Shock-hardened Penetrator Data Recorder to Support Hard-Target Fuze Development

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Background / Problem Statement

- Measure component-level impact environments for B61-12 Anomalous Environment (AE) nuclear safety sled track test
  - Four, identical modular recorders comprise entire package
  - 48 total analog channels (12 per module)
  - 24 discrete (on or off detect) channels (6 per module)
- Fit within defined envelope of B61-12...but readily adaptable for most penetrator packages (> 4” in diameter)
- Store energy to record post-impact without external power
- Survive impact and then hold data without power
- Accommodate use for other high-shock data acquisition tasks
- Low-pass filter to avoid aliasing recorded data
Strong Pedigree

Sandia 3AMP
- Successfully recorded acceleration of hundreds of penetration events.
- Same packaging techniques employed

Sandia 3DDR-AM
- Similar form factor and functional architecture
  - Multiple data channels
  - Similar sample rate
  - Anti-aliasing low-pass filter
  - Similar power requirements

1.25” 
2.3”
AE Recorder Design Overview

- Stainless Steel Housing with Potting (not shown here)
- Five total Printed Circuit Boards (PCBs)
  - 3 Analog (identical)
  - 1 Power/Interface
  - 1 Digital
- Three MDM Connectors
  - Top: MDM-31P & MDM-15S
  - Bottom: MDM-15P
- Approximately 1.4 lbs
Before Encapsulation
After Encapsulation
Mechanical Modeling & Simulation

- **Goal**: is to increase likelihood that the design is robust
- **Multi-Stage FEA Procedure Captures stress profile of components over entire life cycle**

1. Cool from Potting Cure Temperature to lowest operational temperature
2. Apply compressive preload to chamfers.
3. At lowest operational temperature, accelerate module at chamfered surfaces with defined acceleration.

Modeling reveals no flaws with design.
AE Recorder Block Diagram

- Design divided into functional sections:

  - Interface
  - Energy Store & Power Conversion
  - Comparators
  - Signal Conditioning
  - Control Logic and Memory
  - Unit Configuration & Data Upload
  - Serial Connection

  - Serial
  - Power
  - Fiducial
  - Ext Sigs
  - Accelerometers
  - +6V
  - I2C Control
  - Discrete Signals
  - Analog Signals
Energy Storage & Power Conversion

- Shock-tolerant capacitor powers recorder post impact
  - Battery is expected to fail at impact
  - Store sufficient energy to complete post-impact recording
  - Temperature affects properties: Capacitance, series resistance (ESR)

- Switch-Mode Power Converter improves energy efficiency
  - Efficiency 75%, compared to 37% for linear regulator
  - Reduces required energy storage
Comparators

- Bi-level inputs for additional data
  - Comparator with programmable voltage threshold
- Spare channels for test-specific purposes
  - Record & trigger (if configured) on spare channels for test scenario flexibility
Signal Conditioning

- Low-pass filter excludes high frequency content
  - Accelerometers output high frequency signals that are not useful
  - Must be sufficiently attenuated at sampling frequency
  - Phase compensation avoids time correlation problems

- AE Recorder has programmable gain and balance
  - Adjustable gain to match accelerometer’s wide sensitivity variation
  - Balance to compensate for offset
  - Allows replaceable accelerometers and test-specific changes

Image source: www.wikipedia.org
Sensor Excitation Voltage

- Using 5V accelerometer excitation voltage
  - Reduces power consumption over 10V operation
  - Calibration at 5V is routinely available
- Each Analog board has separate 5V regulator
  - Processing for four sensors per analog board
  - Employ current limit on excitation to mitigate shorted sensor
  - On/off control removes Analog & sensor power during sleep mode, conserving power

Image source: www.endevco.com
Combination reduces board area, complexity

- Microprocessor implements high-level control and configuration
- Logic handles high-speed data movement from ADC to memory
- FIFO buffers acquisition during NAND Flash write cycle
- Serial interface provides external control and data extraction
- I²C interface for inter-board control
Both Circular and Linear Memory

- Requirements: capture pre-trigger data plus post trigger (analogous to an oscilloscope)
  - Pre-Trigger, Circular memory is rapidly written / overwritten
    - FRAM is excellent non-volatile choice, but limited recording capacity
  - Post-Trigger, Linear memory handles continuous recording
    - NAND Flash memory for long recording, but limited rewrite cycles
    - Cannot erase / re-write quickly, so inadequate for pre-trigger

To acquire both a fairly long pre-trigger record in addition to a much longer post-trigger data record requires two different types of memory technology.
Summary and Conclusions

- AE Recorder has many favorable design features:
  - Programmable gain and balance per channel
  - High sample rate
  - Long recording time
  - Multiple analog/discrete channels
- Strong High-G pedigree
  - 3AMP, 3DDR-AM, others
  - Design has been validated in sled track environment

AE Recorder is Sandia’s most advanced/versatile high-G recorder.
Questions?

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Back Up
Component Evaluation for Shock

- Begin with electrical characterization under static loading
  - quasi-static compressive stress axially & laterally
- Drop table, Hopkinson bar and VHG impact testing for dynamic loads
  - Small test circuit built to fit on Hopkinson bar
  - Adapter fixture attaches same circuit for VHG testing

Importance of Check Channels

- Example system, Measurement configuration:
  - Penetrator instrumentation with Bessel LP filter, switched-capacitor type

Gas Gun Launch Pulse

Integrates to correct velocity and displacement
Check Channel Reveals Problem

- A channel with resistor replacing accelerometer
  - Passes thru same filtering as normal channel
  - Piezoelectric components in signal conditioning create bogus signals

**Correct response would have been a flat-line output**