ECE 44X - Senior Design 2021-2022
Team 3 - Electrical Arc Speaker
Executive Summary

Kyle Barton
Ian Scott Paul
Jeffrey Unrein
Zhenglun Yang

Project Purpose:

The plasma speaker project aims to develop a functional speaker by creating and controlling plasma produced by an electric arc. This technology has been demonstrated to be capable of producing speakers with excellent replication of high-frequency sound. Plasma speakers are used in place of a solid diaphragm speaker for the tweeters in some very high-end audio systems due to the material limitations of the solid diaphragm. Our system functions by creating plasma between two electrodes and modulating alternating electrical current passing through the plasma so that the ionized air responds to the produced magnetic field. The resulting movement of ionized particles interacting with the surrounding air creates sound waves. Our goal is to produce an appealing, safe, and easy-to-use plasma speaker design for display in Kelley Engineering Center.
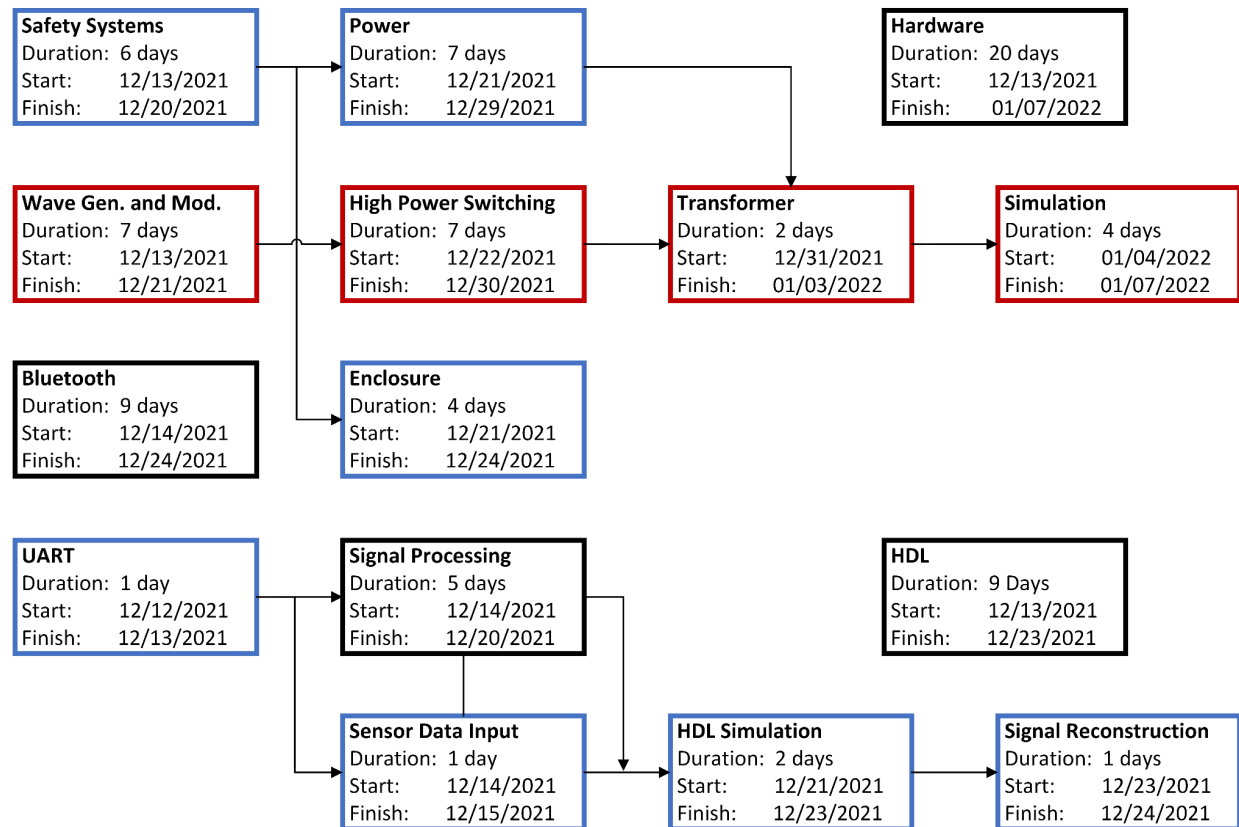
Our Process:

For the first 3 months of the project, the team worked primarily in creating documentation, and learning about how electrical arc speakers work. This documentation set the goals and expectations for the project in the form of impact statements and system requirements. Looking back, it would have been beneficial to do more prototype testing during this phase of the project as we were researching plasma speakers. This would have helped us weed out bad designs and waste less time during the design phase.

The second 3 months of the project we focused on system design. During this phase, we finalized our system's architecture and each member designed two blocks for the system (8 total) . The work was focused on getting each of the blocks working isolated from the system, not yet on integration. This is when the bulk of our technical design occurred.

The last 3 months of the project were split into two phases. (1) System integration, and (2) project closing. During system integration, the team connected all of the previous-designed blocks to construct the full system. This process did not go smoothly, but after redesigns of some of the blocks, the final system was completed and functioned properly. The last phase of the project was the project closing, where the team reflected on how the project went, where improvements could have been made, and lessons learned.

Project Timeline:

Safety Systems		Power		Hardware	
Duration:	6 days	Duration:	7 days	Duration:	20 days
Start:	12/13/2021	Start:	12/21/2021	Start:	12/13/2021
Finish:	12/20/2021	Finish:	12/29/2021	Finish:	01/07/2022

Wave Gen. and Mod.		High Power Switching		Transformer		Simulation	
Duration:	7 days	Duration:	7 days	Duration:	2 days	Duration:	4 days
Start:	12/13/2021	Start:	12/22/2021	Start:	12/31/2021	Start:	01/04/2022
Finish:	12/21/2021	Finish:	12/30/2021	Finish:	01/03/2022	Finish:	01/07/2022

Bluetooth		Enclosure	
Duration:	9 days	Duration:	4 days
Start:	12/14/2021	Start:	12/21/2021
Finish:	12/24/2021	Finish:	12/24/2021

UART		Signal Processing		HDL	
Duration:	1 day	Duration:	5 days	Duration:	9 Days
Start:	12/12/2021	Start:	12/14/2021	Start:	12/13/2021
Finish:	12/13/2021	Finish:	12/20/2021	Finish:	12/23/2021

Sensor Data Input		HDL Simulation		Signal Reconstruction	
Duration:	1 day	Duration:	2 days	Duration:	1 days
Start:	12/14/2021	Start:	12/21/2021	Start:	12/23/2021
Finish:	12/15/2021	Finish:	12/23/2021	Finish:	12/24/2021

Key Lessons Learned:

Throughout the project, the quality of work produced by the team was often times low quality. This caused many problems when integrating all the blocks of the system together near the end of the project. The work done prior was often lacking, just barely meeting expectations, and thus any small change to the original block would require a full redesign. If the initial designs of the block were truly modular and followed solid interface definitions this would have been avoided. In general it was difficult to convey what was expected, and a lack of solid project management and delegation led to some vastly different interpretations of what certain members were responsible for. A lesson learned from this experience would be to set up quality standards for work and documentation at the beginning of the project, and adhere to them throughout.

Our team also struggled with teamwork throughout the project. Although this is expected, there are strategies to be implemented so that the teamwork problems do not affect the quality of the final design. One main lesson learned for this would be to ensure very clear and open communication within the team on each member's progress with their work. Keeping a clear gauge on the team's technical progress will allow more proficient members to pick up the slack, and prevents scrambling to get work done last minute. Although the goal is to split the work

evenly between the members, this is often unrealistic and can hinder a team. For a long-term project like this, ensuring good communication is necessary for success.

A more technical lesson learned from the project is on the design and use of MOSFETs for the high power switching block. This is the step that takes the lower-voltage PWM audio signal, and steps it up to a higher voltage and pulls (or pushes) it through the transformer. This circuit requires 20-40V and 2-6A to be switched relatively quickly at between 7-20kHz. Hence switching this much power is not an easy task.

Our final design used two MOSFETs in parallel to sink current through the transformer (transformer was *above* the MOSFETs in the circuit with the high side tied to Vdd and the low side tied to the drain of the MOSFETs). This layout worked, but still all of that power was getting switched through only two MOSFETs and they got very hot very quickly. To remedy this, we placed low-ohm power resistors in series with the transformer to limit the current. This solution also worked, but the resistors constantly burned power and made the system less efficient.

Likely the best solution for switching the high-power signal would be an H-bridge circuit powered by dedicated gate drivers. This H-bridge would also include the added benefit of switching the direction of current through the transformer, theoretically increasing the fidelity of the output audio. Dedicated gate drivers would supply higher voltage to the gates of the MOSFETs and would allow them to switch more efficiently, dissipating less power and thus less heat. Another possible benefit of an H-bridge circuit would be that it would allow the high-power switching to occur at a higher voltage and thus create a louder speaker. Because of thermal and component limitations, our final speaker did not produce sound as loud as desired.

Since we ultimately switched around 20KHz, there was a large amount of "dead time" where the transformer was saturated. This is what necessitated the 200W 4 Ohm Resistor to be placed in series with the transformer. If a much faster switching speed was used, and the transformer was stopped from basically shorting the switching block, then all the power lost by the resistors would be able to be used in the arc.