ENG 451

Lab 5

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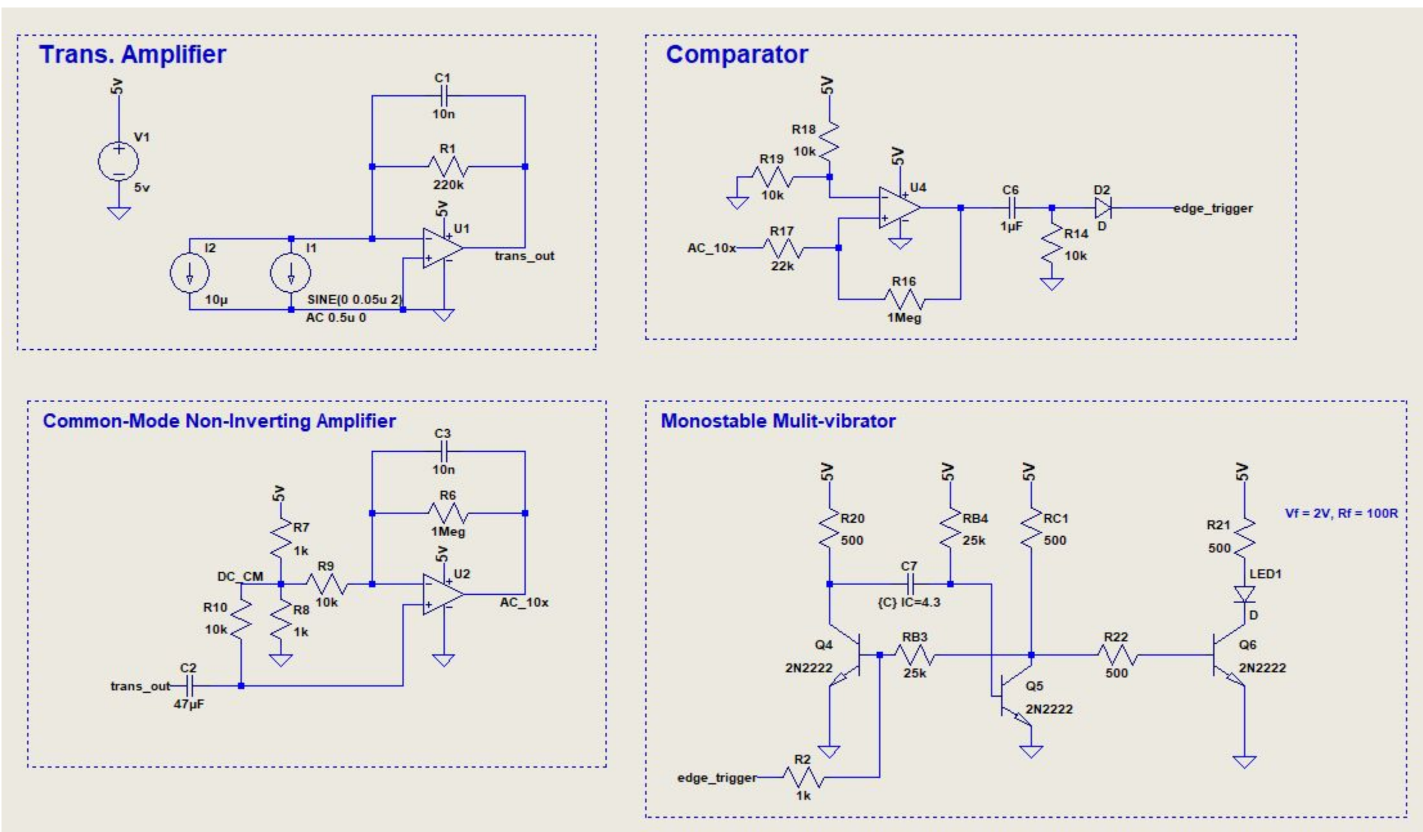
1.0 - Introduction

The final stage of the PPG sensor designed in ENGR451 includes a pulse detection circuit and output driver to flash an LED as an optical indication of a measured heartbeat. The component selection in the circuit is crucial, as the bias points and quiescent currents influence the transistor's operation modes, and more importantly the time constants used to trigger the LED.

2.0 - Circuit Schematic

The circuit's principle of operation is discussed in order to validate design decisions for selecting resistors; R_{c1}, R_{c2}, R_{b2}, R_{b3}, R_d, and R_{in} along with capacitors C_{in} and C_1.



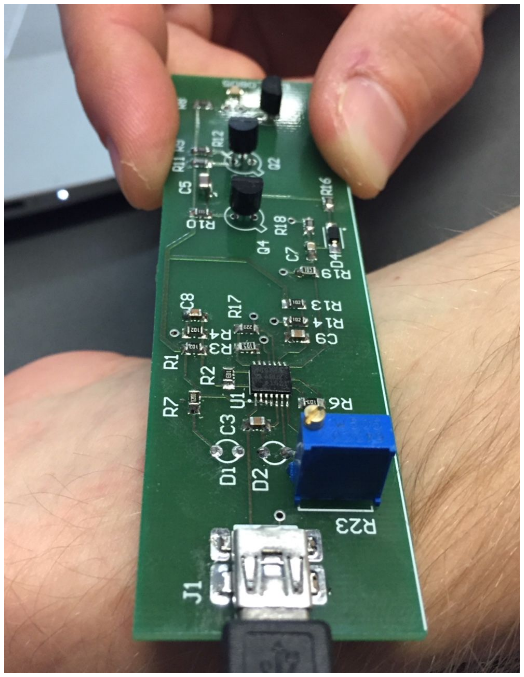
2.1 - Passive Component Selection

The final selection of circuit components are summarized below. The derivation and calculations of these component values can be found in previous lab reports.

Component	Values
Rd1	72 Ohm
Rf	220 kOhm
Cf1	100 nF
C1	2.2 uF
R1, R4	100 kOhm
R2, R3	10 kOhm
R9	1 MOhm
R8	20 kOhm
Cf2	10 nF
R_{c1}	500ohm
R_{c2}	500ohm
R_{b2}	25Kohm
R_{b3}	25Kohm
R_d	170ohm
R_{in}	10Kohm
C_{in}	1uF
C_1	10uF

3.0 - Final Board Design

The final experimental setup and board design can be seen below. The three op amp stages are packaged in ADA4891-3ARUZ-R7 integrated package and power is supplied from a Mini-USB. The detecting and emitting diodes are located on the back of the board for ease of use. A 3D model of the board from Altium is included.

(a) 

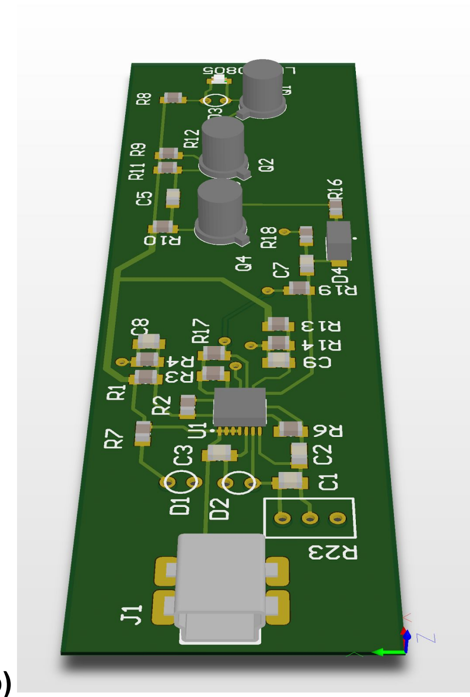
(b) 

Figure 4.1 -(a) Completed heartbeat sensor in operation and the (b) Final board designed in ALTIUM

4.0 - Experimental Results Comparison

The following table compares the scope captures obtained in the lab against the simulated waveforms from LTspice. The similarities and discrepancies are explained below.

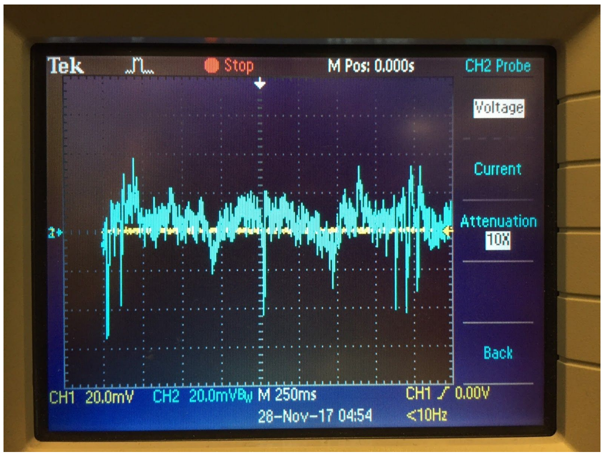
<table>
<tr><th>Experimental</th><th>Simulated</th></tr>
<tr><td>


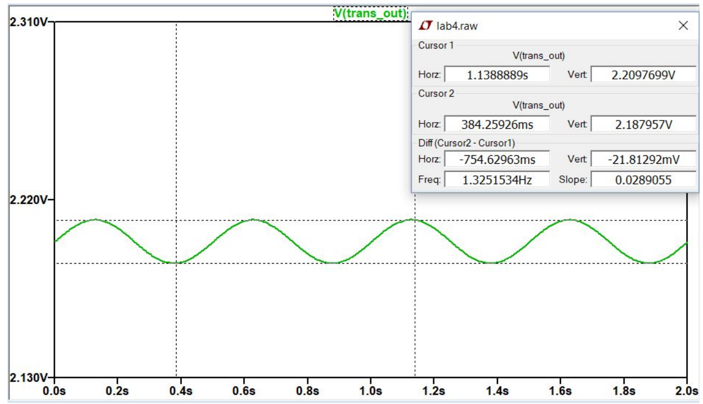
Figure 4.1.2 - V_{o1} Scope Capture
</td><td>


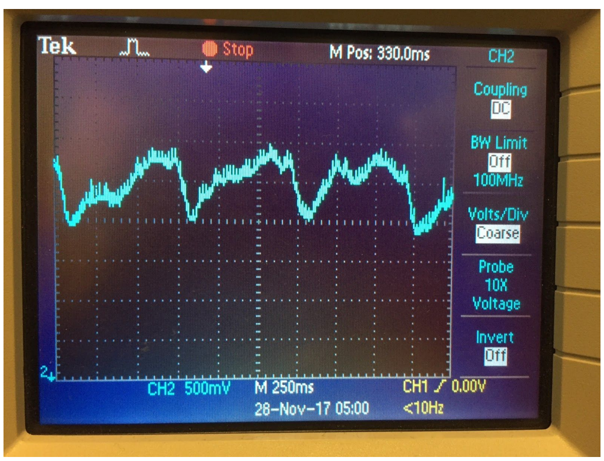
Figure 4.1.3 - LTspice waveform
</td></tr>
<tr><td>


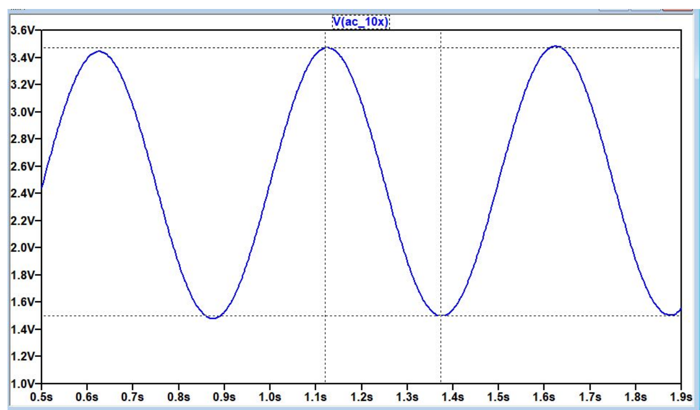
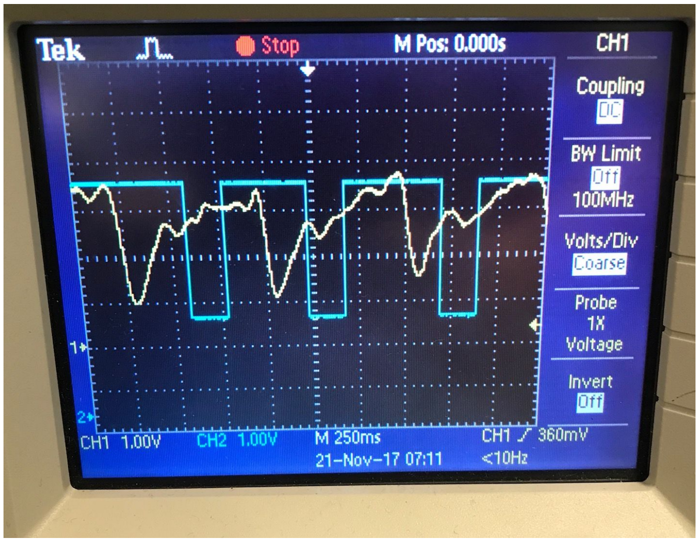
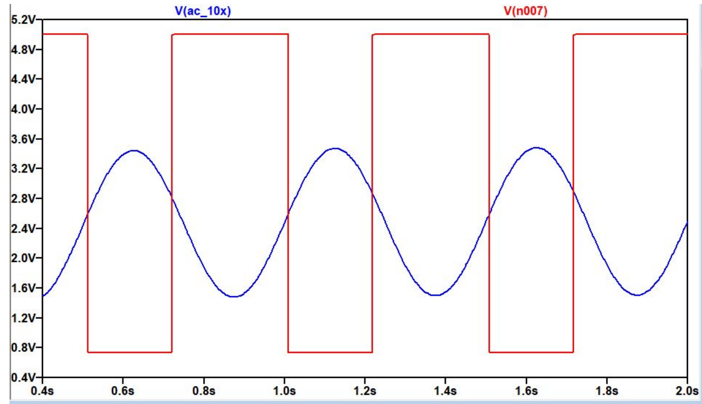
Figure 4.1.3 - V_{o2} Scope Capture
</td><td>


Figure 4.1.4 - LTspice waveforms
</td></tr>
</table>

 Figure 4.1.5 - V_{o2} (yellow) & LED Anode (blue)	 Figure 4.1.6 - LTspice waveforms

Figures 4.1.2 & 4.1.3 compare the output of the transimpedance amplifier. The output waveform in LTspice is generated using a sinusoidal small signal current source. The amplitude of this source was set based on current characteristics identified for the photodetector in the first lab (see schematic). As a result, it's no surprise there is some discrepancy in amplitude between the experimental and simulated transimpedance output.

Figures 4.1.4 & 4.1.5 compare the output of the second stage, the non-inverting amplifier. The pk amplitude voltage is ~500mV in the physical circuit. Again, this can be attributed to the quality of contact between the photoemitter/diode and the patient's skin. The common-mode DC level of 2.5V set by the voltage divider R7 & R8 is present at the output of both the simulated and physical circuit. This DC level is necessary downstream for the comparator to operate correctly. The shape of the simulated wave is perfectly sinusoidal and is different from the real heartbeat pulse showing a dicrotic notch.

The final two figures in the table compare the amplified AC-signal (mentioned previously),as well as the mulitvibrator circuit used to pulse the LED. The scope capture (in blue) shows the voltage at the the LED's anode. When Q6 is driven into saturation mode, this voltage drops to ~2V for a duration of 200ms (while the LED is ON), the exact time constant set by R_c, R_b, & C_1 in lab 4. A discrepancy in the low-level voltage exists because in spice, the diode model had a forward drop of 0.7V, whereas the LED used in our circuit has a V_f of 2.2V. This confirms the operation of all four circuit stages.

5.0 - Test and Optimization

Prior to fabricating a board, the PPG sensor was implemented on a single copper clad milled with a small CNC machine. The prototyping of the board was important in verifying the effectiveness of our sensor. Initial testing showed that some heartbeat pulse caused false triggers. In response to this, R9 was decreased to 500kOhm to increase the hysteresis band.

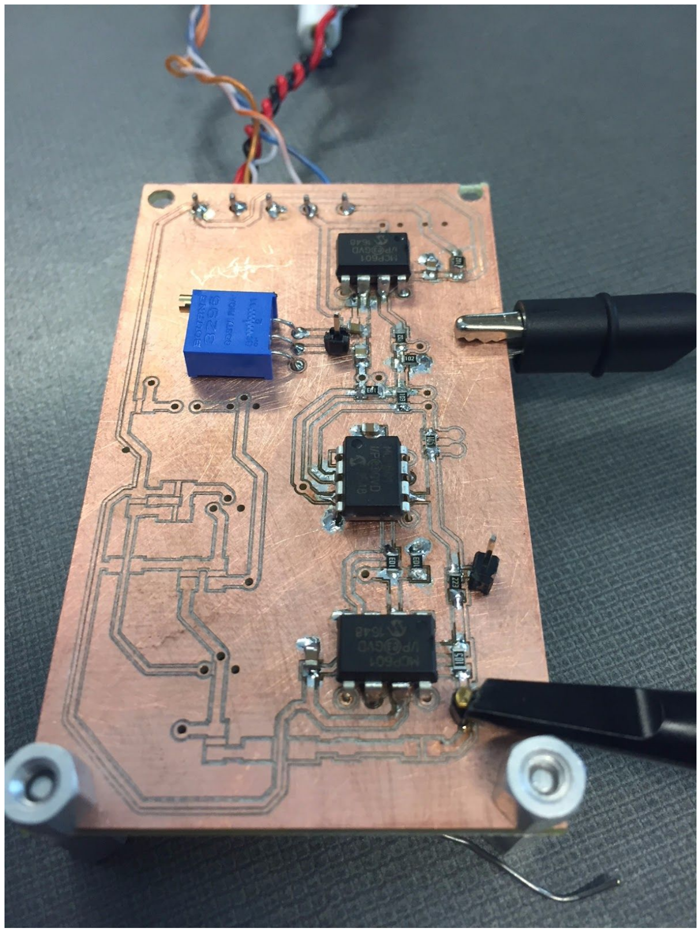


Figure 5.1 - A single copper clad test setup is prototyped and tested prior to complete circuit board fabrication. Note: This image was taken before the complete PPG sensor circuit was soldered on the board.

6.0 - Future Improvements

The heartbeat sensor operates as designed. The induced current in the photodetector is extremely sensitive to placement on the skin and as a result the heartbeat sensor is sensitive. In some instances, the placement of the sensor causes the amplified signal V01 to rail at 5V at the transimpedance amplifier. The operation of this sensor could be improved by the addition of feedback. A control stage for regulating the output DC level to an ideal 2.5V is proposed below in figure 6.1.0. The added op-amp begins to drive the BJT at it’s output in the linear region to increase/decrease the collector current. As a result, the voltage across the trans-impedance amplifier's feedback resistor changes. This voltage is fed-back to the control op-amp. By driving the BJT, the op-amp regulates the output to make its input terminals equal, thus regulating the DC output voltage to the target to 2.5V over a range of currents sunk by the photodetector. This circuit has been simulated and shown to operate effectively with a DC current level of 5-25uA.

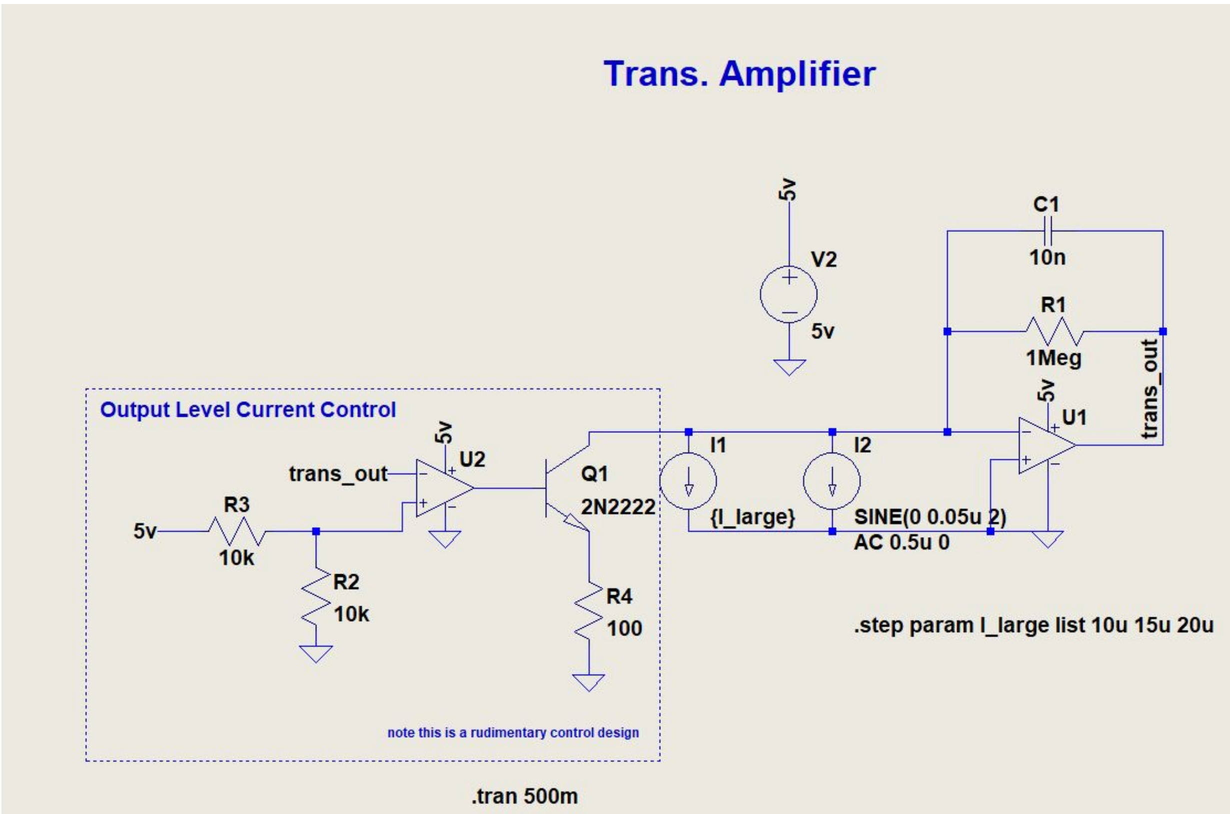


Figure 6.1.0 - DC output regulator for Trans-impedance ampifier

4.0 - Conclusion

A functional heartbeat sensor and indicator circuit is successfully synthesized from intermediate stages consisting of a (1) lowpass filter and gain stage, (2) high pass filter and common mode amplifier, (3) comparator with hysteresis band, (4) differentiating edge detector, (5) monostable multivibrator and (6) LED driver. The complete circuit is designed in Altium and milled out of a single layer copper clad board. The results and bench testing show design goals were met and circuit functionality was complete.