Team 3:
Cummins Self-Powered Wireless Sensor

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Team 3

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Lead Controls and Programmer

Meghan Busch:

Quality Control and Financial Advisor

Thomas Dodamead:

Team Leader

Omar Rodriguez:

Lead EE and Webmaster

Caleb Stallings:

Lead CAD Designer

Sponsored by Cummins

- The senior design project, self-powered wireless sensor, was funded by Cummins.
- Budget: $2,000.00
- Sponsor: Dr. Michael Hays

FAMU-FSU
College of Engineering

Agenda

- Introduction
- Design Process
- Final Design
- Testing & Validation
- Conclusion

Introduction

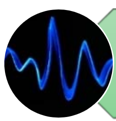
Caleb Stallings

Project Objective

Design, build, and demonstrate a method to power a sensor that will transmit data of a specific variable wirelessly to the Engine Control Module (ECM) in a Cummins' diesel engine.

Self-powered sensor with no wired connections to ECM

Begin transmitting data during engine startup



Wireless transmission at least 5 meters and 1 Hz

Reliable operation in harsh engine environment

Background

- Sensors are essential for monitoring important engine parameters during operation
- Sensor wiring harnesses must perform reliably in harsh environmental conditions
- Cummins has spent considerable funds for warranty claims on wiring harnesses.
- **Solution**: Wireless Sensors
- **Objective**: Powering these Sensors

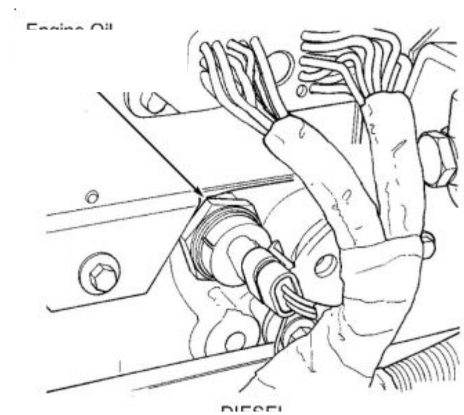


Figure 1. Picture of engine sensor with unprotected wiring harnesses

Assumptions

- ECM compatible with chosen wireless communication protocol
- ECM will send wake-up signal at engine start
- Sensor is engine oil temperature sensor
- Oil pan has necessary hardware for assembly

Design Process

Thomas Dodamead

Functional Decomposition

- Self-Powered Wireless Sensor
  - Power Supply
    - Harvest and Supply Energy
  - Wireless Sensor
    - Measure and Wirelessly Transmit a Parameter
  - Housing
    - Maintain System within Operating Conditions

Power System

Power Supply

Wireless Sensor

Housing

Harvest and Supply Energy

Measure and Wirelessly Transmit a Parameter

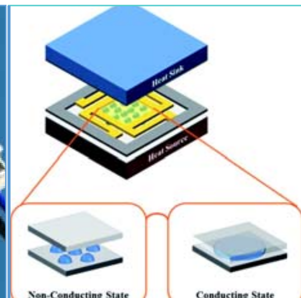
Maintain System within Operating Conditions

Energy Harvesting

- Energy Harvesting – any technology or technique that converts ambient energy into electrical energy in isolated applications (i.e. satellites, wireless sensors)
- Some common energy harvesting methods:

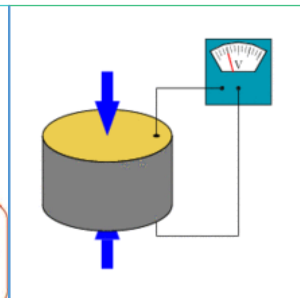
Thermoelectri c

- Harvests heat energy from temperature



Pyroelectric

- Harvests heat energy from temperature change



Piezoelectric

- Harvests mechanical energy from applied force

Micro-turbine

- Harvests kinetic energy from fluid flow

Solar

- Harvests electromag-netic energy from the sun

Energy Harvesting

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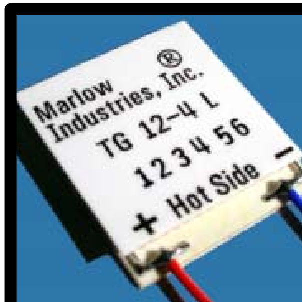
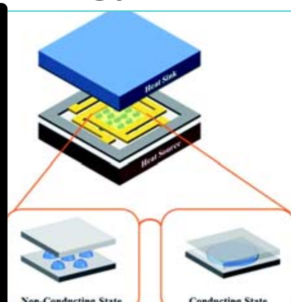
- Some common energy harvesting methods:



Thermoelectric
- Harvests heat energy from temperature



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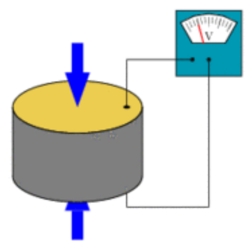

Piezoelectric
- Harvests mechanical energy from applied force

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Thermoelectricity

Advantages of TEG's

- Compact size
- Highly reliable
- Good for low-power applications

Advantages of TEG's in Engines

- Abundance of heat energy
- Moving vehicle may provide some forced convection
- Power output is predictable and during the majority of sensor operation

Disadvantages of TEG's

- Low efficiency (2-5%)
- Difficult to maintain temperature difference

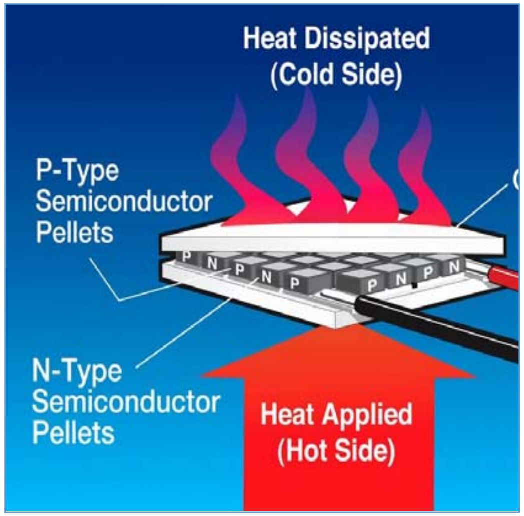


Figure 2. Basics of Thermoelectricity

Thermoelectric Generator (TEG)

- Marlow TG12-4 producing 4 watts max was chosen for design
- Specifications indicate a **60°C** temperature difference is needed to produce **0.61 W**

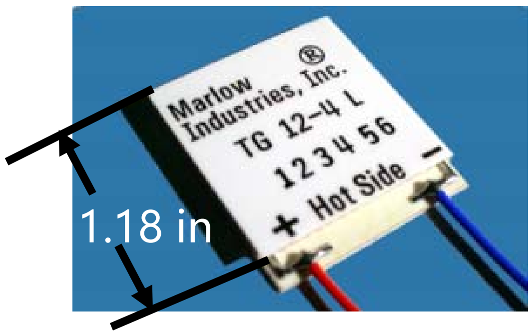


Figure 3. TEG chosen for design showing small size of 1.18 in. square

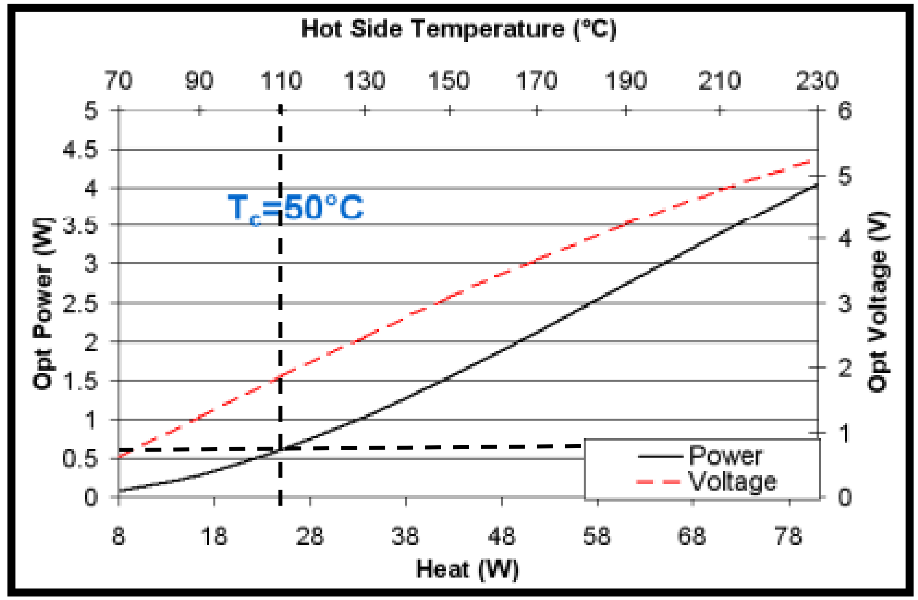


Figure 4. Power and voltage output of chosen TEG at various hot side temperatures with 50˚C cold side

Heat Sink Selection

- Heat sink should maximize heat dissipation from TEG to maintain highest temperature difference
- Chosen heat sink features:
  - Long symmetrical fin design for more effective heat transfer
  - Pressure mounting using spring hooks
  - Thermal grease for good thermal contact

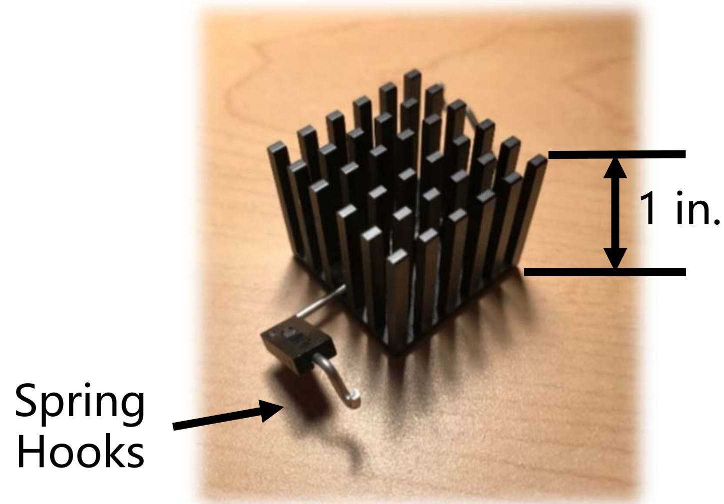


Figure 5. Chosen heat sink with 1 in. fins and spring hooks.

Thermal Analysis

Initial Conditions

- TEG hot side temperature: 140 ˚C
- Ambient temperature: 50 ˚C

•Results

- Fins maintain ΔT ≈ 35 ˚C across TEG
- Corresponds to TEG power output of 0.36W

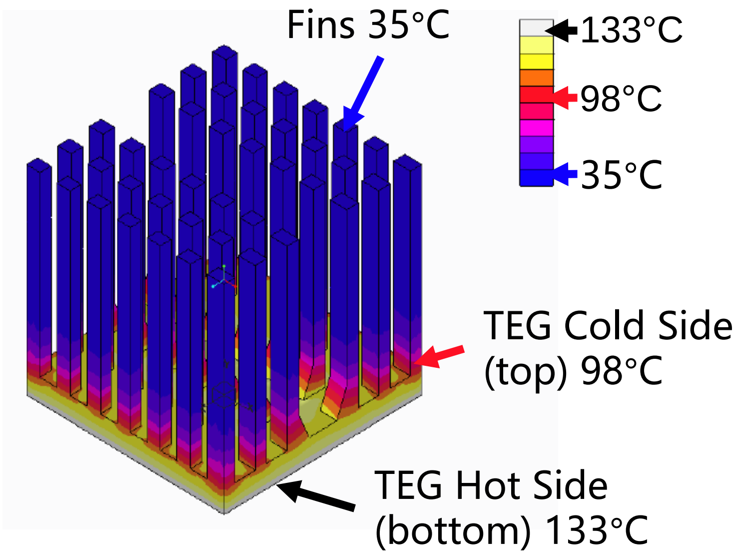


Figure 6. Thermal analysis of heatsink with results showing hot side at 133°C and cold side at 98°C

Wireless Sensor

Power Supply

Wireless Sensor

Housing

Harvest and Supply Energy

Measure and Wirelessly Transmit a Parameter

Maintain System within Operating Conditions

Temperature Sensor

- Free to choose any engine parameter to monitor
  - Temperature sensors are common in engines
  - Oil pan location provides good forced convection
  - Thermocouples produce their own signal and do not need to be powered
  - Type-K thermocouple for reliable high temperature measurements (± 2˚C)
  - Disadvantage:
    - Requires amplifier to boost signal

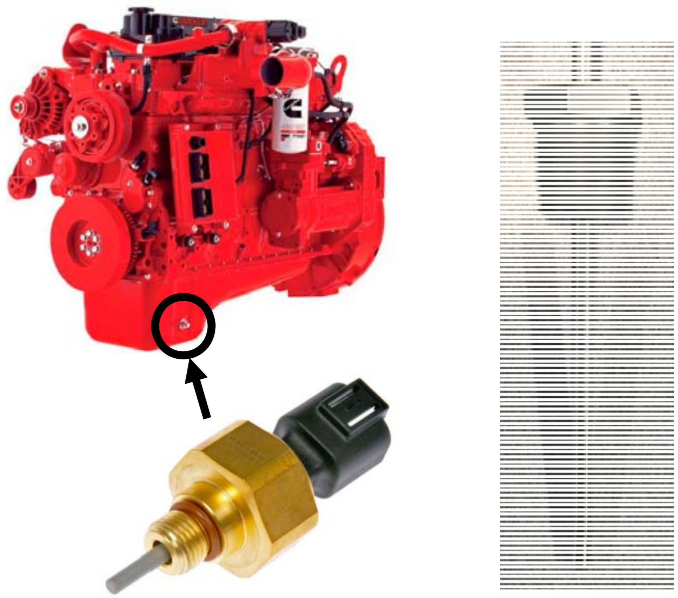


Figure 7. Cummins Diesel Engine showing oil sensor location and current design (left) and thermocouple sensor used in design (right)

Microcontroller

- The Adafruit Feather nRF52 Bluefruit
  - Bluetooth LE wireless transceiver
  - Integrated Power Management Unit (PMU)
    - Voltage regulation and battery charging
    - Continuously optimize the system to achieve lowest power consumption

Table 1. Estimated Power Consumption

Mode	Power Consumption	Time	Battery
Operating	0.026 W	50 h	1.3 Wh
Stand-By	7.4 μW	20 yr	1.3 Wh

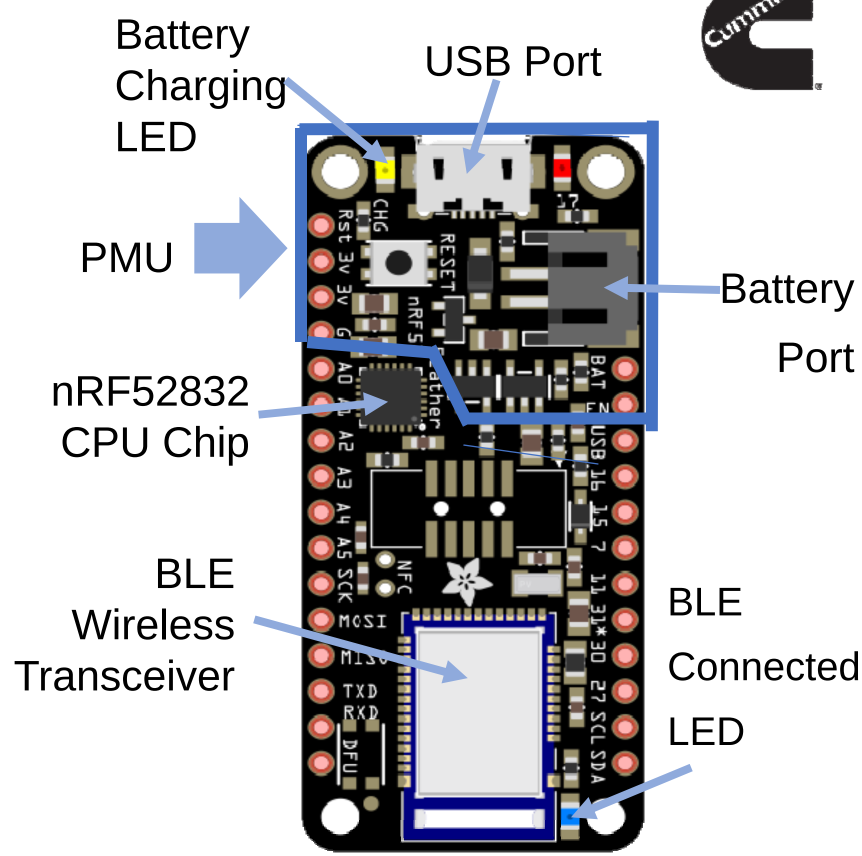


Figure 8. Adafruit Feather nRF52

Circuit Design

- Power Supply
  - Feather PMU
    - Voltage regulator needs 3V minimum
  - Thermoelectric Generator
    - Outputs around 1.2V from a 60 ˚C temperatures difference
  - Additional voltage regulator used to boost voltages from 0.8V to 5V
- Wireless Sensor
  - Feather BLE Transceiver
  - Type-K Thermocouple
  - Thermocouple Amplifier
    - Pre-calibrated with built-in cold

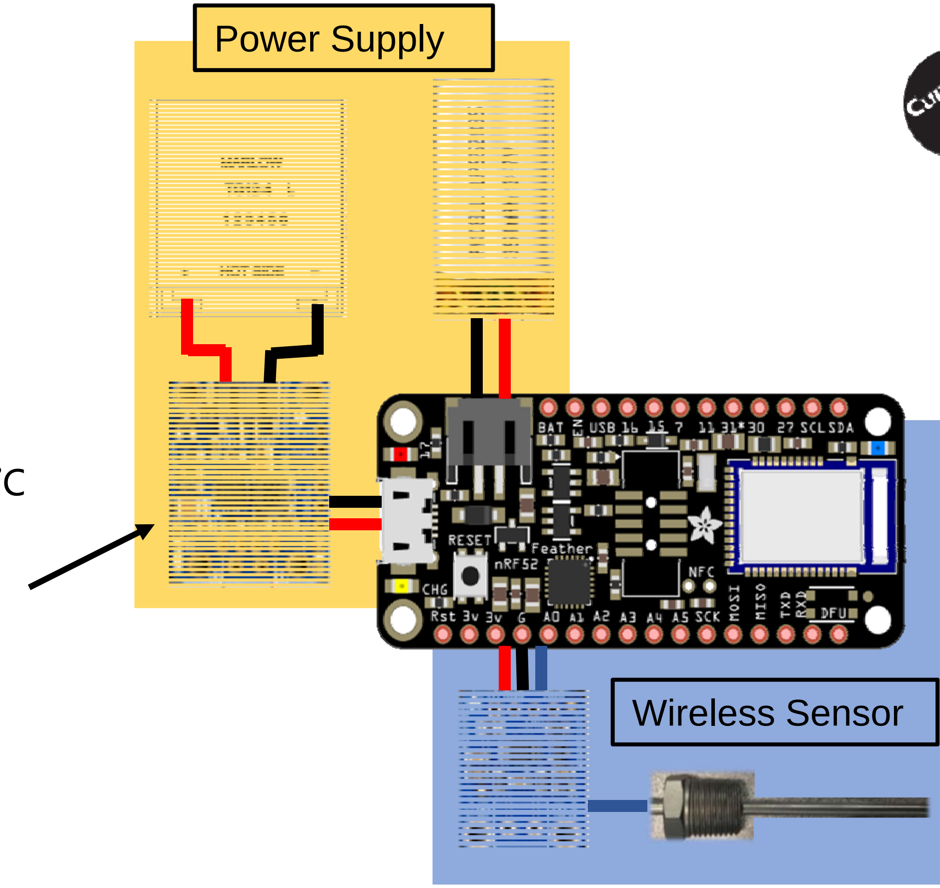


Figure 9. Wiring Diagram showing Power and Wireless Sensor Systems

Housing System

Power Supply

Harvest and Supply Energy

Wireless Sensor

Measure and Wirelessly Transmit a Parameter

<u>Housing</u>

Maintain System within Operating Conditions

Housing Selection

- Enclosure to protect electrical components from harsh operating conditions
  - Must be compact and wirelessly transparent
- Advantages of chosen housing:
  - Polycarbonate plastic is tough and good for high temperature applications
  - Wirelessly and optically transparent
  - Rated IP65, NEMA 4X, NEMA 13 for use in corrosive, oily and washdown environments
- Disadvantages:
  - Requires drilling holes to run wires externally
  - Bulky at 7.73 in^3

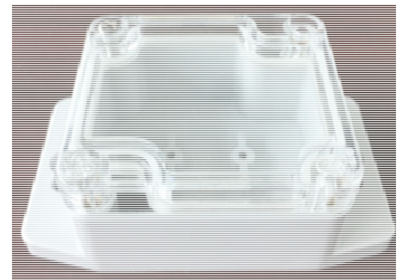
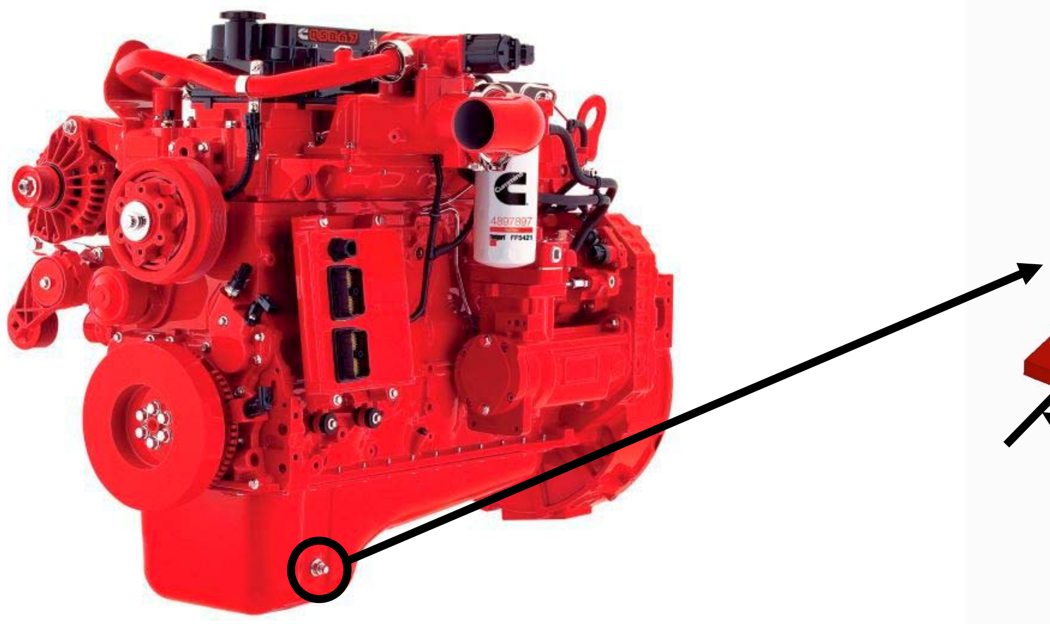


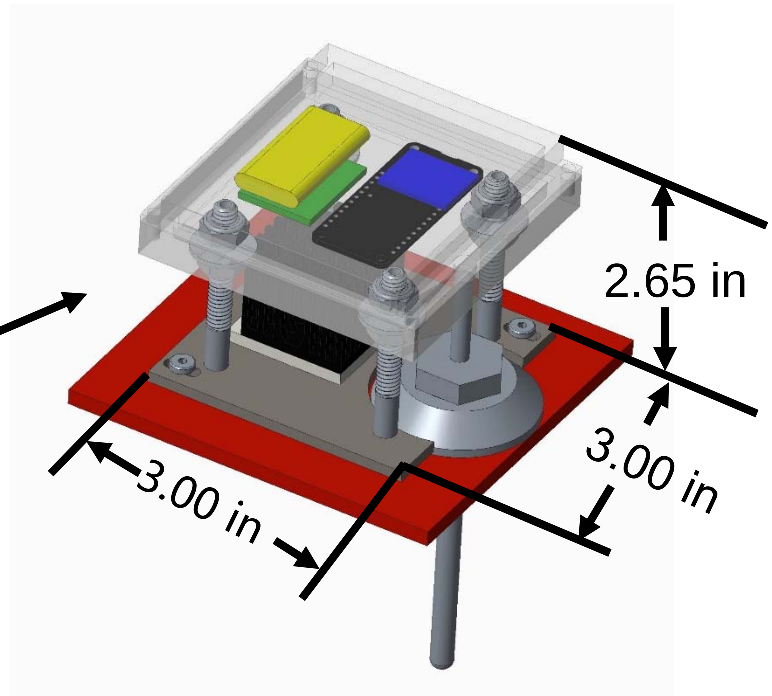
Figure 10. Chosen housing enclosure (top) and housing containing electrical components (bottom)

Final Design

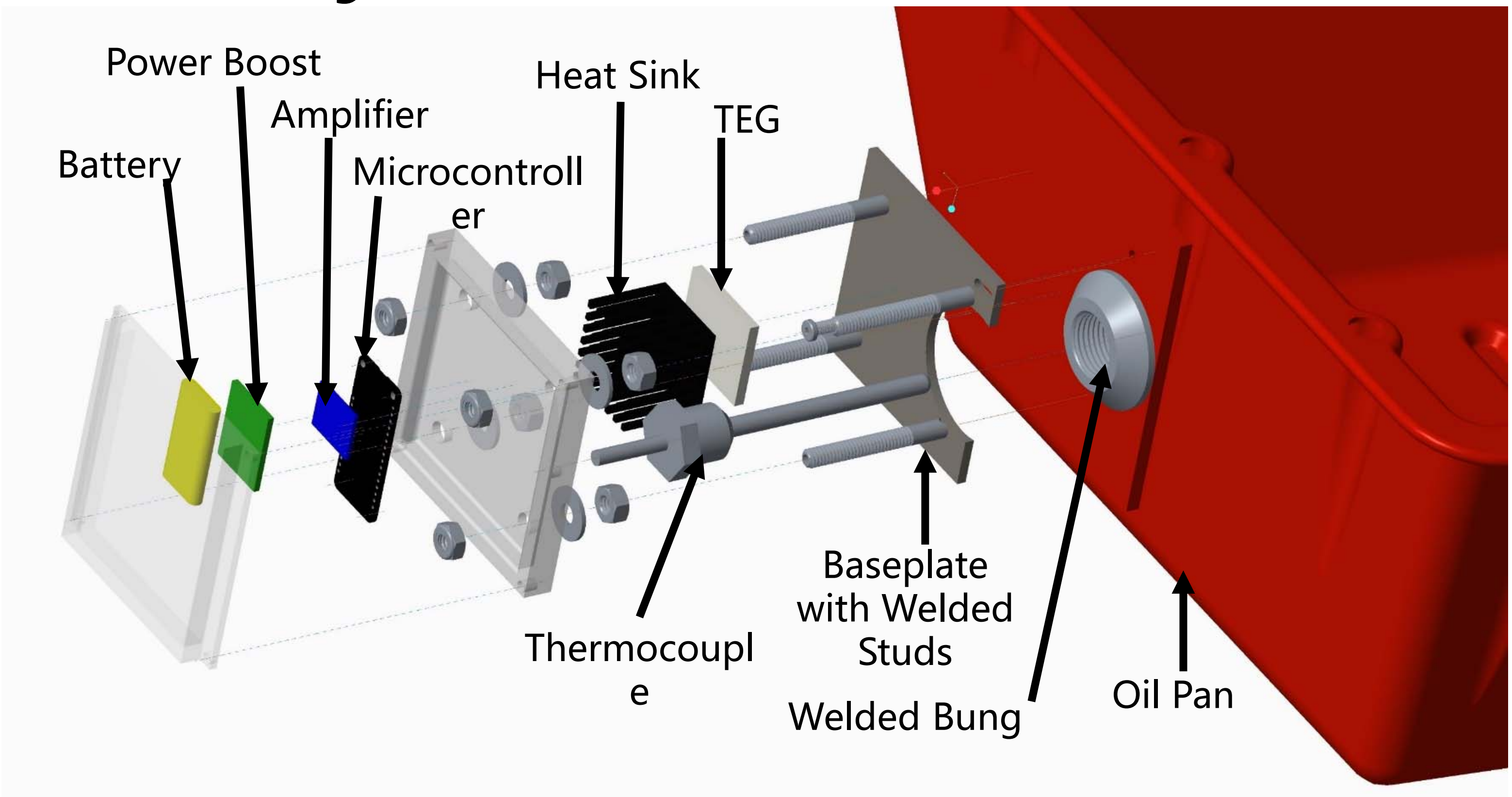
Meghan Busch

Final Product and Location



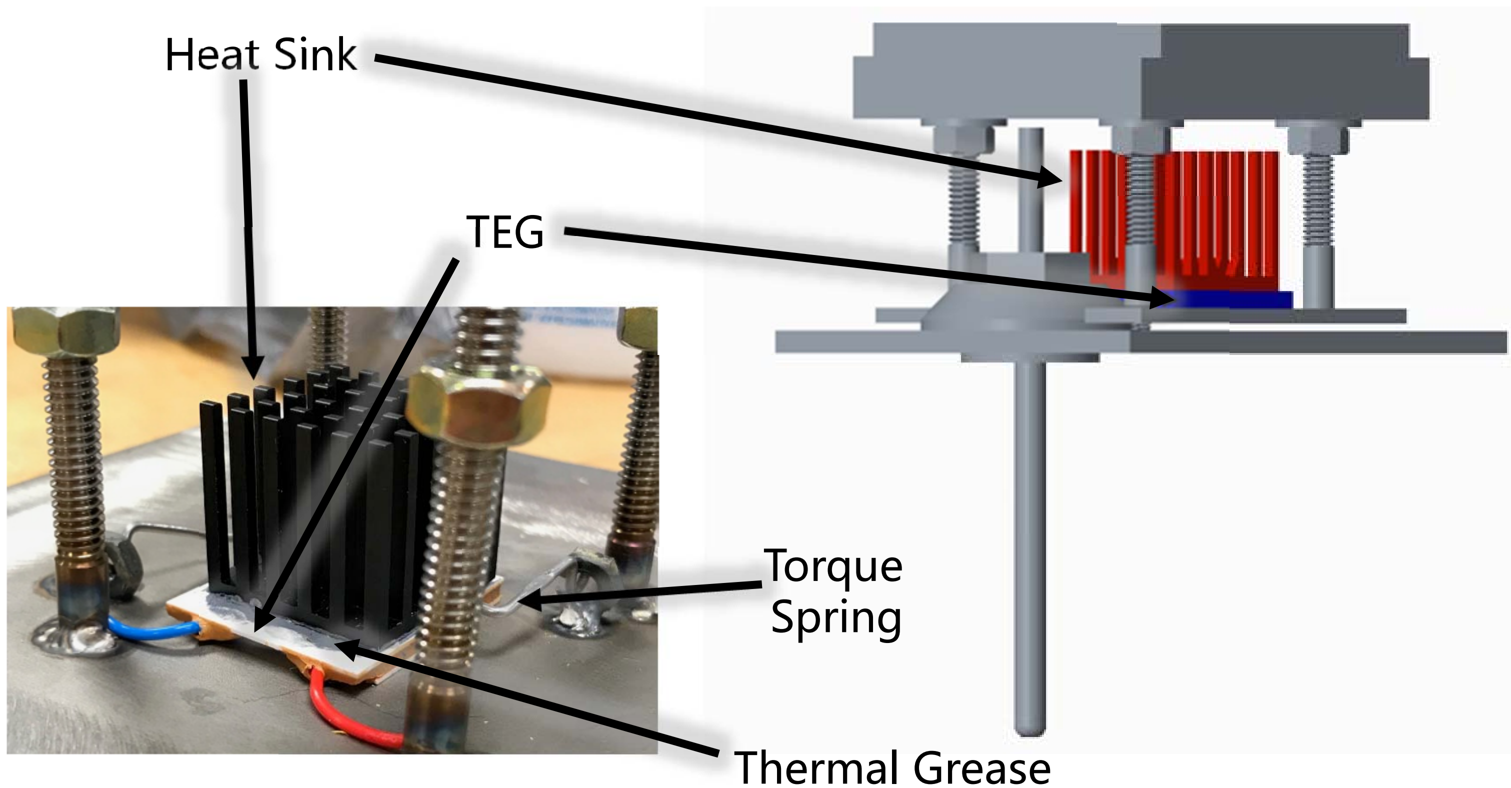


Assembly



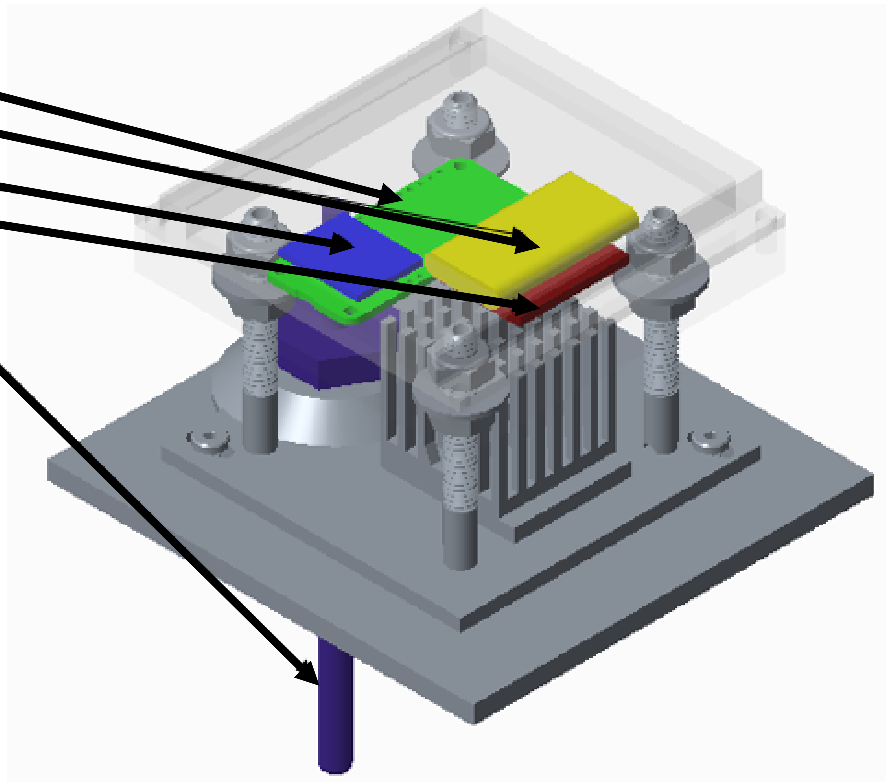
Power Boost
Heat Sink
Amplifier
TEG
Battery
Microcontroll
er
Baseplate
with Welded
Studs
Thermocoupl
e
Welded Bung
Oil Pan

Power Components



Electrical Components

Board (Green)
Battery (Yellow)
Amplifier (Blue)
Power Booster (Red)
Thermocouple (Purple)



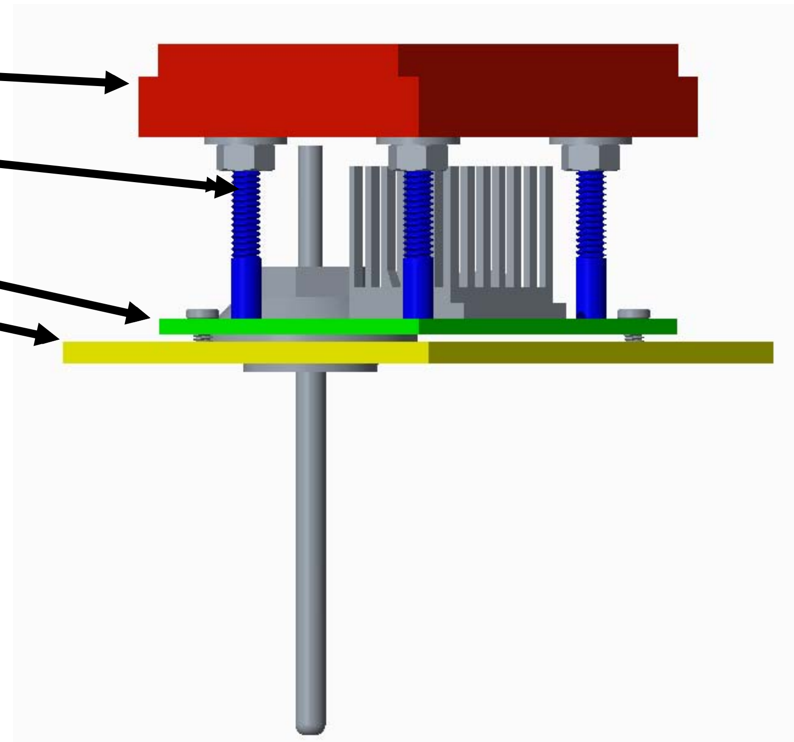
Housing Components

Housing (Red)

Hollow Threaded Studs (Blue)

Baseplate (Green)

Oil Pan Connection (Yellow)



Testing and Validation

Omar Rodriguez

Testing Method

- Assumptions
  - The ECM is simulated using the Adafruit Bluefruit App for iOS
  - The heat sink experiences forced convection from 1 - 3 m/s at room temperature
- Break-down of Testing Procedure
  1. Determine accuracy of temperature measurement
  2. Measure power consumption of system
  3. Measure power generation of TEG
  4. Verify the system is reliably self-powered and other objectives are met

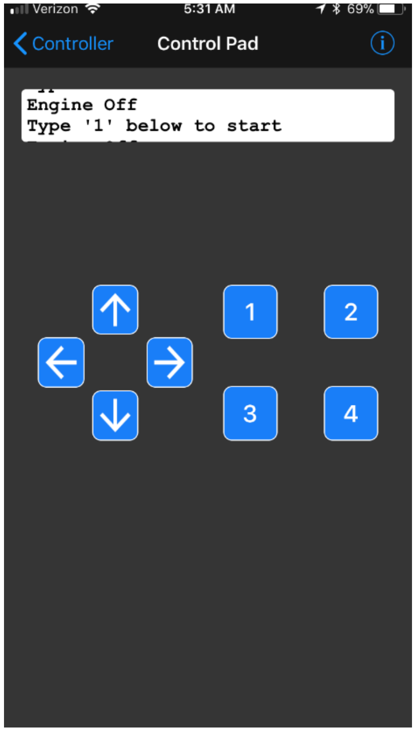


Figure 11. Engine Control Module represented by Bluefruit App Interface

Testing Procedure

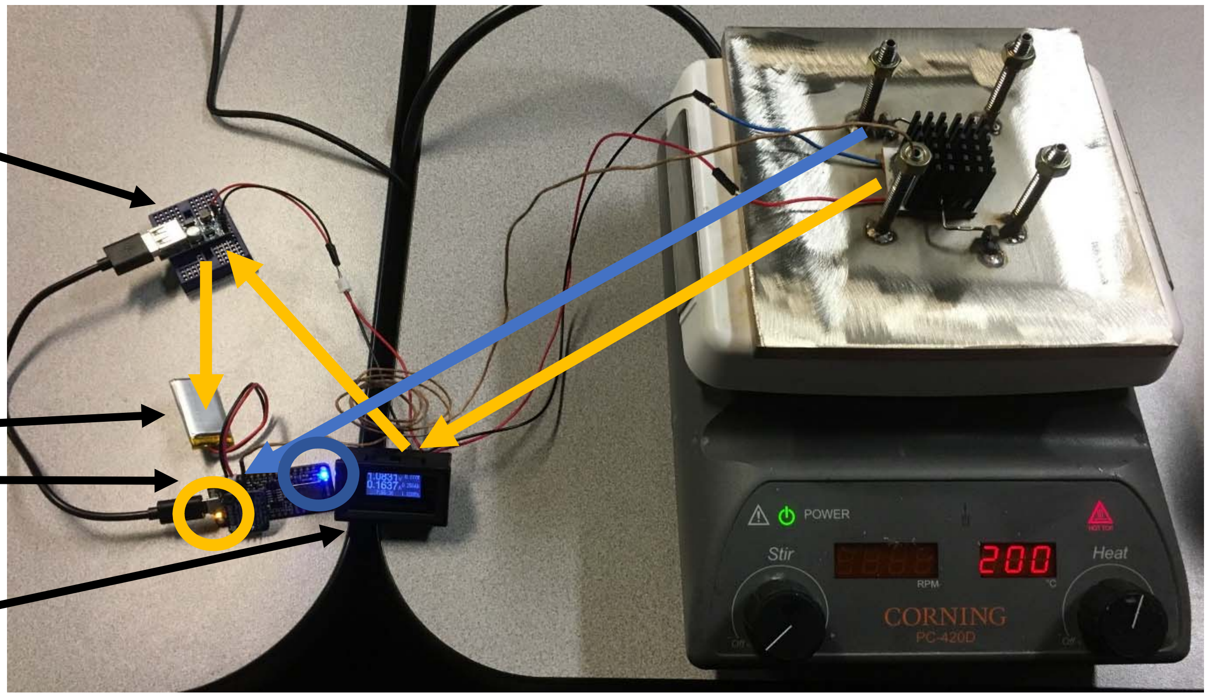
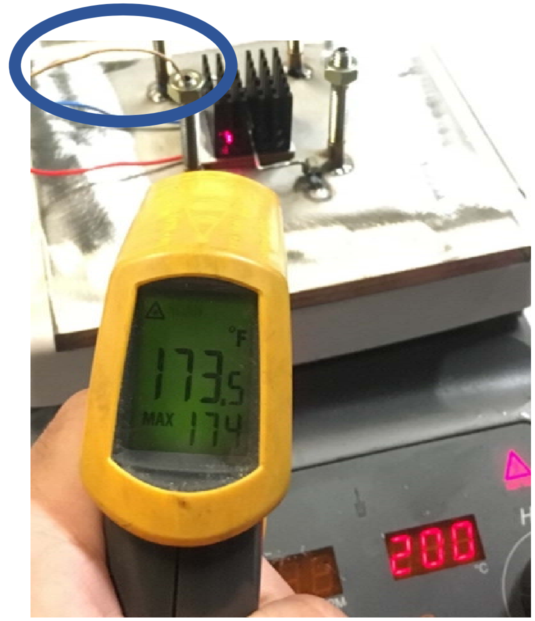


Figure 12. Testing setup.

- **Heat**
  - Baseplate reaches 170 ˚F in 6 minutes
- **Voltage Boost**
  - TEG reaches 0.8V and begins to power wireless sensor outputs 5V
- **Convection**
  - TEG began charging Battery

Sensor Measurement

- Hot plate set to 200˚C (392 ˚F) resulted in 170 ˚F on base plate surface (TEG hot side)
  - Verification using IR thermometer measurement: 173 ˚F
- Thermocouple sensor tested inside hollow stand-off (shown in blue circle)
  - Sensor measurement: 170 ˚F




```
Oil Temperature = 21.9 C (71.4 F)
Oil Temperature = 21.4 C (70.6 F)
Oil Temperature = 21.9 C (71.4 F)
Oil Temperature = 21.3 C (70.3 F)
Oil Temperature = 21.1 C (70.1 F)
```

Figure 13. Sensor test results in room temperature air

```
Oil Temperature = 76.7 C (170.0 F)
Battery Voltage = 3.914 V (76.2%)
Oil Temperature = 76.8 C (170.3 F)
Battery Voltage = 3.906 V (75.5%)
Oil Temperature = 76.2 C (169.2 F)
```

Figure 14. Sensor measurement during testing

Power Consumption

Table 2. Power Consumption with 1.3 Wh battery measured with Power Monitor tool.

Mode	Consumes	Life
Active	18 mW	72.2 hours
Stand-by	7.4 µW	20 years

- Less than estimated consumption of 0.026 mW

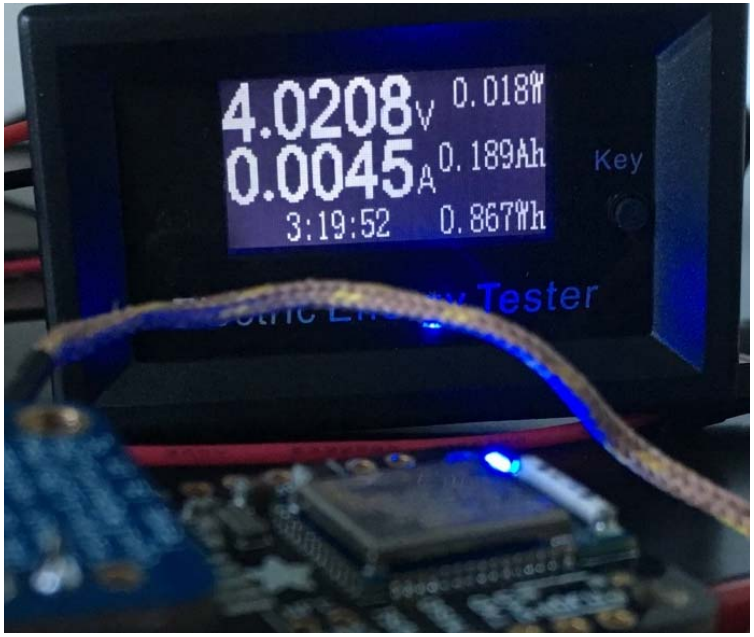


Figure 15. Power Monitor tool showing battery voltage, current draw, and power consumption of wireless sensor during operation.

Power Supply Testing Results

- Steady state power supply of 175mW after 6 minutes in test conditions

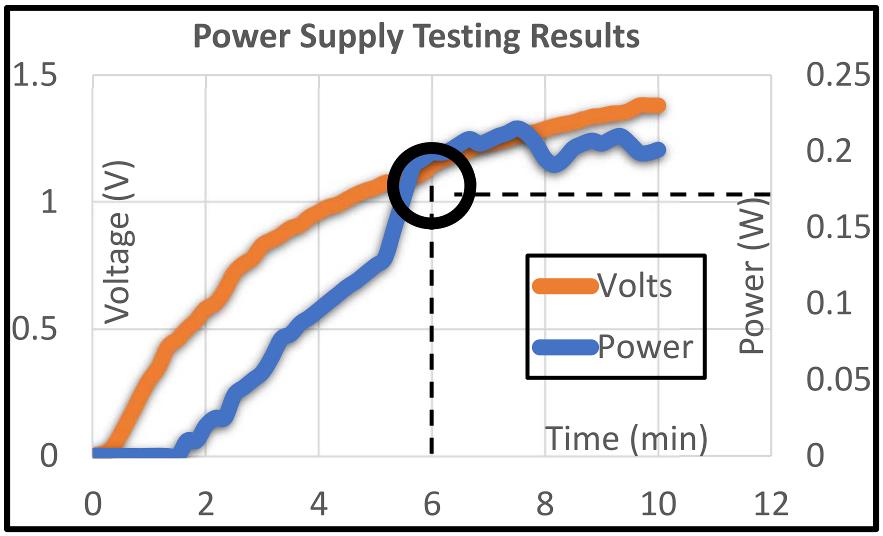


Figure 16. Power supply testing results showing power and voltage over 10 minutes.

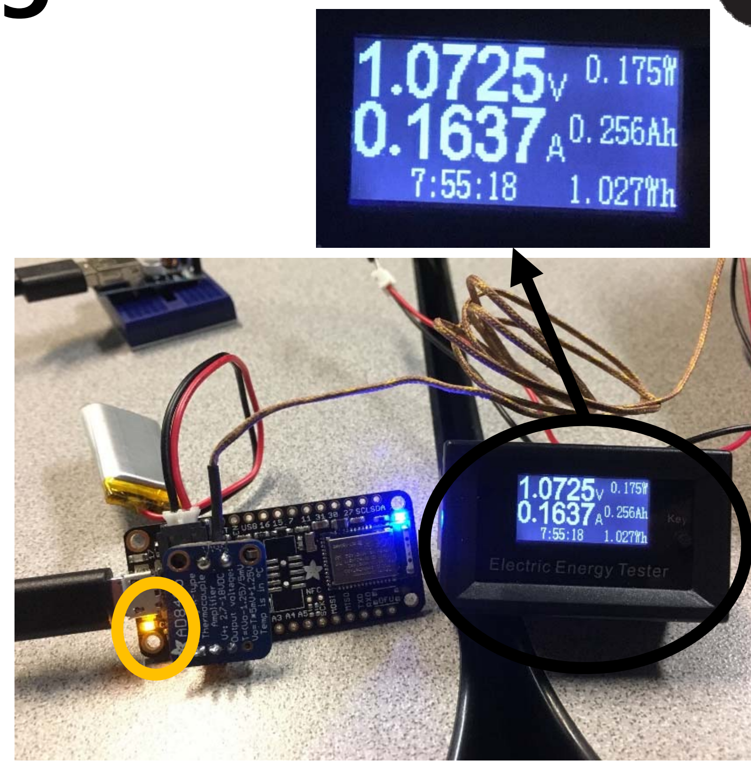


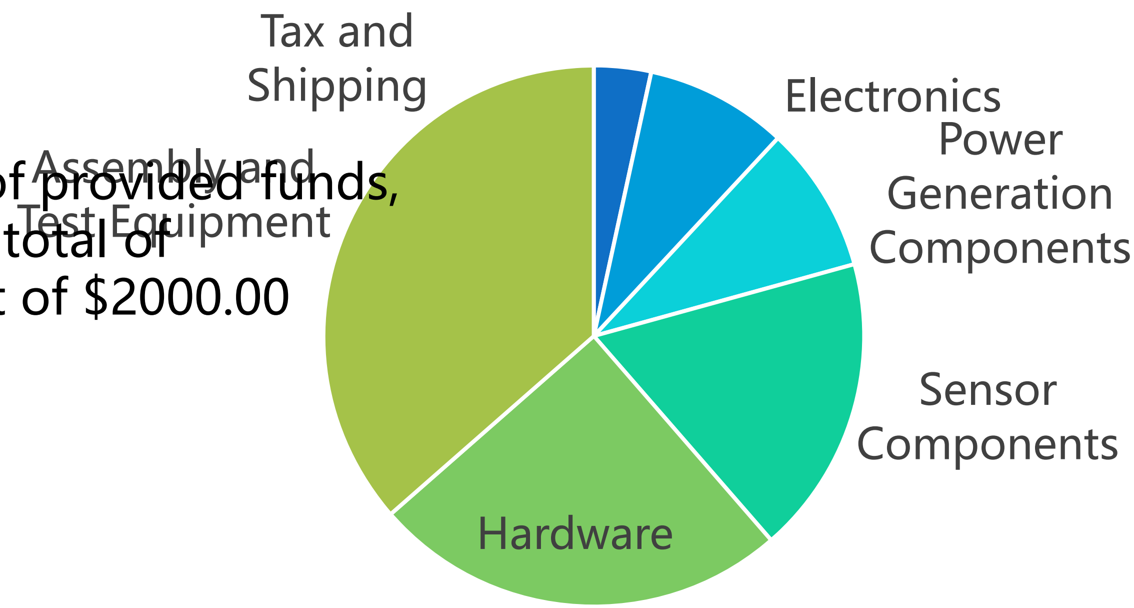
Figure 17. Power supply testing results.

Conclusion

Jacquelyn Burnham

Budget Allocation

Used 50% of provided funds, spending a total of $997.84 out of $2000.00



Project Outcome

- The wireless sensor is self-powered by a TEG which provides 175 mW while it consumes 18 mW
- The wireless sensor wakes just before engine cranking to begin transmitting data
- The wireless sensor communicates oil temperature wirelessly using BLE at 1 Hz up to 12 meters

Future Work

- Decrease size by further integrating components
- Increase reliability by better protection of TEG and heatsink
- Higher temperature tolerance for electronics could increase the number of possible applications
- Alternative power generation methods and sensor pairs:
  - Wind turbine and air flow sensor
  - Using vibrations from the vehicle to recharge battery, piezoelectric
- Integration of energy harvester and sensor
  - Both thermocouple and TEG operate by the Seebeck Effect

Lessons Learned

- Substantial background research, brainstorming and critical analysis early in the design process lead to a good design
- Due to lack of experience in electrical design, the team focused on it in the beginning and fell behind in the hardware design
- Dividing responsibilities among the group helped us work more efficiently.

Acknowledgments

- Dr. Shayne McConomy, Dr. Michael Hays, and Dr. Chiang Shih for organizing this opportunity and advising us along the way
- Dr. Camilo Ordonez (team's advisor) and Dr. Jerris Hooker for their expertise and advice in mechatronics, electronics, and programming
- Dr. Juan Ordonez for his expertise and advice in thermal design

Questions??