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Project-Based Learning: Wireless Sensor Node Project for 2nd-Year ECE Students

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1. Abstract

Today's student must be able to combine theoretical and hands-on design skills to create and test effective engineering designs. Project-based learning experiences are especially important to engineering students because they require students to combine theoretical knowledge with practical design skills not typically covered in most undergraduate engineering courses. By developing design skills in an engineering undergraduate program, students can be better prepared to meet the needs as they enter the workforce. This paper explores a wireless sensor node design project implemented in an ECE sophomore-level project-based learning course.

This course is the first project-based learning class offered in the ECE department at Virginia Tech. The students enrolled in the course are typically in their second semester of their second year and have taken or are finishing their core ECE coursework so they have a basic knowledge of circuits, digital systems, embedded systems, and signals and systems. All project options are open-ended, and each project contains both hardware and software designs and is inspired to address real-world issues.

The wireless sensor node is one project designed as an option for students in this course. This project considers a fire detection system that can be used to prevent forest fires that has been a major concern to society. Students working on this project need to tackle several design problems both in the transmitter side (a battery charging circuit that can charge a 9V battery from a solar panel, a thermistor and a wireless communication device handled by a microcontroller to transmit temperature data, and a power save implementation on the microcontroller) and in the receiver side (a custom-made GUI for displaying the temperature information). This paper will discuss the details of the project and how it was designed, tested, and implemented in this course to help improve students' understanding of technical skills and ability to create real-world engineering designs.

2. Introduction

Engineering programs must continue to implement hands-on skills for designing and testing real-world prototypes in engineering undergraduate programs to meet the needs of the 21st century engineering job market. While historically engineering curriculum has swung between focusing on hands-on skills and theoretical knowledge, today's engineers need to have a mastery of both sets of skills to create and improve realistic and effective engineering designs [1]. This need requires students to not only have a deep understanding of the theoretical knowledge in their fields, but also significant exposure to hands-on learning experiences in their undergraduate education where they can create their own designs using this technical knowledge. Additionally, engineers are constantly communicating ideas, designs, and progress updates both within and outside their companies, often spending the majority of their time communicating in some manner [2]. Good communication, as well as good teamwork, are considered professional skills that are highly important and sought after in engineers working in industry [3], [4], but integrating these skills into engineering curriculum can be difficult if engineering courses focus on technical content and do not integrate these professional skills into their courses. To help future engineers continue to develop their technical skills while also giving them opportunities to practice their professional skills, future engineering courses need to be designed thoughtfully to integrate them in realistic settings with real-world problems.

Project-based learning focuses on creating projects that allow students to practice their technical and professional skills on problems that embody those that they will work on and solve after completing their degrees [5]. These types of experiences have been shown to help students by improving their learning of the technical content, giving them freedom to explore their own designs and solutions while remaining relevant to their future career [6]. Many project-based learning experiences exist either in Capstone courses for students during their final undergraduate year, or occasionally in Cornerstone courses, sometimes seen in first-year engineering courses [7]. The 'middle years' of engineering programs often focus on developing foundational knowledge of engineering professions [7], which makes them an ideal time to help students develop and test their hands-on skills and intuition in engineering design. By creating more opportunities for students to develop their engineering design technical skills through hands-on learning experiences while working with their peers and developing important professional skills, engineering educators can continue to help students develop and gain valuable engineering design experience. This paper demonstrates a project designed to help ECE students gain such experience by working on a wireless sensor node project in their second year of their program.

3. Background

The wireless sensor node project discussed in this paper was developed for a project-based learning class at Virginia Polytechnic Institute and State University. The Electrical and Computer Engineering (ECE) department at Virginia Tech underwent significant curriculum changes in 2019 with the support of Revolutionizing Engineering Departments program (RED grant) from the National Science Foundation with the vision of bringing more hands-on learning experiences to undergraduate students. One of such curriculum changes was to create a new course for sophomore ECE students with the mission of helping students develop practical research, design, and hands-on skills while also developing their technical communication and teamwork skills. This course, called Integrated Design Project, is a two-credit hour course where students meet in lab once a week for two hours to discuss progress on their project with their instructor (along with a weekly seminar on different professionalism topics such as technical writing, career fairs, and presentation skills). Each section of this course is led by an instructor and has a maximum of 16 students.

Students typically take this course during the second semester of their sophomore year, after having taken prerequisite courses on circuits and embedded systems from prerequisite courses, which are critical skills needed for their projects. Additionally, students usually are enrolled in courses on physical electronics and signals and systems while taking this course. To help them practice these skills before their design projects, each student completes a lab during the first week of the semester. The topics on this lab cover a variety of important skills, including the simulation, design, and testing of circuits from basic voltage dividers, amplifiers and filters, and practical circuits for shifting and limiting voltage.

After the first week, students are put into groups of two to work on a semester-long design project, such as the wireless sensor node project discussed in this paper. All projects are designed to address real-world issues and require students to use both hardware and software designs to accomplish their solutions. The projects are also open-ended to allow for different possible successful designs. Project descriptions are given to students with specifications and requirements that their final design has to meet. To help students scaffold skills into their projects and break their projects into more manageable steps, each project is broken down into four milestones throughout the semester, and each milestone is broken down into multiple deliverables. Each group is asked to turn in a weekly report that documents the design process of the deliverables they accomplished or are still working on, which helps guide the weekly meeting each group has with their instructor. Technical communication is a huge emphasis in this class, in which the engineering design process is strictly followed and evaluated in all reports and presentations.

One of the biggest challenges in a project-based learning course is to evaluate students' work. Unlike traditional theory classes where homework assignments and exams typically have just one solution, the projects in this course do not have a single, uniform solution because every project is open-ended. Students are encouraged to think out of the box in their designs, and two teams working on the same project can come up with quite different solutions. Instructors grade students' projects by reading their weekly reports and milestone reports and evaluate their following the design process and their effort in describing and documenting any decisions they made, as well as the simulation and physical testing to verify each of their designs. Students are provided expectations for each of the reports, as well as the rubrics used to evaluate them.

Student outcomes are also a very important aspect of the course, as they guide in the design of the course and projects by focusing on what skills students should develop throughout the course. After completing the course and the project, students should be able to: (1) design and implement a solution to an open-ended engineering problem that involves both hardware and software designs; (2) use simulation and measurement tools to devise a test and validation plan;

(3) document and present detailed engineering design process of the project solution; (4) recognize and assess the ethical issues and societal impacts of the designs and solutions.

4. Wireless Sensor Node Project

The project was inspired to provide a possible solution to notify first responders whenever a forest fire has been detected. It is important for students to design projects in class that have real-world applications, so that they can recognize and assess global and ethical issues when designing the projects. If temperature information must be gathered constantly throughout a forest to quickly detect when a fire starts and prevent its spread, one solution is to have hundreds of self-powered devices scattered across the forest to detect spikes in temperature and transmit that information back to the base station. A wireless sensor network consists of nodes that gather sensory information, process it, and communicate it through other connected devices in the same network. By using a wireless sensor node, emergency response personnel can monitor the temperature information throughout the entire forest and quickly respond to any potential fires. In this project, the sensor node contains a sensor to measure local temperature, a transmitter to send its data, a rechargeable battery, and a solar panel to provide power to the device constantly, and a microcontroller to control the whole system.

4.1 Project Requirements

This project was designed to be open-ended and allow for multiple designs, as long as a few specific requirements are met. Students must use the ±5V power supply from their Analog Discovery 2 power supply (connected to an external 5V wall wart supply) to mimic a solar panel whose input voltage can range between 4V and 5V. Students must also design a DC/DC converter circuit that can regulate the output voltage to power an Arduino Uno microcontroller and charge a 9V rechargeable battery, using a pulse width modulation (PWM) feedback control with a switching frequency greater than 10 kHz. Because this power system should have high efficiency to reduce power losses, students must conduct an efficiency test to explore the efficiency of their power stage.

For the project, students use their Arduino Uno to process the information from the temperature sensor and transmit the data through Bluetooth to a laptop or phone to represent an easy-to-configure initial prototype of sending data through a longer-range communication method, such as radio. The project also requires students to consider how to design the system for the wireless sensor node to last as long as possible on a battery, so they must consider how to implement power saving techniques. If the input source (representing the sun) is available, the battery voltage should be charged or maintained at the fully charged battery voltage level. If the input source is not available (such as rainy days and at nights), the wireless sensor node needs to enter a power saving mode, in which the Arduino should process and send the temperature information less frequently and conserve power for the rest of the time.

4.2 High Level Design

A block diagram of the system is shown in Figure 1. A 5V DC power supply from Analog Discovery 2 (AD2) is used for this project as the solar panel (input voltage can be varied) to charge a 9V rated Nickel Metal Hydride battery. For this application, a step-up boost converter is used to convert the input source with a maximum of 5V to a higher voltage to charge the battery. Although this is a 9V rechargeable battery, in order to charge the battery fully, the output voltage of the boost converter has to be higher than 9V. There are several common ways to charge the battery, such as constant current charging, constant voltage charging, or the combination of the two. Constant current charging focuses on speed by charging the battery at a faster rate, but constant voltage charging focuses on safety by ensuring the battery voltage does not go over its rated voltage. In this project, students often choose one of these techniques or adopt a combination of both to produce a solution that balances both fast charging and safety.

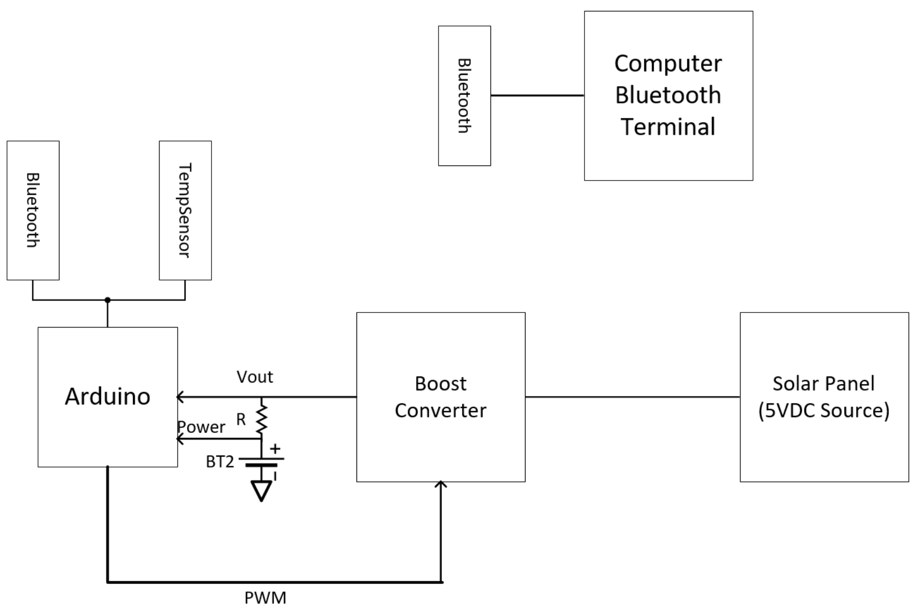

Figure 1: System Block Diagram

Because the boost converter is a switching circuit and its output has to be regulated, students use their Arduino Uno to provide a PWM feedback control to regulate the output voltage. In this project, integral control is used because of its simplicity for students who have not taken a controls course yet. The Arduino first measures the boost converter output voltage and then compares it with the output reference voltage to decide whether to increase or decrease the duty cycle of the boost converter. The Arduino also collects the temperature data using a thermistor and then sends that data through Bluetooth. In order for this self-power wireless sensor node system to last longer, a sleep mode can be implemented for the Arduino. During the sleep mode, the Arduino processor and other peripherals can be turned off to save power when the battery is fully charged, and only a watchdog timer will be enabled to occasionally send an interrupt to wake up the processor to check the battery voltage level. If the battery is not fully charged or the battery voltage is low, the Arduino has to be on to perform PWM feedback control to charge the battery. On the receiver side, students can download the Bluetooth Terminal application or make a customized GUI on their computer to connect to and receive the temperature data through Bluetooth.

4.3 Milestones and Deliverables Considerations

While students in the course had basic knowledge of circuits and embedded systems, many may have limited experience in creating their own designs for a design project. To help students breakdown the project into smaller steps, the project uses specific milestones that students can work toward at specific periods of time. These milestones act as guardrails to help the students to keep subsystems in mind without getting lost in the big picture, and they help the instructors keep the students on track considering their tasks and timeline. For this project, the milestones help students "divide and conquer" by splitting the project into four milestones, each milestone with several deliverables for completing subsystems of the entire design. Each milestone has both hardware and software design components to help students gradually make progress on both aspects. Students had three weeks to complete each milestone, where they were expected to finish all deliverables within the given milestone by the due date in order to move on to the next milestone.

The following sections discuss the purpose of each milestone and the expectation of students, and the full list of milestones can be found in the Appendix.

Milestone 1

Milestone 1 focuses on introductory research about topics used in the project, and consists of six questions that focus on boost converters, losses in power systems, inductor saturation, feedback control basics, battery charging, and microcontroller power saving. Students are expected to research each of these topics and begin thinking about a high-level design that incorporates them into a wireless sensor node.

a) The biggest circuit design component in this project requires students to design a boost converter that can step up the DC voltage to charge a 9V battery. Students coming into this class have knowledge of diodes, transistors and second order circuits, but have not learned about power electronics. Students complete some basic research into power electronics and DC/DC converters including how the component values are calculated and what transistor or diode to use to satisfy the requirements, using resources and guidance from their instructor.

b) Because power electronics relies on high efficiency circuits, students are asked to consider and research the parasitic elements in this boost converter and explore how they affect the efficiency of the circuit. While these parasitic elements are not extensively covered in a theory class, they are important concepts for students to learn as they have real implications to their design's efficiency. Additionally, efficiency is affected by their choice of diode and MOSFET, so students are asked to compare two diodes and three MOSFETS available to them and discuss which ones are viable for their design and will lead to higher efficiency for the circuit.

c) Another important concept that is not extensively covered in a theory but is important in the overall design is inductor saturation. Students are asked to research what inductor saturation is and some potential solutions to reduce the amount of inductor saturation, given the constraint that the battery needs to be charged as fast as possible.

d) In order to make the boost converter regulate the output closed loop, students also need to know what feedback control is. The theory behind the PID control has not covered in their other courses so far, but fortunately the feedback control for this project is relatively simple. For this project, are only expected to implement integral control using their Arduino. Using references provided, students are asked to explore and discuss the use of control for regulating the output voltage and will draw a flowchart representing how they will implement feedback control using the reference voltage, the output voltage, and the duty cycle of their boost converter.

e) The purpose of the boost converter is to supply power to an Arduino while also recharging a 9V battery, so students are asked to research and consider the characteristics of their rechargeable batteries, such as minimum and maximum current and voltage. Additionally, students are asked to conduct research about different possible batteries charging schemes and decide what single or combination of schemes they will use for their project.

f) Because the wireless sensor node should remain powered for as long as possible if the simulated solar panel cannot supply power, students need to devise a strategy for saving power when needed. Students are asked to look through their microcontroller datasheet and explore potential power saving options available to them. While their microcontroller has multiple ways to dramatically reduce the power used by the processor chip, students are asked to explore at least two potential methods.

Milestone 2

After students complete thorough research of the project through milestone 1 (and receive feedback from their instructor), they can begin implementing their design. Milestone 2 has two deliverables pertaining to the design of a boost converter used to charge the battery: its power stage and its feedback control. The engineering design process is strictly followed, and each deliverable asks for testing and verification of each design step.

a) The first step is to design an open loop boost converter that meets the project requirements, where its switching frequency needs to be higher than 10kHz, the boost converter should operate in continuous conduction mode, and the capacitor voltage ripple should be less than 1% of the output voltage. They also must decide and justify what switching frequency is appropriate for their design and can be output from their Arduino. It is important for their designs to avoid inductor saturation, so using an inductor core provided to them, students must avoid saturation through designing the switching frequency for their MOSFET. To demonstrate a successful open-loop design, they must include simulated and measured results for inductor current waveform (where the inductor current waveform looks like a proper triangle waveform), output voltage waveform, and transistor drain-source voltage waveform. The simulation and measurement results should be similar with no big discrepancies.

b) The second step of this milestone is to implement feedback control in their boost converter using their Arduino Uno by measuring the output voltage and adjusting the duty cycle of the converter. They are asked to demonstrate that under different input voltages between 4V to 5V, their boost converter can regulate its output voltage at the desired voltage.

Milestone 3

Milestone 3 has three deliverables, and the first two deliverables are built upon on the boost converter they designed in milestone 2. The first deliverable asks students to conduct efficiency analysis (defined as output power divided by the input power) of the boost converter they designed because the ultimate goal for this project design is to maximize efficiency. The second deliverable asks students to modify the boost converter to charge the 9V battery and study the battery's charging and discharging characteristics. The third deliverable asks students to design a working system and measures the temperature and transmits its value over Bluetooth.

a) Students are asked to run an efficiency test on their closed-loop DC/DC converter and plot its efficiency curve, where the y-axis of the efficiency curve is the DC/DC converter efficiency and the x-axis is the load resistance. Students must include at least 6 data points, and the load current should be between 10 mA and 150 mA for the test. For a design to be considered successful, there should exist an optimal efficiency greater than 70%. In improving the efficiency of the designs, students should consider the parasitic elements in the inductors, transistors, etc. previously researched and select appropriate devices for their system and for power efficiency. Typical optimal efficiency is between 80% to 90% for student projects.

b) After studying the efficiency of their system, students are asked to modify their boost converter circuit and Arduino code to charge their battery. They are asked to show battery charging (using their boost converter circuit) and discharging waveforms (voltage vs. time with a specified input or output current, starting from a fully charged or discharged battery). Additionally, they must compute the mAh of the battery and show they can get at least 150 mAh into and out of the battery.

c) Students must also design a working temperature sensing system, a Bluetooth module, and a GUI on the receiving end that can display the temperature information. While they can use the Bluetooth Terminal to start, they are encouraged to design a more user-friendly GUI on their own.

Milestone 4

Milestone 4 is the final milestone of the project; students need to have a complete functioning prototype of the wireless sensor node at the end of this milestone. This milestone includes implementation of power saving measures and combining all subsystems together to work seamlessly.

a) Students need to implement a power saving mode under the conditions of the input source. If the sun (input source) is not available, the Arduino should process and send the temperature information every 30 seconds and go to the designed power saving mode for the rest of the time; if the sun (input source) is available, the wireless sensor node should not go to the power saving mode because it needs to be on to charge the battery or maintain the battery voltage at the fully charged level.

b) Finally, students combine all the subsystems together to have a working prototype that satisfies all specifications listed for the project

4.4 Verification and Validation

Students are required to test and validate each deliverable in each milestone as they work on their project. However, in the final report, students are required to verify their design with the following specifications.

a) Simulated and measured output voltage, inductor current, and transistor drain-to-source voltage waveforms of their boost converter without large discrepancies between the simulations and the physical systems

b) A triangular-shaped inductor current waveform without operating in the discontinuous conduction mode
c) A closed-loop boost converter than can generate the desired output voltage under input voltages between 4V and 5V
d) An efficiency curve with at least 6 data points for their designed boost converter with higher than 70% efficiency
e) A battery charging curve with calculated mAh charged and a discharging curve with calculated mAh discharged.
f) Verification testing to show their thermistor temperature matches with a commercial thermometer under different ambient temperatures, where the temperature is verified on the Arduino and on the temperature monitor GUI
g) Measured current in mA flowing from the battery to the Arduino when it is in power save mode and active mode, and a calculated duration the system can last on a fully charged battery

Students are also required to validate the prototype working as expected by including a design validation video that shows key points of the prototype operating as expected, including: the battery charging when the input source is available, the receiver displaying the temperature information, the system going into power save mode when the input source is not available, and the system coming out of the power save mode when the input source is available again.

5. Students Outcomes and Conclusions

The project-based learning experience has proved to be extremely important to students' engineering education. Students are able to bring the theoretical knowledge they have learned from their theory class and put it in use and learn something new from it when working on their project. For example, using what they learned about second order circuits and transistors from their circuits course, they can combine these two concepts when designing a DC/DC converter in the wireless sensor node project that has uses in many applications. When designing, implementing, and testing the boost converter, students learn practical design considerations that may never be brought up in their theory class. For example, students may not encounter inductor saturation in their theory courses, but inductor saturation is something they encounter when they build their boost converter and have to be able to recognize it and design around it. This example highlights moments where learning happens in hands-on courses, where students realize they made a mistake or did not consider a part of their design and then iterate their design to address the issue identified.

Throughout the use of this project over the past few years, surveys have been sent to students at the end of the semester asking for their feedback about the course and the wireless sensor node project. The results have been overwhelmingly positive; most of the students reported they had a very rewarding experience and they felt a lot more confident in designing and testing projects independently. They have gained practical, hands-on design skills from working on the project, technical communication skills from writing technical reports and giving presentations and improved their teamwork and time management skills. They have benefited tremendously from this project in their development as engineers who can create realistic, thoughtful designs using their technical knowledge from other courses and their own research. This project and these skills are also a common discussion point when talking with the recruiters at job fairs, and many students have obtained internship opportunities. In addition, the instructors of senior capstone projects reported that the students who went through the IDP class are more prepared to finish their senior capstone projects.

6. Conclusion and Summary

In the ECE department at Virginia Tech, the wireless sensor node project was developed to help students integrate their technical knowledge into a design-based, hands-on, team project. This project helps students to improve their skills related to technical design research, making design decisions based on requirements, and simulating and testing physical circuits, while gaining valuable experience in developing professional skills like technical communication and working in a team. By thoughtfully scaffolding the subsystems of the wireless sensor node and the design decisions students need to make, this project allows sophomore ECE students to go through the engineering design processing in an ECE specific context using recent course technical course content (such as Circuits, Embedded Systems, and Signals and Systems) to design a functioning system before having taken many of their later and more advanced ECE courses. Additionally, the topic of the project, wireless sensor nodes, helps students relate to and design a working prototype for a wireless sensor node, which represents a real-world engineering problem similar to what they might work on after they graduate. This course has been successful in helping students develop these skills and gain valuable hands-on experience early in their undergraduate programs.

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Appendix

Project Timeline:

Weeks	Task	Description
1-2	Pick project	Select your project and begin working with your partner on Milestone 1
3	Milestone 1	Research your project and provide answers to the questions posed in the project description for Milestone 1
4-6	Milestone 2	Report focused on meeting milestone design and testing goals, clearly describing all relevant schematics, test results that demonstrate your subsystems work correctly, clear descriptions of your code, and a clear reasoning behind all design choices in your hardware and software
7	Presentation 1	Presentation to discuss progress of project so far and next steps in project design
8-10	Milestone 3	Same as Milestone 2
11-13	Milestone 4	Same as above with entire system complete and working
14	Final Report, Final Presentation	Report and presentation to discuss the final design of the project and its capabilities in meeting the design requirements

Milestone Objectives:

Milestone 1: Please provide answers through research to the following questions:

a). What are power electronics? What is DC/DC converter? What type of DC/DC converter do we use for this project? Design a converter with an input voltage of 10V and an output voltage of 20 V that has an inductor current ripple of 80 mA, a capacitor voltage ripple of 20 mV, and a switching frequency of 50 kHz; the load resistance is 200 Ω. Calculate the duty cycle, the inductance, capacitance, and resistance values. Follow the derivations and equations provided in DC/DC Converter Steady State Analysis Book chapter and associated slides on Canvas.

b). In every electrical component, there are parasitic elements (the non-ideal elements). What is inductor DCR and how would this impact the circuit efficiency? What is capacitor ESR? Look through the data sheets for the 3 different MOSFETS, 2 different diodes in your parts kit, and discuss the major differences between them? Which MOSFET and diode would lead to higher efficiency for the circuit?

c). What is inductor saturation? What parameters in your DC/DC converter circuit you can change to reduce the amount of inductor saturation? You want to charge the battery as fast as possible subject to no significant inductor saturation.

d). What is feedback control? For this project, we only need integral control. Draw the flowchart logic for the feedback control used for the DC/DC converter with variables: Vout(output voltage of the DC/DC converter), Vref (the desired output voltage), duty cycle. In addition, discuss how you would generate the PWM waveform needed for your DC/DC converter.

e). What is the minimum battery discharge voltage? What is the maximum battery charging current? What is the limited charge voltage? You can find this information on the battery specs sheet (the link is under Resources in this document). What are the possible battery charging schemes? How would you determine whether the battery is fully charged for our specific battery? Once it is fully charged, how would you maintain the battery at full charge? You are going to use the DC/DC converter to charge the battery.

f). Look through the microcontroller datasheet, list potential power saving options. There are multiple ways to dramatically reduce the power used by your final system when powered only by the battery. Brainstorm at least two potential methods.

Milestone 2:

a). Design an open loop DC/DC converter that meets the project requirements; refer to the DC/DC Converter Steady State Analysis on Canvas if needed. You can use a function generator to generate a PWM signal with an appropriate duty cycle. Include simulated and measured results (they should be reasonably matched) for inductor current waveform (the correct inductor current waveform looks like a triangle waveform), output voltage waveform, and transistor drain-source voltage waveform. Discuss simulation and measurement results. (Make sure the DC/DC converter is in continuous conduction mode in which the inductor current is always positive; the capacitor voltage ripple should be less than 1% of the output voltage). Use the AD2 to measure the series inductance and series resistance of your inductor (refer to the Winding Inductors slides for hints).

b). Design a closed loop DC/DC converter with PWM feedback control using an Arduino; demonstrate that under different input voltages (from 4V to 5V), its output voltage is still regulated at the desired voltage.

Note: you have to use a diode-based over-voltage protection circuit to protect the analog pins on your Arduino. Refer to ECE 2024 Circuits and Devices materials if you have questions. And just to be extra cautious, avoid having the external power supply, battery, and the laptop USB all connected to your DC/DC converter and Arduino at the same time. You can use your multimeter to measure the voltage of the 5V pin on your Arduino when it is connected to your laptop through a USB cable to see whether you have a low computer USB voltage.

Milestone 3:

a). Run an efficiency test on your closed-loop DC/DC converter and plot its efficiency curve. The y-axis of the efficiency curve is the DC/DC converter efficiency, and the x-axis is the load resistance. Include at least 6 data points (the load current range should be from 10 mA to 150 mA). The optimal efficiency needs to be greater than 70%. Discuss the major causes of inefficiency in the circuit.

b). Modify your DC/DC converter to charge the battery. Show battery charging (using your DC/DC converter circuit) and discharging waveforms (voltage vs. time with a specified input or output current, starting from a fully charged or discharged battery). Explicitly compute the mAh and show you get at least 150 mAh into and out of the battery.

c). Construct a working temperature sensing system with a Bluetooth module and a GUI on the receiving end that can display the temperature information. (Using the Bluetooth Terminal is minimum; designing a better GUI is always encouraged)

Milestone 4:

a). Power saving implementation: if the sun (input source) is not available, your Arduino should process and send the temperature information every 30 seconds and go to your designed power saving mode for the rest of the time; if the sun (input source) is available, your wireless sensor node should not go to the power saving mode because it needs to be on to charge the battery or maintain the battery voltage at the fully charged level. Don't worry about pairing Bluetooth with your laptop for this implementation.

b). Create a working prototype that satisfies the following specifications:

1. Arduino-based temperature sensing system that can transmit the temperature information via Bluetooth to a base station that can display the information.
2. A DC/DC converter with Arduino-based feedback control for charging the battery and maintaining a fully charged battery if the input source is available.
3. A way to save power when there is no solar power (5V source) available and the battery is not being charged.
4. Your final system must be able to run indefinitely without any external connections except to a 5V source. If the source is unplugged, the system should continue to run for a week until the 5V source is reconnected before the battery is completely depleted. How long can your system run without reconnection to the 5V source? Justify your answer.

<u>Design Verification:</u>

In the final report, you must verify your design with the following specifications.

1. Show the simulated and measured output voltage, inductor current, transistor drain-to-source voltage waveforms of your DC/DC converter. Your inductor current waveform should have triangle shape. Explain any discrepancies between the simulated and measured results. There should be no large discrepancies.
2. Show under the input voltages of 4V and 5V, your converter output voltage is still at your desired voltage level.
3. Show your converter's efficiency curve with at least 6 data points. The efficiency needs to be higher than 70%.
4. Show your battery charging curve, and calculate the mAh charged. In addition, show the battery discharge curve and calculate the mAh discharged.
5. Verify your thermistor temperature match with a commercial thermometer under different ambient temperatures. Show the temperature displayed at the receiver matches with the temperature transmitted.
6. Show the measured current in mA flowing from the battery to the Arduino when it is in power save mode and active mode. Calculate how long your system can last on a fully charged battery.

<u>Design Validation:</u>

Include a design validation video that shows key points of the prototype operating as expected: battery is charging when the input source is available, and the battery voltage is increasing; receiver is displaying the temperature information; the system goes to power save mode when the input source is not available, and the system comes out of the power save mode, etc. The Arduino should not be connected to the computer as it is a standalone system.