Mechanical Aspects of Fuze MEMS G-Switch Encapsulation

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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

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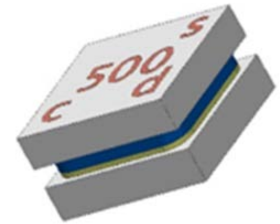
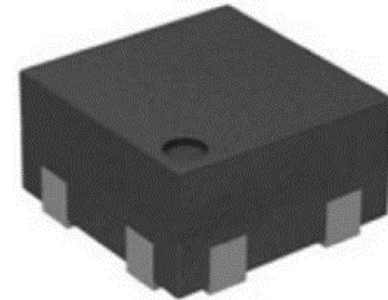
BACKGROUND

- 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

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

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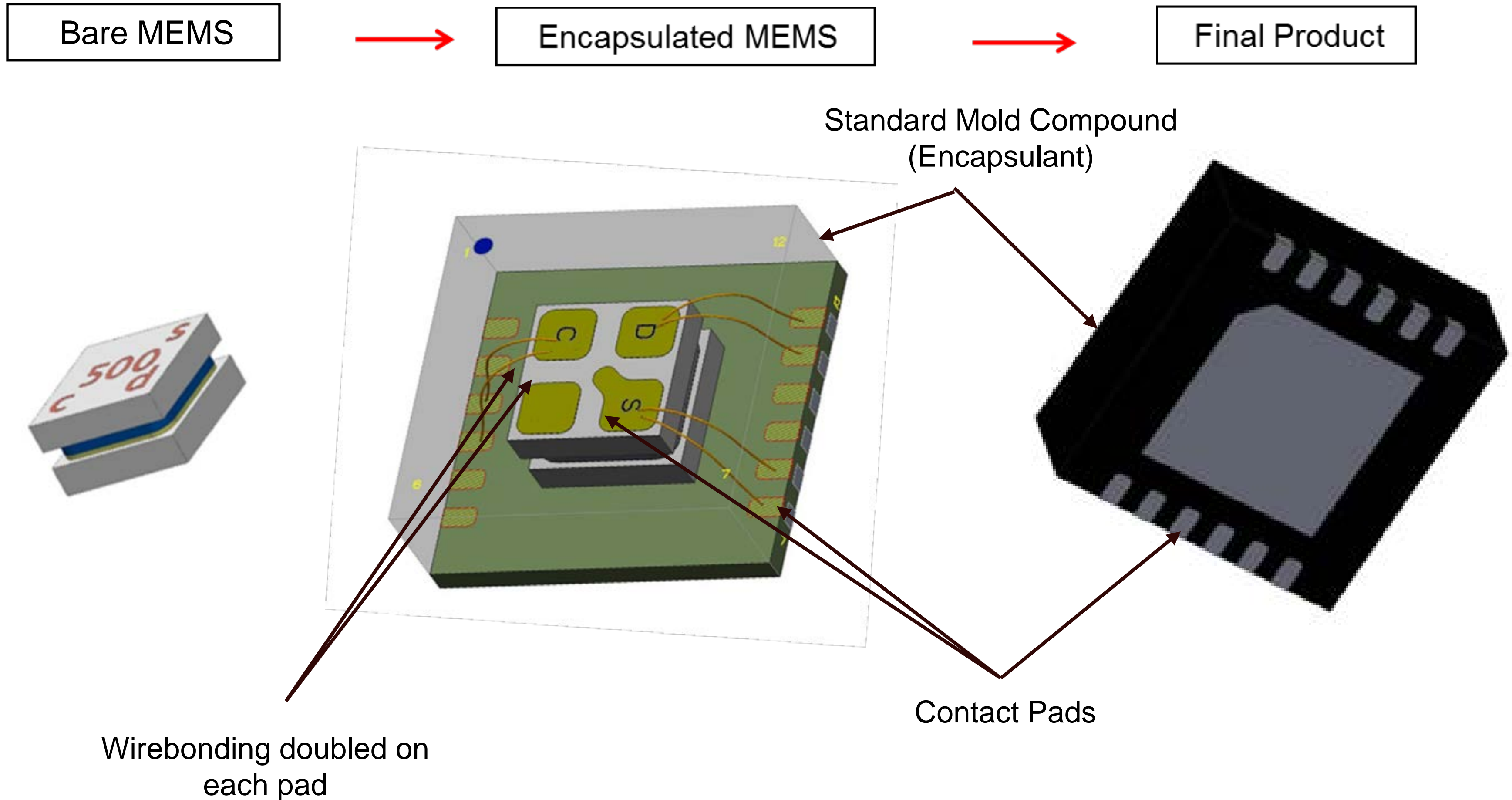
Design Concept

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



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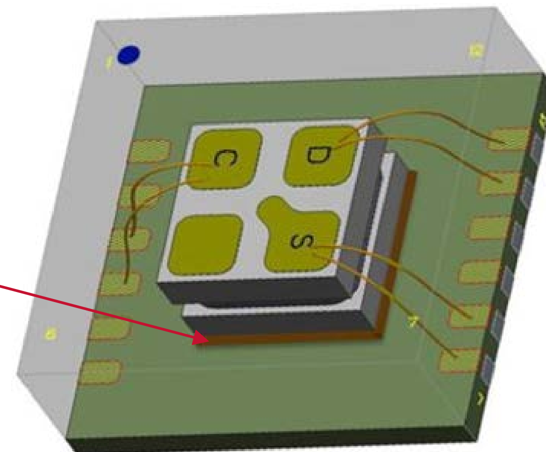
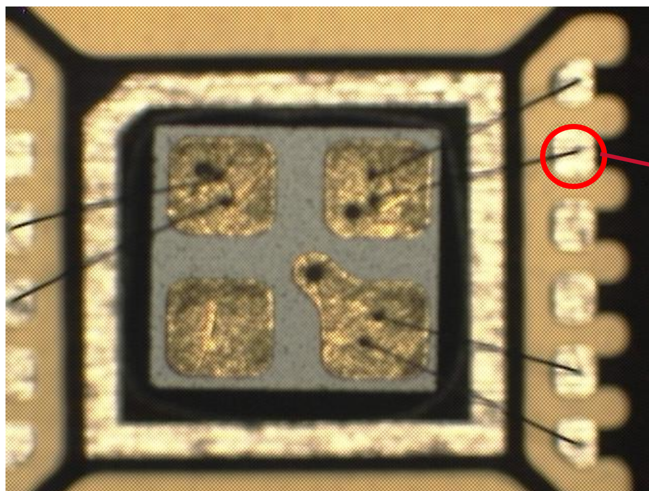
Encapsulation Highlight 1



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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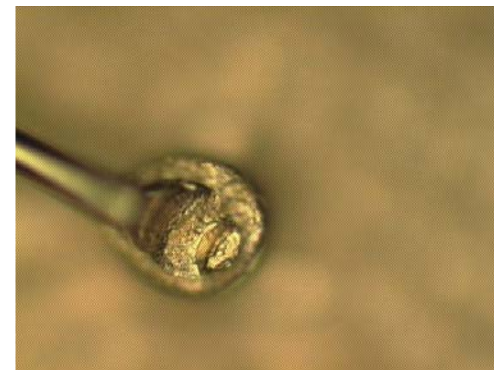
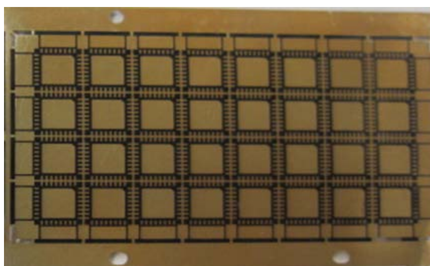


* Promex Inc. provided

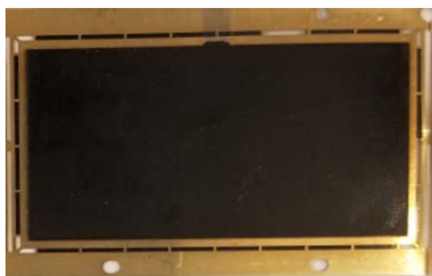
Encapsulation Highlight 2

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

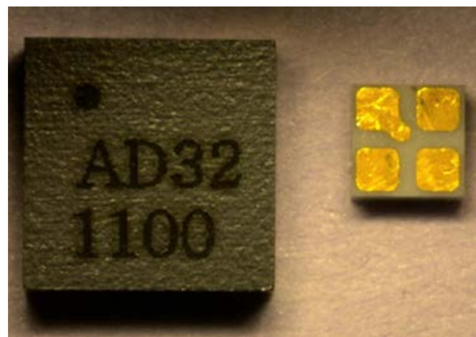
* Blank Lead Frame



* Mold Insert



* Overmolded Lead Frame



Encapsulated Product and Original G - Switch

* Promex Inc. provided

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ENCAPSULATION PROCESS

Parts from HTM Arrive at Promex

Kitting & Visual Inspection of Waffle Pack from HTM

Engineering Sample Process

Die Attach Setup & Cure

Die Shear Test

Visual /Optical Inspection

Argon Plasma Clean

Wirebonding Setup & Reverse Option

Wirebonding Pull Test

Visual /Optical Inspection

Check Mold Sweep & Broken Wires

Argon Plasma Clean

Mold Setup Insert Molding

X- Ray

Visual /Optical Inspection

Laser Mark

Singulate

Final Inspection

Packaging & Shipping

Parts Arrive at HTM for Testing

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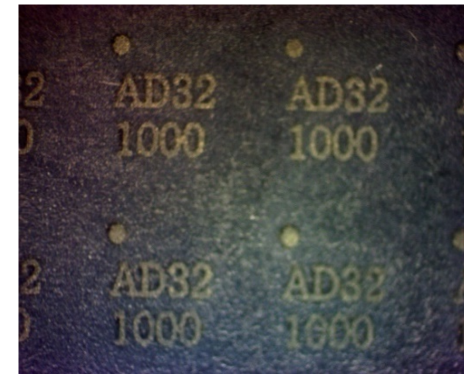
TECHNICAL CHALLENGES

ARDEC

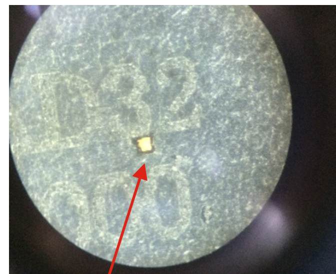
- Voids occurred on top of wire contact area during the molding process in the initial 3 x 3 x 1.5 encapsulation design.
  - Space between wire and top surface was too shallow.
  - Wire bonding was too stiff in vertical angle.
- Problem solving
  - Reverse wire-bonding adopted
  - Mold height increased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

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



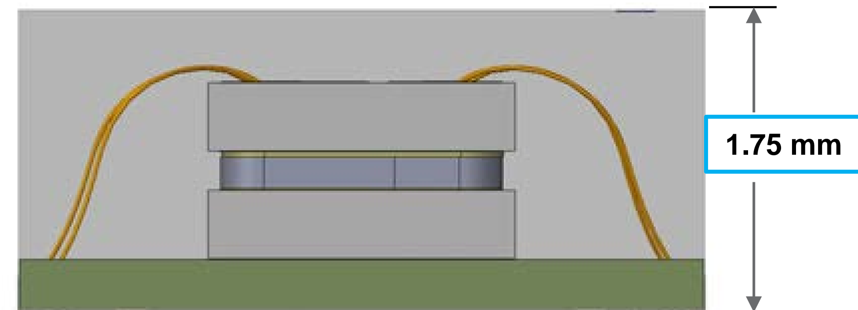
Laser Mark & Model Name

* Void on Wirebonding



No Void

1.50 mm



* 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

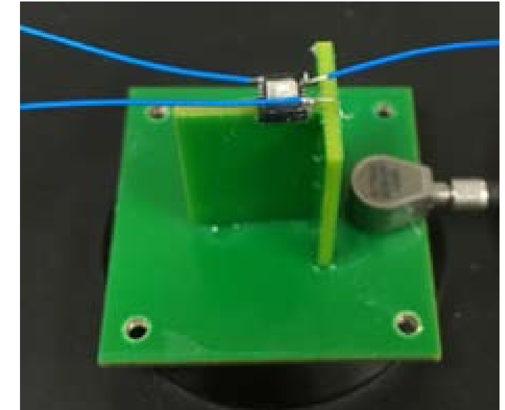
- Centrifuge test for baseline functionality before and after encapsulation to observe any changes
- Pass/Fail criteria
  A device is considered to pass if there is no apparent physical damage or deterioration and the switch still functions with its closures at threshold.

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

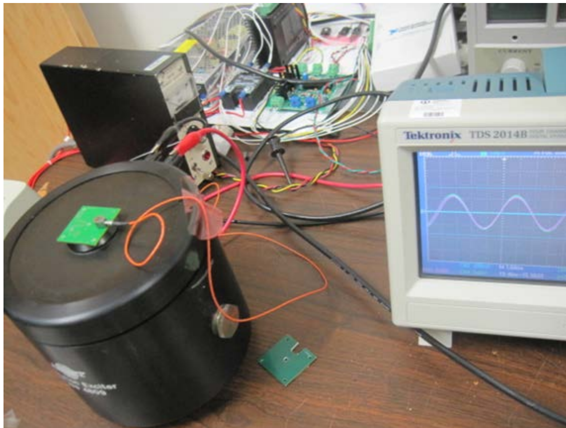
Centrifuge spinner setup

VIBRATION TEST

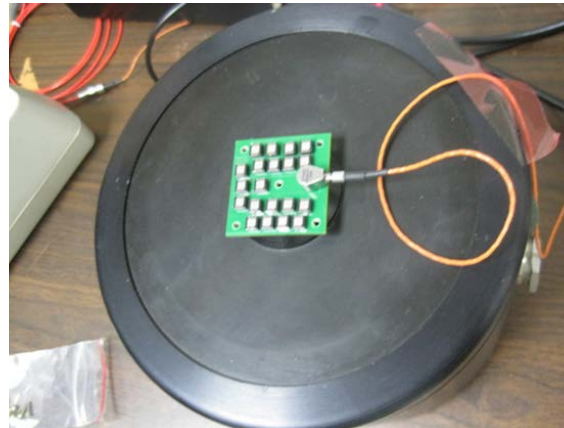
- Purpose
  Component to withstand moderate to severe vibration as a result of motion produced by transportation or field operation.
- Method
  Vibration, Variable Frequency (MIL-STD-883, Test Method 2007.3)
- Result
  All units showed an expected closure pattern at threshold range without abnormal behavior.



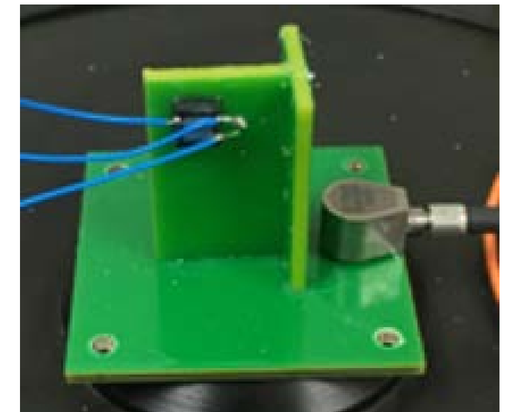
* ***Horizontal setup for spin sensing***



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



* ***Group test setup***



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

* HT Micro Inc. provided

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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

Hot chamber above and cold chamber bottom at HT Micro

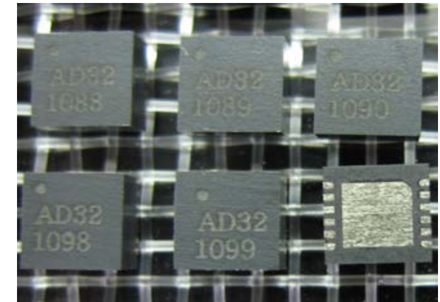
- Result
  Test data appeared to be very similar to the vibration test data and is interpreted as 'non-affected'.

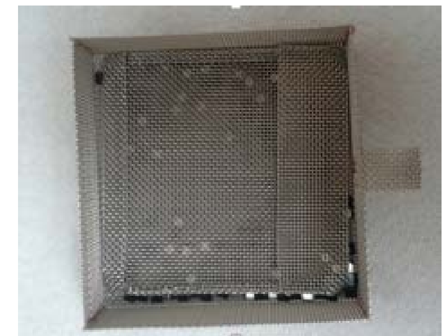
THERMAL SHOCK

- 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





MEMS devices soaked in netted container tested at HT Micro

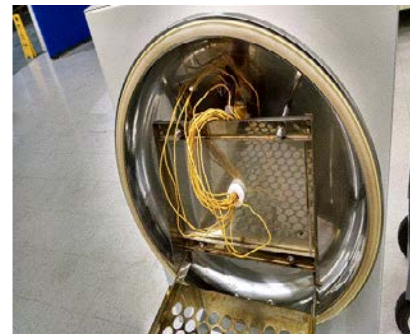
- Result
  Test data showed evenly distributed reactions in data graph indicating that the harsh environment with extreme temperatures and high humidity does not impact the functionality of the switch and the encapsulation work was well processed as well.

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)	130ºC/ 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.

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HIGH G AIR-GUN TEST

ARDEC

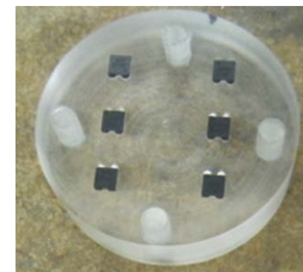
- Survivability Test for encapsulated devices subject to severe impact as a result of suddenly applied forces or abrupt changes in motion.
- Air-gun Test Configuration

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) >

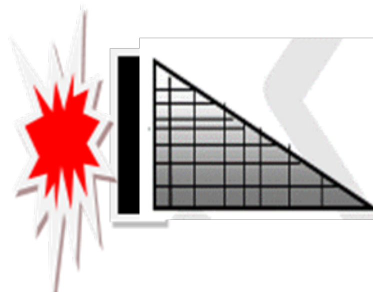
* Tested at Picatinny

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.

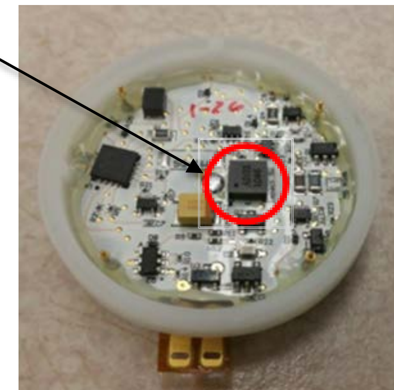
MK-19 Grenade Launcher

* Tested at Picatinny



Target with collecting net

Encapsulated G Switch



< OBR bottom view >

< OBR top 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.

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.**

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Questions?

Thank You!

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