BM4111 – Mini-Project

Inductance Belt

Contents

Scope and Objectives

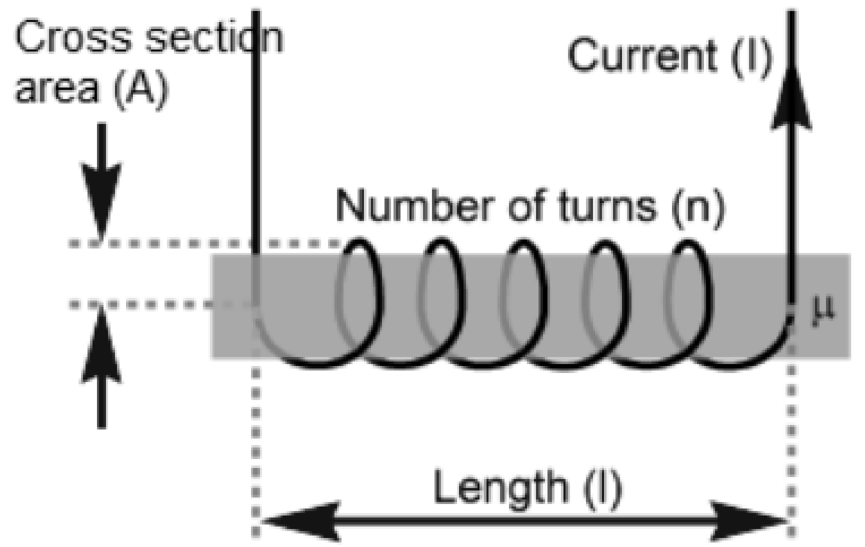
- Understand the physical principles behind the Inductance belt as a sensor and its potential applications
- Develop an analog interfacing circuit for inductance belt application: Respiration
- Apply signal processing algorithms to test the performance of the sensor interfacing circuit
- Characterize the sensor specifications: Sensitivity

Implementation pipeline

- Literature Review and Background Study
- Design Proposals
- Simulations and Design Evaluations
- Shortlisting Designs
- Testing the Selected Designs on Breadboards
- Final Design Selection
- PCB Design (Schematic and Layout)

Introduction to Sensor Technology

- Inductance belt consists of a sinusoid wire coil insulated and placed within a 2.5 – 4 cm wide, lightweight elastic and adhesive band
- A change in the cross-sectional area of the thorax results in a change in the geometric form factor of the inductance of the belt
- A change in the inductance is electrically reflected by a variation in the frequency of the oscillator's sinusoidal output
- We can convert the frequency to a voltage using an FM demodulation circuit



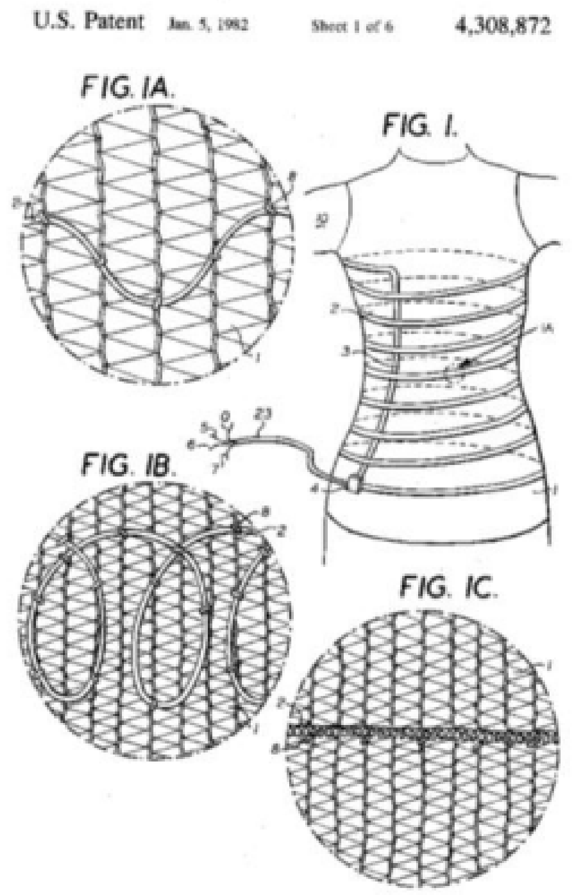


Image source: US Patent Number: 4 815 473

Potential Applications

- Numerous applications of the inductive belt in medical instrumentation:
  - Respiratory monitoring
  - Physiological monitoring in cardiac chest motions
  - Sleep monitoring (Polysomnography)
  - Psychiatric research (anxiety and stress) and psychophysiology
  - Anesthesia
  - Cardiac and pulmonary research (asthma, dyspnea)

Potential Applications

In this project, the inductive sensor belt is expected to be utilized in the application of

Respiratory Plethysmography

Respiratory inductive plethysmography

- Accurate measurement of pulmonary ventilation or breathing often requires the use of masks or mouthpieces coupled to the respiratory tract
- Alternatively, respiratory inductive plethysmography (RIP) could be employed at the body surface to deduce the respiratory rate
- In such techniques, changes in thoracic volume are inferred from the displacement of the rib cage
- The said displacements are sensed by the inductive belt

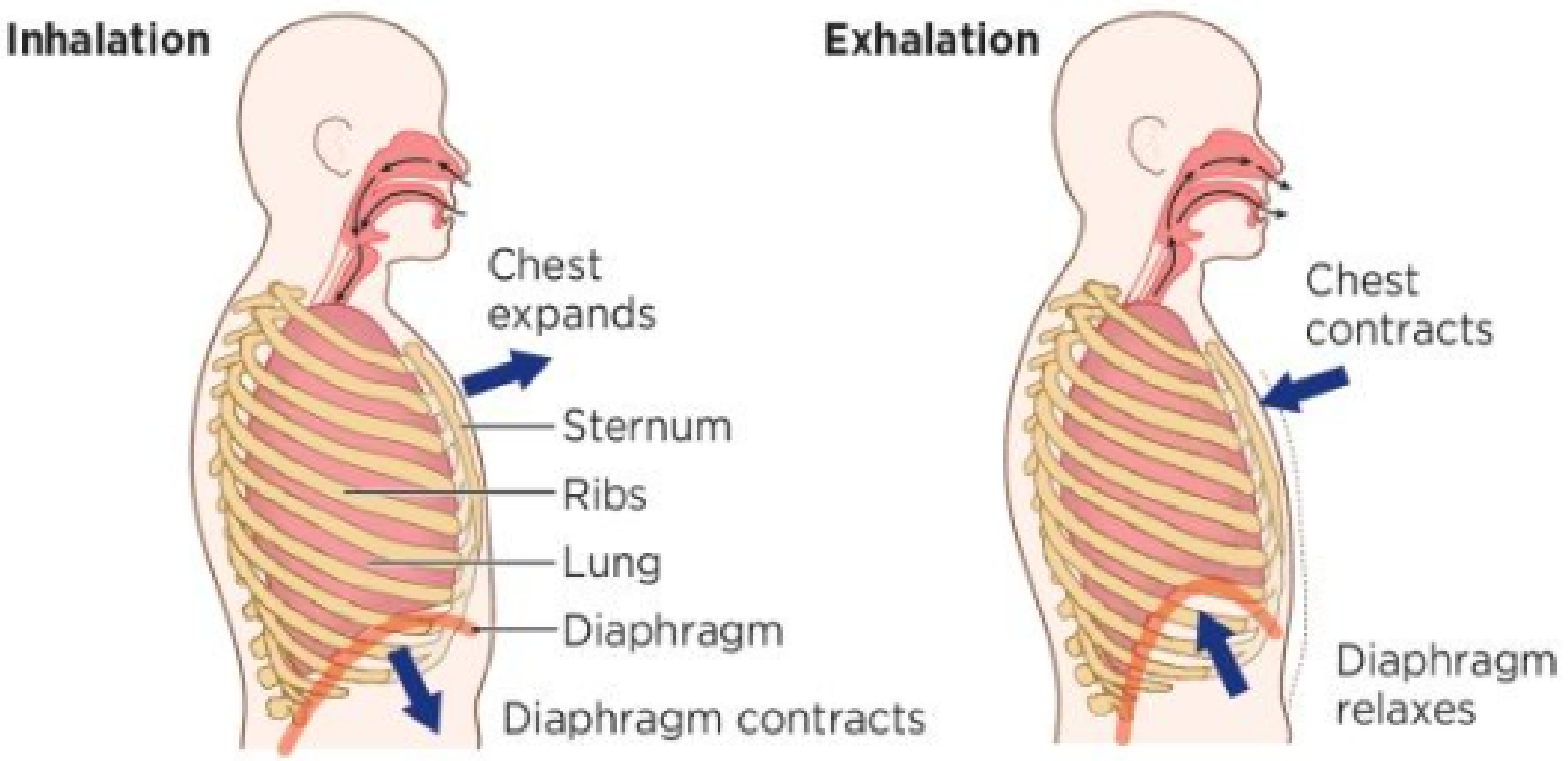


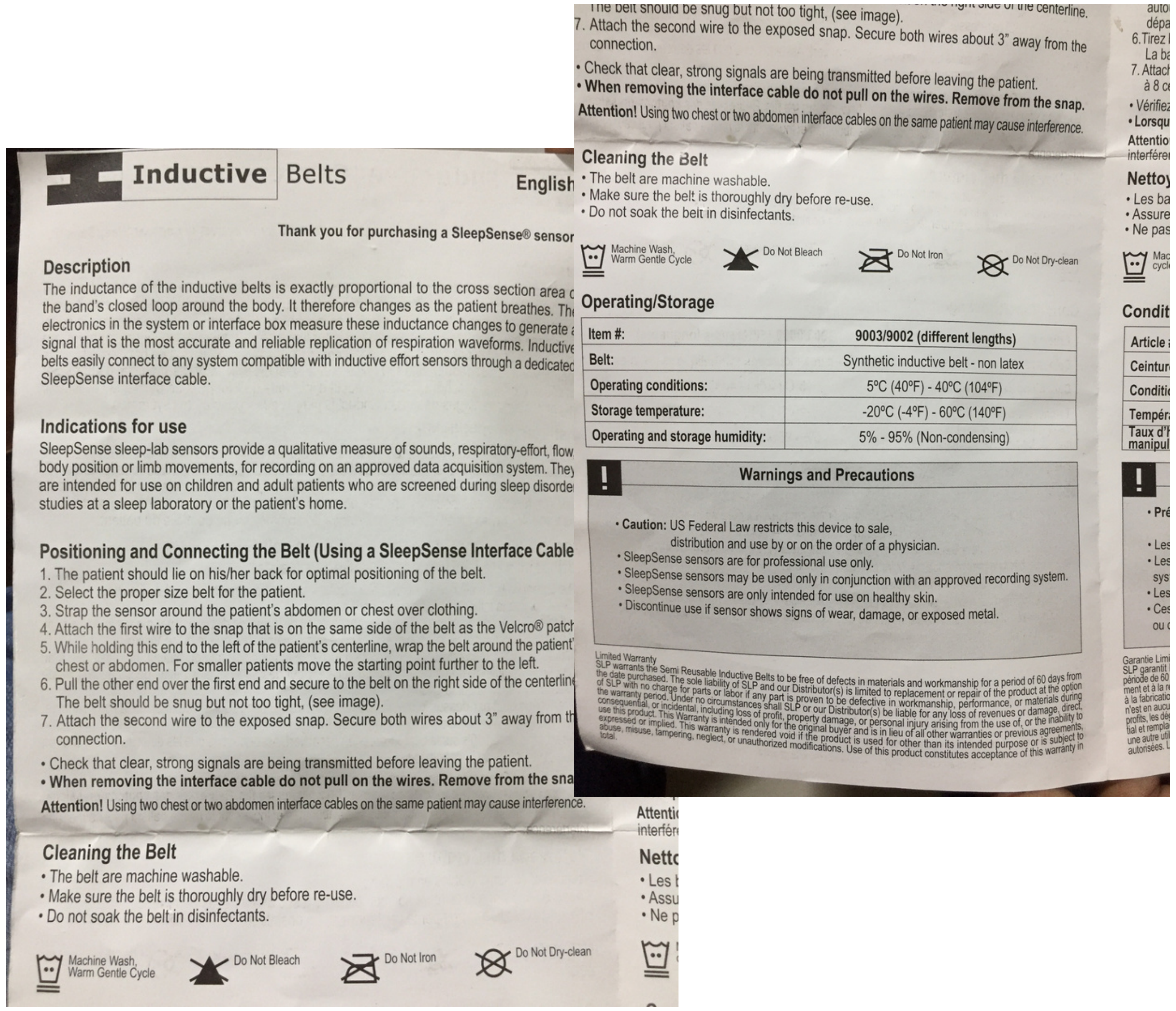
Image Source: https://www.nursingtimes.net/clinical-archive/respiratory-clinical-archive/respiratory-rate-3-how-to-take-an-accurate-measurement-25-06-2018/

The given Sensor Specifications

- The given sensor belt is an **inductive coil** made of **insulated wires** woven or sewn in a **sine wave or zig-zag pattern** on an expandable belt
- The belt is placed **around the rib cage** and during respiration, the length of the belt changes and, therefore, **self-inductance of the coils changes proportionally**
- By measuring variation in the coils' self-inductance, we can detect variations in the rib cage's **circumference or cross-sectional area**

The given Sensor Specifications

- Item name: 9003/9002
- Non-latex synthetic inductive belt
- Operating conditions
  - 5 celsius to 40 celsius in operation
  - -20 celsius to 60 celsius in storage
  - Non-condensing 5% to 95% humidity in operation



The given Sensor Specifications

- Sensitivity
  - The transfer-ratio of output to input OR the slope of the calibration curve
  - Adapted sensitivity (S) could be defined here as:
    - S = Change in output voltage / Change in cross-section of the belt
  - The manufacturers claim that the inductance of the inductive belts is exactly proportional to the cross-section of the belt's closed loop

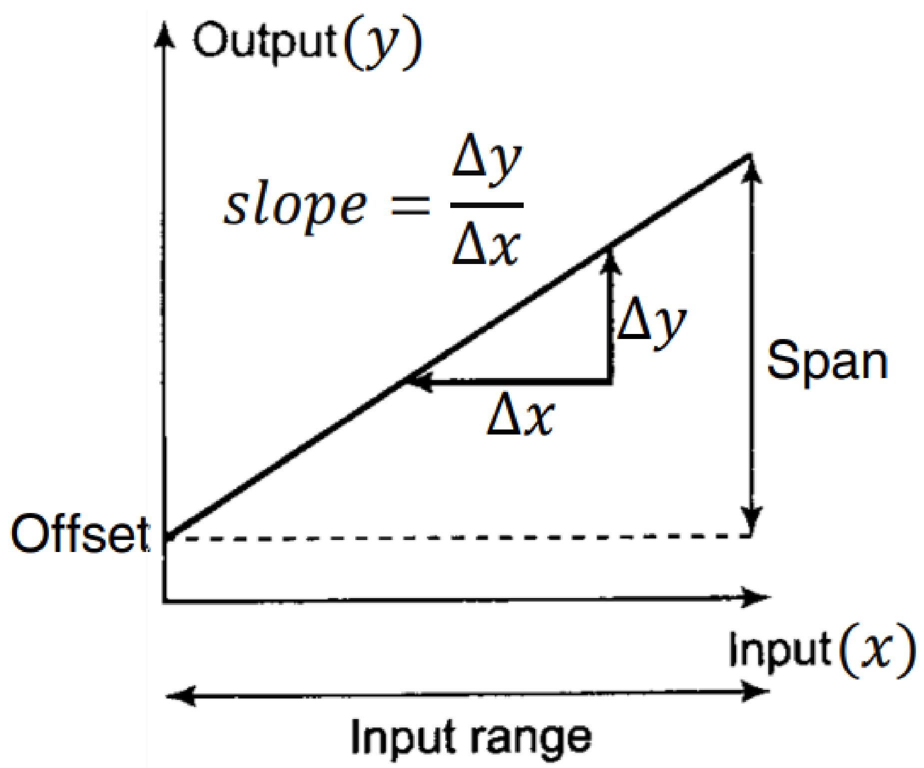


Image source: Webster Fig. 1.3a and Khandpur Fig. 3.1

Literature Review Summary

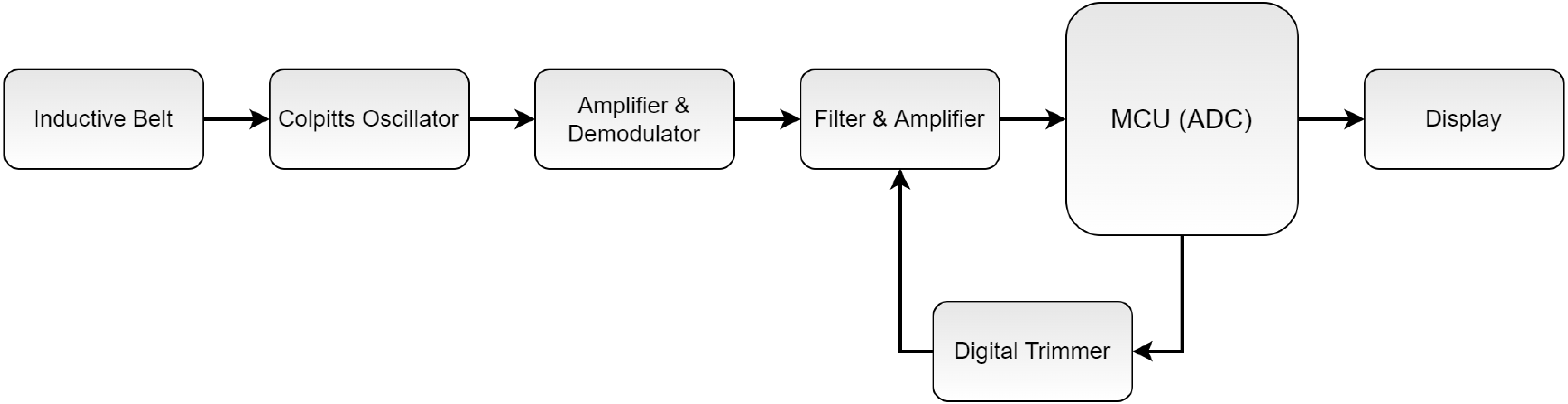
Design of an inductive plethysmograph for ventilation measurement [1]	**Two elastic bands encircle the chest and abdomen and Colpitts oscillator implementation**
Method and apparatus for monitoring respiration [2]	**Patients' chest cross-section area and variable frequency LC oscillator**
A Portable Respiratory Monitor Using Respiratory Inductive Plethysmography [3]	**Portable respiratory monitor and sensor sensitivity and linearity can be improved by designing**
Development of a Multisensory Wearable System for Monitoring Cigarette Smoking Behavior in Free-Living Conditions [4]	**Monitors the breathing patterns through inductive and bio-impedance respiratory sensors, cardiac activity and chest movement (three-axis accelerometer) etc.**

Design Choices for Interfacing Circuit

1) Colpitts oscillator-based inductive sensing
2) Variable frequency oscillator-based inductive sensing

- The oscillator is followed by a frequency-to-voltage converter/demodulator, (scaling) amplifier and filter stages with digital trimming and ADC at the end

Design Choice 01

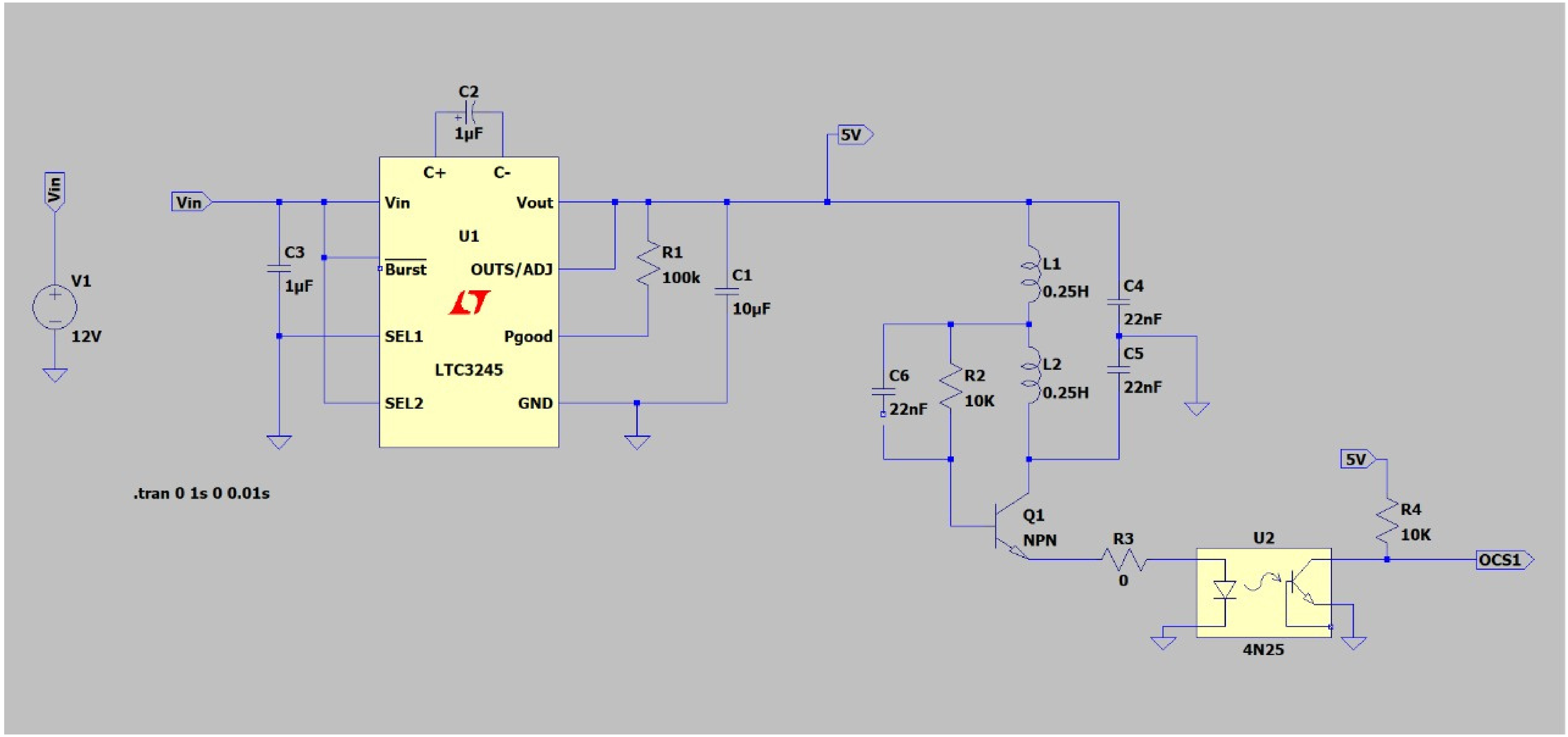


- To obtain digital waveforms, the inductive belt should be connected to an oscillator followed by a demodulation circuit
- The digital respiration waveform's amplitude is proportional to the inspired breath volume
- The typical pitch of the wire sinusoid is in the range of 1–2 cm
- The inductance of the belt is ~ 2–4 microhenries per metre

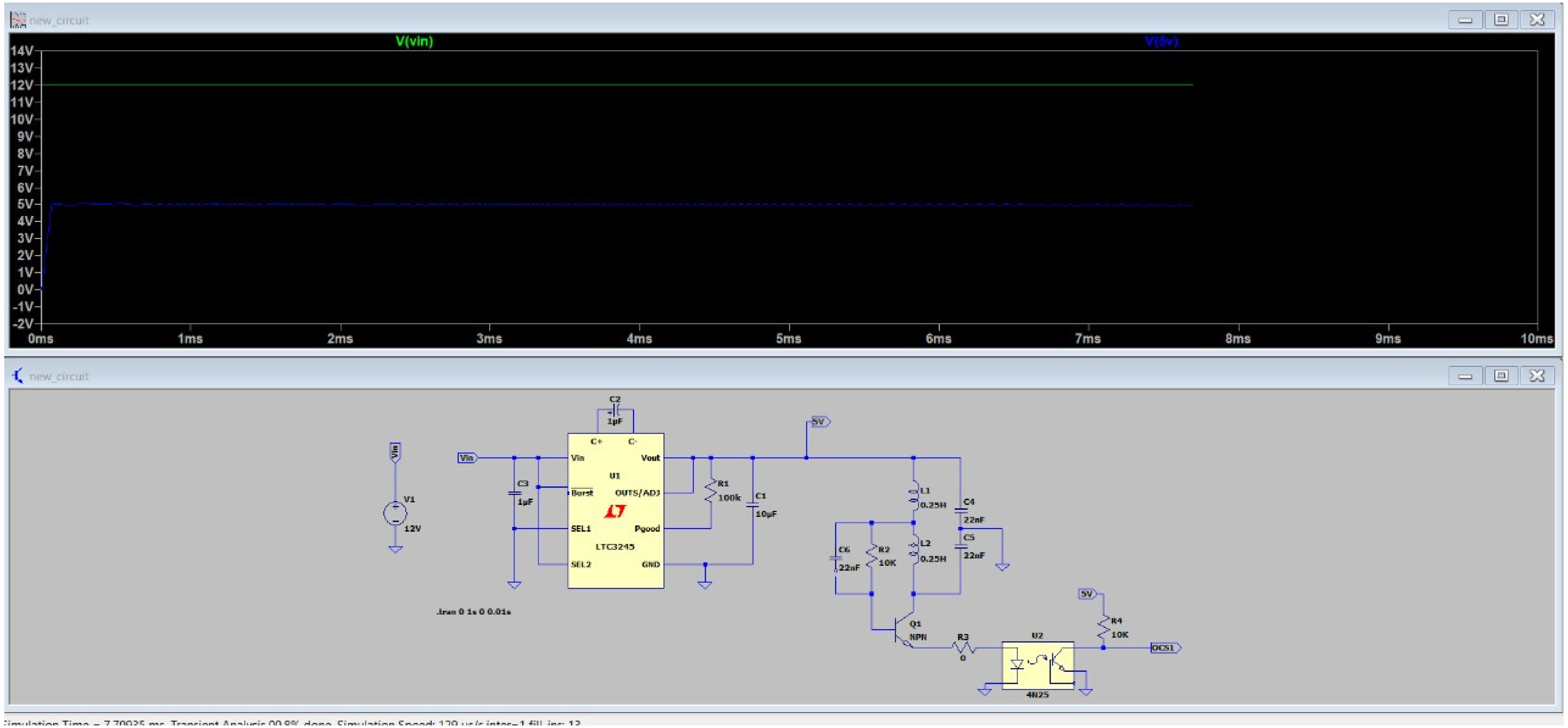
Proposed Interfacing Circuit

- Colpitts Oscillator: 2N3300 (NPN) transistors and inductive belt
- Demodulation circuit: CD54HCT4046A
- ADC: 6N137 – 20
- Filter and amplifier: LMP7702

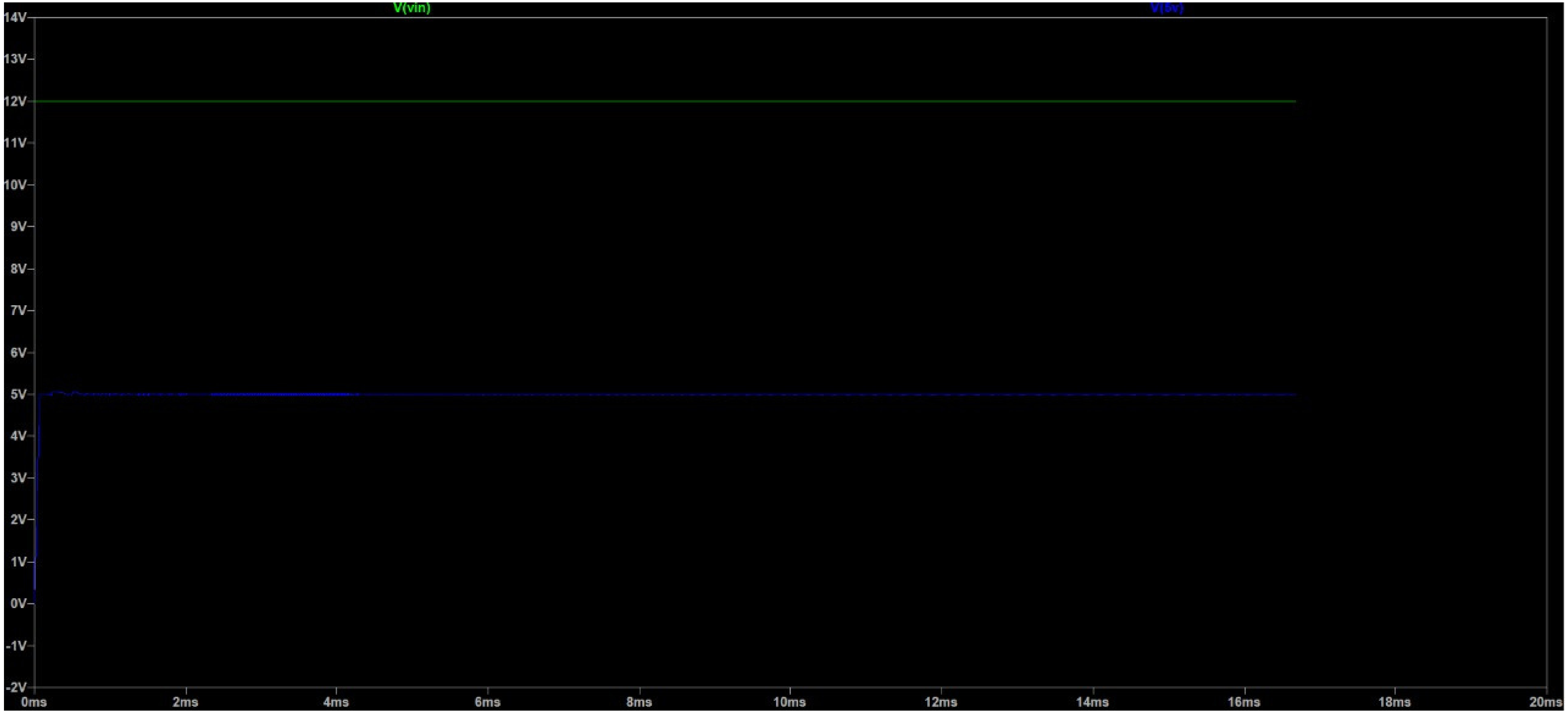
Colpitts Oscillator



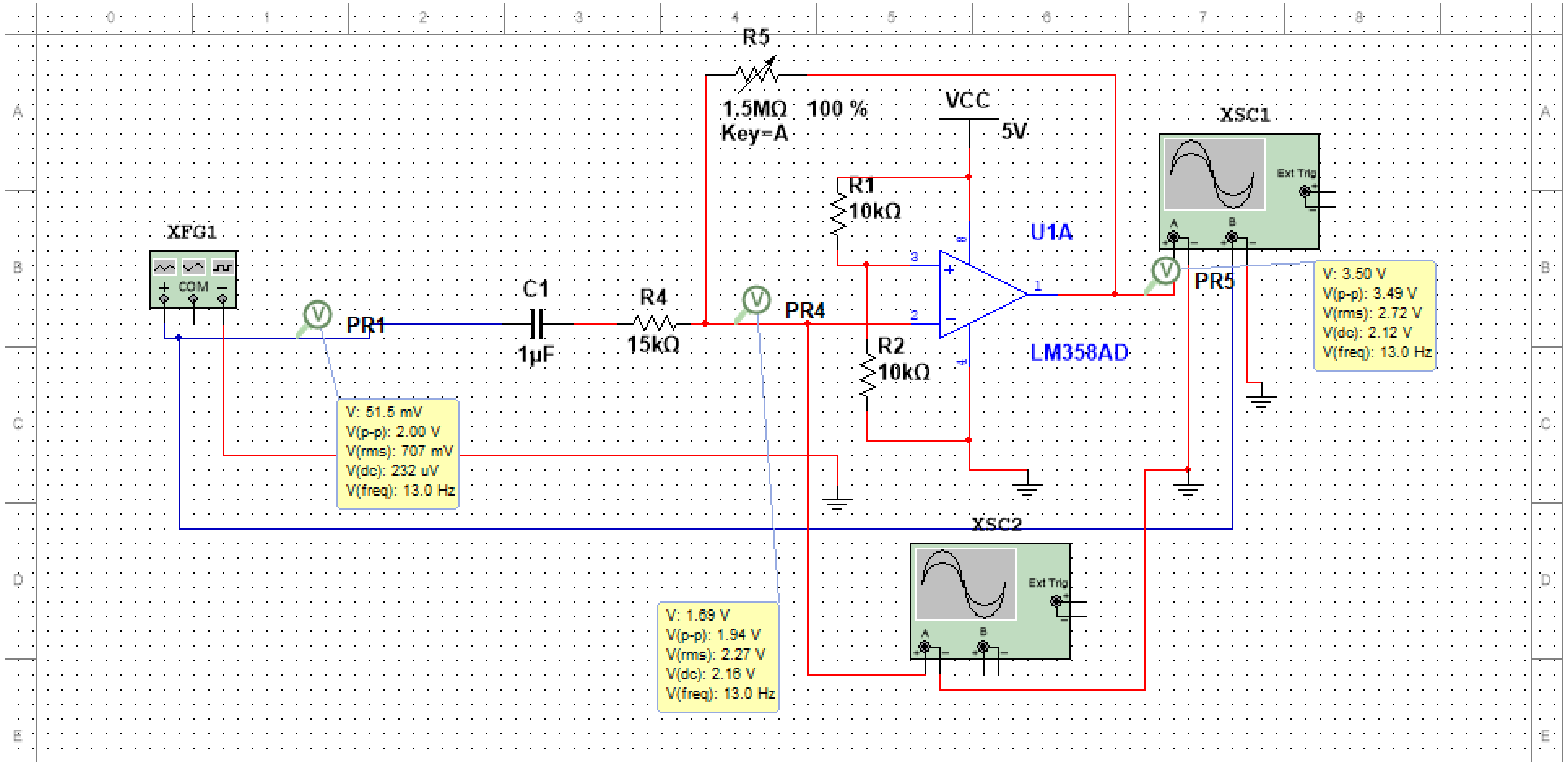
Colpitts Oscillator



Colpitts Oscillator

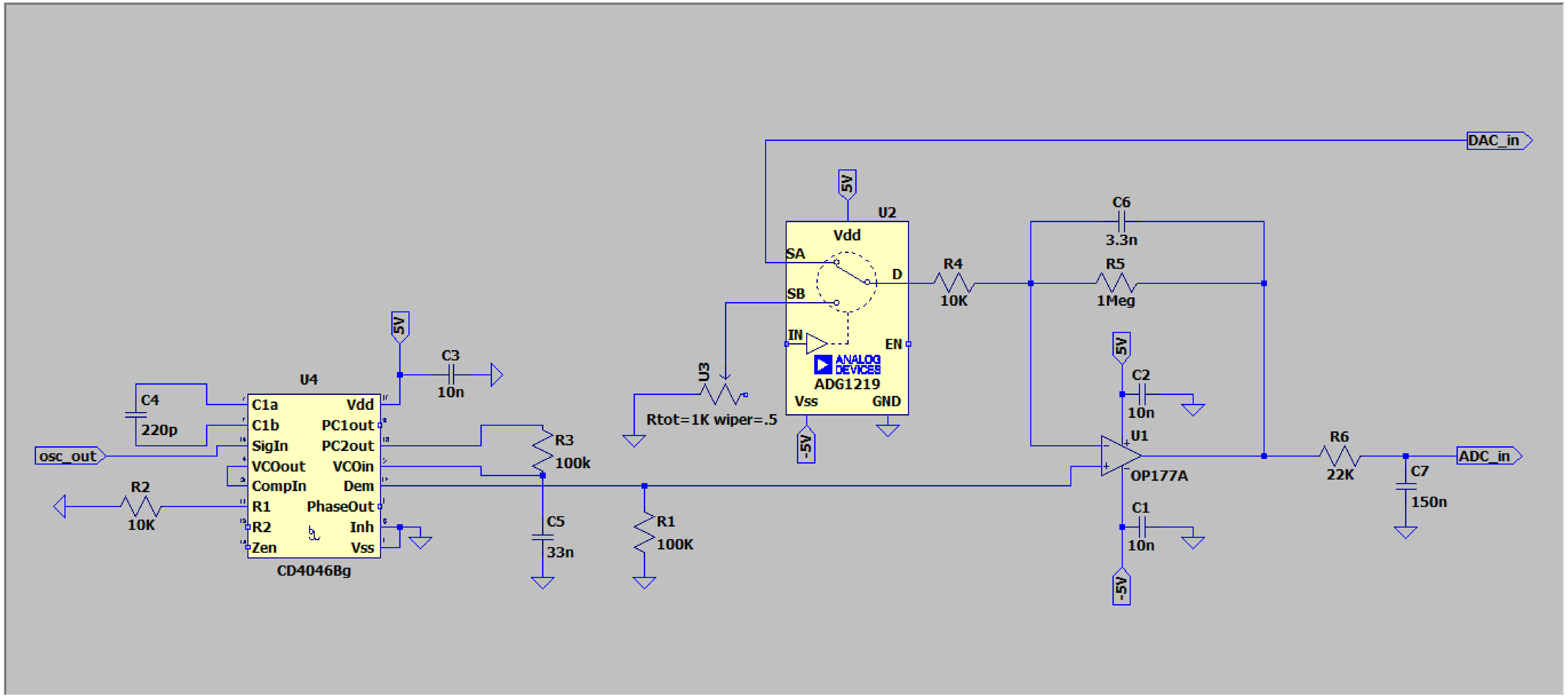


Amplifier

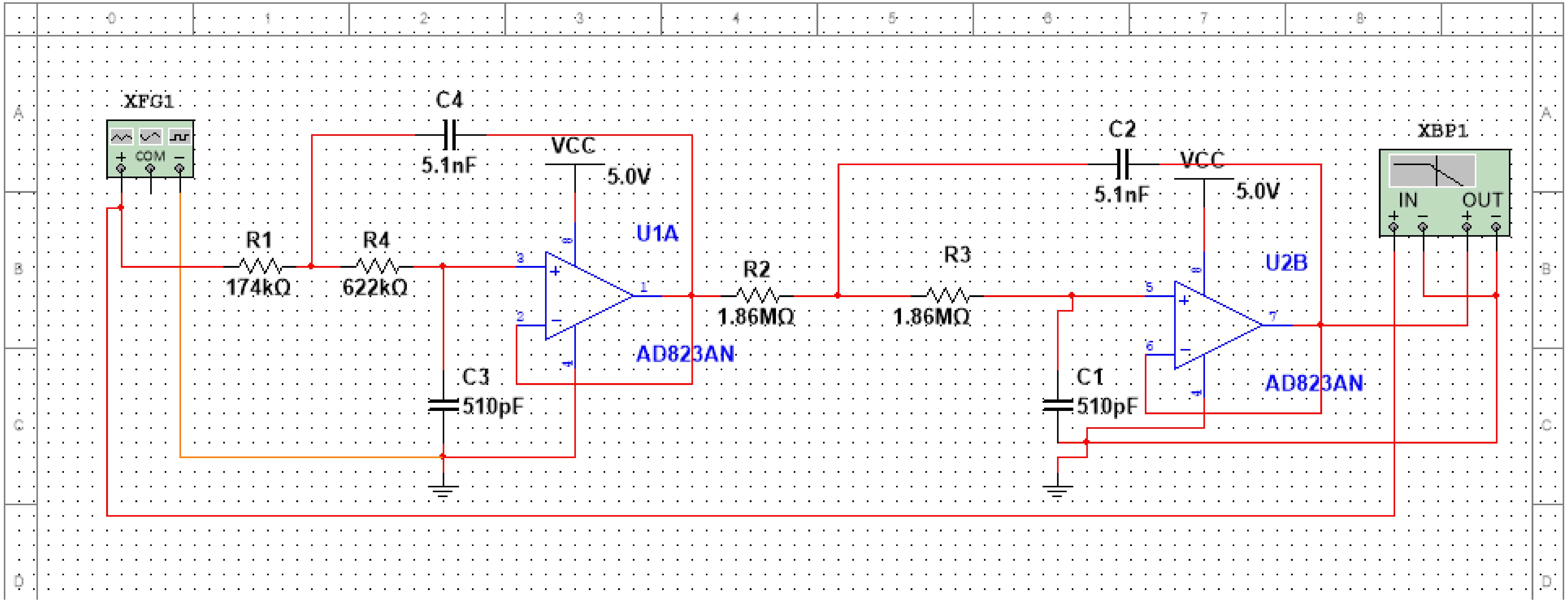


R5
1.5MΩ 100 %
Key=A
VCC
5V
XSC1
Ext Trig
A
B
R1
10kΩ
U1A
XFG1
COM
C1
R4
PR4
PR1
1µF
15kΩ
R2
10kΩ
LM358AD
PR5
V: 3.50 V
V(p-p): 3.49 V
V(rms): 2.72 V
V(dc): 2.12 V
V(freq): 13.0 Hz
V: 51.5 mV
V(p-p): 2.00 V
V(rms): 707 mV
V(dc): 232 uV
V(freq): 13.0 Hz
XSC2
Ext Trig
V: 1.69 V
V(p-p): 1.94 V
V(rms): 2.27 V
V(dc): 2.16 V
V(freq): 13.0 Hz

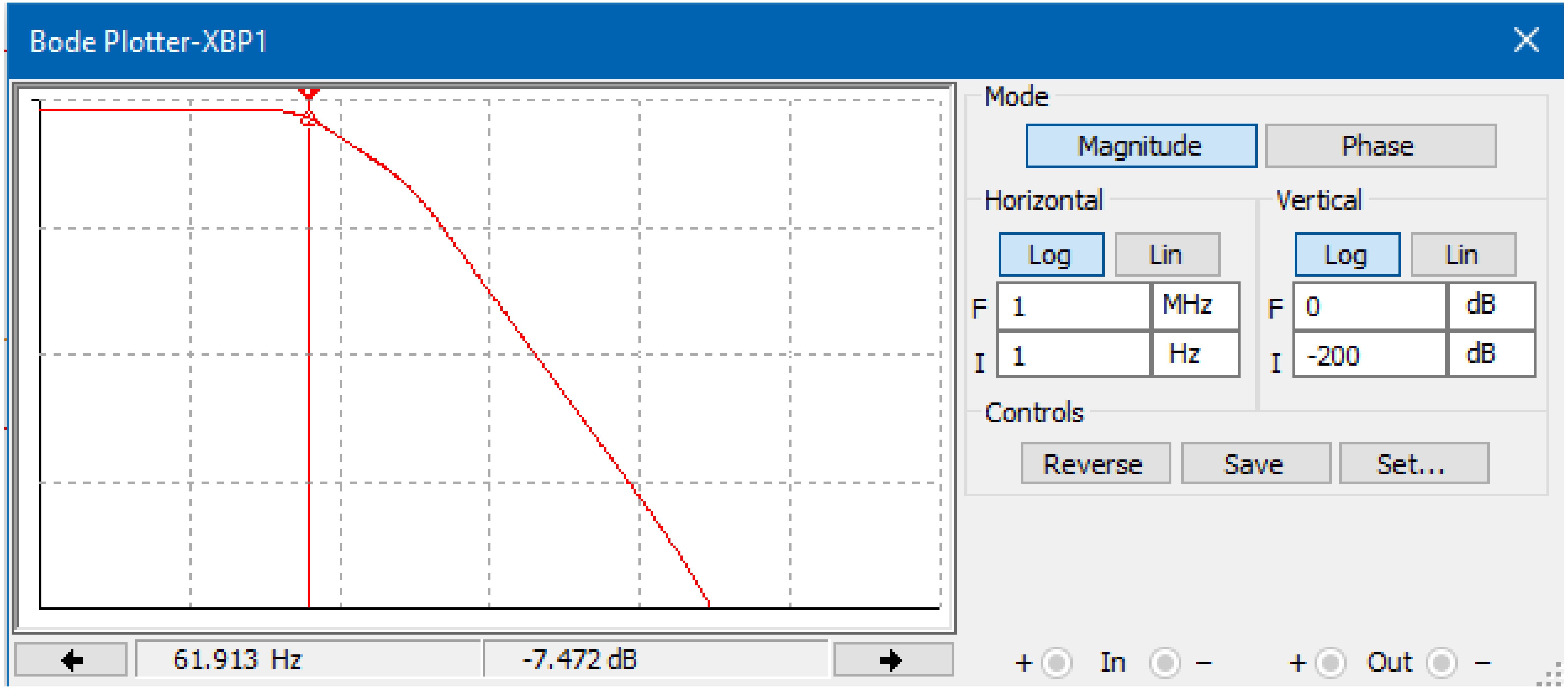
Demodulator



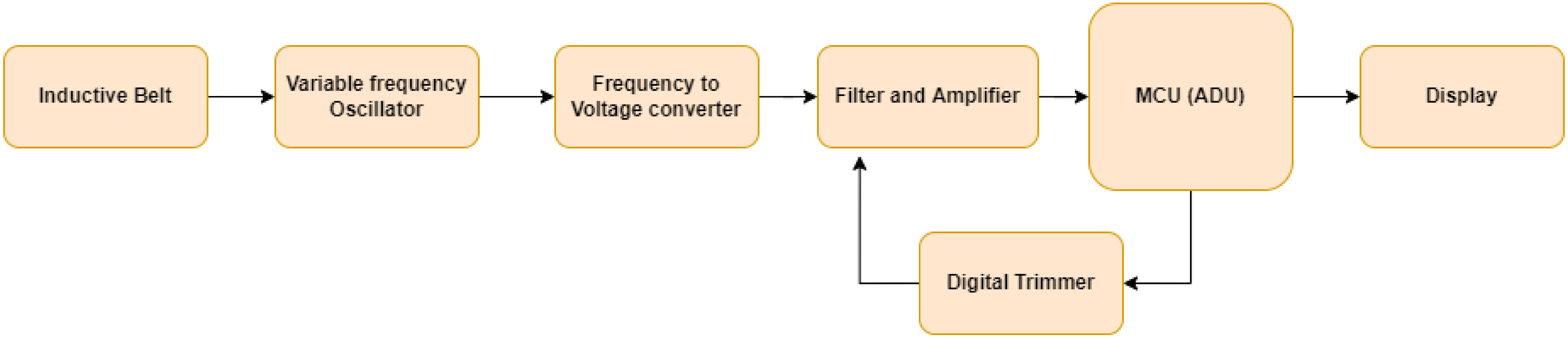
Low Pass Filter



Low Pass Filter

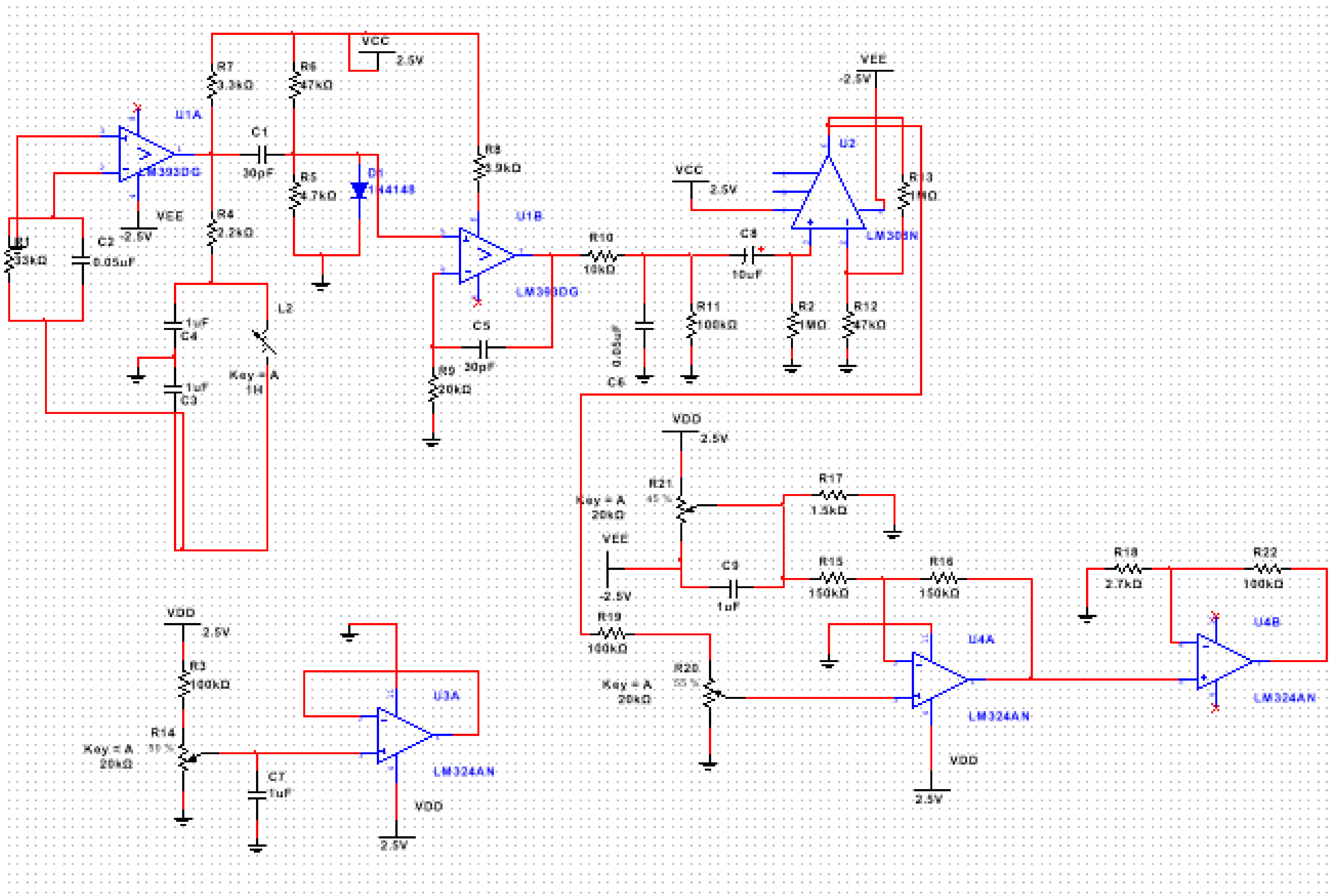


Design Choice 02

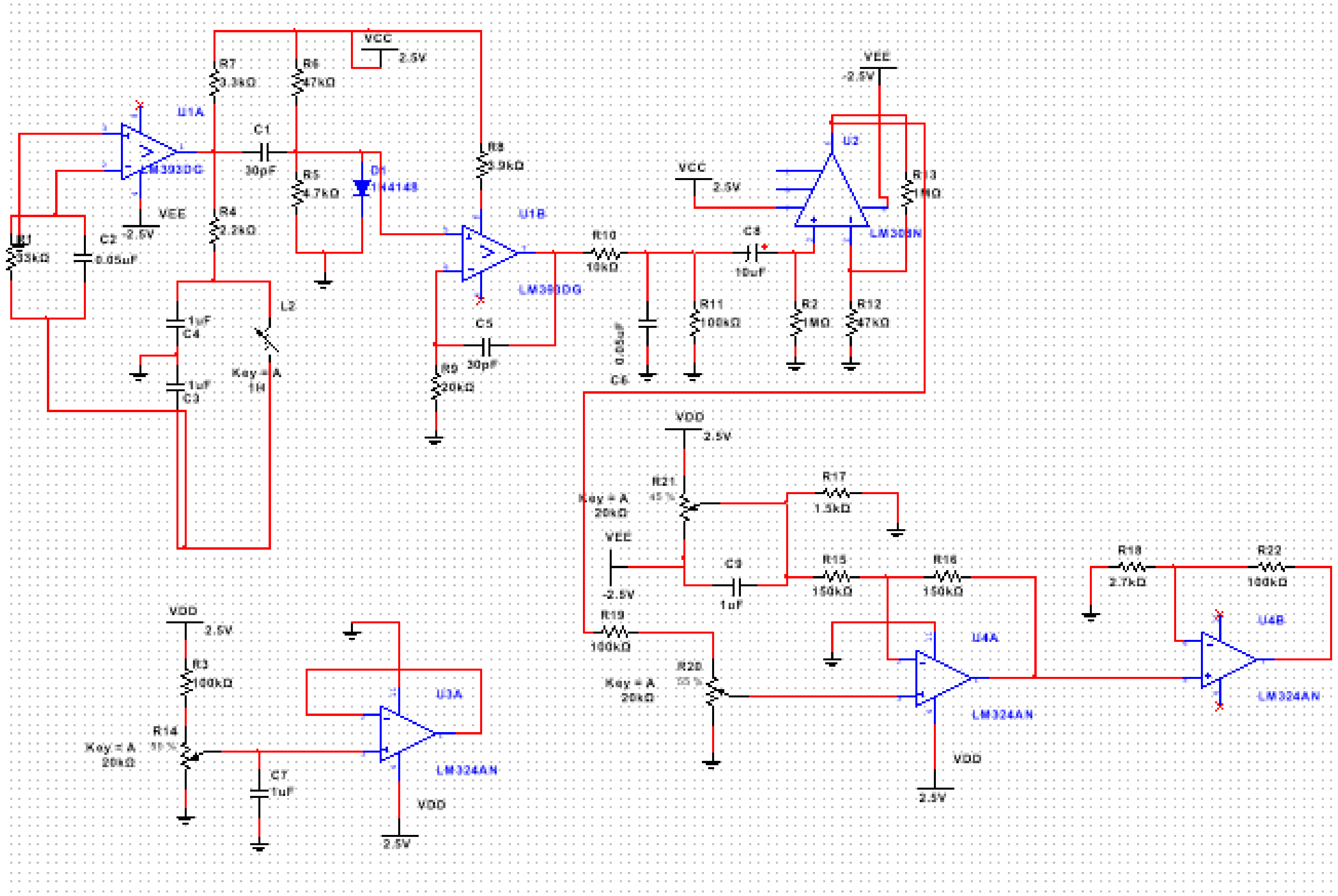


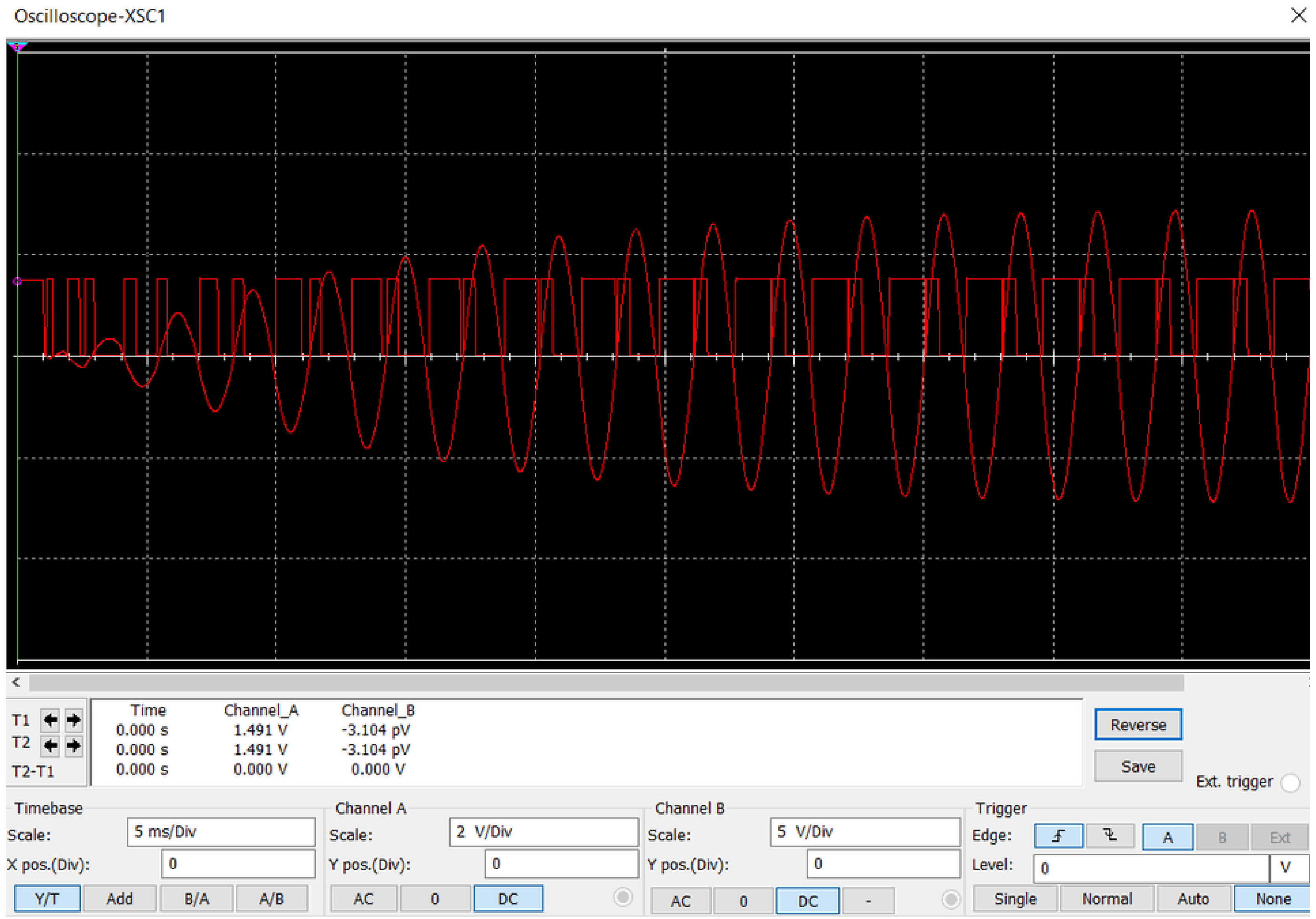
- To obtain digital waveforms, the inductive belt should be connected to an oscillator followed by a frequency-to-voltage converter circuit
- The digital respiration waveform's amplitude is proportional to the inspired breath volume
- An optocoupler and an isolated DC-DC converter are to be used for power and signal isolation

Simulation Circuit – MultiSim



Simulation Circuit – MultiSim



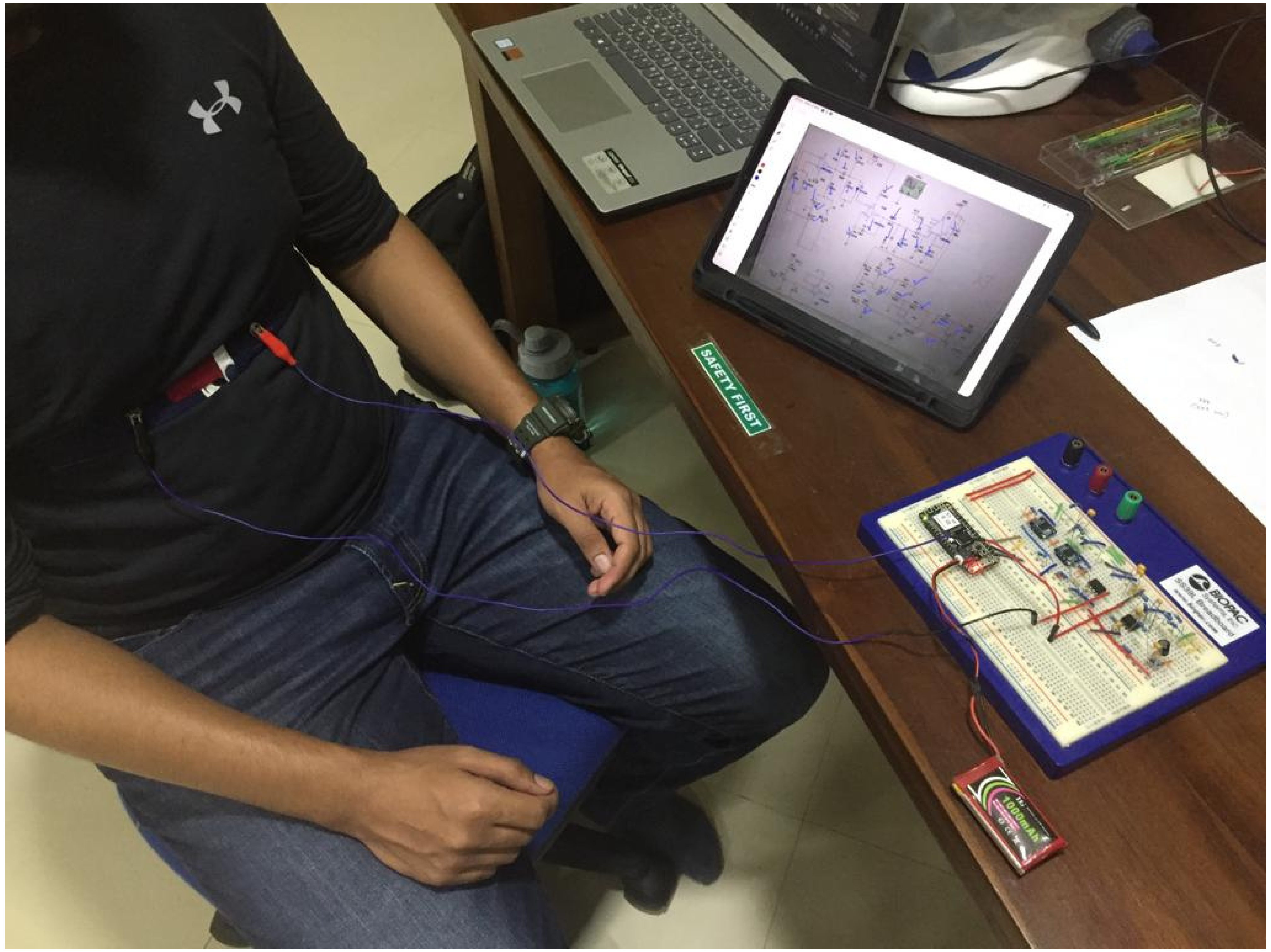


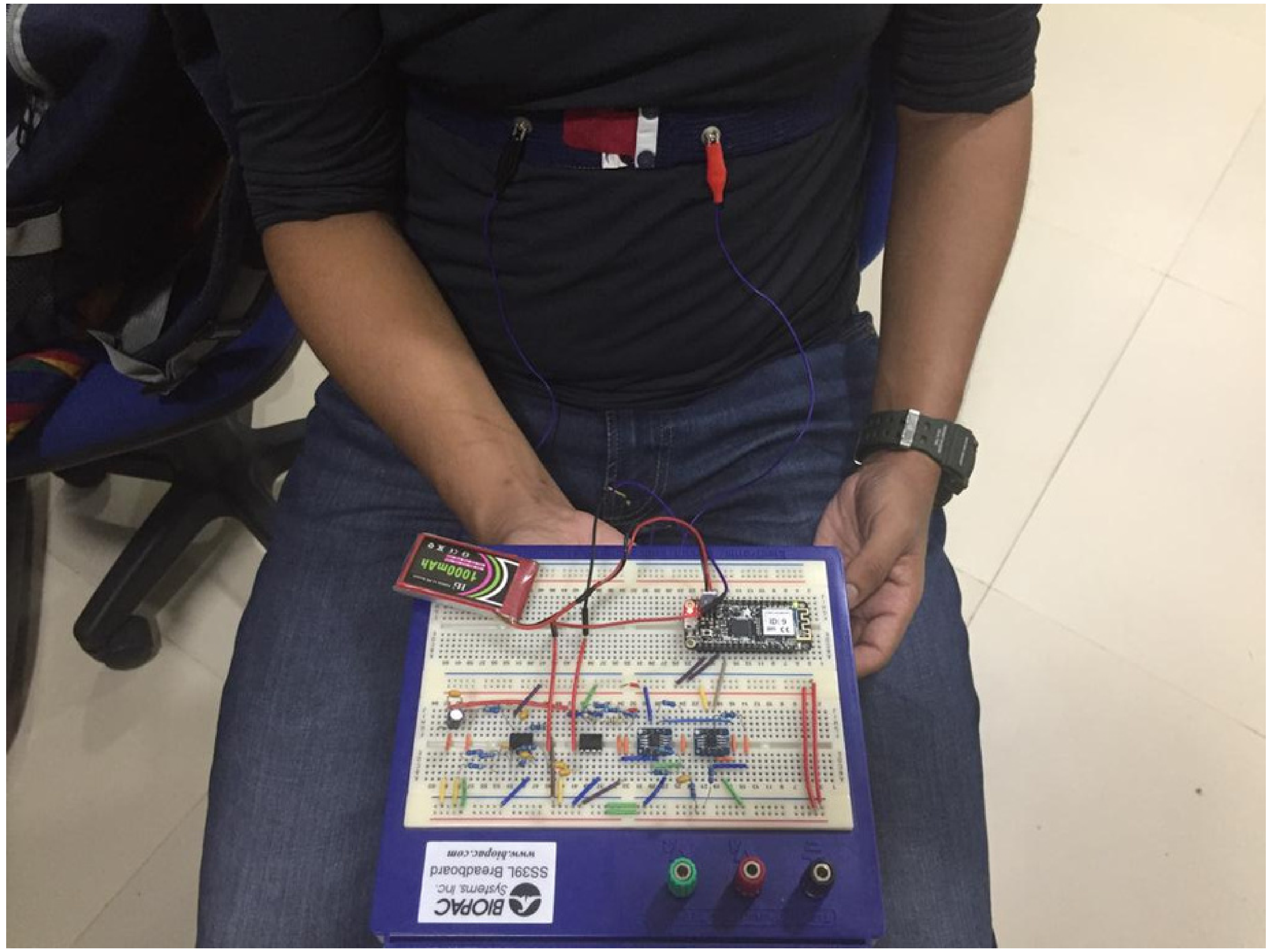
Design Choice Comparison and Selection

Design 01: Colpitts oscillator module	Design 02: Variable frequency oscillator
Less controllability in terms of resistor, capacitor selection	More controllability in terms of resistor, capacitor selection
A subset of the variable frequency oscillators	The superset of variable frequency oscillators
The components are less available	Could build from fundamental components and thus, more available

Due to above factors and considerations, design 02 is identified to be utilized

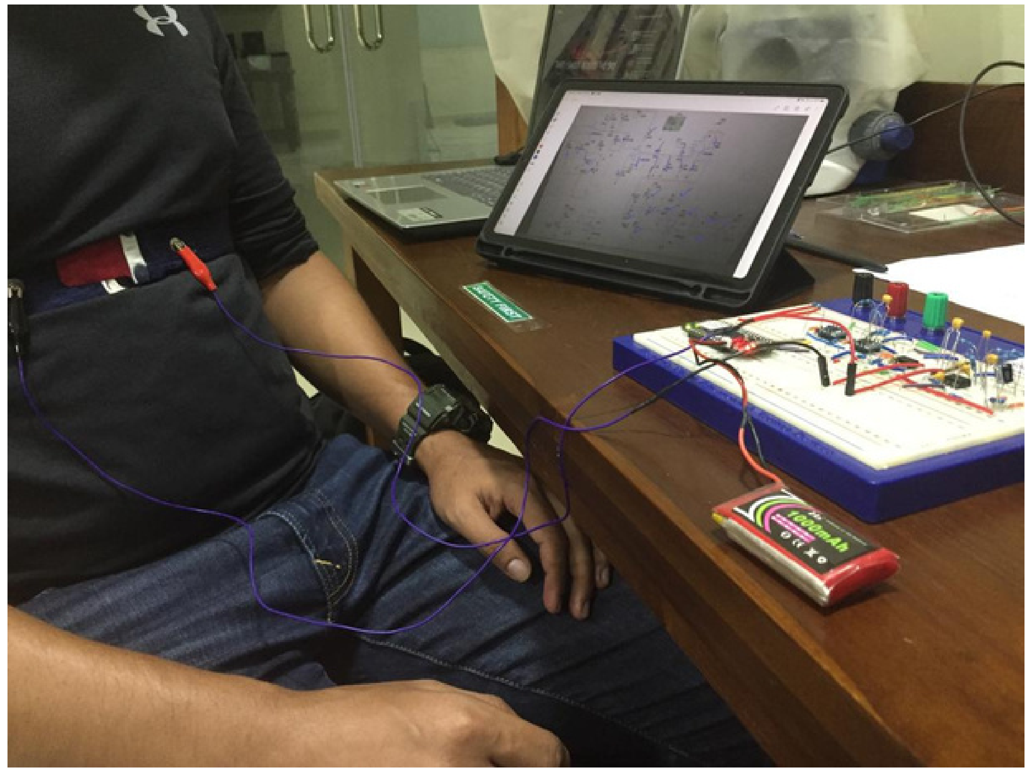
Implementation in a Testing environment

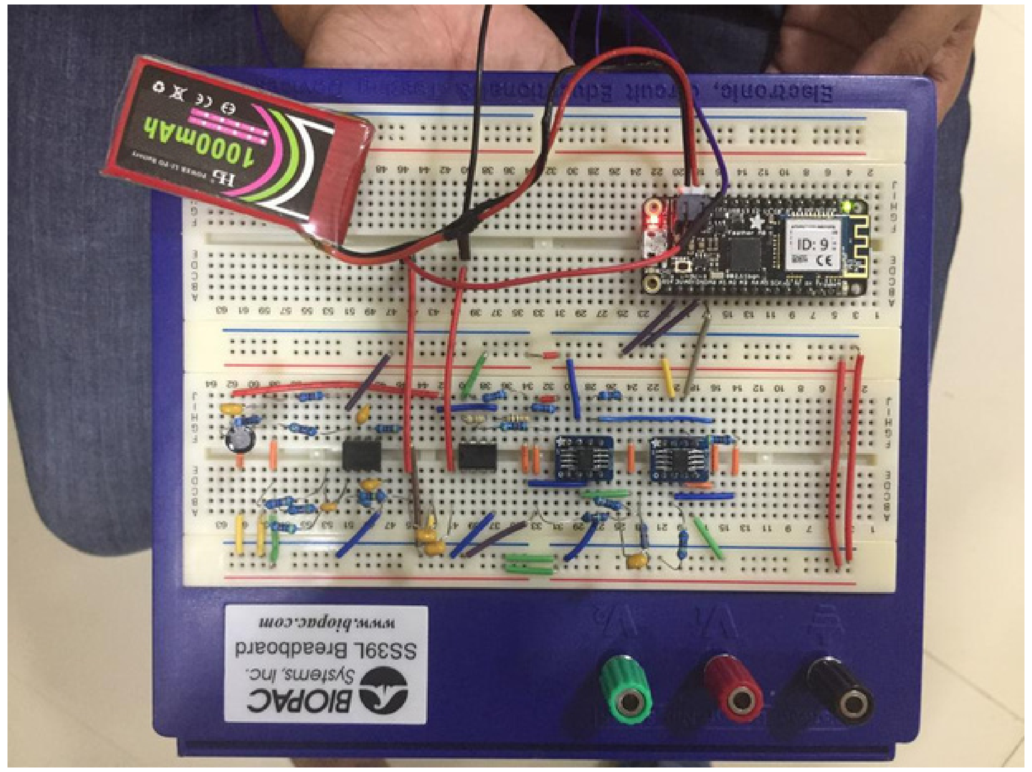


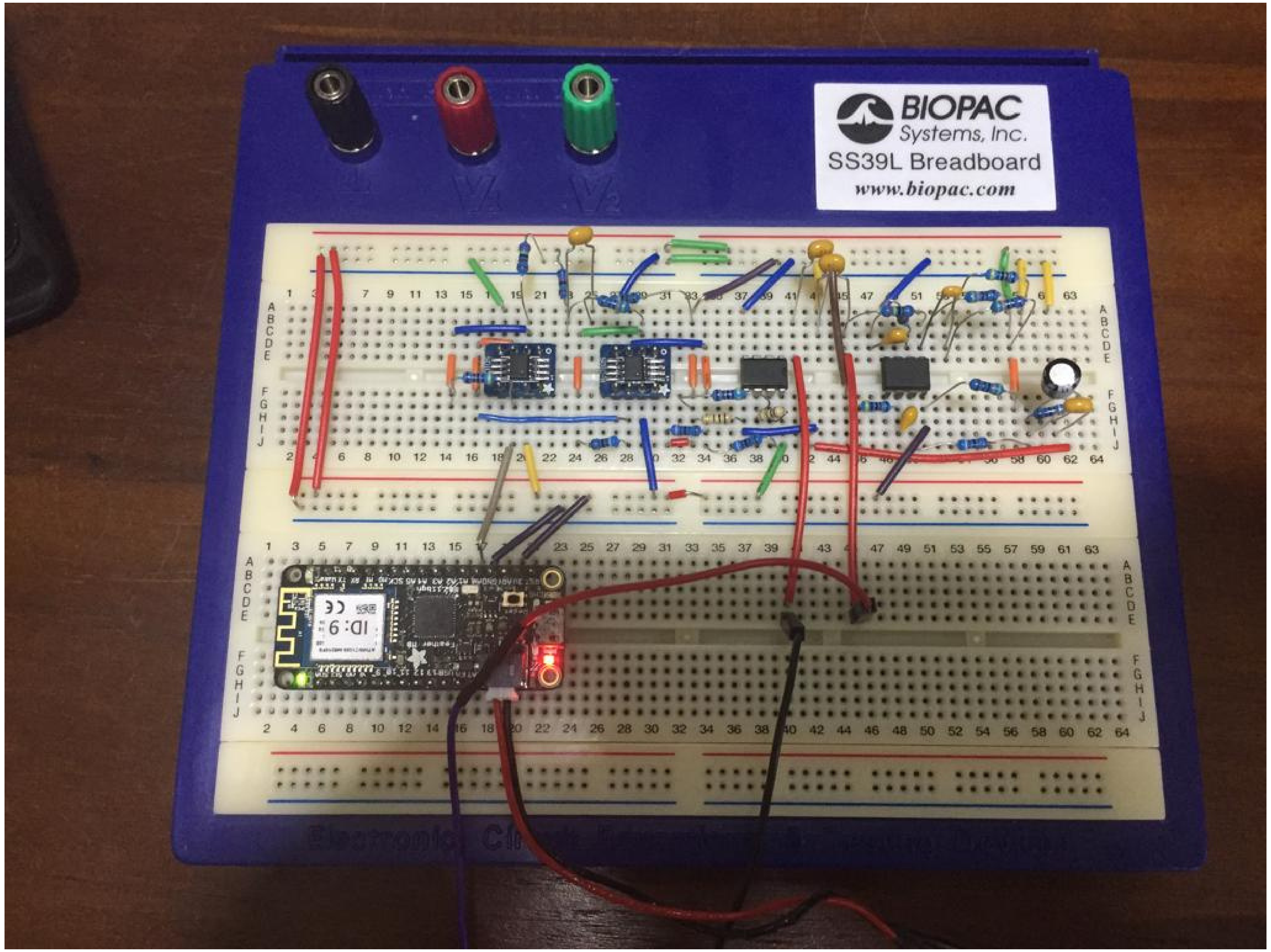


The setup for interfacing and the implemented circuit on a breadboard

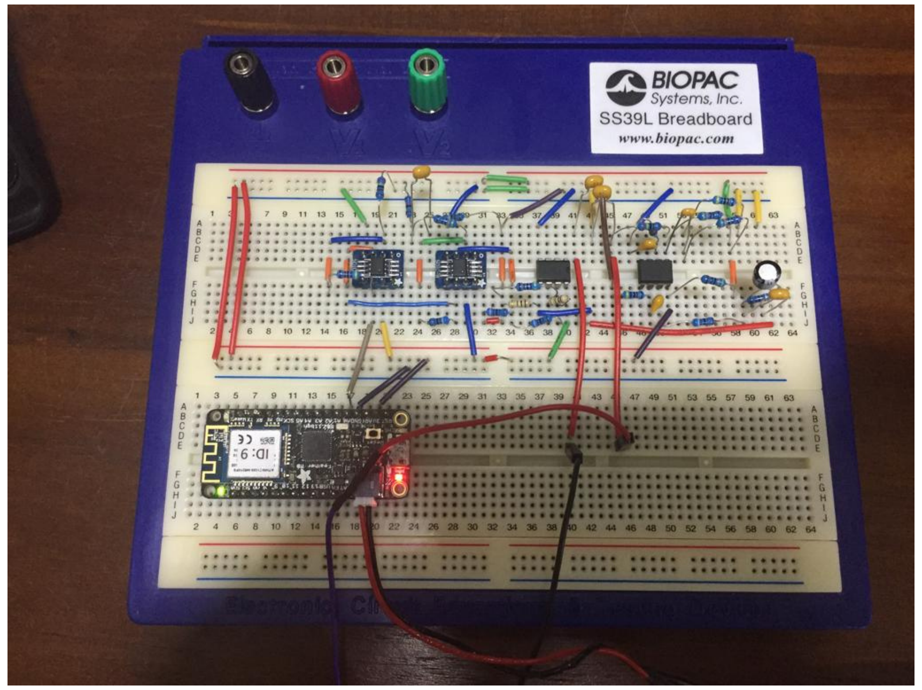
Implementation in a Testing environment

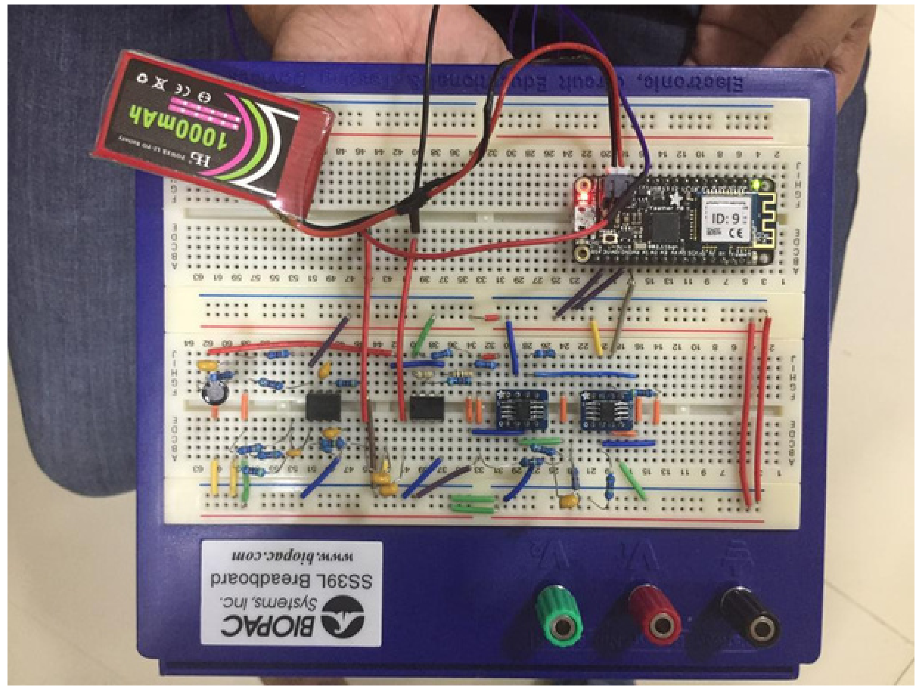






Implementation in a Testing environment





MATLAB-based Firmware and Post-Processing

Derived from the code ADL ECG practical resources, the live plot was saved and processed through a custom MATLAB code to be saved

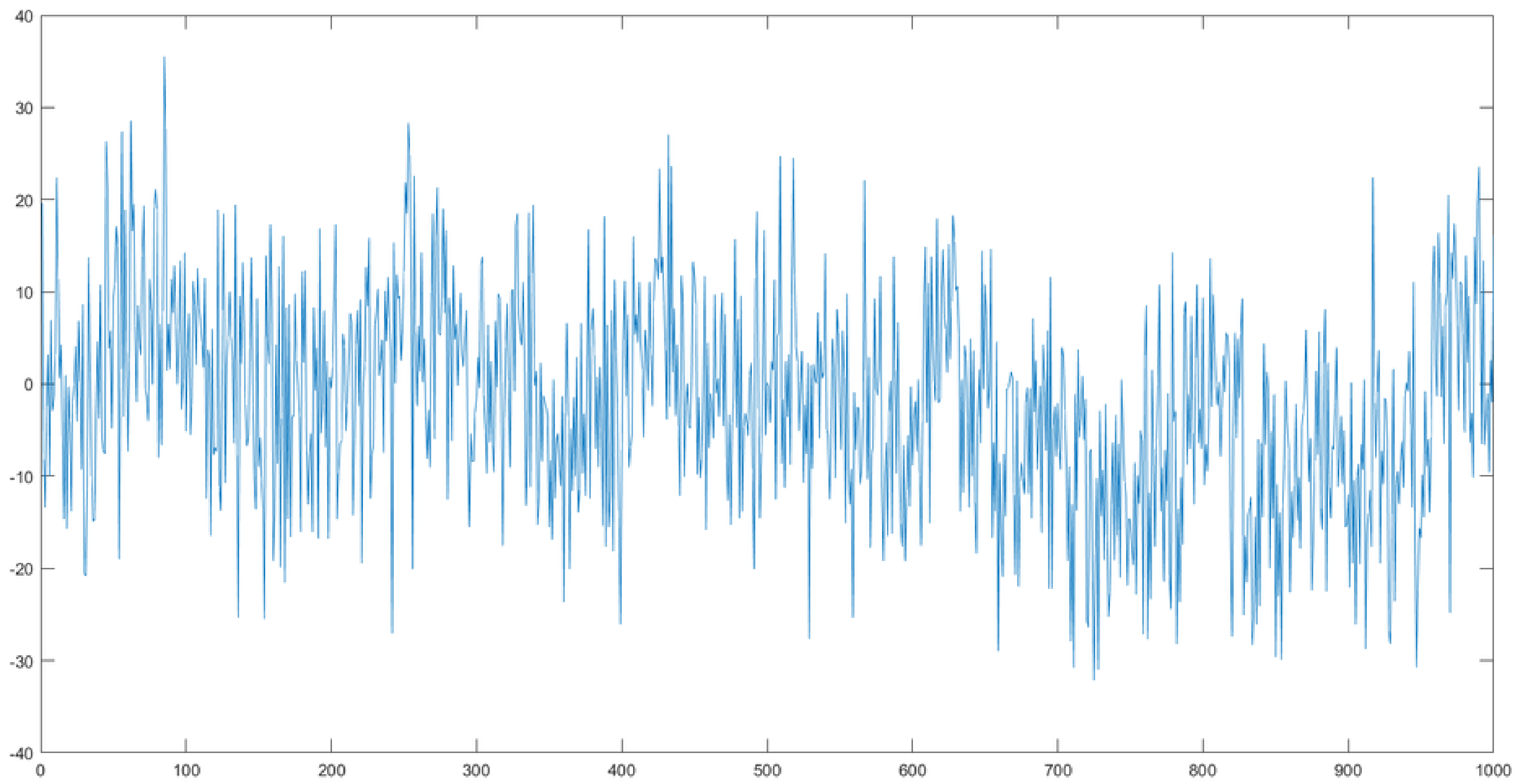
```
    %% Plot and save data (obj.Data)
    function handle = plot(obj)
        handle = plot(obj.TimeAxis,obj.Data');
        xlim([obj.TimeAxis(1) obj.TimeAxis(end)]);
        xlabel('time [sec.]');
        ylabel('Amplitude [V]');

        T = table(obj.TimeAxis', obj.Data, 'VariableNames', { 'time', 'data'} );
        % Write data to text file
        writetable(T, 'Data.txt');
    end
```

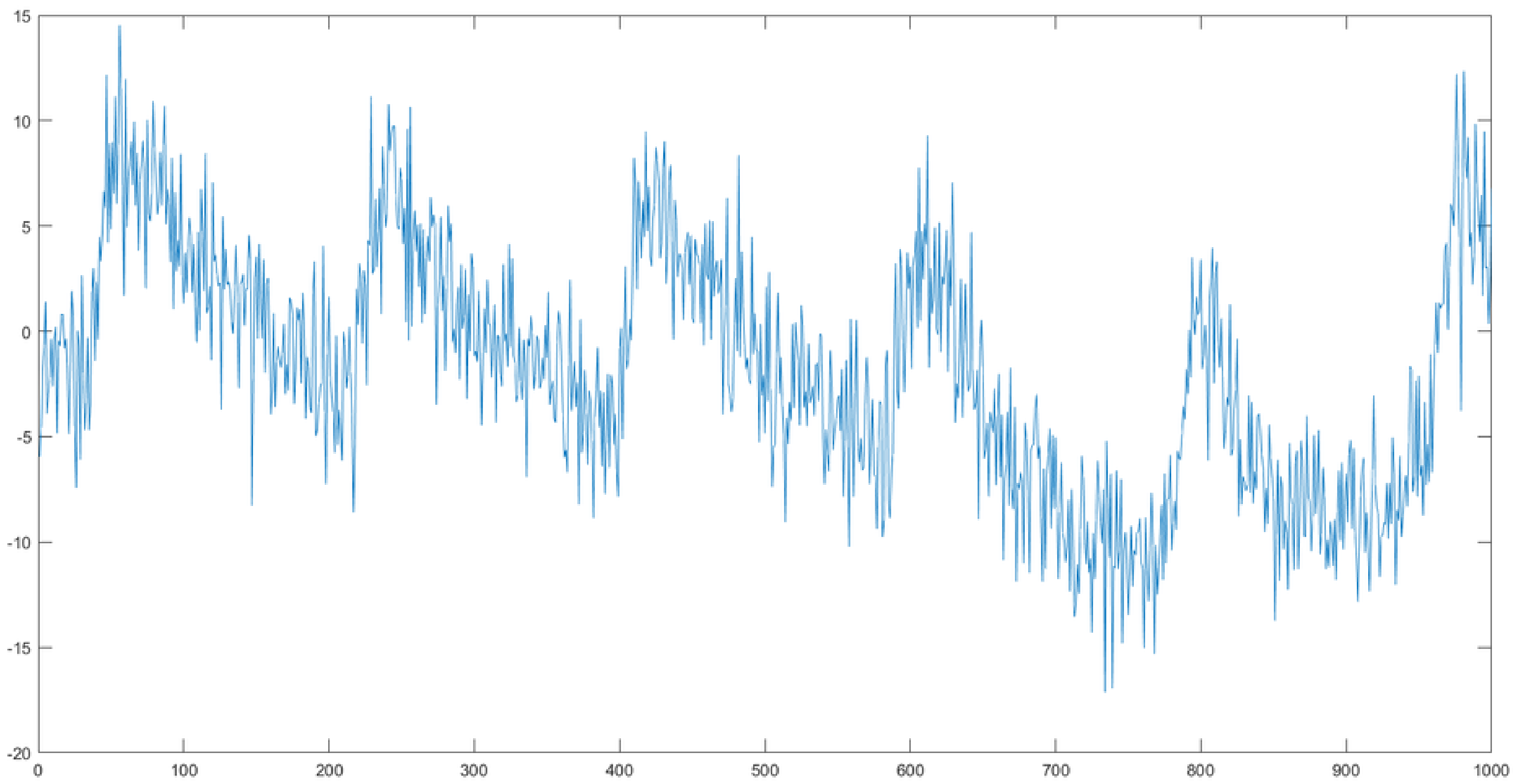
Denoised the data in the post-processing steps via MATLAB implementation:

- The empirical Bayesian method with a Cauchy prior with the sym4 wavelet is used with a posterior median threshold rule
- Denoising is down to the minimum of floor(log2N) and wmaxlev(N,"sym4") where N is the number of samples in the data

Implementation in a Testing environment

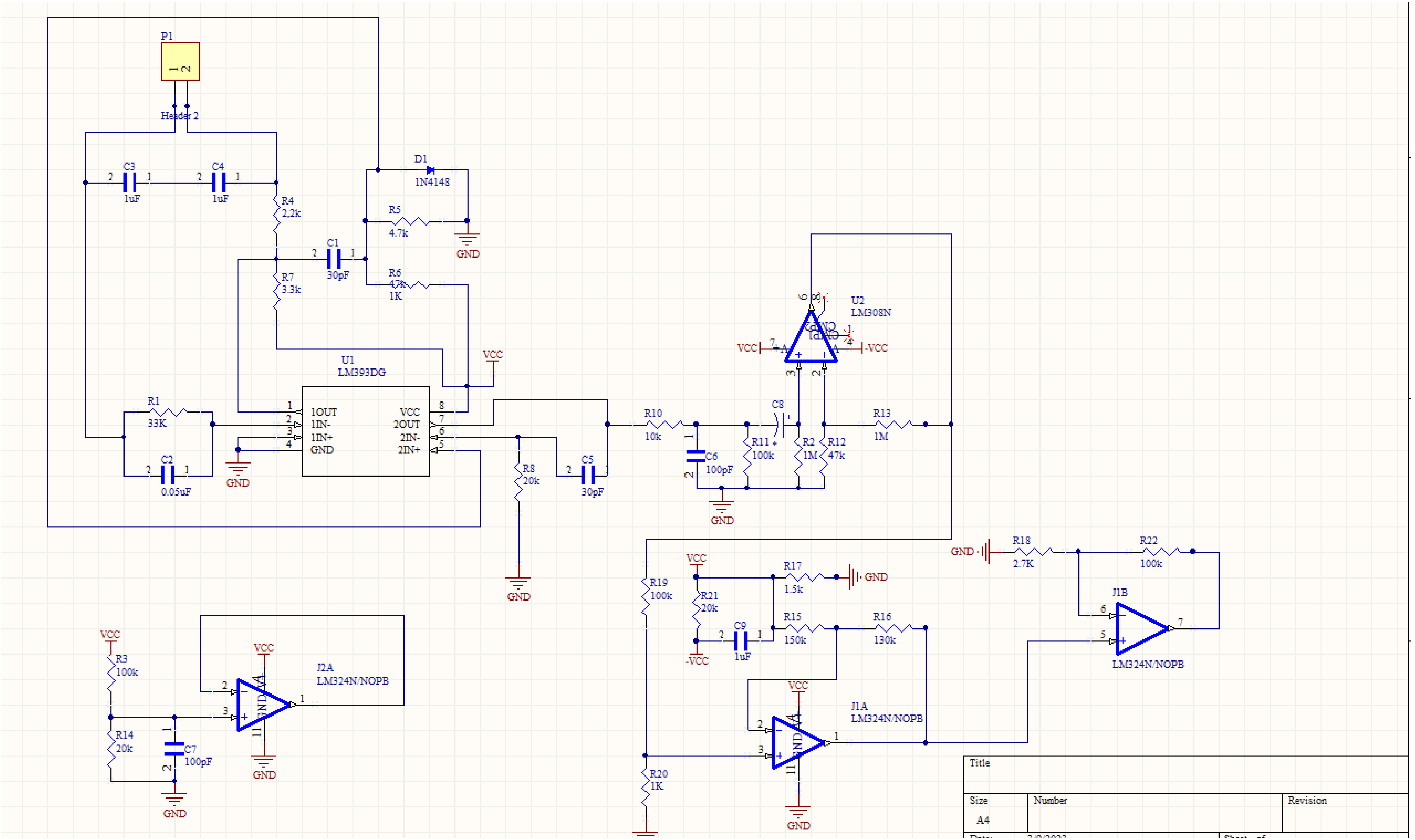


The raw signal obtained through the setup and the connected Adafruit Feather M0 development board
(The utilized firmware was derived from the code ADL ECG practical resources and the live plot was saved and processed through a custom MATLAB code)

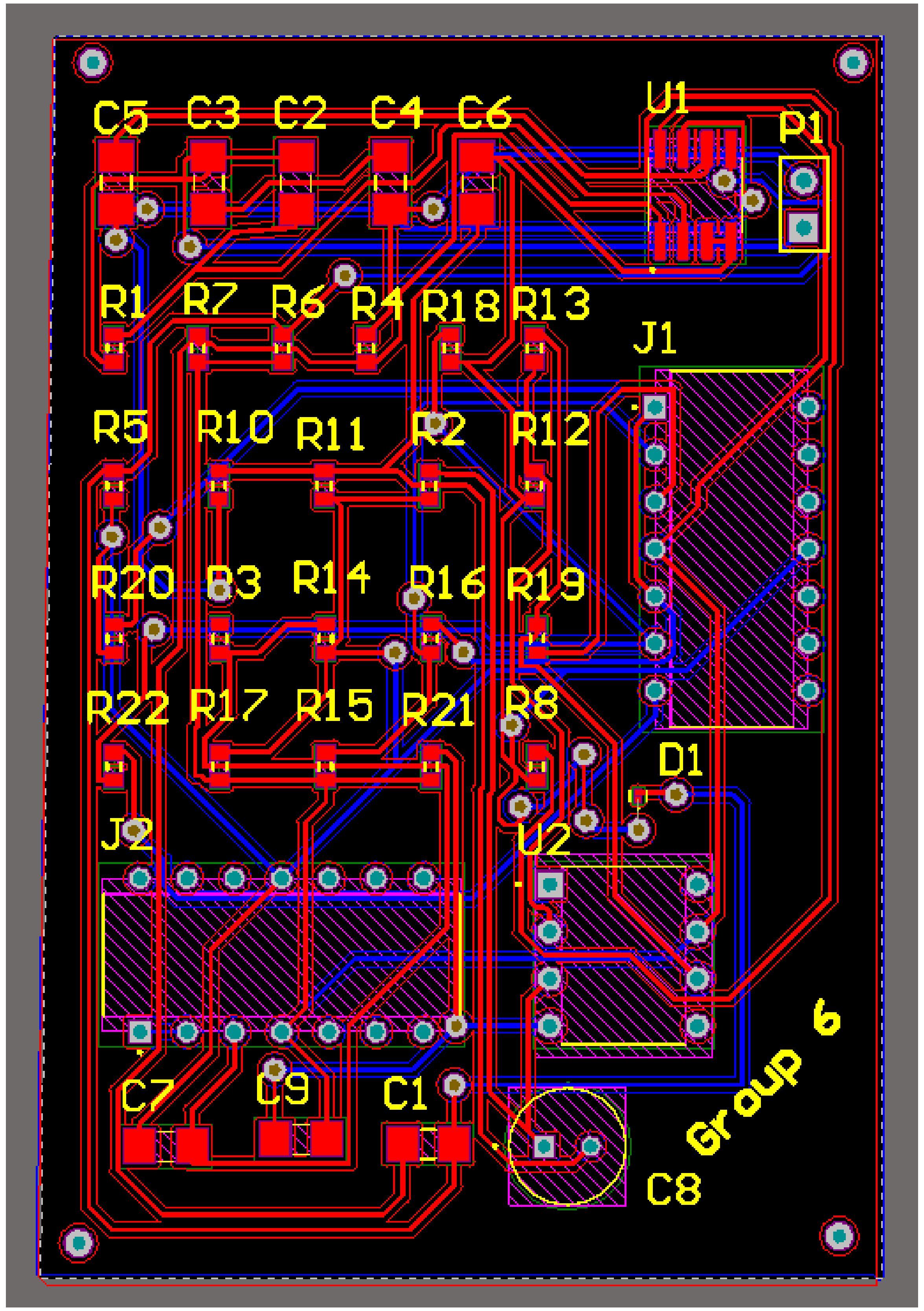


Through the assumption of additive white Gaussian noise, the cleaned signal via Wavelet denoising
(Here, a slight pattern of breathing could be perceived)

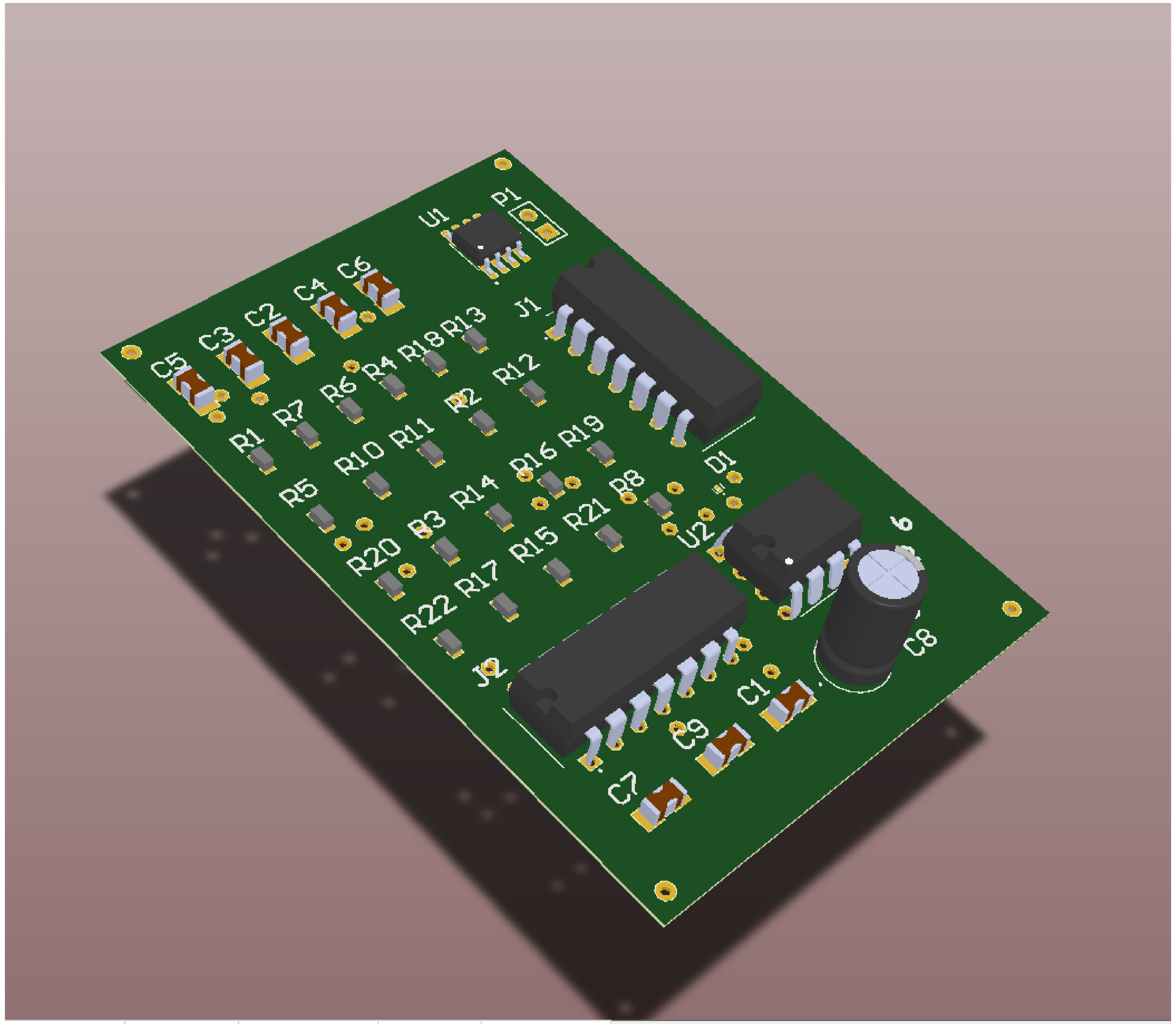
PCB Schematic Design

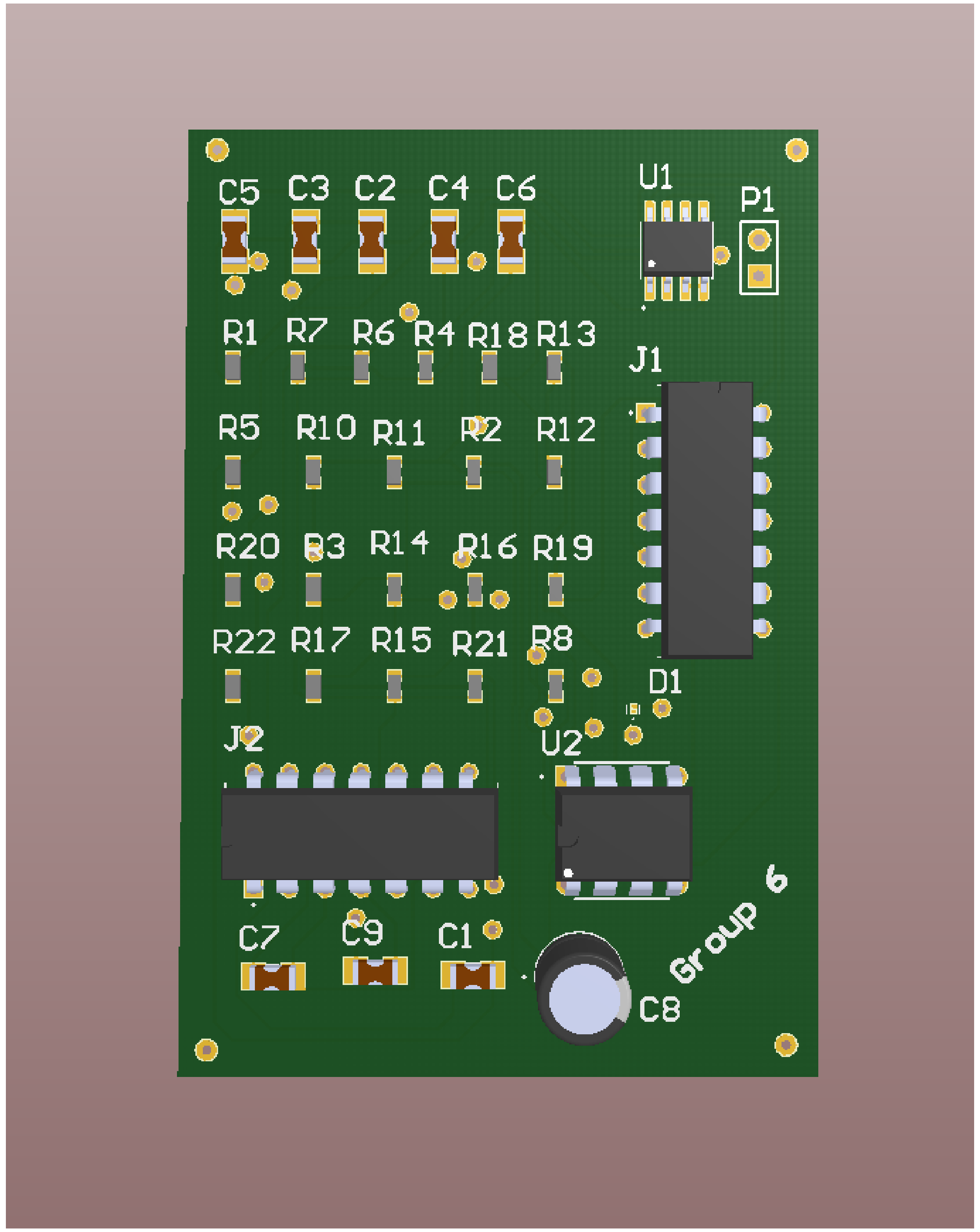


PCB Layout – 2D

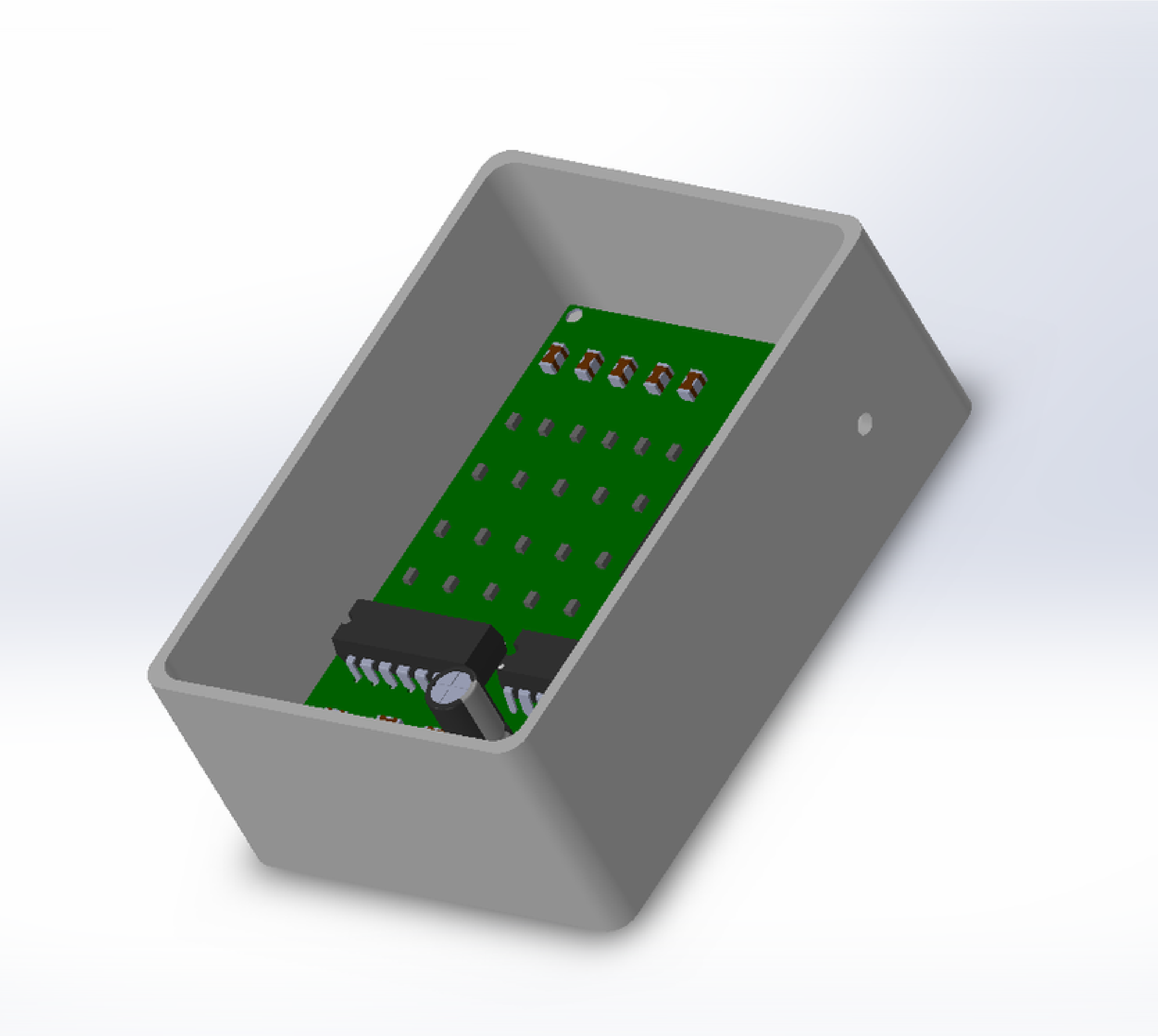


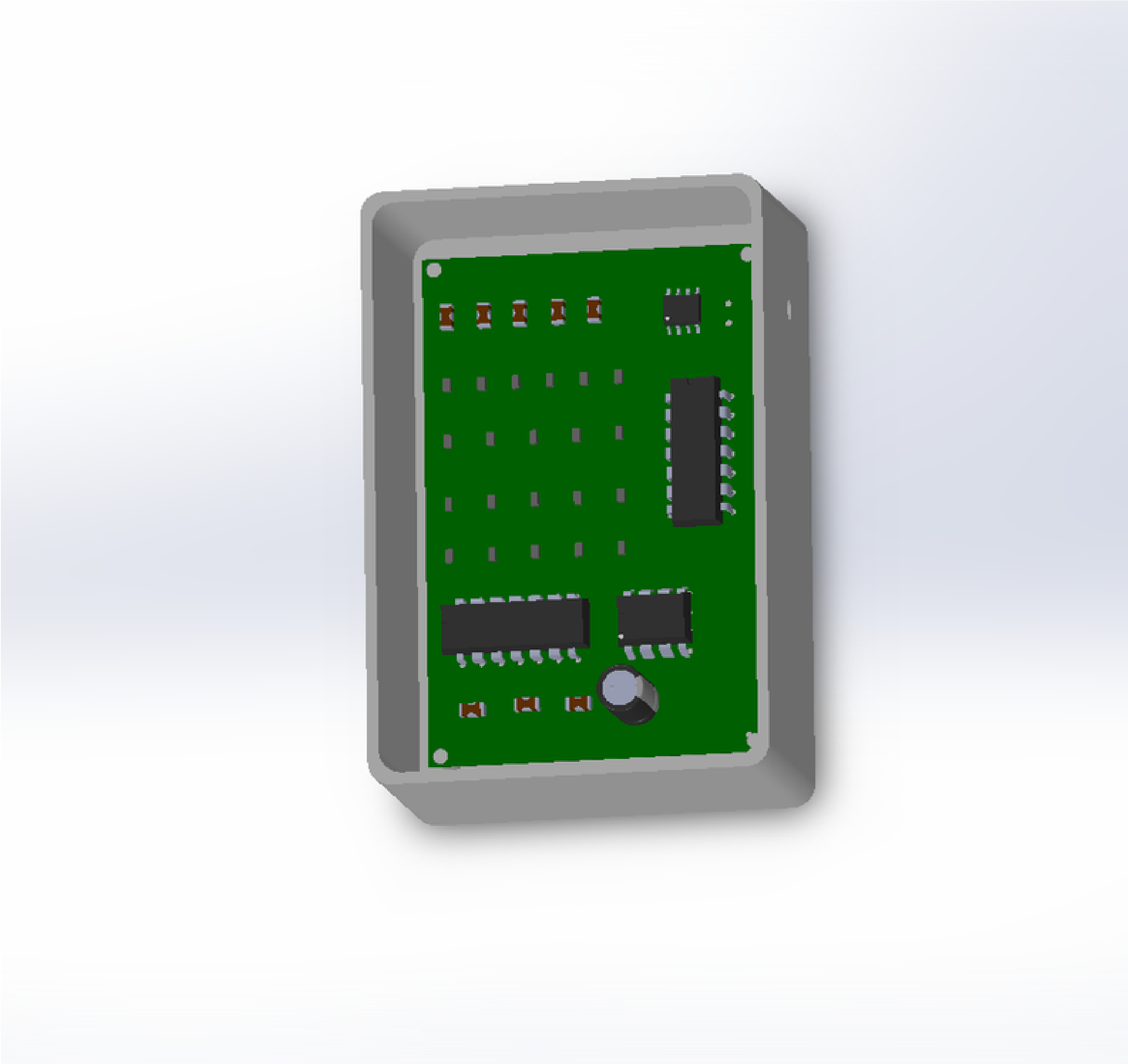
PCB Layout – 3D





Enclosure Design





Challenges

1. **The complexity of the project**
2. **Limited resources**
   - Electronic components are not available even in simulation platforms
   - Some simulations (variation of self-inductance of inductive belt) cannot be effectively done in the software
3. **Design Constraints**
   - Limited components are given for the project
   - Some application-specific components are not included in the list (Isolated DC-DC converters such as PWR1300)
4. **Debugging difficulties**
   - Hard to identify the issues in circuits due to some of the components being damaged.

Further Enhancements

Potential options for calibration of the sensor overall

- Measure the area variations for a few breaths while directly measuring the volumes of breath
- Re-continue the process for at least two anatomical positions
  - Sitting
  - Supine

Evaluate the sensitivity of the belt

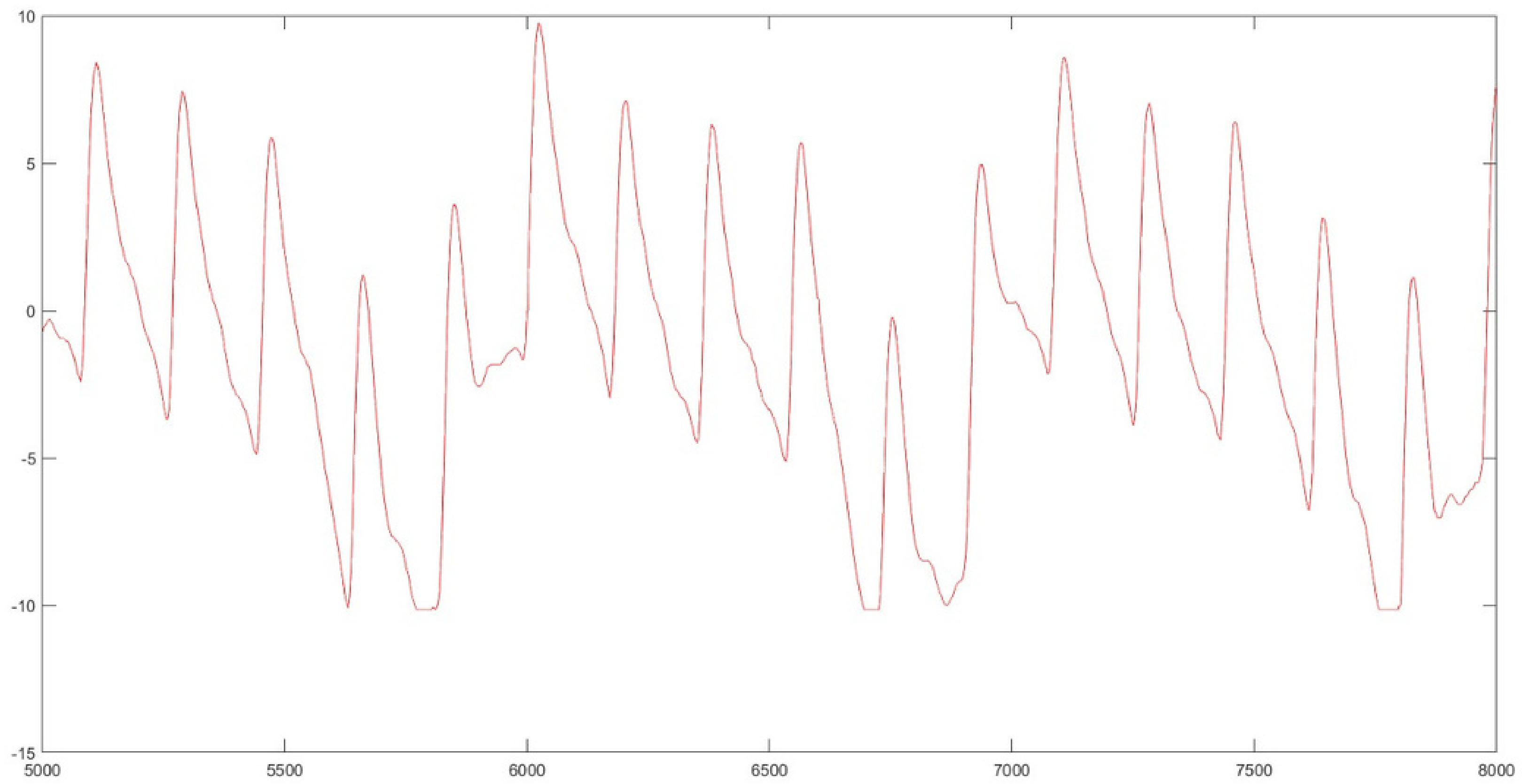
S = Change in output voltage / Change in breath volume

- Need to get value pairs of both breath volume (through a direct measurement) and the output voltage change from the setup
- Plot Voltage change against the breath volume change and calculate the slope
- Thus, could verify the constant sensitivity and sensor linearity

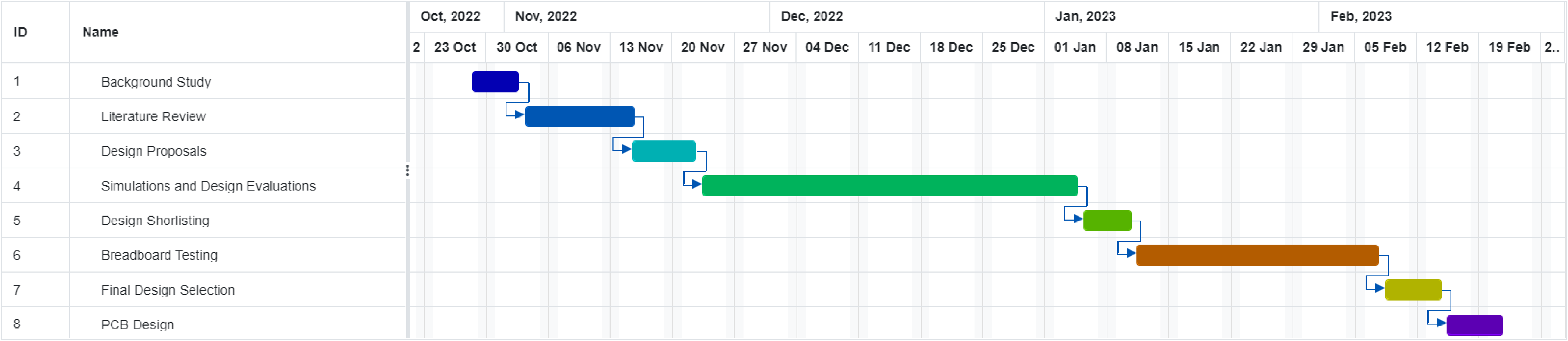
Further Enhancements

Implement isolation measurements for power isolation and signal isolation

Utilization of better noise reduction techniques in the post-processing steps as in compared to commercially available devices and waveforms



GANTT Chart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2..
1 Background Study
2 Literature Review
3 Design Proposals
4 Simulations and Design Evaluations
5 Design Shorlisting
6 Breadboard Testing
7 Final Design Selection
8 PCB Design

Work Division

Task	Nuwan	Sahan	Dasun
Background Study and Literature Review	X	X	X
Design Proposals	X	X	X
Simulations and Design Evaluations	X	X	X
Breadboard Testing	X	X	
Firmware modification and MATLAB post-processing	X		
PCB Design and Enclosure		X	X

BM4111: Mini Project

Group Inductance Belt

Inductance Belt for Respiration:
Interfacing circuit and implementation

Electronic and Telecommunication Engineering

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Sahan
180237G

Dasun
180497C

References

[1] Cohen, K. P., Panescu, D., Booske, J. H., Webster, J. G., & Tompkins, W. J. (1994). Design of an inductive plethysmograph for ventilation measurement. Physiological Measurement, 15(2), 217–229. https://doi.org/10.1088/0967-3334/15/2/009

[2] Method and apparatus for monitoring respiration. (1989). Available at: https://image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/4815473 [Accessed 11 Mar. 2023]

[3] Ngo, H.T., Nguyen, C.V., Nguyen, T.M.H. and Van Vo, T. (2013). A Portable Respiratory Monitor Using Respiratory Inductive Plethysmography. IFMBE Proceedings, pp.222–225. doi:https://doi.org/10.1007/978-3-642-32183-2_57

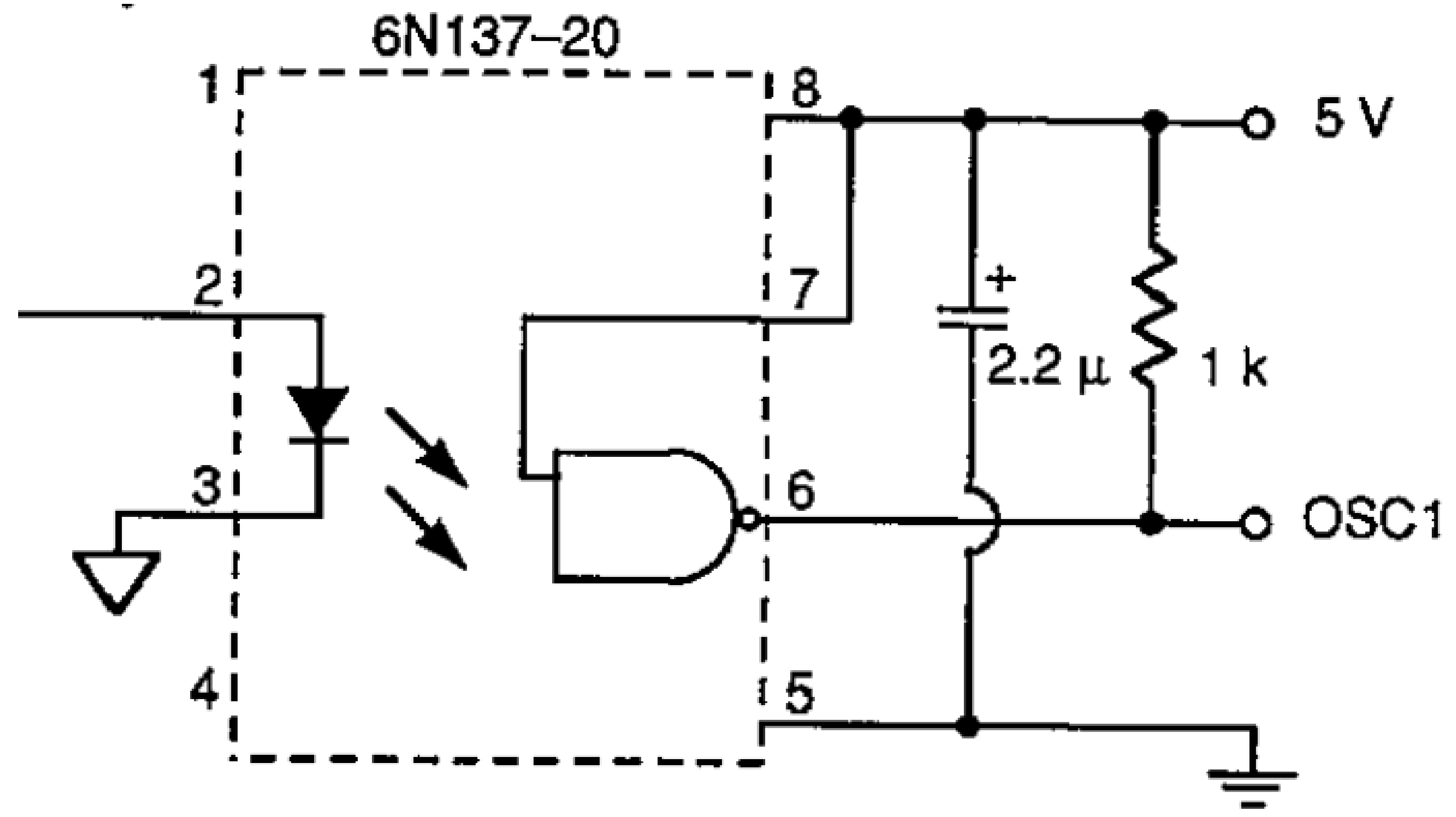
[4] Imtiaz, M., Ramos-Garcia, R., Senyurek, V., Tiffany, S. and Sazonov, E. (2017). Development of a Multisensory Wearable System for Monitoring Cigarette Smoking Behavior in Free-Living Conditions. Electronics, 6(4), p.104. doi:https://doi.org/10.3390/electronics6040104

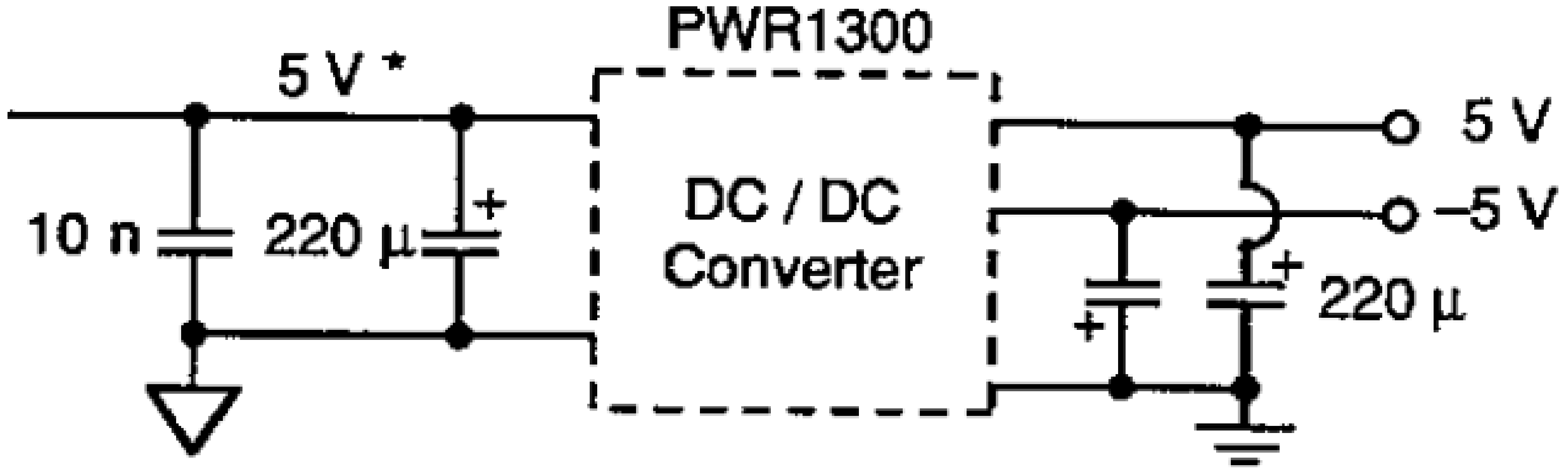
[5] Gargiulo, G.D., O'Loughlin, A. and Breen, P.P. (2015). Electro-resistive bands for non-invasive cardiac and respiration monitoring, a feasibility study. Physiological Measurement, 36(2), pp.N35–N49. doi:https://doi.org/10.1088/0967-3334/36/2/n35

[6] Zhang, Z., Zheng, J., Wu, H., Wang, W., Wang, B. and Liu, H. (2012). Development of a Respiratory Inductive Plethysmography Module Supporting Multiple Sensors for Wearable Systems. Sensors, 12(10), pp.13167–13184. doi:https://doi.org/10.3390/s121013167

[7] Lin, Q., Sijbers, W., Avidikou, C., Van Hoof, C., Tavernier, F. and Van Helleputte, N. (2022). Photoplethysmography (PPG) Sensor Circuit Design Techniques. [online] IEEE Xplore. doi:https://doi.org/10.1109/CICC53496.2022.9772851

THANK YOU


6N137-20
1
2
3
4
8
7
6
5
5 V
2.2 µ
1 k
OSC1


PWR1300
5 V *
10 n
220 µ
DC / DC
Converter
5 V
–5 V
220 µ