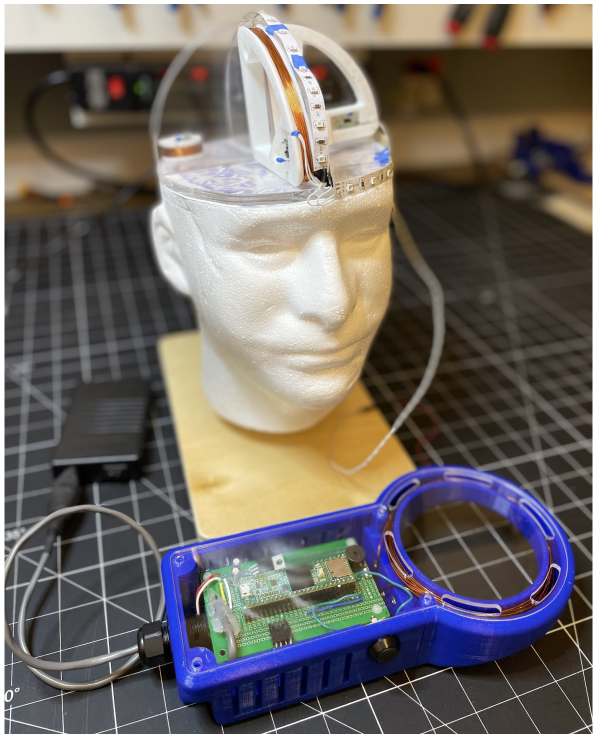
DEMONSTRATING ELECTROMAGNETIC INDUCTION TO NON-PHYSICISTS PATIENTS



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Project 2207

Engineering Physics 459

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April 4, 2022

Executive Summary

Transcranial Magnetic Stimulation (TMS) is a treatment for several neurological conditions, e.g., depression. The treatment involves using a series of short magnetic pulses directed to the brain to stimulate nerve cells via electromagnetic induction, a concept difficult to grasp for patients without a physics background. The Non-Invasive Neurostimulation Therapies (NINET) Lab would like a demonstrative model of the TMS device to explain to patients its underlying physics to clear doubts during the patient consent process.

Our project aimed to demonstrate wireless power transfer between a transmitter (mini-TMS model) and a receiver (head model) in the context of TMS treatment. In the transmitter, we used an H-bridge to drive an inductor-capacitor (LC) circuit in series to generate the time-varying magnetic field, and another LC circuit in our receiver to power our loads. We focused on maximizing power transfer given the constraints of the coil sizes and power source.

We tuned the receiver and transmitter to similar resonance frequencies and found that a higher resonant frequency increases the power transferred. Furthermore, there is an operating point where we could drive the transmitter circuit off-resonance and transfer enough power for the loads while not drawing large amounts of current.

This project still has room to improve by reducing its form factor or further implementing educational features to illustrate TMS.

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Introduction

Background

The Non-Invasive Neurostimulation Therapy (NINET) Lab researches and provides psychiatric consultation for non-invasive neurostimulation therapies[1]. A treatment method studied by the NINET Lab is Transcranial Magnetic Stimulation (TMS), a therapy used to treat conditions like major depressive disorder by electromagnetically inducing fields that can stimulate a targeted region in the brain[9]. Electromagnetic induction is an esoteric subject, and this poses a problem for clinicians and educators, especially during the consent stage of the treatment process. The physics behind the TMS mechanism is difficult to explain to general patients. Clinicians would benefit from a demonstrative device that aids in explaining electromagnetic induction. In particular, the NINET lab would like a tool to improve the consent process by increasing patients' understanding of how transcranial magnetic stimulation works.

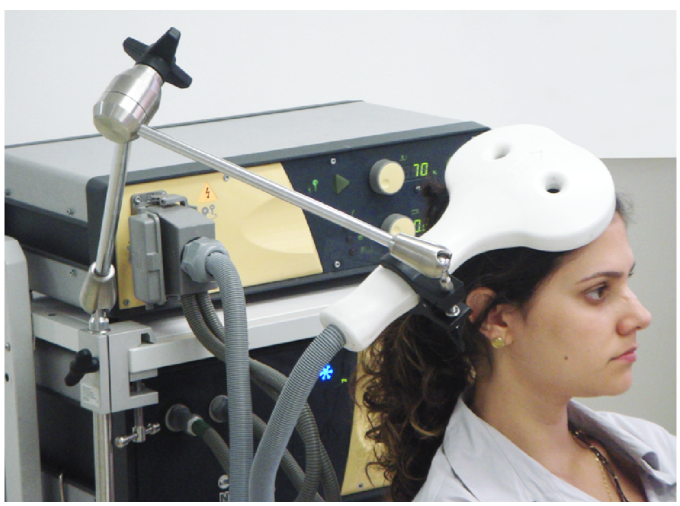


Figure 1: The transcranial magnetic stimulation (TMS) device used on a patient.[2]

Project Objective

A common application of electromagnetic induction is wireless power transfer systems. The NINET lab previously used a wireless power transfer demonstration with a single LED load to educate patients on electromagnetic induction (figure 2). This project focuses on building an improved tool to demonstrate the physics of the TMS treatment. We designed a wireless power transfer system that consists of a transmitter, which we call the *mini-TMS*, and a receiver system dubbed the *head model.* These provide an intuitive understanding of electromagnetic induction by including features that are relevant to the TMS treatment. The mini-TMS provides visual and auditory feedback (LEDs, motors, and buzzers) when used on the head model to mimic the TMS and its effects on the brain.

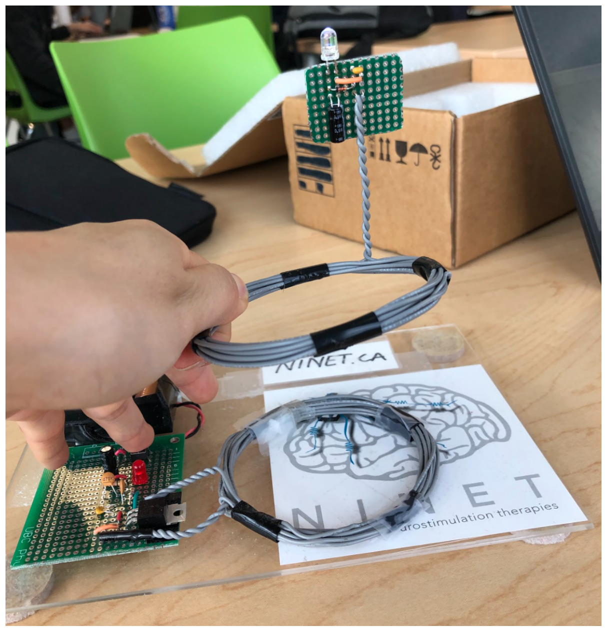


Figure 2: The original wireless power transfer demo prototype that the NINET lab uses to teach patients the mechanism behind TMS. Dr. Vila Rodriguez has received positive responses from patients and students with regards to its effectiveness in demonstrating induction.

Scope and Limitations

This project aimed to produce a functional wireless power transfer demonstration that consists of a transmitter and receivers. The mini-TMS transmitter must generate a time-varying magnetic field capable of inducing sufficient current in the receivers to power required loads. Since the mini-TMS and head model are separate, portable objects, the power transfer system must be designed with air as the transfer medium. In addition, the mini-TMS should include 1 Hz and 10 Hz pulse trains that mimic typical protocols used in TMS treatment, as well as a speaker to produce TMS sounds. Lastly, the demonstration must be portable and requires a portable power source that can supply sufficient currents and voltages determined by the design of the transmitter circuit.

The receivers that constitute the head model require loads that include hobbyist LEDs, LED strips, and a small brushless motor. The power specifications of these loads are in the electrical design section. The head model should resemble a human head visually and be of similar size. However, the receivers need to be small enough to be placed on the head model following placements suggested by the sponsor.

Discussion

Theory

TMS operates by inducing a localized current on a region within your brain, which stimulates/suppresses neural activity based on how and where the treatment is applied[3]. The physics behind this treatment is electromagnetic (EM) induction explained by Faraday's Law, which states that a changing magnetic field within the area enclosed by a conductive wire loop will induce a current in the wire. Ampere's Law states that current passing through a wire generates a perpendicular magnetic field. We can combine the two to conclude that a time-varying magnetic field can be generated by running an alternating current through a coil.

$$\varepsilon = \oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi}{dt}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

Figure 3: Equations for Faraday's Law (top) and Ampere-Maxwell's Law (bottom).

The TMS device houses copper coils that generate a changing magnetic field when an alternating current runs through it. When placed near the skull, the changing magnetic field from TMS interacts with the conductive media within the brain to induce a current, which can be strong enough to polarize neurons and pass electrical signals to other areas of the brain[6].

Our project leverages another application of EM induction: wireless power transfer (WPT). In WPT, a transmitter device is connected to an alternating current source to generate a time-varying magnetic field, which can transmit power across air to a receiver device. This is categorized into near-field and far-field WPT[8], and we work with the former in this project. In near-field WPT, two inductive coils transfer power to each other through electromagnetic induction much like a transformer. Because WPT utilizes air instead of a ferromagnetic core between the coils, it is more prone to radiative losses in the magnetic field and designing for optimization is critical.

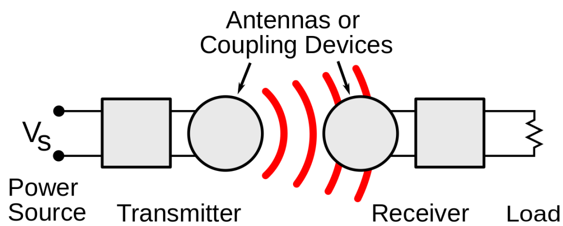


Figure 4: Block diagram of a wireless power transfer circuit.[5]

Two major parameters to optimize for are defined in the underlying physics. Faraday's Law says the receiver coil induces an electromotive force (ϵ) proportional to the change in magnetic flux, the total magnetic field passing through a given area. To increase ϵ-induced, we maximize the receiver coil area that comes in contact with the time-varying magnetic field, or we can adjust the rate of change of the magnetic field, which can be done by either increasing the driving frequency or increasing the amplitude of our emitted field.

A way to increase the amplitude is to utilize resonance, a phenomenon where increased amplitudes are observed when driving an oscillating system close to its natural frequency. Both transmitter and receiver are made up of inductors (L) and capacitors (C), meaning they are LC circuits that oscillate at a natural frequency determined by the formula

$$f = \frac{1}{2\pi\sqrt{LC}}$$

If the alternating current passing through the inductor is driven at a similar frequency, resonance occurs, and we can maximize the amount of magnetic field emitted from the transmitter and the amount of ϵ-induced at the receiver.

In low power resonant applications, the transmitter tends to have the capacitor in series with the inductive coil, while the receiver has the capacitor in parallel.[8] The closer the circuit is to resonance, the more its impedance, a measure of an LC circuit's resistance to electrical flow, rises or falls. In a series LC circuit, the impedance is close to zero at resonance, which allows it to behave like a short circuit. When more current passes through the inductor, it generates a stronger magnetic field. In a parallel LC circuit, the impedance approaches infinity at resonance and acts as an open circuit. When connected to a load, this topology minimizes the current flow into LC components of the receiver, maximizing the current flowing to the load, thus maximizing power transfer to the load.

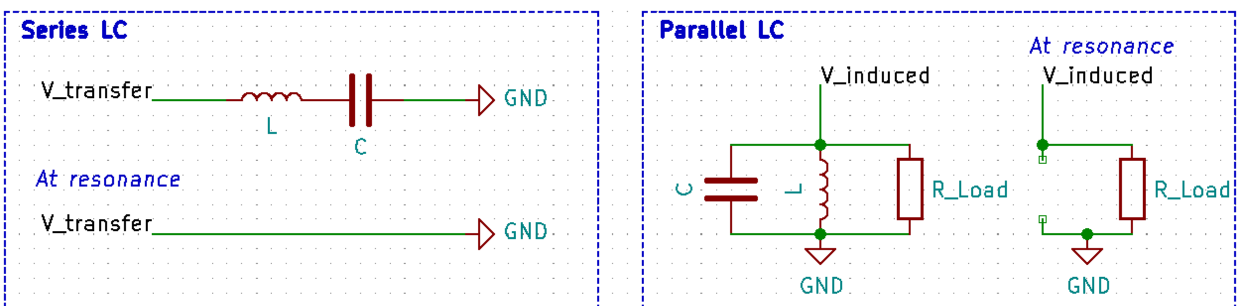


Figure 5: Equivalent circuits for Series and Parallel LC at resonance. The series LC acts like an ideal wire, and the parallel LC acts like an open circuit, thus allowing current to pass through desired loads in both cases.

Approach

The concepts in the previous section allow us to define the scope of our project. We aimed to create a wireless power transfer circuit that can educate patients about TMS. To mimic the effects of the TMS on the brain, we would need to utilize electrical loads that provide visual clues. LEDs and LED strips represent exciting neurons in the brain and demonstrate the network effect. Small DC brushless motors showcase the finger movement associated with the testing process for the TMS motor threshold. We added two settings (1 Hz, 10 Hz) paired with sound cues from a piezo buzzer to showcase TMS protocols.

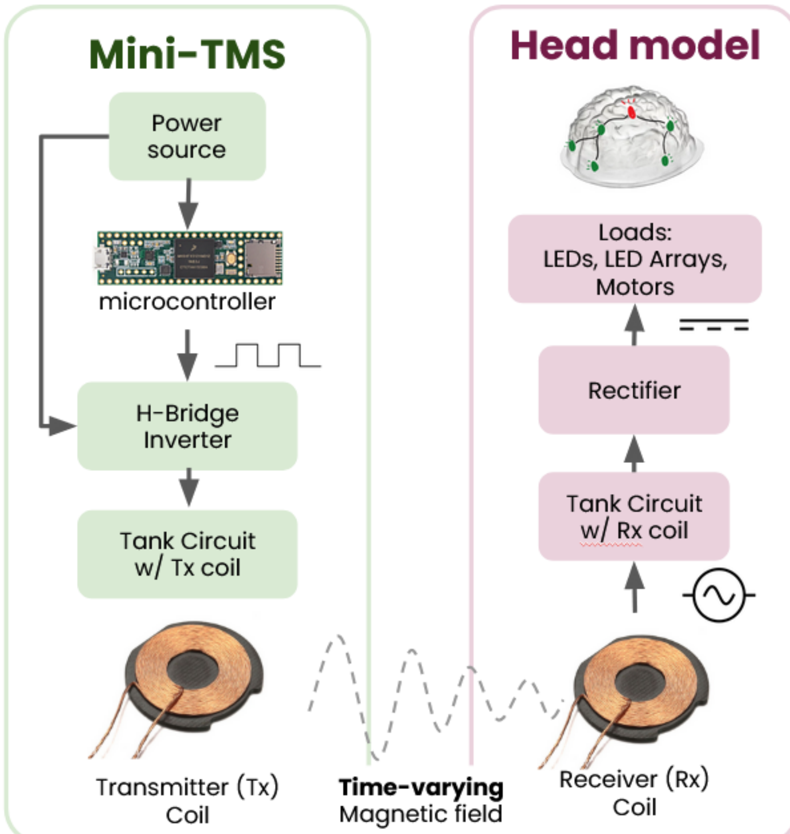


Figure 6: System-level diagram.

The system diagram shown above defines our WPT circuit. On the mini-TMS, we have a direct-current (DC) power source connected to an inverter, a DC to alternating current (AC) converter. This AC output from the inverter is connected to the transmitter coil to generate the time-varying magnetic field. On the receiver circuit, we connected a full-bridge rectifier to the coil. The rectifier ensures that current flows through the load in one direction, thus providing continuous power.

Electrical design

The high-level problem guiding our electrical design is to power loads using electromagnetic induction with air as its medium. The problem breaks down to three components: wireless power transfer between the transmitter and receiver; a transmitter circuit; and receiver circuits.

Wireless power transfer between the transmitter and receiver

Wireless power transfer requires two coils: a transmitter (Tx) coil; and a receiver (Rx) coil. The transmitter coil's function is to generate a time-varying magnetic field to induce a current in the receiver coil. The goal is to be able to power LEDs, LED strips, and a small DC motor wirelessly. Below are the power requirements for each load in the Rx circuits (table 1).

Load	Current required (mA)	Voltage required (V)	Power required (W)
White LED	30	3.3	0.09
LED Strip	120	9	1.08
Small brushless DC motor	140	3.7	0.518

Table 1: Power requirements for the load in the Rx circuits.

We designed and tuned LC circuits for the transmitter and each receiver to meet the power requirements of the receiver loads at a minimum separation distance of 10 cm between the Tx and Rx coils. We chose this minimum separation based on the furthest distance from our model head surface to its center.

Coil design

Coil geometry is crucial to consider for our design. The relevant design parameters are coil size, number of turns, and wire size. The wire size is important when considering resistive heating. The coil size and number of turns affect how much magnetic flux passes through a surface, thus affecting how much power we can transfer. Coil geometry also affects the inductance of the coil. It is critical because the coils' inductances affect the resonant frequency of the LC circuits created. We need LC circuits with similar resonant frequencies to couple for power transfer to occur. The head model limits the Rx coil size, and the Tx coil size should be similar in size to the TMS. Inherently the coils will have different inductances. We can tune the resonant frequencies of the LC circuits using capacitors. We constructed transmitter and receiver coils and measured their mean inductances to tune them to a given frequency. Table 2 contains each coil and tuning capacitor values. The geometry of the coils can be found in Appendix B.

Coils	Capacitance (nF)	Resonant Frequency (kHz)
Transmitter Coil	15	304.5
Receiver Coil 1 (for LED)	15	270.6
Receiver Coil 2 (for LED Array)	10	298.3
Receiver Coil 3 (for motor)	10	301.7

Table 2: Chosen capacitance and their resonance with respect to coils.

The coils are tuned so that their resonance frequency is near 300kHz, which is the highest frequency that we were able to drive the Tx circuit. The electrical components selected for the Tx circuit restrict our operating frequency.

Transmitter

We want to drive our LC circuits close to their resonance of 300 kHz, so we must be able to supply an alternating current through this circuit close to its resonant frequency for it to transfer maximum power. To meet the requirements, we designed an H-bridge inverter to convert DC into AC with a frequency close to the resonant frequency of the LC circuit. The main components of the H-Bridge are the MOSFETS and the gate drivers.

Our design uses N-Channel MOSFETs because of their higher switching speeds compared to the alternative, P-Channel MOSFETs. We had two MOSFETs to select from: the FCP650N; and the IRFZ44N. The FCP650N is resilient to high drain-source voltage (rated for 800V) and resilient to changes in voltage with time ($\frac{dV}{dt}$), but the FET's switching performance was inadequate at high frequencies (i.e., >100 kHz) based on our test shown in figure 7.

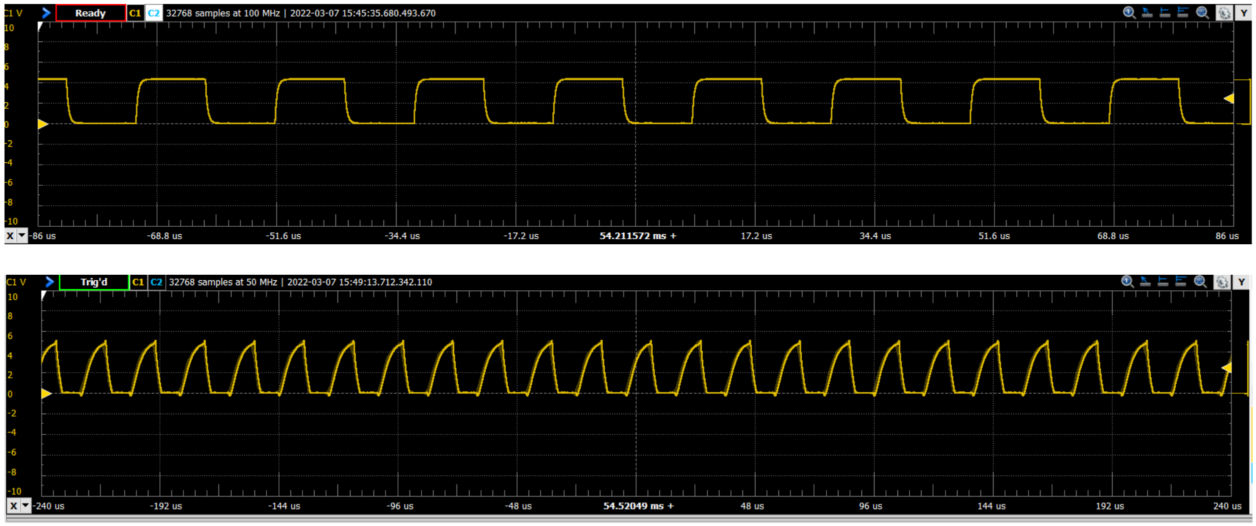


Figure 7: Comparison of IRFZ44N and FCP650N at 50 kHz. Above is the performance of the IRFZ44N. Below is the performance of the FCP650N.

Resilience to voltage and $\frac{dV}{dt}$ is important to avoid parasitic switching (unwanted switching) with the MOSFETs, which can cause shoot-throughs in the H-Bridge and damage the FETs by drawing too much current resulting in higher power loss. Slow switching speeds will also result in higher power loss. Higher power loss is problematic because MOSFETs dissipate power via heat. Increased heat from excessive power loss may damage the FET. In these aspects, both MOSFETs performed well at frequencies up to 300 kHz (i.e., maintaining temperature in its operating range.) With that in mind, we opted to use the IRFZ44N instead, which is less resilient to high drain-source voltage (rated for 55V) but performed better when switched at high frequencies.

We found, through tests, that we had much better performance with the IRFZ44N, and we could avoid parasitic switching despite a lower resilience to voltage.

With MOSFETs selected, we required a gate driver capable of switching these MOSFETs near the Tx circuit's resonant frequency. We had two options for the gate drivers: a full-bridge driver; or two half-bridge drivers. The full-bridge driver available to us was the IRS2453 full-bridge driver. We decided not to use the chip because of its switching frequency limit (~100kHz.)

Another reason we opted out of the IRS2453 was because of its low current output (high and low outputs rated for 180mA and 260mA, respectively.) MOSFETs, in reality, have parasitic capacitances between each terminal (gate, drain, and source), and these capacitances affect how fast a MOSFET switches since these capacitors charge before the gate. Low current output affects the charging speed of the capacitors, thus impacting our switching speed. We used two half-bridge drivers for a full-bridge drive instead. Specifically, we used the IR2184 half-bridge drivers whose typical high output and low output currents are 1.9A and 2.3A, respectively. The chip was also able to operate at the desired frequency of 300kHz.

The circuit in figure 8 is the H-Bridge inverter designed with the components selected above. The two IR2184 chips are powered at 12V and switched by two 3.3V PWM signals from a Teensy 3.5 microcontroller. We used the enable pin (i.e., SD) to create pulse trains of 1 Hz and 10 Hz mimicking the TMS protocols.

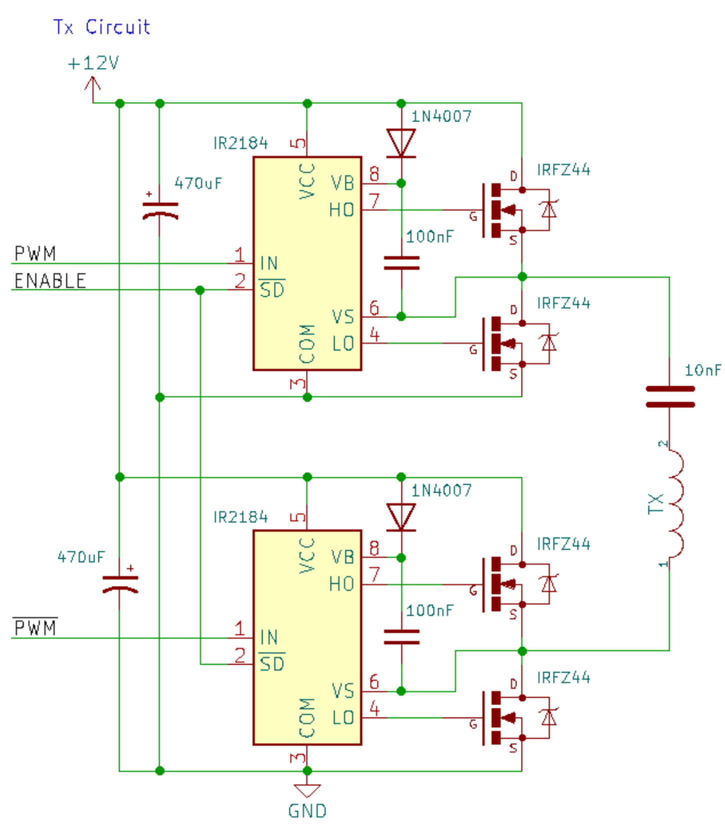


Figure 8: Schematic of h-bridge inverter.

Receiver

The receiver circuits include coils, LEDs, and small motor loads. The transmitter induces a current in the receiver coils that alternate near the resonant frequency. The LEDs are diodes, meaning the AC reverse current does not power them, and the motor does not spin in any consistent direction with kilohertz frequency alternating current. Thus, we used a full bridge rectifier to convert the AC into a current that only flows in one direction.

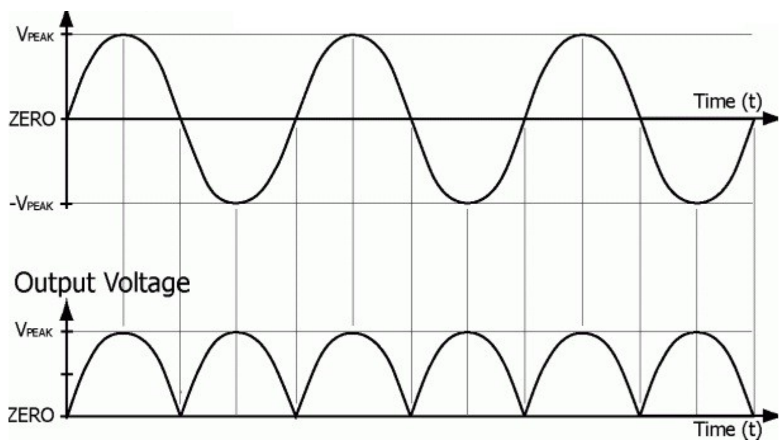


Figure 9: Graph of pre and post signals processed by a full bridge rectifier.[4]

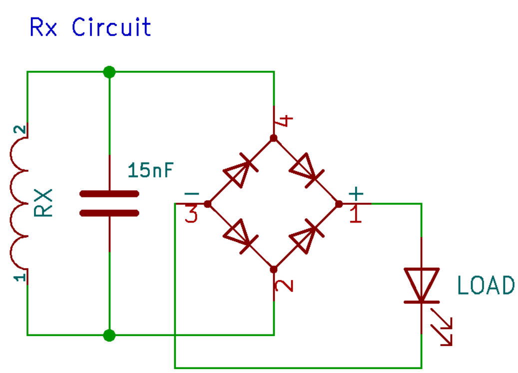


Figure 10: Schematic of the receiver circuit.

Optimization for wireless power transfer

Once we had functional Tx and Rx circuits and multiple different coils, we wanted to determine which coils and capacitors to use for the Tx and Rx. We want to power our loads from 10 cm. Hence, we conducted tests to find a suitable driving frequency for the transmitter LC circuit.

We conducted two tests. First, we compared two different pairs of Tx and Rx. One with Tx and Rx resonant frequencies of 101.2 kHz; and another with resonant frequencies of 304.5 kHz. We previously mentioned that the Tx and Rx must have similar resonance when pairing them up. We drove the two circuits at roughly 95% of resonance with each other (96 kHz for 101.2 kHz resonant frequency and 289kHz for 304.5kHz resonant frequency). From this test, we found out that the coil pair with resonant frequency 101.2kHz could not power the motor and LED strip. Whereas the coil pair with resonant frequency 304.5 kHz could. Therefore, we decided to use the 304.5 kHz resonant frequency pair for our final design.

After deciding to use a 304.5 kHz resonant frequency, we needed to know how close we should drive the Tx circuit to its resonant frequency. We conducted tests by driving the Tx circuit at different frequencies close to its resonant frequency. We measured the voltage and current observed in the resistor of the Rx coil at set distances of 3, 10, and 15 cm. The results of the test are below in figure 11 and figure 12.

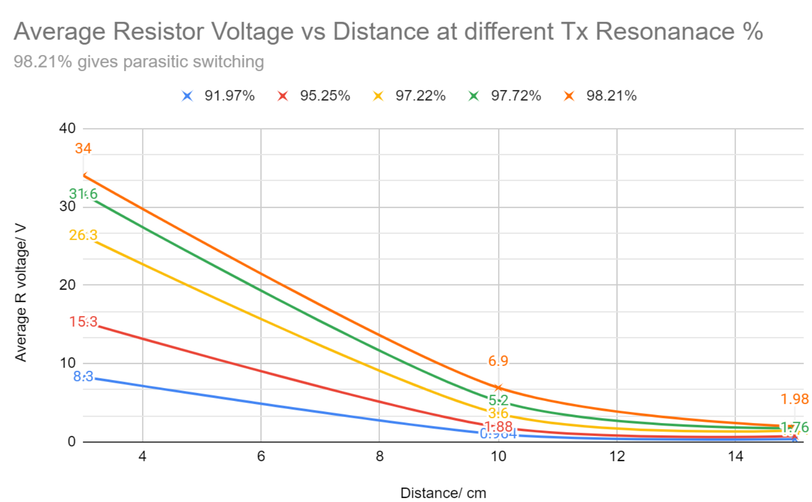


Figure 11: Average resistor voltage vs distance at different % Tx Resonance.

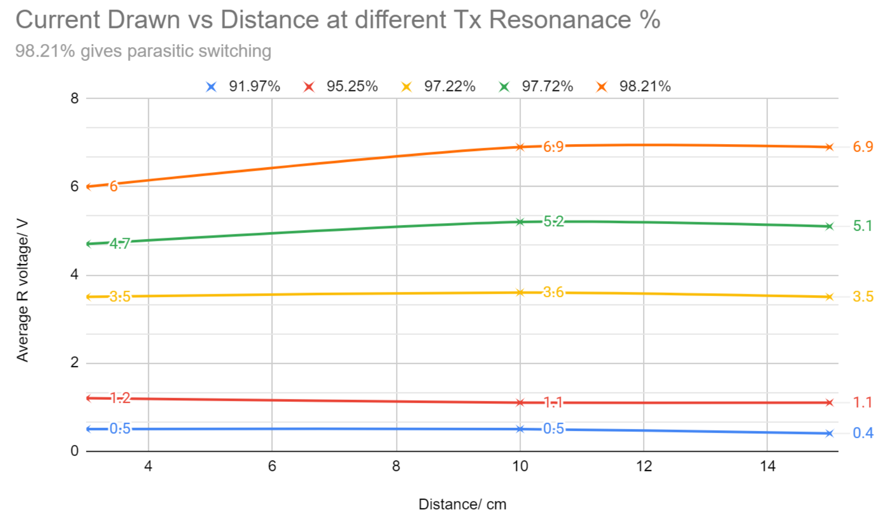


Figure 12: Current drawn vs distance at different % Tx Resonance.

An important thing we found when conducting the test is parasitic switching occurs when we get to 98.21% of the resonance frequency. This limits our driving frequency to be below this value.

The results from the test show that although setting a driving frequency closer to resonance would increase the voltage observed of the resistor in the Rx circuit, it would increase the current drawn in the Tx circuit. This observation applies to all distances between the Tx and Rx.

There are problems associated with the high current draw in the Tx circuit. Some of which include heating of the coil and MOSFETs and increased power source requirements (i.e., a power source that can supply 12V at a high current). Consequently, there is a trade-off between power transferred to the Rx circuit and current drawn in the Tx.

We decided to drive the Tx coil with a frequency of 93% of resonance, which translates to 283 kHz. This driving frequency would only draw a maximum of 0.6 A of current with an average of 0.5 A. At this setting, we observed the MOSFET and Tx coil reaching temperatures of 55 °C when we left it on for around 10 minutes.

To summarize, we made sure each LC circuit had a resonant frequency of around 300 kHz. We considered the coil shapes and adjusted capacitor values accordingly to achieve this. We drove the Tx circuit at 283 kHz because this setting could power all our loads at a 10 cm separation distance while only drawing 0.5 A.

Firmware design

To fulfill the requirements of portability and the TMS protocol selection, we opted to include a microcontroller in our system. Our microcontroller needed to be able to generate PWM at 300 kHz frequency, provide digital I/O for a button, and communicate with a buzzer for sound effects. It should also be usable by our sponsor.

We chose Teensy 3.5 due to its low cost, Arduino compatibility, and its 120 MHz bandwidth. The code and pinout of the microcontroller are attached in Appendix A.

Structural design

The mini-TMS and head model are tools clinicians will use with patients interactively. As discussed, the mini-TMS and head model consist of coils in their respective circuits. This section describes the design considerations in building structures that contain these components with user experience in mind.

As seen in figure 13, clinicians hold the TMS coils over the head of the patient. The mini-tms should mimic the visual and tactile features of the TMS to strengthen the educational link between the demonstration tool and the actual TMS. The mini-TMS enclosure (figure 13) houses all the transmitting system components. It protects the circuitry from external damage and protects users from contacting sharp or hot elements of the circuit. A transparent cover encloses the mini-TMS body and allows users to view the transmitter coil and some of the circuitry. The cover can be easily removed for access to circuits. Vents are added to the enclosure body and cover to allow air to flow and passively cool the circuit components. See Appendices B and C for a complete list of the components in the mini-TMS enclosure and engineering drawings.

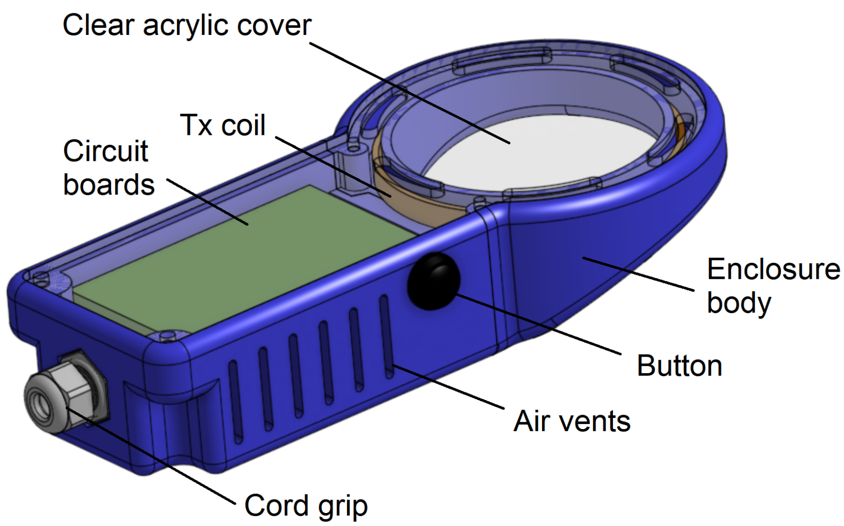


Figure 13: CAD model of the mini-TMS enclosure.

The head model system consists of three main load types: single LEDs, LED strips, and a small motor. Clinicians can make use of these loads to represent different responses in the brain. These loads are parts of their receiving coil and small processing circuits, which are all contained in units that can be mounted separately to a platform. Another design criterion required the head model system to resemble a human head. Our platform (figure 14) consists of three perpendicularly mounted pieces of clear acrylic cut in the shape of three sections of a head. The platform is mounted to a styrofoam head, as seen in figure 14. We designed coil mandrels (figure 14) that facilitated the production of custom coils, which also contained the remaining circuitry and loads. The mandrels for the motor and LED strip loads fill the area of a mounting quadrant on the acrylic platform to maximize the coil area. The mandrels are mounted to the acrylic platform by nylon screws and can be easily removed for demonstrations of individual receiver units.

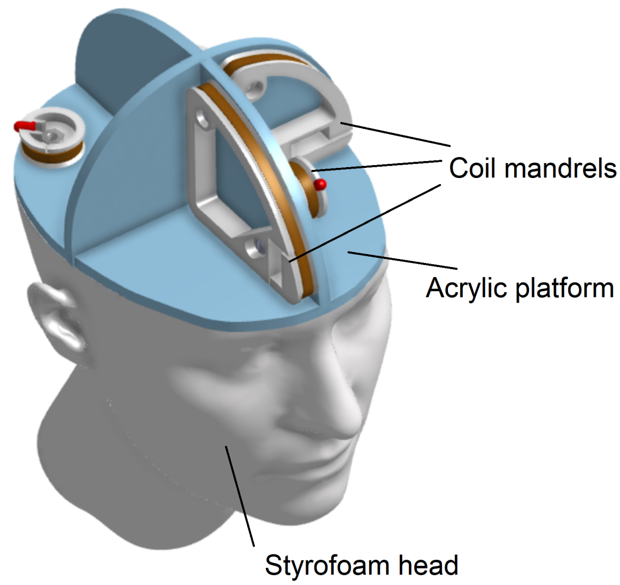


Figure 14: CAD model of the head model. Loads shown: LEDs. Loads not shown: LED strips and motor.

Conclusion

High current and high-frequency electronics introduce problems that are non-factors in low current and low-frequency electronics. Some of these problems include parasitic capacitance, MOSFET transients, and heating. Due to this, we must carefully select components capable of running at high current and high frequency.

A high resonance frequency of the transmitter and receiver circuits is desirable for wireless power transfer. However, there is a limit to a circuit's resonant frequency before the parasitic capacitances become a significant problem. Furthermore, driving the Tx circuit closer to resonant frequency would increase the current drawn by the circuit, which would lead to another range of issues like MOSFET and coil heating. However, there is an operating point where you can be off-resonance but still apply enough power for your application.

Remaining Issues/ Risk

The mini-TMS prototype and head model are safe to use by TMS clinicians. There is some concern that the MOSFETs, voltage regulator, and Tx coil can reach temperatures of 55 °C when left on for longer than 10 minutes. While this temperature is within the operating range of the components, any components touching the 3D printed enclosure may cause the PLA material to reach its glass transition temperature. We conducted tests to observe the effects of leaving the mini-TMS on for periods of 10 minutes and did not notice the enclosure heating up significantly. However, we would still not recommend not leaving the device on for long periods (i.e., more than 10 minutes).

Additionally, the amount of power that the mini-TMS can transfer to the head model at intended operating distances (5 to 15 cm) exceeds the required amount. This makes the LEDs shine very brightly and may cause discomfort if looking at them directly. It also makes it more difficult to target individual Rx components with the mini-TMS: at some operational distances, the mini-TMS can power more than one load simultaneously, whereas, for educational purposes, the intention is to power only one load at a time. Due to its strength, the mini-TMS damaged the wireless charging function of a team member's phone when it was nearby (within 1 cm). We would advise that users keep electronic devices sensitive to electromagnetic interference, such as cell phones and pacemakers, away from the mini-TMS when it is in use.

Recommendations

We encourage a few recommendations that would improve the limiting aspects of the mini-TMS/head model demonstration set.

Engineering recommendations include:

- Replacing the proto-board with a smaller, more compact printed circuit board,
- Changing the driving frequency of the transmitter to reduce load overpowering, and
- Adding an active cooling component to the mini-TMS.

Additional TMS-related concepts that could be improved include:

1. An animated neuron network using addressable LED strips, and
2. A tunable motor threshold demonstration.

Details on how these recommendations could be implemented are found in Appendix D.

Deliverables

1. 1 mini-TMS unit with a 12 V portable battery pack and charger
2. 1 head model unit with 3 LED, 1 LED strip, and 1 small motor receiver units.

Appendices

Appendix A: Firmware implementation

Figure A.1: Hand-drawn schematic of microcontroller circuit

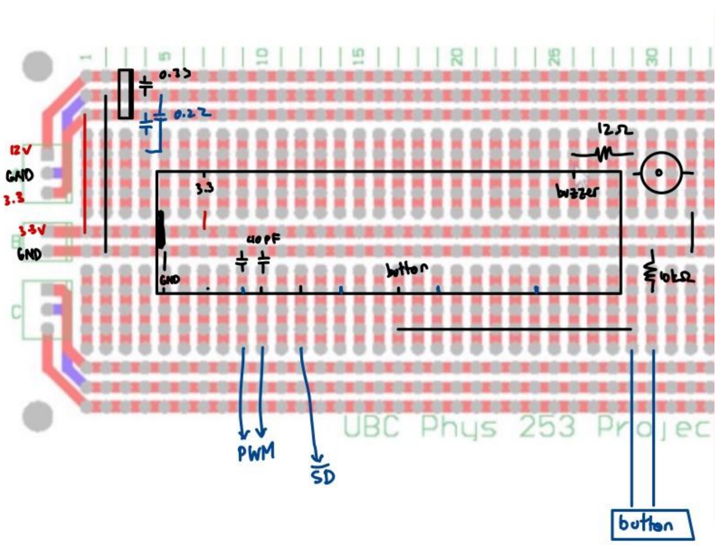
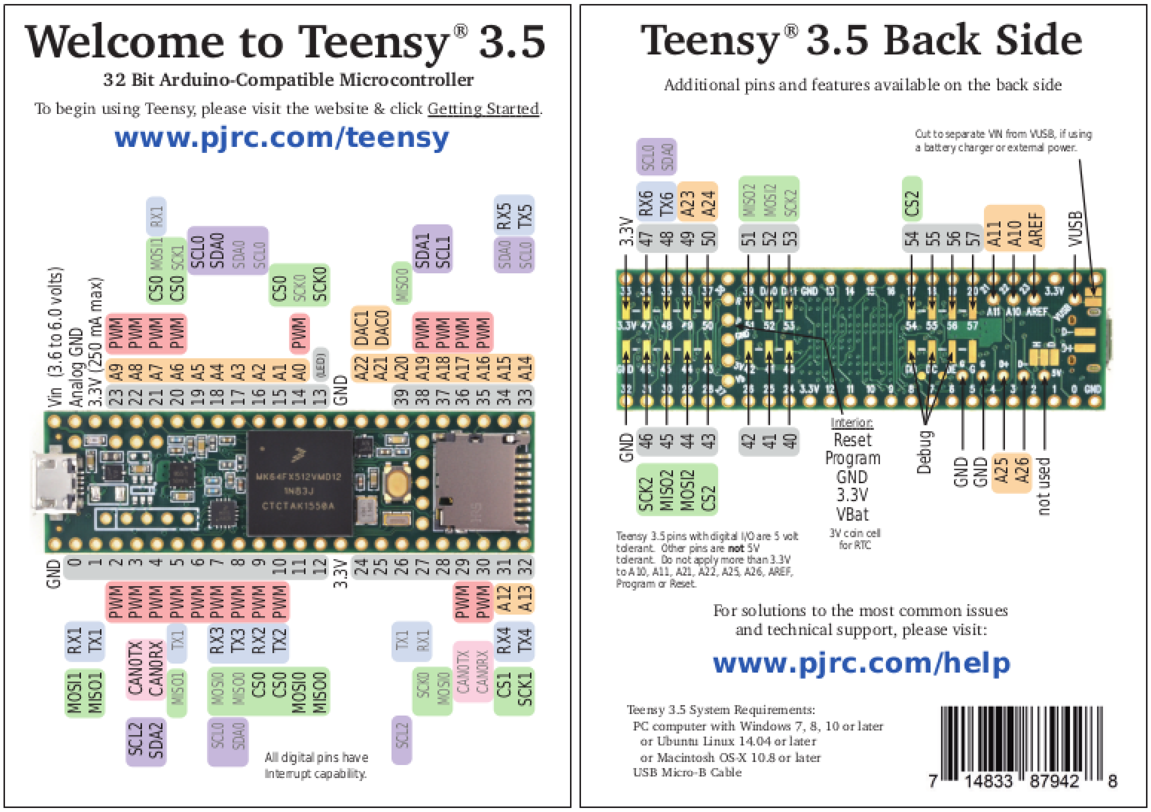


Figure A.2: Teensy 3.5 Pinout

Source: https://www.pjrc.com/store/teensy35.html



A.3 Firmware code

Git repo: https://github.com/ENPH459-2207-TMS-Demo/mini-tms-uc

Appendix B: Part tables and data sheets

Table B.1: Parts in mini-TMS enclosure

Part	Qty.	Details
Enclosure body - handle	1	3D printed with PLA
Enclosure body - mandrel	1	3D printed with PLA
Enclosure lid	1	3 mm clear acrylic
Threaded heat inserts	5	3 mm; 5.7 mm long
16 mm screw	4	3 mm; button head socket cap
6 mm screw	3	3 mm; button head socket cap; to join the two enclosure body parts
Hex nut	2	3 mm
Button	1	Digi-Key part number: 2449-EH12NMB2ZX-ND
Cord grip	1	McMaster-Carr part number: 69915K52

Table B.2: Parts in head model

Part	Qty.	Details
Styrofoam head	1	Joined to the platform with hot glue
Platform base	1	6 mm clear acrylic; joined to other platform sections with hot glue
Platform front section	1	6 mm clear acrylic; joined to other platform sections with hot glue
Platform side section	1	6 mm clear acrylic; joined to other platform sections with hot glue
LED coil mandrel	3	3D printed with PLA; attached to the platform base and side section with a nylon screw
LED strip coil mandrel	1	3D printed with PLA; attached to the platform side section with 2 nylon screws

Motor coil mandrel	1	3D printed with PLA; attached to the platform front section with 2 nylon screws
Nylon screw	7	Size 10-32; round head slotted
Nylon hex nut	7	Size 10-32
Wooden base	1	

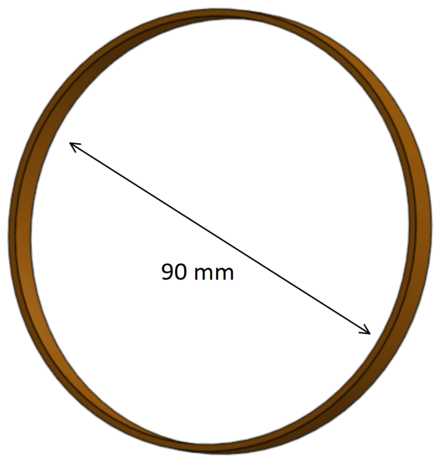


Figure B.1: Transmitter coil geometry.

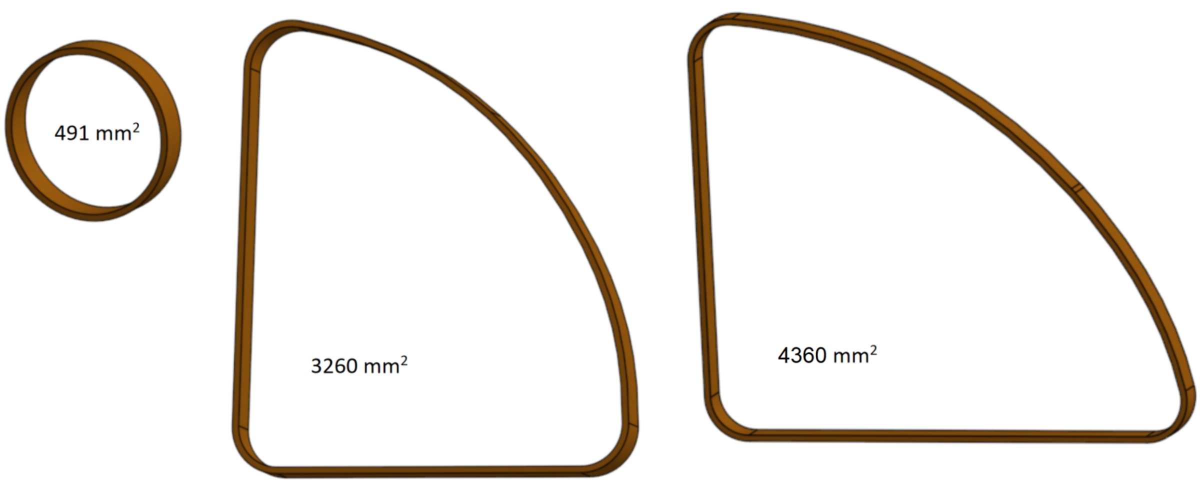


Figure B.2: Receiver coil geometries. In order from left to right, the coils are for receivers 1, 2, and 3

Data sheets:

1. MOSFETs: https://www.infineon.com/dgdl/Infineon-IRFZ44N-DataSheet-v01_01-EN.pdf?fileId=5546d462533600a40153563b3a9f220d
2. Gate drivers: https://www.infineon.com/dgdl/Infineon-IR2184(4)(S)-DataSheet-v01_00-EN.pdf?fileId=5546d462533600a4015355c955e616d4
3. LEDs: http://www1.futureelectronics.com/doc/EVERLIGHT%C2%A0/334-15__T1C1-4WYA.pdf
4. LED strip specifications based off of: https://learn.adafruit.com/rgb-led-strips/overview
5. Motor specifications based off of: http://www.robotpark.com/Micro-Dc-Motor-20000-Rpm-3-7Volt-Smallest-Dc-Motor
6. Schottky diode bridge: https://www.mouser.ca/datasheet/2/80/CDBHD140L_G_Thru__CDBHD1100L_G_RevC-2504984.pdf
7. Teensy 3.5 microcontroller: https://www.pjrc.com/store/teensy35.html

Appendix C: Engineering drawings

Figure C.1: Enclosure body handle drawing

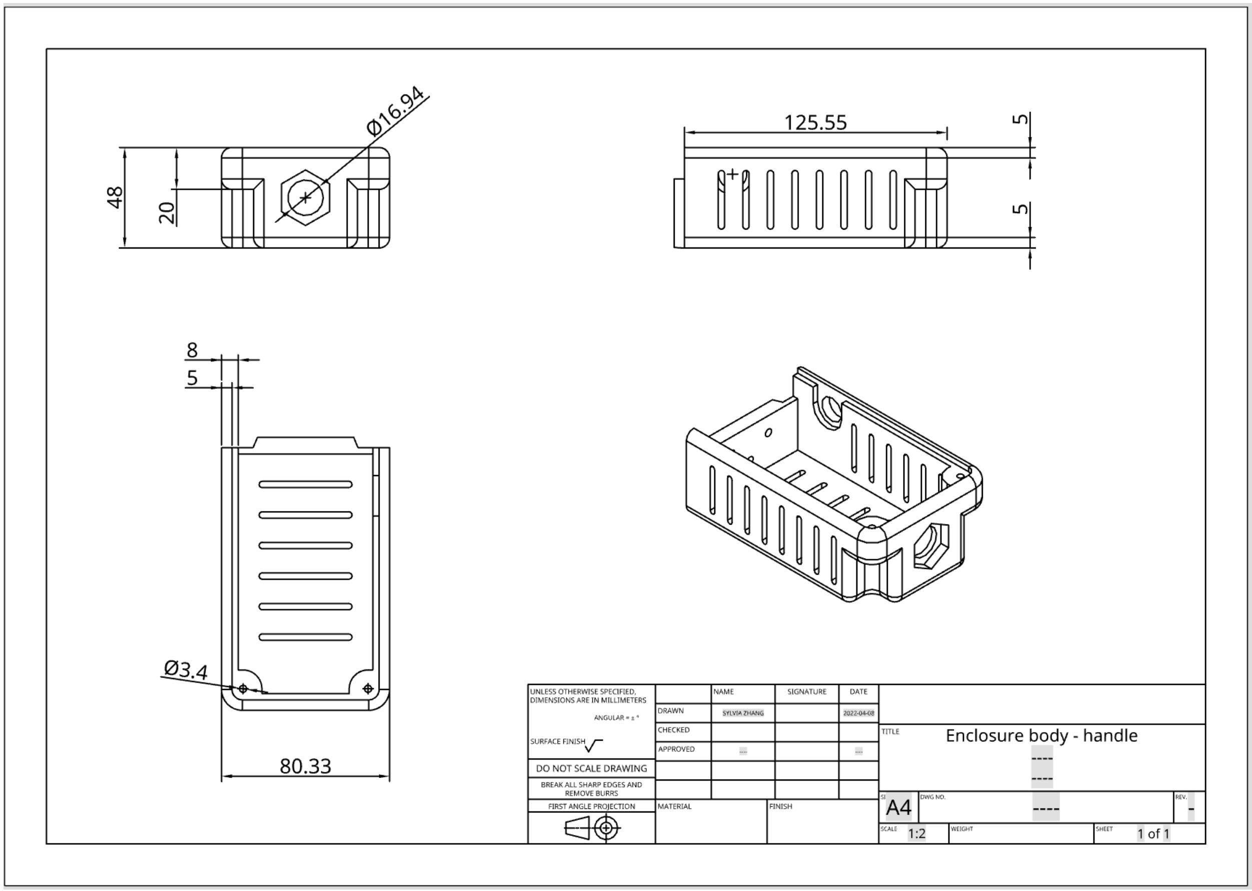


Figure C.2: Enclosure body mandrel drawing

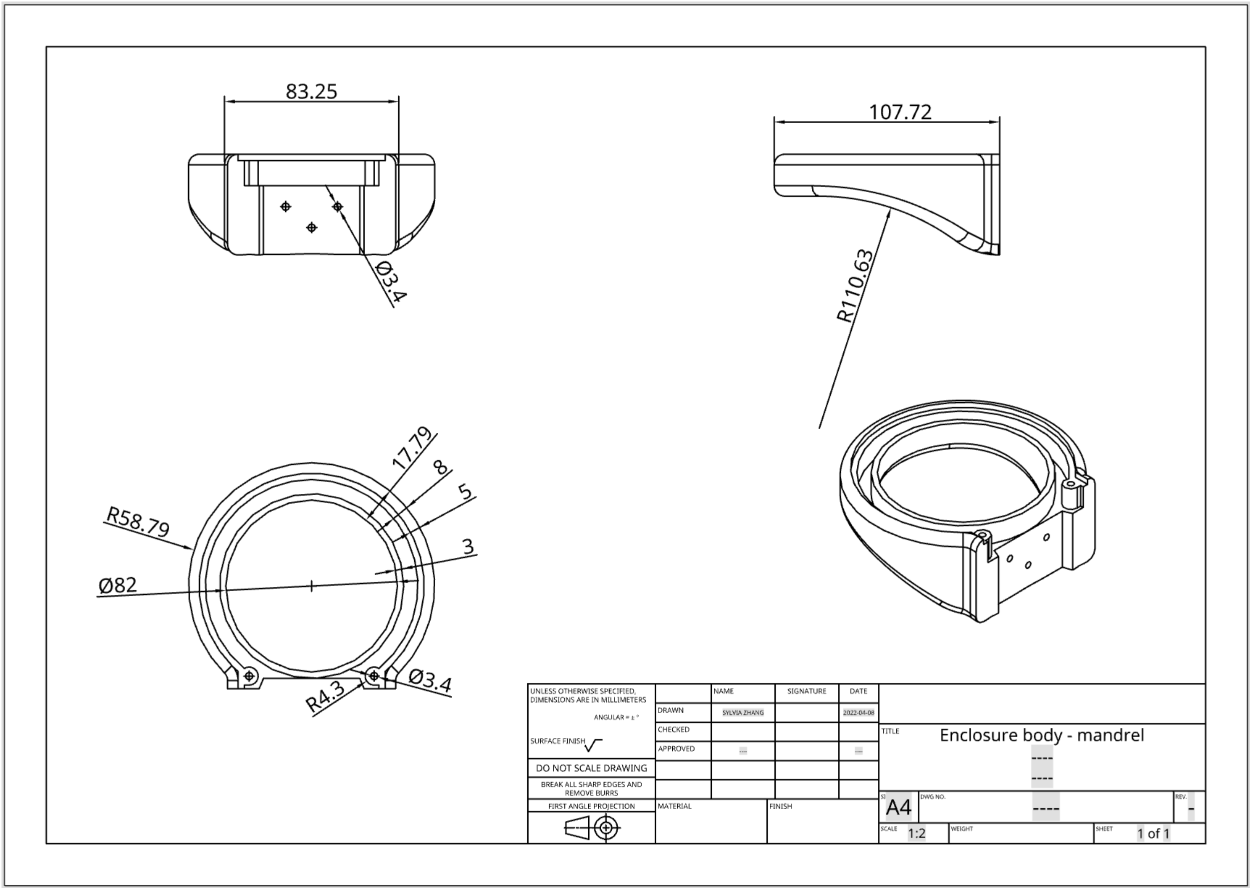


Figure C.3: Enclosure cover drawing

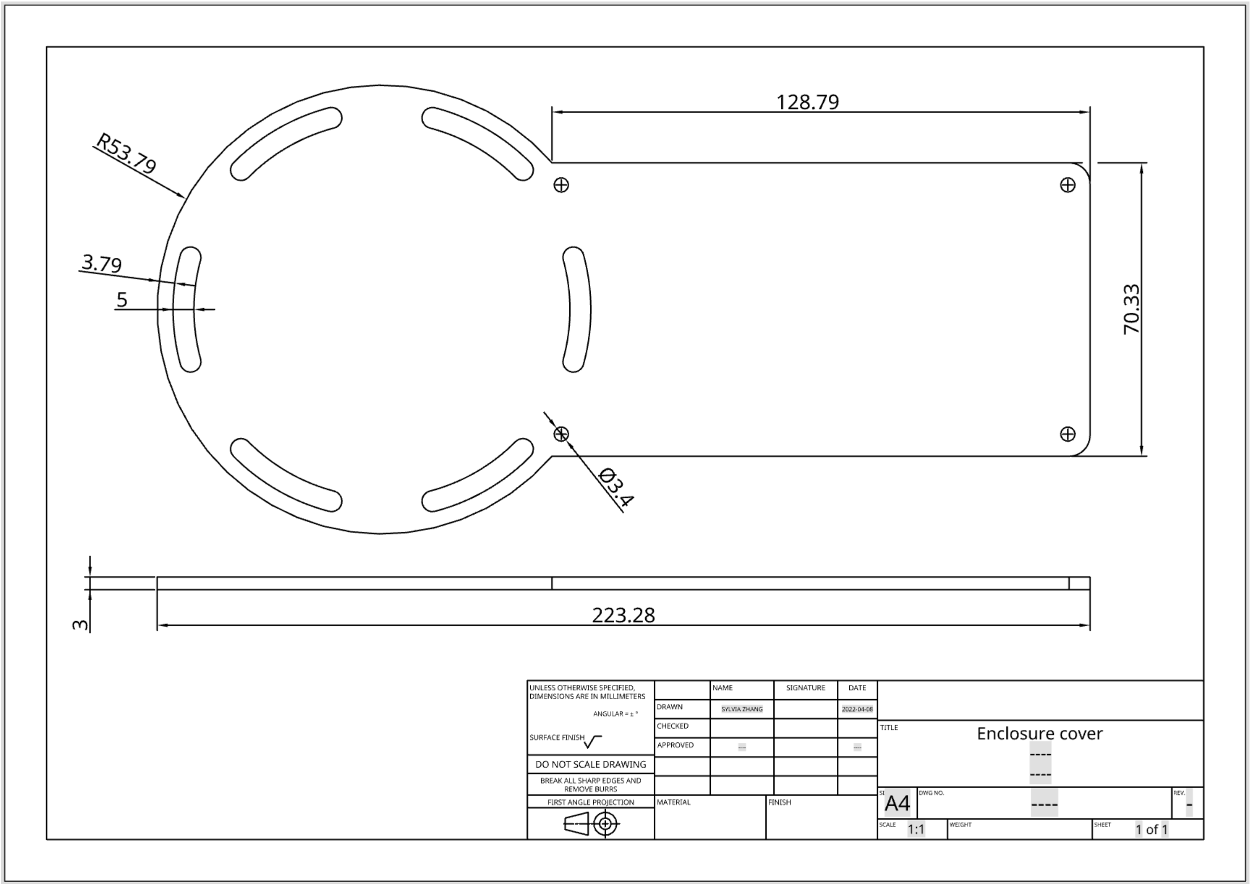
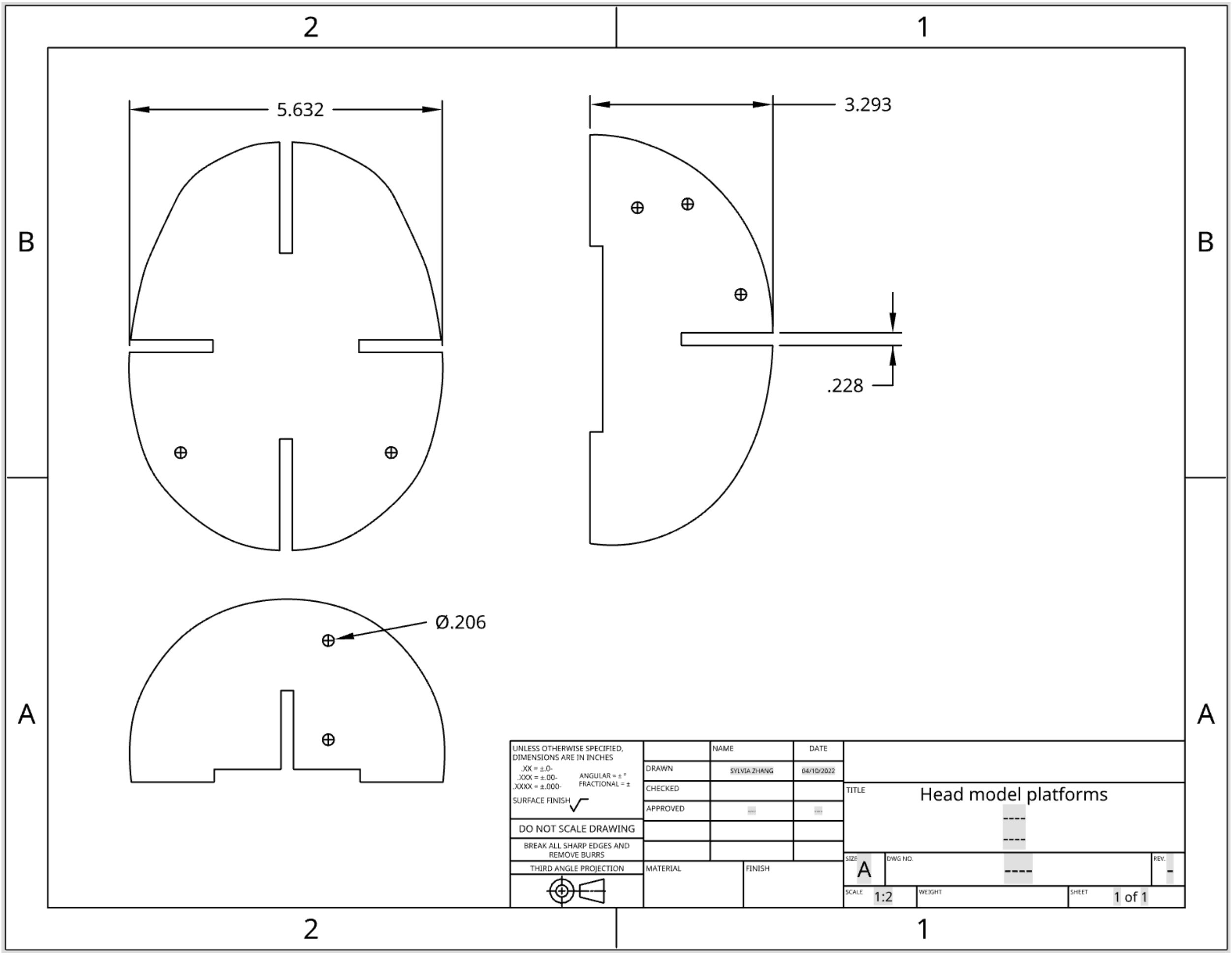


Figure C.4: Head model platform drawing



Appendix D: Recommendations

Engineering recommendations

Currently, the Tx circuit is hand-soldered onto a proto-board with through-hole components. To improve electronic connections and reduce the form factor, this circuit board could be replaced by a PCB. A smaller form factor would allow for a smaller mini-TMS enclosure that would look nicer and be easier to hold.

To resolve the load overpowering issue, we have some suggestions. The first is to change the driving frequency of the transmitter. By either reducing the frequency and re-tuning the coils or just simply shifting the frequency further from resonance, the rate of magnetic field change can be decreased, which should shorten the power transfer range and induce a lower current in the loads. Conversely, one can reduce the current through loads by modifying the receiver circuits to include a resistive load in parallel with the LED loads. The last suggestion is to increase the size of the head model to increase the space between receiver coils to avoid interference.

A final suggestion is to add an active cooling component to the mini-TMS to mitigate heating issues.

Educational recommendations

In reading about neurology and the biological aspect of neurostimulation technologies, we as a team enjoyed learning about concepts like neuron networks and motor thresholds. We developed some ideas that could be integrated with the mini-TMS and head demo representing these concepts.

We explored addressable LED strips that visually resemble the LED strips currently in the head model, but can light up individual diodes at different times. These strips could be used to add a light animation depicting the travel of signals in the brain network but would require further exploration in adding logic circuits in the receiving circuits.

We also discussed adding a feature in the mini-TMS that would allow the user to tune the strength of the changing magnetic field, similar to features present in real TMS devices. These could be implemented by adding microcontroller code that changes the output frequencies. Clinicians could use this feature to explain the concept of motor threshold, values of which are different for each person and imitate the practice of tuning the TMS device to meet the patient's motor threshold.

Another thing we did not implement was programming more complex TMS protocols such as theta-burst stimulation[10]. Our demo is hard-coded to mimic 1 Hz and 10 Hz TMS protocols, but can theoretically be reprogrammed for other TMS protocols.

Due to the time constraints of this project, these features were not implemented, but we encourage future developments that improve the educational capacities of the demonstration.

Acknowledgements

This project would not have come to fruition without the support of many people. We would like to thank:

- Dylan for his endless knowledge and advice for all of our troubleshooting problems,
- Bernhard for the many mechanical improvements to our product,
- Miti for helping us find the perfect power supply,
- Mark from the e-Lab for valuable circuit design insight, and
- Last but not least, Dr. Vila-Rodriguez for sponsoring this inspiring project.

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