Department of Electronic & Telecommunication Engineering,
University of Moratuwa,
Sri Lanka.

ECG Amplifier
Design Report

210218M Herath HMSI

Submitted in partial fulfillment of the requirements for the module
BM 3110 Electronic Instrumentation

December 14, 2024

Contents

1 Introduction

The design and implementation of an electrocardiogram (ECG) amplifier play a essential role in monitoring the electrical activity of the heart, which is essential for diagnosing various cardiac conditions. This report focuses on the design of an ECG amplifier circuit that amplifies low-level ECG signals while reducing noise and common-mode interference, which are common in biomedical signal acquisition. The primary objective of this project is to design a ECG amplifier that conditions the ECG signal. The following sections provide a detailed description of the design specifications, component selection, and performance analysis of the implemented ECG amplifier.

2 Design Specification

The input signal level in ECG typically ranges from 0.2mV to 1mV within a bandwidth of 0.05Hz to 150Hz with most essential parts are in the range of 0.5Hz - 35Hz. The following are the minimum specifications implemented in the design:

- Gain: 1000
- CMRR: 100 dB
- Input Impedance: 10MΩ
- Input Voltage Offset: $< 100\ \mu$V
- Input Voltage Noise $< 200\ \mu$V (max)

2.1 Instrumentation Amplifier Selection

Based on the design requirements, the following instrumentation amplifiers were considered:

- AD620A [1]
- AD8220A [2]
- AD627A [3]

Three instrumentation amplifier ICs selected for the amplifier as an initial step.

2.1.1 Specifications and Scoring of Considered INAs

The considered instrumentation amplifiers are evaluated based on criteria such as CMRR, noise voltage and current, PSRR, offset voltage, and cost-effectiveness. The scoring system used is from 1 (Poor) to 5 (Excellent).

2.1.2 Scoring Criteria

Parameter	**Weight**
CMRR	25%
Input Impedance	15%
Gain Range	5%
Bandwidth	10%
Input Voltage Noise	15%
Input Offset Voltage	20%
Supply Current	5%
Cost	5%

2.1.3 AD620A

Table 1: Key Specifications for AD620ARZ

Specification	**Value**	**Score**
CMRR	130 dB (G = 1000)	4/5
Input Impedance	10 GΩ – 2 pF	3/5
Gain Range	1 to 10,000	5/5
Bandwidth	10 kHz (G = 1000)	3/5
Input Voltage Noise	7 nV/$\sqrt{\text{Hz}}$	4/5
Input Offset Voltage	30 μV (max)	5/5
Supply Current	0.9 mA	4/5
Cost	Moderate	4/5

Weighted Score: 0.8

2.1.4 AD8220A

Table 2: Key Specifications and Scores

Specification	**Value**	**Score**
CMRR	94 dB (G = 1000)	2/5
Input Impedance	10^4 GΩ – 5 pF	4/5
Gain Range	1 to 1000	4/5
Bandwidth	14 kHz (G = 1000)	4/5
Input Voltage Noise	10 nV/$\sqrt{\text{Hz}}$	4/5
Input Offset Voltage	125 μV (max)	2/5
Supply Current	0.75 mA (max)	4/5
Cost	Moderate	4/5

Weighted Score: 0.62

2.1.5 AD627A

Table 3: Key Specifications and Scores

Specification	**Value**	**Score**
CMRR	112 dB (G = 1000)	4/5
Input Impedance	100 GΩ – 2 pF	5/5
Gain Range	1 to 1,000	4/5
Bandwidth	200 Hz (G = 1000)	3/5
Input Voltage Noise	13 nV/$\sqrt{\text{Hz}}$	3/5
Input Offset Voltage	50 μV (max)	3/5
Supply Current	1.3 mA	3/5
Cost	Low	5/5

Weighted Score: 0.63

2.1.6 Selection Justification

The AD620 achieved the highest weighted score of 0.8, making it the best choice for the ECG amplifier design. Its advantages are:

- Excellent CMRR of 120 dB around the target gain
- Sufficient input impedance of 10GΩ
- Sufficient bandwidth and gain range for ECG applications
- Cost-effective for a three-channel system

3 Schematic Design

3.1 RFI Suppression

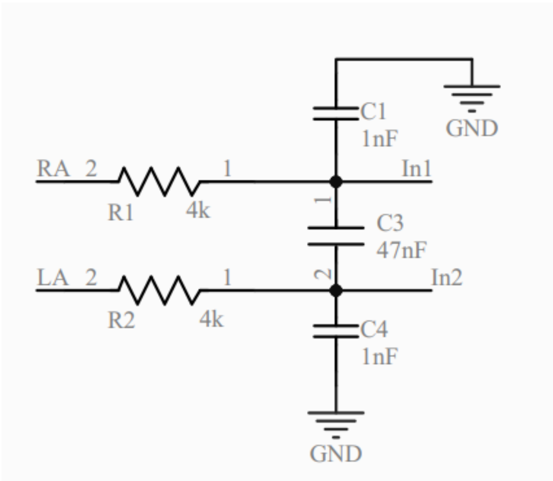


Figure 1: RF Filter

This acts as a Low Pass Filter so that higher frequencies will be rejected and will not pass further through the amplifier [1].

3.2 Instrumentation Amplifier

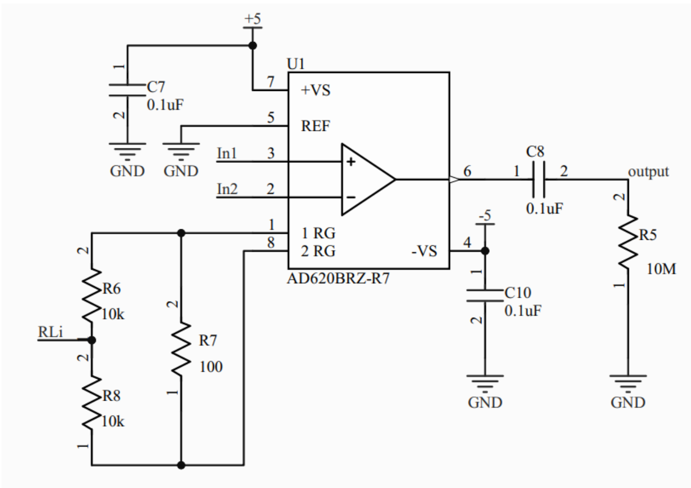


Figure 2: Instrumentation Amplifier

The value of the gain resistor used is 100Ω. Therefore the calculated gain value is approximately 500 which is calculated from the equation

$$R_G = \frac{49.4k\Omega}{G-1} \tag{1}$$

The output is taken through a high pass filter with cutoff around 0.1 Hz

3.3 Right Leg Drive Circuit

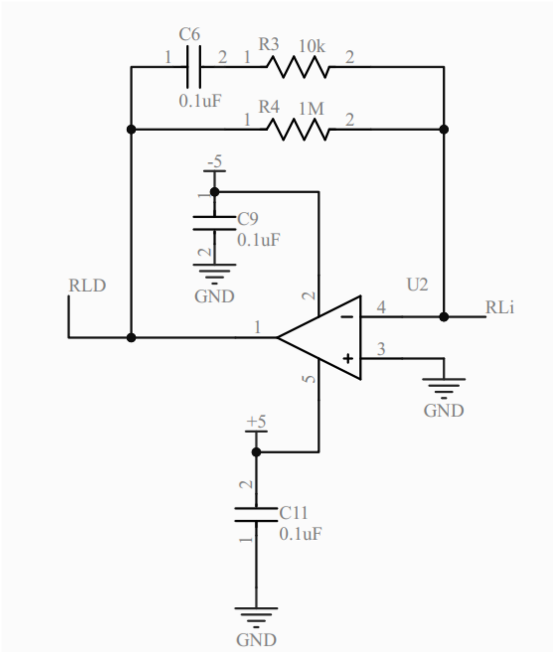


Figure 3: Right Leg Drive Circuit

Right Leg Drive Circuit is used to further increase the CMRR by interrupting the incoming common-mode signal. The value of 1 MΩ is calculated by taking into account the maximum output voltage and the maximum possible output current injected back to the body. The calculated value is 0.5 MΩ for 10uA. Therefore for further safety, 1 MΩ resistor is used.

3.4 Power Input

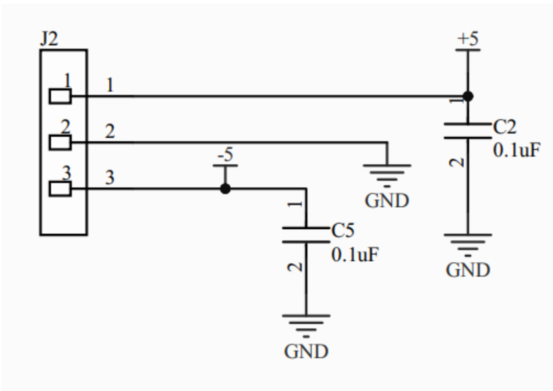


Figure 4: Right Leg Drive Circuit

Power Input circuit is used to supply power both +5V and -5V to the ICs. 3pin connector JST is used and decoupling capacitors help to stabilize the power supply.

4 PCB Design Iterations

4.1 First Iteration

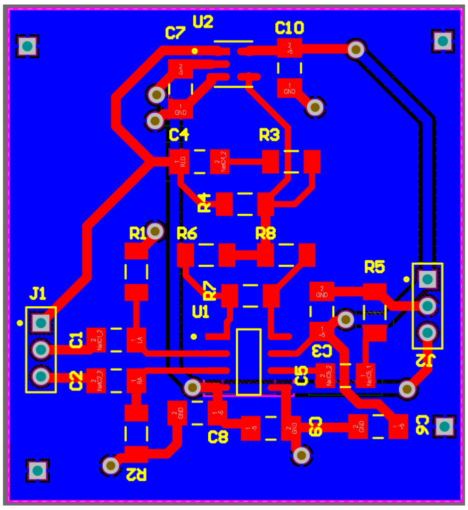


Figure 5: Top Layer

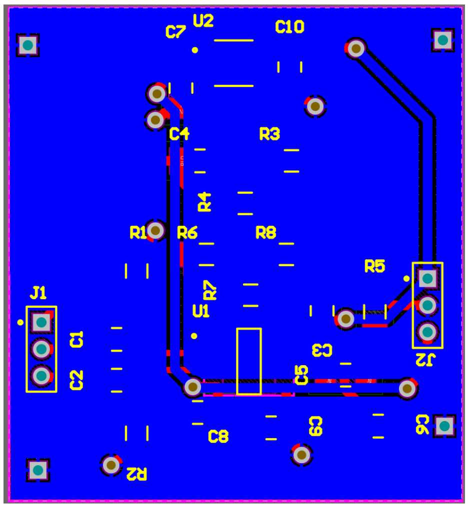


Figure 6: Bottom Layer

4.1.1 Errors

- More damage to the copper pour
- High Loop Areas

4.2 Second Iteration

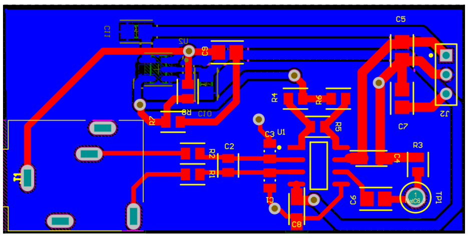


Figure 7: Top Layer

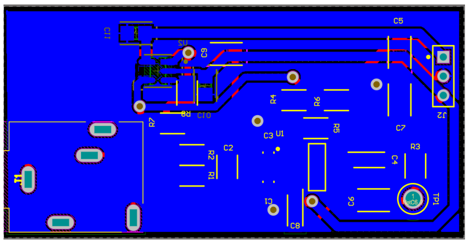


Figure 8: Bottom Layer

4.2.1 Errors

- Still somewhat damage to the copper pour
- Differential pair lengths are different
- Use of a test point to take the output

4.2.2 Improvements

- Reduce damage to copper pour
- Adjust trace widths appropriately and reduced loop areas.

4.3 Third Iteration

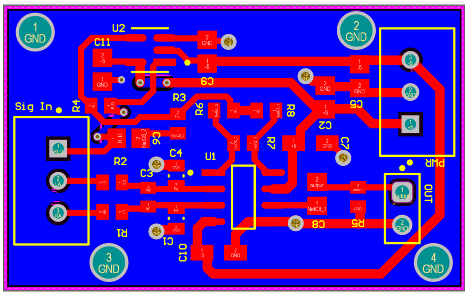


Figure 9: Top Layer

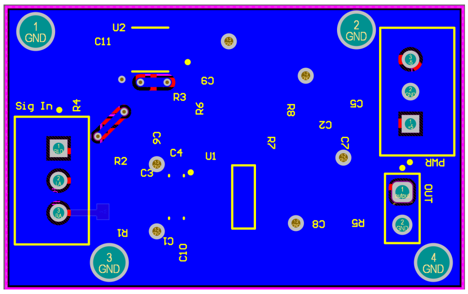


Figure 10: Bottom Layer

4.3.1 Improvements

- Place All components on the same side minimizing damage to copper pour.
- Replaced test point with JST to take the output.
- Used balanced trace lengths for the differential signal.
- Reduce the return path lengths and loop areas.

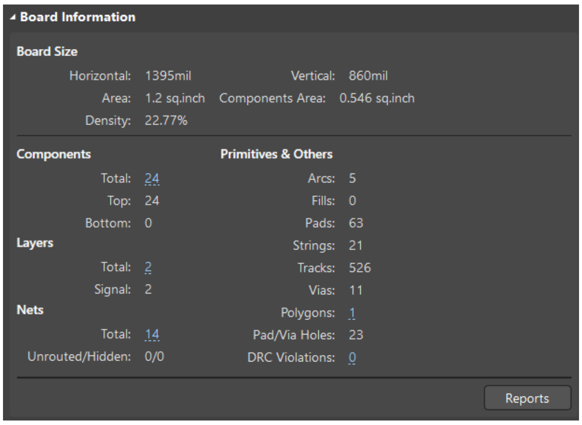


Figure 11: Board Information

5 PCB Design Considerations

5.1 PCB Current Considerations

Current carrying capacity of the PCB with no significant damage is an important factor to consider. Since this is a small signal amplifier mainly we have to consider about power and ground traces. PCB is found to have maximum current rating of 2.695A. Since circuit was expected to draw far less amount of current it confirms that PCB can handle required current optimally.

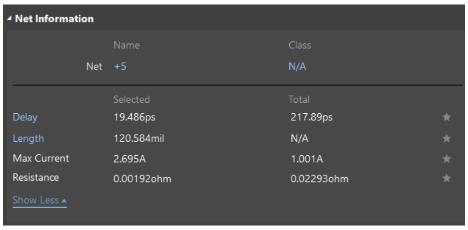


Figure 12: Information for +5V trace

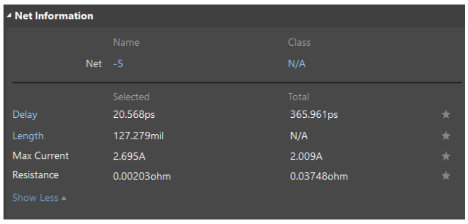


Figure 13: Information for -5V trace

5.2 Power Analysis

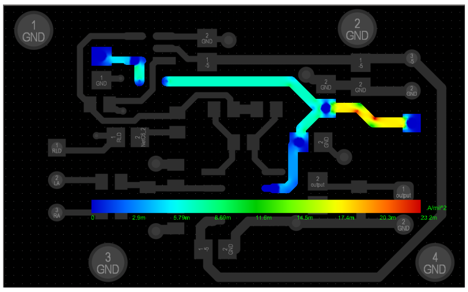


Figure 14: +5V Current Flow HeatMap

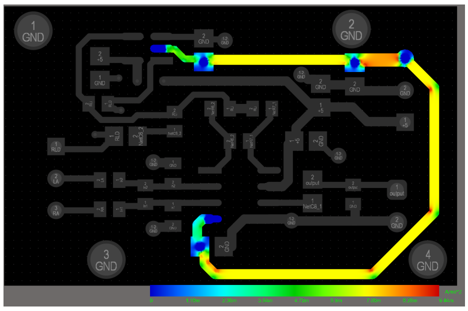


Figure 15: -5V Current Flow HeatMap

Power analyzer by keysight is used to ensure that the circuit can handle the expected maximum current, minimizing the risk of overheating or power related failures.

5.3 Loop Area Reduction

To minimize inductive coupling and improve signal integrity, loop area is reduced as much as possible. Specifically, the loop areas for the differential inputs and the signal-to-ground loops, power traces minimized in various design iterations.

5.4 Addressing Signal Integrity Issues

Further improvements to the signal integrity of the ECG amplifier design were achieved through the implementation of several techniques:

- **Power Supply Decoupling**: Decoupling capacitors were placed close to the power pins of ICs to filter out high-frequency noise and stabilize the supply voltage to reduce power supply fluctuations introduce noise into the ECG signals.
- **Differential Pair Routing**: Differential signal pairs routed together with matched lengths and consistent spacing to maintain signal integrity and minimize EMI to verify differential signals remain balanced to cutoff common inteference(make inteference common).
- **Common Ground Reference**: Use a common ground plane across the entire design made signals share the same ground reference minimizing the risk of ground loops and reduces noise coupling between different parts of the circuit.
- **Component Placement**: Components are placed to minimize signal path lengths and reduce the chance for noise coupling.

6 Completed Design

6.1 3D View

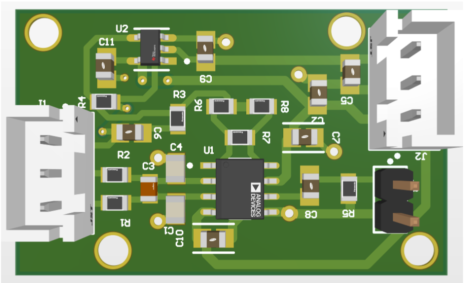


Figure 16: 3D Design

6.2 Bare PCB and Soldered PCB

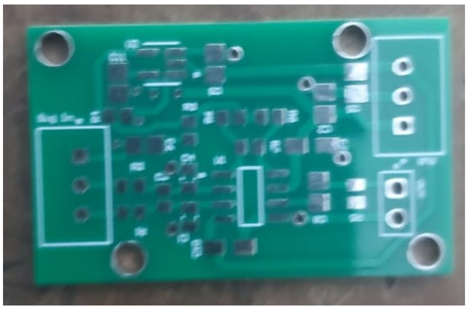


Figure 17: Bare PCB

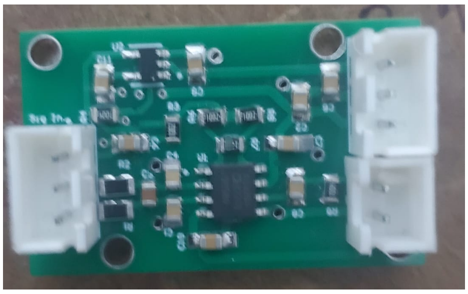


Figure 18: Soldered PCB

6.3 PCB Testing with Fluke

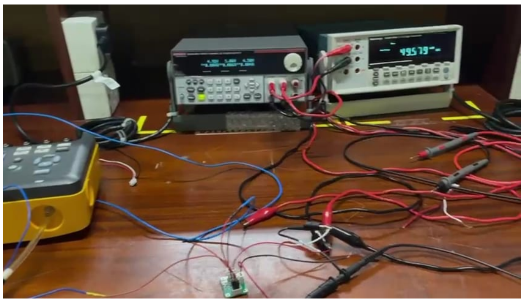


Figure 19: Testing

Figure 20: Fluke

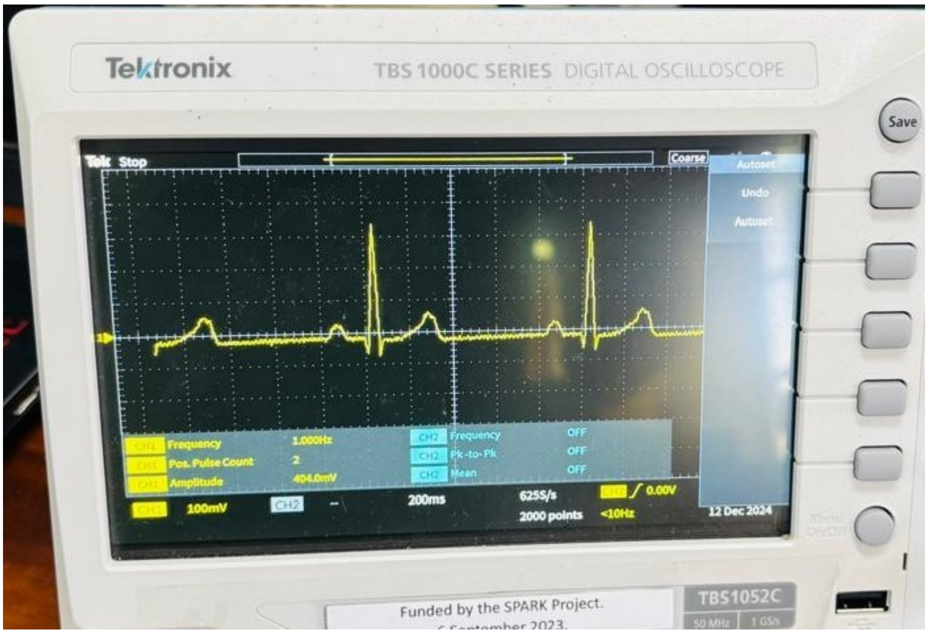


Figure 21: Obtained Waveform

7 Acknowledgement

My special gratitude to Senior Prof. Jayasinghe for his supervision and insights throughout this project.

8 BOM and Total Cost

Table 4: Bill of Materials (BOM) and Total Cost

Name	Quantity	Unit Price ($)	Total ($)
AD620ARZ(Instrumentation Amplifier)	1	11.7	11.7
TLV9151IDBVR(OpAmp)	1	0.75	0.75
0.1 µF Capacitor	7	0.1	0.7
1 nF Capacitor	2	0.25	0.5
47 nF Capacitor	1	0.17	0.17
100 Ω Resistor	1	0.15	0.15
4 kΩ Resistor	2	0.2	0.4
10 kΩ Resistor	3	0.2	0.6
1 MΩ Resistor	1	0.1	0.1
10 MΩ Resistor	2	0.1	0.1
B3B-XH-A(LF)(SN) Connector	2	0.21	0.42
B2B-XH-AM LF Connector	1	0.05	0.05
Total			**15.6**

Total cost for PCB manufacturing 2$
Total manufacturing cost without shipping and taxes 17.6$

9 Conclusion

In this project, I successfully designed and built an ECG amplifier that effectively amplifies the heart's electrical signals while minimizing noise and interference. By selecting the AD620 instrumentation amplifier and optimizing the schematic and PCB design, achieved required performance with a cost-effective approach. The iterative PCB design process helped us to improve the layout for better signal integrity and ease of assembly, resulting in clear and accurate ECG waveforms during testing.

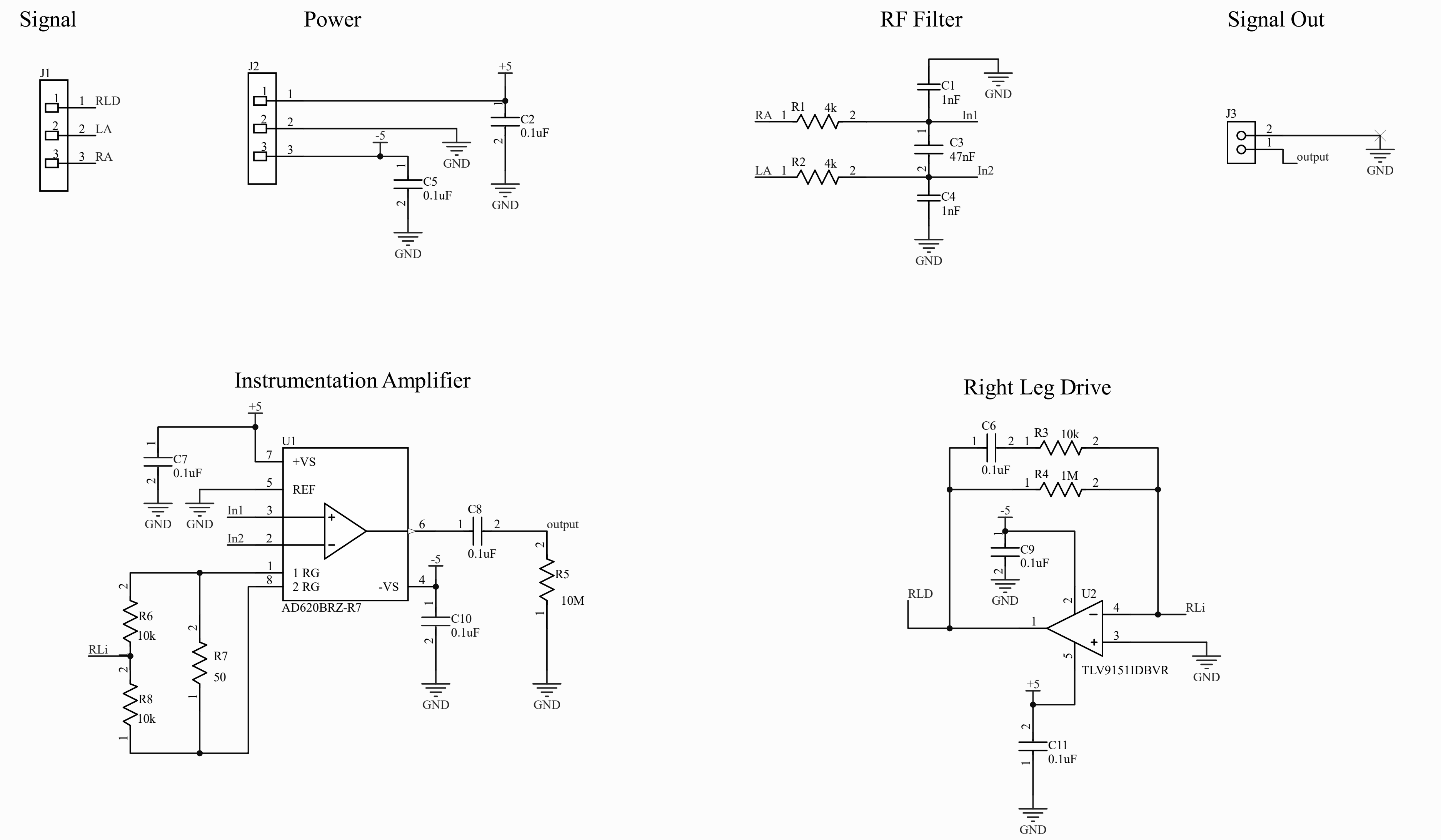
References

[1] A. D. Inc., *AD620 Datasheet*, 2024, retrieved from Analog Devices website. [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/AD620.pdf

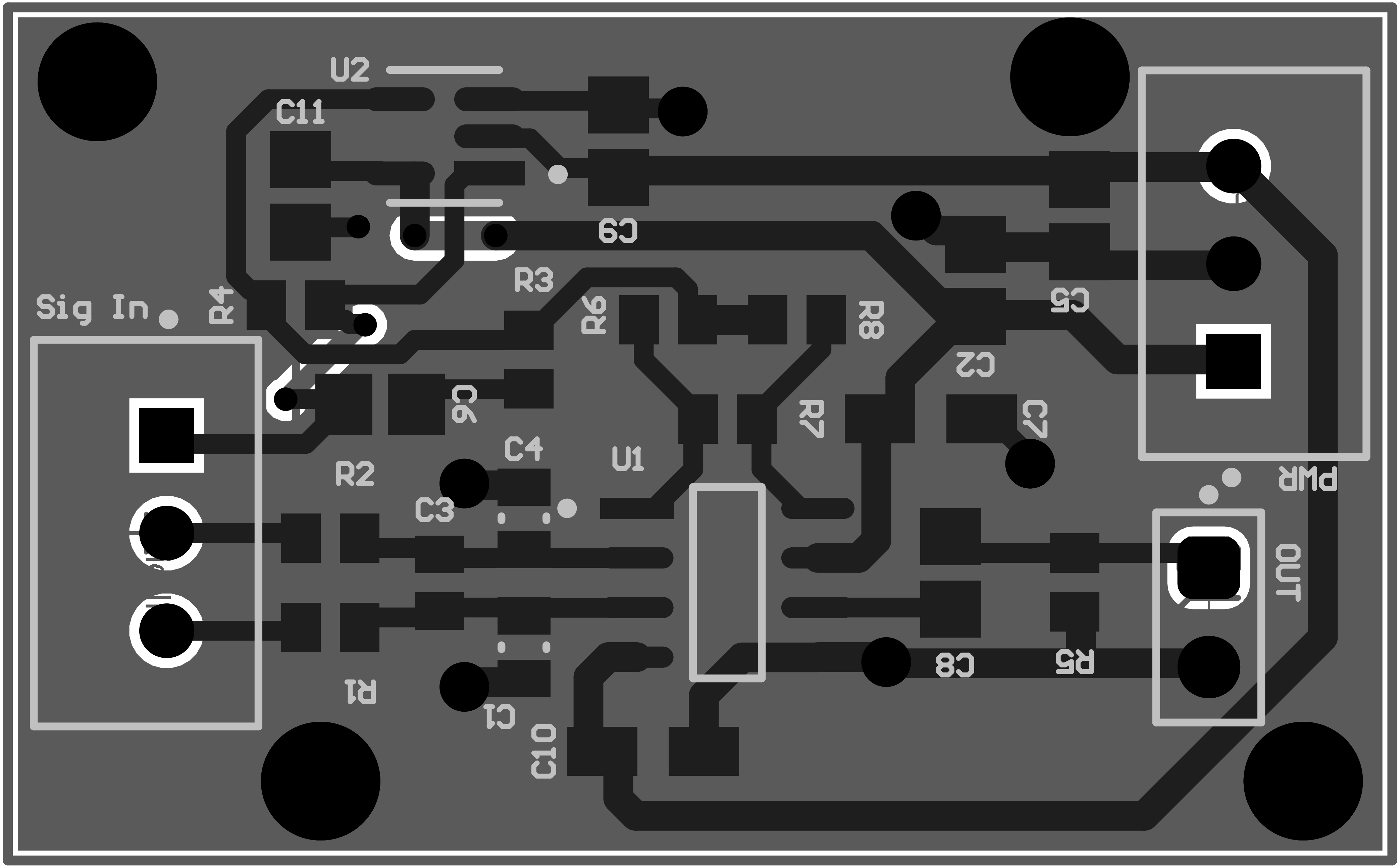
[2] A. Devices, "Ad8220: Low power, precision instrumentation amplifier," Analog Devices, Inc., Tech. Rep., 2023.

[3] Analog Devices, "Ad627 low power, low cost instrumentation amplifier," 2024, accessed: 2024-12-14. [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/AD627.pdf

A Schematic Design



Title	Low Noise Amplifier		
Size: A4	Number		Revision: 3
Date:	12/14/2024	Sheet1 of 1	
File:	D:\projects\..\Sheet1.SchDoc	Drawn By: Sandun Herath	


U2
C11
C9
R3
Sig In
R4
R6
R8
C5
C2
C6
R7
C7
C4
U1
R2
C3
PWR
OUT
R1
C1
C10
C8
R5