Practical Circuit Design

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1. **Task : Simulate the RLC filter using LTspice**
   Use a low resistance coil with a high enough current rate.
   - a 22μ H Coilcraft DT3316P-223 from the library.

   a)To see the effect of different capacitors run the simulation with:

   - a tantalum low ESR capacitor 10μF T521D106M050ATE120 from KEMET

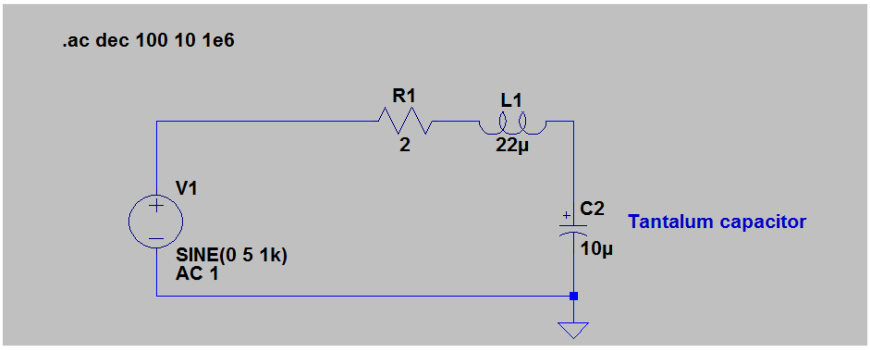


Figure 1: The figure above shows the circuit using a tantalum low ESR capcitor

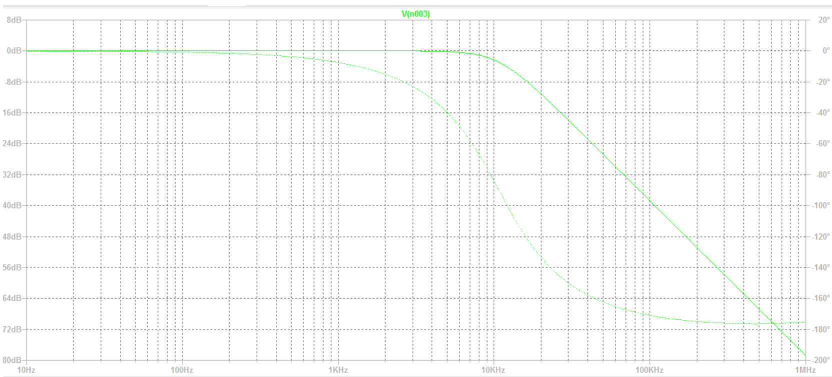


Figure 2: The figure above shows the Bode plot when using a tantalum low ESR capacitor.(over the capacitor).

- and an Al type 10μF UPG1H100MPH from Nichicon. The

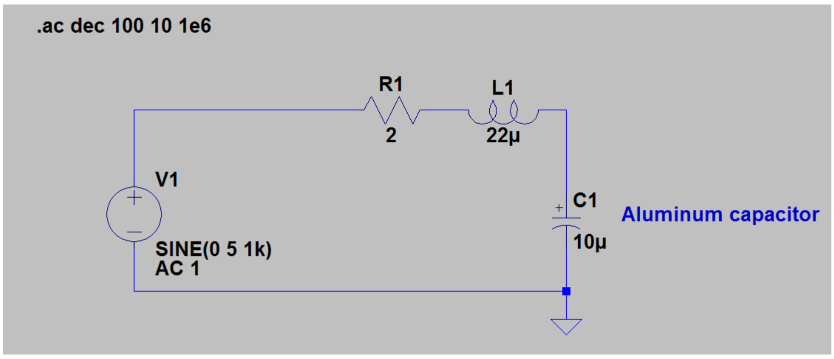


Figure 3: The figure above shows the circuit using a Al capacitor.

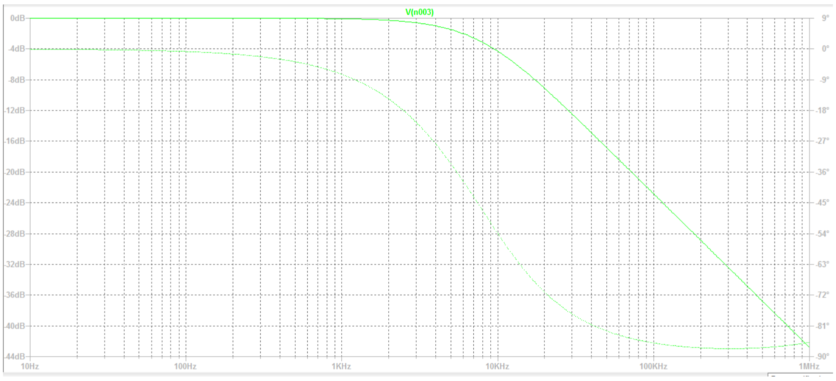


Figure 4: The figure above shows the Bode plot when using an Al capacitor.(voltage drop over the capacitor)

cut-off frequency in the tantalum low ESR capacitor is higher than that of the Al capacitor.

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

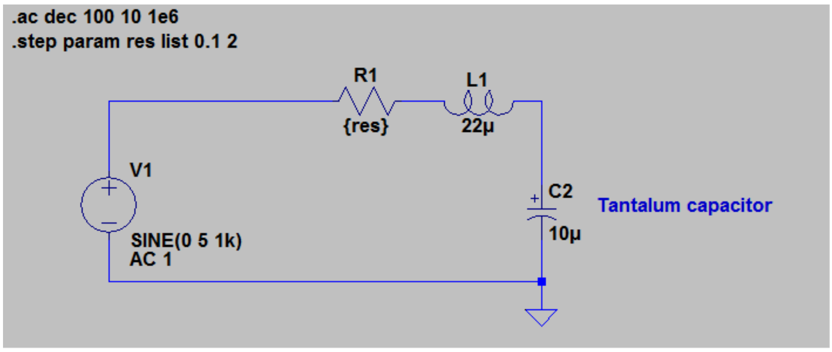


Figure 5: The figure above shows the RLC circuit using a tantalum low ESR capacitor while varying the resistor R1.

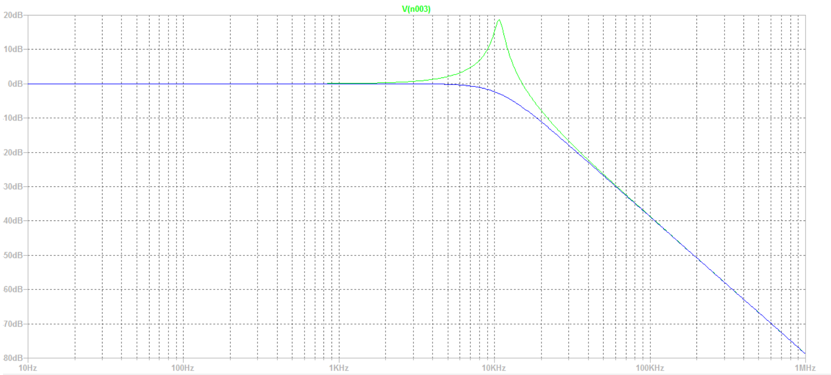


Figure 6: The figure above shows the Bode Plot using a tantalum low ESR capacitor while varying the resistor R1.(voltage drop over the capacitor)

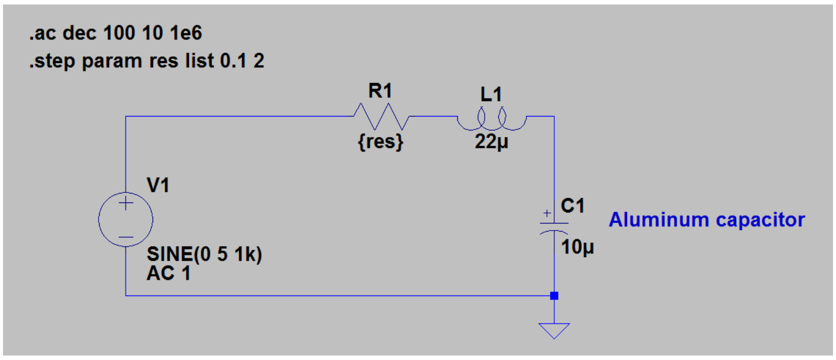


Figure 7: The figure above shows the RLC circuit using an Al capacitor while varying the resistor R1.

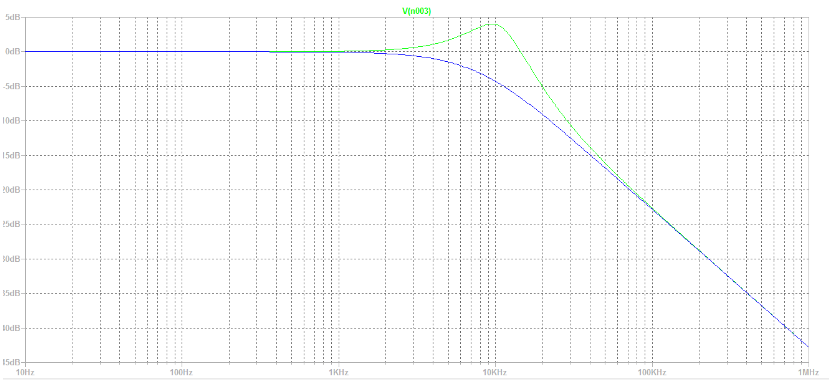


Figure 8: The figure above shows the Bode Plot using an Al capacitor while varying the resistor R1.(voltage drop over the capacitor)

As we reduce the resistance in the circuit the damping in the circuit changes causing an overshoot(over damped response) in the Bode plot.

We choose the Tantalum capacitor(-80 dB to 20 dB) because the dB range it overs is larger than that of an Al capacitor(-45 dB to 5 dB).

2. **Determine the properties of the instrumentation amplifier:**

    - Verify the calculated values in the following list. R206 from the schematic is a fixed 1k00Ω resistor.
      We performed these calculations in MATLAB(script bellow).

```
clc;
clear all;
close all;
%%%Constants

%Max input for ADC
    vref  = 1.1;
%Fixed resistor in the schematic
    r_206  = 1000;
%% Resistors used to produce an output voltage
    r_203 = 1000;
    r_202 = 1000;
    r_204= 1000;
%%Parameters for PT100 equation
    %temperature coefficient
        a    = 3.85e-3;
    t_min = -15;
    t_max = 55;
    %Making a matrix from -15 to 55
    temp = linspace (t_min, t_max, 71);
    %Resistance at zero degrees
        r_0=1000;
    %Reference temperature of the sensor
        t_0=0;
    %r_t=r_0*(1+(a*delta_T))
        %delta_T=temp-t_0 therefore delta_T is equal to temp
        %r_t is the resistance at temps
         r_pt = r_0 * (1 + a * temp);

    adc_bits = 10;

%% Voltage difference (Voltage )
 v_diff = vref * ((r_202./(r_202 + r_203))-...
 (r_204./(r_204 + r_pt)));
 %the gain of the amplifier is the  output divided by
```

```
 the input however that produces a value less than
 % 1 which means that the resistor gain will be negative.
 % In order to prevent this I used the
 %definition of the in the solutions.
        delta_v_diff=(v_diff(71)+abs(v_diff(1)));
        gain = vref/delta_v_diff;
% Gain resistors used (formula from data sheet)
rgain = 100e3 /(gain-1);
% Standard resistors used(5.6k and 510).
rgain_real=6710;
G_real     = 1+(100e3 / rgain_real);
% Offset for the amplifier.(intial amplification)
v_off = abs(v_diff(1)) * G_real;

% Determine offset voltge divider.We know that r_206 is
%1000.We have to determine the resistance of r_207 and r_208.
i_off = v_off/ r_206;
r_207and208  = (vref - v_off) / i_off;
%Resistors used
r_207 = 3000;
r_208 = 240;
r_2078=r_207+r_208;
v_off_real   = vref * r_206 / (r_207+r_208 + r_206);

%Voltage amplifier
v_amp = v_diff * G_real + v_off_real;
%% This was obtained from the solution as the error
%calculations were not required
% calculate the ideal linear input change at the ADC
% bitvalues, slope of the function
bit = linspace(0, 2^adc_bits-1, 71);
m = (v_amp(1) - v_amp(71)) / (temp(1) - temp(71));
u_ad_lin = (0 - vref)/(0 - 2^adc_bits-1) .* bit;
%%
fprintf ('Min. Voltage = %6.4gV - Max. voltage =
          %6.4gV\n', ...v_diff(1),  v_diff(71));
fprintf ('Max. voltage difference for ...
  %+d to %+d degree is %8.4eV\n', t_min, t_max, delta_v_diff);
fprintf ('Max. amplification for ADC reference...
           %4.2gV is %g\n', vref, rgain);
fprintf ('Gain resistor for AD623 is %6.2f\n', rgain);
```

```
fprintf ('Gain resistor used %5u results to G = %6.2f\n',...
            rgain_real, G_real);

fprintf ('Min. offset for the amplifier is %6.4gV\n', v_off);
fprintf ('Offset voltage divider - Lo R = %6.2f - Hi R = %6.2f \n', ...
         r_206, r_207and208);
fprintf ('Hi R = %5u results to offset voltage %6.4gV \n',...
          r_2078, v_off_real);
%% Ploting(obtained from solutions not required in task)
% shift the plot window to to upper left corner

% plot the voltage over the bridge from t_min to t_max
plot (temp, v_diff)
tit = sprintf ('Bridge voltage over range %+d to %+d degree',...
                 t_min, t_max);
title (tit)
xlim ([t_min t_max])
xlabel ('T in degree'); ylabel('V in V')
grid

% second figure with amplifier output and ideal output
plot (temp, v_amp);
hold on;
plot (temp, u_ad_lin, 'Color',[1 0 0]);
ylabel('V in V')
xlim ([t_min t_max]); ylim([0 1.2]);
grid;

% third figure with error
err = (u_ad_lin - v_amp) ./u_ad_lin *100;
plot (temp, err);
xlim ([t_min t_max]); ylim([-5 5])
grid
%
```

Output of the MATLAB:

```
Min. Voltage = -0.01635V - Max. voltage = 0.05266V
Max. voltage difference for -15 to +55 degree is 6.9010e-02V
Max. amplification for ADC reference  1.1V is 6693.54
Gain resistor for AD623 is 6693.54
Gain resistor used  6710 results to G =  15.90
```

```
Min. offset for the amplifier is 0.2601V
Offset voltage divider - Lo R = 1000.00 - Hi R = 3219.84
Hi R =  3210 results to offset voltage 0.2613V
```

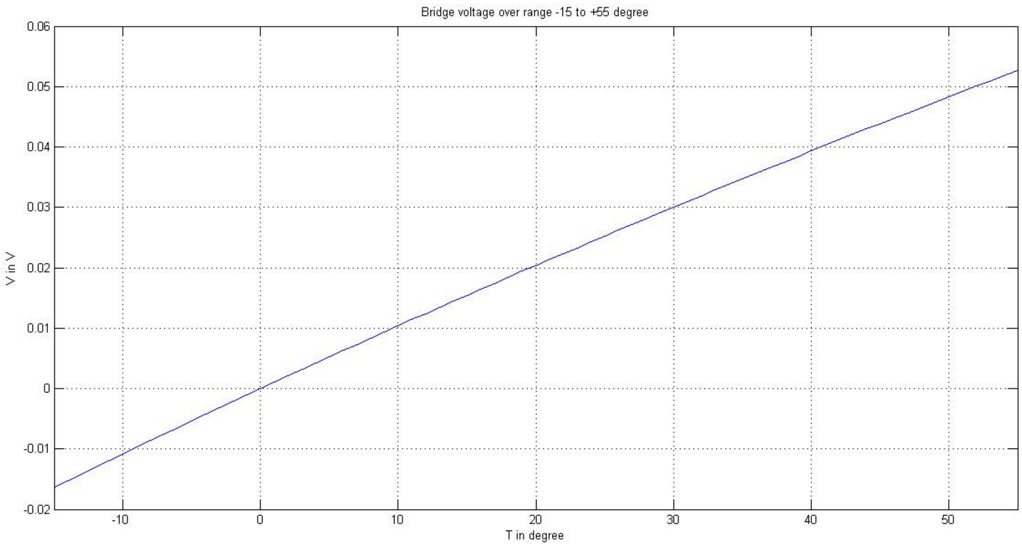


Figure 9: The figure above shows the output of the MATLAB Script

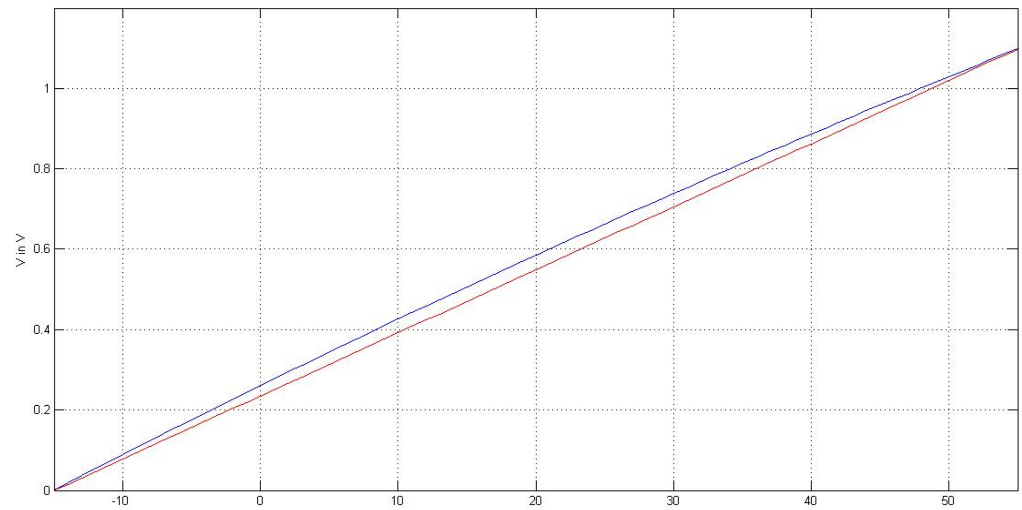


Figure 10: The figure above shows the output of the MATLAB Script

Table 2.

Parameter	Test Conditions/ Comments	AD623A			AD623ARM			AD623B			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
GAIN	$G = 1 + (100\ k/R_G)$										
Gain Range		1		1000	1		1000	1		1000	
Gain Error[1]	G1 V_{OUT} = 0.05 V to 3.5 V										
	G > 1 V_{OUT} = 0.05 V to 4.5 V										
G = 1			0.03	0.10		0.03	0.10		0.03	0.05	%
G = 10			0.10	0.35		0.10	0.35		0.10	0.35	%
G = 100			0.10	0.35		0.10	0.35		0.10	0.35	%
G = 1000			0.10	0.35		0.10	0.35		0.10	0.35	%
Nonlinearity	G1 V_{OUT} = 0.05 V to 3.5 V										
	G > 1 V_{OUT} = 0.05 V to 4.5 V										

Figure 11: The figure above shows were the resistor gain value was taken(http://www.analog.com/media/en/technical-documentation/data-sheets/AD623.pdf)

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Figure 12: The figure above shows were the standard resistor values were taken.(https://ecee.colorado.edu/∼ mcclurel/resistorsandcaps.pdf)

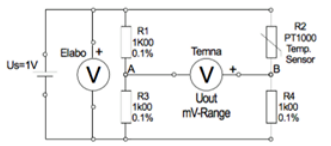
- Verify the function of the circuit using LTSpice. Check the bridge values and the output of the amplifier

3. EAGLE

7.4 Part 2 : Unbalanced DC Wheatstone bridge

7.4.1 Objective

The circuit for the next experiment is shown to the left. R_1, R_3, and R_4 are high precision resistors. R_2 is a Platinum PT1000 temperature sensor. The PTC behavior of metal is used to unbalance the bridge. At $0°C$ the voltage drop over A-B is zero. Above and below the drop becomes positive or negative.



As a reminder the function of the PT1000 resistor over temperature:

$$R_T = R_0 * (1 + \alpha * \Delta T)$$

R_T = Resistance (Ω) at temperature T ($°C$)
R_0 = Resistance at $0°C = 1000\Omega$
T = Temperature of environment in $°C$
T_0 = Reference temperature of the sensor - here $0°C$
$\Delta T = T - T_0$ - Temperature in $°C$
α = temperature coefficient $3.850 * 10^{-3}\ °C^{-1}$

7.4.2 Preparation

Because of the small sensor and to keep a good accuracy the circuit is already assembled on a printed circuit board which you can find in the experiment box. Add the supply and the two voltmeters.
Take care of the polarity of the multimeters!! After assembling everything do not touch the circuit anymore! This is necessary that the temperature can stabilize at the PT1000. Wait about 5 minutes to continue!

7.4.3 Execution

- For the evaluation it is important to know the exact input voltage. Measure and record U_S with the Elabo multimeter. **For accuracy use the optimum range!**
- Record the voltage at U_{OUT}. **Use the mV range of the Tenma multimeter!!**
- Set U_S to 10V. Wait about 10 minutes then record U_S and U_{OUT} again.

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Figure 13: The figure above shows were the PT1000 formula was obtained.(Lab Manual ,Spring 2016,GEN EE ——)

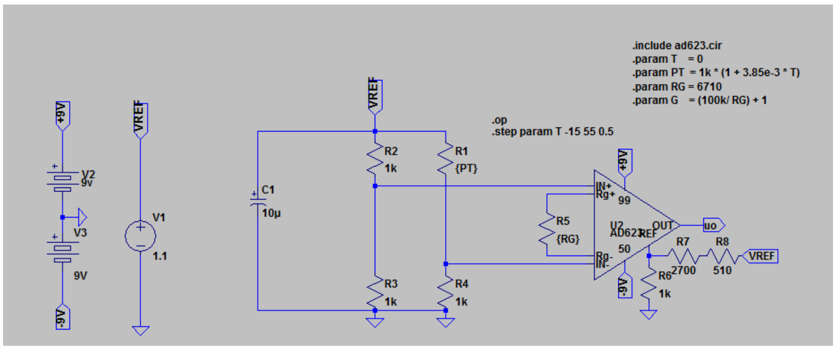

Figure 14: The figure above shows the LTSpice of the Instrumental amplifier.

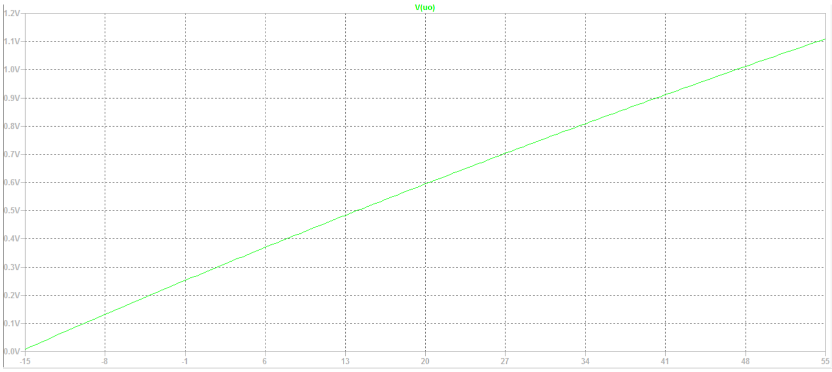

Figure 15: The figure above shows the graph of the output of the circuit.

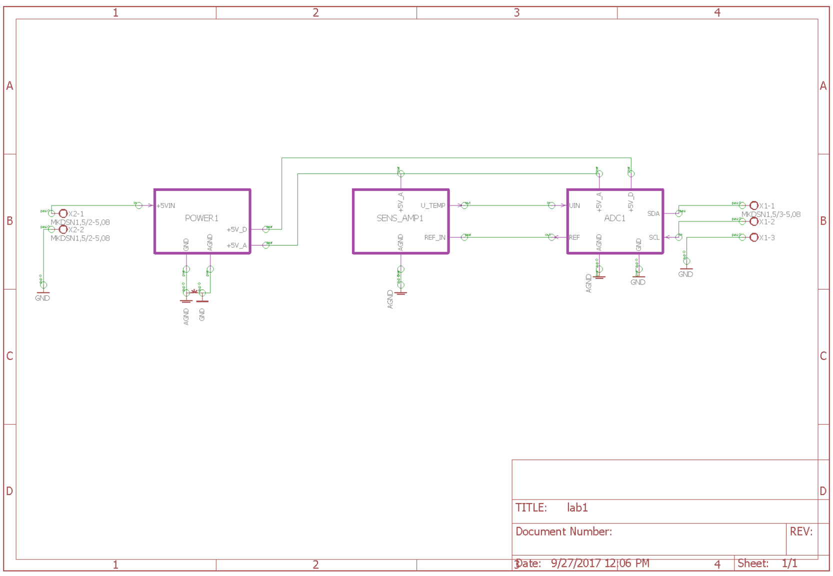

Figure 16: The figure above shows the schematic of the various blocks.

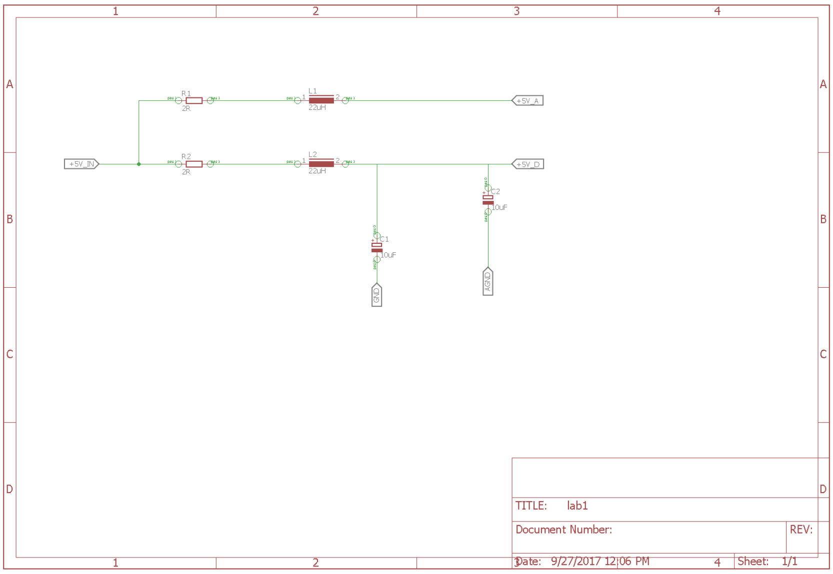

Figure 17: The figure above shows the schematic of the power block.

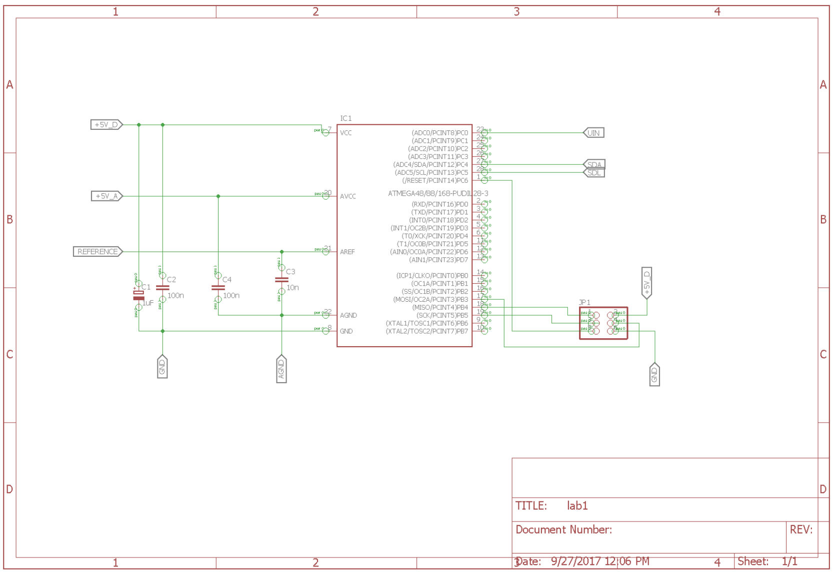

Figure 18: The figure above shows the schematic of the ADC.

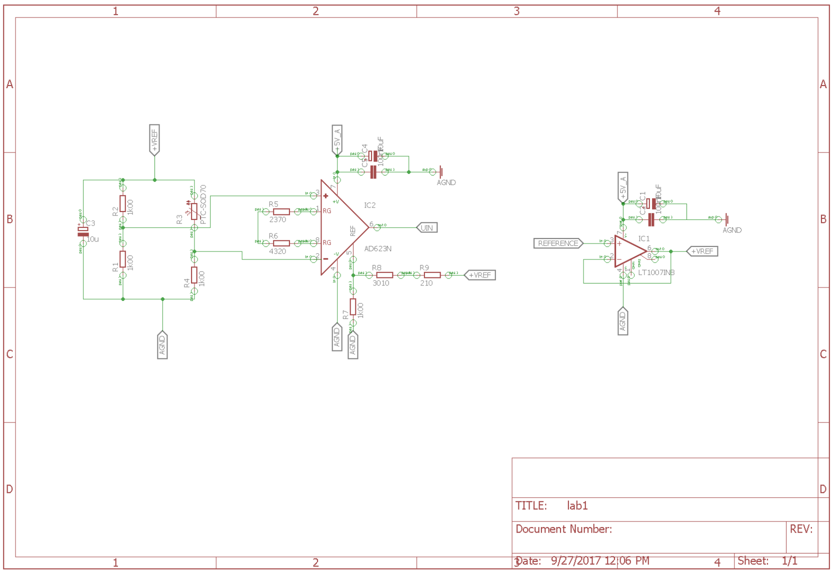

Figure 19: The figure above shows the schematic of the senseamp.

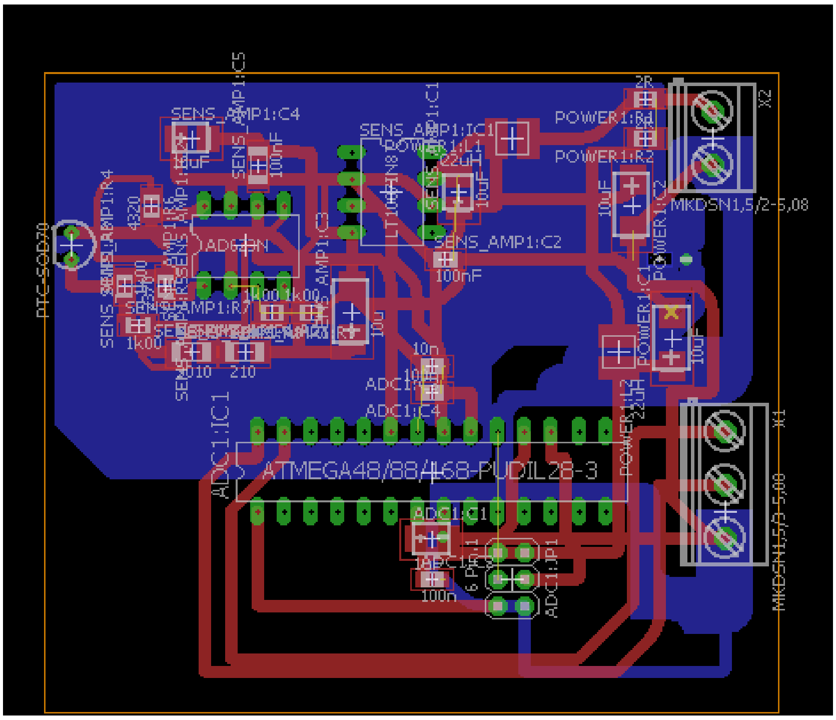

Figure 20: The figure above shows the PCB Design.