ECE 445

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Project Proposal

Team HeartRestart

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Introduction

Problem

Research has shown that defibrillators delivering a single shock achieve relatively low survival rates of only 13.3%. In contrast, Double Sequential External Defibrillators (DSED), which deliver two rapid consecutive shocks, significantly improve survival rates to 30.4%. However, DSED currently requires two separate defibrillators, making it impractical in emergencies, particularly in ambulances where only one defibrillator is typically available. Furthermore, the timing between each shock is on the order of milliseconds apart, which further pushes the impracticality even further with two defibrillators. In the current market, most defibrillators lack impedance measurement capabilities, which limits their ability to adjust shock strength and timing to account for variations in patient body type. Those that do have impedance sensing are much larger and more expensive as well.

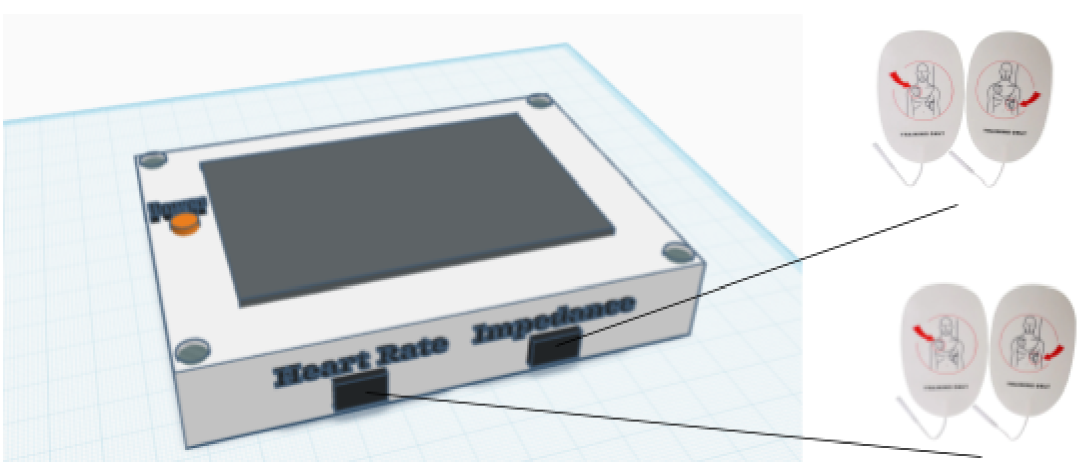
Solution

Our project aims to design and build a core subsystem that can later be integrated into a full AED capable of delivering two sequential shocks. Due to time constraints and complexity, we are not building the complete double-shock device, but instead designing a system that integrates heart signal monitoring, impedance measurement, and real-time data processing into a single PCB. The PCB will contain four main modules: the power module, the EKG module, the impedance module, and the microcontroller module.

The power module will use a rechargeable battery and likely some DC-DC step-down converters to provide the necessary power for other parts of the PCB. The EKG module will monitor heart activity by processing signals from the AED pads after they pass through filtering circuits. The impedance module will operate in a similar way, using signals from a separate set of pads that are filtered and then analyzed to determine the patient's body impedance. Finally, the microcontroller module will process EKG and impedance inputs, handle user commands via a start/stop button, and output real-time heart rate and impedance readings on an LCD display.

Visual Aid

Our device will be a small box with a power button, LCD screen, with ports that connect to AED pads for heart rate and impedance measurements.

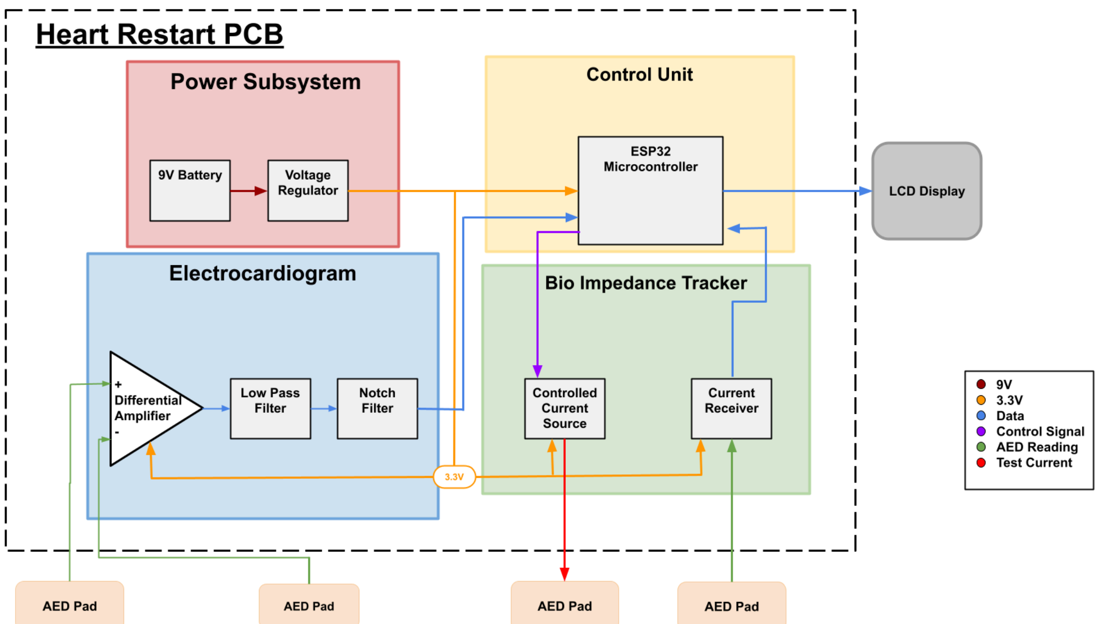


High-level requirements list

- Measure patient impedance with an accuracy of ±5%.
- Measure patient heart rate with an accuracy of ±2%.
- Display patient impedance and heart rate on an LCD Screen with a 240x320 pixel resolution at 15Hz

Design

Block Diagram



Subsystem Overview:

Power

The power subsystem in the end project will supply two main components: the PCB board, which comprises the ECG and impedance filters, along with the microcontroller, and the charging circuit for the power electronic circuit. The power subsystem will be required to step down the voltage for the main PCB board, as almost all components will not require more than a couple of watts of power. This can be done with a couple of step-down converters. In terms of the actual voltage that would have to be evaluated, depending on the microcontroller, in this case, we are going to use the ESP32 microcontroller.

What will supply the entire power distribution board will be a battery. In the typical portable AED, they utilize a standard 9 V battery.

Subsystem Requirements:

The power distribution board should supply around 3.3 V and 0.5 A to the microcontroller board for the microcontroller to function at the advertised performance.

EKG

The EKG component will be on the main board with the microcontroller and the impedance sensor components. The EKG will take in two signals, one for + and the other for -. These inputs will come from the standard pads of an AED. The EKG itself will be made up of a differential amplifier, a low-pass filter, and a notch filter.

The amplifier will boost our signal to be readable, while the low-pass filter will filter out any higher frequencies beyond 300 hz, and the notch filter will smooth out the noise from the amplified signal.

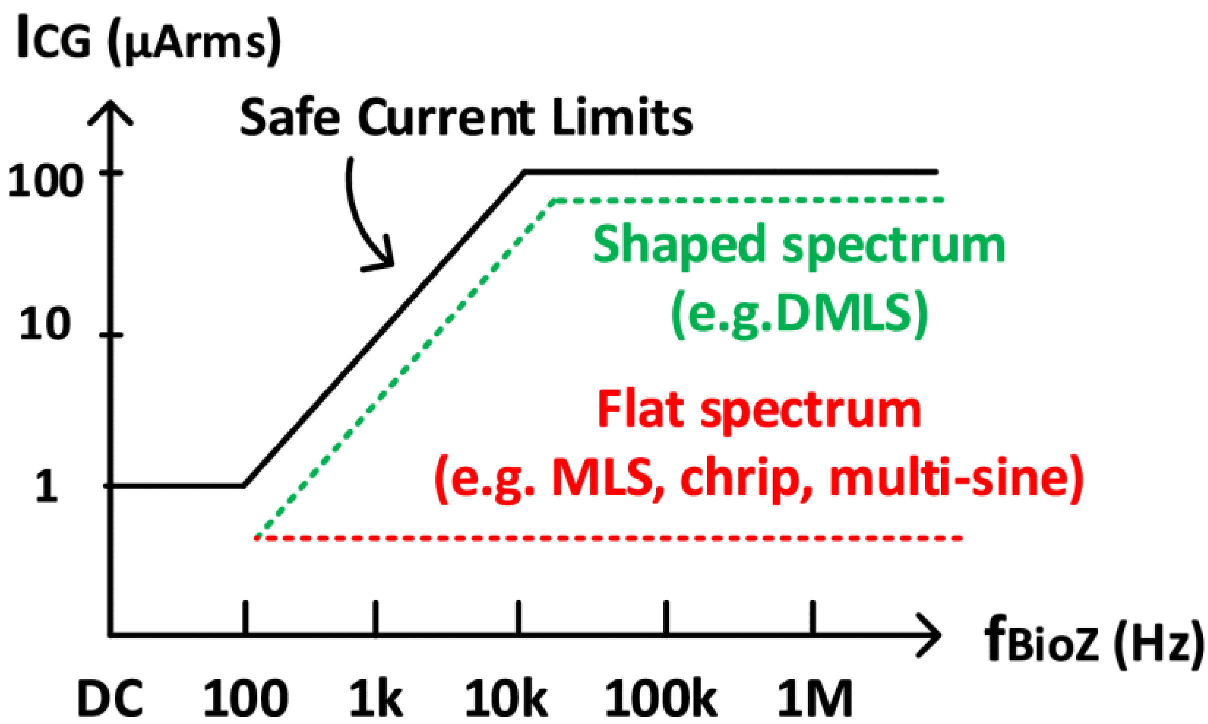
Subsystem Requirements:

Measure the heart rate and be accurate to within ± 2%. Filter out high frequencies and making the signal readable.

Impedance

The impedance component will also be on the main board with the microcontroller and EKG components. Like the EKG, it will also have two signal pins, one for sending current and the other to receive current. We will have to make a controlled current source that maintains a safe level of current as it passes through the heart. It will be an AC of less than 100 uA and will be controlled by the microcontroller.

The rest of the component will be an amplifier to boost the signal to be readable by the microcontroller, a low pass filter to filter out any higher frequency signals that can harm the patient, and along with some small filters for noise considerations.



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Disclaimer: Image shows safe currents through the arms, however our pads will be placed on or near the heart. Currents will be adjusted to safe levels with further research and consideration.

Subsystem Requirements:

Measure the body impedance to within ± 5% and doing so at a safe current level.

Microcontroller

The system receives analog signals from the ECG and impedance modules, which are processed by an ESP32 microcontroller to calculate and display heart rate and impedance values on the LCD. The ESP32 subsystem includes a USB-to-serial converter for programming, a power regulator for stability, memory for data storage and video caching, and protection diodes to safeguard the analog inputs. The processed data is sent to the LCD display for visualization, with all components working together to ensure accurate measurement, reliable operation, and clear output for the user.

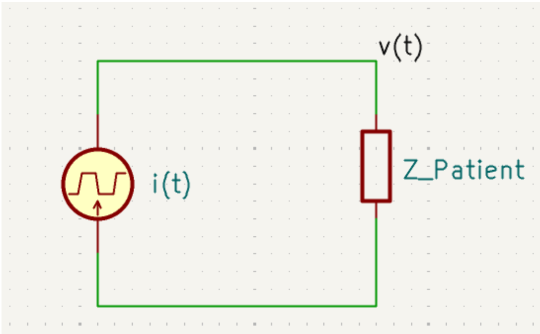
Subsystem Requirements:

Processing the data coming from the sensors and displaying it to the display.

Tolerance Analysis

The impedance module poses the greatest risk to successful completion because it requires safely injecting a small current into the patient. Additionally, there is limited readily available information on designing such devices.

The theory behind our design is to send a pulse-wave current into the patient and record the resulting voltage response. By sampling both the voltage and current at a sufficiently high frequency, we ensure adequate resolution in our measurements. After collecting several periods of data, we can convert the signals into the phasor domain by calculating their RMS values, and then apply Ohm's law to determine the magnitude of the impedance.



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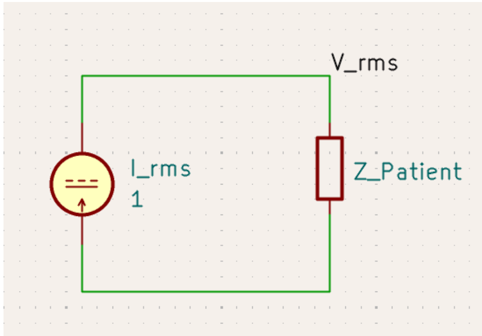

$$I_{rms}^{2} = \frac{1}{T}\int_{0}^{T}(i(t))^{2}dt$$

$$V_{rms}^{2} = \frac{1}{T}\int_{0}^{T}(v(t))^{2}dt$$

$$Ohms\ Law:\ V_{rms} = I_{rms} * Z_{Patient}$$

Ethics and Safety

Potential Safety Concerns

The primary safety concern is injecting current for impedance measurement. Secondary concerns include electrical hazards from the battery and DC–DC circuitry, as well as potential software errors in the microcontroller module. We mitigate these risks with careful circuit design, isolation, overcurrent protection, and thorough verification of software functionality prior to testing.

Safety and Regulatory Standards

Our project will comply with all relevant safety and regulatory standards throughout the design and development process. Because the planned design will involve passing a small electric current through human subjects to measure impedance, we will adhere to the American National Standard Safe Current Limits for Electromedical Apparatus, which specifies both the maximum permissible current levels to ensure human safety and the standardized testing procedures used to verify compliance. We will also follow the ECE 445 course battery safety standard, as the final device is intended to be portable and battery powered. All team members have completed the university's laboratory safety training, and we will strictly observe the requirement that a minimum of two people be present in the laboratory at all times during testing or design activities.

Ethical and Safety Issues

The primary safety concern in our project is the measurement of patient impedance, which requires injecting small currents into the body at different frequencies. While these currents are extremely low, we recognize the potential risk and are working with medical professionals to ensure they remain within clinically safe ranges. Potential misuses of our project include exceeding safe current limits during impedance measurements and assuming that the prototype can function as a fully operational AED capable of delivering shocks.

Ethical Standards

The IEEE Code of Ethics requires prioritizing public safety, health, and welfare, and promptly disclosing any factors that may pose risks. Our team will act lawfully, avoid conflicts of interest, reject bribery, provide and accept honest feedback, correct errors, make accurate claims, and give proper credit to others. We will maintain technical competence and only undertake tasks for which we are qualified or disclose any limitations.

Avoiding Ethical Breaches

To avoid ethical breaches, we will prioritize safety and honesty. We will only use clinically safe currents, clearly state that the device is a prototype and not a real AED, and thoroughly test all hardware and software before use. We will follow state and federal regulations, industry standards, and campus policies, and keep clear documentation of all procedures.