Proposal:
Application of IR-transmitter/receiver as PPG finger pulsometer

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Abstract

An infrared finger pulsimeter is proposed as a creative and useful application for the transmitter module of the Optical Link project. The criticality of efficient and user-friendly heart rate measurement for both health and personal fitness applications is outlined, and background theory of photophelthysmography (PPG) for pulsimetry is overviewed. The proposed device operation is described, including the key features of the pulsimeter. Preliminary measured characteristics of the Optical Link transmitter/receiver are given, and their effects on pulsimeter functionality are discussed. Relevant qualifications of both team members are stated and sufficient experience with the necessary technology is demonstrated. Lastly, a cost analysis for design and production of the proposed pulsimeter is performed.

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1 Introduction

This proposal is written in reply to a call for proposals for creative applications of the transmitter module of the Optical Link project, shown as a system-level schematic in Figure 1.

Figure 1: System-level schematic of the optical link

The overall Optical Link project concluded with the implementation of both an LED signal transmitter and receiver/amplifier, serving as a platform for simple wireless communication at a range of tens of meters.

A heart rate monitor, widely known as a pulsimeter, is an increasingly well-known medical device that can be designed to incorporate infrared (IR) optical signal technology. In this exposition, the effectiveness of IR as a carrier signal for the pulsimeter application will be considered, and the importance of pulsimetry to both healthcare and personal fitness will be discussed.

2 Background

In both the general medical field and in personal fitness care, heart rate (pulse) is one of the most important metrics of human performance. Heart rate as a variable is dependent upon seemingly limitless factors: exercise, physical health, mental emotions and stress, drug and alcohol use, and all variety of health hazards. As a result, the ability to measure it precisely, efficiently, and cheaply is of strong importance to medical professionals and laypeople alike.

Literature review of both craftperson websites and scientific/medical journals has aided in the development of this IR transmitter application. Websites [1] and [2] demonstrate the feasibility for technology-savvy persons to develop their own pulsimeter at home, although notably, neither makes use of IR optical signals. [3] provides a detailed summary of the development of PPG pulsimeter devices to date, and argues clearly for their necessity to all manner of medical assessment. [4] evalutes novel proposed pulsimetry techniques, in particular with regard to noise filtration and adaptation of pulsimeter devices to related applications such as the measurement of oxygen concentration in blood, and measurement of artifacts and arrythmias in heart function. Overall, pulsimetry is a very well-known area of study, and myriad data is publicly available to aid in the adaptation of this particular Optical Link transmitter for heart rate measurement.

3 Proposed Work

A block diagram for the overall operation of the proposed pulsimeter device is shown in Figure 2.

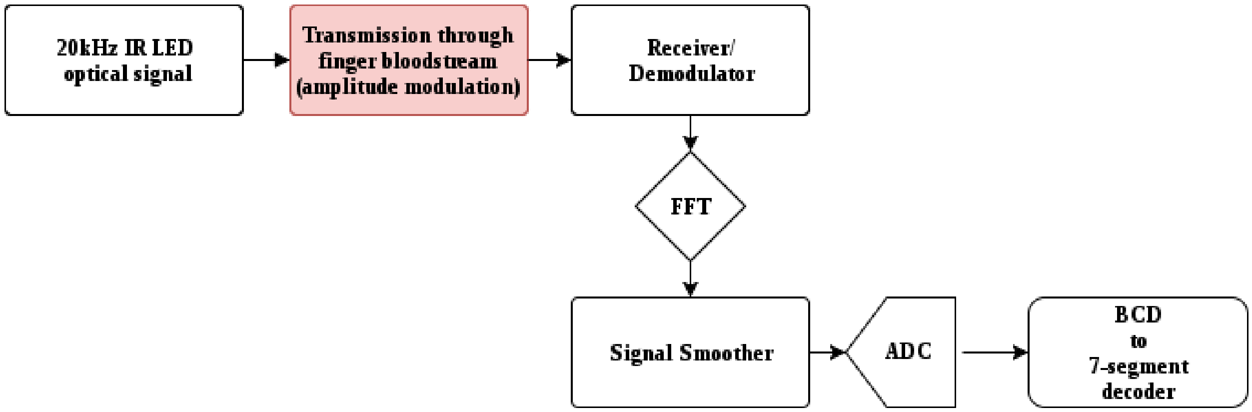

Figure 2: System-level schematic of the pulsimeter

The already-implemented Optical Link transmitter and receiver will be supplemented with an analog demodulator, which will extract the PPG heart rate signal from the 20kHz carrier frequency. This signal will be Fourier-transformed in order to measure the fundamental frequency which corresponds to heart rate. Additional signal processing and smoothing will be provided by a programmable digital signal processor (DSP) chip. The diverse calculating power provided by this chip will allow the pulsimeter design to be expanded to suit consumer needs; in many heart-monitoring applications, additional signal processing to measure the variability of heart rate and to identify heart disfunctions.

The signal input to this device will be the density of human bloodflow, measured from finger blood vessels. The opacity of water to light in the near-infrared range makes such a measurement technique viable. The primary additional input will be an on/off switch controlling current flow from the 9V power supply.

The pulsimeter will output a constantly-updating numerical heart rate value on a three digit, 7-segment display for easy user interfacing.

4 Preliminary Results

The previously constructed Optical Link transmitter module consists of a CMOS astable multivibrator circuit providing the input signal for an LED driver circuit. A schematic for the combined implemented transmitter is given in Figure 3.

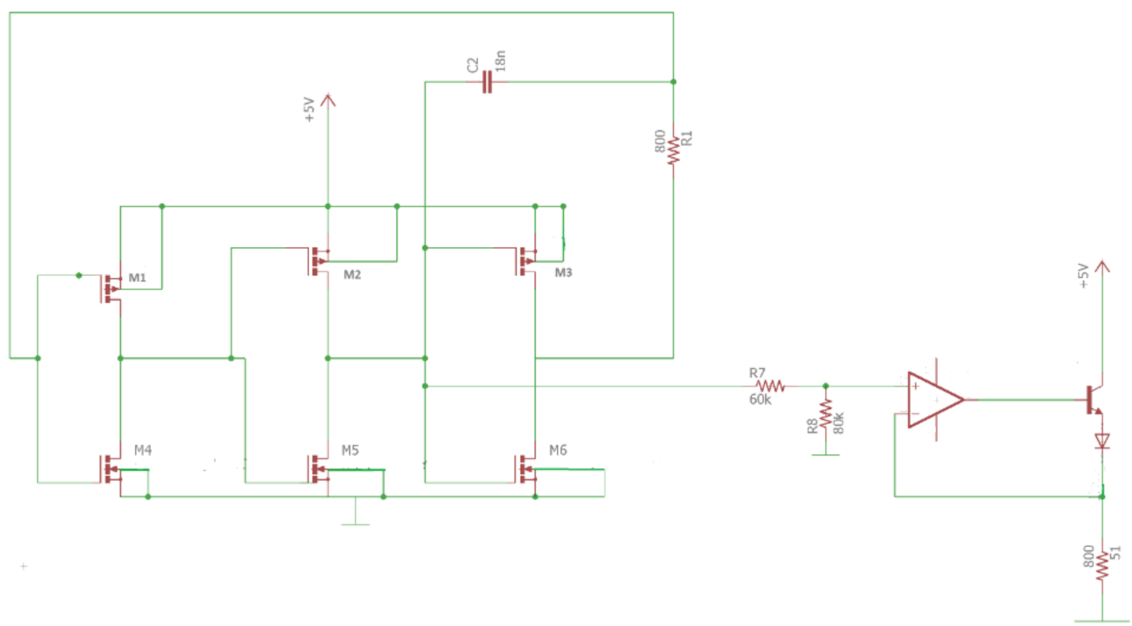

Figure 3: Circuit schematic of implemented transmitter module

The astable multivibrator in Figure 3 is constructed on a single CD4007 MOS package, which includes three NMOS and three PMOS transistors. The adjacent LED driver circuit includes an MCP6004 quad-op-amp and a 2N3904 NPN BJT, controlling current through an IR1503 infrared LED.

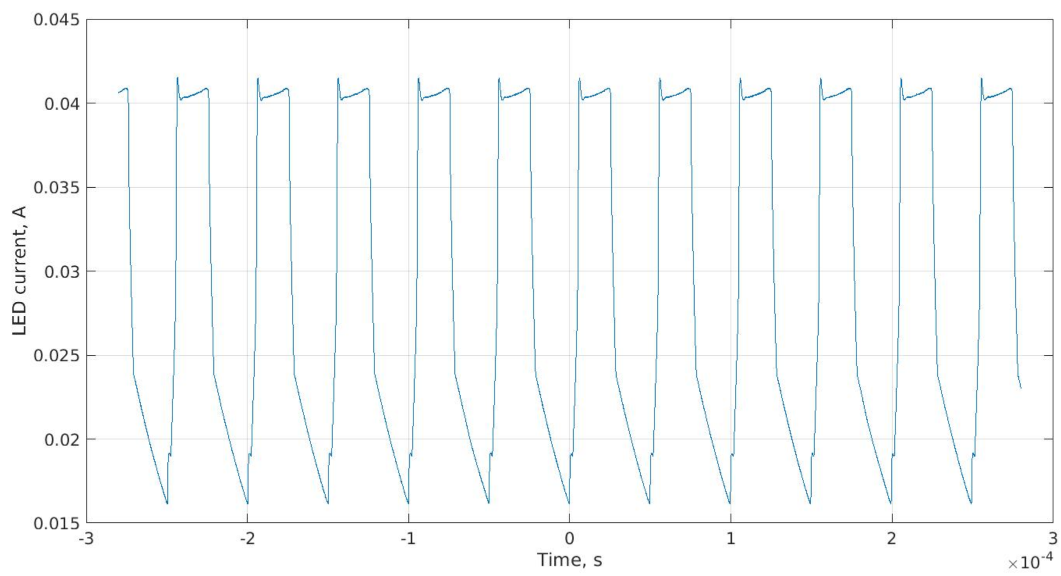

Figure 4: Current signal of implemented LED driver circuit

As shown in Figure 4, the maximum LED current measured was 40.5 mA, with a duty cycle of 44.89%. This duty cycle was determined with TA guidance to be sufficiently close to the ideal 50% for successful optical signal transmission to occur.

On the receiving end, an OP999 photodiode was applied to convert the optical signal to a current signal, which was then magnified via a transimpedance amplifier (TZA). This combined circuit is shown in Figure 5.

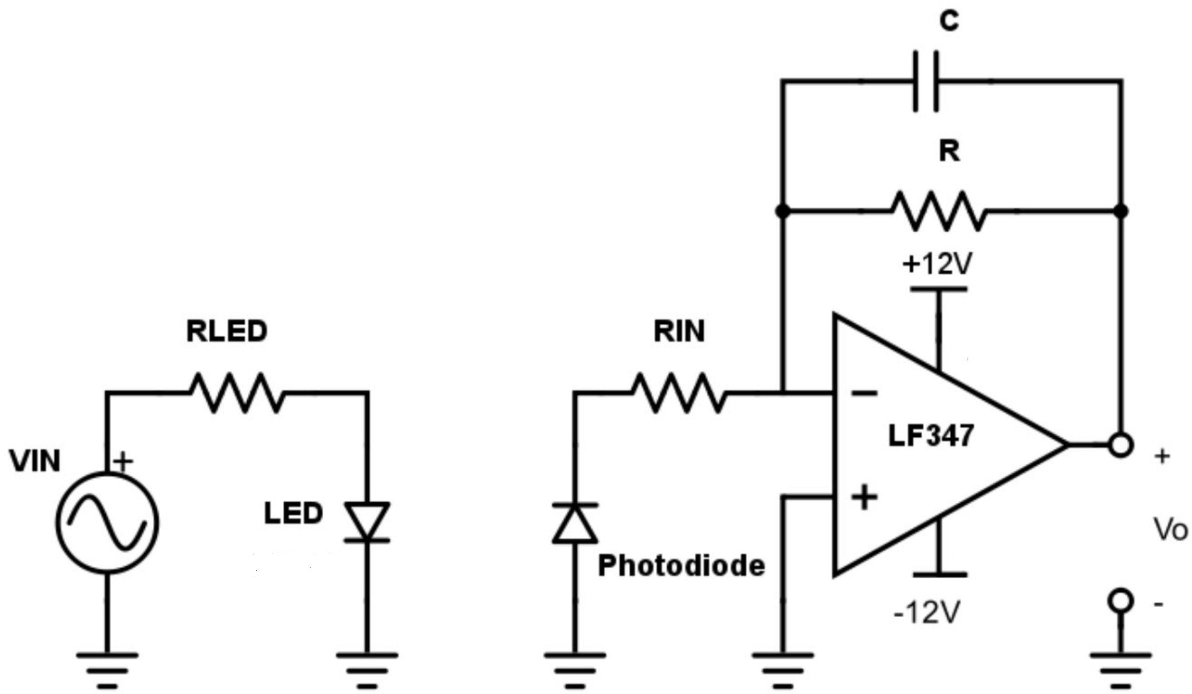

Figure 5: Schematic of implemented TZA/photoreceiver and test LED signal

The frequency response for the above circuit is shown in Figure **??** with slightly varied resistor and capacitor values, demonstrating the adaptability of this particular op-amp topology.

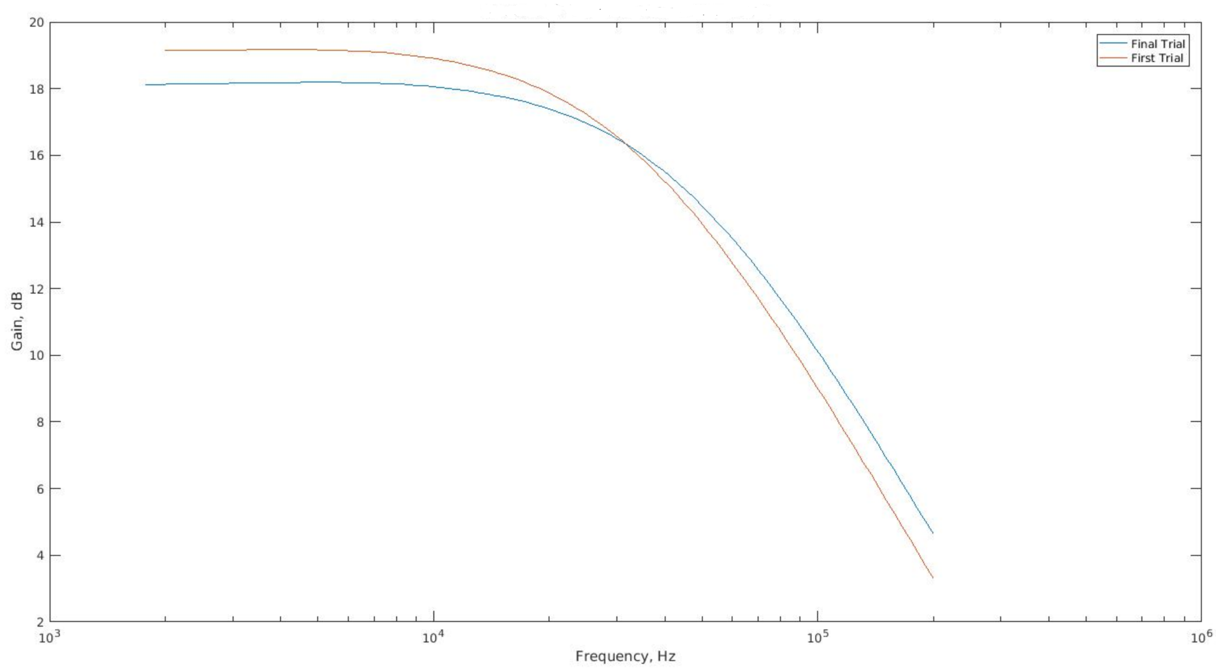

Figure 6: Frequency response of TZA receiver for two sample compone selections

The 20dB gain demonstrated in the above response was supplemented in the Optical Link project by a subsequent 60dB gain multiple-feedback bandpass filter centered at 20kHz. For this application, such a bandpass filter would eliminate desired heartrate modulation frequencies; however, a low-pass filter with similarly high gain would pose an effective replacement.

5 Team Qualifications

Both Graham and Berkay have completed, at the time of receipt of this proposal, a semester course ECE 342 in Electronics which included the design, construction, and successful testing of the Optical Link Project. This course has covered the theory and use of transistor filters and amplifiers, both of which will be necessary for the design of the IR finger pulsimeter. They have also both completed a semester course ECE 275 in Digital Logic, which specifically included the use of BCD-to-7-segment encoding and relevant Verilog logic circuit design, likely to also be necessary for the pulsimeter.

Graham has completed a semester course ECE 314 in Signals and Systems, which included the analysis of amplitude-modulated signals as well as demodulation, both of which will be necessary for the design of the IR finger pulsimeter. He is a junior undergraduate in good standing, studying electrical engineering and physics at the University of Maine.

Berkay is a third year student at the University of Maine double majoring in Electrical and Computer Engineering. Prior to this project, he has worked on a radar project with REU program which consisted of building a data acquisition system to determine the health of honey bee colonies.

6 Cost Analysis

The attached cost analysis spreadsheet outlines the necessary expenditures for both development and mass production of the proposed pulsimeter device. Parts of the currently-implemented Optical Link device were specifically accounted for in this analysis, whereas parts of the outlined signal processing elements of the pulsimeter were more approximately considered, as specific chip choices will be subject to change as development progresses.

In the table below, the final cost of the project is summarized with NRE and manufacturing costs as well as sales/marketing and profit margin. The cost of each section is outlined in further detail in the attached Appendix.

Determining Selling Price	
NRE Costs	$9,600.00
Manufacturing Costs	$7,920.33
Sales/Marketing	$3,504.07
Profit Margin	82%
TOTAL SELLING PRICE	**$38,306.45**
PRICE PER CIRCUIT	**$9.58**

It is to be noted that the customers will be responsible for supplying their own batteries and covering shipping costs while purchasing the product. This will help to lower the cost to consumers of the pulsimeter device itself.

7 Conclusion

An infrared finger pulsimeter was proposed as a creative and useful application for the transmitter module of the Optical Link project. The components and function of the pulsimeter device were described, including important features and benefits. Preliminary measured characteristics of the Optical Link transmitter/receiver were given, and their effects on pulsimeter functionality are discussed. Relevant qualifications of both team members were stated, and a cost analysis for both design and production of the proposed device were performed.

8 References

[1] Jul 17, 2013 Daniel Torres | Electronic Design. (n.d.). Build A Wrist Heart-Rate Monitor Using An Ultra-Low-Power MCU. Retrieved December 12, 2016, from http://electronicdesign.com/digital-ics/build-wrist-heart-rate-monitor-using-ultra-low-power-mcu

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