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High Voltage LED System for Optogenetic Control of Rhodopsin-expressing Zebrafish

Introduction

Design conditions

The Cardiac Autoregulation & Arrhythmias Laboratory had asked us to create device that can power 1-12 LED arrays. These arrays were to work in two modes.

- Mode 1 is to control the intensity of the LED such that it can follow a waveform input from the operator.
- This mode has a focus on precision and speed, as the waveform must be produced within 100us and accurate to within 1ms.
- Mode 2 is to flash the LEDs with specific controllable parameters regarding intensity, frequency and duration.

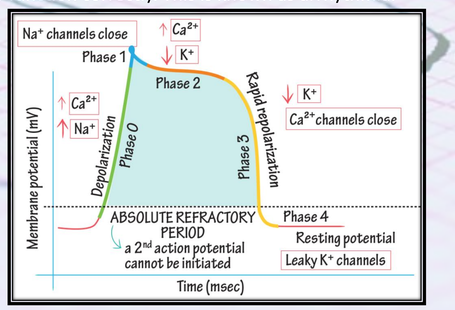
Use Case

- The device is to perform experiments on light sensitive cells, these cells react to light by changing their electric potential.
- Mode 1 is intended to change light intensity to form a specific waveform in heart cell's electric potential. This has the potential to stop arrhythmia.
- Mode 2 is intended to stress the heart through rapid stimulus, this is to provide damaged hearts for mode 1 to experiment on.

Background

Heartbeat and Arrhythmia

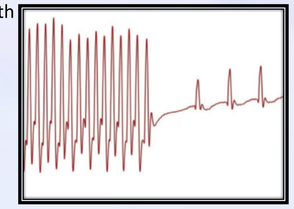
•The heart beats using electric signals.
•These electric signals, known as action potentials, spread across the heart with every beat, and cause the cells to contract.
•When the signal is disturbed, or out of sync with the surrounding cells, the heart fails to function correctly. This is known as arrhythmia.



•The action potential signal is caused by chemical changes in the cell through voltage activated protein channels and pumps.
•Depending on the concentration of ions in the cell, the cell membrane potential is pulled to a corresponding voltage. The changes in voltage over time form the distinct action potential wave.
•Different ion types have different effects on the cell voltage

Optogenetics

•Optogenetics is a technique for controlling cardiac and nerve cells using light.
•Made possible through light reactive proteins found in nature, engineered into cells.
•Optogenetic proteins act as light activated ion channels in cells
•There are different types of optogenetic channels, each activated by a specific light wavelength and each controlling specific ion types
•This allows for the control of the membrane potential of a cell through light, and thus control the cell.



Application

Through controlling the cells membrane potential it's possible to stop an arrythmia by forcing the signal back into a stable state.

Details of Design

Summary

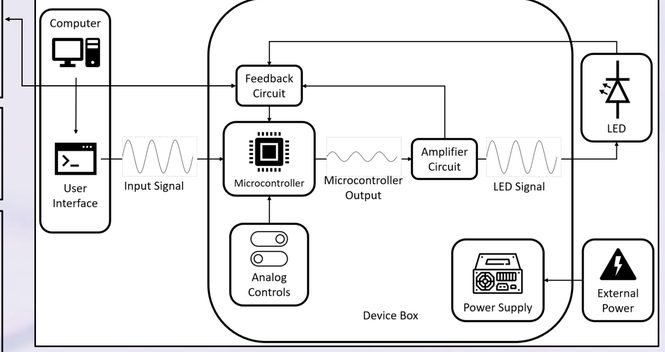
This device is an LED controller for optogenetic purposes. It is possible to choose the LED output signal using either the analog controls or the user interface. The microcontroller takes the input data from the controls and converts it to the desired output, which is corrected and boosted to the intended values using the amplifier circuit. The power supply provides filtered power to support all device systems and allow for precise values. The device supports up to 12 LED arrays.

Feedback Circuit
- Samples voltages at both the LEDs and in the amplifier circuit
- Converted to input signal for microcontroller
- Ensures output stability

PC Software
- User interface for inputting desired output signal and initializing/stopping output

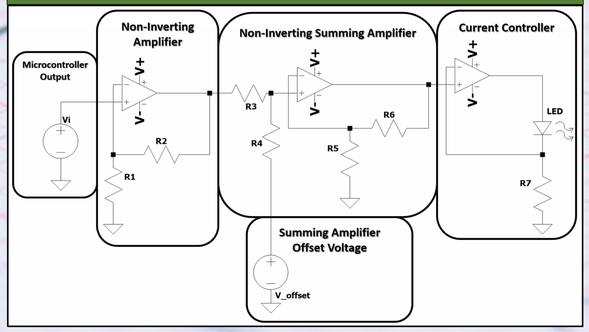
Microcontroller
- Takes input from PC
- Processes input data to determine output signal
- Outputs signal using built-in digital-to-analog converter
- Uses feedback signal to correct output

Full Device



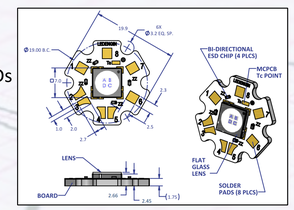
Analog Controls
- Device controls without PC connection
- Limited to simple signals

Amplifier Circuit

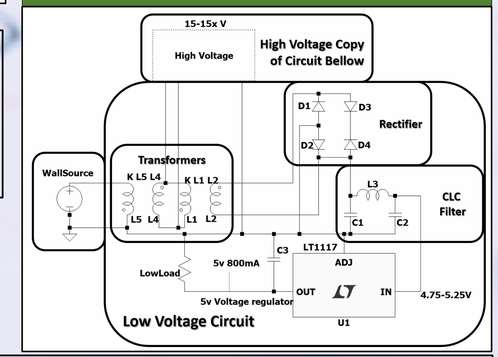


Amplifier Circuit
- Amplifies microcontroller output to LED operating range
- Non-Inverting Amplifier increases signal amplitude
- Summing Amplifier adds offset (the LED only activates at 700mA)
- LED is current controlled for more linear radiant flux control

LEDs
- 1-12 LEDs
- 1-4 sets of 1-3 LEDs in series
- Easy to add or remove LEDs

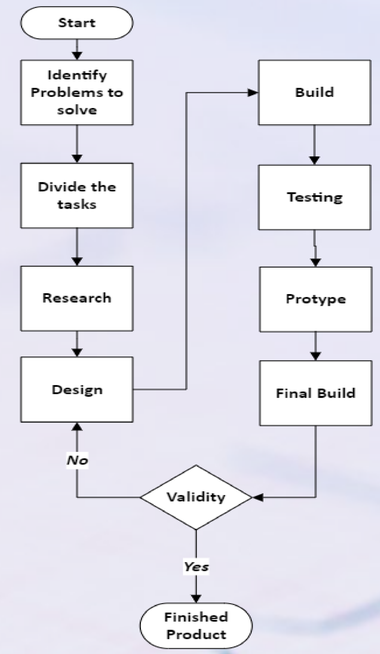


Power Supply



Power Supply
- Accepts basic wall 120V 60Hz output and transform it to voltages used by amplifier subcircuit, as well as a lower 5V to power accessory circuits
- Both high voltage and low voltage lines are converted from AC to DC power using full bridge rectifiers and filters
- Low voltage line has manufactured voltage regulators available
- High voltage line requires custom designed voltage regulator

Design Process



Conclusion and Recommendations

- The device should be viable for production in its current state, it would benefit from optimization and the addition of secondary features.
- Potential features include hot swap LED's, independently addressable LED's when using more than one, indicators for analog control, full analog controls for mode 2 and possible analog control for mode 1.
- Potential optimization can be found in part selection for a lower price, specifically the ratio of signal amplification sets vs the price of different voltage power supplies.
- A lowpass filter may need to be added to amplifier circuit to reduce noise. This decision will be based off test results.
- Safety considerations must be taken to avoid electrocution risks. The LED current and voltage are high enough to be dangerous.

References

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