ME3000 Analog Electronics

Lab 5

Practical Op-Amp Circuits

Objective

i) To understand typical operational amplifier circuits and their characteristics

Equipment Required

i) ME3000-M2 Analog Electronics Training Kit
ii) Digital Multimeter, recommendation : Agilent 34405A or U2741A
iii) 50 MHz Oscilloscope or equivalent, recommendation : Agilent DSO1002A 60 MHz or U2701A
iv) 10 MHz Function Generator or equivalent, recommendation : Agilent 33220A or U2761A
v) Dual Output (+/- 12V, 0.5A) DC Power Supply, recommendation : Agilent E3631A

Accessories Required

i) 1 x 4-way power supply cable
ii) 1 x BNC(m)-to-grabber clips coaxial cable
iii) 6 x jumper cables terminated with grabber clips at both ends
iv) 1 x antistatic wrist strap

Caution:
An electrostatic discharge generated by a person or an object coming in contact with electrical components may damage or destroy the training kit. To avoid the risk of electrostatic discharge, please wear the antistatic wrist strap and observe the handling precautions and recommendations contained in the EN100015-1 standard. Do not connect or disconnect the device while it is being energized.

1. Introduction

An operational amplifier (op-amp) is an integrated circuit capable of amplifying the voltage difference between its two input terminals. As shown in Figure 1, a general purpose op-amp has two input terminals which are the *non-inverting* (+) and *inverting* (–) inputs, a single output terminal, and two voltage supply terminals (V_+ and V_-). Most of the op-amps require dual power supplies (±5 Vdc, ±15 Vdc, and so forth), but some op-amps (such as LM3900) may be powered from a single supply.

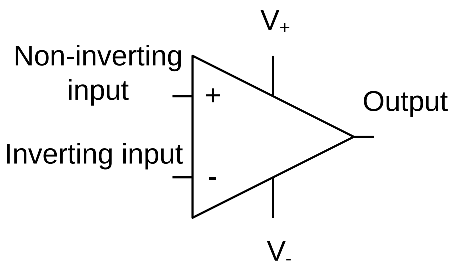

Figure 1 – Op-Amp Circuit Symbol

The simplest form of an op-amp comes in an 8-pin IC package, such as the commonly used 741. The connection diagram for the 741 op-amp is depicted in Figure 2.

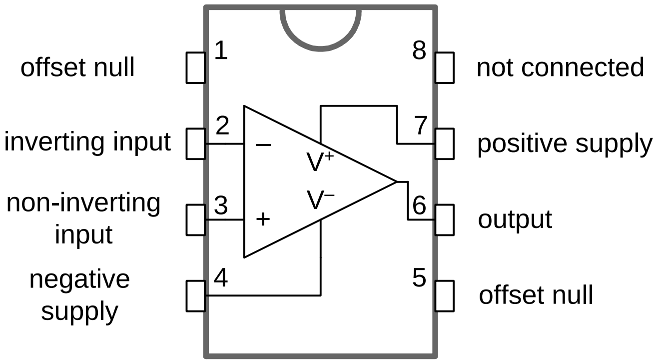

Figure 2 – 741 Op-Amp Connection Diagram

An op-amp has the following three important characteristics:

- High open-loop gain
- High input impedance
- Low output impedance

Different configurations of a negative feedback network are used to reduce voltage gain of op-amps to produce practical and linear circuits. In the following experiments, five typical op-amp configurations are introduced, namely the inverting amplifier, summing amplifier, non-inverting amplifier, differential amplifier, and buffer.

2. Inverting Amplifier

1. Locate the Inverting/Summing Amplifier section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Inverting/Summing Amplifier section.
3. Insert jumpers J22 and J24 to construct an inverting amplifier circuit shown in Figure 3.

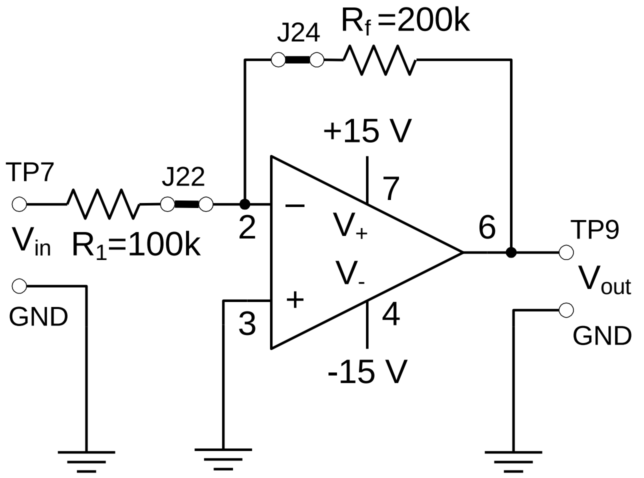

Figure 3 – Inverting Amplifier Schematic Diagram

4. With $V_{in(pp)}$ = 1.0 V, predict $V_{out(pp)}$ using the following equation:

$$V_{out} = -\frac{R_f}{R_1} V_{in}$$, negative (–) sign indicates a 180° phase shift

5. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP7 (V_{in}). Connect the CH2 probe of the oscilloscope to TP9 (V_{out}). Connect the instrument references to the GND terminals.
6. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly **+15 V** and **-15 V**, respectively. Set both current limits to 0.5 A. Turn on the power supply. Refer to Appendix for details.
7. Apply a 1.0 V peak-to-peak sine wave of 1 kHz to input V_{in} of the inverting amplifier.
8. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
9. Use the multimeter to measure $V_{out(pp)}$ (this measured value should be close to the predicted value) and record the phase shift of V_{out} with respect to V_{in} (ϕ). Calculate the ratio of $V_{out(pp)}/V_{in(pp)}$.
10. Turn off the power supply and disconnect all the cables from the Inverting/Summing Amplifier section.

3. Summing Amplifier

1. The Inverting Amplifier section on the ME3000-M2 training kit can be modified into a Summing Amplifier.
2. Insert jumper J23 to construct a two-input summing amplifier circuit shown in Figure 4.

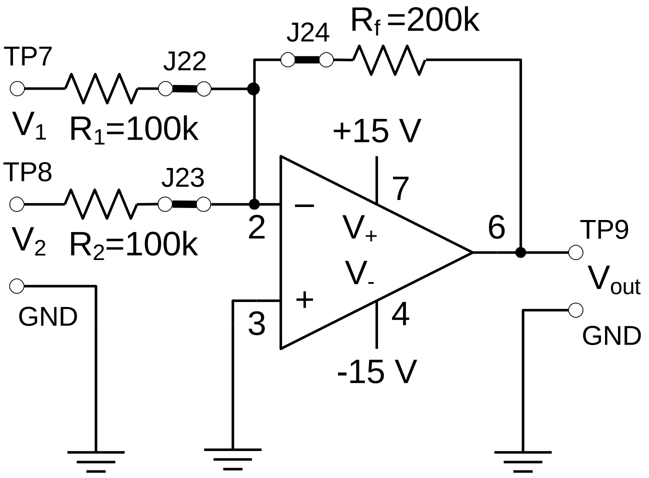

Figure 4 – Two-Input Summing Amplifier Schematic Diagram

3. With V_2 = 2 V, predict V_{out} when V_1 = –1 V, 0 V, and +1 V using following equation:

$$V_{out} = -\frac{R_f}{R_1}(V_1 + V_2)$$

4. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP7 (V_1). Connect the CH2 probe of the oscilloscope to TP9 (V_{out}). Connect the instrument references to the GND terminals.
5. Connect TP15 (–7.5 V ~ +7.5 V adjustable DC voltage source) to TP8 (V_2) using the jumper cable.
6. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly **+15 V** and **-15 V**, respectively. Set both current limits to 0.5 A. Turn on the power supply.
7. Adjust the potentiometer VR_1 to obtain V_2 = 1.0 V. Use the multimeter to measure V_2.
8. Apply a 2.0 V peak-to-peak sine wave of 1 kHz to input V_1 of the summing amplifier.
9. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
10. Measure V_{out} when V_1 = –1 V, 0 V, and +1 V.
11. Slowly adjust V_2 by turning VR_1. Observe how V_{out} changes when V_2 is varied between 0 V and 5V. Comment on your observation.
12. Turn off the power supply and disconnect all the cables from the Inverting/Summing Amplifier section.

4. Non-Inverting Amplifier

1. Locate the Non-Inverting Amplifier section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Non-inverting Amplifier section.
3. Insert jumpers J25 and J26 to construct a non-inverting amplifier circuit shown in Figure 5.

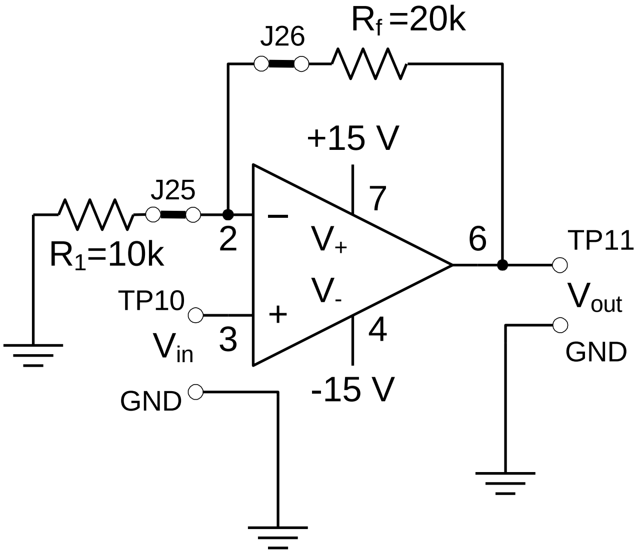

Figure 5 – Non-Inverting Amplifier Schematic Diagram

4. With $V_{in(pp)}$ = 1.0 V, predict $V_{out(pp)}$ using the following equation:

$$V_{out} = \left(1 + \frac{R_f}{R_1}\right) V_{in}$$

5. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP10 (V_{in}). Connect the CH2 probe of the oscilloscope to TP11 (V_{out}). Connect the instrument references to the GND terminals.
6. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly **+15 V** and **-15 V**, respectively. Set both current limits to 0.5 A. Turn on the power supply.
7. Apply a 1.0 V peak-to-peak sine wave of 1 kHz to input V_{in} of the inverting amplifier.
8. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
9. Measure $V_{out(pp)}$ (this measured value should be close to the predicted value) and record the phase shift of V_{out} with respect to V_{in} (ϕ). Calculate the ratio of $V_{out(pp)}/V_{in(pp)}$.
10. Turn off the power supply and disconnect all the cables from the Non-inverting Amplifier section.

5. Differential Amplifier

1. Locate the Differential Amplifier section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Differential Amplifier section.
3. Insert jumpers J27, J28, J29, and J30 to construct a differential amplifier circuit shown in Figure 6.

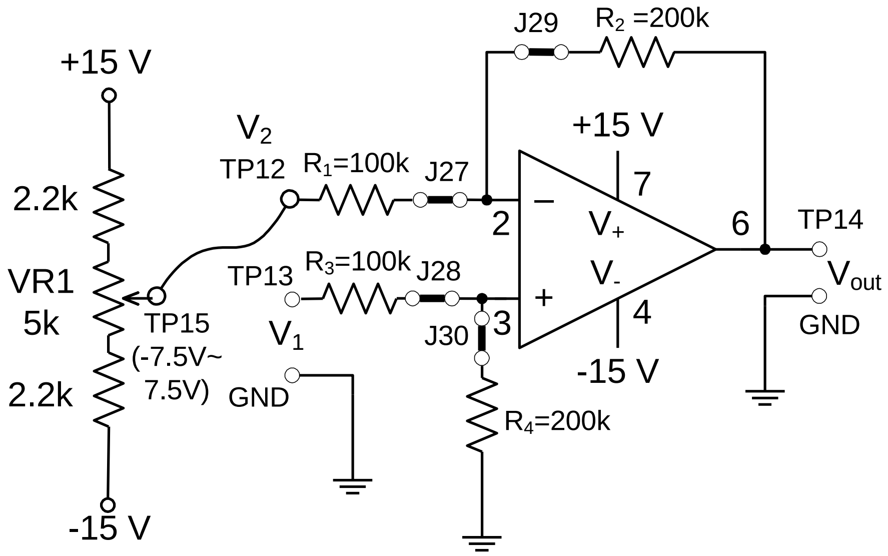

Figure 6 – Differential Amplifier Schematic Diagram

4. With V_2 = 2 V, predict V_{out} when V_1 = –1 V, 0 V, and +1 V using the following equation:

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

5. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP13 (V_1). Connect the CH2 probe of the oscilloscope to TP14 (V_{out}). Connect the instrument references to the GND terminals.
6. Connect TP15 (–7.5 V ~ +7.5 V adjustable DC voltage source) to TP12 (V_2) using the jumper cable.
7. Connect the power supply to the training kit using the 4-way power supply cable. Press Set the dual channel output voltages to exactly **+15 V** and **-15 V**, respectively. Set both current limits to 0.5 A. Turn on the power supply.
8. Apply a 2.0 V peak-to-peak sine wave of 1 kHz to the input V_1 of the differential amplifier. Adjust the potentiometer to obtain V_2 = 1.0 V. Use the multimeter to measure V_2.
9. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the waveforms.
10. Measure V_{out} when V_1 = –1 V, 0 V, and +1 V. Sketch the V_1 and V_{out} waveforms.
11. Slowly adjust V_2 by turning VR_1. Observe how V_{out} changes when V_2 is varied between 0 V and 5 V. Comment on your observation and compare with the results of the summing amplifier.
12. Turn off the power supply and disconnect all the cables from the Differential Amplifier section.

6. Buffer Circuit

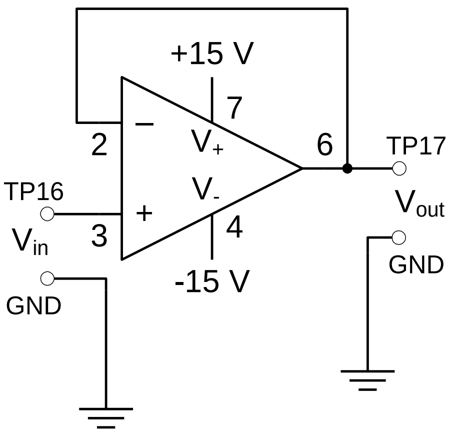

Figure 7 – Buffer Schematic Diagram

1. Locate the Buffer Circuit section on the ME3000-M2 training kit.
2. Disconnect all the jumpers located in the Buffer Circuit section.
3. Connect the function generator output using the BNC-to-grabber clips coaxial cable and CH1 probe of the oscilloscope to TP16 (V_{in}). Connect the CH2 probe of the oscilloscope to TP17 (V_{out}). Connect the instrument references to the GND terminals.
4. Connect the power supply to the training kit using the 4-way power supply cable. Set the dual channel output voltages to exactly **+15 V** and **-15 V**, respectively. Set both current limits to 0.5 A. Turn on the power supply.
5. Apply a 1.0 V peak-to-peak sine wave of 1 kHz to input V_{in}. Measure $V_{out(pp)}$ and record the phase shift of V_{out} with respect to V_{in} (ϕ). Calculate the ratio of $V_{out(pp)}/V_{in(pp)}$. Sketch the V_{in} and V_{out} waveforms.
6. The next experiment tests the buffer ability to reduce loading effect.
7. Disconnect the function generator and oscilloscope from TP16 and TP17.
8. Connect the function generator output and CH1 of the oscilloscope to TP19. The function generator forms a high impedance source with R19 at TP18.
9. Connect TP18 to TP20 using the jumper cable. This connects the high impedance source to the load circuit (R20), as shown in
10. Figure 8.

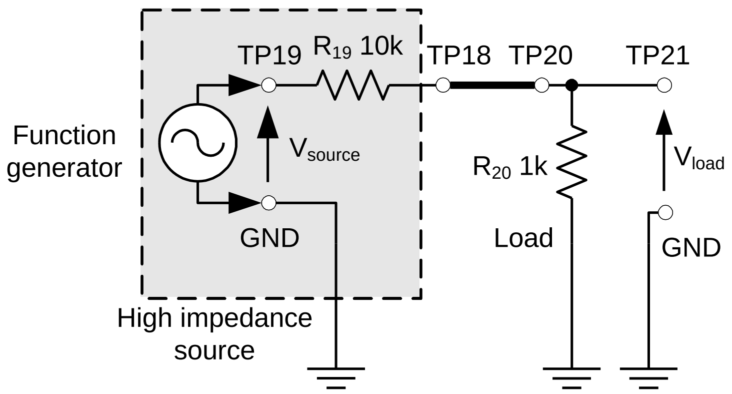

Figure 8 – Setup to Study the Loading Effect

11. Connect CH2 of the oscilloscope to TP21.
12. Set the trigger source to CH1. Set Time/div to display two cycles of the waveforms on the screen. Set Volt/div of CH1 and CH2 to clearly display the waveforms. Sketch the V_{source} and V_{load} waveforms.
13. Measure $V_{load(pp)}$.
14. Disconnect TP18 from TP20.
15. Connect TP18 to TP16 (V_{in} of the buffer) and TP20 to TP17 (V_{out} of the buffer), as shown in Figure 9.
16. Using the oscilloscope, observe and sketch the V_{source} and V_{load} waveforms.

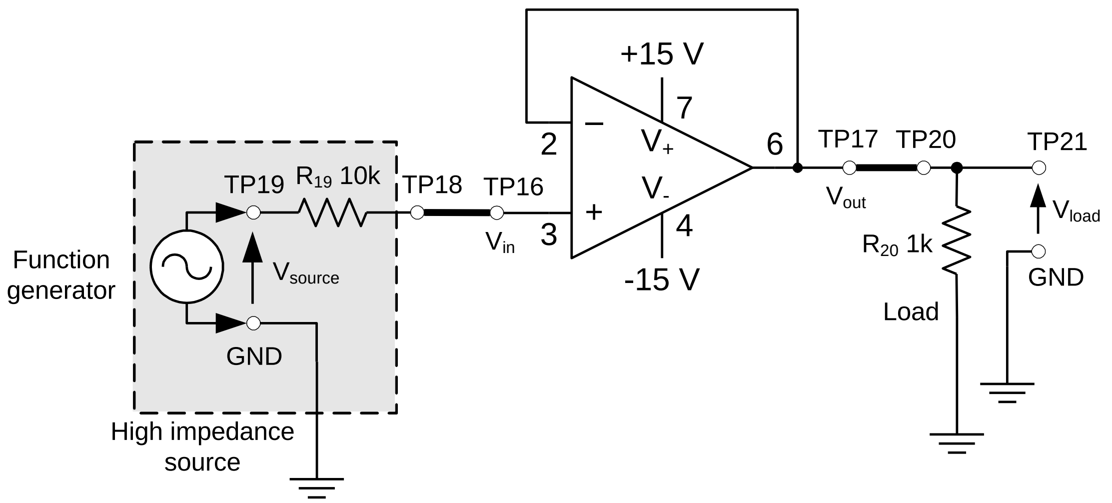

Figure 9 – Buffer Connections to Minimize the Loading Effect

17. Measure $V_{out(pp)}$. Comment on your observation.
18. Turn off the power supply and disconnect all the cables from the Buffer Circuit section.