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EML4551-2

Team 3: Self-Powered Wireless Sensor

Jacquelyn S. Burnham, Meghan E. Busch, Thomas E. Dodamead, Omar G. Rodriguez, Caleb B. Stallings

FAMU-FSU College of Engineering 2525 Pottsdamer St. Tallahassee, FL. 32310

Abstract

Disclaimer

Acknowledgement

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Notation

A17	Steering Column Angle
A27	Pan Angle
A40	Back Angle
A42	Hip Angle
AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled

Difference between the calculated and measured

Difference BOFRP to H-point

DRR Death Rate Ratio

DRS Driving Rehabilitation Specialist

EMM Estimated Marginal Means

FARS Fatality Analysis Reporting System

FMVSS Federal Motor Vehicle Safety Standard

GES General Estimates System

GHS Greenville Health System

H13 Steering Wheel Thigh Clearance

H17 Wheel Center to Heel Pont

H30 H-point to accelerator heel point

HPD H-point Design Tool

HPM H-point Machine

HPM-II H-point Machine II

HT H-point Travel

HX H-point to Accelerator Heel Point

HZ H-point to Accelerator Heel Point

IIHS Insurance Institute for Highway Safety

L6 BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

Project Description

Design, manufacture, 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 (McConomy, 2017, *Project Scope*).

Key Goals

The key goal of this project is to reduce warranty claims on failed engine sensors by designing a powering method that will allow the sensor to operate wirelessly. Some other important goals include (McConomy, 2017, *Project Scope*):

- Reduce maintenance frequency and costs by eliminating a cable harness.
- Increase robustness of sensor design to withstand harsh environments and increase lifespan.
- Communicate data at a fast sampling rate, and at a far distance.
- Introduce wireless technologies to sensors in Cummins' diesel engines.
- Choose a variable to sense that is widely used to add value to the project.

Market

The product will be designed for use in a Cummins' Diesel engine, so the primary market is for vehicle owners (commercial grade and private license). This product could be useful in other wireless sensing environments. Secondary markets will include scientific research laboratories (like wind tunnels and fluid flow research). Wireless sensing could also be useful in computing applications, off-grid sensing, building management applications, HVAC applications, and aerospace applications (McConomy, 2017, *Project Scope*).

Assumptions

To design and test a method to power a wireless sensor before the deadline of the project, the team produced assumptions. These assumptions include (McConomy, 2017, *Project Scope*):

- Not designing the sensor itself, just the powering and communication method.
- The purchased sensor will perform to the manufacturer's specifications, and the sensor will need little testing to ensure that it works properly.
- The ECM is compatible with the wireless communication method chosen for the sensor.
- The team is designing the power and communication of one sensor and is not creating a wireless communication network of multiple sensors.
- The sensor will only be used for highway applications only.
- The team will not need to design the attachment method for the sensor to the vehicle.
- The sensor can be used anywhere in the engine and does not need to be designed for a specific application.

Stakeholders

Cummins will be the primary stakeholder for this project. Other stakeholders include the members of the team. Additional outside stakeholders for the desired product include but not limited to fleet managers of semi-trucks and other types of box trucks, diesel truck warranty and insurance companies, and diesel truck manufacturers. Any of these stakeholders above can be impacted by the project (McConomy, 2017, *Project Scope*).

1.2 Customer Needs

To define the customer needs it is necessary to first establish the project objectives. After analyzing the initial general project description that was provided by the client. The design team started a direct communication with the sponsor, Michael Hays, via conference call to establish the principal project objectives. The result of this first direct contact with client allowed the design team to identify the main goals of the project and the needs for the creation of this product. Table 1 below shows the interaction with the client and identifies existing functions that a new design can resolve (McConomy, 2017, *Customer Needs*).

Table 1
Customer Needs

Question/Prompt	Customer Statement	Interpreted Need
In general, what are your problems with sensing currently?	Cummins has spent considerable funds for warranty claim on wiring harnesses. Typically, wiring harnesses are damaged due to harsh environmental conditions in the motor.	The wireless sensor does not use any wires to communicate with ECM.
Which current wired sensors are your priority to make wireless?	Any sensor within the engine can be used: thermal sensor, speed sensor, pressures sensor, etc.	The variable to be measured will be up to the design team to decide.
What applications will these wireless sensors be operating in? Diesel? Commercial or Consumer vehicles?	Cummins makes engines from 2.8L to 120L. Any sensor that is utilized in this type of engines is appropriate for the project. For example an ISX sensor.	The wireless sensor can be used in engines ranging from 2.8 L to 120 L

Are you currently using wireless sensors anywhere in your products?	Cummins has some similar prototypes designed. However, these prototypes will not be used in this project.	There are no current prototypes available for iterations or comparison.
What type of wireless communication do those wireless sensors use?	Any communication type can be implemented into the ECM.	The wireless communication can be adapted to the ECM.
Do your ECMs already sense wireless signals? If not, will an attachment need to be made.	The ECMs currently do not sense any wireless signals. However, the ECMs can be updated to any type of signal.	The wireless sensors can use any type of signal to transmit the data.
Expectations or preferences in terms of powering the wireless sensor?	The sensor and wireless receiver must be fully operational at the time of engine start and be able to remain in a ready condition for up to 36 hours. A battery can be attached to the sensor to store energy if necessary.	The wireless sensor is self-powered and can last up to 36 hours.
Locations of the sensors? With respect to the ECM?	Any sensor can be use for the project. Therefore, the location of the sensor can be determined.	The wireless sensor can communicate with the ECM from any location.
Approximate Size Constraints for the sensors?	No more than 6 in^3.	The wireless sensor does not require more than 6 in^3 spacing.
Any ratings/standards the design needs to meet?	The sensor does not need to meet any ratings.	The wireless sensor does not need to meet any ratings.
What expectations do you have for the prototype?	For a successful project, the team must demonstrate wireless communication of the agreed upon variable with the ECM (or analog) at a frequency no lower than 1 Hz at a 5 meters.	The wireless sensor needs to have an sampling frequency no lower than 1 Hz to avoid aliasing and operate at a distance of 5 meters.

After the team interpreted the sponsor's responses as customer needs for the project, the team condensed the needs and ranked them according to importance in Table 2 (McConomy, 2017, *Customer Needs*).

Table 2
Condensed and Ranked Customer Needs

Rank of Importance	Interpreted Need
1	Power supply to operate the sensor
2	Communicate to the ECM wirelessly
3	Needs to have a sampling frequency no lower than 1 Hz
4	Sensor's power supply last 36 hours after engine shut off
5	Operate at 5 m
6	Decide on a variable for the sensor to measure
7	Design has a volume less than 6 in^3
8	Can use any signal communication between ECM and sensor
9	The wireless sensor can be used in engines ranging from 2.8 L to 120 L
10	No specific safety or fire ratings need to be met

After interpreting our customer needs, we determined a ranking. Based on our conversation it was clear that powering the sensor would be the highest priority for the project; therefore, it is ranked first. Once the sensor is powered, it is important for the sensor to communicate with the ECM; this need is ranked second. These are the two most important goals of the project. To have an accurate and usable sensor, it is essential that the sampling frequency is sufficient to accurately detect changes in the system; this is ranked third. The customer explicitly stated that the sensor must be powered for 36 hours after last engine start; this parameter is fourth. After these qualifications are met, the sensor will need to be able to communicate at a reasonable distance. The customer indicated 5 m as an acceptable distance; this is ranked fifth. The next most important customer need is deciding on the type of sensor. According to the customer, the variable that is being sensed was not a priority, but the type of sensor the team choose will be important in designing other parameters so this is ranked sixth. Size considerations are ranked seventh. The customer did not state a size consideration until asked and provided a volume of 6 in3 when prompted. For this reason, size is near the bottom of the ranking. The bottom three ranked customer needs are extra parameters with little importance for our design. The project will be determined complete by how many needs that are met in the order of the ranking. For example, a design that meets the third customer need but not the first two will not be a complete or usable design.

1.3 Functional Decomposition

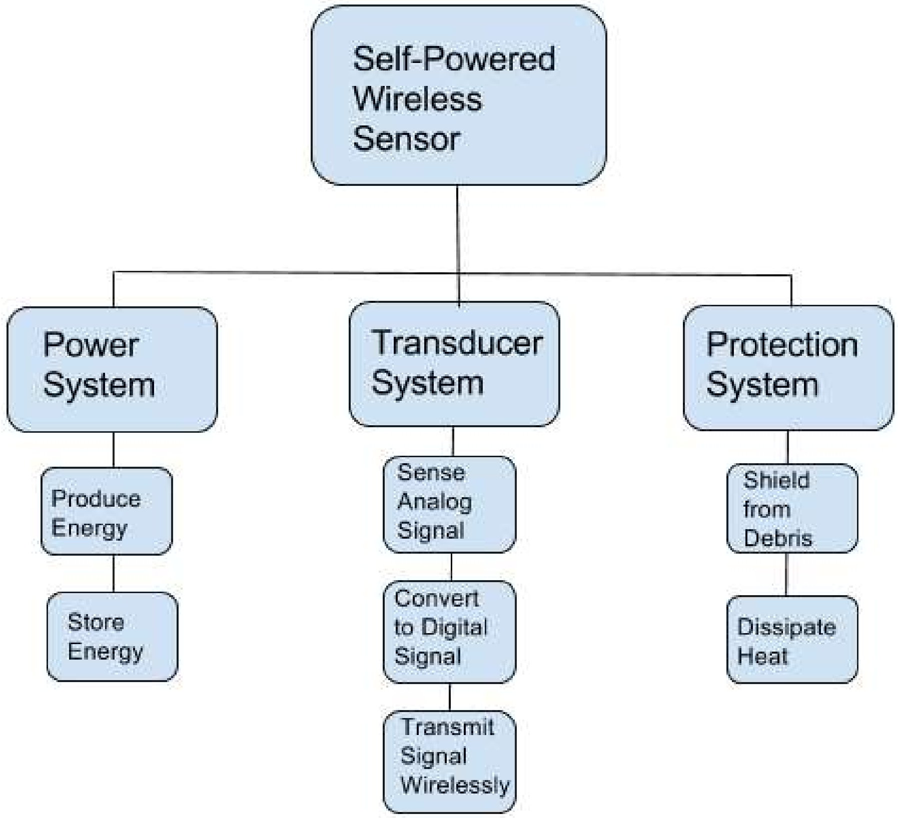

Figure 1. Functional Decomposition Diagram

In order to gain a better understanding of what is needed to design the Self-Powered Wireless Sensor the function it must perform was analyzed by decomposing the system into subsystems. The value of the functional decomposition comes from looking at the physical outcomes of each subsystem in a general sense. This allows the team to then identify ways and means of accomplishing these physical outcomes that may not be obvious. The diagram in Figure 1 above shows the results of the functional decomposition on the Self-Powered Wireless Sensor. The three subsystems are listed below of main system, and the functional outcomes of each subsystem descend below.

The overall function that the system as a whole must accomplish is to communicate information about the operation of an engine to the engine control module. Three main subsystems can be derived from the main system that are required to accomplish the overall function. These subsystems are the the Power System, the Transducer System and the Protection System. By analyzing these subsystems, the functions they must accomplish individually and how they relate to the overall function the team will gain a deeper understanding of how to design the system.

The Transducer System must accomplish several important outcomes. First, it must sense the agreed upon engine parameter which will be in the form of an analog (continuous) signal. This signal, whether is be a temperature, pressure or flow rate, must then be converted to a digital (discrete) signal so that it can be used by electronic devices. Once the signal is in a digital form so a computer can understand it, the signal must be wirelessly transmitted to the engine control module. The signal must be sent at a frequency of at least 1 Hz and must be receivable at a distance of 5 meters. This subsystem accomplishes the previously mentioned overall function of the system as a whole, however in order to do this power is required.

The Power System is the most important project objective. This is because wireless sensors are already a mature technology but powering these sensors without using wires to some external power source is a nontrivial task. The Power System must provide power to the sensor at the time of engine start up and must be able to power the sensor for up to 36 hours after engine shut off. To accomplish this, at least two functions are required. The first and the most important is the ability to produce electric power from energy in the surrounding environment, such as a heat source, electromagnetic radiation etc. The Power System may also have to store some of the electrical power it produces in case it is not always able to produce enough power.

The Protection System plays a crucial role in keeping the entire product in working condition. This is because these sensors encounter extreme conditions which cause them to fail in the current wiring harness design. The Protection System is responsible for shielding the product from any stray debris which the system could encounter on highway conditions. High temperature swings are also a problem which the protection system will help to resolve. Chemical exposure also poses a threat in the current system design which proves the task of protecting the product even more complex. In Table 3 below the subsystems are mapped to their corresponding functions.

Table 3
Functional Decomposition Matrix

	Power System	Protection System	Transducer System
Energy Storage	X		
Energy Production	X		
Shields from Debris		X	
Dissipates Heat		X	
Transmits Signals Wirelessly			X
Wireless	X	X	X
Self-Powered	X	X	X

1.5 Concept Generation

Concept generation, also called ideation, is the process of creating feasible design ideas. It is beneficial to produce as many creative design concepts as possible to increase the chance of finding an innovative or novel design. This was achieved by combining extensive background research with the knowledge gained from the functional decomposition to systematically produce design concepts. The functional decomposition helped the team determine the subsystems needed for the self-powered wireless sensor to function: the Power System, the Transducer System, and the Protection System. These subsystems were then further decomposed into the components that make up the subsystem. Various options of the components are then introduced and relevant background information is discussed for each component. Potential design concepts are then be presented for the most promising combinations of the subsystem components along with advantages and disadvantages of each. Before discussing the various subsystems, some important design considerations for a self-powered wireless sensor design need to be addressed.

A self-powered wireless sensor can take many forms because the type of sensor used in the design is unimportant to the customer, given that the sensor is used in a Cummins engine. Different types of sensors operate using different principles and therefore have different power requirements. The type of sensor chosen will also determine where in the engine or vehicle chassis the sensor is located and therefore what environmental conditions it is exposed to. The environmental conditions are very important because the design needs to be able to generate power from its surroundings, while protecting itself from harsh environmental conditions. Apart from the sensor, there are many possibilities for each of the other components. These complexities are what lead the team to decompose the system into its components, which makes it possible to determine metrics and targets for each component and simplify the concept selection process.

Transducer System

A transducer is a generic term for a device that converts one form of energy into another. For the purposes of this design, the Transducer system refers to the components that handle the signal acquisition and transmission, which are the sensor, the microcontroller, and the communication method.

Sensor

The type of sensor used for the design is very important because it will determine many other aspects of the design. Sensors are transducers that convert the energy of the sensing parameter into a voltage so it can be interpreted by a controller. There are many different types, and each operate using different principles. A typical Cummin's engine uses an Engine Control Module (ECM) which is wired to various sensors that monitor the performance of the engine. The reliability of the sensor readings is directly affected by its operating conditions. For instance, if the sensor is not maintained at it's appropriate operational temperatures and voltages, the sensor could fail resulting in damage to the engine. In addition, sensors are interconnected with other systems such as power and controls. Therefore, it is important to evaluate the different type of engine sensors available along with their ideal operational conditions. The following table 4 shows a variety of sensors with their electrical components rating and measurements ranges.

Concept 1: Temperature Sensor

There are two common types of temperature sensors: thermocouples and thermistors. A thermocouple operates when two different materials that are joined at a junction experience a temperature difference, usually between the medium being measured and ambient. A voltage is created across the junction due to the Seebeck effect. The voltage is proportional to the temperature difference and is interpreted to measure the temperature of the medium. Thermocouples are desirable because they are widely commercially available and don't require any input power because the voltage is created by the heat source via the Seebeck effect. Their main limitation is that it is difficult to achieve high accuracies.

A thermistor is a variable resistor that changes its resistance based on the temperature. The temperature is proportional to the voltage drop across the resistor according to Ohm’s Law. This style of temperature sensor does require a small power input to create a voltage drop that can be measured.

Concept 2: Pressure Sensor

A pressure sensor or manifold absolute pressure (MAP) are used to continuously monitor the manifold pressure or Barometric pressure and send the analog voltage signal for the absolute pressure measured to the Electronic Control Module (ECM). This data allows the ECM to evaluate the air density and control the mass flow rate of the engine. Typically, pressure sensors require +5V to operate; however, this sensors can also output a range of (0 to 4.8) V depending on its pressure reading (“MAP sensors,”.n.d). This information can be useful to design a system that requires a small input to output voltage ratio.

Concept 3: Mass Air Flow Sensor

A mass air flow sensor is designed to measure the amount of air entering the engine. Typically, there are two commonly used types of sensors Hot-Wire and Vane meter sensors. A hot-wire mass air flow sensor has a small electrically heated wire (hot wire) and a small temperature sensor installed close to the hot wire. The temperature sensor measures the temperature of the air near the hot wire. When the temperature sensor detects a change in temperature, an electrical current is sent through the wire to maintain its temperature. For instance if the engine is idling and there is no air flow, only a very small current is required to keep the wire hot. This is because the temperature of the wire is proportional to the mass air flow. The second common mass air flow sensor is the Vane meter sensor. This type of sensors contain a spring loaded flap that is placed in-between the air filter and the intake manifold. As the air enter the intake the air has to pass through the flap. Based on the amount of air flowing through the intake, the flap will open relatively. With the help of a potentiometer, the air flow can be estimated by measuring the angle of the flap as it opens (Laukkonen, 2013).

Concept 4: Throttle Position Sensor (TPS)

A throttle position sensor is an important part of the fuel management system. It helps estimate the amount of air to fuel mixture ratio that goes into the engine. Typically, the sensor is located in the butterfly spindle/shaft and monitors the position of the throttle (Wooten,2016). One of the benefit if this sensors is that are usually placed in areas where temperatures range from (0 to 60)°C. For design purpose, it is important to keep temperature ranges low to avoid malfunctions in other components of the system.

Concept 5: Oxygen Sensor or O_2 Sensor

Oxygen sensor or O_2 sensor: This sensor manages the exhaust emissions of petrol, diesel and gas of the engine. The emissions are estimated by measuring the amount of oxygen left in the exhaust gases. The signal is transmitted to the engine management system in the form of an electric voltage. Based on the oxygens sensor reading, the control unit can determine if a fuel and oxygen mixture is too lean or rich. The control unit reduces the quantity of fuel in the A/F ratio if it is too rich, and increases it if it is too lean("Joel,"2009). Typically, O_2 sensors require +5V to operate; however, this sensors can also output a range of (0 to 4.8)V depending on the output reading. This information can be useful to design a system that requires a small input to output voltage ratio.

Table 4

Different Type of Sensors and Parameters.

Sensor Type	Sensor Variable	Variable Range	Voltage Supply	Resistivity	Operational Temperature
Engine coolant temperature	Temperature	-40 - 130°C	1.0 - 5.0 V	89 - 46k Ohm	-60 - 180°C
Air temperature	Temperature	-40 - 150°C	5.0 V	46 - 99k Ohm	-60 - 180°C
Barometric pressure/manifold absolute pressure	Pressure	10 to 350 kPa	0.1 - 5.0 V	50 - 50k Ohm	-25 - 110 °C
Mass air flow	Air flow	0 to 450 kg/hr	0.1 - 5.0 V	--	--
Throttle position	Angular Position	0° - 360°	5 V	<1k Ohm	- 45 °C - 125 °C
Oxygen	Oxygen levels	0% - 100% O2	0.1 5.0V	10 Ohm	--

Micro-controller

Choosing a microcontroller poses the biggest challenge because it is itself a system made up of many components. It can be thought of as the brains of the system and can have the biggest impact on total system power. Basic microcontrollers consist of input and output ports, a microprocessor, a memory and a clock. Many modern microcontrollers also have integrated analog to digital converters, signal amplifiers and filters and wireless transceivers. To choose the proper microcontroller for the design the team needs to balance the required signal processing and memory performance with the power consumption required for different level of performance. For example, the processing and memory performance of a laptop or smartphone would far exceed what is needed for a wireless sensor and would require a relatively large amount of power. There are many commercially available microprocessors that are specifically designed for handling data acquisition on a low power budget and will likely meet the needs of the design.

The sensor, the transciever, and the power system will need to be connected to a microcontroller that will be responsible for facilitating the communication between the components. It will regulate the power system by requesting power, and indicating when the power system should move between charging a battery and powering the unit. The transciever needs a command to send or receive communication from the ECM, which will come from microcontroller logic. Voltage changes from the sensor will need to be interpreted by the microcontroller, and any power regulation to the sensor will be done through the microcontroller. The unit will also be used in a high temperature environment, with a desirable small size and low voltage requirement.

There are some options when it comes to a microcontroller solution, the team could use a premade board like the Raspberry Pi, BeagleBone Black, Arduino Uno Rev 3, or Teensy 2.0. The Raspberry Pi, BeagleBone Black, and Arduino Uno Rev 3 are all made to be like computers with endless add on options and additional capabilities that might not be necessary for this project, and they are also larger than some other options available. On the other hand, these types of boards have many resources and help available for coding the boards, and use languages the team is already familiar with.

Concept 1: Rasberry Pi

This option is bulky because it has a lot of add on options and is made to act like a computer, with dimensions of 85 by 56 mm. The design for this project will not use most of its capabilities, like the 1.2 GHz processing power and the customizable memory storage of up to 128 GB (Starts at 1 GB). It is easier to code because it has a large user base and uses coding language the team is familiar with. It requires 5.1 V, which is average for this sensor type. The Raspberry Pi is guaranteed for a temperature range of 0 to 70 C which is lower than average for these boards ("Power Supply," n.d.).

Concept 2: BeagleBone Black

The BeagleBone is similar to the Raspberry Pi because it also designed to have many capabilities and add ons similar to a computer. It has a similar size and voltage requirement. The operating temperatures are also average for printed circuit boards (PCBs) which -40 to 85 C. Though the memory is not customizable, it offers 4GB of storage which is plenty for this application. The processing power is close to that of the Raspberry Pi at 1GHz. BeagleBone also has a large user base and is popular indicating it will be easier to code ("Beagleboard: BeagleBoneBlack," n.d.).

Concept 3: Arduino Uno Rev 3

This is the second to the smallest of the computer like boards, at 68.6 by 53.4 mm. The Arduino board contains the same controller chip as the Teensy, along with some other capabilities and optional plug ins that won't be necessary for this project. It has the same power usage and temperature range as the other PCBs. The Arduino software provides a coding structure with a large user base and is also very popular, making it easier to code as well ("Arduino Uno Rev 3," n.d.).

Concept 4: Teensy 2.0

The smallest of these types of boards is the Teensy 2.0. It uses the Arduino coding interface, but is much smaller at around 36 by 18 mm. One issue with the smaller board is that the design is limited to the processing power, and memory of the smaller board which is significantly smaller at 1 KB of EEPROM and 16MHz. It uses a range of 2.7 to 5V which is a low power consumption compared to the other boards. This board can withstand temperatures that are about average for most microcontrollers -40 to 85 C ("ATmega16U4 / ATmega32U4," n.d.).

Concept 5: Microcontroller Chip PIC24FJ

If the team manufactured a board of their own, there are hundreds of microcontroller chips to choose from, especially for high temperature, sensor applications. One such microcontroller chip is the PIC24FJ series of chips by Microchip. This chip is designed to have an acceptable operating range of -40 to 125 C, which is the highest of all the controllers. Since it is just the chip, which is 12.7 by 12.7 mm, small compared to all the other options. It uses the least amount of power of the options at 3.6 V. This chip also has the lowest processing power with 7.37 MHz. A circuit board would be fitted with the microcontroller chip and wired to each subsequent system on the board, like the transciever, power system, and sensor. The microcontroller chip option allows the team a greater customizability without the extra options the design would not use. This option would be the most difficult option because the team would need to determine a method of programming the microcontroller chip without the common communication ports, and find a circuit board that would withstand appropriate temperatures (“Microchip High-Temperature Products and Solutions,” n.d.).

Table 5
Different Type of Microcontrollers and Parameters.

Microcontroller	Voltage Requirement (Volts)	Operating Temperatures	Size	Memory Storage	Processing Performance
Raspberry Pi	5.1 V (Micro USB Supply)	0 to 70 C	85 by 56 mm	1 GB, Can add up to 128 GB with SD card	1.2 GHz
Teensy 2.0	2.7-5.5	-40 to 85 C	35.56 by 17.78 mm	1 KB EEPROM	16 MHz
BeagleBone Black	5v	-40 to 85 C	86.36 by 53.34 mm	4 GB	1 GHz
Arduino Uno Rev 3	5 V	-40 to 85 C	68.6 by 53.4 mm	1 kb EEPROM	16MHz
PIC 24FJ	3-3.6V	-40 to 125 C	12.7 by 12.7 mm	32 kb Flash	7.37 MHz

Wireless Communication Method

There are many different modes to communicate wirelessly between the entire sensor assembly and ECM. If the sensor is active with a power supply, the design will need to contain a transceiver (or a separate receiver and transmitter). The signal utilized for a transceiver is radio frequency (RF). The transmitter portion is needed to send the parameter's data to the ECM. The ECM will also need to communicate to the unit to notify when the engine is on or off. This notification will be accepted by the transceiver to switch the battery on and off to conserve power. Some important parameters for the transceiver are bandwidth, frequency, size, power, and range. The transceiver will most likely be integrated into the micro-controller; however, they can be purchased as add-ons to the controller. The communication method will also need to be able to combat electromagnetic interferences, such as metal and other wireless communication signals. Engines experience harsh environmental conditions, such as high temperatures (up to 125°C). These components will need to operate in these conditions. Printed circuit boards (PCB) can only withstand temperatures to 85°C. Some common transceivers and modes of communication include Wi-fi, Low Energy Bluetooth (LEB), Zigbee, and Texas Instrument Automotive CAN Bus Transceivers.

Concept 1: Wi-fi (ESP8266)

Wi-fi operates in two frequencies: 2.4 GHz or 5 GHz. The 2.4 GHz frequency is the most commonly used. The 5 GHz frequency is used by fewer devices; it cannot go through walls and has a shorter range ("Learn Wireless Basics," n.d.). This concept utilizes the 2.4 GHz frequency. Wi-fi is known for having low-power. However, compared to other modes of transceivers in Table , Wi-fi requires the most power. Wi-fi requires the largest current out of the other transceiver options. It also has the furthest communication distance and can withstand temperatures up to 125℃.

Some advantages of Wi-fi include the ease of integration and convenience, mobility, and expandability. Users can access the information from any easy location and can utilize the internet from outside the working environment. Wi-fi also makes it easy to set up a network of multiple sensors 9. Some disadvantages include a wide variety of uncontrollable interference, security problems, and complexity of installing networks (Agarwal, n.d.). An image of this Wi-fi module is found in the following figure 1.

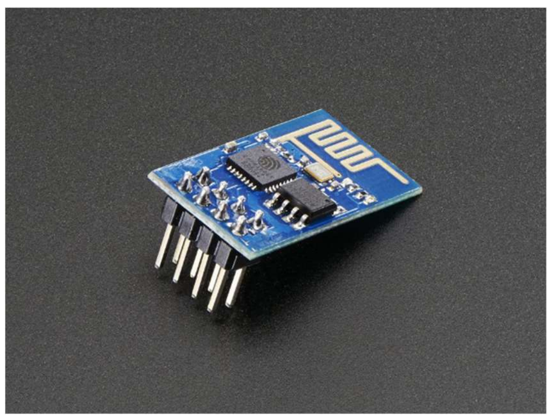

Figure 1. Wi-fi module for a transceiver addition to the micro-controller ("ESP8266 WiFi Module," n.d.).

Concept 2: Bluetooth Low Energy (nRF8001)

Bluetooth Low Energy (BLE) is a communication method that requires lower power and is low cost. In table , it is the lowest power consumed, but it can only withstand a temperature of 85℃, which is lower than the highest operating temperature in an engine. An image of this BLE module is found in the following figure 2.

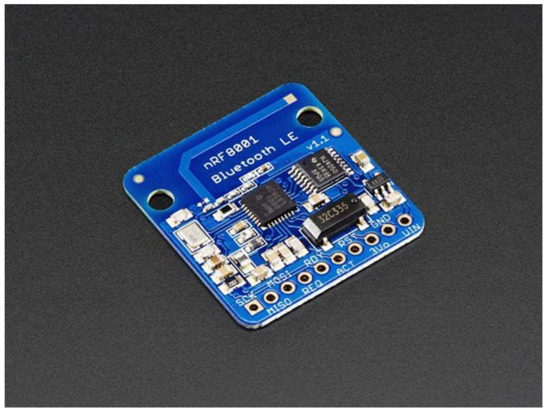

Figure 2. BLE module for a transceiver addition to the micro-controller ("Bluefruit LE - Bluetooth," n.d.).

Concept 3: ZigBee (Digi XBee® SX 868)

ZigBee is a wireless communication standard commonly used in data from sensors and is also low-power and low-cost (Agarwal, n.d.). ZigBee operates similarly to BLE but requires more energy. An image of this ZigBee module is found in the following figure 3.

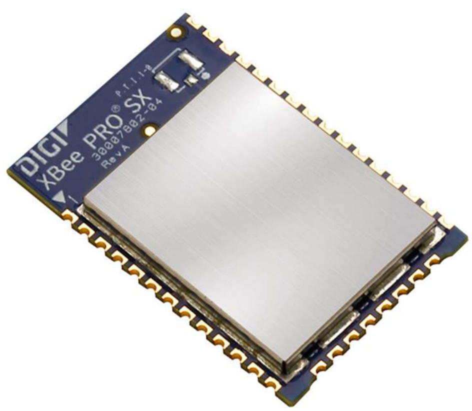

Figure 3. ZigBee module for a transceiver addition to the micro-controller ("Digi XBee® SX 868," n.d.).

Concept 4: Texas Instrument Automotive CAN Bus Transceivers (SN65HVD233-Q1)

This Texas Instrument transceiver is another kind of transceiver that has a large bandwidth and the highest operating temperature. This quality is good for the harsh environments in the Cummins engine. An image of this Texas Instrument module is found in the following figure 4.

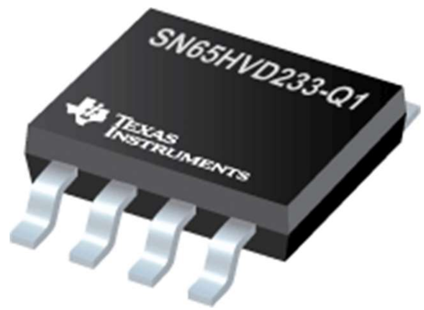

Figure 4. Texas Instrument module for a transceiver addition to the micro-controller ("SN65HVD233-Q1," n.d.).

The following table shows all the parameters for each transceiver concept:

Table 6
Different Type of Transceivers and Parameters.

	Wi-fi (ESP8266)	BLE (nRF8001)	Zigbee (Digi XBee® SX 868)	Automotive CAN Bus Transceivers (SN65HVD233-Q1)
Power Consumption (W)	0.24 - 0.288	0.033	0.096 - 0.198	0.005 - 0.07
Voltage Requirement (V)	3 - 3.6	3	2.4 - 3.6	-0.5 - 7
Current Requirement (mA)	80	11	40-55	10
Communication Distance (m)	30-100	10	10-30	--
Frequency (GHz)	2.4	2.4	2.4	2.4

Bandwidth (MHz)	2	--	1	3 - 3000
Temperature Range (°C)	-40 - 125	-40 - 85	-40 - 85	-40 - 150
Size (mm)	25 X 15 X 1	29 X 28 X 0.8	22 X 33.8 X 3	4.9 X 3.91 X 1.58

Wireless Communication Method Continued

Passive sensor designs include another means for wireless communication. These sensors do not need to be powered directly and usually include an antenna design. IEEE defines antenna as "a means for radiating or receiving radio waves." Surface Acoustic Waves (SAW) sensors and RF patch antennas are some options explored.

Concept 5: Surface Acoustic Wave Based-Sensor (SAW)

There are not many commercially SAW sensors available. SENSeOR is one company that produces SAW sensors. These sensors are connected to an antenna. A transceiver unit located at the ECM powers the SAW sensors by emitted radio waves. The RF waves are an electromagnetic pulse that is converted to a Surface Acoustic Waves on the sensor due to the piezoelectric effect. These SAW change under different physical parameters like temperature. These sensors can withstand higher temperature environments due to the materials. However, the return signal can be heavily affected by the reflection of metal in the engine ("How SAW Sensors Operate?," n.d.). An image of this SENSeor SAW sensor is found in the following figure 5.

Figure 5. A breakdown of the components in a SAW sensor and the different forms (“How SAW Sensors Operate?,” n.d.).

Concept 6: RFMicron RFID RFM3240

RFMicron has created wireless, battery-free, and little maintenance passive sensors through radio-frequency identification (RFID). RFID contain tags with electronically stored information (impedance) that can be read by an interrogating radio wave. The change in environment changes the impedance. RFMicron has rugged wireless temperature sensors that can combat EMI and even work on metal plates by using switchgear contactor points, electric and busbar monitoring (“RFM3240 Long-Range Wireless Temperature Sensor,” n.d.). This sensor has a read range up to 19 meters and can operate up to a temperature of 125℃.

Concept 7: Microstrip Patch Antenna

There are currently no microstrip patch antennas commercially available. Most applications are found in aerospace and mobile radio devices. The microstrip patch antenna works by having a radiating patch and a ground patch on either side of its dielectric substrate. This radiating material is often some highly conductive material. This concept would be desirable because of the lightweight, low volume, and simple geometric design. The frequency of patch depends on the permittivity of the substrate and the geometry of the patch. The permittivity of the substrate also changes with changing ambient temperature. Most of patch antennas consist of simple geometries and can be printed very easily. The problem with this design is that the size of the printed antenna is directly related to the wavelength and resonant frequency ("Microstrip (Patch) Antennas," 2016). A diagram of this antenna is in figure 6.

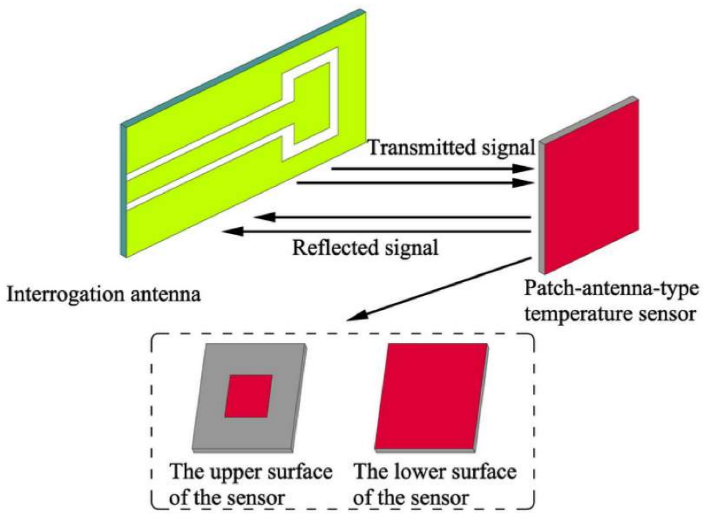

Figure 6. A diagram of the microstrip patch antenna (Yan, Dan, et al., 2017).

Power System

The power system is the most important aspect for the design. This is because it was made clear in the project description and customer needs that the goal is to figure out how to power a wireless sensor. To accomplish this, the team needs to know exactly what is being powered so that the maximum power demand can be determined. With this information a power supply can be designed that will meet this demand using a small scale power generation component and if necessary an energy storage component. There are various methods of generating power, from spinning an electric generator to shining light on a photovoltaic cell. In the case of engine sensors, there is an ample amount of energy available in the form of waste heat from the engine. Modern diesel engines have a fuel efficiency of close to 50%, which is the highest of any internal combustion engine. Even with this relatively high efficiency, the other 50% of the energy contained in the fuel becomes waste heat that must be dissipated. The engine coolant dissipates most of the heat through the radiator and can reach temperatures of around 250°F while the rest is expelled in the exhaust or goes into heating up the engine block and many other engine components to several hundred degrees above ambient. These high temperatures represent an abundant source of energy to power the sensor unit, given that the energy can be properly harvested. Sources of energy in a diesel engine can also take the form of a flow such as the intake air and exhaust gasses or even the mechanical vibration of the engine. What follows is an overview of some different power generation and storage concepts.

Power Generation

Concept 1: Thermal Electric Generator

Thermoelectric generators are a widely available and have been used to increase the thermodynamic efficiency of automobiles by harvesting some of the waste heat produced by the engine and reducing the load on the alternator. They work by converting heat energy into electrical energy using the Seebeck Effect. The Seebeck effect is created when two semiconducting materials with different Seebeck coefficients are connected together between a hot side and a cold side. When heat is applied to the hot side and the cold side is actively cooled a voltage is created between the two materials and when connected in a circuit an electric current will flow. Thermoelectric generators are desirable because of their small size, lack of moving parts and commercial availability, however they have low efficiencies and are typically expensive. It is also challenging to actively cool the cold side, which can require some type of heat exchanger such as fins and a small fan or a cooling liquid. The table below shows some thermoelectric generators commercially available from the vendor Marlow Industries Inc. Table 6 demonstrates different kinds of thermoelectric generators.

Table 7
Different Type of Thermal Electric Generators and Parameters.

	TG12-2.5-01LS POWER GENERATORS (Figure 7a)	EHA-L37AN1-R02-L1 EVERGEN ENERGY HARVESTERS (Figure 7b)	EHA-PA1AN1-R02-L1 EVERGEN ENERGY HARVESTERS (Figure 7c)	EHA-L37L37-R01-L1 EVERGEN ENERGY HARVESTER (Figure 7d)
Description	Generic	Heat Source: Liquid Heat Sink: Air	Heat Source: Surface Heat Sink: Air	Heat Source: Liquid Heat Sink: Liquid
Typical Temp Diff (C)	180	60	10	5
Voltage (V)	5.33	3.3	5	5
Power (W)	2.71	0.0017	0.0003	0.001

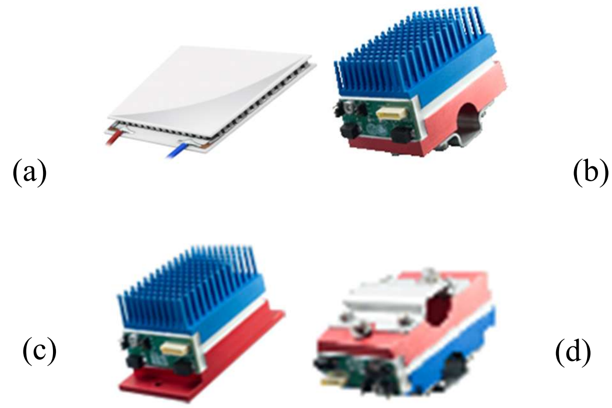

Figure 7. Different types of thermoelectric generators (“EVERGEN® ENERGY HARVESTERS”, n. d.), (“THERMOELECTRIC GENERATOR (TEG) MODULES”, n. d.).

Concept 2: Induction

Electrical current can be induced in a metal from a distance when a changing magnetic field is applied. This phenomenon is how the majority of all electricity is created because it is the operating principle of electric generators and is applicable to various concepts for generating power for a wireless sensor.

As mentioned previously, energy can be derived from the flow of a fluid in an engine. A way of accomplishing this would be with a small scale electric generator connected to some type of turbine which is spun by the flow.

Another device that can generate power using electromagnetic induction is a linear electric generator. This style of generator works by sliding a magnet back and forth inside of a solenoid. A current is induced in the solenoid while the magnet is moving through it, so the magnet must be continuously oscillated back and forth. Some flashlights use this design and rather than needing batteries, are charged by shaking them back and forth by hand. This power generation concept can be applied to harvest energy from the mechanical vibration of the engine itself. However, to properly design such a device the frequency of the vibrating engine must be known to so that the linear generator can be designed to resonate at that frequency. Although a linear generator can be oscillated using an engine component that oscillates back and forth such as a valve or a piston.

A passive sensor concept involving electromagnetic induction is wireless power transfer. With this concept, power is not actually generated by the sensor unit but transferred from a central source such as the ECM to the sensor unit. This transfer can happen in two ways, near-field or far-field. Near-field is the most common form of wireless power transfer, however it is likely not feasible for our design as the transmitting coil and the receiving coil must be within a few centimeters of each other. Far-field induction can work over much larger distances because it uses a focused beam of electromagnetic energy such as microwaves or light waves in the form of a laser. This may not be practical because it requires direct line of sight between the transmitter and receiver and small scale long range inductive chargers are not commercially available.

Concept 3: Pyroelectric Generator

A pyroelectric generator is another device that can potentially convert heat energy into electrical energy. They are made from certain types of crystals that are naturally electrically polarized and thus contain an electric field. When the crystal is heated or cooled a voltage forms across the crystal and when connected to a circuit a current will flow. This is different from a thermoelectric generator in that the entire crystal is heated or cooled resulting in a voltage across the crystal where as a thermoelectric generator needs a temperature difference between its hot side and cold side. Despite this they are similar in many ways to a thermoelectric generator as far as being easily scaled down and having no moving parts, however they have very little if any commercial availability.

Energy Storage

The energy storage component chosen to be used in the power system is of great importance because of the need for the sensor to be running from engine start-up. A battery will likely be used for power storage because of its availability and how it fills our needs. Fuel cells were briefly considered for power storage, but they were discarded because of their limited availability and failure to fit our needs. The fuel cell would prove more difficult to recharge than the battery, and the size constraints of the project would make the large fuel cell hard to integrate into the design. The battery will allow the system to consume power before any power is generated. It is also a necessity for the battery to be rechargeable so that the powering system can recharge the battery for engine start-up and energy storage. The type of battery most applicable for our product is the lithium-ion battery because of its high energy density, small size, and rechargeability. The types of lithium-ion batteries available are: lithium cobalt, lithium titanate, lithium manganese, lithium nickel manganese cobalt, lithium iron phosphate, and lithium nickel cobalt aluminum.

Concept 1: Li-Cobalt Battery

The lithium cobalt battery is the most common of the lithium ion batteries. It is the most widely used and tested. Some of the desirable features of this battery are its high energy density, high voltage output, and large availability. A drawback this battery has is its low thermal runaway temperature.

Concept 2: Li-Titanate Battery

The lithium titanate battery has a relatively low energy density, but it has the longest cycle life. The cycle life of this battery is the highest available among the lithium ion batteries The battery is safe and reliable. It also does not require a high voltage to charge. A very enticing facet this battery has is its very low cost. A drawback from this battery is its low energy density.

Concept 3: Li-Manganese Battery

The lithium manganese battery is a considerable choice for its high energy density, high voltage output, and high thermal runaway temperature. The high thermal runaway temperature would be especially useful in a temperature sensor which may encounter harsh temperatures. A drawback from this battery is its higher relative cost and low cycle life.

Concept 4: Li-Nickel Manganese Cobalt Battery

The lithium manganese cobalt battery has a high energy density which means it will be a smaller battery. The size of the battery is of importance because of the 6 cubic inch size constraint. Other desirable features of this battery include its high thermal runaway temperature, cycle life, and voltage output. A drawback of the battery is its high relative cost

Concept 5: Li-Iron Phosphate Battery

The lithium iron phosphate battery contains the highest thermal runaway temperature, desirable in thermal sensors. It also has a good cycle life. The implementation of this battery in high temperature environments is most suitable. The battery also has limited drawbacks.

Concept 6: Li-Nickel Cobalt Al Battery

The lithium nickel cobalt aluminum battery has the highest energy density. This would be desirable if the other components in the sensor take up more room. The other desirable features of this battery are its high voltage output and low cost. A drawback this battery has is its low thermal runaway temperature.

In table 8, the types of lithium ion batteries and their specs are listed.

Table 8
Battery Options.

Name of Battery	Type	Energy Density	Volts	Charge Rate	Discharge Rate	Cycle Life	Thermal Runaway	Relative Cost
Li-Cobalt Battery	Li-Ion	110-190 Wh/kg	3 - 4.2V	.7-1C, 4.2V	1C, 2.5V	500-1000	150 C (302 F)	Higher
Li-Titanate	Li-Ion	50-80 Wh/kg	1.8-2.85V	1C, 2.85V	10C, 1.8V	3000-7000	177 C (350.6 F)	Lower
Li-Manganese	Li-Ion	100-150 Wh/kg	3-4.2V	.7-1C, 4.2V	1C, 2.5V	300-700	250 C (482 F)	Higher
Li-Nickel Manganese Cobalt	Li-Ion	150-220 Wh/kg	3-4.2V	.7-1C, 4.2V	1C, 2.5V	1000-2000	210 C (410 F)	Higher
Li-Iron Phosphate	Li-Ion	90-120 Wh/kg	2.5-3.65V	1C, 3.65V	1C, 2.5V	1000-2000	270 C (518 F)	Higher
Li-Nickel Cobalt Al	Li-Ion	200-260 Wh/kg	3-4.2V	.7C, 4.2V	1C, 3V	500	150 C (302 F)	Low

Protection System

The protection system is responsible for housing the sensor unit and protecting it from damage from large temperature swings, chemical exposure, debris and other environmental factors. This is a less important aspect of the design because it was not specifically stated as necessary by the customer, even though it was deemed important in the customer needs interpretation. An important function of the protection system is to maintain the temperatures of the microcontroller and other sensitive components below their maximum operating temperature. This could prove difficult as very high temperatures exist in and around a diesel engine in operation. A way of achieving this could be to thermally isolate the housing unit from what it is connected to by using non-heat conducting materials such as plastic spacers. Another way is to include fins on the housing to increase heat dissipating.

Housing

The system housing will need to be able to withstand the harsh environments it is placed in. The primary concern for the product is the high temperatures encountered from the engine. In order to combat these high ambient temperatures, a fully enclosed casing will be needed to keep the inner components from reaching inoperable temperatures. Another need from our housing is that the enclosure would not interfere with wireless signals

Concept 1: Vacuumed Casing

Vacuum sealed casing is a method which has been used in many applications to keep inside temperatures constant. The absence of a medium means that heat will not be able to flow through casing. The effectiveness of this insulation is only as good as how 'perfect' the vacuum is. Another factor affecting the vacuum is the seal. When exposed to high temperatures, the seal may begin to loosen. This would render the casing worthless. Utilising this solution would also be a costly one.

Concept 2: Thermal Insulated Casing

An insulated casing would be a much cheaper and less risky option that could be implemented. The insulation would be dependent on the thermal conductivity constant of the material. This option would allow a wide variety of options for which material is used as the insulator.

Design Concepts

Before combining components into feasible design concepts, the team had to look back and reexamine the customer needs and project scope. This reiterated the fact that the problem is figuring out how provide power for sensors without using wires. Since the type of sensor doesn't matter, ideally all the sensors would be wireless and self-powered so the ideal design solution would be one that is applicable to every sensor in the engine. This would ultimately be a self-powered wireless data transceiver that can be used with any sensor. The most likely option for achieving this would be a passive sensor design, which is discussed more in concept 3.

Another way to approach designing a self-powered wireless sensor is use a different power generation method for each sensor, each one suited for harvesting energy from the particular location of the sensor. This is conceivable because sensors are often used to monitor a high energy medium so harvesting some of the energy to power the sensor is a clear direction.

An important consideration is approximately how much energy the sensor unit will consume. This amount will vary depending on the specific components used, but the research shows that between 1 and 5 mW is enough to power a well design sensor ("Five Building Blocks of Self-Powered Wireless Sensor Nodes", n.d). Below, three examples of feasible design concepts are presented.

Design 1: Temperature Sensor Thermoelectric Generator Combination

A temperature sensor is usually used to monitor high temperatures, and the high temperature medium such as exhaust gases or engine coolant represent a harvestable energy source. In this design, a thermocouple will be used to measure the temperature of the engine coolant while the thermoelectric Energy Harvester seen in Figure 7b with a capacity of about 1 mW will be used to harvest energy from the engine coolant. This thermoelectric generator is designed to harvest energy from a liquid at on the hot side and dump heat on the cold side using long fins and natural convection. This is desirable over actively cooling with a fan because the amount of power needed is small so the temperature difference required is small. It will incorporate a low power microcontroller such as the Teensy 2.0 which is designed for use with sensors. A low power Bluetooth transceiver such as the Bluefruit LE will be incorporated into the microcontroller. A battery component will be necessary to power the system when the thermoelectric generator is not producing power, such as at engine startup or after the engine has been shut off. The battery will be of the lithium ion variety and have a capacity of 100 to 200 mAh at a voltage of 3.7V. The housing will be sealed plastic or thermally insulated aluminum. This design has a number of pros, namely commercial availability of the components.

Design 2:Mass Flow Sensor Electric Generator Combination

Harvesting energy from a flow is another design concept the team has discussed. In this design, a very small turbine will be installed in air intake flow and is connected to an equally small electric generator which is spun to create electricity. The mass flow sensor will likely be of the hot-wire verity because a vane style may interrupt the flow. The microcontroller and wireless transceiver will be the same kind used in design 1, focusing on using low power devices. A smaller battery will be used in this design because the electric generator will have a greater generating capacity and capacity factor. This design may pose challenges because electric generators on the small scale desired are not readily commercially available.

Design 3: Passive Sensor Design

An important design decision is was whether to pursue an active or passive sensor design concept. These two types of sensors are very different in that an active sensor uses energy to actively make measurements while a passive sensor only makes measurements when an external energy signal is sent to the sensor. This design is not technically self-powered, but instead requires a central hub to transmit an energy signal to the sensor and to collect the sensors return signal. This is a promising design concept because it can be applied to every sensor in the engine, although it requires that a hub such as a transceiver at the ECM is powered and can communicate with all the sensors in the engine. This may be challenging because of interference from the engine and other sources. This is also a new technology and would need to be thoroughly tested in the environment of an engine. Commercial options do exist for passive wireless sensors but only for a couple types of sensors.

1.4 Target Summary

Metrics and targets are used to validate that the system and subsystems are performing their functions. A metric is simply a measurable quantity with units such as power generated in watts or temperature in degree Celsius. A target is the desired value or range of values that the metric must meet to validate the function of the design. The functional decomposition and concept generation sections describe how the system was organized into subsystems and the subsystems into components. To comprehensively test and validate the functionality of the design, some targets were defined for the system as a whole. Some are relevant to a specific subsystem, while most are used to define component specifications.

The self-powered wireless sensor is still in the initial design stages and consequently exact values could not be determined for every target. This is because many of the metrics and targets will change for different design concepts. For example, some of the targets for the sensor will depend on whether a temperature sensor or mass flow sensor is used. However, many targets and metrics are applicable to a wide variety of design concepts. For the sensor example, every sensor is a transducer that converts some continuous physical parameter to a voltage. Therefore, voltage is an important metric that will have a target value for every design, even though the target value may change for different sensor types. Voltage and other important metrics were used to create the target catalog found in Appendix B. To produce some initial target values for these metrics, background research was performed in order to determine industry benchmark targets and IEEE 802 standards for the important metrics. Some targets are given in a range because of the uncertainty of the correct target values at this stage of the design process or because the desired value can be any number within the range. Other targets are TBD (to be determined) because their values vary widely based on which design concept is used.

Some of the important targets that pertain to the system as a whole were found through our customer needs assessment. The first of these targets is that any power system we use will need a standby mode time of 36 hours or more. Another target that all design concepts should meet is that their overall volume of 6 inches cubed or less. Each concept should transmit the data at a frequency of 1 hertz or greater and be able to communicate over a distance of 5 meters or greater.

Other key targets were found by researching common specifications of the components we will need in the design. Some examples of these components and their specifications is given in the concept generation section. Many sensors and microcontrollers operate at a voltage of 3 to 5 volts, so our power system would need to supply voltage in this range. Many low power transceivers also operate in this range. These three components also draw some small amount of current at their required voltage which corresponds to the amount of power they consume. Many of the components we will be using in our design have a maximum operating temperature, and if exceeded, it will damage the component and cause it to malfunction. This will vary widely depending on where in the engine or vehicle chassis the unit is located. Operating temperatures for many sensors is around 180 degrees celsius while most microcontroller boards have a lower maximum temperature of around 120 degrees celsius. It is important that the component with the lowest maximum temperature is used as the maximum allowable temperature for the system, so the maximum temperature target is 120. The protection system will be used to increase the robustness of our design and protect against overheating of a component and other harsh environmental parameters.

As mentioned previously, the metrics and targets contained in the target catalog represent the most important metrics which can pertain to many different design concepts. The targets were determined in one of two ways: by applying the customer needs to the system and subsystems or industry benchmarking by researching component specifications to produce target values in a range that represents the variety of different components available. As the design progresses toward selection and a prototype, the target values will be updated to represent the desired functionality of the prototype.

1.6 Concept Selection

This section describes the process of selecting a final design concept. Three steps divide up this process: concept selection criteria, elimination of concepts, and evaluation through Pugh matrix. Through comparison with the concept selection criteria, the team removed the component concepts that were clearly not feasible, and they evaluated the remaining concepts and compared to each other with the Pugh method. Through engineering judgement, the team evaluated three complete design alternatives with all the components. There is a summary of the project objectives and some important design consideration before giving a detailed explanation of each of these steps.

The initial problem statement develops the project scope, and a summary of the scope is powering a wireless engine sensor. The team is to design and demonstrate the best integration of the different components and not simply purchase a wireless sensor. In the project description, the customer stated that the design could be for any sensor in the engine, if it is self-powered and wireless. The team interpreted this to mean that the type of sensor is unimportant, and an ideal design is one that utilizes any sensor at any location in the engine. For this reason, the team did not include the sensor component in the concept selection process. Instead, the team chose a sensor to base the design concepts around. They decided that a temperature sensor would serve as the best sensor for the design for the following reasons:

- There are many temperature sensors in engines.

- Temperature sensors monitor high energy mediums, which are a convenient source of energy.
- The sponsor and faculty advisers recommended temperature sensors.

Further discussion with the team sponsor will be needed before choosing a specific temperature sensor. The team can either use a thermocouple or a thermistor. A thermocouple is preferred because it does not require any power input, and would reduce the overall power consumption of the system. However, thermocouples tend to be less accurate and it may be that thermistors are better suited as engine sensors. Another decision whether to use a generic temperature sensor or a temperature sensor that is specifically built for Cummins engines. The team will likely use a cheap generic thermocouple in the initial prototype and a true Cummins engine sensor in the final prototype, depending on what the sponsor prefers. As was previously mentioned, the type of sensor was not specified in the project description and was deemed unimportant by the design team.

There will be further discussion with the team sponsor choosing a specific temperature sensor. The team can either use a thermocouple or a thermistor. A thermocouple is preferred because it does not require any power input and would reduce the overall power consumption of the system. However, thermocouples tend to be less accurate, and thermistors may be better suited as engine sensors. Another decision to consider is whether to use a generic temperature sensor or a temperature sensor that is specifically for Cummins engines. The team will likely use a cheap generic thermocouple in the initial prototype and a true Cummins engine sensor in the final prototype, depending on the sponsor's preferences. As previously mentioned, the type of sensor was not included in the project description, and the team deemed it unimportant.

Design Criteria

The team combined certain aspects of decision theory and the key functions, targets, and objectives of the projects to produce suitable design selection criteria. The customer needs analysis produced a list of the interpreted needs ranked by importance. This helped to create a list of the absolute design criteria, which are filters used to screen out concepts that are not feasible or do not meet the project objectives. There is a list of the important criteria used in this process found below:

1. Reliability of power supply
    a. The sensor must always have access to power to be able to gather data and communicate to the ECM when the engine is on. It must also be available to do this for 36 hours after the engine is off.
    b. For the microcontroller and transceiver, this means having low power consumption is ideal.
    c. For the energy harvester and battery component, this means that producing and storing enough electricity to meet the demand of the system under worst case conditions is important.
2. Wireless Communication Performance
    a. The problem of powering a sensor comes from the desire to make it wireless.
    b. The sponsor provided specific expectations regarding the minimum wireless transceiver performance. It must be able to communicate over a distance of at least 5 meters, and it must be able to transmit the data at a frequency no lower than 1 Hz.

3. Feasibility/Technology Readiness
    a. Many of the design concepts generated in the concept generation phase are either not a mature technology or are not feasible.

Some less important but considerable concept selection criteria will also factor into the final design decision. These include cost which we would like to minimize but must be less than the budget of $2,500. Also, it would be optimal to minimize the size and weight but must be no bigger than 6 cubic inches. Finally, the system should also be robust and able to operate in the harsh environment of an engine. These selection criteria are less important because they were not explicitly in the project description. Warranty claims due to harsh environmental conditions was described as the reason for moving to wireless sensors, but the need for the system to be robust or to operate in harsh conditions was not mentioned. While the robustness of components is in the selection process, a protection system will not be included in the initial prototype. Table 9 below lists and describes the design selection criteria.

Table 9
Selection Criteria

	Weight	Type	Optimal	Range	Description
Reliability of Power Supply	10	Optimization	Low demand High supply	Supply > Demand	Must always have power
Wireless Communication	8	Yes/No	High	>= 5m >= 1Hz	Transmit at least 5 meters at 1 Hz
Technology Readiness	8	Yes/No	Mature technologies	n/a	Is technology readily available?
Robustness	6	Quality	High	0-1	Heat/shock resistant

Cost	4	Value	Low	<= $2,000	Less than budget
Size	6	Value	Low	<= 6 in^3	Smaller the better

Microcontroller Selection

From the functional decomposition portion of the design process, it was determined that a microcontroller was needed in the transducer subsection. The function of the transducer subsection was defined as follows: sense an analog signal, convert the analog signal to a digital signal, and transmit the digital signal wirelessly. The microcontroller will facilitate the analog to digital (A/D) conversion, perform power system control, and execute the logic that will control the sensor and the wireless transceiver. From the team's research, it was determined that the microcontroller would draw power from the power supply, control the sampling frequency of the sensor with A/D conversion, potentially provide a significant volume contribution to the overall design, and will be sensitive to environmental conditions in the engine like temperature, electrical interference, and vibration. This component will also need the appropriate number of ports and acceptable memory and processing power for communicating between the different components and completing control tasks. Once a microcontroller is chosen, it will need to be programmed to do the appropriate tasks. It is important that the microcontroller chosen will be easy to use by the team, requiring little assembly, and upfront learning, with many resources available to complete the project in a timely fashion. An optimal design would possess the following:

- Low power consumption
- Moderate processing speed and memory

- Small size
- Resistant to adverse environment conditions
- Simple programming and assembly

The low power consumption requirement is necessary because of the power storage and generation component of the overall design. A microcontroller that required more power would require more power generation, which will already be a challenge. Minimizing the power requirements of the microcontroller will help minimize the size and power requirements of the power generation subsystem. Low power microcontrollers also tend to be smaller. The sponsor also requested that the design have a volume of less than 6 cubic inches. The microcontroller will optimally be of the smaller variety to keep within the size constraint. A/D conversion capabilities that allow for a sampling frequency of at least 1 Hz was directly requested from the sponsor. The design will not be useful to the sponsor if the microcontroller does not provide the appropriate sampling frequency to ensure proper data collection; this is directly related to processing speed and memory. The appropriate number of programmable ports and memory should be moderate; however, power and size constraints limit these attributes. It is important that the team chooses a microcontroller that balances these properties. Most printed control board circuits including microcontroller boards have optimal operating temperatures of 85°C, which will be exceeded in most engine applications. Though the design will include a housing and heat protection element, this is still an important design consideration to consider, along with any vibrational or electrical interference.

During the concept generation phase, several microcontrollers were considered. These were the Raspberry Pi, Beagle Bone Black, Arduino Uno Rev 3, Teensy 2.0, or the

Microcontroller Chip PIC24FJ by Microchip. The sponsor suggested using the Raspberry Pi controller for the design, so through the Pugh matrix method, the other concepts were compared against the Raspberry Pi. Additionally, the Raspberry Pi is large and requires a relatively high amount of power with a low starting memory. It could also be improved upon with other concepts. The concept data that was collected in Table 5 in the microcontroller concept generation section was used. For ease of assembly and programming, the programming support and the team's familiarity with the interface was assessed in comparison to the datum concept. The team has experience with the BeagleBone Black and already has one in possession. For the Raspberry Pi and Arduino interfaces, both have plentiful resources online, but the team would need to learn the interface. Additionally, there would be a time cost with those design options. The Arduino Uno Rev 3 and Teensy 2.0 use the same interface. Table 10 demonstrates the first iteration of the Pugh matrix.

Table 10
Microcontroller Concept selection iteration 1.

		Concepts			
Criteria	Datum: Raspberry Pi	Concept 1: Beagle Bone Black	Concept 2: Arduino Uno Rev 3	Concept 3: Teensy 2.0	Concept 4: PIC24FJ
Power Requirement	5.1 V	S	S	+	+
Resistance to Harsh Environment	0 to 70°C	+	+	+	+
Size	85 by 56 mm	S	+	+	+
Processing Power and Memory	1 GB and 1.2 GHz	S	-	-	-

Ease of Assembly and Programming or Familiarity	+	S	S	-
# of Pluses	2	2	3	3
# of Minuses	0	1	1	2

From the first iteration of the Pugh matrix method, the team determined that the most noteworthy design with the most pluses and a significant number of minuses was the Microchip PIC24FJ. The Pugh method indicated that this design is a good choice, but it could be improved upon. The second iteration of the Pugh matrix was executed using the Microchip PIC24FJ as the datum, shown in table 11.

Table 11
Different Type of Microcontrollers and Parameters.

		Concepts		
Criteria	Datum: PIC24FJ	Concept 1: Beagle Bone Black	Concept 2: Arduino Uno Rev 3	Concept 3: Teensy 2.0
Power Requirement	3-3.6 V	-	-	+
Resistance to Harsh Environment	-40 to 125°C	-	-	-
Size	12.7 by 12.7 mm	-	-	-
Processing Power and Memory	32 KB and 7.37 MHz	+	+	+
Ease of Assembly and Programming or Familiarity		+	+	+
# of Pluses		2	2	3

# of Minuses	3	3	2

From the second iteration of the Pugh matrix process, it was determined that the Teensy 2.0 microcontroller would be chosen. It offers a moderate amount of processing power and speed, an attractive small size (comparative to a quarter), and an adjustable and low power requirement even though the temperature limits are not as high. This is fitting for the design of the microcontroller because the protection system will help protect the electronics from harsh conditions, and the design can be altered to offset the electronics from hot elements in the engine.

Wireless Communication Selection

In concept generation, there was a discussion of different modes of active and passive wireless communication methods. The adaptability of the ECM for any communication method was an important assumption kept in mind while researching and brainstorming ideas. Transmitting a signal wirelessly is the most important function for the wireless communication.

Passive sensors (also known as antennas that reflect emitted waves and require no power at the sensor node) are not readily available and are still mainly on the research level. Due to the time constraint for this project, the team eliminated passive sensor concepts for the wireless communication selection. From customer needs, the wireless communication is less important than the self-powered need for the sensor. This leaves active transmitters and/or receivers as the only concepts left for selection.

Another concept chosen for elimination was the active sensor concept, CAN Bus transceivers. The ECM in vehicles currently utilize CAN Bus transceivers with harnesses for the sensor network. It is important to keep in mind that the project scope focuses on removing harnesses from sensors to the ECM in engines. Wireless CAN bus bridges and adapters do exist on the market and could be noteworthy in this application especially for sensor networks. However, this concept is too robust for the project description, which focuses on one sensor and not a network of sensors. If other design teams carry on this project in the future, this concept could be for later iterations. Currently, the assumption is one sensor type chosen by the design team.

This leaves three main concepts left to compare and analyze: ZigBee, Wi-fi, and BLE. In concept generation, the team discussed specific products for concreteness. Table 12 demonstrates a comparison of the most important performance parameters for each concept. Each parameter for each method displays a range of these metrics taken from the different product options offered by Texas Instrument to try to compare the whole communication protocol ("Wireless Connectivity," n.d.). Power consumption is one of the most important deciding parameters because the main function of the design needs to be self-powered; it is important to know the highest power consumed by the communication method. The highest power consumed is during receiving or transmitting a signal (Rx, Tx). The voltage requirement is also important because it effects which microcontroller to use. Additionally, the voltage requirement correlates to the power consumption. Lastly, the highest operating temperature range is crucial due to the harsh conditions in the engine.

Table 12
Most important performance parameters (range for different TI products) for wireless communication concepts ("Wireless Connectivity," n.d.).

	Wi-fi	BLE	ZigBee

Power Consumption of Rx/Tx (W)	1.186	0.035 – 0.067	0.034 – 0.104
Highest Voltage Requirement (V)	4.8	3.6 – 3.8	3.6 – 3.8
Highest Operating Temperature (°C)	85	105 – 125	85 – 125

Zigbee and BLE have the lowest power consumption during transmission. Wi-fi has a larger bandwidth, therefore, requiring more power. Large bandwidths are not a concern for the sensor because it will be transmitting small amounts of data. BLE and ZigBee also have similar low voltage requirements due to the correlation of power consumption. Both methods also can reach up 125°C, which is a positive for the design. A downside to Bluetooth Low Energy is the possible interference with other devices in the car or with the user's personal communication devices. ZigBee utilizes a protocol that not many other devices use.

To evaluate the concepts, table 13 portrays a Pugh matrix. The datum for the Pugh is Wi-fi because table 12 shows that it is far more robust than what the design calls for. Additionally, ZigBee and BLE fit many of the design functions but are very similar, so these were the concepts to compare to the datum. The comparison (+, -, and S) came from research for these concepts and specifications sheets for products.

Table 13
First Pugh matrix comparing to datum of CAN Bus transceivers (wired) currently used in engine.

		Concepts	
Selection of Criteria	Datum: Wi-fi	BLE	ZigBee
Lowest Power Consumption for Tx		+	+

Highest Operating Temperature	+	+
Small Size	+	+
Communication Distance	-	-
Unwanted Interference	S	+
# of Pluses	3	4
# of Minuses	1	1

The two noteworthy criteria are communication distance and unwanted interference. Wi-fi has the best communication distance due to the large bandwidth; however, this distance exceedingly surpasses the function to communicate at 5 m. BLE and ZigBee can still communicate further than 5 m meeting the need of the customer. Wi-fi and BLE both have a higher chance to have unwanted interference with other devices due to the common communication protocol. Due to meeting all the functions required for the wireless communication method and having the best score on the Pugh matrix, ZigBee is the concept selected for wireless communication method.

Energy Harvester Selection

One of the principal aspects of this project is to create a system that is self-powered. During the concept generation, different types of energy harvesters were evaluated. Each concept was analyzed using the design selection criteria in order to determine which concepts were suitable for the application. As power system reliability was found to be the most important factor in the design, it is important that the concept selected can generate sufficient power to meet the system demands in all conditions. During the concept generation, six different harvesters were evaluated: Thermoelectric, Piezoelectric, Pyroelectric, Induction, Micro-Turbine and ambient electromagnetic energy harvesting.

After researching these concepts, it was found that three of these concepts do not pass the absolute design criteria filters. The method of induction was removed because it does not meet feasibility and technology readiness needs. Wireless induction charging induces electrical current through a magnetic field. The mature technology of near-field induction charging is only feasible over a distance of a few centimeters. Far-field induction is possible, but the technology is immature and it is not feasible because there must be line-of-sight between the charger and the sensor. Also, interference with the engine can affect the magnetic field generated by the power source and cause damage in parts of the engine.

The micro-turbine generator concept was ruled out because such generators are not readily available. It would not be feasible to perform the necessary research and development to create a suitable micro-turbine generator. Also, this concept could cause significant interruption of the flow which could impede engine performance.

The concept of harvesting energy from ambient electromagnetic signals is an exciting technological advancement. Researchers have been able to harvest enough energy to power small electronics using an antenna that picks up a very wide range on frequencies. Unfortunately, this is the least mature concept considered and was ruled out as a result.

With unfeasible concepts ruled out, the rests of the concepts were compared to each other using the following design selection criteria relevant to the power system; power supply capacity, supply voltage, energy source, and approximate cost. It is desirable to optimize the power generation capacity to the point where it reliably meets the system power demands under all conditions. The marginal utility gained from having extra generation capacity beyond the optimal amount decreased significantly. The ideal supply voltage is the voltage at which the other components operate so that that voltage will not need to be stepped up or down, which will reduce the power supply capacity because of the inefficiencies involved in voltage regulation. The energy source will determine the capacity factor of the power generation and the location of the sensor because the source may not be available at all places in the engine. For example, the capacity factor of a temperature based energy harvester will be less the 100% because it takes approximately 5 minutes for the engine to heat up. Ideally, the cost should be minimized. However, the team was allotted a $2,000 budget and is to free to spend it as necessary, given that we do not exceed it. A summary of the average important parameters determined through research of commercially available components is shown below in Table 14.

Table 14
Most important performance parameters for harvest energy concepts.

	Thermoelectric generators	Piezoelectric	Pyroelectric
Power Supply(mW)	0 – 6800	1.1 -4.7	1.1- 10
Voltage Supply(V)	0 – 3.2	16 - 18	20-25
Energy source	Temperature	Vibration	Temperature
Approximate cost ($)	5 - 90	61 - 265	5-40

The Piezoelectric has the lowest power supply compared to the other concepts. The Piezoelectric generator generates energy with the use of vibrations. This could be beneficial since vibrations occur everywhere in the engine. However, Piezoelectric generators only generate their rated power output at specific vibrational frequencies which limits the locations at which this generator can be used.

Next, Pyroelectrics generators work like the thermoelectric generators, they convert thermal energy into electrical energy. This is useful because it can generate energy from any heat source in the engine. However, it only generates a voltage as it is being heated or cooled. When the maximum temperature is reached and the temperature becomes constant no power is generated. This means the capacity factor will be very low. If the engine is run or 3 hours at a time on average and the maximum temperature is reached within 20 minutes, the capacity factor will be only 11%.

Thermoelectric generators show the greatest promise for choosing an energy harvesting component. They are readily commercially available, not very expensive and generate energy based on a temperature difference across the device. The hot side would be in thermal contact with a hot surface such as the engine surface or the pipe containing the engine coolant and the cold side will be fitted with fins that dissipate the heat via convection. A small temperature difference of approximately 10 degrees can be maintained with no air flow but the air flow through the front grill of the vehicle while it is in motion will cool the cold side further and produce more power as a result.

To evaluate the concepts and chose the most appropriate one, a Pugh matrix (table 15) was used. The thermoelectric generator was selected to be the reference concept because the team determined that initially it shows the greatest promise. The team wanted to know how Pyroelectric and Piezoelectric generators compare to the thermoelectric generator and used the research produced during concept generation to evaluate them.

Table 15

First Pugh matrix comparing the different types of energy harvester concepts.

Selection of Criteria	Datum: Thermoelectric	Concepts: Piezoelectric	Concepts: Pyroelectric
Power Generation Capacity		+	-
Supply Voltage		+	+
Operating temperature		-	-
Capacity factor		+	-
Cost		-	+
# of Pluses		3	2
# of Minuses		2	3

Final Design Selection

The final design selection will consist of a temperature sensor, a Teensy 2.0 for the microcontroller, a ZigBee as the source of communication, and a thermoelectric generator as the method in which the unit is powered. The Teensy 2.0 was chosen for its ability to meet our power requirements, its resistance to harsh environments, and ease of assembly. The ZigBee was also chosen because of its ability to limit unwanted interference better than the BLE and Wi-Fi options. The thermoelectric generator concept was chosen because of its ability for a better self-powered, wireless system. When all of these facets are implemented into our design, they meet the optimal design specifications of consuming low amounts of power, moderate processing speed and memory, small size, resistance to adverse environments, and simple programing. Other facets of our design will include a battery and heat shield for protection. The final concepts are in table 16.

Table 16
Final design concepts.

Section:	Available Options:					Desired Option:
Type of Sensor	Given the option of any sensor in the engine...					Temperature Sensor
Microcontroller	Raspberry Pi	Beagle Bone Black	Arduino Uno Rev 3	Teensy 2.0	PIC24 FJ	Teensy 2.0
Wireless Communication	Wi-Fi	BLE		ZigBee		ZigBee
Energy Harvester	Thermoelectric Generators		Piezoelectric	Pyroelectric		Thermoelectric Generator

The battery to be chosen will be a 3.7V and 500mAh lithium ion polymer battery. The maximum wattage requirements from our ZigBee microcontroller is 0.1W, and the maximum wattage requirements for our Teensy 2.0 is 1.5 W. Therefore, the maximum watts needed for our battery would be 1.6W. The battery chosen will give a value of 1.85W. This option will allow for a .25W clearance which will clear the possibility of the battery not having enough power to power the system from engine startup (t=0). The battery is necessary for our system from t=0, because the thermoelectric generator will not have generated any energy to power the system yet. Once the thermoelectric generator begins generating power, the battery will then be recharged, and the sensor, microcontroller, and wireless communication will be powered by the generator. The battery will have enough capacity to run the Teensy 2.0 and ZigBee on its own for over an hour, but the thermoelectric generator is expected to generate enough power to charge the battery and system after about 10 minutes when the engine has heated up.

A heat shield will be implemented for the purpose of keeping our hardware at a temperature in which it can operate. Another purpose the for the heat shield is that it will provide a significant change in temperature for our thermoelectric generator to harvest power. The heat shield will be made out of a highly conductive material such as aluminum or copper. The effectiveness of the heat shield will determine the effectiveness of the generator. The heat shield is not needed for our prototype and more research will be needed before implementing an effective solution.

1.8 Spring Project Plan

In this section the plan for project completion will be outlined. The goal is to have a functioning prototype by the end of this design course. To facilitate this, the team will begin with the end in mind and work backwards to gain an understanding of what it will take to achieve this goal. In this way the team hopes to visualize any potential problems that may be encountered during Senior Design II and plan ahead to avoid or mitigate those problems. A representation of the Gantt chart for next semester is in Figure 9.

Beginning with the end in mind means visualizing the final design of the self-powered wireless sensor. Every step that has preceded this has been for building each team's understanding of the design problem in order to think through and visualize the best design that will solve the problem. Therefore, the team has a fairly complete understanding of the final design and have illustrated it in a number of different diagrams. The most recent diagram depicting the design concept is in Figure 8.

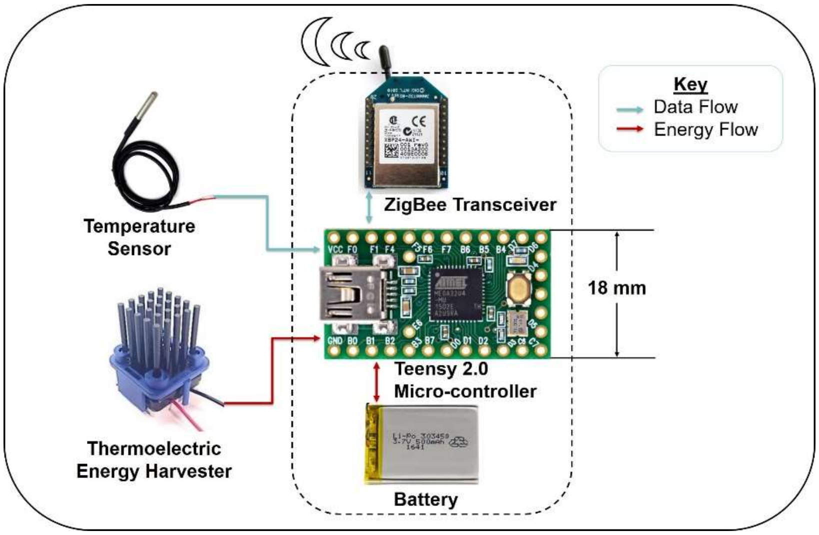

Figure 8. Current Design Diagram.

Figure 8 shows a Teensy 2.0 micro-controller at the center of the box representing the protective housing. Also in the housing is a 3.7V 500 mAh battery and a ZigBee transceiver. Outside of the housing the thermoelectric energy harvester is located alongside the thermocouple temperature sensor. The specific locations are arbitrary, but the whether the component is inside or outside of the housing is an important distinction. The components inside the housing are sensitive to high temperatures and must be protected from the environment that the thermoelectric generator and sensor will be in. These specific components have been preliminarily chosen for the design because of their promising characteristics, but they are not necessarily the components that will be used for the prototype or final design. This is because there are a number of potential problems that may arise from this design that could hinder the completion of this project. Some of these potential problems include: underestimating the power consumption, overestimating the power generation, buying components that are not compatible with each other, buying components that do not accomplish the design objectives, damaging the components due to lack of electrical circuitry experience, problems with programming the microcontroller and many others. Team 3 must be especially diligent to foresee possible problems because the self-powered wireless sensor is entirely an electronic system and the team consists of mechanical engineers only (challenge accepted). The potential problems that may be encountered and how the team can avoid them or mitigate the effects is described in more detail below.

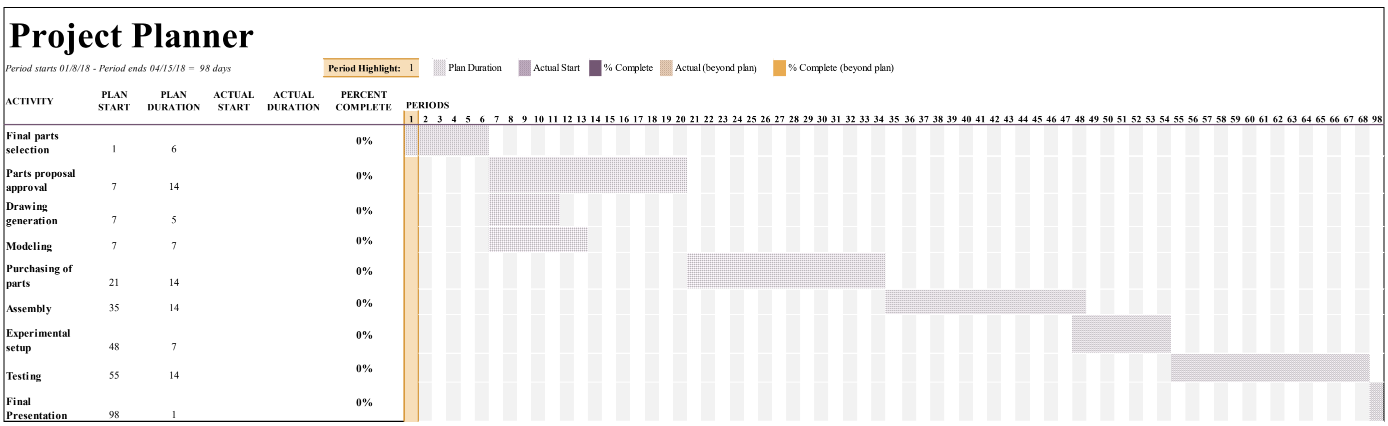

Figure 9. Gantt chart for spring 2018.

Mitigating Potential Problems

Many of the problems that may be encountered during Senior Design ll stem from the team's lack of electrical engineering knowledge. In order to minimize these problems the team has and will continue to consult our faculty advisor, the team sponsor and other faculty members and resources that can be used to supplement the lack of knowledge. A number of meeting have already been held with faculty to get expert perspectives on what needs to be done and how to go about it, which has been invaluable in getting to this point.

Moving forward the team will continue to take advantage of the knowledge of the faculty members to achieve the design objectives. The team will also begin to use the facilities available at the College of Engineering such as the mechatronics lab when it comes time to begin assembling the prototype. Designing the sensor to be self-powered is the most important objective of the design and as such will need to be analyzed further. Specifically, an in depth analysis on the power consumption of the system and the power generation of the energy harvester will be performed for all possible scenarios and the worst case scenario to base our design around to ensure the design performs its function in all situations. The analysis will then need to be checked by a faculty member to expert to guarantee its validity.

Fortunately, the components that will make up the design are all fairly inexpensive with most of them costing only a few dollars. For this reason it is not detrimental if the team needs to reorder a component for whatever reason. However, the lead time between ordering the component and receiving it may be longer than desired. It will be beneficial to order the parts as soon as possible to begin prototyping, identifying any problems and reordering new components in order to have the final design completed by the end of spring semester.

Parts and Assembly Drawings

In the part drawing section, the team will need to draw all of the parts that will be in our design. While most of these components should be relatively simple to design, a few of the parts will take time to get the dimensions correct. Some of the part drawings will already be available online, but many of our parts will be custom built which will need to be measured in detail. The accuracy and precision of our measuring instruments will determine how accurate and precise our drawings will be. Once all the parts have been generated with our CAD modeling system, the team can begin our 3D CAD assembly. The assembly drawing will allow for an assembled view and detailed exploded view of our design. Detailed drawings will then be able for print once all above steps have been completed. These drawings will be useful for the purpose of completing thermal analysis of our system. This analysis will give us more insight on what components need more protection from the adverse environments they exist in.

Prototype

Following the drawings and analysis of the design. The team is going to be able to generate an accurate parts list to begin assembling and testing the product. Table 17 shows an estimated cost and delivery time to acquire the main components of the design. The team decided that miscellaneous component such as screws and plates, can be purchased after the completing a working prototype. After acquiring the components for our prototype, the assembly process can initiate. The assembly process will consist on connecting, adapting, and programing all the components together. Ideally the assembly process should take no more than 2 week. The time for assembly was estimated considering that most of the process should be done with the collaboration of faculty, and typically any faculty meeting should be schedule with time in advance. However, the success of this project is only determined during the testing process. The be able to determine if the targets of the projects were achieved. The prototype should be tested under the expected conditions. From previous research the team concluded that the approximate time for the experimental set should be about 1-2 weeks. After this multiple test should be done to obtain and analyze different data from the system.

Table 17
Parts list of selected design.

Part	Qty	Delivery time (days)	Cost ($)
Temperature sensor	1	3-5	15.00

Teensy 2.0 Micro-controller	1	7-14	14.37
Thermoelectric generator	1	3-5	35.60
ZigBee Transceiver	1	3-5	17.50
Battery	1	3-5	12.50
Housing material	-	-	-
Total			94.97

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

A.1 Mission Statement

Team 3 is committed to ensuring a positive engineering work environment that supports professionalism, integrity, organization, respect, and trust. Every member of this team will contribute a full effort to the creation and maintenance of such an environment in order to bring out the best in all of us as well as this project.

A.2 Roles

Each team member is delegated a specific role based on their experience and skill sets. In an event where someone needs to step down from his/her role, the team will collectively vote on someone else to fill that position. Each role description and responsibility is laid out here-within (Table 1):

Table 1

Organizational chart for team roles.

	Team Leader	Financial Advisor and Bookeeper	Webmaster	Lead Controls and Programmer	Lead CAD Designer
Jacquelyn Burnham				X	
Meghan Busch		X			
Thomas Dodamead	X				
Omar Rodriguez			X		
Caleb Stallings					X

Team Leader – Thomas Dodamead

Manages the team as a whole by developing a plan and timeline for the project, delegating tasks among group member according to their skill sets, finalizing all documents, and providing input on other positions where needed. The team leader is responsible for promoting synergy and increased teamwork. If a problem arises, the team leader will act in the best interest of the project.

The team leader keeps the communication flowing, both between team members and sponsor. The team leader takes the lead in organizing, planning, and setting up of meetings. Finally, the team leader gives or facilitates presentations by individual team members and is responsible for overall project plans and progress.

Financial Advisor and Book Keeper – Meghan Busch

Manages the budget and maintains a record of all credits and debits to project account. Any product or expenditure requests must be presented to the advisor, whom is then responsible for reviewing and the analysis of equivalent/alternate solutions. They then relay the information to the team and if the request is granted, order the selection. A record of these analyses and budget adjustments must be kept.

Takes notes during all crucial meetings: design, sponsor, faculty, and prototype testing meetings. Transfers any handwritten to digital records on the Google Drive. Responsible for keeping a record of all correspondence between the group and 'minutes' for the meetings. Creates a synopsis of meetings to missing group members via group chat. Keeps track of schedule for project and Google Calendar events.

Webmaster – Omar Rodriguez

Webmaster shall develop a website dedicated to follow the development of team's 3 project. Also, to compile and update any information regarding team 3 or the project.

Lead Controls and Programmer – Jacquelyn Burnham

Lead Controls and Programmer will be responsible for the programming and controls function of the design. Will be responsible for assigning specific controls and programming work to other team members depending on work load. All programming and controls work done in this team will be reviewed by her and approved accordingly.

Lead CAD Designer – Caleb Stallings

Responsible for details of the design. Manages and oversees all CAD work to be completed. Will also have the responsibility of assigning group members specific CAD related projects. He must also review all models sent to him before submission. He will also send final designs in for submission.

All Team Members

- Are responsible for tasks they are delegated
- Agrees to the project goals and success
- Deliver on commitments by the agreed upon date
- Will communicate as early and often as possible
- Listen and contribute constructively
- Be clear and concise when communicating
- Be open minded to all ideas
- Respect others roles and ideas

- Will attend fun events for team building reasons

A.3 Communication

The main forms of communication will be via group chat, text messaging, email, and regular group meetings. For the passing of information, i.e. files and presentations, Google Drive and occasionally email will be the main form of file transfer and proliferation.

Each group member must have a working email for the purposes of communication and file transference. Members must check their emails and group chat at least twice a day to check for important information and updates from the group. Although members will be initially informed via a group chat, meeting dates and pertinent information from the sponsor will additionally be sent over email or group chat.

If a meeting must be cancelled, an email or group message must be sent to the group at least 12 hours in advance.

Any team member that cannot attend a meeting must give advance notice of 12 hours informing the group of his absence. Reason for absence will be appreciated but not required if personal. Repeated absences in violation with this agreement will not be tolerated. If possible, attending the meeting virtually, through FaceTime or skype will be acceptable.

A shared Google calendar will be maintained in order to keep the team up to date on when each team member is available. The team member who will be unavailable should let the team know via group chat.

A.4 Team Dynamics

The students will work as a team while allowing one another to feel free to make any suggestions or constructive criticisms without fear of being ridiculed and/or embarrassed. If any member on this team finds a task to be too difficult it is expected that the member should ask for help from the other teammates. If any member of the team feels they are not being respected or taken seriously, that member must bring it to the attention of the team in order for the issue to be resolved. We shall NOT let emotions dictate our actions. Everything done is for the benefit of the project and together everyone achieves more.

A.5 Ethics

Team members are required to be familiar with the NSPE Engineering Code of ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics.

A.6 Dress Code

Team meetings will be held in casual attire. Sponsor meetings and group presentations will be business casual to formal as decided by the team per the event.

A.7 Weekly and biweekly Tasks

Team members will participate in all meetings with the sponsor, adviser and instructor. During said times ideas, project progress, budget, conflicts, timelines, and due dates will be discussed. In addition, tasks will be delegated to team members during these meetings. Repeat absences will not be tolerated.

A.8 Decision Making

Decision making is conducted by consensus and majority of the team members. Should ethical/moral reasons be cited for dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. Individuals with conflicts of interest should not participate in decision-making processes but do not need to announce said conflict. It is up to each individual to act ethically and for the interests of the group and the goals of the project. Achieving the goal of the project will be the top priority for each group member. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss among the group.
- Tentative Solutions – Brainstorms possible solutions. Discuss among group most plausible. Perform background research.
- Data/History Gathering and Analyses – Gather necessary data required for implementing Tentative Solution. Re-evaluate Tentative Solution for plausibility and effectiveness.
- Design – Design the Tentative Solution product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for Tentative Solution and gather data. Re-evaluate for plausibility and effectiveness.
- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

A.9 Conflict Resolution

In the event of discord amongst team members the following steps shall be respectfully employed:

- Communication of points of interest from both parties which may include demonstration of active listening by both parties through paraphrasing or other tool acknowledging clear understanding.
- Administration of a vote, if needed, favoring majority rule.
- Team Leader intervention.

- Instructor will facilitate the resolution of conflicts.

A.10 Statement of Understanding

By signing this document the members of Team 3 agree the all of the above and will abide by the code of conduct set forth by the group.

Name	Signature	Date
Jacquelyn Burnham		9/26/17
Caleb Stallings		9/26/17
Omar Rodriguez		9/26/17
Meghan Busch		9/26/17
Thomas Dofomerd		9/26/17

Appendix B: Target Catalog

Table 18
Target Catalog Before Conception Selection

Subsystem	Target	Value	Units
Power System	Power Generation Capacity	1-5	Milli-Watts
(energy generation and storage)	Generation Voltage	4	Voltage
	Generation Current	0.0001 - 0.001	Amperes
	Generation Capacity Factor	50 - 100	%
	Battery Storage Capacity	0.1 - 0.5	Amp-hours
	Battery Voltage	3 - 5	Voltage
	Battery Current	TBD	Amperes
	Battery Life	300	Cycles
	Standby Time	36	Hours
Transducer System	Sensing Parameter	TBD	Unit of Parameter
(sensor, microcontroller, transceiver)	Sensor Power Requirement	0.001 - 0.01	Milli-Watts
	Sensor Current Requirement	TBD	Amperes
	Sensor Voltage Requirement	3 - 5	Volts
	Sensor Sampling Frequency	1 - 10	Hertz
	Sensor Accuracy (error)	0.1 - 1	%
	Microcontroller Active Power Consumption	0.01-1	Milli-Watts
	Microcontroller Standby Power Consumption	0.001 – 0.01	Milli-Watts

	Microcontroller Voltage Requirement	3 - 5	Volts
	Microcontroller ATD Resolution	16	# of bits
	Microcontroller Amplification	TBD	Decibel
	Microcontroller Filter Range	TBD	Hertz
	Microcontroller Memory Storage	100	Kilo Bytes
	Microcontroller Processing Performance	0.01 - 1	Giga Hertz
	Wireless Transceiver Power Consumption	0.02 - 1	Milli-Watts
	Wireless Transceiver Voltage Requirement	3-5	Volts
	Wireless Transceiver Current Requirement	11-80	Milliamperes
	Wireless Communication Distance	5	Meters
	Wireless Transceiver Frequency	2.4	Gigahertz
	Wireless Transceiver Bandwidth	1 - 2	Megahertz
<u>Protection System</u>	Volume	6	Cubic Inches
(housing and environmental parameters)	Weight	100	Grams
	Maximum Temperature	120	Celsius
	Electrical Noise	0	Hertz

References

Agarwal, T. (n.d.). Wireless Communication Technologies Types and Advantages. Retrieved November 01, 2017, from http://www.efxkits.us/different-types-of-wireless-communication-technologies/

ARDUINO UNO REV3. (n.d.). Retrieved November 05, 2017, from https://store.arduino.cc/usa/arduino-uno-rev3

ATmega16U4 / ATmega32U4. (n.d.). Retrieved November 5, 2017, from https://www.pjrc.com/teensy/atmega32u4.pdf

Balanis, C. A. (2005). Antenna Theory Analysis and Design (3rd ed.). Hoboken, NJ: A John Wiley & Sons, INC., Publication.

Beagleboard:BeagleBoneBlack. (n.d.). Retrieved November 05, 2017, from https://elinux.org/Beagleboard:BeagleBoneBlack#BeagleBone_Black_Description

Bluefruit LE - Bluetooth Low Energy (BLE 4.0) - nRF8001 Breakout - v1.0. (n.d.). Retrieved November 01, 2017, from https://www.adafruit.com/product/1697

Digi XBee® SX 868. (n.d.). Retrieved November 01, 2017, from https://www.digi.com/products/xbee-rf-solutions/sub-1-ghz-modules/digi-xbee-sx-868

ESP8266 WiFi Module. (n.d.). Retrieved November 01, 2017, from https://www.adafruit.com/product/2282

Gabay, J. (05-01-2015) Microcontrollers for Sensors and Data Acquisition, https://www.digikey.com/en/articles/techzone/2013/may/microcontrollers-for-sensors-and-data-acquisition

How SAW Sensors Operate? (n.d.). Retrieved November 01, 2017, from http://www.senseor.com/saw-technology/saw-sensors-operation

Joel.(November 28,2009). “Taking the mystery out Oxygen Sensor”.http://www.autorepairinstructions.com/archives/oxygen-sensors/

Laukkonen, JD. (October 11,2013). “What is a Mass Air Flow Sensor?”. http://www.crankshift.com/mass-air-flow-sensor/#Types_of_Mass_Air_Flow_Sensors

Learn Wireless Basics. (n.d.). Retrieved November 01, 2017, from https://commotionwireless.net/docs/cck/networking/learn-wireless-basics/

Manifold absolute pressure sensor,(MAP). Rev. 8.0 MPX4250A. 25 July 2017. NXP.com

McConomy, S (2017). *Customer Needs* [Powerpoint Slides]. FAMU-FSU College of Engineering

McConomy, S (2017). *Project Scope* [Powerpoint Slides]. FAMU-FSU College of Engineering

Microchip High-Temperature Products and Solutions. (n.d.). Retrieved November 5, 2017, from http://www.microchip.com/design-centers/high-temperature

Microstrip (Patch) Antennas. (n.d.). Retrieved November 01, 2017, from http://www.antenna-theory.com/antennas/patches/antenna.php

Pathare, N. Cooper, W. (n. d.) Five Building Blocks of Self-Powered Wireless Sensor Nodes, http://www.batterypoweronline.com/articles/five-building-blocks-of-self-powered-wireless-sensor-nodes/

Power Generators, http://www.marlow.com/power-generators.html

Power Supply. (n.d.). Retrieved November 05, 2017, from https://www.raspberrypi.org/documentation/hardware/raspberrypi/power/README.md

SN65HVD233-Q1. (n.d.). Retrieved November 01, 2017, from http://www.ti.com/product/SN65HVD233-Q1

Texas Instruments. Wireless Connectivity. Retrieved November 28, 2017, from http://www.ti.com/wireless-connectivity/overview.html

Wooten,D.(January 12, 2016).”Symptoms of a Bad or Failing Throttle Position” .https://www.yourmechanic.com/article/symptoms-of-a-bad-or-failing-throttle-position-sensor

Yan, D., Yang, Y., Hong, Y., Liang, T., Yao, Z., Chen, X., & Xiong, J. (2017). AlN-Based Ceramic Patch Antenna-Type Wireless Passive High-Temperature Sensor. Micromachines, 8(10), 301. doi:10.3390/mi8100301