Cummins Self-Powered Wireless Temperature Sensor

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Abstract

In recent years, Cummins has spent substantial funds due to warranty claims on wiring harnesses for on-highway application vehicles. The purpose of the project is to eliminate the need for wired connections from the Engine Control Module (ECM) to sensors throughout the engine. Wireless sensors are the key solution to combating these issues. However, powering these sensors has become a non-trivial issue. The project scope is to design, build, and demonstrate a method to power a sensor. This sensor must transmit data of a specific variable without wires to the ECM in a Cummins diesel engine. The project includes many functions. Firstly, the sensor must harvest and supply energy. This will be done with a thermo-electric generator which is in contact with the oil pan of the engine. In order for our product to work it would need to generate 0.03 Watts. However, even with natural convection we were able to generate 0.05 Watts. The product must also sense a variable and transfer it to the ECM without wires. This will be done using a thermocouple to measure the oil temperature. The data will then be sent through Bluetooth to the ECM. The data was able to be sent at a distance of 12 meters which surpasses the customer needs of a distance of 5 meters. The long-term goal of the prototype is to reduce maintenance frequency and costs by eliminating cable harnesses. Also, this project will reduce waste while providing a convenient and efficient product for the consumer.

Keywords: [Click here to add keywords.]

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- The evolution in wireless systems has allow manufactures to incorporate this technology and make better products. For some applications wired connections could be more reliable. However, the installation of this wired connections are typically costly and require constant maintenance. In addition, wires are usually exposed and can get damaged by external variables such as heat, humidity, and others. For example, engine sensors communicate with the engines control module by a wire. These wires could get damaged with time and can cause bigger issues. To solve this problem, wireless technology could be implemented by combining three systems into one. Electrical system, power generation system, and protection system.
    - The electrical system allows the device to sense a variable and wirelessly communicate with the ECM. To efficiently achieve this, the electrical components need to be of low power consumption capabilities.
    - The Power generation system allows the electrical component to function. The principal problem with power generation is the source of energy. Since the system is designed for an engine. Power generation can be achieved by transforming thermal energy into electrical energy.
    - The protection system allows the electrical components to be protected from the harsh environment that the sensors typically undergoes. However, the system cannot increase the communication interference with the ECM.
- In the past years, Cummins has spent a large amount of money for warranty claims on wiring for sensors. To resolve these issues, Cummins and the FAMU – FSU College Of Engineering have decided to partner up to <u>Design</u>, <u>build,</u> and <u>demonstrate</u> 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

[The body of your paper uses a half-inch first line indent and is double-spaced. APA style provides for up to five heading levels, shown in the paragraphs that follow. Note that the word *Introduction* should not be used as an initial heading, as it's assumed that your paper begins with an introduction.]

Method

The design was functionally decomposed into three main components: power supply, wireless sensor, and housing. The power supply must harvest and supply energy to the system. The wireless sensor must measure and wirelessly transmit a parameter. The housing must maintain the system within operating conditions. To meet the objectives of the project, each component is crucial.

Power Supply

The power supply consists of the energy harvesting component and the battery. The energy harvesting is the primary source of power for the system, and the battery is the secondary source. A lithium polymer battery stores excess energy harvested from the primary source for when the system is not running in optimal conditions to harvest energy.

The system's power supply must come from an energy harvesting technique. The method used in this design was a thermoelectric generator (TEG). The TEG depends on a temperature gradient to supply power. The voltage produced is proportional to this temperature gradient. The TEG was the selected energy harvesting method due to the excess supply of heat in the engine. The engine will also be susceptible to forced convection when the vehicle is in motion, which can be beneficial to heat transfer to generate more power. Some additional advantages to thermoelectricity is compact size, high reliability, and application to low-power systems. Figure 1 depicts the selected TEG with a size of about 30 mm by 30 mm square.

The oil pan was the selected location for the TEG to harvest the energy. It is ideal due to its planar geometry for the TEG to have maximum contact. The oil pan is also located at the bottom of the engine and is more susceptible to forced convection while the vehicle is in motion. Additionally, the oil in the pan can get to high temperatures of about 140°C. Figure 2 illustrations the location of the oil pan integrated in a Cummins engine.

According to the Marlow Industries Inc. specifications sheet, the TEG can produce 0.61 W with a 60°C temperature difference. The maximum power consumption of the microcontroller is 0.026 W. Therefore, the selected TEG will provide more than enough needed power if a 60°C temperature difference is maintained. The TEG's performance approximately produces about 0.03 W for a temperature difference of 10°C (Figure 3).

In this design, a heat sink consisting of fins and forced convection from the moving vehicle maintains this temperature difference. An engine operates in many different environments and temperatures ranging from below zero to above 50°C. The heat sink selected had a similar length and width to fit on the TEG. The height of the fins was optimized to allow for maximum heat transfer but still short enough to be low lying and noninvasive.

Power Generation Testing Setup

There were multiple preliminary tests performed on the TEG for power output using a hot plate, multimeter, and table fan. The hot plate represents the excess heat of the oil in the oil pan. The table fan represents the forced convection occurring on the system while the car is in motion. The multimeter is the measuring device. Two main tests demonstrate the performance of the TEG. The first test was performed with and without the presence of the heat sink in natural convection. The second test was performed with and without the presence of the forced convection both with the heat sink. This was a total of four tests.

The TEG was in the center of the of the hot plate with the hot side facing down. The multimeter was connected to the positive and negative lead of the TEG to measure the voltage and current versus time. Measurements were taken every 10 seconds for about five minutes until the temperature gradient reached a steady state. The hot plate read 140°C, and the surrounding temperature in the room was 21.2°C. Figure 4 illustrates this setup for the experiment. For the tests with forced convection, a fan was placed a foot from the system at a speed of 3 m/s.

Wireless Sensor

The wireless sensor component consists of the temperature sensor, amplifier, and microcontroller.

Housing

The components that exist in the protective housing are the board, thermocouple amplifier, and the battery. All these components are sensitive to high temperatures. A conservative value 60 degrees Celsius should not be exceeded, but no damage will occur to the electrical components until 85 degrees Celsius. To be sure this threshold temperature is not exceeded, multiple measures were taken to keep the operating temperatures around the housing as low as possible. A heat sink will be used in conjunction with the thermo-electric generator to ensure more heat is dissipated around box. Since this product’s main purpose is for on highway applications, airflow around the heat sink is expected to produce even lower temperatures through forced convection. Another method used to reduce operating temperatures is the incorporation of standoffs to increase the distance between the hot oil pan and protective housing. Other factors which could damage our system, besides high temperatures, is debris, chemical exposure, and water. To shield the sensitive electrical components from this, we are using a hard plastic casing. This casing will protect the components from any small debris from the road, of if any harmful liquids were to come in contact with it.

Results and Discussion

Final Design

Product Integration

Prototype Testing

Power Supply

Talk about results, show graphs, explain how we needed a power boost

Wireless Sensor

Results of integrated product, bluefruit app

Housing

What we found to be the material most readily available, effect, and inexpensive for our heat sink is aluminum 2024 which is coated in black anodized aluminum. This heat sink was chosen for its low cost, high thermal conductivity, and corrosion resistance. The heat sink was put through a finite element analysis (FEA), and we found that the heat sink dissipates the heat to about 58 degrees Celsius at the tips. This achieves the goal of reducing the temperature below 85 degrees Celsius. This can be seen in Figure 5 of the FEA results.

The threaded standoffs used are a length 1.75 inches. This give enough clearance from the heat sink to the protective housing to allow for significant airflow. The hard plastic casing will fend off debris while also causing minimal signal interference. The inside of the casing also has thin stands for the electrical components. This will allow for air to cool both the top and bottom sides of the electrical components. This is important for keeping the temperature inside the box from reaching critical temperatures. Figure 6 illustrates a picture of the box.

Conclusion

The project was to create and demonstrate the operation of a self-powered wireless sensor. A TEG and Thermocouple were chosen as the sensor type and power generation methods. The TEG was tested and it was determined that without a heatsink it could produce 0.0073 W of power. The thermocouple was assembled to a microcontroller with an amplifier, and the data from the thermocouple was sent via Bluetooth5 to a Bluetooth capable device. The range of the Bluetooth signal was tested and found to be 12m, while the error in the thermocouple was found to be ±2°C. The power consumption of the microcontroller and electronics was tested to be 0.026 W, so the power output of the TEG needed to be increased using a heatsink. Testing, thermal analysis, and FEA was done to determine an appropriate heatsink for the TEG that would maximize power output. The appropriate heatsink was chosen with a thermal resistance of 5.5 °C/W for a 1 m/s air flow rate. With the heatsink the power output of the TEG was increased to 0.047W. A rechargeable lithium polymer battery was chosen for the project that produced a voltage of 3.7 V to store power from the TEG and run the device. A housing was designed for the components to minimize size and offset sensitive electronic parts from the heat of the oil pan.

Future Work

After the completion of this project, it was noted that some improvements could be made to the design, along with variations along the same thought process of this project. The concept of a self-powered wireless sensor can be expanded into other sensors, power generation methods, and power storage and allocation methods. This project can also be continued to include an even smaller and more compact design with even higher temperature tolerances. For this design using a TEG, and thermocouple temperature sensor combination, the electronics boards and component specifications reach a maximum of 60 °C while most engine applications require higher temperatures. The design also is in an open format, which doesn't provide protection to the fins. These can be improved upon in future iterations of this project. Though this design is already minute, size can still be optimized for but more difficult to assemble. Future attempts could also design for assembly and manufacturing. Alternative power generation methods could include piezoelectric energy generation using vehicle vibrations.

Acknowledgements

The project team recognizes Dr. Hay's from Cummins for project sponsorship. Also, Dr. McConomy and Dr. Shih for organizing the senior design program and providing feedback on the project. They also thank Dr. Camillo Ordonez, and Dr. Hooker for advice and direction in terms of electronics and programming assistance and Dr. Juan Ordonez for advice and direction in the thermal design and testing.

References

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Marlow Industries, Inc. (n.d.). *Technical Data Sheet TG12-4 Thermoelectric Generator.* Retrieved from Digi-Key Electronics: https://cdn2.hubspot.net/hubfs/547732/Data_Sheets/TG12-4.pdf

Tables

Table 1

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Figures

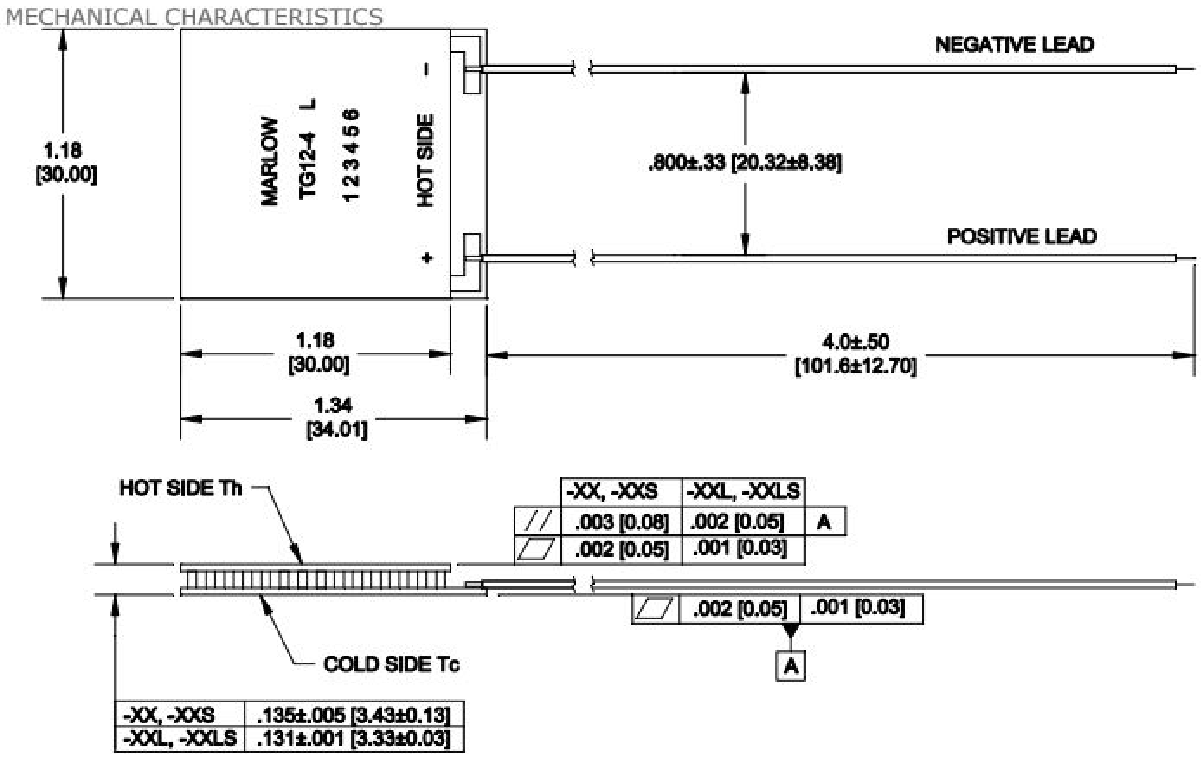


Figure 1. The mechanical drawings of the TEG (Marlow Industries, Inc.).

Figure 2. Cummins engine and oil pan location (Cummins, n.d.).

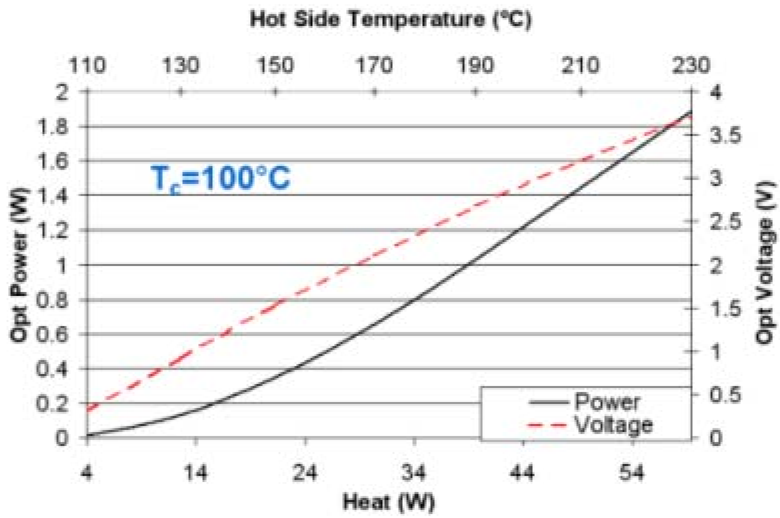


Figure 3. Typical performance curve of the TEG with the cold side at 100 degrees Celsius (Marlow Industries, Inc.).

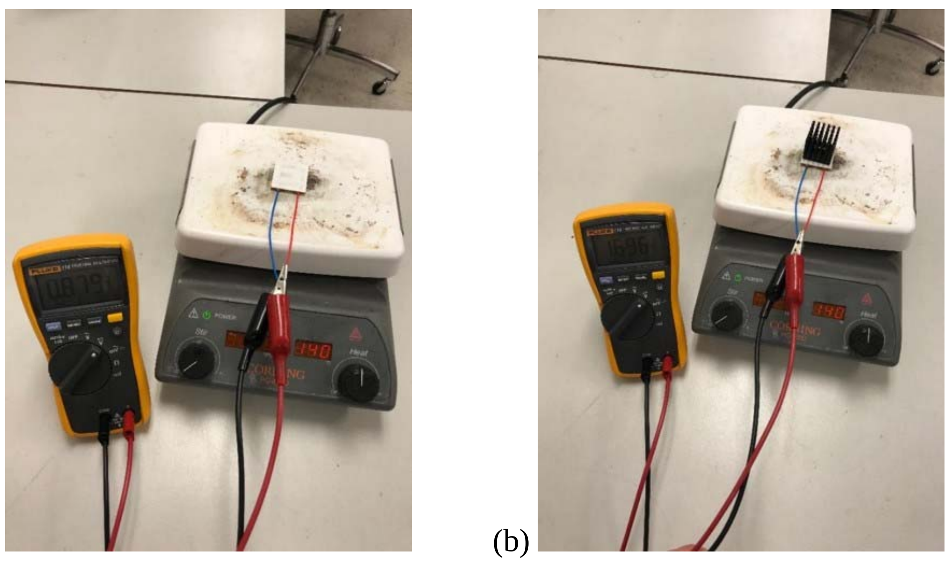
(a)  (b)

Figure 4. Experimental setup to test the voltage and current of the TEG (a) without and (b) with the heat sink.

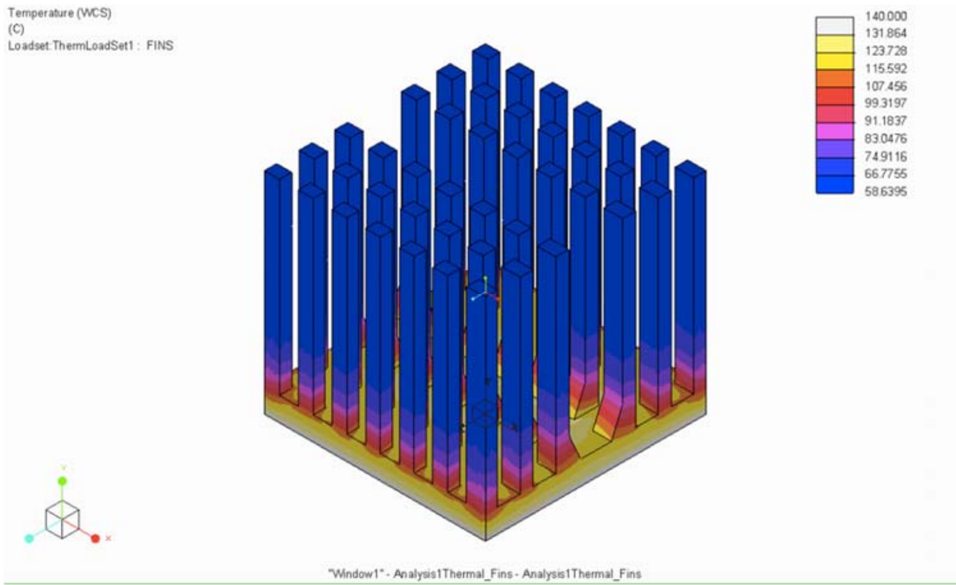


Figure 5. FEA temperature results of the heat sink.

Figure 6. The hard plastic casing which will store the electrical components.