TACOM

Mobility and Firepower for America's Army

NDIA Small Arms Conference

21-24 June 1999

MEMS-Based Fuze Safety and Arming Device

presented by:

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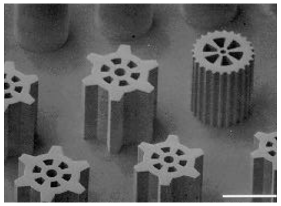


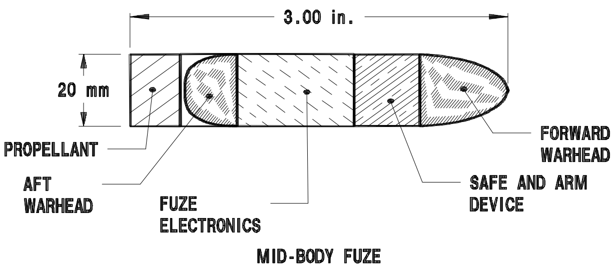
Key Technology: MEMS

- **MEMS = Micro-electro-mechanical Systems**
- **Methods of MEMS Fabrication:**
  - ▷ **Low Aspect Ratio: structures 1 to 10's ?m deep**
  - → *surface* micromachining: deposition layer(s) become structure
  - → *bulk* micromachining: substrate becomes structure (54.7 degree angle)
  - → *RIE* (reactive ion etching): substrate becomes structure (90 degree angle)
  - ▷ **High Aspect Ratio: 10's to 100's of ?m deep, vertical edges**
  - → **LIGA** (Deep X-Ray Lithography), 200-micron **Nickel**
  - → **DRIE** (Deep Reactive Ion Etching), 200-micron **Silicon**
- **For mm-sized parts transmitting forces laterally on a plane, High-Aspect-Ratio (HAR) MEMS is needed.**

Why MEMS in Fuze Safety and Arming?

- **Low cost and miniaturization of fuze S&As for projectile munitions**
- **Reduce reliance on dwindling on-shore industrial base of small-precision-parts manufacturers, instead utilize installed micro-electronics industrial base.**
- **"Enabling" technology for special applications**
  - — distributed fuze architectures (versus puck-shaped S&A)
  - — places where ESAs are currently impossible : e.g., 20-mm fuze
  - — unpowered sensing and recording of setback / spin
  - — "fuze on a chip" -- 10 years out?
- **Technology transferable to other weapon platorms**
- **Meet usual requirements for logistics and handling safety** (e.g., 40-ft handling-drop) **same as "macro" designs**
- **Eliminate shelf-life problems caused by lubricants in conventional mechanical S&As** (MEMS parts require no lubrication)

Components and Requirements of a Fuze



Fuze

- 20-year storage
- 10-sec operational life
- Gun-launch survivability
- No maintenance

Safety and Arming Device (S&A)

MEMS

- Two independent launch signatures
- Derive arming energy from launch environment
- Physically move initiator from “safe” to “armed” position
- Safety failure rate < 1 in 10^6 uses

Timer / Target Detector

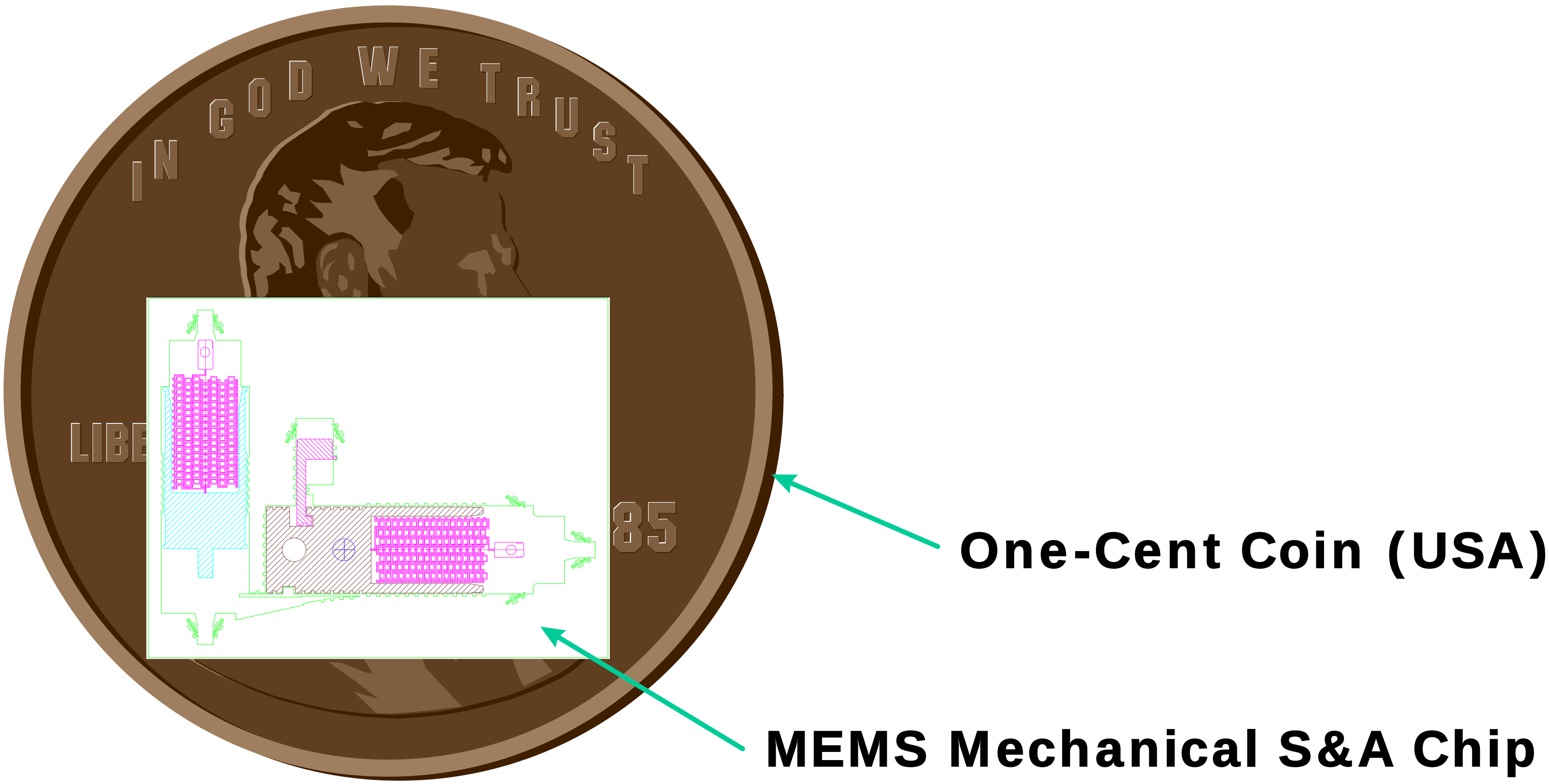
- Turns counting for range
- Impact / Graze switch
- Clean-up delay timer

Explosives Initiation System

MEI / MEMS

- Store initiation energy
- Transfer initiation energy
- Initiate detonation

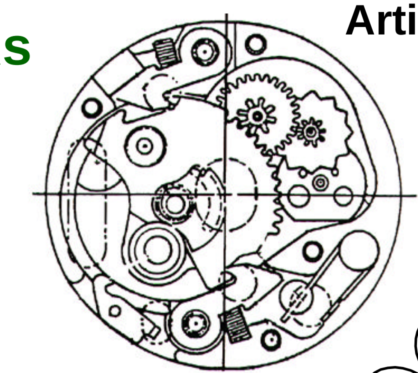
How Small Can a Mechanical S&A Get?

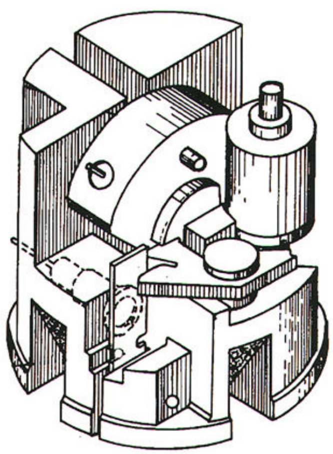


Insertion of MEMS Technology

Conventional Mechanical S&As

Artillery

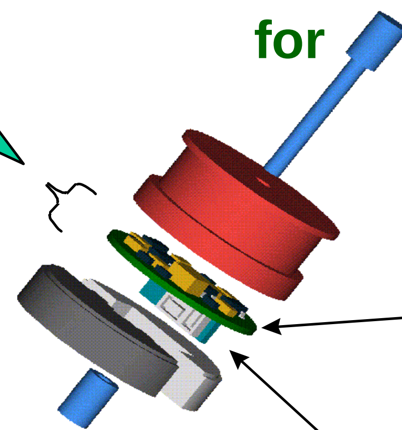




Missile

This concept takes all the functions embodied in a conventional mechanical S&A and implements them in a single S&A die which is integrated with a fuze circuit board.

Concept Fuze for OICW



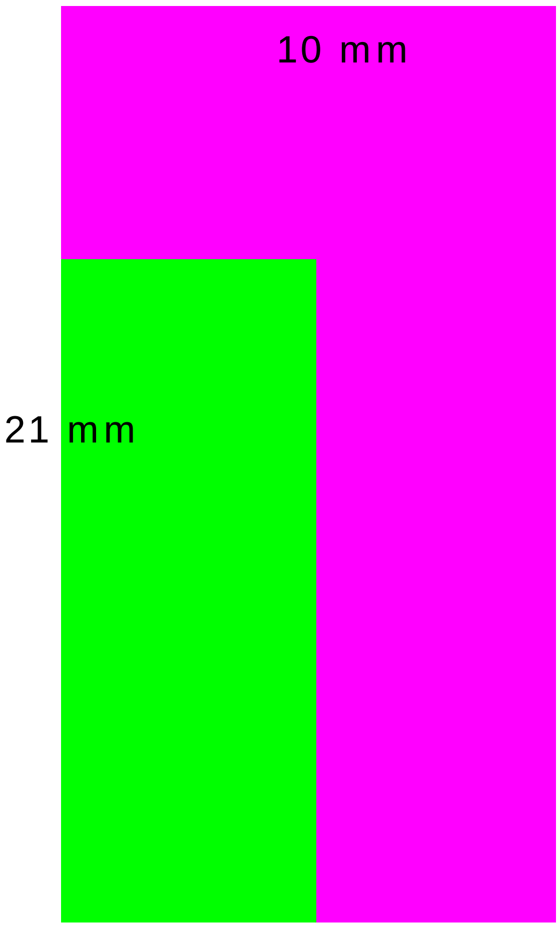
Note: a MEMS mechanical S&A is not a "sensor" per se, but rather its components intrinsically combine both sense and actuate functions in a single unpowered chip.

MEMS Teaming Efforts to Date

- **CRADA with MCNC, FY96**
  - → HI-MEMS Alliance, DARPA funding, fabrication by MCNC/CAMD
  - → designed, prototyped, tested *first microscale zig-zag slider*
- **Commercial Technology Insertion Program (CTIP), FY97**
  - → ONR funded, developed & prototyped *first single-chip mechanical S&A*
- **Commercial Technology Insertion Program (CTIP), FY98**
  - → developing air flight sensor (AFS) for G-MLRS fuze S&A using COTS MEMS
  - → mortar test of prototype AFS in FY97
- **MEMS S&A Feasibility Study, XM-80 Submunition on ERGM, FY98**
  - → funded by NAVSEA through NSWC-IH Underwater Technology Division
  - → developed S&A design and investigated MEMS fabrication technologies
- **DARPA/JSSAP, Development of MEMS S&A for OICW/OCSW, FY99**
  - → current effort
  - →
  - →

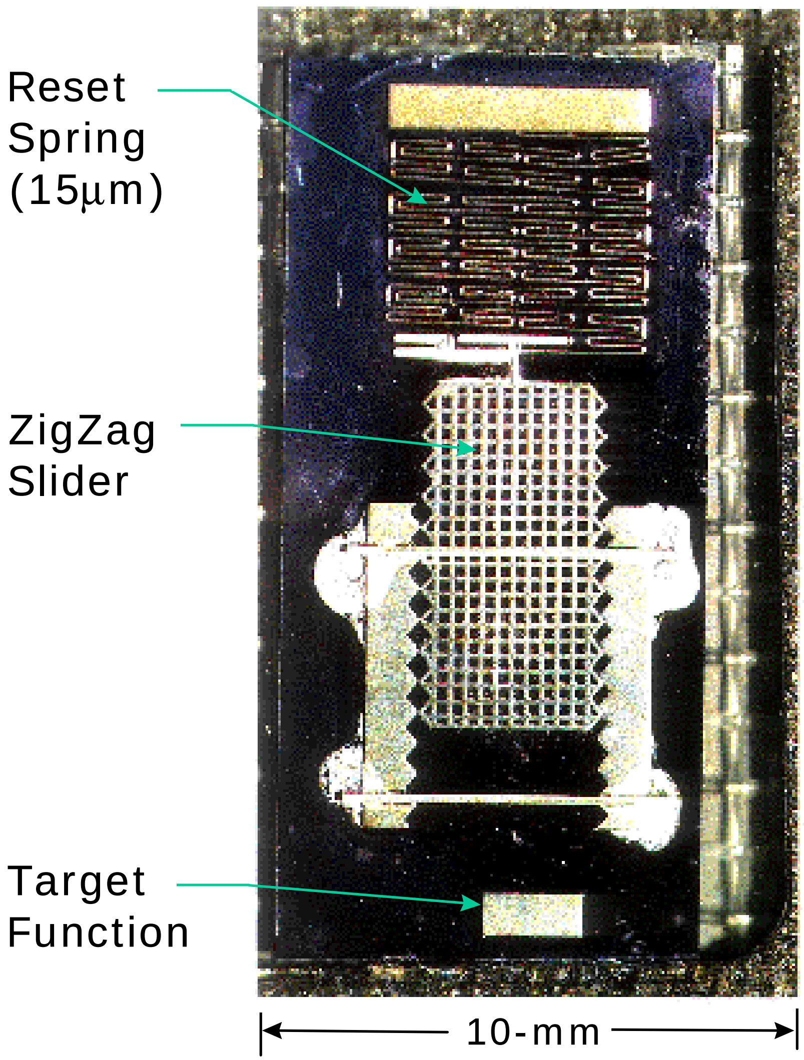
MEMS Zig-Zag Slider:

"Inertially-Actuated, Inertially-Damped, Delay Slider/Actuator"



- **small, planar vs. cylinder (historical)**
- **high-aspect-ratio MEMS**
- **design variables:**
  - $\rightarrow$ **mass of slider**
  - $\rightarrow$ **"throw" (about 4-mm)**
  - $\rightarrow$ **number of "stages"**
  - $\rightarrow$ **spring stiffness**
  - $\rightarrow$ **side stroke and tooth angle**
  - $\rightarrow$ **operating acceleration range**
- **design requirement:**
  - $\rightarrow$ **40-ft drop safety**

Fabricated and Tested Zig-Zag Delay Device



Characteristics:

- fabricated in 200-µm LIGA (nickel) at MCNC in 1996
- launch acceleration moves zig-zag mass down the track
- stop/start motion approximately integrates accel-time curve
- programmed delay set by number of stop/start "stages"
- spring resets mass after small inputs
- performance demonstrated in centrifuge test, July 1996
- patent No. 5,705,767

Current Efforts--Sponsorship

Development of MEMS S&A for OICW / OCSW

This Effort is Part of the OICW Systems Enhancements STO

DARPA/JSSAP Funding $1.4M

- **OICW/OCSW MEMS Mechanical S&A**
  - → 6.2-type effort to develop a MEMS mechanical S&A device for the OICW/OCSW fuze, using analysis methods, designs, and data obtained in part from the ILIR effort.

Other ARDEC Funding $75K

- **ILIR**
  - → 6.1-type effort to evolve analysis methods, designs, and test data to form the knowledge and design base for future MEMS mechanical S&A designs (not specific to the OICW)

Implementing MEMS S&A in OICW

Approach

- **Develop, demonstrate and evaluate a MEMS mechanical S&A**
- **Embody well-understood approach of existing mechanical S&As**
  - → Dual independent launch signatures (provide handling safety)
  - → Multiple sequential interlocks on arming slider
  - → Launch-environment-driven mechanical arming
  - → Consistent with MIL-STD-1316 (Fuze Safety Starndards)
  - → Outputs detonation wave to secondary explosive
- **Mechanical S&A is not a “sensor” but a “machine”**
  - → its components intrinsically combine sense / actuate functions
- **Conduct laboratory and dynamic field test demonstrations**

Benefits

- **Reduce length/volume of S&A device**
  - → allows larger warhead or reduced cartridge size
- **Reduced explosives volume in S&A may reduce hazard in manufacturing**

MEMS S&A for OICW -- FY99

1.1 Concept Generation: requirements, architecture, action timeline

1.2 High-Aspect-Ratio MEMS Fabrication Technologies

- → DRIE fabrication at MCNC/Cronos Integrated Microsystems
- → LIGA and Optical-LIGA at MCNC/Chronos

1.3 Device Design and Analysis:

- → design mass, spring, rotor, latch, and zig-zag test structures
- → design individual components, e.g., spin latch elements
- → analyze performance as medley of components

1.4 First Fabrication (June): test structures in DRIE

1.5 Second Fabrication (Nov 99): MEMS components, packaging, MEI

1.6 Device Testing: centrifuge and drop table testing

2.0 FY00-- More of same, ending in field test demonstration

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Parallel Effort: Micro-Energetic Initiator (MEI)

- **The MEI is a key element for MEMS S&A designs**
- **MEMS and “macro” detonators (e.g., M100) do not mix:**
  - → M100 is too large for MEMS devices to manipulate
  - → MEMS chip cannot block explosive output of a detonator
- **Requirements of MEI**
  - → small enough for MEMS components to manipulate
  - → powerful enough to detonate secondary explosives

Summary

→ **First Small Arms MEMS S&A Being Developed**

- **reducing designs to practice in DRIE or LIGA**

→ **Development of Micro-energetic initiator (MEI) Key Element**

→ **Protection of Intellectual Property Paramount**

→ **MEMS Will Reduce S&A Cost 50+%**

→ **DARPA/JSSAP Co-Funding MEMS S&A Initiative**