Operating Room Power System
EE 4951W Personal Summary

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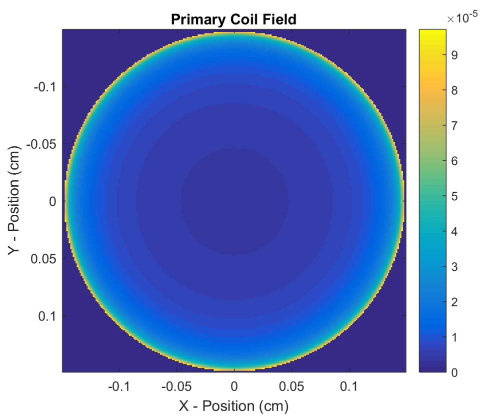
Summarium

Throughout the course of this semester, I have lead the technical efforts within my design team to develop our product. Our product is a wireless power transfer system intended for use in operating rooms to reduce the number of cables used. As follows is a brief overview of the product and motivations to introduce the reader to the work before describing the process of my involvement.

The premise of this project was brought forth by Dr. Daniel Glumac (Medical Devices Center), based on his observation of operating rooms he has visited. In particular, he noticed the general crowdedness and density of cables and equipment. These cables represent a hazard to those in the OR, constrain equipment and people mobility, and increase set up time during and before surgery. Therefore, this project was envisioned to remove cables from OR environments. Beyond this initial vision, our team was given almost total freedom in the design of our product. Thus, the first step of our product lifecycle was to ideate a solution to power medical equipment in the OR sans cables. Myself, having worked the previous summer at the Sandia National Laboratory on research pertaining to wireless power transfer, pushed the idea of using resonant inductive coupling to wireless transfer power to equipment in the OR having researched the technology previously. Ultimately, this was the technical direction we chose to pursue in our design. After this decision, we proceeded to brainstorm how this technology would actually be built into an operating room. My idea, which was also the ultimate direction taken, was to built a transmitter system that could be integrated into the floor of an OR, and a receiver system that can be integrated into the medical carts of the OR. The transmitters would wirelessly couple power to the carts, which would then convert the received energy into 120V AC locally on the cart. This could then be used to power standard, unmodified medical equipment. With both a general idea set and a technical direction, we then proceeded to break up the work. The project was broken up into a computer control system used to sense alignment of the transmit/receive systems, the transmitter electronics, and the coil system for both the transmitter and receiver. My responsibility was the design of the transmitter electronics.

My work with the transmitter electronics was to choose an appropriate architecture to drive our coil system. For our design, we had settled on a resonant-inductively coupled transformer that would operate at 6.78 MHz for regulatory reasons. Initially, I planned to use a self-oscillating ZVS inverter to drive the coil, but found this was not feasibility due the narrow bandwidth allowed in the 6.78 MHz ISM band (the design would be rather low-Q). Therefore, after much research into high frequency inductive wireless power transfer, I found the best solution was to construct a class-E power amplifier with a stable crystal oscillator acting as the frequency reference. With this choice in mind, the only remaining variables needed to be resolved before making the final design schematic and order the parts and PCB was to determine the operating power level for the system and to know the final coil design. I decided upon the power level while working on the design proposal by finding the mean power consumed by typical medical equipment in ORs based on a paper provided by Dan Glumac. This was set to be 125W for our proposal. The final coil geometry was decided upon at this time. At this point, I began component selection for the transmitter driver board. I selected a Gallium Nitride FET as the Class-E switch, after reading several papers suggesting their superiority for our application. The remaining parts selected were some power electronics and supporting electronics to create a gate driver for the FET. In order to determine a matching network for the coil system, I wrote a script in MatLAB to evaluate the coil inductance and coupling coefficients for arbitrarily sized and separated coils, via a numerical integration of the Biot-Savart law. Below are simulation results showing the field calculation (in Tesla) for two 12" coils driven by 1A at 6" separation. The matching network used in the design was based on the simulation pictured (L was found to be approx. 0.944 nH, k = 0.091).



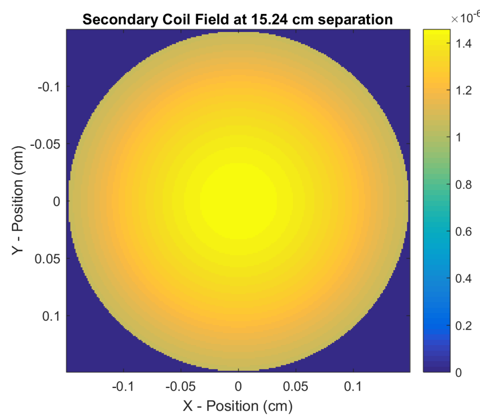


Figure 1: Coil Simulation Field Plots (field in T)

The next step I took was to create the PCB for the transmitter power amplifier. This was done in EAGLE PCB, with special attention to isolate the grounding of the power amplifier from the ow voltage electronics. Below is a picture depicting the board fabricated (showing only the top layer).

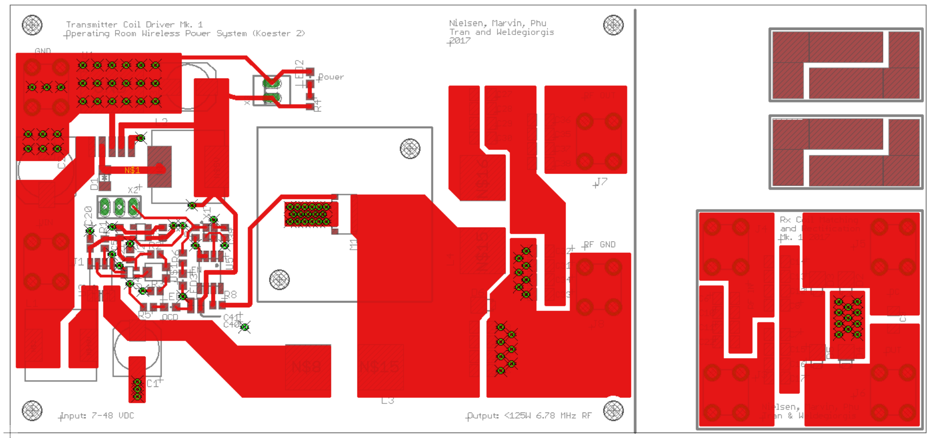


Figure 2: PCB Layout

Simultaneously with the board design I was working on the engineering review presentation, where I took lead of the final formatting and editing of the presentation. Following the presentation, I was mostly idle until the PCB arrived, with my main achievement having been the construction of a prototype coil system in that time. The prototype was constructed out of some spare tubing I had, and I was able to verify that the design would achieve resonant transfer at low power levels near our target distance.

Once the PCB and components arrived, I met with Tri and Sissay a couple times to integrate all the components onto the board. We found a couple of issues on the board, such as a unconnected pin and an unconnected diode. These issues were quickly identified and resolved without any further problems. The soldering process was informative as I learned to reflow solder parts (we used solely SMD parts, several requiring solder paste and reflow soldering). Below is a picture of the integrated board.

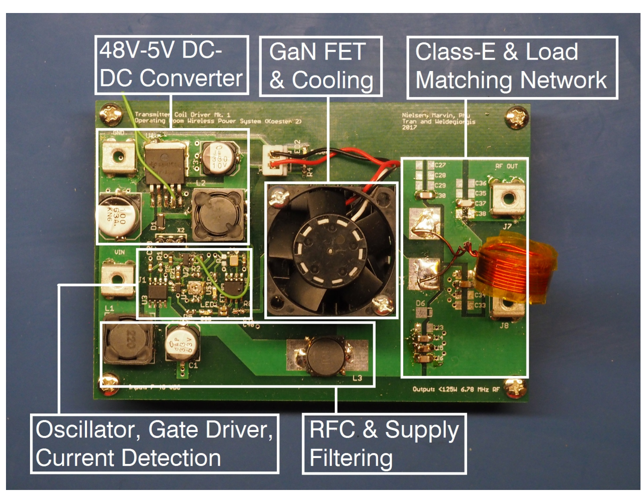


Figure 3: Constructed PCB

I began the testing process shortly after testing the board with Sissay. Initially I tried a smoke test by just connecting the power amplifier to our 10 ohm test load and ramping up the supply voltage. In the initial run I observed 30W into the load before an inductor in the Class-E amplifier network began to overheat. I manually wound a new air-cored inductor with larger gauge magnet wire, seen in the previous board shot, and the overheating issue was resolved. With the PA working successfully, I moved to soldering on the matching network components and trying a test run of the fully integrated system. On our first run of tests of the full system we managed to observed 50.5W into the load across a separation of about three inches, confirming the design works. Below are figures showing the initial testing setup and a plot showing voltage across the 10.3 Ohm test load attached to the receiver coil:

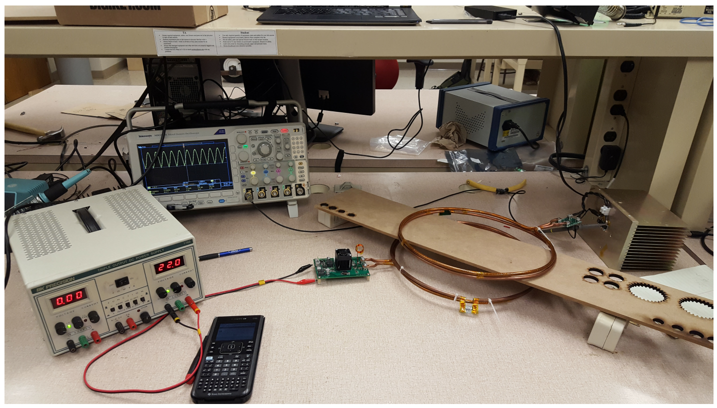


Figure 4: System Testing

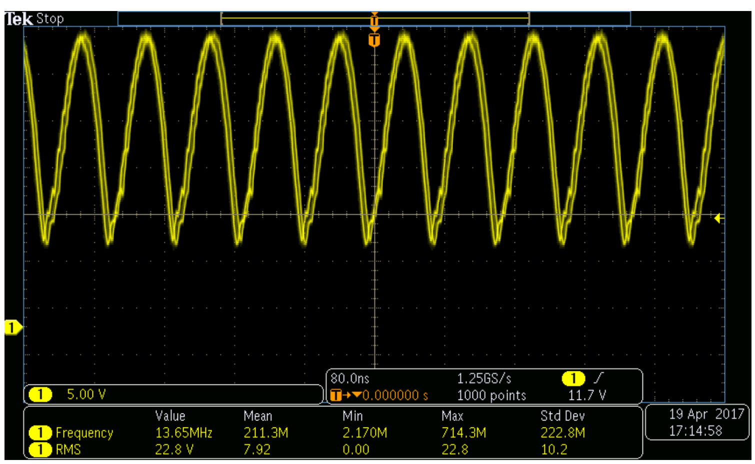


Figure 5: Power at receiver side 10.3 Ohm load, 50.5W equivalent transfer

After this point a couple things were apparent, (1) the coil system wasn't tuned quite to the design specs and (2) a better testing setup needed to be built, particular for demonstrating at the design show. To address the tuning issue, Sissay and I set out to measure the coil network parameters (coil inductance and coupling) in the lab. The method I devised was to form a RL divider using a low-values resistor (about 1 ohm) and the coils (the inductor). Using a signal generator, we were able to measure the inductance by finding the corner frequency for the circuit, and then calculating for the inductance. Coupling was determined by shorting out the secondary coil, and then measuring the inductance of the primary coil with the receive coil placed at the desired distance from the primary. Coupling was easily determined knowing the unloaded and loaded inductances. These measured inductance values were used to calculate a new matching network, which at this time has not yet been received or tested. Regarding the testing setup, Mason and I set out to construct a laser cut test stand at the Anderson labs for the coils. We designed in AutoCAD an adjustable stand to hold both the primary and secondary coils. This stand was cut out and assembled with the coils and electronics to form our final design, below:

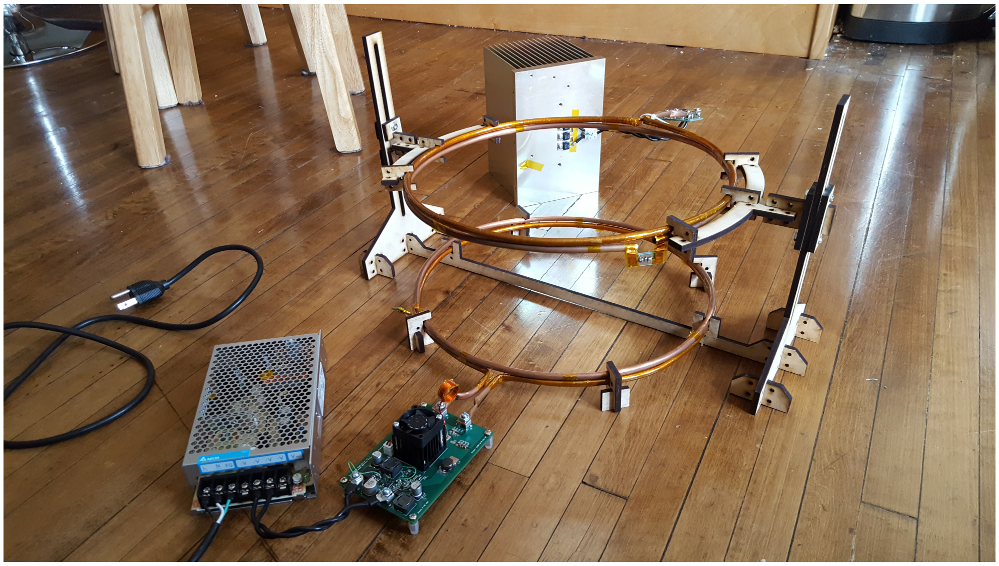


Figure 6: Final product assembly

To wrap up the term, I have been working on the poster show poster, where I have taking the lead on formatting and creation of the poster. Before the design show, I intend to get a couple more tests in with the new matching network before the design show to be able to demonstrate the wireless power transfer system closer to our design specification.

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