Restated Project Definition and Updated Scope

Team 15

Design of a Compact Pressure Sensor for Multi-Layer Insulation Inside a Vacuum Environment

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Abstract

Team 15, sponsored by the NASA Marshall Space Flight Center, is tasked with developing a compact pressure sensing device that is capable of measuring the interstitial vacuum pressure between layers of Multi-Layer Insulation (MLI). The additional requirements for the pressure sensor are that it maintains the MLI's structural integrity, minimizes heat flow into the interstitial space, utilizes minimal power consumption, and takes at least one measurement per second. The device must be able to read pressures as low as 10^{-2} Pa (10^{-4} torr) and would be beneficial if it can measure up to atmospheric pressure. From a House of Quality, the most important engineering characteristics with respect to customer requirements was determined and considered in designing concepts. Three main concepts were generated: a capacitor pressure sensor, a multi-stage capacitor pressure sensor, and a fiber optics pressure sensor. The prototype fabricated will be a single stage capacitor at a larger scale than envisioned in order to test the capabilities of a capacitor type pressure sensor. If a single stage capacitor works, it is anticipated that a multi stage capacitor will be fabricated and tested.

1.0 Project Overview

1.1 Project Statement

Cryogenic propellant tanks, heat shields and sensitive spacecraft instrumentation are thermally insulated in space through the use of MLI. Multi-Layer Insulation consists of alternating layers of Double Aluminized Mylar and webbed Dacron spacers. This “interstitial” region between layers is essentially a vacuum, and the effectiveness of the MLI depends on the vacuum level in this region. Sometimes, due to phenomena like outgassing or improper evacuation, there could be residual gas in the interstitial region; at a certain critical pressure, the residual gas causes heat to be transferred through two additional mechanisms: conduction and convection thereby increasing the overall heat transfer through a cryogenic system. Thus, it’s important to measure and regulate the pressure in the MLI interstitial region. With a 5mm stack thickness and 12 layers total, the interlayer spacing is 0.4mm, a size that’s unable to accommodate traditional pressure sensors.

The following statement was developed that summarizes the customer’s need:

“Due to their size, current pressure sensing devices are unable to measure the interstitial vacuum pressure between layers of multi-layer insulation (MLI) and generate excess heat and power while in operation”

The ultimate goal of this project is:
To design and develop a compact device best suited to measure pressure within Multilayer Insulation.

1.2 Project Scope

Design a minimally invasive pressure sensor that can be embedded within layers of MLI to determine the interstitial pressure between layers. The sensor must take one sample per second and have a reading range from 10^{-2} Pa to 101 kPa. Since space is a vacuum, heat cannot dissipate similar to earth and therefore, the sensor must produce minimal heat.

1.3 Project Objectives

The following project objectives were set forth based on information obtained from Team 15's sponsor, James Martin

Objectives:

- Sensor must be able to read pressures as low as 10^{-2} Pa (if possible, read a range from 10^{-2} -101kPa)
- Minimize the heat produced by the sensor
- Be reliable and able to work in space.
- Minimize power consumption.
- Minimize size in order to be as minimally invasive as possible to the MLI.

2.0 Concept Design & Analysis

2.1 Capacitor Pressure Sensor

The single stage capacitor pressure sensor design was created in order to tackle the value of the interrogation equipment needed to analyze the fiber optic pressure sensor's light. The capacitance sensor begins with a solid cylindrical silica base as seen in figure 5 (yellow plate on the bottom), which is reduced down in size to the required length. Next, a rigid capacitor plate, made of either a thin metal, or a thick silica plate Nano-coated in metallic particles, is applied to one end of the cylindrical silica core by either a thermal fusion process, or using UV-set polymers. Next, a cavity will have to be formed in order to allow for a vacuum pressure to reside within the sensor as a gauge pressure. This cavity is formed by using HF acid to etch a parabolic cavity into the pure silica. This cavity etching process has been shown to be easily repeatable and highly accurate, as long as the material properties of the silica cores and the acidic properties of the HF acid stay consistent. Next, the flexible pressure sensing diaphragm will need to be created. The diaphragm consists of a pure silica outer rim, with a germanium doped silica core as seen in figure 5 (top yellow plate). The diaphragm is sized down to an approximate thickness, and is prepared for its final etching process. When HF acid is introduced onto the diaphragm, the germanium doped inner core etches faster than the pure silica outer rim. This allows the diaphragm to be etched down to the appropriate thickness, as well as to allow the raised pure silica outer rim to protect the diaphragm against any obtrusions that might damage the sensor. Finally, the flexible diaphragm is attached to the cylindrical silica core on the etched cavity side. This process, however, has to occur inside of a vacuum chamber in order to seal the pressure sensor with a vacuum pressure inside. This final diaphragm attachment can once again use either a thermal fusion process, or the UV-set polymers.

The thickness of the diaphragm will dictate the pressure ranges the sensor can adequately sense. A thinner diaphragm will result in decreased stiffness, making it more susceptible to pressure ranges. However, due to the yield point of the material, over deflecting the material too far will ensure it will not return back to its equilibrium. This concern means that the cavity length for the single-stage capacitor will have to be determined to ensure that the diaphragm will rest on the cylindrical silica core far before the diaphragm material reaches its yield point. This will ensure that the capacitor will be able to repeat pressure readings, without damaging the diaphragm.

The major downfall of the single stage capacitor design is that its pressure reading range is limited by the thickness of the diaphragm. In order to read the low pressure ranges, it will require a thinner diaphragm, which will deflect more with low pressures. However, the diaphragm will “bottom out” on the silica core after a small pressure range, and its sensing capabilities will be nonexistent, until the pressure returns to within the small range of the capacitance sensor. The sponsor for this project, NASA, relayed to team 15 how it would be beneficial to create a sensor that would be able to read both the low pressure ranges of 10^{-2} as well as reading atmospheric pressures. This suggestion led our team to create a second design, using a multistage capacitance sensor to read more than just one diaphragms’ adequate range.

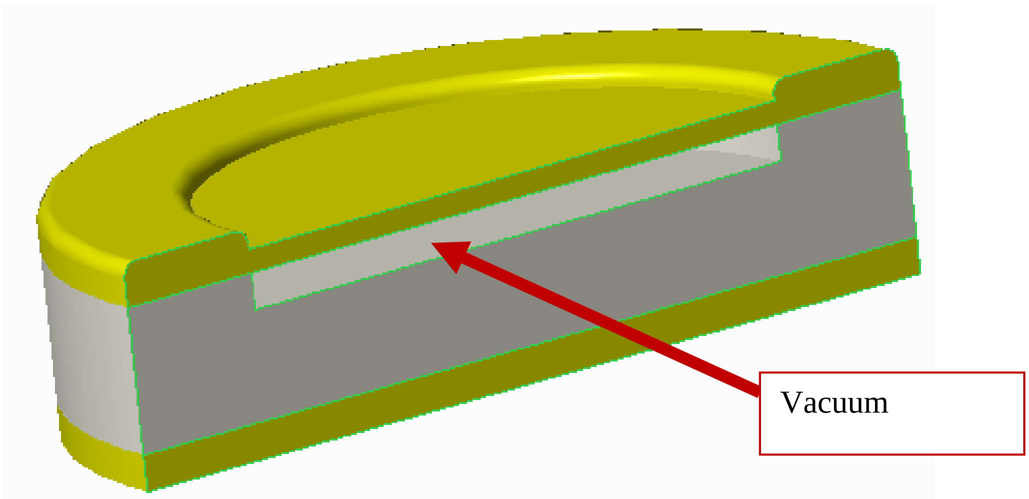


Figure 1- Cross sectional view of the capacitor sensor displaying the layers and vacuum chamber.

2.2 Multi-Stage Capacitor Pressure Sensor

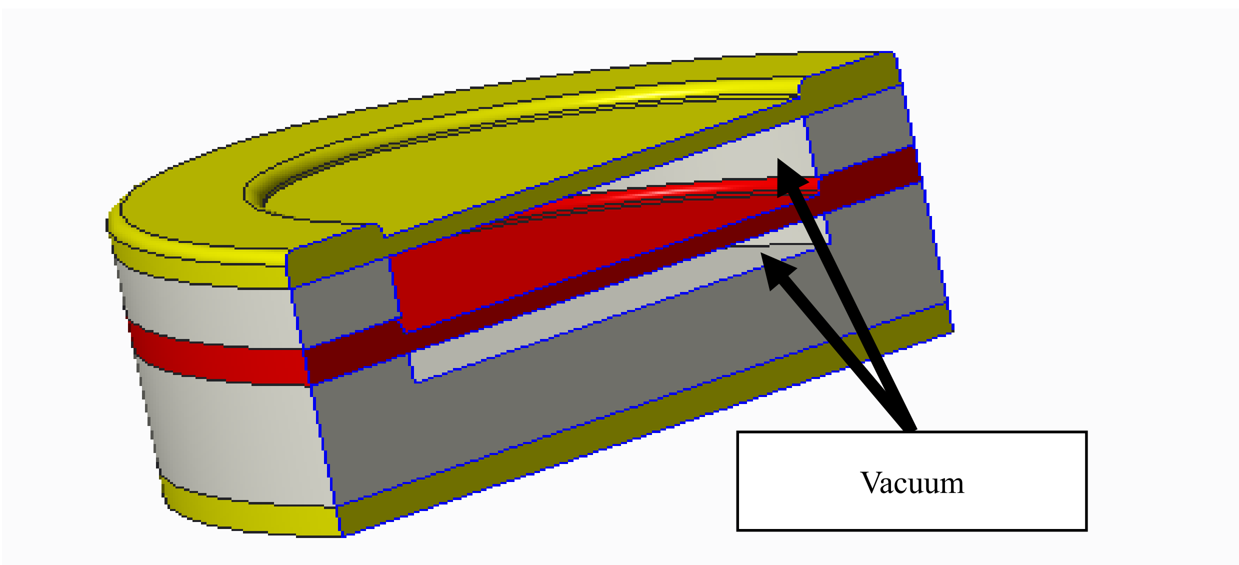


Figure 2 - Cross sectional view of the multi-stage capacitor sensor displaying the layers and two vacuum chambers.

In order to tackle the pressure range requirement that NASA has implemented, a multistage capacitor design was needed. The multistage only differs from the single stage capacitor by the amount of diaphragms in parallel as seen in figure 6. By stacking the diaphragms on top of each other, with the lowest stiffness diaphragm on the outside of the pressure sensor, it enables multiple reading ranges to occur. When the more flexible diaphragm on the outside finishes its reading range in its cavity, it will begin to touch the second diaphragm, whose stiffness is greater. These two diaphragms stiffness will add in parallel, and allow for a second higher pressure reading range to occur. However, it is important to remind ourselves of the yield point constraint as described earlier. The more flexible outer diaphragm will no longer deflect only in its cavity, but will also will traverse through the second cavity during the second reading range. It is important to ensure that the distance the first diaphragm will travel when in contact with the second diaphragm in the second cavity is still underneath the yield point stress of the material chosen. Special consideration of cavity lengths and diaphragm thicknesses will need to be taken to ensure proper functionality and repeatability of the sensor.

2.3 Fiber Optics Pressure Sensor

For the fiber optic design, fiber optic cables in the micrometer range are placed through the layers of the MLI as see in figure 7. Figure 8 is a close up of the fiber optics. An external power source sends a pulse of light through the fiber optic and hits a germanium doped silicon core membrane. This membrane is deflected due to the ambient pressure which is exerted on it, and sends the light back with different wave qualities. The qualities of this new wave, polarization, wavelength, and light intensity, or mainly transmit time can be measured with a sensor and correlated to pressure.

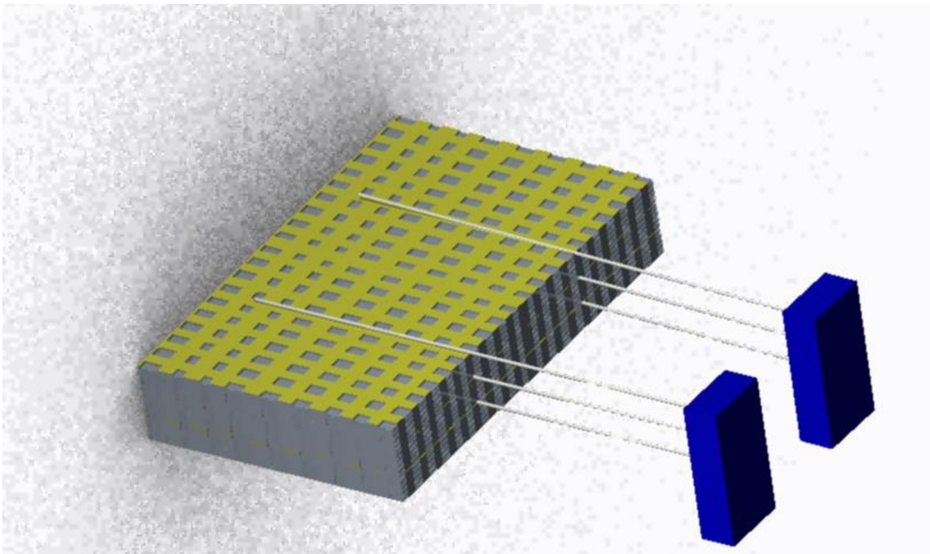


Figure 3 - Fiber optics sensor embedded within the MLI

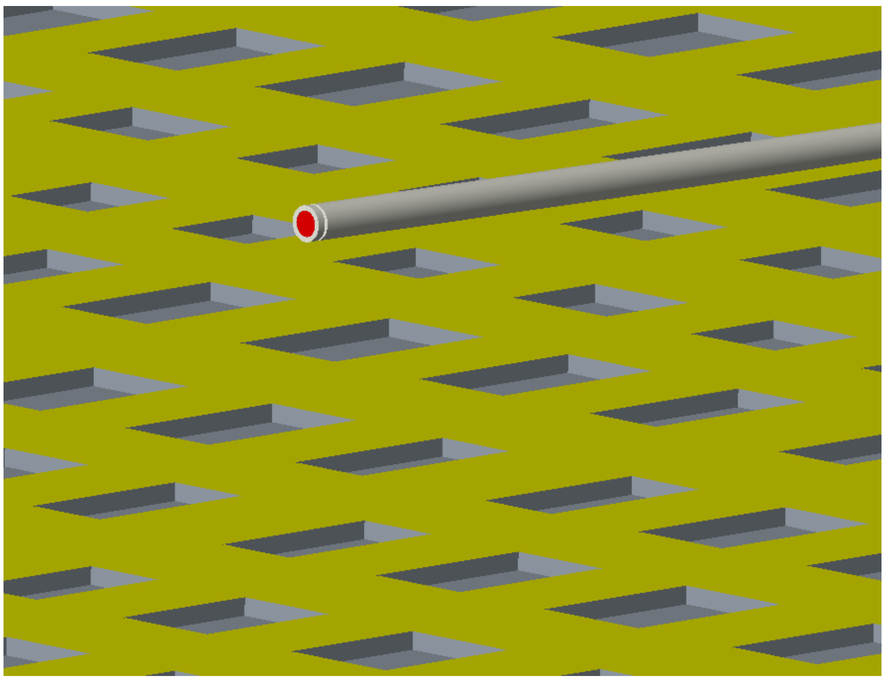


Figure 4 - Close up on the end of a fiber optics cable

3.0 Methodology

3.1 Plan

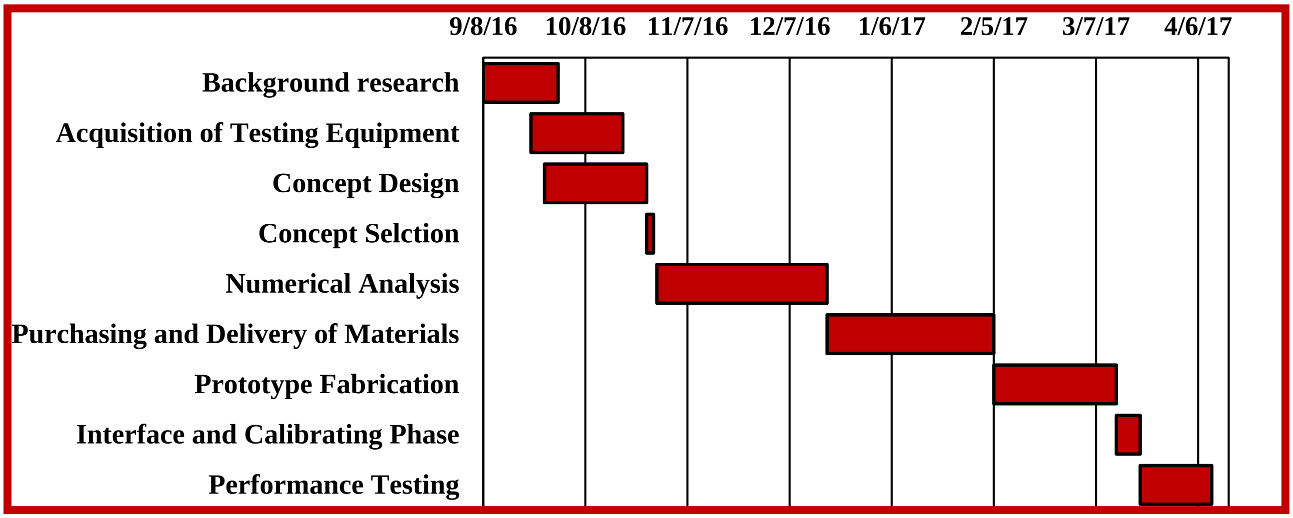
For the prototyping phase, the team will fabricate the single stage capacitor. The multi-stage capacitor was selected as the primary concept. However, the single stage capacitor was chosen to be constructed because the multi stage capacitor design is based upon it. If the single stage capacitor were to not operate correctly, then the multi-stage capacitor would not function either. The prototype will be produced at a larger scale. The reason for this is because of the unachievable goal of nano – manufacturing the sensor due to time and budget constraints and lack of availability of resources and specialized equipment. If done to scale, the pressure sensor would also be more likely to break making it difficult to complete the project during the time allotted.

The team is planning on meeting with Dr. Xu soon and will discuss the feasibility of fabricating the prototype and reading the capacitance with a network analyzer.

3.2 Gantt Chart

As seen in Table 1, the Gantt chart contains the future planned time frames for the project tasks. For a Gantt chart with more detailed dates, please refer to Appendix A-1. Starting in Spring 2017, the design team is currently in the purchasing and delivering of materials phase. A meeting is scheduled with Dr. Xu in order to discuss the development of the capacitor pressure sensor. She will inform Team 15 about what materials her lab consists of and what she can provide for fabrication. Dr. Xu's lab will also be assisting in constructing the prototype sensor and thus, after the meeting, a more accurate schedule can be created. After the prototype has been fabricated, the team will proceed with interfacing the sensor with a computer in order to evaluate and analyze the data and calibrate the system. During the testing phase, the single capacitor prototype will tested for accuracy and precision. The prototype will also be evaluated for its upper limit, lower limit and resolution. If time permits, the team will fabricate and test the multi-stage capacitor design.

Table 1- Gantt Chart



4.0 Progress Made

It was recently discussed with Dr. Shih that the prototype should be produced at a larger scale. Thus, Team 15 scheduled a meeting with Dr. Xu in order to discuss the recent changes in the manufacturing process. This meeting will be held once Dr. Xu is back in town. A single stage capacitor was selected as the design prototype since the multi-stage capacitor design relies on the idea of the single stage capacitor.

5.0 Challenges

Depending on how the meeting with Dr. Xu proceeds, alternate routes may need to be explored. If the pressure sensor can be fabricated in Dr. Xu's lab, then the challenges that follow would be fragility of the pressure sensor, design and configuration of the electrical circuit, reading the capacitance with a network analyzer, and determining a calibration curve for the sensor. If the pressure sensor were the rupture or break, this would vastly delay the design team. Team 15 would have to restart the fabrication phase and will possibly not complete the project depending on when the sensor breaks. If a predesigned circuit is not readily available, then the design of one is necessary. This will cause a slight delay in the project schedule. In order to ensure that this isn't a hindrance, Team 15 will approach the electrical engineering department for assistance. If Dr. Xu is unable to provide the team with a network analyzer, other faculty members will be contacted in order to obtain one or Team 15 will potentially purchase a commercial network analyzer that meets specifications. Determining the calibration curve for the sensor should only delay the project slightly as Dr. Guo can provide plenty of assistance along with other faculty members who may be consulted.

If the meeting with Dr. Xu does not go as intended, then fabricating the sensor will become a challenge. Team 15 will aim to produce a vastly larger prototype. This can potentially delay the prototype fabrication phase of the project from a week to a month. This task duration is dependent on finding a feasible way for the team to manufacture it themselves. The previously mentioned challenges could also occur.

6.0 Conclusion

In conclusion, a large scale prototype of the single stage capacitor will be made in order to accomplish the testing during the allowed time. A meeting has been scheduled with Dr. Xu in order to determine the extent of assistance her lab can provide Team 15. The Gantt chart has been updated, but it is subject to change depending on the meeting with Dr. Xu. The single stage capacitor was selected, for the prototype, because the multi-stage capacitor is dependent on the success of the single stage capacitor. If time allows, then the multi stage capacitor will be manufactured and testing but this is not the team’s primary goal.

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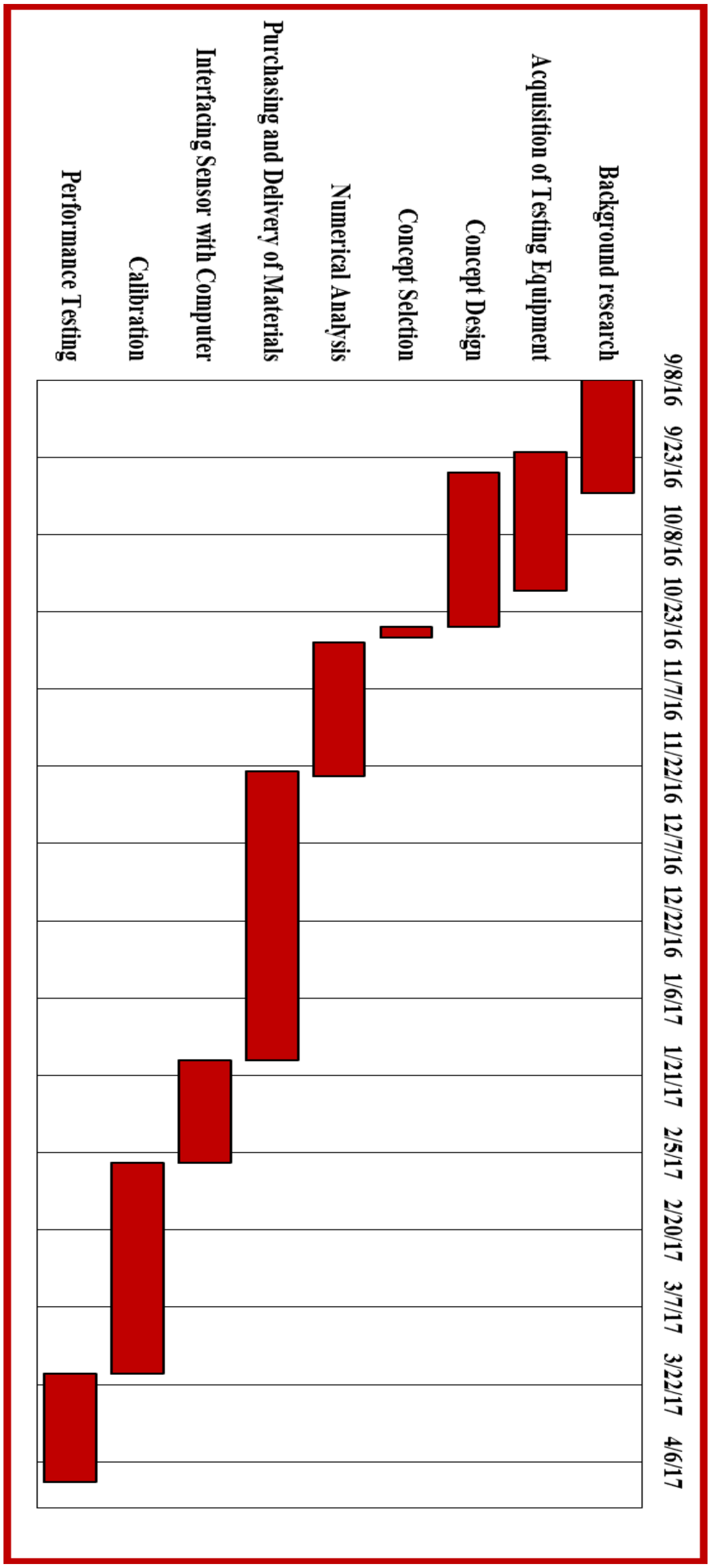
Appendix A


Background research
Acquisition of Testing Equipment
Concept Design
Concept Selction
Numerical Analysis
Purchasing and Delivery of Materials
Interfacing Sensor with Computer
Calibration
Performance Testing
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