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Analog Electronics Lab #5 – Study of Instrumentation Amplifier using LM741

Objectives

To study the Instrumentation Amplifier using op-amp LM741 and find out

1. Value of resistance (R_f) for DC null point,
2. Common mode gain (A_{cm}) for the instrumentation amplifier,
3. Differential mode gain (A_{dm}) for the instrumentation amplifier,

and find

a) the common mode rejection ratio (CMRR) for the instrumentation amplifier,
b) compare the results from simulation with the theoretical values of the quantities.

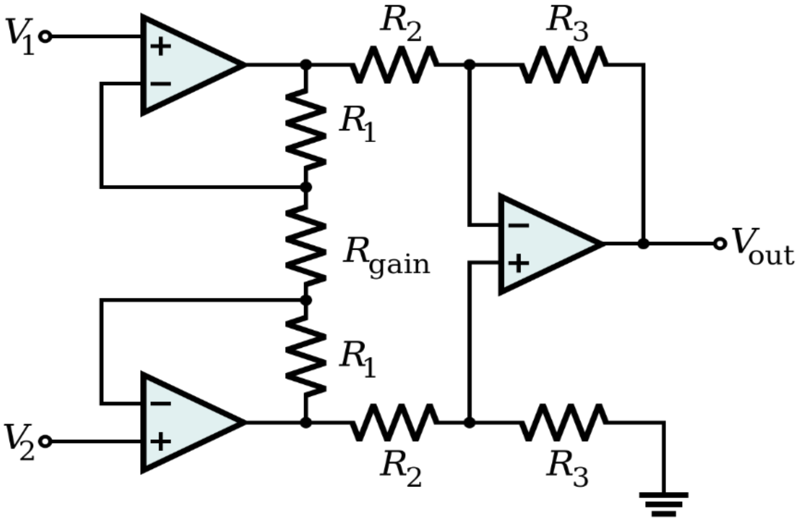
Also, draw schematic for each case.

Instrumentation Amplifier

An **instrumentation amplifier** is a type of differential amplifier that has been outfitted with input buffer amplifiers, which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment.

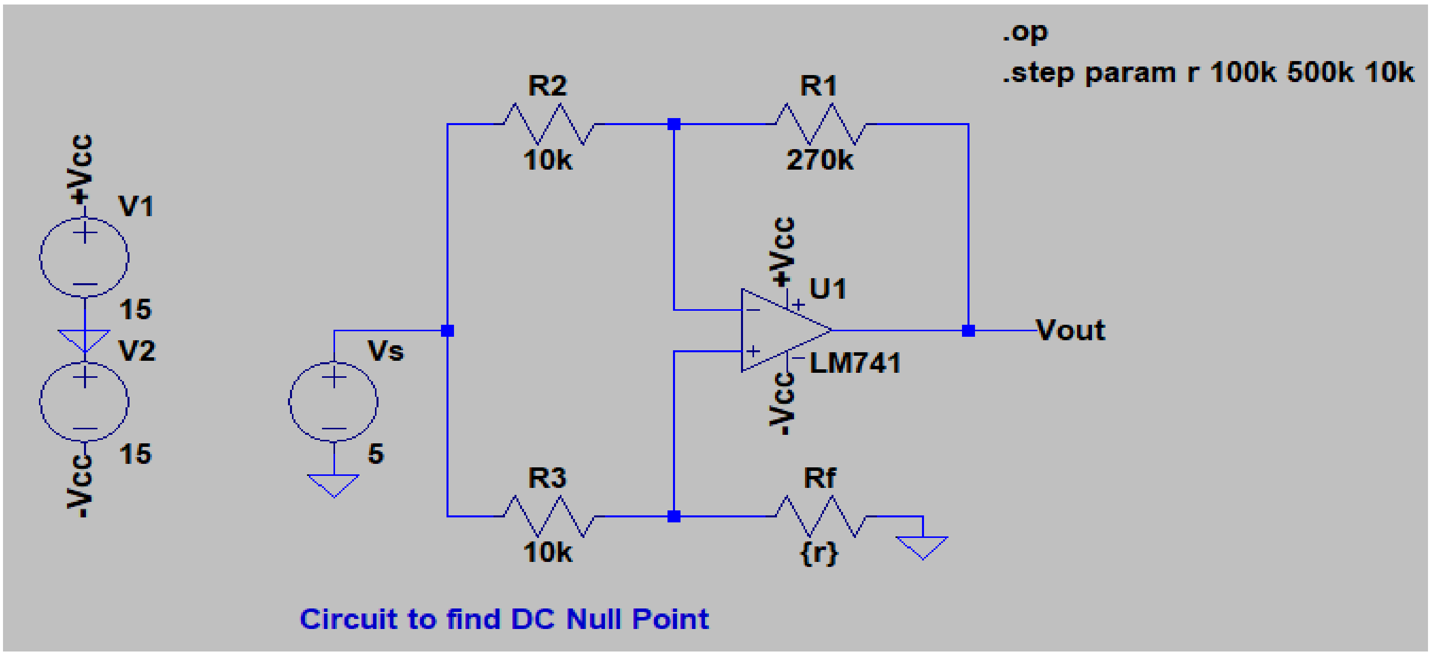
Additional characteristics include **very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio**, and **very high input impedances**. Instrumentation amplifiers are used where great accuracy and stability of the circuit both short and long-term are required.

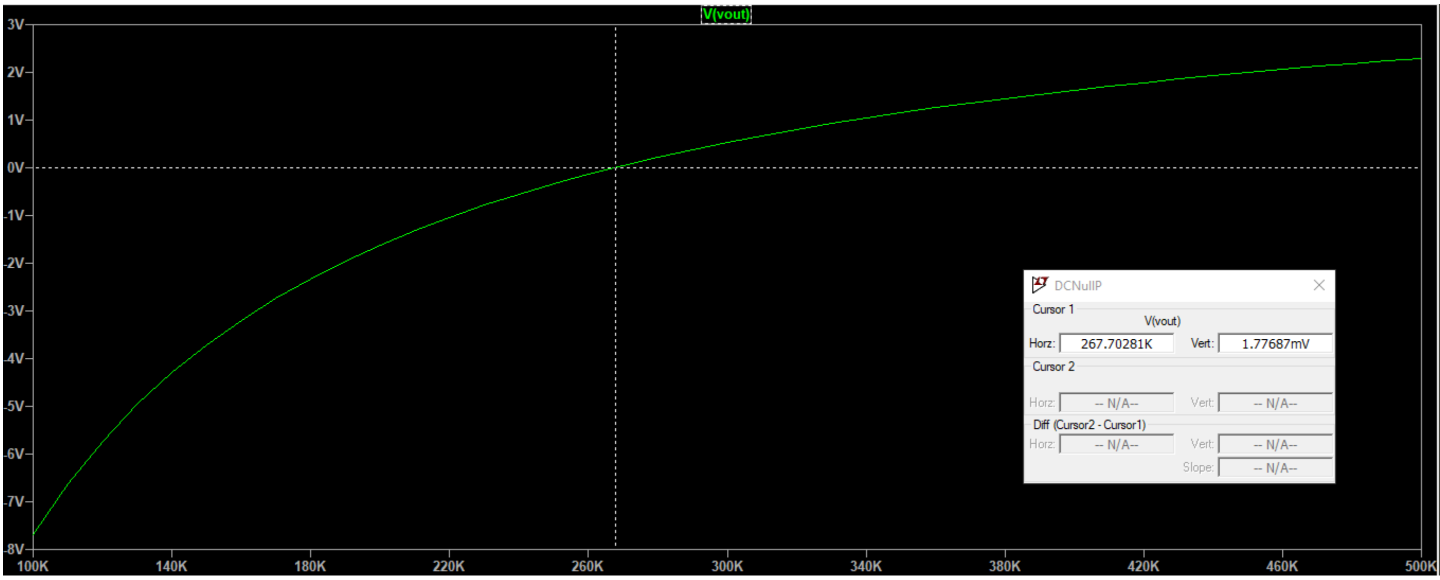
$$A_{dm} = \frac{V_{out}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{gain}}\right) \cdot \frac{R_3}{R_2}$$

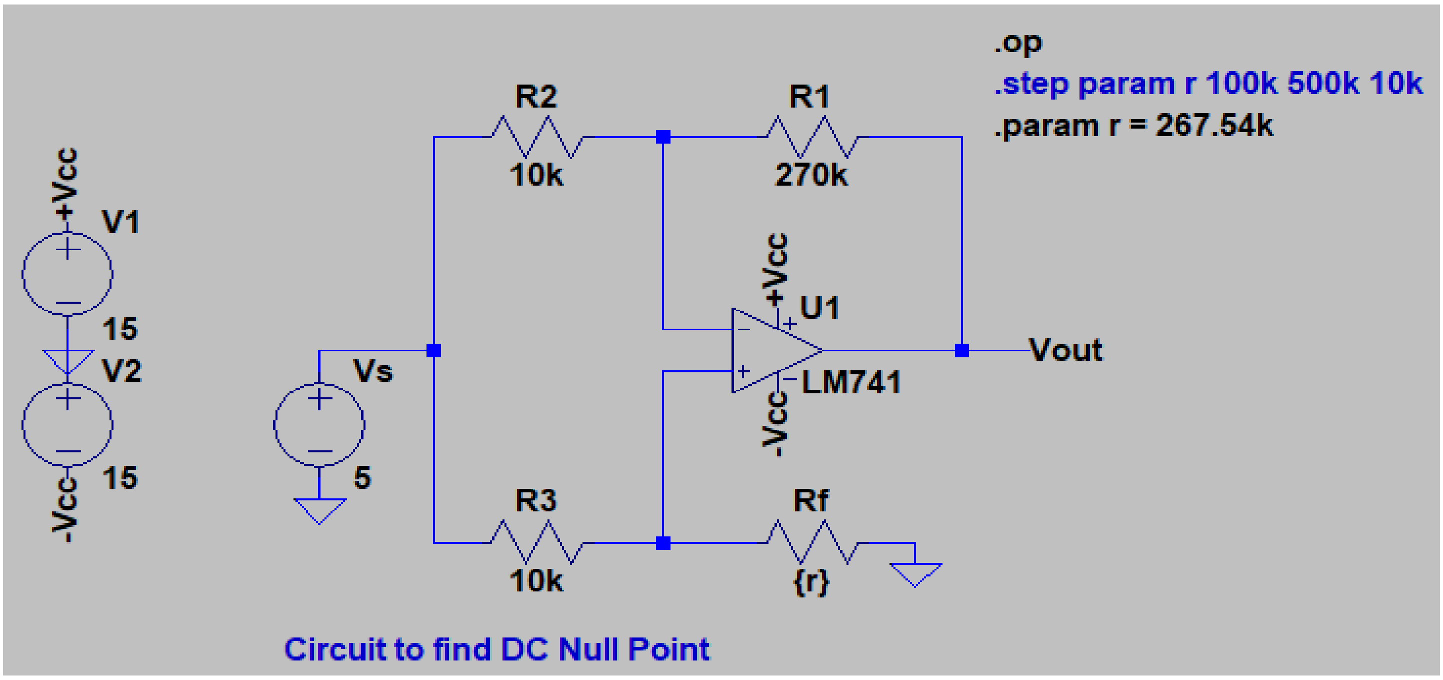


DC Null Point

Schematic and results from AC analysis







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        --- Operating Point ---

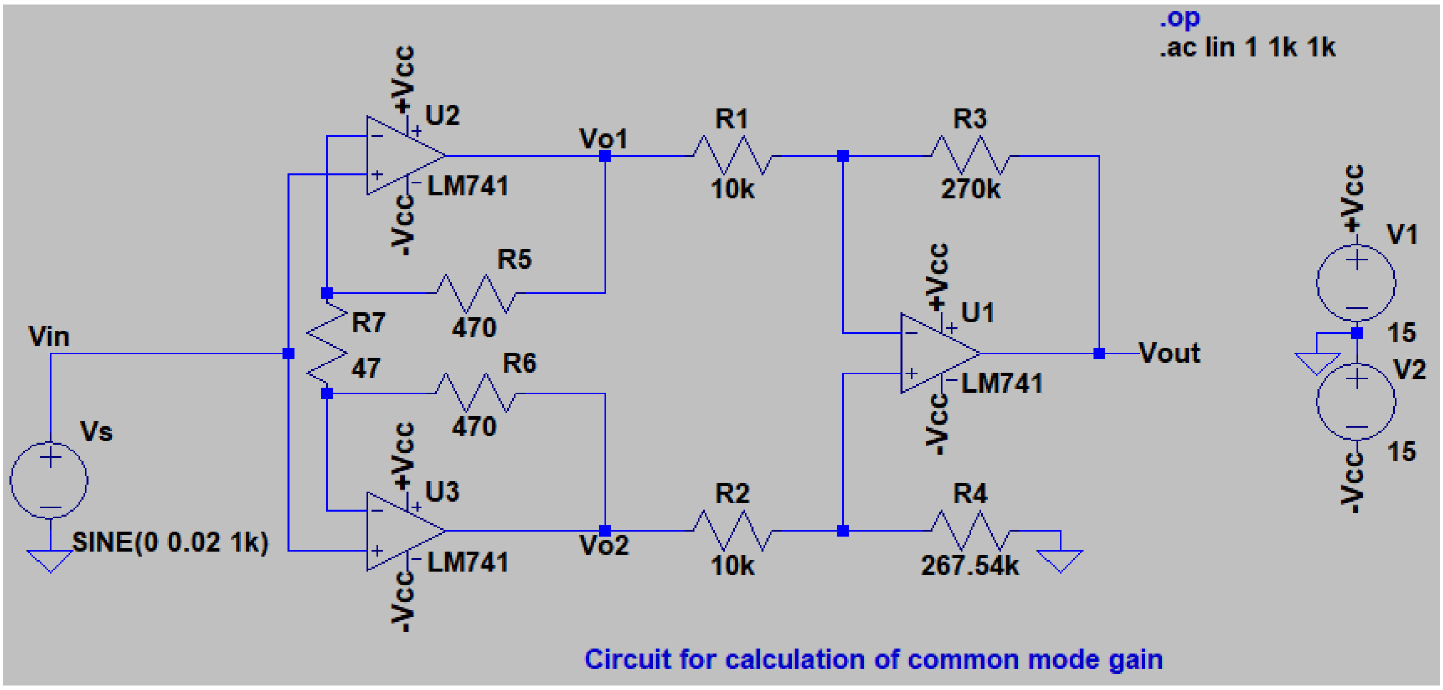
V(-vcc):          -15              voltage
V(+vcc):          15               voltage
V(n002):          4.82044          voltage
V(n003):          4.81929          voltage
V(vout):          -8.98765e-009    voltage
V(n001):          5                voltage
I(R1):            -1.78535e-005    device_current
I(Rf):            -1.80133e-005    device_current
I(R3):            -1.80709e-005    device_current
I(R2):            -1.79557e-005    device_current
I(Vs):            -3.60266e-005    device_current
I(V1):            -0.00169262      device_current
I(V2):            -0.00171063      device_current
```

Results

The value of resistance R_f at DC null point (V_{out} = -9 nV ≈ 0 V) comes out to be approximately **267.54 kΩ**.

Common mode Gain (A_{cm})

Schematic and results from AC analysis



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       --- AC Analysis ---

frequency:     1000            Hz
V(+vcc):       mag:          0 phase:           0°        voltage
V(-vcc):       mag:          0 phase:           0°        voltage
V(n002):       mag:   0.0192806 phase: -0.0446768°        voltage
V(n003):       mag:   0.0192799 phase: -0.0512222°        voltage
V(vout):       mag: 0.000170154 phase:     157.787°       voltage
V(vo1):        mag:   0.0200005 phase: -0.0513552°        voltage
V(vo2):        mag:   0.0200005 phase:  -0.051356°        voltage
V(n001):       mag:   0.0200005 phase: -0.0512658°        voltage
V(vin):        mag:        0.02 phase:          0°        voltage
V(n004):       mag:   0.0200005 phase: -0.0512658°        voltage
I(R7):         mag: 8.91962e-013 phase:       161°        device_current
I(R6):         mag: 6.69902e-011 phase:   -88.5097°       device_current
I(R5):         mag: 6.63867e-011 phase:   -89.9522°       device_current
I(R3):         mag: 7.19936e-008 phase:    179.766°       device_current
I(R4):         mag: 7.20637e-008 phase:    179.949°       device_current
I(R2):         mag: 7.20622e-008 phase:    179.945°       device_current
I(R1):         mag: 7.1995e-008 phase:     179.77°        device_current
I(Vs):         mag: 1.33365e-010 phase:   -89.2621°       device_current
I(V2):         mag: 3.60151e-008 phase:  -0.157312°       device_current
I(V1):         mag: 3.60505e-008 phase:    179.843°       device_current
```

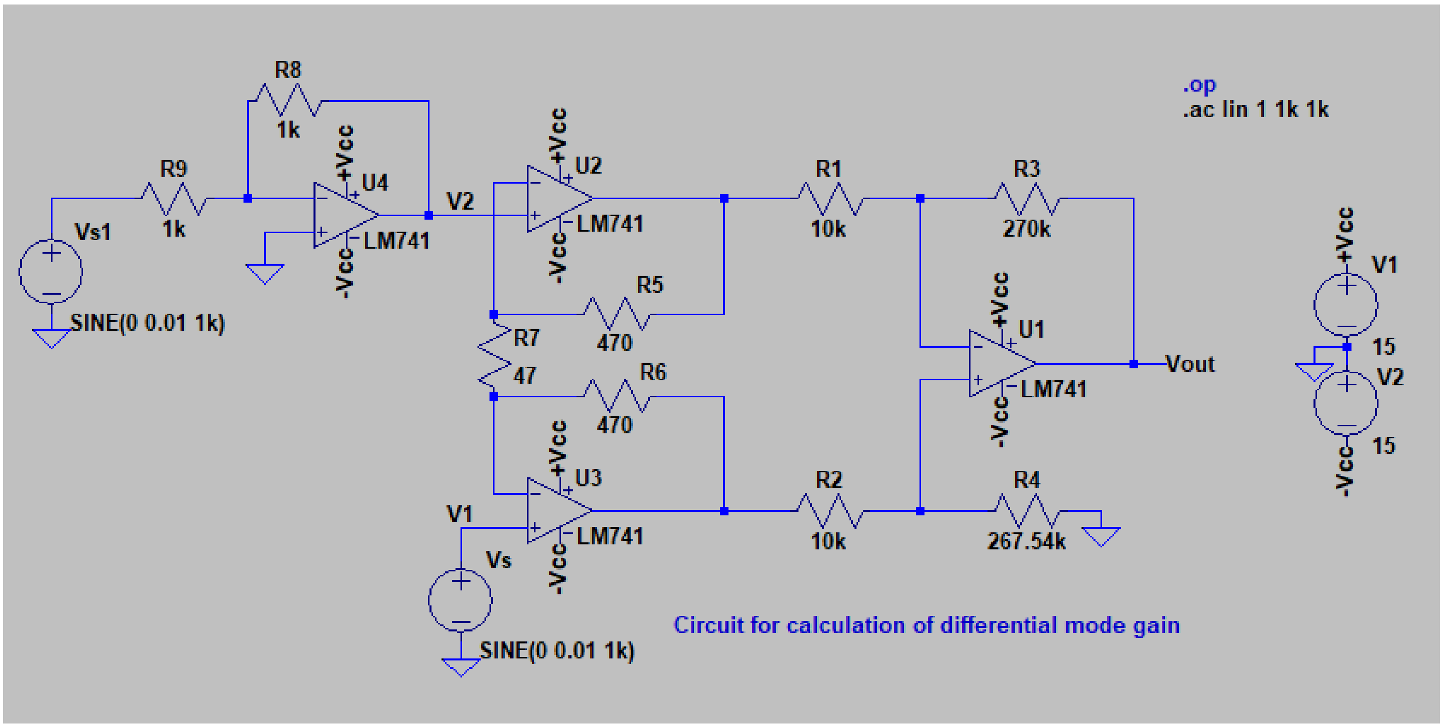
Results

- The value of common mode gain from simulation comes out to be **A_{cm} = V(vout)/V(vin) = 0.000170154/0.02 = 8.5077 mV/V = -41.404 dB**.

- The theoretical value of common mode gain should be **$A_{cm} = -\frac{R_3}{R_1}V_{o1} + \left(1+\frac{R_3}{R_1}\right)\left(\frac{R_4}{R_2+R_4}\right)V_{o2}$**
= -(270k/10k) × 0.0200005 + (1+(270k/10k)) × (267.54k/(10k+267.54k)) × 0.0200005
= -0.5400135 + 0.539836 = -0.0001773 V/V = -75.026 dB.

Differential mode Gain (A_{dm})

Schematic and results from AC analysis



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```
        --- AC Analysis ---

frequency:    1000          Hz
V(+vcc):      mag:         0 phase:          0°        voltage
V(-vcc):      mag:         0 phase:          0°        voltage
V(n005):      mag:  0.202267 phase:   -5.02225°        voltage
V(n006):      mag:  0.202313 phase:   -1.81952°        voltage
V(vout):      mag:   11.3257 phase:   -3.42458°        voltage
V(n004):      mag:  0.209888 phase:    178.282°        voltage
V(n008):      mag:  0.209888 phase:    -1.7101°        voltage
V(n001):      mag: 0.00999483 phase:   178.199°        voltage
V(v2):        mag: 0.00999987 phase:   179.864°        voltage
V(n007):      mag: 0.00999455 phase:  -1.62726°        voltage
V(v1):        mag:      0.01 phase:          0°        voltage
V(n002):      mag:      0.01 phase:          0°        voltage
V(n003):      mag: 1.1816e-005 phase:    89.6166°      voltage
I(R9):        mag: 9.99993e-006 phase:    179.932°     device_current
I(R8):        mag: 9.99993e-006 phase:    179.932°     device_current
I(R7):        mag: 0.000425306 phase:    178.286°      device_current
I(R6):        mag: 0.000425306 phase:   -1.71425°      device_current
I(R5):        mag: 0.000425306 phase:    178.286°      device_current
I(R3):        mag: 4.11982e-005 phase:   -3.39553°     device_current
I(R4):        mag: 7.56197e-007 phase:     178.18°     device_current
I(R2):        mag: 7.58551e-007 phase:   -178.791°     device_current
I(R1):        mag: 4.11984e-005 phase:   -3.33976°     device_current
I(Vs1):       mag: 9.99993e-006 phase:    179.932°     device_current
I(Vs):        mag: 1.00805e-009 phase:    -91.939°     device_current
I(V2):        mag: 0.00011908 phase:    -1.8693°       device_current
I(V1):        mag: 0.000128319 phase:   -1.72878°      device_current
```

Results

- The value of differential mode gain from simulation comes out to be $\mathbf{A_{dm} = V(vout)/(V(v1) - V(v2)) = 11.3257/0.02 = 566.285\ V/V = 55.061\ dB.}$

- The theoretical value of differential mode gain should be $\mathbf{A_{dm}} = \left(1 + \frac{2R_5}{R_7}\right) \cdot \frac{R_3}{R_1}$ $\mathbf{= 567\ V/V = 55.07\ dB.}$

Calculation of CMRR

The simulated value of common mode rejection ratio (CMRR) is

$$\mathbf{CMRR = \frac{\mathit{Adm}}{\mathit{Acm}} = \frac{566.285}{0.0085077} = 66561.468 = 96.4645\ dB}$$

The theoretical value of CMRR is

$$\mathbf{CMRR = \frac{\mathit{Adm}}{\mathit{Acm}} = \frac{567}{0.0001773} = 3.2 \times 10^6 = 130.0975\ dB}$$

Hence, practical circuits like the instrumentation amplifier using LM 741 do not have ideal infinite CMRR, but are limited to some finite large value due to mismatch. The theoretical value of CMRR is much higher than simulated value as per calculations.