Conceptual Design of a Compact Pressure Sensor for Multi-Layer Insulation in a Vacuum

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Presentation Overview

- Project Scope
- Needs and Goal Statement
- Project Constraints
- Background Research
  - Multi-Layer Insulation
  - Pressure Sensing Technology
  - Environmental Conditions
- House of Qualities
- Design Concepts and selection

Sebastian Bellini

Project Scope

- The aim of this project is to design and implement a compact pressure sensor that can easily fit between layers of Multi-Layer Insulation.
  - Fast Response Time
  - Ability to measure a large pressure range
  - Noninvasive to the MLI

- This interstitial pressure is measured to quantify the heat transfer through the system.

Jason Carvalho

Needs and Goal Statement

- ## Needs Statement

Due to their size, current pressure sensors are unable to measure the interstitial vacuum pressure between layers of MLI and generate undesirable heat and excess power while in operation.

- ## Goal Statement

Design a minimally invasive pressure sensor that can be embedded within layers of MLI and doesn’t cause significant heating.

Project Objectives

- Develop a pressure sensing concept with minimal parts
- Minimize the wiring and power consumption of the device
- Minimize heat produced by the sensor
- Ensure that the device is small enough to fit between layers of MLI
- Demonstrate the operation of the device in a sample of 30 or more layers

Project Constraints

- Be able to measure a pressure range of 101 kPa to 10^{-2} Pa
- Have a minimum response rate of 1 sample per second
- Sensor dimensions shouldn’t exceed interlayer spacing
- Temperature conditions range from 293 K to 77 K
- Working environment

Multi-Layer Insulation (MLI)

- High Performance Thermal Insulation System
- Comprised of Alternating Layers of a Polymer Film and Spacer Material
  - Film Layers are Mylar or Kapton
  - Metallic Coating applied to both sides of film to increase reflectivity, creating radiation shields
- Spacers
  - Constructed from Dacron, or Polyethylene Terephthalate
  - Webbed Pattern
  - Low thermal conductivity material

Figure 1 Layer of MLI with spacer

Multi-Layer Insulation

- Thermal Performance based on the interstitial pressure
  - Works best at Interstitial Pressures < 10^{-2} Pa
- Thickness of layers varies and is determined by application
- Layers held together by silicone-based adhesives or metallic tape with low outgassing properties
- Perforations allow venting as MLI transitions to a low pressure environment
- Outermost and Innermost Layers have special construction considerations

Applications of MLI

- Liquid Cryogenic Propellant Storage
  - Requires many layers of MLI determined by the boil off rate of the fluid
- Spacecraft, Satellites, Rovers
  - Instrumentation and Equipment
  - Structural Members
- Spacesuits

Figure 2 MLI being applied to a probe

Pressure sensors

- Detects an event or change in environment and responds with a corresponding output

- Common types:
  - Thermal
  - Piezoelectric
  - Capacitance
  - Sound Acoustic Wave (SAW)
  - Ionization
  - Fiber Optic

Space Research

- Space is a vacuum.
  - Convection does not naturally occur
  - Conduction is very minimal
- Cold welding
  - Common among mechanical parts
- Out-gassing
  - Release of trapped air inside of materials
  - Can cause arcing between electrical components
  - Components are baked in a thermal vacuum chamber

House of Quality

Table 1 House of Qualities for Pressure Sensor Design

Customer Requirements \ Engineering Characteristics	Customer Importance	Materials	Power Consumption	Geometry	Cost	Can Work in Vacuum
Minimal Invasiveness	5	3	6	9		
Accuracy	5		6		6	9
Minimal Heat Produced	4	3	6			3
Reading Range	4				6	6
Reading Speed	3		6		6	3
Total Weight		27	102	45	72	90

Piezoelectric Pressure Sensor

- Piezoelectric effect
  - Greek piezein meaning to squeeze
  - Crystals, certain ceramics, DNA, and even bones
  - Usually quartz crystals
- Pros
  - High frequency response
  - Rugged
- Cons
  - Sensitive to temperature change
  - Tough to form correct geometry for specific use of crystal
  - Limted pressure range
  - Fairly small in size (centimeters)

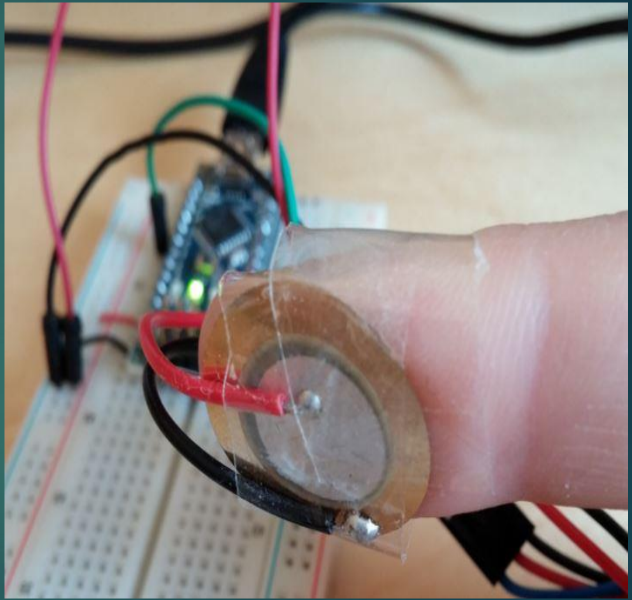


Figure 3 Demonstrates the size of the Piezoelectric Sensor

Michael Kiefer

Surface Acoustic Wave (SAW)

- Surface Acoustic Wave
  - Converts electrical signal (IDT) to mechanical wave back to electrical signal
  - Changes in amplitude, phase, frequency, and time delay
- Pros
  - High frequency response
  - Maintenance and recalibration free
  - Size
  - Pressure range (≈0-80^6 Pa)
- Cons
  - May be difficult to get SAW through MLI

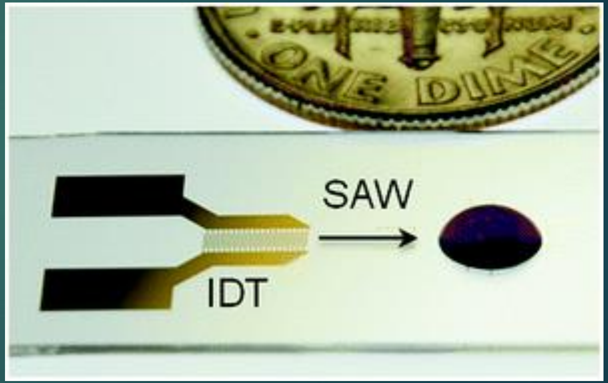


Figure 4 Demonstrates the size of SAW and IDT

Fiber Optic Pressure Sensor

- Observes change in phase, polarization, transmit time, or wavelength to measure pressure
- Fabry-Pérot pressure sensor
- Pros
  - Good in high vibrational, wet, noisy, corrosive, and extreme heat environments
  - Immune to electromagnetic interference
  - Ability to measure a large range of pressures
  - Size (125 micrometers)
- Cons
  - Relatively difficult design
  - High cost

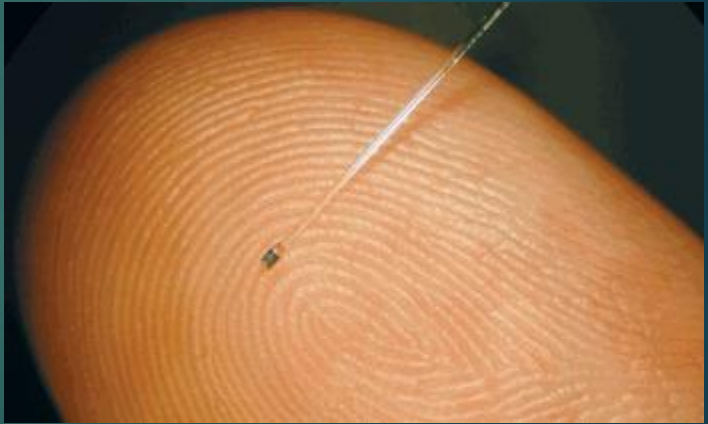


Figure 5 Fabry-Pérot Fiber optics pressure sensor size

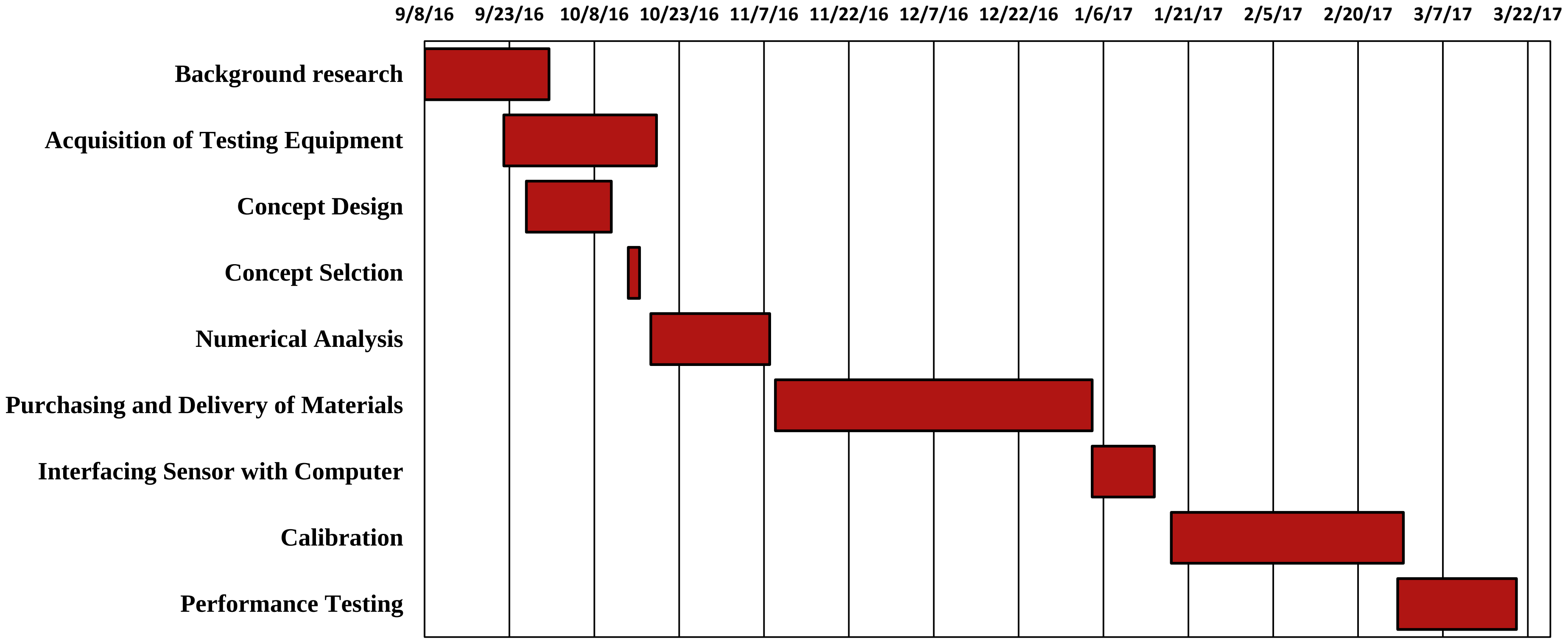
Michael Kiefer

Decision Matrix

Table 2 Pugh decision matrix for pressure sensor concepts

	SAW	Fiber Optics	Piezoelectric
Accuracy	0	1	-1
Minimal Invasiveness	0	1	-1
Heat Production	0	-1	0
Reading Range	0	1	-1
Reading Speed	0	0	0
Total	0	2	-3

Gantt Chart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1/21/17
2/5/17
2/20/17
3/7/17
3/22/17
Background research
Acquisition of Testing Equipment
Concept Design
Concept Selction
Numerical Analysis
Purchasing and Delivery of Materials
Interfacing Sensor with Computer
Calibration
Performance Testing

Conclusion

- Design a compact pressure sensor capable of measuring the pressure within MLI

- Two main constraints:
  1. Working Environment
  2. MLI

- Fiber optics was selected as the initial design.
  - Compact (125 micrometers in diameter)
  - Large pressure range

References

- MLI Picture - https://www.google.com/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=0ahUKEwjni8eJ8OjPAhVGSyYKHWXSDH0QjRwIBw&url=https%3A%2F%2Fen.wikipedia.org%2Fwiki%2FMulti-layer_insulation&bvm=bv.136499718,d.eWE&psig=AFQjCNEOqoxn2H03Q3iFInkqihO41KH7eQ&ust=1477034598902982

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Questions?