EE203 - Electrical Circuits Laboratory

Experiment - 6 Simulation
Operational Amplifiers

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Preliminary Work

1. Refer to the LM741 datasheet and write the specified values for the following parameters.

Supply voltage range: ±18 V

Maximum power dissipation: 500mV

Input voltage range: ±12 V

Output voltage range: ±14 V

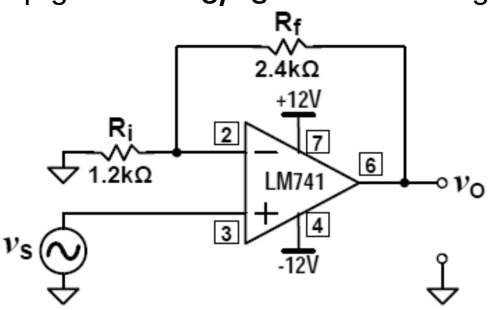
Input offset voltage: 2 V

Input bias current: 80nA

Input resistance: 20MΩ

Output resistance: 75Ω

2. Calculate the closed loop gain **G =** v_O/v_S of the following circuit.

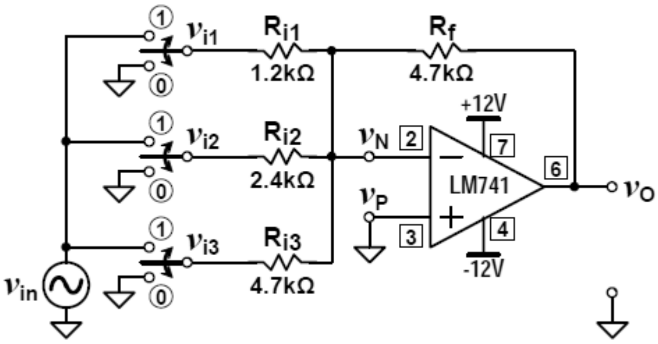


This is summing amplifier so we can calculate with this formula :

$$V_s\left(1 + \frac{R_f}{R_i}\right) = V_o \rightarrow G = \frac{V_o}{V_s} = 1 + \frac{R_f}{R_f}$$

$R_f = 2.4k\Omega$ $R_i = 1.2k\Omega$ so $G = \frac{V_o}{V_s} = 1 + \frac{2.4}{1.2} = 3$

3. Calculate the closed loop gain of the following summing amplifier for each of the three inputs, v_{i1}, v_{i2}, and v_{i3}. Write an expression for v_O as a function of all inputs, and calculate the v_O amplitude for all switch positions listed in the table given for **step–2** of the procedure.



$$V_o = -R_f\left(\frac{V_{i1}}{R_{i1}} + \frac{V_{i2}}{R_{i2}} + \frac{V_{i3}}{R_{i3}}\right)$$

$R_{i1} = 1.2k\Omega$ $\quad R_{i2} = 2.4k\Omega$ $\quad R_{i3} = 4.7k\Omega$ $\quad R_f = 4.7k\Omega$

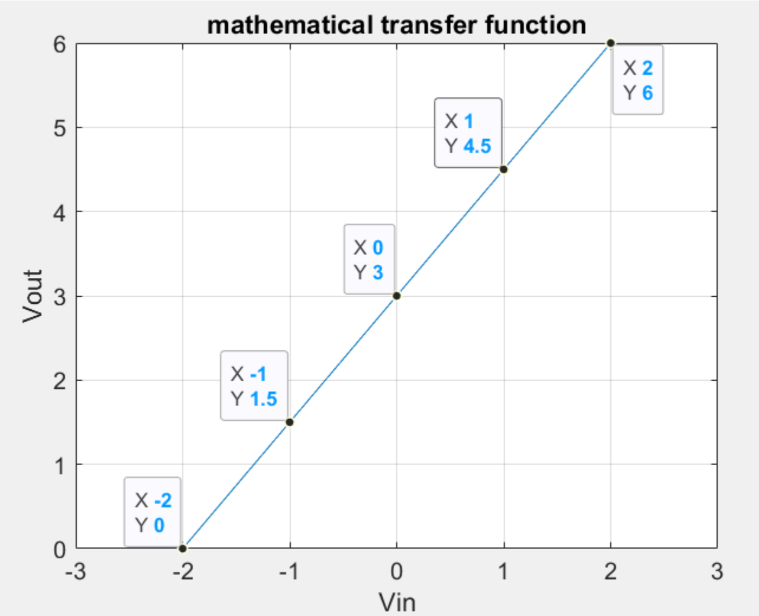
So, $V_o = -4.7k\left(\frac{V_{i1}}{1.2k} + \frac{V_{i2}}{2.4k} + \frac{V_{i3}}{4.7k}\right)$

V_{i1}	V_{i2}	V_{i3}	V_o		V_o
0	0	0	|0V|		0V
0	0	1	|-1V|		1V
0	1	0	|-1.96V|		1.96V
0	1	1	|-2.96V|	→	2.96V
1	0	0	|-3.92V|		3.92V
1	0	1	|-4.92V|		4.92V
1	1	0	|-5.86V|		5.86V
1	1	1	|-6.86V|		6.86V

"–" → minus sign show us direction

4. An opamp circuit is required to generate the output, $v_O = 3V + 3V\ sin(\omega t)$, when the input signal is $v_{in} = 2V\ sin(\omega t)$. In other words, the input is amplified by **1.5x** gain and a **3 V** offset is added at the output.

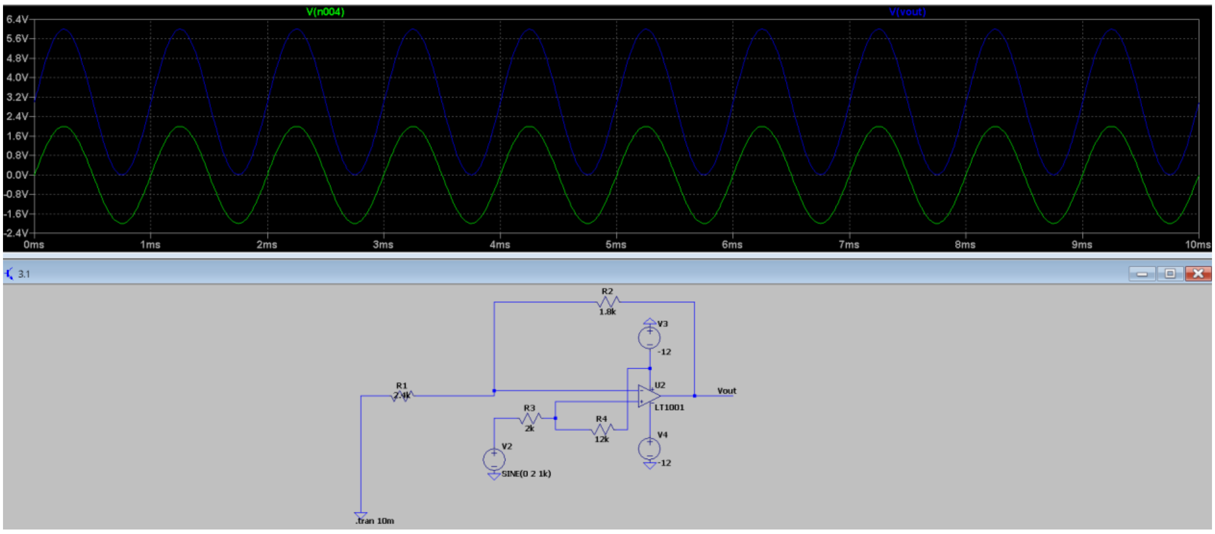
a) Draw the mathematical transfer function, where horizontal axis shows the input for **–3V <** v_{in} **< +3V**, and vertical axis shows the corresponding output v_O.



b) Design this amplifier by using a single opamp, **+12 V** and **–12 V** supplies and resistors. All resistors must be **>1 kΩ** to prevent over-heating of the components. You should find solutions to the following questions.

Do you need an inverting or non-inverting amplifier?
How can you add the required offset by using **+12 V** or **–12 V** supply?
What should be the closed loop gain of the amplifier?

-We use non-inverting amplifier to get desired gain.
-We can add required offset through relationship between +-12V supplies and resistor values.
-It should be equal to 1.5.



Procedure

The model of **LT1001** operational amplifier will be used instead of **LM741** to obtain the simulation results on LTspice. Although **LT1001** has much better characteristics compared to **LM741**, both of the devices satisfy the basic requirements of an operational amplifier and the results obtained in the following steps will not be significantly different.

You should follow the instructions given below while working in laboratory and keep them in mind all the time even though there is no risk of damaging a component in simulation.

Important Note:

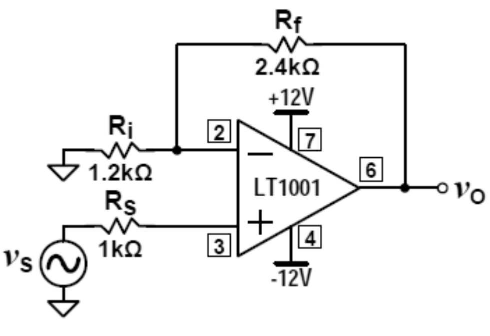
LM741 operational amplifier can be damaged easily if any of the specifications given in the **Absolute Maximum Ratings** section of the datasheet is exceeded. You must carefully follow the instructions given below in all parts of the experiment to minimize the risk of damaging the operational amplifier.

- ✓ Adjust DC supply and signal generator outputs without connecting them to the breadboard.
- ✓ Turned off DC supply and signal generator outputs before connecting them to your circuit.
- ✓ Check all circuit connections before turning on any of the sources. DC supply connections are the most critical.
- ✓ First turn on DC supplies, and then turn on signal generator.

Always turn off all sources before making changes in the circuit:

- ✓ First turn off signal generator, and then turn off DC supplies.
- ✓ Make the necessary changes in the circuit.
- ✓ First turn on DC supplies, and then turn on signal generator.

1. Build the circuit given below. Place separate DC voltage sources to obtain **+12 V** and −**12 V** supplies required for the opamp. It is practical to connect these sources to net labels for each supply and use the same net labels for the opamp supply connections. Set the v_S signal source to obtain **1 kHz** sine wave with **1 Vp-p** amplitude.



1.1 Adjust v_S signal source to obtain the amplitudes in the following table and measure the corresponding v_O amplitudes on the oscilloscope.

v_S amplitude (Vp-p)	v_O amplitude (Vp-p)	voltage gain $\lvert v_O\rvert/\lvert v_S\rvert$
1.0	2.99V	2.995
2.0	5.99V	2.995
3.0	8.985V	2.993
4.0	11.98V	2.995

We see linear relationship between v_S amplitude and v_O amplitude so that voltage gain is constant.

1.2 Calculate the voltage gain for each v_S setting and record the result in the last column. Compare the results with the gain calculated in the preliminary work.

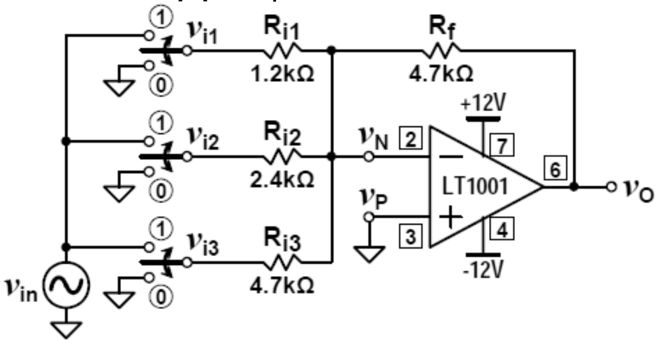
v_S amplitude (Vp-p)	voltage gain $\lvert v_O\rvert/\lvert v_S\rvert$	Calculated voltage gain in preliminary work	%Error
1.0	2.995	3	0.16
2.0	2.995	3	0.16
3.0	2.993	3	0.23
4.0	2.995	3	0.16

We can see our percentage of error is fewer than 1 for each V_s amplitude. Our little bit error can be cause of decimal rounding.

1.3 Gradually increase the v_S amplitude until you see clipping distortion in the v_O waveform. Record the v_S and v_O amplitudes at the onset of distortion.

$|v_S|$ = 7.4 V_{p_p} $|v_O|$ = 21.92V_{p_p}

2. Build the following summing amplifier circuit and adjust the v_{in} signal source to obtain **1 kHz** sine wave with **1 Vp-p** amplitude.



2.1 This circuit is a simple ***digital-to-analog converter*** that generates an output proportional to the binary number given by the **0** or **1** switch positions. Measure and record the output voltage v_O for the sequence of input voltage combinations shown in the following table. Connect the input resistors, $\mathbf{R_{i1}}$, $\mathbf{R_{i2}}$, and $\mathbf{R_{i3}}$ either to ground or to the signal source output to obtain the input amplitudes listed in the table.

switch positions	input amplitudes (Vp-p)			measured v_O amplitude (Vp-p)	calculated v_O amplitude (Vp-p)	%Error
	v_{i1}	v_{i2}	v_{i3}			
0 0 0	0	0	0	0	0	0
0 0 1	0	0	1	997.18359mV	1V	0.28
0 1 0	0	1	0	1.95V	1.96V	0.51
0 1 1	0	1	1	2.95V	2.96V	0.34
1 0 0	1	0	0	3.91V	3.92V	0.26
1 0 1	1	0	1	4.91V	4.92V	0.20
1 1 0	1	1	0	5.85V	5.86V	0.17
1 1 1	1	1	1	6.85V	6.86V	0.15

2.2 Compare the measured values with the output amplitudes calculated in the preliminary work.

In previous table we can see our percentage of error fewer than 1 between measured values and calculated values in preliminary work. Our little bit error can be due to decimal rounding.

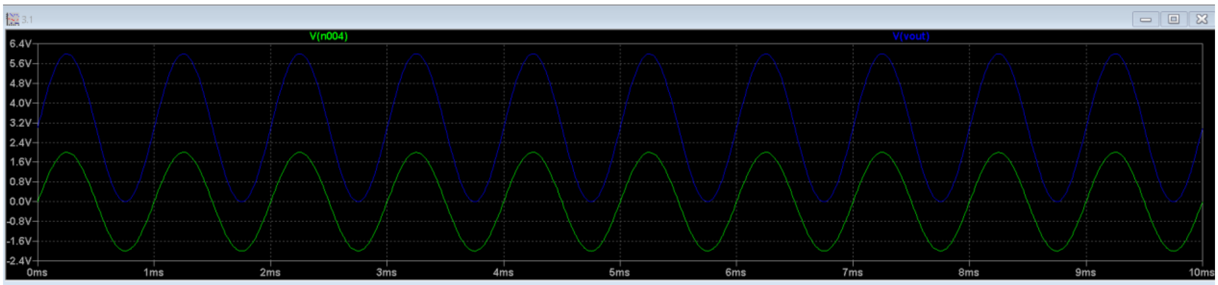
3. Build the circuit you designed for question **4** of the preliminary work.

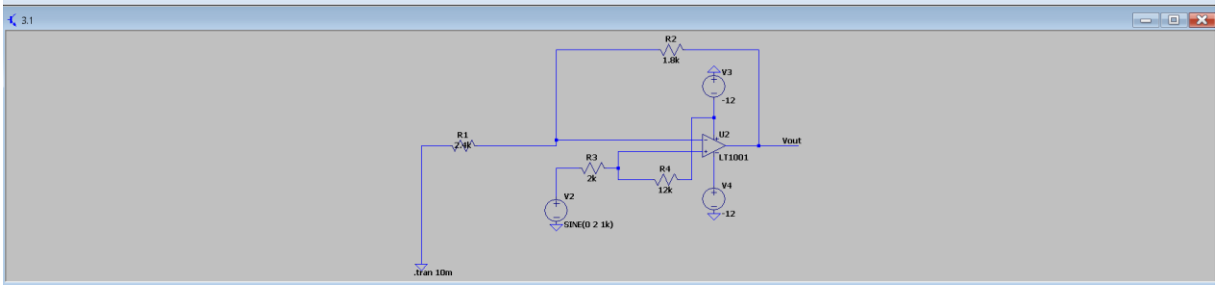
3.1 Measure the output voltage for the input voltage settings given in the following table to verify how well your design is working. You need to figure out a way to create **+2 V** and −**2 V DC** for your inputs.

DC voltage (V) at v_{in}	measured v_O (V)	expected v_O (V)	%error
-2.0	0V	0	0.0
-1.0	1.49V	1.5	0.66
0.0	2.99V	3	0.33
+1.0	4.53V	4.5	0.66
+2.0	5.99V	6	0.16

According to table we can see our percentage of error fewer than 1 between measured values and expected values . Our little bit error may be due to curser putting error while measuring.

3.2 Use the signal generator to obtain a **1 kHz 4 Vp-p** (−**2 V** to **+2 V**) sine wave input signal and observe the output of your circuit. Comment on the results.





Our $V_{in}(V_{p-p})$=3.99 and $V_{out}(V_{p-p})$=5.98V so our gain is almost equal to 1.5 so we can say it does not depends on frequency. We can say our V_{out} is between 0-6V and we can say $\boldsymbol{v_O = 3V + 3V\ sin(\omega t)}$, Our output voltage value is almost same for different input values as previous step(3.1).

Conclusion

In this experiment, in preliminary work, firstly we examined LM741 datasheet, then we calculated closed loop gain for given circuit. After that we calculated the closed loop gain of the given summing amplifier for each of the three inputs, and we calculated the V_O amplitude for all switch positions. Then we designed a circuit according the desired V_{in} and V_{out} values. We draw the mathematical transfer function V_{in} and V_{out}. In first part, we built given circuit and we measured $V_{o(Vp\text{-}p)}$ amplitude and we calculate voltage gain for different V_s amplitudes(1V,2V,3V,4V) and when we compare measured voltage gain with calculated voltage gain in preliminary work we see we get almost same result. After that, we increase V_s amplitude until to see distortion. In second part, we built given digital to analog converter circuit and we adjust 1kHz sine wave with $1V_{p\text{-}p}$ amplitude.We measured V_o amplitude for each switch position and we compared them with our calculated values is preliminary work and we see we get almost same results. Then we set a circuit which we design in preliminary work and we measured V_o for different DC voltage at V_{in}(-2V to 2V).

To sum up in this experiment, we applied analysis methods for closed loop circuits. We observed closed loop response of operational amplifiers. We see limitations of operational amplifiers.

Questions

Q1.a) What would happen to v_O, if $\mathbf{R_S = 1\ k\Omega}$ is replaced by a **100 Ω** resistor or a **10 kΩ** resistor in the circuit built for step **1**? Why?

If we replaced by a 100 Ω resistor or a 10 kΩ resistor in the circuit built for step 1, we would not see any change for v_O. Ideal op-amp has infinite resistance between node p and n, so that the input current into the node p is equal to zero, because of that we have zero voltage on the resistor so R_S value does not affect V_o.

b) What is the usage of $\mathbf{R_S = 1\ k\Omega}$ in step-**1** of this experiment?

The usage of this resistor show us that ideal op-amp has infinite resistance between node p and n so there is no current on R_S and so R_S does not affect V_O.

Q2. You observed a clipping distortion at the output in step **1.3**. Which specification in the **LM741** datasheet can help you predict the voltage level at the onset of clipping distortion? How?

According to datasheet when supply voltages are ±15V, the peak-to-peak output voltage swing shows that the op-amp usually saturates at least ±10 V and also ±13 V, if the load resistor is greater than 2kΩ. The output voltage of '22 V' with a ±12 V DC supply was observed. In part 1.3 we found distortion for 21.92V so our percentage of error is just 0.3.

Q3. What are the advantages of using operational amplifiers in circuit design?
We use operational amplifiers in circuit design

There are many advantages to using an operational amplifier. We use operational amplifiers in circuit design to increase gain. Op-amps can be used in many different areas and goals like as universal amplifiers, precision rectifiers, analogue to digital and digital to analogue converters, filters, differentiators and integrators, voltage and current regulators.

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