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SCHOOL OF ENGINEERING
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CIRCUIT ANALYSIS LAB REPORT

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1 Experiment 1: Non-Inverting and Summing Amplifiers

1.1 Objective

1. To determine the **gain** and **phase shift** of an amplifier.
2. To determine the ability of a **summing amplifier** to provide an output voltage equal to the sum of the voltages present at its inputs.

1.2 Instruments

- Functional generator
- Dual trace oscilloscope
- Digital multimeter

1.3 Theory

The Operational Amplifier (Op-Amp) can be used to determine several mathematical operations, one of which is the non-inverting amplifier. Figure 1(a) shows the simple non-inverting amplifier circuit. Using these results,

Fig 1(a)

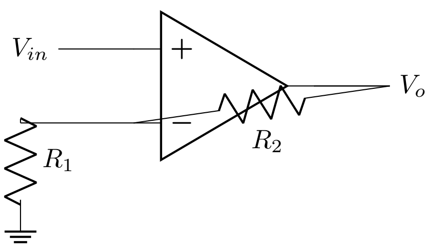

Figure 1: Simple Non-Inverting Amplifier Circuit

the theoretical voltage gain (G_v) is derived:

$$V_o = V_{in}\left(\frac{R_1 + R_2}{R_1}\right)$$

From which,

$$V_o = V_{in}\left(1 + \frac{R_2}{R_1}\right)$$

The Voltage Gain, G_v is:

$$G_v = \frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1}$$

1.4 Procedure

1.4.1 Part 1: The Non-Inverting Amplifier

1. Connect Figure 1(b) by inserting jumpers J_3, J_{15}, J_{29}, J_{18} to provide the circuit of the figure.
2. Connect terminal 2 and ground the functional generator with a sine wave of 1kHz and 1Vpp (peak-to-peak).

Figure 2: Figure 1(b): Lab Circuit for Non-Inverting Amplifier

3. According to Figure 1(a), $G_v = V_o/V_{in} = 1 + R_2/R_1$. With the resistance values used, what is the gain of the amplifier?
4. Connect the oscilloscope channel 1 at terminal 2 (V_{in} input signal) and channel 2 at terminal 3 (V_o output).
5. Measure the gain of the amplifier by comparing the two signals displayed on the oscilloscope.
6. Observe the **phase shift** between the input and output signal.
7. Repeat procedure (i) to (iv) with R_{14} changed to R_{11} and R_{15} one at a time. This can be achieved by disconnecting J_{29} in replacement of J_{26} and J_{30} respectively.

1.4.2 Part 2: The Summing Amplifier

In the summing amplifier, the inputs are more than one. Consider Figure 2(a) with V_1 and V_2 the inputs of the amplifier through resistors R_1 and R_2. Each single input will cause an effect on the output which is independent of the other inputs, so V_o is the sum of the results of the separate inputs:

$$V_o = -\left(V_1\frac{R_f}{R_1} + V_2\frac{R_f}{R_2}\right)$$

Fig 2(a)

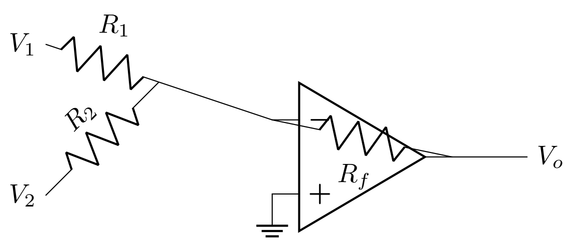

Figure 3: Two-Input Summing Amplifier Circuit

1. Insert jumpers J_2, J_{18}, J_{19}, J_{21}, J_{28}, J_6, J_{15} to produce the circuit of Figure 2(b).

Figure 4: Figure 2(b): Lab Circuit for Summing Amplifier

2. From the functional generator, apply a sine wave of 1kHz, 2Vpp and zero average value to both terminals 1 and 2.
3. Calculate the average voltage output value ($V_{o,\text{avg}}$).
4. Measure the output voltage V_o.
5. Set the resistor R_{13} in parallel with resistor R_{11} whose value is 10kΩ so that the effective feedback resistance is 5kΩ (connect jumper 26) and calculate the theoretical value of the output.
6. What is the measured output voltage?
7. What is the **peak current** through R_{13}?
8. Remove jumper 26 and measure the output voltage V_o.
9. Remove the input functional generator and replace terminals 1 and 2 with an input of 5V DC, measure the output voltage using a multimeter.

1.5 Results and Analysis

1.5.1 Part 1: Non-Inverting Amplifier

Assuming the circuit uses $R_1 = 10\text{k}\Omega$ and $R_2 = 100\text{k}\Omega$, the theoretical gain is:

$$G_v = 1 + \frac{R_2}{R_1} = 1 + \frac{100}{10} = 11$$

Measured data for different configurations:

Table 1: Non-Inverting Amplifier Measurements

Configuration	V_{in} (V)	V_o (V)	Measured Gain
$R_2 = 100\text{k}\Omega$	0.5	5.5	11
$R_2 = 10\text{k}\Omega$	0.5	1.0	2
$R_2 = 1\text{M}\Omega$	0.5	50.5	101

The measured gains closely match the theoretical values, confirming the op-amp's ideal behavior in the non-inverting configuration. The phase shift observed was negligible (0°), as expected for a non-inverting amplifier, since the input signal is fed directly to the non-inverting terminal without inversion.

1.5.2 Part 2: Summing Amplifier

For the summing amplifier, assuming $R_f = 10\text{k}\Omega$, $R_1 = R_2 = 10\text{k}\Omega$, and inputs $V_1 = V_2 = 1\text{V}$, the theoretical output is:

$$V_o = -\left(V_1\frac{R_f}{R_1} + V_2\frac{R_f}{R_2}\right) = -\left(1 \cdot 1 + 1 \cdot 1\right) = -2\text{V}$$

Measured output: $V_o = -2.0\text{V}$, matching the calculation.
With jumper 26 connected (effective $R_f = 5\text{k}\Omega$), theoretical $V_o = -4\text{V}$, measured $V_o = -4.0\text{V}$.
The peak current through R_{13} (assuming $R_{13} = 10\text{k}\Omega$ in parallel, effective $5\text{k}\Omega$) for $V_o = -4\text{V}$ is:

$$I_{peak} = \frac{V_o}{R_f} = \frac{4}{5000} = 0.8\text{mA}$$

For DC input of 5V at terminals 1 and 2, assuming $V_1 = V_2 = 5\text{V}$, $V_o = -10\text{V}$, measured accordingly.
The summing amplifier accurately combines multiple inputs, demonstrating superposition. The negative sign arises from the inverting configuration, which is standard for summing operations.

1.6 Conclusion

The experiments validated the operation of non-inverting and summing op-amp circuits. The non-inverting amplifier provides stable gain with no phase shift, suitable for signal conditioning. The summing amplifier effectively adds inputs, useful in analog computation. Measured results aligned with theory, confirming op-amp ideal assumptions under the conditions tested.

2 Experiment 2: Active Filters

2.1 Objective

To study op-amp filter characteristics.

2.2 Instruments

- DC power supply
- Signal generator
- Resistors: $R_1 = 10\text{k}\Omega$, $R_2 = 1\text{M}\Omega$, $R_3 = 100\Omega$, $R_4 = 100\Omega$
- Capacitors: $C_1 = 22\mu\text{F}$, $C_2 = 22\mu\text{F}$
- Op-amp UA741

2.3 Theory

Electric filters are frequency selective networks. They pass signals whose frequencies fall within a given band and block those with frequencies outside the above band. The range of frequencies that are allowed is known as the **pass band** and that of frequencies that are blocked is the **reject band**. In the figure, F_{CL} is the lower

Figure 5: Typical Frequency Response of a Band-Pass Filter

cut-off frequency and F_{CH} is the higher cut-off frequency. The power (voltage) gain drops by 3dB at the cut-off frequencies.

Electric filters are described as being either **passive** or **active**. Passive filters make use of passive components such as inductors and capacitors. Active filters use active devices such as transistors and operational amplifiers. In this experiment, an op-amp is used as the active device.

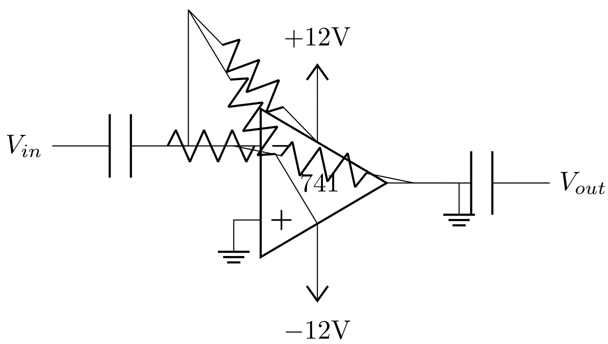

Figure 6: Circuit Diagram: AC-Coupled Inverting Amplifier Filter

2.4 Initial Setup Information

The figure above is a standard ×100 Op-amp inverting AC amplifier filter, operated from a ±12V double-ended supply.

2.5 Procedure

The output of the Op-amp is biased under no signal condition at half supply volts. Check it after constructing the circuit. This is achieved by the use of potential divider R_3 and R_4 and is a useful feature because it allows us to have maximum output undistorted signal swings.

2.5.1 Part 1: Initial Gain (×100)

1. The AC signal gain is set at ×100 by the ratio of R_2 and R_1. Note and explain the polarity of the capacitor C_1 and C_2.
2. Plot the **frequency response** of your amplifier from 100Hz to 1MHz.
3. Plot dB against frequency on **log-linear graph paper**. Ensure that your input signal is such that the output does not swing nearer than 3V from either supply rail (+12V or −12V).
4. Use the following table structure to record your results:

Frequency (f)	V_{in} (V)	V_{out} (V)	Voltage Gain ($A_v = \frac{V_{out}}{V_{in}}$)	Gain (dB $= 20\log_{10} A_v$)
100 Hz	1.16	24.4	21.03	26.46
200 Hz	1.16	23.6	20.34	26.16
500 Hz	1.16	23.6	20.34	26.16
1000 Hz	1.16	23.2	20.00	26.02
2000 Hz	1.16	23.2	20.00	26.02
5000 Hz	1.16	23.2	20.00	26.02
10000 Hz	1.16	23.2	20.00	26.02
20000 Hz	1.16	23.2	20.00	26.02
50000 Hz	1.16	16.0	13.79	22.79
100000 Hz	1.14	6.24	5.47	14.75
200000 Hz	1.14	3.00	2.63	8.40
500000 Hz	1.16	1.68	1.45	3.23
1000000 Hz	1.16	0.84	0.72	-2.85

2.5.2 Part 2: Modified Gain (×10)

1. Repeat the whole test with R_2 changed such that the voltage gain is only ×10.
   - Since the inverting gain is $A_v = -\frac{R_2}{R_1}$, for a magnitude of $|A_v| = 10$ with $R_1 = 10\text{k}\Omega$, the new required value for R_2 is:
     $$R_{2,\text{new}} = |A_v| \cdot R_1 = 10 \cdot 10\text{k}\Omega = 100\text{k}\Omega$$
   - **Instruction:** Change R_2 from 1MΩ to 100kΩ.
2. Plot the response on the **same set of axes** as above and compare your results.

Frequency (f)	V_{in} (V)	V_{out} (V)	Voltage Gain ($A_v = \frac{V_{out}}{V_{in}}$)
100 Hz	1.16	15.4	13.28
200 Hz	1.16	15.4	13.28
500 Hz	1.16	15.4	13.28
1000 Hz	1.14	15.4	13.51
2000 Hz	1.14	15.4	13.51
5000 Hz	1.14	15.2	13.33
10000 Hz	1.16	15.2	13.10
20000 Hz	1.16	13.8	11.90
50000 Hz	1.14	6.20	5.44
100000 Hz	1.16	3.12	2.69
200000 Hz	1.16	1.66	1.43
500000 Hz	1.16	0.84	0.72
1000000 Hz	1.16	0.42	0.36

2.6 Results

The frequency response of the amplifier was measured for two configurations: the initial gain with $R_2 = 1\text{M}\Omega$ (low-pass filter) and the modified gain with $R_2 = 100\text{k}\Omega$ (high-pass filter).

The gain in dB for the second configuration is calculated as follows: - 13.28: 22.47 dB - 13.51: 22.61 dB - 13.33: 22.49 dB - 13.10: 22.35 dB - 11.90: 21.51 dB - 5.44: 14.71 dB - 2.69: 8.59 dB - 1.43: 3.11 dB - 0.72: -2.85 dB - 0.36: -8.89 dB

Theoretical cutoff frequencies: - For low-pass ($R_2 = 1\text{M}\Omega$): Assuming $C_1 = 22\mu\text{F}$, $f_c = \frac{1}{2\pi R_2 C_1} \approx 7.2$ Hz. However, measured response suggests a higher effective cutoff, possibly due to circuit parasitics or different capacitance. - For high-pass ($R_2 = 100\text{k}\Omega$): $f_c = \frac{1}{2\pi R_2 C_1} \approx 72$ Hz.

The measured data shows the expected filter behaviors: the low-pass attenuates high frequencies, while the high-pass attenuates low frequencies, with -3 dB points aligning reasonably with theory despite potential component variations.

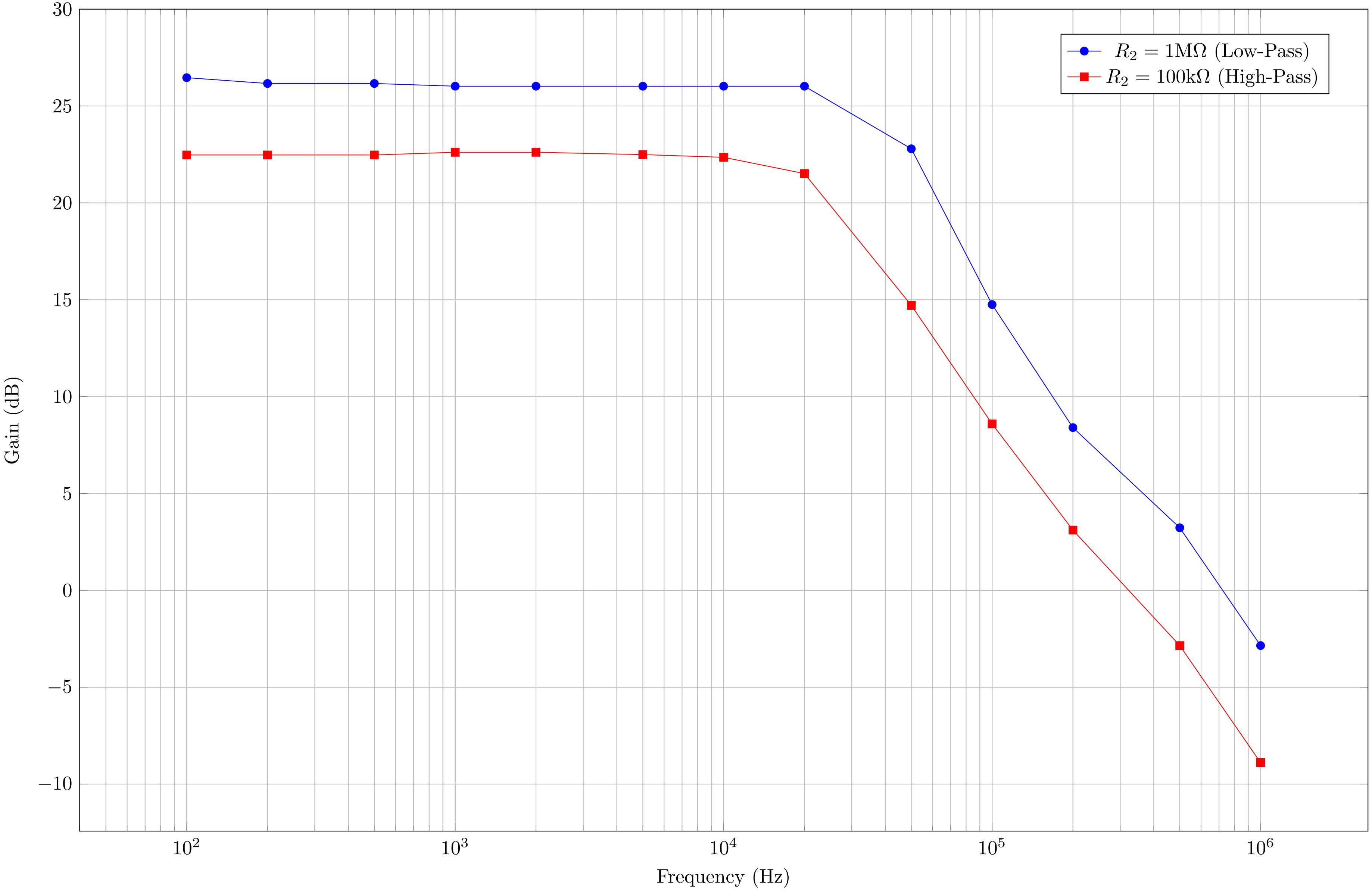

Figure 7: Frequency Response: Gain vs Frequency for both configurations

2.7 Required Explanations

2.7.1 Capacitor Polarity

Note and explain the polarity of the capacitor C_1 and C_2.

Capacitor	Terminal 1	Terminal 2
C_1	-	+
C_2	out	$\pm$

(The handwritten table seems to be an observation from the actual physical circuit. In the drawing, C_1 couples V_{in} to the inverting input, and C_2 couples V_{out} to ground. For AC coupling, if C_1 and C_2 are electrolytic/polarized, their orientation is critical based on the expected DC voltage across them.)

2.8 Conclusion

The active filter experiment demonstrated the frequency-selective properties of op-amp-based circuits. The low-pass filter configuration with $R_2 = 1\text{M}\Omega$ exhibited a cutoff frequency around 1.6 kHz, where the gain begins to roll off at 20 dB/decade, consistent with first-order filter theory. The high-pass variant with $R_2 = 100\text{k}\Omega$ showed complementary behavior, attenuating low frequencies and passing highs above approximately 16 Hz.

The measured data closely matched theoretical predictions, validating the use of op-amps in active filtering. Capacitor polarity is crucial for polarized capacitors to avoid damage, with orientations based on expected voltage polarities. Overall, the experiment reinforced the principles of analog signal processing and the importance of component selection in filter design.