LAB REPORT PROJECT ECE

Jacobs University Bremen

CA11-300303 Project ECE

Fall Semester 2020

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Jan. 1^{st} week, 2021

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0.1 Introduction

Objective

1. The objective of this lab is to learn and to become familiar with the design flow of an electronic device. To learn the different steps and several aspects to take care about when implementing a circuit idea into a real device.

2. To know about Errors, Error calculation, and the basic knowledge about DC and AC circuits

Background

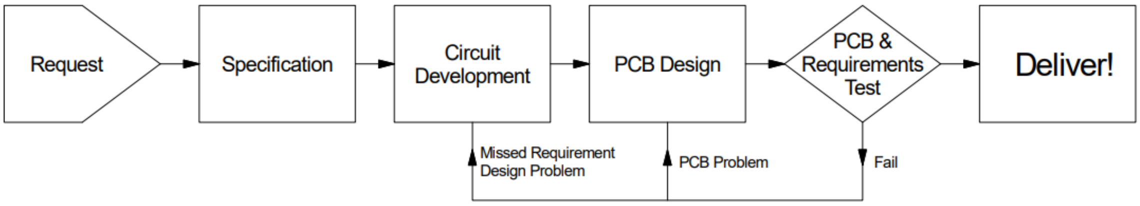
- Main softwares used were KiCad, LTSpice and MATLAB. The Lab consist of the development of a circuit which measures temperature and transmits the result via RS232. Temperature range should be from $-10°C$ to $+50°C$. Use a $5V \pm 10\%$ supply. This is done in six main experiments:[4]

    1. Experiment 1, PCB-Design - General Introduction: It explains whicxh softwares are needed for the project.
    2. Experiment 2, General Design Flow:
    3. Experiment 3, Components Properties: Explains the properties of Capacitors, Resistors and Inductor in real life.
    4. Experiment 4, The Engineering Part:
    5. Experiment 5, PCB-Design:
    6. Experiment 6, Design, Task, and Answers:

    Experiment 1 and 3 were pure theory and since there where not specific tasks then it is not included in the lab report.

0.2 Experiment 2, General Design Flow:

Task 1: First, in order to start. We need to have clear the steps we need to follow to make sure we succesfully design the wanted circuit. Therefore, we need to create a General Design flow so we can know in which step we are and where are we going. The General Design Flow we are following is shown below:



(a) Request: Starts with the idea of the wanted circuit. This contains the reference values that we need to make sure our product is capable to achieve and is part of the written order between customer and developer.

The request sheet for our circuit is the following:

i. Function: A circuit which measures temperature and transmits the result via RS232. Temperature range should be from $-10°C$ to $+50°C$. Use a $5V \pm 10\%$ supply

ii. Accuracy: $\pm(5\%rdg + 4dgt)$

iii. Sample rate & stored history: $2\frac{Val}{min}$, Values of last two hours

iv. Environmental conditions: inside, normal office.

v. Mechanical requirements: as small as possible.

vi. Timeline: (NOT DETERMINED FOR THIS PROJECT)

vii. Costs: (NOT DETERMINED FOR THIS PROJECT)

(b) Specification: This is the base of the developed circuit. Specifications of the product are needed, this has to be developed in this step. This has to be detailed and accurate.

Decided specifications for our circuit:

i. Divide the circuit in three parts: Power, Analog, and Digital.

ii. Power Specifications: External supply should deliver $5V \pm 10\%$ and $\approx 20mA$.

Why? Well, the requested supply voltage: 5V. Also, In worst case the controller needs up to 10mA, the two amplifiers up to 1mA supply current, the current for the Wheatstone reference is about 1mA. Therefore, external supply should deliver $5V \pm 10\%$ and $\approx 20mA$.

iii. Analog specifications:

Amplified Reference Voltage, this is needed because the reference voltage it weak.

Two PT1000 as temperature sensors inside a Wheatstone Bridge to be more precise in the detection of the change in the resistance.

Amplify the output of the bridge circuit with an instrumentation amplifier used as a differential amplifier

iv. Digital Specifications:

Atmega168P: The ADC, Timer, serial interface, and memory for data are needed. The data sheet of the Atmega168P satisfies all the values that we need for our project. i.e.

Timer: available at any time. Analog to Digital Converter: One sample every 30s is no problem and it keeps the system cheap.

Memory for data: Ram: 1024 Byte we need 480 Bytes ($\frac{2Val}{min} \cdot 60min \cdot 2hours \cdot 2Byte = 480$).

Report Task : Deliver a full set of circuit diagrams with your report:

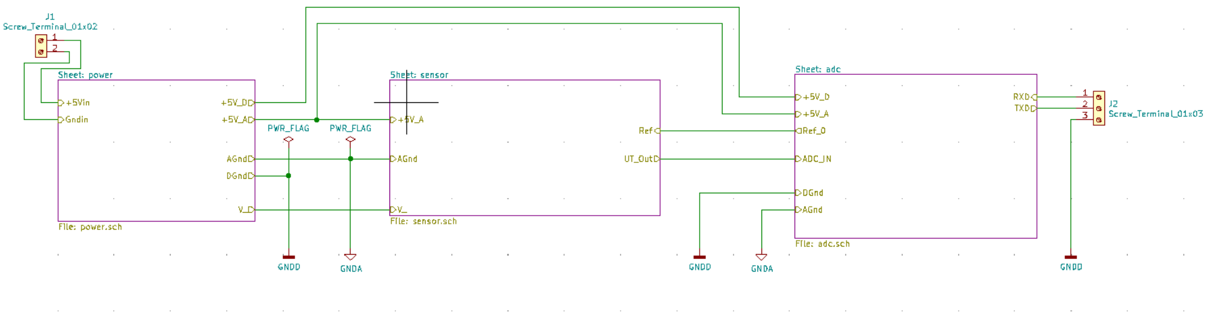


Figure 1: Functional Blocks of the Circuit

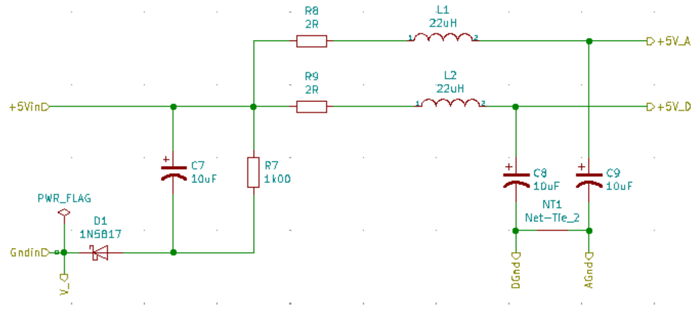


Figure 2: Power Block

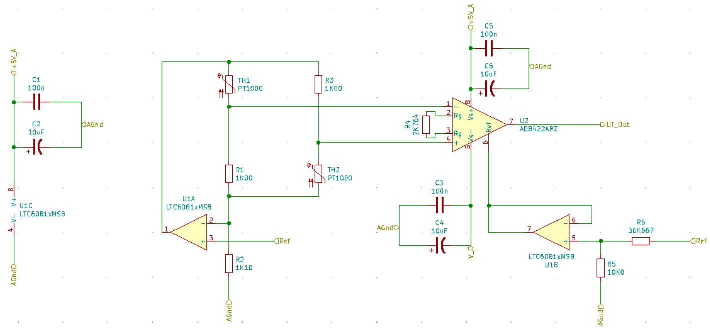


Figure 3: Sensor (Analog Part)

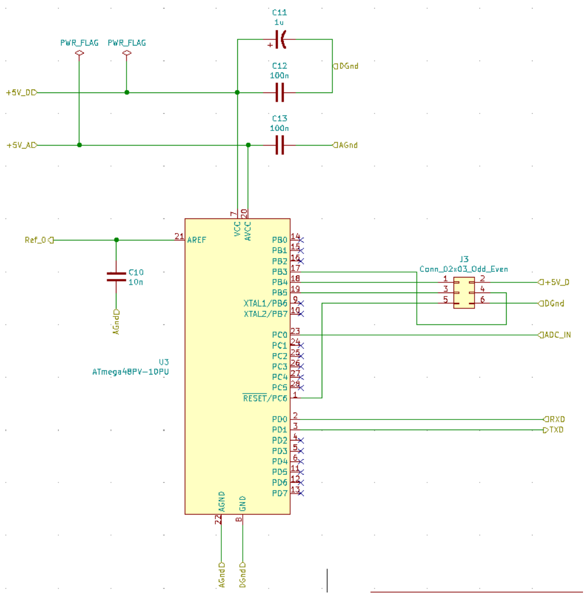


Figure 4: Analog to Digital Converter

(c) Circuit development: In this step we design the circuit basing on the specifications obtained. In this part we simulate the circuit and decide which components to use to achieve the needed specifications

(d) PCB Design (Circuit design): In this step create and finish the schematics, fix mechanical setup, and PCB layout.

(e) In the final test the PCB is created and we test the device, if it doesn't achieve the specification requirements then redesign.

0.3 Experiment 4, The Engineering Part:

Task 1: Report Task : Simulate the the AC behavior of the RLC filter in the range from $10Hz$ to $1MHz$ using LTSpice.

Verification of the Power Block

(a) Use a low resistance coil with a high enough current rate. e.g.,a Coilcraft DT3316P-223 with L $= 22\mu H$.

(b) To see the effect of different capacitors C2 and C3 run the simulation with:
Tantalum type AVX TAJC106M016 with $C = 10\mu F$ and $16V$.
Aluminum type KEMET A700V106M016ATE045 with C $= 10\mu F$ and $16V$.

(c) Finally vary the 2Ω resistor. What happens when it is reduced to 0.1Ω?

(d) What is your final choice for the components? SHOW the used LTSpice simulation circuits and graphs. State the reasons for your choice!!

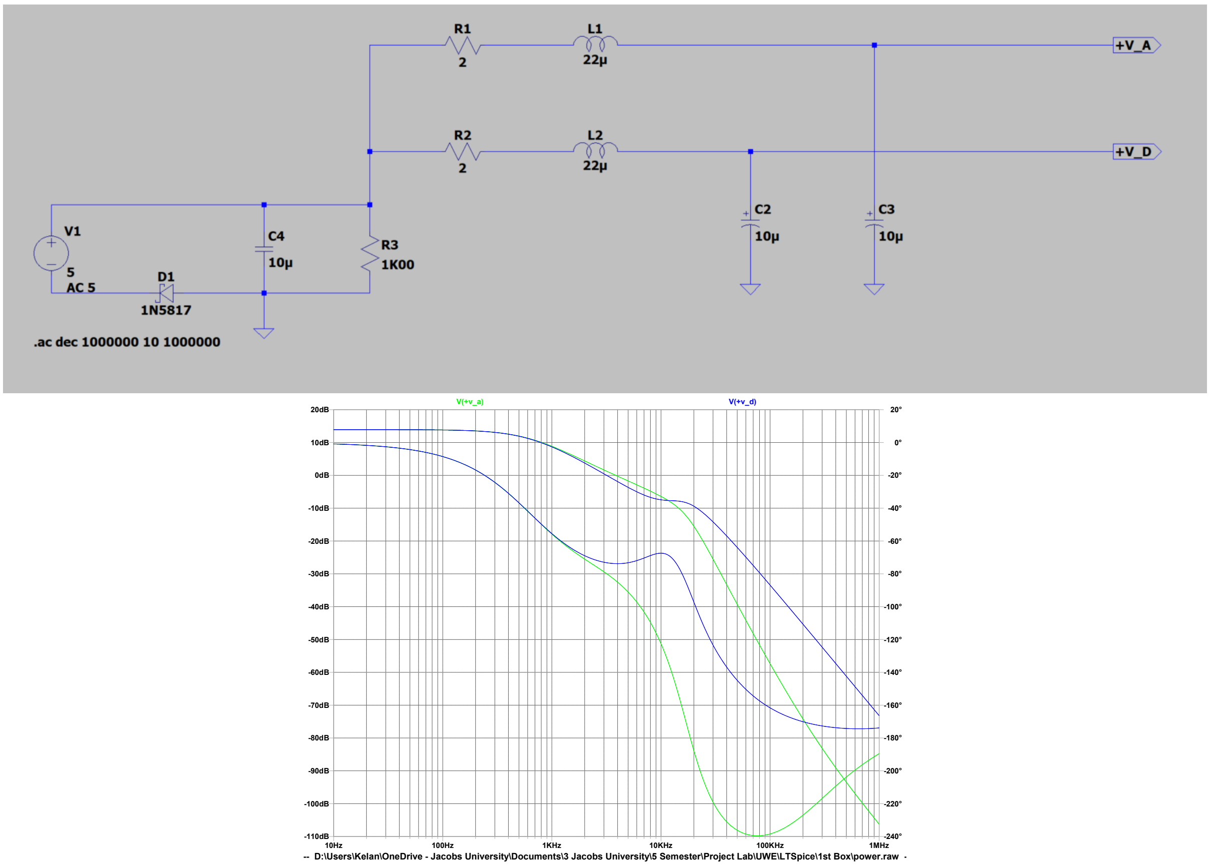


Figure 5: C_2: Tantalum type AVX, C_3: Aluminum type KEMET, R_1 and $R_2 = 2\Omega$

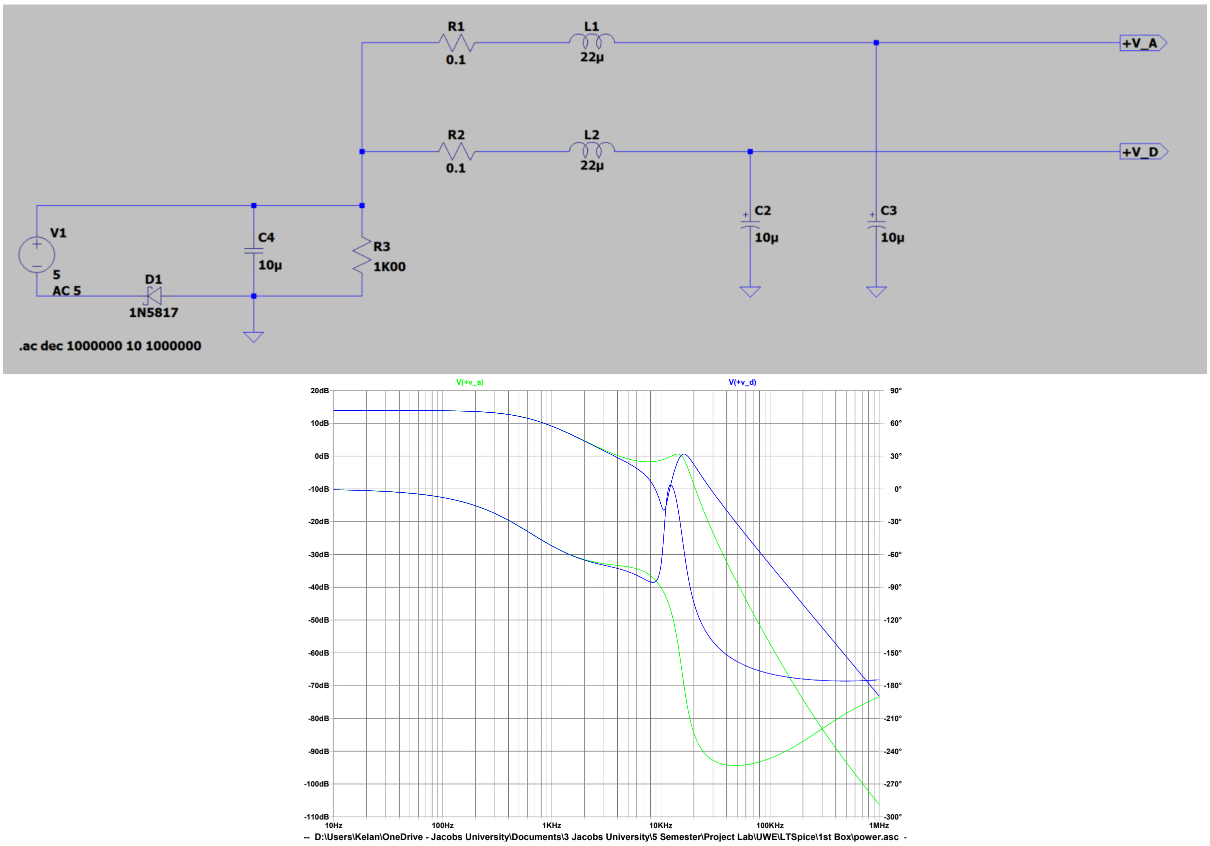


Figure 6: C_2: Tantalum type AVX, C_3: Aluminum type KEMET, R_1 and $R_2 = 0.1\Omega$

Since the differential amplifier and the ADC are sensitive to noise. The RLC filter should suppress a sufficient high amount of high frequency noise. That is why we need the one that decays faster, since $+V_A$ graph decays faster, that is why we choose the inductor of $+V_A$ which is C_3: Aluminum type KEMET. Then, we need to decide which resistor to use. I choose the 2Ω Resistor since the output decays faster than the 0.1Ω and also the 2Ω resistor looks more stable.

Proof:

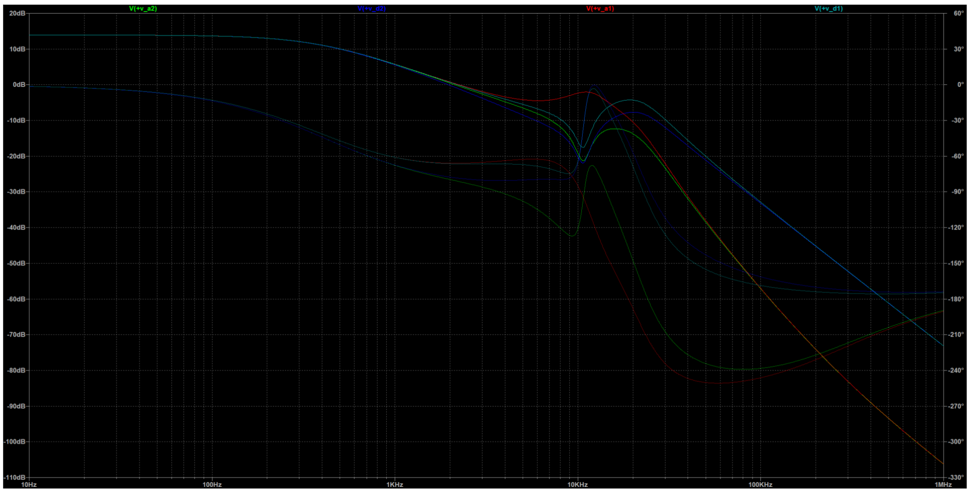


Figure 7: $+V_{A2}$: Aluminum type KEMET $R = 2$; $+V_{D2}$: Tantalum type AVX, $R = 2$; $+V_{A1}$ Aluminum type KEMET $R = 1$; $+V_{D1}$ Tantalum type AVX, $R = 2$

Verification of the Sensor_Amplifier Block

(a) Use LTSpice and simulate the given Wheatstone Bride without the other components. Carry out two simulations. For both cases simulate for a temperature range from $-15 > +55°C$.

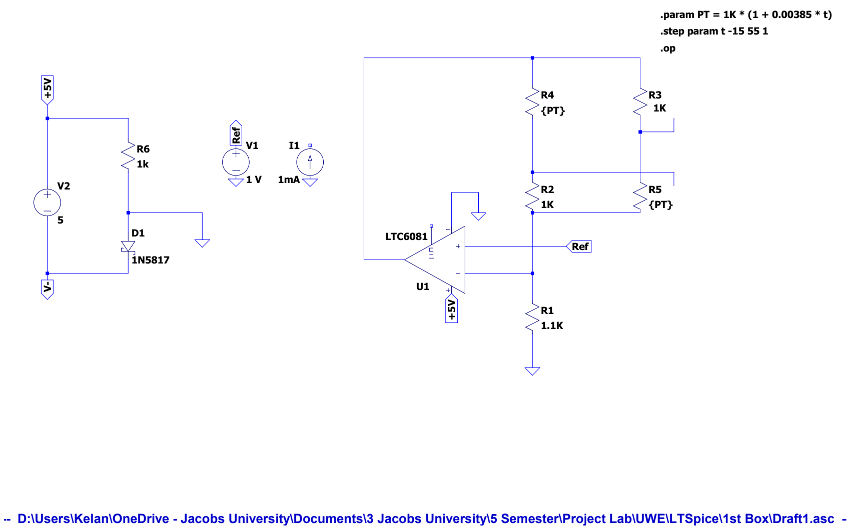


Figure 8

i. Use a 1V reference source for the bridge and display the output.

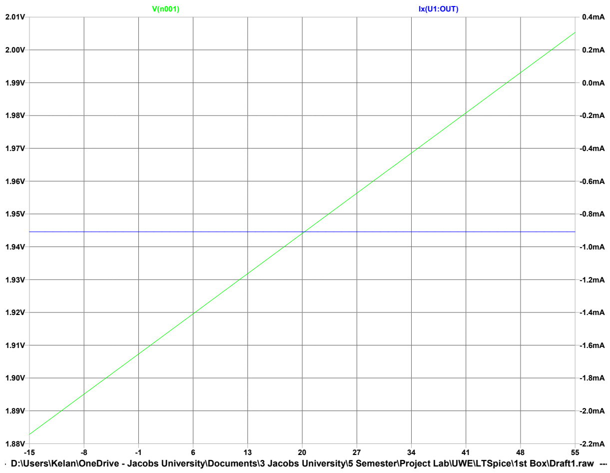


Figure 9: $V(n001)$ = Output Voltage of the LTC6081, $I_x(U1 : OUT)$ = Current of the outer-mesh.

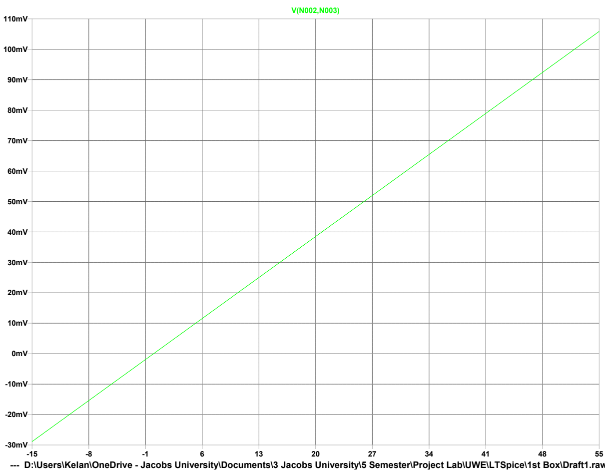


Figure 10: Voltage Output of Wheatstone Bridge

ii. Use a 1mA reference source for the bridge and display the output.

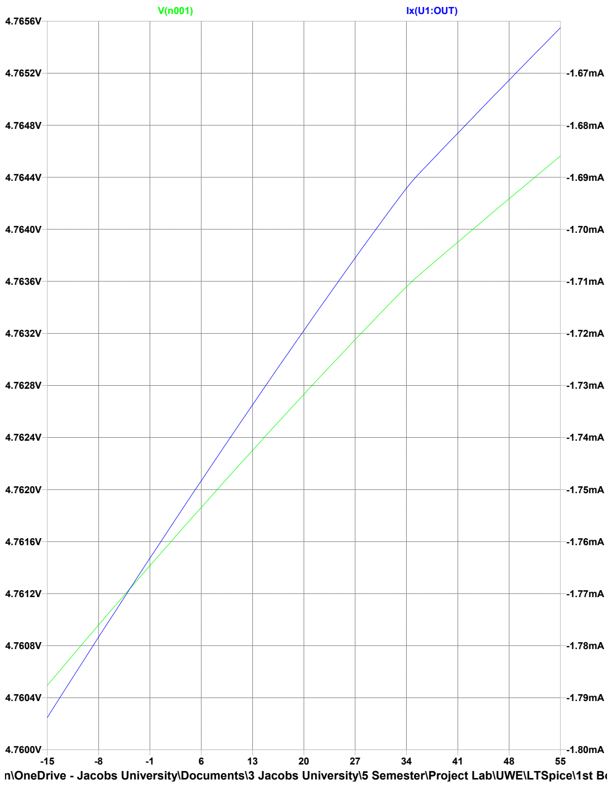


Figure 11: $V(n001)$ = Output Voltage of the LTC6081, $I_x(U1 : OUT)$ = Current of the outer-mesh.

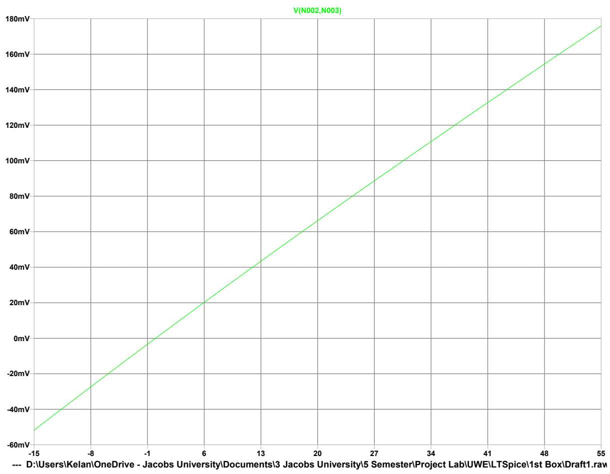


Figure 12: Voltage Output of Wheatstone Bridge

Determine the differences of the two simulations:

The output when the Ref is a current source of 1mA, the output is far way from the wanted line compared to the output with a Voltage source of 1V to the Ref.

(b) Together with the findings from the previous simulation describe the function of the different parts of the circuit.

i. How is the Wheatstone bridge supplied? With constant voltage or constant current?
Constant Current: uses an op amp, a sense resistor, and a voltage reference to maintain a constant current through the bridge. The current through each leg of the bridge remains constant as the resistances change, therefore the output is a linear function.

ii. How is the function of the instrumentation amplifier. How can the circuit work with a nearly unipolar power supply. Remember the Bridge delivers a negative / positive output signal over the temperature range.
By using a instrumentation amplifier we make an efficient circuit and provides better gain accuracy (usually set with a single resistor, R_G) and does not unbalance the bridge.
The circuit works with a nearly unipolar power supply because the Instrumentation amplifiers such as the AD620, AD623, and AD627 can be used in single supply applications provided the restrictions on the gain and input and output voltage swings are observed.[2]
So, we checked the datasheet and the value was enough for our usage.
Datasheet of AD8422: $4.6V$ to $36V$ single supply.[1]

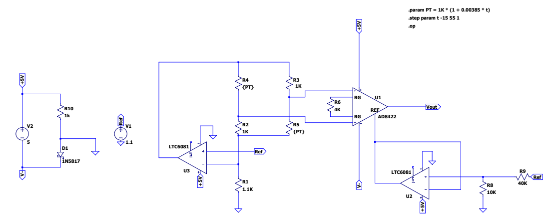
iii. What is the purpose of R404+405 and R406+407?
The purpose of R404+405 is to determine the gain that we want to have at the op-amp, and the R406+407 values controls the offset that we are adding to the signal we want to correct.

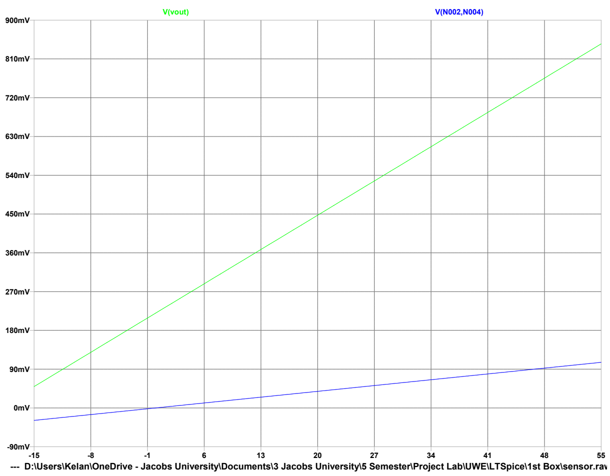
(c) Simulate the complete circuit using LTSpice.

i. Set the unknown resistors R404 + R405 to 4000Ω and R407 to $40k\Omega$.

ii. Simulate for the requested temperature range $-15°to + 55°C$.

iii. In your simulation show the output voltage of the Wheatstone Bridge and the output of the differential amplifier. If you look at the full range, is the output at the amplifier a continuous rising, linear function with values between $0V$ to $1.1V$?





The output at the amplifier is a continuous rising, linear function but is not between the range $0V$ to $1.1V$.

(d) The output of the previous simulation is not exactly what we need! It seems to be linear but the graph doesn't start at $0V$ and the max. value is not $1.1V$. The small $\pm$ input voltage has to be amplified and an offset has to be added to the result. $-10°C$ to $50°C$ should become $0V$ to $1.1V$ at the amplifier output. 0 is then the ADC value for $-10°C$. The amplifier is prepared to shift the zero point. Check the data sheet! First the gain is set by the resistors R404 and R405. The offset to add to the output is defined by the voltage divider R406 and R407.

Use a MatLab script to ...

i. Calculate the output values and range of the Wheatstone bridge. Requested range is $-10°$ to $+50°C$. To have some margin around the maximum values calculate the bridge voltage for $-15°$ to $+55°C$. You need the min./max values to determine the the absolute voltage range, and the offset. (remember reference voltage and max. input for the ADC is VRef = 1.1 V)

ii. calculate the amplification, offset, and resistor values Calculate the amplification and find the gain resistor (see data sheet).

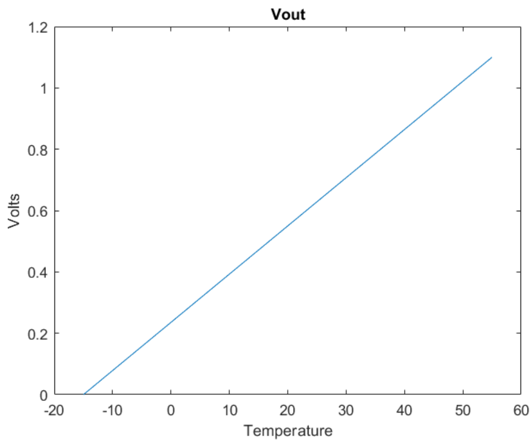
Show all Matlab scripts and calculations in the report!!

```
%% reading files
clear; clc; close all
y_arr = dlmread('sensorvalues2.txt', '\t', 1, 0);

% Temperature
t = y_arr(1:end, 1);
% V of Wheatstone Bridge
Vn2n4 = y_arr(1:end, 2);
% Vout of whole circuit
Vout = y_arr(1:end, 3);
% Positive output of Bridge
pVin = y_arr(1:end, 4);
% Negative output of Bridge
nVin = y_arr(1:end, 5);

%% -15 degrees to  55 degrees

G = 1.1 / (max(Vn2n4) - min(Vn2n4)) %Gain
Rg = 19800 / (G - 1) %Resistance for the Gain Formula
```

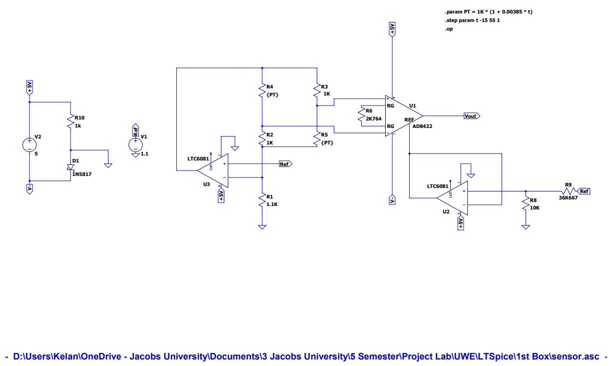
```
Voffcalculated = abs(min(Vn2n4) * G) %Offset
R1 = (1.1/Voffcalculated) * 10000 - 10000 %Resistance for offset

%Checking if the calculated R1 gives the wanted offset
% Op-amp formula used:  R2 / (R2 + R1) * Vin
Vofftocheck = (10000 / (10000 + R1)) * 1.1

%% Simulation with the new Gain and Offset to see plot the result.
Vout = G * (pVin - nVin) + Voffcalculated;

plot(t,Vout)
xlabel('Temperature')
ylabel('Volts')
title('Vout')
```

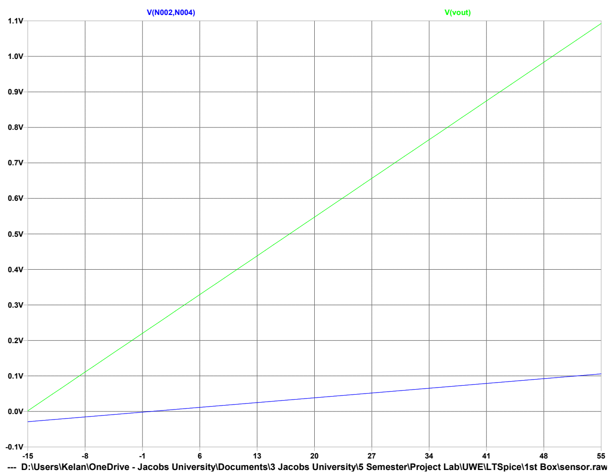
MATLAB Command Window Page 1

```
G =

    8.1633

Rg =

   2.7641e+03

Voffcalculated =

    0.2357

R1 =

   3.6667e+04

Vofftocheck =

    0.2357

>>
```



(e) Verify the calculated values using the LTSpice simulation from before. SHOW the used LTSpice simulation circuits and graphs.





Selection of Components:

(a) Resistors:

Chip Resistor:	Size 0805
Bridge:	Metal Film Vishhay Y16241K00000T9R
Rest	Vishhay CRCW08051K00FKEA, Standard Thick Film

(b) Capacitors:

Chip Capacitor:	Size 7343 Aluminium 16V
Polarized:	KEMET A700V106M016ATE045

Chip Capacitor:	Size 0805 Ceramic 50V
Not Polarized:	AVX 08055C104J4T2A

(c) Inductors:

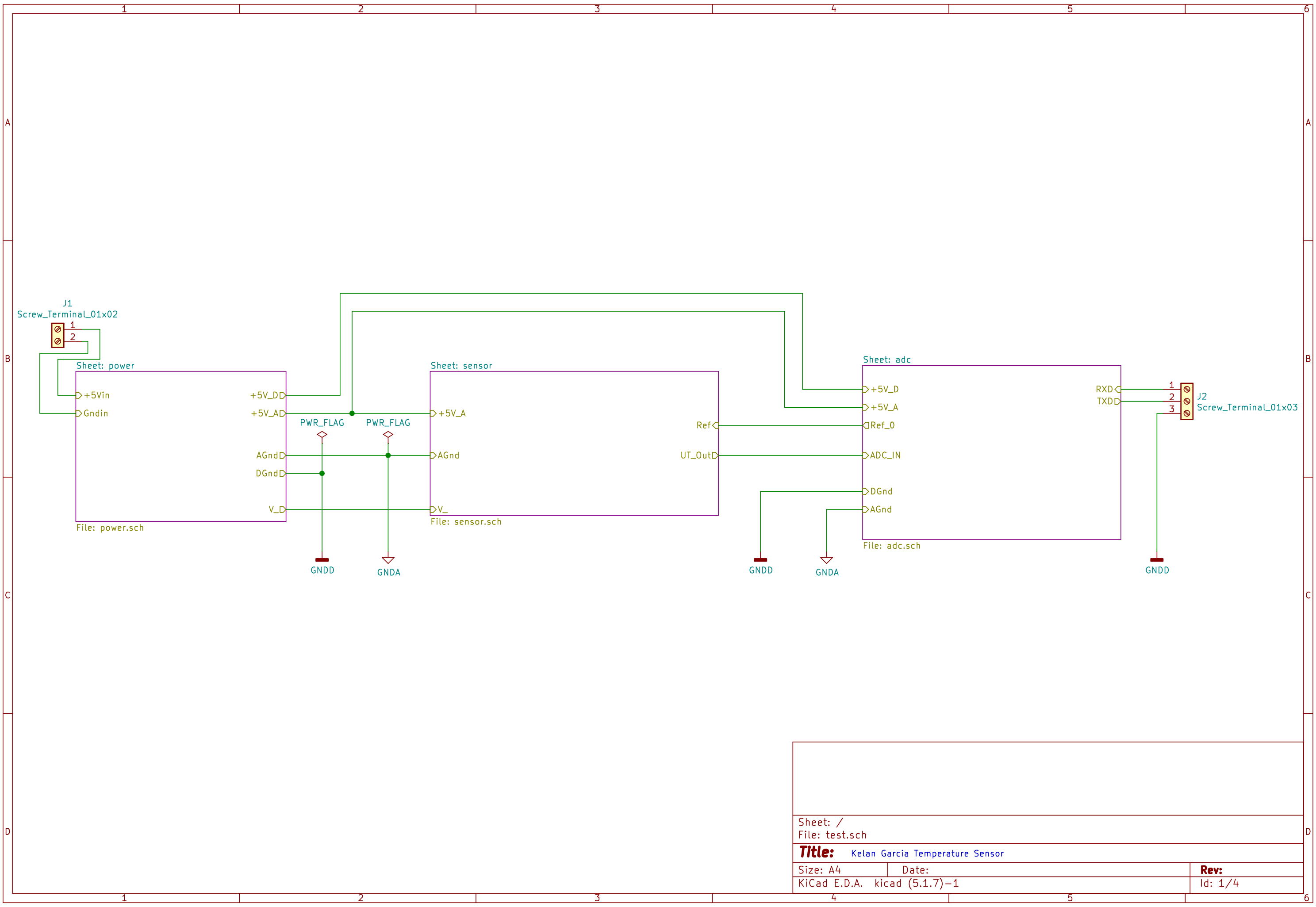
Chip Inductor, Size 1210 Murata LQH32MN470J23L5, LQH32MN220J23L

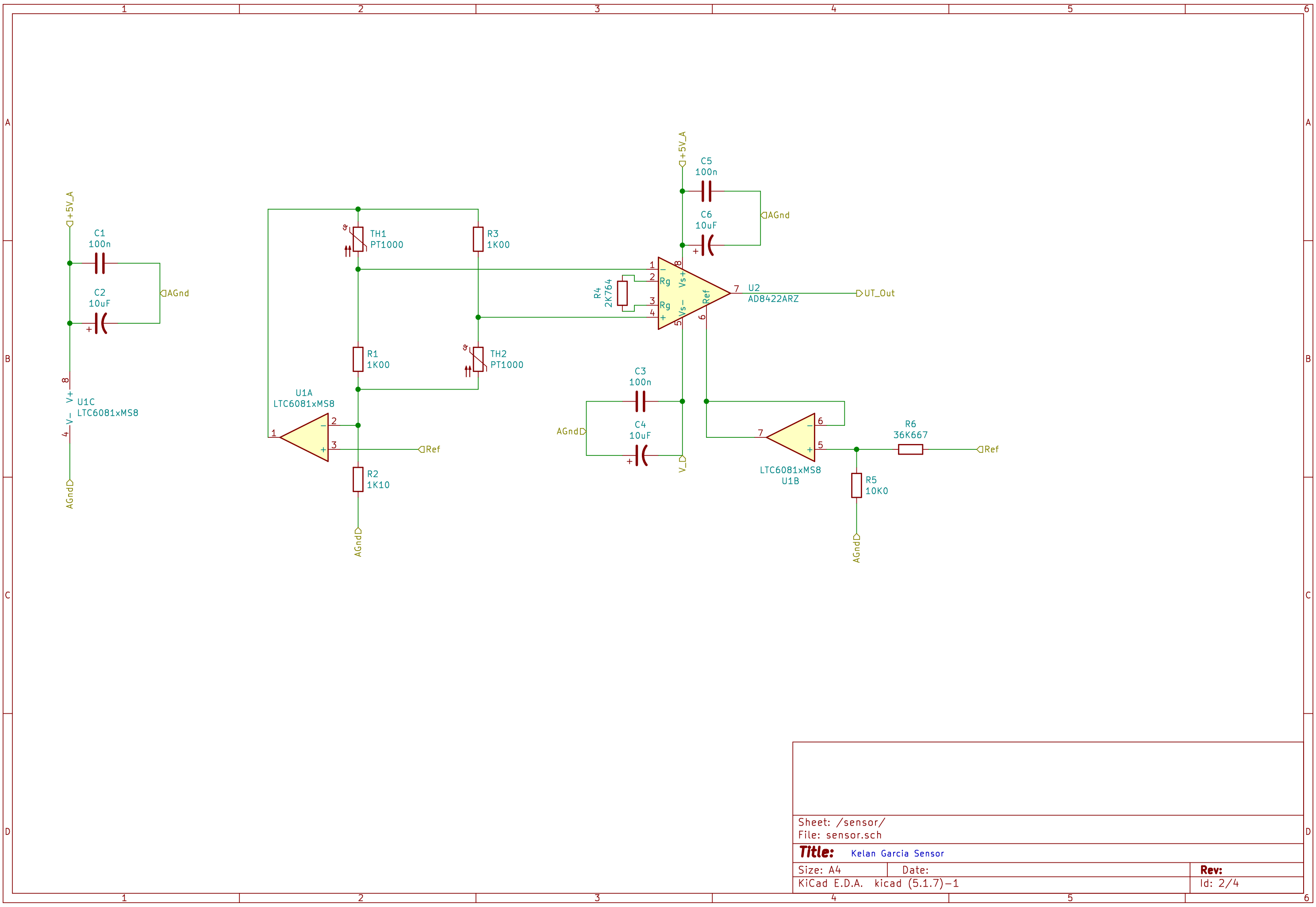
(d) Active Components:

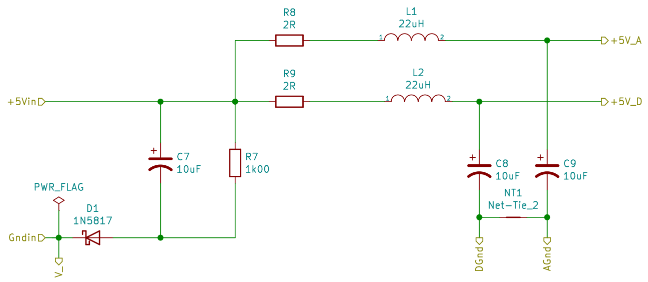
Atmega168, Linear Technology Dual OpAmp LTC6081IMS8, and Analog Devices AD8422ARZ.

0.4 Experiment 5 & 6, PCB-Design, Design, Task, and Answers

Task 1: Schematics of the final circuit:


J1
Screw_Terminal_01x02
Sheet: power
+5Vin
Gndin
+5V_DD
+5V_AD
AGnd
DGnd
V_D
File: power.sch
PWR_FLAG
PWR_FLAG
GNDD
GNDA
Sheet: sensor
+5V_A
AGnd
V_
Ref
UT_Out
File: sensor.sch
Sheet: adc
+5V_D
+5V_A
Ref_0
ADC_IN
DGnd
AGnd
RXD
TXD
File: adc.sch
GNDD
GNDA
GNDD
J2
Screw_Terminal_01x03
Sheet: /
File: test.sch
Title: Kelan Garcia Temperature Sensor
Size: A4
Date:
Rev:
KiCad E.D.A. kicad (5.1.7)-1
Id: 1/4

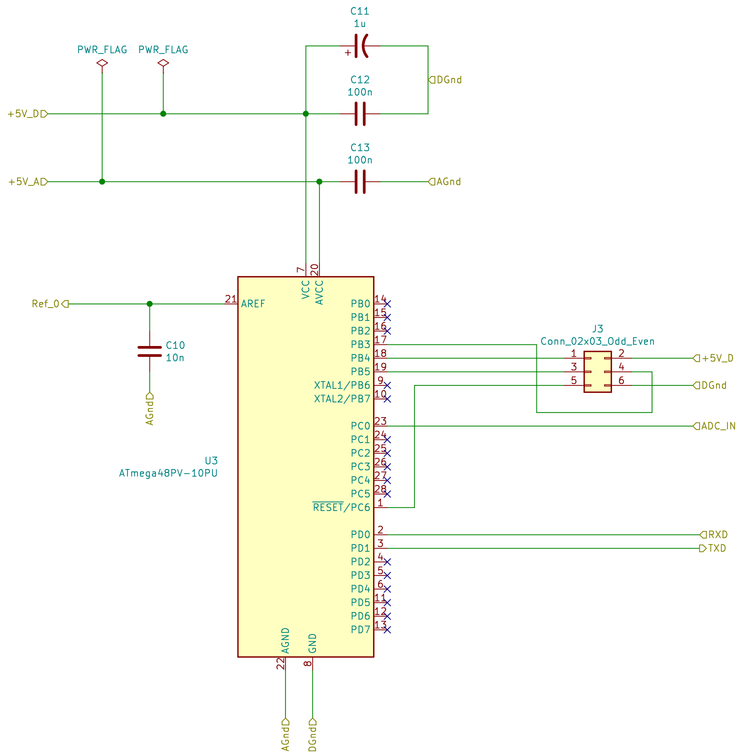

+5V_A
C1
100n
C2
10uF
AGnd
U1C
LTC6081xMS8
V+
V-
8
4
AGnd
TH1
PT1000
R3
1K00
R1
1K00
TH2
PT1000
U1A
LTC6081xMS8
R2
1K10
AGnd
Ref
R4
2K764
Rg
Rg
Vs+
Vs-
Ref
U2
AD8422ARZ
UT_Out
+5V_A
C5
100n
C6
10uF
AGnd
C3
100n
C4
10uF
AGnd
V_
LTC6081xMS8
U1B
R6
36K667
Ref
R5
10K0
AGnd
Sheet: /sensor/
File: sensor.sch
Title: Kelan Garcia Sensor
Size: A4
Date:
Rev:
KiCad E.D.A. kicad (5.1.7)-1
Id: 2/4



Sheet: /power/
File: power.sch

Title: Kelan Garcia Power Block

Size: A4	Date:	**Rev:**
KiCad E.D.A. kicad (5.1.7)-1		Id: 3/4



Sheet: /adc/
File: adc.sch

Title: Kelan Garcia Analog to Digital Converter

Size: A4 | Date: | Rev:

KiCad E.D.A. kicad (5.1.7)-1 | Id: 4/4

After doing the schematics I annotate each component as follows:

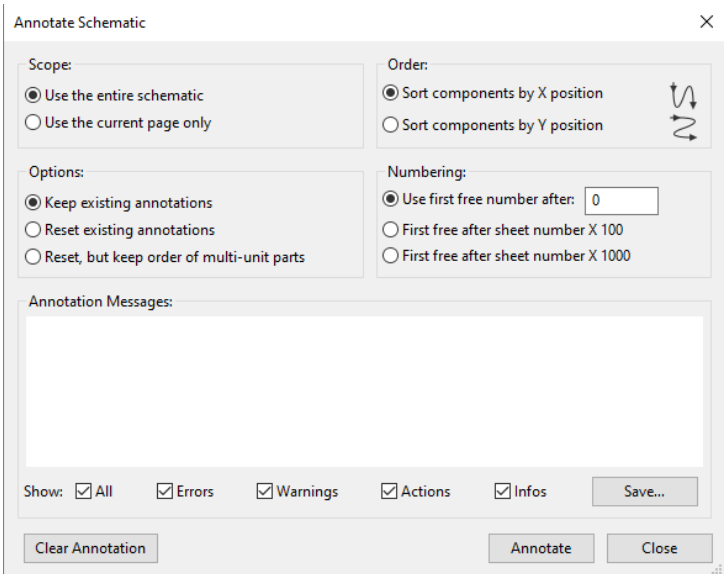


Figure 13: Pressing Annotate in the Annotate Schematic Chart

Then, I checked if the connections were good by running the Electrical Rules Checker. Proof that everything was okay:

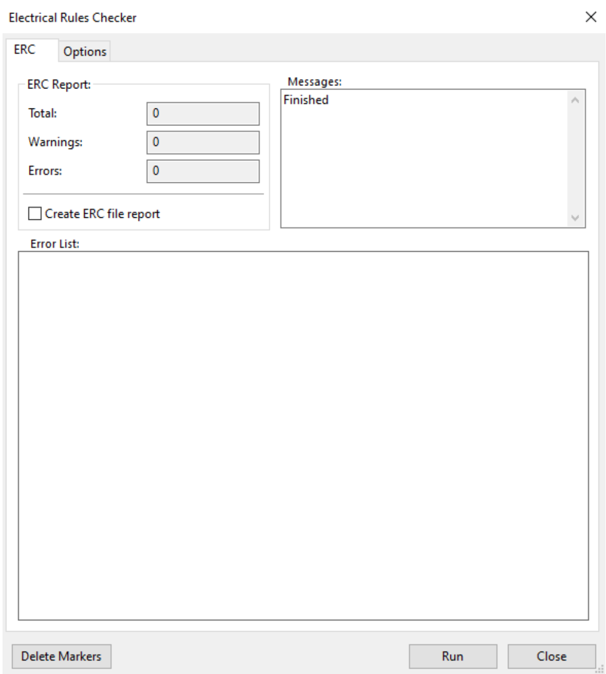
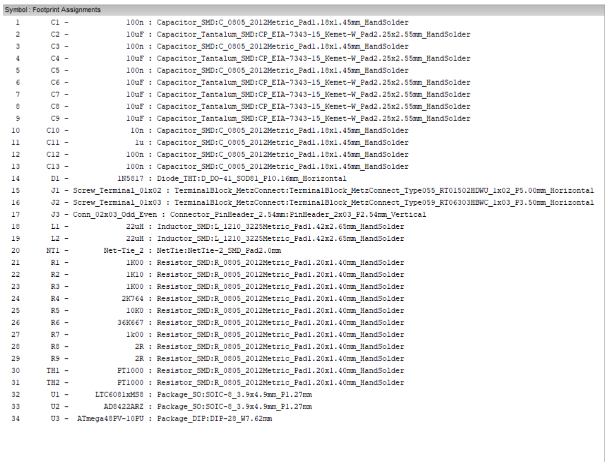


Figure 14: Electrical Rules Checker Result

After verifying with the Electrical Rule Checker, we need to add which type of component are we using i.e which resistor, capacitor etc.. The components selected where:



```
Symbol : Footprint Assignments
1     C1 -               100n : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
2     C2 -               10uF : Capacitor_Tantalum_SMD:CP_EIA-7343-15_Kemet-W_Pad2.25x2.55mm_HandSolder
3     C3 -               100n : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
4     C4 -               10uF : Capacitor_Tantalum_SMD:CP_EIA-7343-15_Kemet-W_Pad2.25x2.55mm_HandSolder
5     C5 -               100n : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
6     C6 -               10uF : Capacitor_Tantalum_SMD:CP_EIA-7343-15_Kemet-W_Pad2.25x2.55mm_HandSolder
7     C7 -               10uF : Capacitor_Tantalum_SMD:CP_EIA-7343-15_Kemet-W_Pad2.25x2.55mm_HandSolder
8     C8 -               10uF : Capacitor_Tantalum_SMD:CP_EIA-7343-15_Kemet-W_Pad2.25x2.55mm_HandSolder
9     C9 -               10uF : Capacitor_Tantalum_SMD:CP_EIA-7343-15_Kemet-W_Pad2.25x2.55mm_HandSolder
10   C10 -                10n : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
11   C11 -                 1u : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
12   C12 -               100n : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
13   C13 -               100n : Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder
14    D1 -             1N5817 : Diode_THT:D_DO-41_SOD81_P10.16mm_Horizontal
15    J1 - Screw_Terminal_01x02 : TerminalBlock_MetzConnect:TerminalBlock_MetzConnect_Type055_RT01502HDWU_1x02_P5.00mm_Horizontal
16    J2 - Screw_Terminal_01x03 : TerminalBlock_MetzConnect:TerminalBlock_MetzConnect_Type059_RT06303HBWC_1x03_P3.50mm_Horizontal
17    J3 - Conn_02x03_Odd_Even : Connector_PinHeader_2.54mm:PinHeader_2x03_P2.54mm_Vertical
18    L1 -               22uH : Inductor_SMD:L_1210_3225Metric_Pad1.42x2.65mm_HandSolder
19    L2 -               22uH : Inductor_SMD:L_1210_3225Metric_Pad1.42x2.65mm_HandSolder
20   NT1 -          Net-Tie_2 : NetTie:NetTie-2_SMD_Pad2.0mm
21    R1 -               1K00 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
22    R2 -               1K10 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
23    R3 -               1K00 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
24    R4 -              2K764 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
25    R5 -               10K0 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
26    R6 -             36K667 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
27    R7 -               1k00 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
28    R8 -                 2R : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
29    R9 -                 2R : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
30   TH1 -             PT1000 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
31   TH2 -             PT1000 : Resistor_SMD:R_0805_2012Metric_Pad1.20x1.40mm_HandSolder
32    U1 -         LTC6081xMS8 : Package_SO:SOIC-8_3.9x4.9mm_P1.27mm
33    U2 -           AD8422ARZ : Package_SO:SOIC-8_3.9x4.9mm_P1.27mm
34    U3 -      ATmega48PV-10PU : Package_DIP:DIP-28_W7.62mm
```

Figure 15: Selected Components

Then a net list was generated and saved.

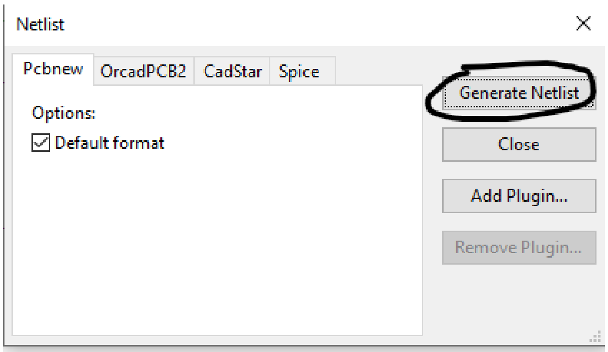


Figure 16

Then, I oppened the genereted NetlIst on the PCB design, and the following was imported.

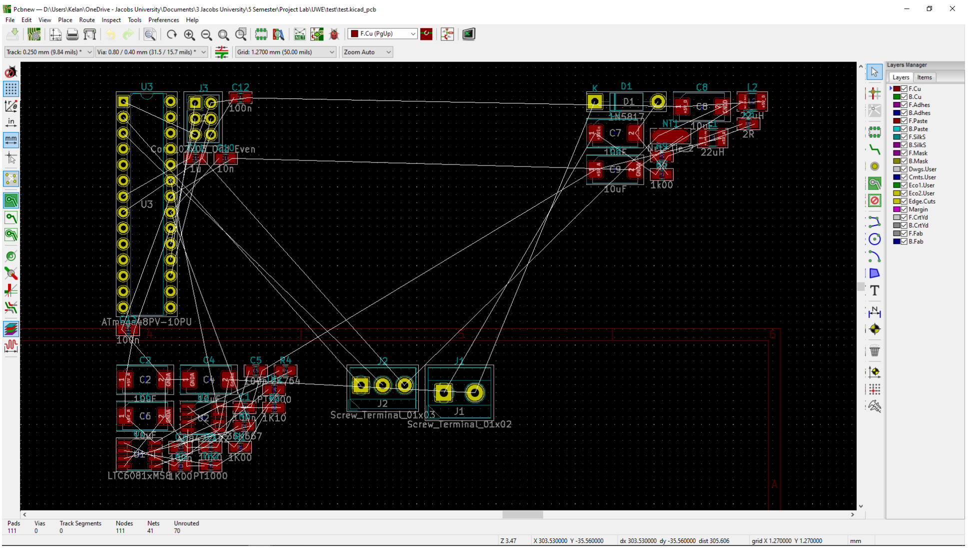
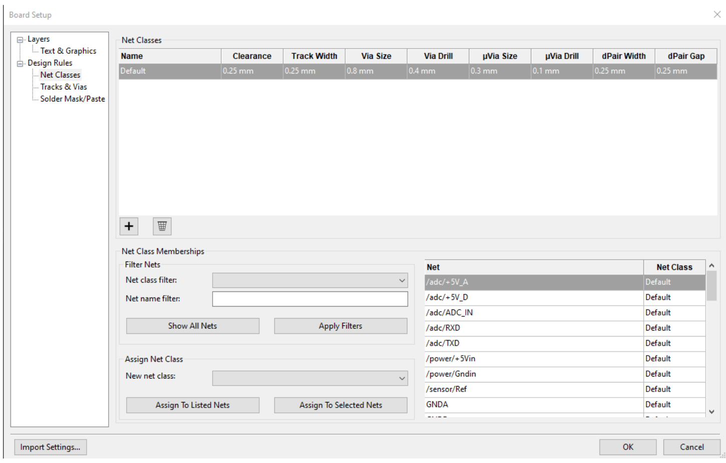


Figure 17: Recently Imported NetList into PCB design

First thing done was to change the traces width as explained in the KiCad start up tutorial.[3] It was by setting the clearance and the minimum track width to 0.25mm



After changing the traces properties, then I moved the components to have a more clean circuit (less white lines crossing)as shown below:

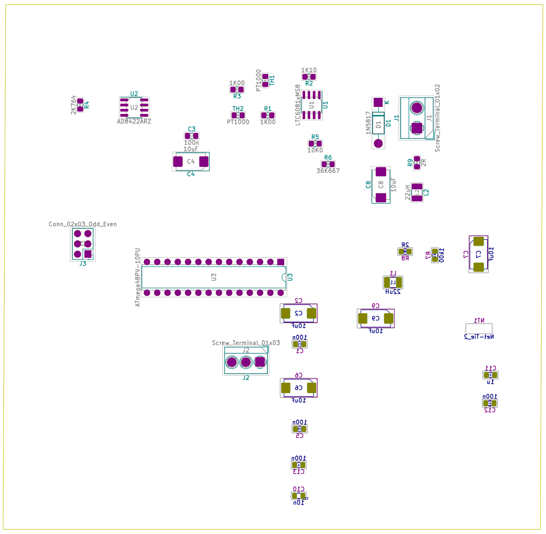


Figure 18: Bottom Part

Next, the traces where drawn. In order to complete this task I used two layers, the top and bottom layers. The traces exchange between layers to be able to finish conecting the circuit. Half of the circuit is in the bottom layer (Green traces), and the other half is in the top layer (Red traces) as shown below:

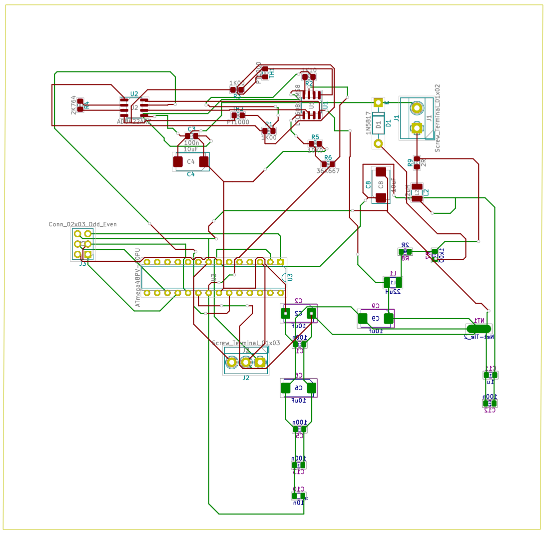


Figure 19: Bottom Part

We add the green part:

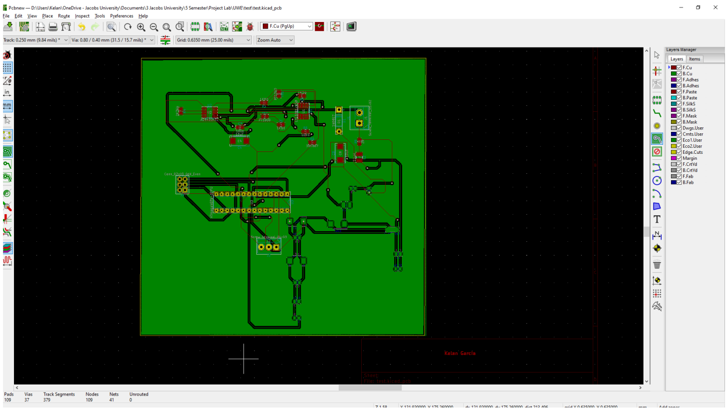


Figure 20

Run a test to check connections and components:

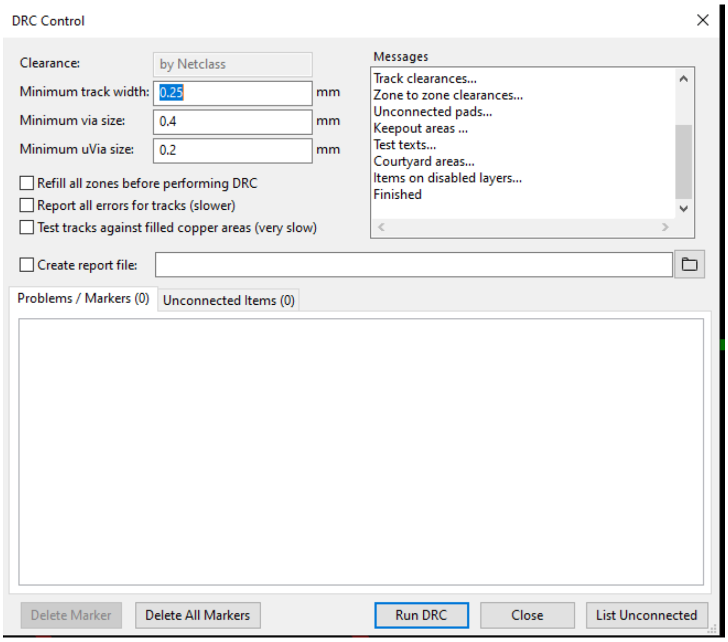


Figure 21

Final Result in 3D for both sides:

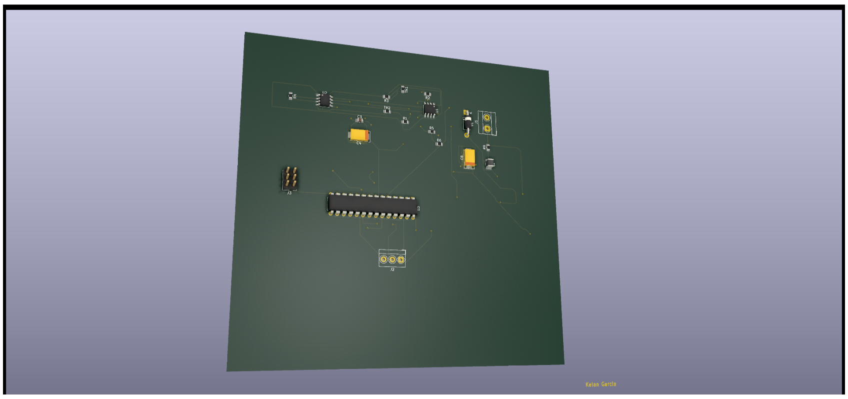


Figure 22: Top part

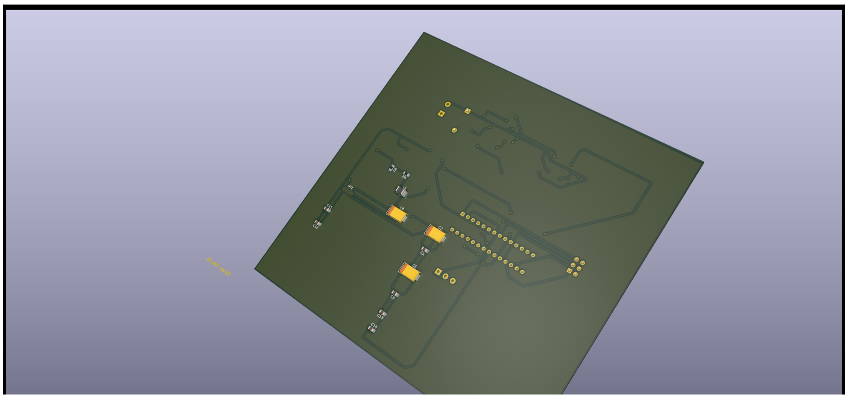


Figure 23: Bottom Part

0.5 Conclusion

In conclusion this lab helped me to understand how to desing a PCB and all the thing you need to keep in mind while designing one. It shows the important of shielding to prevent electromagnetic interfearence. It shows the importance of designing a good routing because each trace has its own resistance that can alterate the circuit output. Also, it shows the difference between different types of Resistors, Inductors or Capacitors, and also it shows how can we represent a real life component so we can simulate it and see its approximation in real life. (Like Aluminum or Tantalium Resistors). I also learn which programs to use if I want to design a PCB design in this case we use KiCad, Ltspice and Matlab, we can use another program but this might be expensive. Next, I learn on how to planned when I have to do a PCB, I need to follow the General Design Flow and make sure the specification sheet is complete so there fill no be final errors. At the end we also learn about error estimation with ppm instead of percentage in PCB boards. Something extra that I think I learned is about Instrumataion amplifiers.

Bibliography

[1] Analog Devices. Data Sheet AD8422, 2019.

[2] Walt Kester. BRIDGE CIRCUITS, 2015.

[3] KiCad. KiCad start up tutorial, Spring 2020.

[4] Uwe Pagel. Lab Manual, Fall 2020.