MANIPAL UNIVERSITY JAIPUR
(University under Section 2(f) of the UGC Act)

B.TECH FIRST YEAR

ACADEMIC YEAR: 2023-2024

COURSE NAME: EES

COURSE CODE : EE 1002

LECTURE SERIES NO :

CREDITS : 4

MODE OF DELIVERY : (POWER POINT PRESENTATION)

FACULTY

EMAIL-ID

PROPOSED DATE OF DELIVERY:

MANIPAL UNIVERSITY JAIPUR

VISION

Global Leadership in Higher Education and Human Development

MISSION

- Be the most preferred University for innovative and interdisciplinary learning
- Foster academic, research and professional excellence in all domains
- Transform young minds into competent professionals with good human values

VALUES

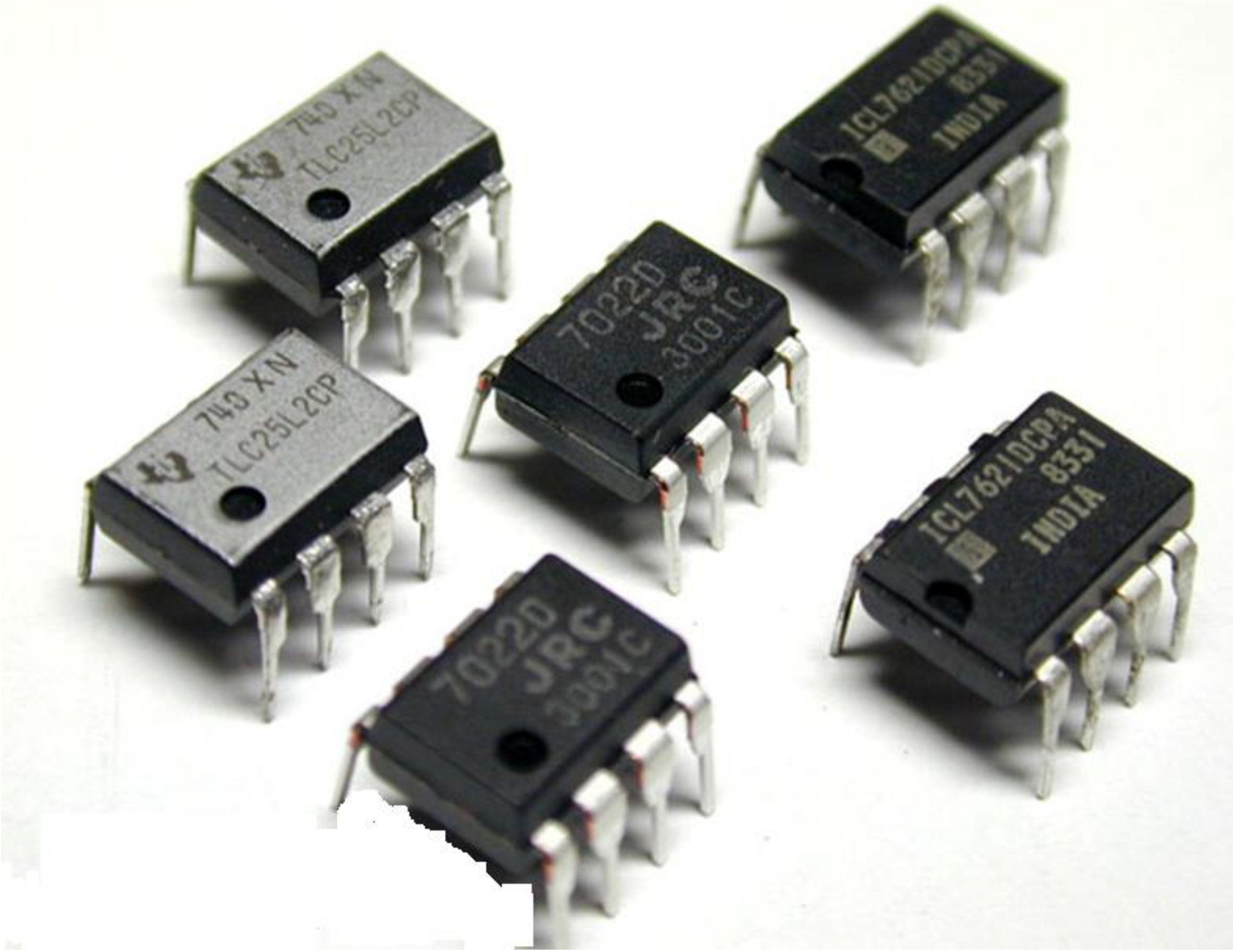
Integrity, Transparency, Quality,
Team Work, Execution with Passion, Humane Touch

OPERATIONAL AMPLIFIER (OP-AMP)

<u>Refernce Book:</u>

- 1. OPAMPS and Linear Integrated Circuits

  by Ramakanth Gayakwad



CONTENTS

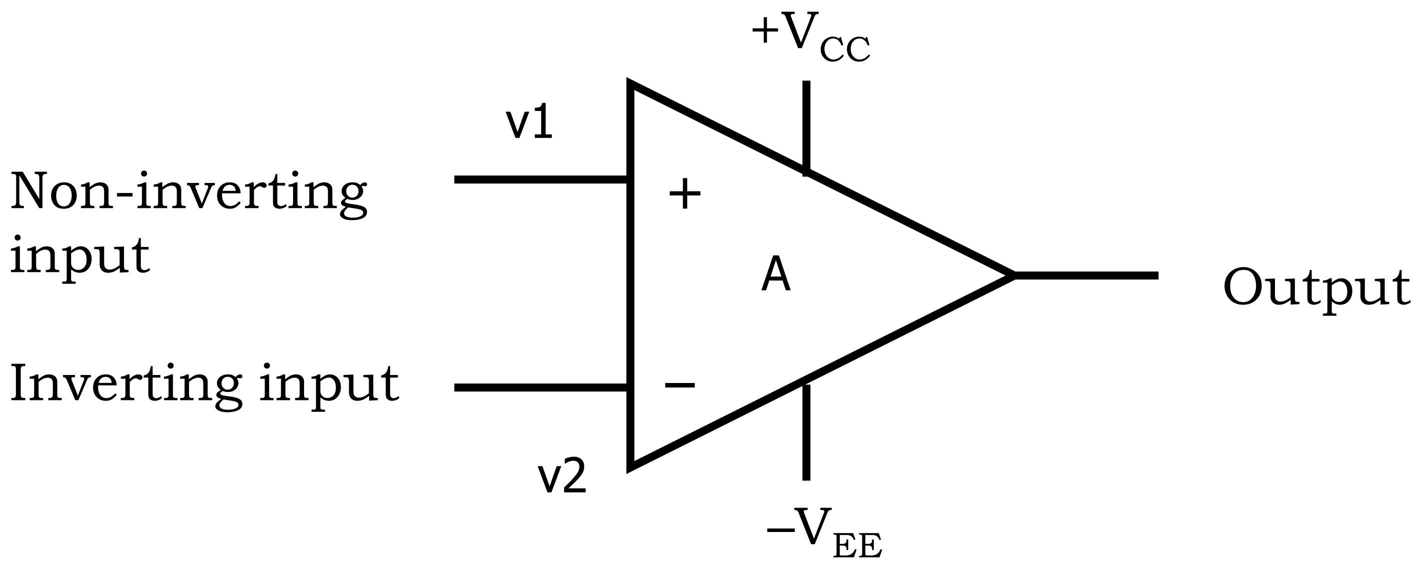
INTRODUCTION

- Operational Amplifier (OPAMP) is a direct coupled high-gain amplifier fabricated on Integrated Circuit (IC)
- Op-amps are linear devices that are ideal for DC and AC amplification and are used often in signal conditioning, filtering .
- Earlier, op-amp were used primarily to perform mathematical operation such as summation, subtraction, differentiation and integration etc. so named as op-amp.
- Typical application of op-amp includes –
  1. Audio amplifier-voltage amplitude change
  2. Signal generators- oscillators,
  3. Signal filter circuits
  4. Instrumentation circuits---Biomedical Instrumentation

INTRODUCTION

- Advantages of OP-AMP over transistor amplifier
  - Less power consumption
  - Costs less
  - More compact, fabricated in a single chip.
  - More reliable
  - Higher gain can be obtained
  - Easy design

OPAMP TERMINALS



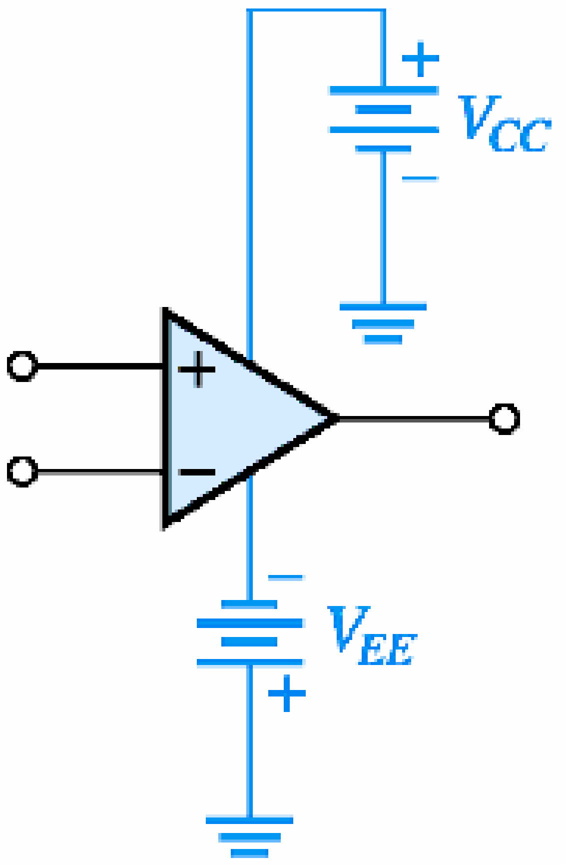
Here, A= Large signal voltage gain

OP-AMP TERMINALS

- If input is applied to non-inverting input terminal, then output will be in-phase with input
- If input is applied to inverting input terminal, then output will be 180 degrees out of phase with input
- If inputs are applied to both terminals, then output will be proportional to difference between the two inputs

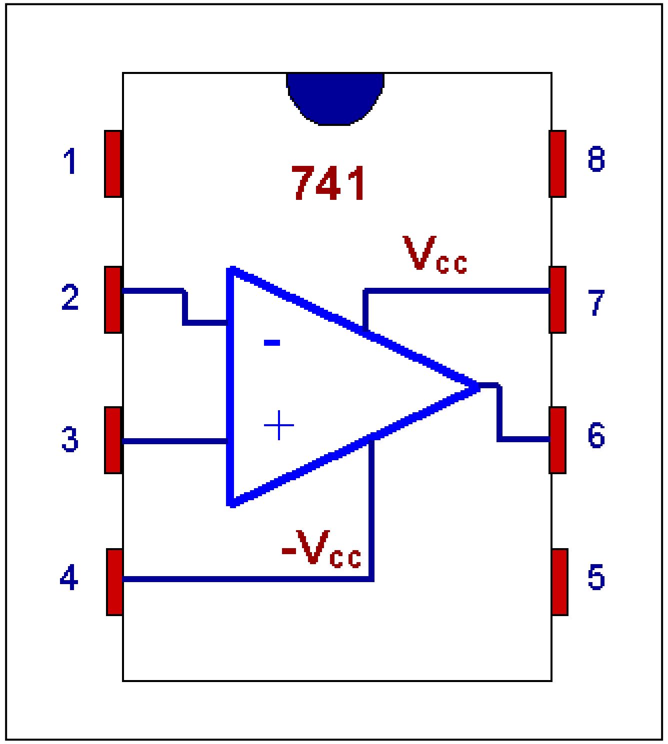
OPAMP TERMINALS

- Two DC power supplies (dual) are required
- Magnitudes of both may be same
- The other terminal of both power supplies are connected to common ground
- All input and output voltages are measured with reference to the common ground



OPAMP TERMINALS

Integrated Circuit



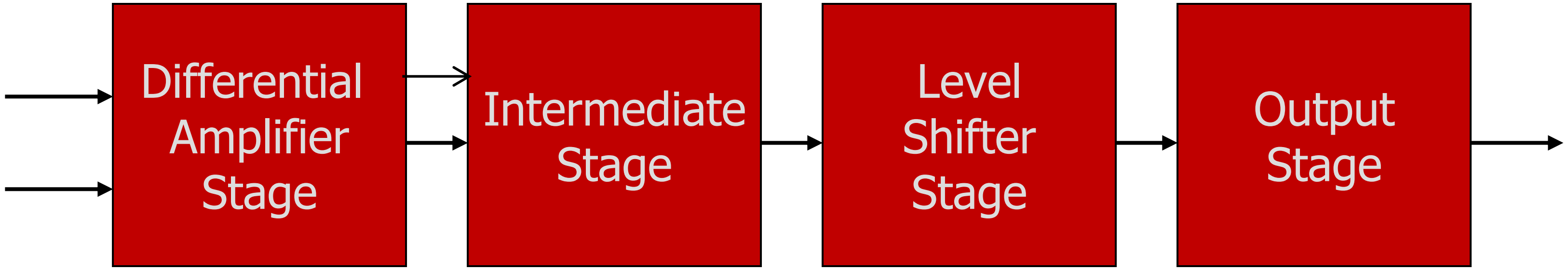
Pin Diagram

- Pin 1 & 5 Offset null
- Pin 2 & 3 input
- Pin 4 & 7 VCC

Pin 6 Output

Pin 8 Not connected

INTERNAL BLOCK DIAGRAM



Dual input,
Balanced output
Differential amplifier

Dual input
unbalanced output
Differential amplifier

Such as
emitter follower
Using constant
current source

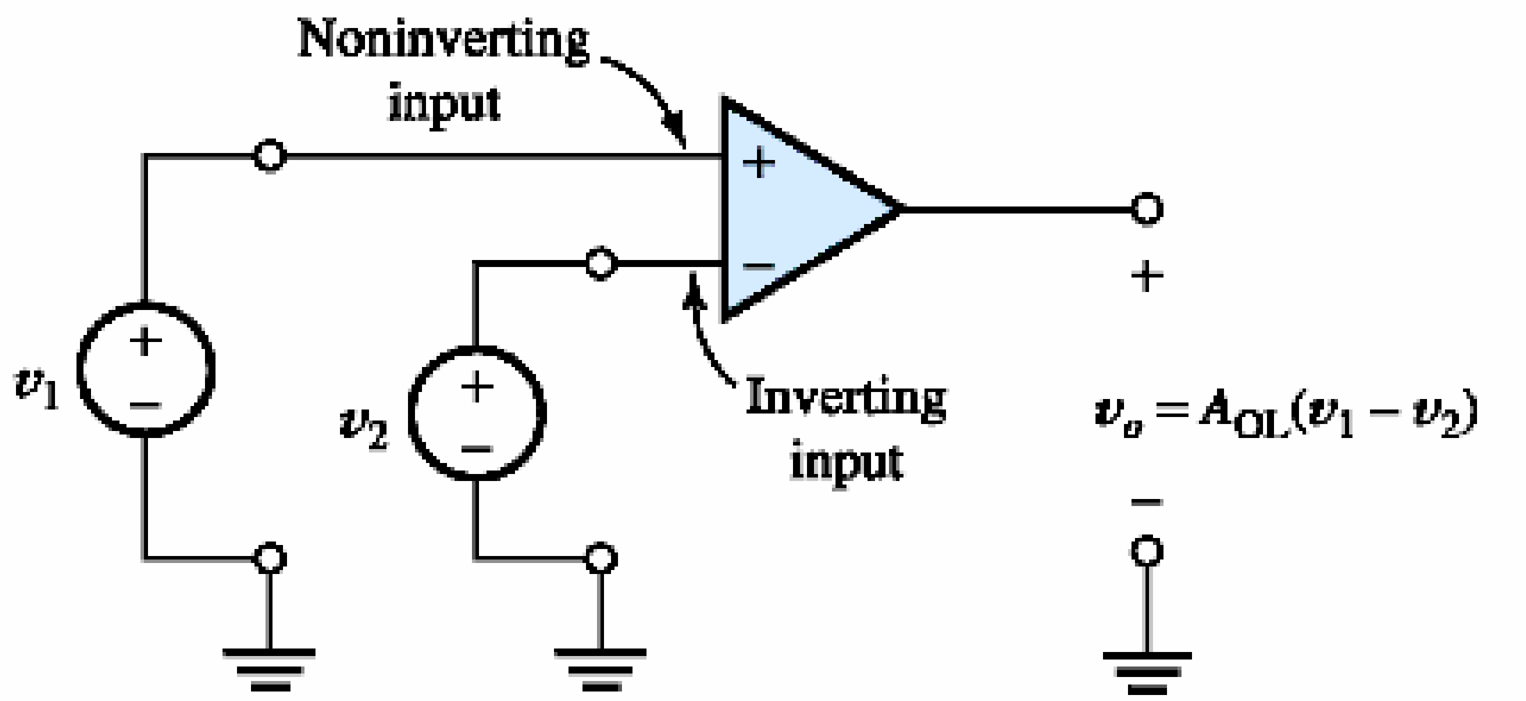
Complementary
symmetry
push-pull amplifier

INTERNAL BLOCK DIAGRAM

Four stages can be identified –

- Input stage or differential amplifier stage can amplify difference between two input signals; Input resistance is very high; Draws zero current from the input sources
- Intermediate stage (or stages) use direct coupling; provide very high gain
- Level shifter stage shifts the dc level of output voltage to zero (can be adjusted manually using two additional terminals)
- Output stage is a power amplifier stage; has very small output resistance; so output voltage is the same, no matter what is the value of load resistance connected to the output terminal

OPEN-LOOP CONFIGURATION



If $v_1 = 0$, then $v_o = -A_{OL}v_2$ Inverting amplifier

If $v_2 = 0$, then $v_o = A_{OL}v_1$ Non- inverting amp

OPEN-LOOP CONFIGURATION

- A_{OL} is the open-loop voltage gain of OPAMP

  Its value is very high

  Typical value is 0.5 million
- So, even if input is in micro volts, output will be in volts
- But output voltage cannot cross the value of power supply V_{CC}
- So, if input is in milli volts, output reaches saturation value $V_{sat} = V_{CC}$ (or V_{EE})

OPEN-LOOP CONFIGURATION

- If $v_1 = v_2$, then ideally output should be zero
- But in practical Op-Amp, output is

$$v_o = A_{cm}\left(\frac{v_1 + v_2}{2}\right)$$

Where, A_{CM} is the common-mode gain of Op-Amp

- So, final gain equation is:

$$v_o = A_d(v_1 - v_2) + A_{cm}\left(\frac{v_1 + v_2}{2}\right)$$

$$v_o = A_d v_{id} + A_{cm} v_{icm}$$

OPEN-LOOP CONFIGURATION

- Common-mode rejection ratio
  - It is a measure of the ability of Op-Amp to reject the signals common to both input terminals (noise)
  - Defined as

$$CMRR = \frac{A_d}{A_{cm}}$$

$$(CMRR)_{dB} = 20\ log_{10}\left(\frac{A_d}{A_{cm}}\right)$$

PROBLEMS

- An OPAMP has differential voltage gain of 100,000 and CMRR of 60 dB. If non inverting input voltage is 150 µV and inverting input voltage is 140 µV, calculate the output voltage of OPAMP

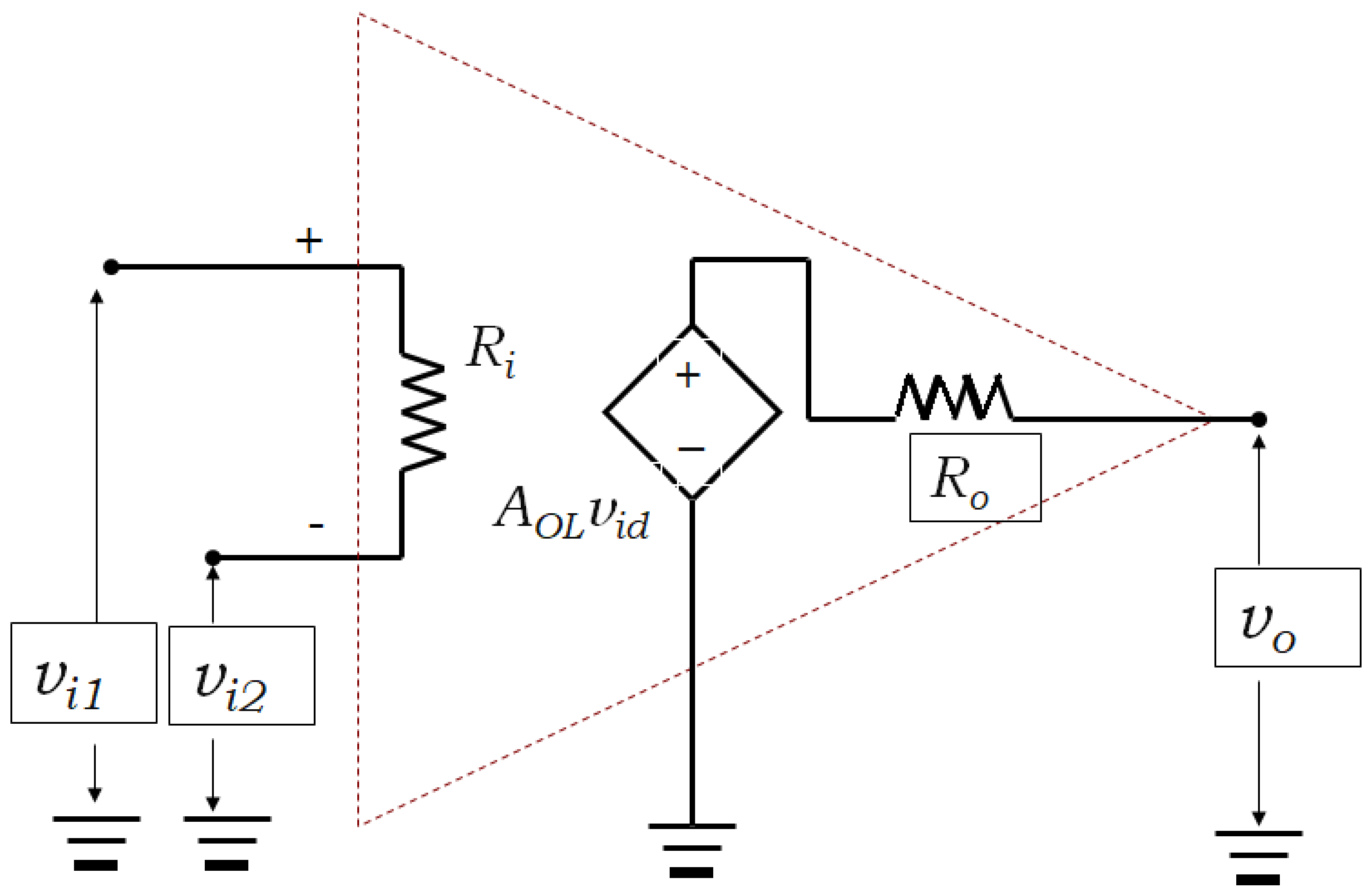
  Ans: 1.01 V

- For an OPAMP, when v1 is 0.5 mV and v2 is –0.5 mV, output voltage is 8 V. For the same OPAMP, when v1 = v2 = 1 mV, output voltage is 12 mV. Calculate the CMRR of the OPAMP

  Ans: 56.48 dB

OPAMP equivalent circuit

Practical OPAMP



OPAMP CHARACTERISTICS

- Differential mode gain A_d
  - It is the factor by which the difference between the two input signals is amplified by the OPAMP

- Common mode gain A_{cm}
  - It is the factor by which the common mode input voltage is amplified by the OPAMP

- Common mode rejection ratio $CMRR$
  - Is the ratio of A_d to A_{cm} expressed in decibels

OPAMP CHARACTERISTICS

- Input resistance R_i
  - It is the equivalent resistance measured between the two input terminals of OPAMP
- Output resistance R_o
  - It is equivalent resistance measured between output terminal and ground
- Bandwidth
  - It is the range of frequency over which the gain of OPAMP is almost constant

OPAMP CHARACTERISTICS

- Output offset voltage V_{oo}
  - It is the output voltage when both input voltages are zero
  - Denoted as V_{oo}
- Input offset voltage V_{io}
  - It is the differential input voltage that must be applied at the input terminals in order to make output voltage equal to zero
  - $V_{io} = |v_{dc1} - v_{dc2}| \quad \text{for } v_o = 0$

OPAMP CHARACTERISTICS

- Input offset current I_{io}
  - It is the difference between the currents in the input terminals when both input voltages are zero
  - $I_{io} = | I_1 - I_2 | \quad$ when $v_1 = v_2 = 0$

- Input bias current I_{ib}
  - It is the average of the currents in the input terminals when both input voltages are zero
  - $I_{ib} = (I_1 + I_2) / 2 \quad$ when $v_1 = v_2 = 0$

OPAMP CHARACTERISTICS

- Slew rate *SR*
  - It is the maximum rate of change of output voltage with respect to time
  - Slew rate has to be very high if OPAMP has to operate efficiently at high frequencies

- Supply voltage rejection ratio *SVRR*
  - It is the maximum rate at which input offset voltage of OPAMP changes with change in supply voltage

OPAMP CHARACTERISTICS

- Practical characteristics of 741C OPAMP
  - Differential mode gain is 200,000
  - CMRR is 90 dB
  - Input resistance is 2 MΩ
  - Output resistance is 75 Ω
  - Unity-gain Bandwidth is 1 MHz
  - Slew rate is 0.5 V / μs
  - Output offset voltage is 1 mV
  - Input offset current is 20 nA
  - Input bias current is 80 nA

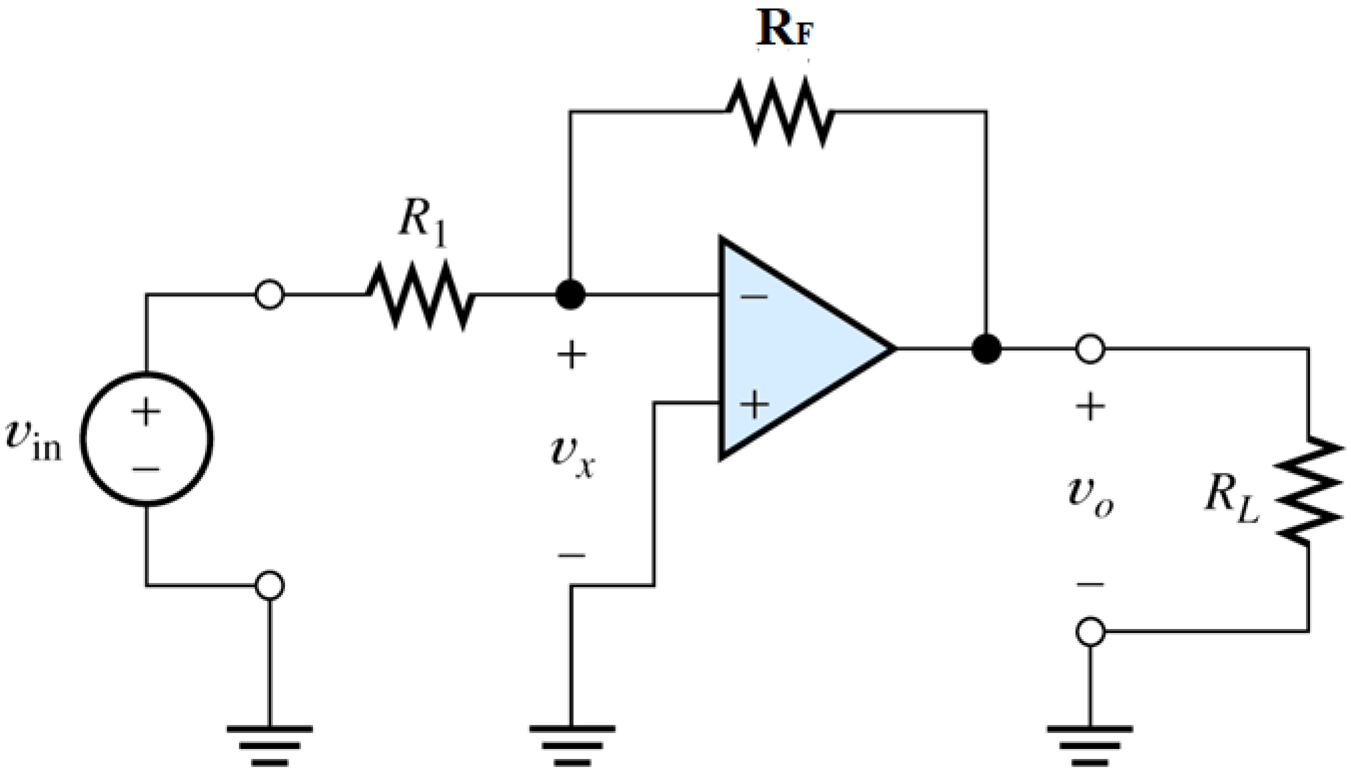
- Ideal OPAMP
  - Infinite differential mode gain
  - Zero common mode gain
  - Infinite CMRR
  - Infinite input resistance
  - Zero output resistance
  - Infinite bandwidth
  - Infinite slew rate
  - Zero input offset voltage
  - Zero input offset current
  - Zero output offset voltage

OPERATIONAL AMPLIFIER (OP-AMP)

CLOSED-LOOP CONFIGURATIONS

- Open-loop voltage gain of OPAMP is very high; such high gain is not required in most applications
- In order to reduce gain, a part of output signal is fed back to the inverting input terminal (called negative feedback)
- Many other OPAMP characteristics are improvised with this

INVERTING AMPLIFIER

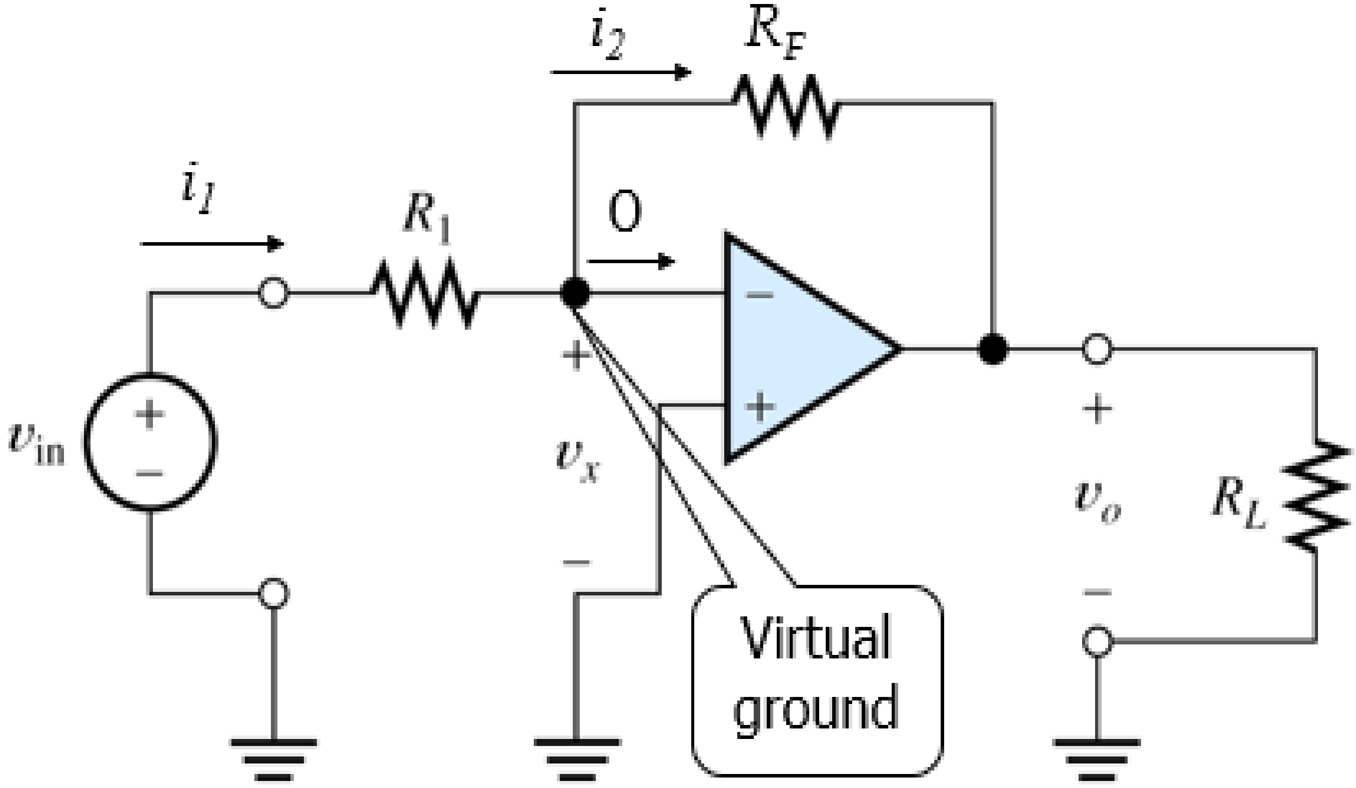


INVERTING AMPLIFIER

- Input is applied to inverting terminal
- Non-inverting is grounded
- Feedback is given to inverting terminal through resistor R_F
- Assuming v_o is less than V_{CC}

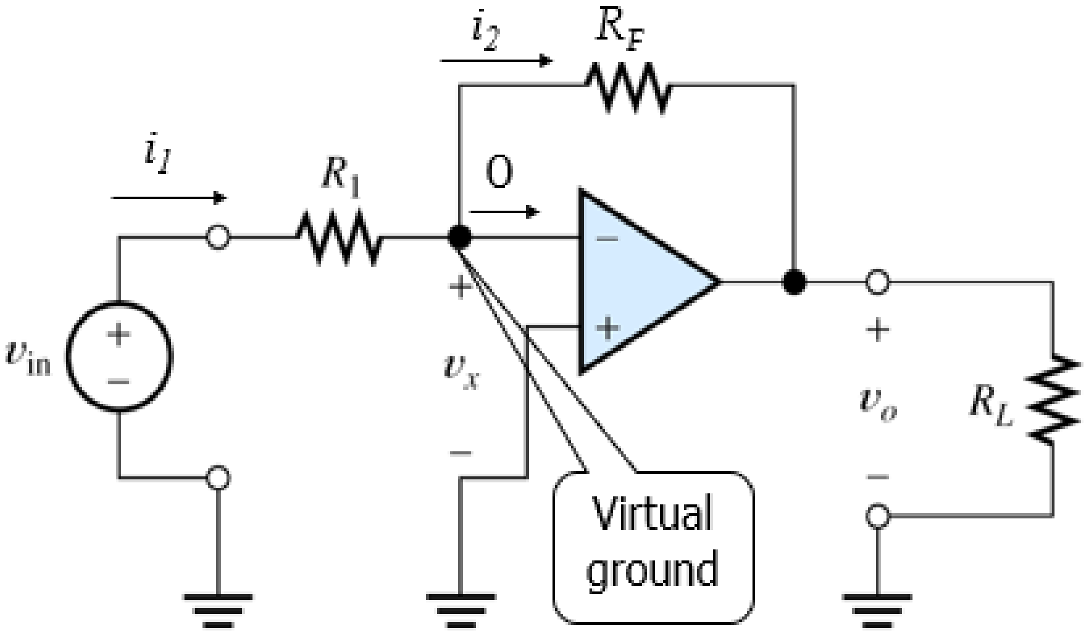
  since A_d is very high, v_{id} should be very small; v_{id} taken as almost zero
- Current entering OPAMP input terminal is almost zero

INVERTING AMPLIFIER



INVERTING AMPLIFIER

$$i_1 = \frac{v_{in} - 0}{R_1} = \frac{v_{in}}{R_1}$$



$$i_2 = \frac{0 - v_o}{R_F} = \frac{-v_o}{R_F}$$

$$i_1 = i_2$$

$$\frac{v_{in}}{R_1} = \frac{-v_o}{R_F}$$

$$v_o = -v_{in}\frac{R_F}{R_1}$$

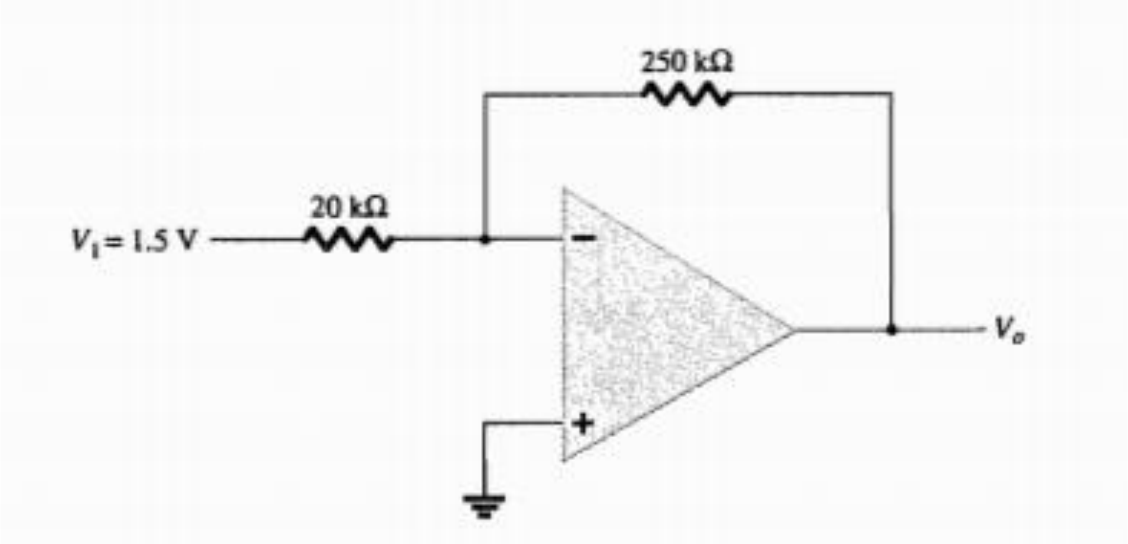
$$A_V = \frac{v_o}{v_{in}} = -\frac{R_F}{R_1}$$

PROBLEMS

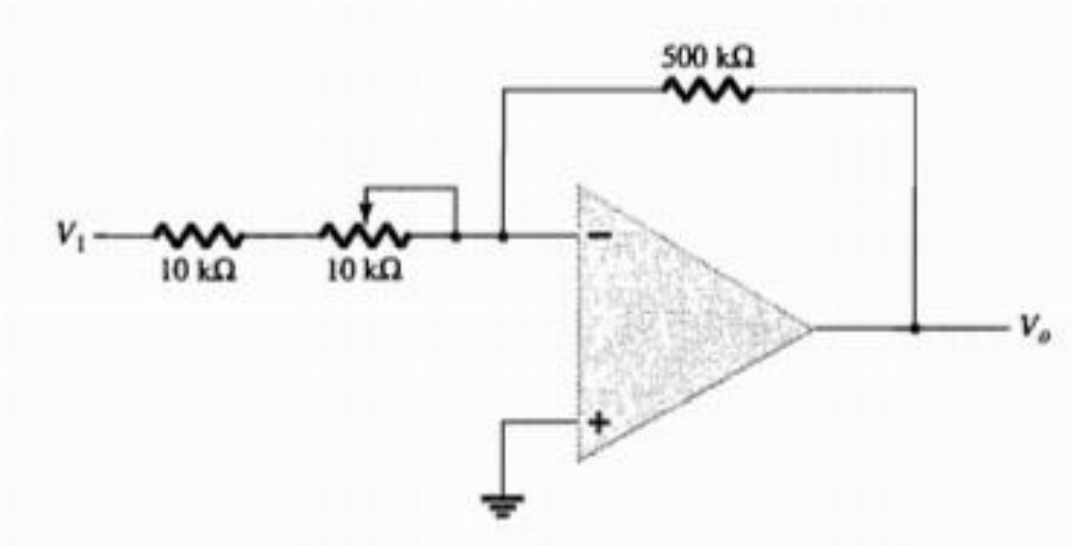
1. For an inverting amplifier using OPAMP, R_1=1K, R_F=100K, $v_{in}=0.1\sin(\omega t)$. Find v_o.
2. For an inverting amplifier, R_1=10K, R_F=100K. Calculate v_o if v_i = 25 mV dc.
3. An ac signal of rms value 2 mV needs to be amplified to 1.024 V rms, 180 degree phase shifted. Design a suitable amplifier choosing R_1=1.2K
4. Design an amplifier to get an output amplified by 25 times of the input signal .

EXAMPLE 5

Find the output voltage Vo for the following circuit, where Vin is the input voltage .

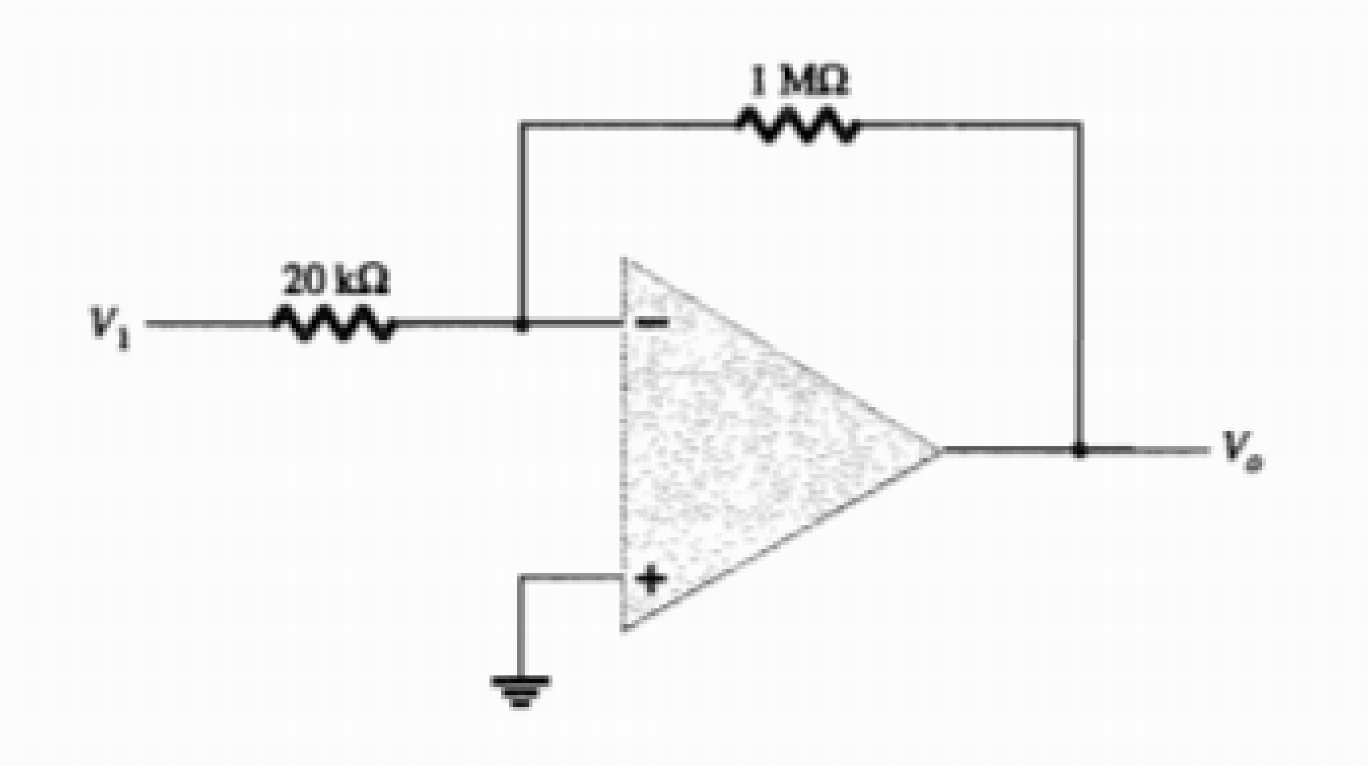


Find the range of output voltage gain adjustment for the following circuit, where Vi is the input voltage .



EXAMPLE 6

What input voltage will result if an output voltage Vo =2V for the following circuit, where Vi is the input voltage .



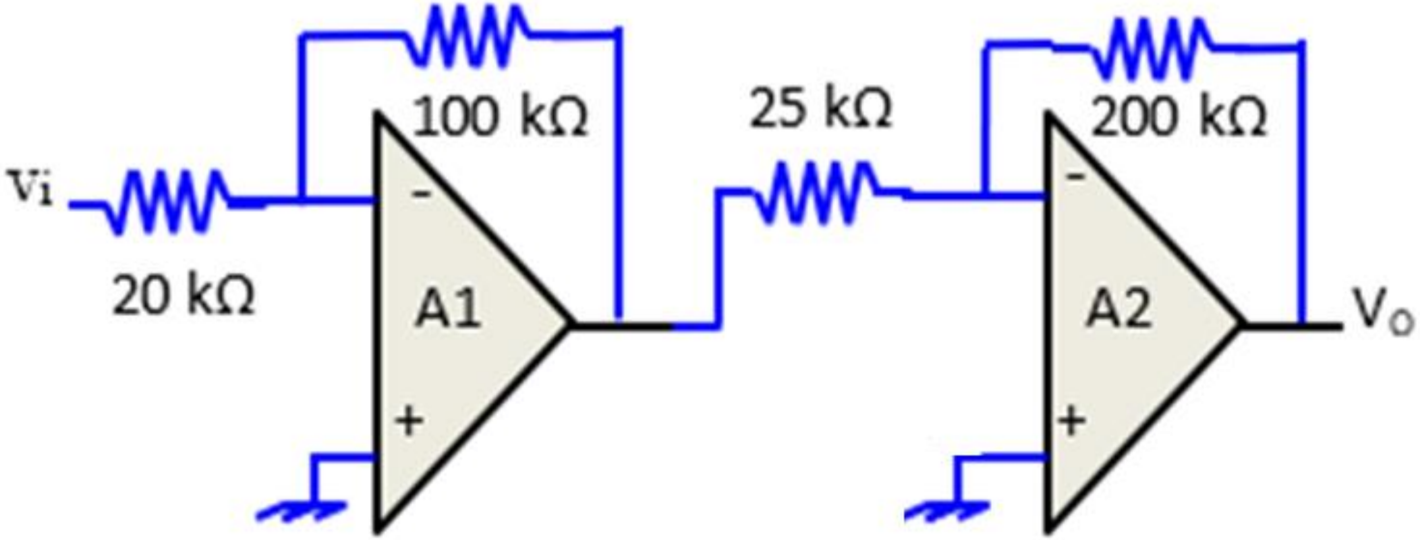
EXAMPLE 7:

Calculate the output voltage Vo for the following circuit, where Vi is the input voltage

Solution :

The output of Op-Amp A1 is (say)

$$v_{o1} = -\frac{100}{20} v_i = -5v_i$$

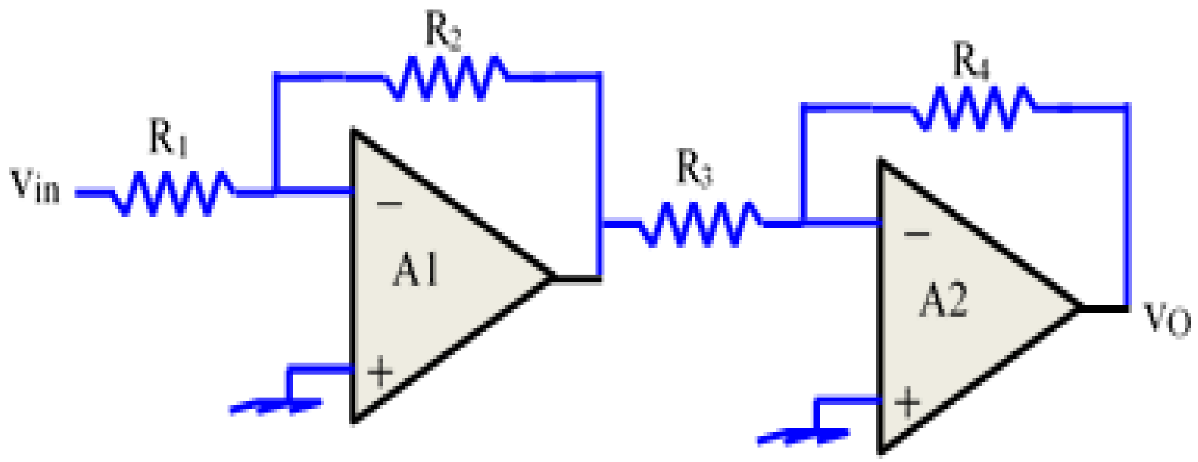


The output of Op-Amp A2 is

$$= -\frac{200}{25} v_{o1}$$
$$= -8(-5v_i)$$
$$= 40v_i)$$

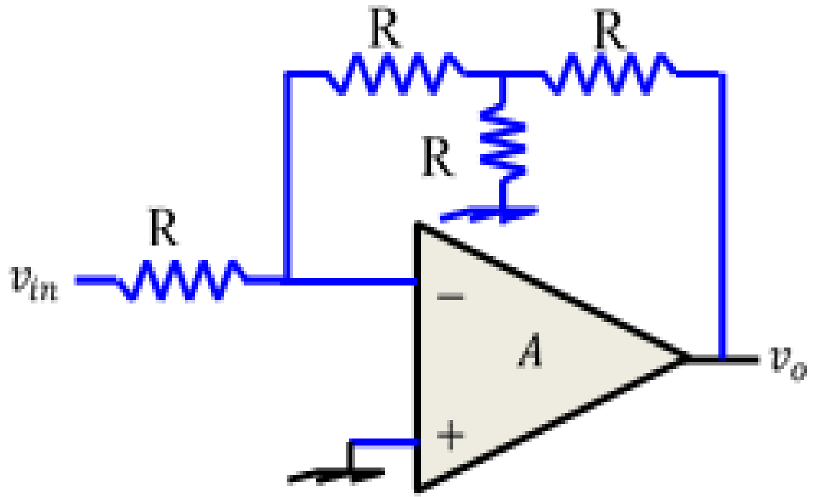
EXAMPLE 8

Find an expression for the output voltage Vo for the following circuit, where Vin is the input voltage .



EXAMPLE 9

Find the expression for output voltage V_o of the following circuit.



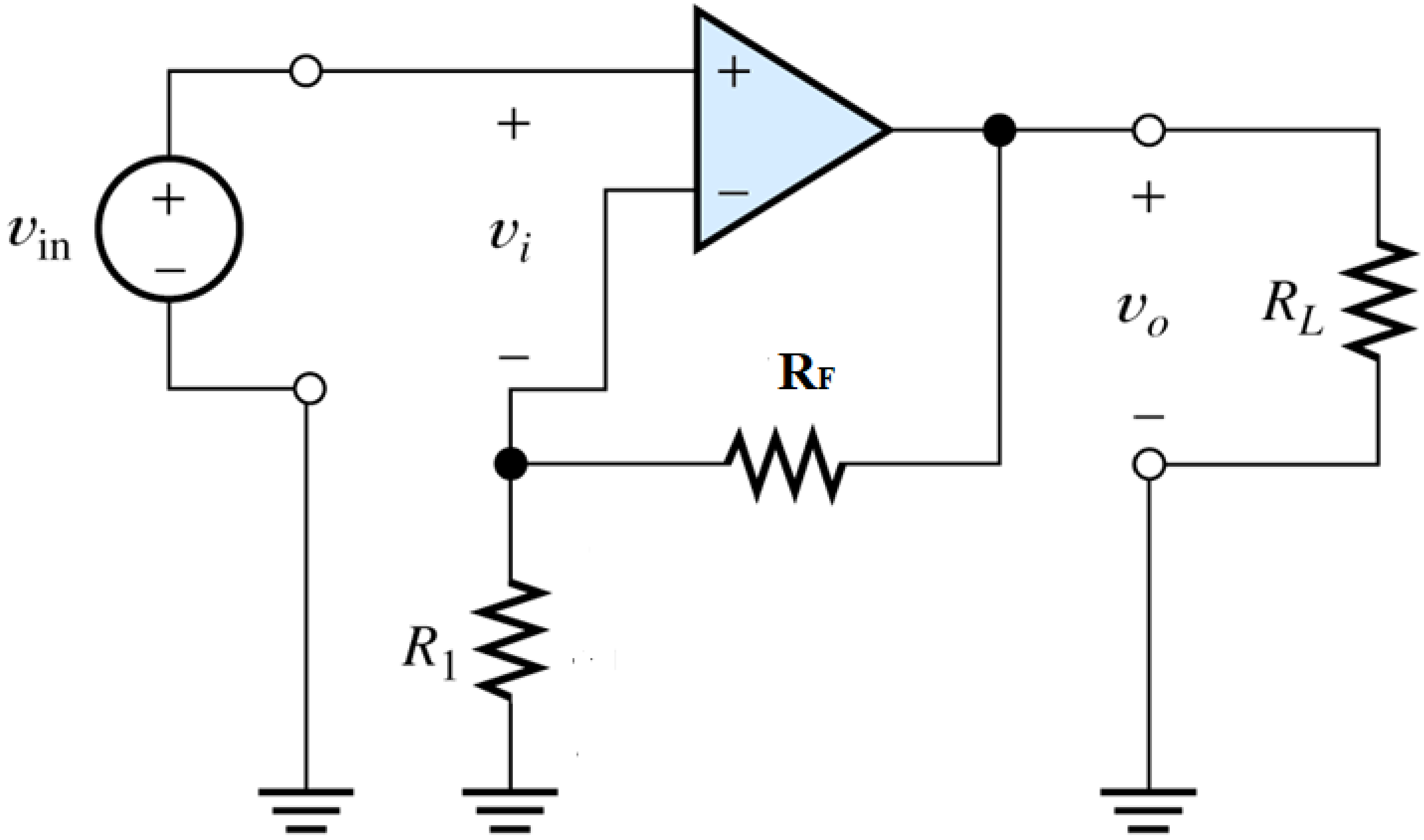
Soln.

Apply KCL.

Thank you

OPERATIONAL AMPLIFIER (OP-AMP)

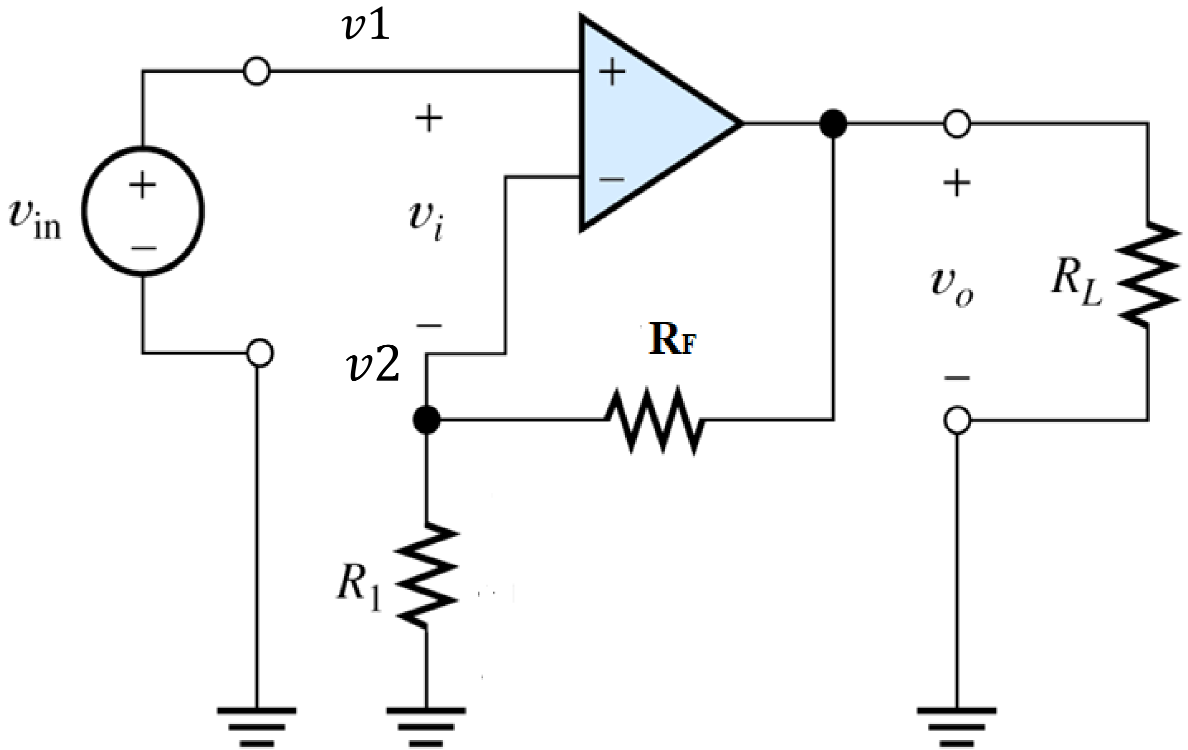
NON-INVERTING AMPLIFIER



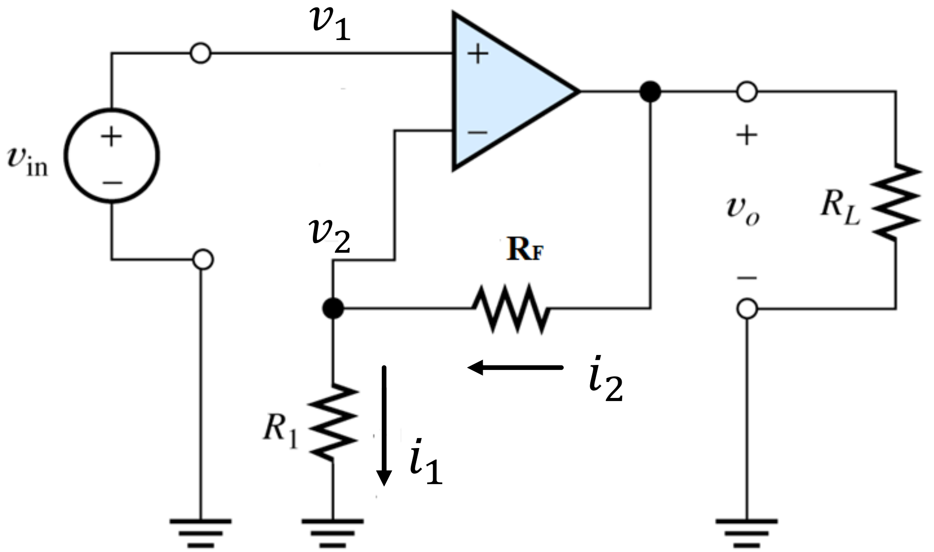
NON-INVERTING AMPLIFIER

- Input is applied to non-inverting terminal
- Feedback is given to inverting terminal
- Output voltage will be in-phase with input voltage
- Here again, the following assumptions are made
  - Since A_d is very high, v_{id} should be very small; v_{id} taken as almost zero
  - Current entering OPAMP input terminal is almost zero

NON-INVERTING AMPLIFIER



NON-INVERTING AMPLIFIER



$$v_{id} = 0 \qquad v_1 = v_2 = v_{in}$$

$$i_1 = \frac{v_2}{R_1} = \frac{v_{in}}{R_1} \qquad i_2 = \frac{v_o - v_2}{R_F} = \frac{v_o - v_{in}}{R_F}$$

$$i_1 = i_2$$

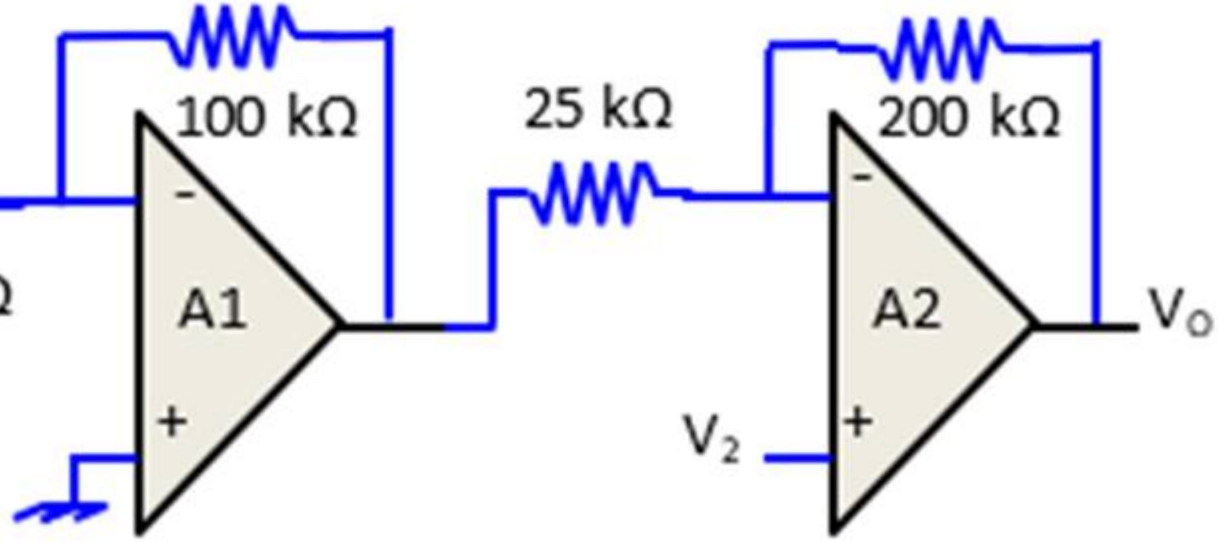
$$\frac{v_{in}}{R_1} = \frac{v_o - v_{in}}{R_F} \qquad v_o = v_{in}\left(1 + \frac{R_F}{R_1}\right)$$

PROBLEMS

1. For an non-inverting amplifier using OPAMP, R_1=1K, R_F=100K, v_{in}=0.1sin(ωt). Find v_o.
2. For a non-inverting amplifier, R_1=10K, R_F=100K. Calculate v_o if v_i = 25 mV dc.
3. An ac signal of rms value 2 mV needs to be amplified to 1.2 V rms, and output must be in same phase as input. Design a suitable amplifier choosing R_1=2K

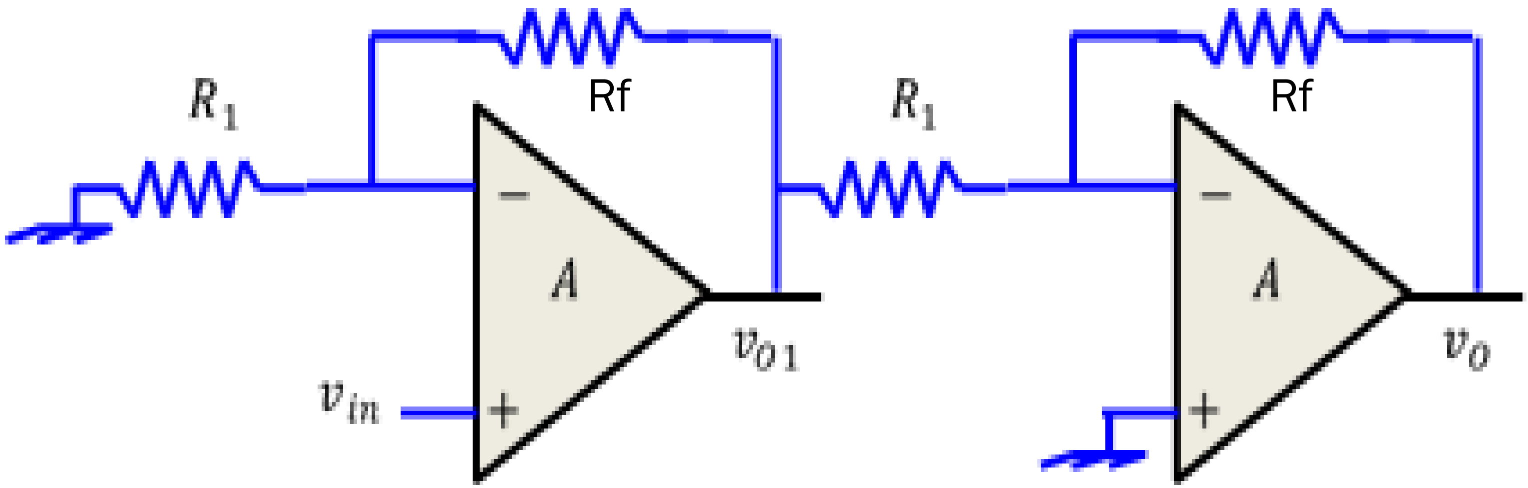
EXAMPLE 4

Fin the output voltage V0 for the following circuit if v1= 2V =V2.



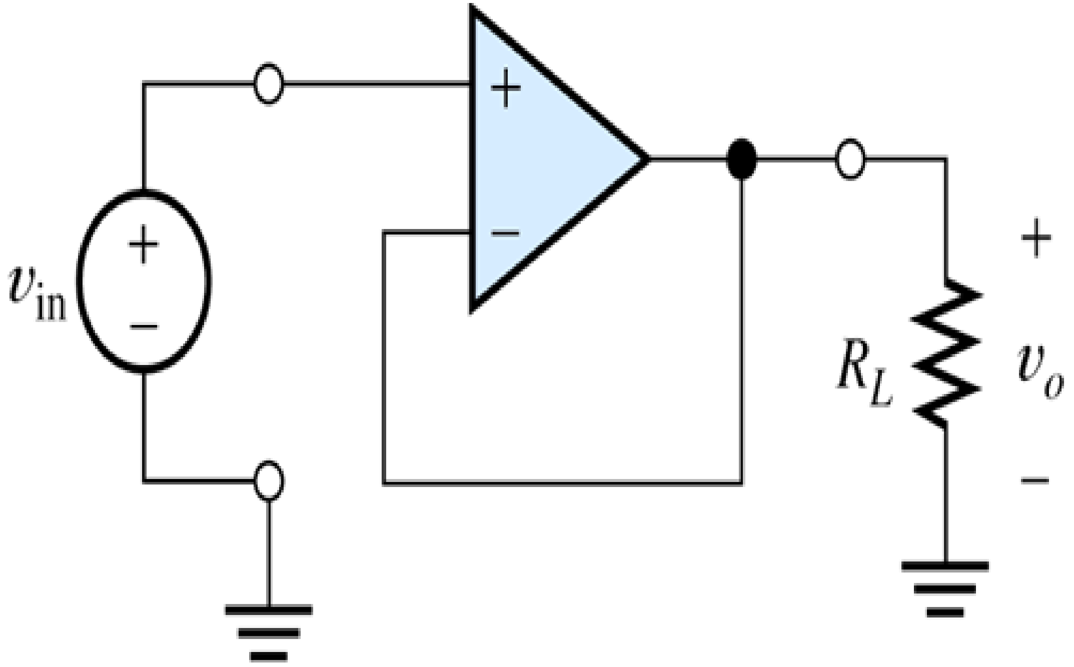
EXAMPLE 5

Fin the output voltage V0 for the following circuit if Vin= 2V , R1=2k and Rf= 10k.



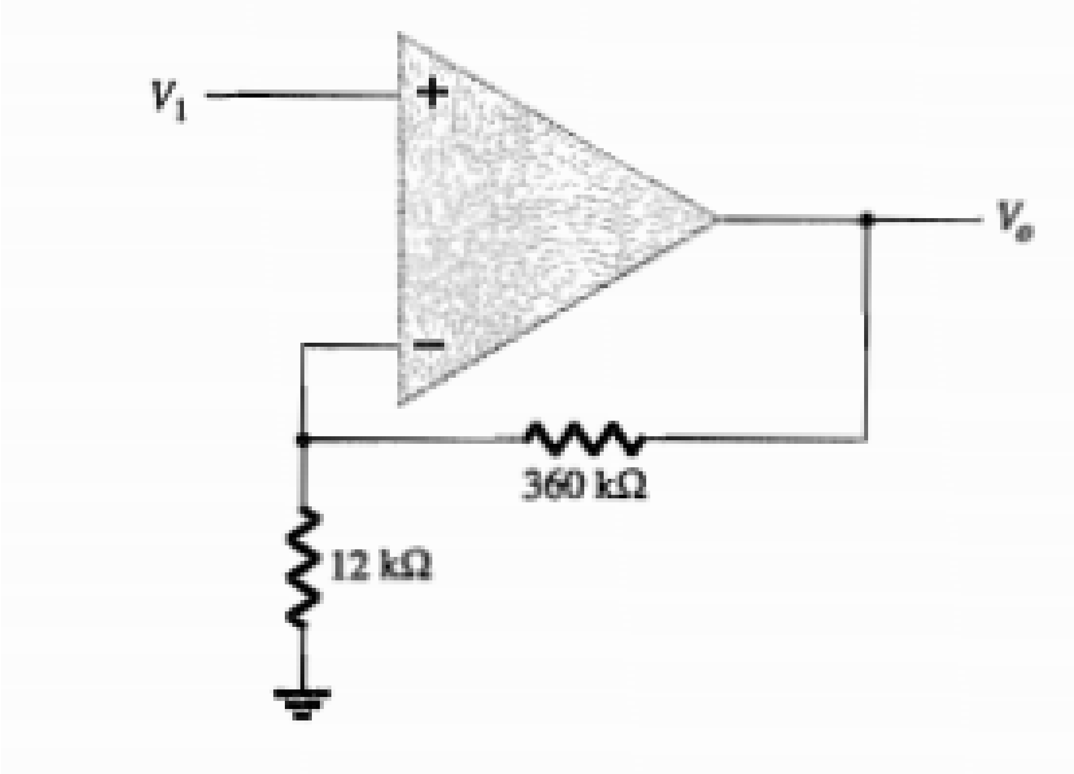
VOLTAGE FOLLOWER

- Special case of non- inverting amplifier where $R_F=0$
- Voltage gain is unity. $v_o = v_{in}$
- Has very high input resistance and very low output resistance; Used as buffer for impedance matching



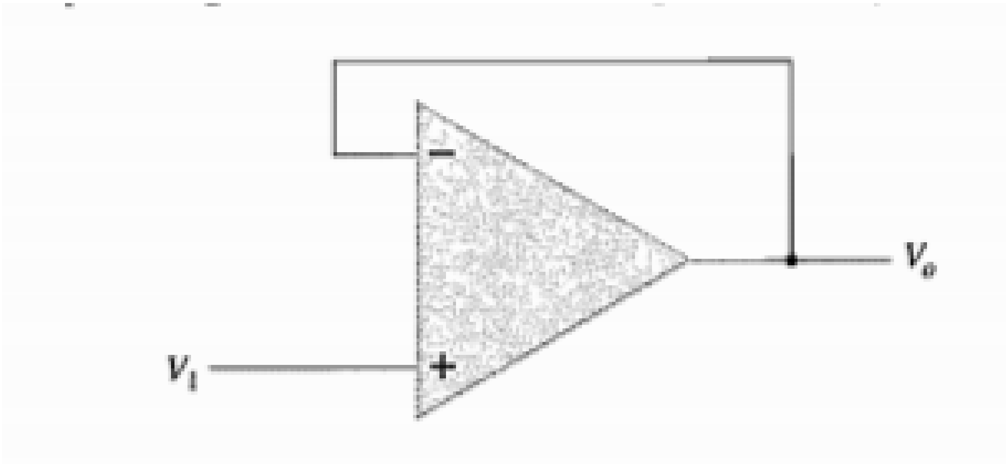
EXAMPLE 6

Fin the output voltage V0 for the following circuit if v1= 2V =V2.

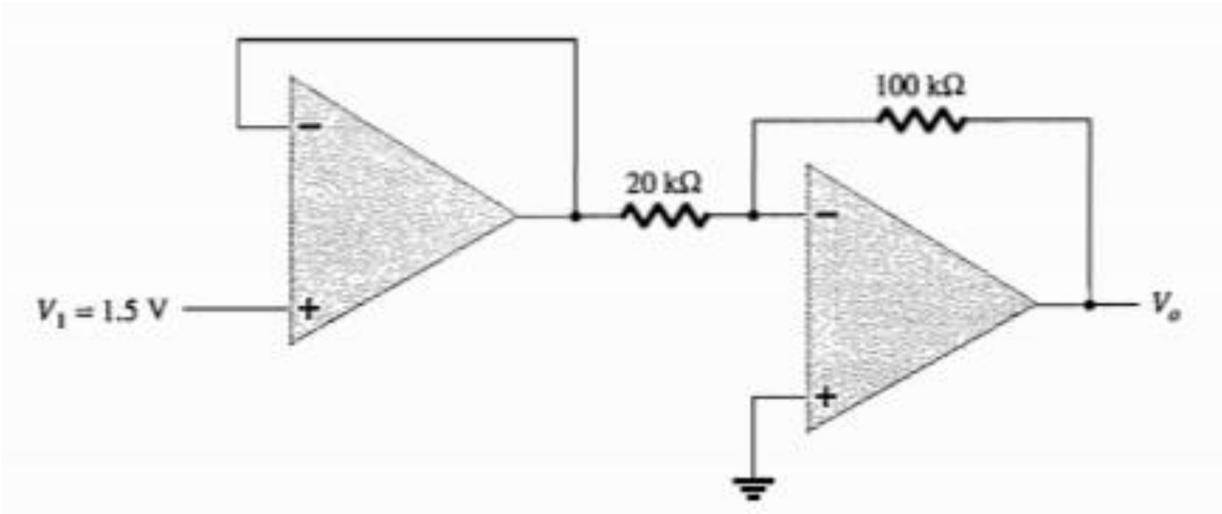


EXAMPLE 7

Fin the output voltage V0 for the following circuit if v1= 2.V.

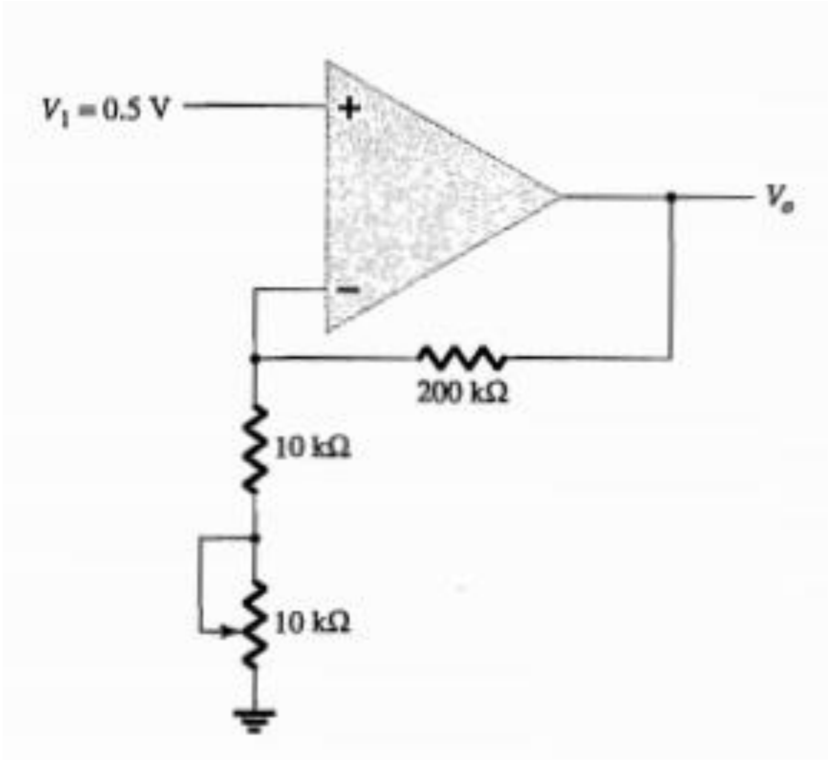


Fin the output voltage V0 for the following circuit.



EXAMPLE 8

Calculate the range of output voltage for the circuit.



Thank You