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Abstract: Ultrasound imaging is a vital medical technology, as it allows professionals to get a closer look at the inside of what they are studying without actually having to open the person or object they are attempting to observe. Because it is minimally invasive, it is widely implemented, with a large variety of machines available to accomplish this task of imaging. While this variety allows people the ability to choose exactly what they want in a machine, many industry machines are designed with a great deal of adjustable features, and therefore cost a great deal of money. The goal of this project is to design a low-cost ultrasound pulser/receiver. As time allows, additional features will be added, but the most important part of this project is getting the pulser/receiver to be fully functional. In this paper, I provide a brief overview of ultrasound technology, the specifics of the project goals, and a short synopsis of past work. From there, I outline specific design requirements for this device, and explain how the device will be tested. The final part of this paper provides a rough week-by-week outline of how the project will progress. The primary goal of the project is to design the pulser/receiver, but because the later features are so open-ended, the current plan is to have this phase of the design completed by the end of fall term. The first half of winter term will entail adding optional features to the device, and the second half ensuring that the overall device is functional and presentable. While aesthetics and manufacturability are not a primary concern of this project, the final device is expected to be neat, easy to use, and most likely easy to replicate.

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Problem Definition:

Overview of Topic: Ultrasound imaging is an incredibly useful medical technology that allows medical practitioners to see what is happening inside a patient or subject while being minimally invasive. The imaging technology works by sending sound pulses into the subject's body, and measuring the signal that is "bounced back." From the wavelengths of these sounds, an image can be formed. One common usage of ultrasound imaging is to allow pregnant women to begin to form an idea of what their unborn children may look like, and to allow these women's doctors to diagnose any easily visible medical concerns for the fetus. In Professor Buma's case, he is using ultrasound imaging to get a close look at the biological organisms he studies.

Problem Definition: Professor Buma has a large, expensive ultrasound pulser/receiver. While this machine serves the purpose he needs to use it for, he is hoping that a cheaper, simpler alternative can be made. Though the machine he already owns has a lot of different input conditions and options, he is hoping for a simpler version that he can use more easily. He is not expecting it to have the high level functionality of the industry standard machine and is more focused on prototyping and designing a less expensive, more accessible version. This version is not meant to replace the industry standard, but merely to gain a better understanding of how the technology works. For this specific case, it will ideally provide a cheaper alternative to the expensive machine Professor Buma already owns.

Goal of Project: The main goal of this project is to design the ultrasound transmitter and receiver. Once these two main goals have been accomplished, additional modifications will be made to the overall device, such as an adjustable gain. Because this project can very easily be built in stages, the final goal will vary depending on the challenge and depth of each individual stage. This means that I will have to make sure to continue updating the final goal, keeping it challenging but realistic. Though greater functionality is often desired, I will have to balance that need with the functionality of each step of the project. As many of the more challenging aspects of this project will be the additional functions (adjustable gain, adjustable pulse width, external triggering, etc), I will definitely have to ensure that I am updating my goals every week or two, just to ensure that what I am doing is attainable while still providing the appropriate level of difficulty for a senior project. I will not necessarily be designing as I go, as Professor Buma has many long-term desires for the device, but I will have to ensure that I am not skipping steps in the design process. Essentially, there is no point in adding an adjustable gain or pulse width if the device cannot produce a reliable signal.

Literature Review: Jeremy A. Brown and Geoffrey Lockwood have already begun to tackle this problem, as described in their paper, "A Low-Cost, High-Performance Pulse Generator for Ultrasound Imaging." In their paper, they discuss the trade off between high voltage and high frequency signals, as well as how to ensure that excess noise is not added to the signal. The removal of excess ringing is accomplished through the use of diodes. Because of the very high voltage demands, the circuit makes use of power FETs, in order to ensure that the desired output is sustainable under the high input conditions. Their design will be the basis for my own project, but as I begin work, I will likely end up modifying their original design quite a bit, making changes or improvements to the work they have already completed where I see fit. The design they have come up with is only meant to cost around $50 USD, making it a realistically affordable project for me to pursue in the coming year.

Design Specifications:

Performance: The pulser will produce a negative voltage spike around 150 volts or greater, for 20 nanoseconds or less. A greater voltage spike would be more desirable, but 150 volts is a starting baseline. The repetition rate should begin at 1 kHz, but can (and should) eventually be able to be adjusted to go as high as 20 kHz. 5-10 kHz would be considered more typical. The unit would ideally also have two different trigger options; an internal trigger, that would keep time and self-trigger, and an external trigger, that would operate on a 0-5 volt logic scale. Adjustability in regards to both the repetition rate and the triggers would be longer term goals, but are both eventually desired. For initial testing, the load will be assumed to be 50 ohms. The receiver should be capable of measuring the pulse echo. One cable will be used both to transmit and receive, and as such, needs to be able to route a very high voltage signal and a very low voltage signal with no data loss at either extreme. The receiver circuitry would also need to be protected against the very high voltage pulse by using a duplexer and limiting diodes.

Economic: As the project is meant to be a cheaper alternative to Buma's approximately $2,000 machine, the economic cost of this project is definitely a constraint. The design proposed in Jeremy A. Brown and Geoffrey R. Lockwood's paper costs around $50, so the final project, which would ideally have more functionality than that proposed design, would ideally be under $100. This would also be useful for SRGs, as there is definitely a limit to how much funding can be granted.

Energy: The pulser/receiver should run off the 120 volt wall line, and will be designed with those limitations in mind.

Safety: The project should be safe for anyone to use. It probably will not be used to take measurements on living beings, but it should still be safe in case of such an eventuality. Because of the very high voltage, the system will have to be designed with careful attention paid to the current running through components and the amount of power dissipated.

Ergonomics: The pulser/receiver will be connected to the transducer by a coaxial cable, so the coaxial cable connection should be easy to access and not unwieldy to attach. Another cable will be used for the external trigger, which should have similar specs to the transducer cable. The same can be said of the power cord, which should also be easy to access and plug into the wall.

Legal: The project should be designed following the legal specifications of Buma's more expensive machine.

Materials: The project will use a great deal of components, all mentioned in Brown and Lockwood's paper, including, but not limited to, a current-feedback amplifier, MOSFET pairs, electrolytic and metalized polyester film capacitors, and resistors.

Manufacturability: The project probably will not be manufactured, but based on the way it will be designed, should be easy to repeatedly manufacture.

Aesthetics: There are no specific aesthetic demands for this project. However, the general demands of this project are that it look neat and aesthetically pleasing. Circuit components should be neat and well laid out, and as much as can be will ideally be implemented with PCBs. As the project wears on, and the final product becomes more clear, more features would ideally be added, such as a (user-)adjustable gain, pulse width, etc. These inputs should be easy and somewhat intuitive to apply.

Testing Plan:

Pulser: The pulser will initially be tested alone. In order to do this, a scope probe can be used to measure the system output. The output will be measured with a 50 Ω load and without a load. The voltage amplitude, duration of the pulse, and any pulse ringing will be the main aspects of the signal to observe.

Receiver: The receiver will also be tested by itself before it is implemented with the pulser. A function generator will be used to model the input signal. Again, a scope probe will be used to measure the output of the receiver. In this case, the amplifier gain, frequency response, and noise will be the observed parts of the signal.

Pulser/Receiver: When both the pulser and receiver are tested together, the output (of the pulser)/input (of the receiver) cable will be connected to an ultrasound transducer. The transducer will then be placed in front of an acoustically reflective device, and a pulse will be sent. The final output of the receiver will be measured using a scope. Here, it is the peak frequency and bandwidth of the received pulse that will be measured.

These methods can be used to test each step of the device individually, but will also be used in the future to test the device when additional features are added. Assuming that a successful pulser/receiver is designed, the final result of those tests will be used as a benchmark for the device's future functionality, with appropriate scaling.

Project Schedule for Fall Term: Overall, each week will include a revision of the final goal for the term and the next week's goals and, hopefully, a meeting with Professor Buma to go over what was successful and what wasn't. Much of the aesthetic elements of the project will be implemented during the winter term, after various sub-functions are confirmed to be working as expected. Revisit project schedule at the end of Week 5 and adjust as needed. The goal for the end of the term is to have the pulser and receiver elements of the device functioning, and a preliminary design for the final device housing should be implemented. The final product by the end of this term will be very rough, as the ability to add the additionally features discussed previously must be part of this design.

Pre-Week 1: Come back to campus prepared with research on based on Brown and Lockwood's design. During this research, see if I can find other circuit designs, and really gain an understanding of what the device is supposed to do, and what functionalities are less necessary than others Figure out what parts of their paper can be updated based on technological advancements, and research various components. Have a backup plan for each component, understand what each component does and how it can be replaced or improved upon. Some minor research should also be done into the design and implantation of PCBs.

Week 1: Meet with Buma before applying for funding or buying parts. Ensure that the circuit schematic from Brown and Lockwood's paper is doable, and compatible with Union's lab equipment. Design and run a digital simulation of the project (update this throughout the course of the project). The simulation should include both the pulser and receiver stages at this point, but the more long-term goals can be added to the simulation/schematic as the need for them arises. These functionalities *must* be added to the schematic as they are added to the prototype. Schematic must be revisited throughout the term to ensure it is current.

Week 2: Run simulation and adjust as needed. Buy necessary parts, continue researching ultrasound topic, and prepare space in the lab.

Week 3: Hopefully have parts by now. If not, try to build a device that might have a lower voltage depth with parts already at Union, just to ensure that I understand how components work with each other. If I have parts, design an initial prototype of the pulser circuit (based on simulation), keeping in mind that parts of it will also have to be used for the receiver.

Week 4: Continue working on the pulser circuit. Ideally, this will be working by the end of the week. If not, the plan for the rest of the term will obviously change.

Week 5: If the pulser circuit is working at this time, begin designing the receiver circuit. At this time, it does not have to be connected to the pulser circuit. Make adjustments as needed

Week 6: Continue work on the receiver circuit. It should be working by the time this week is over. Adjust circuit and schematic as needed.

Week 7: Combine pulser and receiver circuits so that pulser output is shared by receiver input. Fix any issues encountered here. Begin preliminary work with PCB design.

Week 8: Continue working with breadboarded prototype. Get breadboarded prototype working to the point where I would be comfortable not replacing vital components. If these "vital" components need to be replaced, understand exactly what it is that went wrong in their implementation. Also continue working on PCB design.

Week 9: Have PCB design finalized for pulser/receiver circuit. Breadboarded circuit should be functional under almost all test conditions. Begin working on initial casing//housing for device.

Week 10: Pulser/receiver circuit should be working. Have rough design for casing/housing. Rough design must include ability to add longer term goal functionality. If work this term has gone faster than expected, have designed and tested at least one long term goal by now. Remember to update schematic/simulation as new components and functionality are added.

Goals for Winter Term: Each week, a new function, such as adjustable gain, adjustable rate, or external trigger should be added. These functions will require meeting with Buma each time to ensure that they are both what he desires and that they are implemented appropriately. By Week 7/8, the final device should be completely breadboarded and planned for the PCB, so the remainder of the term can be devoted to ensuring the device works once it is implemented on a PCB, and that the housing for the device fits the ergonomic and aesthetic requirements. By the end of Fall Term, the goals for Winter Term should be clearly defined.

Works Cited:

J. A. Brown and G. R. Lockwood, *A Low-Cost, High-Performance Pulse Generator for Ultrasound Imaging,* IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control., vol. 49, no. 6, june 2002