ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

NeuroGuard

A Dual Electrocautery-Nerve Monitoring Device to Prevent Injury during Mastectomy

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Team No. 31

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1 Introduction

We provide details as to the problem we aim to address revolving around nerve injuries during masectomies, along with our proposed solution, in context.

1.1 Problem

Over 100,000 mastectomies are performed yearly in the U.S., with 40-60% resulting in nerve injury that can lead to a variety of symptoms, notably post-surgical pain [1]. In particular, damage to the intercostobrachial nerve (ICBN) is common during mastectomy and axillary lymph node dissection, a set of procedures common in treating metastatic breast cancer. Recently, surgeons have begun utilizing nerve-sparing techniques to ensure greater patient quality of life; however, these innovative techniques require meticulous dissection that can be complicated by anatomical variation and intraoperative bleeding.This highlights an urgent need for a device that provides real-time feedback to surgeons, enhancing safety and precision while also being easily integrated into existing workflows. To address this problem, we propose NeuroGuard, a device designed to alert surgeons when they are approaching the ICBN nerve during operations, thereby reducing nerve injury rates and improving patient outcomes.

1.2 Solution

Inspired by recent multifunctional surgical devices like a dual monopolar probe and suction tool, we are working with the NeuroGuard team to integrate contactless nerve detection and cautery functionalities into a single, cost-effective device. Over the course of the semester, we will work to design and simulate a circuit that demonstrates the ability to switch between predefined electrocautery and nerve stimulation waveforms at specified time intervals. We will work to prototype this circuit that can be integrated with an electrosurgical unit and standard monopolar electrocautery probe. This project is a proof of concept for the hardware platform, demonstrating the capability to integrate power conversion and waveform generation that could be used with a standard cautery probe. The scope is strictly limited to the development and testing of this hardware; the detection of neural activation and the development of a feedback mechanism are considered future work beyond the scope of this project.

1.3 Visual Aid

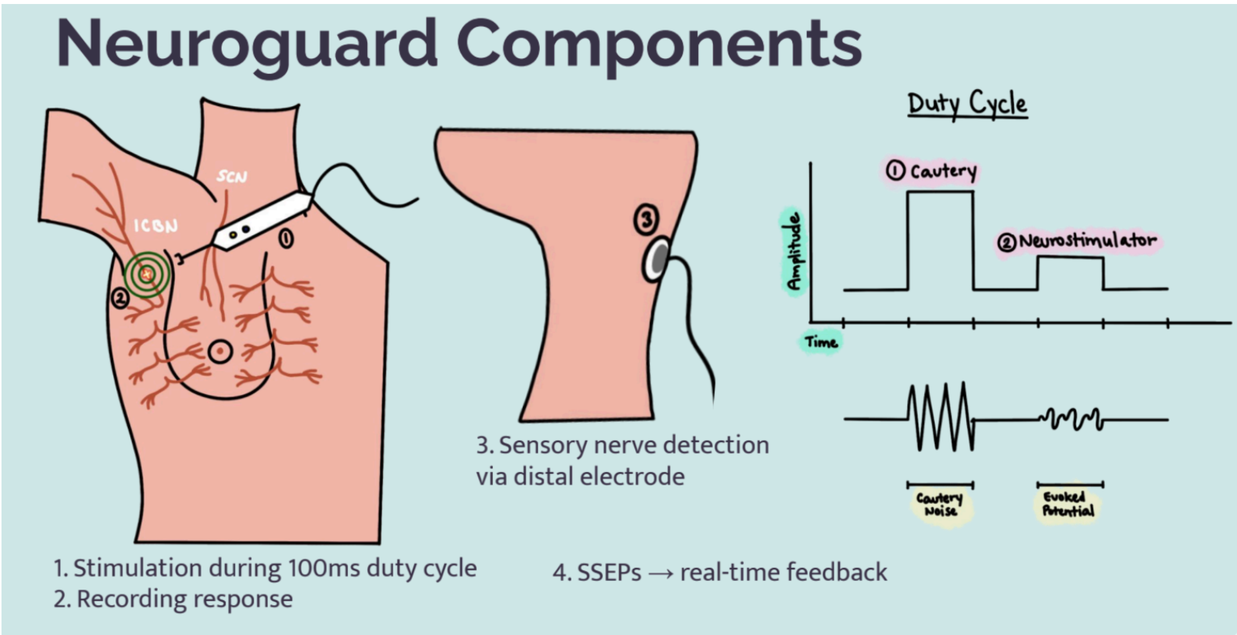

Figure 1: Overview of the Neuroguard system

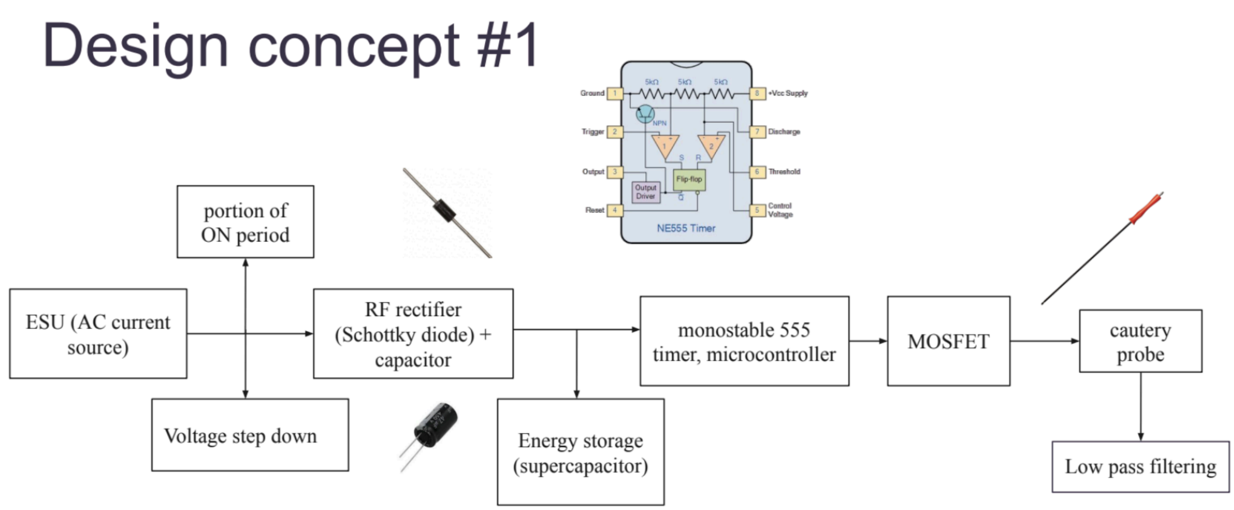

Figure 2: Initial design concept from the Neuroguard team

1.4 High-Level Requirements

To consider our project successful, we aim to accomplish the following goals:

1. Creation of 2000V to 5V step down converter system that is compatible with existing cautery power supplies
    a. Suitable sub systems for safe testing. This will involve a high voltage inverter and transformer to step down the voltage from 2000V to ~100V. This 100V AC will then go through a rectifier and buck converter to step it down to a suitable 5V that will be used by the circuit components.
2. Creation of suitable nervous stimulatory waveform from a 555 timer IC
3. Creation of a power MOSFET and a super capacitor to provide suitable pulsed current waveforms for neuron detection
4. Creation of interface hardware that will detect when to send out the nerve stimulating waveform.

Circuit Design

The system functions by employing pulse width modulation, alternating the standard cautery voltage settings with a smaller, pre-calculated neurostimulator waveform. These settings would reduce electrical noise interference, while enabling accurate downstream sensing of neural activation. The NeuroGuard system itself would reside between the electrosurgical unit (ESU) and the probe, modulating the waveform to include a component that allows for contactless activation of the ICBN. This modulation could occur by harvesting the existing power source of the ESU at specific time points within the duty cycle, or as an external power source that overlays the nerve-specific waveform onto the existing cautery duty cycle. In the first setup, the high-frequency AC current from the ESU would be rectified to a DC current, followed by a voltage step down mechanism and filtering. A supercapacitor can serve as the charge storage mechanism, with the discharge timed by a MOSFET, 555 timer, or other pre-programmed timing component. In the second setup, an external power unit, rather than the ESU, can be the source of the nerve-specific stimulation waveform.

2. Design Overview

2.1 Block Diagram

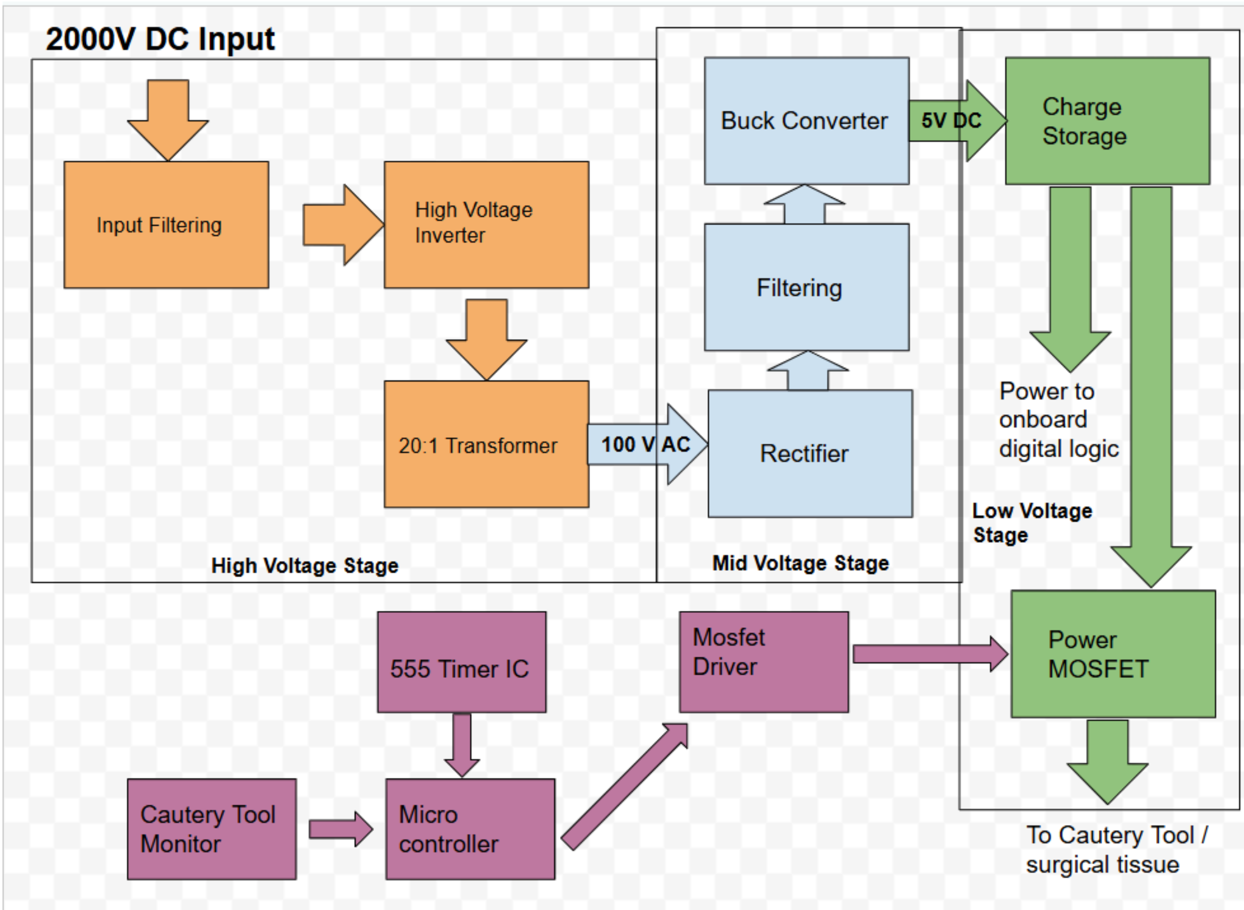

Figure 3: Block Diagram

2.2 Power System Overview

2.2.1 High Voltage Stage

A single stage buck is infeasible to safely and efficiently step down a 2000V DC input to a 5V DC output. We use 2000V DC as this is the output of the electrosurgical unit (ESU). Because of this, we will be implementing a multi stage power conversion system. The high voltage stage will take the 2kV DC and invert it to create a 2kV DC output. This will go through a transformer that will then step it down to 100V AC. This 100V AC will then be sent to a full bridge rectifier and filtering circuitry.

2.2.2 Mid Voltage Stage

The Mid Voltage Stage contains the rectifier and filtering circuitry, as well as a final buck converter to do the final step down to 5V DC. This 100V AC input, once rectified and filtered, will output 100V DC that is then sent to a buck converter that will do the final step down to 5V DC.

2.2.3 Low Voltage Stage

The input being the 5V DC from the mid-voltage stage, a supercapacitor can serve as the charge storage mechanism that is connected to a power mosfet. (This part of the circuit design has been simulated to be working besides the microcontroller input by the Neuroguard med students already). A capacitor provides sufficient energy to deliver short, low-current pulses. The stored energy is selectively discharged through a resistor (simulating nerve tissue) via an N-channel MOSFET, whose gate is driven by a 5V pulse signal from the microcontroller. When the gate receives a high signal, the MOSFET turns on, allowing the capacitor to release its energy as a precise stimulation pulse across the load.

2.2.4 Timer & Microcontroller Stage

The microcontroller detects when to alternate between the standard cautery function (pass-through) and the nerve stimulation waveform. The 555 timer IC as recommended in the Neuroguard med proposal controls when nerve stimulation is delivered to time the discharge of the capacitor. It also takes as input the 5V DC from the low voltage stage and uses it to deliver to detect the OFF periods of duty cycle of the ESU, which is when the nerve stimulation is allowed to be delivered. This PCB also provides the Cautery Tool Monitoring. This will output a signal to the mosfet driver that when high (5V), will turn MOSFET turns on, allowing the capacitor in the low voltage stage to release its energy as a precise stimulation pulse across the load.

2.3 Subsystem Requirements

2.3.1 High Voltage Stage

Power supply can successfully output 100V AC 5% tolerance. The entire apparatus is safe to use under medical criteria.

2.3.2 Mid Voltage Stage

Power supply can successfully output 5V DC 5% tolerance at 100mA 5% tolerance with voltage ripple less than 10% (Output supply maximum ripple is from 4.5V to 5.5V, DC output is maintained from 4.75V to 5.25V). The entire apparatus is safe to use under medical criteria.

2.3.3 Low Voltage Stage

When the Mosfet receives a high signal, the MOSFET turns on, allowing the capacitor to release its energy as a precise stimulation pulse across the load is measured to be 0.1V at 50 Hz - 1 kHz. The waveform generated during the OFF period is still the ESU source.

2.3.4 Timer & Microcontroller Stage

The microcontroller, given a 5V input with a certain % Duty Cycle, is able to time when nerve stimulation occurs. The microcontroller must output 5V to the Mosfet Driver during the OFF portion of the Duty Cycle, and according to the 555 timer.

2.4 Risk Analysis

Significant considerations must be taken on the PCB layout and design for this power system. High voltage DC will require larger trace tolerances and specialized PCB dielectric to prevent arcing between traces. This entire apparatus must then be placed into an insulating chamber for improved safety. While buck converters are generally the most efficient method to step down DC voltages, because of the large jump from input voltage to output voltage required (100V DC to 5 V DC), efficiency will be closer to ~50% depending on the specific buck converter chosen. Thermal considerations are incredibly important so the buck converter does not overheat and shut down. The final large consideration is EMI filtering from the buck converter and Inverter sub systems. The DC power supply NeuroGuard will receive is incredibly sensitive to backpropagated conducted EMI. Significant filtering will need to be in place in order to ensure that this does not disrupt the cautery power supply.

The figure below shows the feasibility of the low voltage stage, as it shows the output of the nerve stimulation generation by the Neuroguard medical team with their proof of concept circuit.

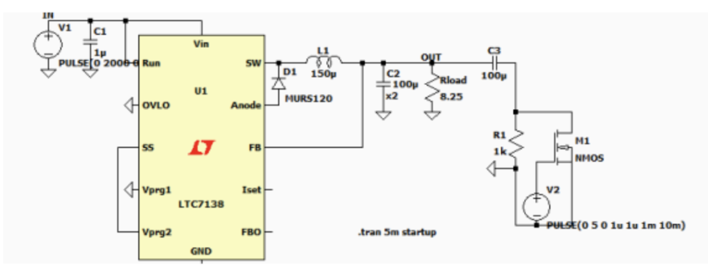

Figure 1. Circuit design consisting of buck converter (Integrated Circuit LTC7138, Analog Devices), capacitor bank, and MOSFET switch.

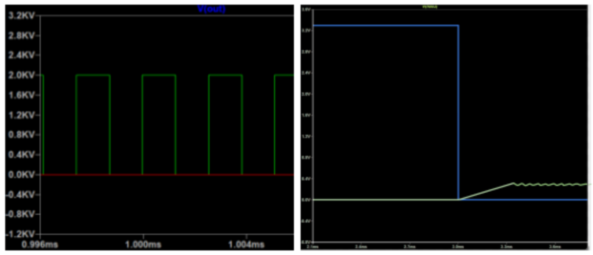

Figure 2AB. (A) Simulation output in LTspice, demonstrating ability to switch between electrocautery voltage (2000V) and smaller nerve stimulation waveform. (B) Adjustment of original circuit (Vin=3.3V, C3=200uF) to improve visualization of precise capacitor discharge timing.

Figure 4: Circuit Diagram and Simulation Output from the IEEE abstract [1].

3 Ethics & Safety

To make sure our group is working on our project safely and effectively, we will follow the IEEE Code of Ethics that was adopted by the IEEE Board of Directors in 2020[2]. We understand that technologies affect the quality of life around the world and we must work with a high ethical standard as a professional team. Some of the most important, but not the only, ethics to follow for our team are:

1. **Seek, accept, and offer honest criticism of technical work, acknowledge and correct errors, be honest, and realistic in stating claims or estimates based on available data [2].**
2. **Treat all persons fairly and with respect, to avoid harassment or discrimination, and to avoid injuring others [2].**
3. **Work to improve our technical competence but consider our qualification from training or experience and disclose notable limitations [2].**

To ensure safety in our design and following all regulations, we will take a number of precautions to minimize danger in development and operation of our device. Because we will be dealing with high voltage, possibly of 2000 Volts if connected to the hospital supply, it is important to make sure all components included in our design can withstand these voltage levels, even after step-down converters are included. Also, we will make sure that all devices, such as microcontrollers, and software follow relevant licensing requirements.

4 References

1) M. Singhal, K. Kiunga, N. Kelhofer, P. Dullur, N. Chigullapally, S. Pappu, and M. L. Oelze, *"Expanding the Scope of Intraoperative Neuromonitoring with Nerve-Specific Stimulatory Waveform Design,"* Carle Illinois College of Medicine and Department of Electrical and Computer Engineering, University of Illinois Urbana-Champaign, Urbana, IL, USA.
2) IEEE. "”IEEE Code of Ethics”." (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 09/19/2025).