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Wireless Power Transfer

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Wireless Power Transfer Final Report

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Faculty Advisor: Dr. Robert Albright
Industry Advisors: Weng-Kai Sit, Kyle Gray

Special Thanks: Jared Rees, Dr. Joseph Hoffbeck

Introduction

The Wireless Power Transfer Team is testing the theory of wireless power transfer through RF signals. Currently, wireless charging is done through electromagnetic induction through an induction pad and the device at close distances. Our goal is to transmit and receive RF signals to convert into power for our devices to use at much farther distances. Our project consists of two major portions, a transmitter and a receiver. Our transmitter is a signal generator with an amplifier and a Yagi antenna attached. The receiver end is a PCB board we designed along with a QFN Chip provided by e-peas as our main component from converting the signal into a source of power.

The first half of our project was mainly research. Our first milestone was researching what we can legally transmit through the air according to FCC regulations. The next step was to decide how we were going to design the transmitter and receiver for our design project. Another early obstacle we encountered was defining our project. Our project changed scope from harvesting wireless power to delivering and receiving wireless power. The research revealed that we would not be able to harvest enough energy in ambient conditions. Consequently, we decided to construct our own RF transmitter to control our testing environment.

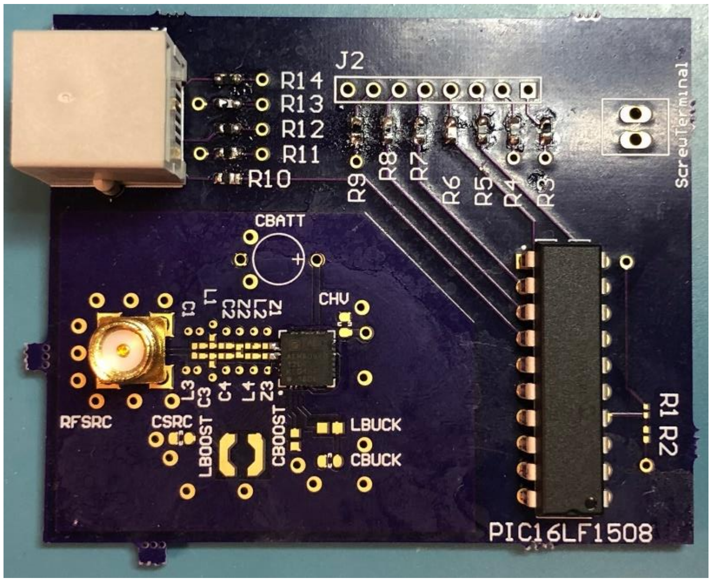


Figure 1. PCB Board

During the second half of our project, our first major milestone was getting our microcontroller to be powered on and turn on an LED running off harvested energy collected by the e-peas demo board. During the next sprint, we were able to create a SPI driver to allow the microcontroller to communicate with the LCD and display messages, which was not expected to be completed as we lost our CS team member at the start of the semester. Our last major milestone was successfully designing and fabricating custom PCB that integrated our entire system. The major issue we had with the PCB was that the PCB design tools had a much steeper learning curve than anticipated. Fortunately, the fabrication and assembly process was executed smoothly.

Our team did a fantastic job of working together to fully realize the goals of our project, especially because we started as a 5-member team and were down to a 3-member team by the last semester where the majority of the design work was done. One major area that we could have improved upon in the early stages of our project was more clearly defining our project, as we shifted our focus many times due to limitations in what we were able to do. If we had better defined the scope and goals of our project, it is possible that we could have made a more complex system based around the energy harvesting chip.

The following sections of this report will cover more in depth of what our project is and what we aimed to achieve, the process of our project, and how well did we meet our goals.

Technical Outcomes

Our capstone project consists of two components, a transmitter and a receiver. The transmitter needed to provide a stable signal within 902 – 928MHz range with an output power max of 1W. With this in mind we decided to use a signal generator as the basis for our transmitter. With the signal generator we monitor the specific frequency of our signal, staying between 902 – 928 MHz at 10dbm. This then outputs to signal amplifier provided by our industry advisors from Garmin. The amplifier boosts our signal up to 30dbm while sustaining our desired frequency range. Finally, the amplifier connects over to a Yagi antenna. The Yagi antenna is a 6dbm directional antenna. The Yagi antenna was chosen due to its directional radiation pattern. This allows for the bulk of the signal to be transmitted towards our receiver to obtain as much as of the signal as possible.

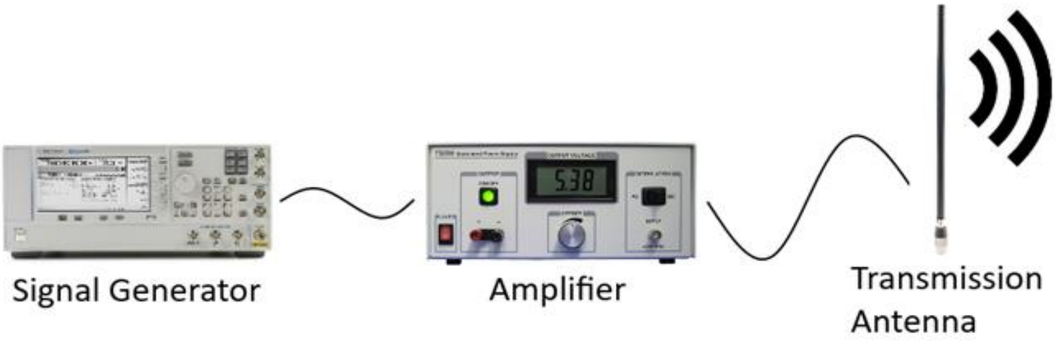


Figure 2. Transmitter Block Diagram

The receiver end of our design was a PCB with the main component being an ASIC chip we acquired from a company names e-peas. The ASIC chip is their AEM 40940 energy harvesting chip. Its purpose, on our PCB, is to translate the signal we send out into power and distribute that across the entire board. On the PCB, we have an omnidirectional SMA antenna to receive the signal. From there, the signal then goes through a matching circuit to reduce the reflection of the signal by matching the impedance. The signal travels to the AEM 40940 chip to be converted into a 3.3 voltage source for our PCB. A capacitor is used to slowly charge up enough power before outputting to the microcontroller and LCD.

The power stored by the charging circuit needed to be used in a meaningful way so that the viable uses of wireless power transfer can be demonstrated. Our team chose to use the power collected to turn on a microcontroller that measures and records the current temperature, as a primary application of wireless power transfer is for use with wireless sensors that are placed in a location that is hard to access and replace batteries or where it's impossible to use wired power. Our system uses a PIC16LF1508 microcontroller with a thermistor to measure the temperature and the temperature measured is displayed on a Nokia 5510 LCD.

The PIC16LF1508 is an ultra-low power 8-bit microcontroller, using only 30µA/MHz, which is why our group selected it. The PIC is able to determine the temperature of the environment by using the Voltage Divider equation (equation 1) and a resistive network using a thermistor, a resistor that changes its resistance based on the temperature. The PIC uses an analog to digital input with 10-bit resolution to accurately measure and convert the analog voltage into a temperature value in Fahrenheit. With this conversion completed, the PIC controller uses its Master Synchronous Serial Port (MSSP) to send the temperature value to the LCD to be displayed, before powering off.

$$V_{out} = \frac{R_2}{R_1 + R_2} * V_{in}$$

Equation 1

The PIC microcontroller is powered for one second every ten seconds, and when it is turned on it uses an analog input which reads a voltage that is temperature dependent. The voltage is converted into a temperature value, which the PIC then sends to the LCD via a Serial Peripheral Interface(SPI) bus. See the diagram below for a block diagram of this system.

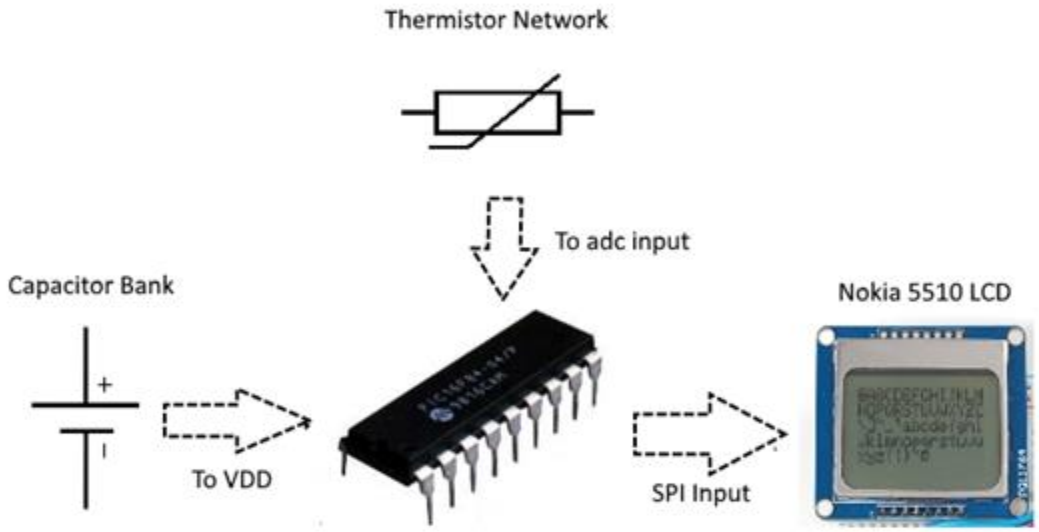


Figure 3. Receiver Block Diagram

The final implementation of the microcontroller system is very close to how we had anticipated it to work, even going slightly further than our initial plan. In our initial designs, were not going to be doing anything other than displaying some text on the LCD, and we were expecting the AEM40490 to be able to provide continuous power once it was able to charge up enough to kick start the board. Additionally, our plan was to use an ultra-low power e-reader LCD display as after the screen is drawn, it won't change even if it loses power.

Even though our project is not able to have continuous power, we are able to do more than we had originally planned as we are able to provide much more power than initially expected, as with the capacitor bank being fully charged, we are able to supply over 30mA of power for a brief period. This allowed us to use the Nokia 5510 LCD despite the increased power consumption, which was unfeasible to use due to the extreme complexity of programming the screens as well as their cost being significantly higher.

Process Outcomes

At this point in time, the project is almost complete. The transmitter side has been completed since the end of the first semester. Luckily, the school had a signal generator that supported frequencies in the range that we needed, we were able to secure a signal amplifier through our industry advisors at Garmin and the directional Yagi antenna was a great choice to increase the strength of our signal. The signal generator as our transmitter saved us a lot of time during this project. Originally, we had discussed the possibility of creating our own system to transmit our desired frequencies but, our industry advisors at Garmin advised us not to since it would be on the same level as another standalone capstone project. We were also lucky to discover e-peas' RF ASIC chip. During the early stages of the project, researching how to efficiently harvest a signal and convert that into a power source that we could use seemed nearly impossible. The discovery of the ASIC chip gave our team a chance to make this project a reality. With the transmitter section figured out after the first semester, we only needed to focus on the receiving end of this project.

This team was comprised of MECOP students, meaning there was a six-month gap in between the two semesters working on the project. We had originally planned to meet up occasionally over the gap but those plans fell through. Looking back, it would have been smarter to stay up-to-date about the project or at least ramp up a couple weeks before the new semester began. The beginning was a slow start due to the time remembering what we had accomplished during the first half of this capstone project. Time became an issue, as we now had to get up to speed while still making progress on our capstone.

One risky assumption we made about the project concerned the budget. The initial estimates were mostly correct. We initially expected the antennas to be much more expensive since our design required rigorous specifications to comply with FCC rules. However, we were able to save nearly $100 by buying off the shelf antennas. We were also able to save $200 on RF transmitter modules because e-peas graciously supplied us with a demo board and several chips for free. Unfortunately, we severely underestimated the PCB fabrication and assembly budget. Our initial estimate for fabrication was off by $30, and we did not consider assembly costs which quoted up to $100. Thankfully, Jared was able to assemble our PCB for free, and we were able to save $10 by designing the physical board smaller. Also, we spent a considerable amount of time retrieving quotes from various vendors before settling OSH Park. Overall, the differences between the actual costs and the expected budget balanced out.

PCB design for this project was very difficult. We were using tools that we were unfamiliar with on a concept that we had little to no exposure with. We decided to use Circuit Maker due to it being a free version of Altium. During the PCB process there were a lot of limitation during the design process due to not knowing what was possible with the tool and the limited documentation online. I believe if we could have purchased a license for Altium to use its full service and customer support would have been helpful. Many hours were spent learning how to use circuit maker with the limited resources we had to learn.

With our project plan in mind, we fell behind schedule with the schematic and PCB board design. Our original plan was to have a rough draft of both schematic and PCB done by the first term, but due to complications with our original ideas, and eventually settling in to what we have now took longer than expected. The PCB design aspect also took longer than expected. The board layout was a larger challenge than expected. There was a decent learning curve for learning how to design the PCB board as well as learning how to use Circuit Maker.

Throughout this entire project, our group worked together for the majority of the work and progress. We all had contributions to both components of our design regarding the transmitter and receiver. The PCB board and schematic design was a joint effort from all of us learning separate tools to use in circuit maker. For the microcontroller, Dylan was the driving force for programming the microcontroller. The following section details our individual contributions to the project.

Individual Contributions

Dylan Shuler

Firmware, PCB, schematics

Dylan's main contribution to the project was the receiver end of the project, starting with the design and testing of our own rectification circuit before the group found the e-peas AEM40490. During the second half of the project with the loss of a team member, Dylan took over the responsibility of coding the PIC controller and getting it to communicate with our LCD. Lastly, he helped work with the entire team in getting our PCB designed and built.

Anthony Lieu

Logistics, PCB, schematics

Anthony's contribution to the Wireless Power Transfer Team has mainly been on the transmitter for this capstone project. The first semester, Anthony worked closely with Phillip about the legal regulations that our device must comply with. Phillip and Anthony also research our first transmitter idea of a RF module, before we switch over to the current plan of the signal generator with an amplifier. During the second semester, Anthony was the main point of contact between our industry advisors. He was in charge of scheduling meetings and design reviews.

Phillip Manalili-Simeon

Finance, Oscilloscope Tech, PCB, Schematics

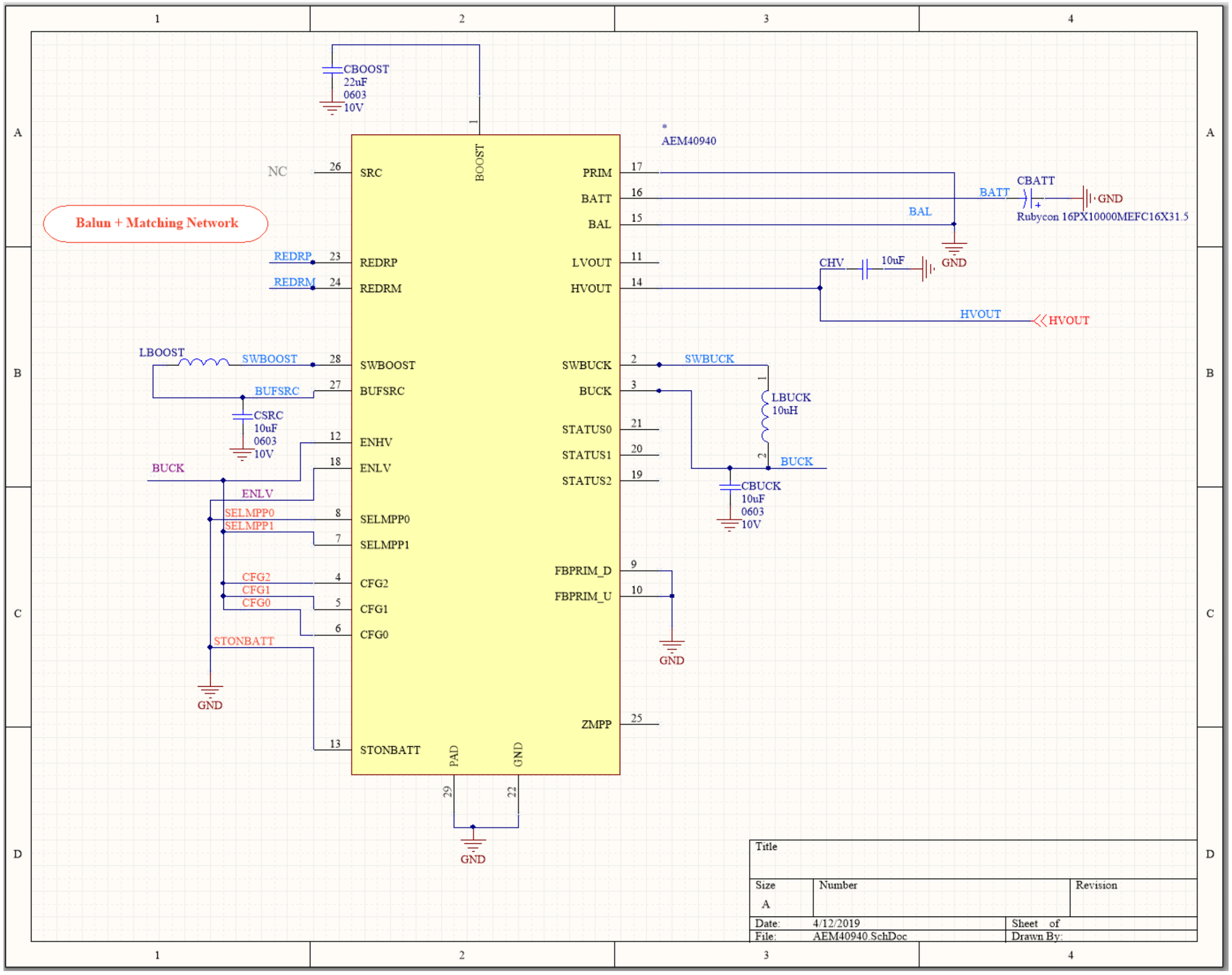
Phillip's primary contributions to the project included finance and communication with external vendors. He compared multiple different vendors based on their turnaround, cost, and assembly capabilities. When the budget was starting to look tight, Phillip redesigned the board layout to save more money in fabrication. With regards to technical aspects of the project, Phillip led the technical parts of taking test measurements on the oscilloscope and configuring other test equipment. During the first semester, he worked closely with Anthony to research and evaluate the legality and feasibility of the project.

Conclusion

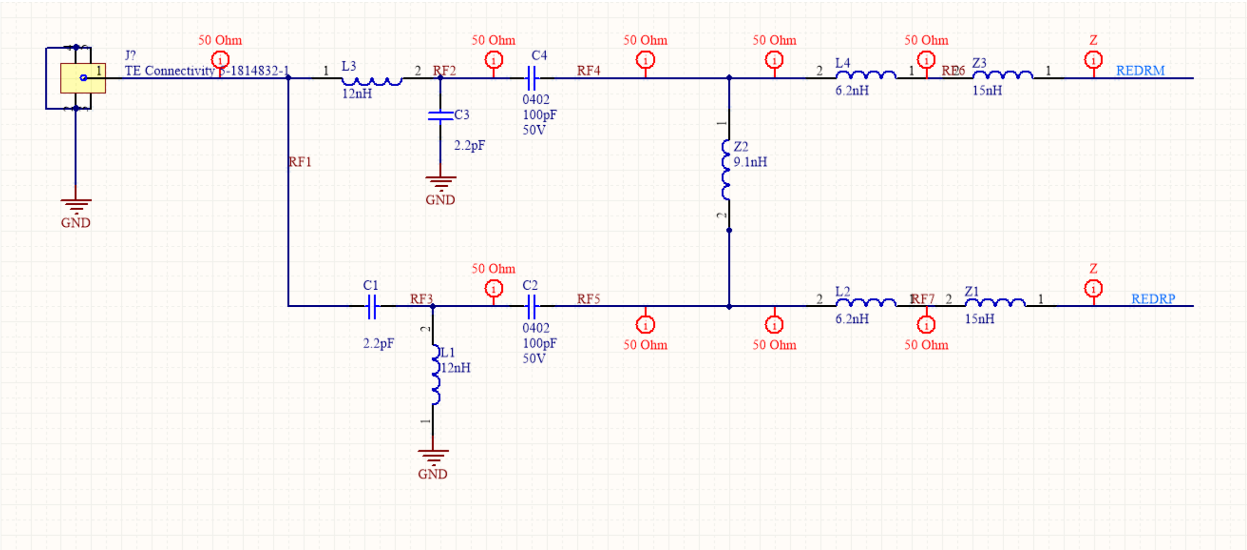
Overall, we are very pleased with the progress we have made with this capstone project. Despite the reduction to three members we continued on with our original design that were decided during the first semester. At the beginning of the second semester we were all weary of the outcome of this project. Majority of the work of the receiver was still needed and we have not started programming the microcontroller, and we definitely under-estimated the design process for the PCB. At the end of the semester we have fabricated our PCB boards and mounted our components to the boards. The microcontroller is programmed and functional with the LCD Display. There were many challenges that originally seemed impossible to complete, yet we still managed to do so.

Appendix A: Schematics

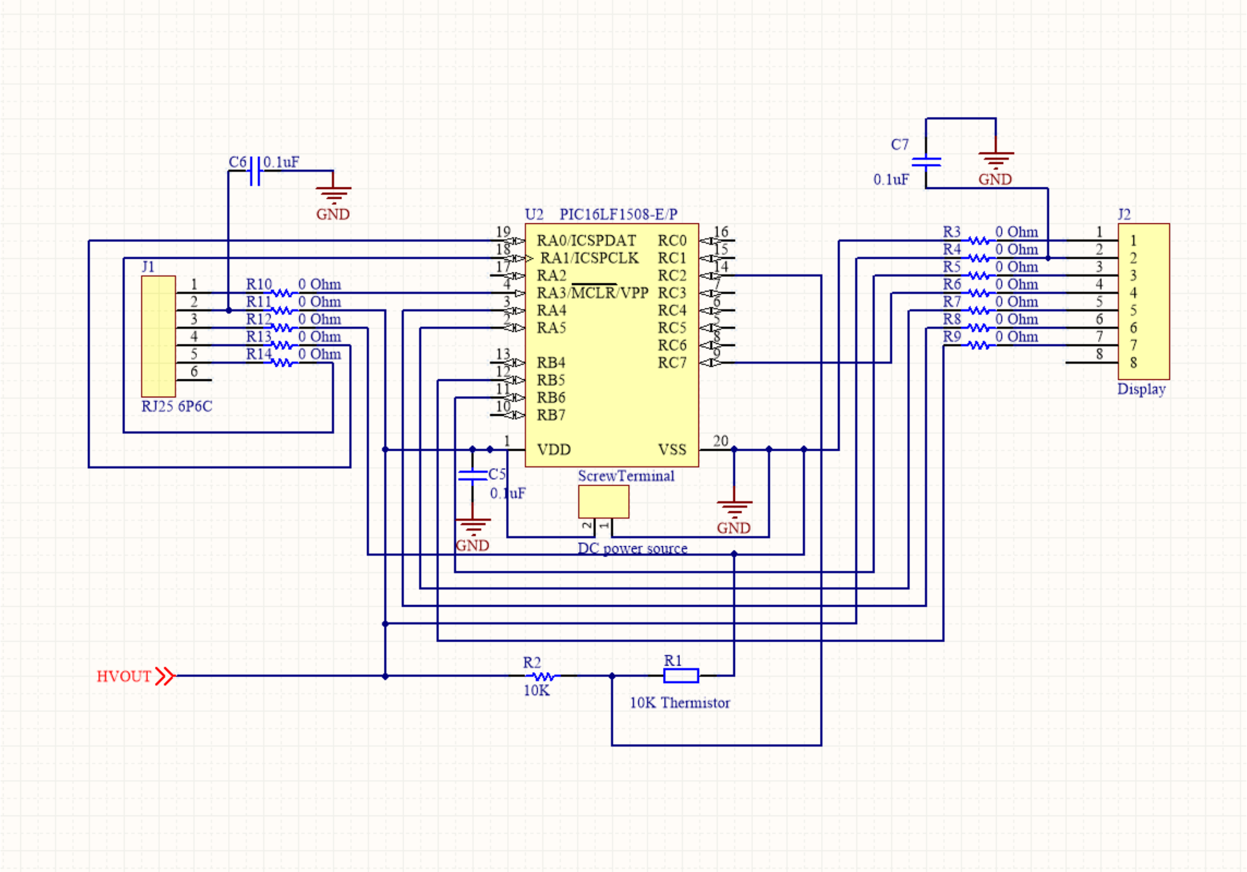
e-peas RF Harvesting IC



Matching Circuit



Microcontroller



Appendix B: PCB Layout