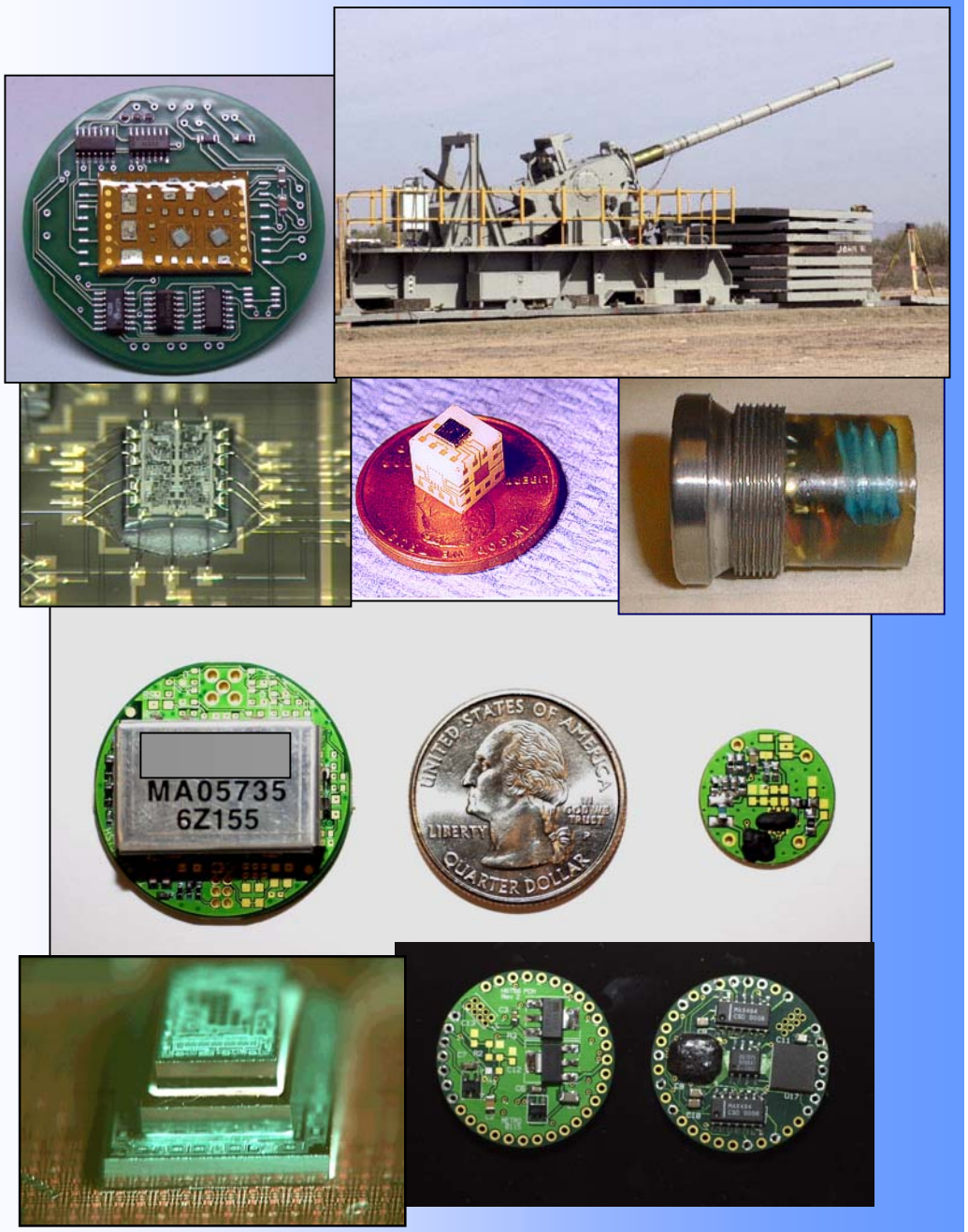
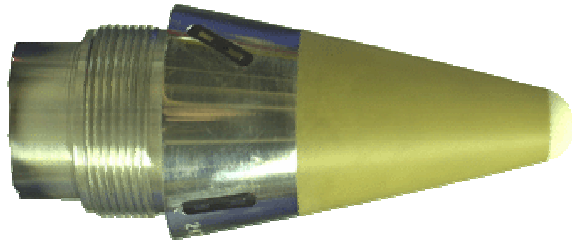




Embedded Instrumentation Technologies for Munitions

David H. Lyon

Chief, Advanced Munitions Concepts Branch

Weapons and Materials Research Directorate
Army Research Laboratory

Embedded Instrumentation
"The Way it Was, Is Now, and Shall Be"

- Used to be - On-board instrumentation was a "nice to have" but seldom made the cut
  - Devices were obtrusive and difficult to integrate
    - Power hungry, heavy, bulky, expensive, limited capability
  - Solutions often required swapping payload for TM
- Then - A combination of developments
  - Microelectronics industry blossomed
    - PCs, Cell phones, GPS receivers
  - MEMS sensors proliferated into the commercial market
- By the Way - Data requirements for smart munitions increased dramatically
- Now – A proven suite of technologies exists for truly embedded instrumentation & telemetry solutions
  - Complete KE tracer well systems
  - Extreme capability on-board recorders

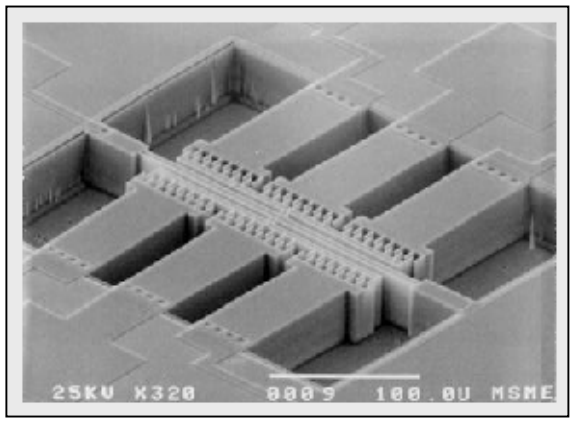
Why Munition-Specific Developments?

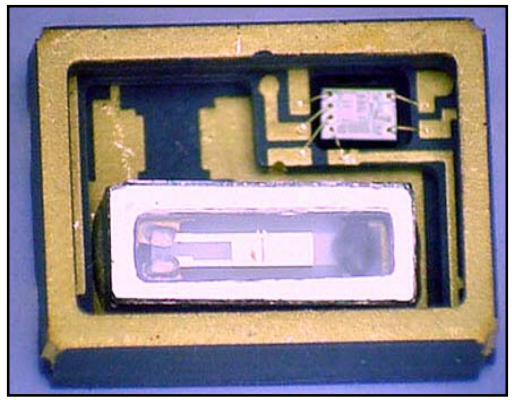
- The Army and OSD identified T&E gaps and created programs to address them
  - Hardened Subminiature Telemetry and Sensor System (HSTSS) Program, tri-service
  - Army Research Laboratory commitment
  - Central Test & Evaluation Investment Program (CTEIP) related efforts
- T&E applications logically transform into embedded solutions (tactical)

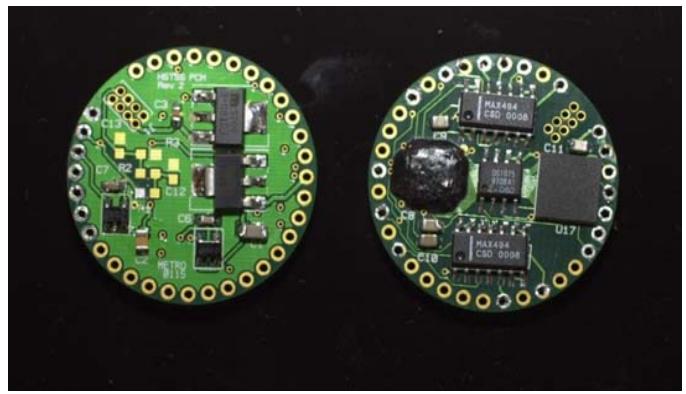
Hardened Subminiature Telemetry and Sensor Systems (HSTSS)

Goal: **Develop advanced instrumentation and packaging for the T&E of high-g, gun-launched smart munitions**

Approach: **Utilize COTS technology, leverage DARPA investments, use ARL as technical lead and systems integrator**







Pacing Technologies:

- Design and procurement of die level comp.
- Advanced packaging technologies - MCM, Chip Stacking, Flip Chip
- MEMS based sensors

DoD/Warfighter Payoffs:

- Lower-cost and lower-risk development cycle for smart munitions
- Embedded diagnostics in every round for seemless transition from R&D, to Production, to Life Cycle monitoring

Components (Reference Oscillator)

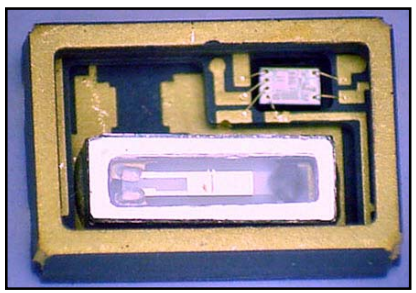
STATEK

Statek Crystal Reference Oscillator Requirements

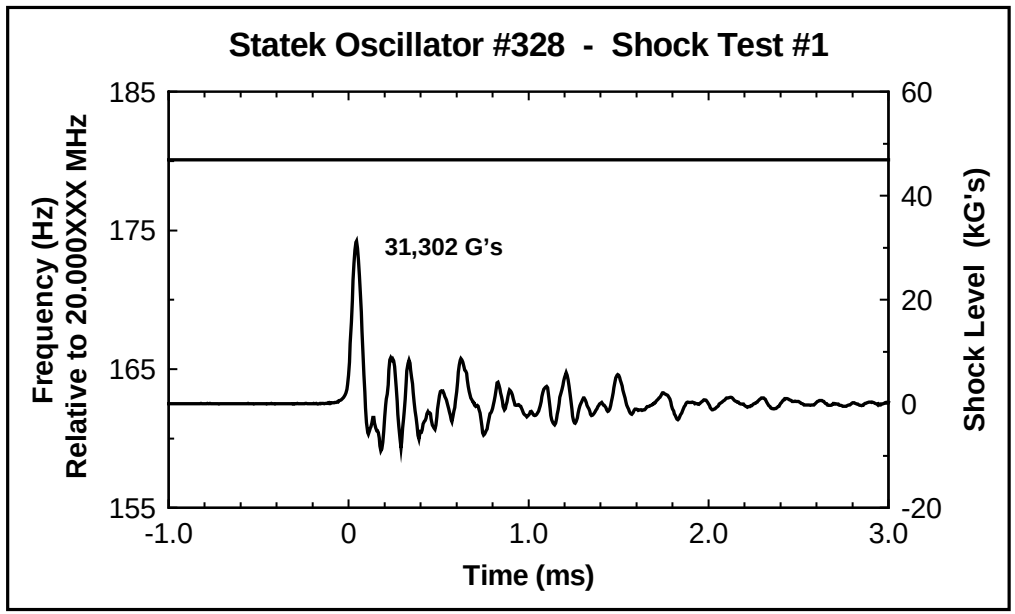
Nominal Output Frequency	20MHz	**Acceleration Sensitivity**	0.4Hz/G
Frequency Stability	+/- 20ppm	**Phase Noise**	-140dBc/Hz max at 100kHz
Output	Square Wave	**Jitter**	250ps max
Supply Voltage	3.0V (+/- 5%)	**Rise/Fall Time**	8ns max
Max Physical Size	350 x 300 x 150 mils	**Duty Cycle**	40% - 60%
Operational Temperature Range	-40 to +85degC	**Current Draw**	5mA max
Shock Ranges	500G, 30kG, 100kG	**StartUp Time**	10ms max

Crystal Resonator

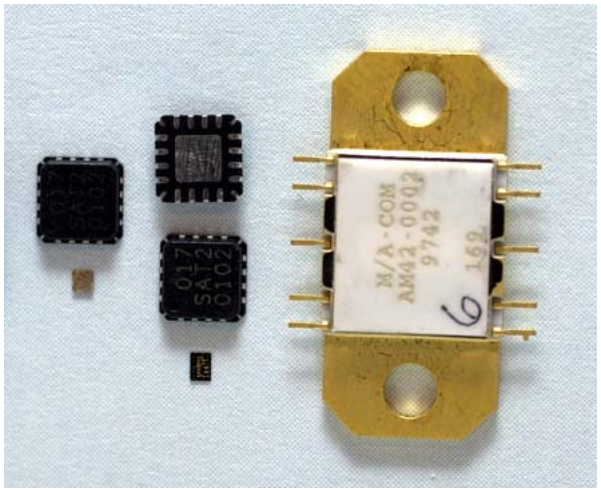
Oscillator

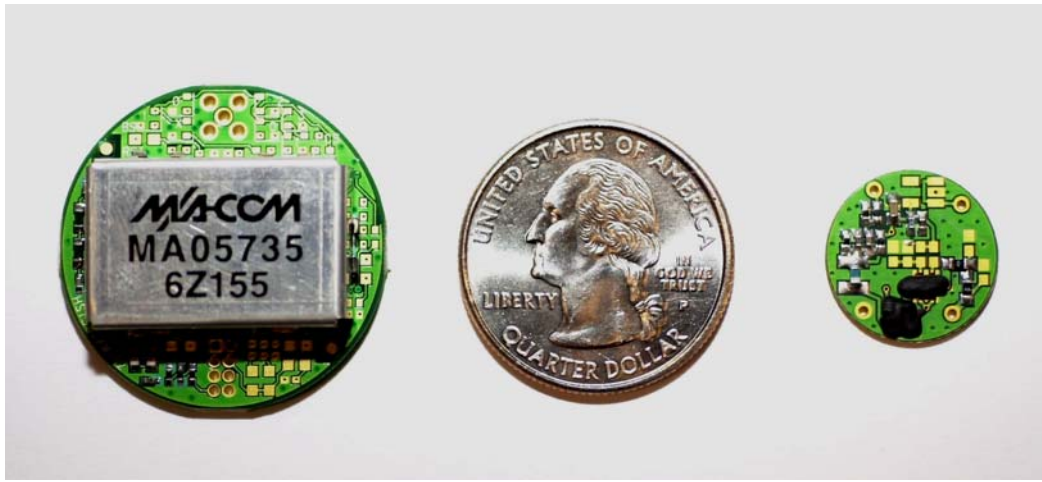


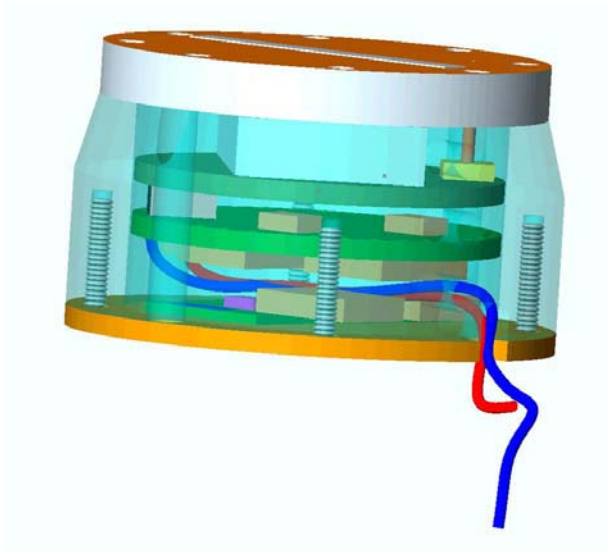
Crystal Resonator Mounted Inside Oscillator Package



Components (Transmitters)



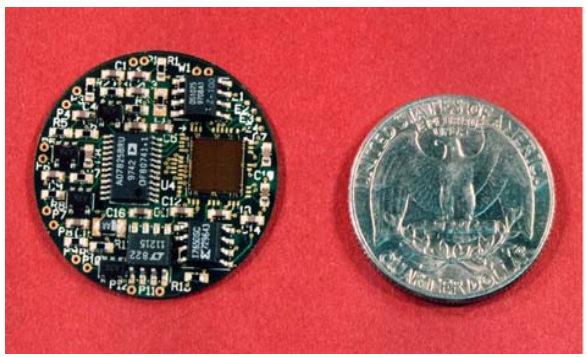




tyco Electronics MACOM

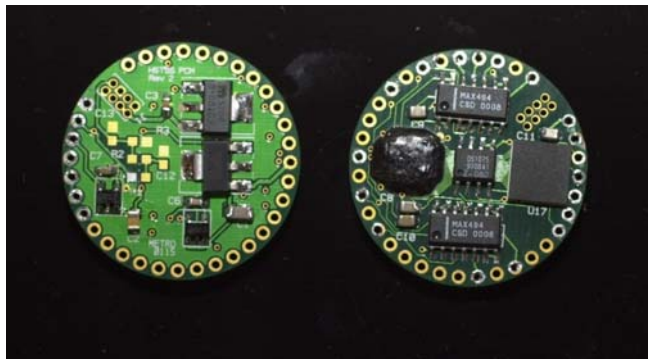
Modules (Data Acquisition)

- CPLD based Pulse Code Modulation encoders (ARL)
- FPGA and PIC based PCM encoders (NAWC)



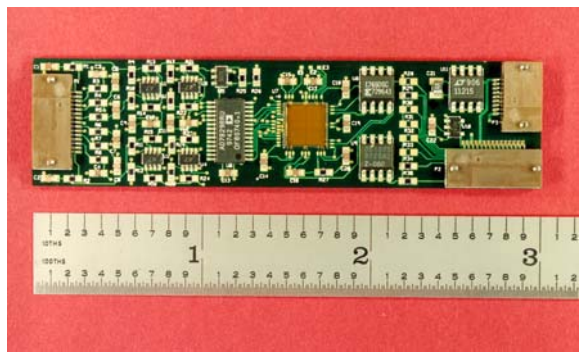
4 Channel/8 Bit

- **500 Kbps**
- **SR = 8.93KHz/ch**
- **30 mA @ 5 V**



16 Channel/12 Bit

- **Up to 5 Mbps**
- **SR = 37.9 KSPS/ch**
- **65 mA @ 5 V**



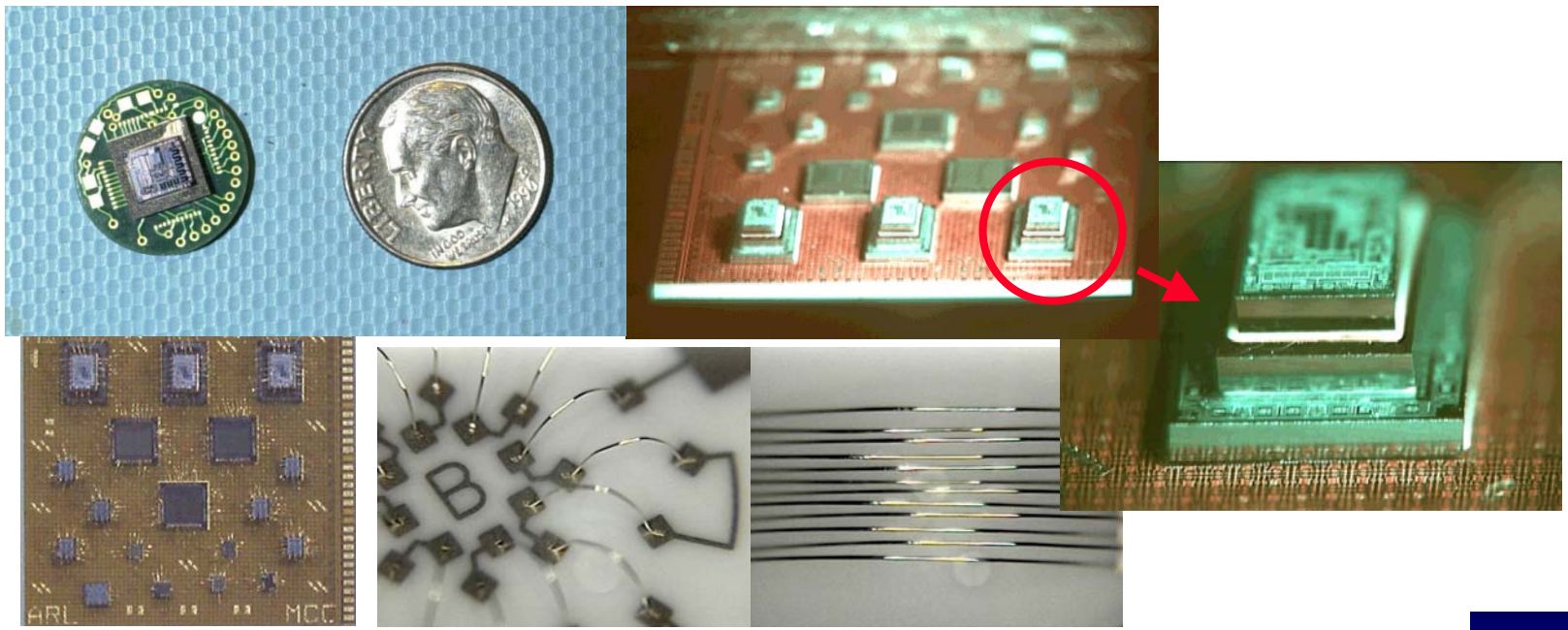
8 Channel/8 Bit

- **240 Kbps**
- **1 ch sampled @ 10 KHz**
- **7 ch sampled @ 2 KHz**

Pete Muller (ARL) and Gary Borgen (NAWC)

Technology (Advanced High-g Packaging)

- Develop & qualify microelectronic assembly techniques for ballistic environments
  - Adopt & modify commercial techniques
  - Examine substrate materials, adhesives, interconnects, etc.



Nate Hundley, Pete Muller and Ed Bukowski

MCC

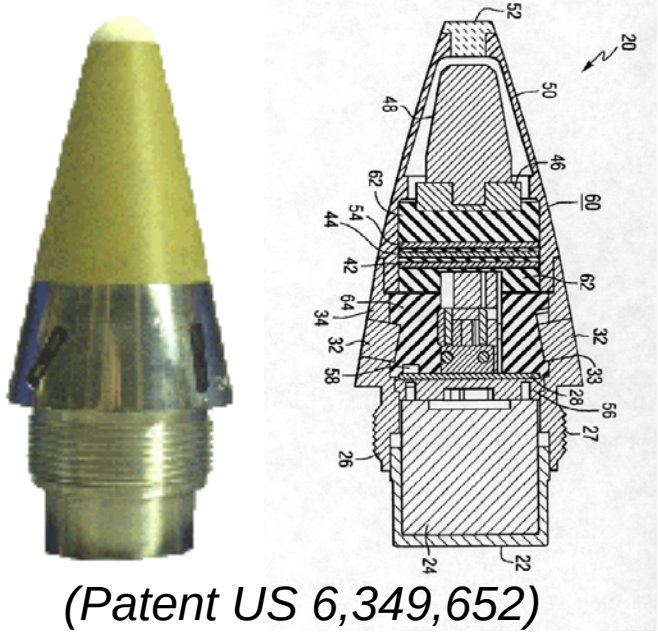
Applications and Integrations So What?

ARL Aeroballistic Diagnostic Fuze (DFuze)

- **Problem:** Ground-based instrumentation (i.e. radars, photos, and pressure gages) have limited capabilities.

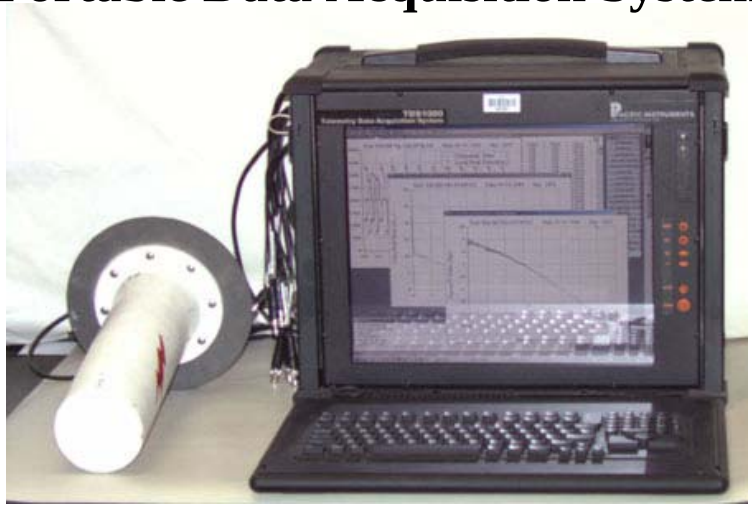
DFuze – Projectile-borne, non-intrusive Instrumentation System

Artillery Nose Fuse Replacement



(Patent US 6,349,652)

Portable Data Acquisition System

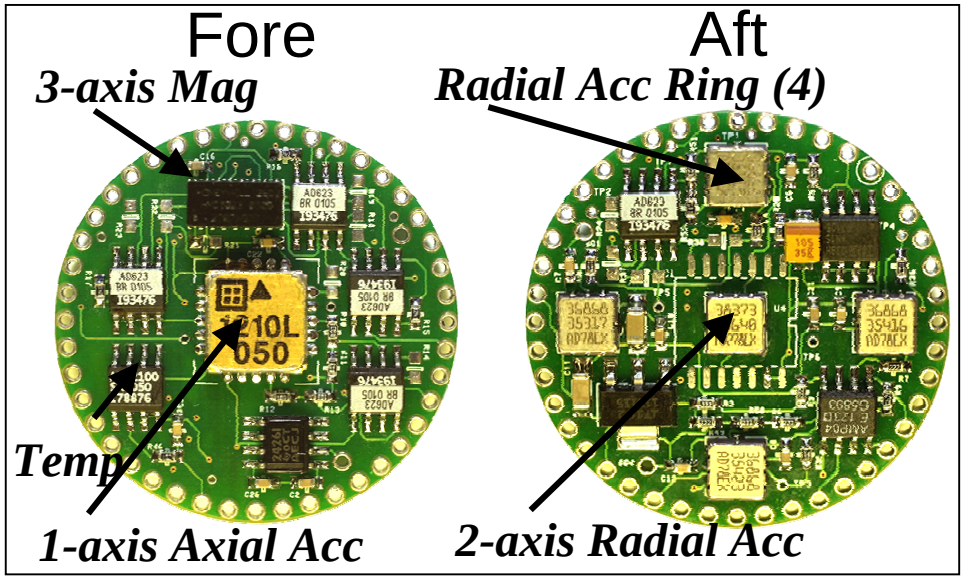


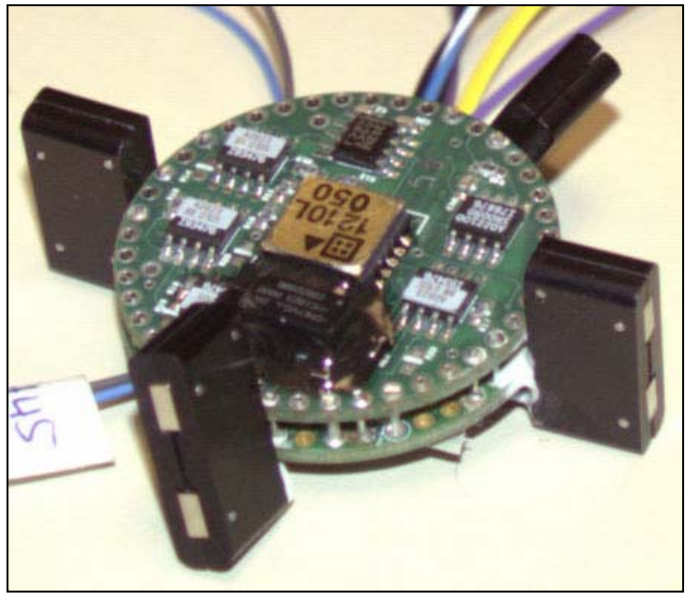
- Post-Flight processing
  - ➢ Quick Look - 6 minutes

- **Solution:** Verifies flight performance, provides on-board diagnostics, validates aerodynamics, used as a ground truth measurement.

DFuze Sensor Suite – 1.4” Dia.

- 36 mm printed circuit board
- 9 measurement channels
- Uses low-cost parts
- High-G survivable





MEASUREMENT	ABBREV.	PART	MAKER	SELECTABLE RANGES
1-axis Axial Acceleration	Acc I	SD1210	SDI	+/-5, 10, 25, 50, 100, 200, 10k* g's
2-axis Radial Acceleration	Acc J, K	ADXL278	ADI	+/-35, 70 g's
3-axis Magnetic Field	Mag I, J, K	HMC1023	Honeywell	+/-6 Gauss
Accel Ring Spin Rate	Spin	ADXL78 (4 ea.)	ADI	+/-35, 70, 120, 250 g's (0 - 70 Hz)
Solar Field Optical Sensors	Solar	SLIT (4 ea.)	ARL	
Temperature	Temp	AD22100	ADI	-50 to 150 degree C
Temperature can replace one channel				

DFuze-Related Products

- Various form factors, shapes, and sizes
- Instrumented Army & Navy munitions and NASA sounding rockets

NATO-compatible fuze replacements

155-mm Army XM982 Excalibur
5-inch Navy CMCO
5-inch Navy EX171 ERGM
155-mm-inch Navy AGS
5-inch Navy ANSR

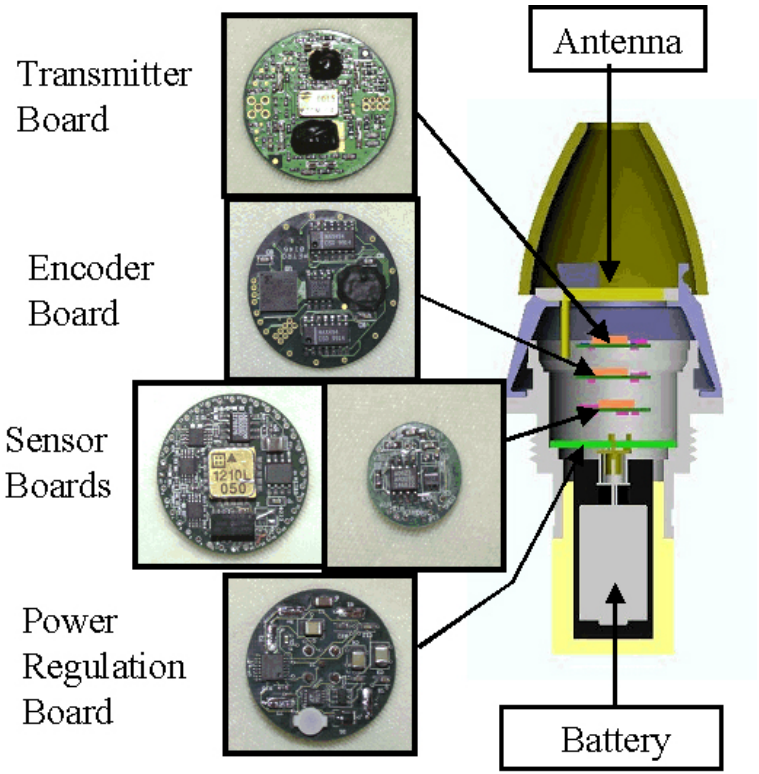
40-mm DARPA SCORPION

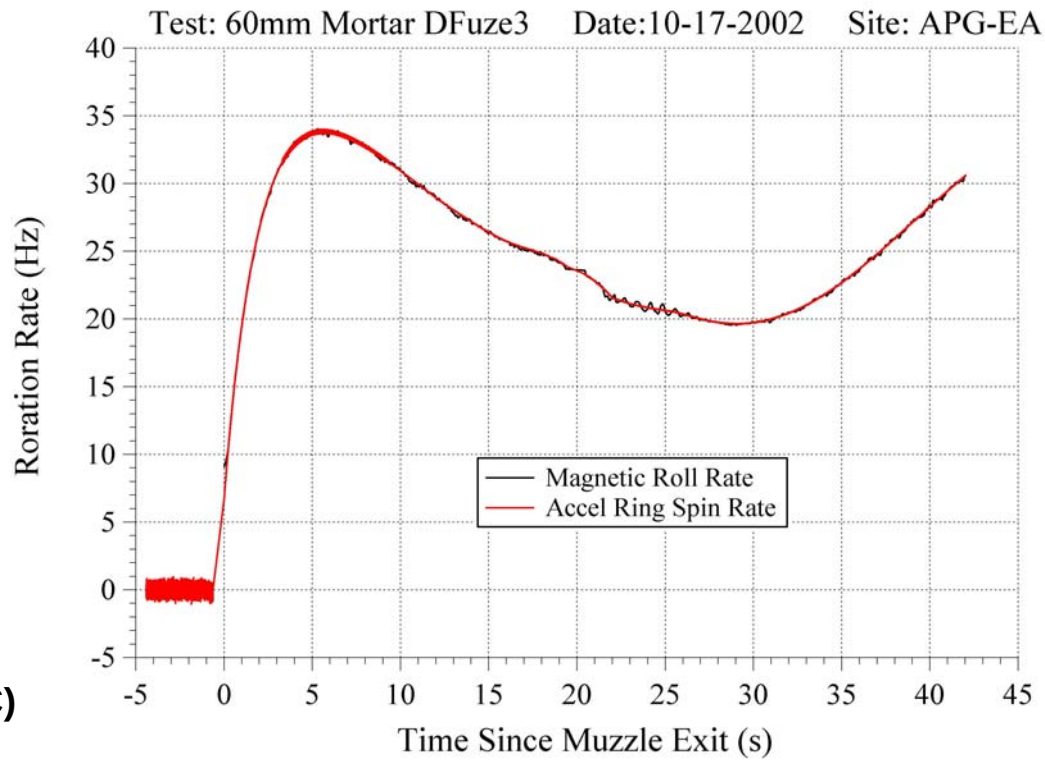
5” Navy BARRAGE

120-mm Army TERM-KE

14-inch NASA T-Lynx Sounding Rocket

Mortar Fuze Application

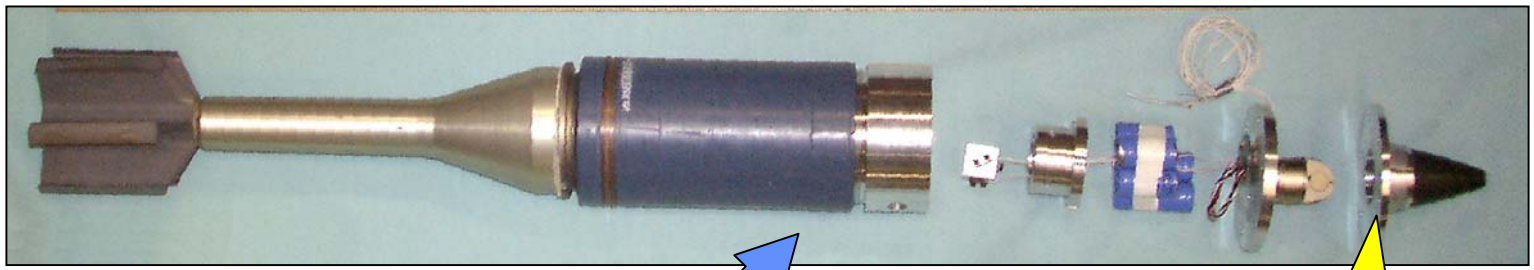


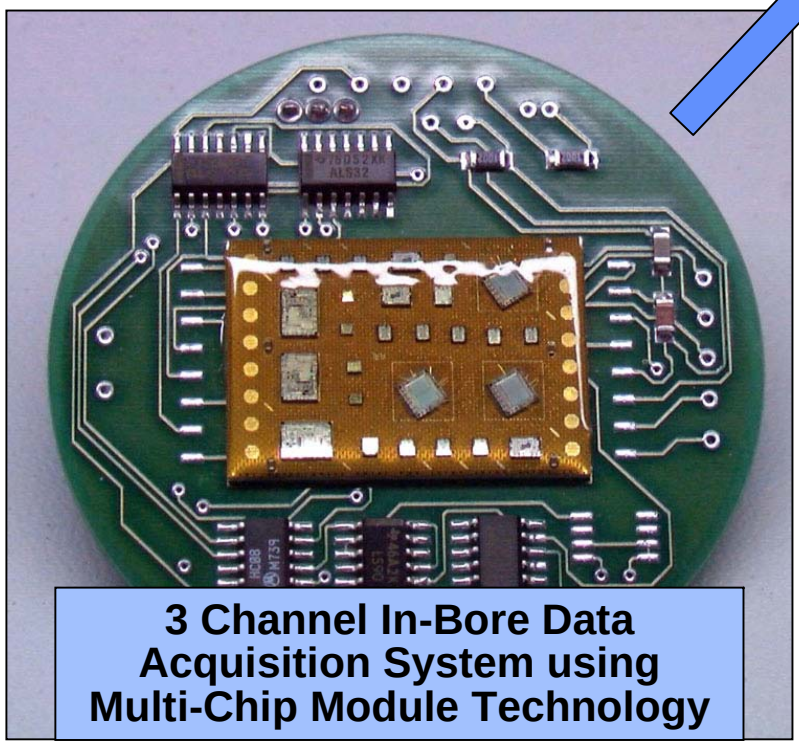


Brad Davis (ARL) and Ken McMullen (ATC)

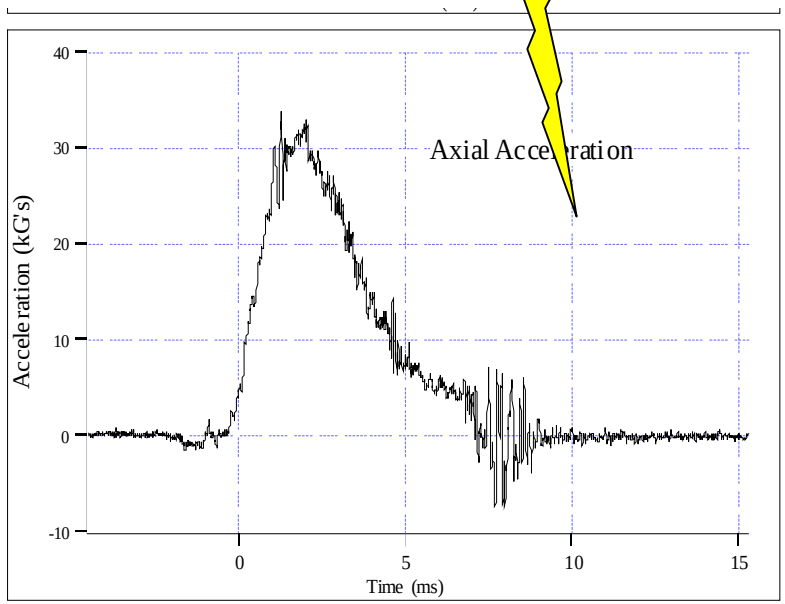
Tank Cartridge Demonstration
M831 HEAT (120mm Tank)

Provides In-bore and Free Flight Telemetry Capability





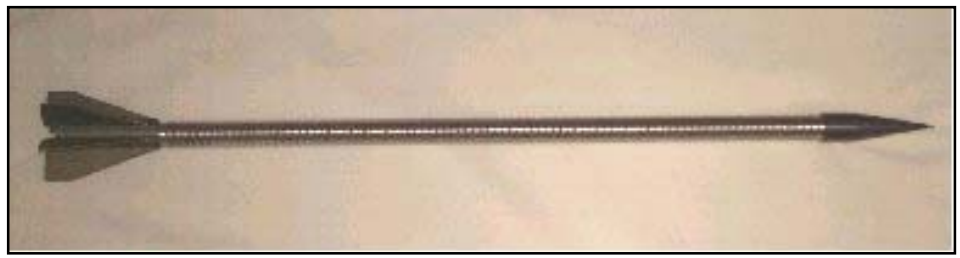
3 Channel In-Bore Data Acquisition System using Multi-Chip Module Technology



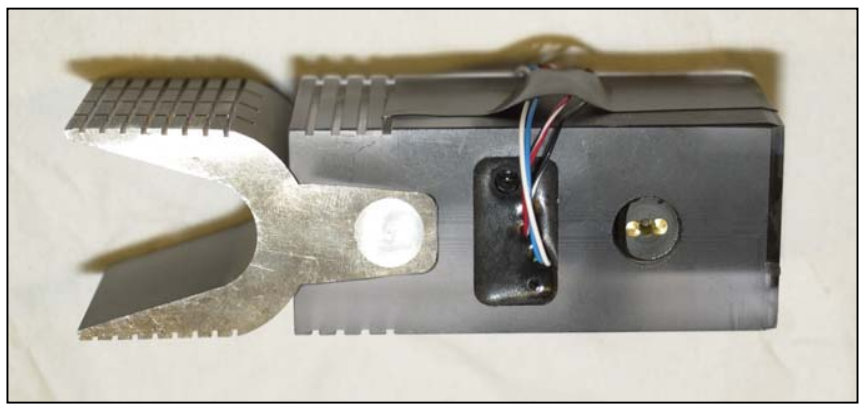
In-Bore Axial Acceleration

Truly Harsh Environment Applications

- 120mm KE Tracer Well (Spin Sensor)

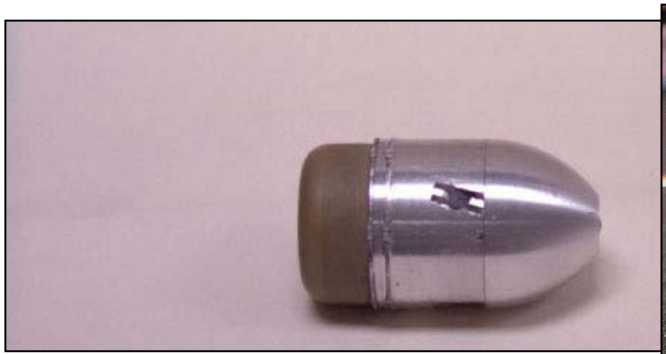


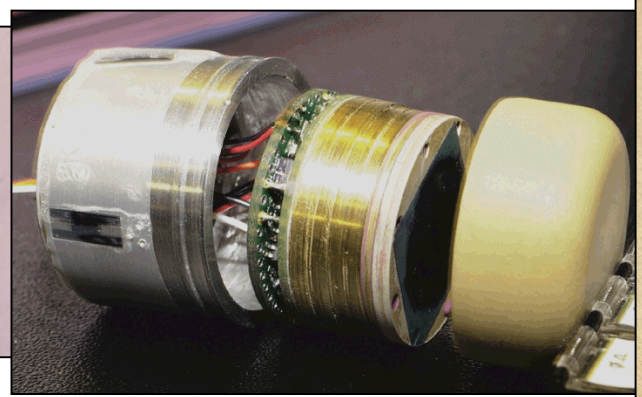
- EM Gun Projectile (In-Bore Accel.)

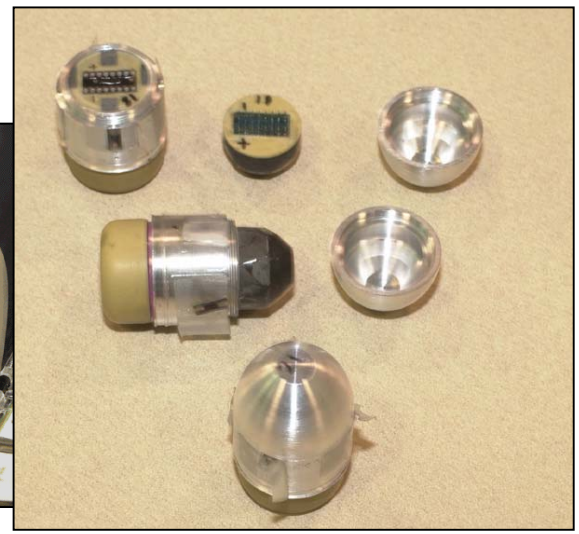


SCORPION 40mm Guided Grenade

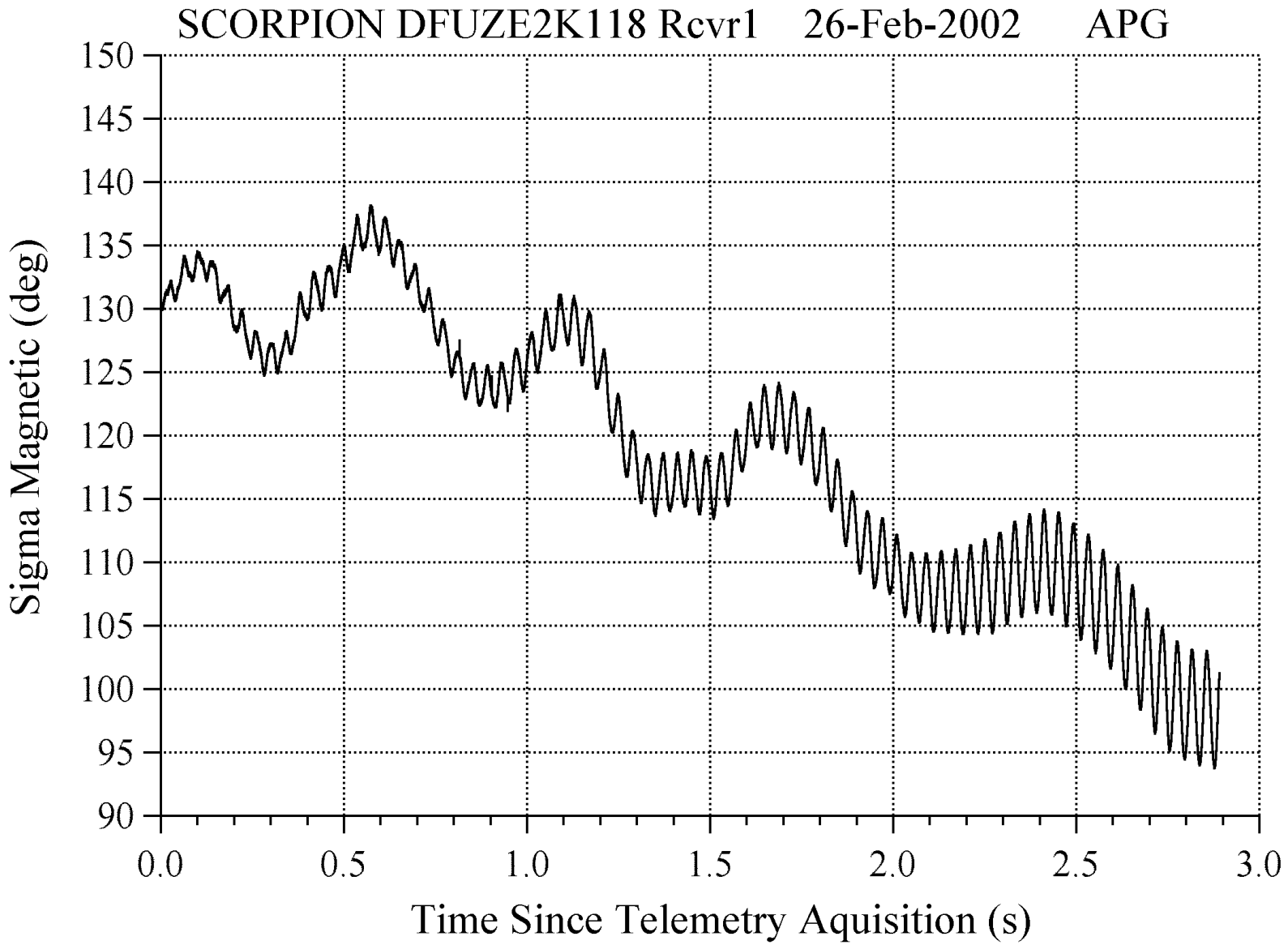
- 40mm Grenade utilizing Micro Adaptive Flow Control to provide maneuver
  - Capture 8 channels sensor data to characterize flight behavior
  - Integrated sensors, PCM encoder, transmitter, antenna and battery
  - Acquired data using ground station







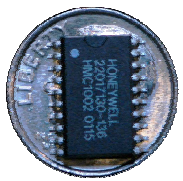
SCORPION Flight Dynamics Data

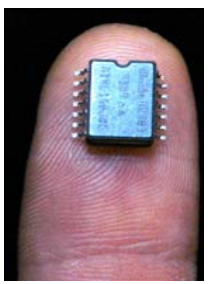


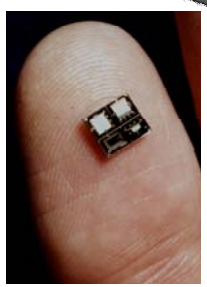
Michael Hollis and Pete Muller

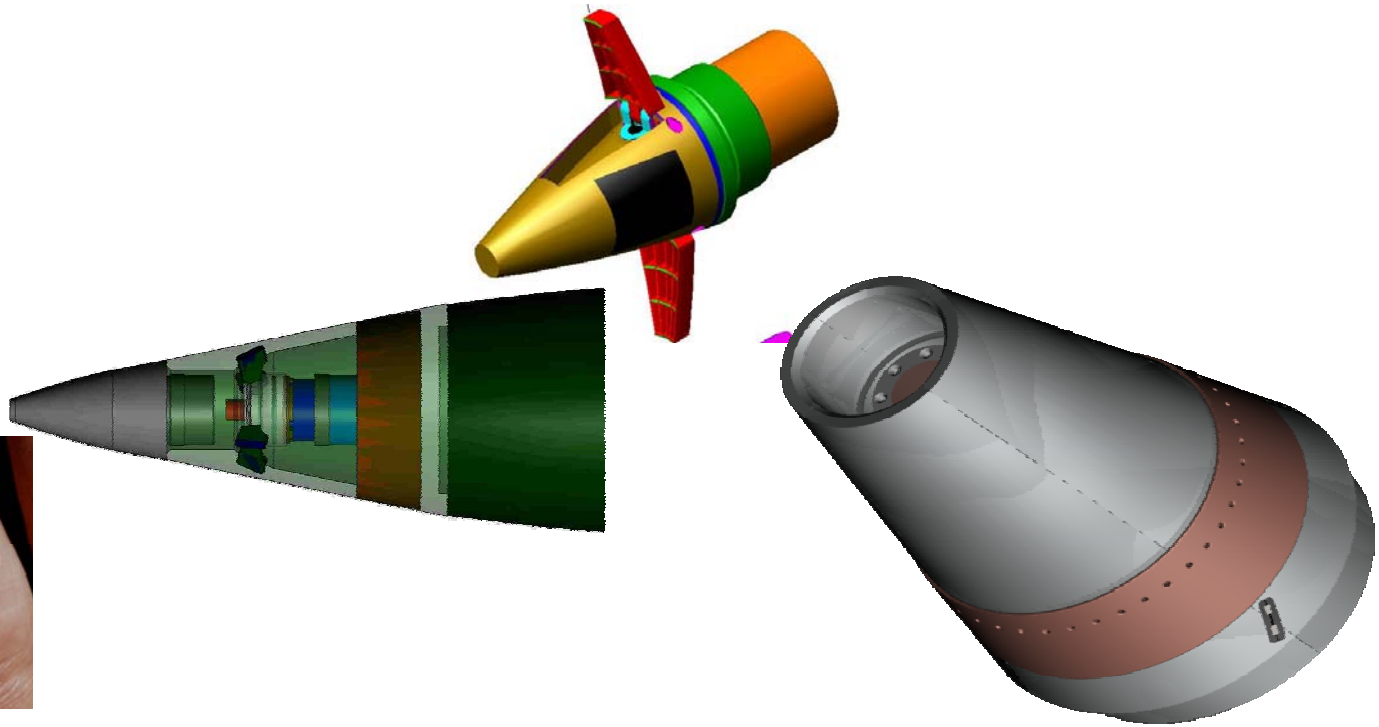
Ogive Diagnostic System for Course Correcting Fuze

- Provides independent “ground truth” measurements of flight dynamics and transmits CCF function data



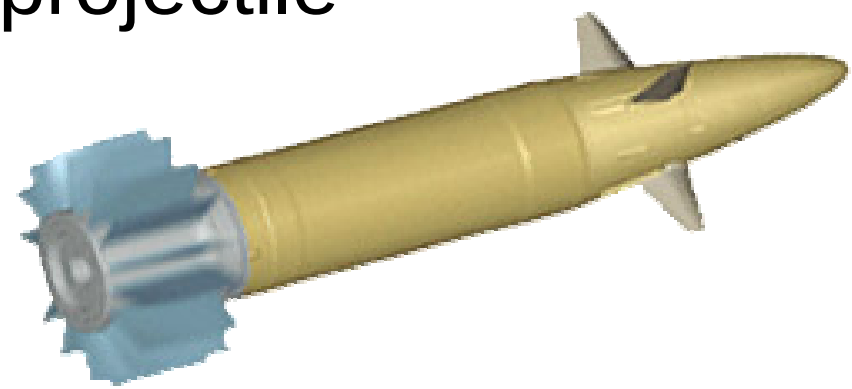






On-Board Recorder (Excalibur, 105mm and 120mm)

- Capture of high fidelity data critical to understanding in-bore and in-flight phenomena
- 32 channels, 4M samples each, up to 100khz sample rate, fully programmable, USB interface and GUI
- Integrated into SRV projectile



How Do They Do It?

Summary

- Technology gaps were identified and addressed by concerted efforts
- Technologies now exist to overcome the toughest of instrumentation and telemetry problems for munitions
- Solutions proven in a variety of applications
- Enable munition developers to achieve TRL goals on time

Bottom Line

There are no longer any excuses for missing test data

"Go Embedded From the Start"