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MEMS Safety and Arming Device for OICW

**US Army TACOM ARDEC
Fuze Division, AMSTA-AR-CCF-A
Adelphi, Maryland
301-394-0754**

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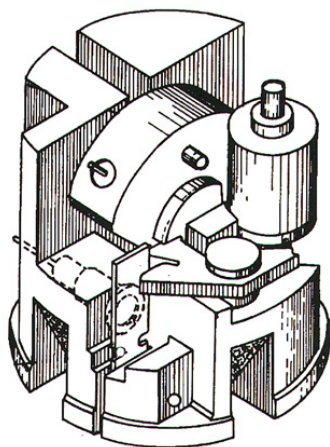
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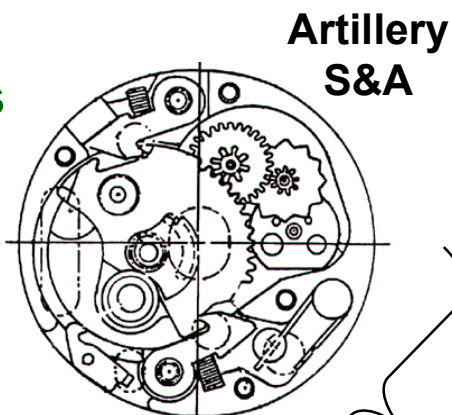


Insertion of MEMS Technology

Conventional Mechanical S&As



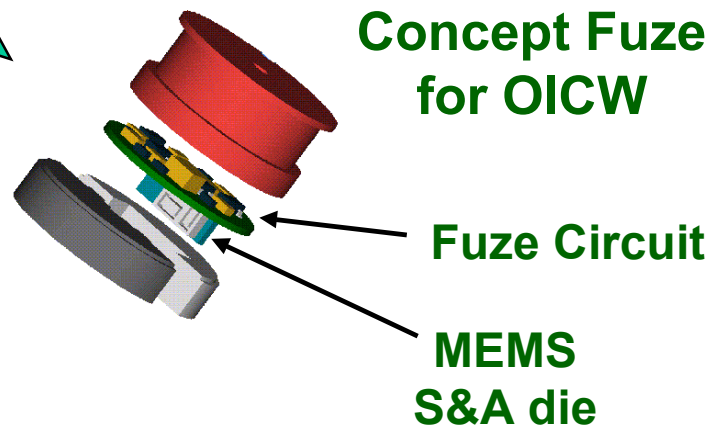
Missile S&A



Artillery S&A

Incorporate the functions of a conventional mechanical S&A in a single S&A die integrated with a fuze circuit.

A MEMS mechanical S&A is not a “sensor” per se. Rather, its components intrinsically combine both sense and actuate functions in a single unpowered chip.





MEMS S&A Team

- **PM Small Arms - Customer**
- **JSSAP - Program Sponsor**
 - OICW System Enhancements STO (Tech Base Funding)
- **Engineering Development**
 - TACOM ARDEC Fuze Division, technical and project lead
 - China Lake, explosive train (MSF) development
 - WECAC, MSF producibility
 - ARL, engineering and test support
 - Alliant Technology, test hardware



MEMS Mechanical S&A

- **Goal - Demonstrate the Feasibility of:**

- MEMS mechanical S&A device for 20-mm OICW weapon system, with
- A compatible MEMS-scale firetrain (MSF)

- **Why OICW?**

- Reduce cost, weight, volume of S&A (increase lethality)

- **Why MEMS? (micro-electro-mechanical systems)**

- Robust in high-G environments---due to scaling laws
- Economies of high-volume production---via semiconductor industry
- High-accuracy miniaturization---feature resolution of 0.5 μm (0.02 mil)
- Readily integrated with fuze electronics---sandwich CMOS with MEMS chip
- Similar mechanical S&A architecture for many weapon systems
- Implement design changes via optical mask versus retooling production line



Technical Approach

- Concept, design, analysis

- MEMS “inertial mechanical logic,” two *inertial* locks, one *command* lock
- Map S&A functions to planar domain
- Firetrain is offshoot of NAWC-CL ‘smart detonator’ technology

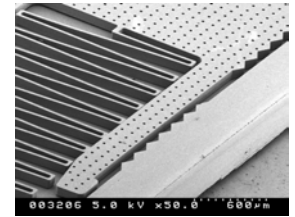
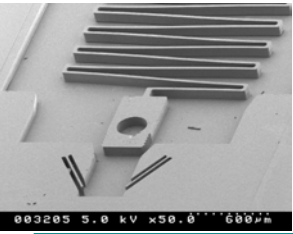
- Fabricate MEMS test structures and S&A prototypes

- Inertial (zig-zag) delays, sliders, springs, locks, latches, anchors, rotors
- Need “high-aspect-ratio” to transport meaningful amount of energetics
 - **LIGA** (Deep X-Ray Lithography), 50-200-micron, **Nickel features**
 - **DRIE** (Deep Reactive Ion Etching), 80-300-micron, **Silicon features**
- Distinct from “low-aspect-ratio” multi-layer processes such as Sandia’s

- Demonstration Tests:

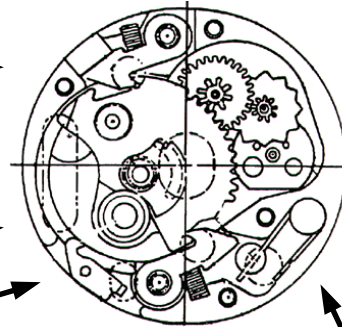
- Bench demonstration of a MEMS-scale firetrain
- Flight demonstration of MEMS S&A hardware in Sept ‘01

Enabling Technology: MEMS



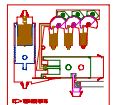
• BAD Things About *Conventional Mechanical High-G S&As*

- Large parts count
- Pick-and-place assembly
- Dissimilar materials
- Lubrication (can denature)
- Miniature 'clockworks' (shrinking domestic industrial base)
- Large 'cube' of S&A could be used other ways



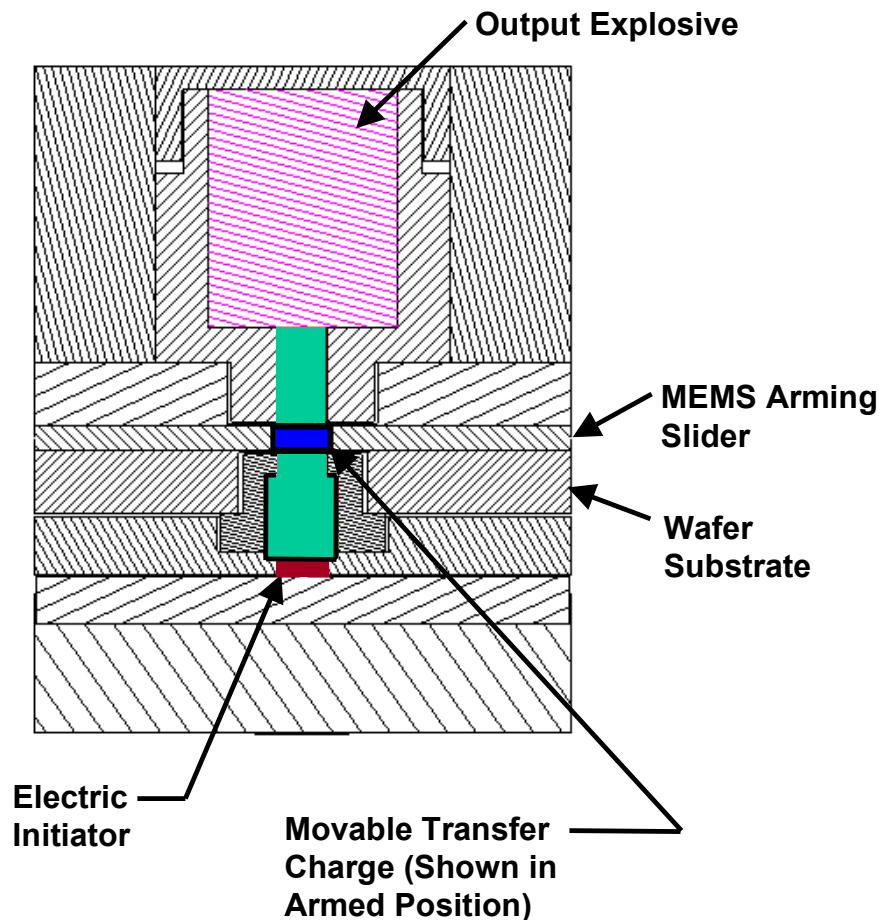
• GOOD Things about *MEMS Mechanical High-G S&As*

- Moving parts fabricated 'in situ' (wafer level assembly)
- All functional parts of same material (nickel)
- No lubrication
- Commonality for use across multiple high-g applications
- Greatly reduced mass of lead-containing explosives in MSF

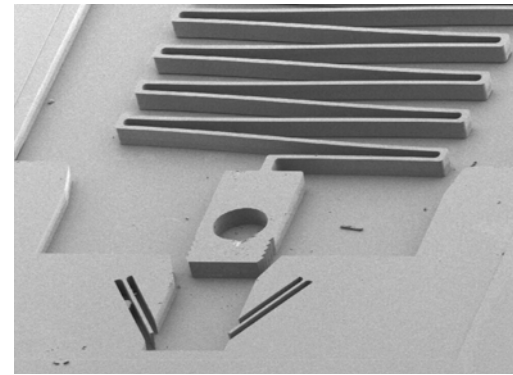




Micro-Scale Firetrain per MIL-STD-1316, and Material Selection



High Aspect Ratio

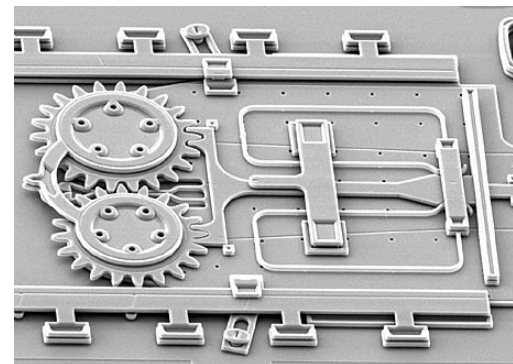


ARDEC

200- μm Nickel

Inertially-Actuated

Surface Micro-Machined



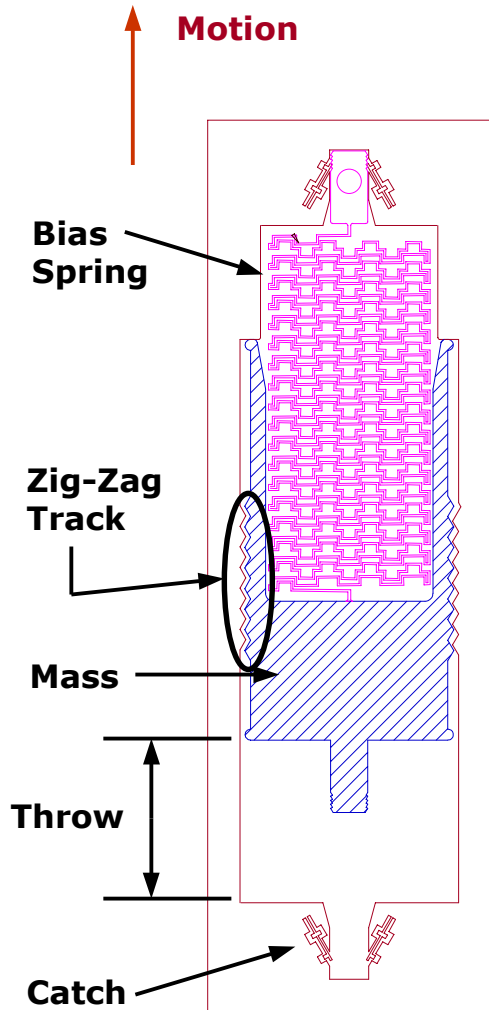
Sandia

2- μm Poly-Si

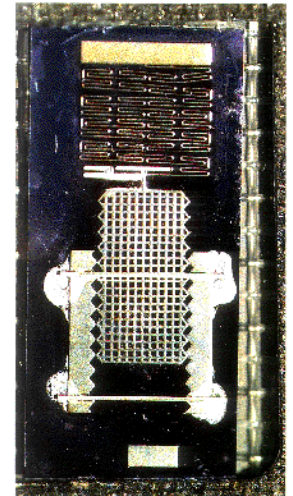
Electrically Actuated



Zig Zag Inertial Delay Slider Design



- Requirement: 40-ft Drop Safety
- Integrates axial acceleration pulses (e.g. setback) $\rightarrow \Delta V$
- Removes first lock on MEMS arming slider
- Spring resets mass after small inputs
- Design variables:
 - $\rightarrow$ slider **mass**
 - $\rightarrow$ “**throw**” distance
 - $\rightarrow$ number of zig-zag (stop/start) “**stages**”
 - $\rightarrow$ rack parameters (**pitch and depth**)
 - $\rightarrow$ **spring** stiffness and bias
- First prototype demonstrated in 1996 $\rightarrow$
- Patent no. 5,705,767

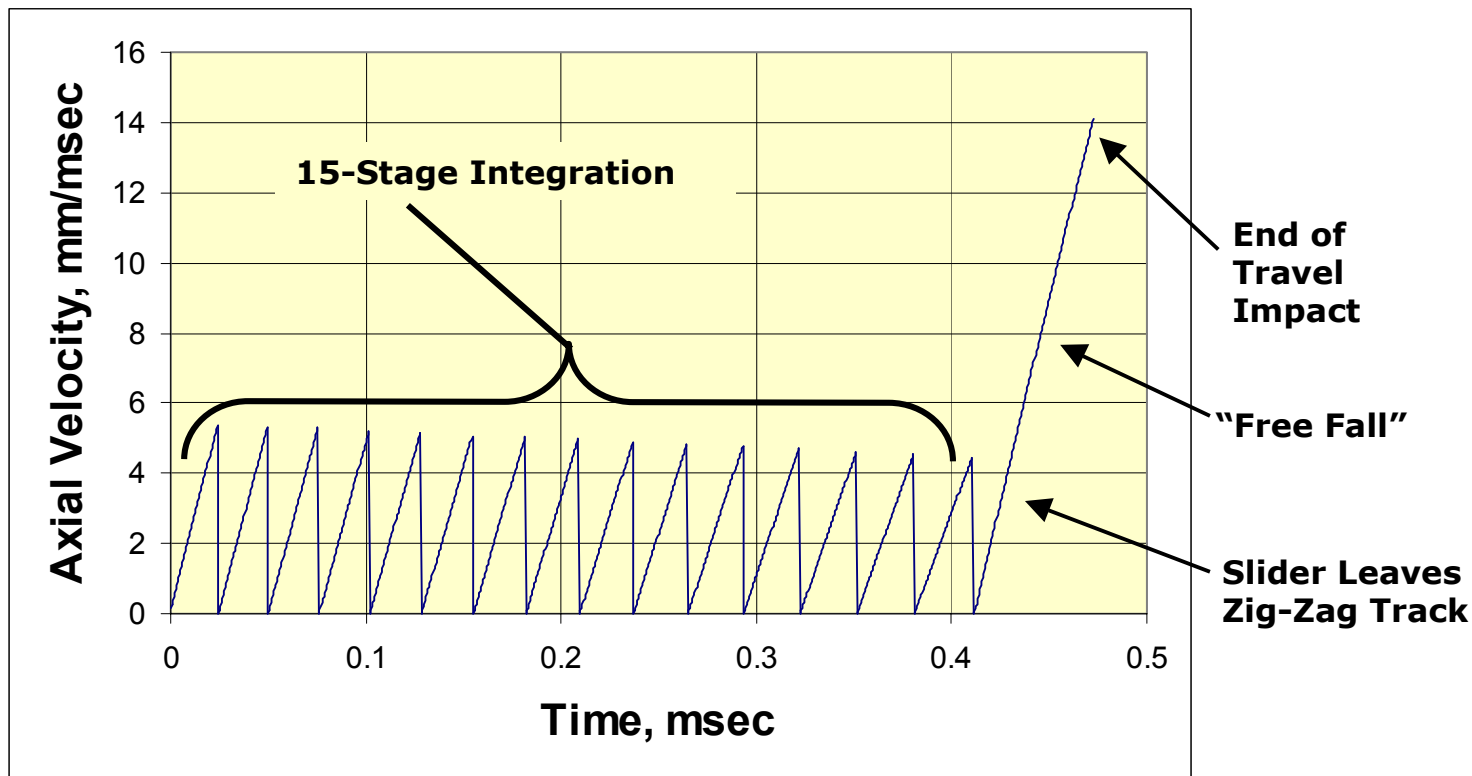
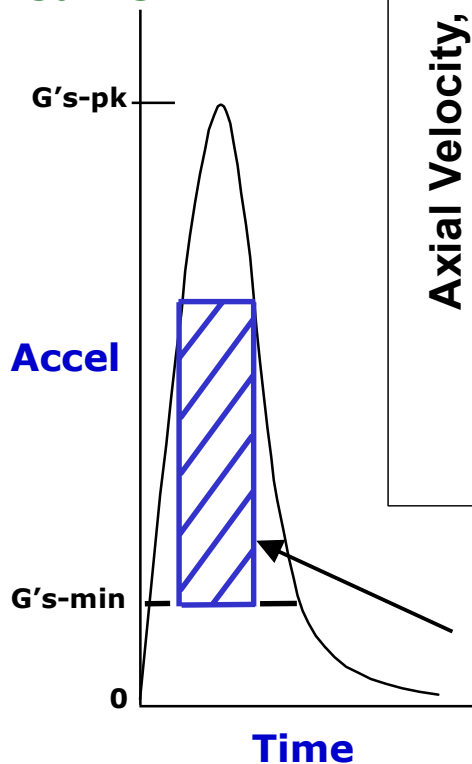




Calculated Zig-Zag Slider Motion

(Spring Pre-Bias, 45kG OICW Launch Acceleration)

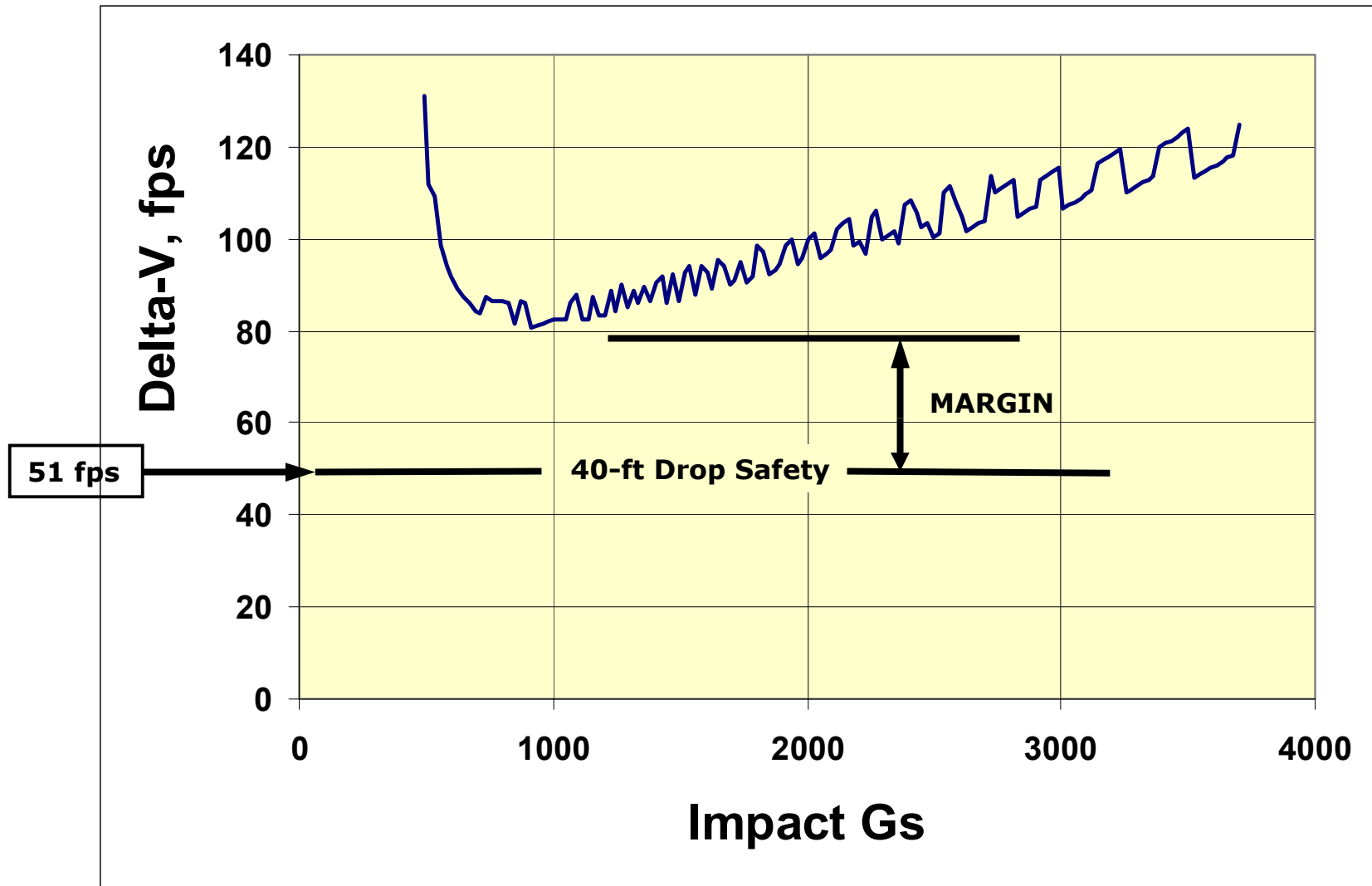
**Launch
Acceleration
Curve**



$$\Delta V = (\text{Acceleration})(\text{Time})$$
$$= \text{Area Under Curve}$$

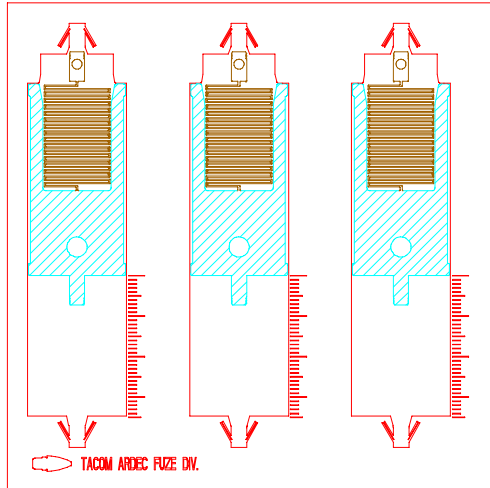


Calculated Zig-Zag Slider Arming Curve

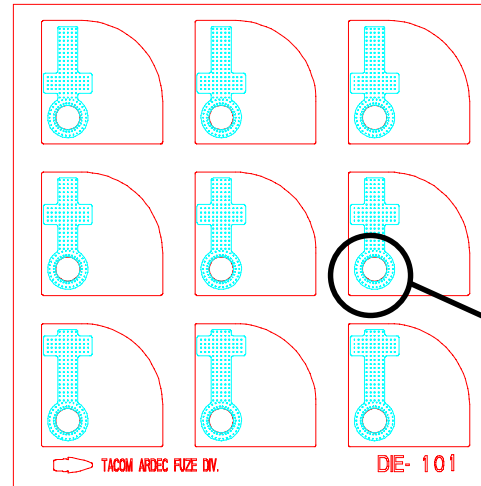




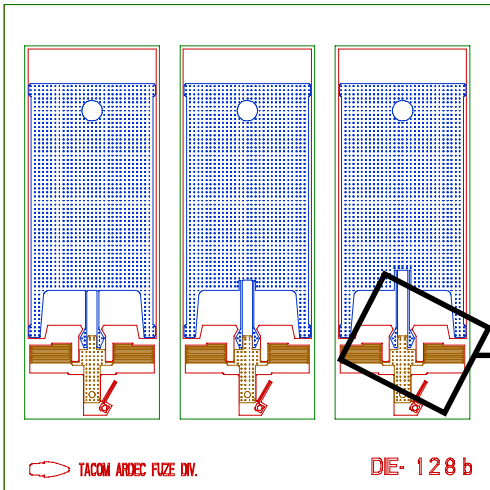
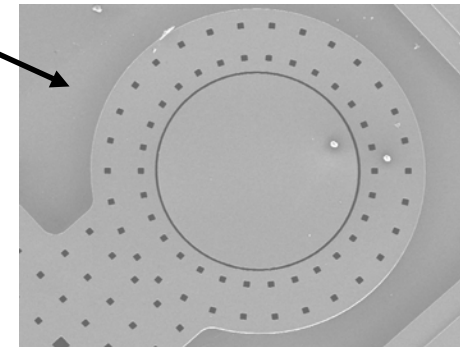
DRIE-Fabricated Silicon Structures Used to Prove out Concepts and Generate Data



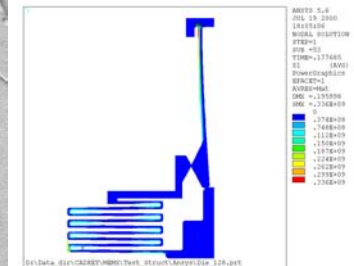
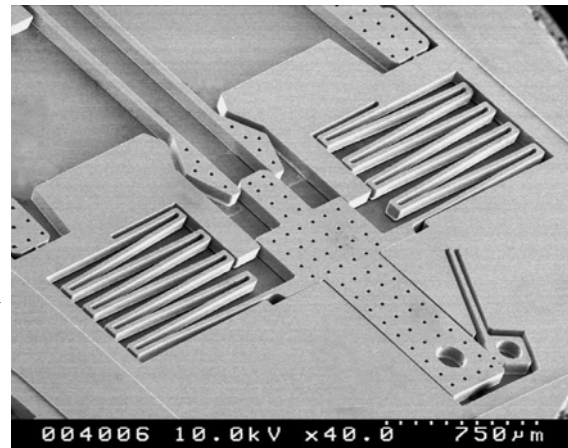
Spring/Mass with Latches



Rotors (varying radial clearance and torque)



Reversible Anchors

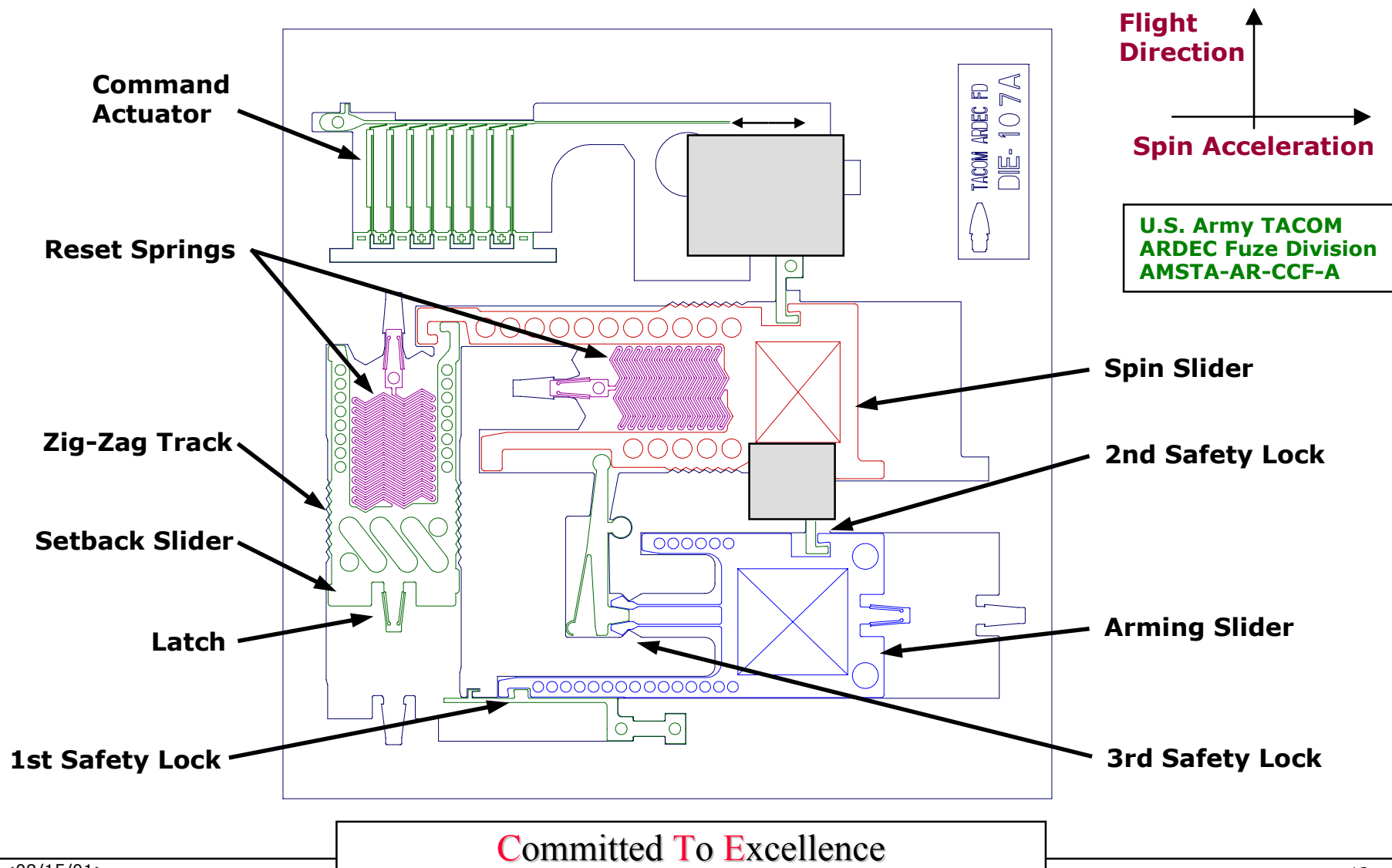


**U.S. Army TACOM
ARDEC Fuze Div.,
AMSTA-AR-CCF-A**

Committed To Excellence

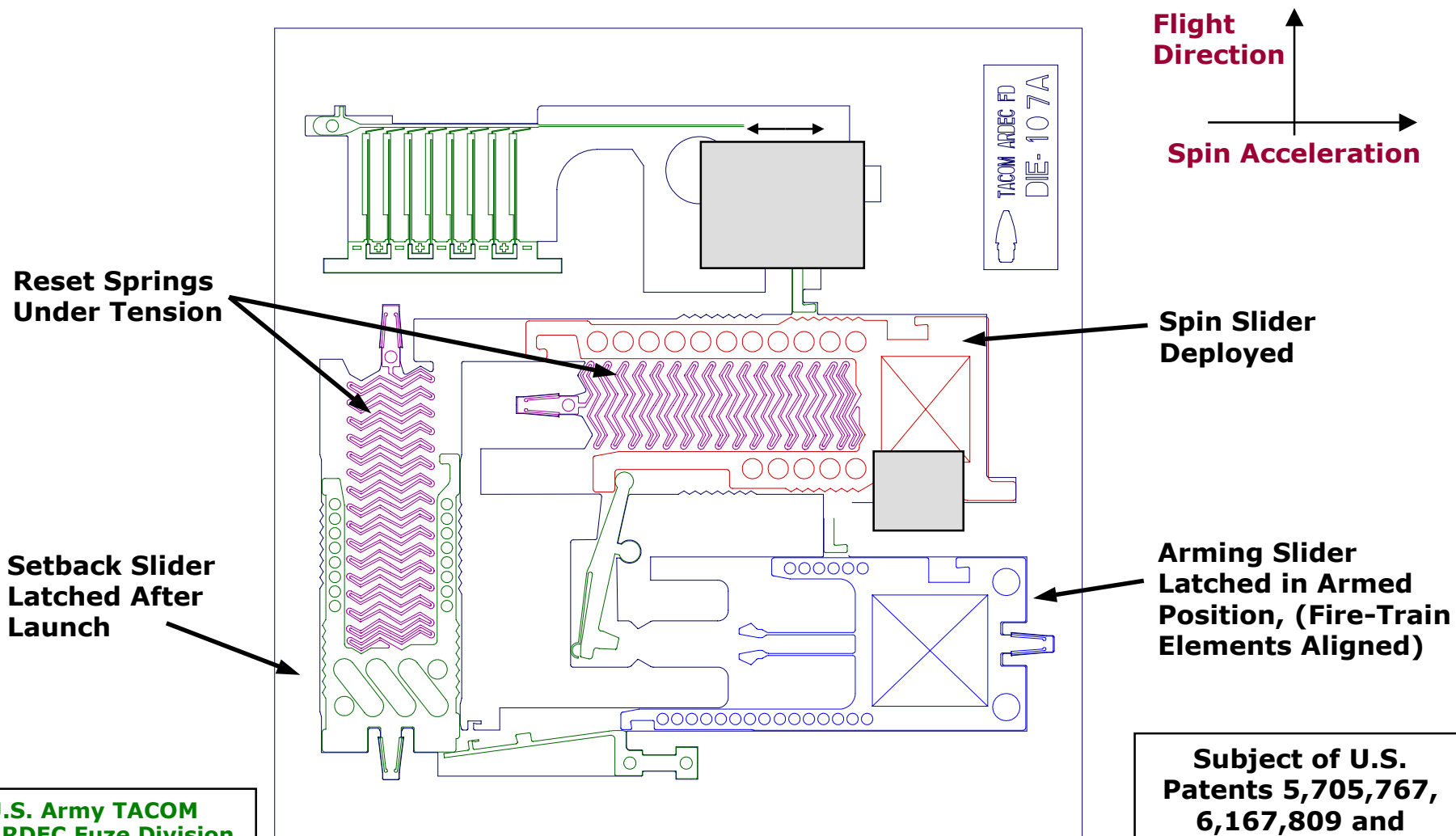


MEMS Mechanical S&A for OICW





MEMS Mechanical S&A for OICW: Armed



U.S. Army TACOM
ARDEC Fuze Division
AMSTA-AR-CCF-A

Committed To Excellence

Subject of U.S.
Patents 5,705,767,
6,167,809 and
Patents Pending



Technical Issues / Challenges

Micro-Scale Firetrain (MSF)

→ Demonstrated MSF at NAWC-CL using MEMS S&A parts, June 2001

- ♦ Test quantity was 24 units, four times that for the November '00 tests
- ♦ Samples distributed between safe, armed, and partially armed
- ♦ Obtained no detonations when in safe position
- ♦ Armed units detonated
- ♦ Partial-arming tests yielded a first cut on the 50% point (it is near 75% armed)

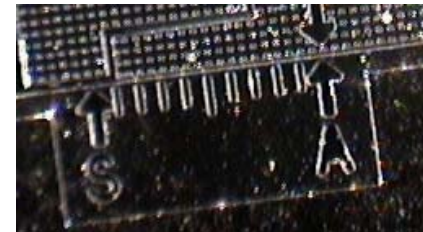
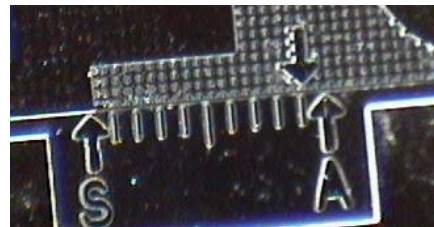
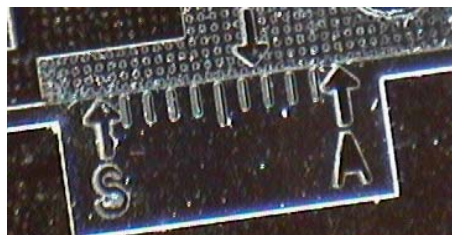
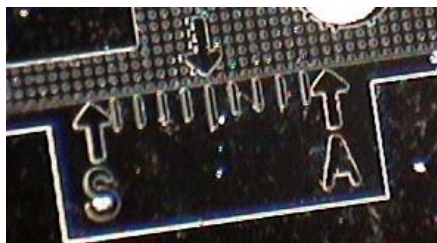
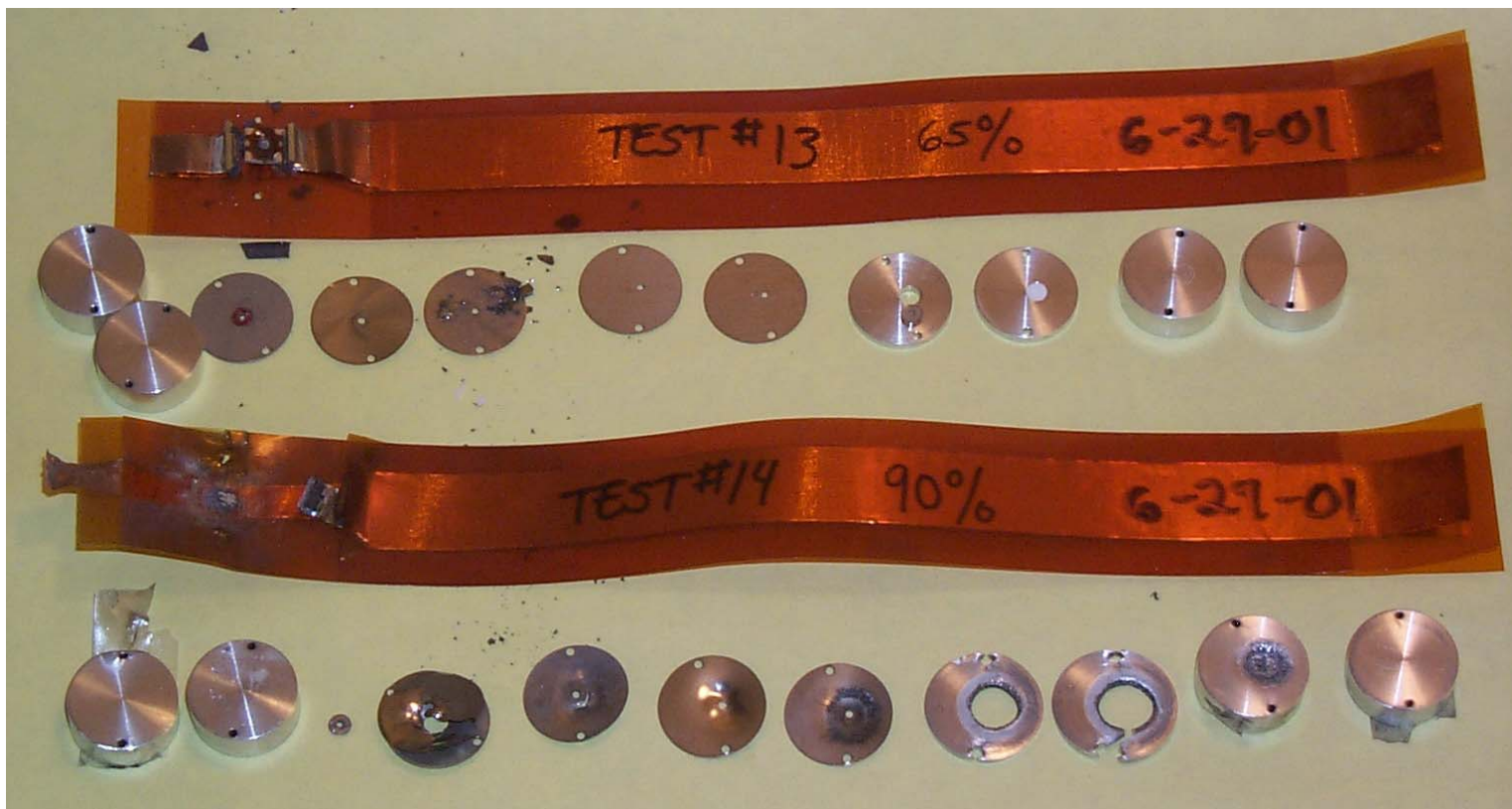
→ Next steps

- ♦ More firetrain demonstrations next month (Sept '01)
- ♦ Will be in sufficient quantities for a statistical analysis
- ♦ TACOM-ARDEC WECAC investigating economical explosive loading methods for MSF

→ Environmental: *MSF has 95% less lead-containing explosives than the M100*



Microscale Firetrain (MSF) for MEMS S&A, Preliminary Testing, June 01



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Technical Issues / Challenges

MEMS Mechanical S&A for OICW: GETTING PARTS

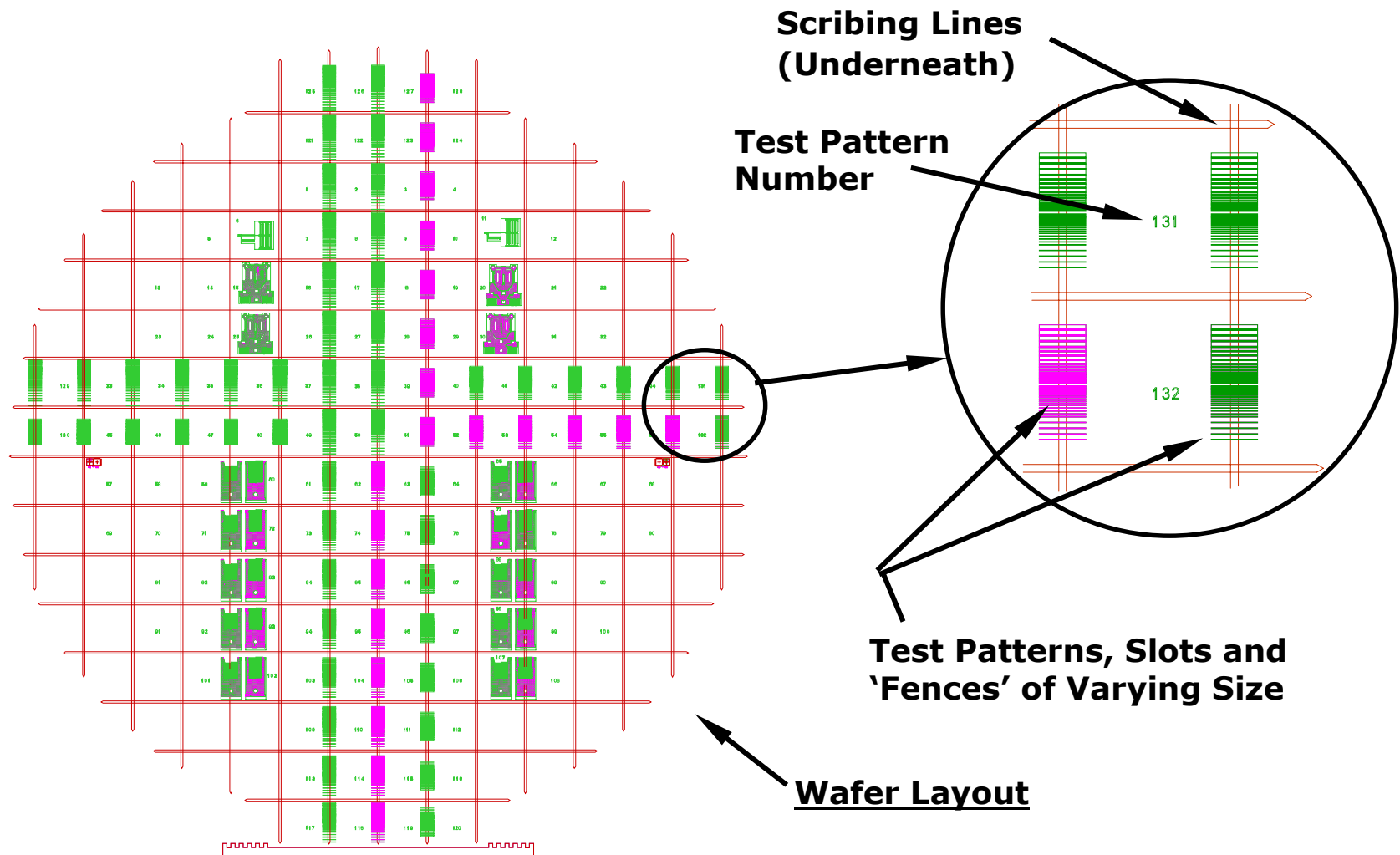
A. Demonstrated concepts, designs, analyses, properties of structures in *silicon*

- Defining features and implementing ‘mechanical logic’ appears viable
- DRIE (silicon) parts delivery later this month, BUT...
 - a. Fabrication cycle time is long (~ 6 months) and yield is low (< 20%)
 - Pursuing “massively parallel iterations,” trying many approaches at once
 - b. ‘Stiction’: parts don’t release or they release and then re-adhere
 - Developed special process methods to avoid liquid immersion
 - c. Impact testing showed silicon parts vulnerable at high strain rates
 - d. Silicon for demonstrating concepts, need ductile material for functional parts

continued...



Test Patterns to Investigate Silicon Deep-Etch Process Variation





Technical Issues / Challenges

MEMS Mechanical S&A for OICW: GETTING PARTS, continued

B. Next stage is move to nickel (LIGA) parts for ductility

C. Anticipate improved MEMS fabrication methods in future

- Manufacturability based on high-volume “printing” of nickel parts via LIGA “master”
- With improved firetrain can resort to well-established HAR fabrication techniques

D. Doing a MEMS S&A cost study for OICW production

- Consulting high-throughput MEMS manufacturers
- “Assuming 10M parts using advanced MEMS technology five years from now...”
- Investigating breakthrough wafer-scale explosive loading techniques for MEMS



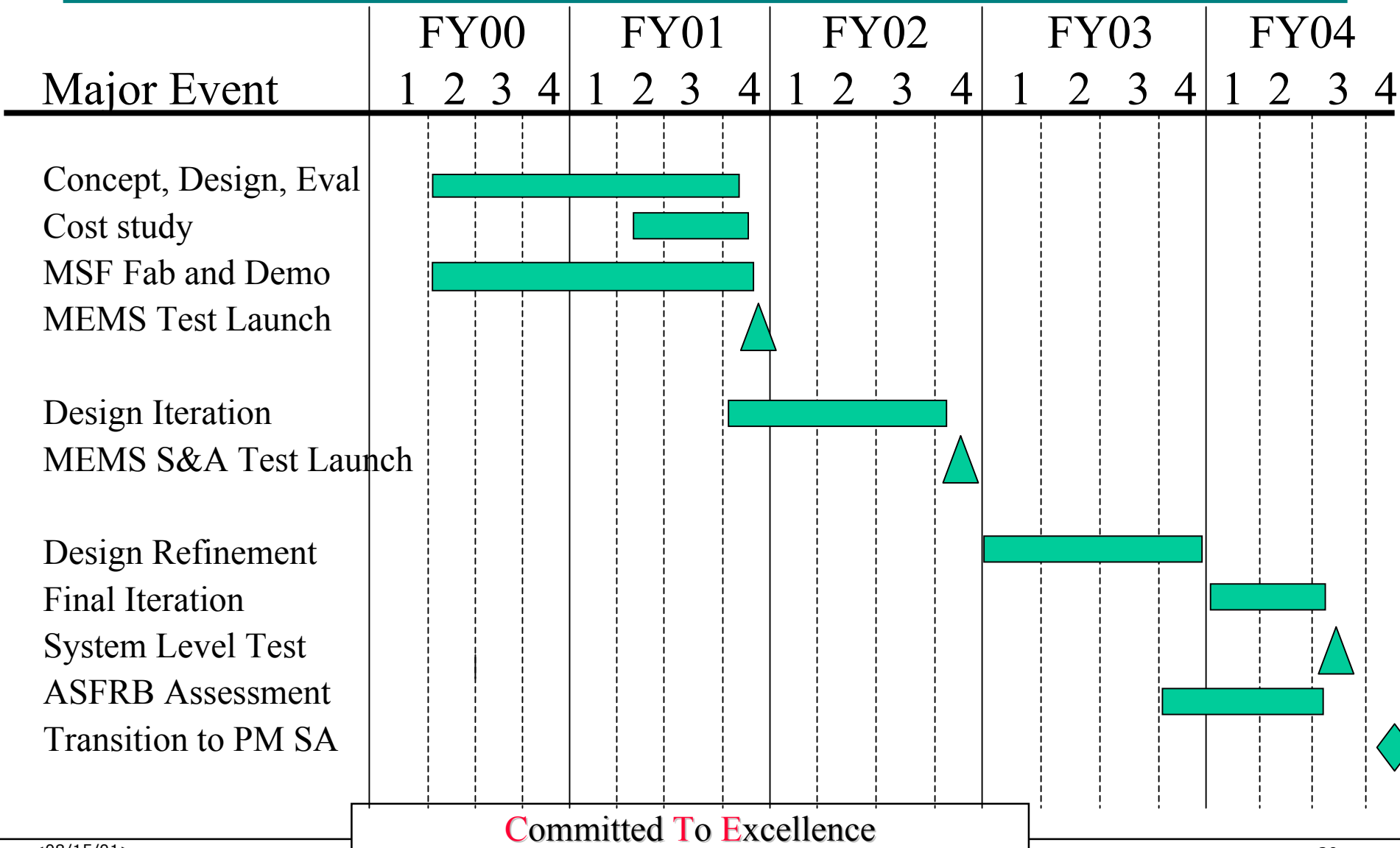
SUMMARY

- **MEMS - Enabling Technology for Fielding of OICW and OCSW**
 - Meet S&A cost and volume (lethality) targets
 - Revolutionize fuzing for small arms
- **Technology Barriers Remain:**
 - “MEMS is an emerging technology” (M. Huff, CNRI MEMS Exchange, July 2001)
 - New fabrication technologies still coming on line
 - Infrastructure is behind the demand curve...judicious prototyping
 - We will continue to work out the feasibility...
 - But *the next major challenge will producibility.*



MEMS S&A for OICW

(OICW System Enhancements STO)





OICW System Enhancements

Technology Readiness Level (TRL) Maturity

