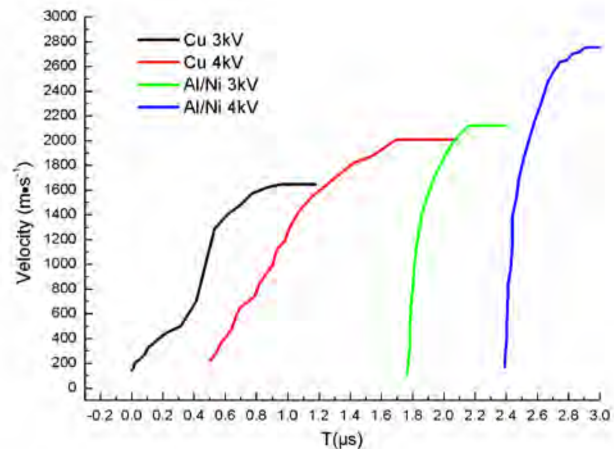


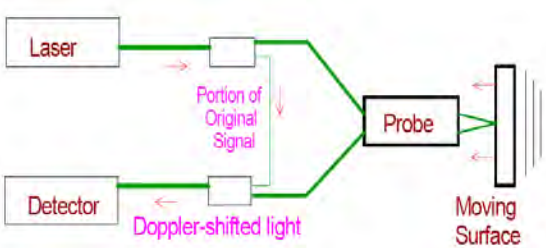
Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni

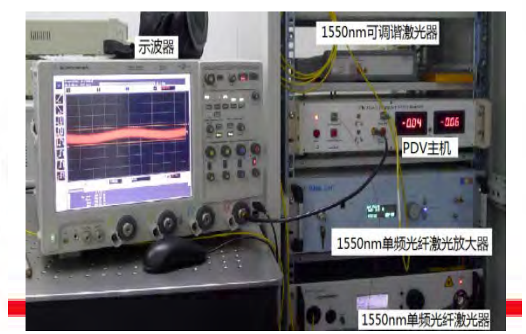
D. Photonic Doppler velocimetry (PDV)

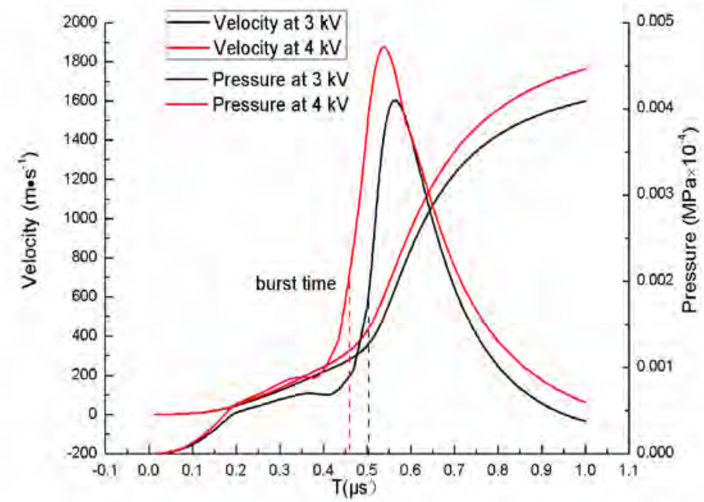
In a separate set of tests with identical samples, we used PDV to measure the resulting velocities of the flyer material when connected to the same high voltage firing circuit used in the streak spectroscopy measurements. This technique quantified the Doppler shift in frequency $\Delta f(t)$ of light reflected off a moving target—in this case the flyer—relative to the light emitted from the end of a fiber optic probe.[38] The measured difference in frequency $\Delta f(t)$ is related to the flyer velocity $u_f(t)$ according to

$$\Delta f(t) = 2\frac{u_f(t)}{\lambda_0}, \qquad (6)$$









Thank you for your attention

Always a Step Ahead
ARDEC
ARMAMENTS

Mechanical Aspects of Fuze MEMS G-Switch Encapsulation

15 May 2018

Presented by:
Mr. Jintae Kim
Co-Author:
Mr. Al DeSantis

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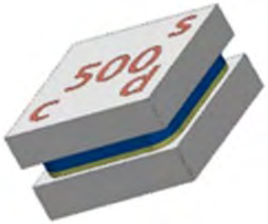
OUTLINE

- MEMS G-Switch Background
- Requirement Establishment
- Standards
- Design Concept
- Encapsulation Process & Highlights
- Technical Challenges and Solutions
- Qualification Tests
- Live Fire Test
- Summary

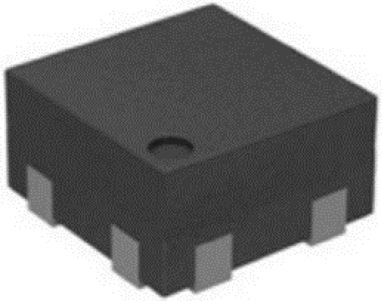
BACKGROUND

- U.S. Army PM-MAS Planned Application
  - M433 low velocity M550 fuze improvement program incorporates an electronic interface to the M550 mechanical fuze.

- Current MEMS G-Switch (HT Micro Inc. production) demonstrated improvements on 40mm low velocity grenade
  - Soft target performance
  - Graze angle impact performance



- Commercial Encapsulation Process (Promex Inc. provided) Needed to:
  - Withstand environmental extremes
  - Provide better resistance to shear force loads
  - Provide a standard package amenable 'pick and place'



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REQUIREMENT ESTABLISHING

ARDEC

1. Physical Requirements:
   - ✓ Size: Maximum dimension (L x W x H): 4 x 4 x 1.75 in milimeter
   - ✓ Package frame type: Quad Flat No-lead (QFN) or Dual Flat No-Lead (DFN) package with 4 to 12 leads
   - ✓ Serial number and model name with laser mark
   - ✓ Electronics protection: wire bonding, electronics contacts
   - ✓ Packaging color: Black with gold or white lead pads
   - ✓ Vendor's process specification: encapsulant, wire bonding and die attaching material and physical dimensions

2. Operation/ Transportation Environment Requirements
   - ✓ Mechanical shock, impact and vibration
   - ✓ Thermal shock, temperature cycling and humidity environment

3. High reliability required
   - ✓ Maintain MEMS device functionality and provide physical protection.
     - No voids or warpage
     - Resist corrosion and contact discontinuity
   - ✓ Meet storage temperature from -65°F to +165°F (-54°C to + 74°C) and shelf life of 20 years.

STANDARDS

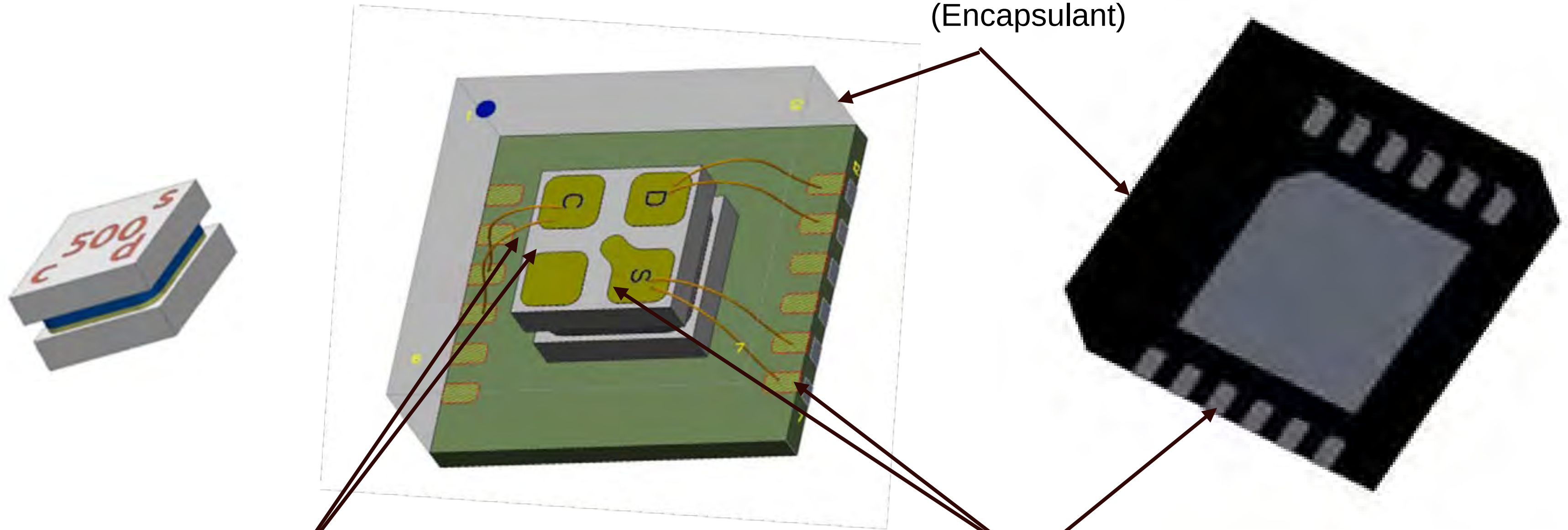
- MIL-STD-883J, ‘Test Method Standard for Microcircuits’
- MIL-STD-331C, ‘Fuze and Fuze Components Environmental and Performance Tests’
- MIL-STD-810G, ‘Test Method STD-Environmental Engineering Considerations and Lab Tests’
- MIL-STD-1316E, ‘Fuze Design Safety Criteria’
- JEDEC No 22-A110B ‘Highly Accelerated Temperature and Humidity Stress Test (HAST)
- MIL-HDBK-338, Electronic Reliability Design Handbook

DESIGN CONCEPT

- Commercial standard
  4 X 4 - 12 lead Dual Flat No-Lead (DFN) package

Bare MEMS → Encapsulated MEMS → Final Product

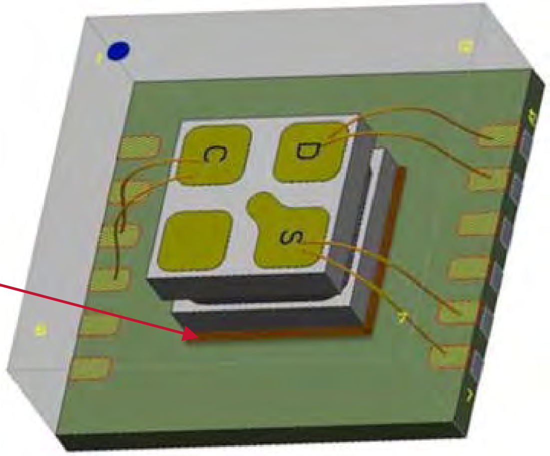
Standard Mold Compound
(Encapsulant)



Contact Pads

Wirebonding doubled on
each pad

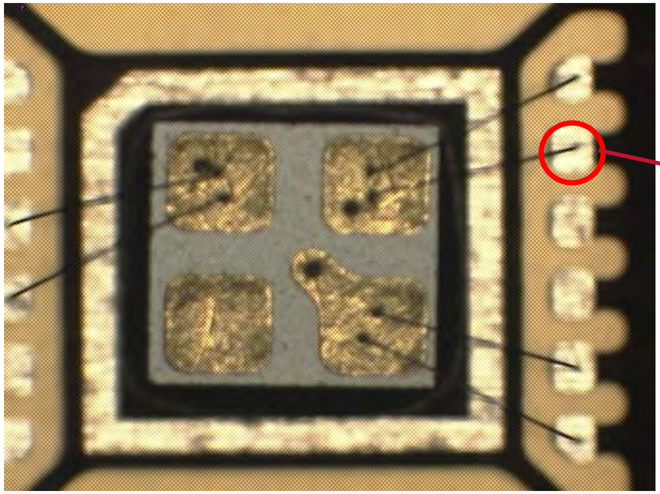
ENCAPSULATION HIGHLIGHT 1



1. Die attaching
   - ✓ MEMS G-switch placed and cemented onto the lead frame
   - ✓ Electrically insulative epoxy adhesive used

2. Wire bonding
   - ✓ Contact pads on G-switch have double gold wires bonded onto each leaf frame pad for a secure connection.
   - ✓ Combination of ball bonding and wedge bonding

*



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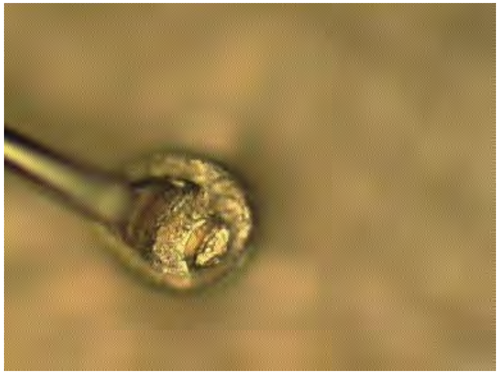
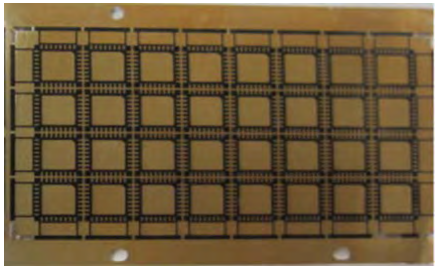


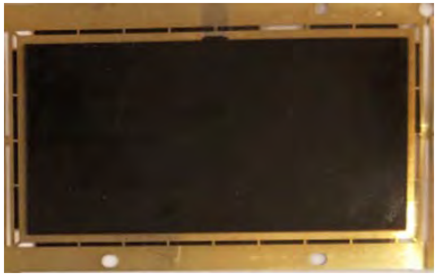
* Promex Inc. provided

Encapsulation Highlight 2

3. Encapsulation
   - ✓ Mold Insert placed onto a lead frame for overmolding
   - ✓ Mold compound forms a strong overmold

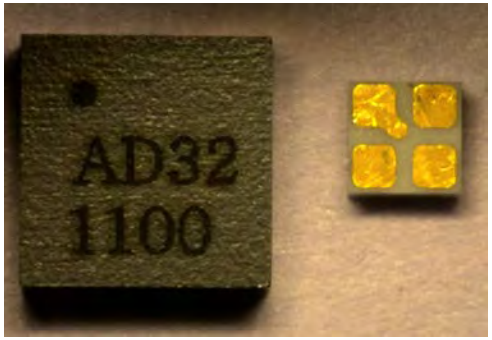
* Blank Lead Frame





* Overmolded Lead Frame

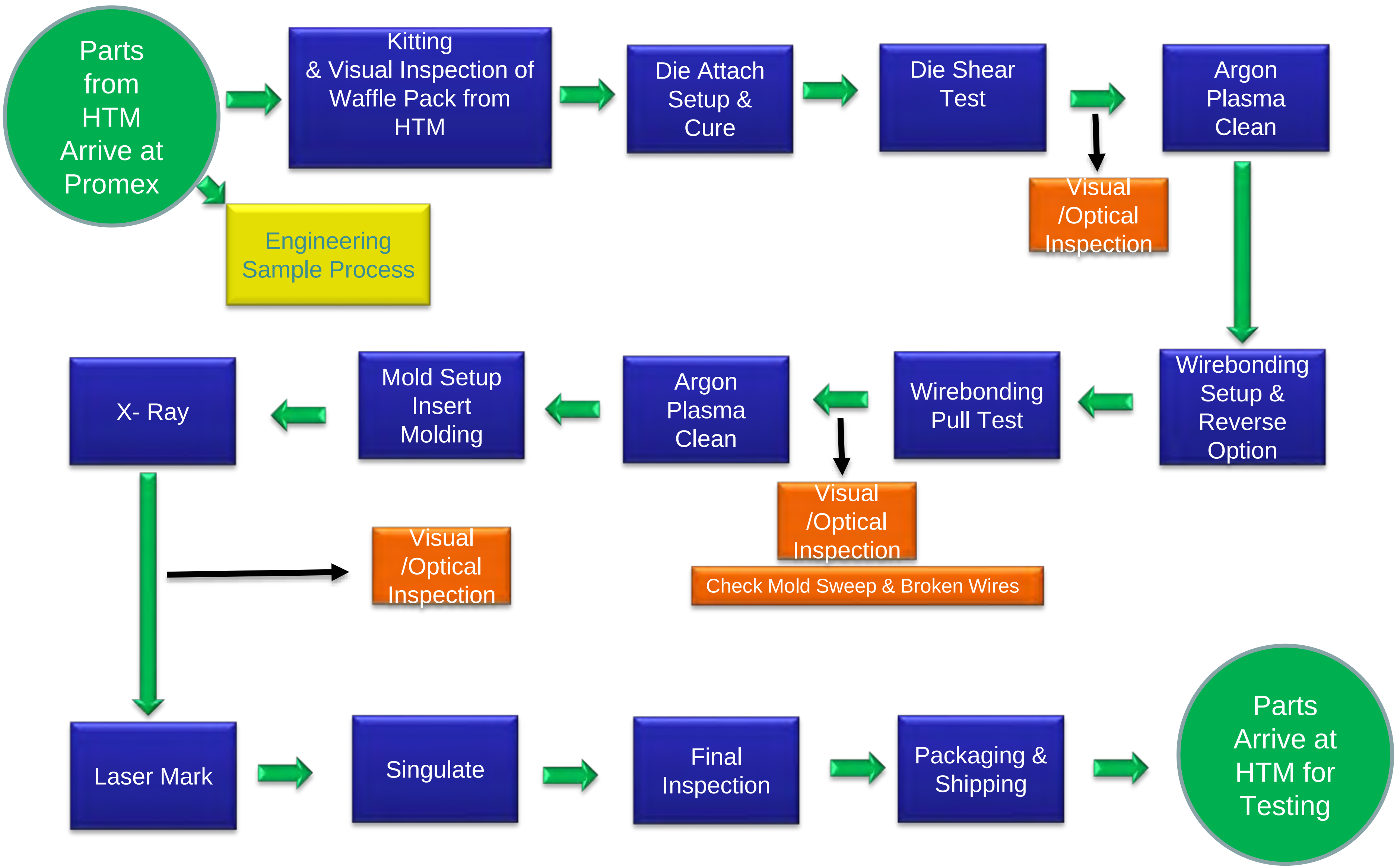
* Mold Insert



Encapsulated Product and Original G - Switch

* Promex Inc. provided

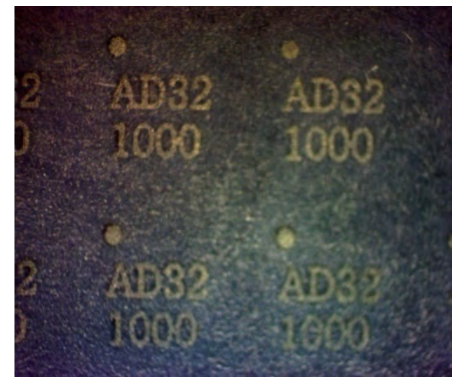
Encapsulation Process



TECHNICAL CHALLENGES

- Voids occurred on top of wire contact area during the molding process in the initial 3 x 3 x 1.5 encapsulation design.
  - Space between wire and top surface was too shallow.
  - Wire bonding was too stiff in vertical angle.
- Problem solving
  - Reverse wire-bonding adopted
  - Mold height increased to 1.75 mm

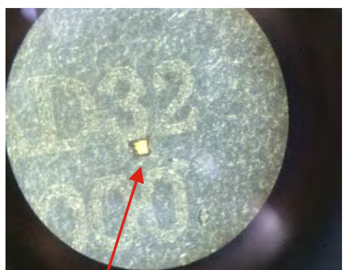
*** Top surface image with laser mark & serial number***

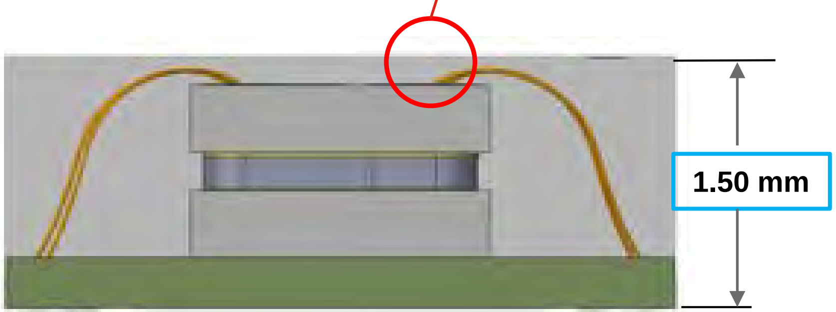


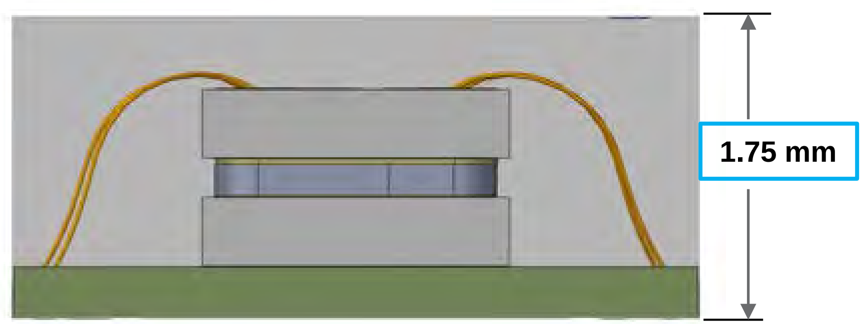
Laser Mark & Model Name

No Void

* Void on Wirebonding







* Promex Inc. provided

Qualification Testing

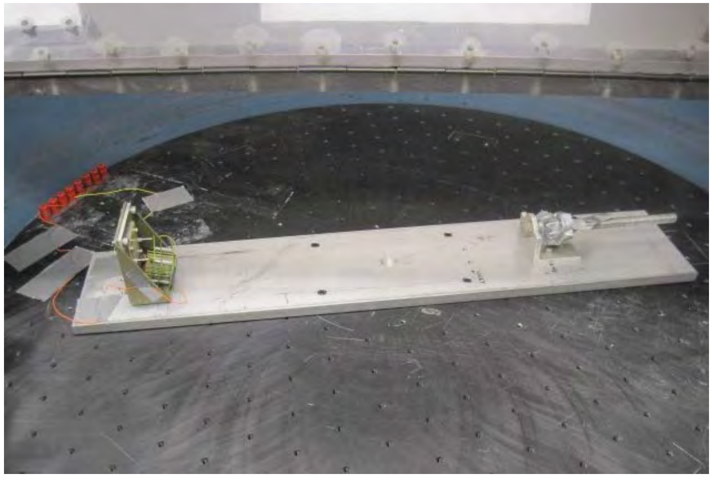
- Environmental testing
  - Centrifuge Functionality Test (before and after encapsulation)
  - Vibration Test
  - Temperature Cycling
  - Thermal Shock
  - Highly Accelerated Stress Test (HAST)
  - All tests followed by centrifuge functionality test
    - * Spin simulation (side orientation)
    - * Impact simulation (down or bottom orientation)
- High G 'shock and impact' testing
  - Air-Gun Test (155 mm Artillery Environment)
  - Shock Arm Test
- Live fire gun testing
  - MK-19 Grenade Launcher (low velocity 40 mm live gun fire)

FUNCTIONALITY TEST

- Centrifuge test for baseline functionality before and after encapsulation to observe any changes
- Pass/Fail criteria

  A device is considered to pass if there is no apparent physical damage or deterioration and the switch still functions with its closures at threshold.

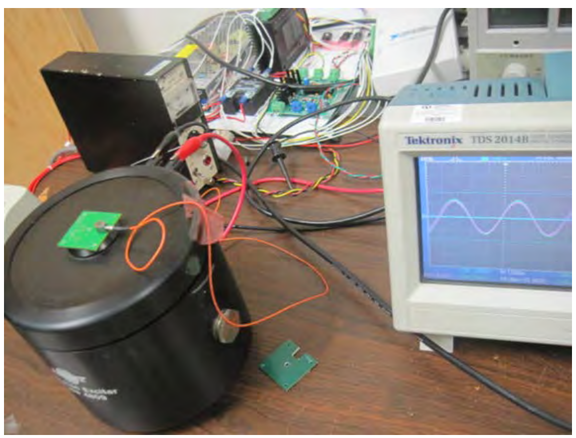
  - ➢ Test showed all switches closed within threshold.
  - ➢ No differences observed between before and after encapsulation.



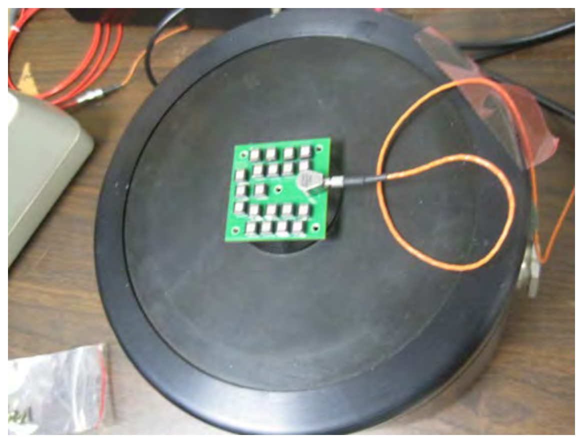
Centrifuge spinner setup

VIBRATION TEST

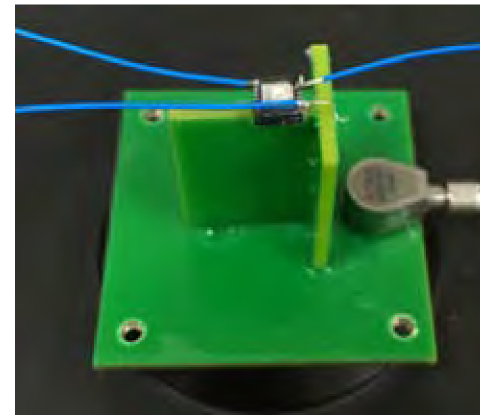
- Purpose
  Component to withstand moderate to severe vibration as a result of motion produced by transportation or field operation.
- Method
  Vibration, Variable Frequency (MIL-STD-883, Test Method 2007.3)
- Result
  All units showed an expected closure pattern at threshold range without abnormal behavior.



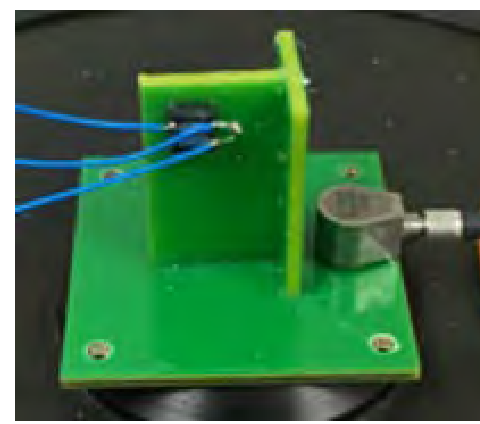
* ***Test setup with vibrator and frequency monitor***



* ***Group test setup***



* ***Horizontal setup for spin sensing***



* ***Vertical setup for impact sensing***

* HT Micro Inc. provided

TEMPERATURE CYCLING

- Purpose
  This test is conducted to determine the resistance of a part to extremes of high and low temperatures, and to the effect of alternate exposures to these extremes.
- Method
  'Dry' test with temperature condition C as in 'MIL-STD-883J, METHOD 1010.8'

Test Condition

Step	Time (Minutes)	Test Condition Temperature (°C)
1 (Cold)	Transfer Time ≤ 1min. if needed Dwell Time ≥ 10 min.	-65
2 (Hot)	Transfer Time ≤ 1min. if needed Dwell Time ≥ 10 min.	150

10 cycles

- Result
  Test data appeared to be very similar to the vibration test data and is interpreted as 'non-affected'.

Hot chamber above and cold chamber bottom at HT Micro

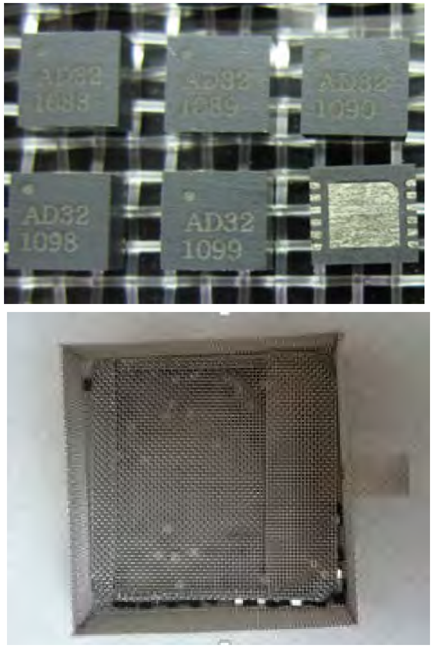
THERMAL SHOCK

- Purpose
  The purpose of this test is to determine the resistance of the part to sudden exposure to extreme changes in temperature and the effect of alternate exposures to these extremes.
- Method (MIL-STD-883E, METHOD 1011.9)
  - Wet Test with 15 cycles of duration
  - Temperature condition B

Test Condition in MIL-STD-883E

Step	Time	Recommended Fluid	Test Condition Temperature (°C)
1 (Cold)	Transfer Time ≤ 10 sec. 2 min ≤ Dwell Time ≤ 5 min.	Perfluorocarbon	-55
2 (Hot)	Transfer Time ≤ 10 sec 2 min ≤ Dwell Time ≤ 5 min *	Perfluorocarbon	125

- Result
  Test data showed evenly distributed reactions in data graph indicating that the harsh environment with extreme temperatures and high humidity does not impact the functionality of the switch and the encapsulation work was well processed as well.



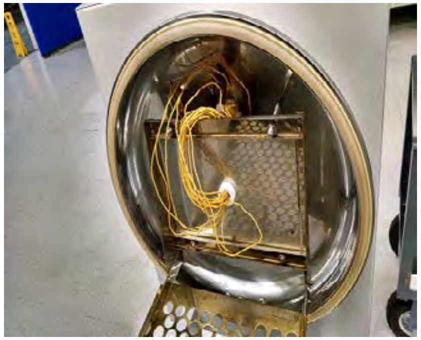
MEMS devices soaked in netted container tested at HT Micro

HAST

- Purpose
  HAST test was performed for the purpose of evaluating the reliability of near hermetic packaged solid-state devices in humid environments. It employs severe conditions of temperature, humidity, and voltage bias which accelerate the penetration of moisture through the external protective material (encapsulant or seal) or along the interface between the external protective material and the metallic conductors which pass through it.

- ***Test Method & Condition: 'JEDEC Standard JESD22-A110-B' in JEDEC Standard***

Test	Condit	Remarks
Highly Accelerated Stress Test (HAST) (JEDEC Standard JESD22-A110-B)	130°C/ 85% R.H./ 2.3 atm./ 96 hrs.	-5V, 0V, +5V bias



Electric connection wire harness to chamber

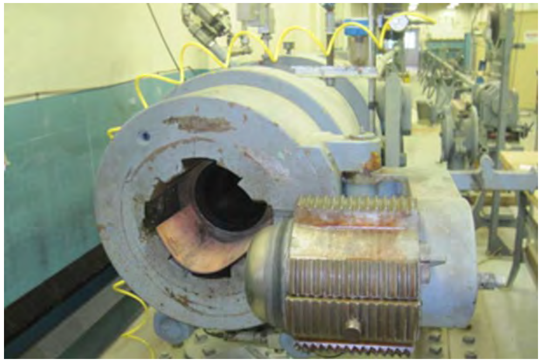
HAST Chamber with humidity control and voltage bias interface. Tested at HASTest Inc.

- Result
  All units that were HAST tested showed no change in characteristics due to that exposure.

HIGH G AIR-GUN TEST

- Survivability Test for encapsulated devices subject to severe impact as a result of suddenly applied forces or abrupt changes in motion.
- Air-gun Test Configuration

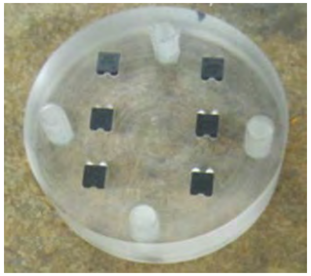
Shot	Acceleration g level (Air Pressure)	No of Devices	Remark
1	52,221 G (Air pressure: 21,530 psi)	6	* 5 inch diaphragm air gun * Piston weight: 8.02 oz. * No. 5 Aluminum shear disc (0.56" size)
2	51,658 G (Air pressure: 21,310 psi)	6	
3	52,221 G (Air pressure: 21,530 psi)	6	Total 18 units



< Air-gun 5 inch diaphragm >

- Test Summary
  - Survived high G environment and functioned at threshold G level.
  - No cracks, warped or damaged surfaces identified.
- Remarks
  - Some differences in G level (average ~40 G) between before and after gun test were found due to multiple severe testing processes in prior tests
  - However they were all above the threshold.

< Encapsulated devices >



< Test vehicle (bird) >

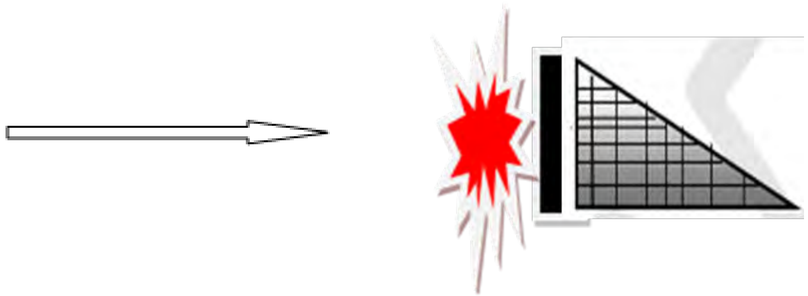
* Tested at Picatinny

Live Fire Gun Test

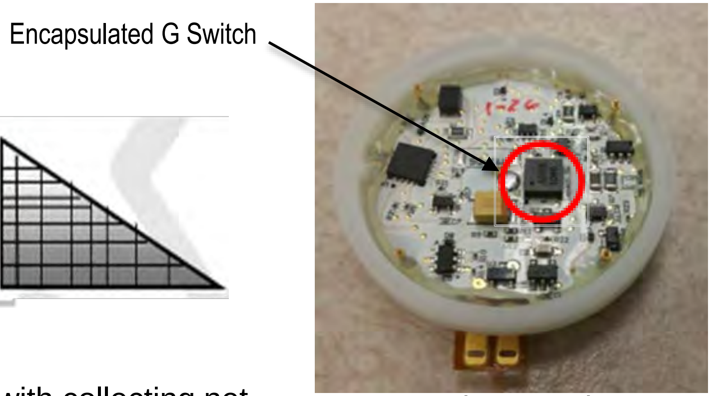
- Test Overview
  - Low velocity 40mm M433 cartridge live fire test.
  - Performed with ‘on board recorder’ (OBR) capability
  - Characterized the encapsulated G-switch’s behavior with real gun fire environment.
  - Collecting net was used for soft catch simulating snow, tree leaves and sand, etc.

MK-19 Grenade Launcher

* Tested at Picatinny



Target with collecting net



< OBR bottom view >

- Test Summary
  - OBR data showed closures at expected target levels
  - Multiple closures observed as penetrating target and landing in the net.
  - 2 data acquisition errors observed but closures already had occurred as expected.

< OBR top view >

SUMMARY

- Requirements were established for mechanical design specifying overall encapsulation process.
- A process was developed to provide commercial-grade encapsulation to increase their ruggedness and environmental protection.
- Promex Industries, Inc. was selected to provide the near-hermetic encapsulation technology.
- Technical challenge was resolved by molding height adjustment.
- Required testing was completed and results were tabulated for switch closures in axial and lateral directions, and the before and after switch closure levels were compared.
- **Testing showed that the encapsulation process does not negatively affect G-switch function relative to its non-encapsulated state.**

Questions?

Thank You!

On Time...On Target
Land, Sea, Air and Space

Software Quality Assurance

Applied towards the Development of VHDL-Based Safety Critical Hardware

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61st NDIA Annual Fuze Conference

San Diego CA

May 16, 2018

Background

- The software used in today’s safety critical systems requires a significant amount of analysis and testing as well as traceability to the requirements
- “Software-like” languages are treated similarly by today’s munition-related safety technical review panels

- Very High Speed Integrated Circuit (VHSIC) Hardware Description Language (VHDL) is one of these "software-like" languages
- Requires the generation of the appropriate LOR and the resultant analyses
- Software was created in order to automatically generate the appropriate Level of Rigor (LOR) tasks, establish traceability, & provide transparency

- The implementation of safety features in safety critical systems has evolved significantly in the last few decades
- Initially, safety features were implemented using a mechanical means such as springs, setback weights, rotors and shear pins
- Recently, electronics have been used in order to implement safety features i.e. analog and/or simple digital circuits

Introduction Cont.

- Most recently, software and “software-like” devices are being used to implement safety features
- Field Programmable Gate Arrays (FPGAs) are hardware devices that are being used more often in today’s munition-related safety-critical applications in order to implement safety features
- A high-level language (such as VHDL) is used to design the safety features which are implemented using an FPGA.

Use of VHDL in Safety Systems

- VHDL provides flexibility to the design engineer through being an abstract programming language
- Abstraction provides many benefits but tends to be the opposite of what a safety technical review panel desires
- Current Software System Safety analysis techniques may be applied towards the contribution of VHDL towards the total system risk.

Safety Standards

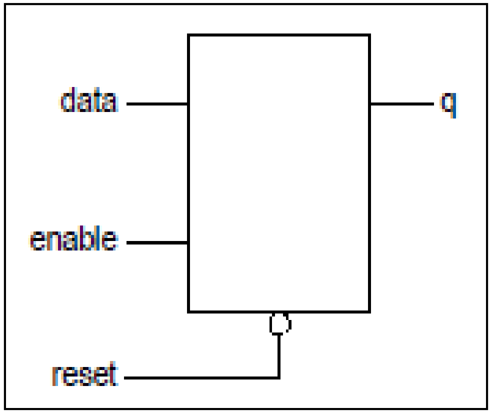
- There is no one specification that governs munition related software safety.
- MIL-STD-882E is the Department of Defense System Safety Standard Practice document that applies to both hardware and software.
- Details of the use of logic devices as safety features are covered in JOTP-051.
- AOP-52 is a NATO document that provides guidance on munition-related software safety.
- The Joint Software Systems Safety Engineering Handbook is a DoD publication whose purpose is to provide guidelines to achieve a reasonable level of assurance that the software will execute within an acceptable level of risk.

- The basic FPGA design flow is as follows:
  - HDL source entry
  - Synthesis
  - Simulation
  - Place and route
  - Back annotated timing analysis
  - Device programming and hardware testing

- Behavioral VHDL allows for a high level of abstraction.
- The system is described in terms of what it does.
- Programmer is specifying the relationship between the inputs and the outputs
- The logic is described in a source code like manner using statements that are typical of conventional programming language

Schematic Entry vs. Behavior VHDL

- VHDL allows for the description of the structure of the system
- Allows for the specification of the system using familiar programming language forms



Digital Latch

```
begin
process (enable, data, reset) begin
      if (reset = '0') then
        q <= '0';
      elsif (enable = '1') then
        q <= data;
      end if;
end process;
```

VHDL Representation of Digital Latch

- Software Quality Assurance (SQA) monitors the entire process of software engineering.
- Assurance may be defined as the “Implementation of inspection and structured testing as a measure of quality.”
- This paper focused on the process and testing aspect of Software Quality Assurance as it applies to “software-like” hardware devices such as FPGAs.

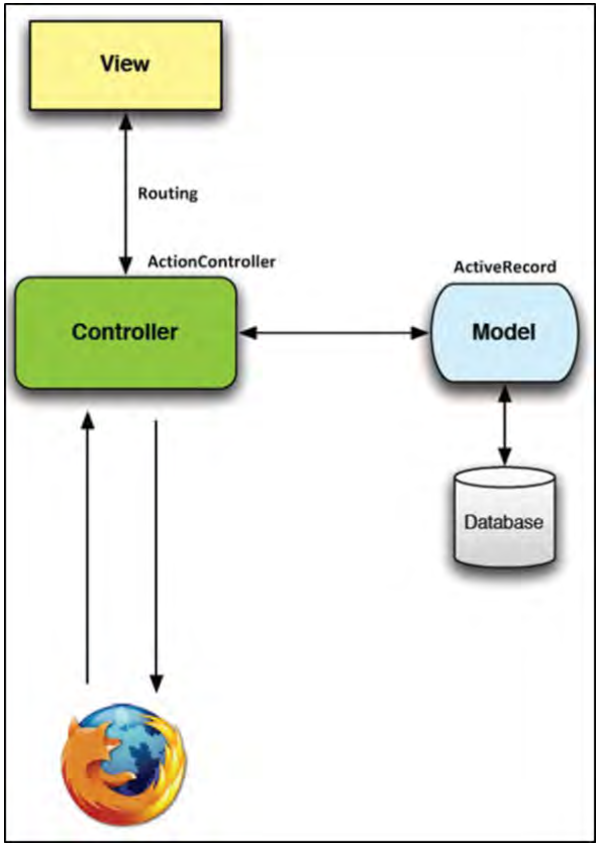
- The process flow could be increased and better traceability to the requirements provided through the use of collaborative, web-based software.
- This software is used to generate the Level of Rigor tasks and track the required artifacts in a real-time, multiuser environment.
- This collaborative program was created using the Ruby on Rails web-based framework. Allows for synergy among all team members.

Ruby on Rails

- Ruby on Rails was chosen as the framework for the development of the Requirements Tracking web application.
- The user would be able to take advantage of collaboration among their colleagues, decreasing the likelihood that a safety critical item being missed.
- The web application framework provides a structure that allows for the creation of the various system safety analyses.
- Each analysis will require specific items or entities that must be entered into the database and tracked.
- These entities will also require relationships among them to be defined.
- The web application will guide the user through the Level of Rigor task selection process and create a common structure for the compliance process.

Ruby on Rails

- Ruby on Rails uses the Model View controller (MVC) architectural pattern
- Browser is routed to the Controller which translates the data from the Model into a viewable form using the View



MVC Architecture, M. Hartl

Guidance on Software Safety

- MIL-STD-882E, contains an appendix on Software System Safety and Analysis (Latest release 2012)
- The Joint Software System Safety Engineering Handbook (Latest release 2010)
- Allied Ordnance Publication, AOP-52 (Latest release 2008)
- The JSSSEH and AOP-52 are the most focused documents on Software System Safety

- Provides the baseline for a Software System Safety (SSS) program
- Created as a result of historical lessons learned from past programs and they “represent the best practices from successful programs.”

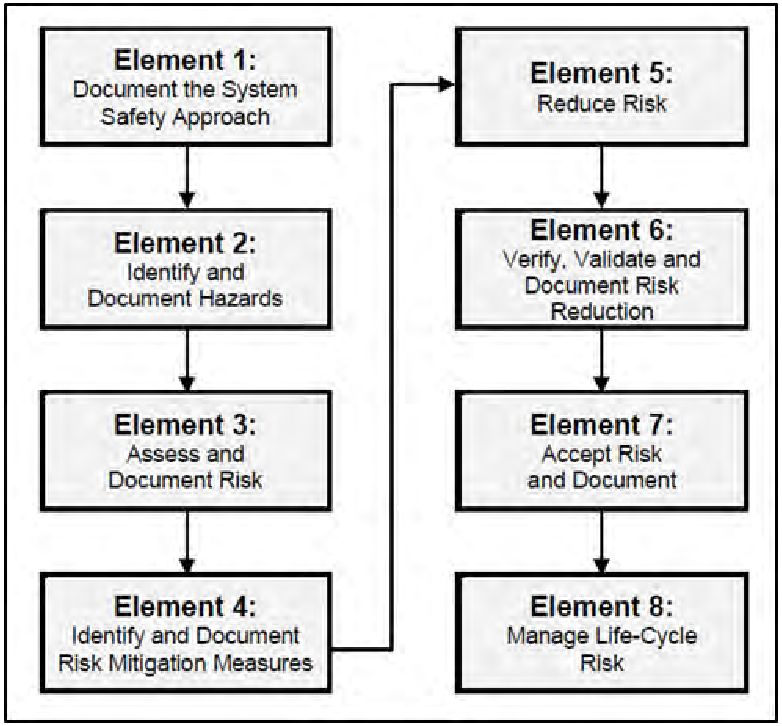
- Developed as a result of political pressure after several catastrophic mishaps which occurred in the 1950s, such as Atlas and Titan rockets exploding in their silos during testing
- Found during the investigations into those events that the failures were related to <u>deficiencies in the design, testing and management of the systems</u>
- Determined that the deficiencies should have been detected and corrected.

- Similar to the JSSSEH, MIL-STD-882 requires the assignment of a Risk Assessment Code (RAC).
- The RAC is the combination of the Mishap Severity and Probability of Occurrence levels.

- The standard acknowledges that risk and probability cannot be the only part of the risk assessment.
- It is very difficult to determine the probability of the failure of a specific software function.
- Therefore, the potential risk severity and the degree of control that the software exercises over the hardware is used to assess the software subsystem's contribution to the system risk

Methodology

- MIL-STD-882E is the System Safety Standard Practice for the Department of Defense (DoD).
- As such, it applies to all military departments and defense agencies in the DoD.
- The graphic below depicts the generic sequence of events that is used with regard to the system safety process.



Methodology

- A relational database was created in order to streamline the generation and traceability of the system software safety requirements known as the Level of Rigor.
- The database requirements were determined by reviewing the applicable standards.

Results

- The web based framework provides an easy means by which the user can record and track safety related information for their program.
- The purpose of the software was to make it easier for the user to generate the appropriate LOR tasks.

Results Cont.

- The index webpage identifies the initial system safety process.
- The user must begin at the first item in the list (PHL) and move downwards though the remaining analyses such as the PHA and FHA.

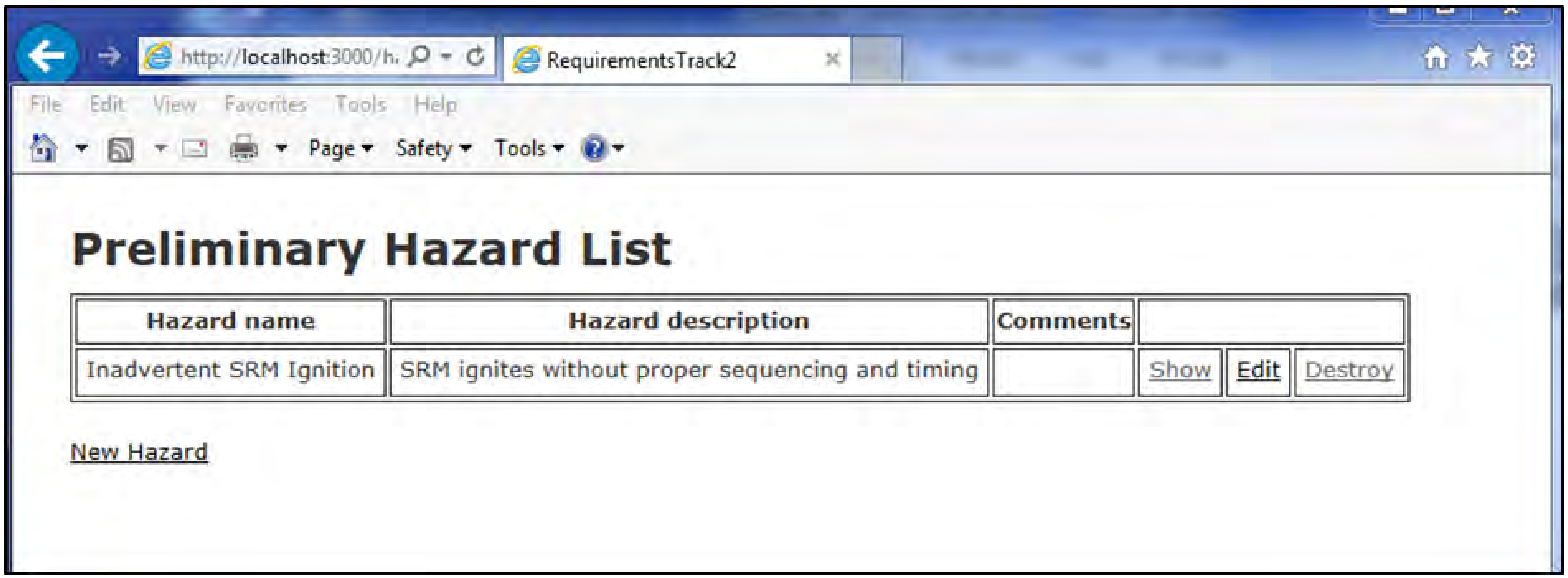
Welcome to Requirements & Hazard Tracker Database

Select Each Link and Complete the Forms to Determine the Level of Rigor for your Program

Analysis	Description
Preliminary Hazard List	The Preliminary Hazard List is a list of potential hazards identified early in the development cycle.
Preliminary Hazard Analysis	The Preliminary Hazard Analysis identifies hazards, allows for the assessment of the initial risks, and identification of potential risk mitigation efforts.
Functional Hazard Analysis	The Functional Hazard Analysis is where the decomposition of the system and/or subsystem into individual functions takes place. The functional description, failure modes and consequences of failure are all identified.
Full Level of Rigor Table	Enter all the possible LOR tasks.
Resources	Resources from the Joint Software Systems Safety Engineering Handbook and MIL-STD-882E are provided for convenience.
My Rigor	The Rigor for my program. The output of the FHA will be the RAC, which when used with JSSSEH Table 3-3, will determine the LOR.
About Requirements Tracker	About this website.

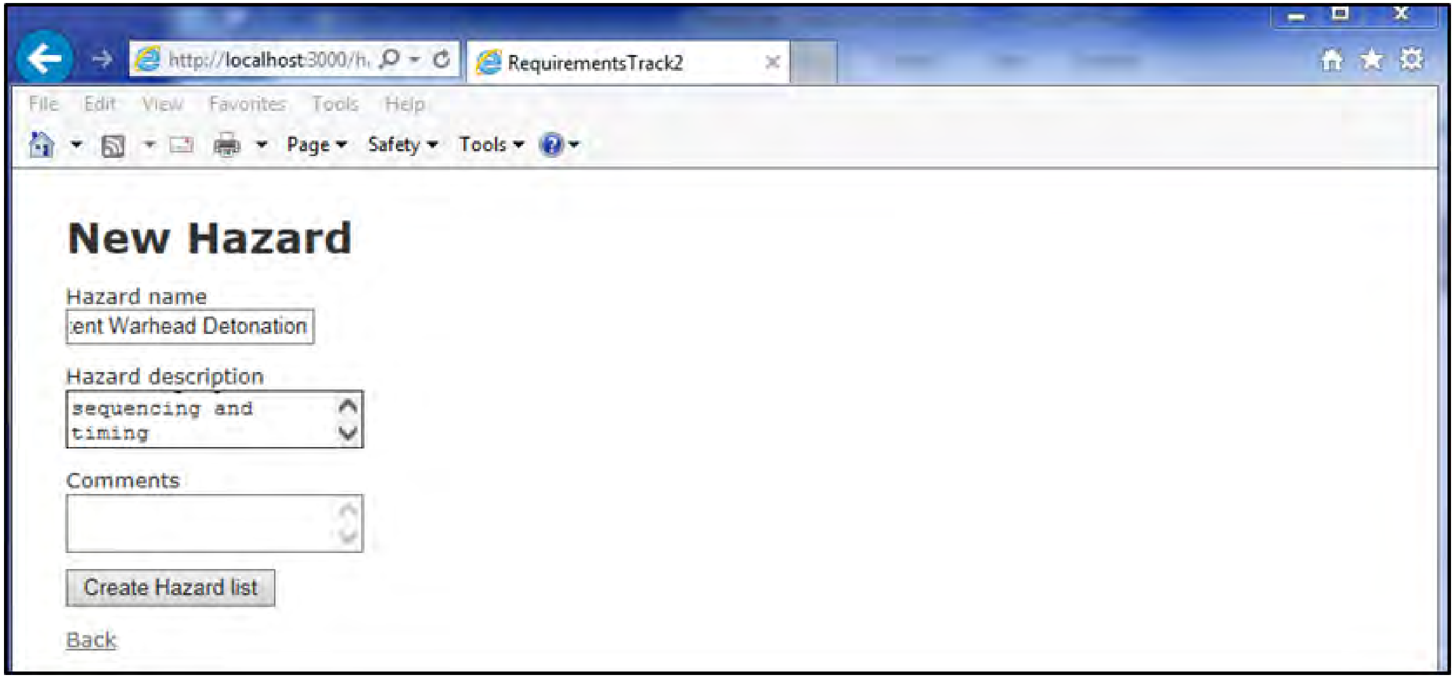
Preliminary Hazard List

- The Preliminary Hazard List is a list of potential hazards identified early in the development cycle.
- The user or users identify such hazards using the webpage.



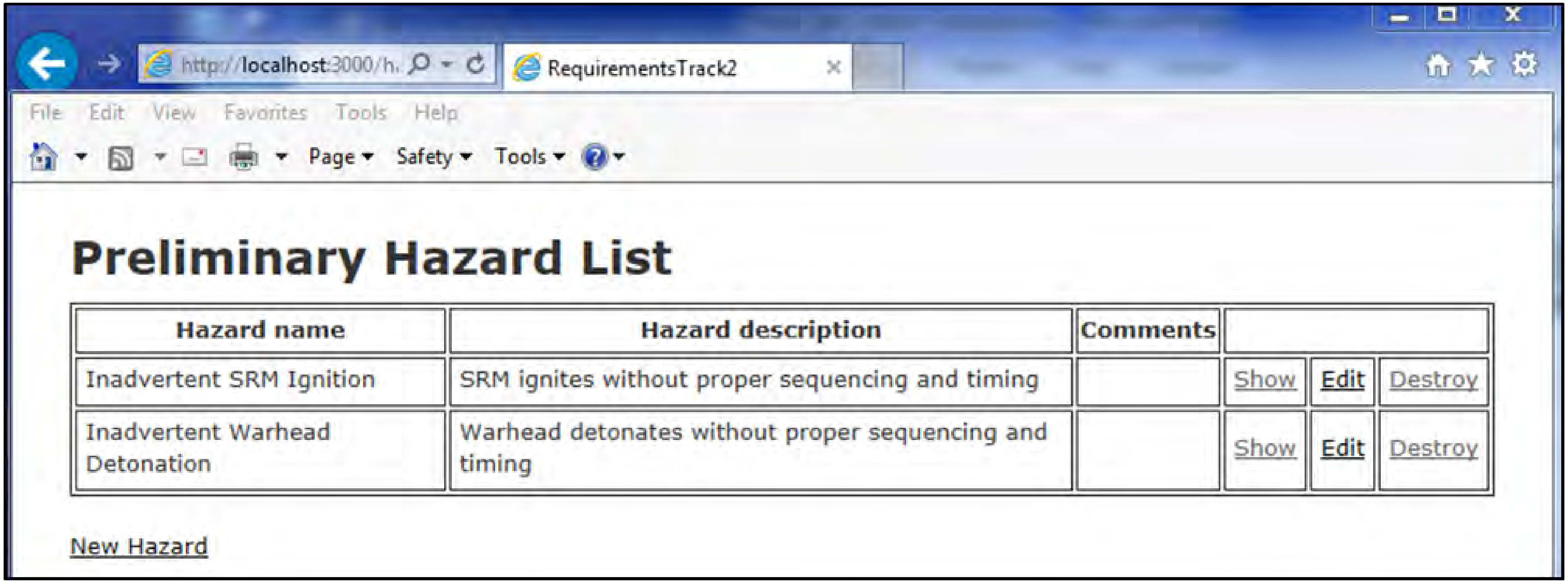
Preliminary Hazard List

- Selecting the “New Hazard” link brings the user to a form that allows them to add a hazard to the list.



Preliminary Hazard List

- The Preliminary Hazard List has been updated with the new hazard.



Preliminary Hazard List

Hazard name	Hazard description	Comments			
Inadvertent SRM Ignition	SRM ignites without proper sequencing and timing		Show	Edit	Destroy
Inadvertent Warhead Detonation	Warhead detonates without proper sequencing and timing		Show	Edit	Destroy

New Hazard

Preliminary Hazard Analysis

- The Preliminary Hazard Analysis identifies hazards, allows for the assessment of the initial risks, and identification of potential risk mitigation efforts

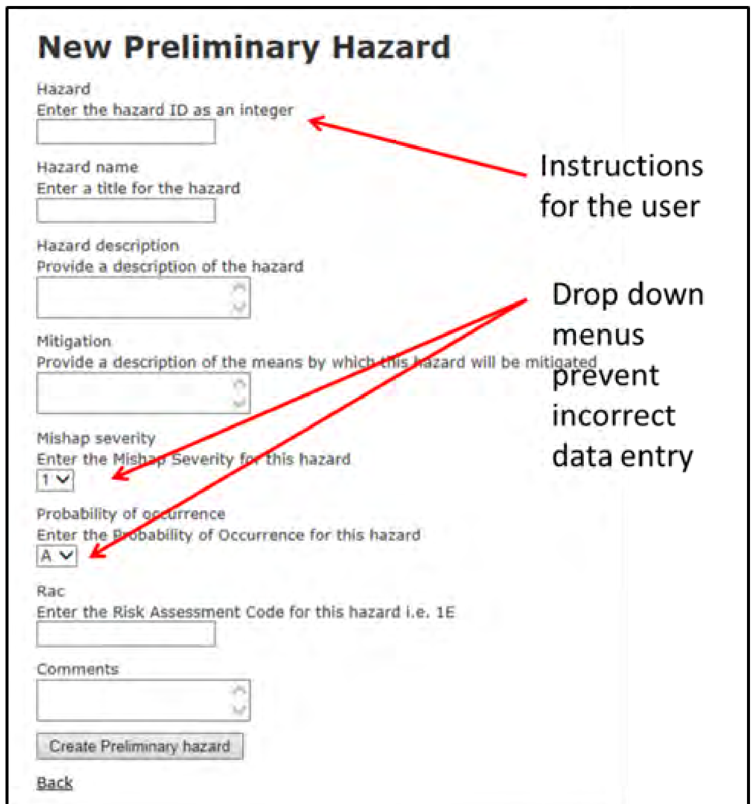
Preliminary Hazard Analysis

Hazard	Hazard name	Hazard description	Mitigation	Mishap severity	Probability of occurrence	RAC	Comments			
1	Inadvertent SRM Ignition	SRM ignites without proper sequencing and timing	Circuitry used to verify that only proper sequence will generate ARMING energy	1	E	1E		Show	Edit	Destroy
2	Inadvertent Warhead Detonation	Warhead detonates without proper sequencing and timing	Circuitry used to verify that only proper sequence will generate ARMING energy	1	E	1E		Show	Edit	Destroy

New Preliminary Hazard

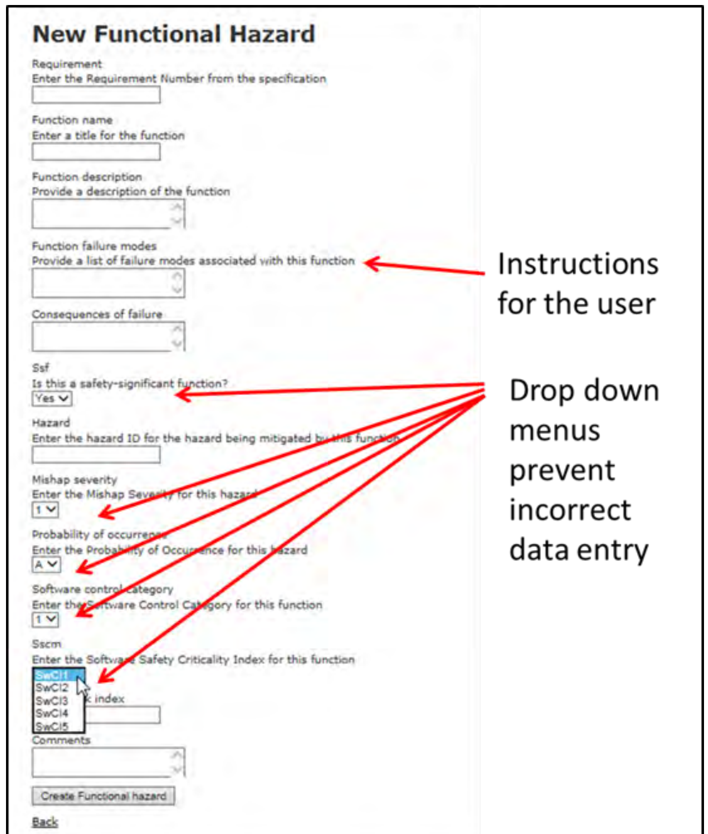
Preliminary Hazard Analysis

- New Preliminary Hazards are entered into the software by using the “New Preliminary Hazard” button
- Instructions are provided to the user and drop down menus are used to improve the quality of the data



Functional Hazard Analysis

- The Functional Hazard Analysis is where the decomposition of the system and/or subsystem into individual functions occurs.
- The functional description, failure modes, and consequences-of-failure are all identified at this stage.



Functional Hazard Analysis

Orbital ATK

- The functions, which are a result of the system decomposition effort, may be associated with the hazards identified in previous analysis phases.
- Example: both requirements 4 and 5 relate to the same hazard "Hazard 1, Inadvertent SRM Ignition."

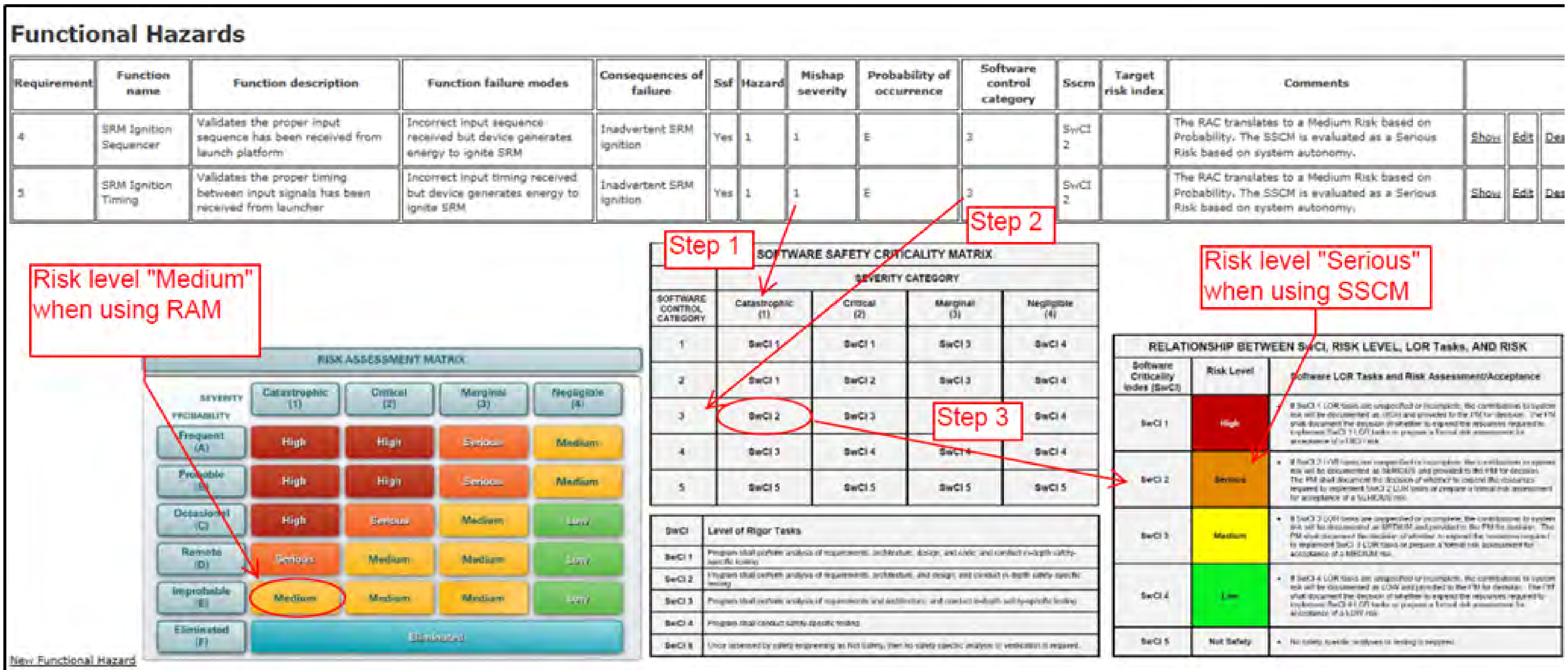
Functional Hazards

Requirement	Function name	Function description	Function failure modes	Consequences of failure	Ssf	Hazard	Mishap severity	Probability of occurrence	Software control category	Sscm	Target risk index	Comments	
4	SRM Ignition Sequencer	Validates the proper input sequence has been received from launch platform	Incorrect input sequence received but device generates energy to ignite SRM	Inadvertent SRM ignition	Yes	1	1	E	3	SwCI 2		The RAC translates to a Medium Risk based on Probability. The SSCM is evaluated as a Serious Risk based on system autonomy.	Sl
5	SRM Ignition Timing	Validates the proper timing between input signals has been received from launcher	Incorrect input timing received but device generates energy to ignite SRM	Inadvertent SRM ignition	Yes	1	1	E	3	SwCI 2		The RAC translates to a Medium Risk based on Probability. The SSCM is evaluated as a Serious Risk based on system autonomy.	Sl

New Functional Hazard

Level of Rigor Determination

- The output of the FHA will be the RAC, which when used with JSSSEH Table 3-3 and the Software Safety Criticality Matrix, will determine the Level of Rigor (LOR)



Full List of LOR Tasks

- The "My Rigor Tasks" table contains all the LOR tasks that must be accomplished as part of the System Software Safety Analysis
- Generated as a result of the worst case LOR
- A link is provided at the bottom of the "My Rigor Tasks" page for the purpose of adding new tasks.

My Rigor Tasks

Lor activity	Primary responsibility	Lor	Artifacts produced	Comments
Perform a Preliminary Hazard Analysis	Developer	Baseline	List of Hazards and Failure Modes PHA	
Perform a Functional Hazard Analysis	Developer	Baseline	Functional Hazard Analysis List of Safety Significant Functions	
Derive Requirements to ensure safety-significant interfaces are validated and controlled at all times	Developer	Serious	Interface Analysis	
Coordinated Safety-significant Requirements Review for correctness and completeness	Developer	Serious	Safety Requirements Review	
Perform a safety review of each test case	Developer	Medium	Safety Review Results	
Review all requirements traceability matrices for coverage and completeness	Developer	Medium	Requirements Traceability Review Results	

New My Rigor Task

Discussion

- The LOR task list was generated with the user requiring only a marginal familiarity with the safety specifications such as MIL-STD-882E, the JSSSEH or AOP-52.
- Of course, the LOR task list will need to be checked and approved by the appropriate safety authority but a significant amount of work is generated for the user with very little effort.
- Collaboration among colleagues allows for greater safety related input to the program.

Conclusion

- The study of Software Quality Assurance techniques and its application towards the development of hardware provides a benefit to hardware developers who may now leverage decades of lessons learned from the study of safety critical software.
- The web based program developed as part of this paper provides a means by which developers can collaborate on the requirements, design and testing of safety critical software or “software-like” systems.

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61ST ANNUAL FUZE CONFERENCE

SAN DIEGO, CA, USA, MAY 15-17, 2018

EMBEDDED HIGH G SHOCK SENSOR BEHAVIOR ANALYSIS FOR SEVERE PERFORATION TESTS

Sérey CHHIM – Aurélien HOTTELET – Don-Pierre ZAPPA – Olivier PIROTAIS – Bernard DEMESURE

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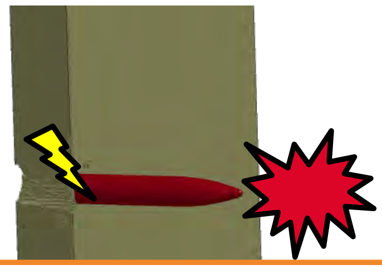
MAY 16, 2018

OVERVIEW

- CEA Gramat is the French leader in research on the lethality of weapon systems
- One field of investigation deals with fuze mechanical resistance to high-velocity projectile impact (military penetration warhead)



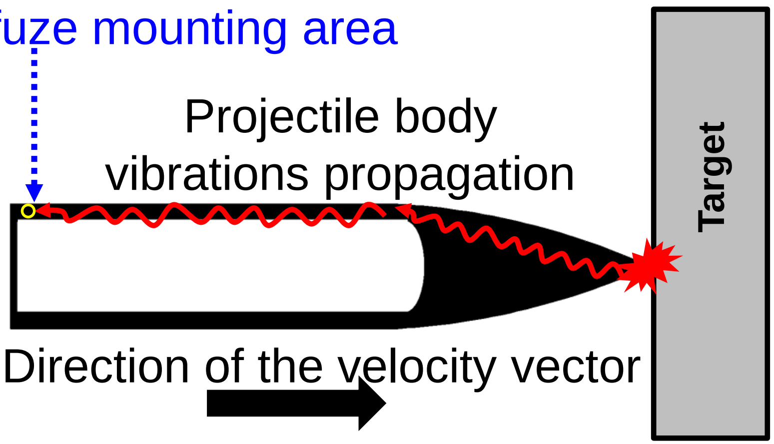
Simulation: perforation of a concrete slab by ammunition

- Objective of CEA Gramat studies: characterize the mechanical shocks that can damage fuzes
  - Mechanical environnement can be used as input for Industry to design fuzes
- In order to characterize the mechanical environment, high-G PCB triaxial accelerometer is used
  - Measurement range of 60 000 g and resonance frequency around 160 000 Hz
    - ► The sensor is limited in maximum range and bandwidth measurement
  - In our applications, we want to measure high acceleration ranges (> 60 000 g) at high frequencies (>160 000 Hz)

ACCELERATION SIGNAL: SENSING PROPERTIES FOR FULL FREQUENCY CONTENT ACQUISITION

GOAL: characterize the mechanical environment transferred from the warhead body to the fuze body

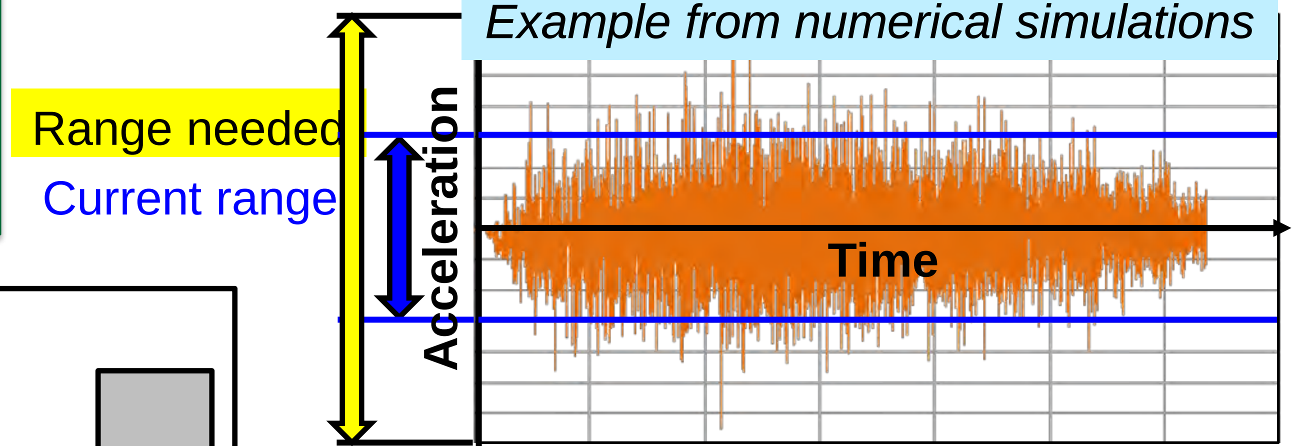
Acceleration location: fuze mounting area

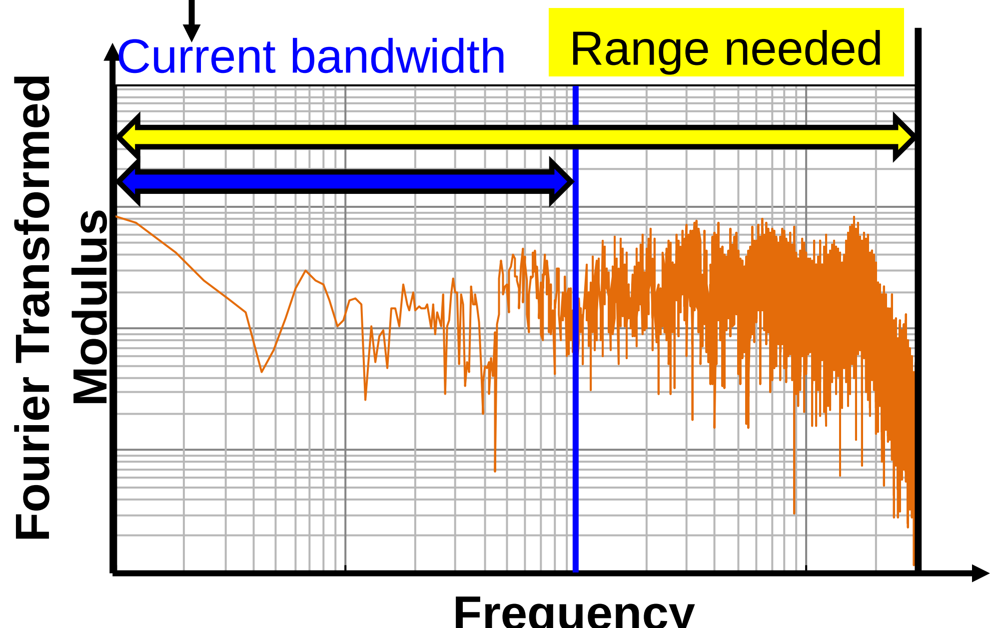


Numerical simulations show that:

- We need x2 Sensor Maximum Range
- We need x30 Sensor Maximum Bandwidth

Acceleration versus time history: Example from numerical simulations



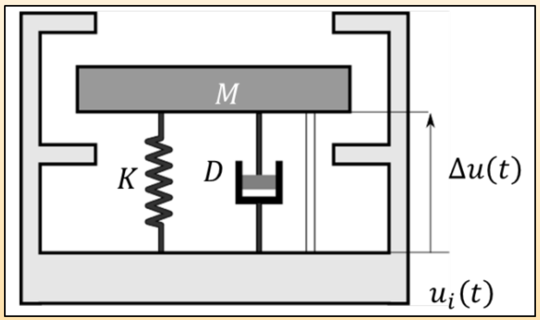


SENSOR MODELLING / SIGNAL CONVOLUTION

Physical value
$(m.s^{-2})$
$\vec{\gamma}(t)$

Sensor response
$(m.s^{-2} \rightarrow pC\ or\ mV)$
$S_{sensor}(t) = G(f) \otimes \gamma(t)$

Acquisition
$(pC\ or\ mV$ -> bits)



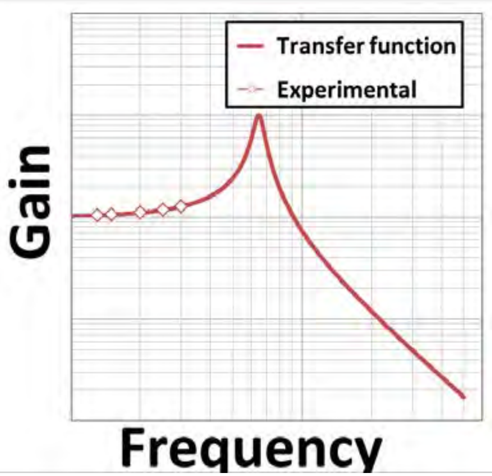
Displacement of M :

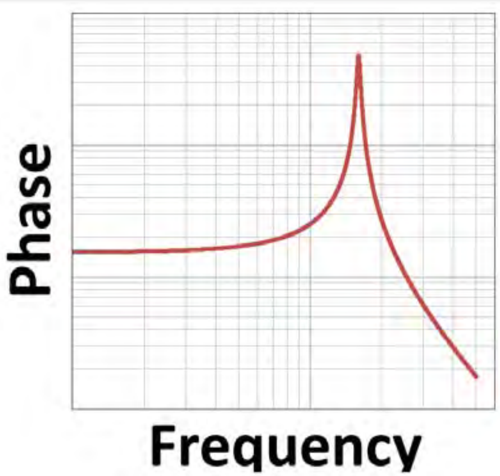
$$\ddot{u} + 2\omega\xi\dot{u} + \omega_0^2 u = \frac{\gamma_i}{m}$$

with $\xi = \frac{D}{2\sqrt{KM}}$ et $\omega_0^2 = \frac{K}{M}$

Transfer function

$G(f) = \frac{G_0}{\sqrt{\left(1-\left(f/f_0\right)^2\right)^2 + \left(2\left(f/f_0\right)^2\right)^2}}$ and $\varphi(f) = -arc\tan\left(\frac{2\xi\left(\frac{f}{f_0}\right)}{1-\left(\frac{f}{f_0}\right)^2}\right)$



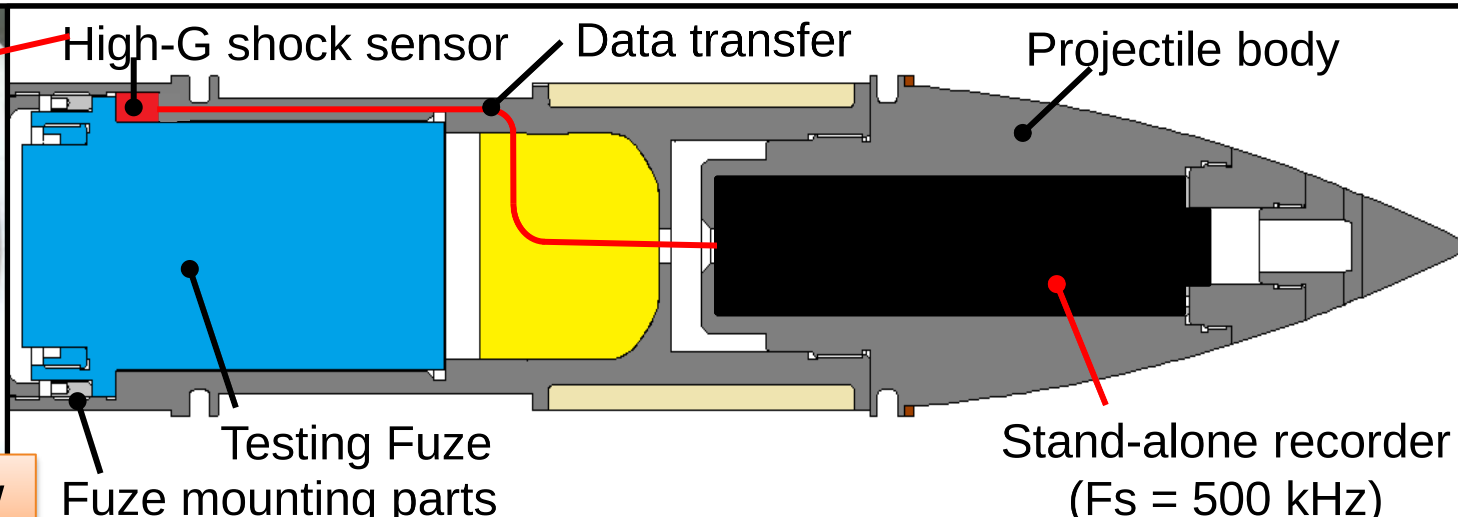


Accelerometric sensors are spring-mass-damper systems

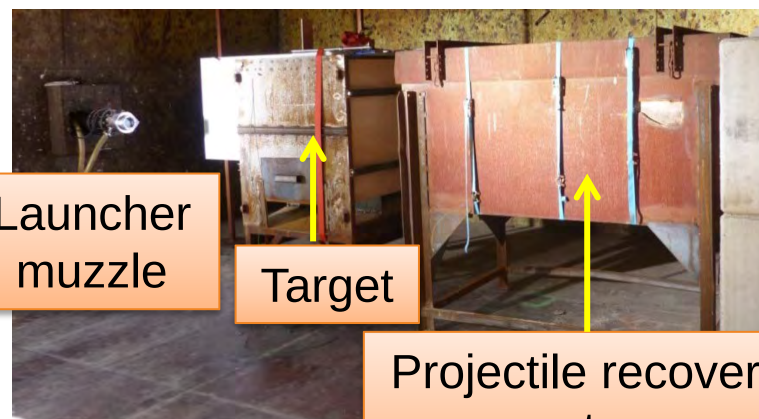
- Physical value is acceleration
- Acceleration is measured through displacement of mass M which modifies piezo-resistive gage resistance
- Mechanical sensor response is given by its transfer function.
- Usable frequency range: where gain is constant and equals to unity
- Knowledge of transfer function allows artificial increase bandwidth by inverse convolution

EXPERIMENTAL SETUP – TERMINAL BALLISTICS

Projectile rear view

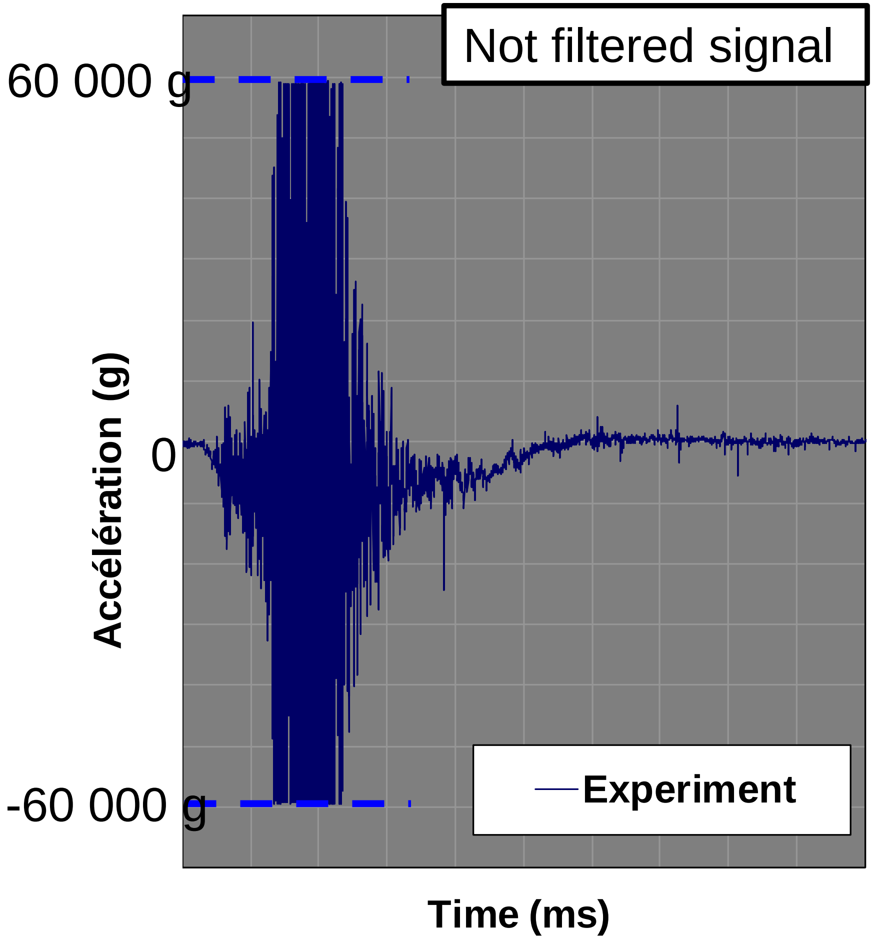


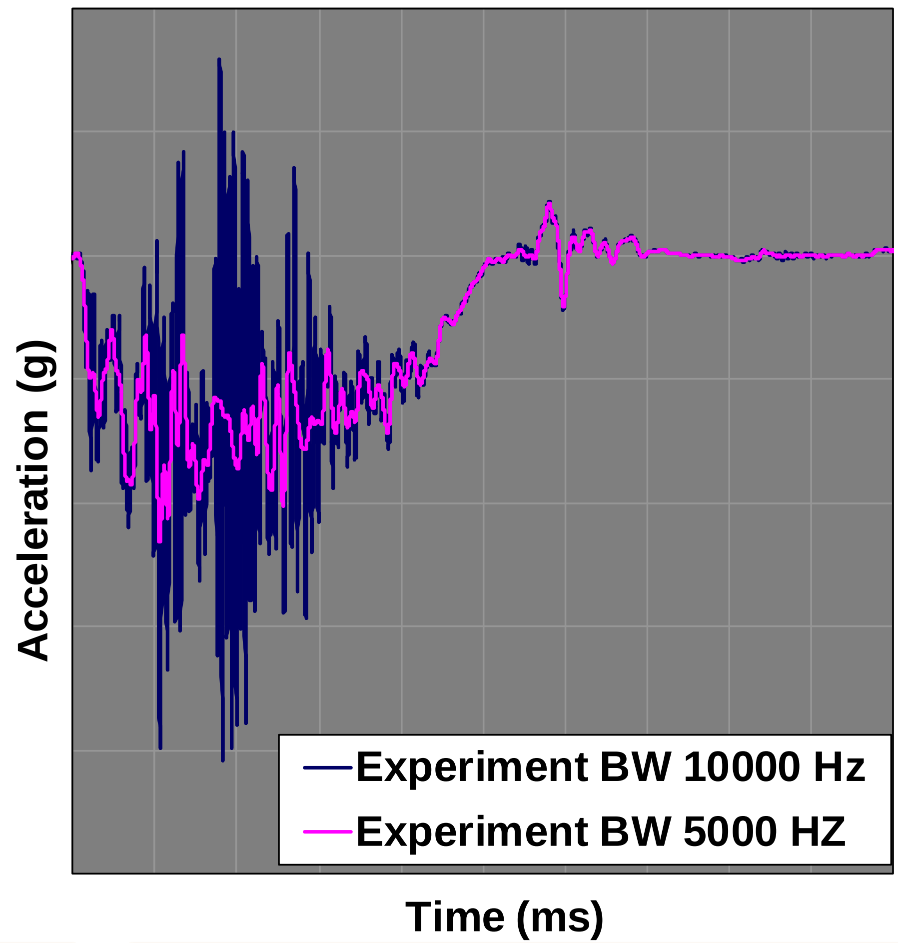
Projectile before impact



Projectile recovery after the test

EXPERIMENTAL RESULTS





Raw signal provided by the sensor

- Longitudinal acceleration
- The signal overruns 60 000 g
- The sensor keeps its full integrity

Butterworth filter (Fc = 10 kHz and 5 kHz)

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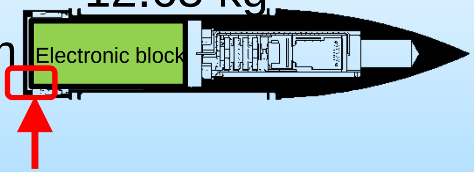
NUMERICAL SIMULATIONS

- Purpose: evaluate the sensor response at the point of interest thanks to numerical simulation

12.65 kg

Ø 98 mm



Measurement of the acceleration signal at the block mounting parts

- **Method:**

1. Penetration simulation with a 3D full description of projectile => output = acceleration time history values at the location of the deported sensor

2. Convolution of the calculated value (cf. slide 'sensor modelling / signal convolution')

3. Comparison with recorded signal of the deported sensor

1 — Physical value

$\left(m.s^{-2}\right)$

$\vec{\gamma}(t)$

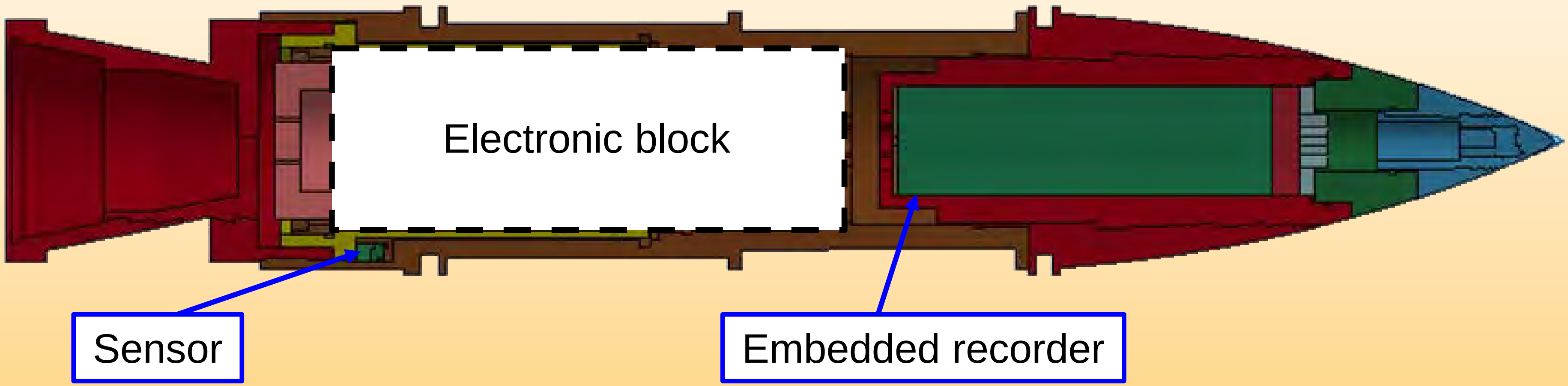
2 — Sensor response

$\left(m.s^{-2} \rightarrow pC \text{ or } mV\right)$

$S_{sensor}(t) = G(f) \otimes \gamma(t)$

3 — Comparison between sensor response 'from simulation' / sensor response from the experiment

NUMERICAL MODEL DESCRIPTION



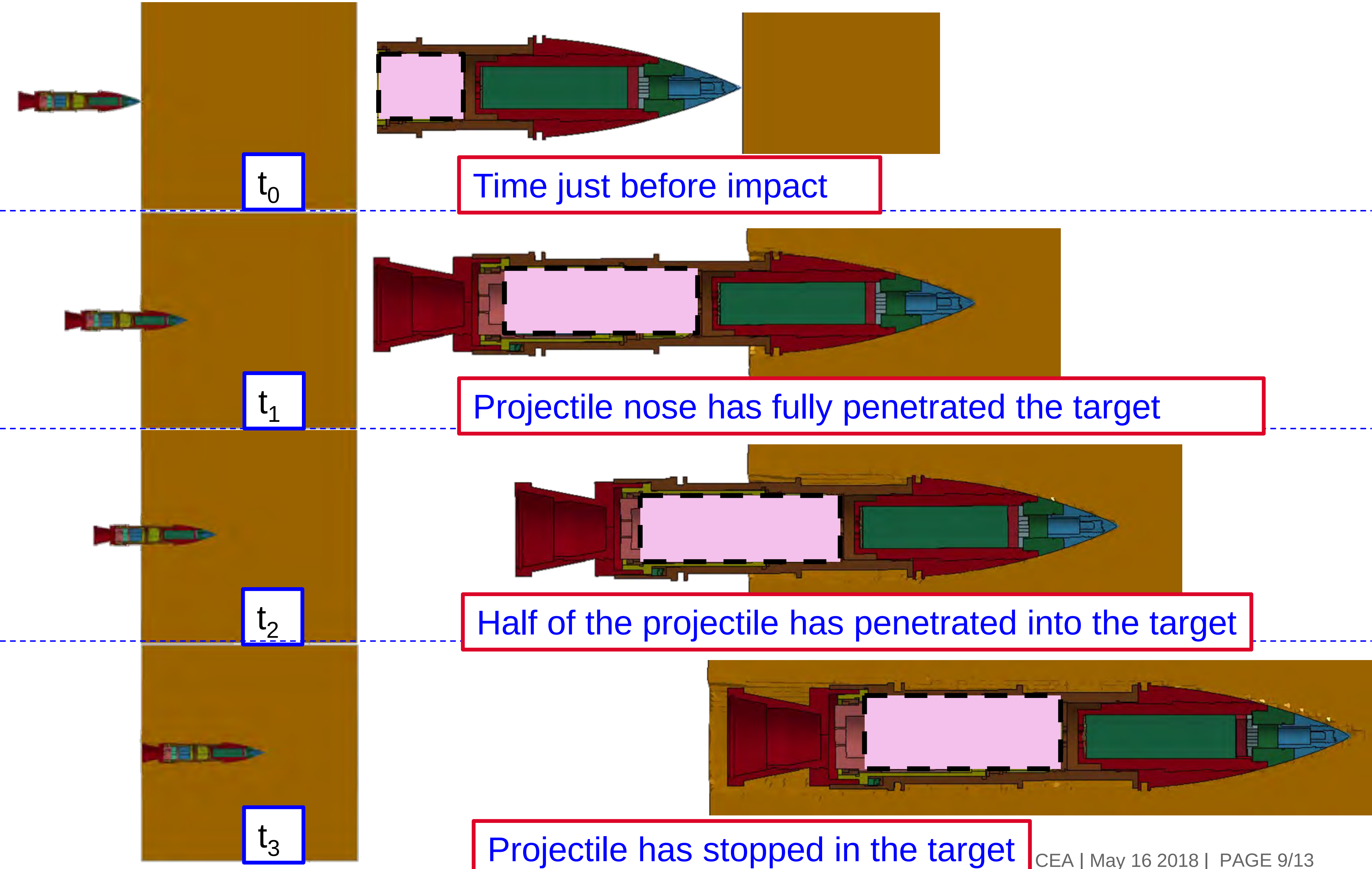
Finite element model

- Total mass: 12.6 kg
- 325 000 brick elements
- Target: 3.3 M brick elements

Simplified assumptions

- No preload, only tied interfaces between components: sensor is tied to the steel confinement
- Finite elements erosion is enabled to allow the projectile to progress through the target
- Target : Elastic and plastic behavior in Ls-Dyna combined with MAT_ADD_EROSION
- No gravitational loads are applied

NUMERICAL SIMULATIONS: RESULTS



NUMERICAL SIMULATIONS: RESULTS

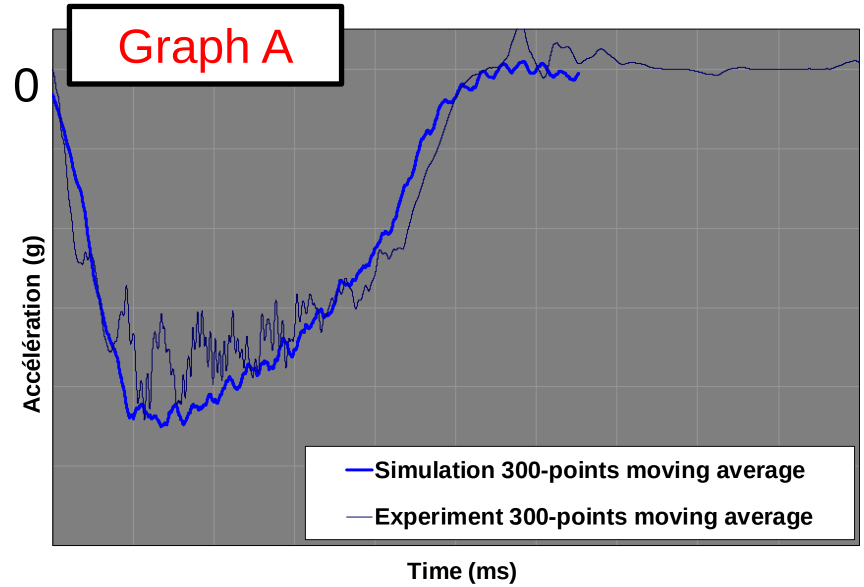
- Graph A: acceleration vs time signals comparison experiment / simulation at low frequencies range (curves are smoothed with a 300-pt moving average ≈ low pass filter)

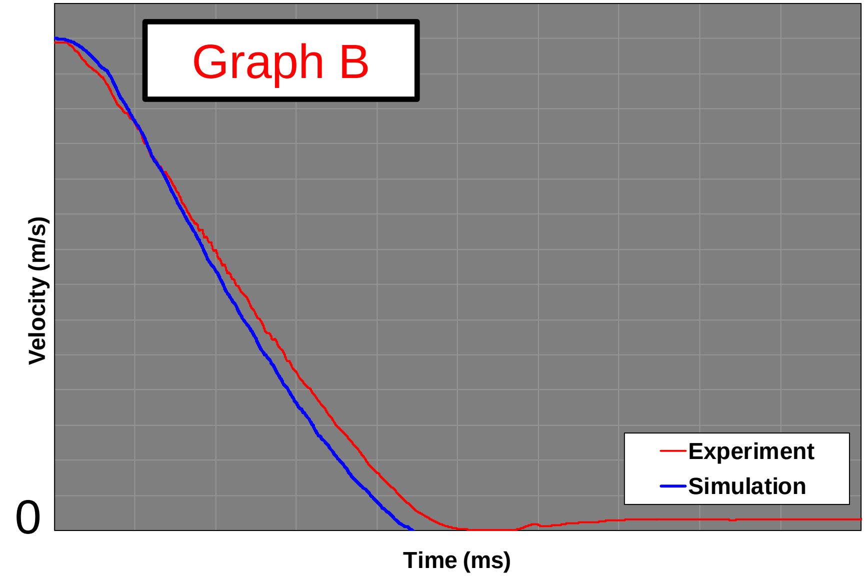
- Good agreement between simulation and experimental acceleration signals
  - Peak acceleration is the same, duration of penetration in the target is the same

- Good agreement between simulation and experimental velocity time histories (Graph B)

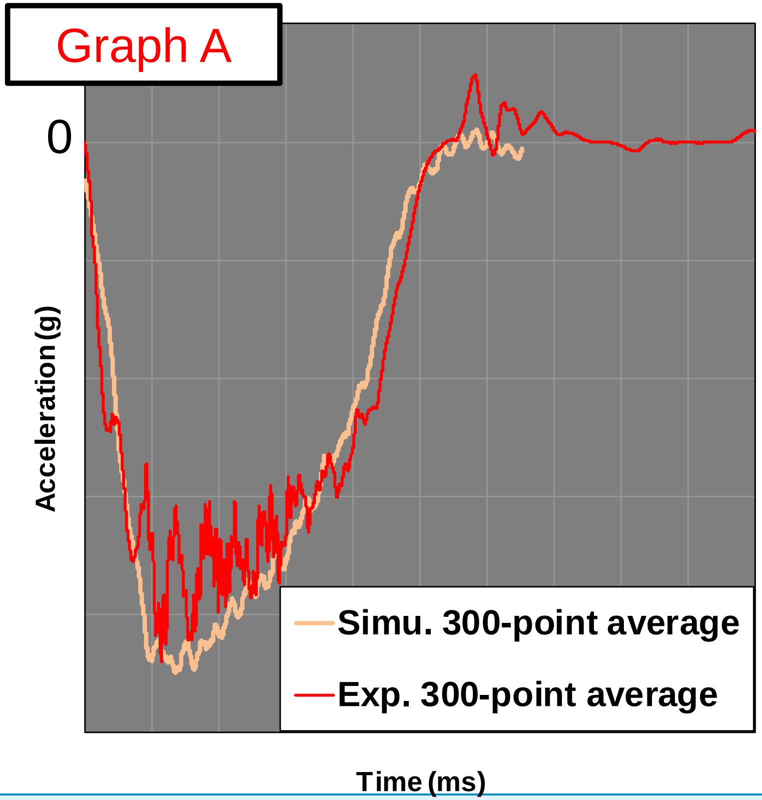
►Simulation results match experimental data

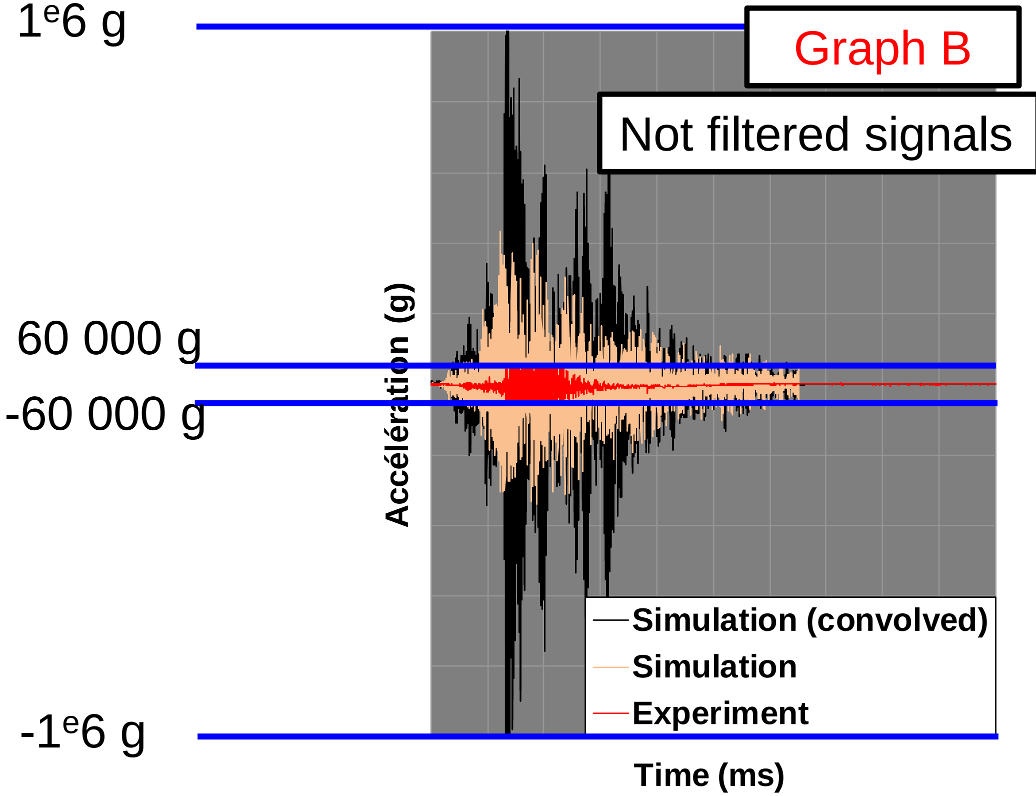
► At low frequencies range (Graph A): calculated acceleration time history matches the experimental data => same duration and amplitude of accelerations





SENSOR BEHAVIOUR APPLIED TO NUMERICAL SIGNAL





Calculated averaged signal of acceleration

- Low frequencies validated by experiment as it has previously been shown

Extended bandwidth signal

- 0 - 300 000 Hz
- The highest acceleration amplitudes are due to sensor resonant frequency

Graph B: Simulated sensor response **is significantly different** from the experiment for the high frequencies range

CONCLUSION

- The mechanical environnement can be used as input for Industry to design fuzes: it has to be characterized

- The 60 000 g sensor used in our experimental setups has several limitations:
  - acceleration range is too low
  - frequency range, where gain is constant, is lower than our requirements
  - resonant frequency can disturb measurement

- The study shows an approach that gives a more accurate fuze mechanical environment focused on high frequencies
  - Based on high performance numerical simulation (evaluation of the physical acceleration signal that is to be to measured)
  - Simulation combines ideal sensor behavior at high frequencies without mechanical stops
  - In practice, sensor bandwidth has been increased

- Observations & Future Works
  - Resonant frequency is preponderant and provides the highest, non-physical acceleration amplitude
  - Sensors need to be improved to collect more physical information:
    - Increase maximum range
    - Increase maximum bandwidth

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Thank you for your attention
Questions?

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RCS Paris B 775 685 019

Direction
Département
Service

PBXN-5 Mechanical Characterization & Proposed Constitutive Model

2018 NDIA Fuze Conference
San Diego, CA

Nathan Millard, Susan Smith, Daniel Peairs
L3 Defense Electronic Systems

Ericka Amborn, Craig Doolittle
Applied Research Associates, Inc.

May 2018

L3 Defense Electronic Systems (L3 DES)

Bulova 1923
General Time Corp 1936
KDI Precision Products 1957
Talley Industries 1970
L3 EDI 1998
L3 KDI 2001
L3 BT Fuze 2003

L3 Fuzing & Ordnance 2009

Bendix Aviation Corporation 1929
Bendix 1938
Bendix Navigation & Control Division 1966
Allied Bendix Aerospace 1983
Allied Signal 1985

L3 Space & Navigation 1999

Interstate Electronics Corporation 1956
Interstate Electronics Corporation a division of ATO 1964
Interstate Electronics Corporation a Figgie International Company 1981
Interstate Electronics Corporation – Scott Technologies 1997

L3 Interstate Electronics Corp 1999

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Presentation Overview

- Project Overview
- Test Capability
- Tests Conducted
- Comparison to Previous Data
- Model Selection
- Model Development
- Model Validation

Project Overview

- Office of the Secretary of Defense (OSD) program addressed the design, development and improvement of prototypes or processes to meet Electronic Safe and Arm Device (ESAD) requirements

  Objectives

  1) Replace legacy electro-mechanical fuzes with ESADs
  2) Support development of the Fuze industrial base

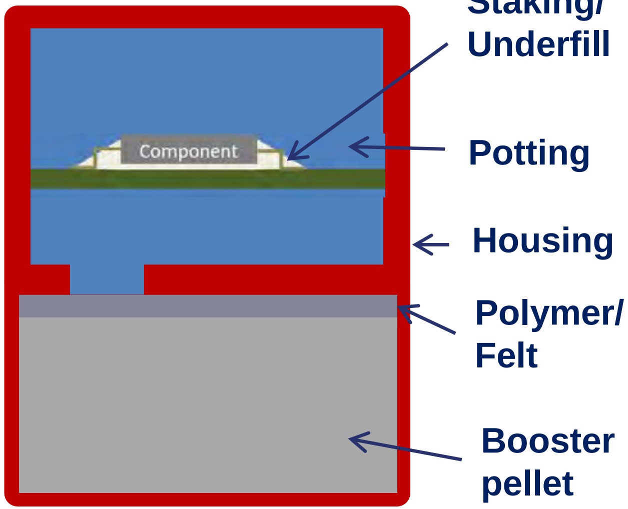
- Main commonalities across ESADs are the materials and electronic and explosive components
- FEA modeling is a key capability for new Fuze development

FEA modeling requires accurate material models in the relevant environments.

Material Downselection

- PBXN-5 selected for study
  - Reviewed "soft" materials used in DES designs
  - PBXN-5 is one of several booster materials typically used
    - Existing data or models requested from USG sources
    - Some data available from LANL
  - Common initiator explosive modeled under an IRAD effort
  - Other "soft" materials tested separately

Representative ESAD

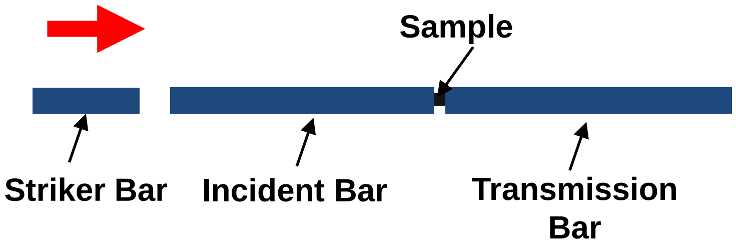


L3 DES Mechanical Characterization Capability

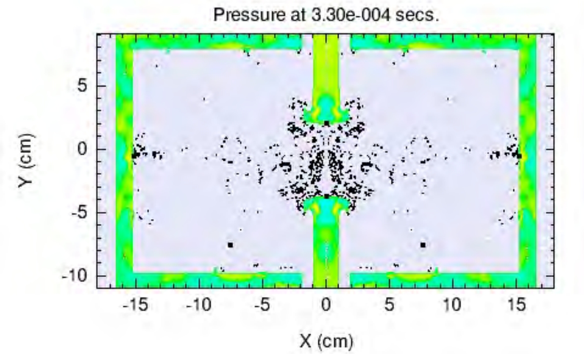
- L3 DES can handle DOD as well as ATF explosives
  - ATF license maintained to test commercial explosives as well as an approved explosives safety site plan to test DoD-regulated explosives under contracts containing DFARS Clause 252.223-7002
  - DOD certification required for most DOD funded contracts under DFARS
- Currently approved for 3.1 g HMX (on Hopkinson bar and universal tester)
  - Higher NEW possible with appropriate analysis
- Hopkinson Bar (developed as part of effort)
- Universal Tester
  - Low rate compression
  - Tension
- DMA (Dynamic Mechanical Analysis)
- TMA (Thermomechanical Analysis)

L3 Hopkinson Bar Facility

- Two Bars
  - 7075 Aluminum for softer material testing
    - 12 ft. incident bar, 8 ft. transmitter bar
  - Maraging Steel for components and hard materials
- Dual function blast box/ remote temperature chamber
  - Analysis completed in CTH to confirm test setup and blast box safety in case of unplanned detonation



L3 Hopkinson Bar

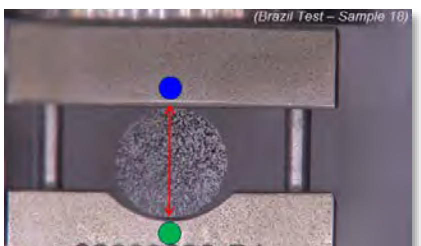


Stress generated in blast box

Universal Tester and Hopkinson Bar Setup

Admet Universal Tester
(for compression, confined compression, Brazil tests)

Hopkinson Bar
(High strain rate tests)



Brazil (Indirect Tension) Test

Confined Compression Fixture

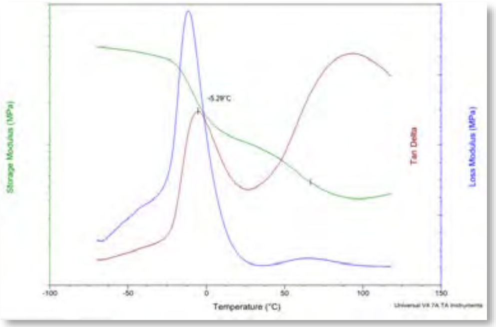
Sample in Hopkinson Bar

DMA, TMA

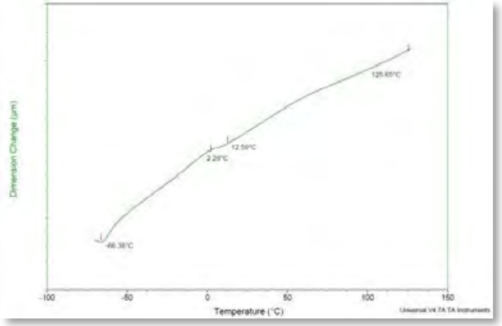
- **Dynamic Mechanical Analysis (DMA) used to assess stiffness modulus across temperature**
- **Thermomechanical Analysis (TMA) used to assess thermal expansion across temperature (CTE)**
- **Glass Transition temperature identifiable by each**

Example DMA Test Configuration

Example TMA Test Configuration



PBXN-5 DMA Results



PBXN-5 TMA Results

Planned Test Matrix

- **Some data points replicate previous data**
- **First known tests for tensile properties and confined compression**

Equipment	Rate	Temperature					
		~-50°C	~-20°C	~0°C	~25°C	~50°C	71°C
Unconfined Compression							
Load Frame	0.001	XO			O	X	O
	0.01						
	0.1	O			O		O
	1	X			X	X	
	100						
Hopkinson Bar	~500	O			O		O
	~1,000	O			O		O
	3,000	XO	X	X	XO	X	O
Tension / Brazil							
Load Frame	0.001	O			O		O
	0.1	O			O		O
Confined Compression							
Load Frame	0.001	O			O		O
	0.1	O			O		O

O	L3 DES tests
X	Data available from literature

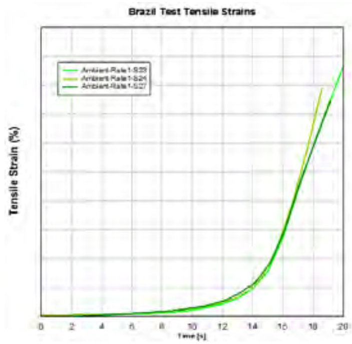
DIC Test Setup

- Digital Image Correlation used for additional strain measurement
- Verifies LVDT measurement

Axial Strain

Brazil Test Horizontal Strain

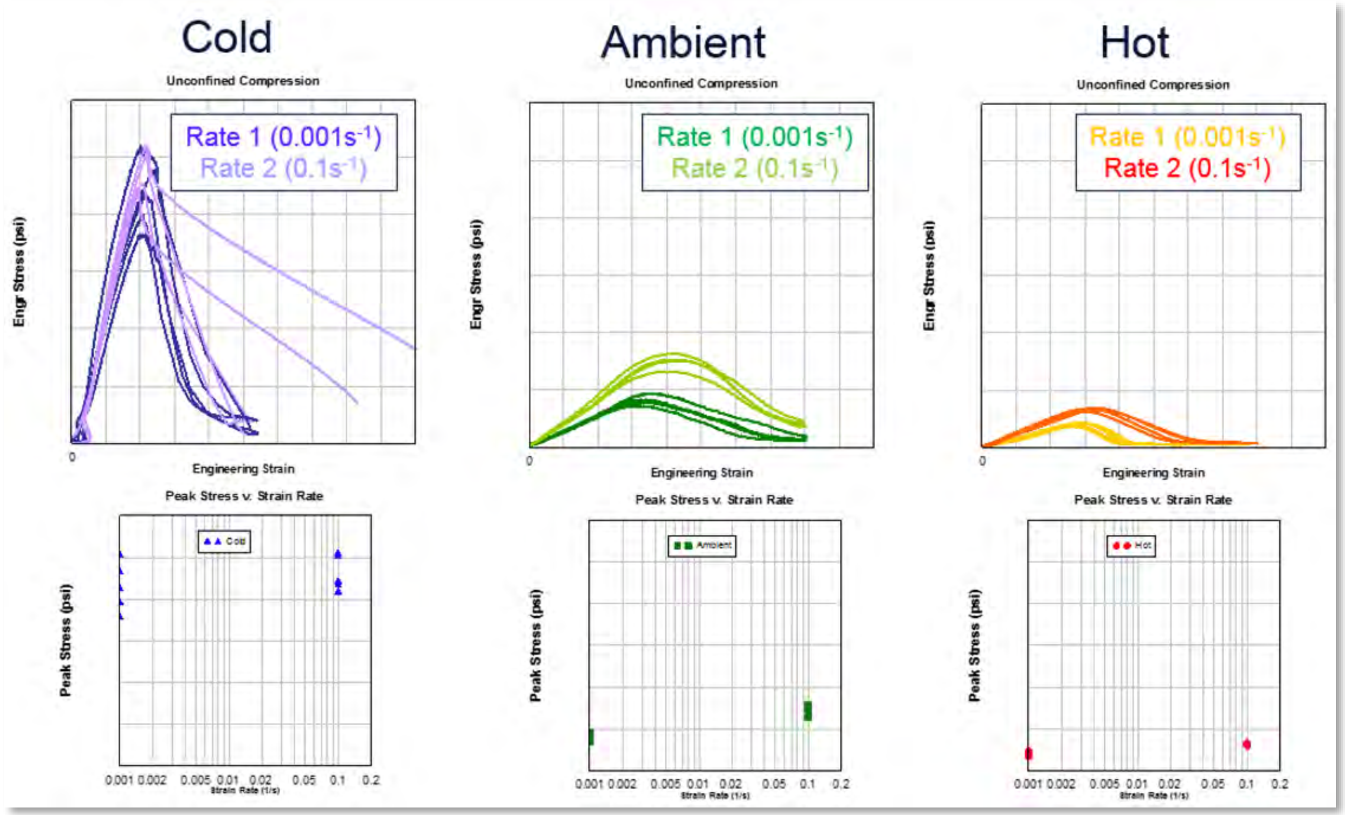
Horizontal Strain



Measured Tensile Strain

Quasistatic Unconfined Compression Results

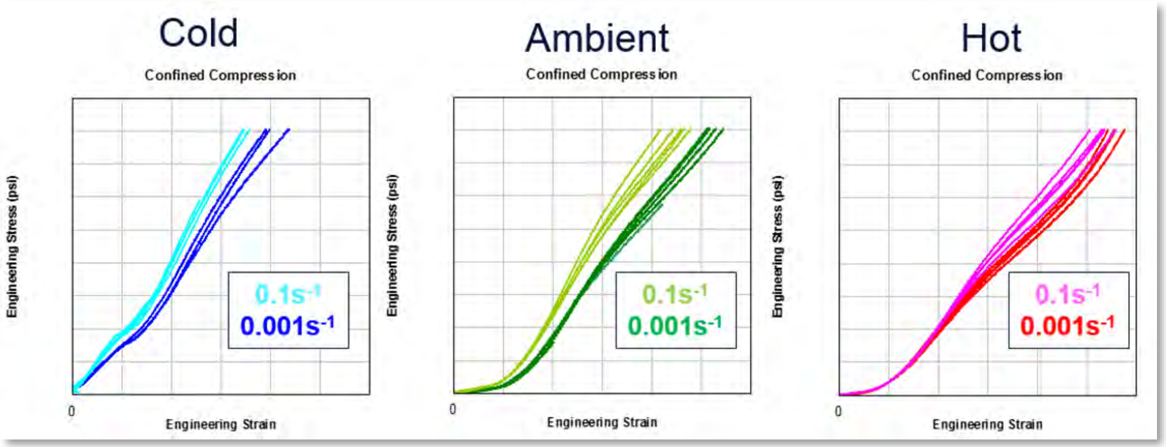
- Clear strain rate dependence at Hot and Ambient, but not at Cold



Confined Compression

- **Confined compression results are repeatable**
  - **Binder response is heavily influenced by temperature**

Confined Compression Fixture

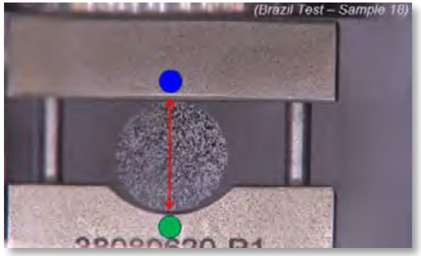


Brazil Tests

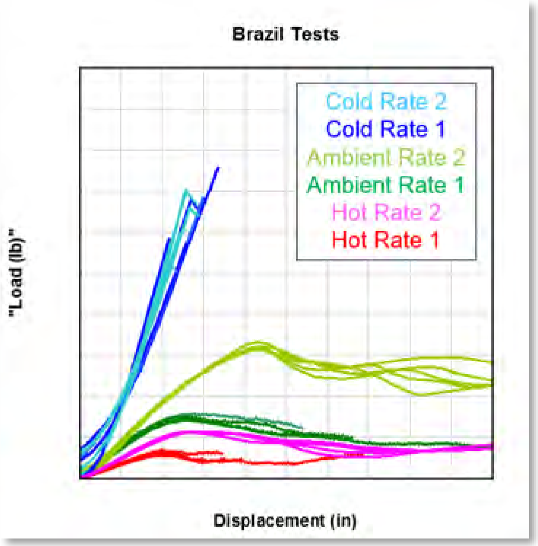
- **Splitting tensile strength calculated from ASTM D3967**

$$\sigma_t = \frac{1.272P}{\pi LD}$$

- **Splitting tensile strengths very repeatable at hot and ambient, more variability at cold**

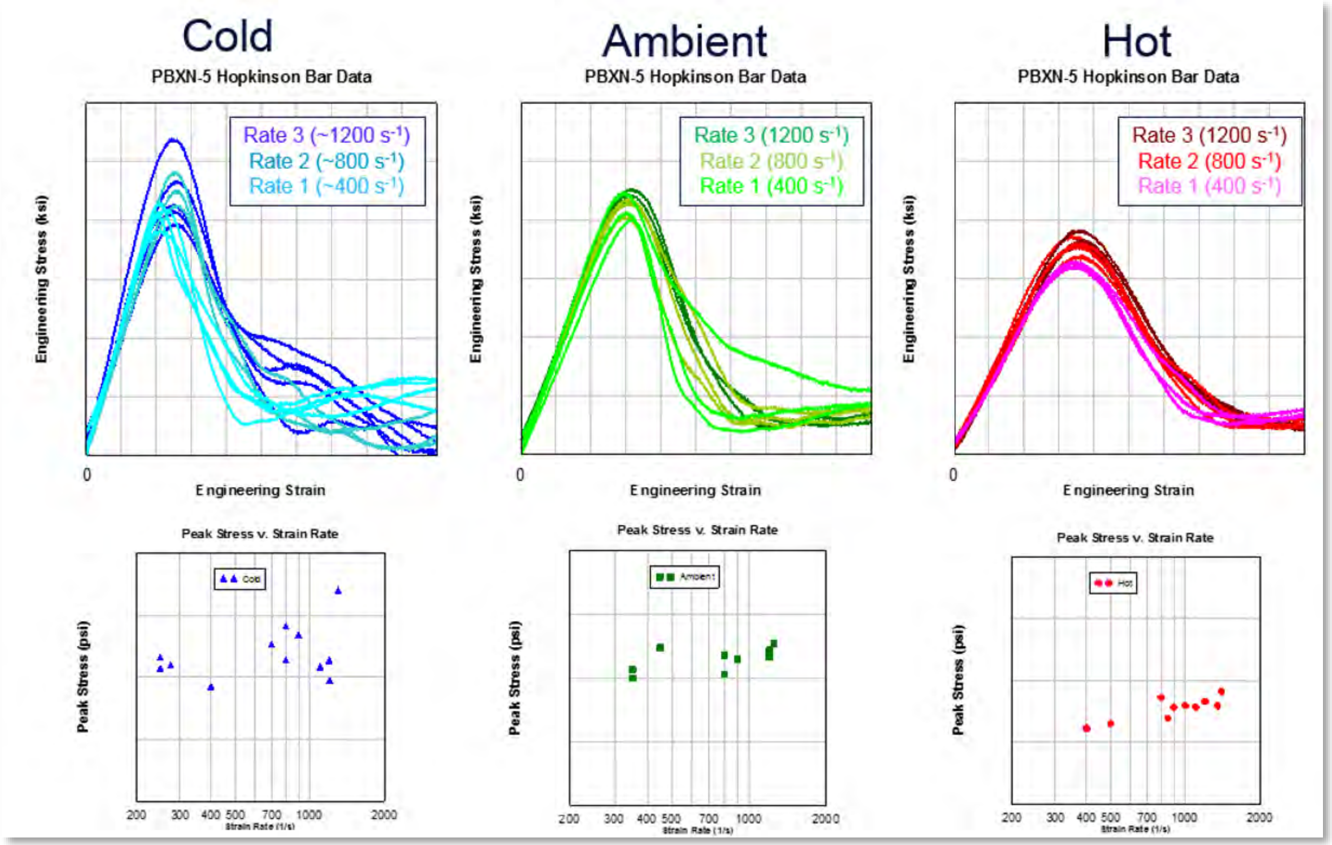


Brazil (Indirect Tension) Test



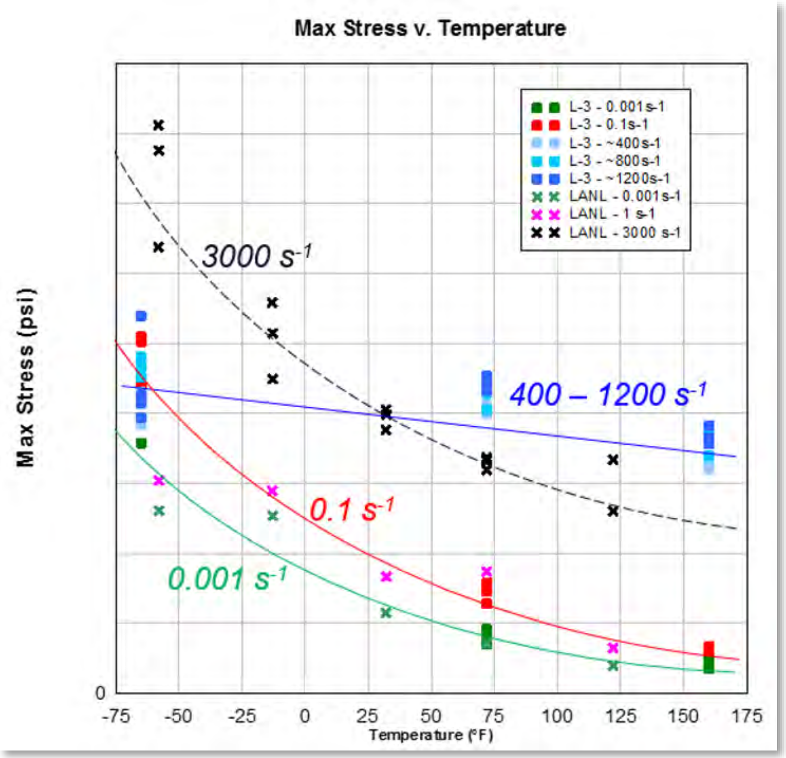
Hopkinson Bar

- **Clear temperature dependence**



Comparison to Literature

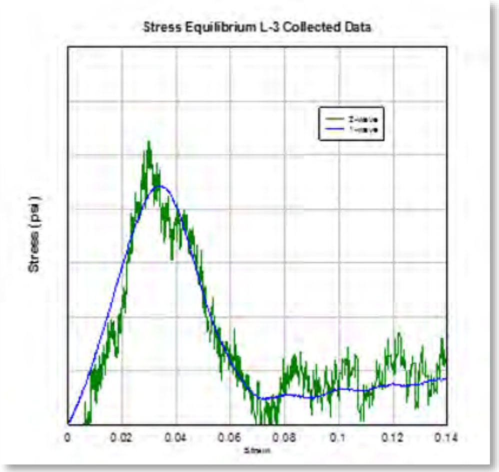
- Low rate data collected during the DOTC effort matches the low rate data collected by LANL*
- LANL temperature dependence seems to match the temperature dependence at lower strain rates
  - Magnitudes of the peak values may be suspect
- L3/ARA high rate data does not show the same temperature dependency at cold temperature
  - ARA estimated LANL peak data based on Rae*
  - (1-wave stress)

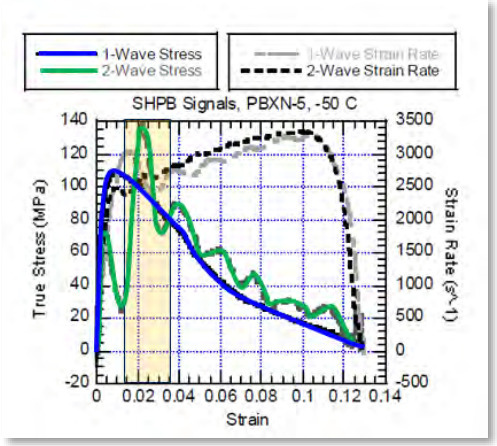


*Rae, P.J. "Compression Studies of PBXN-5 and Comp B as a function of strain-rate and temperature"
*Brown, G.W., Tencate, J.A., DeLuca, R., Rae, P.J., and Todd, S.N., "Dynamic and Quasi-static Measurements of PBXN-5 and Comp-B Explosives", Proceedings of the SEM Annual Conference, June 1-4 2009, Albuquerque, NM

Stress Equilibrium

- **Achieving stress equilibrium during testing of brittle materials becomes harder as the strain rates increase**
  - **During the DOTC testing effort, the ARA/ L3 team struggled to achieve stress equilibrium prior to failure at rates above 1200 s^{-1}**
- **Previously published LANL data was collected data at 3,000 s^{-1}**
  - **Did not reach stress equilibrium prior to sample failure**
  - **LANL indicated that data was valid between 1.5% and 3.5 % which is after the peak stress is reached**
  - **Peak stress values that were previously published may be questionable**



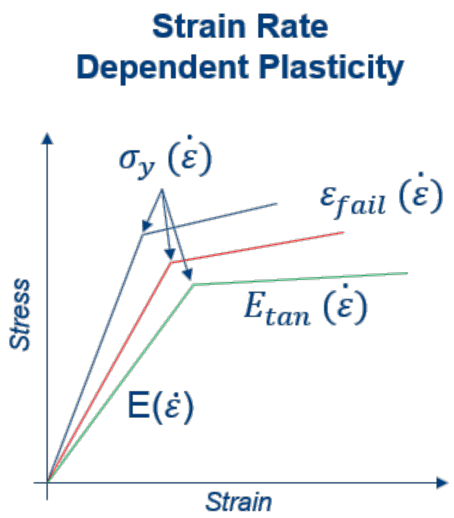


Testing Summary

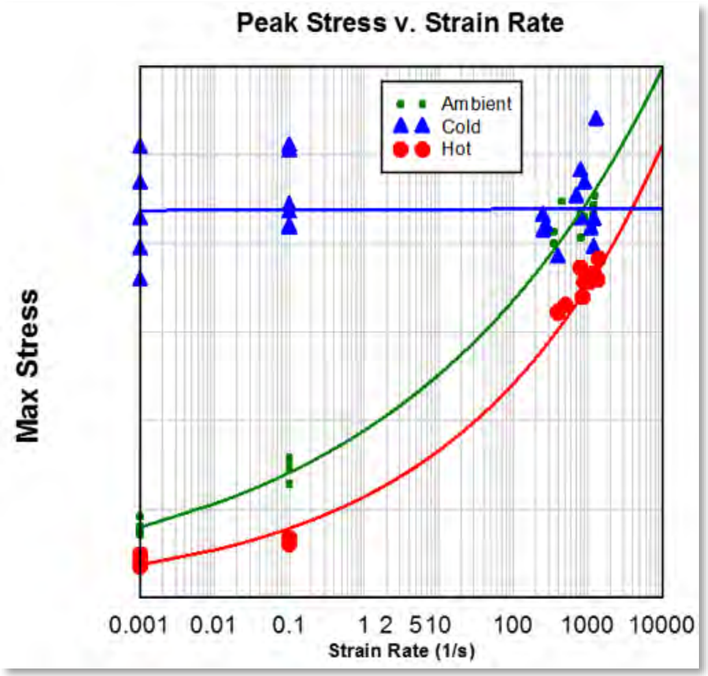
- Compression tests were conducted for 3 different temperatures (-65°F, 72°F, 160°F) over strain rates from 0.001 s^{-1} to 1200 s^{-1}
  - Low strain rate results compare well with literature
  - Less temperature dependency at high strain rate than previous results
- First known confined compression and tensile data

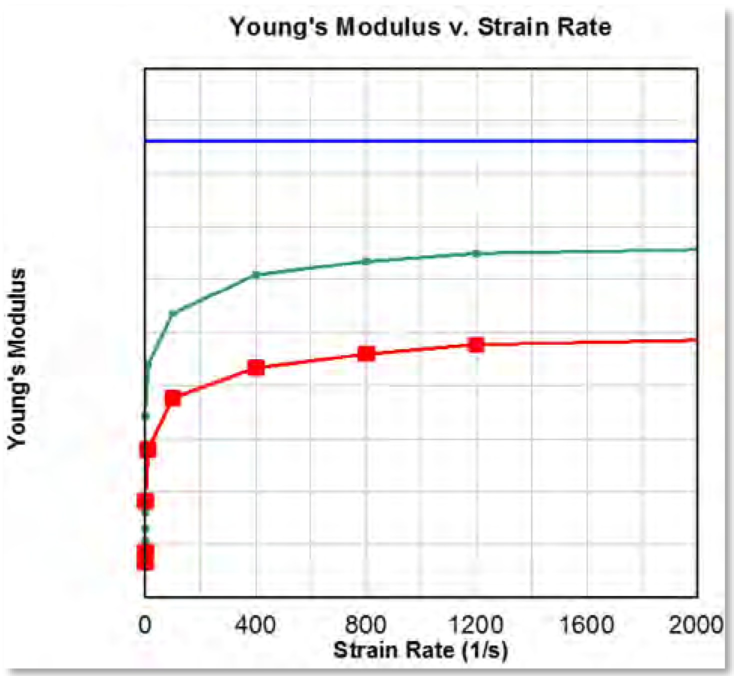
Constitutive Model Selection

- **Strain Rate Dependent Plasticity Model selected**
  - LS-DYNA *MAT_019
  - 1 model produced for each temperature
  - Allows rate dependent control of Elastic Modulus, Yield Stress, Tangent (Hardening) Modulus, Failure Stress
- **Models capture the measured strain rate dependency of PBXN-5 elastic behavior *prior to failure* well**
  - Simplicity makes it very stable
  - Linear (strain rate dependent) bulk modulus
  - Post-failure response not captured explicitly
  - No failure is explicitly modeled, but can be added
  - Model formulation is symmetric (same in tension / compression), does not capture the difference in elongation to failure in tension v. compression
  - Failure is best analyzed post-simulation with engineering judgement
- **Model behaves well in checkout simulations**
  - Responds as expected, stable in all configurations



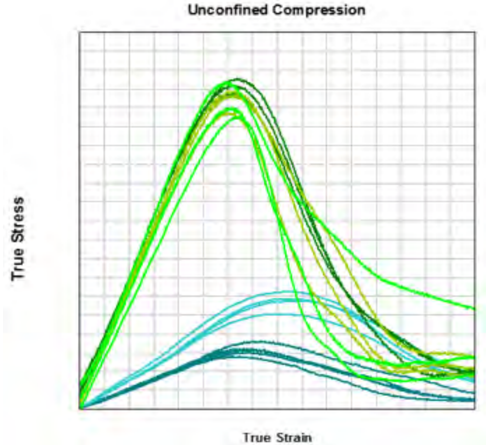
Observed Strain Rate Dependence

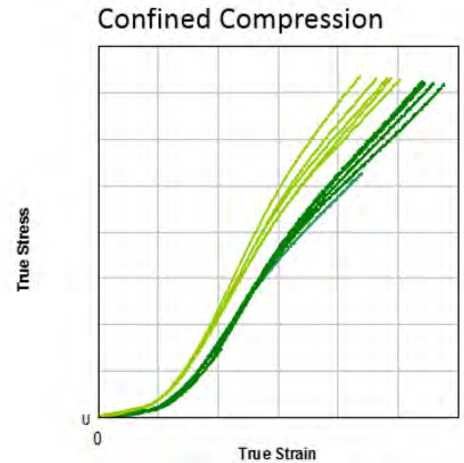




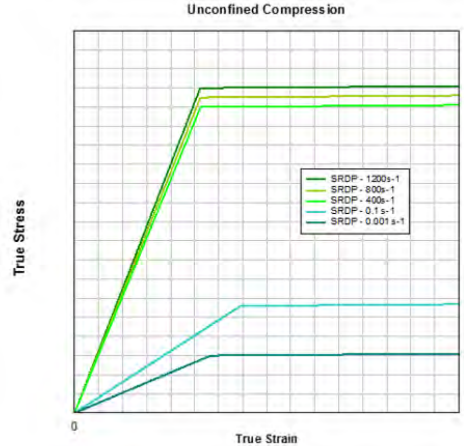
Ambient Model

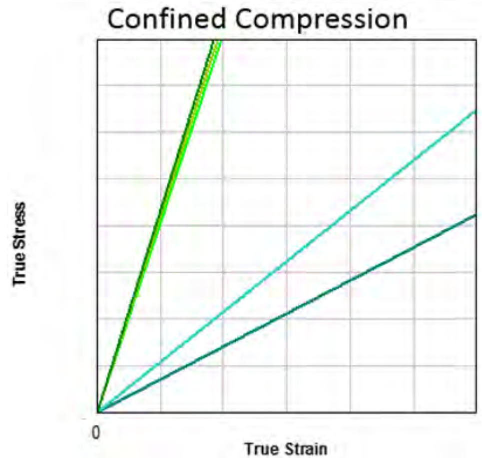
Test Data





Model Response





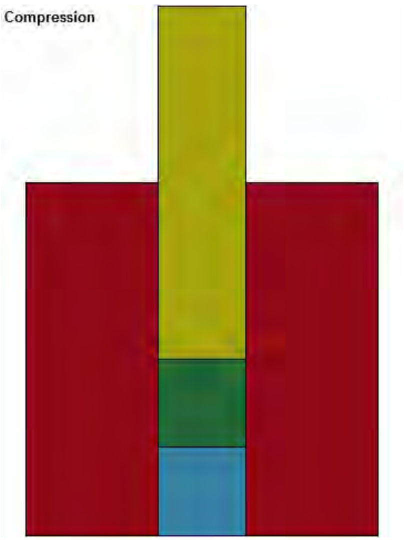
- **Strain Rate Dependent Plasticity Model captures the unconfined compression response prior to failure well.**

- **SRDP model bulk modulus varies**
- **At high rates it is consistent with the observed solids loading**
- **At low rates, it is consistent with the binder loading portion**

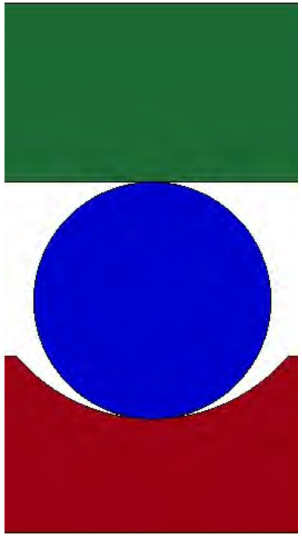
Strain Rate Dependent Plasticity Model

Unconfined Compression

Confined Compression



Brazilian

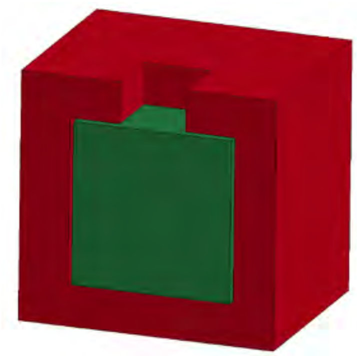


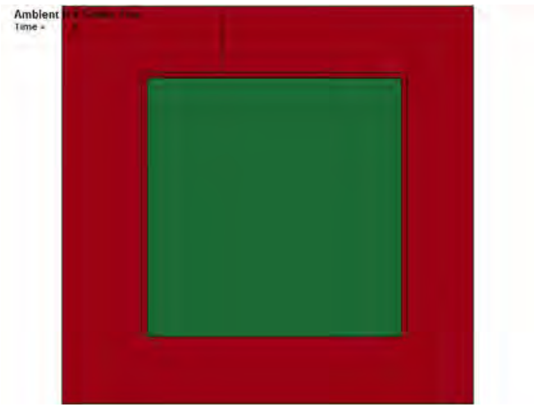
- **Tests modeled to verify behavior**
- **Model response is stable and stress strain response is as expected**
  - **Actual effective strain rate of each element varies over time resulting in some oscillation in the data at the higher rates**

Strain Rate Dependent Plasticity Model

- **To ensure that the model is stable for penetration environments, a shake test was performed with model for a realistic fuze environment**
  - **PBXN-5 Block with 0.010” gaps around the edges to allow the block to move during the simulation**
  - **Hole represents an unsupported region (i.e. firetrain)**
  - **Outer housing driven with velocity from simulation of a penetration environment**

SRDP model remains stable, good for use in penetration environments





Summary

- Suite of material data collected in house at L3 on PBXN-5 has been used to understand the strain rate dependent nature of the material and build material models
- Strain rate dependent plasticity model selected for its ability to capture the strain rate dependency of the material prior to failure
  - Model purpose is to assess risk of material failure and not to capture the response post-failure
  - Models capture the measured strain rate dependency of PBXN-5 prior to failure well
  - Simplicity makes it easy to analyze and stable in penetration environments
  - Constitutive models have been fit for 3 temperatures
  - Failure is best evaluated post-simulation
  - Models are producing results as expected

Acknowledgements

- **This work was funded by the DoD Ordnance Technology Consortium (DOTC) agreement W15QKN-09-1001, W15QKN-09-12-001, 15-01-INIT299**

- **The authors are grateful for the support of Triet Dao, Marc Worthington and Perry Salyers of L3 DES and Frank Marso of ARA.**

Abstract

- **PBXN-5 Mechanical Characterization and Proposed Constitutive Model**
  - **PBXN-5 samples have been mechanically characterized at 3 different temperatures (-65°F, 72°F, 160°F) over strain rates from 0.001 s^{-1} to 1200 s^{-1}. Quasi-static testing included unconfined compression, confined compression, and brazil tests. High rate testing was performed in an unconfined compression configuration with a Split Hopkinson Pressure Bar. The data collected in the unconfined compression testing agrees well with other quasi-static data collected by previous authors. To the author's knowledge, the confined compression and Brazilian test data is the first of its kind for PBXN-5.**
  - **The data collected under this effort was used to fit a constitutive model proposed for use in the design of hard target penetrating fuzes. The proposed model fit will be discussed and the results will be compared with the collected data.**

Test Method to Evaluate High-g Component Susceptibility

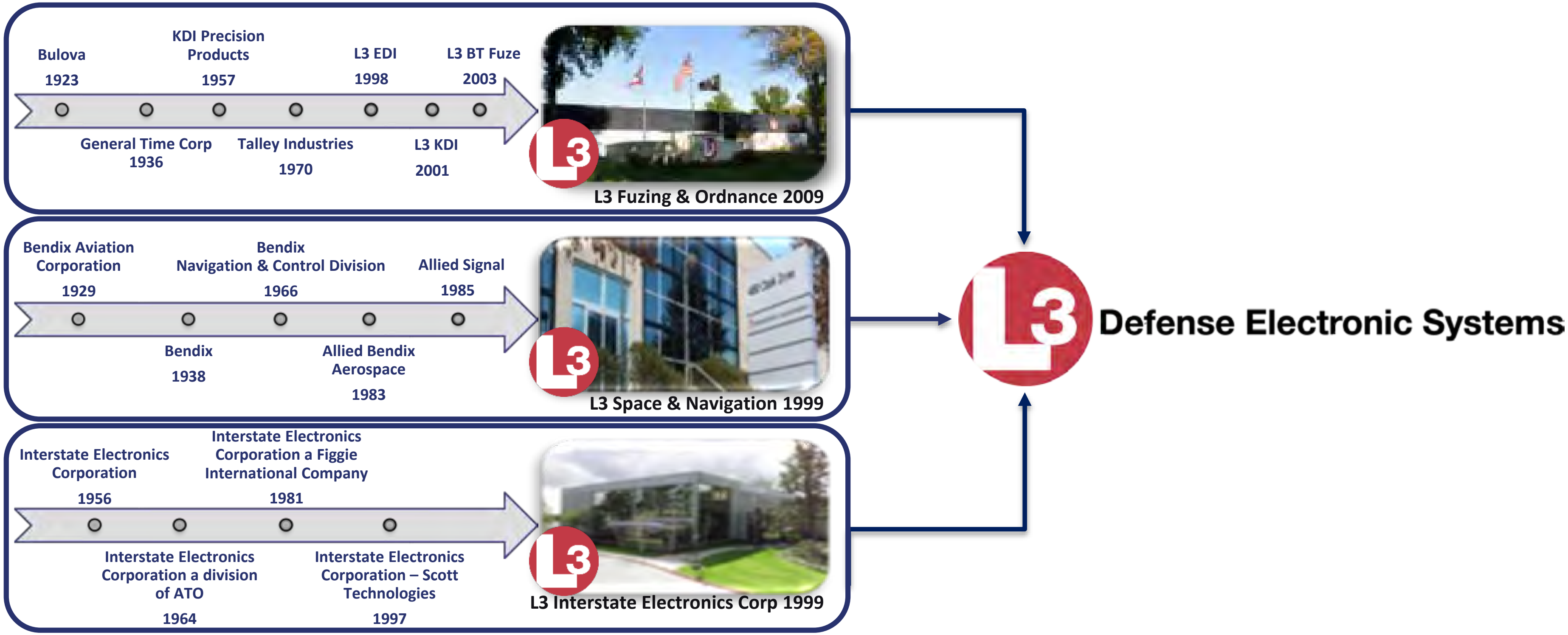
2018 NDIA Fuze Conference
San Diego, CA

Daniel Peairs, Nathan Millard, Triet Dao, Marc Worthington
L3 Defense Electronic Systems

Ericka Amborn, Frank Marso, Craig Doolittle
Applied Research Associates, Inc.

May 2018

L3 Defense Electronic Systems (L3 DES)



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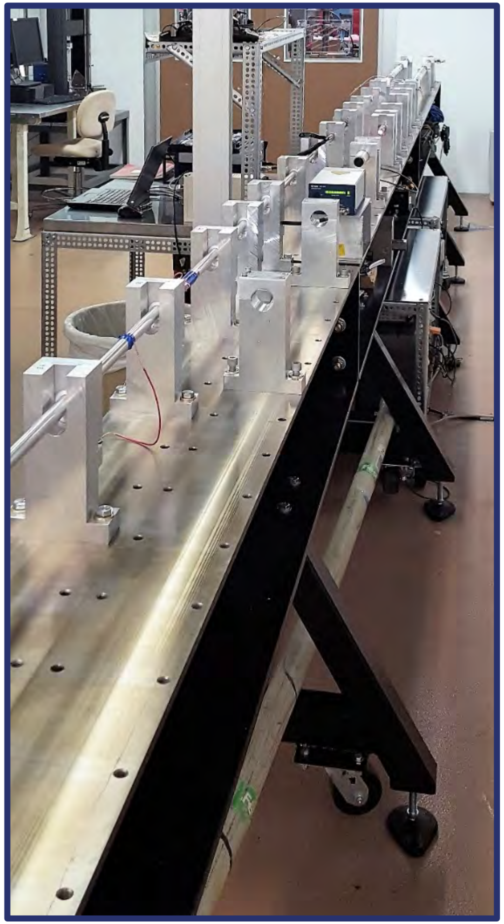
Introduction

- **Fuze level testing under severe loading conditions:**
  - **Expensive**
  - **May not identify risk early in design process**
  - **Difficult to pinpoint cause of fuze level failures**
  - **Components may function normally post-test despite intra-test failure**

The test methodology discussed here allows for a single electronic component to be tested and actively monitored during a shock event.

ESAD Electronics Characterization and Survivability



- **Single Hopkinson Bar Testing**
  - **Conduct high acceleration/high frequency testing of select electronic components**
- **Modeling of components and FEA**
  - **Correlate high fidelity FEA models of components with empirical results**

Test Set Up

- **Single Hopkinson Bar**
  - Steel Striker
  - Steel Bar
  - Threaded interface for tip
  - PCB mounted to tip with single component
  - Strain gauges
  - Laser vibrometer

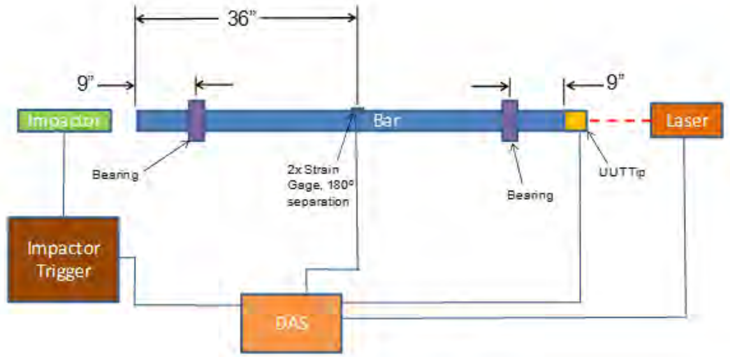


Figure 3. General Test Layout

Test Overview

- Single Hopkinson Bar testing included 3 each of 8 different components commonly used in L3 DES designs
- Tested at 3 different acceleration severity levels
  - System capable of producing pulses ranging from 1000 g's to over 250,000 g's
- Each component tested in an axial and 2 lateral configurations

Axial Lateral x Lateral y

Downselected Component List

- **Selected based on size, availability or previous history in survivable firesets**

Component Type	Description
Oscillator	Oscillator 1 - Delay block
Oscillator	Oscillator 2 - Oscillator for logic timing
Complex Logic	Complex Logic 1 - Leaded microcontroller
Complex Logic	Complex Logic 2 - Bottom terminated microcontroller
Complex Logic	Complex Logic 3 - FPGA
Discrete Logic	Schmitt Trigger
Capacitor	Capacitor 1 - Tantalum capacitor
Capacitor	Capacitor 2 - Ceramic capacitor

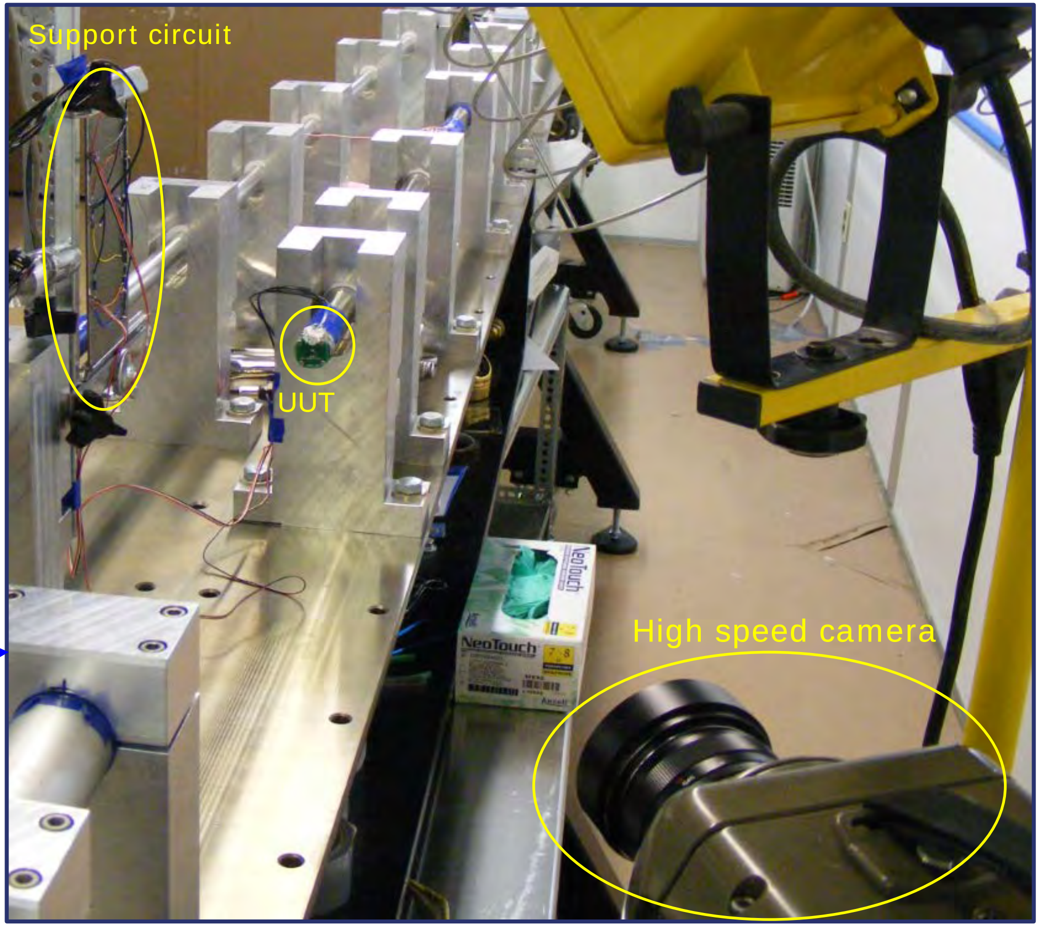
Test Methodology

- **A set of inputs was selected for each individual component in this test. The expected behavior of each component was characterized and recorded before, during, and after each test. Any change in the output was evaluated and analyzed using the appropriate failure analysis method.**
- **The output data was correlated against the strain gage derived acceleration**

Component	Input	Expected Output
Oscillator 2	5V, GND	8MHz Output
Schmitt Trigger	5V, GND 100kHz, 50% duty cycle, 0-5V	Inversion of the input
Oscillator 1	3.3V, GND 50 kHz, 75% duty cycle, 0-3.3V	Output rises 10us after input is enabled. Falls when input is falling.
Complex Logic 1	3.3V, GND	Nominal: 50kHz, 50% duty cycle Reset: 75kHz, 50% duty cycle for ~100us before resuming normal operation
Complex Logic 2	3.3V, GND	Nominal: 100kHz, 50% duty cycle Reset: 200kHz, 50% duty cycle for ~100us before resuming normal operation
Complex Logic 3	3.3V, 2.5V, GND Negative reset, 8MHz clock	Nominal: 125kHz, 50% duty cycle Reset: 500kHz, 50% duty cycle for ~100us before resuming normal operation
Tantalum Capacitor	19kHz, 20% duty cycle, 0-5V	RC charging triangular waveform from 0V to around 3.2V depending on capacitance
Ceramic Capacitor	800Hz, 20% duty cycle, 0-5V	RC charging triangular waveform from 0V to around 3.2V depending on capacitance

Test Setup

Laser vibrometer protection



Results Summary

Key	
Measured Test Severity	
Unaffected	Affected During Test
Affected Post Test	Part Failed
Test Not Conducted Due to Previous Failure	

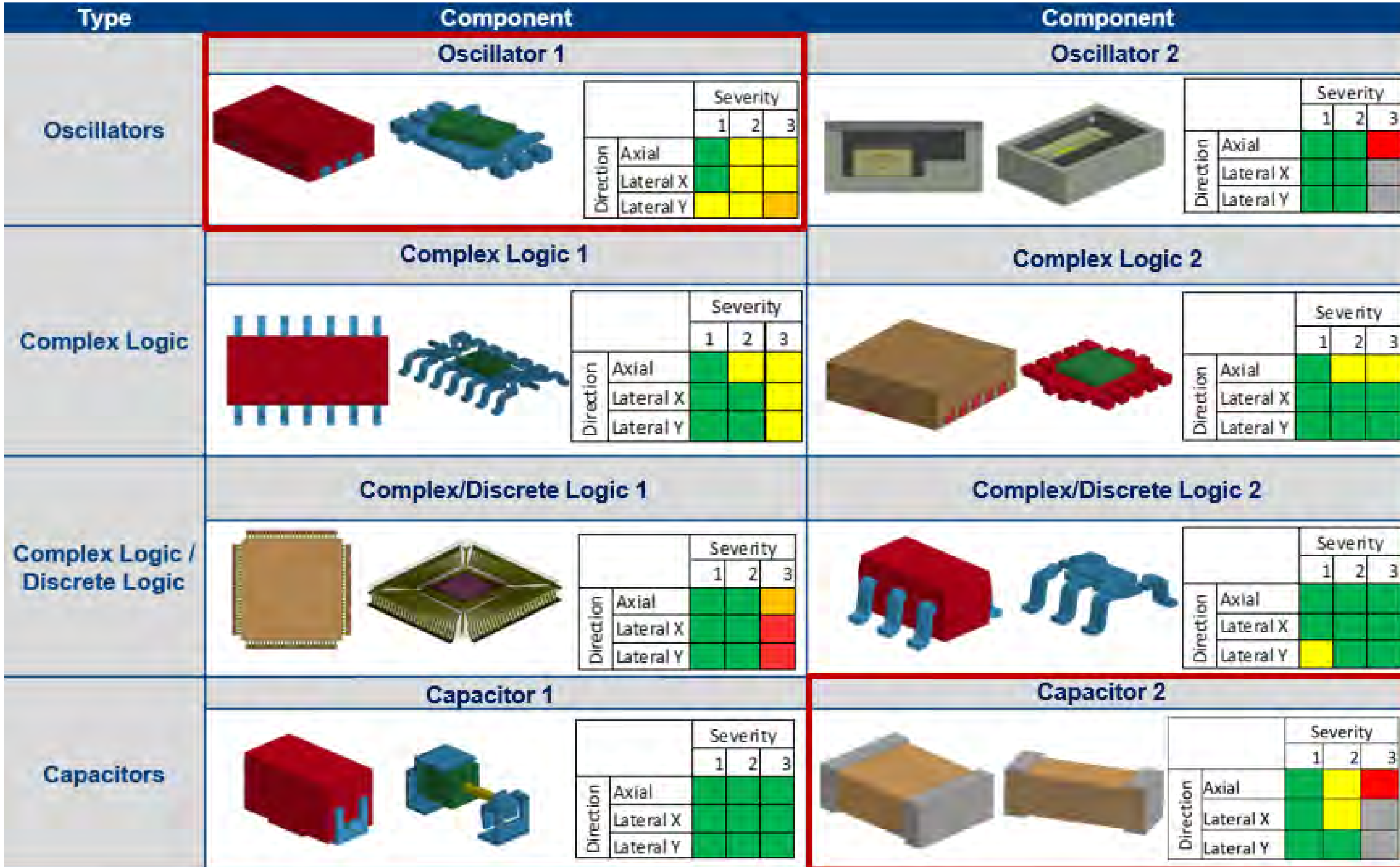
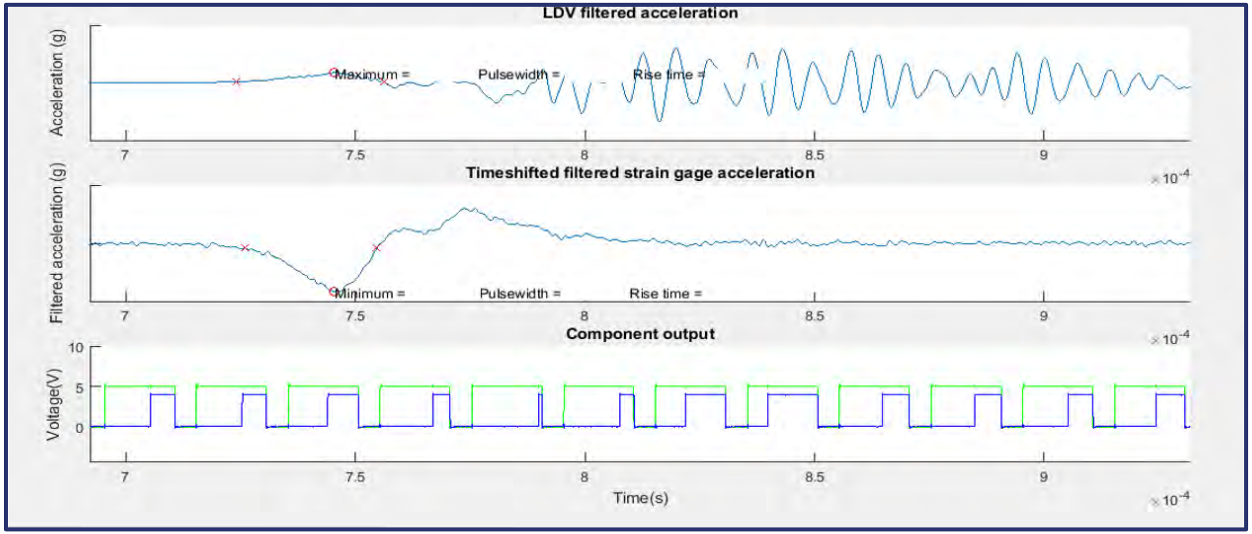


Image from ARA

Oscillator 1 – Axial Impact at Severity Level 3



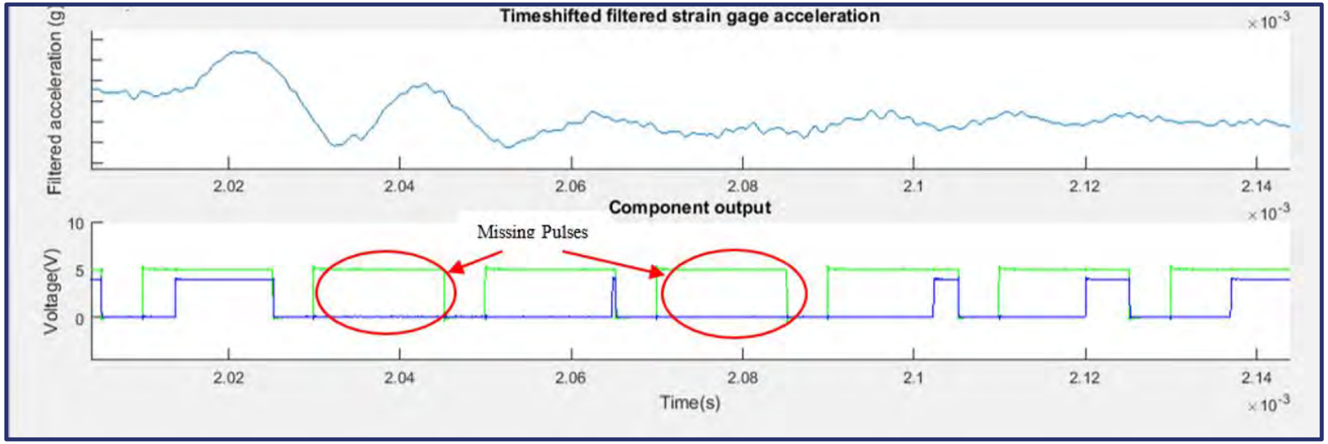
Round 3 Axial Configuration

		Severity		
		1	2	3
Direction	Axial			✖
	Lateral X			
	Lateral Y			

Green = input
Blue = output

- Delays both greater and smaller than the expected 10us can be observed in the above figure.
- In the current setup for a 10us delay, a delay shift as great as ~70% can be observed in an individual pulse. It's unlikely this delay shift would scale in a 10ms set up.
- Further testing is required to verify this claim.

Oscillator 1 – Lateral Y at Severity Level 3



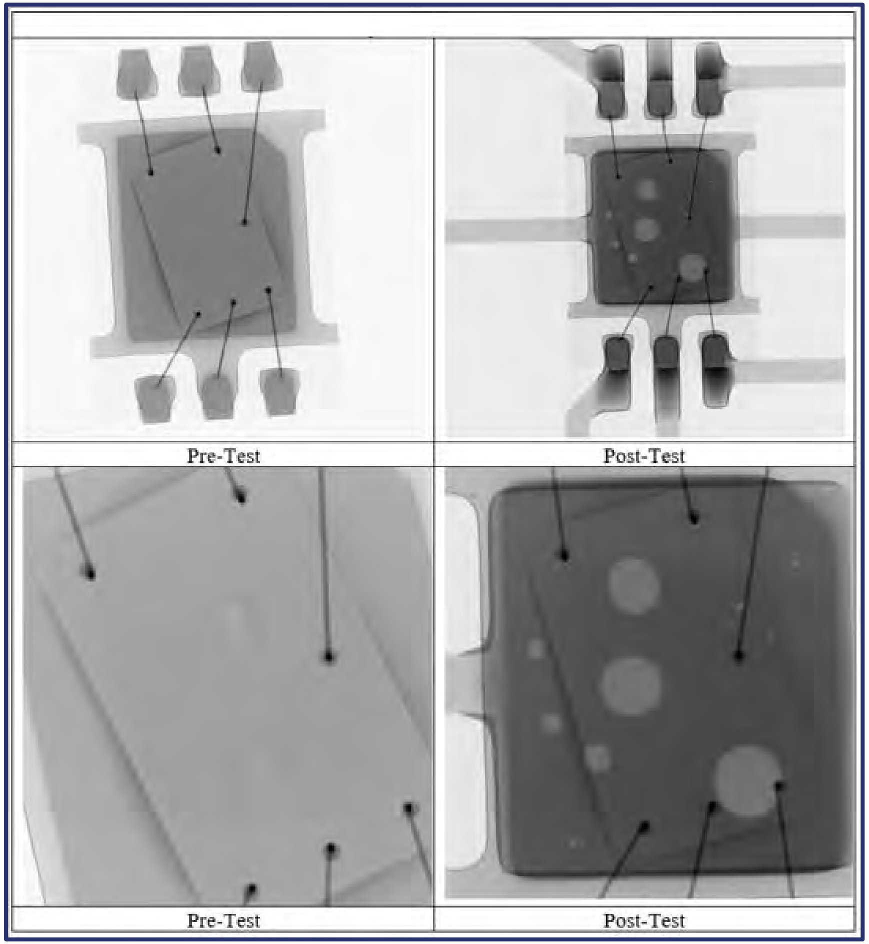
Round 3 Lateral Y Configuration

		Severity		
		1	2	3
Direction	Axial			
	Lateral X			
	Lateral Y			X

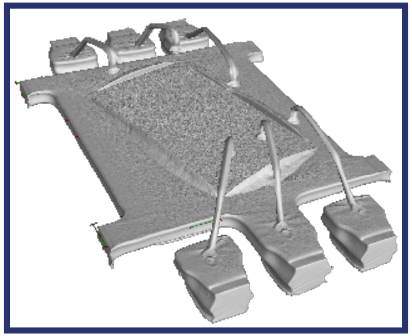
Green = input
Blue = output

- **Missing pulses indicate component malfunction**
- **Component showed a small, permanent increase in on-time pulse width after the test**

Oscillator 1 – Post Test Imaging

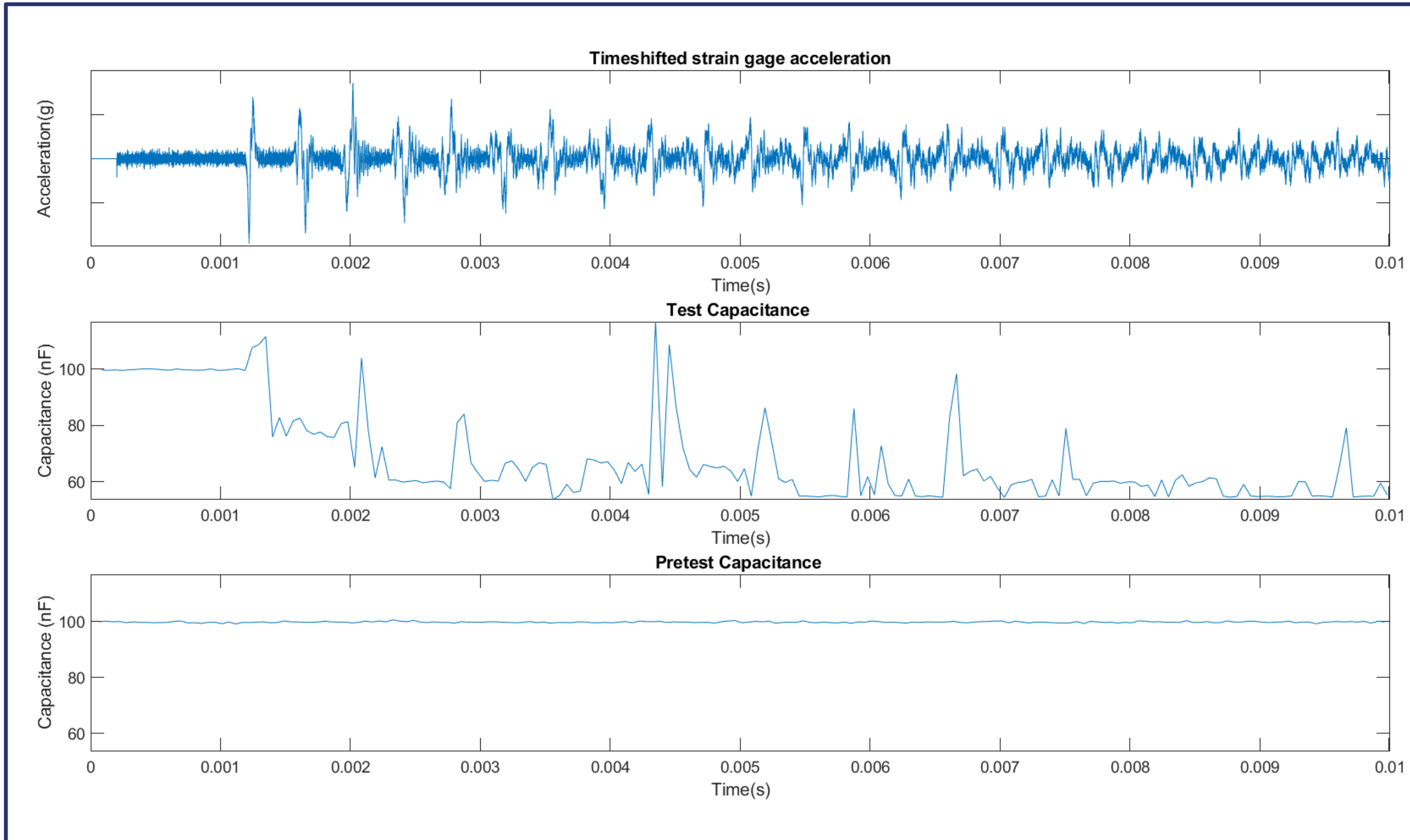


- **Pre and post-test high resolution x-rays were conducted on all components**
- **Internal bond wires appear to be intact**



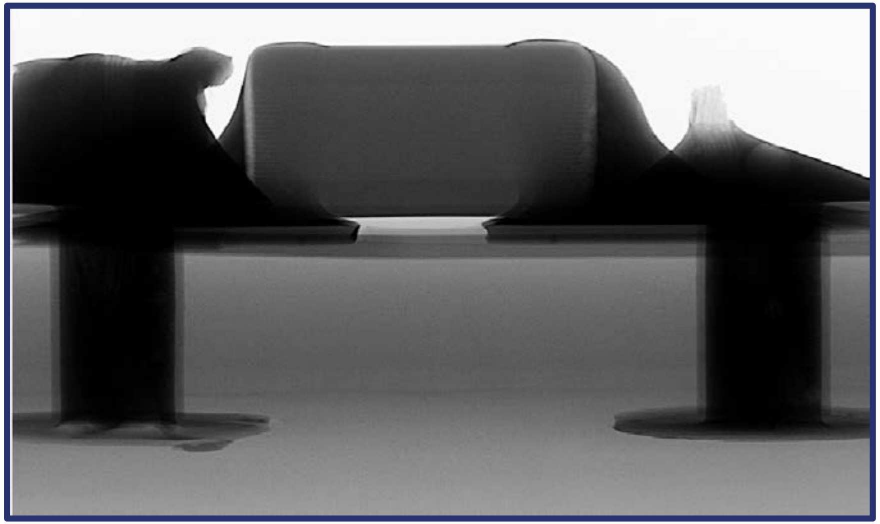
- **CT Scans also conducted to better understand internal geometries**

Ceramic Capacitor – Axial at Severity Level 3



Ceramic Capacitor		Severity		
		1	2	3
Direction	Axial			✖
	Lateral X			
	Lateral Y			

Ceramic Capacitor – Axial at Severity Level 3



	Computed Capacitance (nF)			
	Min	Max	Mean	Standard Deviation
Pre-Test	105.57	106.86	106.32	0.232
Test	55.70	117.63	71.34	17.56
Post-Test	61.37	62.15	61.69	0.145

- **42% decrease in capacitance was observed**
- **High resolution x-rays were not able to identify damage within capacitor layers**

Component Testing Summary

- **Developed enhanced methodology for assessing component susceptibility to high shock environments**
- **Evaluated several classes of components commonly used in ESADs**
- **Actively monitored single components during a shock event**
  - **Permits assessment of risk during High-g events that is not possible with pre and post test interrogation only**

Acknowledgements

- **This work was funded by the DoD Ordnance Technology Consortium (DOTC) agreement W15QKN-09-1001, W15QKN-09-12-001, 15-01-INIT299**

- **The authors are grateful for the support of and Justin Bruno of ARA and Perry Salyers of L3 DES.**

A Low Voltage Command-Arm System for Distributed Fuzing

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

NDIA Fuze Conference
May 15-17, 2018
San Diego, CA

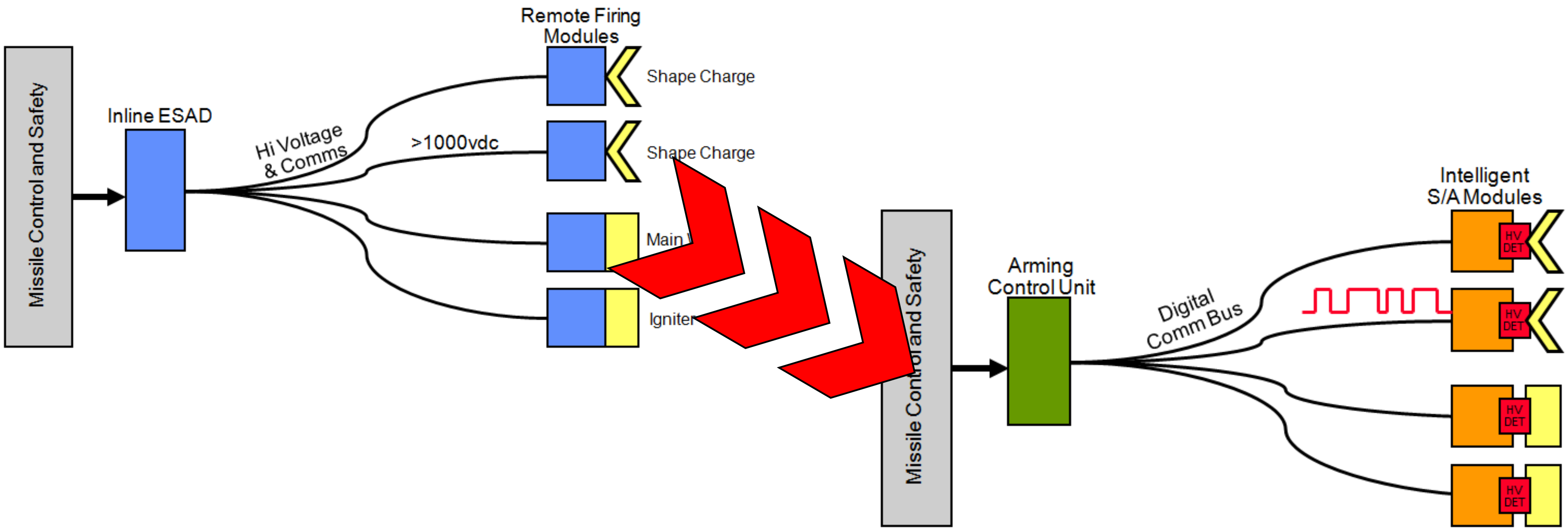
Presented by:

Mark Etheridge

U.S. Army Aviation and Missile Research, Development, and Engineering Center

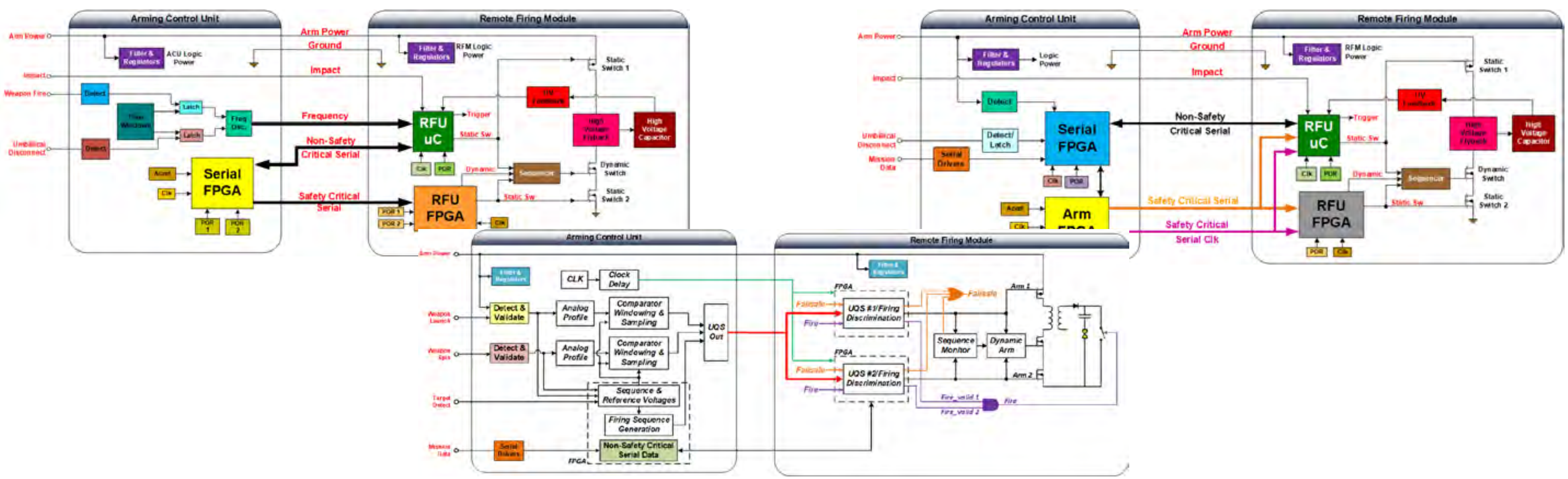
Acknowledgements

- **This project is sponsored by the Joint Fuze Technology Panel (JFTP)**
  - FATG II (Tailorable Effects)
- **Alan Durkey, Naval Air Warfare Center**
- **Adedayo Oyelowo, Naval Surface Warfare Center**



Project History

- **This project began in 2010 with a 6.2 effort to develop some generic architectures so as to define some minimal hardware & signal guidelines.**
  - Participants: Army-AMRDEC, NAWC, Sandia
  - Architectures: Multiple-Try, Frequency Shift, eUQS
  - Successful in gaining acceptance.
    - FESWG ‘approval’ in February, 2014
    - FESWG ad-hoc stood up; JOTP document was started.



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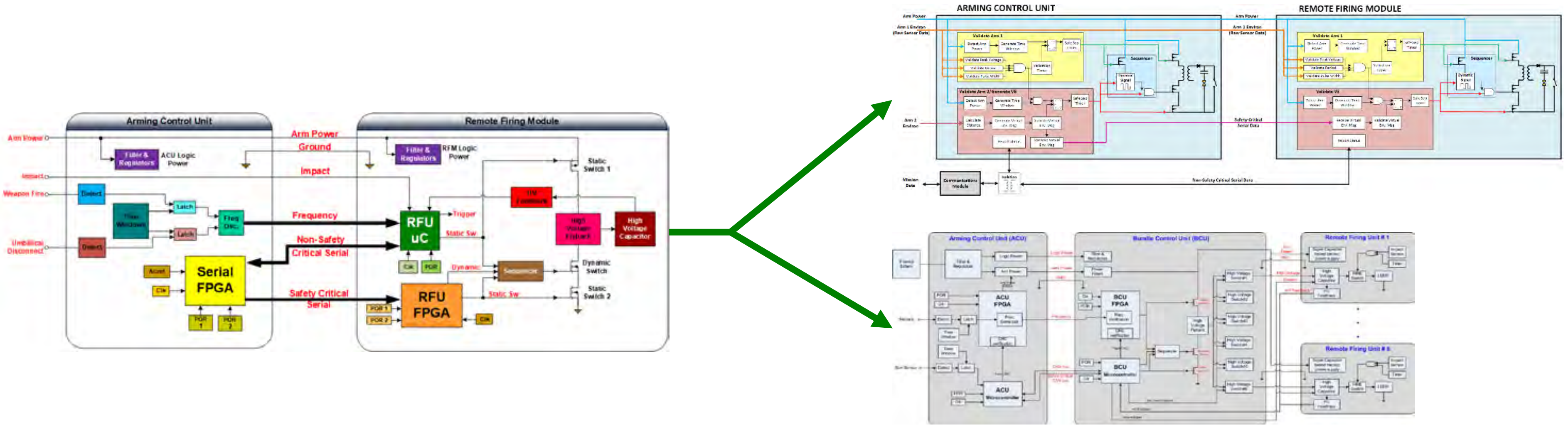
Project History

- **A 6.3 program then began in 2015 to pursue form, fit, and function designs with the goal of further defining the ‘solution space’**
  - Participants: Army-AMRDEC, NAWC, NSWC-IH.
  - Frequency Shift architecture was chosen for implementation
  - Program ending in FY18/19.
  - Goals met!!
    - ➢ Guidelines were refined and new architectures added.
    - ➢ JOTP document completed and under final review.



Guidelines for the design of Low Voltage Command-Arm Distributed Fuzing Systems

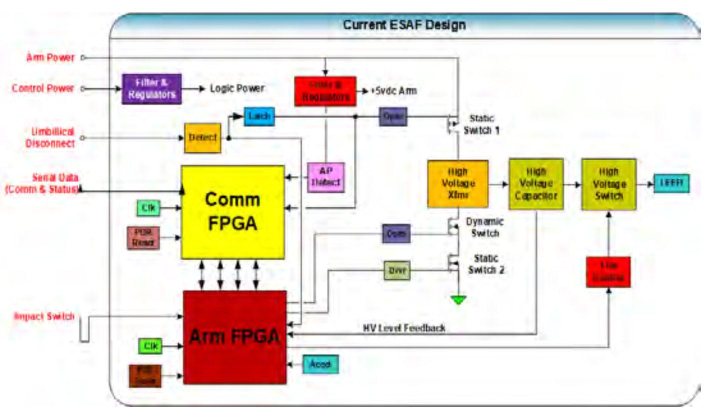
PLEASE NOTE!!

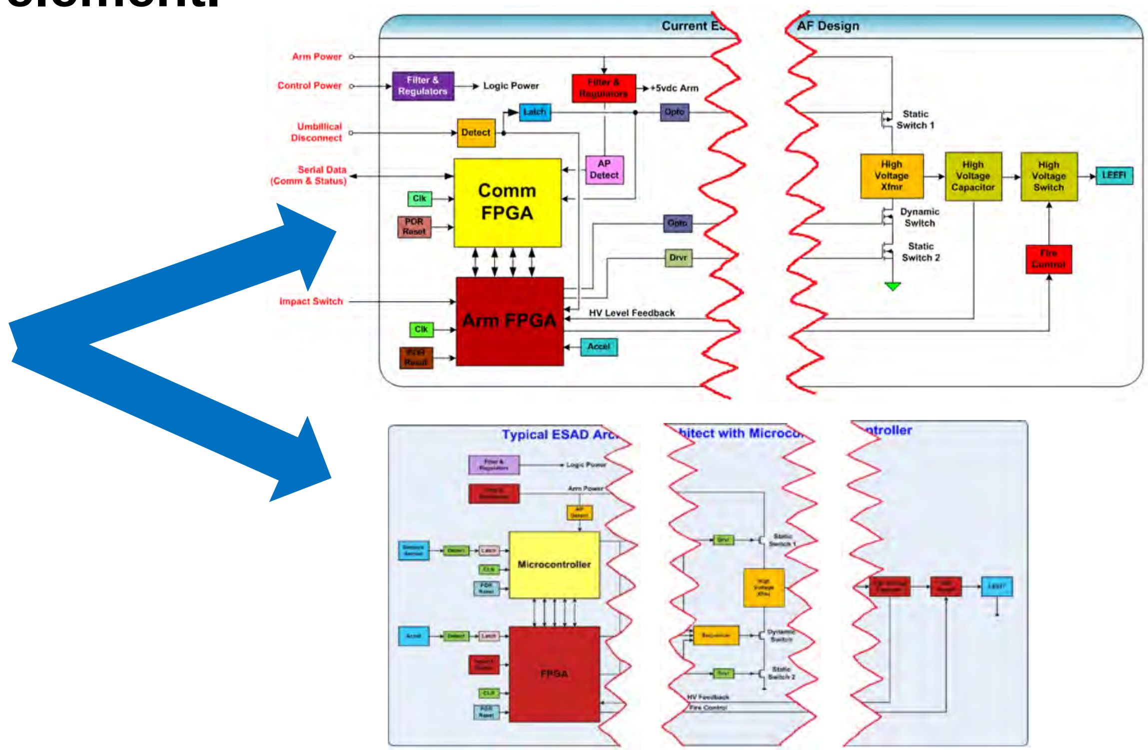
1. **The following slides are *<u>guidelines</u>*…not requirements.** ***Consult with the appropriate Service Safety Authority for acceptability if this guidance cannot be adhered too.***
2. **Some of the guidelines are not presented.**
3. **The document is in final review so there may be some changes from what is presented here.**

Definitions

Distributed Fuze System

- A configuration and/or architecture such that one or more fuze safety critical functions are allocated throughout the munition and/or system such that the environment sensing may occur at some distance and in a physically different module from the explosive or pyrotechnic element.



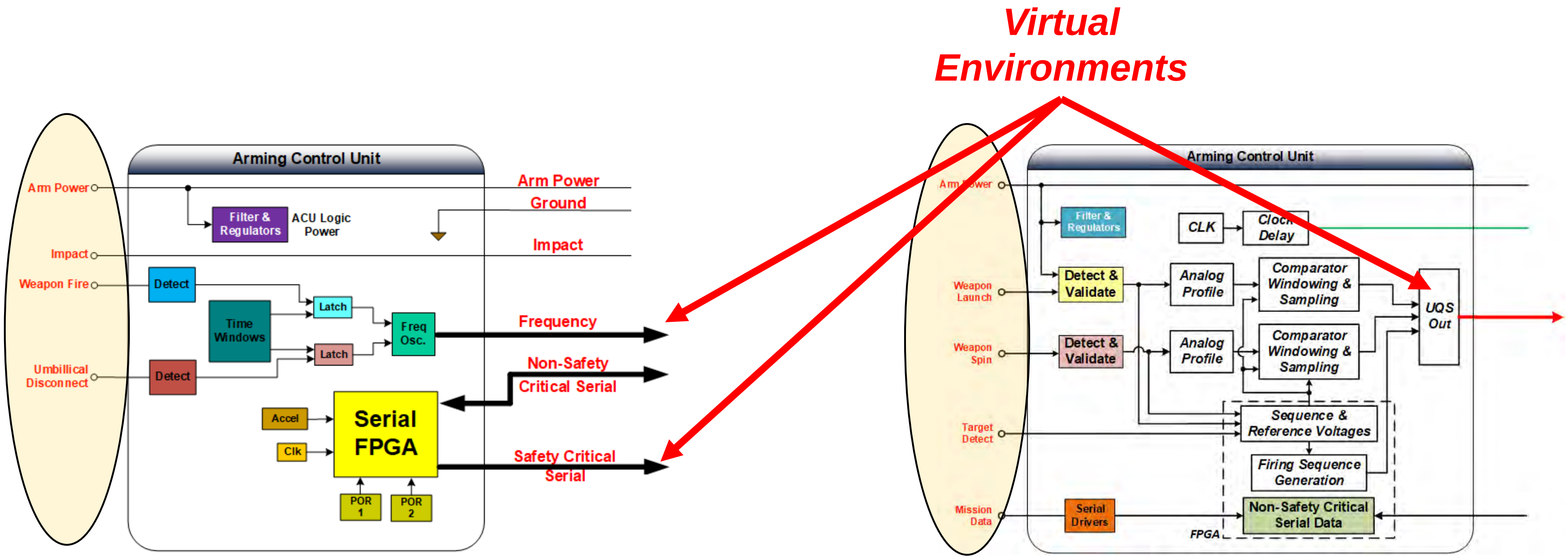


Definitions

- ***Arming Signal:*** **the electrical representation of a unique arming environment that is transmitted, processed, and validated for safety feature activation.**
  - Encompasses both raw sensor data and a virtual environment
- ***Virtual Environment (VE):*** **a unique robust electrical signal that is derived or translated from a physical arming environment sensor output. It is a subset of arming signals.**
  - Encompasses both analog and digital signals
  - VEs are a signal that is designed/engineered to be unique and robust .
- **Both definitions do not limit what an arming signal or VE can be.**

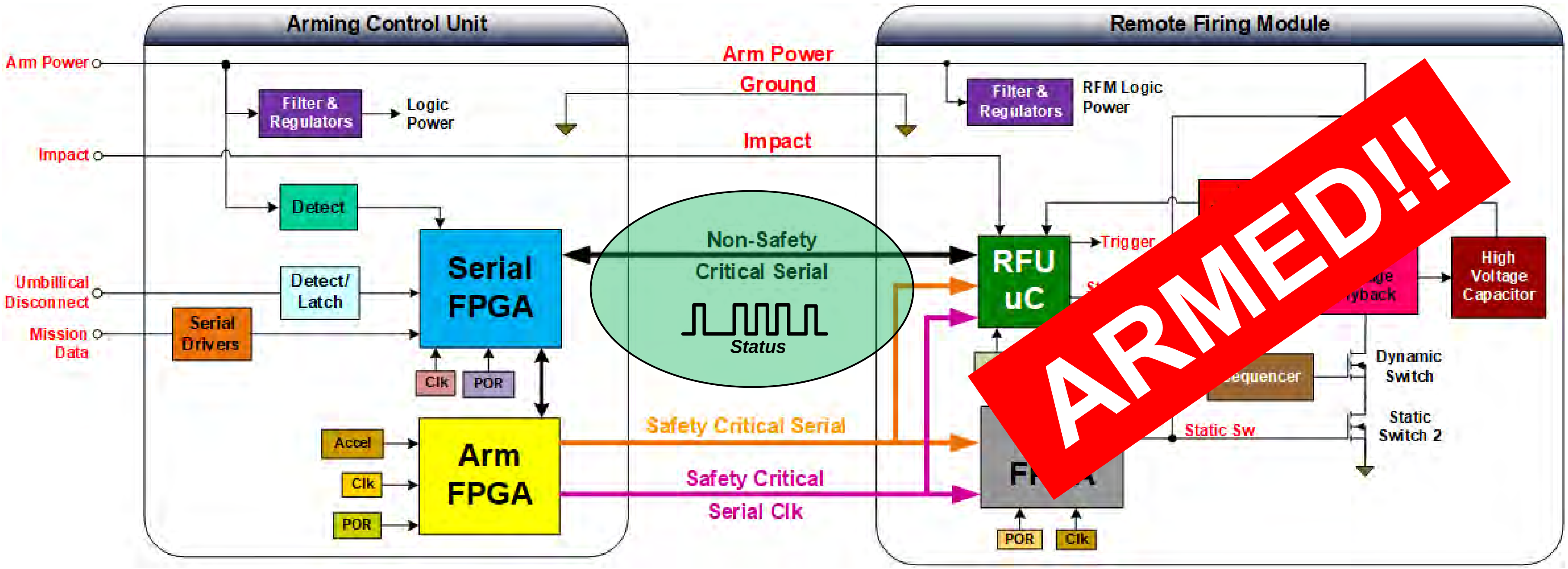
Arming Control Unit (i.e. the Master S&A)

- **The Arming Control Unit (ACU) directly senses, processes, and validates the physical arming environments. The ACU should translate the physical arming environments into Virtual Environments (VE), if necessary, and transmit all arming signals to the Remote Firing Modules (RFMs).**



Guidelines

- **Based on system requirements, the ACU may maintain an active link with all RFMs that are in use after the fuze system is properly armed.**



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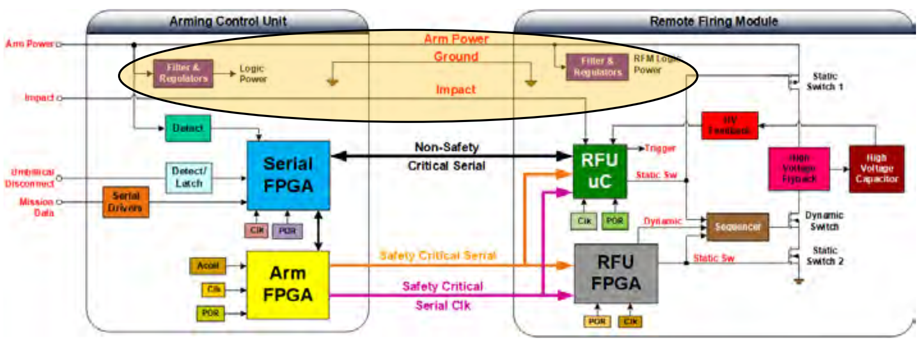
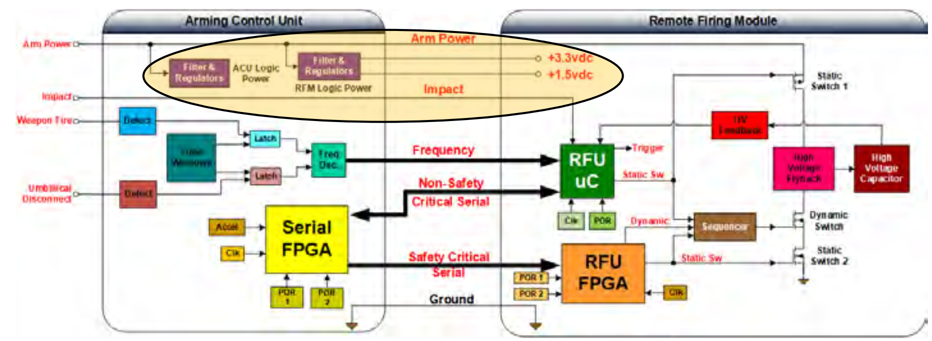
Guidelines

- **The ACU is intended to provide all power for the RFMs including Arm Power where practical.**
  – Can also have the ACU *control* Arm Power to the RFM (ex. Option 3)

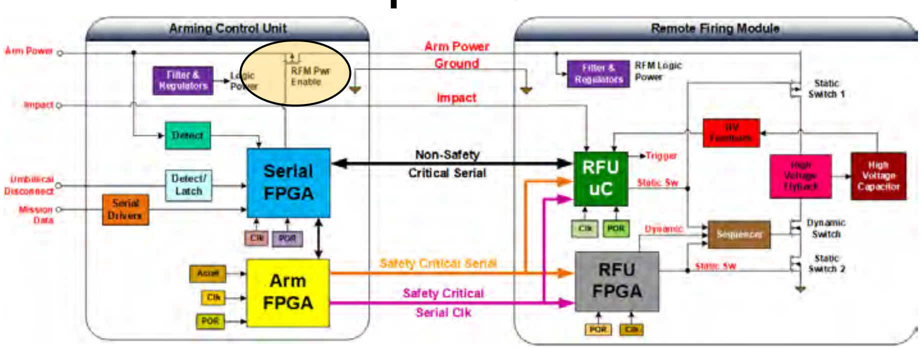
Option 1



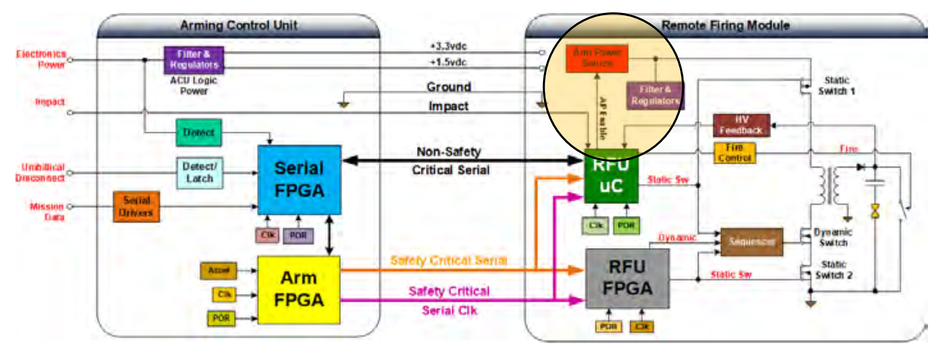
Option 2



Option 3



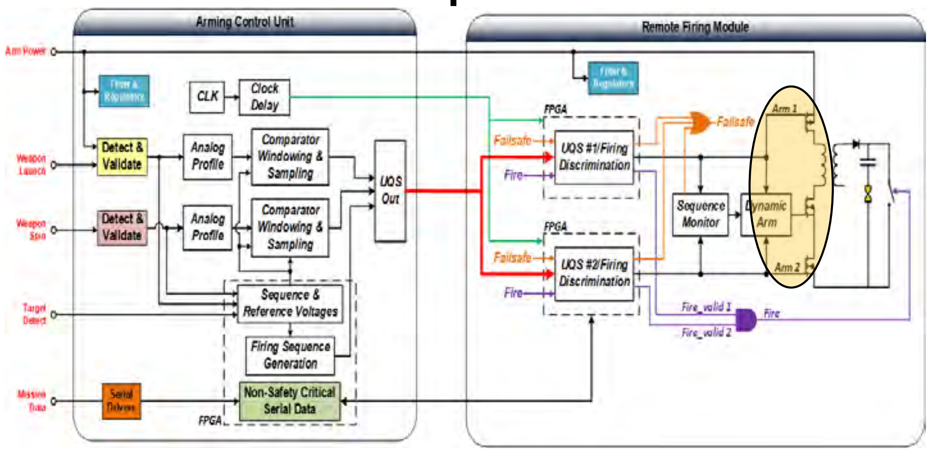
CONSULT!!

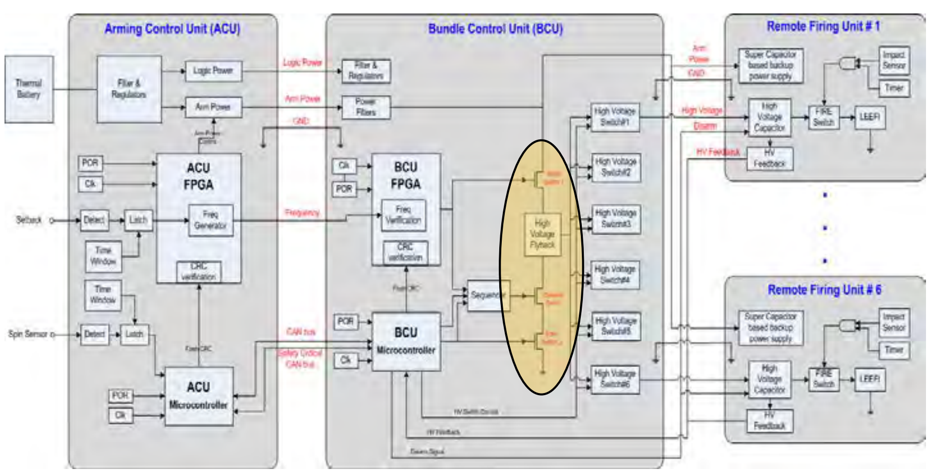


Remote Firing Module

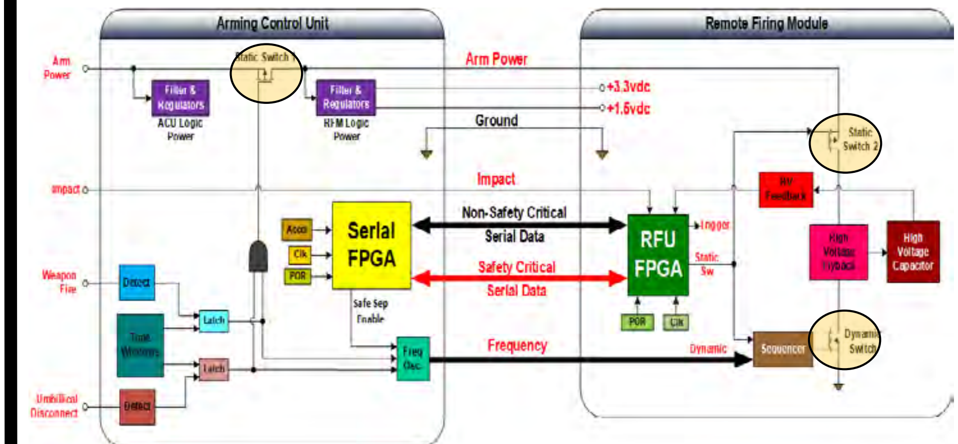
- **The RFM should contain all required arming switches.**

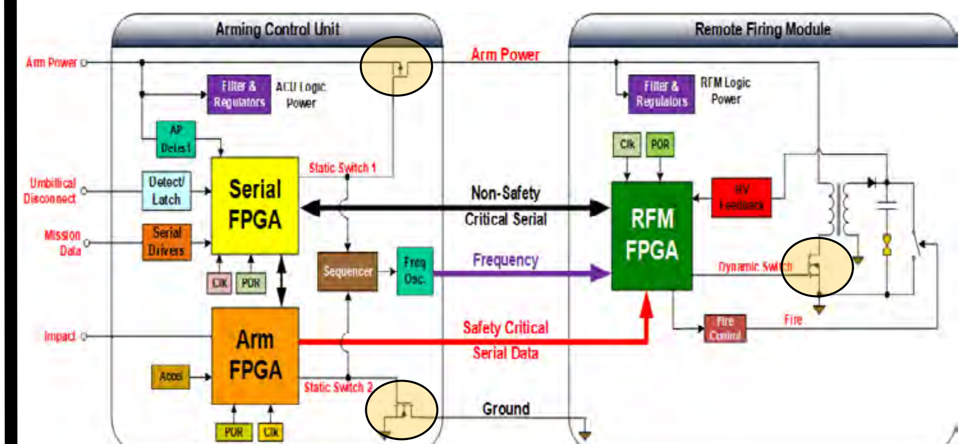
Compliant





Consult!!!





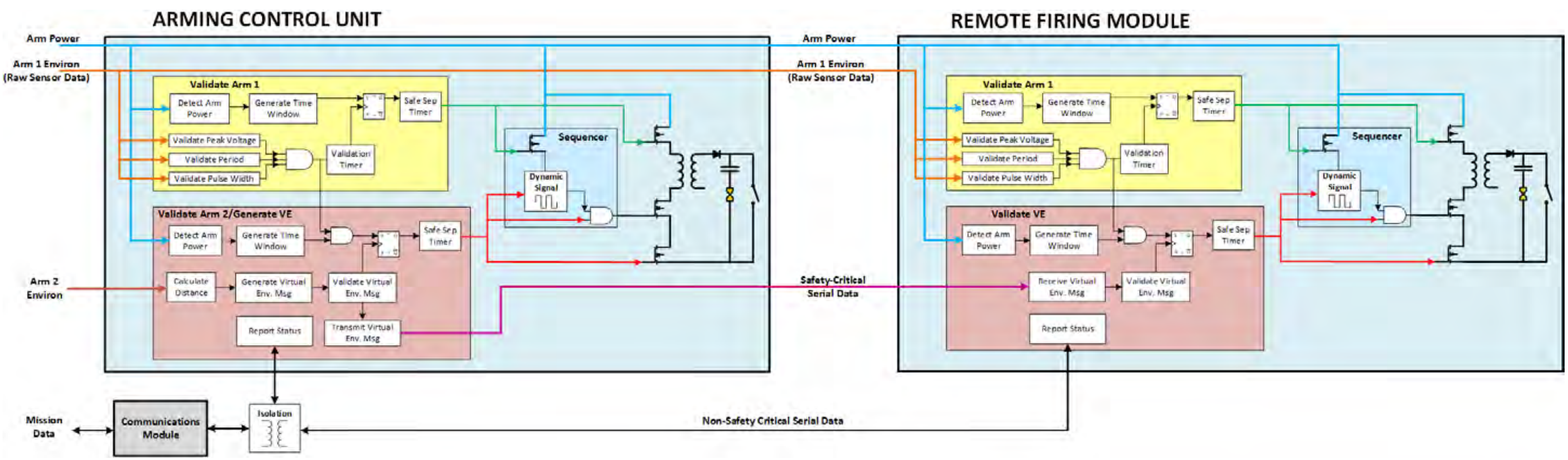
Guidelines

- Power to the safety critical features in the RFM should be applied as late in the launch sequence or operational deployment as practical.
- It is preferred that the dynamic signal for driving the high voltage transformer be generated within the RFM.
- Timing/Sequencing of the VE signals should be validated within the RFM.
- All Arm Delay Timers should reside within the RFM.

Guidelines

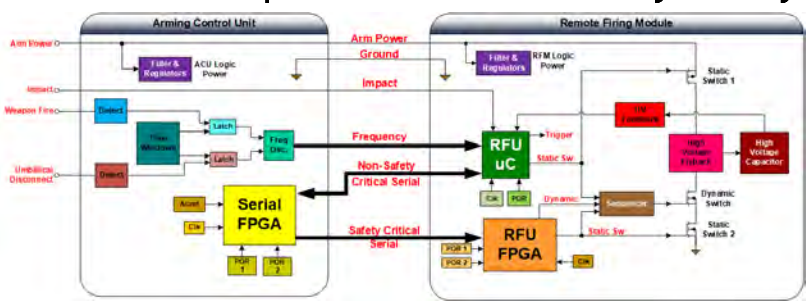
Arming Signals

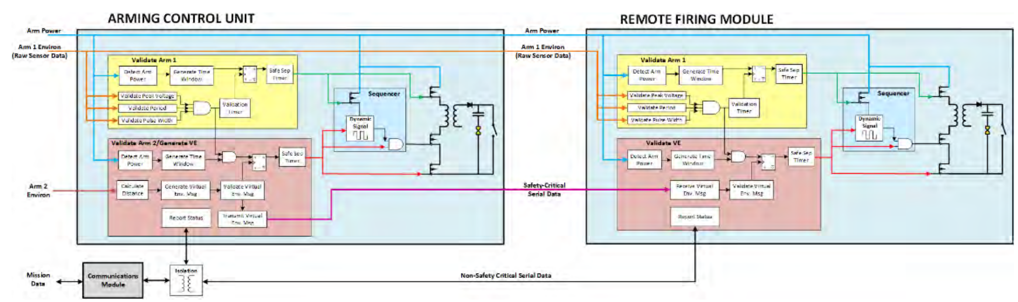
- **There should be a minimum of two unique arming signals transmitted to the RFM for proper arming of the fuze system. A robust physical environmental signal (i.e. raw sensor data) may be used in lieu of a VE arming signal.**
  – "Hybrid" Architecture…1 Physical & 1 Virtual Arming Signal

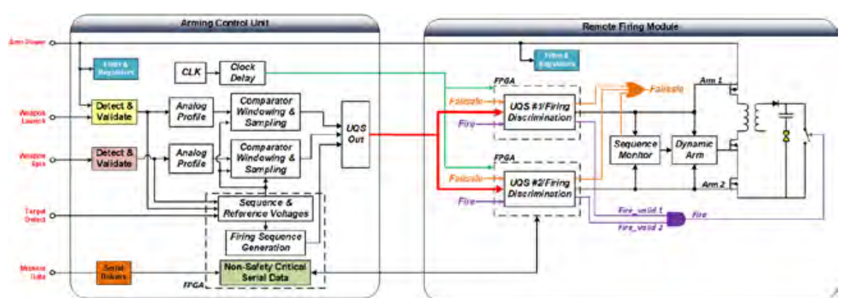


Guidelines

- **The generation of the VE signals should be implemented with independent and dissimilar logic that is physically and functionally partitioned. The degree of dissimilarity should be sufficient to ensure that any credible common cause susceptibility will not result in an inadvertent arming signal transmission in other logic devices. Where practical at least one VE signal should be implemented with discrete components.**
  - This guidance also applies to the processing of the received arming signal at the RFM and subsequent activation of any safety features contained within.



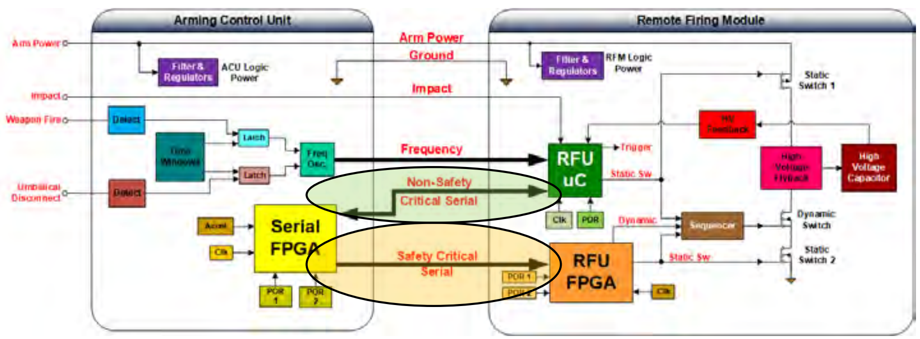


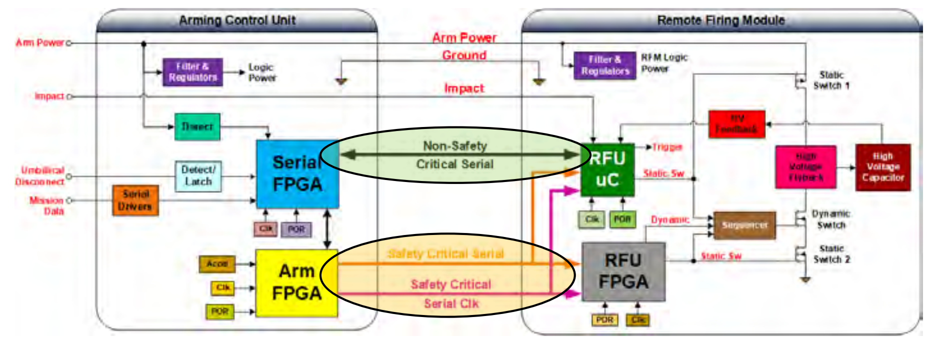


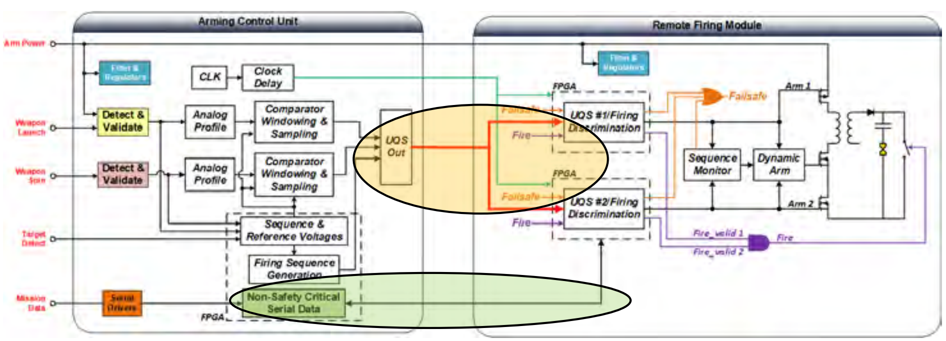
Guidelines

Virtual Environment Messaging

- **Each safety-critical message should be implemented as a dedicated, one-way communication. All non-safety critical messages (polling, mission data, message ack.) may be transmitted/received on a separate communication line.**



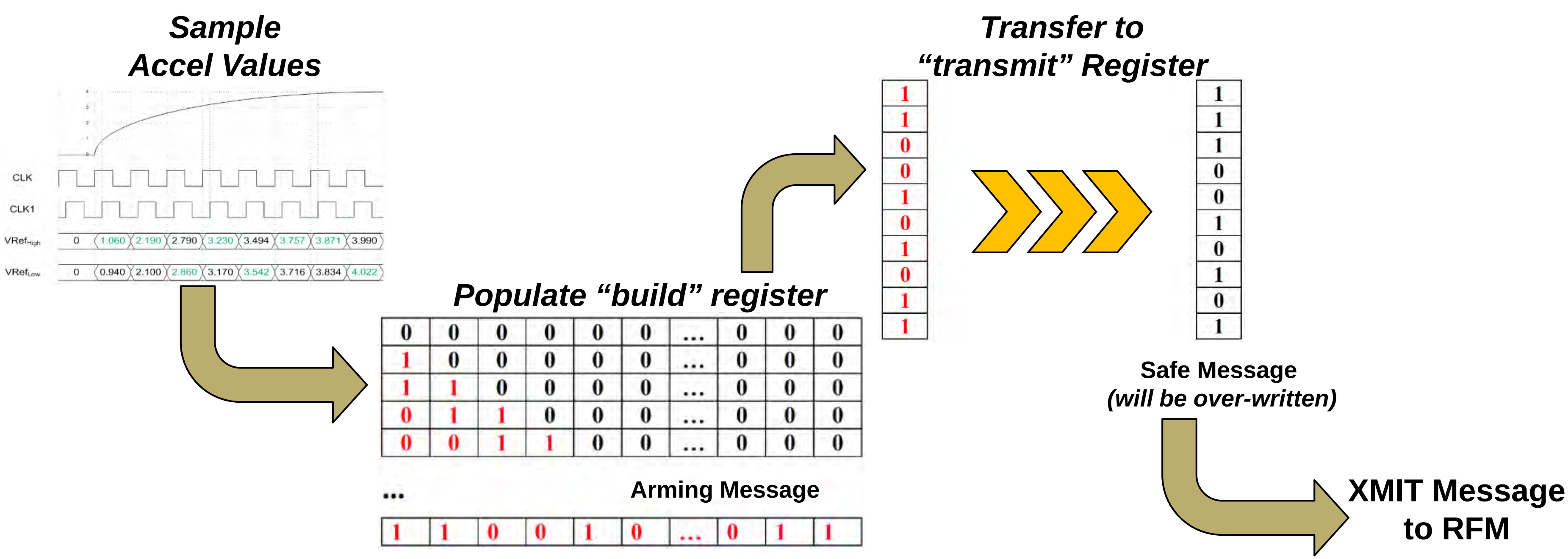




DISTRIBUTION A. Approved for public release; distribution is unlimited.

Guidelines

- **The preferred method is to dynamically generate the VE message based on events that occur throughout an arming environment.**
- **Where generation of the VE message is not practical, pre-stored VE serial messages may be utilized. The message must be further distinguished by a minimum of two additional validation methods or features in order to mitigate subversion of safety features.**
  - Time Windowing, Sequencing, Serial Clock Frequency, etc.



Guidelines

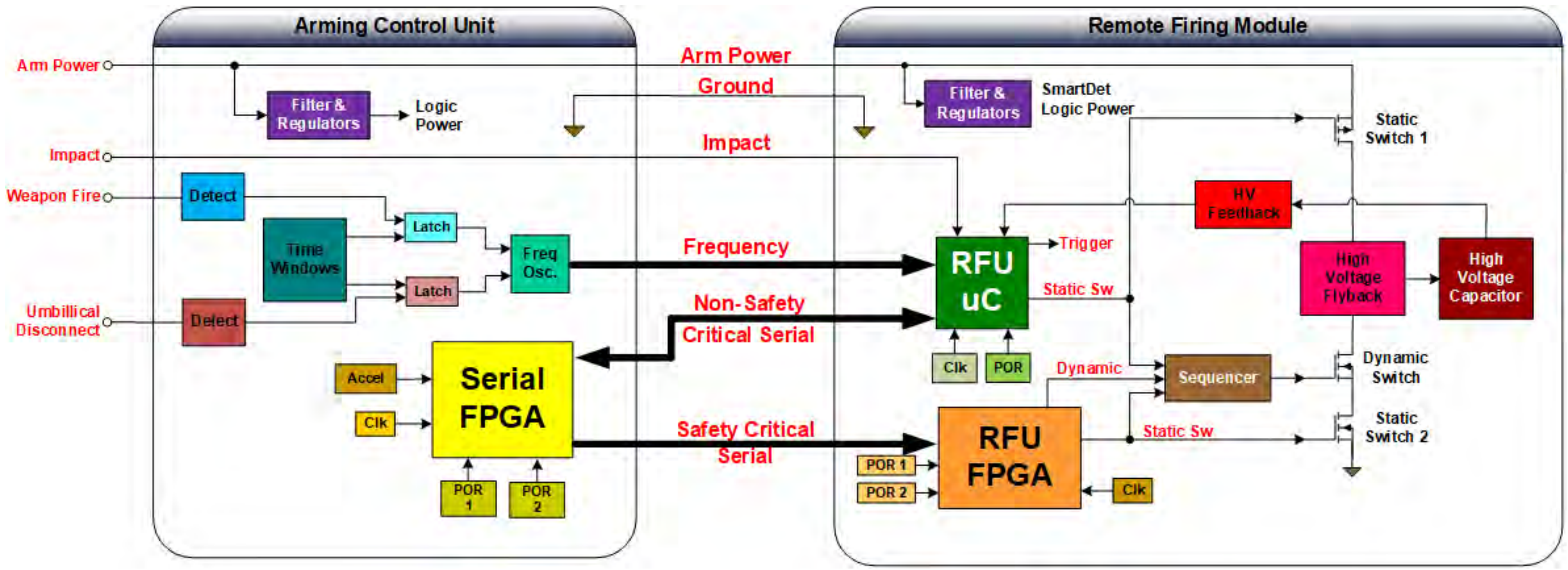
- **Each VE message should be unique and unambiguous, from any and all other VE messages using strong data typing.**
- **Tolerance to corrupt/invalid data should be characterized through analyses and test. Analysis and test methodologies will be provided to the appropriate Service Safety Authority for approval.**

Recommended Data Failure Modes

Failure Mode	Definition
Repetition	The same message is sent all the time (Ex. Babbling idiot)
Deletion	All or part of the messages or message content is missing
Insertion	A message is received unintentionally and is perceived as the correct address (Ex. Data from the wrong source)
Incorrect Sequence	Messages are not received in the correct order
Corruption	One or more data bits are changed in the message
Early Arrival	The message is received correctly before it is expected
Late Arrival	The message is received correctly later than expected
Masquerade	A non-safety-related message could be interpreted as a safety-related message
Inconsistency	Two or more receivers have a different view of the transmitted data or the receivers may be in different states

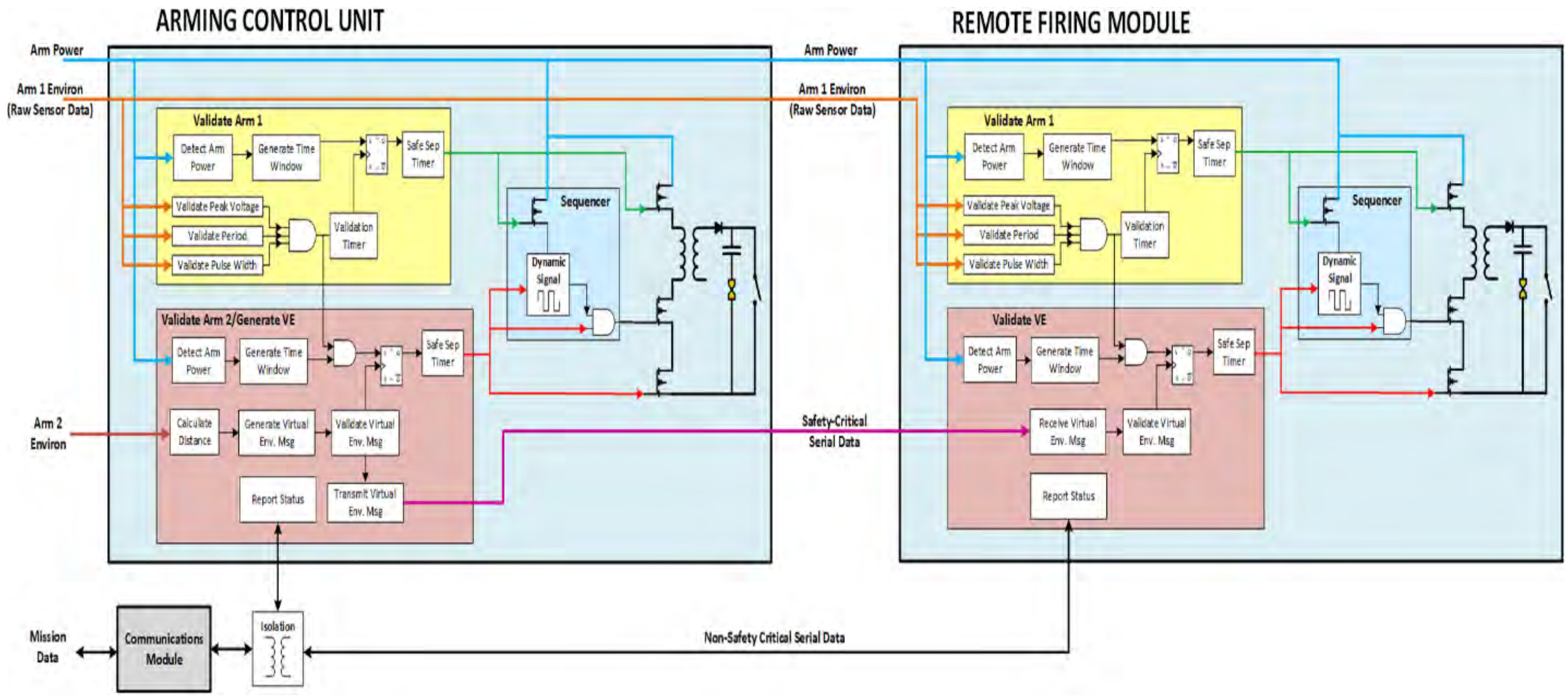
Current Solution Space

- **Frequency Shift Architecture**
  - An initial frequency is sent to the RFM at the beginning of the arming environment and is "shifted" to another frequency at completion of the arming environment. The RFM must detect this change in frequency within a specific time window for it to be valid.
  - ***Arming Signals:*** Analog Square Wave, 32-bit *generated* serial message



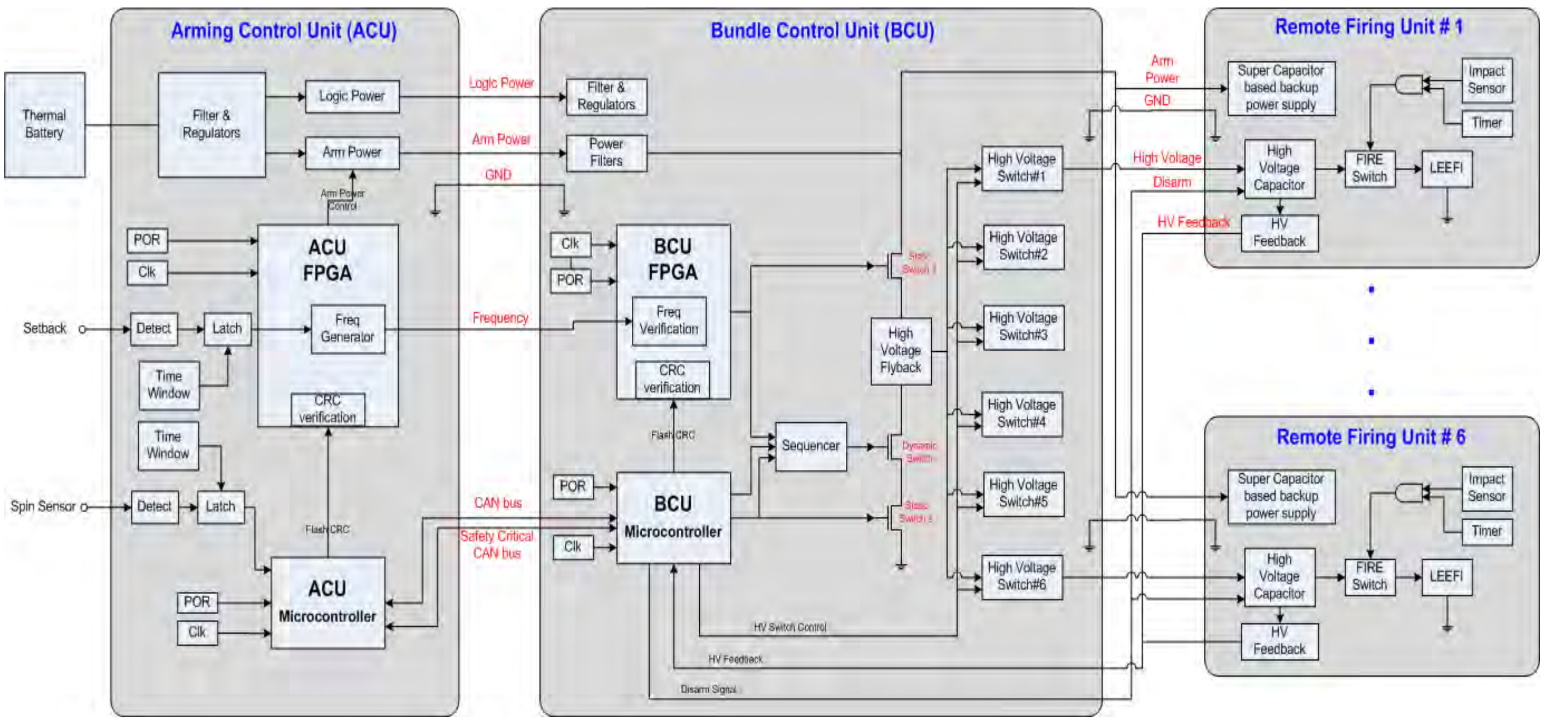
Current Solution Space

- **Hybrid Architecture**
  - This architecture utilizes a robust signal from a physical arming environment and a serial message as a VE. Note that the safety features are located in both the ACU and RFM.
  - ***Arming Signals:*** Raw Sensor Data, 32-bit *generated s*erial message



Current Solution Space

- **Bundle Control Unit**
  - This architecture utilizes a centralized safety module and distributes the firing voltage to the remote locations. The VEs are communicated between the ACU and Bundle Control Unit (BCU).
  - ***Arming Signals:*** Analog Square Wave (Frequency Shift), 7-byte *generated* Controller Area Network (CAN) *broadcast* message



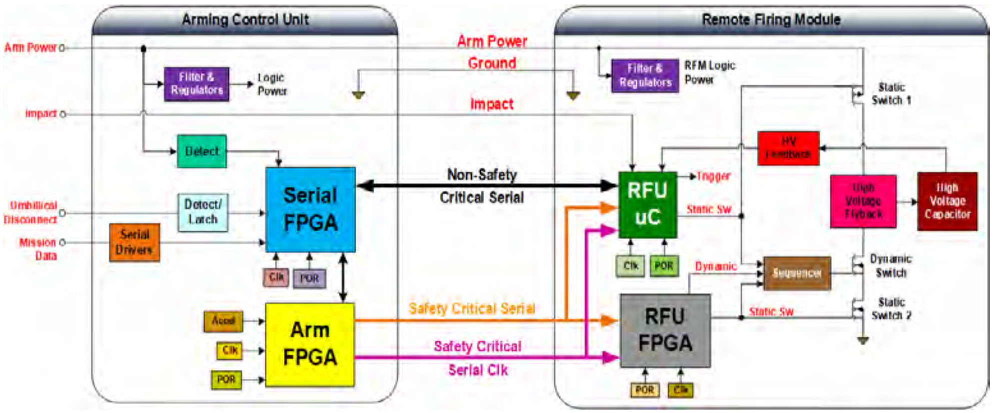
U.S. ARMY RDECOM

Current Solution Space

AMRDEC

- **Multiple-Try Architecture**
  - Multiple attempts at arming.
    - ➢ When given the correct arming sequence, the RFM will arm with four serial commands.
    - ➢ Should any errors occur, the RFM will be locked in a "safe" state and reset for a minimum amount of time defined as the "reset time."
    - ➢ Once the RFM exits reset, the arming process can be attempted again. The ACU must now send a valid reset command *in addition to* and before the previous commands.
  - ***Arming Signals:*** 24-bit *stored* serial messages

Command #	Command Name	Purpose
1	Key	"Unlocks" the remote firset. Fireset must receive key word before it will accept other commands.
2	Static Switch 1	Enables Static Switch 1 on the remote fireset.
3	Static Switch 2	Enables the Static Switch 2 on the remote fireset.
4	Arm	Enables Dynamic Signal generation.
5	Reset	Unlocks the remote fireset from a safe state if an error has occurred.



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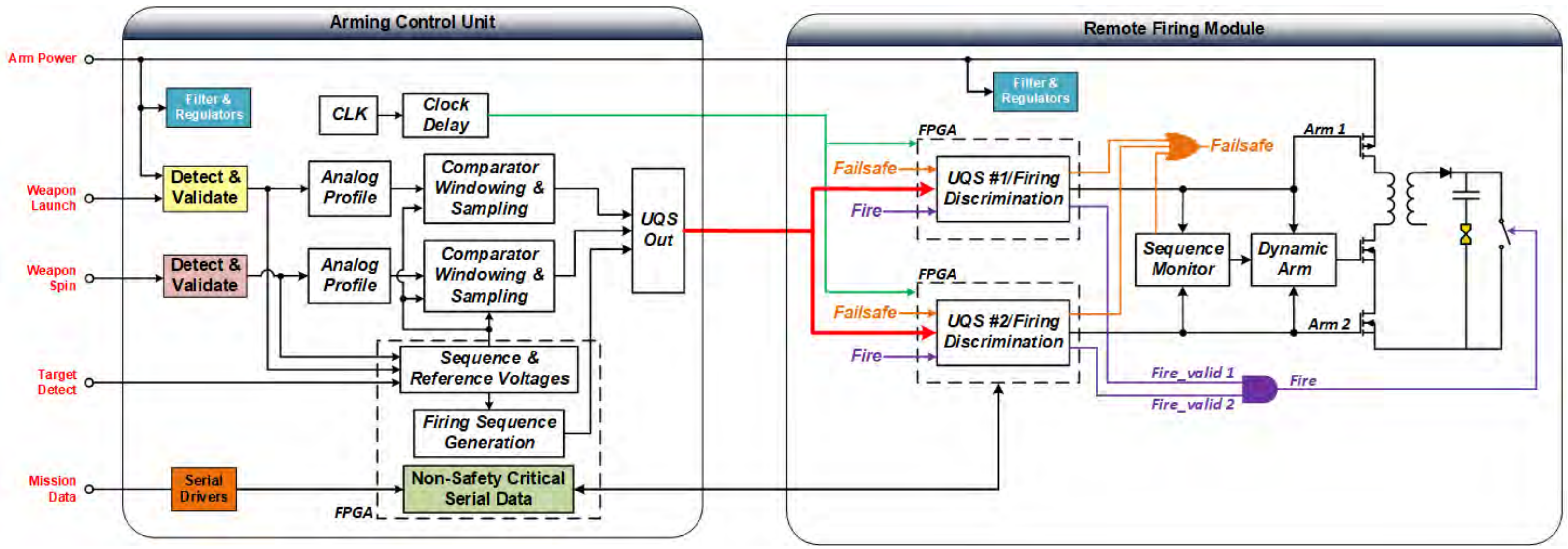
Current Solution Space

- **Electronic Unique Signal (eUQS) Architecture**
  - A sequence of independent events in a specified pattern that is extremely unlikely to happen in normal and abnormal environments
    - ➢ 24 events for Single-Try; "Many more" (application specific) for Multiple-Try
  - Each event is communicated and evaluated one at a time
  - ***Arming Signals:*** Two 24-bit *generated* data streams (one per arming environment)
    - ➢ Data streams are **<u>not</u>** serial communications.



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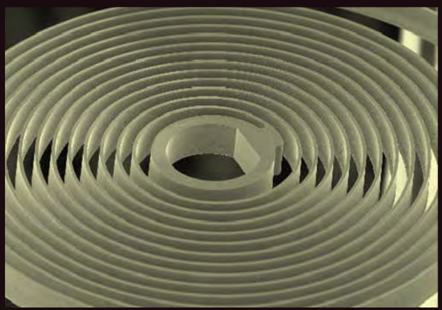
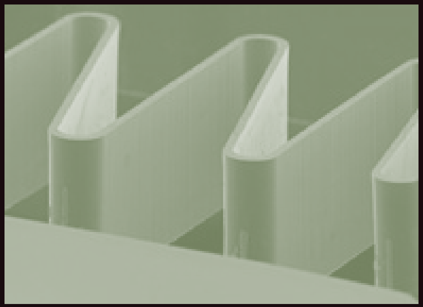
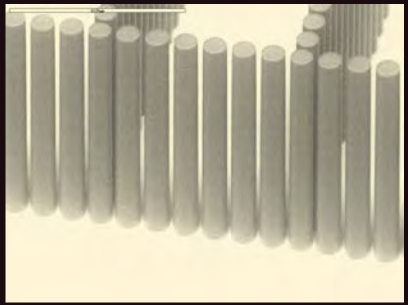
Last but Not Least!!

HTER FOCUSED.

QUESTIONS?

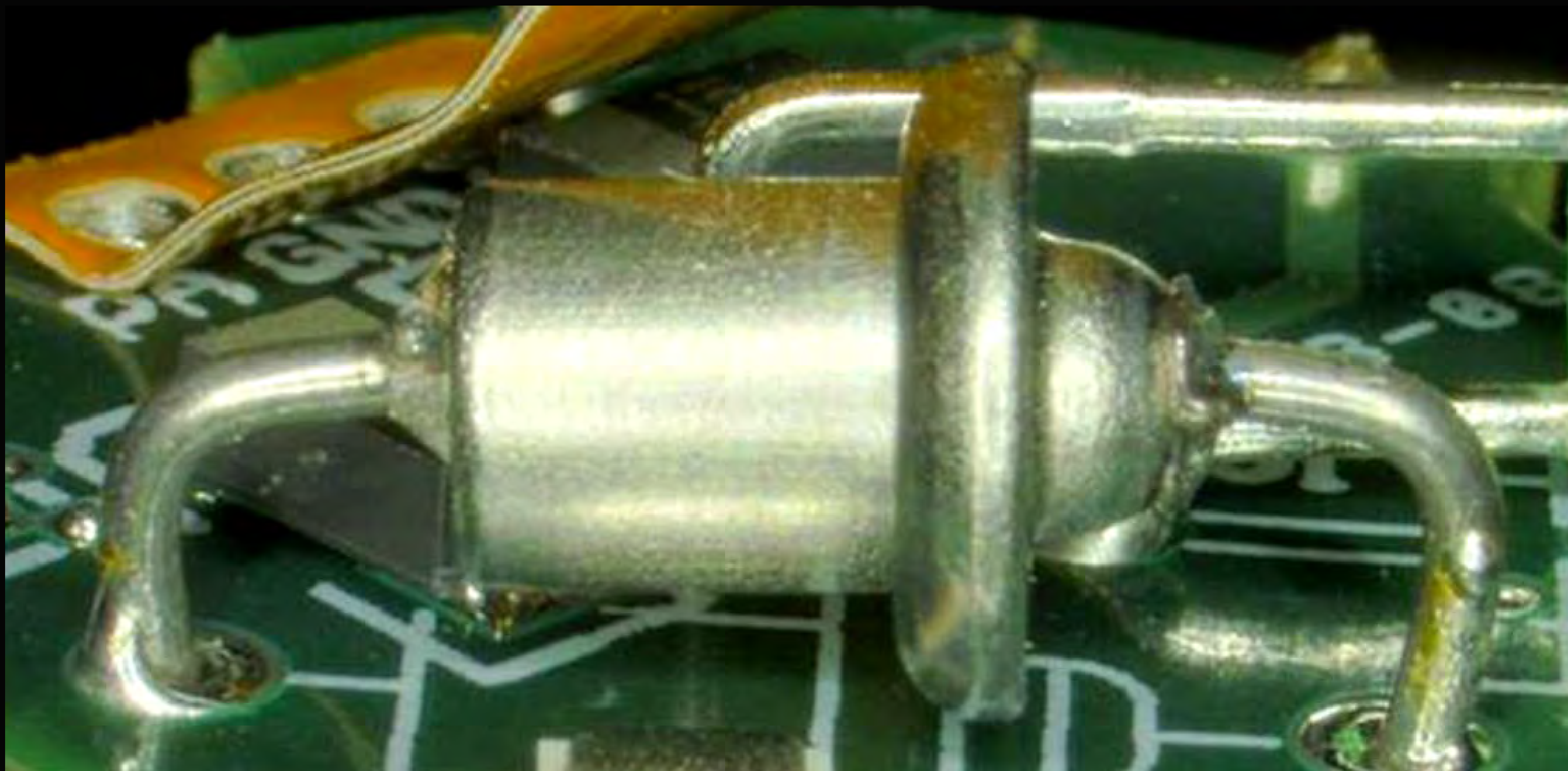
Mark Etheridge
AMRDEC Fuze Office
256-842-7953
mark.e.etheridge2.civ@mail.mil



Low G MEMS Inertia Switches for Fuzing Applications

HT MicroAnalytical, Inc.
Sam Rogers, Danny Czaja, Hopper Chu,
Todd Christenson, Chairman & CTO

todd.c@htmicro.com



Issues

- Reliability
- Scaling

Approach

- Design
- Fabrication

Results

- Initial Testing

Reliability

- Reliability → Force → Δ Energy → Volume

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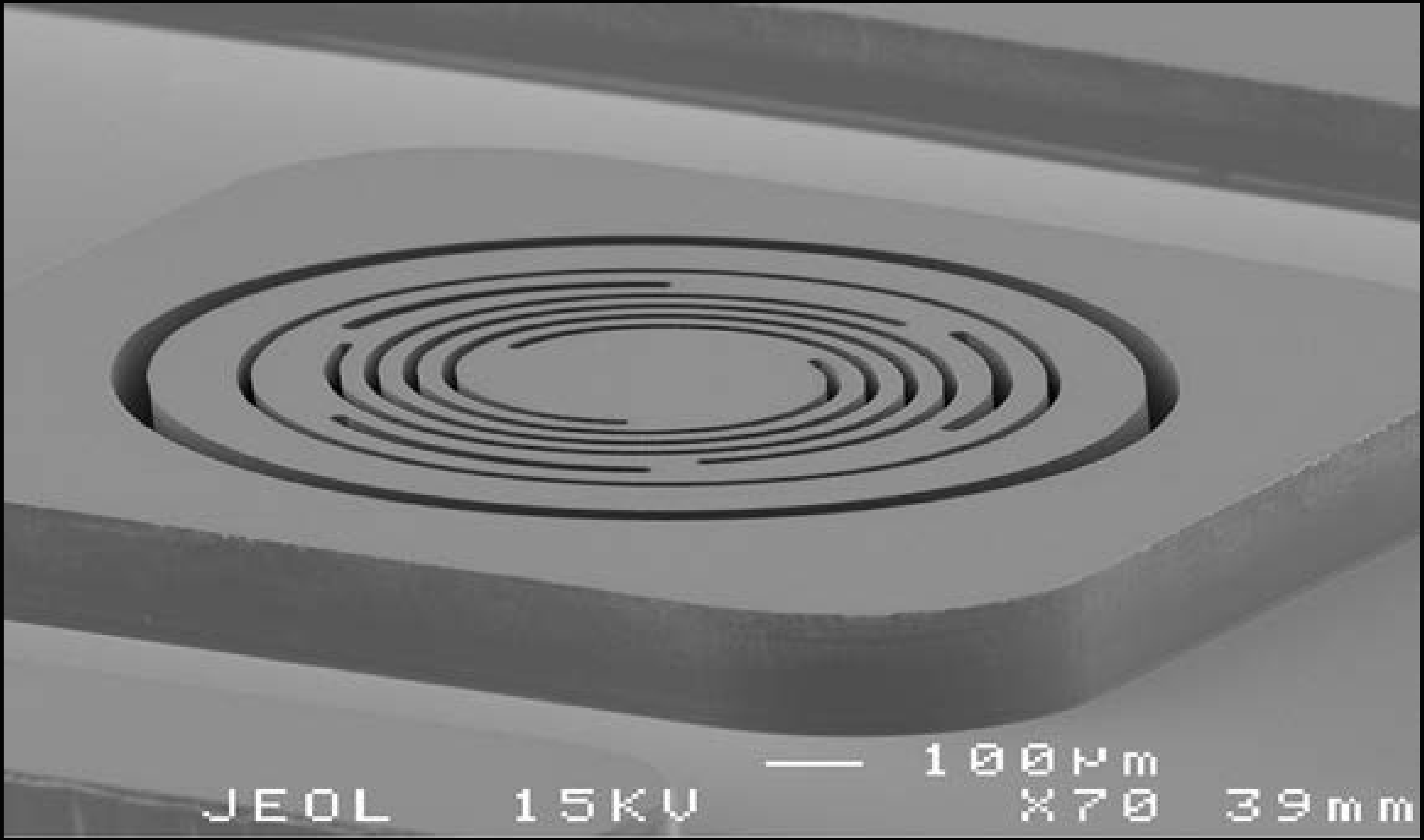
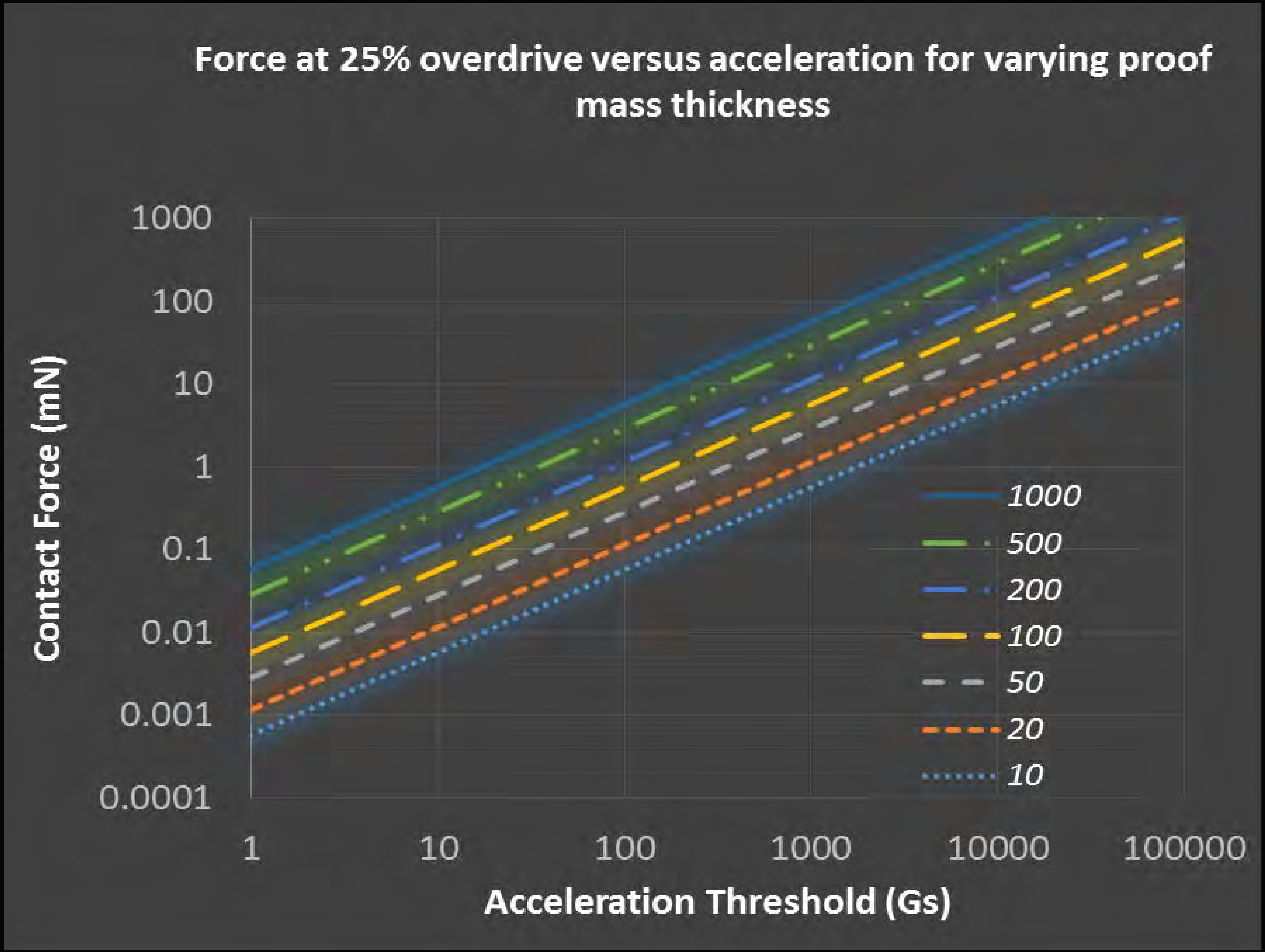
Reliability

$$F_{ctct} = (ma - kx_{ctct})$$

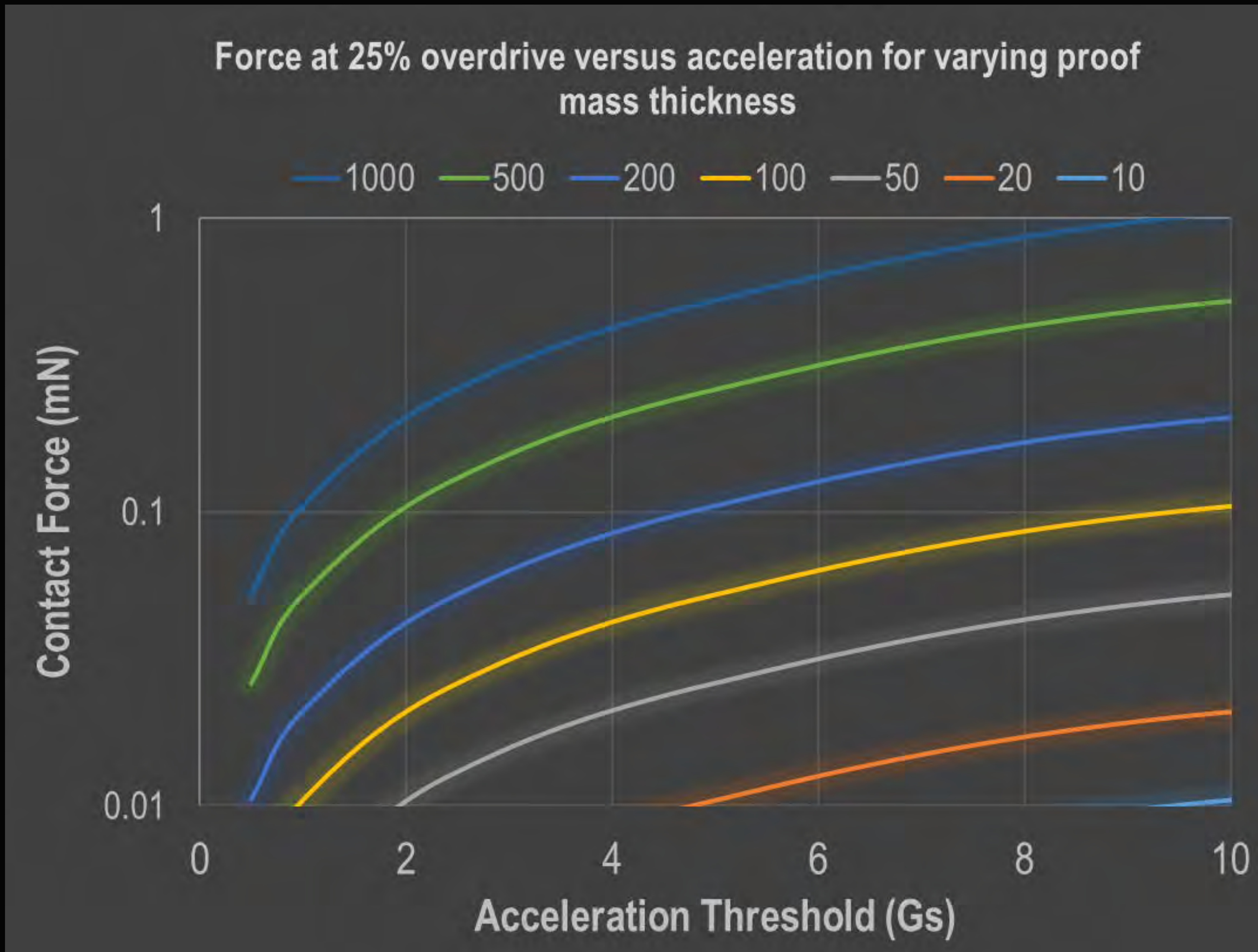
Design



Reliability



Design


Force at 25% overdrive versus acceleration for varying proof mass thickness
1000
500
200
100
50
20
10
1
0.1
0.01
Contact Force (mN)
0
2
4
6
8
10
Acceleration Threshold (Gs)

Design

$$FOM \sim \frac{F\eta}{\$A} \sim \frac{\rho h\eta}{\$}$$

Design




Keys for High FOM / Viable Microfabricated Component

1) Materials – ρ, σ_y , σ-n - $

2) High Aspect Ratio - $

3) Tolerances / Integration / Packaging - $

4) Testing - $

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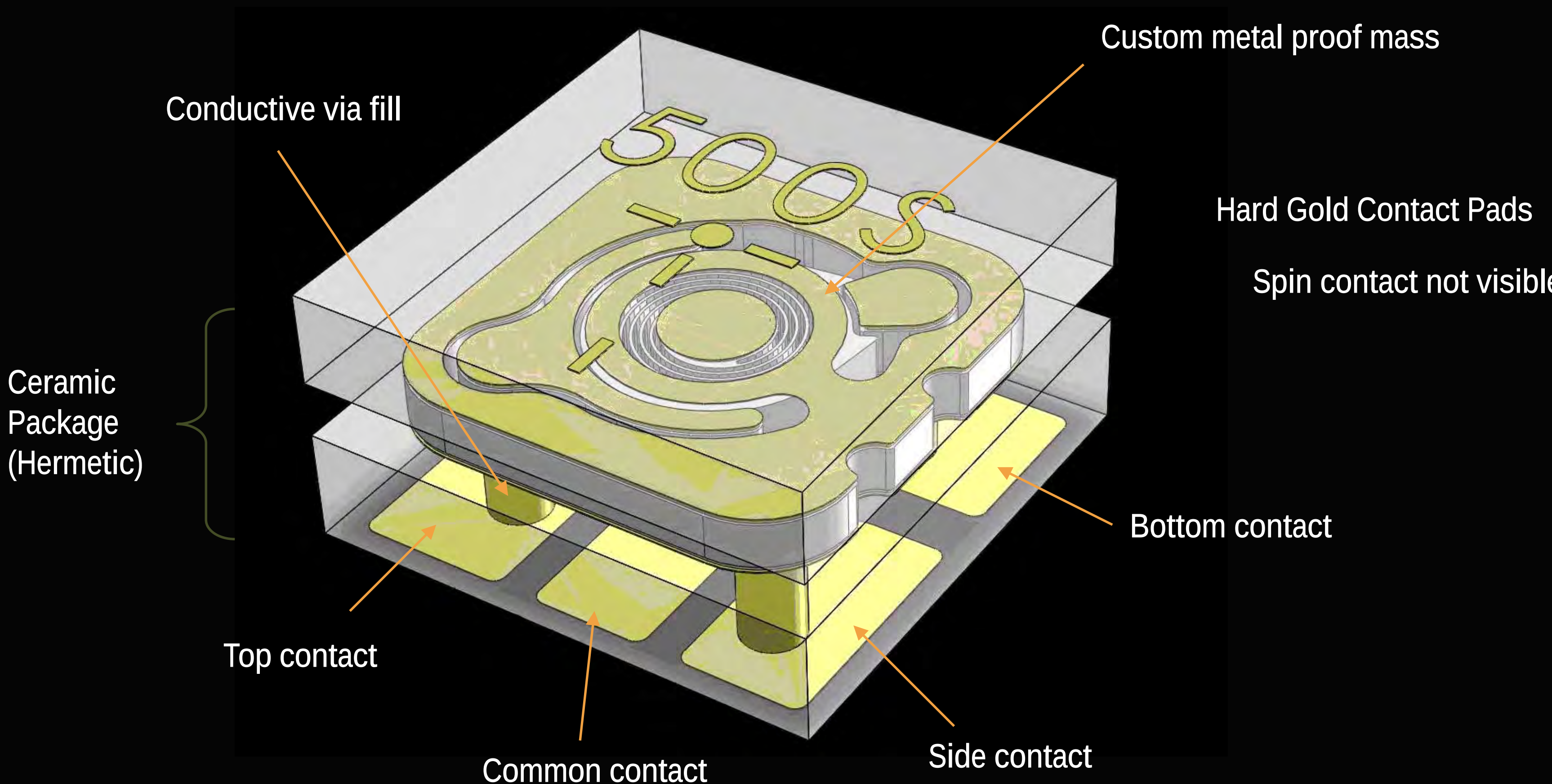
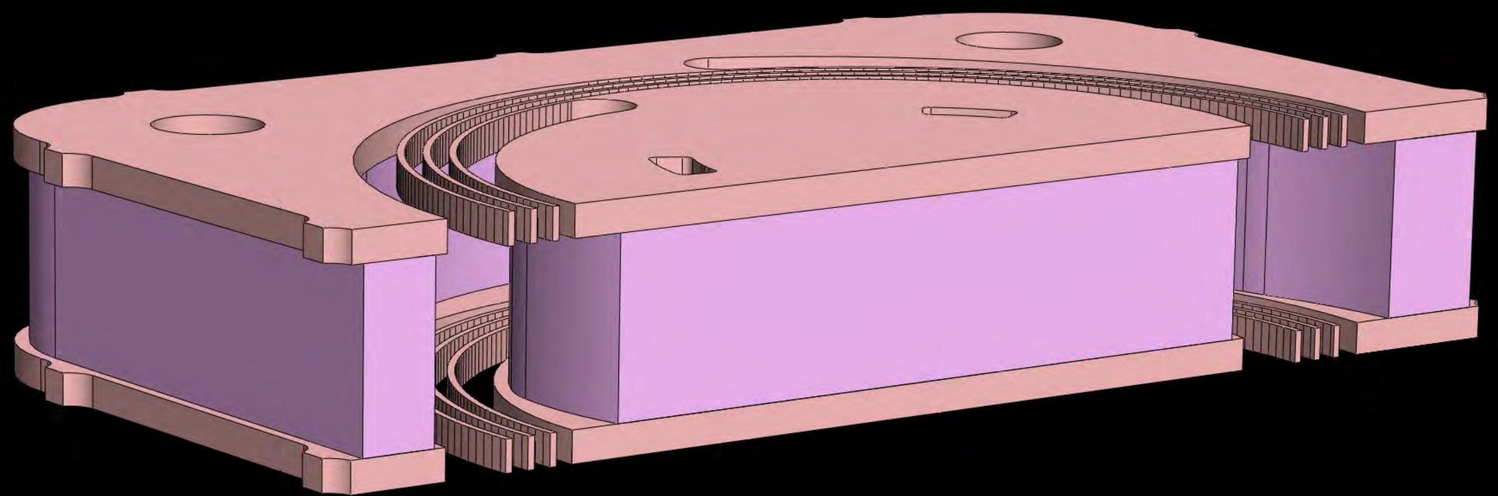
Design

Integrated Inertia Switch Anatomy



Multi-layer spring-mass fabrication



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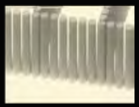
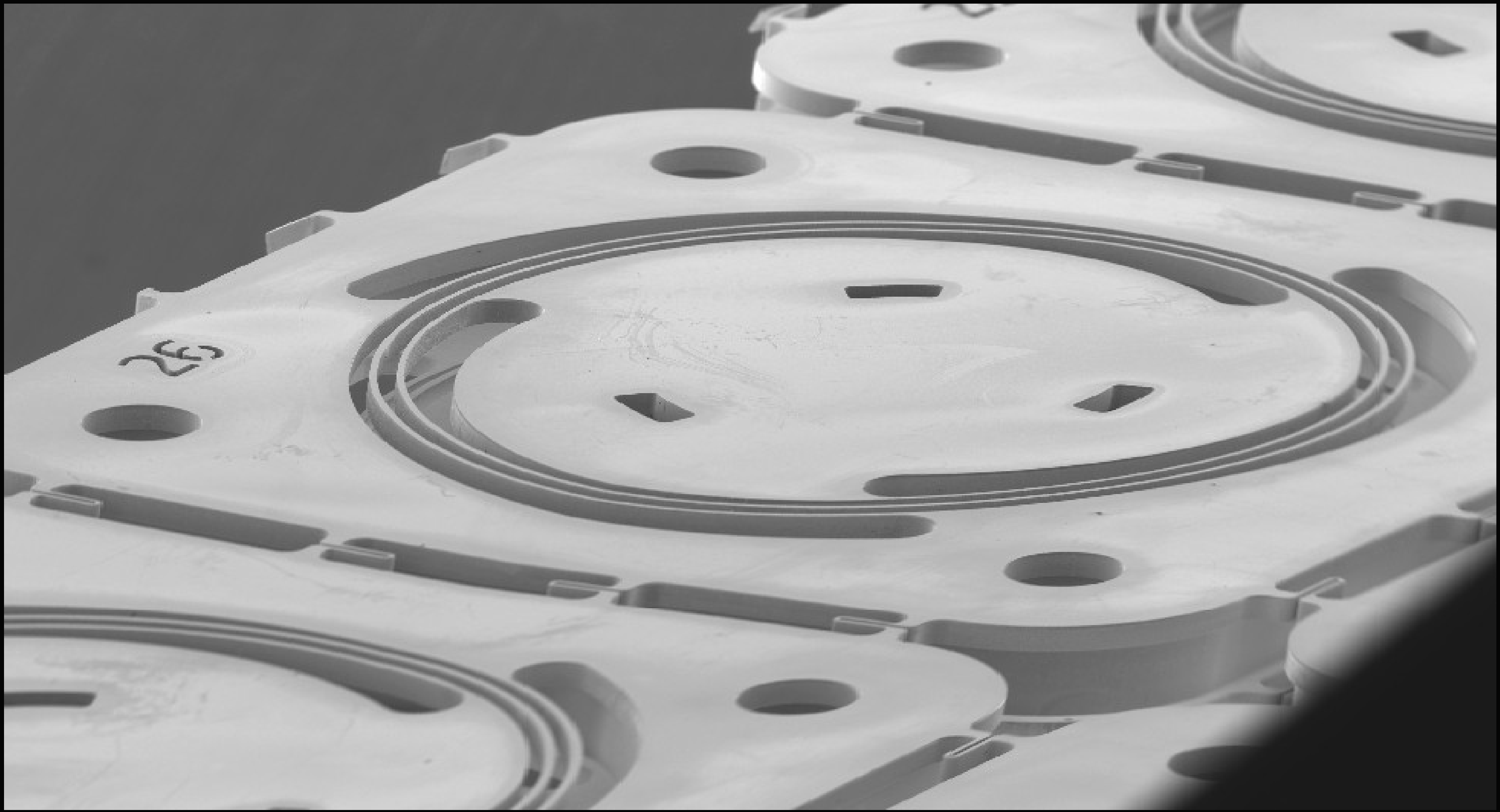
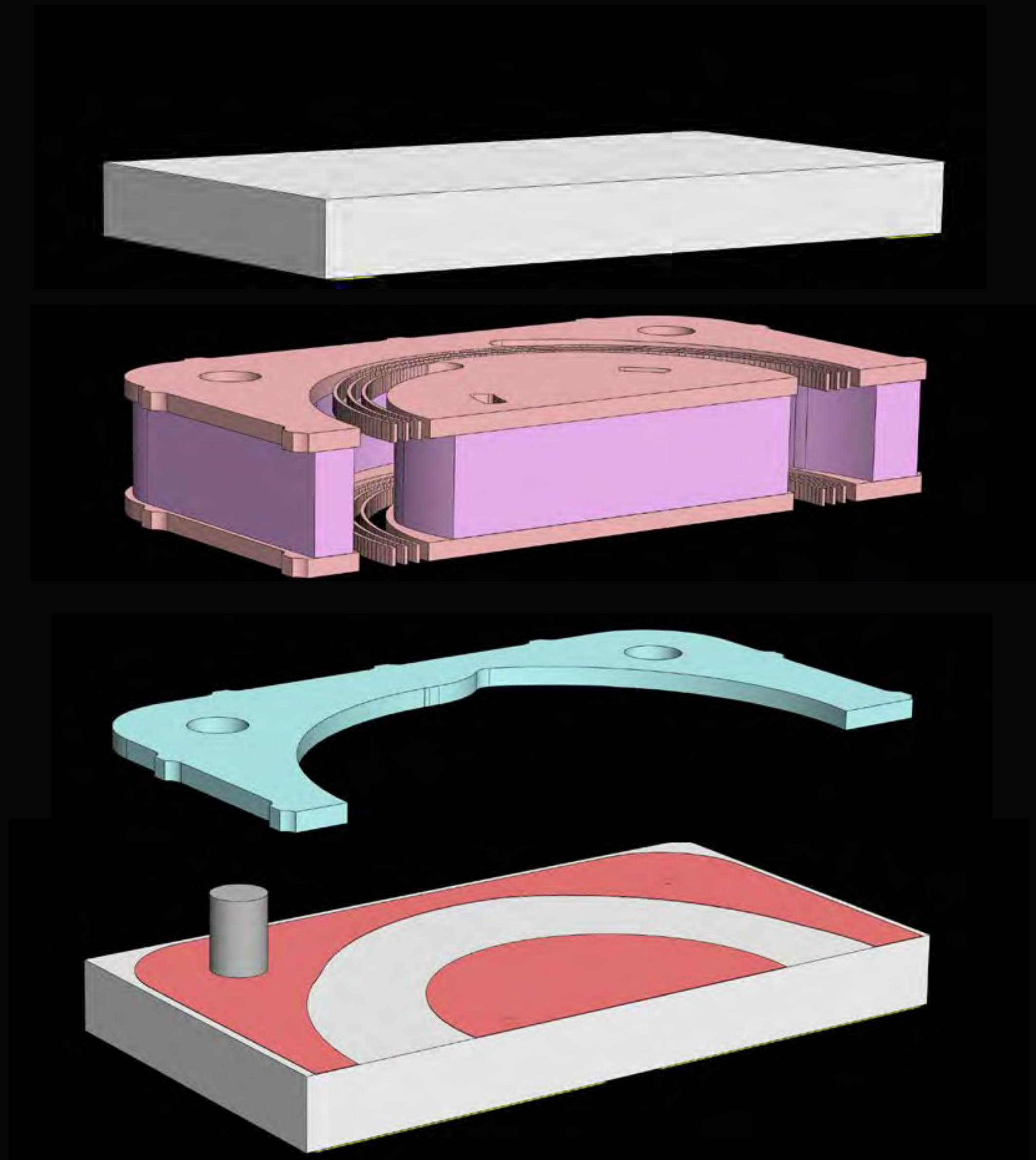
multi-layer fabrication



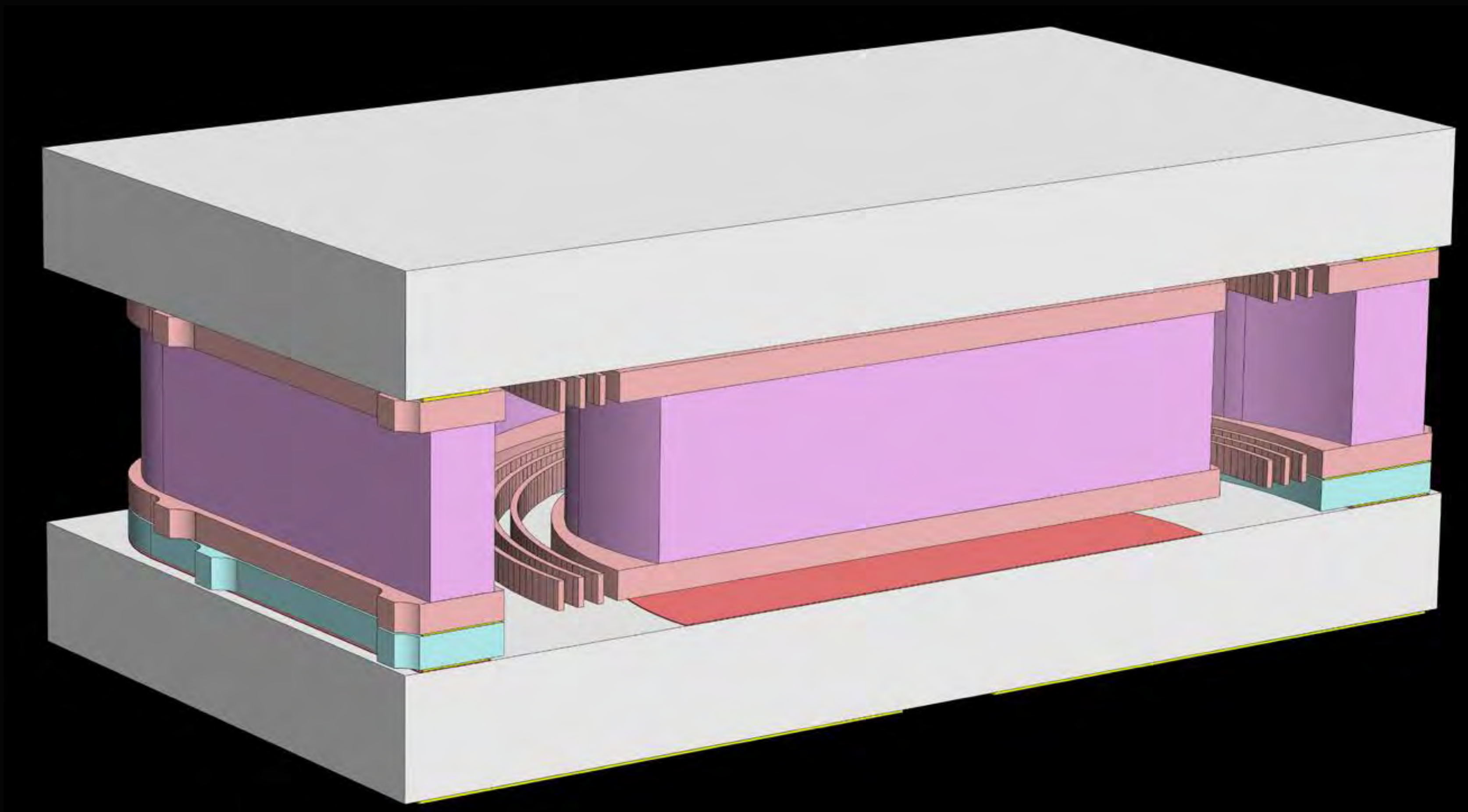





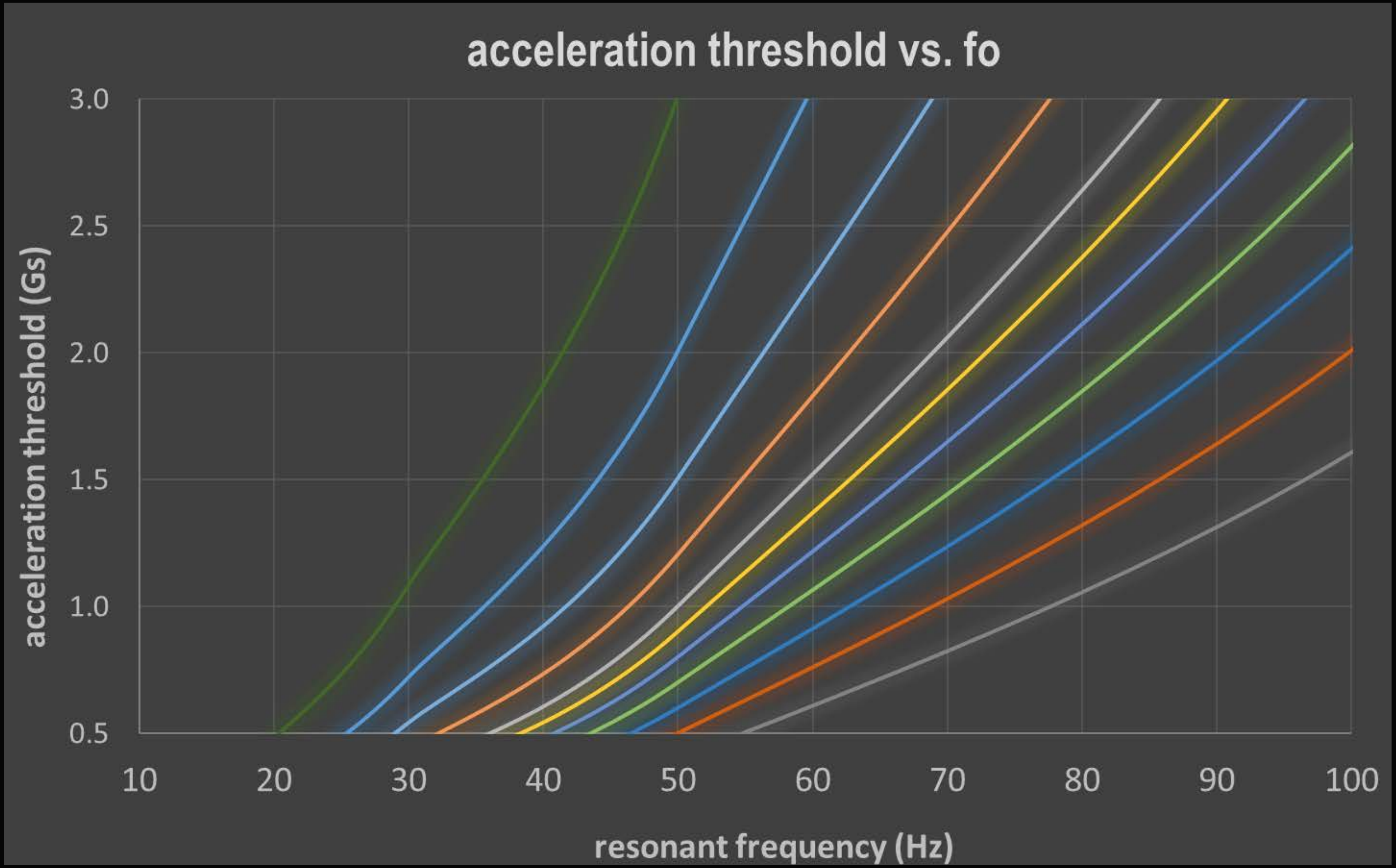
Multi-layer spring-mass fabrication



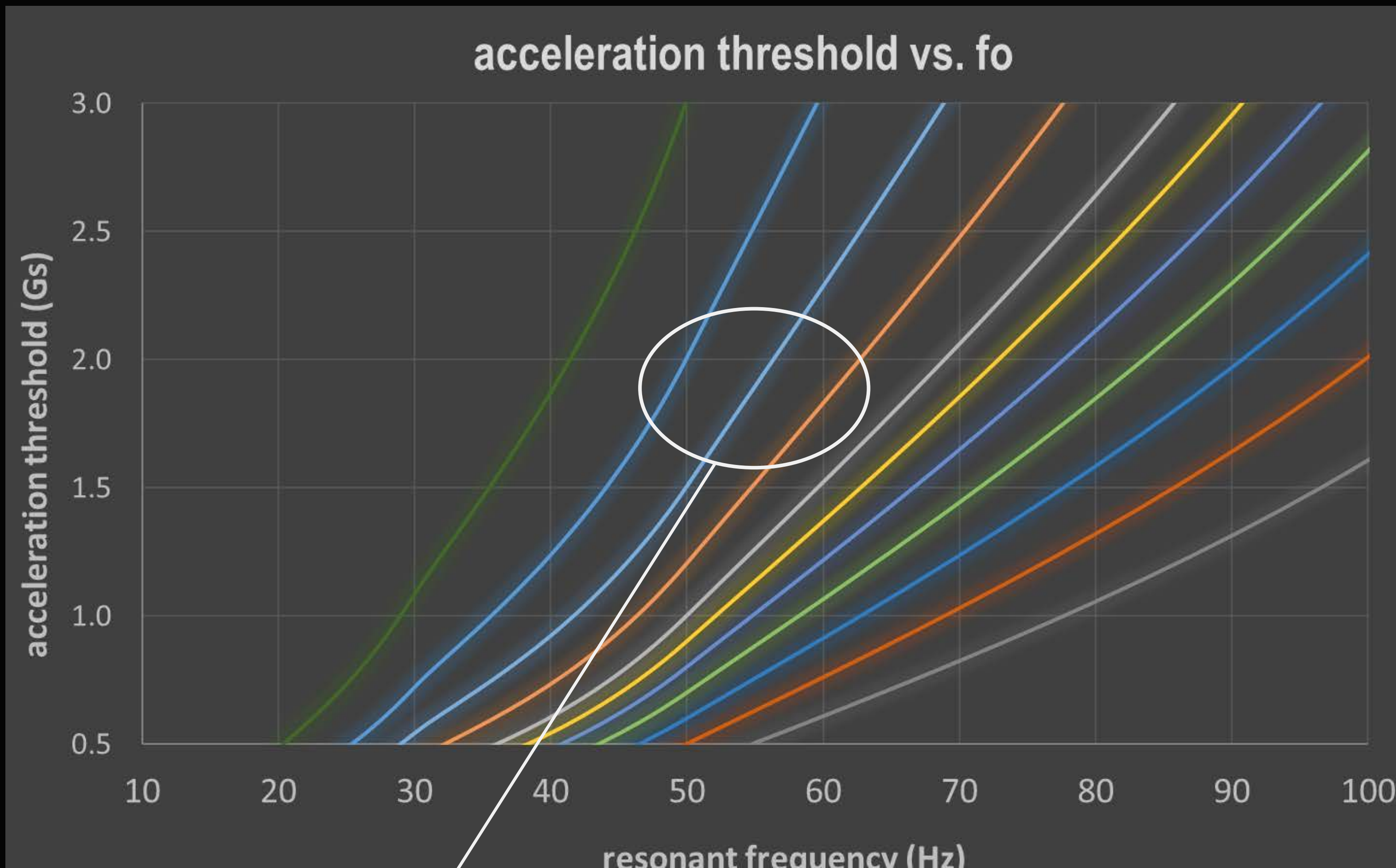
Multi-layer spring-mass fabrication



ma = kx


acceleration threshold vs. fo
3.0
2.5
2.0
1.5
1.0
0.5
acceleration threshold (Gs)
10
20
30
40
50
60
70
80
90
100
resonant frequency (Hz)

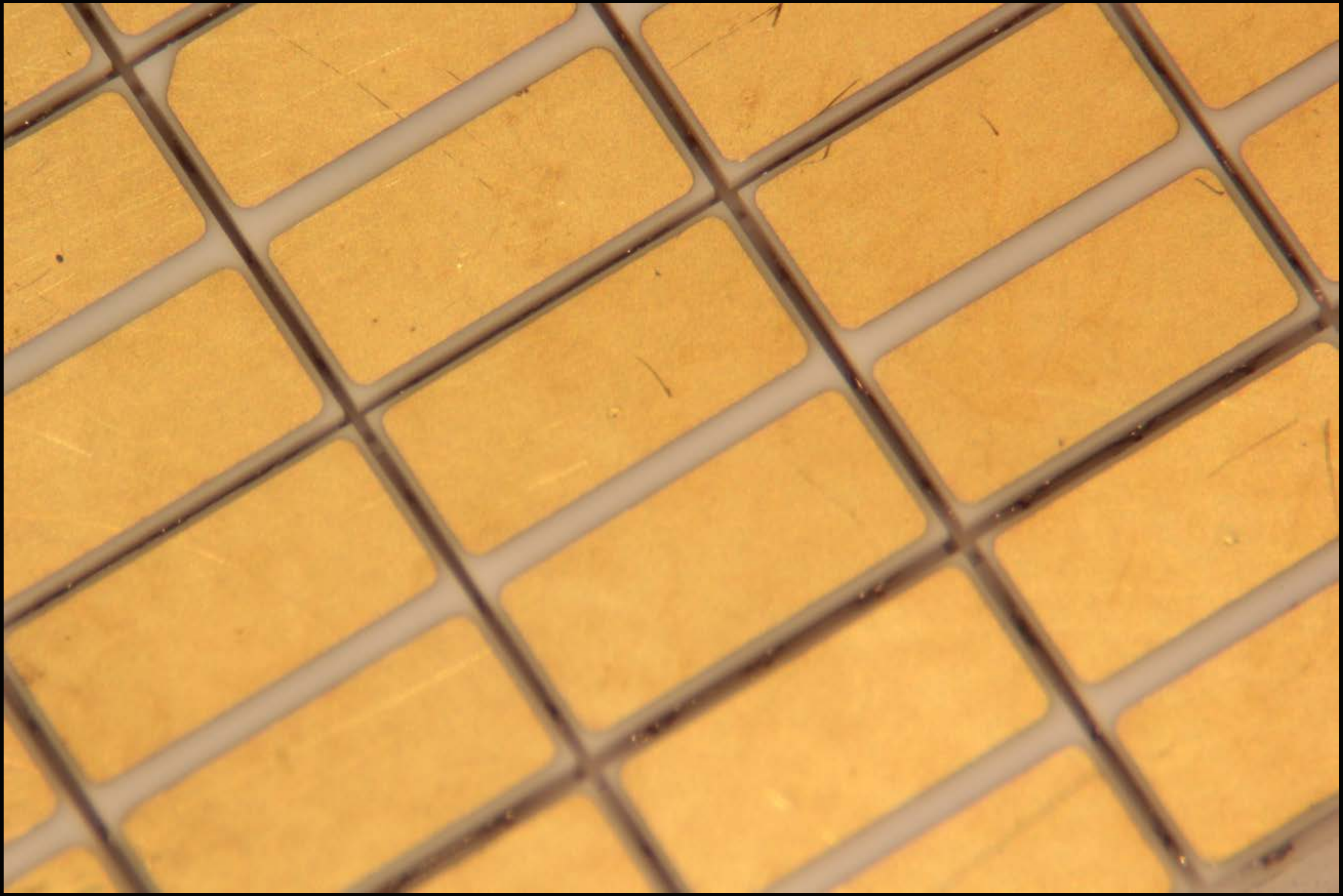
ma = kx



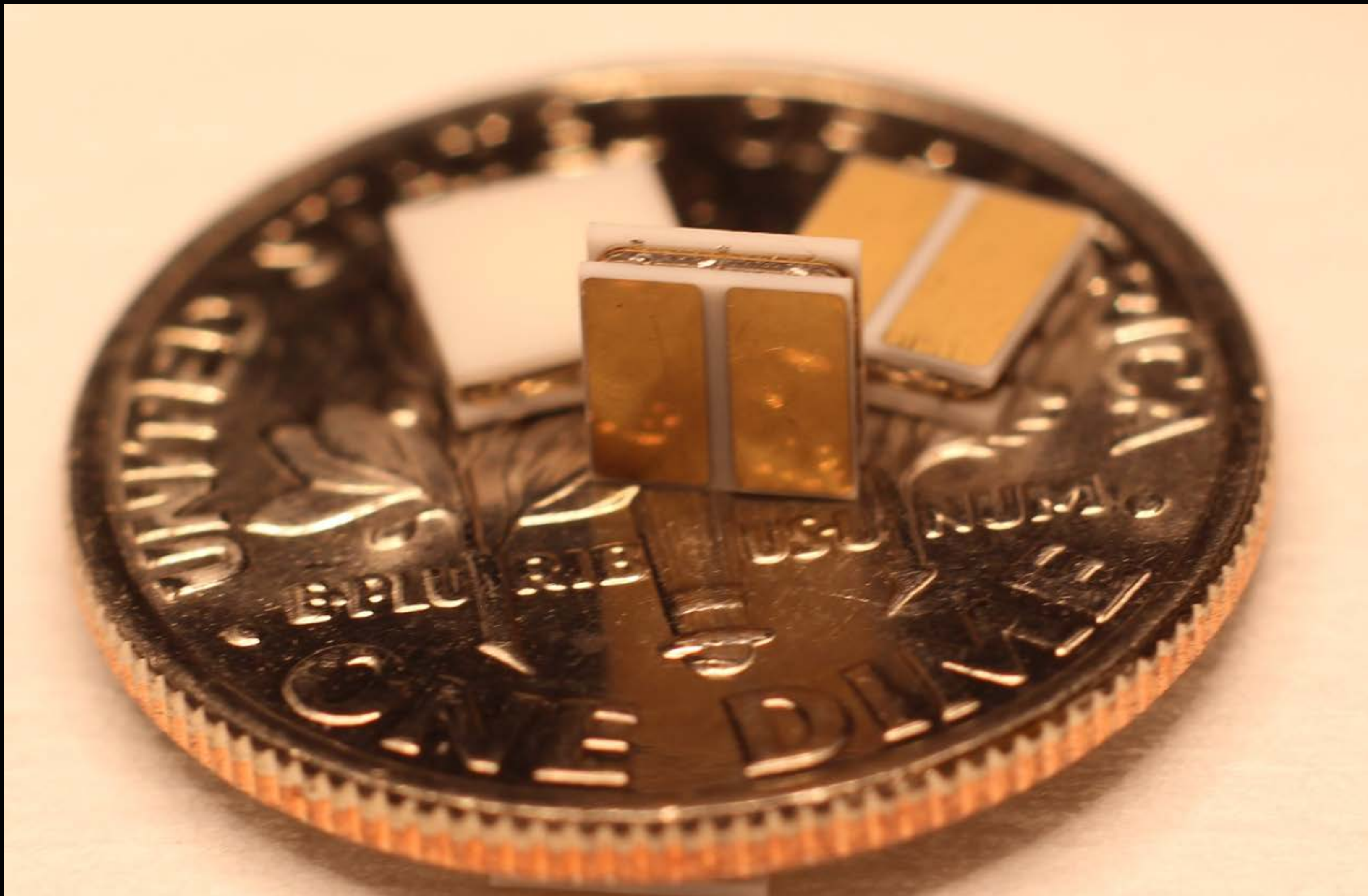
acceleration threshold vs. fo
acceleration threshold (Gs)
3.0
2.5
2.0
1.5
1.0
0.5
10
20
30
40
50
60
70
80
90
100
resonant frequency (Hz)

~ 0.05 G / Hz

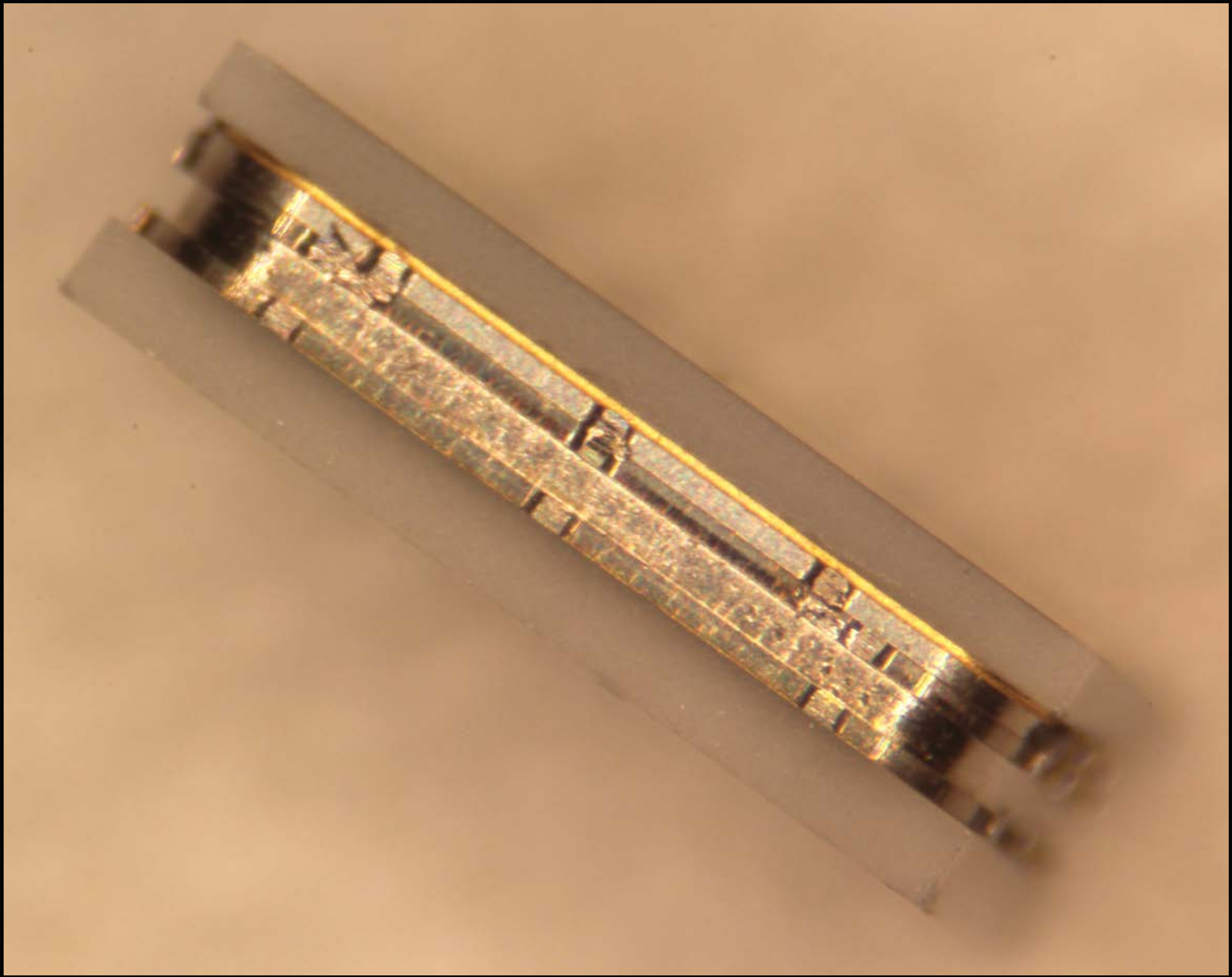
Diced Wafer



‘WLP’ Diced Parts



Edge of Device



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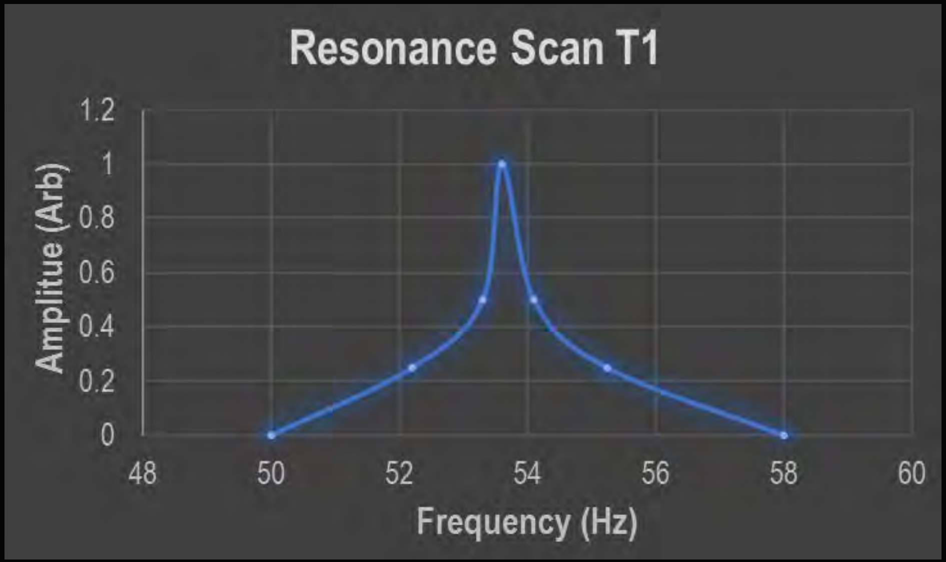
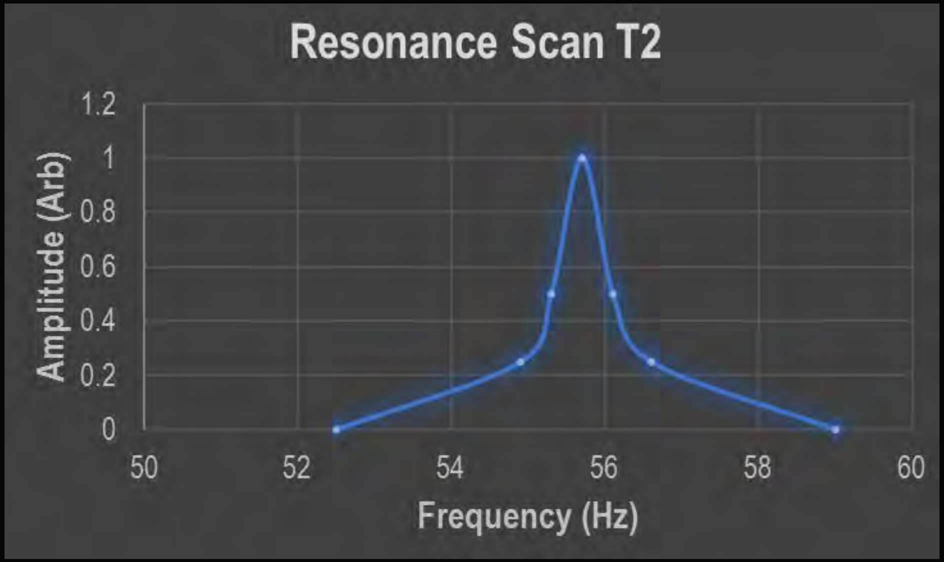
Resonance Measurements





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Acknowledgements

Ryan Knight (ARL)

Daniel Jean (Indian Head)

Edward Cornell (China Lake)

Thank You!

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Dynamic Characterization of Shock Mitigating Materials for Electronics Assemblies Subjected to High Acceleration

61st NDIA Fuze Conference, May 15-17, 2018, San Diego, CA

Presented by

Dr. Vasant Joshi
NSWC Indian Head, MD vasant.joshi@navy.mil, (301)744-6769

Outline

- Introduction and Background
- Objective
- Approach
- Results
- Discussions
- Summary

Introduction

Electronic circuit boards used in high impact application are subjected to:

- High deceleration -10kG to 50kG
- Multiple reverberations leading to bending and flexing of printed circuit board
- Complex loading on electronic components, based on shape/size

Conventional solution for survivability of the printed circuit board assembly as well as for individual components is to encapsulate board using potting materials, wherein the high G levels in multiple frequency ranges are attenuated.

Background

Limitations of potting materials:

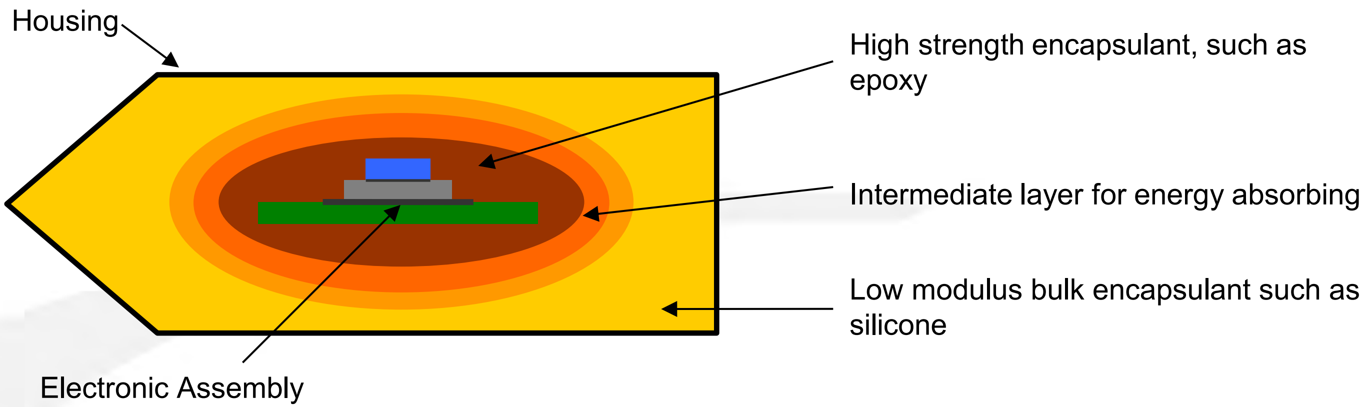
- Soft potting materials may not be strong enough to secure the components
- Hard potting materials may transmit damaging vibration to components
- Combination of hard and soft potting is required, however, response of individual material must be characterized before optimum solution can be implemented

Objectives

- Characterize potting materials for dynamic environment
- Analyze loss in material during impact (damping) which form basis for providing improved material models for potting compounds
- Compare low and high strain rate response from different test methods
- Seek alternative ways of evaluating damping characteristics for developing optimum damping to be used for improving circuit board survivability
- This presentation focuses on frequency response analysis of potting material

Approach

- Typical damping scheme may have multiple materials as shown schematically

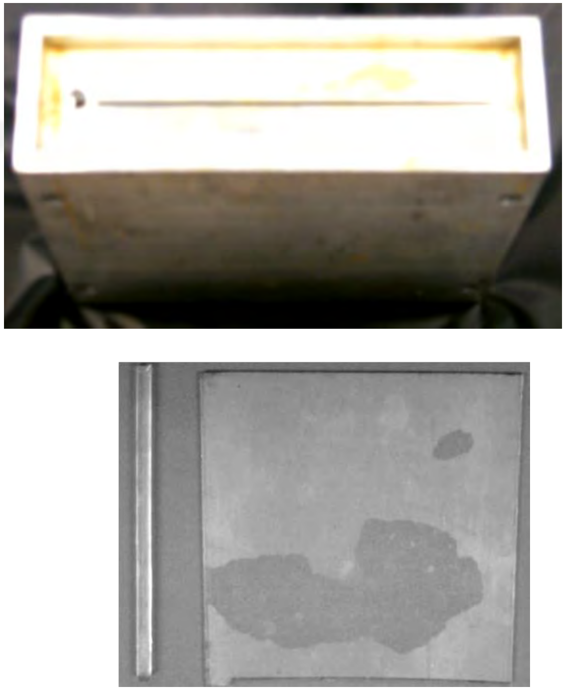


- Current material focuses on a low modulus material Sylgard 184, also known as PDMS
- Use identical material for characterization under different methods
- Conduct DMA test on standard machine, accelerometer based spectrum analysis for high frequency resonant modes to get loss factors and high rate Hopkinson Bar experiments to obtain data

Approach

Material test data is very sensitive to sample processing and preparation, so best way is to avoid machining of soft materials, use dies and molds, cast samples of Sylgard 184 in place for all tests

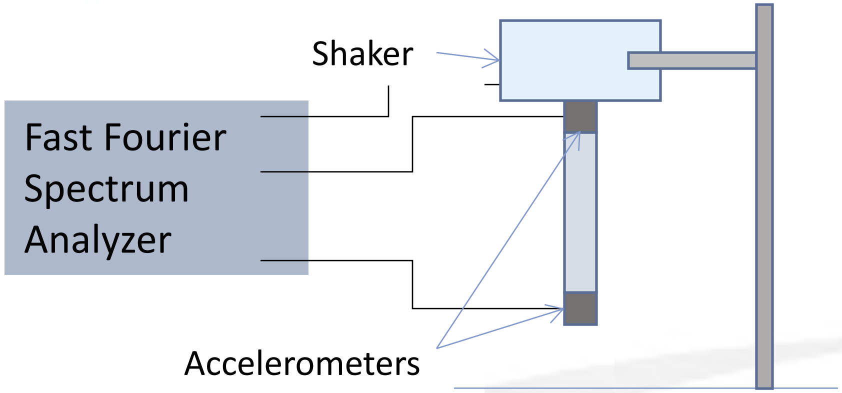
Mold and samples- Cylindrical



Mold and samples-Sheet

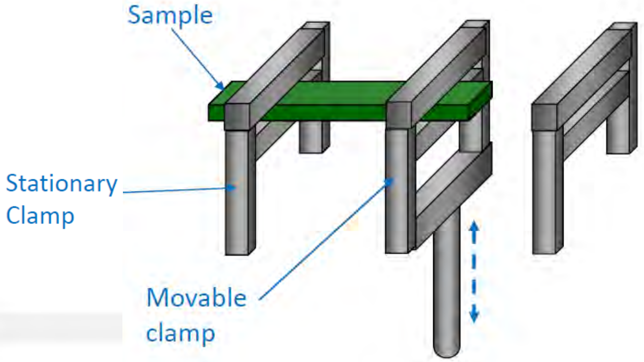
Characterization Methods

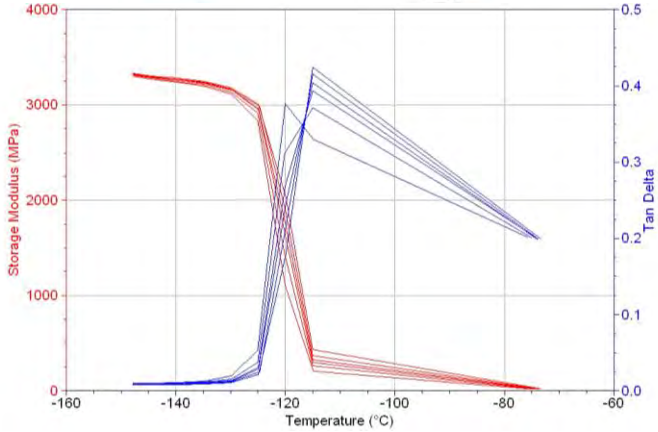
Resonance Scheme



Broadband signal from shaker is transmitted into the sample. Signal input vs. output is recorded for amplitude and phase shift for 10Hz-25Khz

DMA Scheme

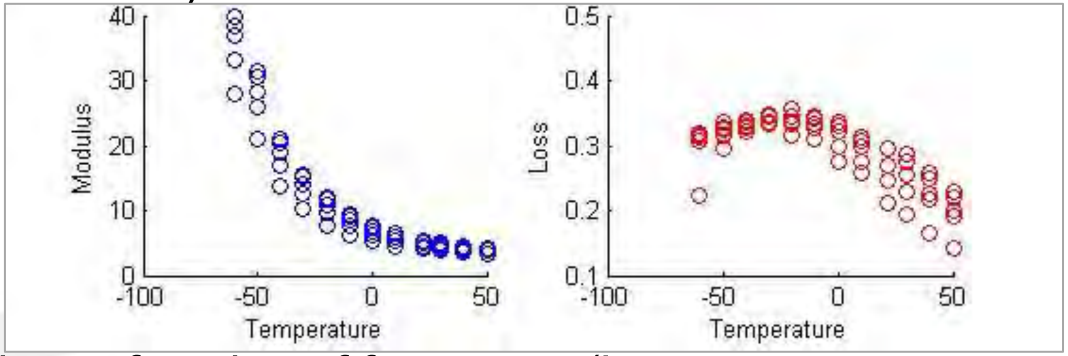




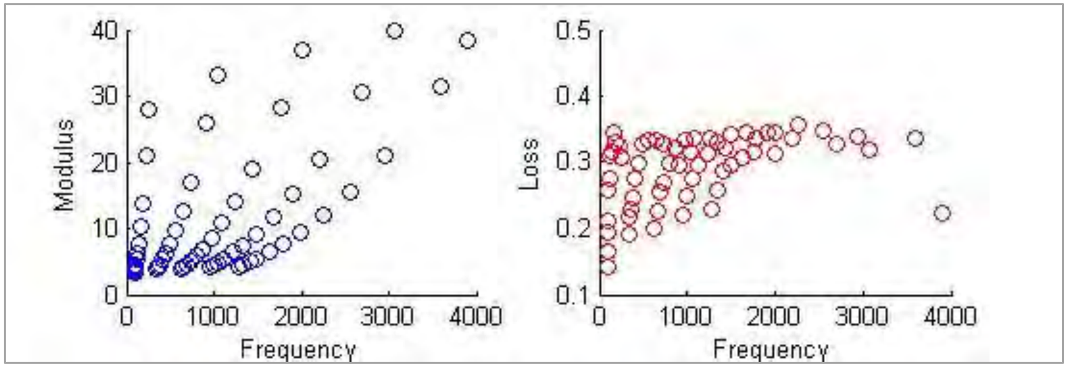
Movable clamp provides predetermined amplitude . Signal input vs. output is recorded for amplitude and loss for 0-10hz

Resonance

- Results from tests conducted at different temperatures show that even when modulus (MPa) changes are large, losses are still low (5 modes for each temperature are shown).



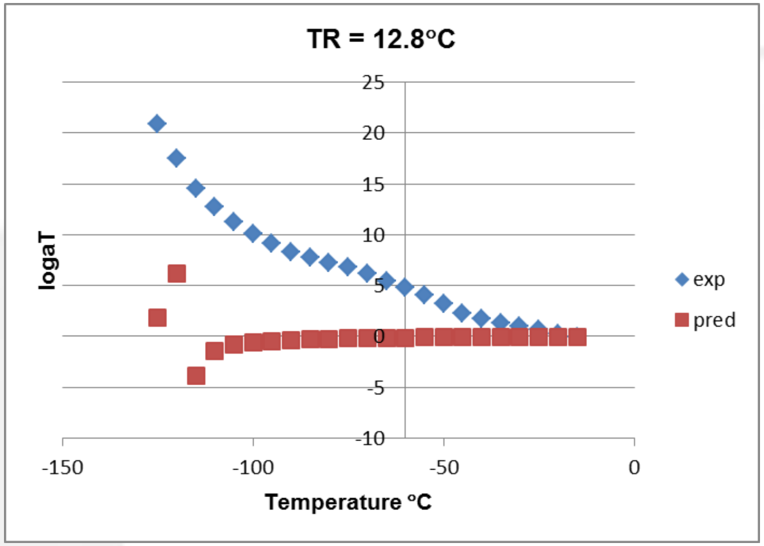
- Results plotted as a function of frequency (lowest temperature correspond to highest modulus and high frequency) also show low loss for high frequency.

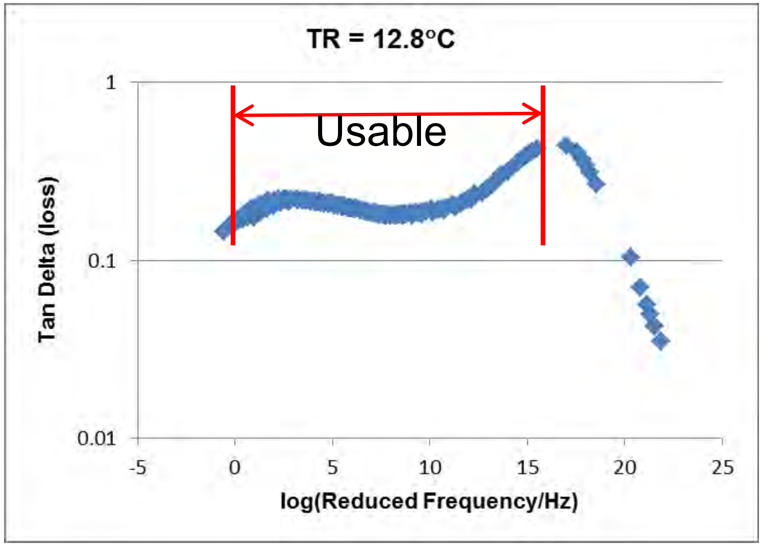


- This leads to interpretation that higher frequencies may have higher attenuation.

DMA

- Data from DMA was analyzed using Temperature-Time Shift (TTS) program and compared to Williams-Landel-Ferry (WLF) model to obtain shift factor from a reference of 12.8°C to enable extrapolation for high frequencies.
- WLF predictions matched the experimental data only in a small regime, indicating that Sylgard 184 does not behave as an ideal viscoelastic material. However, there is a range of usable data as shown below.

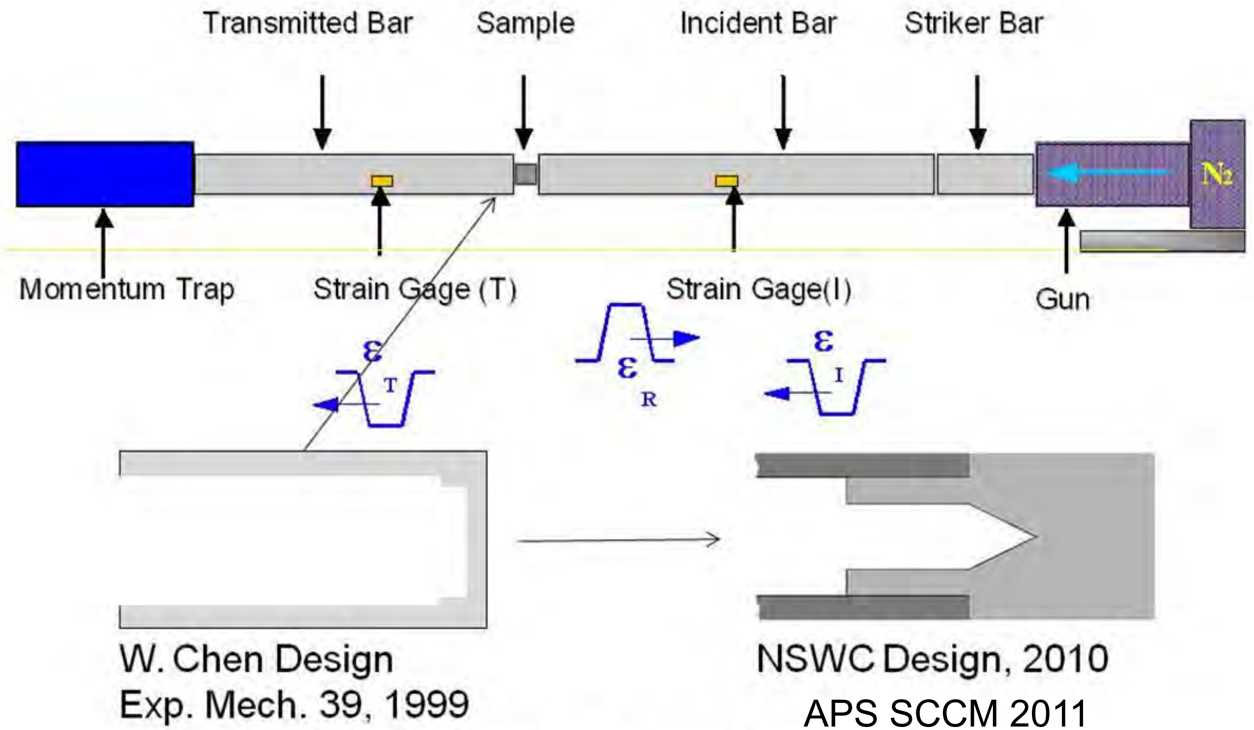




- Extrapolation is not recommended beyond this range, limiting assessment of frequency response to ~3KHz. Also, upper limit of loss factor seems to be about 0.3 (30%) for a calculated strain rate of 140/s.

Hopkinson Bar

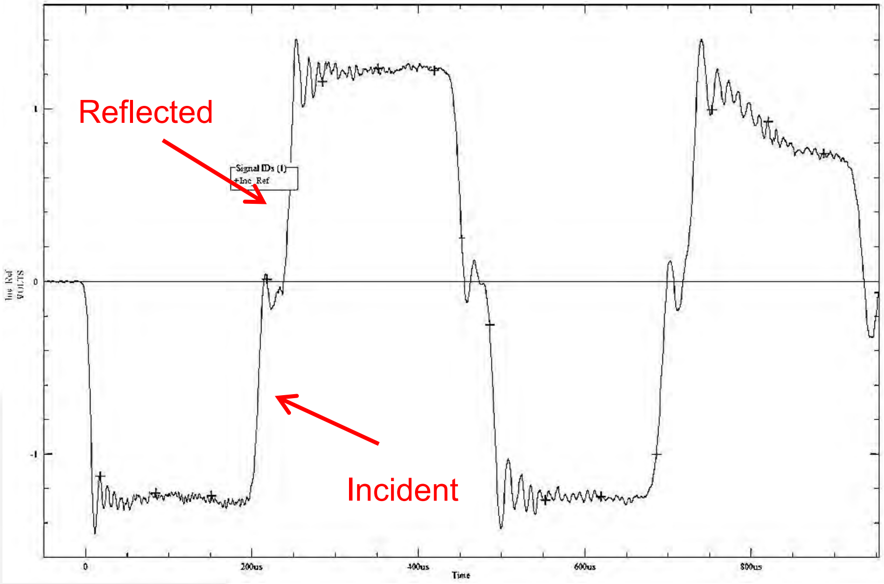
Use Improved Hopkinson Bar (hollow aluminum bar) for high strain rate properties of soft samples (typical strain rate~ 500-5000/s).

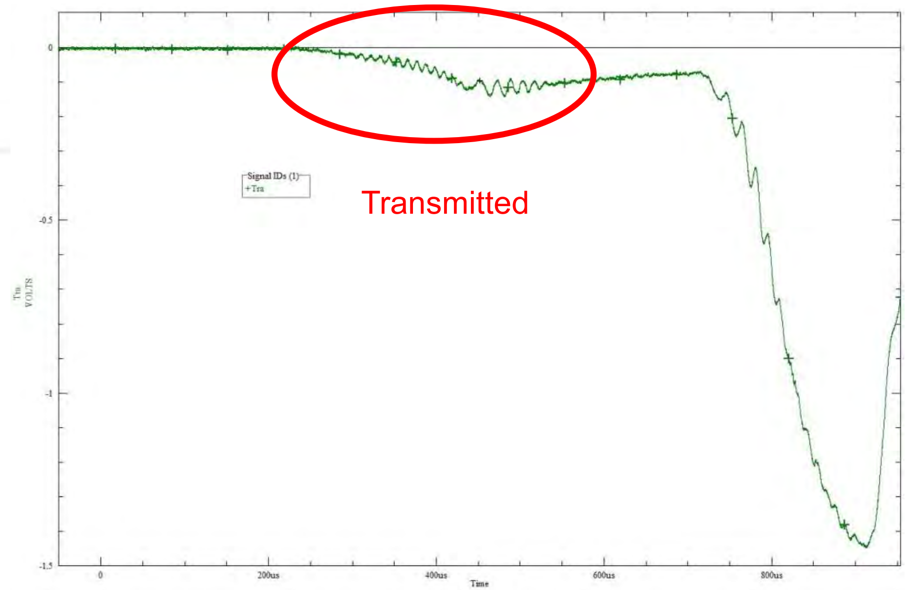


Equivalent Bar Diameter ratio =.59, Area ratio = .39
Reduces dispersion and associated correction issues

Hopkinson Bar

Typical data acquired is in time domain, whereas generation of a frequency response function (ratio of output to input) requires analysis to be done in frequency domain.





Raw waveforms for incident, reflected and transmitted are isolated and used in calculation of Frequency Response Function (FRF), analysis scheme suggested by Vesta Bateman (Sandia TR 1437).

Frequency Response Function

Procedure for FRF

- Isolate incident, reflected, and transmitted signals of the three trials.
- Calculate FFT of incident, transmitted, and reflected signals.
- Use low-pass filter to cut off higher frequencies (above 50kHz).
- Dispersion correction.
- Determine conjugate of filtered FFT.
- Find auto-spectrums and cross-spectrums of signals.

Auto-spectrums

$$G_{ii} = G_i G_i^*$$
$$G_{tt} = G_t G_t^*$$
$$G_{rr} = G_r G_r^*$$

Cross-spectrums

$$G_{it} = G_i \, G_t^*$$
$$G_{ti} = G_t G_i^*$$
$$G_{ir} = G_i G_r^*$$
$$G_{ri} = G_r G_i^*$$

Frequency Response Function

- Use equations to determine H-values
- H_1 minimizes noise at input while H_2 minimizes noise at output

<u>Transmitted</u>

$$H_1 = \frac{\Sigma G_{it}}{\Sigma G_{ii}}$$

$$H_2 = \frac{\Sigma G_{tt}}{\Sigma G_{ti}}$$

<u>Reflected</u>

$$H_1 = \frac{\Sigma G_{ir}}{\Sigma G_{ii}}$$

$$H_2 = \frac{\Sigma G_{rr}}{\Sigma G_{ri}}$$

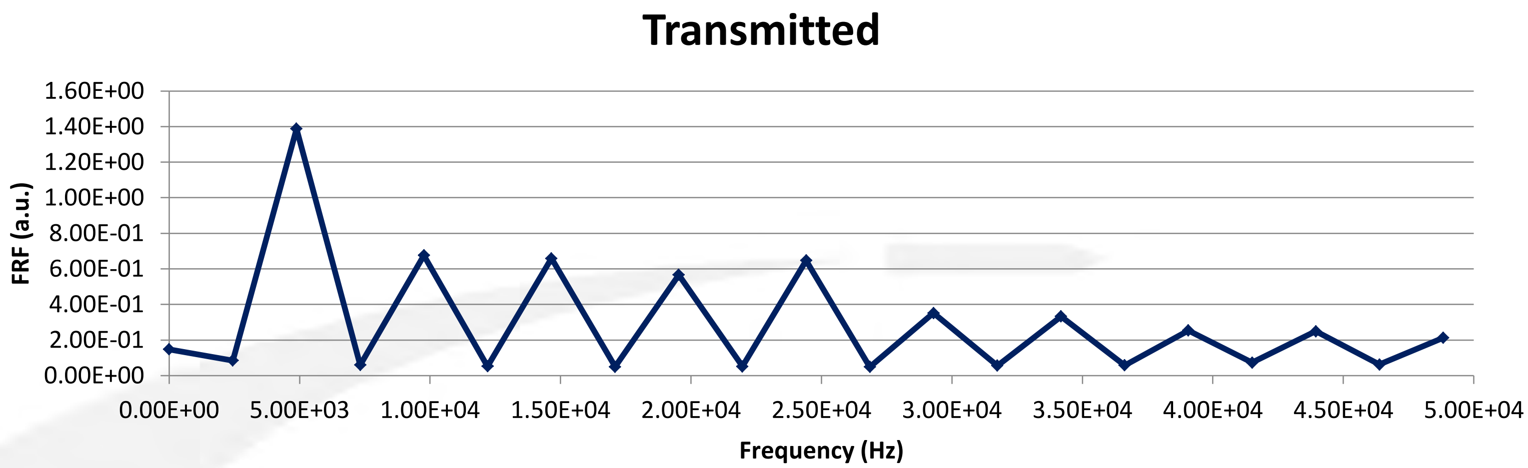
- Obtain H-value by averaging

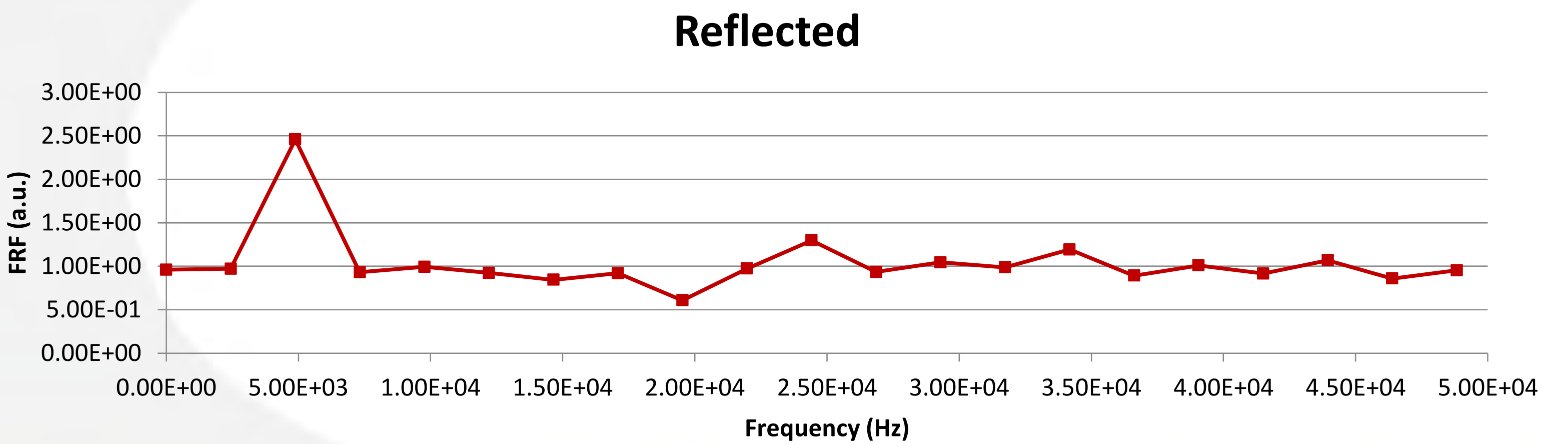
$$H = \frac{H_1 + H_2}{2}$$

- The analysis procedure was developed using 1) SIGNO and 2) MATLAB (both are commercial software).

FRF in SIGNO

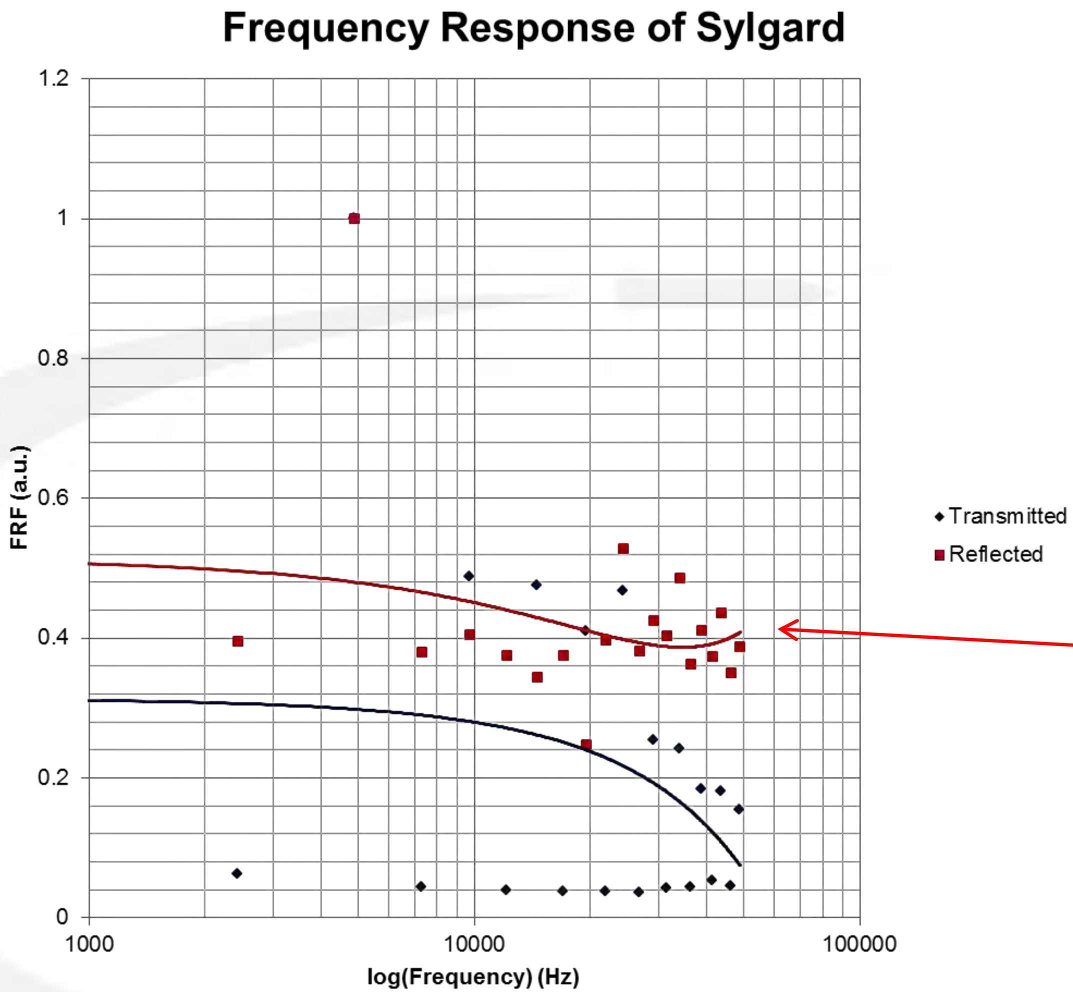
FFT from waveforms





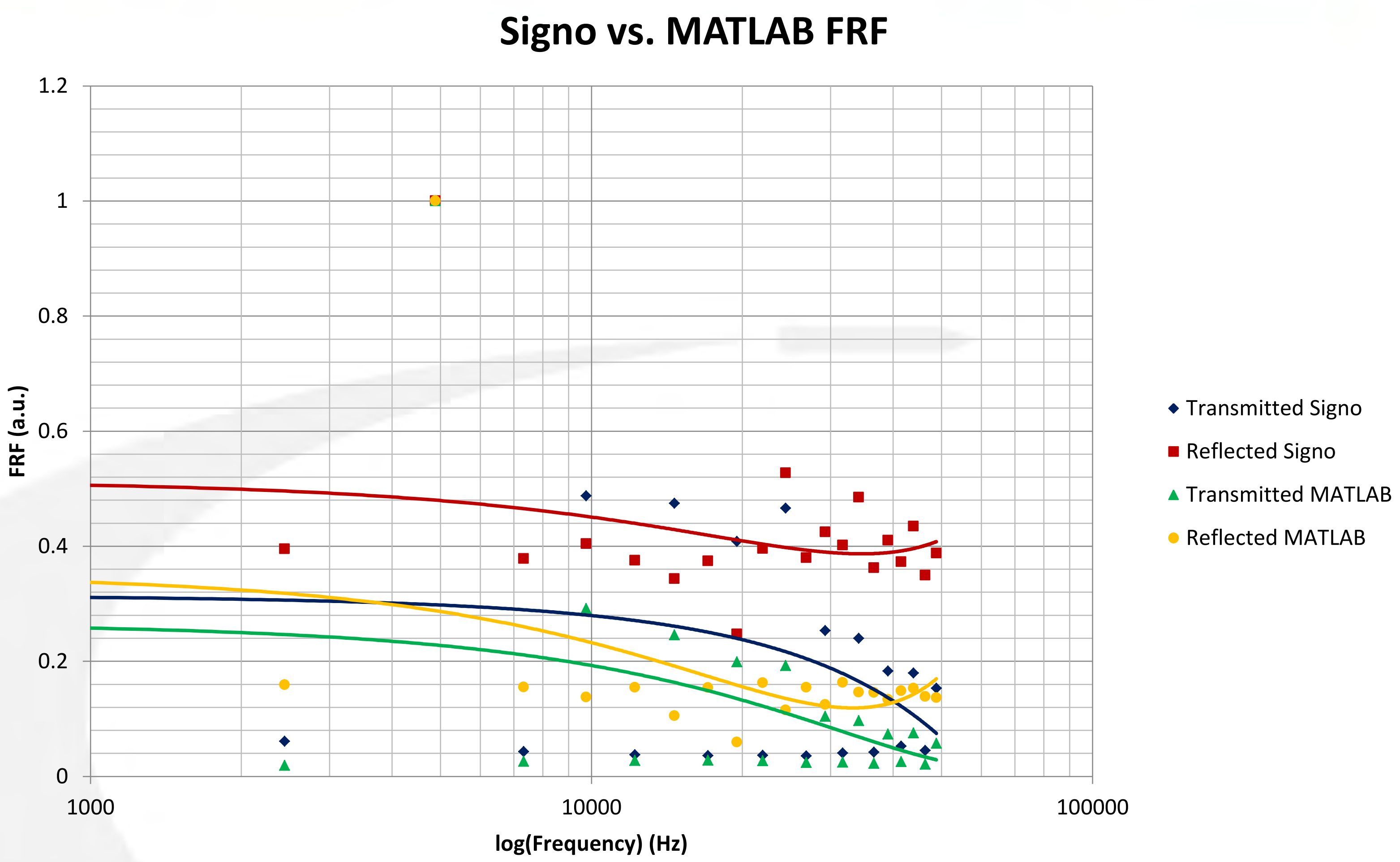
FRF in Signo

FRF trend results were normalized and fitted with a polynomial fit



Loss/damping values are slightly higher than those observed in DMA or Resonance

FRF- SIGNO vs MATLAB



Shapes of trend lines consistent, actual and relative magnitudes differ

Discussions

FRF differences observed due to:

- Algorithms in computing Fast Fourier Transform (FFT)
- Implementation of individual subroutines not standardized
- Automatic generation of number of padding data in Matlab, logic is inaccessible in MATLAB, but well defined in SIGNO
- SIGNO provides more control of individual steps and requires more time
- Dispersion correction routine is built into SIGNO, not in MATLAB

Summary

- Process for calculating FRF formulated in SIGNO and subroutine written in MATLAB for convenient and quicker processing
- Damping factor as a function of frequency obtained for higher frequencies than DMA analysis for Sylgard 184 using this FRF analysis
- Comparing the two processes (MATLAB/ SIGNO) indicate minor differences (based on intrinsic calculations within software)
- Further refinements for minimizing differences due to procedures are being explored

Acknowledgements

- This work was supported by DOD Joint Fuze Technology Program at Research and Technology Department at Indian Head, MD. Austin Biaggne, summer intern from Washington State University , WA, contributed to the programming in MATLAB.
- Efforts of Colin Qualters and Ezra Chen at NSWCIHEODTD, Jaime Santiago at NSWC Bethesda, Summer Intern Kaelyn O'Neill are highly appreciated.

Questions

?

Contact

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DoD MEMS Fuze Explosive Train Evaluation & Enhancement

61st Annual NDIA Fuze Conference, San Diego, CA
Wednesday, May 16th 2017, Open Session IIIA

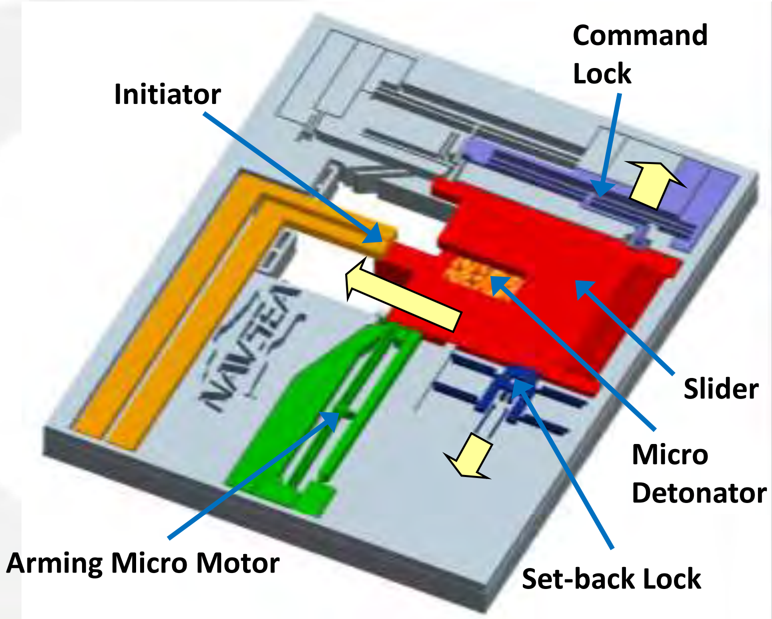
Taylor T. Young

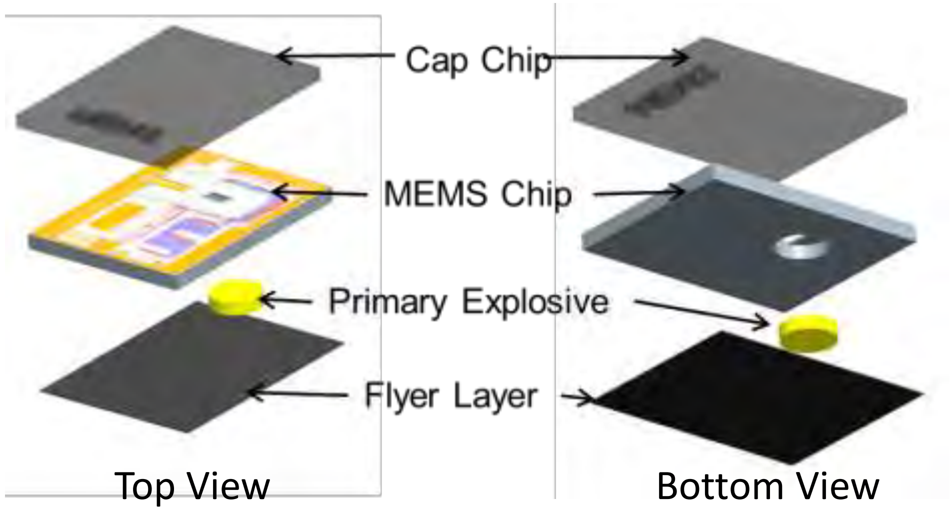
NSWC IHEODTD

301-744-1103 : Taylor.T.Young@navy.mil

MEMS Safe and Arm

- MEMS S&A offers the potential for small volume, low cost, and low energy.
- NSWC IHEODTD has nearly two decades of silicon/SOI MEMS design, fabrication, and packaging experience.
- Safety locks: integrated micromachined direct acting and command actuated lock architectures
- Arming: environmentally derived and command architectures
- All non-explosive components fabricated on SOI wafers using established semi-conductor processes.

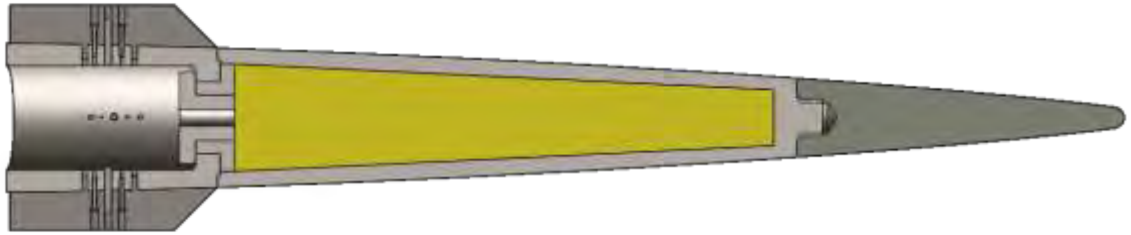




MEMS Fuzing Applications

40 mm Grenade

Gun Launched Projectiles



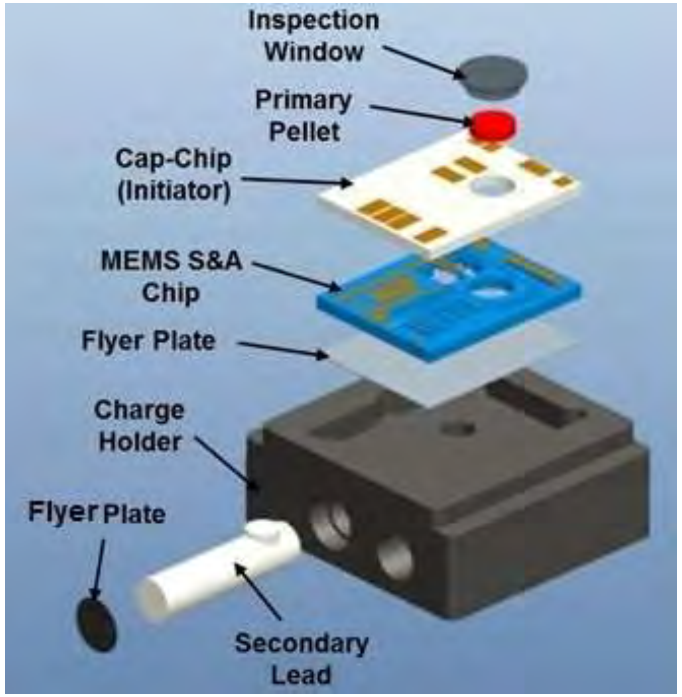
Underwater Systems

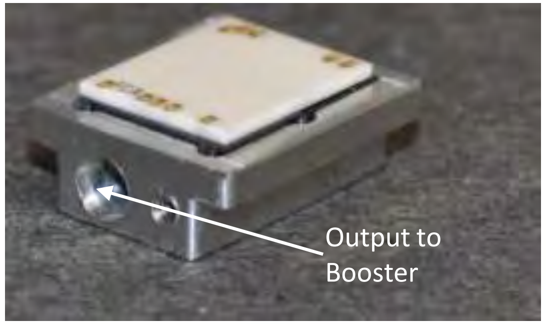
Mortars

Explosive Train Overview

- Studying the explosive trains of both the Navy and Army MEMS Fuze
- Both designs have been demonstrated to TRL6
- Navy Design
  - Vaporizing metal foil bridge initiator fabricated onto the cap chip
  - Pressed silver azide pellet assembled with the MEMS S&A chip drives a flyer to initiate an explosive ink output lead
  - Lead make 90° turn and initiates a booster
- Army Design
  - Metal foil bridge
  - Deposited energetic ink drives small flyer into explosive ink transfer charge
  - Transfer charge makes two 90 ° turns and initiates output lead

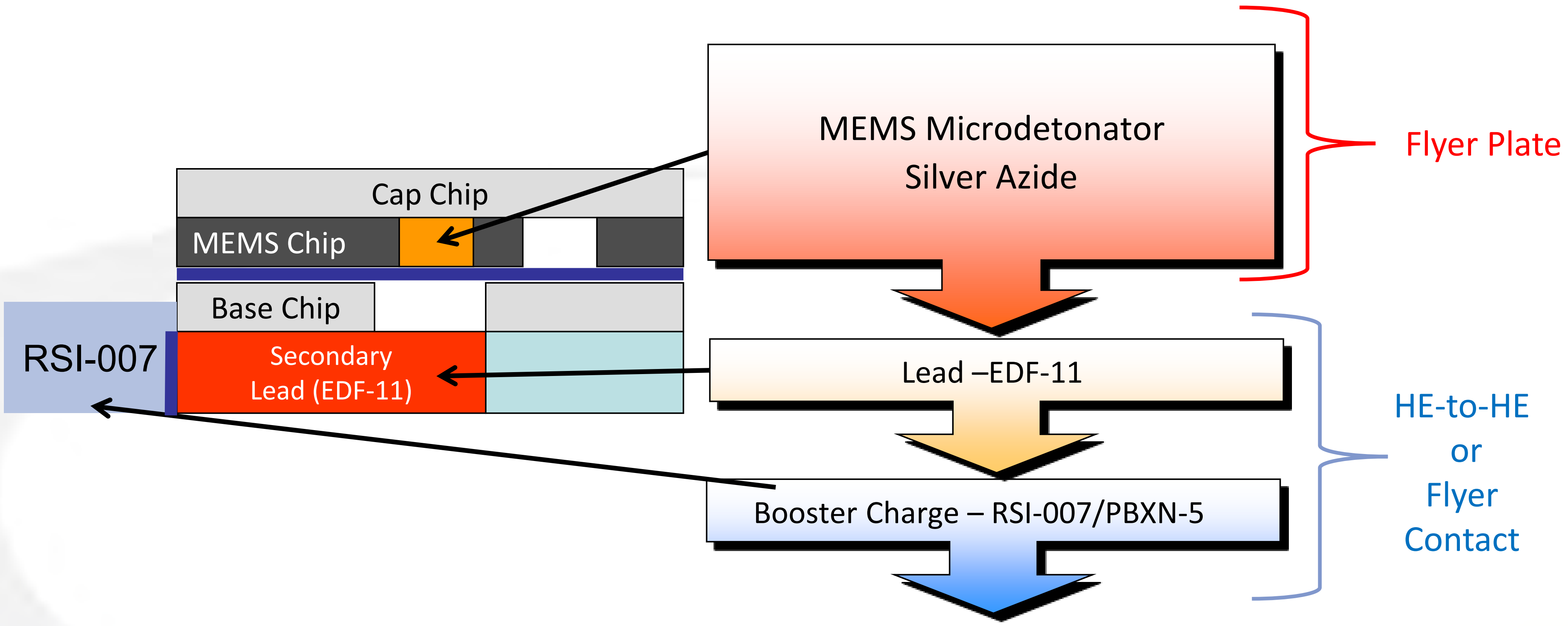
Navy MEMS Fuze Stack up





µDetonator Package

Navy Explosive Train (Basics)



Explosive Train Reliability

- MEMS intentionally pushes the lower limits of explosive component size. We want the smallest size detonators and leads that will work reliably.

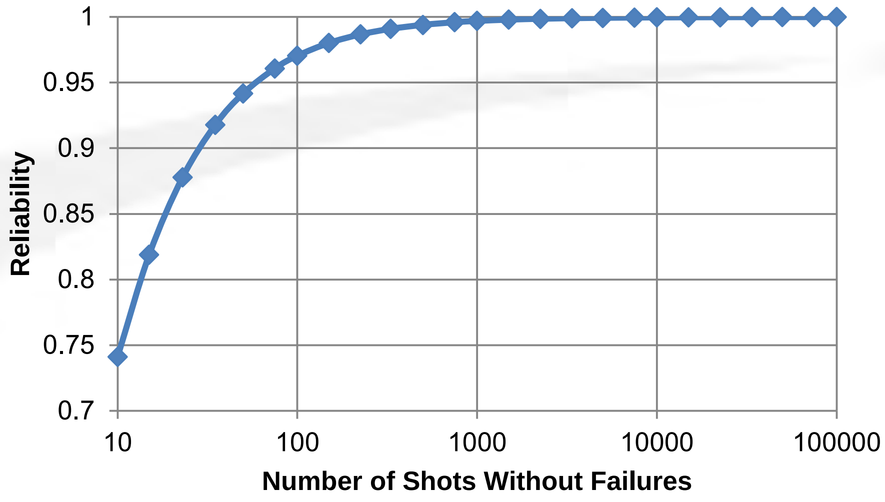
- The need for credible reliability estimates pushes us towards to employ more advance diagnostic techniques such as Hugh James Initiation Criteria.

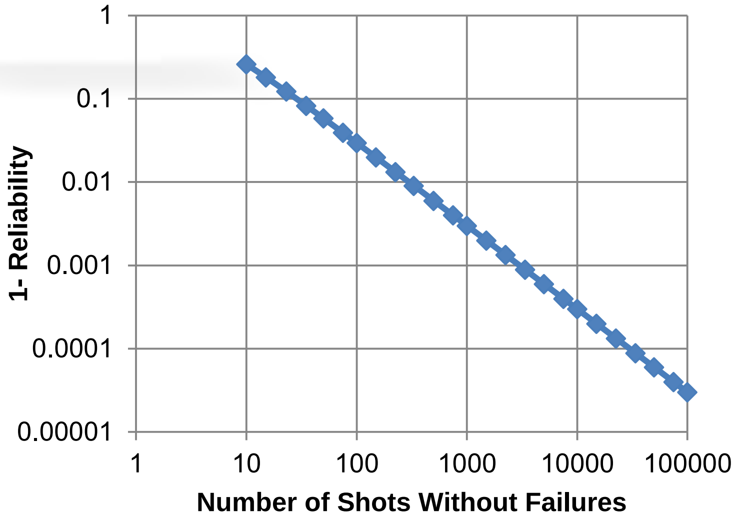
Brute Force Methods

Brute force demonstrations requires excessive number of shots to prove reliability.

99.9% Reliability @ 95% CL: 3000 Shots

Binomial Reliability at 95% Confidence Level (one sided)



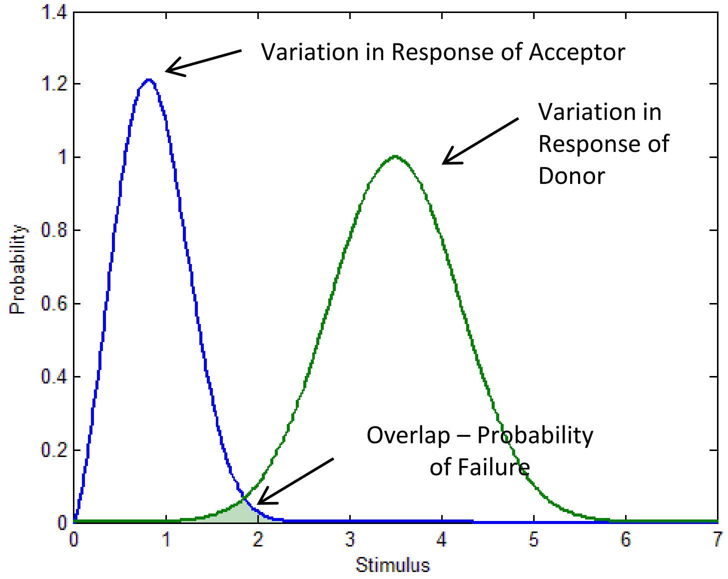


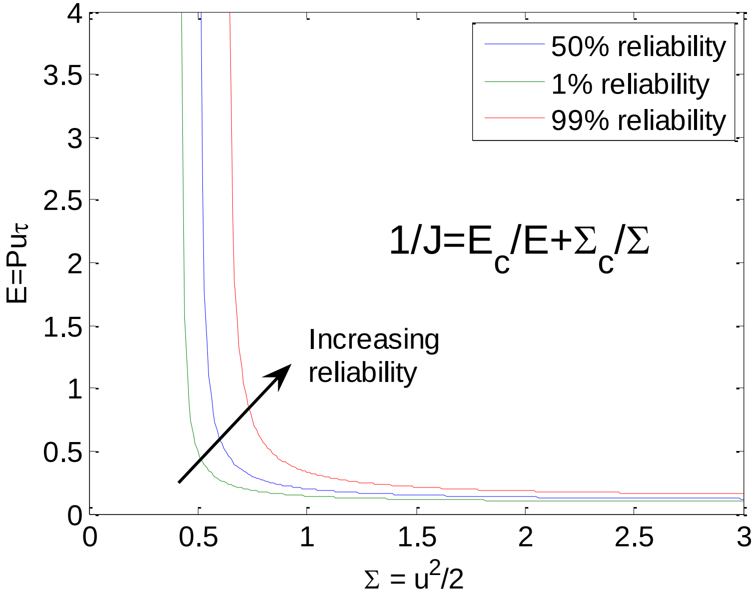
100 shot test series only demonstrates reliability to 97% (@ 95% CL)

Extremely expensive and becomes impractical for an evolving design

Background – Probabilistic Hugh James Space

Hugh James formalism can be used to map out statistical response of acceptor explosive



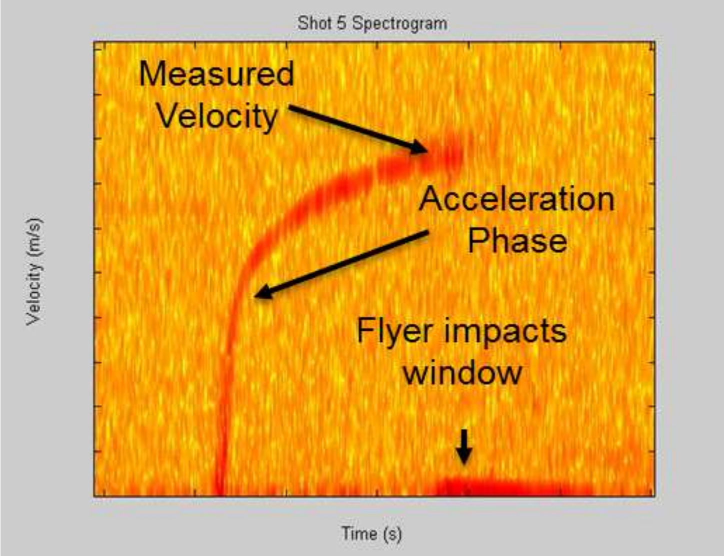


E_c (critical minimum energy) & Σ_c (critical minimum 'power') are defined by the acceptor explosive material. E & Σ can be calculated from variable flyer and gap tests and inherent explosive properties.

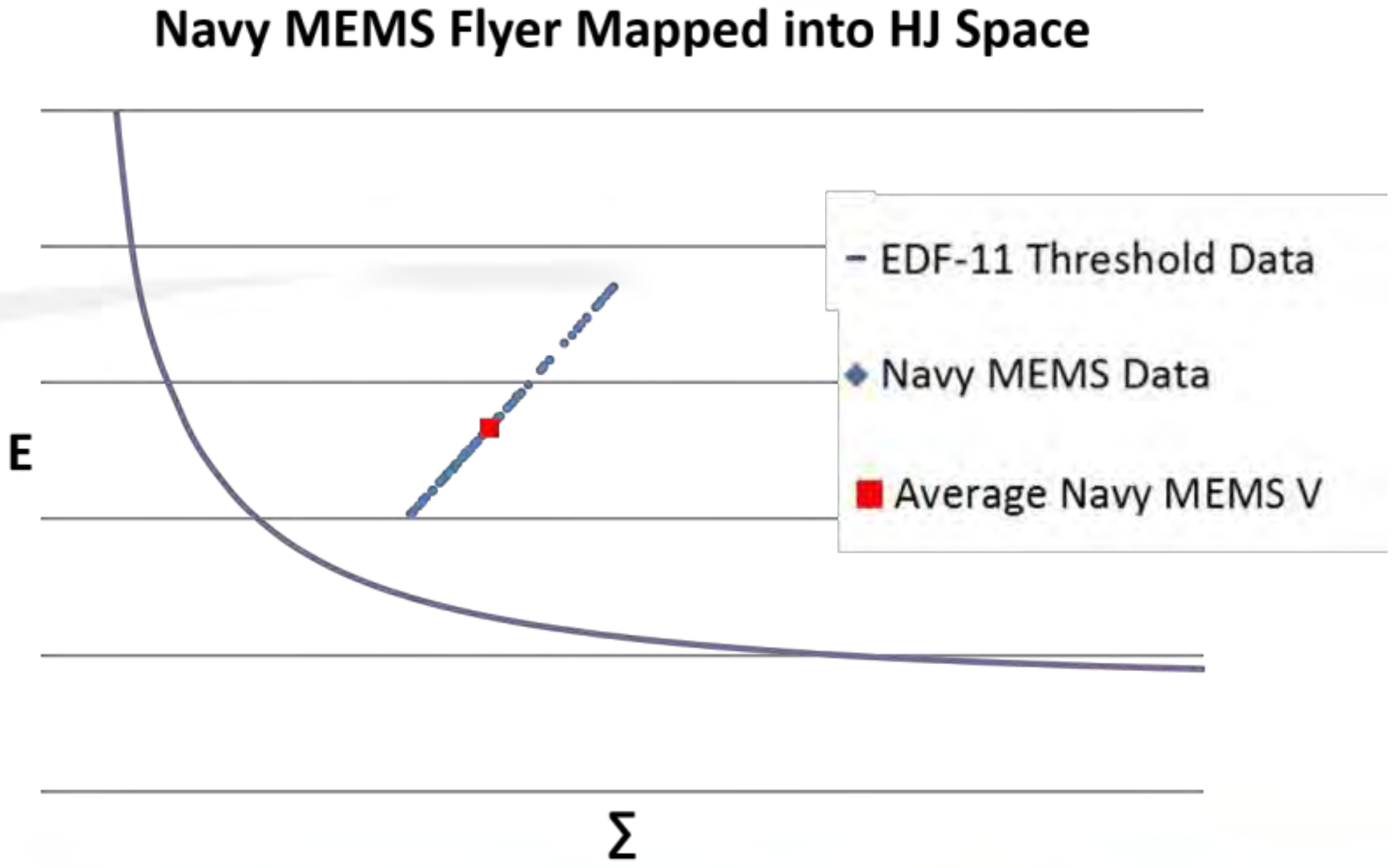
Data can better be used to evaluate a family of similar designs, provide more insight into the system and can be used to optimize designs

These methods were developed at AWE and LLNL and implemented at AFRL.

Detonator Characterization



- AgN_3 flyer velocities measured with PDV
- 107 shots analyzed. Standard deviation 6.3% of mean value



NAVSEA WARFARE CENTERS Indian Head EOD Technology Division

Further MEMS Miniaturization

IHEODTD is also investigating alternative energetic materials and pellet dimensions of the primary explosive pellet with the goal of further miniaturizing the MEMS fuze

- Deflagration to detonation (DDT) length is the main factor controlling performance at these small scales which is very difficult to predict and, at the MEMS scale, no material is a perfect point detonate

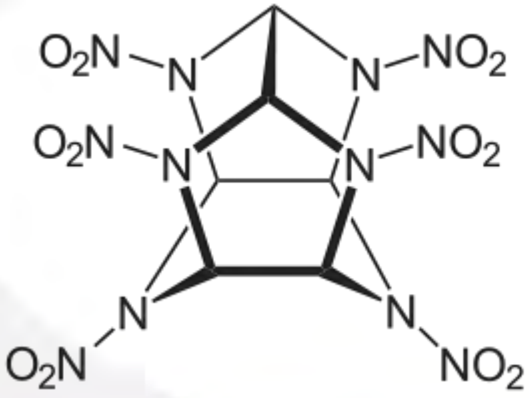
- Potential improvements in MEMS fuze manufacturing are also being investigated

Alternate Primary Energetic Materials

NSWC IHEODTD is looking at replacing the Silver Azide pellet with:

CL-20/AgN_3 Blend

- Homogeneous blend with increased sensitivity and output
- AgN_3 at the initiation side, CL-20 at the output



http://en.wikipedia.org/wiki/Hexanitrohexaazaisowurtzitane

CL-30

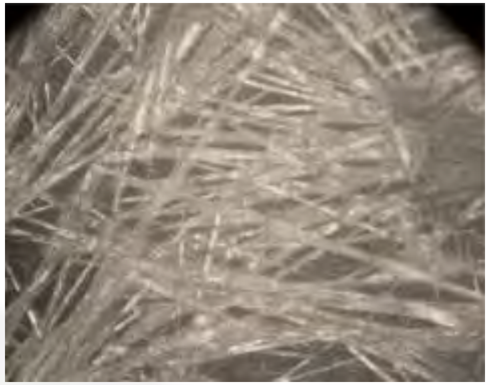
- New molecule developed at China Lake
- Multiple formulations exist, IHEODTD is mostly investigating neat material

FATG-II_13-G-003_Ihnen_JFTP 2014 Fall Review_FINAL_v2

Alternate Primary Energetic Materials - Cont

DAHA/DATA

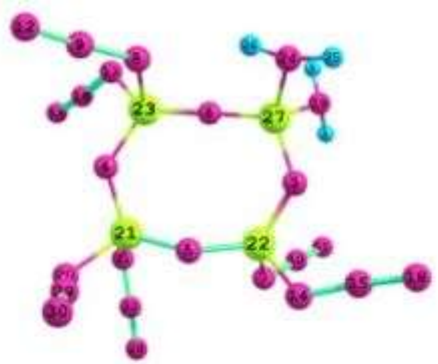
- Melt castable – 72° C melting temp, 230° C decomp temp
- Successfully loaded into MK-1 detonator with increased performance
- Green/Non Toxic



Zhang, Jianguo, et al. *International journal of molecular sciences* 10.8 (2009): 3502-3516.

FTDO

- Has been synthesized by IHEODTD, previously only seen in Russian literature
- Shown to be highly sensitive
- Predictions of detonation properties comparable to CL-20



Simonenko, V. N., et al. "Comb... I. Binary systems." *Comb., Expl. and SW* 50.3 (2014): 306-314.

Pellet Dimension Study

- Investigating reducing the size of the AgN_3 pellet while maintaining reliability
  - Pressing tooling fabricated at multiple sizes
- Designing and fabricating surrogate test hardware to reduce testing time and complexity
- Successful transfer tests to EDF-11 of a particular pellet size will lead to PDV measurements of AgN_3 flyers

Additional Ongoing Testing

- Out of line safety testing

- Transfer lead output test series
  - PDV measurements of lead output
  - Verigap testing to typical booster material

- Cold temperature reliability testing

- Tactical layout Neyer series testing

Conclusions

- New explosive trains require new methods of analysis.
- These new methods can better aid data driven design.
- We are utilizing a new method to quantify the reliability of small explosive trains with a reasonable number of asset firings.
  - 1st DoD MEMS detonators (Navy and Army) to be mapped into Hugh James Initiation coordinates for reliability assessments
- Both and the Navy and Army are employing novel methods to ensure that MEMS fuzing achieves the highest degrees of reliability possible.

Acknowledgments

Thanks to the Joint Fuze Technology Program (JFTP) for funding this work.

Thanks to Chadd May and Lawrence Livermore National Labs (LLNL) for the loan of the electric gun.

Thanks to Eric Welle and the Air Force Research Laboratory for Hugh James implementation support.

Thanks to those who have helped work on the project:

NSWC IHEODTD
Daniel Lanterman
David Muzzey
Matthew Buckler
Kevin Phelps
G. Shane Rolfe

ARDEC
Roger Cornell
Daniel Stec
Charlie Robinson
Jeffrey Smyth
Brian Fuchs

Questions?

Questions?

Always a Step Ahead
ARDEC
ARMAMENTS

LASER DIODE IGNITION

Stephen Redington, PE
Contributors:
John Hirlinger, Gregory Burke
NDIA Fuze Conference 15-17 May, 2018

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& ENGINEERING CENTER

A History for Laser Ignition

Crusader 1980’s-1990’s

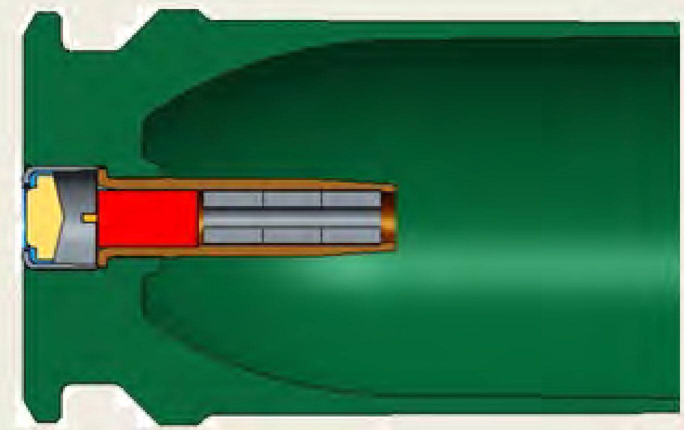
LW155 Artillery 1990’s - 2012

Laser Ignition is NOT new; Efforts began in the 1960’s

- External high power lasers shooting through a window
- Highly successful programs, (from a laser technology perspective)
- Over 25,000 rounds fired on the Crusader using laser ignition
- Over 5,000 rounds fired on the LW155 using laser ignition 2

A History for Laser Ignition

2000- Present



- Laser diode technology begins around 1995
- Technology continues to evolve along with commercial applications
- Very small and mass producible. Similar processing used in IC production.
- Tremendous cost reduction over flash lamp pumped systems
- The entire laser can easily fit inside the space for a standard 30mm primer cup

3

What has changed since the 80's?

- User requirements / desires
  - Increased threat of Electronic Warfare, i.e, RF, ESD, E^3 effects
  - A desire for alternative (green) energetics (Lead Free)
  - The need to have 'smarter' munitions at the lowest cost per round
  - The need to be able to communicate with, and program, munitions
  - Reliability (10,000 hours MTBF)
  - Disposable, environmentally benign materials.
  - Fire control systems that enable coincidence based engagement *

    * TrackingPoint ™ concept elimination of mechanical shear

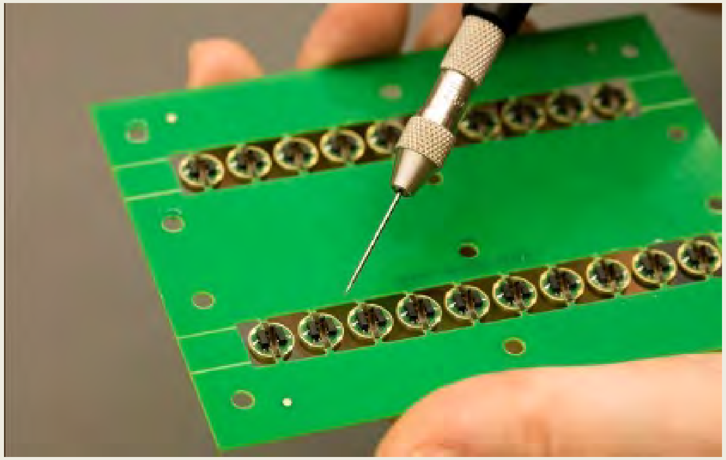
- Technology
  - Commercial availability of laser diodes
  - Power and efficiency of laser diode technology
  - Surface Mount Technology (SMT) and automated assembly on large scales
  - Micro-miniaturization

4

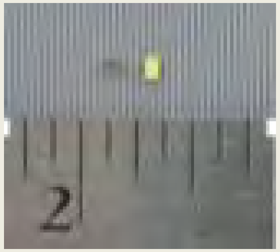
What has been demonstrated/accomplished?

- Demonstrated to pass HERO
- COT's supply, commercial manufacturing and carrier shipping
- Physical separation between energetic from ignition source/electrical stimuli
- Laser Diode emitter can be tested and re-tested to assure functionality
- US based supply of diode lasers: in many energy levels and wavelengths
- Compatibility with novel energetics
- Eliminates lead based compounds
- Mechanical part reduction
- Seamlessly compatible with many existing electric ignition systems
- SMT (Surface Mount Technology) compatible assembly
- ARDEC patented technology (2 complete primary, 8 pending supplemental)
- Coordinated fires, enhanced coincidence

ARDEC Manufacturing Effort



Surface mounting of electronics and laser diodes



Laser Diode

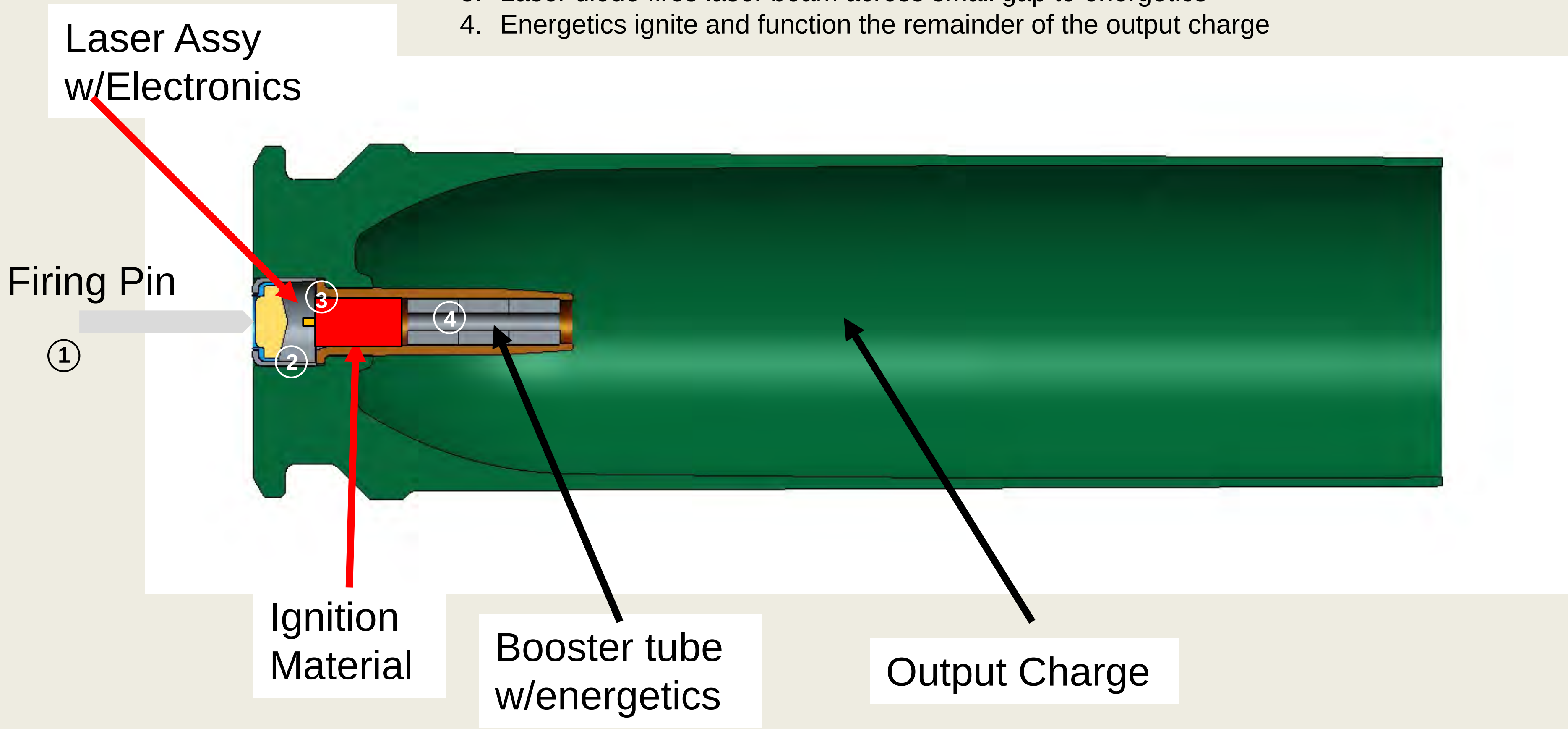
Assembly mounting, post potting

Finish and tested laser diode primer

Packed primers ready for shipping

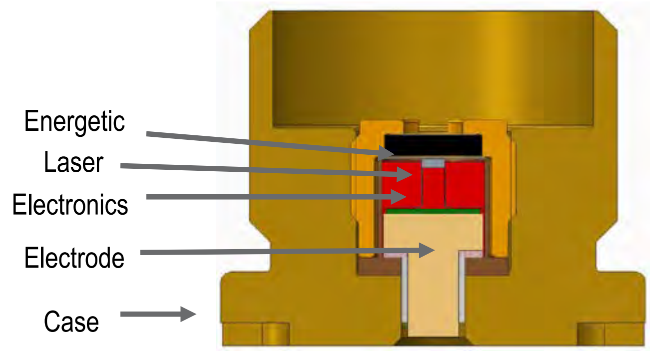
TYPICAL FIRING SEQUENCE

1. Standard electrical firing pulse delivered from firing pin
2. Sufficient amperage delivered to activate laser diode
3. Laser diode fires laser beam across small gap to energetics
4. Energetics ignite and function the remainder of the output charge

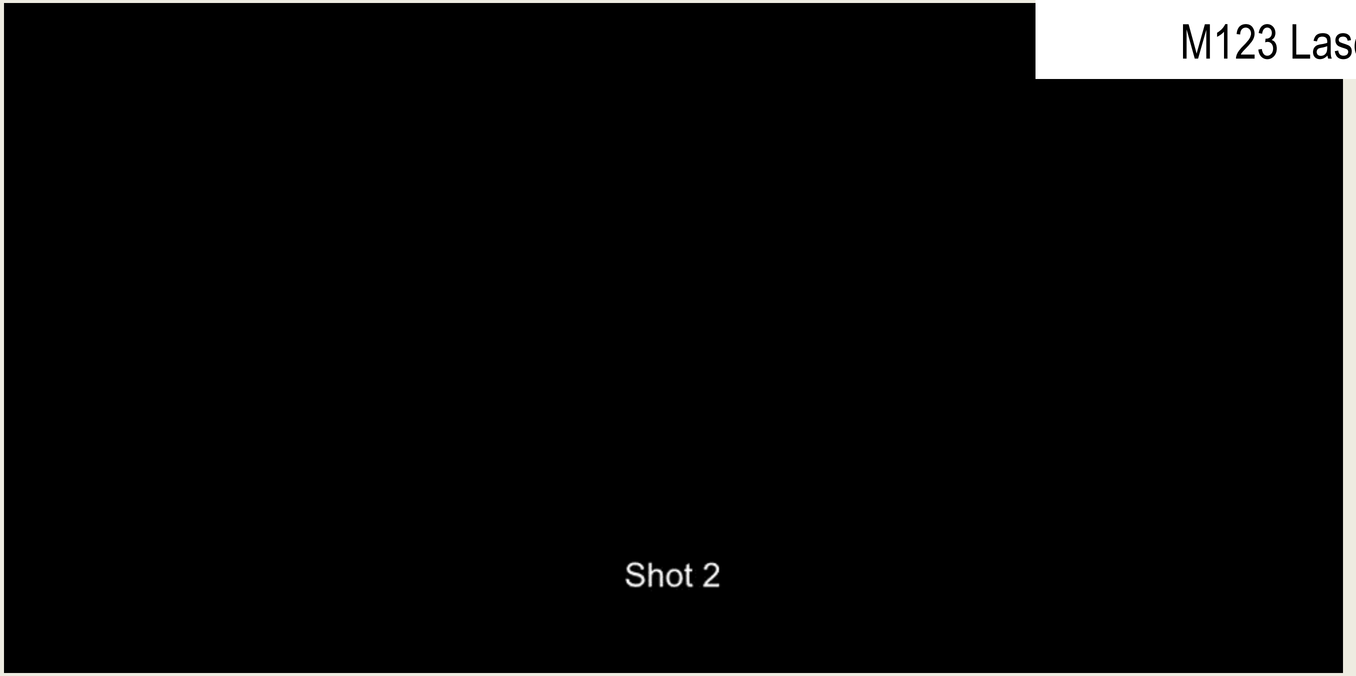


M230 VIDEO

Ignition of Black powder in a 120mm cartridge



M123 Laser Equivalent



•Benefits

- Replaces bridge wire and ignition mix with electronics and a laser diode
  - The initiator becomes an inert element
  - Can be manufactured by any contract manufacturer
  - Shipping and handling not an issue
  - Can be fully tested prior to cartridge assembly
  - Can be verified after cartridge assembly
- HERO Compliant
  - Laser can only be initiated at prescribed current
  - Current threshold can be tuned
- An enabling technology for smart ammo
  - Embedded logistics
  - Lockable ammo
  - Sensor data for precision fires
- Commonality between large caliber platforms

Laser Ignition

- **Who can make a laser primer**
  - Anybody. The Army owns the patent and can license commercial applications or other military applications.
- **Who may want the technology (besides the military)**
  - Mining Industry
  - Automotive Industry (i.e. air bag deployment)
  - Fireworks Industry
  - Demolition / Rescue
- **Why don’t we have it**
  - Lack of infrastructure for mass production
  - Reluctance to adopt new technology

- Conclusions
  - Lasers can replace bridge wire technology
    - Drop in replacement for 30mm electric primer
  - Separation of energetics from the ignitor can increase the manufacturing base for ammunition
  - HERO safety can be achieved
  - An enabling technology for smart munitions
- Questions?

„State of the Art Fuze Batteries and their Performance“

61th Annual Fuze Conference
May 15th - 17th, 2018

Roland Hein
Diehl & Eagle Picher GmbH

Overview

DIEHL & EAGLE PICHER
Batterie-Systeme

- Introduction of the Design Features of Reserve Batteries
- Reserve Battery - Versions
- Reserve Battery - Versions Overview
- Reserve Battery - Application
- Reserve Battery - Testing
- Reserve Battery - Versions Summary
- Recommendations for Fuze Electronic Design
- Future developments

Introduction of the Design Features of Reserve Batteries

DIEHL & EAGLE PICHER
Batterie-Systeme

- *Primary Design Features of all Reserve Batteries*
  - *Lithium Metal Battery*
  - *Lithium Thionylchloride electrolyte ($LiSOCl_2$)*
  - *glass ampoule*
  - *release mechanism/activation mechanism*
  - *metal to glass seal*
  - *hermetically sealed stainless steel case*
  - *100 % helium leak test*

Reserve Battery - Versions

DIEHL & EAGLE PICHER
Batterie-Systeme

Battery Parameter

Diameter max. : 18,2 mm (0.72 in)
Height : 13,7 mm (0.54 in)
Electrode Area : 1,4 cm² (0.22 in²)
Volume : 1,8 cm³ (0.11 in³)

DEP14202

Diameter max. : 32,2 mm (1.27 in)
Height : 25,5 mm (1.0 in)
Electrode Area : 3,5 cm² (0.54 in²)
Volume : 15 cm³ (0.92 in³)

DEP140xx

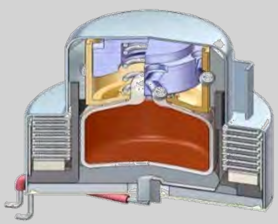
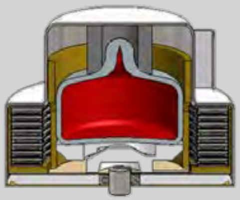
Diameter : 11 mm (0.43 in)
Height : 11 mm (0.43 in)
Electrode Area : 0,4 cm² (0.06 in²)
Volume : 1,0 cm³ (0.06 in³)

DEP14103

Reserve Battery - Versions Overview

DIEHL & EAGLE PICHER
Batterie-Systeme

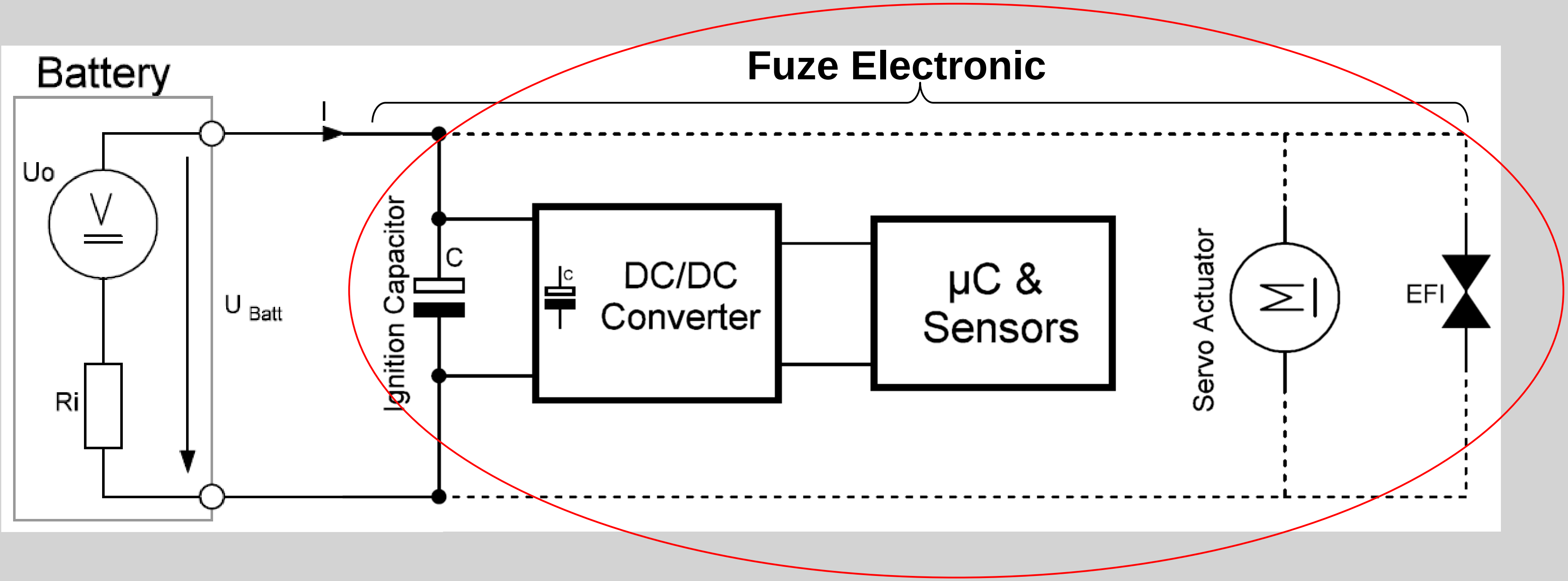
"Large"	"Large"	"Midi"	"Mini"	"Ultra Mini"
DEP14001	DEP14007/17/12	DEP14020/21	DEP14202	DEP14103
5 – 10 cells	5 – 10 cells	1 – 4 cells	1 – 2 cells	1 cell
7 cells	8 cells	2 cells	2 cells	1 cell
25.2 V	28.8 V	7.2 V	7.2 V	3.6 V


Reserve Battery - Application

DIEHL & EAGLE PICHER
Batterie-Systeme

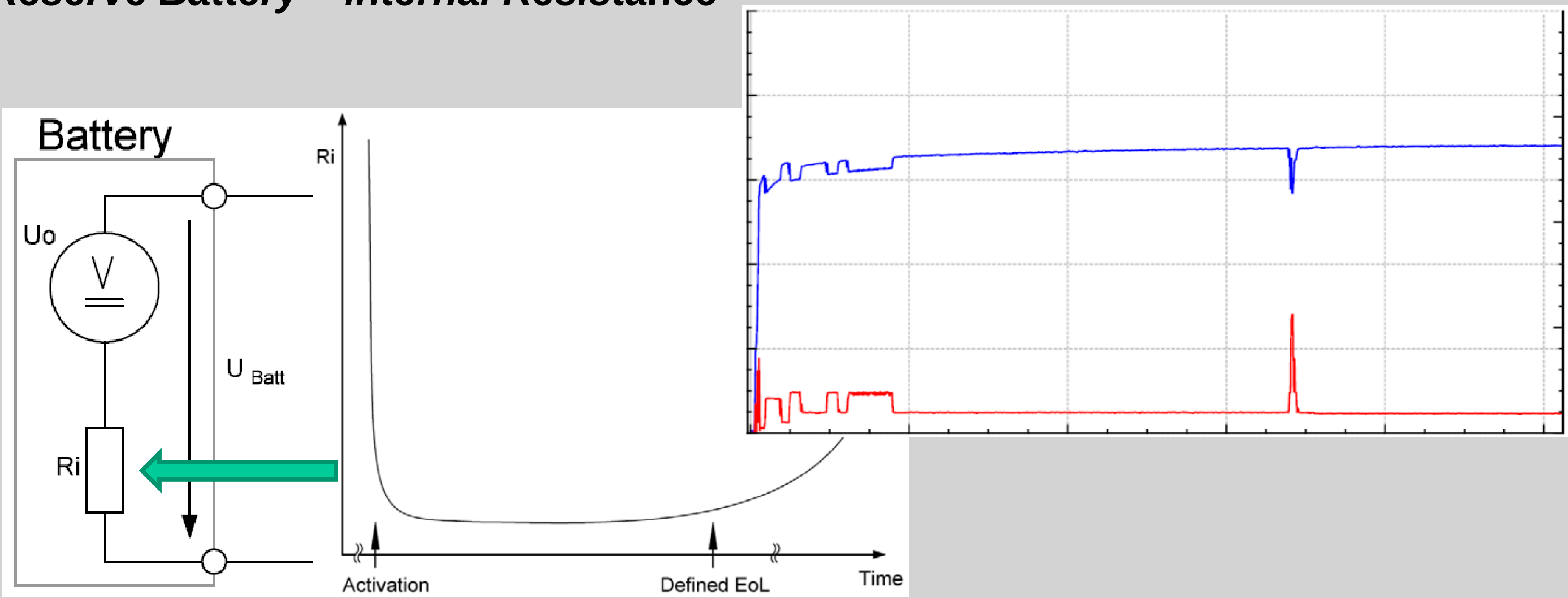
Reserve Battery in a typical application



1. How much Power does the Fuze Electronic need ?

Reserve Battery - Application

Reserve Battery – Internal Resistance



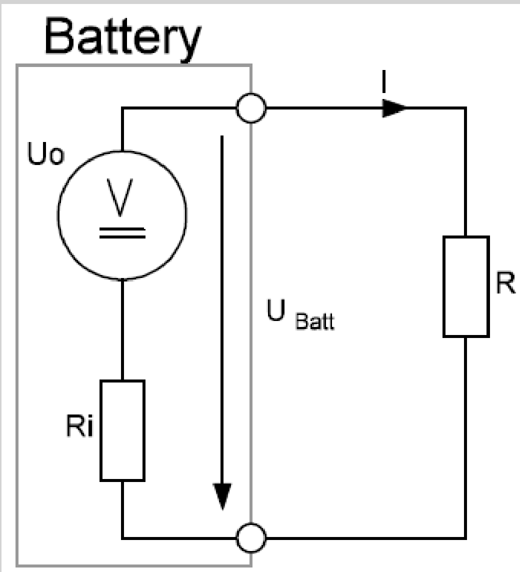
1. How much Power does the Fuze Electronic need ?

2. What is the minimum Voltage for operating a Fuze Electronic ?

Reserve Battery - Application

DIEHL & EAGLE PICHER
Batterie-Systeme

Reserve Battery – Equivalent Circuit Diagram



Some Equations of Electrical Power

$$P = U_{Batt} \times I$$ *or*

$$P = \frac{U_{Batt}^{2}}{R}$$

$$U_{Batt} = U_O - (R_i \times I)$$

$$P = \frac{[U_o - (R_i \times I)]^2}{R}$$

Fuze Electronic

Battery State

DIEHL & EAGLE PICHER
Batterie-Systeme

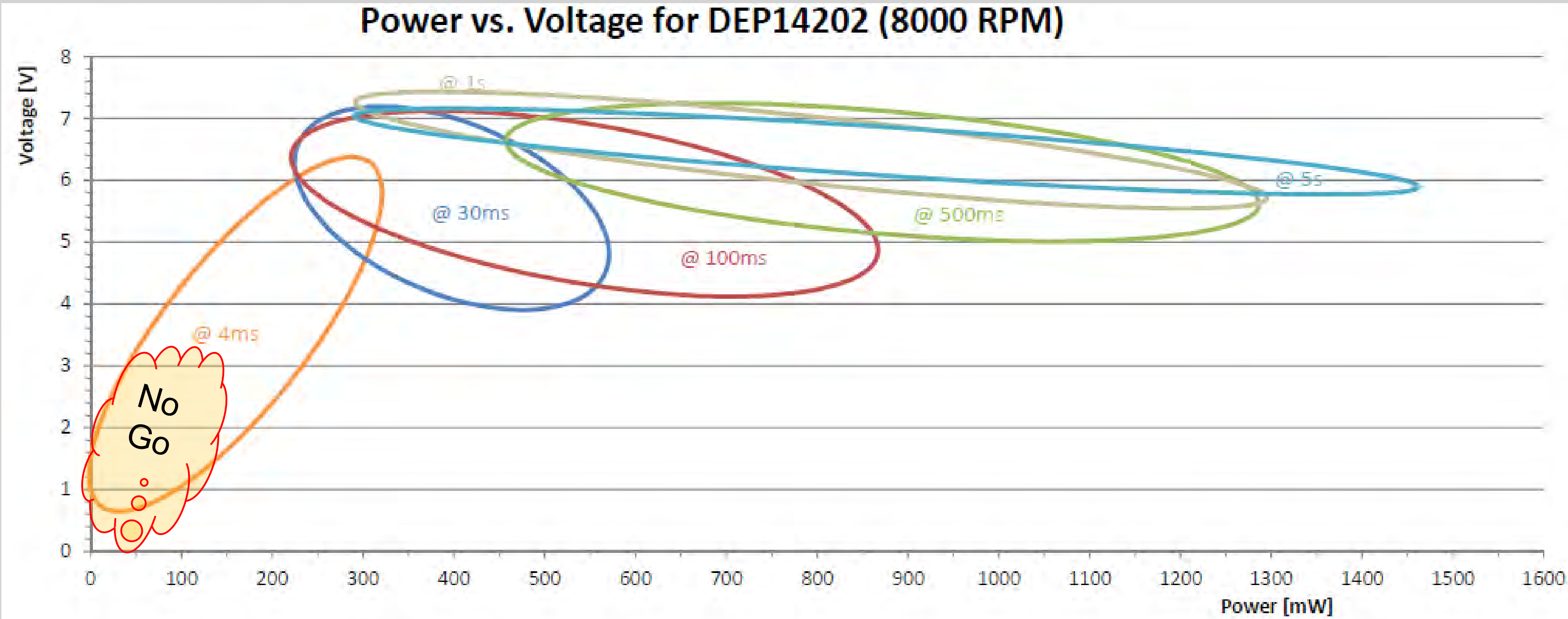
Reserve Battery – Battery-Test-System

Flexibel Configuration of

- ***Acceleration Pulse***
- ***Rotation***
- ***Electrical Load***

DIEHL & EAGLE PICHER
Batterie-Systeme

Reserve Battery – Test Results (Example)

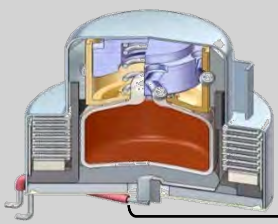
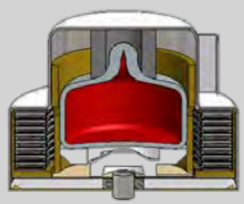


1. How much Power may a Fuze Electronic require at what time ?

2. What is then the minimum Voltage for operating a Fuze Electronic ?

Reserve Battery - Versions Summary

"Large"	"Large"	"Midi"	"Mini"	"Ultra Mini"
DEP14001	DEP14007/17/12	DEP14020/21	DEP14202	DEP14103
5 – 10 cells	5 – 10 cells	1 – 4 cells	1 – 2 cells	1 cell
7 cells	10 cells	2 cells	2 cells	1 cell
25.2 V	28.8 V	7.2 V	7.2 V	3.6 V

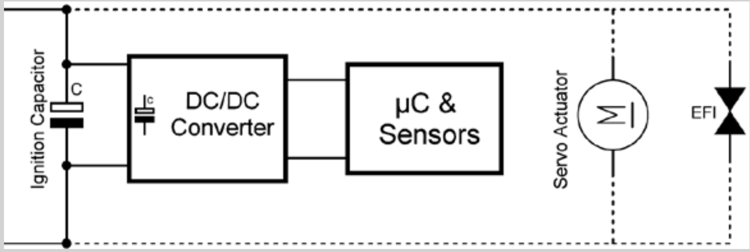




Volume	15 cm³	11,7 cm³	1,8 cm³	1,0 cm³
Cell Area (ea.)	3,5 cm²	3,5 cm²	1,4 cm²	0,4 cm²
Spec. Current	235 mA/cm²	187 mA/cm²	150 mA/cm²	80 mA/cm²
Rec. Max. Power	3100 mW	2800 mW	1400 mW	140 mW

Recommendations for Fuze Electronic Design

DIEHL & EAGLE PICHER
Batterie-Systeme

- Timing of Power Electronic Fuze Parts
  - Controlled Charge of Ignition Capacitors
  - Start Up of µController (delayed)
  - Switched Sensor Start



- No “Big” Capacitors on Power Inlet (DC/DC-Converter)
- Small Power Buffer (Capacitors) for Actuators
- Moderate Power Consumption can lead to Standard Fuze Battery
- Involve D&EP early in Power Consumption of your Fuze Electronic

Future developments

DIEHL & EAGLE PICHER Batterie-Systeme

- 1 & 2 cell batteries for high spin and high acceleration application
- Development on super quick in barrel activation batteries for artillery and naval versions
- Development of new electrode material for higher current / power application

Thank you for your attention!

Questions?

Diehl & Eagle Picher Contact

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61st Annual NDIA Fuze Conference

Small Thermal Battery for High Spin Environments

San Diego, California, CA

May 15-17, 2018

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E-mail: Monica.Stoka@enersys.com

Power/Full Solutions™

A Gun Launch Thermal Battery

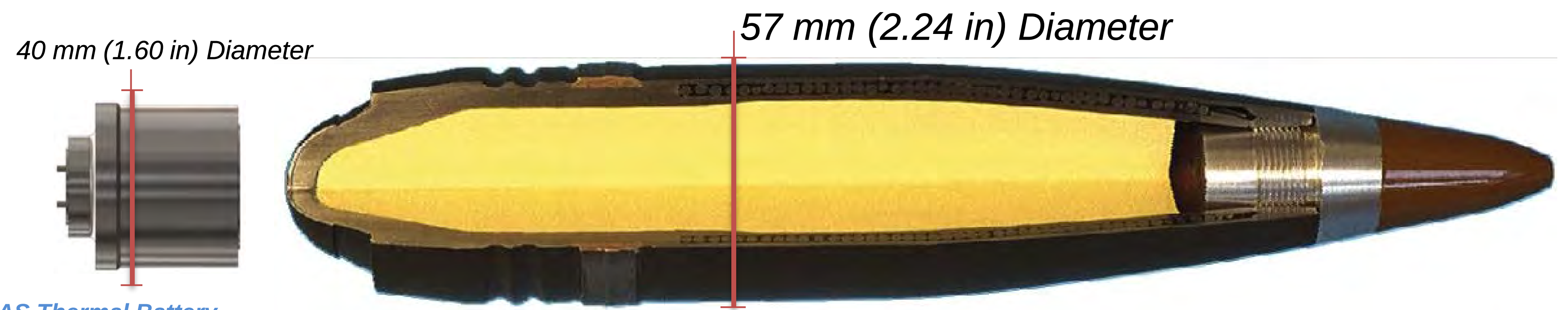
- **Primary Reserve Gun Launch Thermal Battery**
  - *One Time Use – Not Rechargeable (This electrochemistry can be charged)*
  - *Assembled in a Dormant State*
  - *Primer Activated*

- **Characteristics that Make Thermal Batteries Ideal Power Sources for Weapon Systems**
  - *Long Shelf Life (Up to 30 Years)*
  - *No Maintenance Required*
  - *High Power Density*
  - *Rapid Discharge*
  - *Wide Operating Temperature Range*
  - *No Self Discharge*
  - *Low Life Cycle Cost*
  - *Fast Activation (under 60 ms for gun launch)*
  - *Extremely Rugged*
  - *No Out-gassing*
  - *High Reliability (4 - 9's)*
  - *No External Heating Required*
  - *Flexibility in Design (Multiple Voltage Sections in Parallel or in Series)*

EnerSys Power/Full Solutions™

Powering 57mm Smart Munitions

- **EAS thermal batteries now power cutting edge gun launch munitions**
- **Currently flying in a Navy MK Format Smart Projectile**
- **Powering a 24 volt system @ a nominal 50 watt load with power excursions reaching more than 100 watts.**
- **Battery life exceeds typical round flight times with exceptional margins, operating for more than 20 seconds.**



EAS Thermal Battery Powering Smart Round

MK Navy Style Round

Extreme Environments

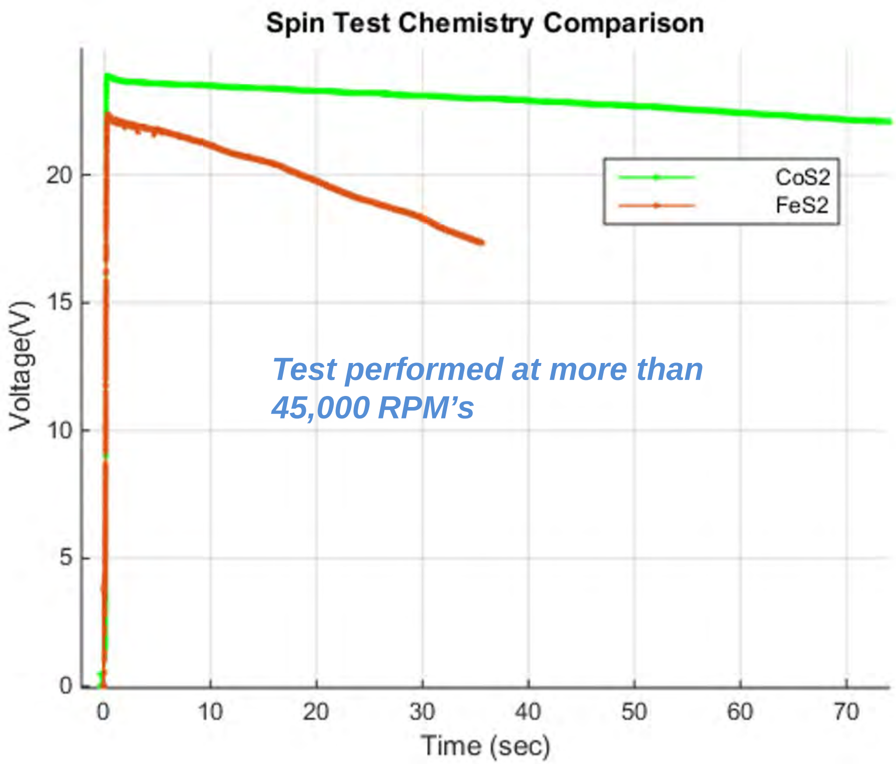
- **Set Back Acceleration**
  - *Continued Operation during applied forces over 35,000 g's*

- **Angular Acceleration**
  - *Continued Operation during applied angular acceleration over 1M rad/sec²*

- **Angular Deceleration**
  - *Continued Operation during applied angular deceleration over -2M rad/sec²*

A Highly Rugged Design, Built to Survive Some of the Harshest Man Made Environments

EAS Cobalt Disulfide Cathode Technology



- **Traditional Cathode Electrochemistry active material, FeS_2, does not perform well under high spin conditions.**

  Voltage noise and higher impedances (overall) plague this chemistry when subjected to high spin environments

- **In a one-to-one spin test comparison, EnerSys Advanced Systems' CoS_2 technology outperforms in impedance, voltage, and capacity - providing more than double the mission capability**

More than Double the Mission Capability when using CoS_2 over the Conventional FeS_2

Gun Launch Thermal Battery Enhancements

With many years of experience and various design iterations, EAS has produced a unique battery that eliminates extreme performance degradation from high spin environments.

- ***The internal wrapping pattern, in combination with advanced insulation materials, ensures a rugged design tempered to survive intense G loads and acceleration forces.***

- ***The primer activation system employs a striker method anvil which is activated under specific gun launch environments ~ making the batteries safe to handle in the event they are dropped.***

- ***A unique lead routing design mechanically immobilized in a propriety blend of epoxy and hardeners, enables strain relief during some of the harshest environments.***

- ***Custom tailoring of the primer assembly allows for various no fire/all fire scenarios to be met.***

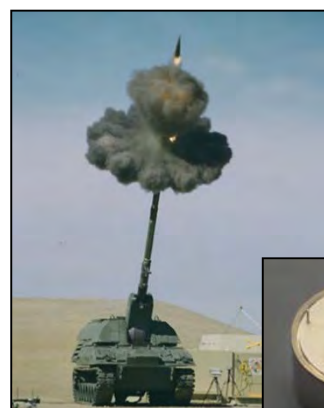
- ***Electrical Isolators are strategically placed in the battery to not only serve as electrical isolators but also to contribute to an already internal rugged core.***

EnerSys
Power/Full Solutions™

Experience in Gun Fired Systems

EnerSys Advanced Systems has demonstrated performance in gun launched systems with both high power density thermal batteries and high energy density liquid reserve batteries.

Thermal Batteries for Cannon & Artillery Applications



Liquid Reserve Cells and Batteries for Small & Medium Caliber Rounds, Artillery & Mortar Projectiles

EnerSys
Power/Full Solutions™

EAS Battery Design Capabilities

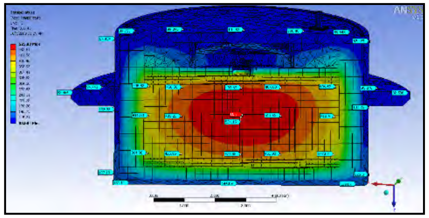
EnerSys Advanced Systems battery design and analysis capabilities ensure that the battery is designed to meet program performance requirements, including the most extreme environmental requirements.

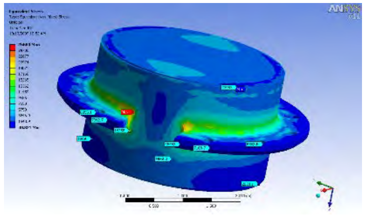
Customer Inputs → MATLAB → *MatLab Outputs* → SolidWorks (DriveWorks Xpress)

DWG Templates → SolidWorks (DriveWorks Xpress) → *Parametric Model Output* → ANSYS

Material Properties → ANSYS → *FEA Model Output* →

High Fidelity modeling to support simplified thermal model. Supports mechanical stress analysis requirements from the customer. Identifies areas for potential risk: thermal runaway, high impedance, stress risers.

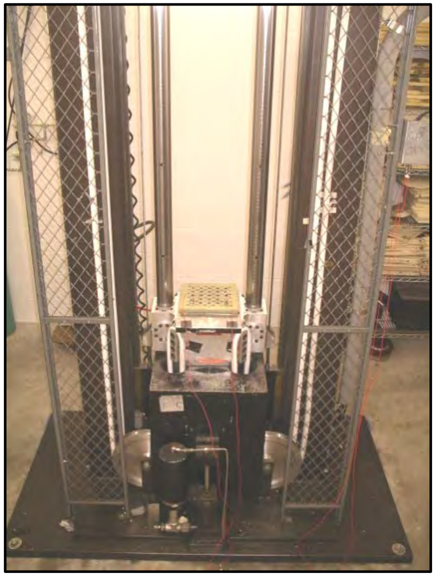




Using a combination of the latest software packages, EAS can generate thermal and mechanical models to reduce cost and time to PDR.

EnerSys
Power/Full Solutions™

EAS Battery Test Capabilities

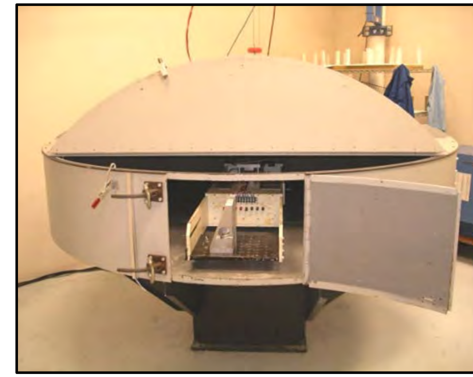


High-g Shock Tower (simulate gun-fire conditions)

Temperature Cycling

Temperature Conditioning

Acceleration Table w/ Slip Rings



Salt Fog Chamber

Programmable Testers and High-Speed Data Acquisition

Altitude Chamber

Vibration Tables / Slip Plates

Capabilities Support Full Range of Product Development, Qualification and Lot Acceptance Test Requirements

- **96 kW Programmable Load Not Shown**

EnerSys
Power/Full Solutions™

Powering the Smart Weapon

Our experienced team of thermal battery engineers at EAS Tampa are ready to discuss your specifications and how we can start powering your smart weapons!

Presented to:

NDIA 61st Annual Fuze Conference

U.S. ARMY RDECOM

US Army/AMRDEC S&T Overview

AMRDEC

Distribution Statement A - Approved for Public Release - Distribution Unlimited. Review completed by AMRDEC Public Affairs Office 20180503. Control number PR3805.

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

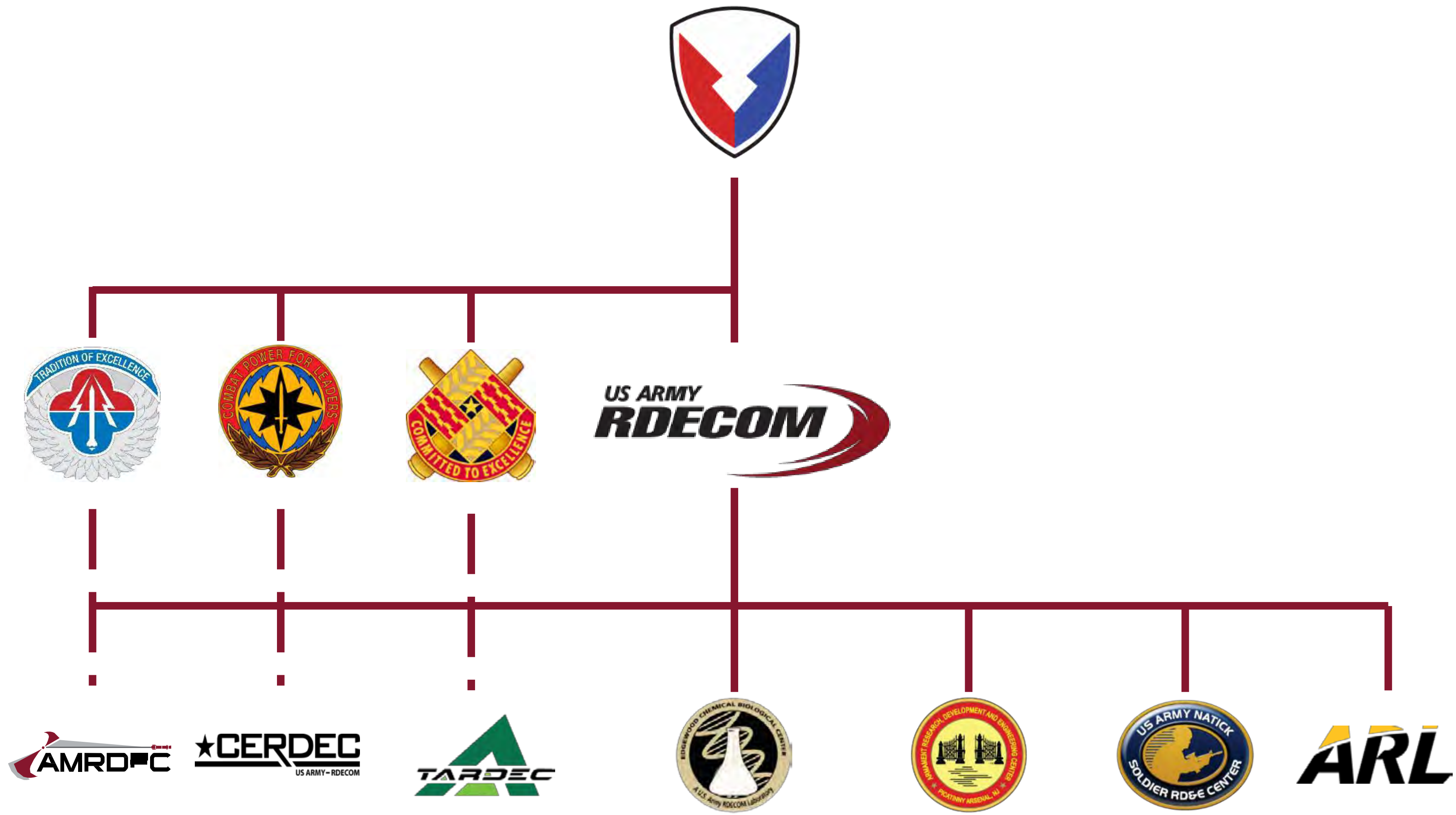
Presented by:

Mr. Shannon Haataja

U.S. Army Aviation and Missile Research, Development, and Engineering Center

16 May 2017

AMRDEC Reporting Structure



Who is AMRDEC?

~9,211 FY17 Strength

2,945 Civilian

16 Military

6,250 Contractor

907 / 5343

SETA Non-SETA

FY17

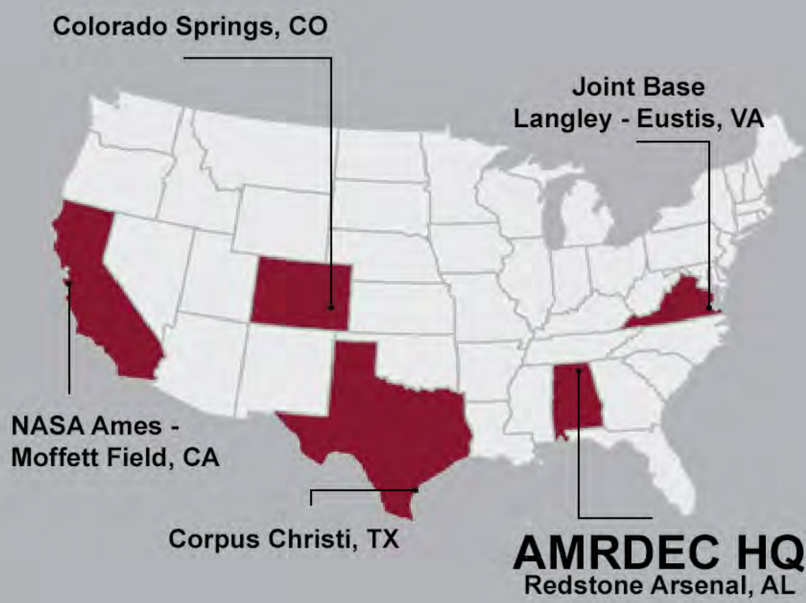
$2,904M

6% Aviation S&T

7% Missile S&T

63% Army

24% Other



Core Competencies

- Life Cycle Engineering
- Research, Technology Development and Demonstration
- Design and Modification
- Software Engineering
- Systems Integration
- Test and Evaluation
- Qualification
- Aerodynamics/ Aeromechanics
- Structures
- Propulsion
- Guidance/Navigation
- Autonomy and Teaming
- Radio Frequency (RF) Technology
- Fire Control Radar Technology
- Image Processing
- Models and Simulation
- Cyber Security

Deliver collaborative and innovative aviation and missile capabilities for responsive and cost-effective research, development and life cycle engineering solutions.

AMRDEC Priorities

#1: Readiness

Provide aviation and missile systems solutions to ensure victory on the battlefield today.

#2: Future Force

Develop and mature Science and Technology to provide technical capability to our Army's (and nation's) aviation and missile systems.

#3: Soldiers and People

Develop the engineering talent to support both Science and Technology and the aviation and missile materiel enterprise

AMRDEC Missile S&T Alignment to Army Modernization Priorities

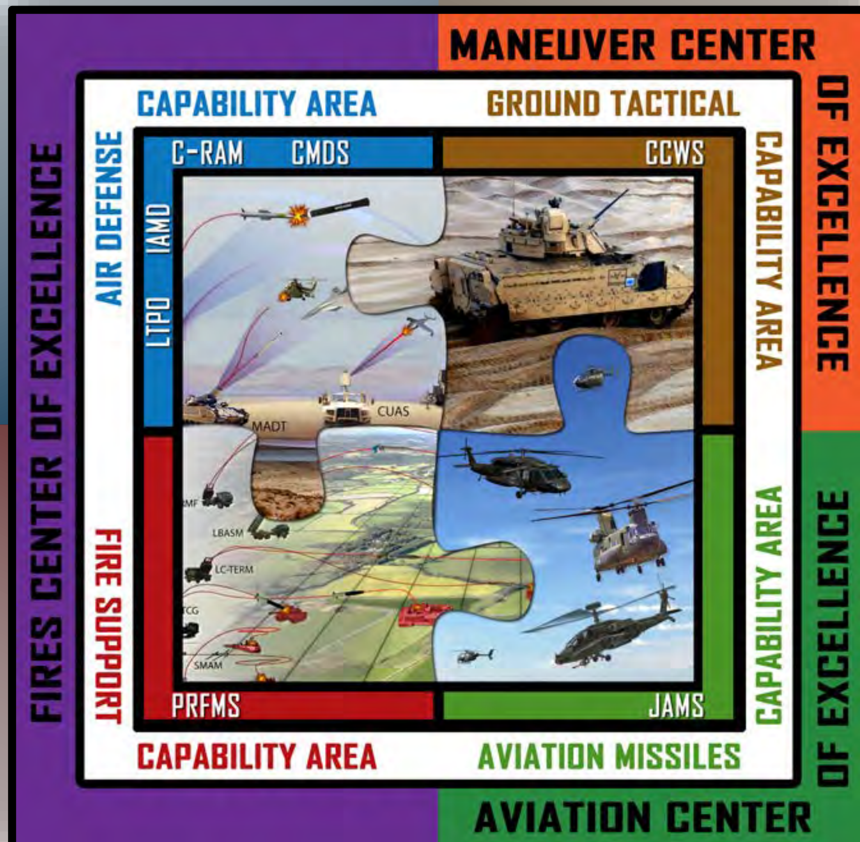
Army Modernization Priorities

Air & Missile Defense

Technologies for the development of mobile air defense systems that reduce the cost curve of missile defense, restore overmatch, survive volley-fire attacks, and operate within sophisticated A2AD and contested domains

Long Range Fires

Technologies for the development, integration and delivery of long range fires at the tactical, operational, and strategic echelons to restore overmatch, improve deterrence, and disrupt A2AD on a complex, contested and expanded battlefield.



Next Generation Combat Vehicle

Technologies for active protection systems that will increase our ability to survive and win in the complex and densely urbanized terrain of an intensely lethal and distributed battlefield where all domains are continually contested.

Technologies for enhanced lethal effects that will increase our capability to win in the complex and densely urbanized terrain of a lethal and distributed battlefield.

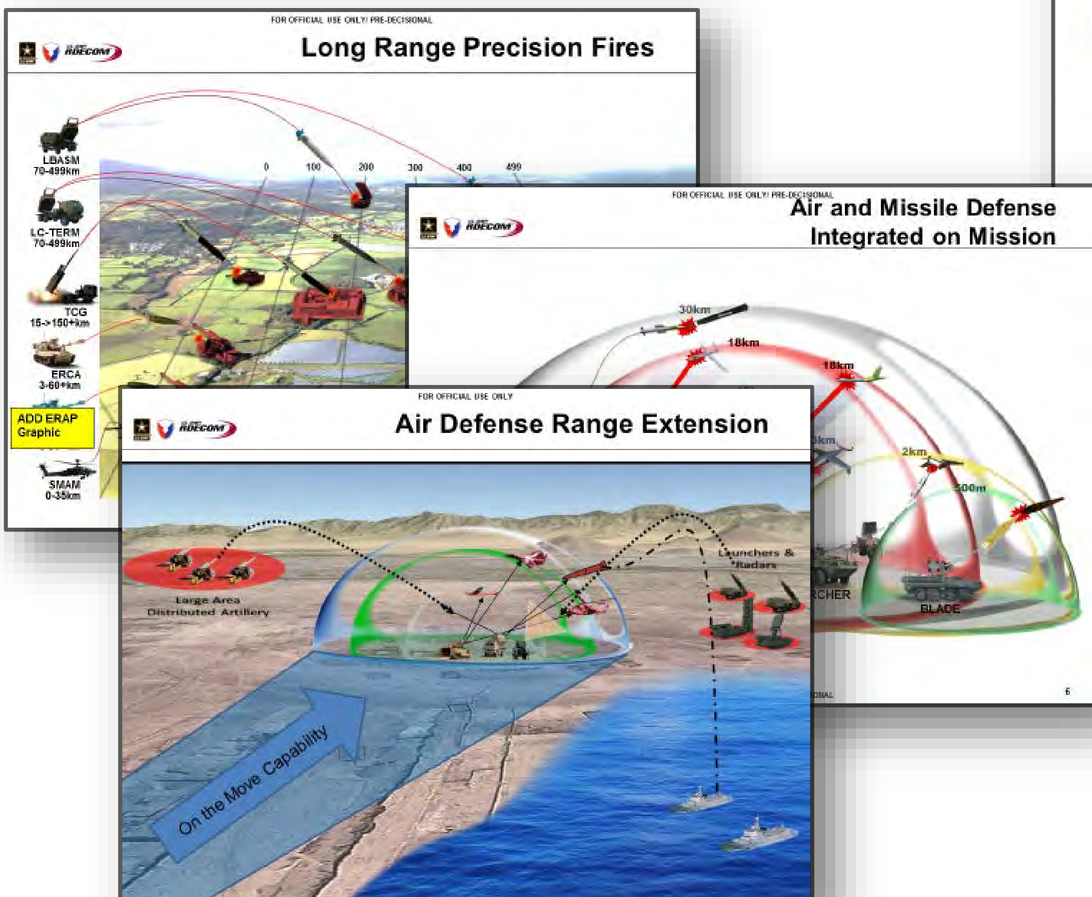
Future Vertical Lift

Technologies for the development, integration, and delivery of aviation launched air-to-ground and air-to-air missile systems to restore overmatch within sophisticated A2AD and contested domains

Engage First **Expand the Dome** **On the Move**

Missile S&T Addressing the CSA Priorities

- **Engage First [Long Range Precision Fires]**
- **Expanding the Dome [Air & Missile Defense]**
- **On the Move [LRPF & AMD]**



SECRETARY OF THE ARMY
WASHINGTON

29 SEP 2017

MEMORANDUM FOR THE DEPUTY UNDER SECRETARY OF THE ARMY

SUBJECT: Science and Technology Portfolio Realignment

1. The August 2017 senior leader review of the Fiscal Year 19-23 Program Objective Memorandum determined that the investment portfolio does not fully support the Army's new modernization priorities:

a. Precision Fires

b. Next Generation Combat Vehicle (NGCV)

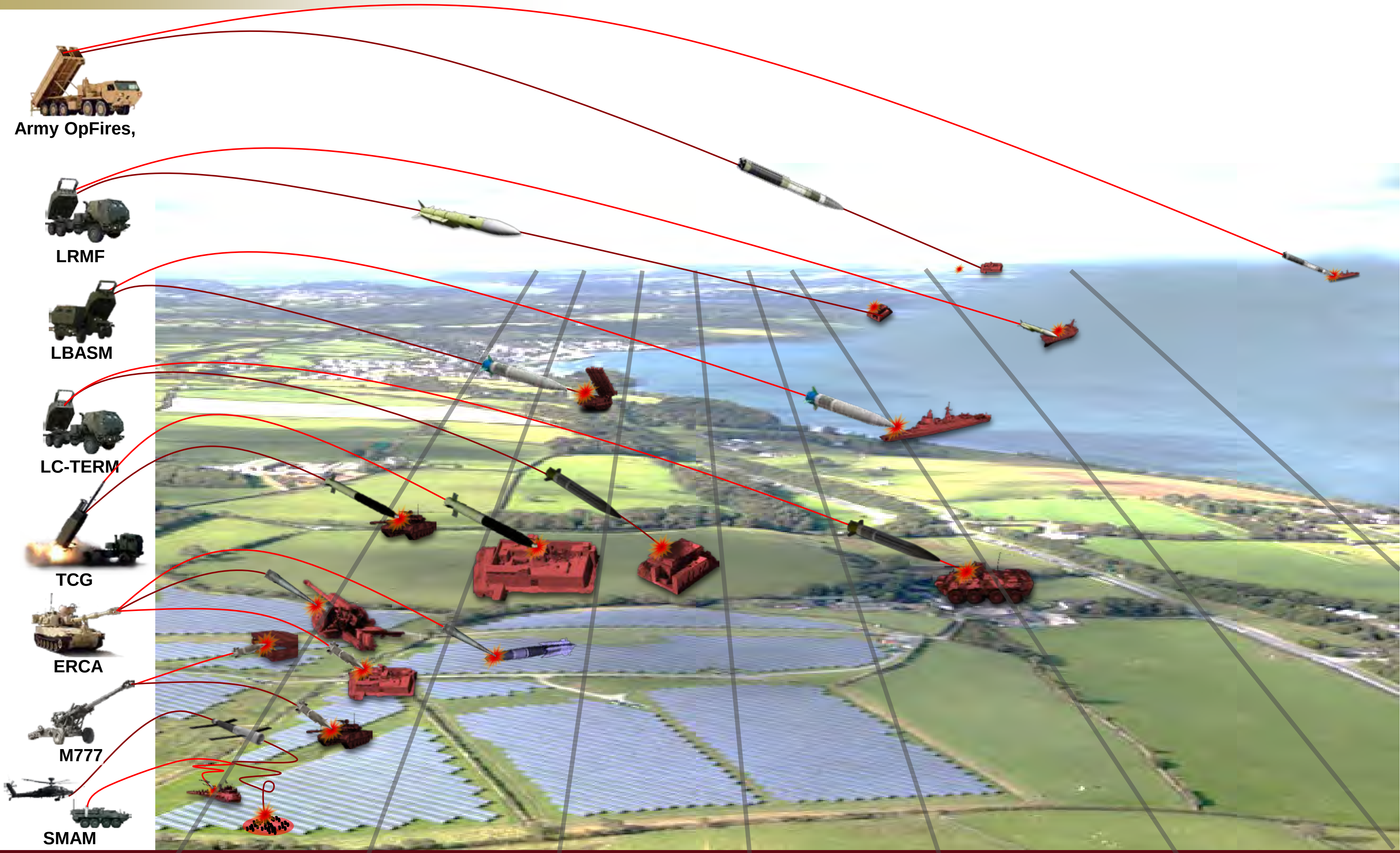
c. Future Vertical Lift (FVL)

d. Network/Command, Control, Communications and Intelligence (C3I)

e. Air and Missile Defense (AMD)

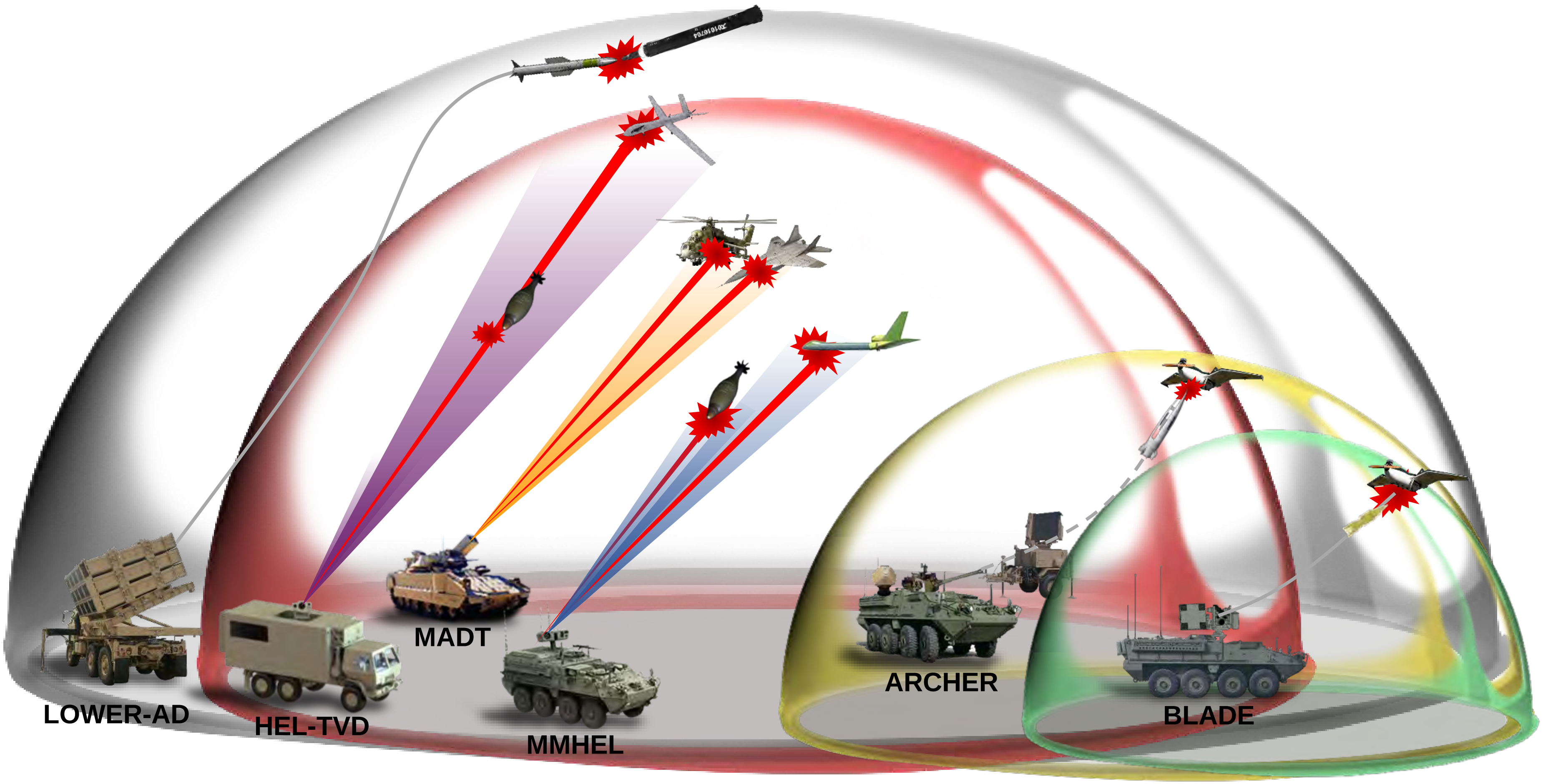
f. Soldier Lethality

Long Range Precision Fires Objective



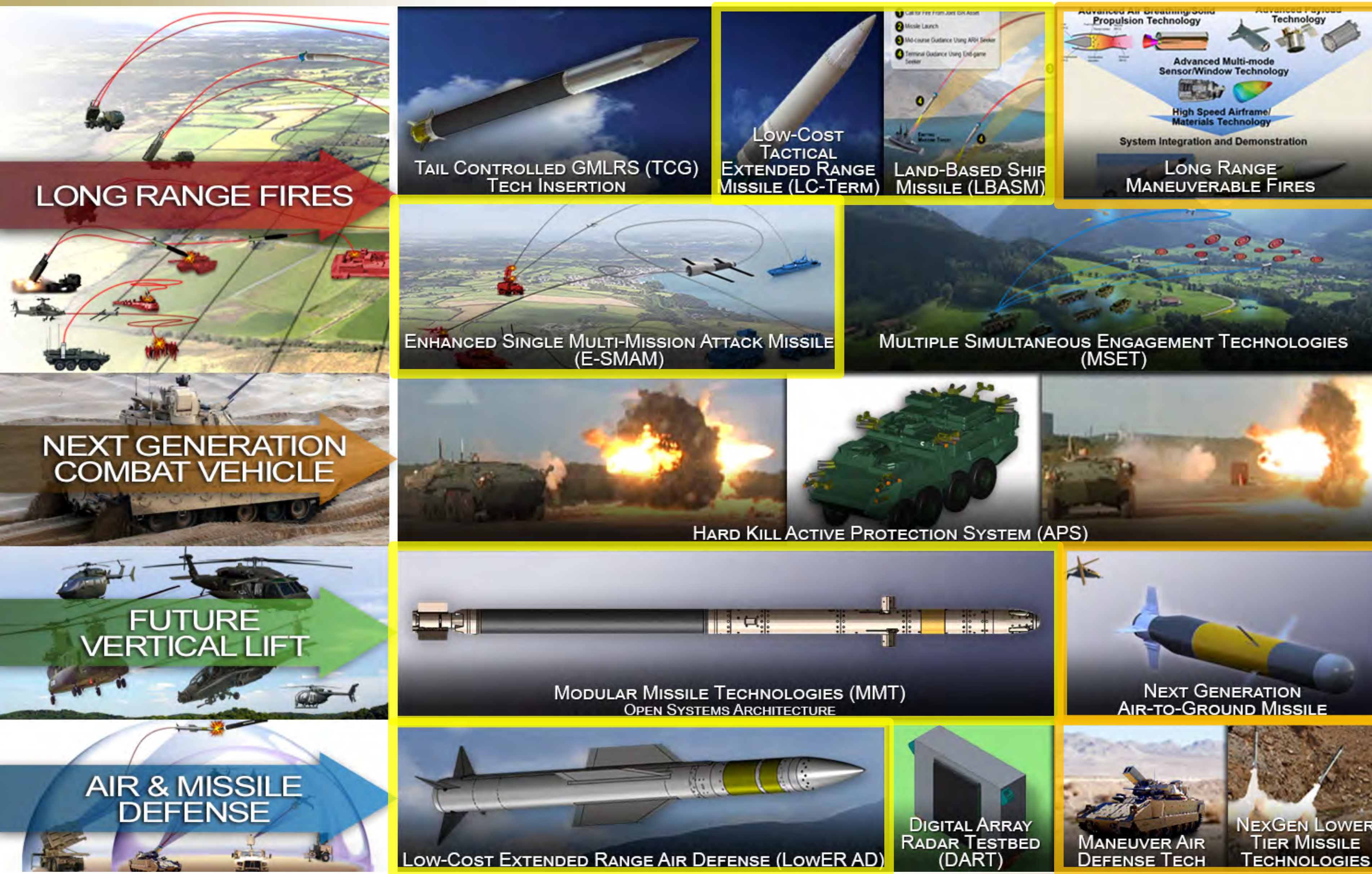
PROVIDE CAPABILITY TO ENGAGE TARGETS AT EXTENDED RANGE

AMD Objective

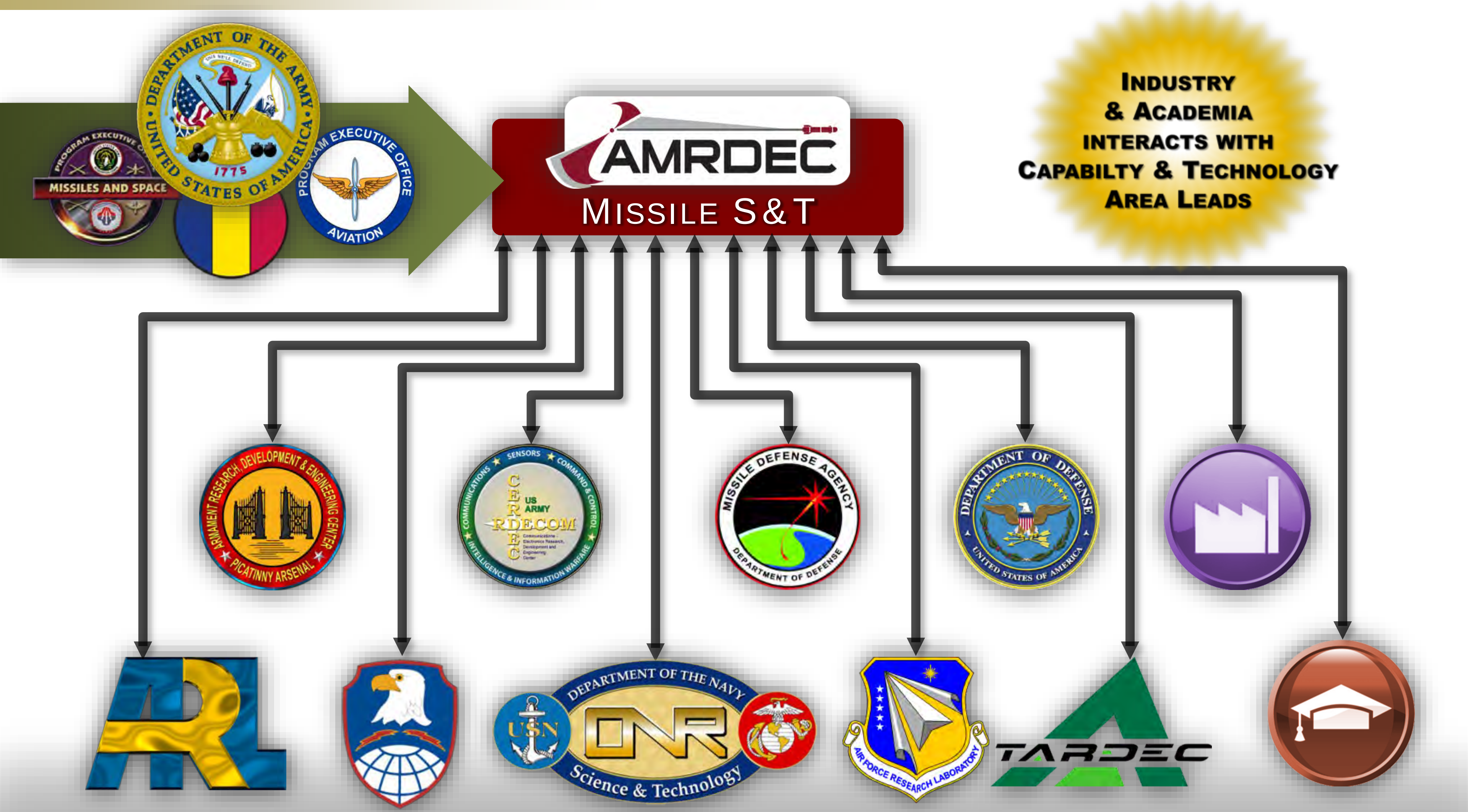


Provide Capability to Engage Targets at Extended Range

AMRDEC Missile S&T Aligned to Army Priorities



Missile S&T Collaboration

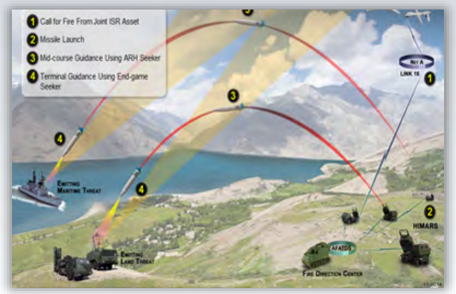


Notional Way Ahead

- The Army Futures & Modernization Command will stand up July 2018 (IOC), with FOC by July 2019
- Modernization strategy has one focus: make Soldiers and units more lethal to win our Nation's wars and come home safely.
- Process will leverage commercial innovations, cutting edge science and technology, and warfighter feedback.
- AMRDEC has a key role in 3 of the 6 identified capabilities

Long Range Precision Fires

- Low-Cost Tactical Extended Range Missile (LC TERM)
- Seekers
- Precision Target Acquisition Seeker (PTAS)
- Land-Based Anti-Ship Missiles (LBASM)
- Long Range Maneuverable Fires (LRMF)

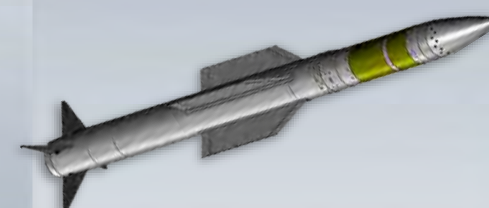


Future Vertical Lift

- Joint Multi-Role Technical Demo (JMR-TD)
- Modular Open System Approach
- Modular Missile Technology
- NexGen Tactical UAS
- Multi-Role Small Guided Missile (MR-SGM)
- Single Multi-Mission Attack Missile (SMAM)
- Degraded Visual Environment-Mitigation

Air & Missile Defense

- Low-cost Extended-Range Air Defense (LowER-AD)
- Maneuvering Air Defense Technologies (MADT)
- Digital Array Radar Testbed (DART)

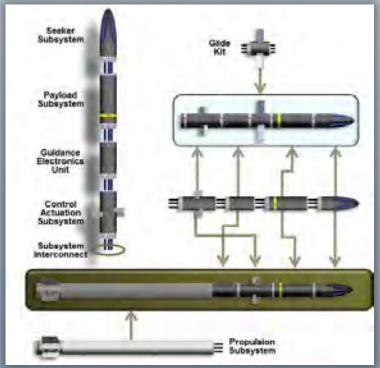


Airworthiness

- Safely attain, sustain, and complete flight in accordance with approved usage limits
- Deliver responsive airworthiness solutions throughout the system life cycle

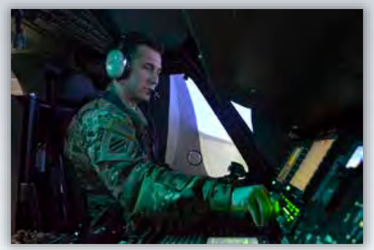
Modular Missile Technologies (MMT)

- Based on a Modular Open Systems Architecture for guided missiles
- Consists of two different airframe types: a canard-controlled forward firing missile and a tail-controlled drop/glide munition



Simulations, Trainers, & Integration Labs

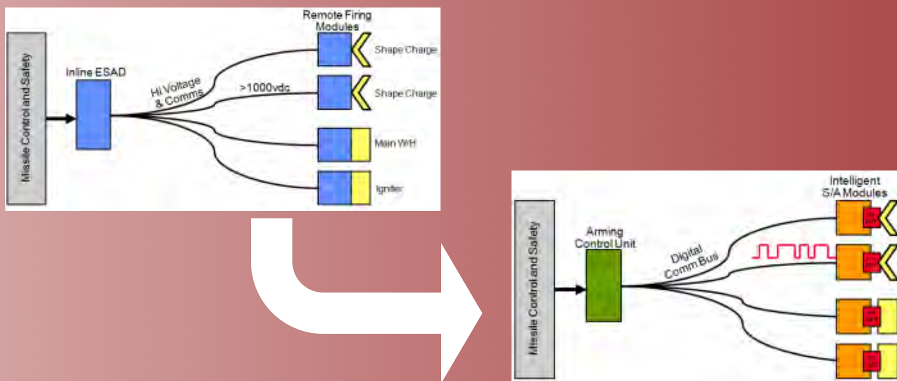
- New methods include creating a PVI that closely replicates the actual aircraft
- Optimal mix of tactical and simulated hardware to keep trainers concurrent with aircraft



Lethal Miniature Aerial Missile System (LMAMS)

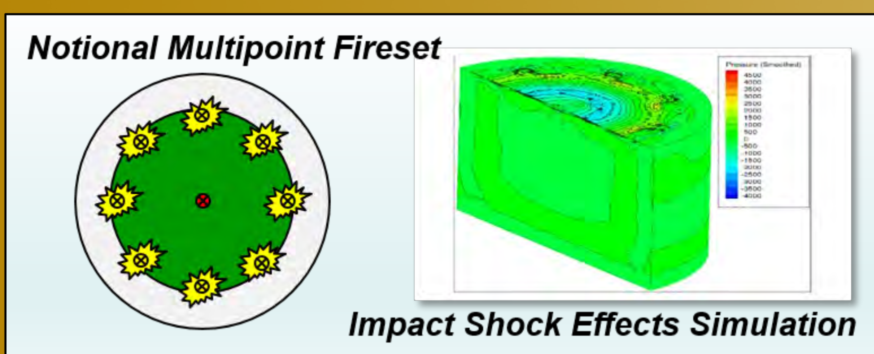
- Soldier-carried, Soldier-launched precision weapon system
- Allows precision engagement of enemy combatants without exposing the Warfighter to direct enemy fire

"Design Guidelines for Implementing a Low Voltage Distributed Fuzing System"



Mark Etheridge
Session TBD, Open Session
Wednesday, 1:20 PM

"Hardened Selectable Multipoint Fuze"



Michael Connolly
Session TBD, Closed Session
Thursday, 9:20 AM

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Always a Step Ahead
ARDEC
ARMAMENTS

TAKE THE FUZE SAFETY DESIGN QUIZ, PART I

61st NDIA Fuze Conference, May 2018

Presented by: Homesh Lalbahadur
Army Fuze Management Office
ENTERPRISE AND SYSTEMS INTEGRATION CENTER (ESIC) / ARDEC

UNPARALLELED
COMMITMENT
& SOLUTIONS

Act like someone's life depends on what we do.

U.S. ARMY RDECOM

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT & ENGINEERING CENTER

FUZE SAFETY DESIGN QUIZ

1. Out-of-Line and In-Line are two possible Safe & Arm architectures. Which of the following is the most important factor in determining which architecture is appropriate?

A. Selection of explosive materials

B. Selection of electrical power source

C. Available operational environments

FUZE SAFETY DESIGN QUIZ

2. Explosive materials are designed to detonate and are characterized via three sensitivity levels: Primary Explosive; Secondary Explosive; and Tertiary Explosive. Only Primary Explosives are permitted to be used in an In-Line S&A architecture. True or False?

A. True

B. False

FUZE SAFETY DESIGN QUIZ

3. The distance at which the fuze becomes armed is called:

A. Safe Separation Distance

B. Arming Delay Distance

C. Safe Escape Distance

D. A & B

FUZE SAFETY DESIGN QUIZ

4. Safe separation distance is the minimum distance at which the hazards posed by the functioning munition are acceptable. True or False?

A. True

B. False

U.S. ARMY RDECOM

FUZE SAFETY DESIGN QUIZ

ARDEC

5. US fuze safety authorities recognize the safe separation distance as the shortest distance at which the probability of hit by a hazardous fragment from the functioning of a munition is:

A. 10^{-6}

B. 10^{-4}

C. 10^{-2}

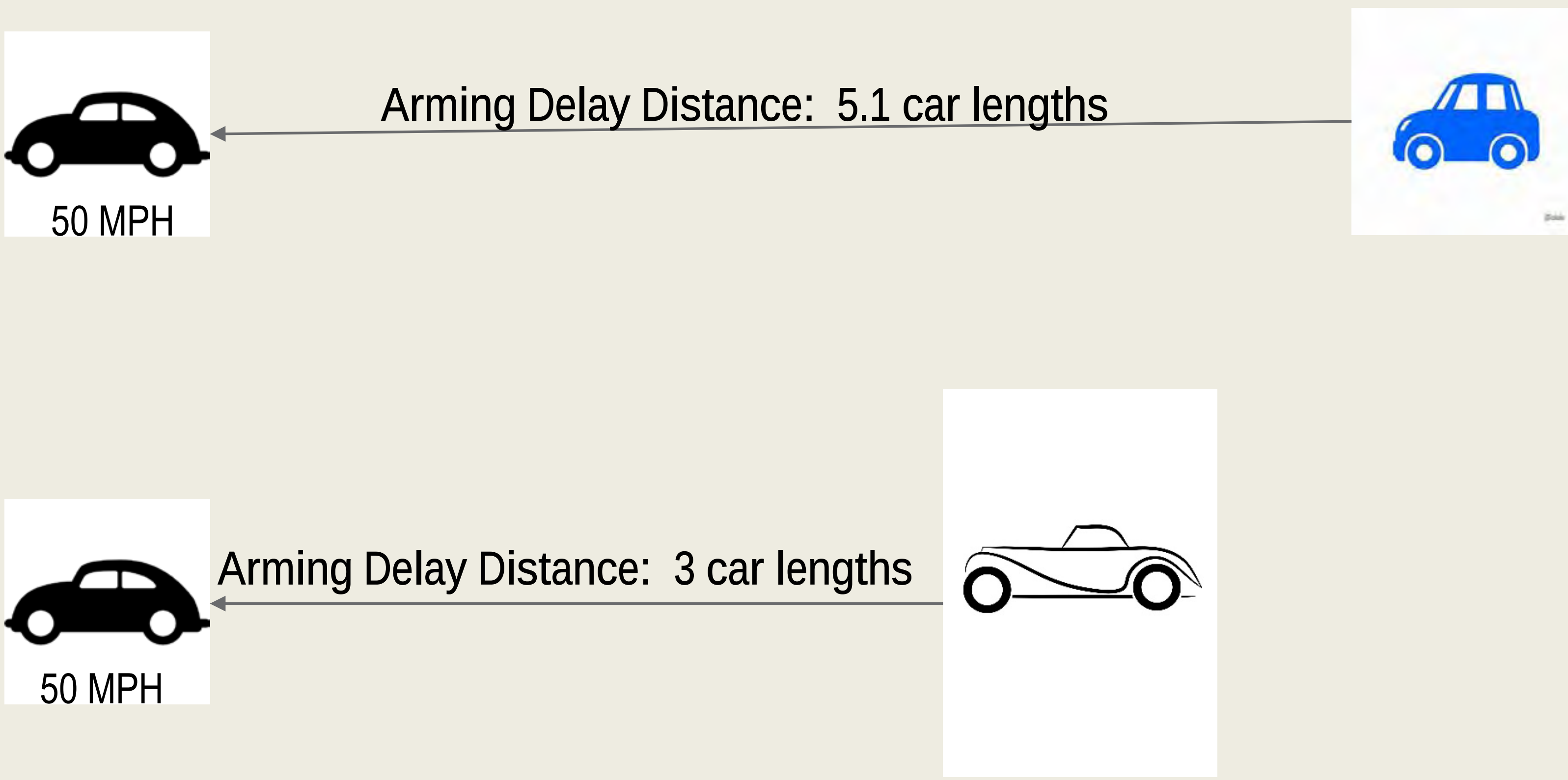
FUZE SAFETY DESIGN QUIZ

6. Fuze safety design standards require the fuze minimum arming delay distance be equal to or greater than the safe separation distance posed by the munition. True or False?

A. True

B. False

Safe Separation Distance: 5 car lengths (Determined by vehicle safety authorities)



FUZE SAFETY DESIGN QUIZ

7. When evaluating an out-of-line or in-line design, the definition of "armed" is not defined the same as when evaluating performance reliability. True or False?

A. True

B. False

DEFINITION OF "ARMED" in MIL-STD-1316F

a. A fuze employing explosive train interruption (see 5.3.3) is considered armed when the interrupter(s) position is ineffective in preventing propagation of the explosive train at a rate equal to or exceeding 0.5 percent at a confidence level of 95 percent.

b. A fuze employing a non-interrupted explosive train (see 5.3.4) is considered armed when the stimulus available for delivery to the initiator equals or exceeds the initiator's maximum no-fire stimulus (MNFS).

FUZE SAFETY DESIGN QUIZ

8. From the *fuze safety design perspective*, a main thrust of a fault tree analysis (FTA) is to examine the design to ensure single point safety failure modes do not exist. True or False?

A. True

B. False

9. In the *fuze safety design world*, the probability numbers employed in a fault tree analysis (FTA) should be obtained from:

A. Conservative engineering judgement
B. Quality Assurance and Inspection data
C. Past performance/historical data
D. MIL-HDBK-217F (Military Handbook: Reliability Prediction Of Electronic Equipment)
E. B & D

FUZE SAFETY DESIGN QUIZ

10. Electronic power should be applied to the fuze safety system as late as possible in the employment cycle (e.g., upon irrevocable intent-to-launch command, etc.). True, False, or Maybe?

A. True
B. False
C. Maybe

FUZE SAFETY DESIGN QUIZ

11. For an in-line system architecture (i.e., ESAD), a dedicated independent arming environment should be utilized to enable a dedicated static switch. True or False?

A. True

B. False

FUZE SAFETY DESIGN QUIZ

12. For an in-line system architecture (i.e., ESAD), what is the preferred method to activate the dynamic arm switch?

A. The dedicated independent arm environment inputs to both static switches should be combined and used towards controlling activation of the dynamic arm switch.
B. Use only the most robust of the two arming environments to control activation of the dynamic arm switch.
C. There is no preference since enabling the dynamic arming switch is a reliability concern. the S&A control logic is already partitioned into two independent static switch drive elements which is comparable to requiring dual safety for a mechanical S&A device.

FUZE SAFETY DESIGN QUIZ

13. It is acceptable to use a microcontroller by itself to execute safety logic functions if once programmed, the microcontroller is disabled from being reprogrammed. True or False?

A. True

B. False

FUZE SAFETY DESIGN QUIZ

PROPOSED FUZE FIRST ARMING ENVIRONMENT

Intent-to-Launch signal → Umbilical Disconnect sensed 1 second after ITL signal → Munition Guidance Processor provides confirmation that accelerometer has sensed 10g's acceleration for 8 seconds duration after ITL signal

14. This is not a valid arming environment for fuzing because:

A. Intent-to-Launch (ITL) signal is an event not an environment

B. Umbilical Disconnect is an event not an environment

C. Launch acceleration is not directly sensed by the fuze

D. Both A & B

MIL-STD-1316 F: The Hidden Message

MIL-STD-1316F

FOREWORD

1. This standard is approved for use by all Departments and Agencies of the Department of Defense (DoD).
2. This standard establishes specific design safety criteria for fuzes. It applies primarily to the safety and arming functions performed by fuzes for use with munitions. The safety and arming requirements specified herein are mandatory fundamental elements of design, engineering, production, and procurement of fuzes. Fuzes shall provide safety that is consistent with assembly, handling, storage, transportation, and disposal.
3. This revision has resulted in many changes to MIL-STD-1316E, but the most significant ones include the following:

a. Paragraph on logic functions (see 4.11) is introduced to address the use of logic devices.

b. Requirements for safety qualification of fuzes is changed to the applicable Joint Ordnance Test Procedures (JOTPs).

c. Explosive Ordnance Disposal (EOD) features is updated.

d. Significant changes are made for non-interrupted explosive train control (see 5.3.4) that addresses energy interrupters.

e. The guidance for non-armed condition assurance (see 4.6.6) is modified.

f. Other requirements for maximum allowable electrical sensitivity (MAES) requirements (see 5.6), and munitions that include sub-munitions (see 5.7) are incorporated.

g. New guidance for non-interrupted explosive train control (see 5.3.4) is incorporated.

h. Definitions such as enabling, explosive train, common mode failures, initiator, maximum no-fire stimulus (MNFS) are revised and a definition for common cause failures is added.

i. On fuze safety system (see 4.2), clarification is provided for operation of safety features and arming of submunitions while new guidance is provided for safety architecture distribution and status checks.

j. Modifications to the safety system failure rate (see 4.3) introduces additional evaluation.

k. Explosives listed for inline use (see Table I) approved by all services is revised.

l. New advisory guidance for addressing electronics counterfeit and cybersecurity concerns are referenced (see 6.0).

m. Inclusion of software development procedures is now identified in analyses (see 4.3.1) and in design for quality control, inspection, and maintenance (see 4.4).

n. Clarification is made for design features (see 4.6) for stored energy, compatibility of fuzes, and electrical firing energy dissipation.

o. On electrical and electromagnetic environments (see 4.8), several new JOTPs are introduced.

p. Visual indication requirement is added for bomb fuzes that utilize internal stored energy.

NDIA's 61st Annual Fuze Conference
NAVY S&T STRATEGY OVERVIEW

San Diego
16 May 2018

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Outline

Navy Organizations

- NSWC IHEODTD
- NSWC DD
- NAWC/WD

Navy Fuze R&D Highlights

Summary

STRATEGIC LOCATIONS

Ogden, Utah: 21 civ. and 4 ctr.
- Co-located at Hill Air Force Base
- CAD / PAD Air Force Integrated Product Team

Indian Head, Md. (two sites): 1,674 civ., 3 mil. and 211 ctr.
- NAVSEA Center of Excellence (CoE) for Energetics
- DoD EOD program lead
  - Combined Explosives Exploitation Cell platoons

Camp Pendleton, Calif.: 4 civ., 2 ctr.
- Demonstration and Assessment Team
- Assigned to D Department

Picatinny, N.J.: 242 civ., 2 mil. and 45 ctr.
- Located at Picatinny Arsenal

- Joint CoE for Guns and Ammo
- Navy Package, Handling, Storage and Transportation, Guns and Ammo

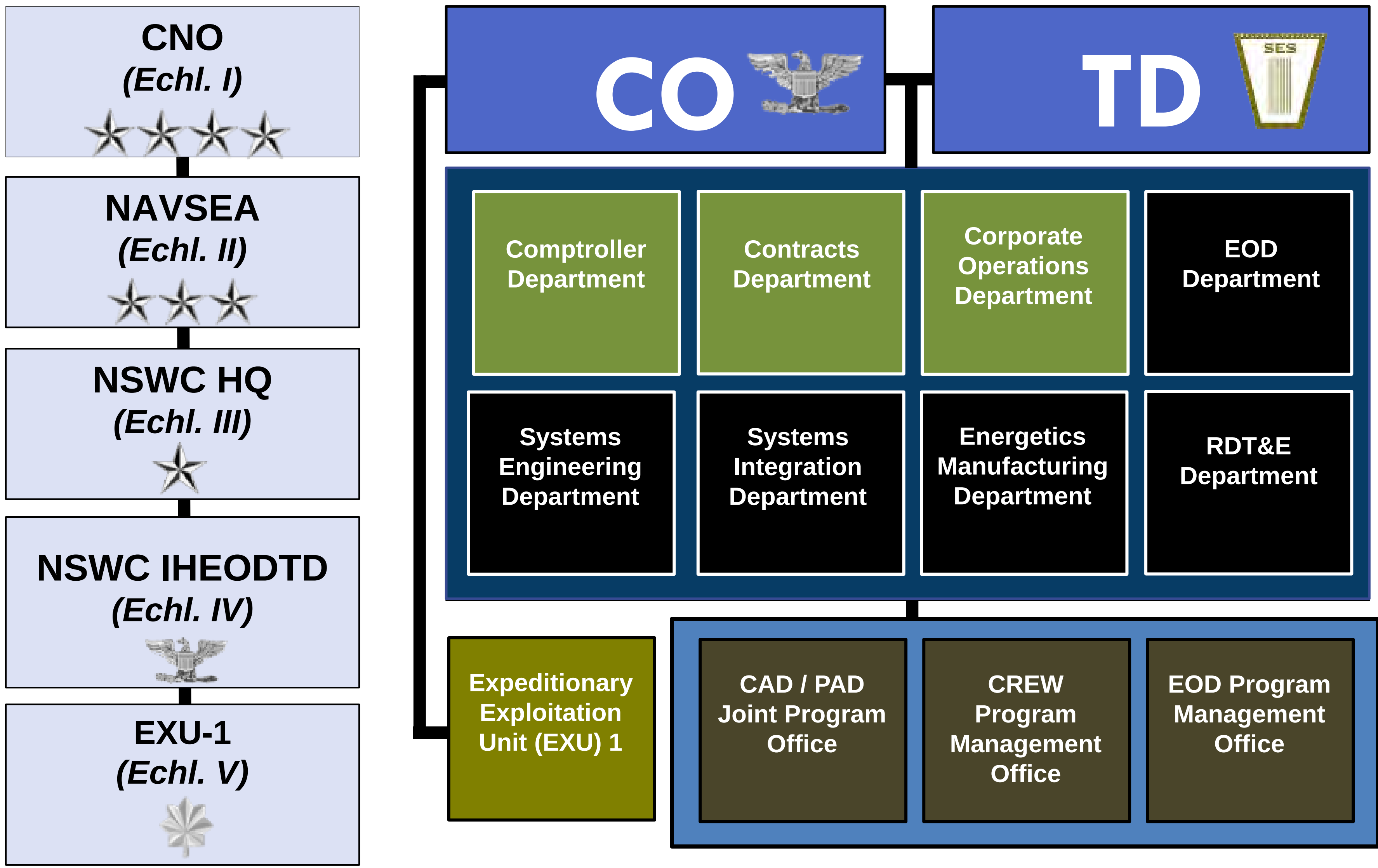
Rock Island, Ill.: 2 civ.
- Quad-Cities Caliber Cartridge Case Facility
- Aligned with G Department

McAlester, Okla.: 39 civ. and 4 ctr.
- McAlester Army Ammunition Plant
- Navy Special Weapons

Louisville, Ky.: 12 civ.
Naval Guns

Norfolk, Va.: 12 civ., 3 ctr.
- Demonstration and Assessment Team
- Assigned to D Department

IHEODTD Organizational Structure



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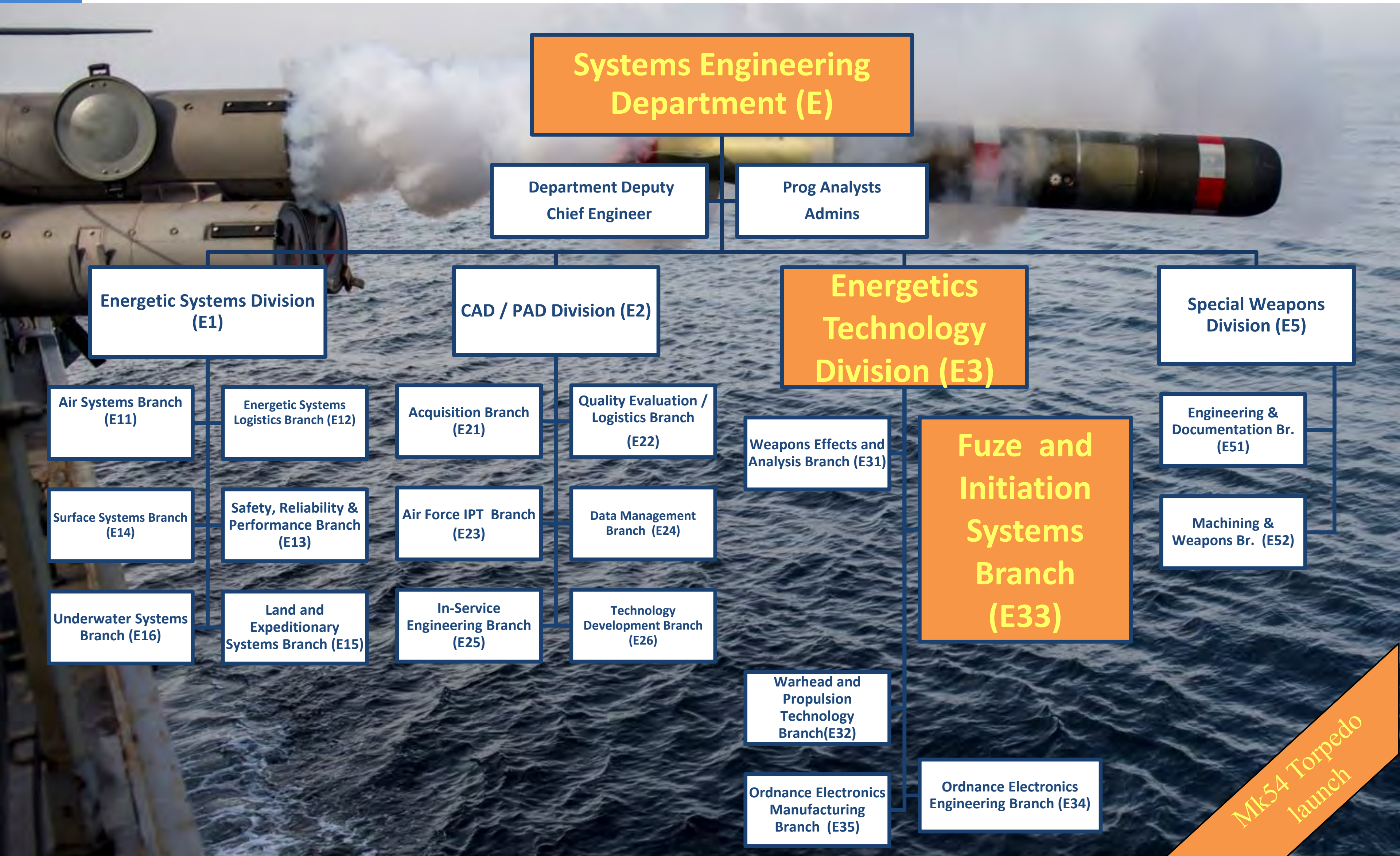
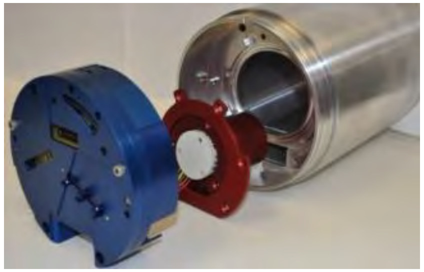
NSWC IHEODTD Systems Engineering Dept (E)



NSWC IHEODTD
Fuze & Initiation Branch Overview

Core Capabilities

- Fuze safety architecture
- Distributed fuzing
- Firesets
- Underwater fuzes
  - Torpedoes (e.g., Anti-Torpedo Torpedo)
  - Mine/mine neutralization
- MEMS and energetics integration (explosively certified cleanroom)
- Energy harvesting
- Powerless environmental sensors
- Rapid prototyping/circuit board layout



Electrical Design and Test

- Electronic Safe Arm Devices (ESADs)
- Sensing technologies, imbedded systems, RF design

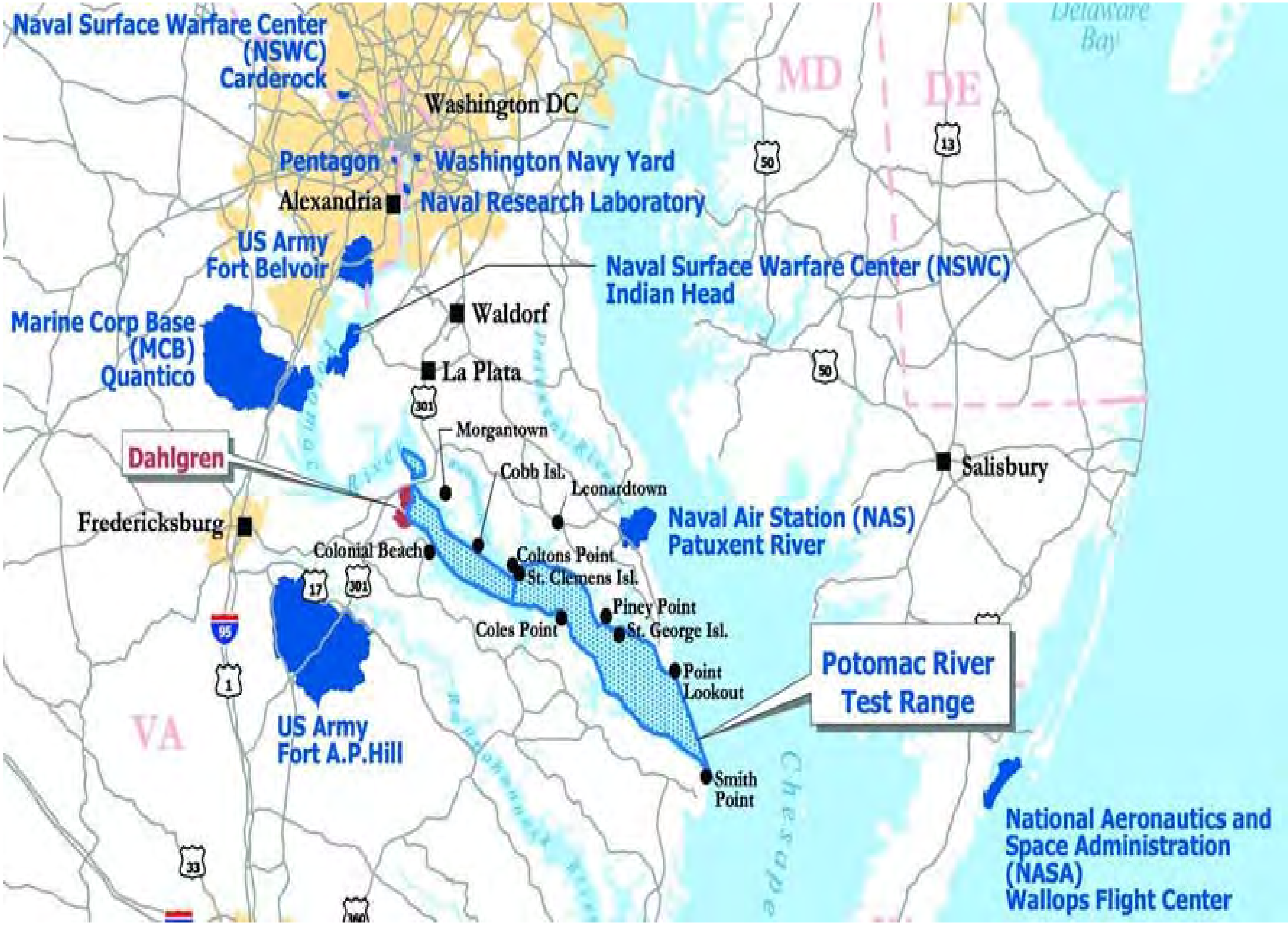
Initiation Systems Design and Test

- Micro-energetics
- Characterization (e.g., Photonic Doppler Velocimetry)

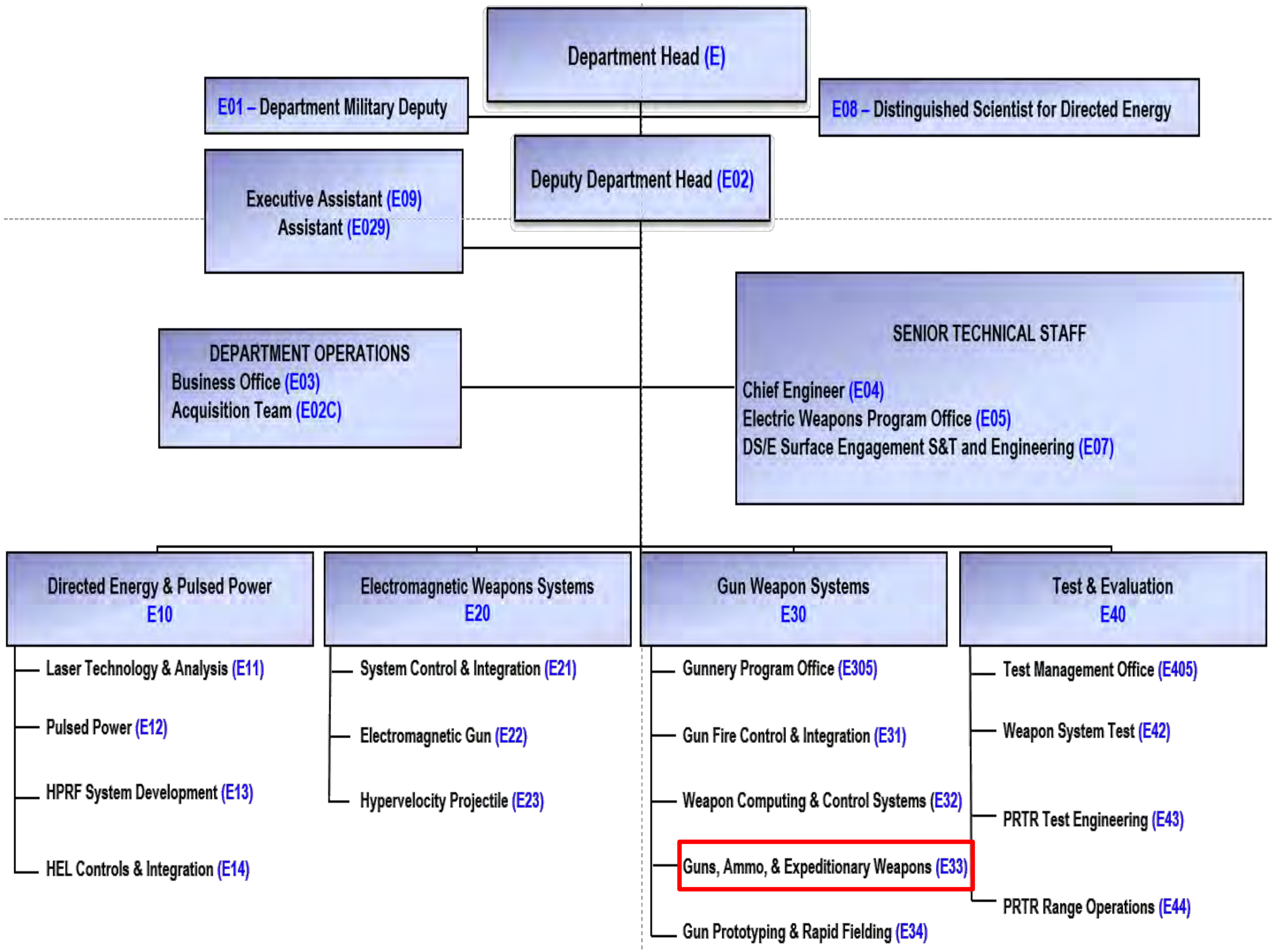
Mech. Design and Test

- Fuze packaging
- Full scale launch and impact testing
- Microelectromechanical Systems (MEMS)
- High G shock testing and survivability

NSWC Dahlgren



NSWC Dahlgren E Department Org Chart



NSWC Dahlgren and E33 Mission Statements

NSWC Dahlgren:

<u>Mission:</u> *NSWCDD's mission is to provide research, development, test and evaluation, analysis, systems engineering, integration and certification of complex naval warfare systems related to surface warfare, strategic systems, combat and weapons systems associated with surface warfare. Provide system integration and certification for weapons, combat systems and warfare systems. Execute other responsibilities as assigned by the Commander, Naval Surface Warfare Center.*

Guns, Ammo, and Expeditionary Weapons Branch (Code E33):

<u>Mission:</u> *Provide research, analysis, design and development, engineering, qualification, integration, and acquisition support of guns, ammunition, and expeditionary weapon systems to ensure battle space dominance for the warfighter.*

25mm MK 38 Mod 2

MK45 5" Mod 2/4

Bofors 57mm

Fuzes

Alamo

Ammunition

Core Fuzing Capabilities

DEVELOPMENT

- Gun-launched, conventional ammo fuzing
- S&A design
- Preparing specs and requirements
- Benchtop electronics testing
- CAD modeling and finite element analysis
- Rapid prototyping

QUALIFICATION

- Closed and open loop HWIL testing
- Execute and approve qualification testing
- Energetics and ballistic testing
- Extensive safety support with FISTRP representation

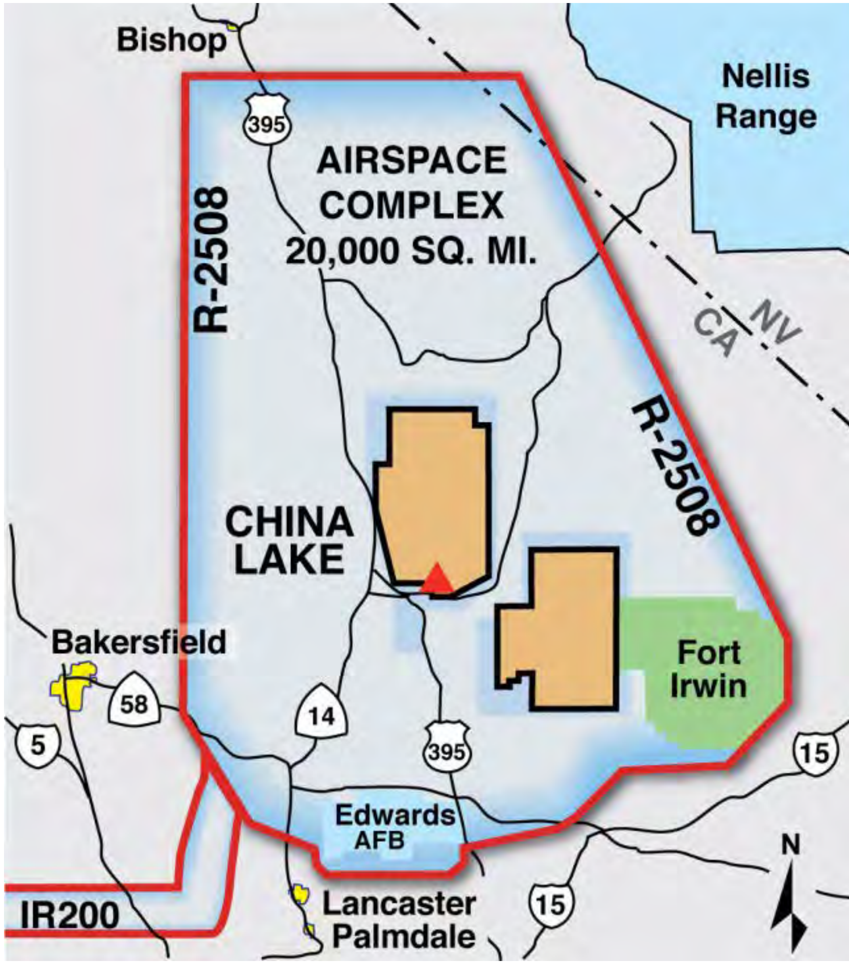
FLEET SUPPORT

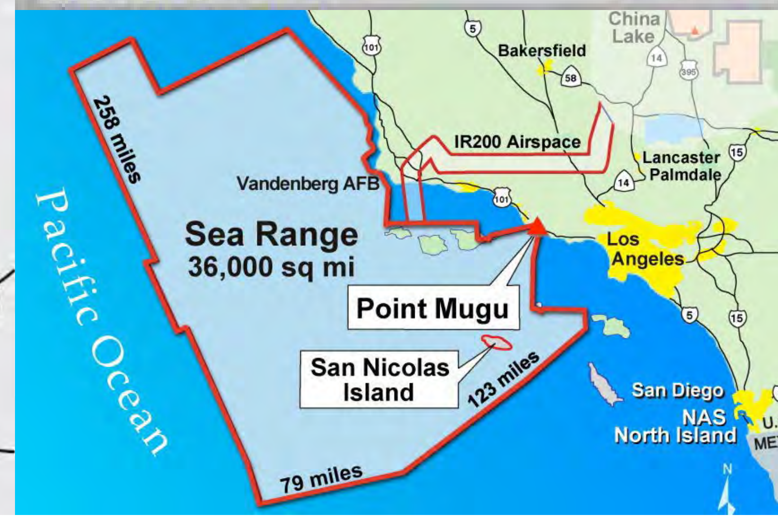
- Direct communication with fleet
- Support various at-sea test events
- Respond to Conventional Ordnance Deficiency Reports (CODRs)
- Provide SME support/training

Potomac River Test Range

- 169 square miles of controlled water
  - Ballistic range of up to 20 nautical miles
  - Airspace clearance to 60,000 feet
- Fully instrumented network of range stations along VA shore of the Potomac River
- Over 2,300 acres of explosive ranges provide full spectrum of capabilities for live fire testing of energetics and directed energy systems
- Test range supports legacy, emergent, and “Navy after Next” programs
- Fuze test facility capable of:
  - S&A spin testing
  - Battery activation testing
  - Detonator time and explosive output testing
  - Fuze electronics testing
  - RF target simulation
  - Environmental testing

NAWCWD Locations





China Lake

Point Mugu

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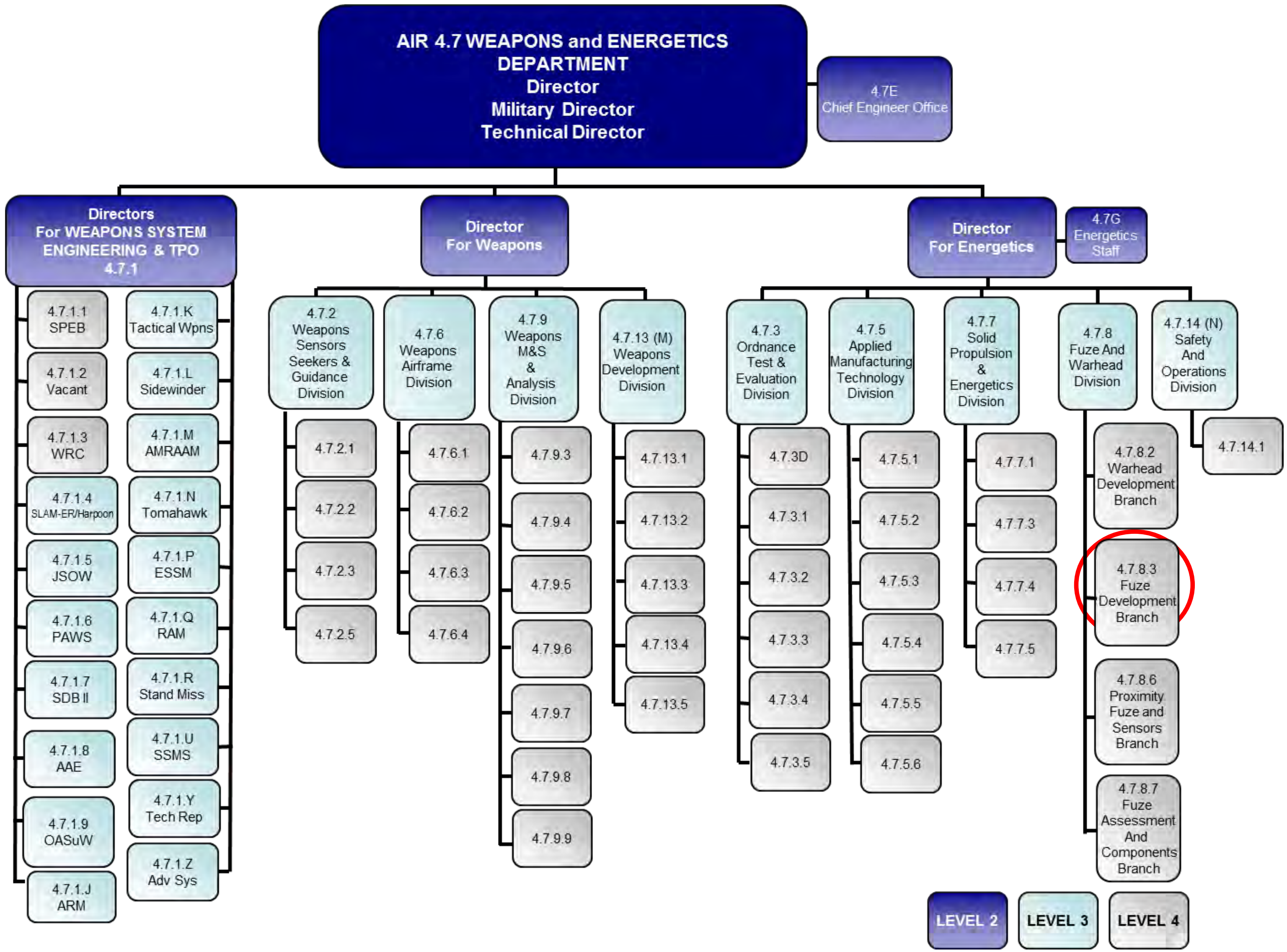
NAWC/WD Engineering Org Chart



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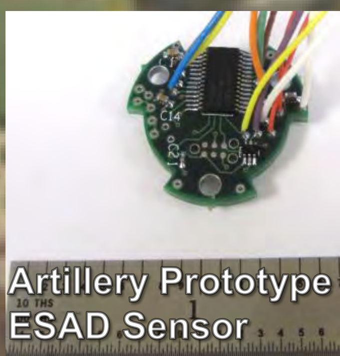
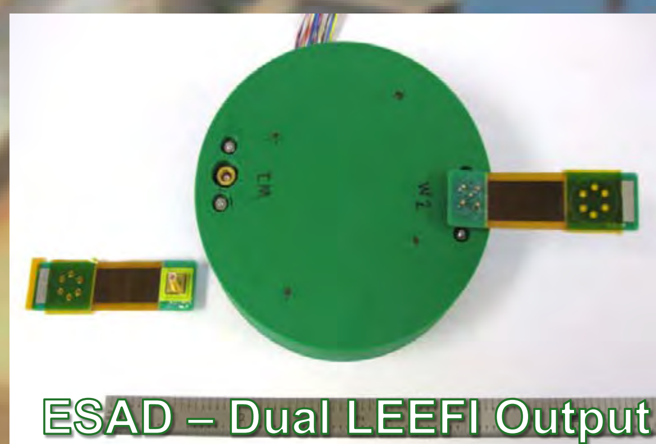
NAWC/WD Engineering Mission Statement/Overview

- ***Mission Statement:*** *"Provide the core technical expertise for research, design, development, fielding, production, and sustainment of fuzing, initiation, and sensor systems to support the fleet."*
- **Overview**
  - Design & Develop New Fuzing Concepts
  - In-Service Fuze SME Support
    - Production Support
    - Life Cycle Sustainment
  - Fuze Testing Capabilities

NAWC/WD Engineering Overview

- Design & Develop New Fuzing Concepts
  - Rapid Prototyping (3D print or machined)
  - FPGA development and logic analysis (up to 208 channel)
  - ESADs, ISDs, FTSAs, Test Range Fire-sets.


Artillery Prototype ESAD Sensor


ESAD – Dual LEEFI Output


Modular In-line Safety Device

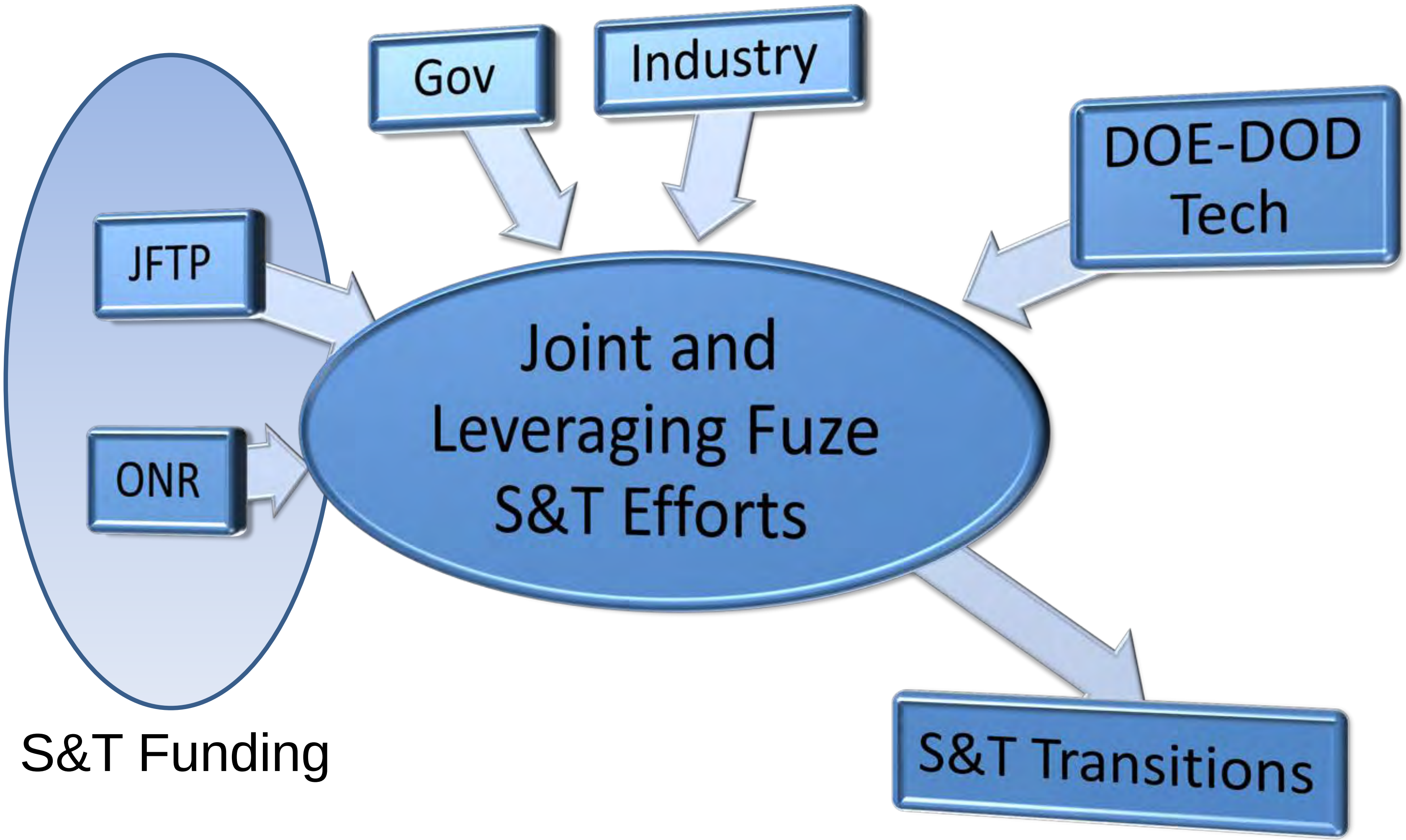
NAWC/WD Engineering Overview

- In-Service Fuze SME Support
  - Over 50 years of combined experience
  - Program support from Production through Sustainment and Ordnance Assessment
  - Respond to Conventional Ordnance Deficiency Reports (CODR) from the fleet

NAWC/WD Engineering Overview

- **Fuze Testing Capabilities**
  - Environmental/Functional test sites to support Qualification, LAT, Ordnance Assessment(OA), Recertification, and experimental testing.
  - Capability on-site to test AUR configurations with both multi-shaker underwing and 6DOF capabilities
  - Full suite of Insensitive Munitions (IM) test facilities.
  - Sled test capability

Navy Fuzing Technology



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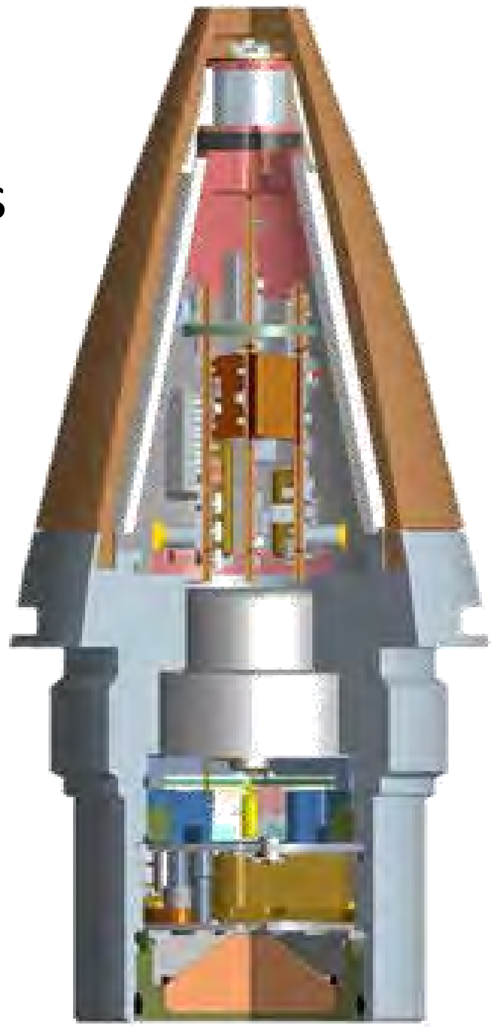
Navy Fuze S&T Efforts

- ONR: High Reliability DPICM Replacement, Hyper Velocity Projectile Fuze
- JFTP (Joint Fuze Technology Program):
  - Advance proximity sensing
  - Hard Target Survivability – Modeling & Simulation, Testing, Encapsulation, Materials
  - MEMS and micro-explosive train reliability
- Navy Briefings at Conference:
  1) Defeating HSMSTS with MK 419 - Session IIIB briefing by Jason Koonts (USN) and Jim Ring (OATK)
  2) High Reliability DPICM Replacement (HRDR) - Session IIIB briefing by Kevin Cochran
  3) DoD MEMS Fuze Explosive Train Evaluation and Enhancement Session IIIA briefing by Taylor Young
  4) Using Modeled Impact Response of 3-D Printed Materials for High-G Survivability - Session IIIB briefing by Ezra Chen
  5) Dynamic Characterization of Damping Materials for Electronics Assemblies – Session IVA briefing by Dr. Vasant Joshi
  6) 40mm C-UAS Grenade Fuzing Technology – Session IVB briefing by Tim Hoang
  7) Gun Hardened Command Armed MEMS Fuze - Session VB briefing by Dr. Daniel Jean

Defeating High Speed Surface Targets with MFF

- Unconventional use of Multi-Function Fuze (MFF) to engage high speed surface targets
- Speed-to-fleet effort to field improved tactics for MFF projectile
  - Overcome standard errors associated with ballistic, unguided projectile
- Various land-based and at sea tests to validate updates
- Direct interaction with the fleet and warfighter to improve ship self defense
- Less than 2 year effort from proposal to fielding



Closed Session IIIB briefing provided by Mr. Jason Koonts (USN) and Mr. Jim Ring (OATK)

High Reliability DPICM Replacement (HRDR)

Objective: Demonstrate a 155mm cannon-delivered area effect munition (C-DAEM) that is in compliance with the 2017 DoD Policy on Cluster Munitions and matches or exceeds the lethality of the legacy M483A1

HRDR 155mm C-DAEM

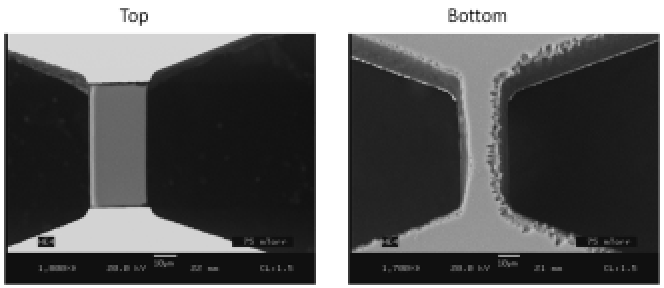
Fuze Technologies

- Distributed Fuze Architecture (DFA)
- Networked signal distribution
- Electronic target detection, initiation, & self destruct

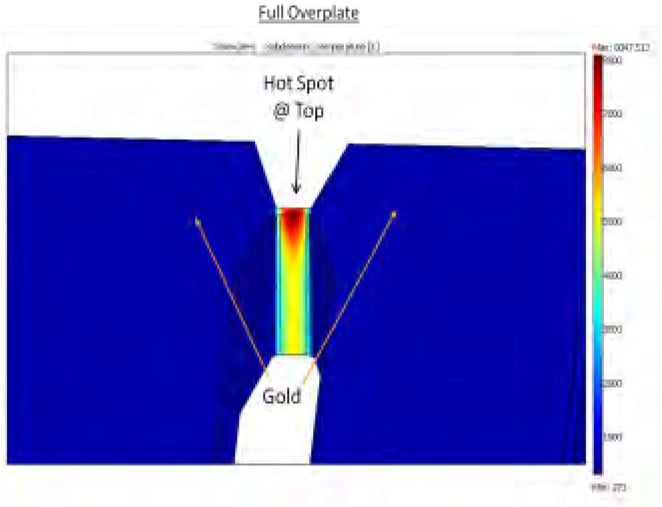
Closed Session IIIB briefing provided by Kevin Cochran

DoD MEMS Fuze Explosive Train Evaluation

- Produce calculated reliability predictions for MEMS based explosive trains
- Characterize shock initiation and material properties of EDF-11
- Combined analysis of (100+) test data sets to determine a reliability of MEMS explosive interface



Model Hot Spots



Open Session IIIA briefing provided by Taylor Young

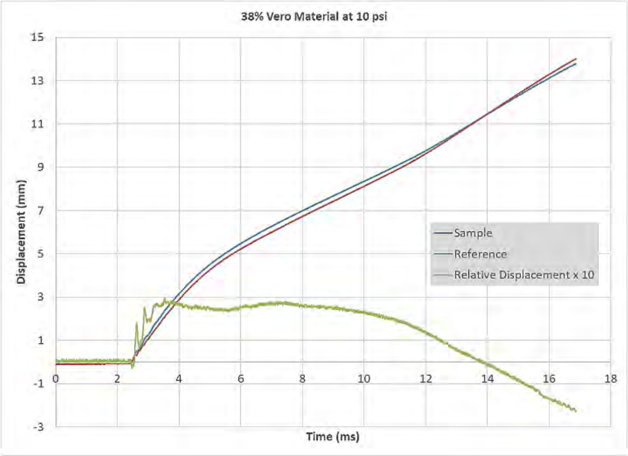
Using Modeled Impact Response of 3-D Printed

- Use 3-D printed structure to enhance shock survivability of vulnerable fuze components

- Various polymers tested on VHG
  - Deformation measured
  - Input and output frequency spectrum observed

Closed Session IIIB briefing provided by Ezra Chen

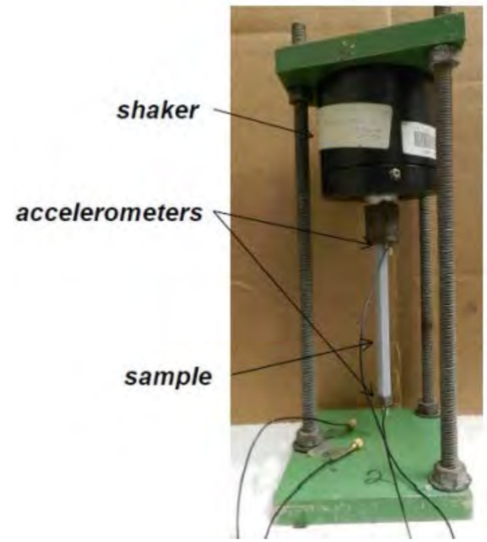
VHG Test Configuration

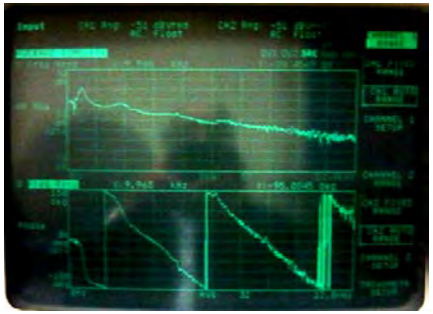


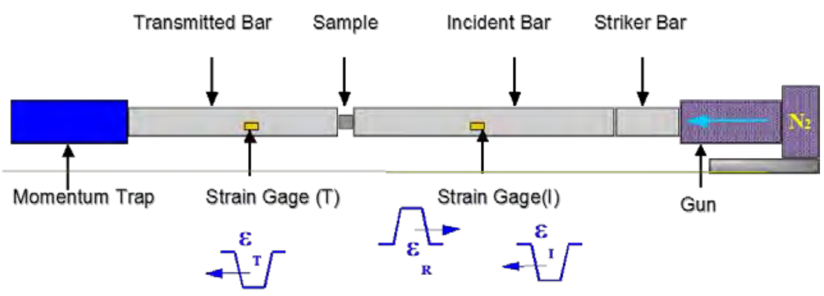
Sample, base, and relative displacement

Dynamic Characterization of Damping Materials for Electronics Assemblies

- Develop an experimental suite of tests to quantify the dynamic response and appropriate rate of loading for damping materials and provide data for numerical models of fuzes under shock.
- Develop new methods to characterize very high G loading on fuze components and sub-assemblies







Open Session IVA briefing provided by Dr. Vasant Joshi

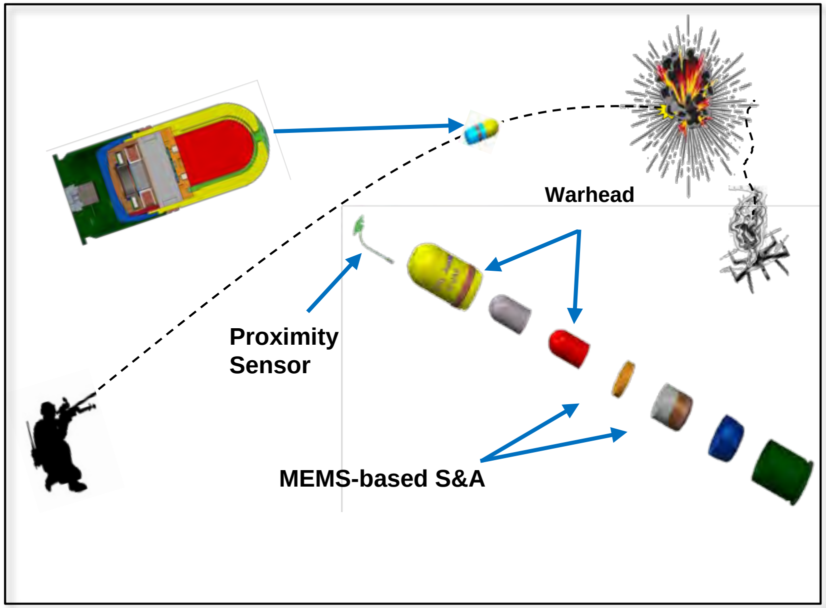
40mm C-UAS Grenade Fuzing Technology for Today and Tomorrow's Threats

Application:

- Develop enabling fuze technologies for a 40mm Counter-Unmanned Aircraft System (C-UAS) grenade to effectively neutralize UAS threats while reducing collateral damage

Fuzing technologies to be presented:

- MEMS-based Safe and Arm
- Proximity target & Omni-directional impact sensors
- Self-destruct for misses to reduce UXO

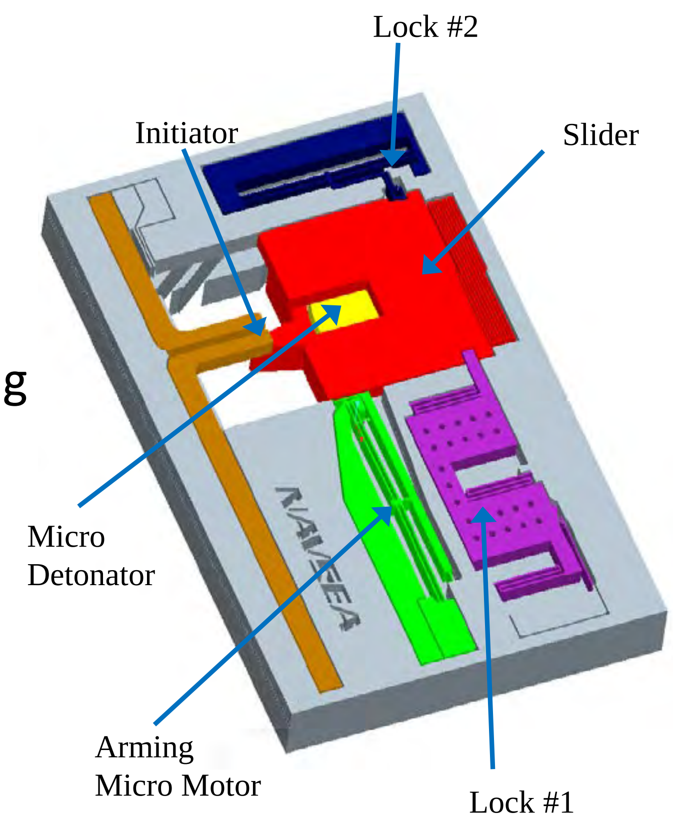


Closed Session IVB briefing provided by Tim Hoang

Gun Hardened Command Armed MEMS Fuze

- MEMS fuze components survived laboratory high-G testing and gun fire high-G testing (29 kG)
- Fuze Attributes
  - Small (<1.5 in^3 with electronics)
  - Command arm
  - Resettable / resafing
- Fuze function demonstrated in laboratory testing
  - MEMS unlocking and arming
  - Explosive train transfer
- MEMS Fuze Applications
  - Gun launched munitions
  - Underwater applications

Closed Session VB briefing provided by Dr. Daniel Jean



Summary

- Navy R&D fuze activity focused on **ESADs, Proximity Sensors and High-G Survivability.**
- Detailed, Navy briefs to follow as part of the 61st Fuze Conference