ME 3109: Measurement & Instrumentation

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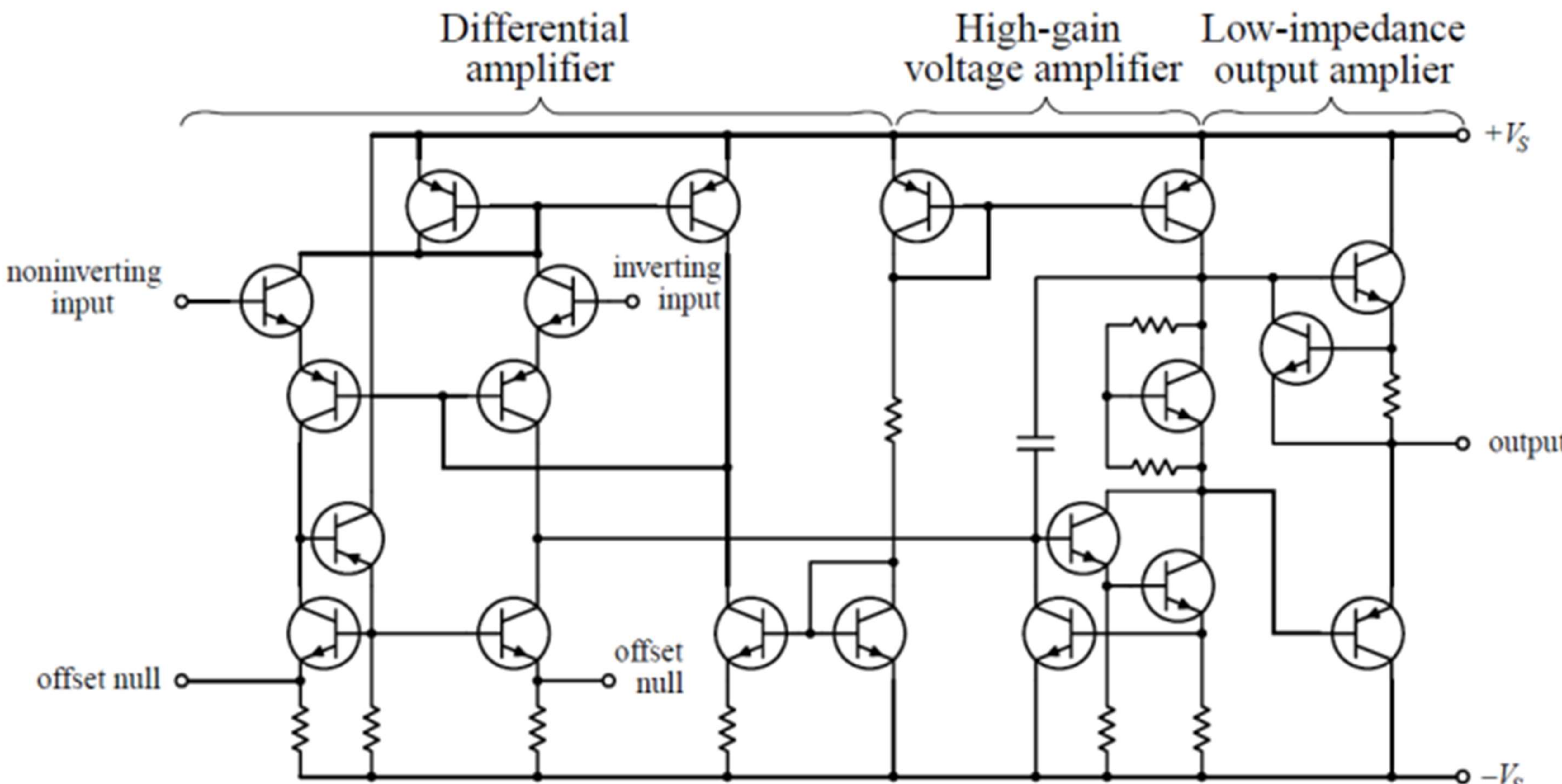
Topic_03: Analogue Signal Processing[2]	
1	Ideal Operational Amplifier (Op Amp)
2	Real Op Amp
3	Practical Example

[2] Histand, ***"Introduction to Mechatronics & Measurement Systems"***, 4th Edition

1. Ideal Op Amp: Op Amp Jungle



1. Ideal Op Amp

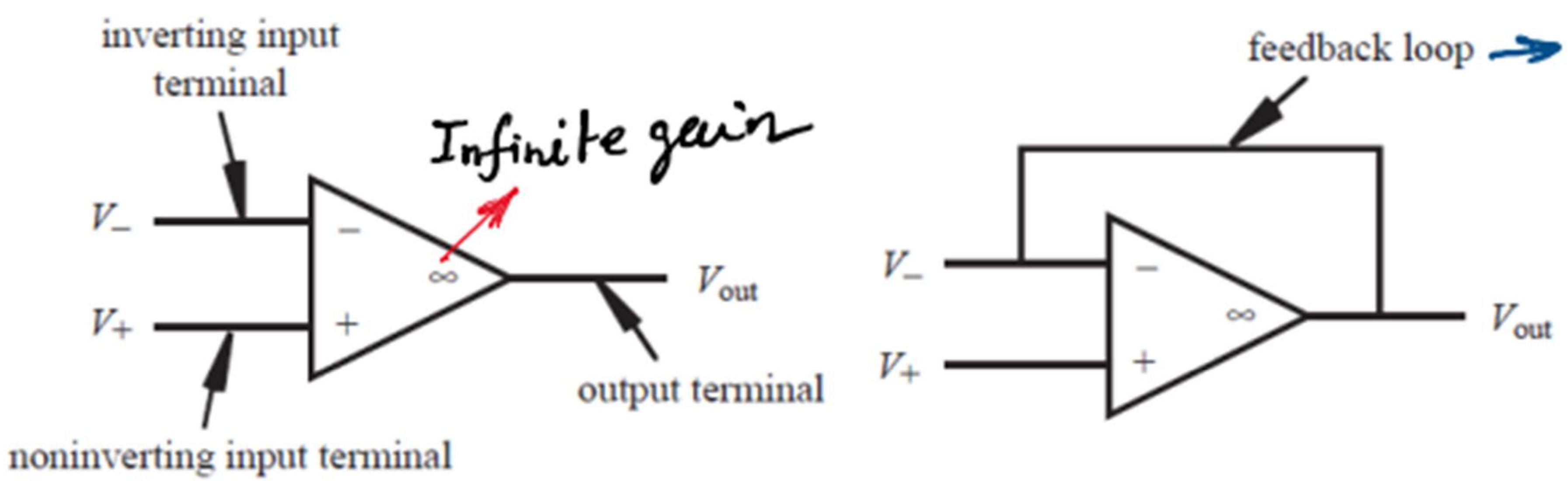
Reasons for Selecting Op Amp:

- ✓ Transducer converts physical quantities into analogue voltage or current
- ✓ These Signals are often too small, noisy, possess DC offset
- ✓ Op Amp is used to process these analogue signals
- ✓ Op Amp is an IC and active device; usually require ±15 V
- ✓ Building block of many important circuits such as Amplifiers; Integrator; Differentiator; Summer; Comparator; A/D and D/A converter; Active filter; Sample and Hold circuit etc.
- ✓ Op Amp are very easy to work with
- ✓ High input impedance and low output impedance
- ✓ Don't connect to power supply incorrectly! Might blow up

1. Ideal Op Amp

Ideal Model of Op Amp:

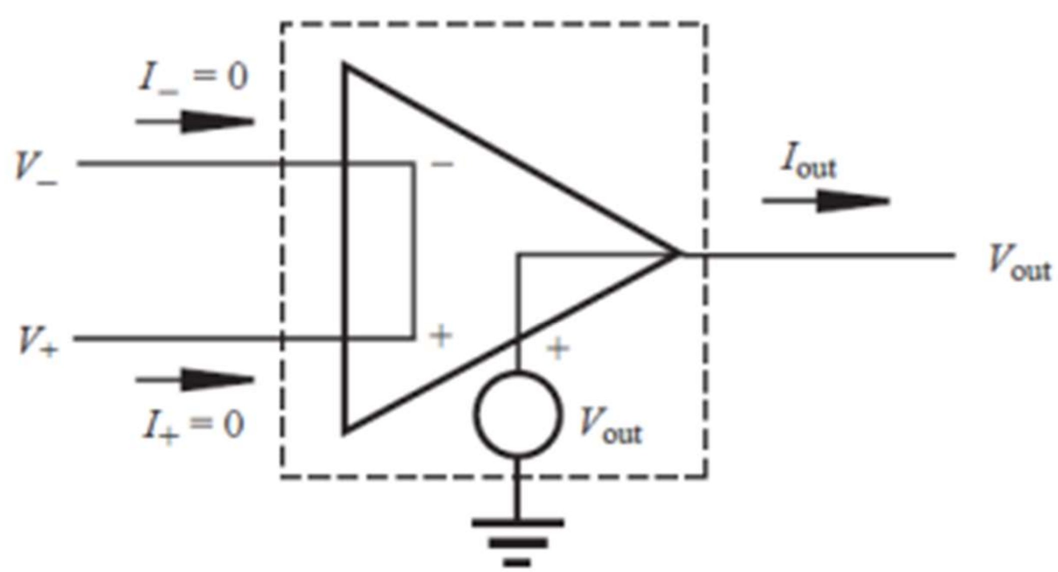
Schematic



Infinite gain

stability and gain control

Ideal Model:



$$V_{out} = A_0(V_+ - V_-)$$

1. Ideal Op Amp

Op Amp Assumptions:

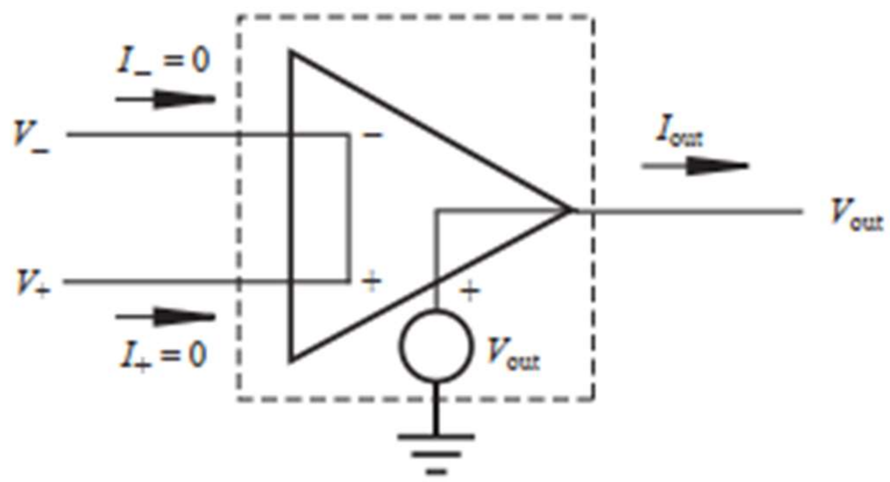
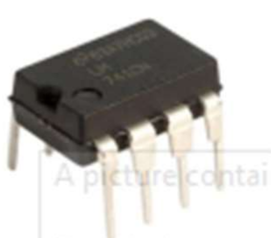
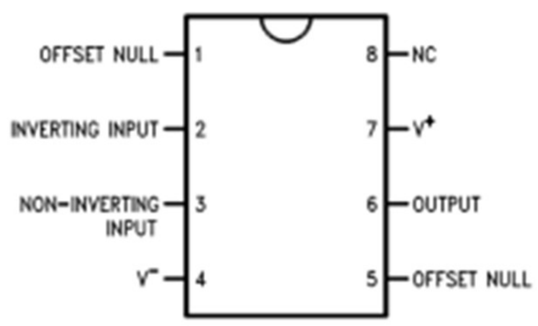


Figure 5.4 Op amp equivalent circuit.





LH 741

1. *It has infinite impedance at both inputs;* hence, no current is drawn from the input circuits. Therefore,

$$I_+ = I_- = 0 \tag{5.4}$$

2. *It has infinite gain.* As a consequence, the difference between the input voltages must be 0; otherwise, the output would be infinite. This is denoted in Figure 5.4 by the shorting of the two inputs. Therefore,

$$V_+ = V_- \tag{5.5}$$

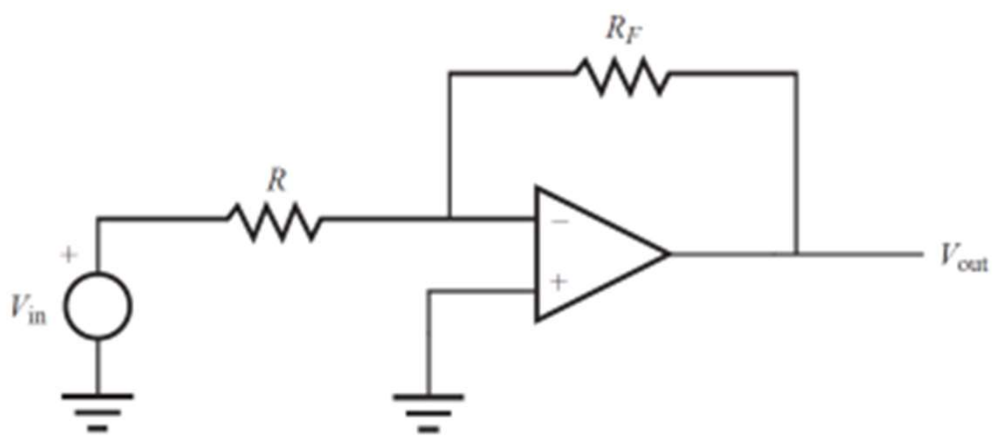
Even though we indicate a short between the two inputs, we assume no current may flow through this short.

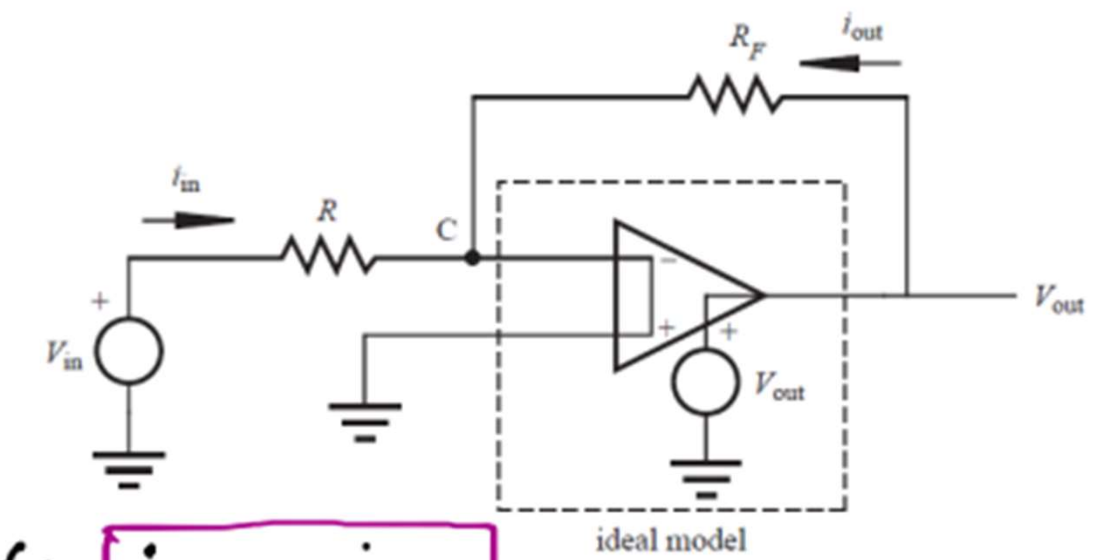
3. *It has zero output impedance.* Therefore, the output voltage does not depend on the output current.

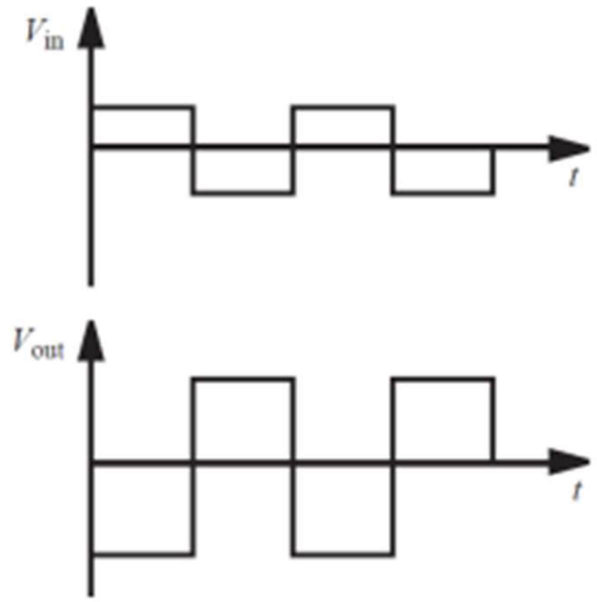
* This "illogical" ideal Op Amp provides close approximation of real op Amp.

1. Ideal Op Amp

Inverting Amplifier:







→ 180° phase-shift for periodic signal

node C, $\boxed{i_{in} = -i_{out}}$ and $V_C = 0$

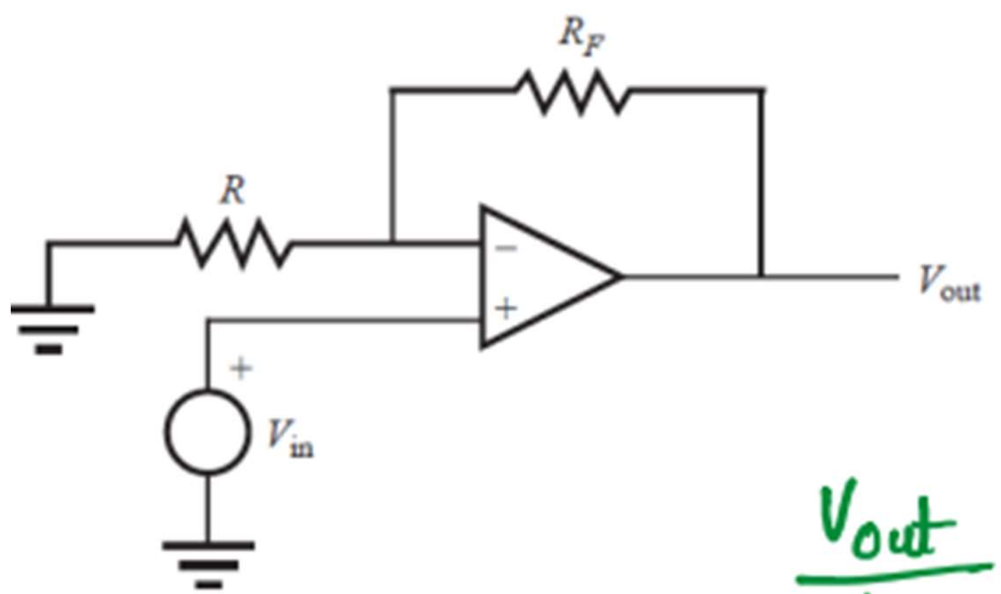
∴ $V_{in} - V_C = i_{in} R \Rightarrow V_{in} = i_{in} R$

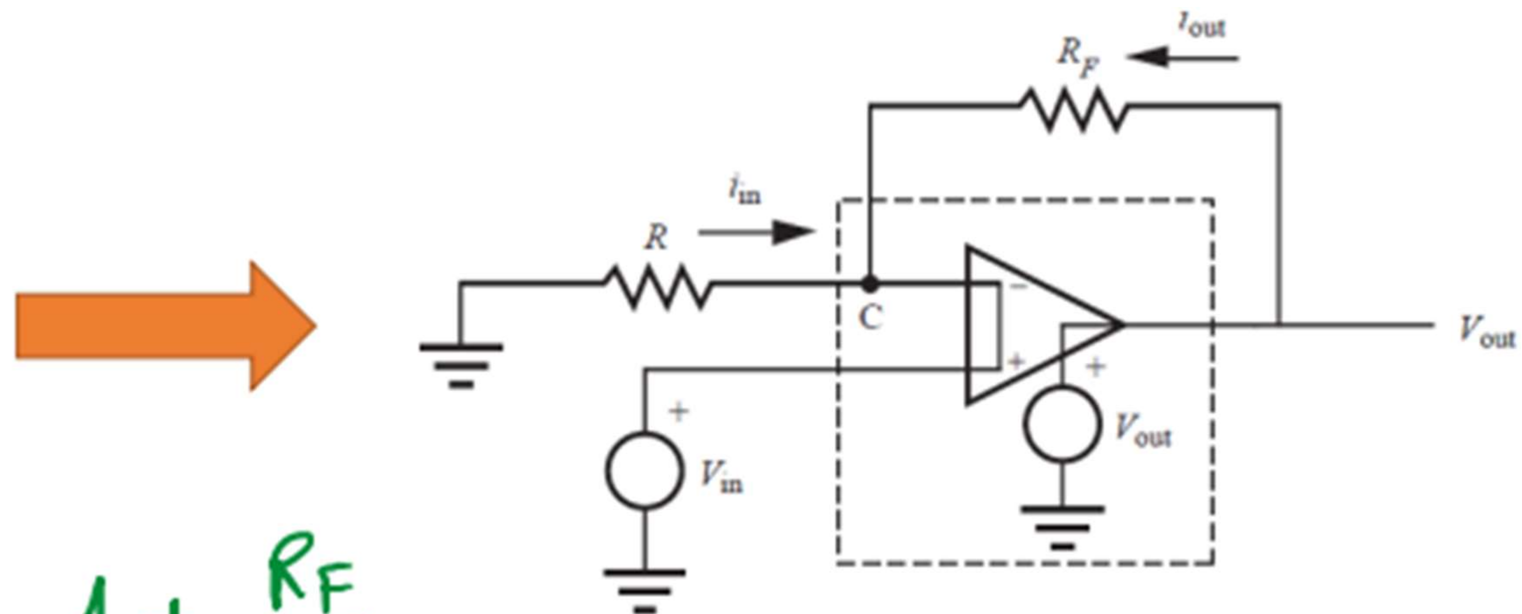
and, $V_{out} - V_C = i_{out} R_F \Rightarrow V_{out} = i_{out} R_F$

So, $V_{out} = -i_{in} R_F$

$$\frac{V_{out}}{V_{in}} = -\frac{R_F}{R}$$ → Voltage Gain

Non-inverting Amplifier:



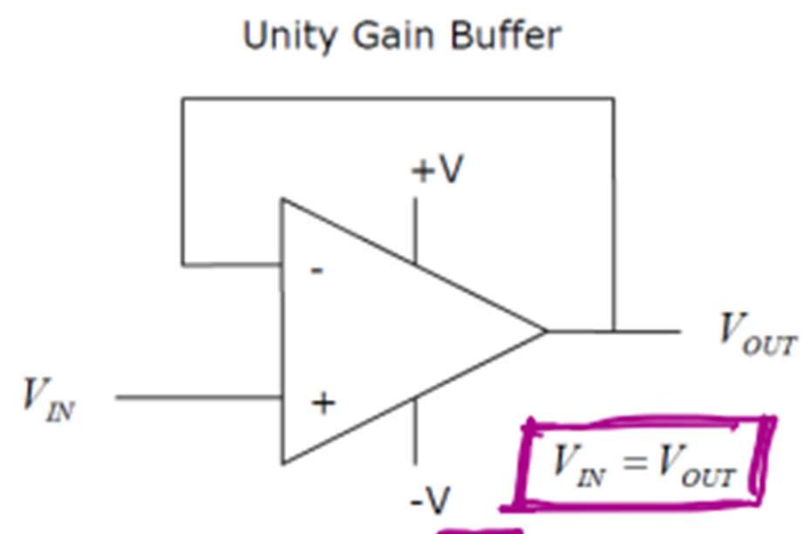


$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R}$$

- ✓ Positive gain greater than or equal to 1 (Don't forget 9st law of thermodynamics)!!
- ✓ Useful in isolating one portion of a circuit from another

1. Ideal Op Amp

Buffer of Follower:

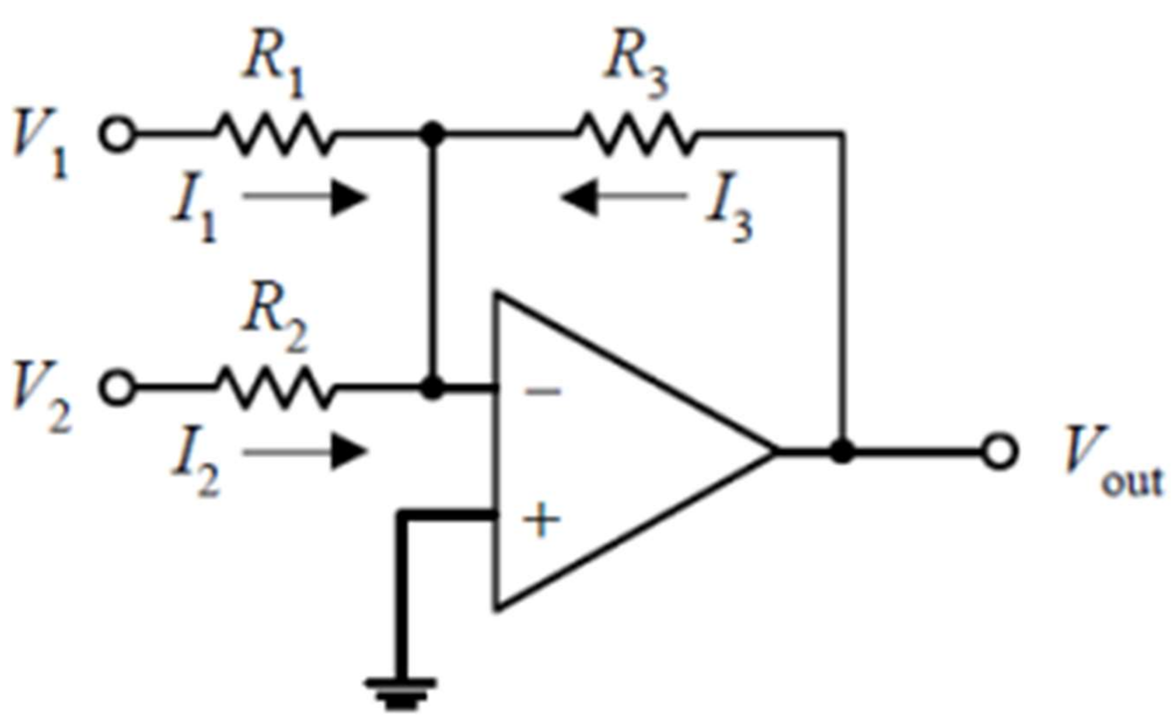


- ✓ R_F=0 and R=∞
- ✓ It has a high input impedance and low output impedance
- ✓ This circuit is useful in applications where you need to couple to a voltage signal without loading the source of the voltage

  ↳ source isolation from rest of the circuit

1. Ideal Op Amp

Summer:



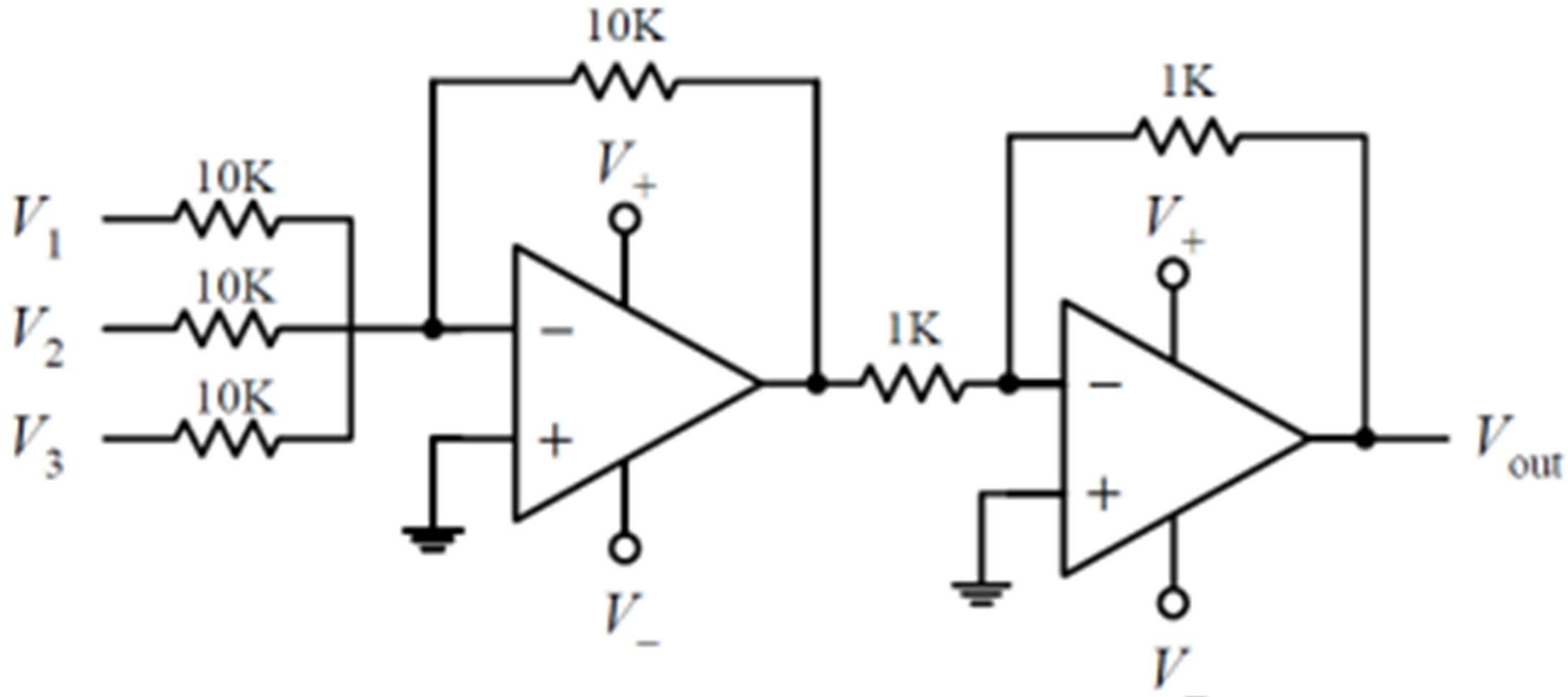
$$V_{out} = -\frac{R_3}{R_1}V_1 - \frac{R_3}{R_2}V_2 = -\left(\frac{R_3}{R_1}V_1 + \frac{R_3}{R_2}V_2\right)$$

Let, $R_1 = R_2 = R_3$

$$\underline{V_{out} = -(V_1 + V_2)}$$

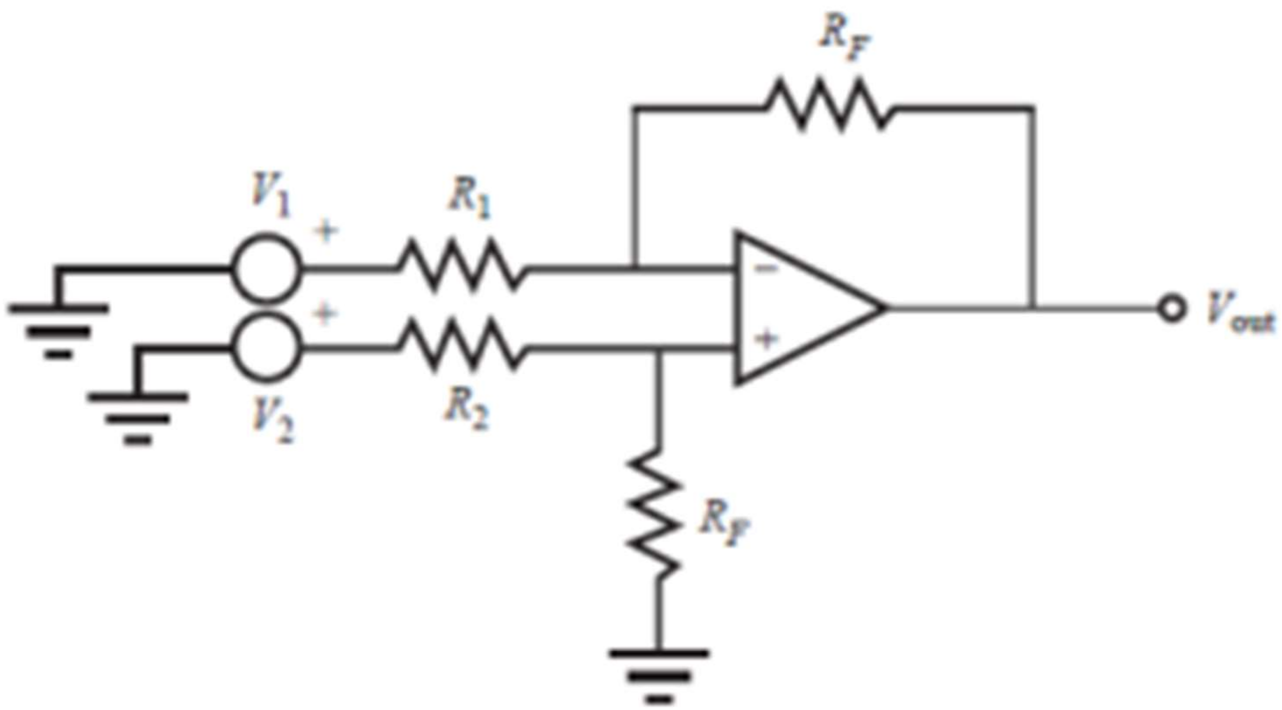
1. Ideal Op Amp

Summer:



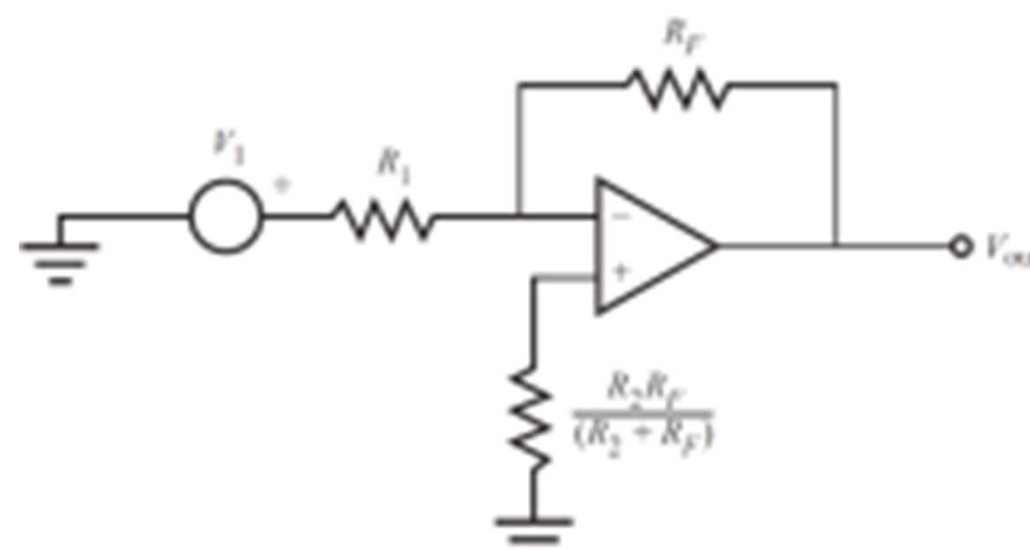
$V_{out} = ?$

Difference Amplifier:



Principle of Superposition ; $V_{out} = V_{out\,1} + V_{out\,2}$

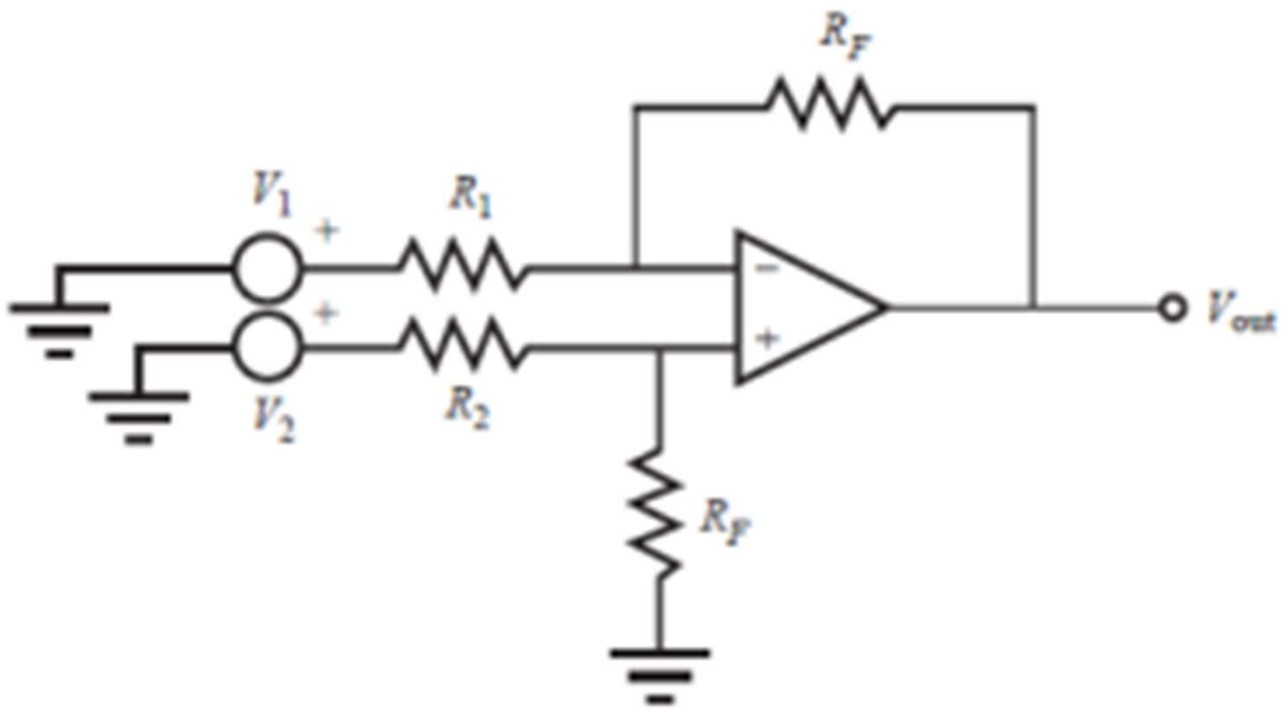
1st, V_2 shorted, R_2 Grounded



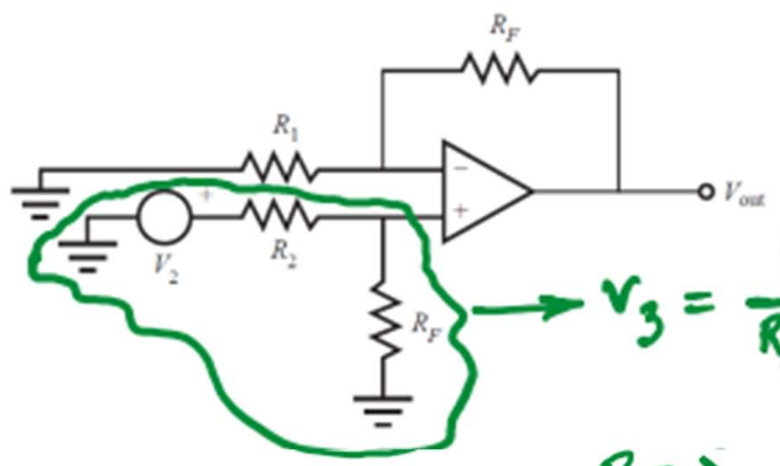
$$\Rightarrow V_{out\,1} = -\frac{R_F}{R_1} V_1$$

1. Ideal Op Amp

Difference Amplifier:



2nd, V_1 shorted and R_1 grounded



$\rightarrow V_3 = \frac{R_F}{R_2+R_F} V_2$

$$\Rightarrow V_{out\,2} = \left(1+\frac{R_F}{R_1}\right) V_3$$

$$\therefore V_{out\,2} = \left(1+\frac{R_F}{R_1}\right)\left(\frac{R_F}{R_2+R_F}\right) V_2$$

If, $R_1 = R_2 = R$

$$V_{out} = \frac{R_F}{R}(V_2 - V_1)$$

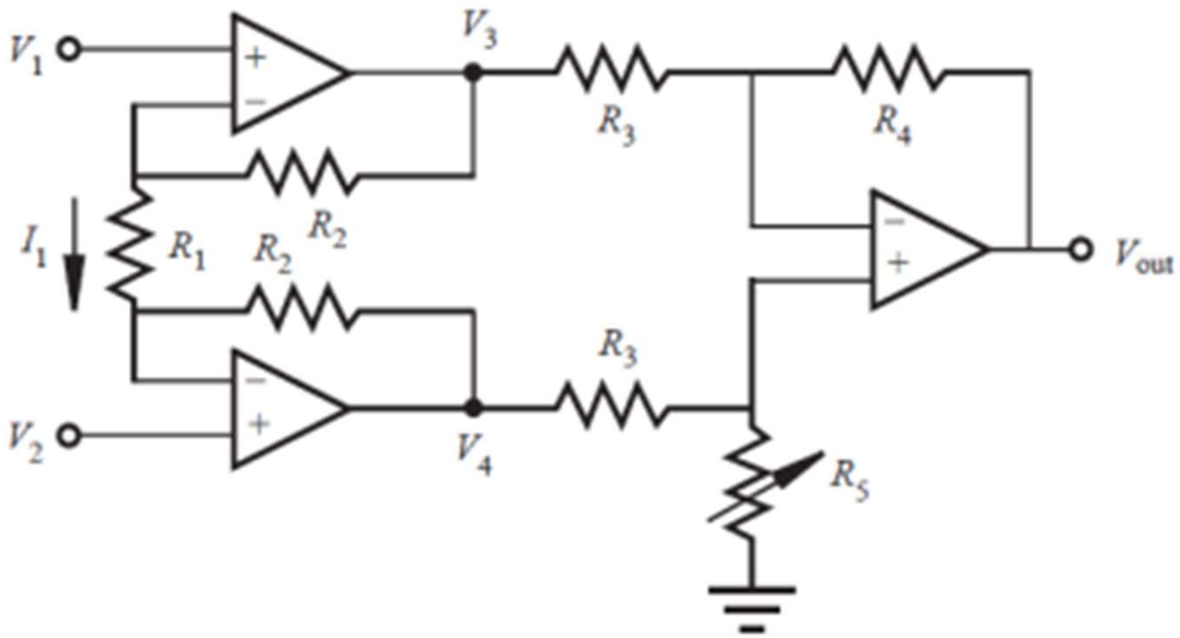
1. Ideal Op Amp

Instrumentation Amplifier:

- ✓ Large Common Mode Rejection Ratio (CMRR). Ideal amplifier CMRR is infinite.

$$\to \frac{\text{Difference Mode Gain}}{\text{Common Mode Gain}} \to \text{Amplification of average of } V_{in}\text{s}$$

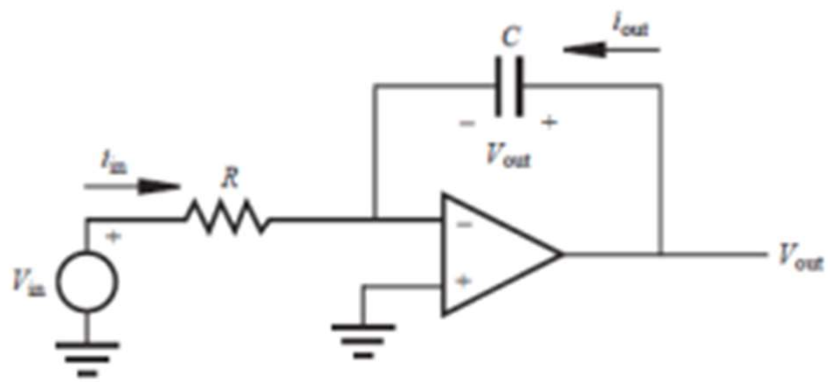
- ✓ Very high input impedance
- ✓ Low-level signals in a noisy environment
- ✓ Consistent bandwidth over a large range of gains
- ✓ A single external resistor is used to set the gain.
- ✓ This gain can be higher and more stable



for Max. CMRR, $R_4 = R_5 \longrightarrow V_{out} = \left[\frac{R_4}{R_3}\left(1+2\frac{R_2}{R_1}\right)\right](V_2 - V_1)$

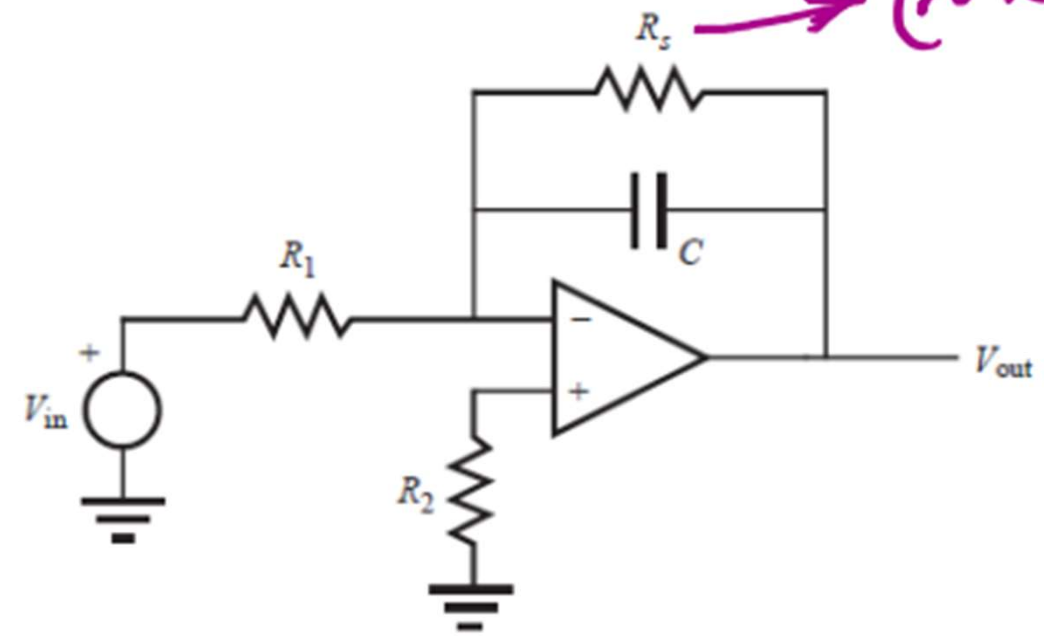
1. Ideal Op Amp

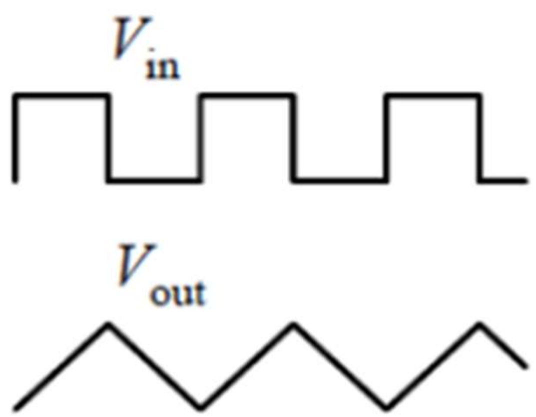
Integrator:



$$V_{out}(t) = -\frac{1}{RC}\int_0^t V_{in}(\tau)\,d\tau$$

$(\sim 10R_1)$

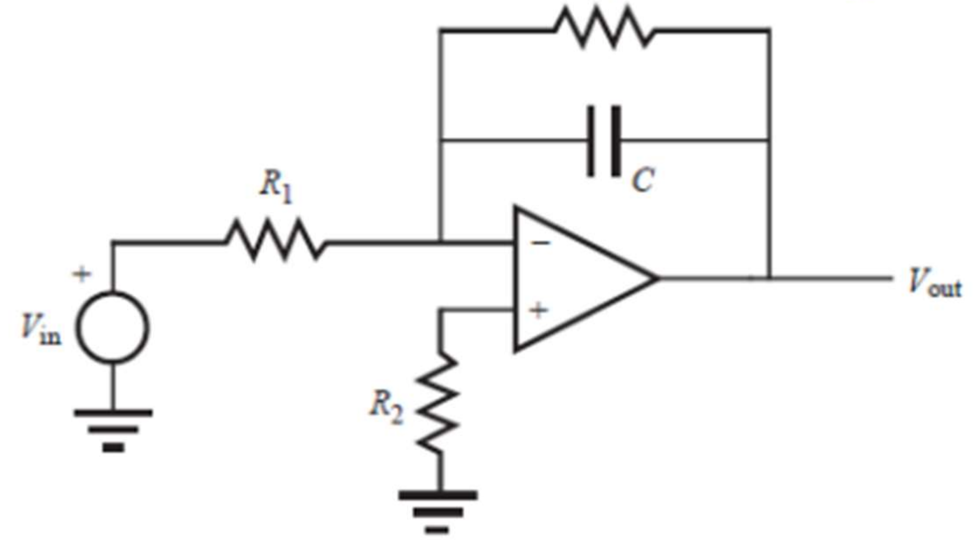




1. Ideal Op Amp

Integrator:

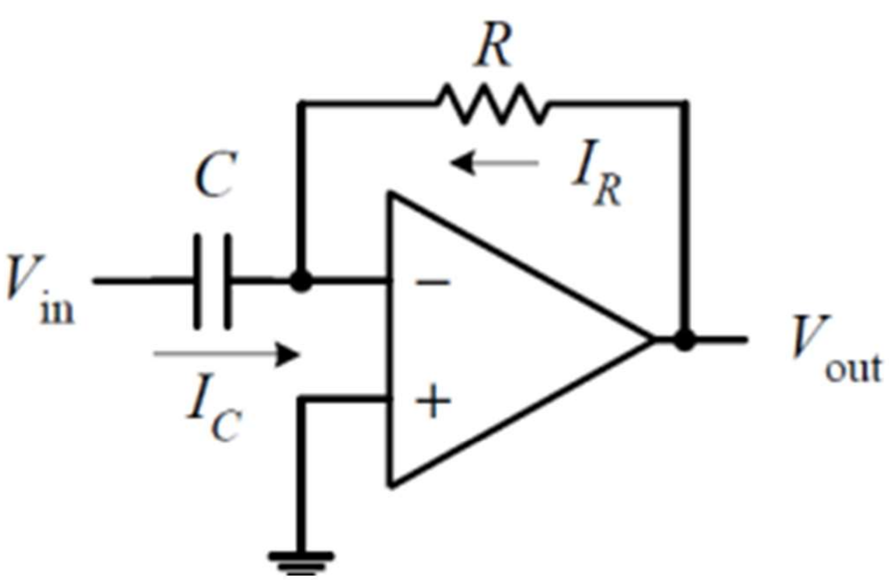
$(\sim 10R_1)$

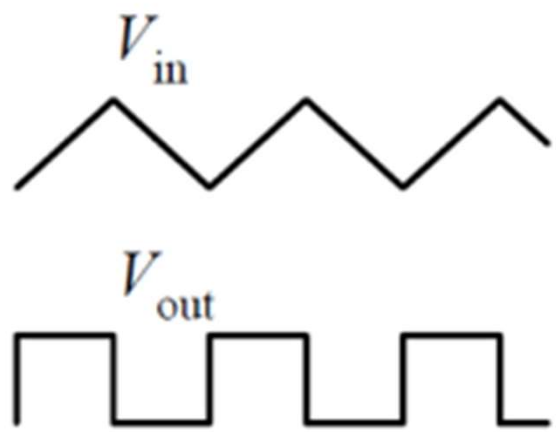


- ✓ The resistor R_s placed across the feedback capacitor is called a shunt resistor whose purpose is to limit the low-frequency gain of the circuit
- ✓ The circuit on the right acts as an integrator only for a range of frequencies
- ✓ Any DC offset due to the input bias current is minimized by R_2 $\rightarrow \frac{R_1 R_s}{R_1 + R_s}$

1. Ideal Op Amp

Differentiator:





$$I_C = C\frac{dV}{dt} = C\frac{d(V_{in}-V_-)}{dt} = C\frac{d(V_{in}-0\,\mathrm{V})}{dt} = C\frac{dV_{in}}{dt}$$

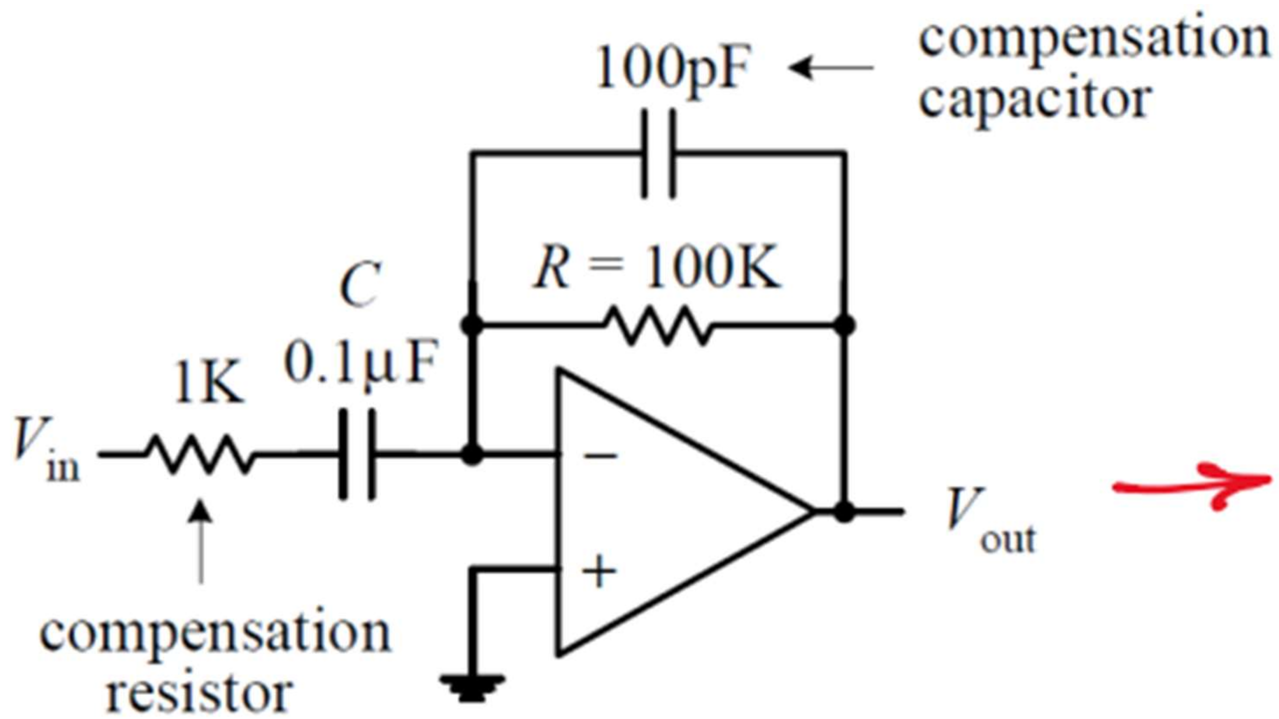
$$I_R = \frac{V_{out}-V_-}{R} = \frac{V_{out}-0\,\mathrm{V}}{R} = \frac{V_{out}}{R}$$

$$I_R + I_C = 0$$

$$V_{out} = -RC\frac{dV_{in}}{dt}$$

1. Ideal Op Amp

Differentiator:

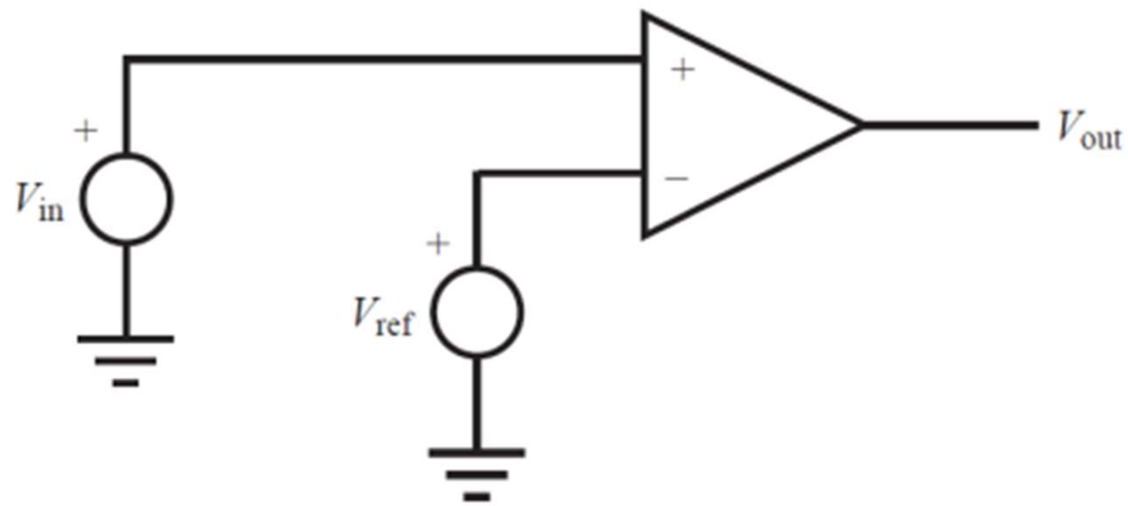


- Improved design
- Fast changing noise → $V_{out} \uparrow\uparrow$
- Compensation Capacitor & Resistor

An additional input-bias compensation resistor placed between the noninverting input and ground may be needed to avoid offset error caused by input bias current

1. Ideal Op Amp

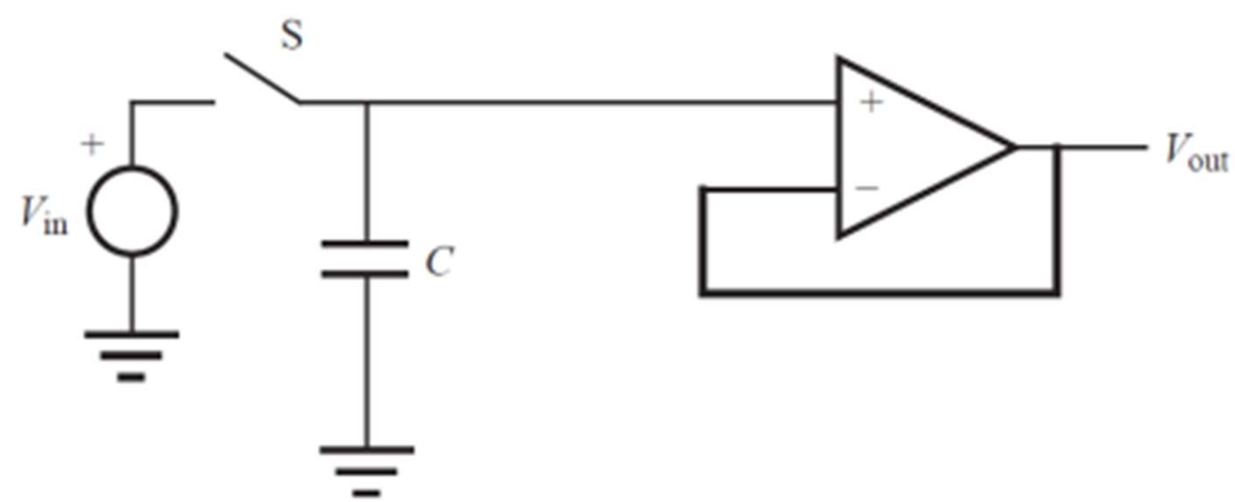
Comparator:



$$V_{out} = \begin{cases} +V_{sat} & V_{in} > V_{ref} \\ -V_{sat} & V_{in} < V_{ref} \end{cases}$$

1. Ideal Op Amp

Sample and Hold Circuit:

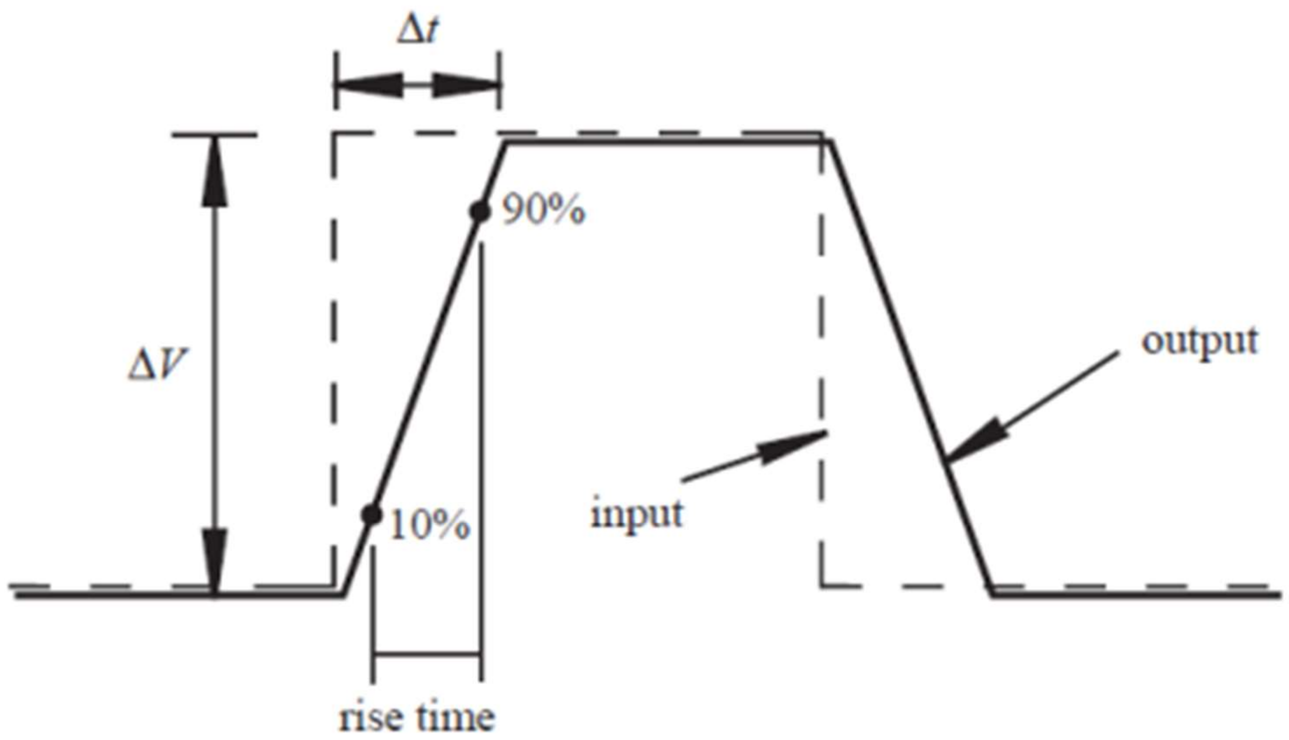


- ✓ Used extensively in analog-to-digital (ADC) conversion to stabilize the signal during conversion
- ✓ Low leakage capacitor is a good choice

2. Real Op Amp

Two important characteristics of a real op amp are associated with its response to a square wave input:

- ❑ Slew rate → $\frac{\Delta V}{\Delta t}$
- ❑ Rise time



Consult data sheet for:

Input Resistance

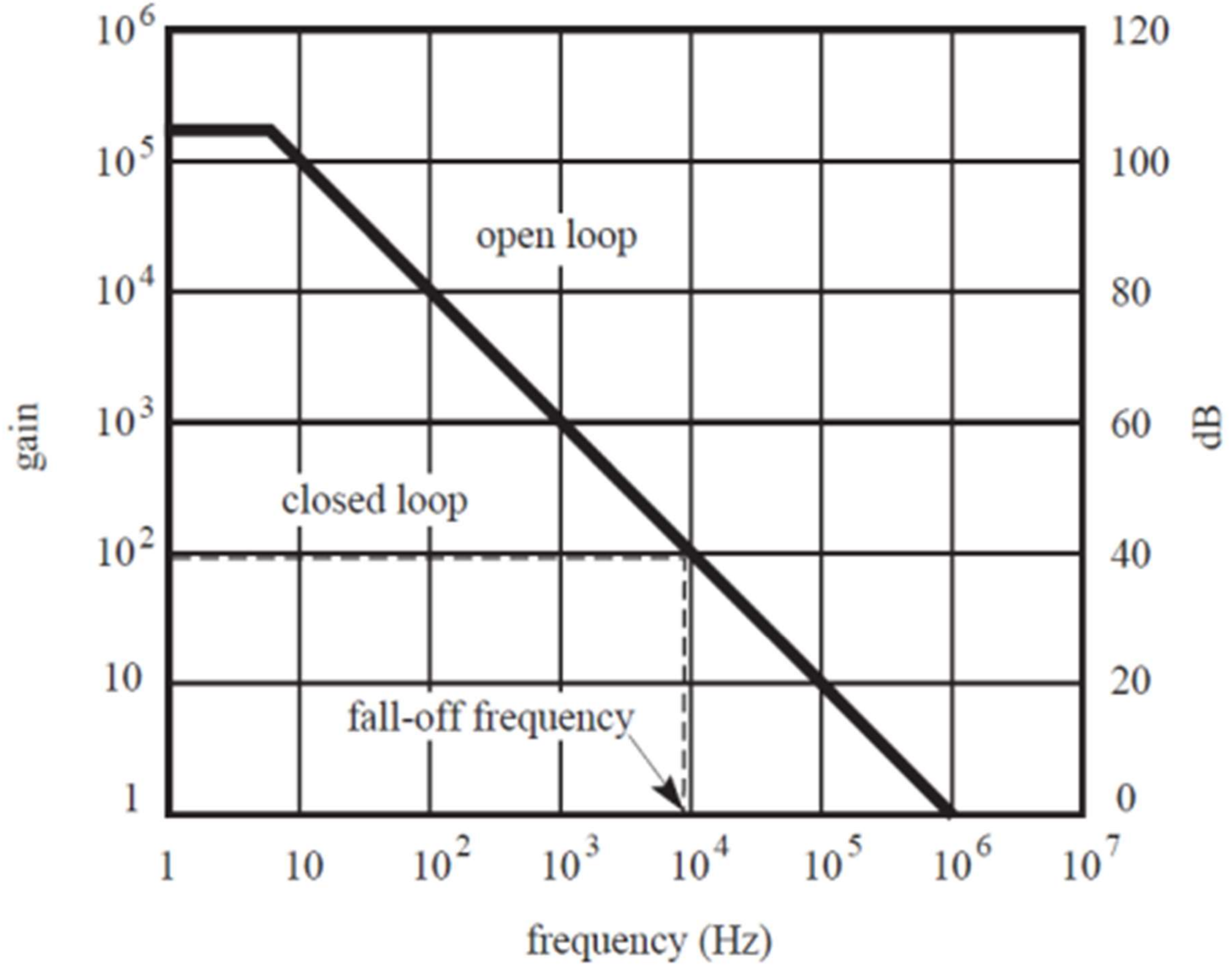
Max. Output Voltage

Gain-Bandwidth Product (GBP)

CMRR

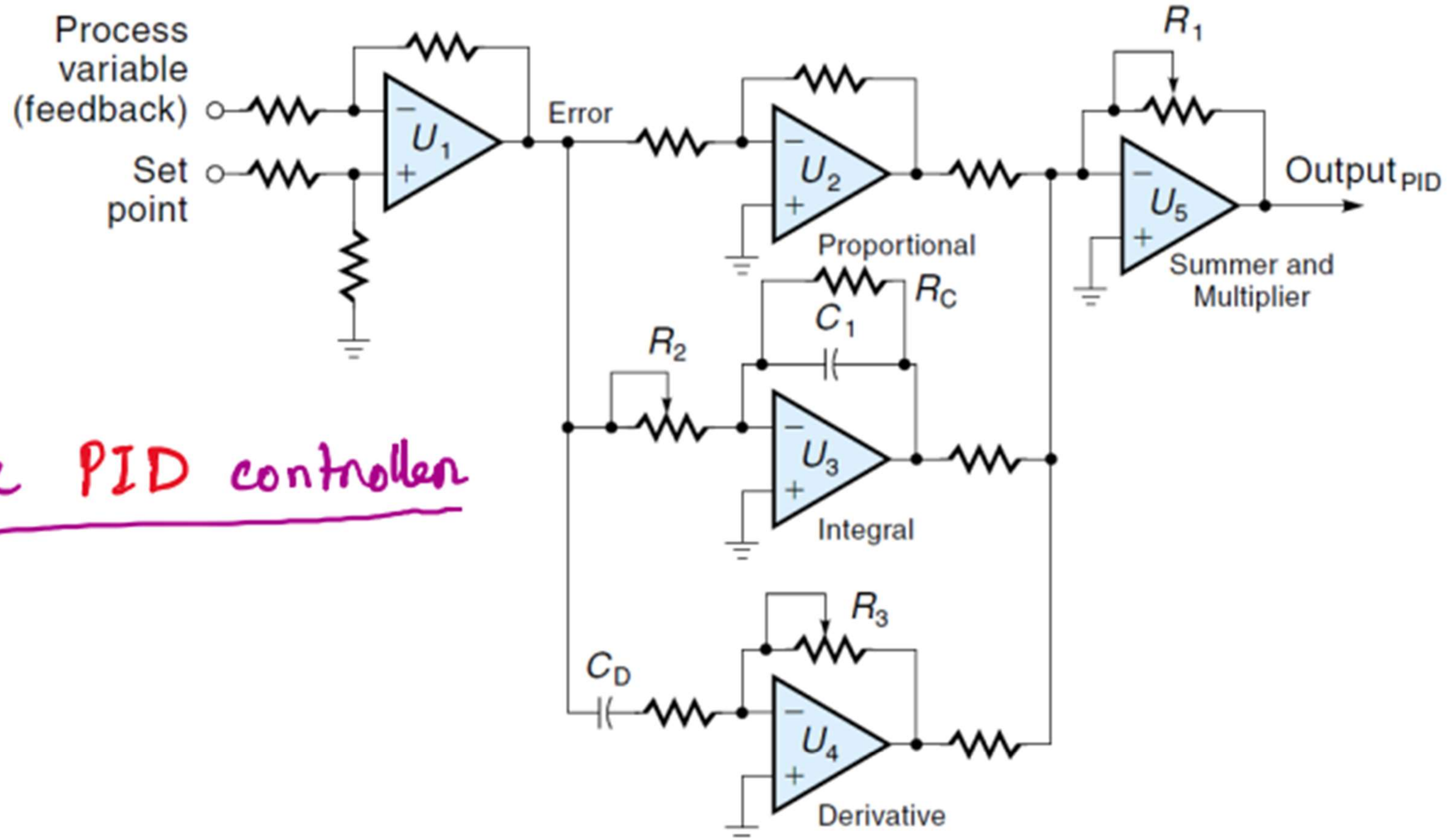
etc.

2. Real Op Amp



gain
dB
10^6
10^5
10^4
10^3
10^2
10
1
120
100
80
60
40
20
0
open loop
closed loop
fall-off frequency
1
10
10^2
10^3
10^4
10^5
10^6
10^7
frequency (Hz)

3. Practical Example

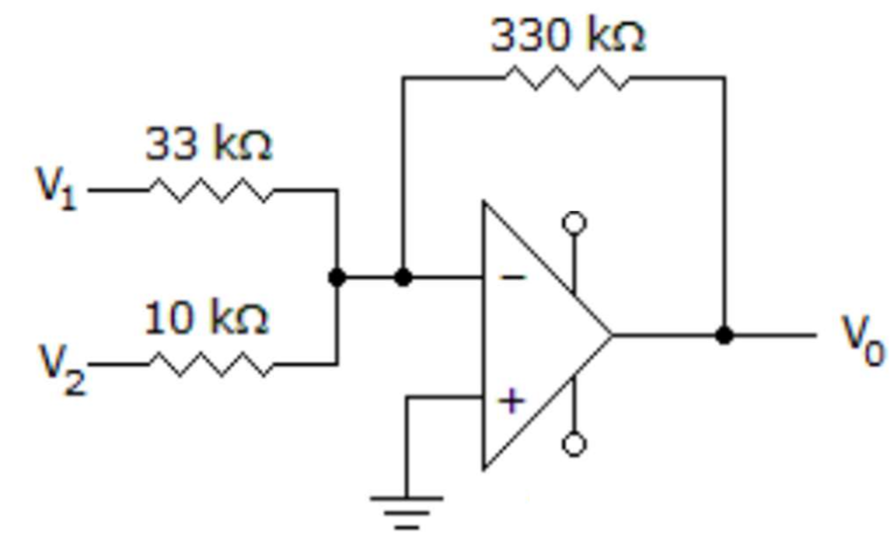


Analogue PID controller

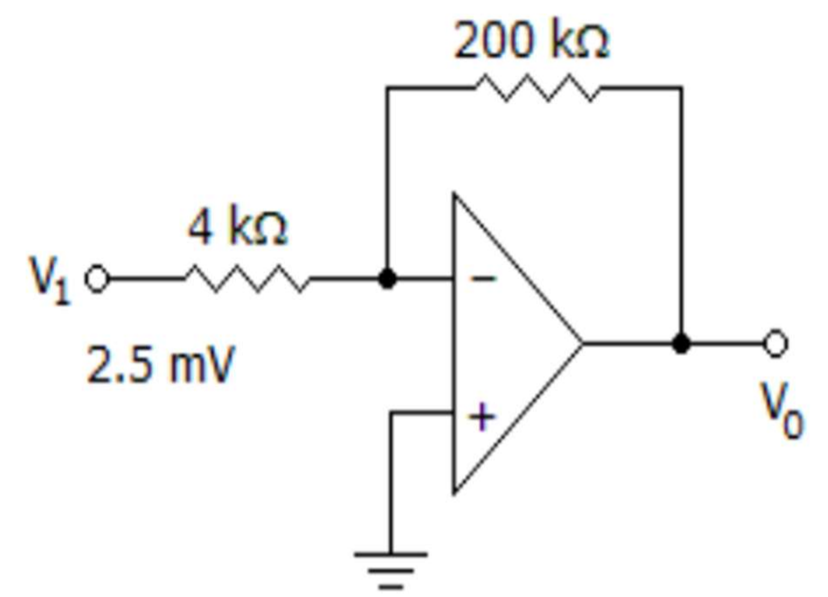
Kilian, "Modern Control Technology", 2nd Edition

Problems

1. Calculate the output voltage (V_o) if $V_1 = V_2 = 0.15V$

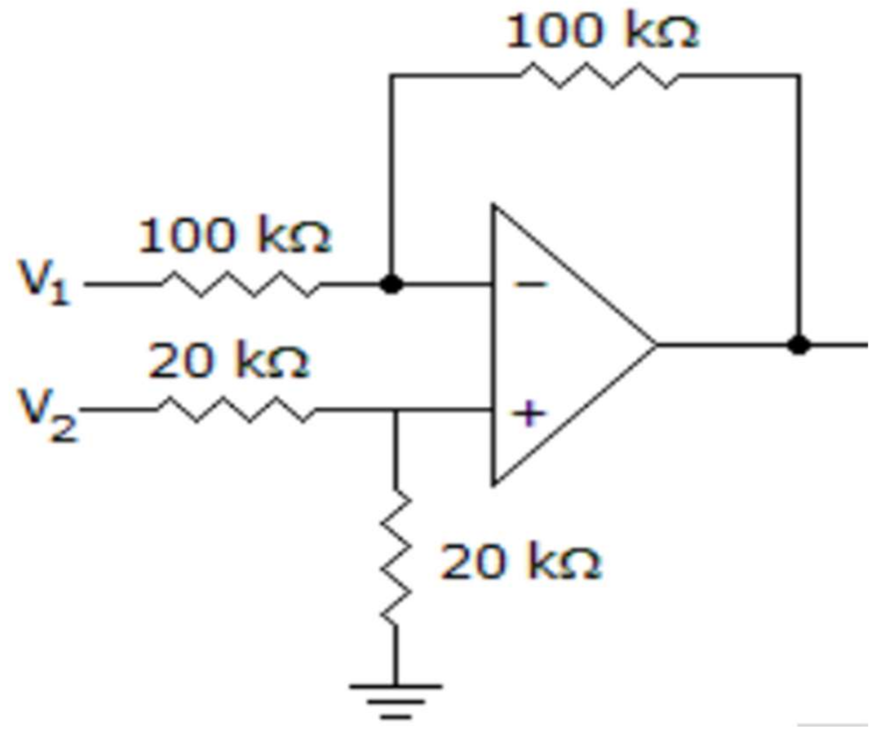


2. Determine the output voltage (V_o) for this circuit with a sinusoidal input of 2.5 mV.



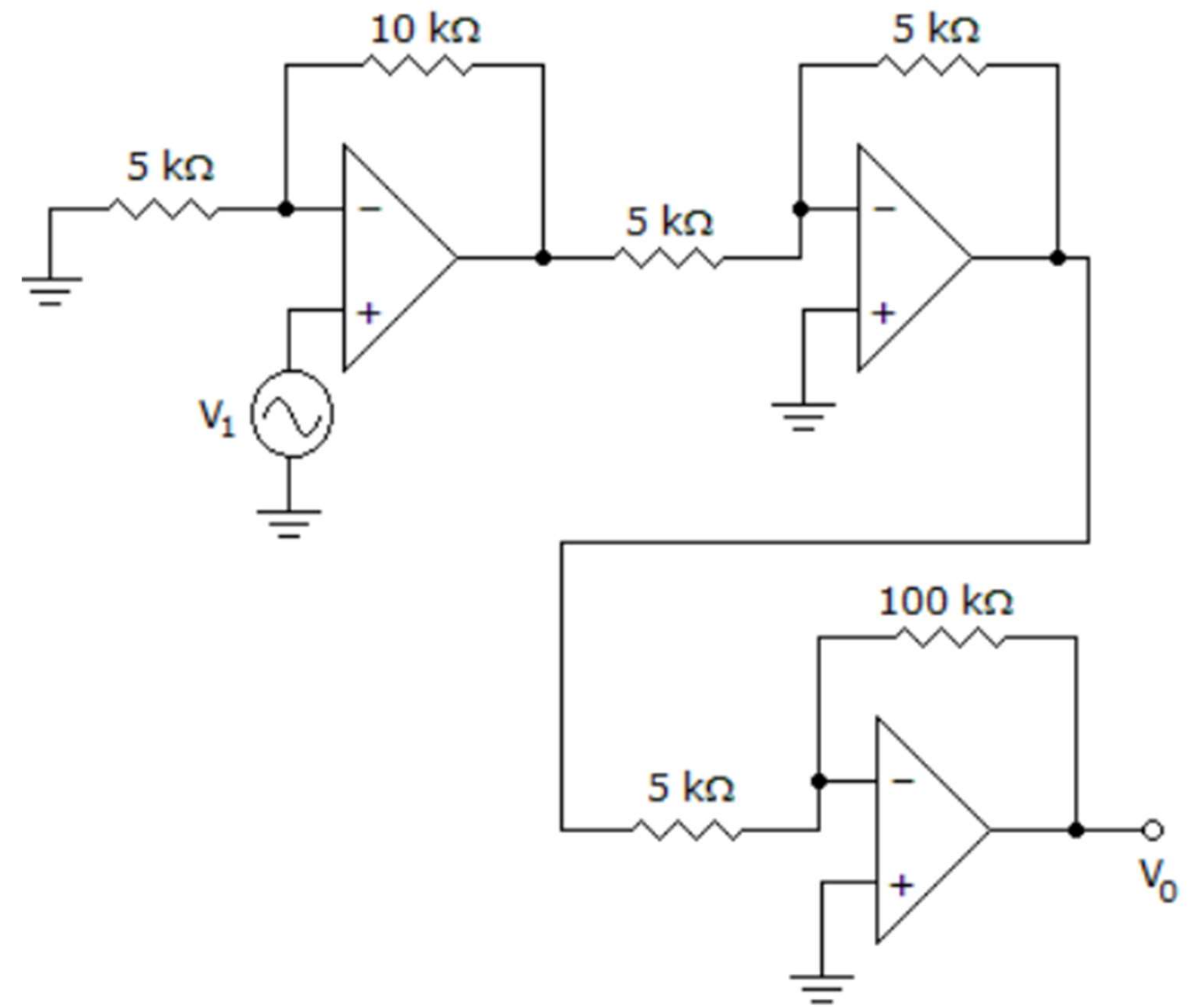
Problems

3. Determine the output voltage (V_o) when $V_1 = V_2 = 1$ V



Problems

4. Calculate the input voltage (V_1) if the final output (V_o) is 10.08 V



Reading

Introduction to Mechatronics and Measurement Systems, 4th Edition, *David G. Alciatore & Michael B. Histand*

- ***Chapter 5***

Thank you