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Lab 7: Project

AJW
5/1/23

Heart Rate Monitor

Equipment/Materials:

Part	Amt	Part	Amt	Part	Amt
74193	4	MCP6002	1	10KΩ Resistor	1
74192	2	7414	1	22KΩ Resistor	1
7-Seg	3	7404	1	Photo transistor NPN	1
7447	3	100K Trim Potentiometer	2	2N3904 NPN	1
0.01μF Cap	2	10K Trim Potentiometer	1	Buzzer	1
0.470μF Cap	1	1KΩ Resistor	2	555 Timer	2
47μF Cap	1	Super Bright LED	1	7408	1
22μF Cap	1	LED	1	7432	1
		220Ω Resistor	1	7476	1
		330Ω Resistor	1	330Ω Resistor Pack	3

Objectives:

1. Use knowledge aquired throughout this semester to design and construct a heart rate monitor.

2. Demonstrate the ability to find data sheets for new components, and use them to design my project.

3. Demonstrate the ability to ~~represent~~ AJW accurately analyze, predict and measure relevant values.

4. Demonstrate the ability to convert an analog input to a TTL input.

Theory of Operation

In this lab, I will be using everything that I have learned so far, to construct a heart rate monitor. In order to do this, I want to turn my heart rate into pulses on a square wave, which I can then use with counters to display my BPM (Beats per minute). To do this, I will be using an LED inside of a clip that goes on your finger, which will illuminate my finger with light. On the other part of the clip, will be a photo transistor, which will detect my pulse by detecting the change in light as my heart pumps blood through my finger.

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My approach to this will be abit different compared to other labs, as I will have to play around, and try different things to find what works.

Figure 7-1-1: Heart Rate Sensor

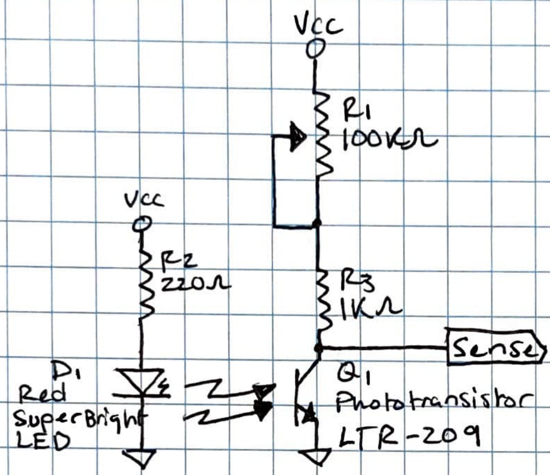

Table 7-1-1 LTR-209 Limitations

Parameter	Value
Power Dissipation	100mW
Collector Dark Current	100nA
On State Collector current	4mA
V_{CE} Breakdown	30V
V_{EC} Breakdown	0.4V

This is the circuit that I found worked the best for detecting my pulse with this phototransistor. I tried different colored LEDs, Infrared LEDs, and found that having the Red Superbright LED on your finger tip, with the transistor on the nail works the best. I have a 220 LED to give it a bit more current to make it brighter to give myself the best illumination. The 1kΩ resistor with a 100kΩ Trim pot are to bias the transistor, so that I can tune it for the best signal out. The 1kΩ is mainly a current limiting resistor to make sure that the transistor is not out of spec, even if the rheostat is 0Ω.

I then need to amplify this Vsense as it only gave me around 50mV out. So I will use an MCP6002 Op Amp. What I found with this however, is that I had a loading issue, resulting in no output from the amplifier, so to correct this, I had to use a voltage follower as a buffer to impedance match my input to the amp which has a high Zin. Then I can put this amplified heart beat into a Schmitt trigger to give me a nice square wave output at 0V to 5V, and this will also help reduce any oscillations I might have from my signal.

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Now, when I built my amp, I found that I had some high frequency oscillations, so between my voltage follower, ASW and my amplifier, I made a low pass filter out of a 10KΩ resistor and a 330µF capacitor, to filter anything above half of a Hertz. However, it took nearly 10 seconds to start giving you a signal for your heart beat, so I began experimenting by swapping the resistor for a 1KΩ one, and tried lower capacitance values. I ended up with a filter made up of a 1KΩ resistor and a 47µF capacitor. It now takes about 2-3 seconds to give you a signal for the capacitor to adjust to the input of your finger. This doesn't give quite as clean of a signal but still works great with the Schmitt Trigger.

~~Figure 7-1-2: Amplifier Stage~~

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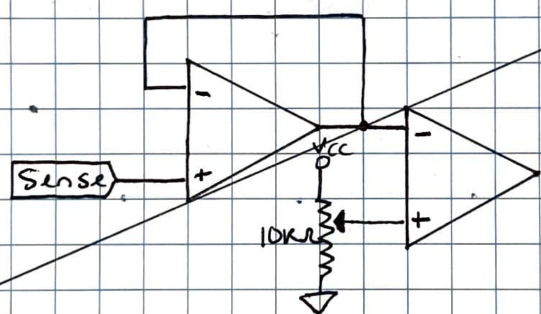

Figure 7-1-2: Amplifier Stage

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ASW
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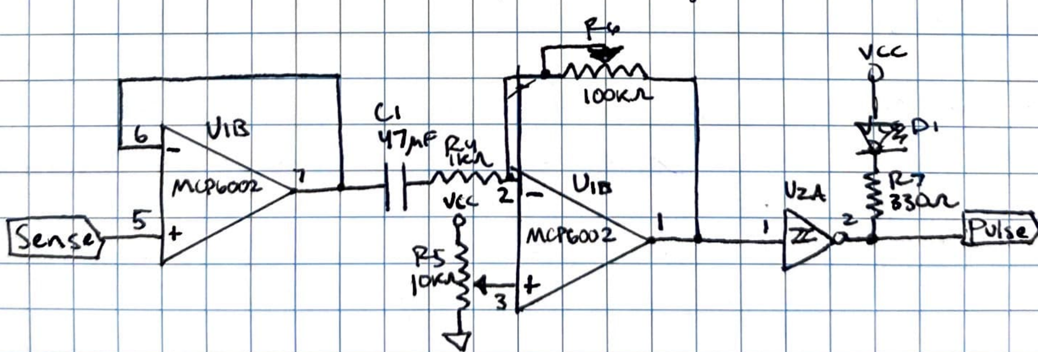
9:30



So this circuit will amplify my heart beat, and turn it into a square wave using the Schmitt trigger. With this, I hooked up an LED to the output of the trigger, and it will give us a normal low, lighting the LED, and a pulse will give me a high, turning it off every time that my heart beats, giving me a visual indicator, but also telling me if I have any oscillations by seeing it flicker when I do.

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The potentiometers on the amplifier are used to hone the amplifier, while the 10K (R5) sets my DC voltage or my zero point. And R6, the 100K is used to set my gain, I ended up just maxing it out to get the most out of it, this made it so that I could get a gain of around 100 with the 1KΩ resistor in there, and made it so I could amplify my ≈50mV to about 5V, which is perfect for trying to make it a digital signal using my schmitt trigger. As well, with my VDD pin to Vcc w/ 5V, it would make it clip at 5V, and 0V, due to Vss being to ground.

Calculations

Now that I have my base circuits, I want to find my Worst Case Loading Calculations so that I can ensure that everything is in spec.

Table 7-1-2: Loading Calcs for Figure 7-1-1

Worst	U#, Pin#	Value
V_{OL}		
V_{OH}		
I_{OL}		
I_{OH}		

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$I_{csat}: R_1 = 0\Omega$
$I_{csat} = V_{cc}/R_3$
~~$I_{csat} = 5V/1k\Omega$~~
$\boxed{I_{csat} = 50mA}$

So with just a 1kΩ resistor, it would actually be out of spec, as it is more than the 4mA in the data sheet, minimum Resistance there should be at least 1.25kΩ to keep it in spec no matter what.

Table 7-1-2: Loading Calcs for Figure 7-1-2

Worst	U#, Pin#	Value
V_{IL}	U2A, 1	0.4V
V_{IH}	U2A, 1	5V
I_{OL}	U2A, 2	7.879mA
I_{OH}	U2A, 2	0A

$I_{OL} = (V_{cc} - V_D - V_{OL})/R_7$
$I_{OL} = (5V - 2V - 0.4V)/330\Omega$
$\boxed{I_{OL} = 7.879mA}$

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Now, I want to hook up a buzzer, to beep as your heart beeps, so I want to beep it on a high. However, it requires a lot of current (over 20mA), so I need to create a driver using a transistor. However, I also don't want it to beep for an extended period of time if left saturated, so I need to come up with some logic to prevent it from constantly buzzing.

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This was the idea that we had come up with for this purpose.

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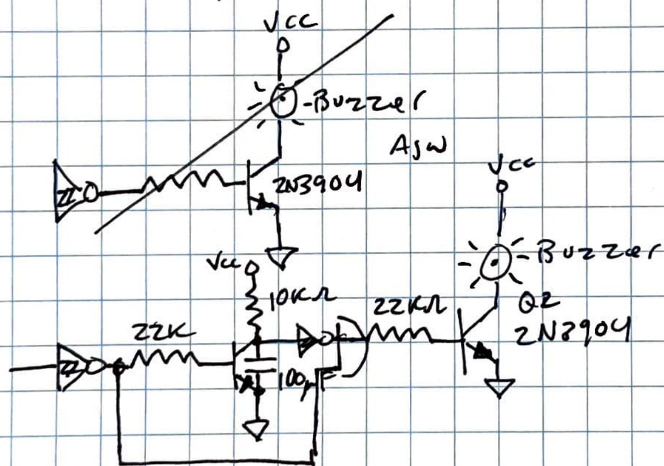
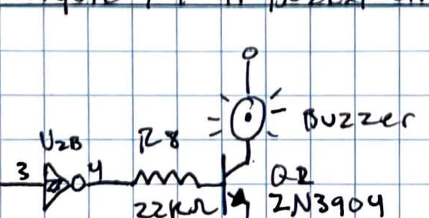
Figure 7-1-3: Buzzer Circuit V1:



The idea with this circuit was to drive the buzzer, but if left saturated for too long, then it would turn off the buzzer, so if anything happened, then it would turn off after a few seconds. However, it didn't really discharge fast enough to work, and charge quick enough to beep it properly. Plus, it also made it always give off this sort of squeal, so we scrapped that and just used a single driver with no cap, because it didn't work like we wanted it to anyways. So this was the circuit that I soldered onto my board.

Figure 7-1-4: Buzzer Circuit V2



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For this circuit, the buzzer wants a lot of current, so that is why I had to use a driver for it, to not damage my TTL components. And I had to make sure to keep I_B high to keep I_C high. For that, I want to keep it saturated when the output of my schmitt trigger goes high.

$I_B = (V_{OH} - V_{BE})/R_B$
$I_B = (4V - 0.7V)/22K$
$\boxed{I_B = 150\mu A}$

$I_C = I_B \cdot \beta$
$I_C = 150\mu A \cdot 200$
$\boxed{I_C = 30mA}$

It's hard to say what my I_{Csat} is, as I don't have any specs for the buzzer.

Measurements

In order to measure this circuit, I had to tune it. To do this, I adjusted my potentiometers while looking at the output of the collector, and both the input and output of the schmitt trigger. I tuned the first 100KΩ one to bias the photo transistor, and get the highest output of it. The 2nd 100KΩ was adjusted to get the most gain that I could. And the 10KΩ was to adjust the input voltage for the amplifier, and adjust the DC level of my output.

I then used the LED as an indicator as to whether or not I was getting a clean signal. This circuit is pretty touchy and there are so many things outside of the circuit that affect it.

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~~Project 7:~~
Lab 7 – Project

Waveforms / Diagrams

Figure 7-1-5: Measured Collector Output

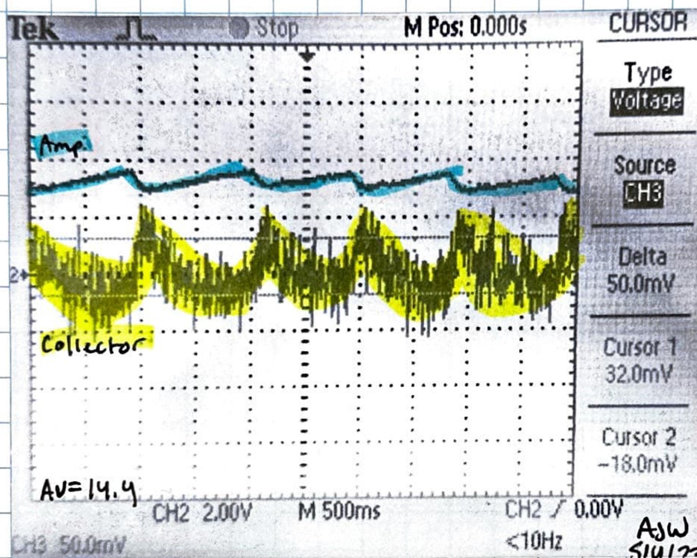

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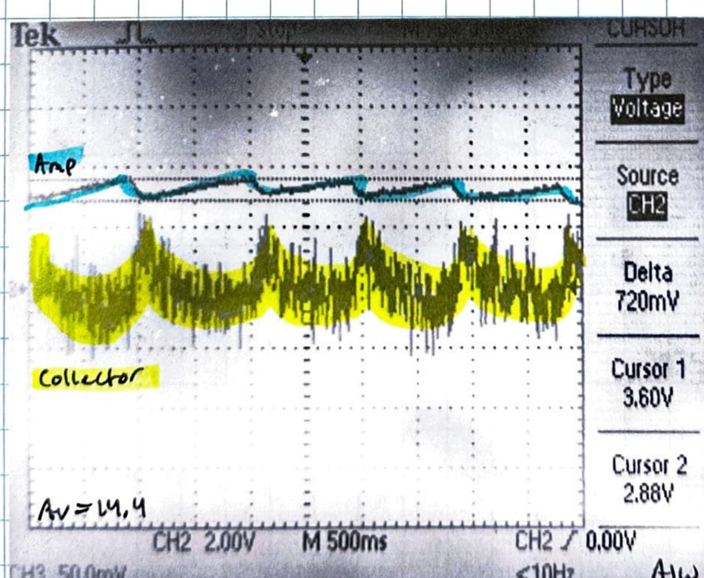
Figure 7-1-6: Measured Amplifier Output



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These show that I was able to get my heartbeat using this circuit, but you could get more or less depending on whether or not you were stationary, or how good of a position your finger was in.

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Lab 7-2: Display Circuit

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Theory of Operation

In this section, I will cover the display circuit that I was going to use for my sensor, to display the beats per minute of the person with their finger in the sensor

To solve this problem, we first tried a circuit that counted in 10ms intervals, the time between heartbeats. This didn't work, because we could set it to be spot on at one interval, but it would get exponentially further away from the actual value due to the non-linearity of heart beats and frequency of beats.

We looked up solutions in books, and then online for how to convert hex ~~to~~ or binary to BCD, in order to hook it up to our 7-segment Displays. We eventually found a solution, but did not have the time to test and/or implement it.

The idea was that we were going use one set of counters to count the amount of heart beats in 7.5 seconds, and then count down the amount of beats times 8, by shifting the input by 3 bits. We would count down to zero, and then at the same time, count up on a set of BCD counters. So we were counting down in decimal, the exact amount of times that we are counting up in BCD, essentially converting it so that we can display the BCD number on our 7-segment displays. This circuit has a lot going on, and because of that, didn't have the time to make sure it worked or solder it.

In case I eventually return to this circuit, or someone picks up from my place to improve/finish it, I will still be going over it.

Calculations

The first things that I want to calculate are my clock sources, for 7.5s and 1kHz

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Lab 7-2: Display Circuit

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7.5s:

$$R_T = \frac{t}{-C(\ln(\frac{V_c - V_F}{V_i - V_F}))}$$

$$R_T = \frac{15s}{22\mu(\ln(\frac{3.333-5}{1.667-5}))}$$

$$\boxed{R_T = 984.082K\Omega}$$

50% Duty Cycle:

$R_B = 10 \cdot R_A$

$R_B = 10/11 \cdot R_T$

$R_B = 10/11 \cdot 984.082K$

$\boxed{R_B = 894.67K\Omega}$

$\boxed{R_A = 89.462K\Omega}$

$\boxed{R_B = 910K\Omega}$

$\boxed{R_A = 91K\Omega}$

1KHz:

$T = f^{-1}$

$T = 1K^{-1}$

$T = 1ms$

$1/3T = 333.333\mu s$

$$R = \frac{t}{-C(\ln(\frac{V_c - V_F}{V_i - V_F}))}$$

$$R = \frac{333.333\mu s}{-470nF(\ln(\frac{1.667-0}{3.333-0}))}$$

$R = 1.024K\Omega$

$\boxed{R = 1K\Omega}$

As that 7.5 second clock makes your circuit accurate or not, you want to be as close to that 7.5s as possible, so you can put a 100KΩ rheostat or something between the cap and RB to adjust/fine tune it.

I also only want to count in that 7.5s that it is low, so during the pulse width, so I will OR the Pulse input with it to only count during the low pulse width.

As well, I will want an edge trigger for my Clear on the first input and $\overline{Load}$ on the second set of counters. So I will have two edge triggers, but the Clear one will need to be buffered first so that we can load and start counting down before clearing the first set of counters.

Then I will need to come up with the logic for making my 3rd set of counters count, and stop counting.

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Lab 7-2: Display Circuit

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Table 7-2-1: Truth Table for 3rd set of Counters

A	B	Count
0	0	Unused
0	1	1 stop count
1	0	0 count
1	1	Unused

Table 7-2-1: Loading Calcs for Display Circuit

Worst	U#, Pin#	Value
V_{IH}	U10A, 1	5V
V_{IL}	U3, 5	0.4V
I_{OH}	U14D, 8	80μA
I_{OL}	U14D, 8	3.2mA

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Lab 7-2: Display Circuit

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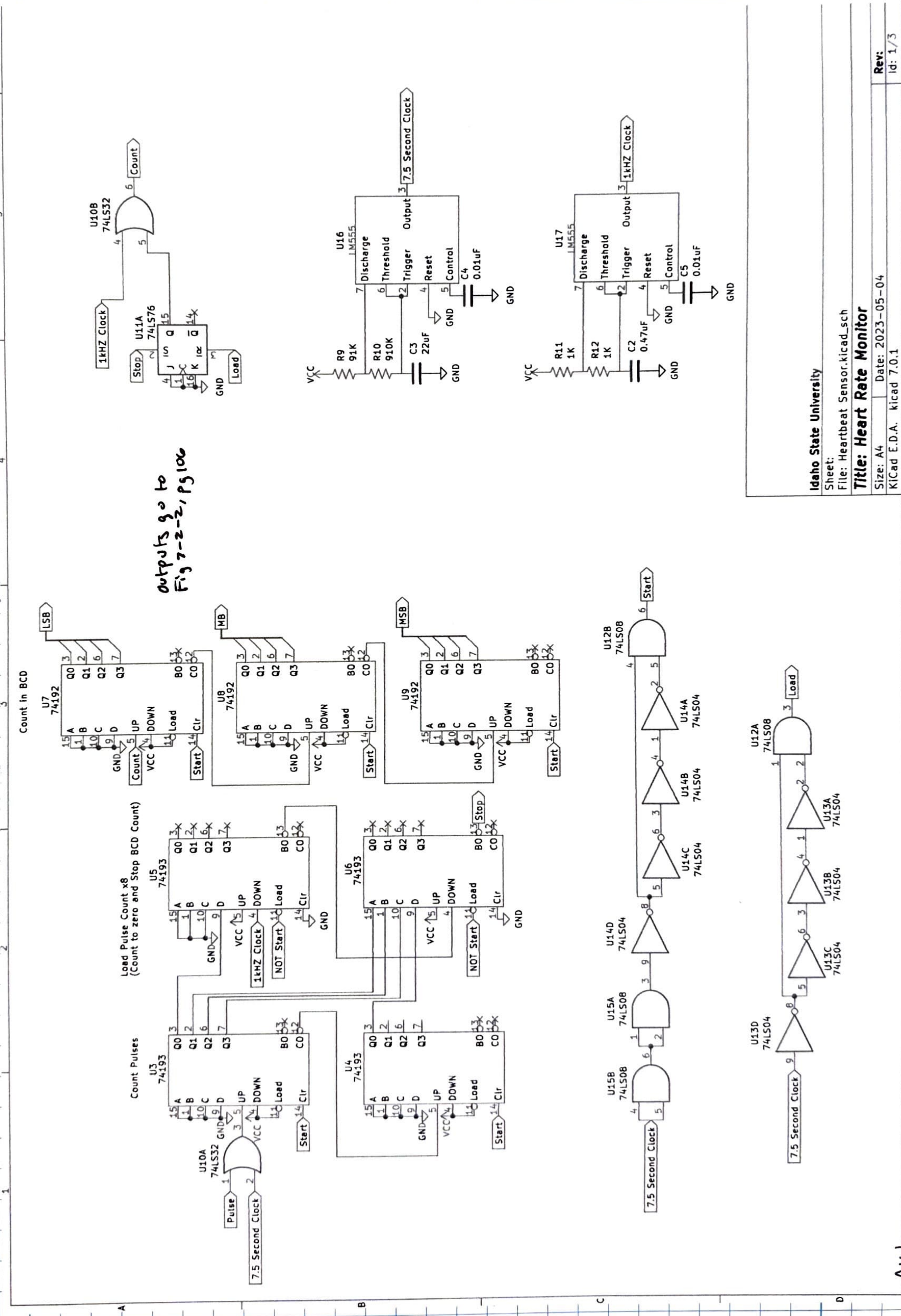
Figure 7-2-1: Display Circuit for Heart Beat Monitor



outputs go to Fig 7-2-2, pg 106

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Lab 7-2: Display Circuit

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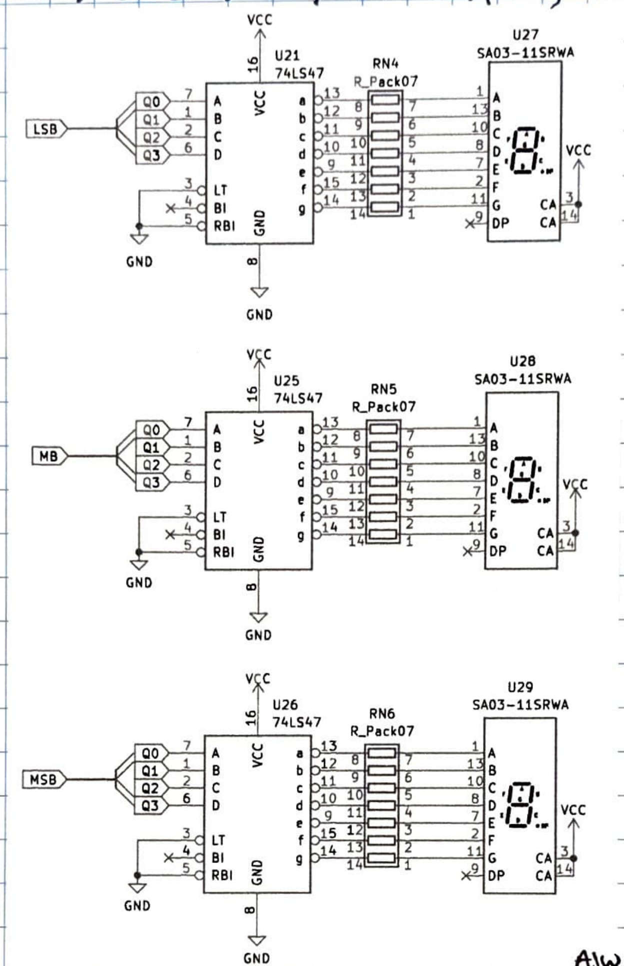
Figure 7-2-2: 7-Segment Display Circuit



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Conclusion

This project was very cool, not only was it challenging trying to use new components, but it was fun applying what I have learned to try and build something with it. There were many challenges with this circuit and plenty of troubleshooting, and time spent working things out on the whiteboard.

I am not entirely satisfied with the end product of this project regarding the stability of it. It is very sensitive to even the slightest of movement. As well, the clip that goes on your finger is something that I struggled with. You need very precise placement in order to get a good signal from it. If I had more time, I would try adjusting the amount of tension on the finger from the spring of the clip. As well, I would finish the display circuit, as it would be much more complete if it told you your heart rate. If I ever get the chance, I would like to finish it, but I

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Lab 7-2: Display Circuit

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believe that overall, I have laid down a very good foundation for someone to build upon/improve. With the main thing being the stability to be improved.

I think that I covered a lot of ground in the time that I worked on this project, starting from scratch basically. An idea that may make the stability better would be 3D printing a new clip, as another problem is the narrow angle of the photo transistor, and trying to improve that in some way.

If I wer return to this project, or someone else picks it up, I am sure that they or I can make it better with what I have learned.

And by doing complex things with these basic components, makes me realize how amazing micro-controllers are, and how they make the possibilities so much better for things you can do. As this would've been much more simple, especially with the display part of it with one

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