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Lab III

Inverting mode, Non-inverting mode, Adder, Subtractor using LM741

Objectives

To study the basic configuration of OPAMP (LM-741)

1. Inverting mode
2. Non-inverting mode
3. Adder
4. Subtractor

and find

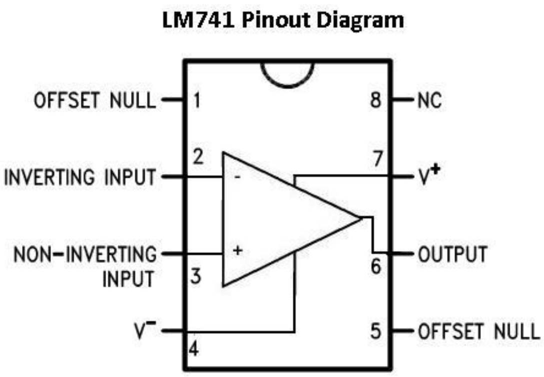
a) Simulated and theoretical values of voltage gain (A_v) and input-output voltage waveforms with magnitude for inverting and non-inverting mode,

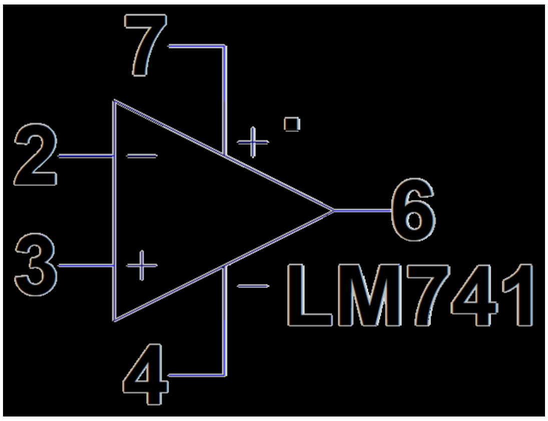
b) Simulated and theoretical values of output voltage (V_o) for adder and subtractor,

Also, record observations and write conclusions for each amplifier configuration.

IC LM741

- LM741 operational amplifier is a DC-coupled high gain electronic voltage amplifier.
- It has only one op-amp inside.
- An operational amplifier IC is used as a comparator, which compares the two signals, the inverting and non-inverting signal.
- The main function of this IC is to do mathematical operation in various circuits.
- Op-amps have large gain and usually used as Voltage Amplifier.
- The LM741 can operate with a single or dual power supply voltage.





1. Inverting Mode – Schematic, .ac results and Waveforms

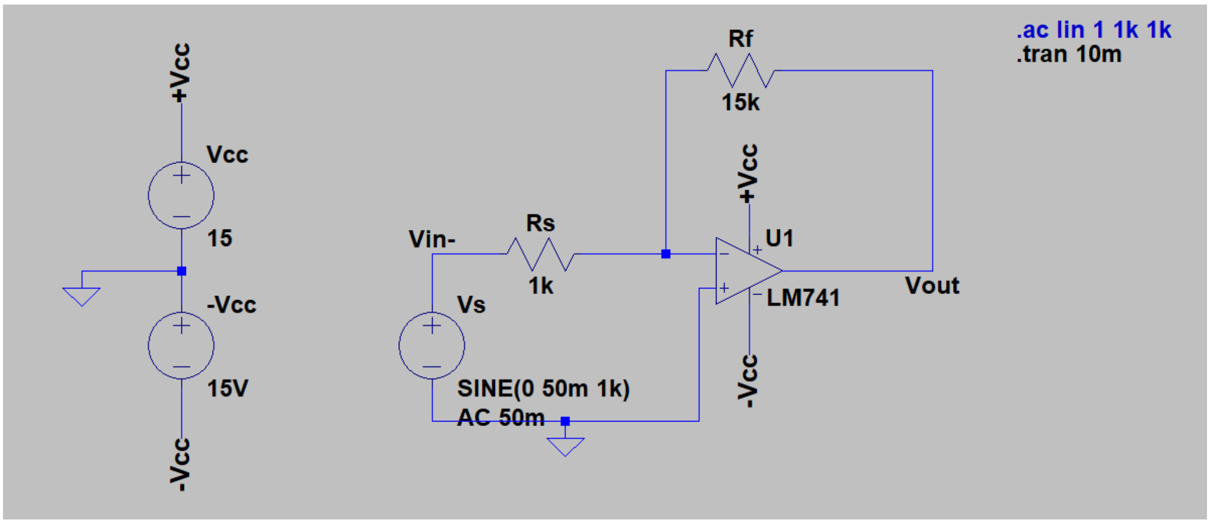


Fig 1.1 - Circuit diagram for Inverting Mode

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       --- AC Analysis ---

frequency:      1000          Hz
V(n001):        mag: 0.000758591 phase:    88.8112°        voltage
V(-vcc):        mag:           0 phase:         0°        voltage
V(+vcc):        mag:           0 phase:         0°        voltage
V(vout):        mag:    0.749846 phase:    179.07°        voltage
V(n002):        mag:        0.05 phase:         0°        voltage
I(Rs):          mag: 4.999e-005 phase:    179.131°        device_current
I(Rf):          mag: 4.999e-005 phase:    179.128°        device_current
I(-vcc):        mag: 2.48267e-005 phase:    179.128°      device_current
I(Vcc):         mag: 2.51633e-005 phase:  -0.872383°      device_current
I(Vs):          mag: 4.999e-005 phase:    179.131°        device_current
Ix(u1:1):       mag: 2.68845e-009 phase:   -91.1901°      subckt_current
Ix(u1:2):       mag: 2.68845e-009 phase:    88.8099°      subckt_current
Ix(u1:99):      mag: 2.51633e-005 phase:    179.128°      subckt_current
Ix(u1:50):      mag: 2.48267e-005 phase:    179.128°      subckt_current
Ix(u1:28):      mag: 4.999e-005 phase:  -0.872383°        subckt_current
```

Fig 1.2 – AC Analysis for Inverting Mode

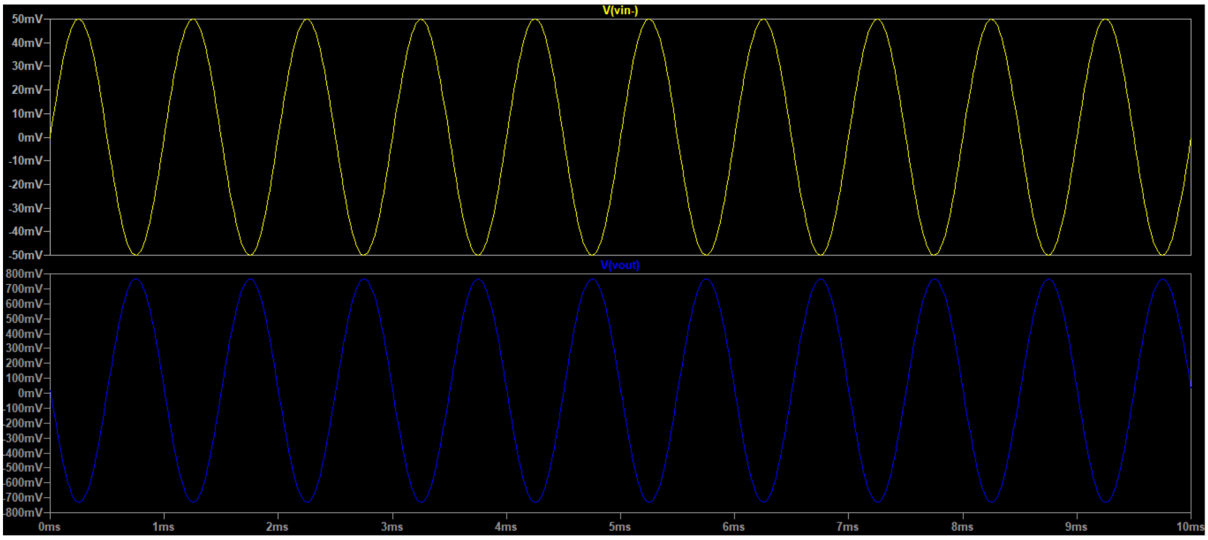

Fig 1.3- Input-Output waveform for Inverting Mode

Observations and Calculations

From Theory:

The output voltage for an inverting amplifier can be calculated using the formula

$$A_v = \frac{V_o}{V_s} = -\frac{R_F}{R_s}$$

As $|\mathbf{V_s}| = \mathbf{50mV}$, so

$$|V_0| = \frac{15k\Omega}{1k\Omega} \times 50mV = 0.75V$$

Negative sign of $\mathbf{A_v}$ indicates phase shift by **180°**. Hence, if $\mathbf{V_s}$ has **0°** phase, the $\mathbf{V_o}$ must have **180°** phase.

Voltage gain ($\mathbf{A_v}$) = **-15**.

Simulated:

The amplitude of $\mathbf{V_o}$ comes out to be **0.749846V** with a phase of **179.07°**.

Voltage gain ($\mathbf{A_v}$) = **-14.99692**.

Conclusions

- The amplitude and phase of simulated waveform are very close to the expected results.
- The waveform is inverted and amplified.
- The simulated results are not exactly equal to theoretical results because the Op-Amp LM741 IC is not an ideal Op-Amp. It draws very small current (in order of nA) at its input, does not have infinite input resistance and zero output resistance, and has a finite gain which are the main causes of deviation from the expected theoretical results.

2. Non - Inverting Mode – Schematic, .ac results and Waveforms

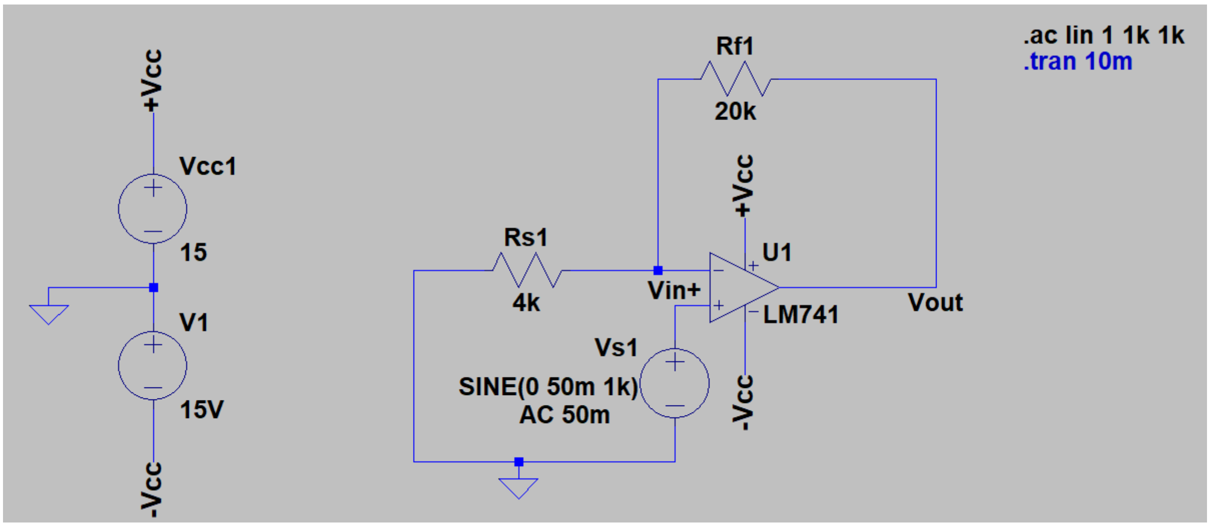

Fig 2.1- Circuit diagram for Non-Inverting Mode

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       --- AC Analysis ---

frequency:     1000          Hz
V(n001):       mag:  0.0499993 phase:  -0.340162°       voltage
V(vin+):       mag:       0.05 phase:          0°       voltage
V(-vcc):       mag:          0 phase:          0°       voltage
V(+vcc):       mag:          0 phase:          0°       voltage
V(vout):       mag:   0.299996 phase:  -0.344212°       voltage
I(Rs1):        mag: 1.24998e-005 phase:  -0.340162°     device_current
I(Rf1):        mag: 1.24998e-005 phase:  -0.345022°     device_current
I(V1):         mag: 6.23647e-006 phase:  -0.345022°     device_current
I(Vcc1):       mag: 6.26335e-006 phase:    179.655°     device_current
I(Vs1):        mag: 1.06018e-009 phase:   -90.4425°     device_current
Ix(u1:1):      mag: 1.06018e-009 phase:    89.5575°     subckt_current
Ix(u1:2):      mag: 1.06017e-009 phase:   -90.4371°     subckt_current
Ix(u1:99):     mag: 6.26335e-006 phase:  -0.345022°     subckt_current
Ix(u1:50):     mag: 6.23647e-006 phase:  -0.345022°     subckt_current
Ix(u1:28):     mag: 1.24998e-005 phase:    179.655°     subckt_current
```

Fig 2.2 – AC Analysis for Inverting Mode

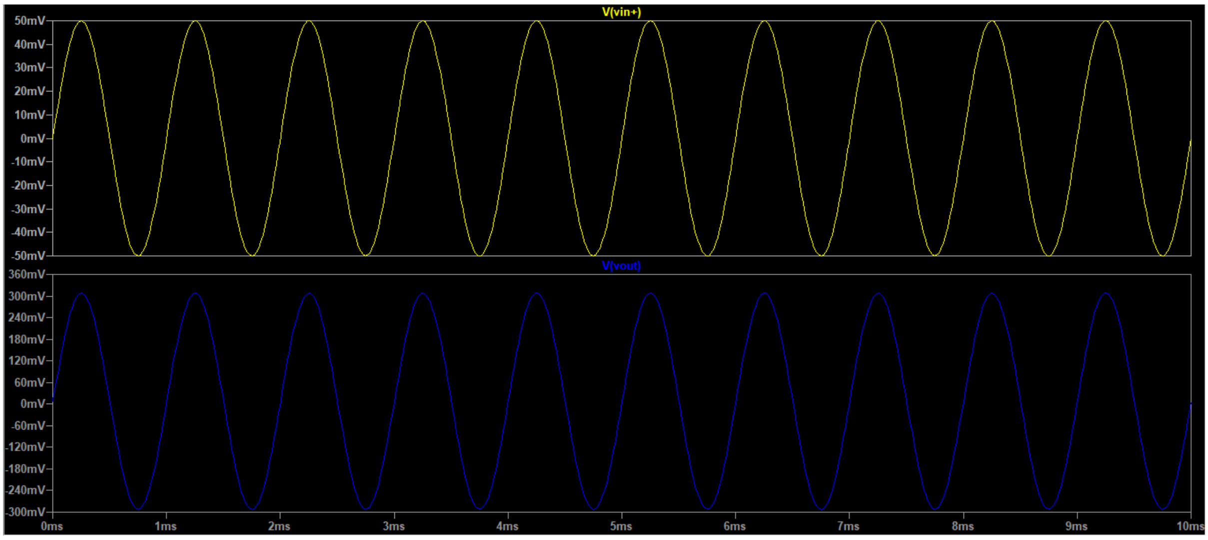

Fig 2.3 - Input-Output waveform for Non-Inverting Mode

Observations and Calculations

From Theory:

The output voltage for a non-inverting amplifier can be calculated using the formula

$$A_v = \frac{V_o}{V_s} = 1 + \frac{R_F}{R_s}$$

As $|\mathbf{V_s}|$ **= 50mV**, so

$$|V_0| = \left(1 + \frac{20k\Omega}{4k\Omega}\right) \times 50mV = 0.3V$$

Positive sign of $\mathbf{A_v}$ indicates no phase shift. Hence, if $\mathbf{V_s}$ has **0°** phase, the $\mathbf{V_0}$ must have **0°** phase.

Voltage gain ($\mathbf{A_v}$) = **6**.

Simulated:

The amplitude of $\mathbf{V_o}$ comes out to be **0.29996V** with a phase of **-0.34212°**.

Voltage gain ($\mathbf{A_v}$) = **5.99992**.

Conclusions

- The amplitude and phase of simulated waveform are very close to the expected results.
- The waveform is amplified and remains in phase.
- The simulated results are not exactly equal to theoretical results because the Op-Amp LM741 IC is not an ideal Op-Amp. It draws very small current (in order of nA) at its input, does not have infinite input resistance and zero output resistance, and has a finite gain which are the main causes of deviation from the expected theoretical results.

3. Adder – Schematic, .ac results and Waveforms

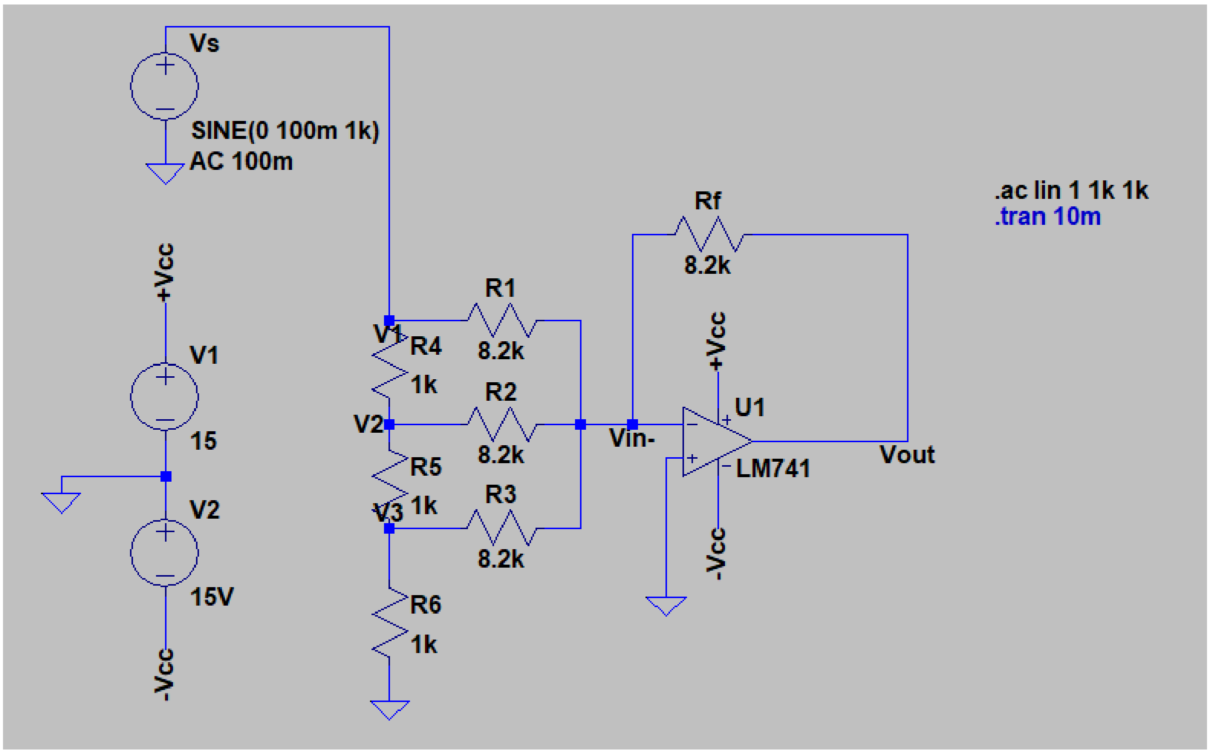

Fig 3.1 - Circuit diagram for Adder

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       --- AC Analysis ---

frequency:    1000          Hz
V(vin-):      mag: 0.000193235 phase:    89.519°       voltage
V(-vcc):      mag:           0 phase:        0°       voltage
V(+vcc):      mag:           0 phase:        0°       voltage
V(vout):      mag:    0.189126 phase:   179.777°       voltage
V(v2):        mag:    0.060581 phase: 0.0198641°       voltage
V(v1):        mag:         0.1 phase:        0°       voltage
V(v3):        mag:   0.0285498 phase: 0.0421505°       voltage
I(R6):        mag: 2.85498e-005 phase:  0.0421505°     device_current
I(R5):        mag: 3.20312e-005 phase: -6.06051e-018°  device_current
I(R4):        mag: 3.9419e-005 phase: -0.0305281°     device_current
I(R3):        mag: 3.48154e-006 phase:    179.654°     device_current
I(R1):        mag: 1.21949e-005 phase:    179.889°     device_current
I(R2):        mag: 7.38776e-006 phase:    179.837°     device_current
I(Rf):        mag: 2.30642e-005 phase:    179.835°     device_current
I(V2):        mag: 1.1501e-005 phase:    179.835°     device_current
I(V1):        mag: 1.15632e-005 phase:  -0.164591°     device_current
I(Vs):        mag: 5.16139e-005 phase:    179.951°     device_current
Ix(u1:1):     mag: 6.84826e-010 phase:   -90.4823°     subckt_current
Ix(u1:2):     mag: 6.84826e-010 phase:    89.5177°     subckt_current
Ix(u1:99):    mag: 1.15632e-005 phase:    179.835°     subckt_current
Ix(u1:50):    mag: 1.1501e-005 phase:    179.835°     subckt_current
Ix(u1:28):    mag: 2.30642e-005 phase:  -0.164591°     subckt_current
```

Fig 3.2 - AC Analysis for Adder

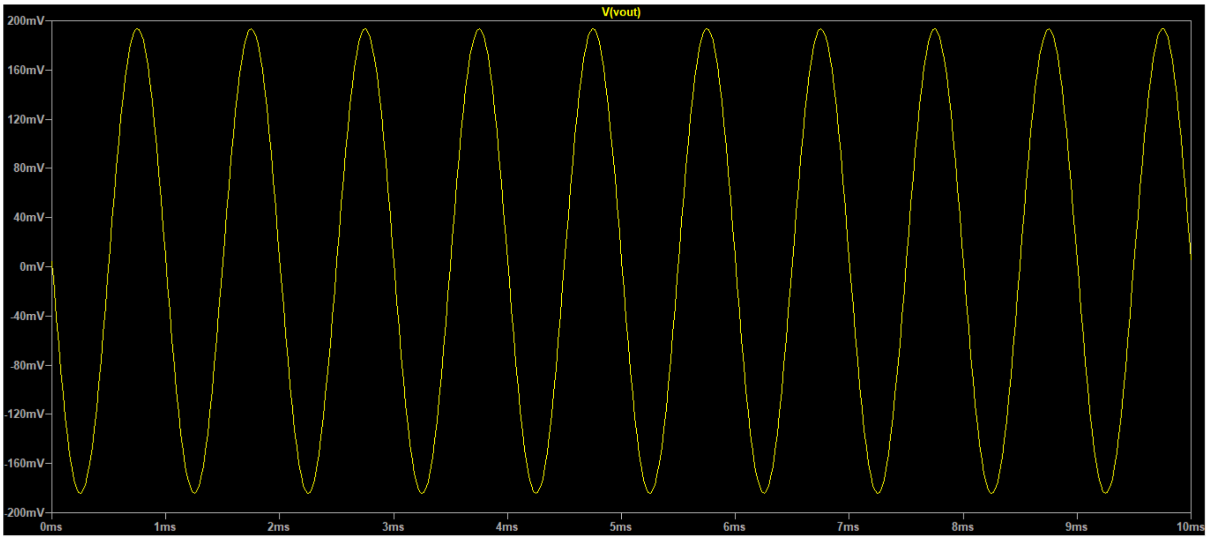

Fig 3.3 - Input-Output waveform for Adder

Observations and Calculations

From Theory:

The output voltage for a summing amplifier (adder) can be calculated using the formula

$$V_o = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right)$$

As $|\mathbf{V_s}| = \mathbf{100\ mV}$, so from the values obtained we have

$$Vs = V_1 = 100\ \text{mV}$$

$$V_2 = 60.581\ \text{mV}$$

$$V_3 = 28.5498\ \text{mV}$$

hence

$$|V_o| = \left(\frac{8.2\ \text{k}\Omega}{8.2\ \text{k}\Omega}\times 100\ \text{mV} + \frac{8.2\ \text{k}\Omega}{8.2\ \text{k}\Omega}\times 60.581\ \text{mV} + \frac{8.2\ \text{k}\Omega}{8.2\ \text{k}\Omega}\times 28.5498\ \text{mV}\right) = 189.13\text{mV}$$

Negative sign of **Av** indicates phase shift of **180°**. Hence, if $\mathbf{V_s}$ has **0°** phase, the $\mathbf{V_o}$ must have **180°** phase.

Simulated:

The amplitude of $\mathbf{V_o}$ comes out to be **0.1892V** with a phase of **179.77°**.

Conclusions

- The amplitude and phase of simulated waveform are very close to the expected results.
- The waveform is inverted and has a higher magnitude than the input voltages.
- The simulated results are not exactly equal to theoretical results because the Op-Amp LM741 IC is not an ideal Op-Amp. It draws very small current (in order of nano Amperes) at its input, does not have infinite input resistance and zero output resistance, and has a finite gain which are the main causes of deviation from the expected theoretical results.
- If by error, we apply voltage division ignoring R1, R2 and R3, then the theoretical results are very different from the results from simulation. Hence, we should use values of V1, V2 and V3 from the analysis itself for theoretical calculations.

4. Subtractor – Schematic, .ac results and Waveforms

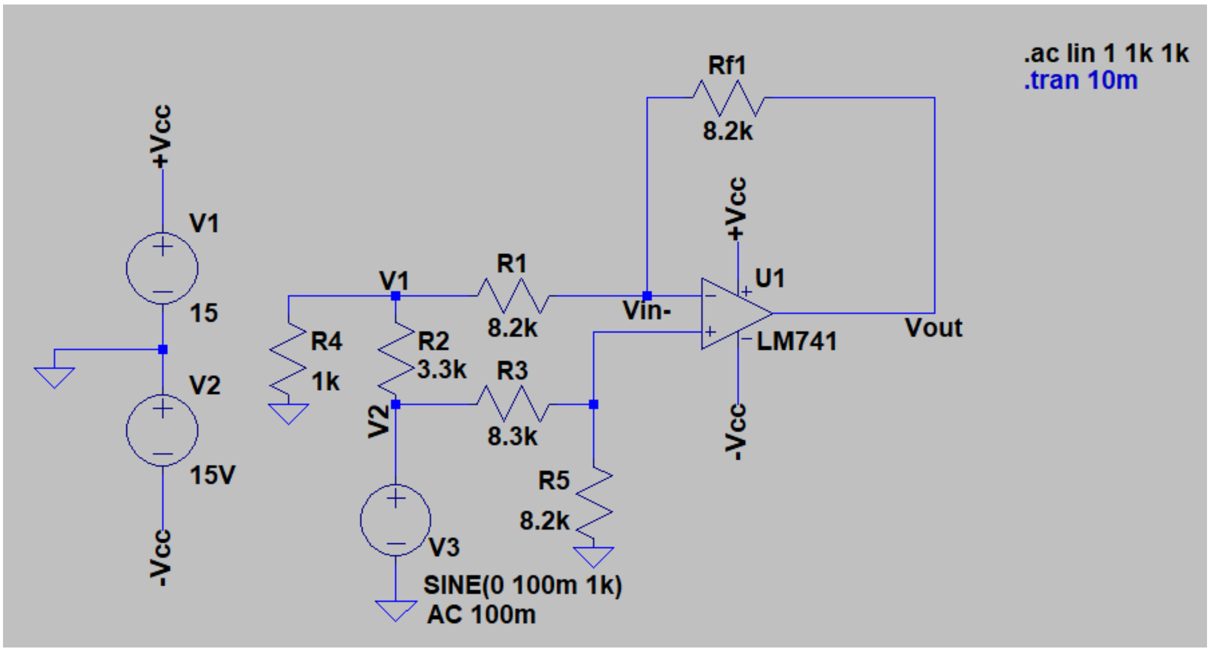

Fig 4.1 - Circuit diagram for Subtractor

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       --- AC Analysis ---

frequency:     1000           Hz
V(vin-):       mag:  0.0496981 phase: -0.0809126°       voltage
V(n001):       mag:   0.049697 phase: -0.00120371°      voltage
V(-vcc):       mag:          0 phase:          0°       voltage
V(+vcc):       mag:          0 phase:          0°       voltage
V(vout):       mag:  0.0738775 phase:  -0.105813°       voltage
V(v1):         mag:  0.0255188 phase: -0.0134857°       voltage
V(v2):         mag:        0.1 phase:          0°       voltage
I(R2):         mag: 2.25701e-005 phase:   -179.995°     device_current
I(R4):         mag: 2.55188e-005 phase: -0.0134857°     device_current
I(R3):         mag: 6.06061e-006 phase:   -179.999°     device_current
I(R5):         mag: 6.06061e-006 phase:    179.999°     device_current
I(R1):         mag: 2.94871e-006 phase:  -0.152075°     device_current
I(Rf1):        mag: 2.94871e-006 phase:  -0.156993°     device_current
I(V2):         mag: 1.47267e-006 phase:  -0.156993°     device_current
I(V1):         mag: 1.47604e-006 phase:    179.843°     device_current
I(V3):         mag: 2.86307e-005 phase:   -179.996°     device_current
Ix(u1:1):      mag: 2.53121e-010 phase:    90.3184°     subckt_current
Ix(u1:2):      mag: 2.53122e-010 phase:   -89.6592°     subckt_current
Ix(u1:99):     mag: 1.47604e-006 phase:  -0.156993°     subckt_current
Ix(u1:50):     mag: 1.47267e-006 phase:  -0.156993°     subckt_current
Ix(u1:28):     mag: 2.94871e-006 phase:    179.843°     subckt_current
```

Fig 4.2 - Analysis for Subtractor

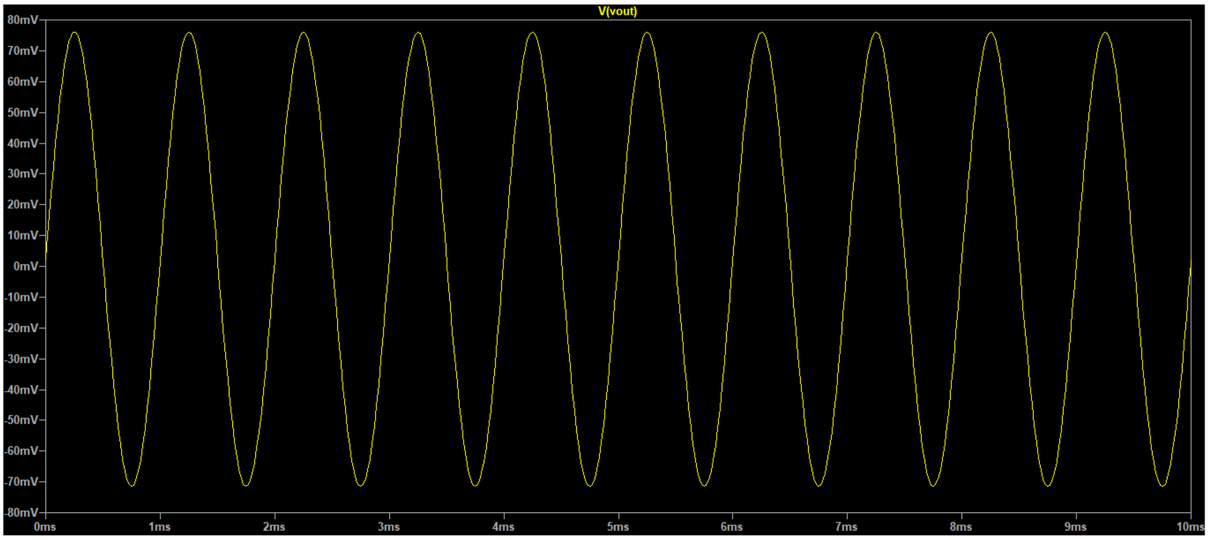

Fig 4.3 - Input-Output waveform for Subtractor

Observations and Calculations

From Theory:

The output voltage for a difference amplifier (subtractor) can be calculated using the formula

$$V_o = \frac{R_F}{R_1}(V_1 - V_2)$$

As **$|V_s|$ = 100 mV**, so from the values obtained we have

$$V_1 = 25.5118 \text{ mV}$$

$$V_s = V_2 = 100 \text{ mV}$$

$$\Rightarrow |V_o| = \frac{8.2 \text{ k}\Omega}{8.2 \text{ k}\Omega} \times (100 - 25.55118) = 74.4882 \text{ mV}$$

Positive sign of $\mathbf{A_v}$ indicates no phase shift. Hence, if $\mathbf{V_s}$ has **0°** phase, the $\mathbf{V_o}$ must have **0°** phase.

Simulated:

The amplitude of $\mathbf{V_o}$ comes out to be **0.0738775 V** with a phase of **-0.1058°**.

Conclusions

- The amplitude and phase of simulated waveform is very close to the expected results.
- The waveform is amplified with respect to difference of the voltages V1 and V2 and remains in phase.
- The simulated results are not exactly equal to theoretical results because the Op-Amp LM741 IC is not an ideal Op-Amp. It draws very small current (in order of nano Amperes) at its input, does not have infinite input resistance and zero output resistance, and has a finite gain which are the main causes of deviation from the expected theoretical results.
- If by error, we apply voltage division ignoring R1 and R2, then the theoretical results are very different from the results from simulation. Hence, we should use values of V1 and V2 from the analysis itself for theoretical calculations.

Results

S.No	Configuration	Simulated Value	Theoretical Value
1	Inverting mode	$A_v = -14.99692$	$A_v = -15$
2	Non-Inverting mode	$A_v = 5.9992$	$A_v = 6$
3	Adder	$V_{out} = 0.189126$ V	$V_{out} = 0.18913$ V
4	Subtractor	$V_{out} = 0.0738775$ V	$V_{out} = 0.0744882$ V