



Design of an Intelligent Counter to Monitor Fatigue Events Experienced by a Gun Barrel (#9894)

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Outline



- Background, Objective, and Requirements
- FOS Overview
- Transducer Selection
- Housing & Mounting
- Storage Requirement
- Power Requirement
- Live Fire Testing Results
- Future Work

Background



- As mechanical systems age, lifetime fatigue causes wear and eventually system failure
- In order to predict 'end-of-life,' the FOS was developed to monitor and record fatigue on a weapon barrel
- Currently, fatigue monitoring is often done by manually recording events in a log book by the warfighter.
 - Prone to errors
 - Time consuming
 - No electronic record keeping
- Focus on large caliber direct line of site weapon systems
- All research was performed on an AST-owned .50cal



Design a system which will detect and count fatigue events on weapon barrel

- Improve event counting accuracy
- Reduce soldier's burden
- Increase soldier's safety
- Lead to a more accurate determination of “end-of-life”
- Provide an electronic inventory and maintenance record

Differentiate round families

- Round Family: round types which induce similar amounts of fatigue

The FOS is only the first stage of improvement, leading to a more accurate count. Once that count has been reached a secondary project has been completed which will individually scan the system for flaws (see AST's poster on the Field Inspection Vehicle).

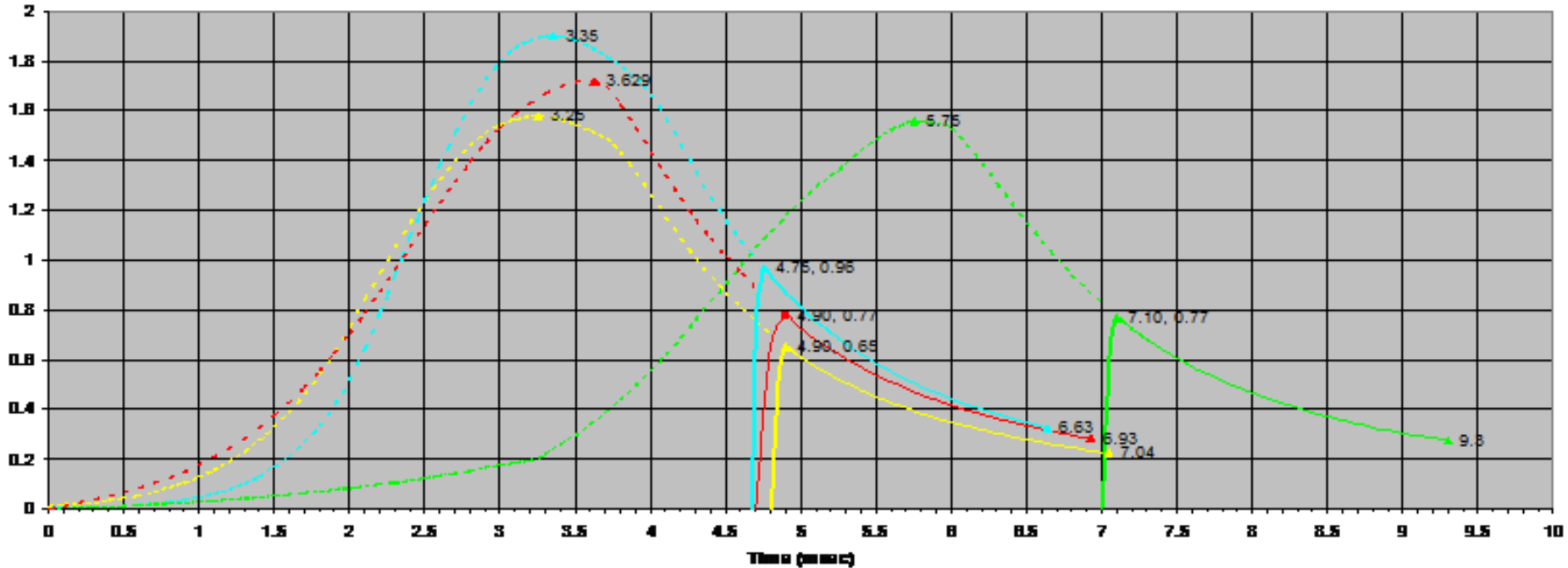
Requirements for Primary Test Platform



1. Count up to 20 rounds per minute
2. Detect and count rounds with an allowable deviation of +2% (no undercounting)
3. Prevent false counts in the system due to external sources of shock and vibration not due to a firing event
4. Sustain and operate at a 300°F barrel surface temperature for “short” periods of time (<1hr sustained)
5. Perform wireless data transfer (but only upon demand)
6. Be capable of storing information from at least 10,000 rounds along with life time maintenance records
7. Be self-powered for up to 30 years (i.e., the life of the device) without the need for battery replacements

FOS Overview

(theoretical design justification)



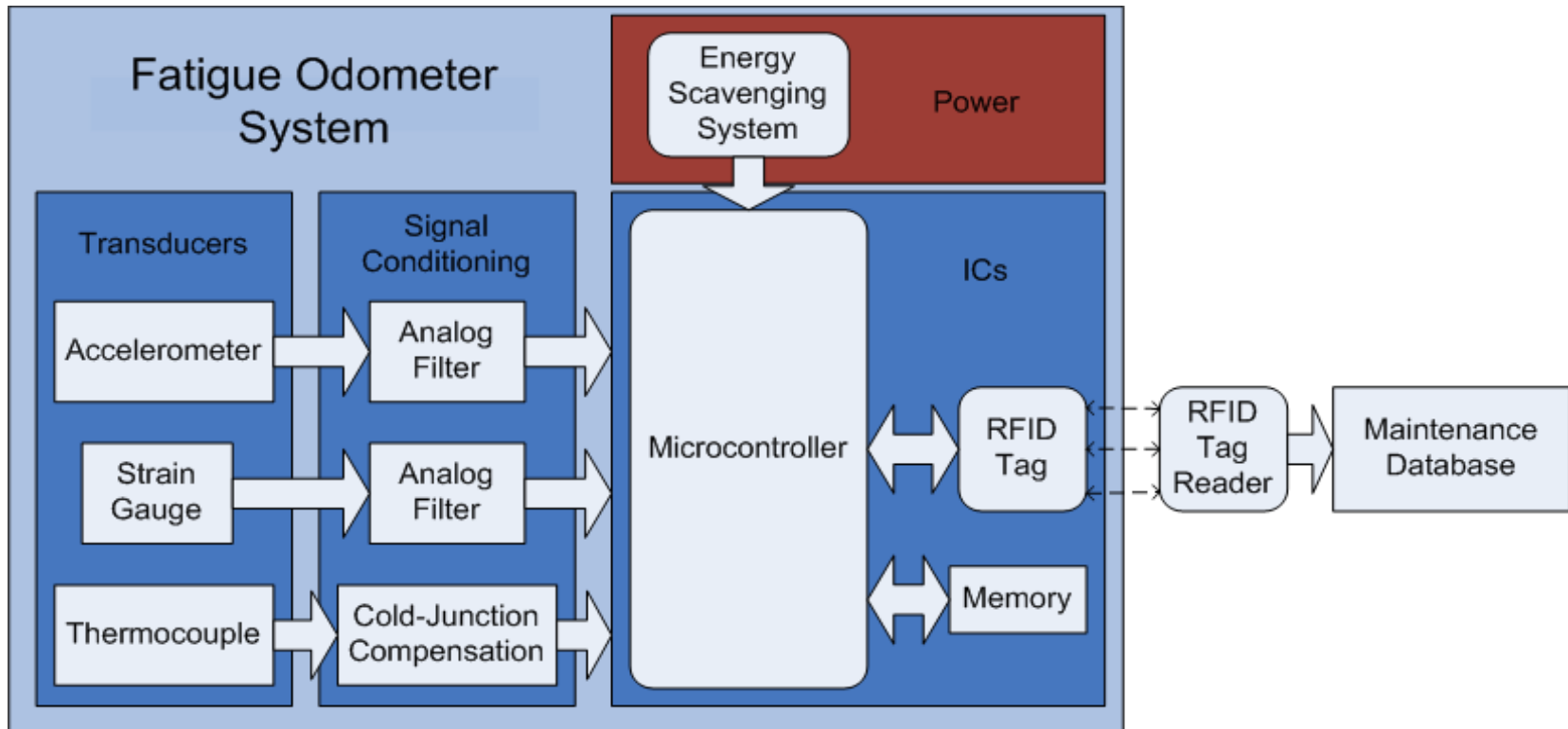
Generic simulation of recoil acceleration and hoop strain on a cylindrical structure when measured at mid-point of a weapon barrel for 4 different round types

FOS Overview

(System block diagram)



- System will measure recoil acceleration, hoop strain, and outer barrel temperature
- Signal filtering and data conditioning prevents 'false' round counts
- System controlled by low power microcontroller
- Data capable of being uploaded to a central database through RFID tag



Transducer Selection

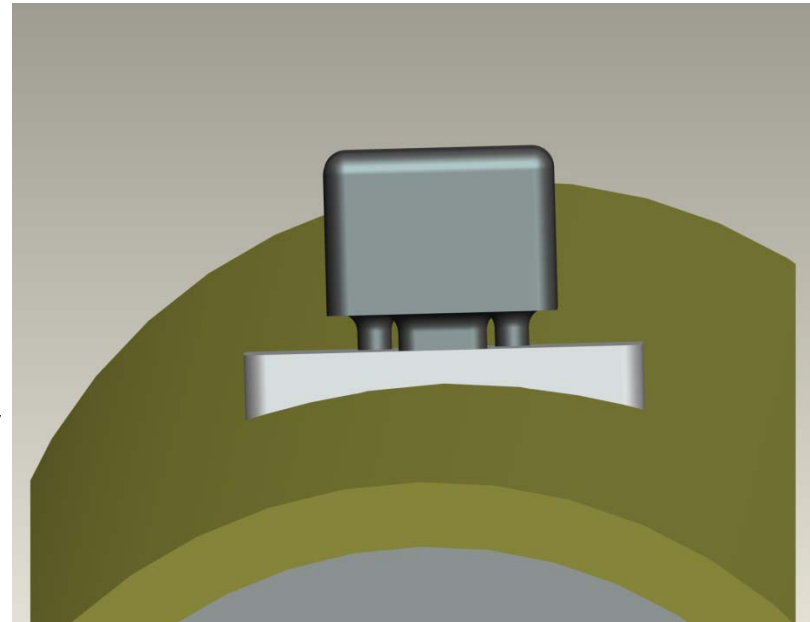


- Monitored signals using passive sensors and low power circuitry in order to keep power consumption to a minimum
- Recoil Acceleration
 - Passive piezoelectric accelerometer
 - Low-power analog filtering
- Hoop Strain
 - Passive, piezoelectric strain-rate sensor
 - Low-power analog filter
- Temperature
 - Required for strain sensor compensation
 - Thermocouple (passive)
 - Cold-Junction compensation for accurate measurement

Housing & Mounting



- Issue: Circuitry can only withstand 185°F but barrel can reach 300°F
- Two-stage housing with ¼” air-gap to thermally isolate circuitry
 - Thermo-isolating PEEK base plate
 - Rapid prototyped housing (needs to be studied for robustness)
 - Verified to 300°F in lab tests (circuitry only reached 175°F)
- Base plate mounted to barrel using high-temperature adhesive



Storage Requirement

(data storage of 10,000 rounds)



- **Primary Data Storage**

- Memory built into RFID tag can hold 500 rounds worth of data as well as maintenance logs
 - Will upload data from Micro to Tag after every round is fired
- It is expected that data will be downloaded from FOS to database every few 100 rounds
- The on-tag data allows for faster data download by user and does not require power from the FOS but does not meet requirement

- **Lifetime Data Storage**

- Data is also uploaded onto on-board EEPROM after every shot fired
- In the event all previous data has been lost or corrupted in database, backup of 10,000 rounds of data stored on FOS can be retrieved
 - This is a slow process and consumes a considerable amount of power directly from the FOS
 - But, would only be used in emergency situations

Power Requirement

(maintenance free for 30 years)



- How do you power a sensor for 30 years without replacing batteries or plugging into power source???
 - FOS, located on a system, often doesn't have access to a power source
 - Battery technology would not meet the 30-year requirement
- Development of an Energy Scavenging Power Supply
 - Uses capacitive energy storage system which can be recharged 'indefinitely' rather than conventional chemical battery system
 - Can store at least 100 Joules at prototype level
- Relies on a number of renewable energy sources
 - **Solar** – Photovoltaic cell provides ample power during sunny conditions
 - **Motion** – Piezoelectric cantilevers produce short bursts of energy during periods of vibration (traveling)
 - **Thermal** – Thermal Electric Device (TED) converts heat from weapon barrel to electricity
- Investigating new sources of energy
 - **Recoil** – Faraday coil to capture recoil energy
 - **Electromagnetic** – Scavenging radio waves for energy

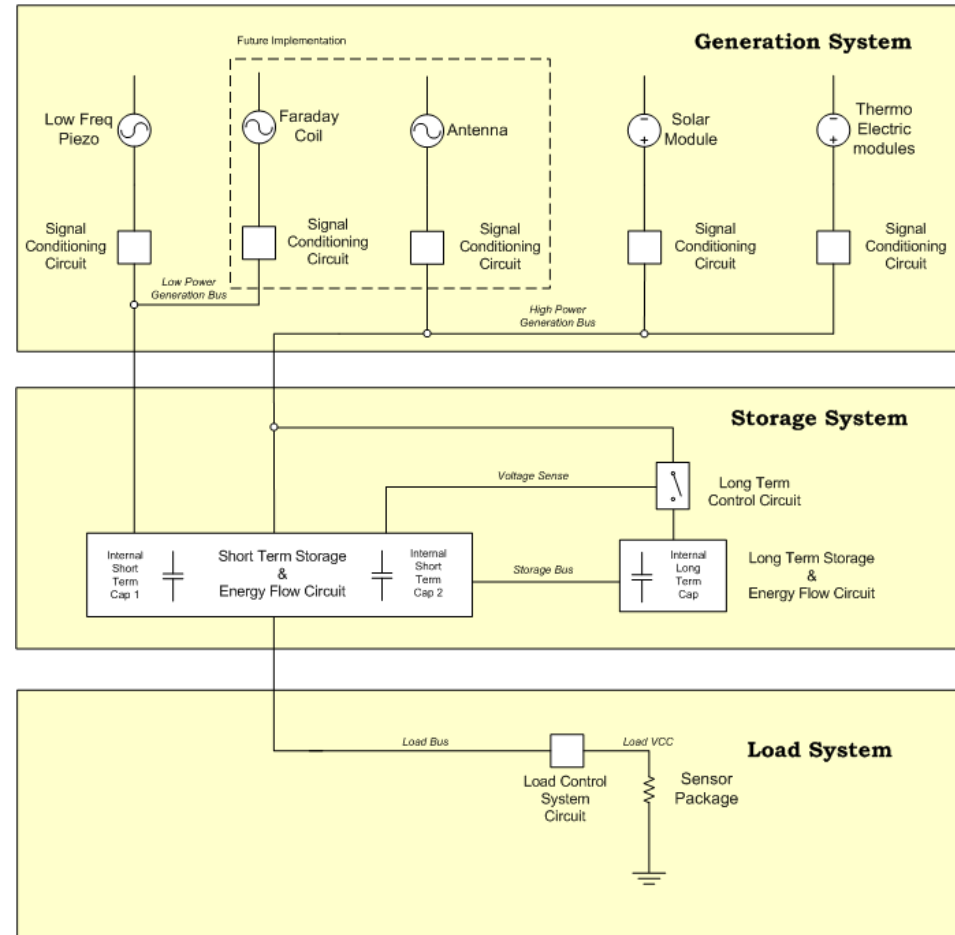
Power Requirement

Block Diagram



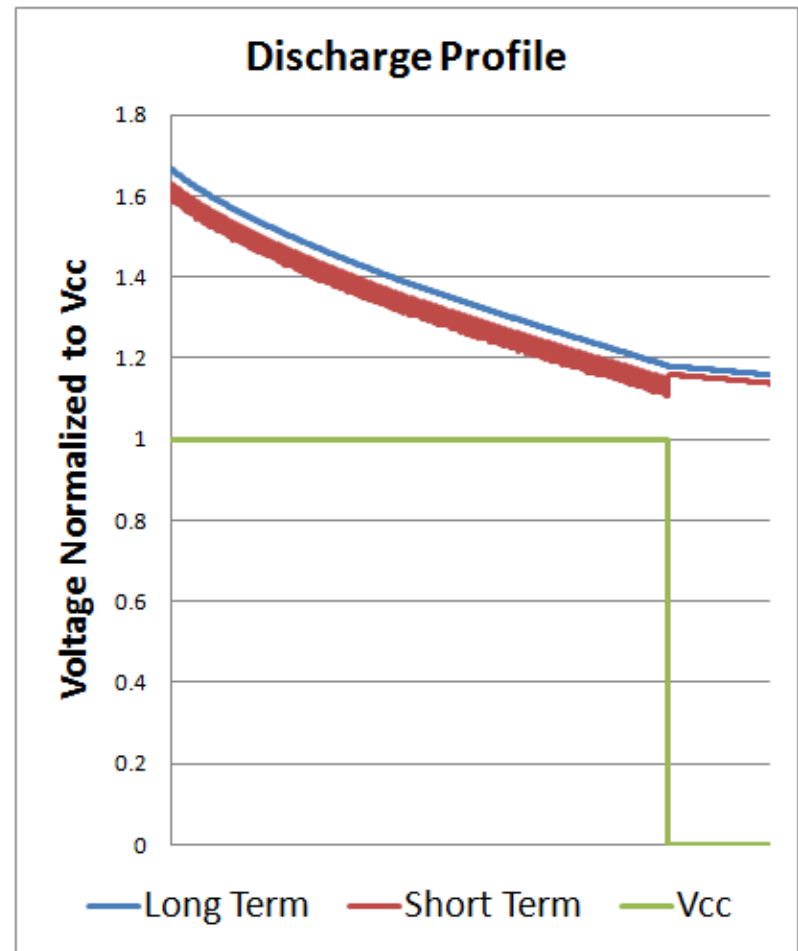
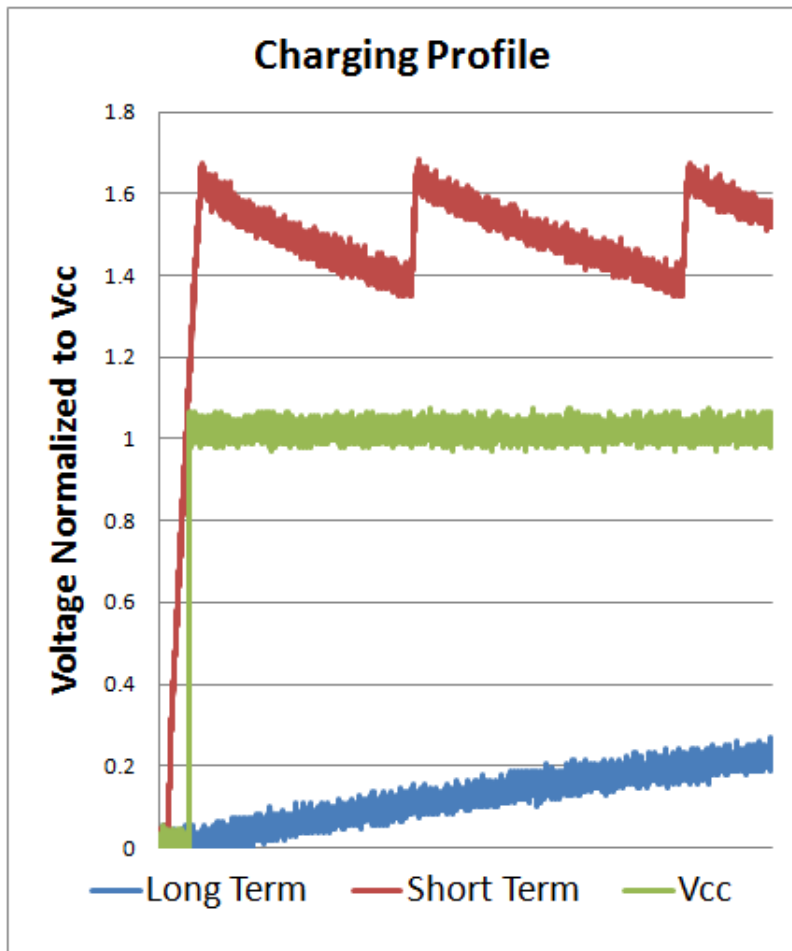
- Three-stage system
 - **Generation System:** Energy is collected and conditioned
 - **Storage System:** Two part
 - Short term: quick charging system which provides power to the load (FOS)
 - Long term: charges after short term is charged and provides power to the short term for extended periods
 - **Load System:** DC output voltage is conditioned to meet load requirement

Functional Block Diagram of Energy Scavenging Power Supply



Power Requirement

Test Results



Power Requirement

Summary



- ESPS currently in development stage
 - Initial prototype ~2" x 2" x 4"
 - ESPS will power the FOS from a full charge for 93 hours without the need for external energy
 - ESPS can be recharged from complete depletion to power the FOS within 5 minutes or less depending on environmental conditions
 - ESPS can be fully recharged in 4 hours
 - Stable output power
 - Either V_{CC} or 0V
 - Solid on/off with no rapid switching
- ESPS can be adapted to power almost any low-power electronic system

Live Fire Tests



- Field tested on smaller-barrel weapons
 - Barret .50 cal as well as 25 mm
- Verified transducer operation, accurate round count, and wireless communication
- Powered with lithium inorganic high-temperature battery
- Tested round identification algorithm in the field



Final Live Fire Test Results



- Nine rounds of .50 BMG ammo fired by multiple users
 - APIT-M20 619gr
 - Summit Tracer-M17 643gr
 - Summit AP-M2 700gr
- FOS was able to:
 - Accurately count each round
 - Identify round type fired
 - Communicate data wirelessly via RFID
 - Perform a memory dump in lab and verify data

Event	Shooter	Type Fired	Identified As
1	A	700	700
2	B	643	643
3	A	643	643
4	B	619	619
5	A	700	700
6	B	619	619
7	A	700	700
8	B	643	643
9	A	619	619

Future Work



- Field test FOS on larger caliber weapons
 - 105 mm, 120 mm, etc.
- Transducer upgrades
 - Transition to surface-mount accelerometer
 - ½ size of previous sensor
 - Eliminates cabling to further decrease FOS volume
 - Adapt analog filtering to larger calibers
 - Adjust analog scaling for different signal magnitudes
- Incorporate energy scavenging power supply
- Package Upgrades
 - Decrease housing volume
 - Test new housing materials





Questions?



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