EE 230 – Analog Lab - 2021-22/I (Autumn)

Experiment 7: Instrumentation Amplifiers

(Ver 1, Sep 21, 2021)

Introduction

In this experiment we shall explore a very common application of Opamp based difference amplifiers, viz. the instrumentation amplifiers, which are employed for field applications. Strain gages are very routinely used as sensors in several field applications for measuring strain/force/load measurements. For such applications, the CMRR of a single-stage difference amplifier is not sufficient. Also, often very large differential gains, say 100 to 1000 may be required for very sensitive measurements.

Part A – TL084 Opamp and INA128 Instrumentation Amplifier

1.1 Pinout Diagrams of TL084 Opamp and INA128 Instrumentation Amplifier

The pinout diagrams of TL084 (Quad Opamps) and INA128 Instrumentation Amplifier ICs are shown in Fig.1 and Fig.2.

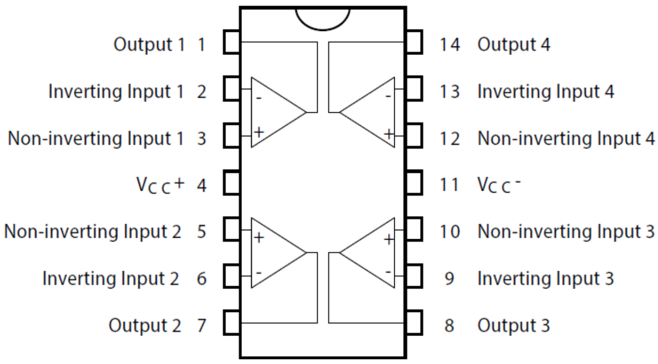


Fig.1 TL084 Quad JFET input Opamps pinout diagram

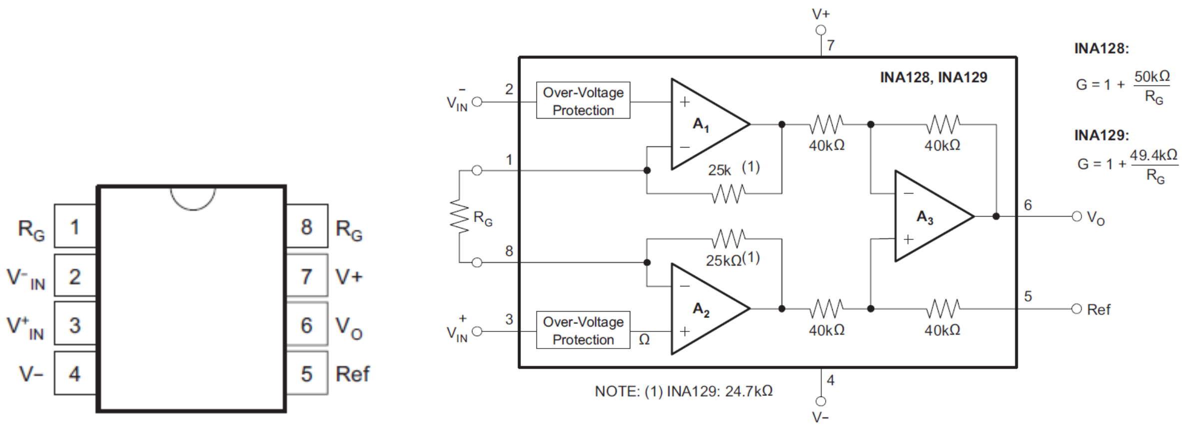


Fig.2 INA128 Instrumentation Amplifier pinout diagram

Part B – Three-Opamp Instrumentation Amplifier using TL084

2.1 Three-Opamp Instrumentation Amplifier using TL084

The circuit diagram of the 3-Opamp instrumentation amplifier is shown below, which is essentially a cascade of two difference amplifiers, viz. the first difference amplifier consisting of Opamp 1 and Opamp 2, and the second difference amplifier made up using Opamp 3.

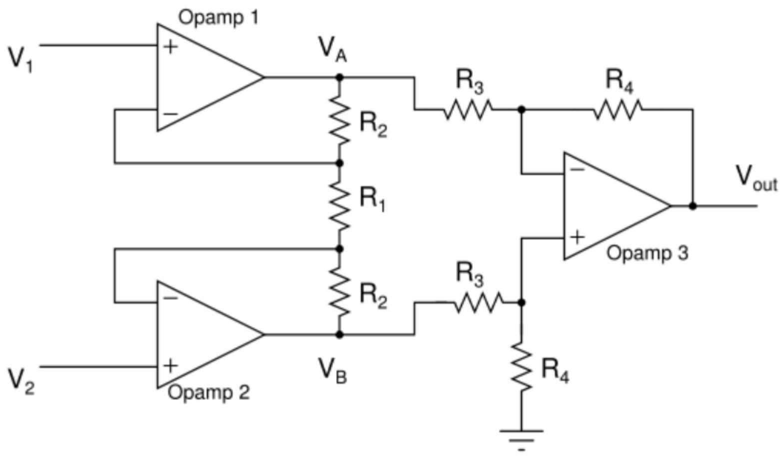


Fig.3 Three-Opamp Instrumentation Amplifier

The differential voltage gain of the above amplifier, $A_d = V_{out}/(V_2-V_1) = (R_4/R_3)\ [1+ (2R_2/R_1)]$, where the second term $[1+ (2R_2/R_1)]$ is the A_d of the first difference amplifier, while (R_4/R_3) is the A_d of the second one. Please refer to the reference notes uploaded to see the detailed derivation for A_d (from Sedra & Smith, Microelectronic Circuits, 7e). Also, identify the major advantages of this instrumentation amplifier.

Three Opamps from TL084 were used to build the above instrumentation amplifier on the bread board.

2.2 Measurement of the Common-mode Voltage Gain, A_{cm}

Circuit values: +Vcc = +15 V, -Vcc = -15 V, $R_1 = R_2$ =10 kΩ, R_3 = 1 kΩ, and R_4 (connected to the inverting input of Opamp 3) = 100 kΩ ; R_4 (connected to the non-inverting input of Opamp 3) = 91 kΩ + 10 kΩ (Pot). $V_1 = V_2 = 10 \sin \omega t$ V

Adjust the 10 kΩ potentiometer (of R_4 connected to Opamp 3 non-in input) such that V_{out} is minimum. $A_{cm} = V_{out}/V_1$.

Note: The peak-to-peak amplitude of the common-mode input signal is 20 V.

2.3 Measurement of the Differential Voltage Gain, A_d

Circuit values: +Vcc = +15 V, -Vcc = -15 V, $R_1 = R_2$ =10 kΩ, R_3 = 1 kΩ, and R_4 = 100 kΩ.

Values are the same as used for A_{cm} with R_4 pot adjusted for min A_{cm}.

Input signal levels: $V_1 = 0$, $V_2 = 10 \sin \omega t$ mV. For the above circuit values, measure V_{out}. Calculate $A_d = V_{out}/V_2$

Note: The peak-to-peak amplitude of the differential input signal is 20 mV.

Part C - INA128 Instrumentation Amplifier

3.1 INA 128 Instrumentation Amplifier

INA 128 is a low cost, general purpose instrumentation amplifier employing the standard three-Opamp instrumentation amplifier design. From Fig. 2 we see that the expression for the differential gain A_d of INA 128 is the same as that of Part B, Sec 2.1, viz:

$A_d = V_{out}/(V_{in+}-V_{in-}) = (R_4/R_3)\ [1+ (2R_2/R_1)]$. By substituting $R_4=R_3$, $R_2 = 25\ k\Omega$, and $R_1 = R_G$, we get the expression, $A_d = [1 + (50\ k\Omega/R_G)]$ as shown in Fig.2.

3.2 Measurement of the Common-mode Voltage Gain, A_{cm}

Circuit values: +Vcc = +15 V, -Vcc = -15 V, R_G = 180 Ω. $V_{in+} = V_{in-} = 10 \sin \omega t$ V

Note down V_{out} value for this case. $A_{cm} = V_{out}/V_{in+}$.

Note: The peak-to-peak amplitude of the common-mode input signal is 20 V.

3.3 Measurement of the Differential Voltage Gain, A_d

Circuit values: +Vcc = +15 V, -Vcc = -15 V, R_G = 180 Ω.

Input signal levels: $V_{in-} = 0$, $V_{in+} = 10 \sin \omega t$ mV. For the above circuit values, measure V_{out}. Calculate $A_d = V_{out}/V_{in+}$

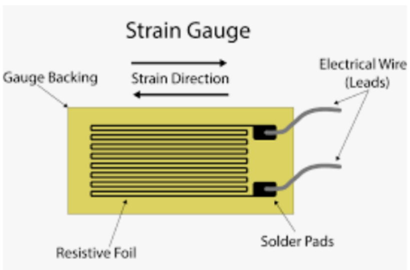
Note: The peak-to-peak amplitude of the differential input signal is 20 mV.

Part D – Loadcell and its Interfacing

3.1 Load Cell

Load cell is a commonly used sensor for measuring weight/pressure. Even though other sensors, such as capacitive sensors can be used for such applications, a full-bridge strain gage network (i.e. a Wheatstone bridge made of four strain gages) is a very popular choice.

Photographs of commercial strain gages are shown below.



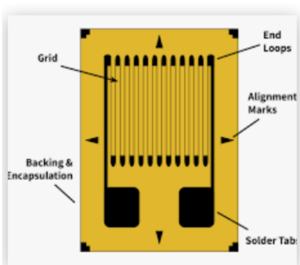
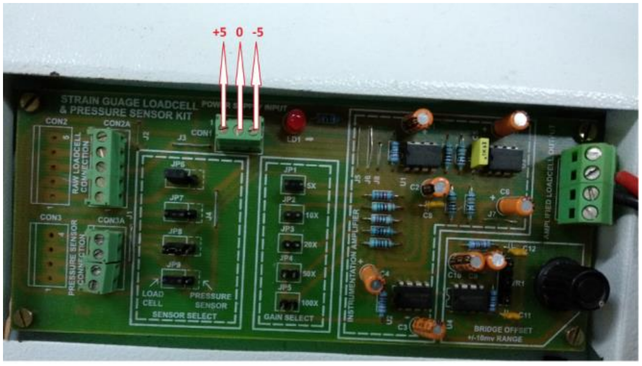
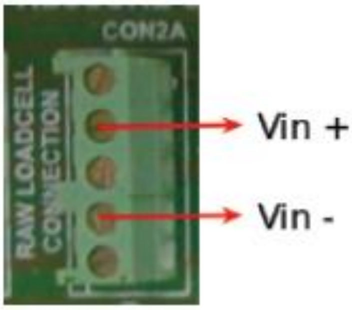


Fig. 4 Strain gages (Source: Internet)

In the lab we shall use a Load Cell for measuring weights up to 180 gm. Photographs of the Loadcell used in the experiment are shown below.

(a)





(b) (c)

Fig. 5 (a) – Loadcell platform with the interface printed circuit board; (b) Interface circuit PCB (provided with the Loadcell); (c) Strain gage bridge output (Raw Loadcell connections)

3.2 Loadcell Interfacing (using TL084 based Three-Opamp Instrumentation Amplifier)

The full-bridge strain-gage of the Loadcell was powered with +5V and -5V supplies (see Fig. 5(b)). The raw Loadcell outputs (i.e. the strain gage bridge outputs) as shown in Fig. 5(c) were used as the differential inputs to the three-Opamp instrumentation amplifier of Part C, Sec 2.3 (made using TL084, with A_d = 300). Amplifier output under no-load condition was noted. Now weights were added (1 gm to 180 gm) and the corresponding V_{out} values were noted. The results were plotted.

3.3 Loadcell Interfacing using INA128 Instrumentation Amplifier

The Loadcell interface circuit was now changed by connecting the raw Loadcell outputs to the INA128 instrumentation amplifier (with $R_G = 180\ \Omega$). Amplifier output under no-load condition was noted. Now weights were added (1 gm to 180 gm) and the corresponding V_{out} values were noted. The results were plotted.

Questions

1. In Sec 3.2 and 3.3, even under no-load conditions V_{out} was found to be non-zero. Give one or two reasons for this.
2. Give two or three major advantages of the three-Opamp instrumentation amplifier as compared to the single-Opamp difference amplifier of Experiment 6.
3. Look at the data sheets of TL084 and INA 128. Identify the major differences between these two ICs – i.e. Opamp parameters crucial for difference amplifier applications, such as the Loadcell application discussed in this experiment.
4. Identify one or two parameters of the INA128 that makes it superior to the TL084 based instrumentation amplifier.

Lab Report

1. For Experiment 7, please limit your Lab report to just 2 or 3 pages – one page for the three-Opamp Instrumentation amplifier and loadcell interface circuit using TL084, and one page for the INA128 Instrumentation amplifier and loadcell interface circuit. No NGSPICE simulations required.
2. In each page, please include the amplifier circuit diagram.
3. Deadline for Lab Report 7: Sep 26, 2021 (Sunday), 11pm.
4. Please do not email the Lab instructor with late submission requests of Lab Reports. Instead, you may write to your Tutor, who would assess your request, and might allow late submission (by say, a maximum of 12 hours) as a one-time concession.

Note: Request all students to refrain from any unfair means, such as copying Lab Reports of others, in part or in full. Defaulters (both parties) will attract very severe punishment – including negative marks (i.e. minus marks, instead of 0 marks for non-submission), and grade penalty. Your names will also be reported to your Faculty Advisor and to Head, EE dept for further action against you.