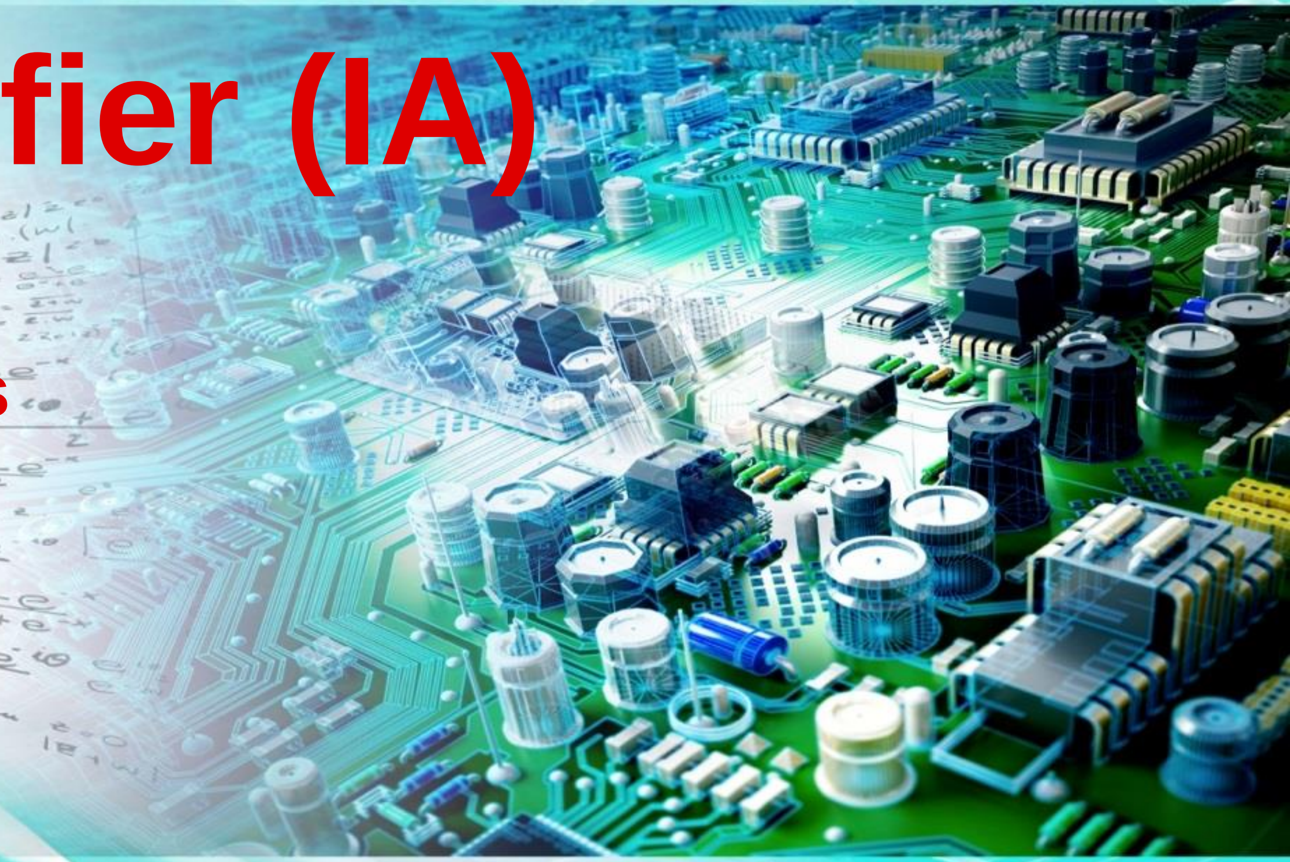
Instrumentation Amplifier (IA) topologies: one-amp

TI Precision Labs – Instrumentation Amplifiers



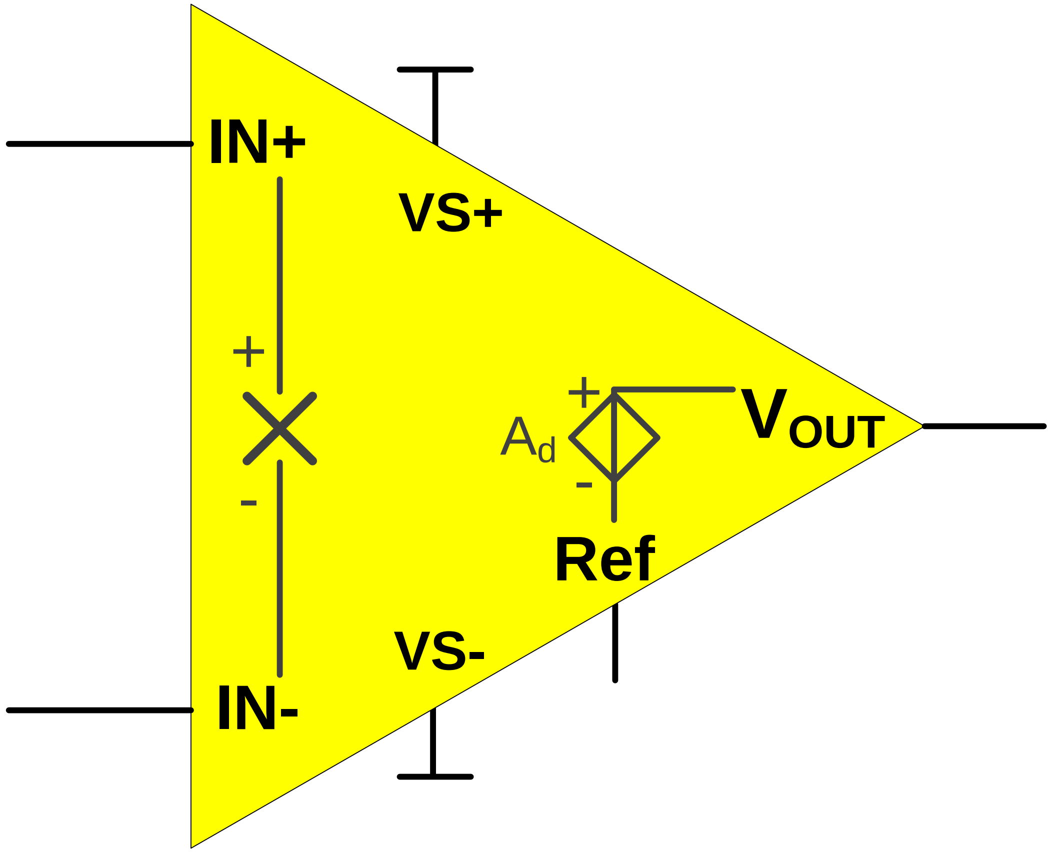
Presented by Tamara Alani

Prepared by Tamara Alani

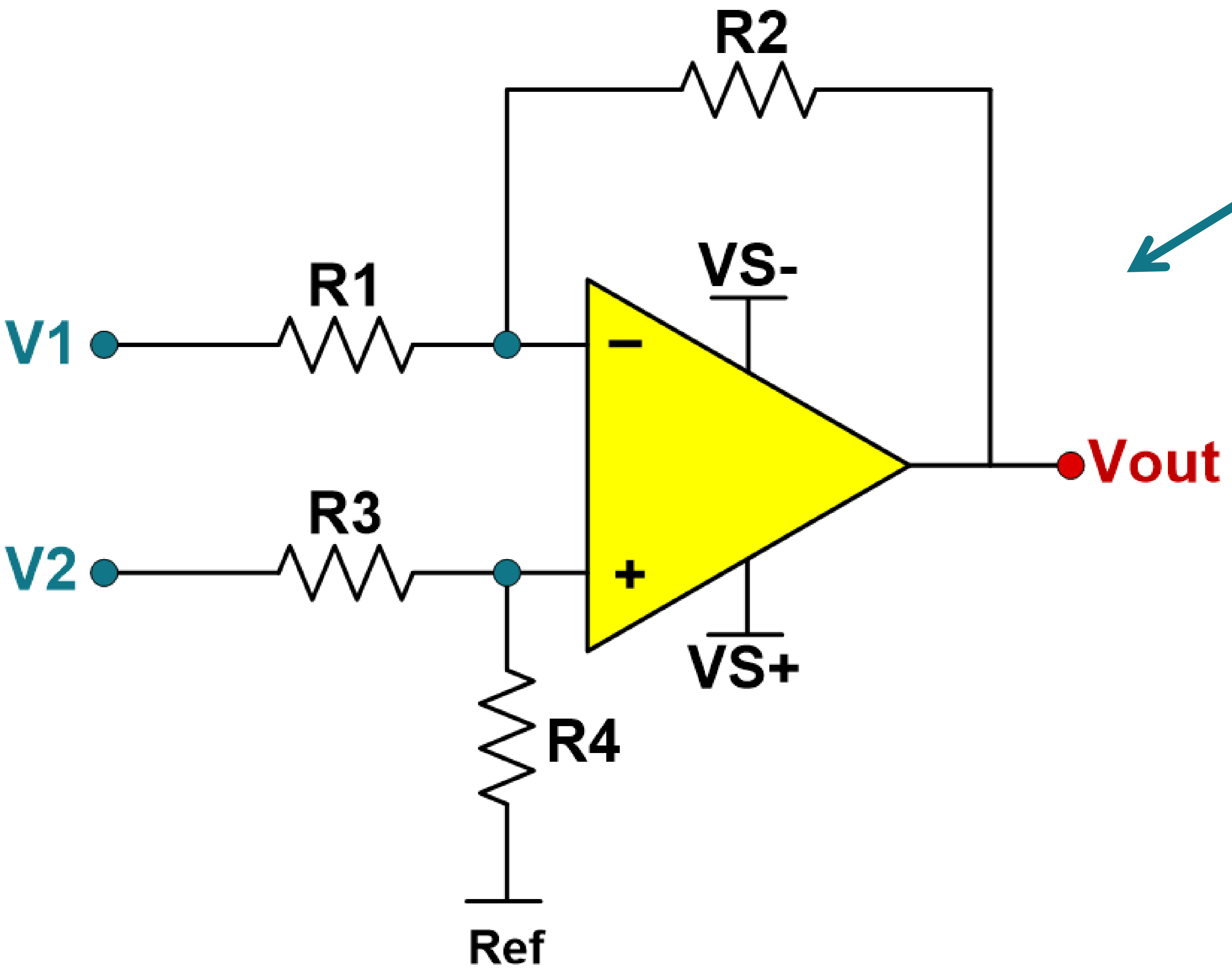
Instrumentation amplifier – Idealized model

Two main characteristics of an instrumentation amplifier:

1. Amplifies the signals that differ between the two inputs
2. Rejects the signals that are the same (common) to both inputs



IA topology – One-amp configuration

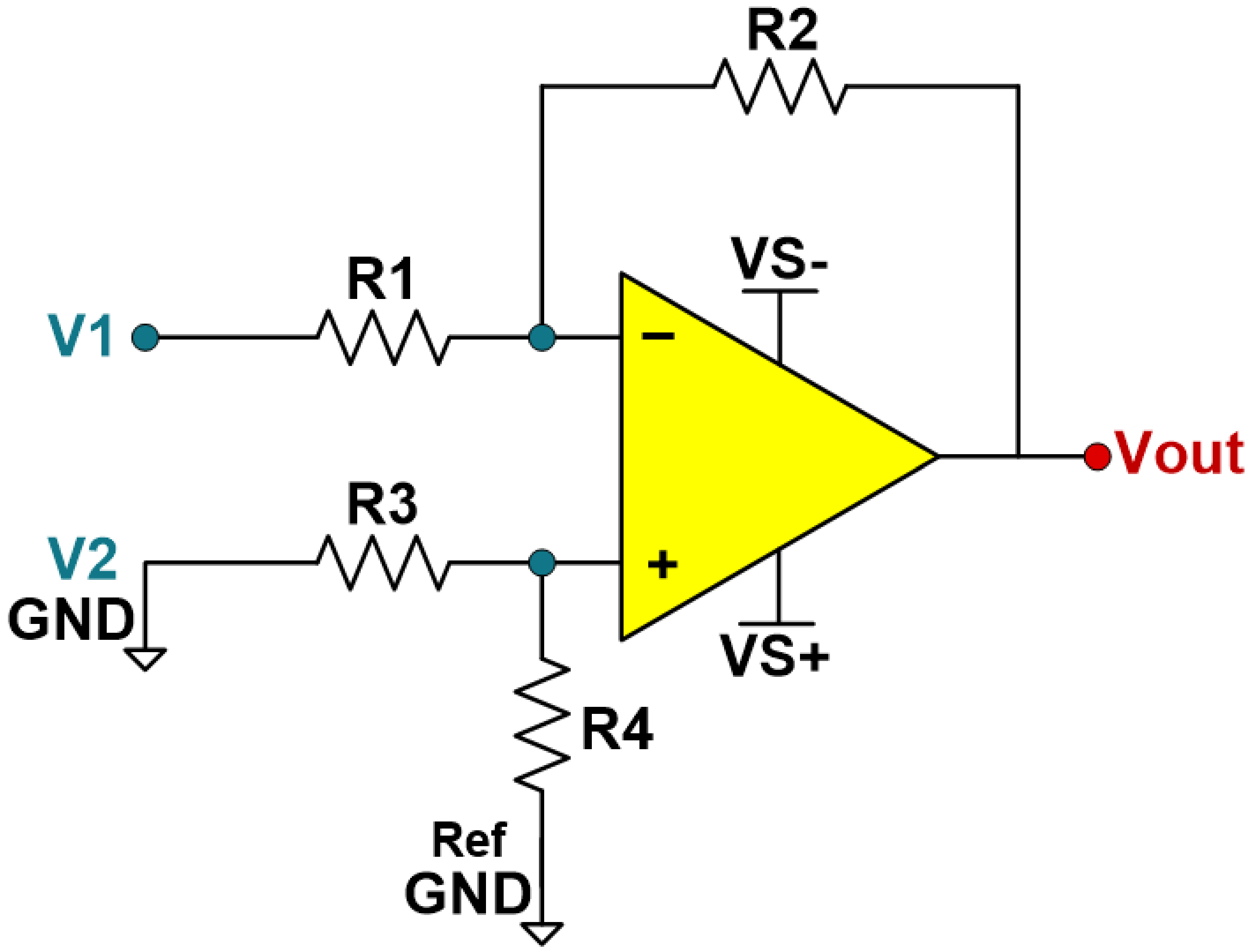


"difference amplifier"

A difference amplifier fulfills the primary behaviors of an idealized IA

Equation	V1	V2	Ref
V1*	Keep	Short	Short
V2*	Short	Keep	Short
Ref*	Short	Short	Keep
Vout = V1* + V2* + Ref*			

Superposition – Derive Vout due to V1



Assume R1 = R2 = R3 = R4

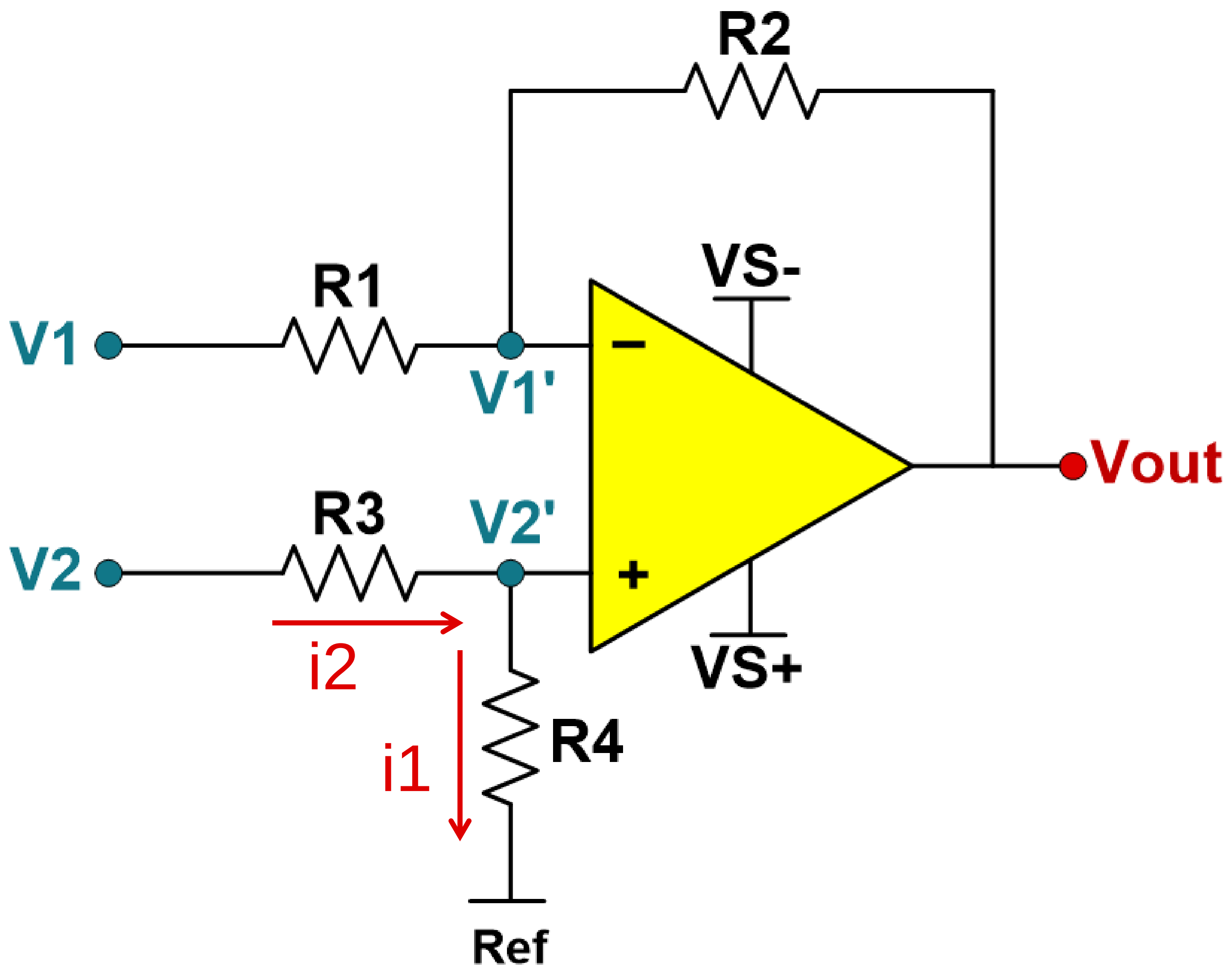
Ground the non-inverting input

$$Vout = V1 \times \left(\frac{-R2}{R1}\right)$$

Since we assumed R1 = R2 = R3 = R4,

Vout = -V1 (Equation V1*)

Voltage between 2 sources – V2' derivation



$$i1 = \frac{V2' - Ref}{R4}$$

$$i2 = \frac{V2 - V2'}{R3}$$

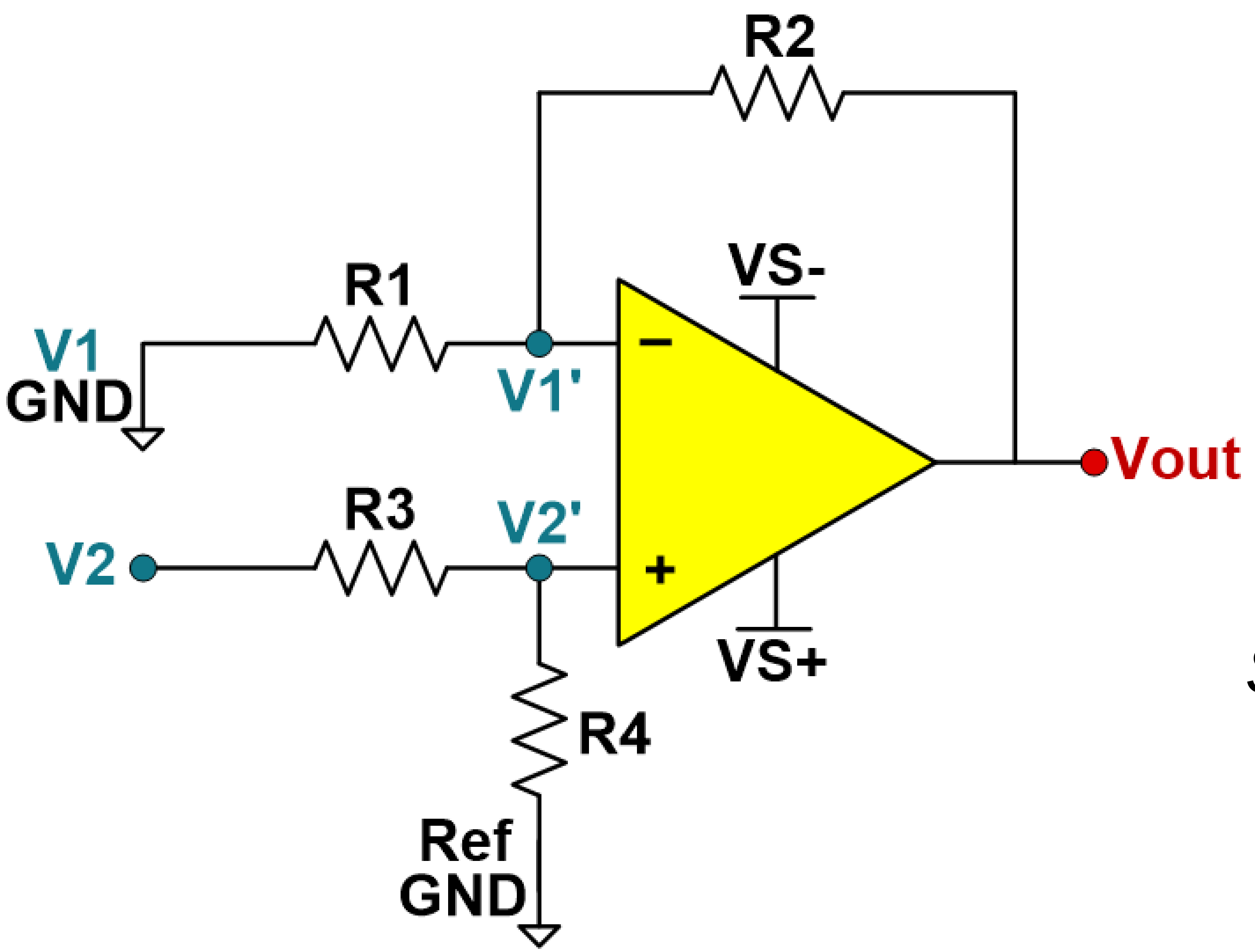
$$i1 = i2 = \frac{V2' - Ref}{R4} = \frac{V2 - V2'}{R3}$$

$$V2' = \frac{(R4 \times V2) + (R3 \times Ref)}{R3 + R4}$$

$$Since\ R1 = R2 = R3 = R4,$$

$$\boldsymbol{V2' = \frac{V2 + Ref}{2}}$$

Superposition – Derive Vout due to V2



$$Vout = V2' \times \left(1 + \frac{R2}{R1}\right)$$

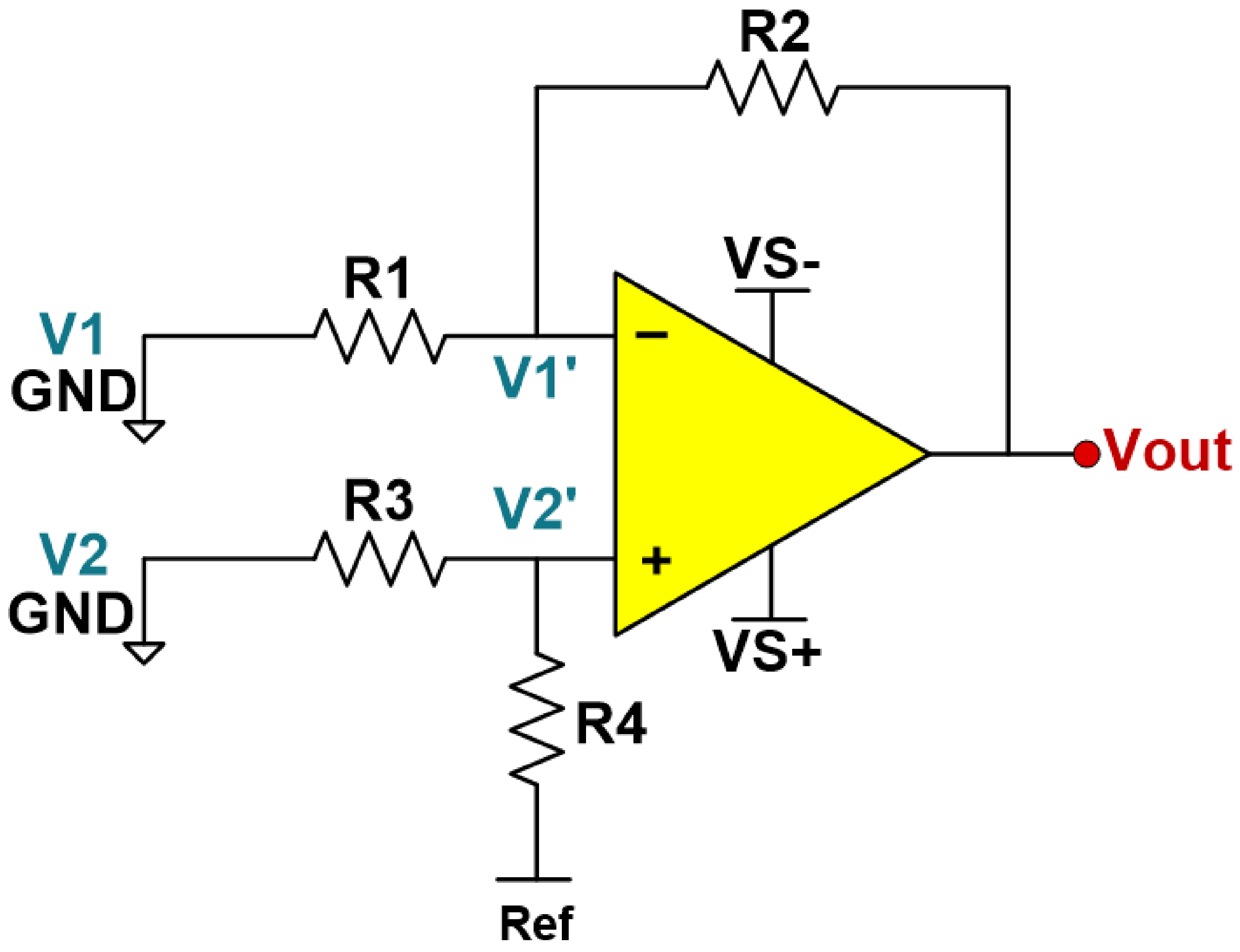
$$V2' = \frac{Ref\ +\ V2}{2}$$

$$Vout = \frac{Ref + V2}{2} \times \left(1 + \frac{R2}{R1}\right)$$

Since R1 = R2 = R3 = R4, and Ref = 0V

***Vout = V2* (Equation V2*)**

Superposition – Ground V1 and V2



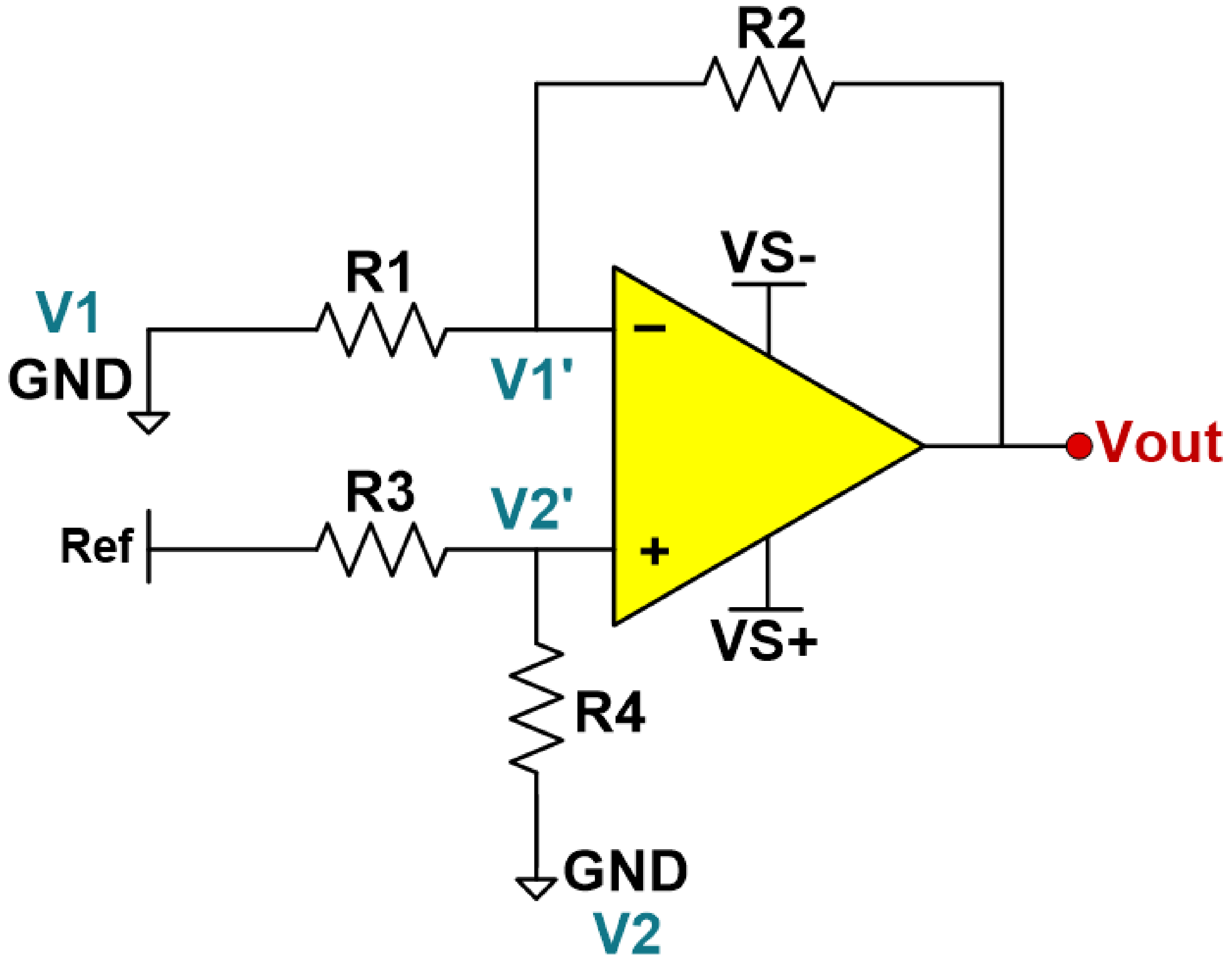
Derive output due to Ref:

Ground inverting and non-inverting inputs

Since R1 = R2 = R3 = R4,

Ref and V2 are interchangeable

Superposition – Ground V1 and V2



Looks like a non-inverting configuration with the following output equation:

$$Vout = \left(1 + \frac{R2}{R1}\right) \times V2'$$

$$V2' = \frac{R4}{R3 + R4} \times Ref$$

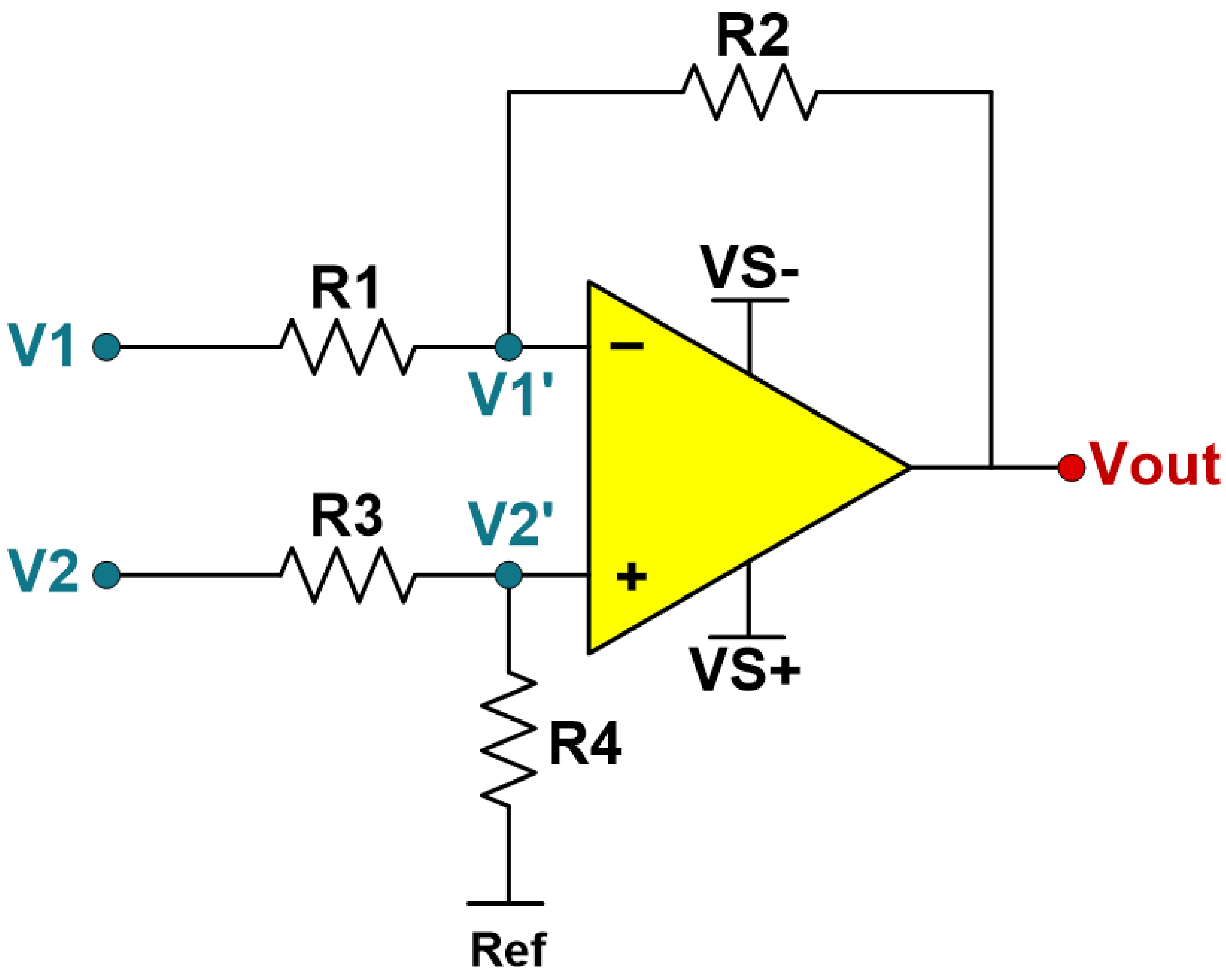
$$Since\ R1 = R2 = R3 = R4,$$

$$V2' = \frac{1}{2} \times Ref, and$$

$$Vout = \left(1 + \frac{R2}{R1}\right) \times \frac{1}{2} \times Ref = Ref$$

Vout = Ref (Equation Ref*)

One-amp IA topology – Ideal model analysis, Vd



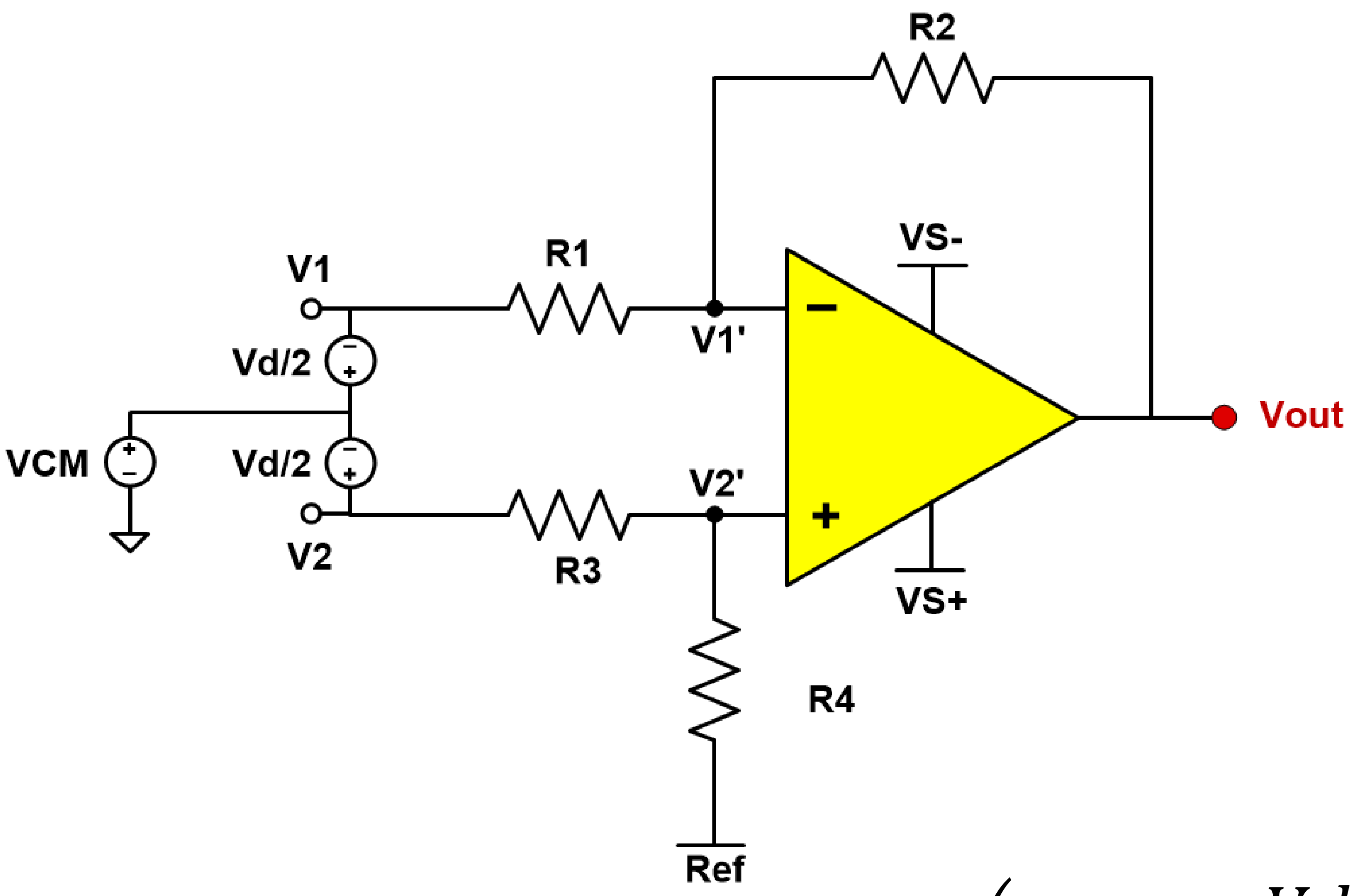
	V1	V2	Ref
V1* = **-V1**	Keep	Short	Short
V2* = **V2**	Short	Keep	Short
Ref* = **Ref**	Short	Short	Keep
Vout = V1* + V2* + Ref*			

Combine Equations V1*, V2* and Ref*:

Vout = V2 - V1 + Ref

Where V2 – V1 = differential voltage, $\mathbf{V_d}$

One-amp IA topology – Ideal model analysis, V_{CM}



Vout = V2 - V1 + Ref

(V2 – V1) = Vd

Common mode rejection analysis:

Common mode input voltage is equal at each input

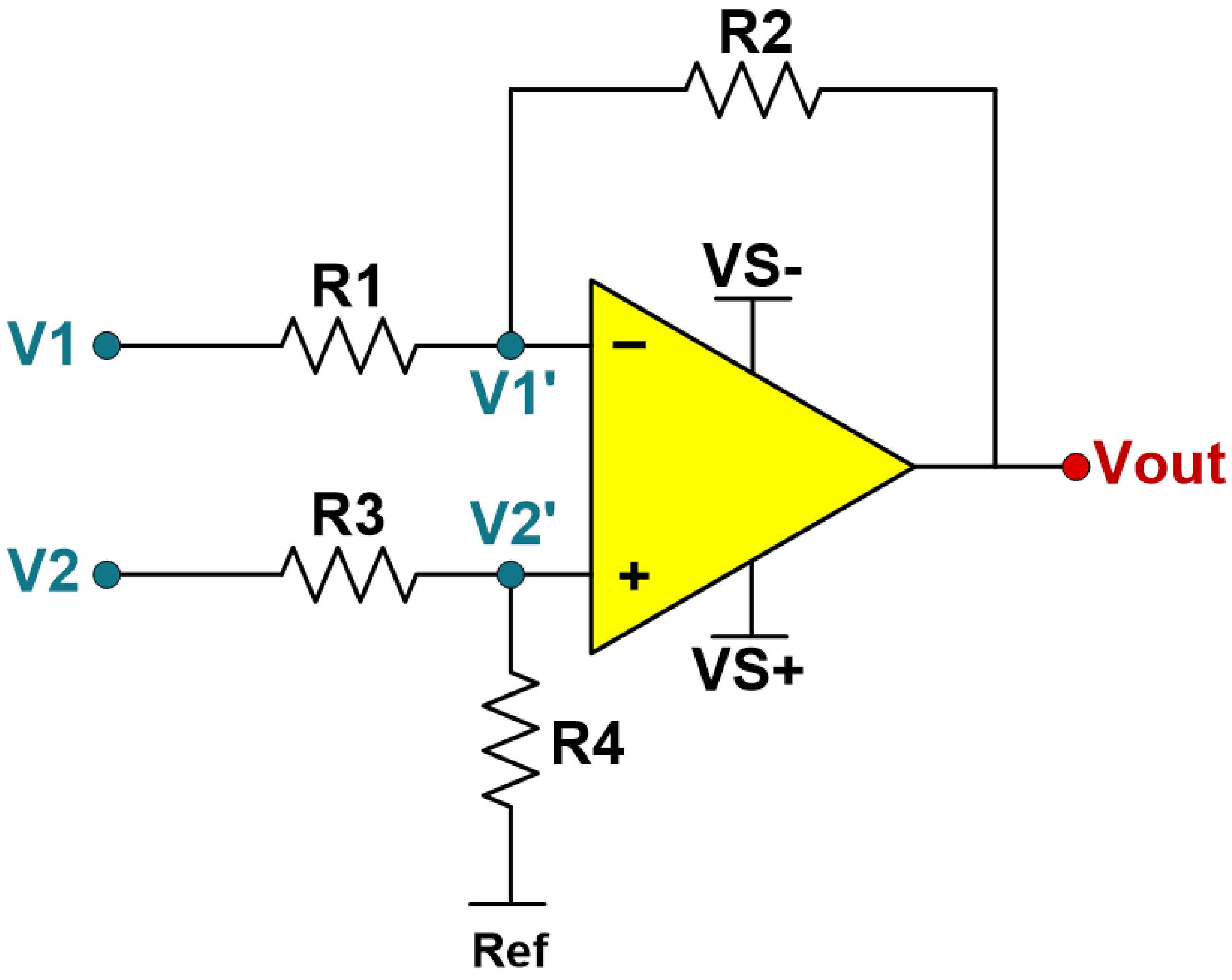
$$V1 = VCM - \frac{Vd}{2}$$

$$V2 = VCM + \frac{Vd}{2}$$

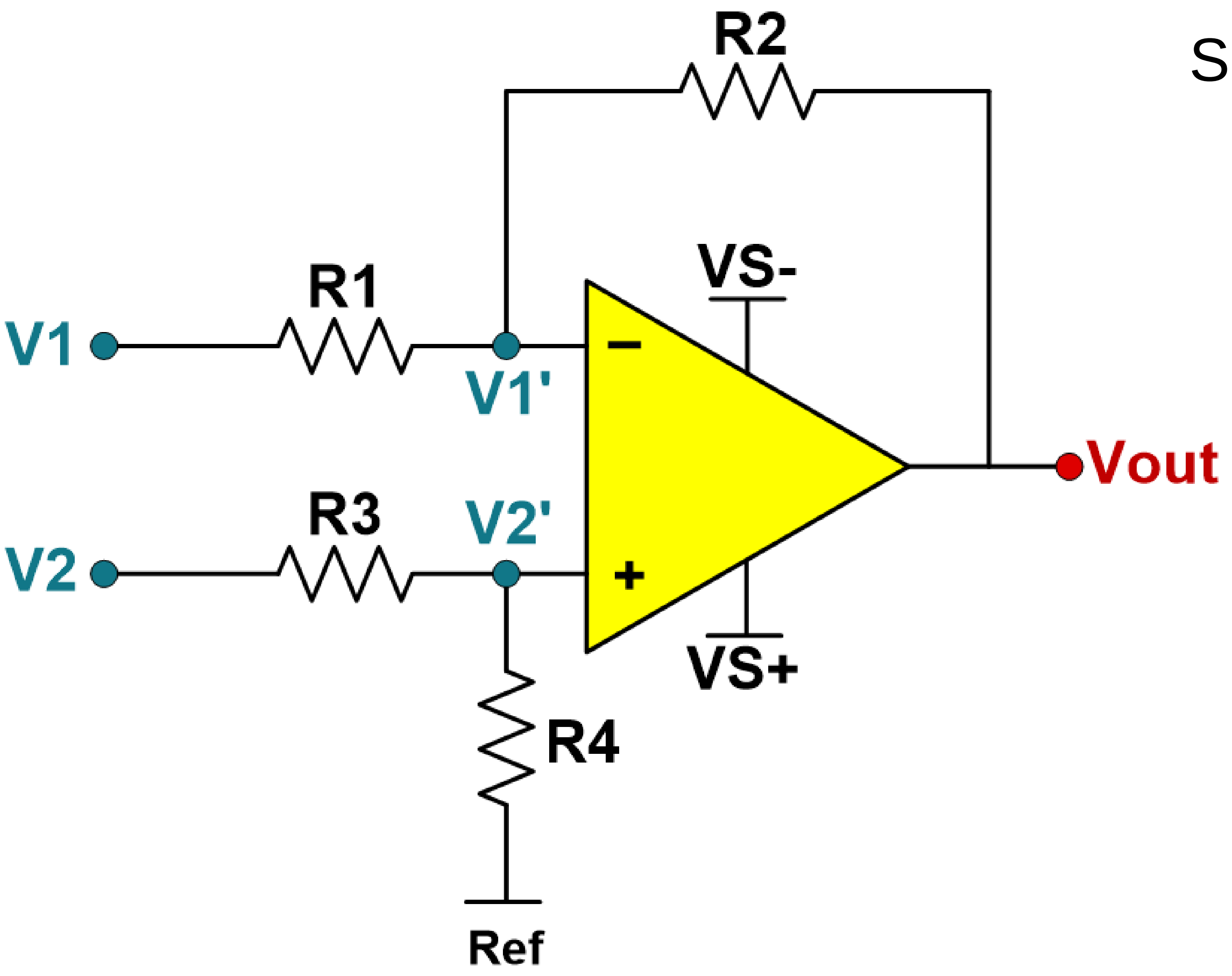
$$Vout = V2 - V1 + Ref = \left(VCM + \frac{Vd}{2}\right) - \left(VCM - \frac{Vd}{2}\right) + Ref = Vd + Ref$$

One-amp IA topology – General equation

$$\text{Vout} = \left(-\text{V1} \times \frac{\text{R2}}{\text{R1}}\right) + \left(\text{Ref} + (\text{V2} - \text{Ref}) \times \frac{\text{R4}}{\text{R3} + \text{R4}}\right) \times \left(\frac{\text{R1} + \text{R2}}{\text{R1}}\right)$$



One-amp IA topology – Simplified equation



Simplified equation:

"Differential gain, Ad"

$$Vout = \frac{R2}{R1} \times (V2 - V1) + Ref$$

"Differential input voltage, V_d"

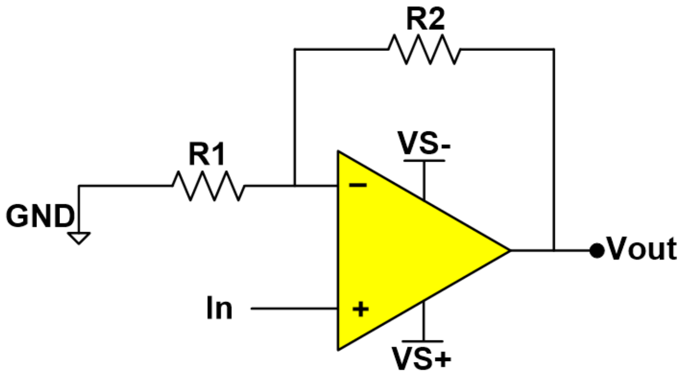
$$\mathbf{Vout = Ad \times Vd + Ref}$$

Bandwidth – Noise gain versus signal gain

Gain – two types:

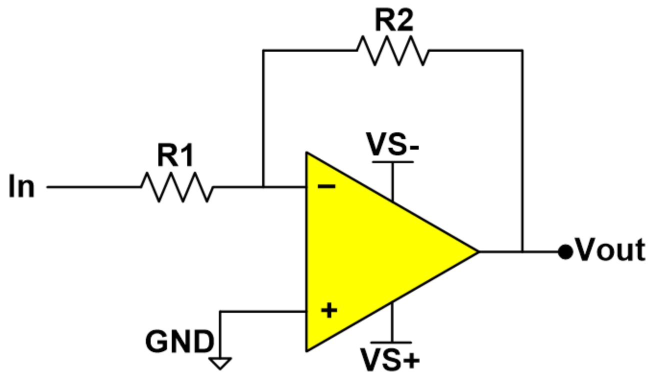
1. Signal gain:
   - Determines the input-output relationship
   - Dependent on amplifier configuration
   - Defined as Ad in an difference amplifier

2. Noise gain:
   - Non-inverting gain of the amplifier
   - Determines bandwidth, stability, and more
     - GBW = Noise gain * BW
   - Noise gain = 1+Ad for the difference amplifier



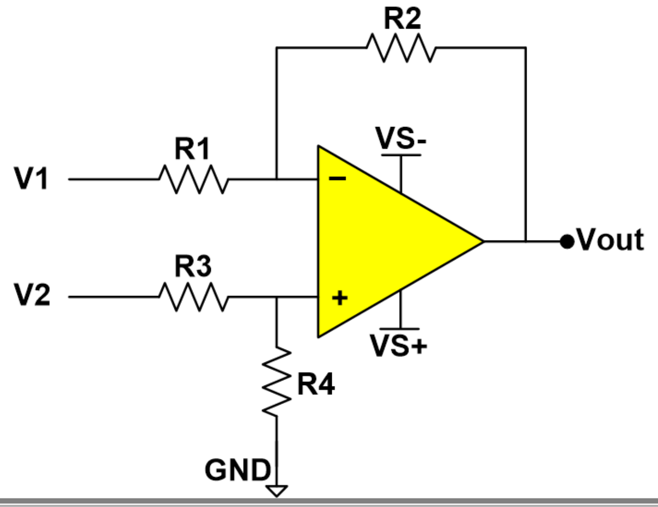
$$Signal\ Gain = 1 + \frac{R2}{R1}$$

$$Noise\ Gain = 1 + \frac{R2}{R1}$$



$$Signal\ Gain = -\frac{R2}{R1}$$

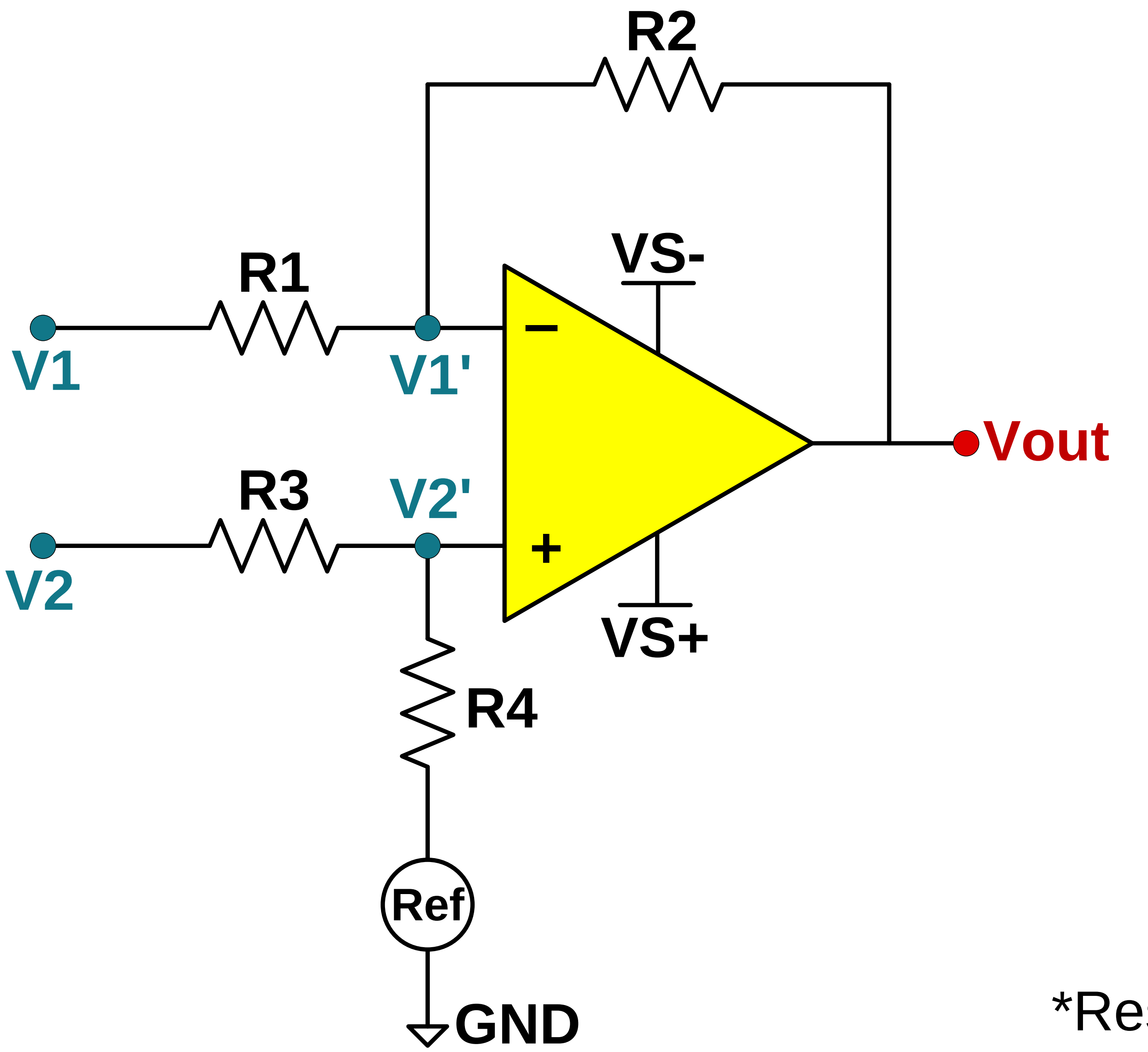
$$Noise\ Gain = 1 + \frac{R2}{R1}$$



$$Signal\ Gain = Ad = \frac{R2}{R1}$$

$$Noise\ Gain = Ad + 1 = 1 + \frac{R2}{R1}$$

One-amp IA topology – General equation



General equation:

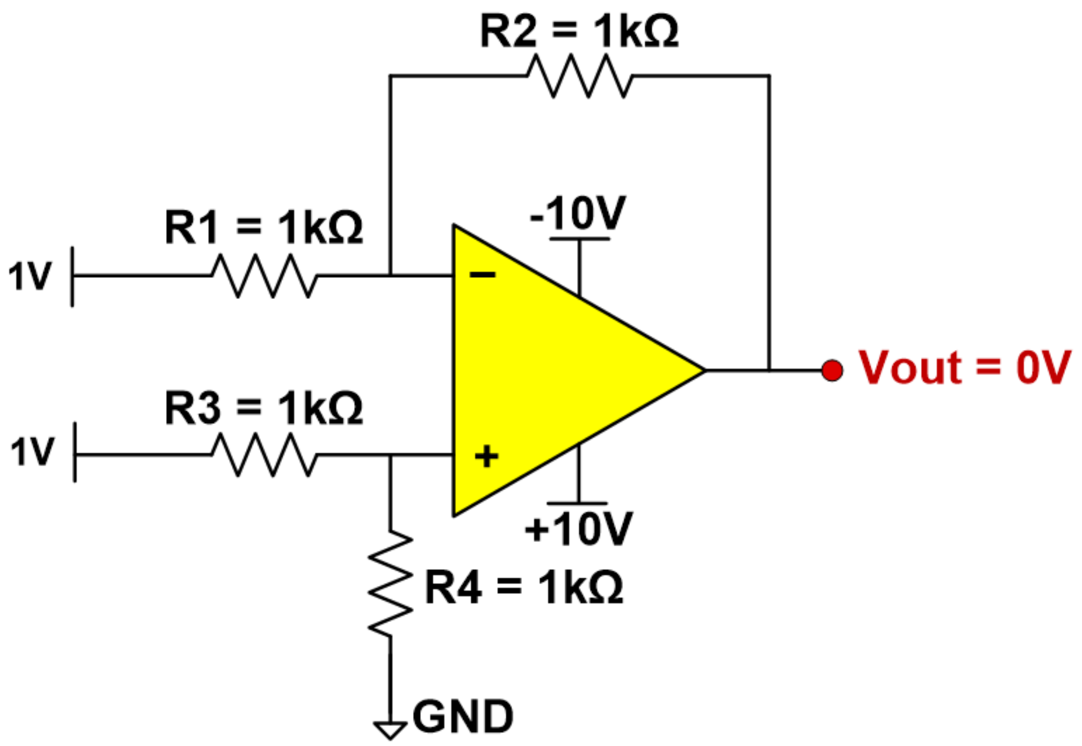
“Differential gain, Ad”

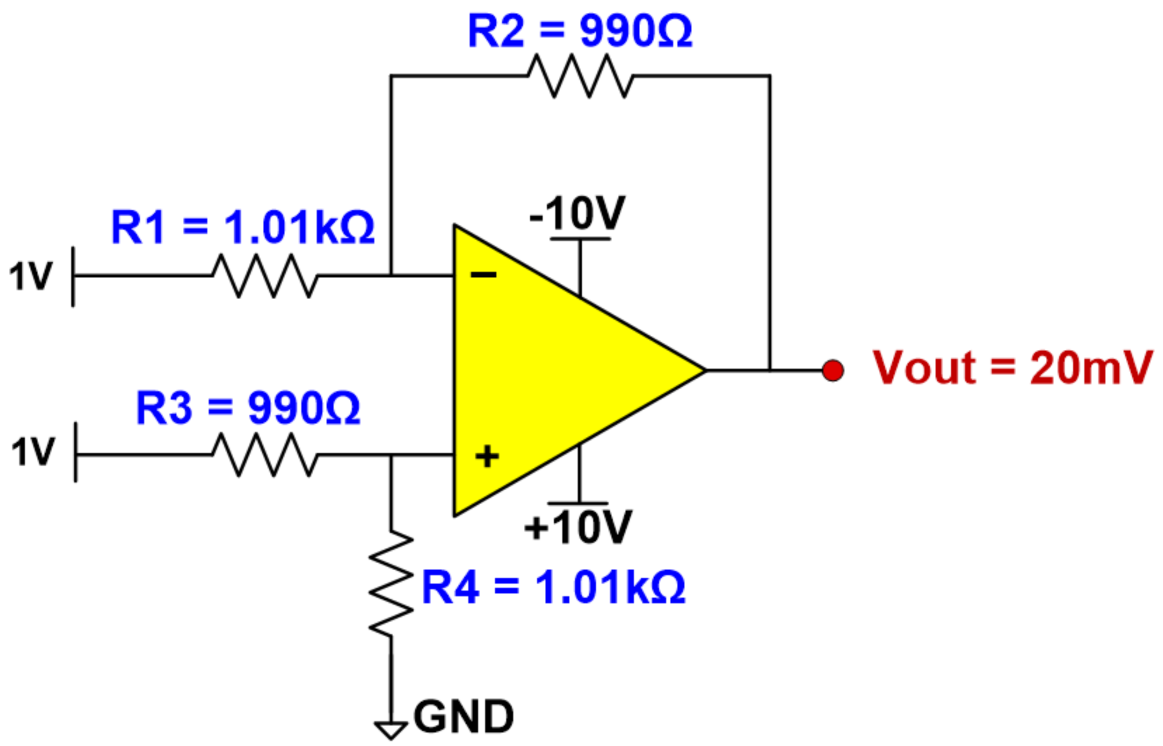
$$Vout = \frac{R2}{R1} \times (V2 - V1) + Ref$$

“Differential input voltage, V_d”

Resistors cannot be perfectly matched so R1 ≠ R2 ≠ R3 ≠ R4 and CMRR will be degraded!

Resistor matching – Mismatch effect



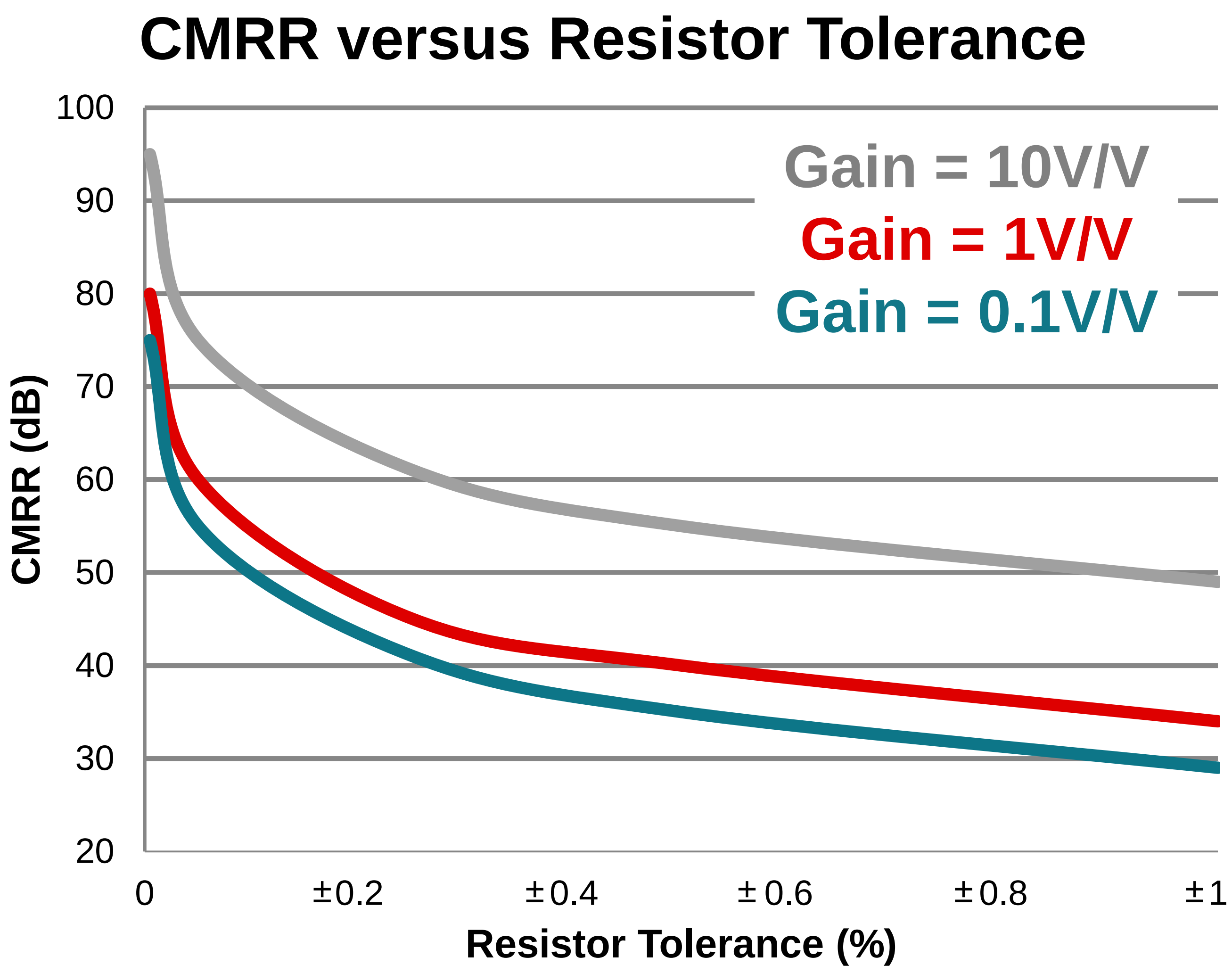


$$CMRR = 20 \times log_{10}\left(\frac{1}{\Delta V_{CM}}\right) = 20 \times log_{10}\left(\frac{1}{20m}\right)$$

$$\boldsymbol{CMRR = 34dB}$$

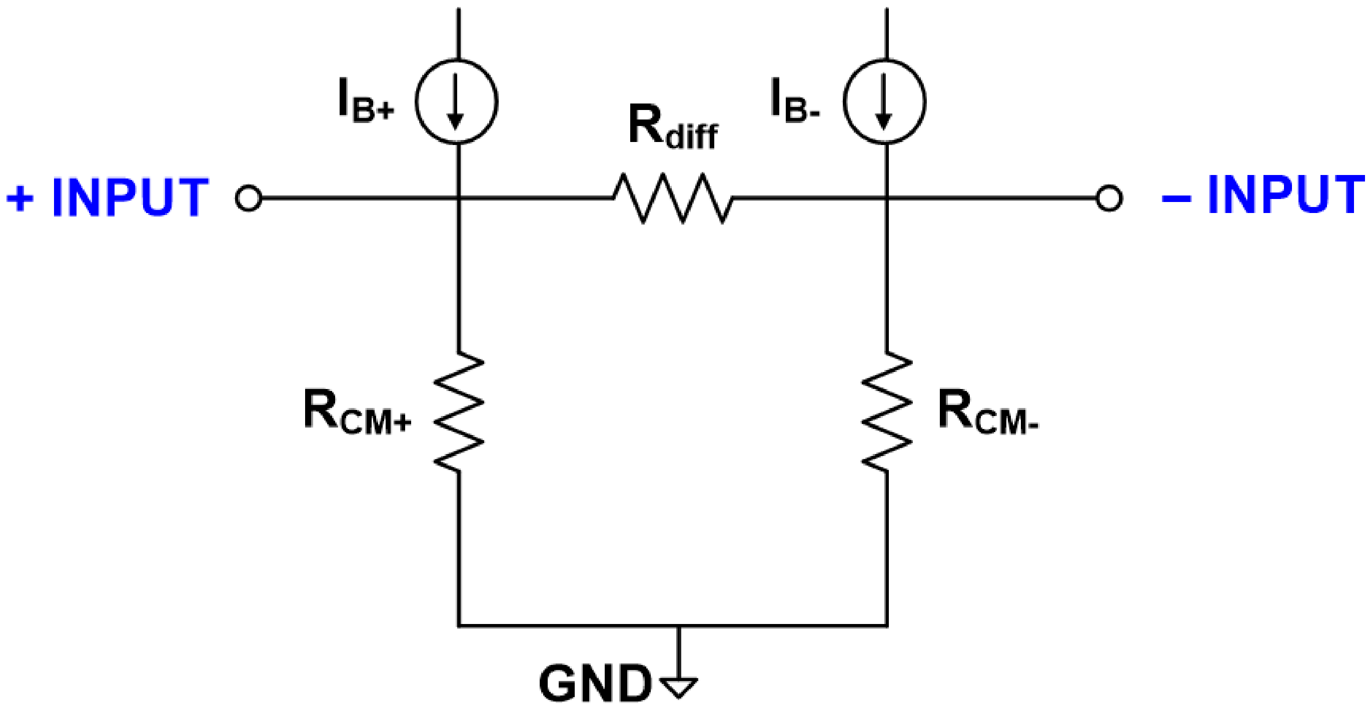
Resistor analysis – CMRR performance

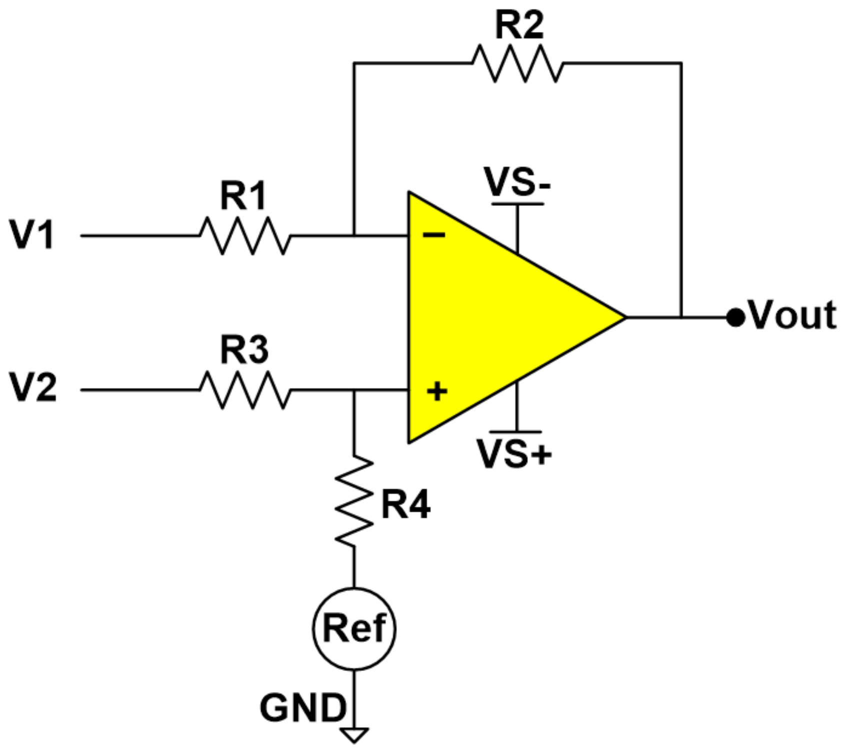
Resistor tolerance mismatch	CMRR Gain = 1V/V	CMRR Gain = 10V/V	CMRR Gain = 0.1V/V
±1%	34dB	49dB	29dB
±0.5%	40dB	55dB	35dB
±0.25%	46dB	61dB	41dB
±0.1%	54dB	69dB	49dB
±0.05%	60dB	75dB	55dB
±0.005%	80dB	95dB	75dB



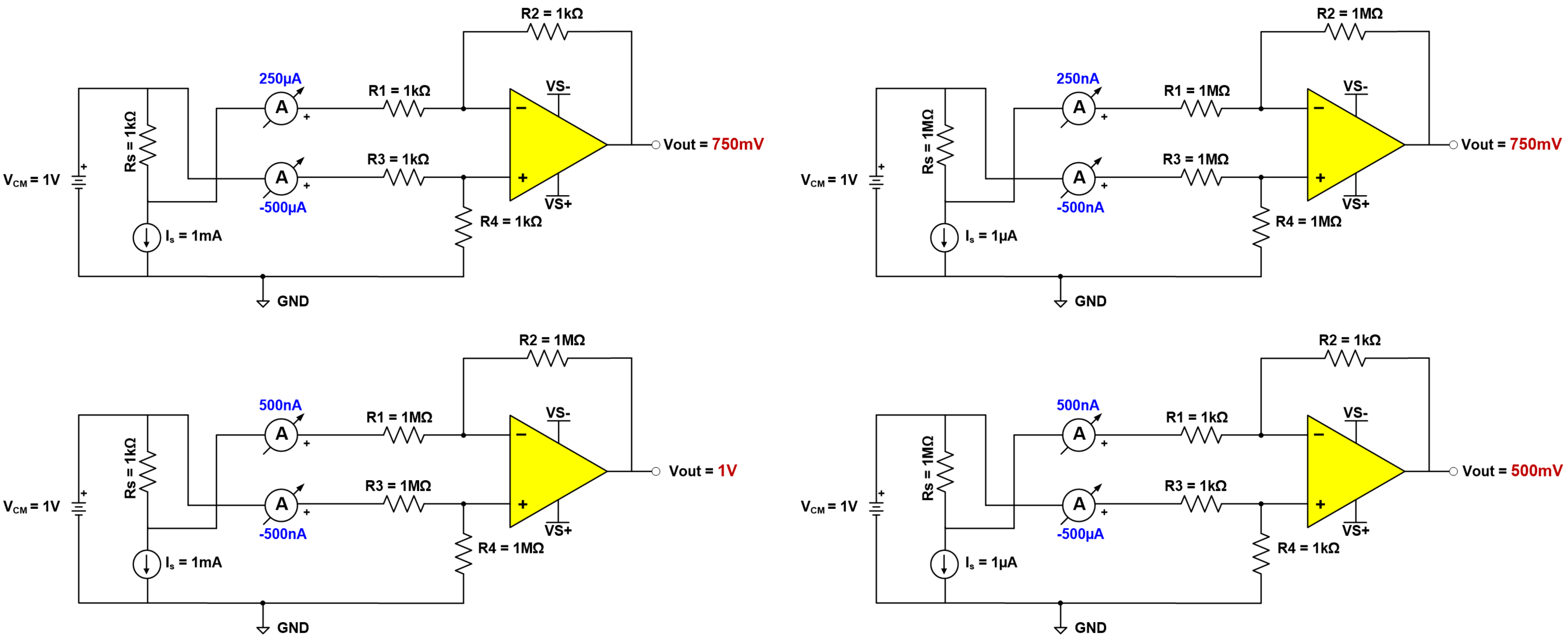
Difference amplifier – Input impedance

- **Input impedance:** change of input voltage divided by the corresponding change in input current.
- Two types:
  1. Differential input impedance: Rdiff = R1 + R3
  2. Common mode input impedance: Rcm+ and Rcm– = (R3+R4)||(R1+R2)



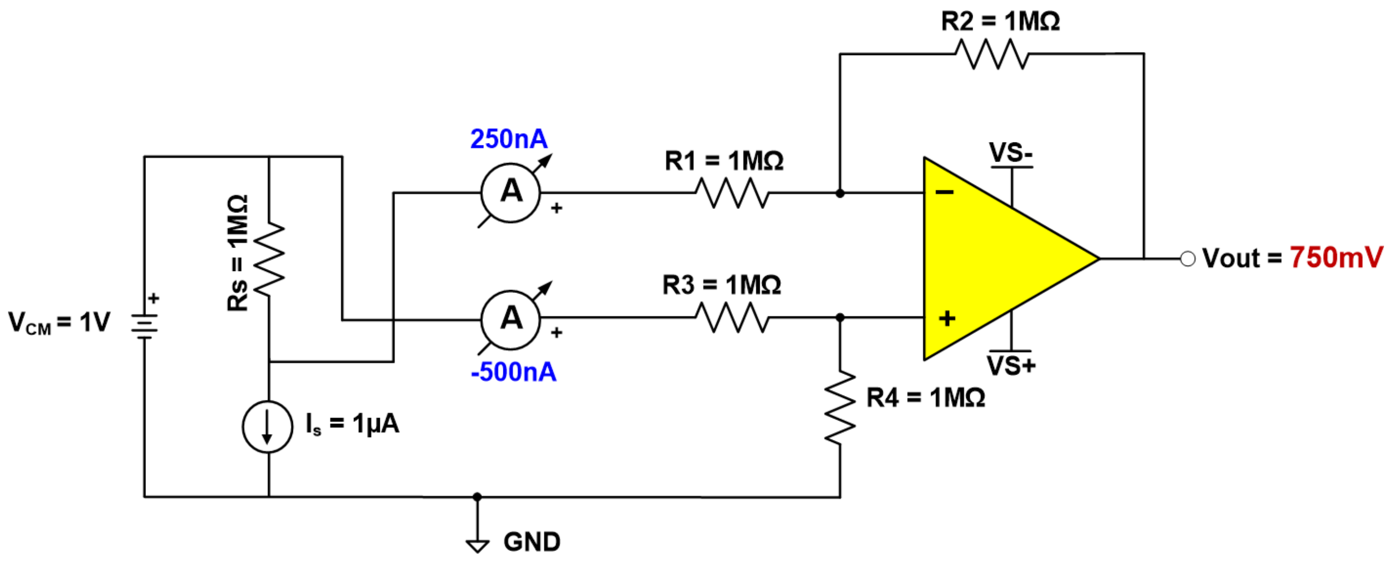


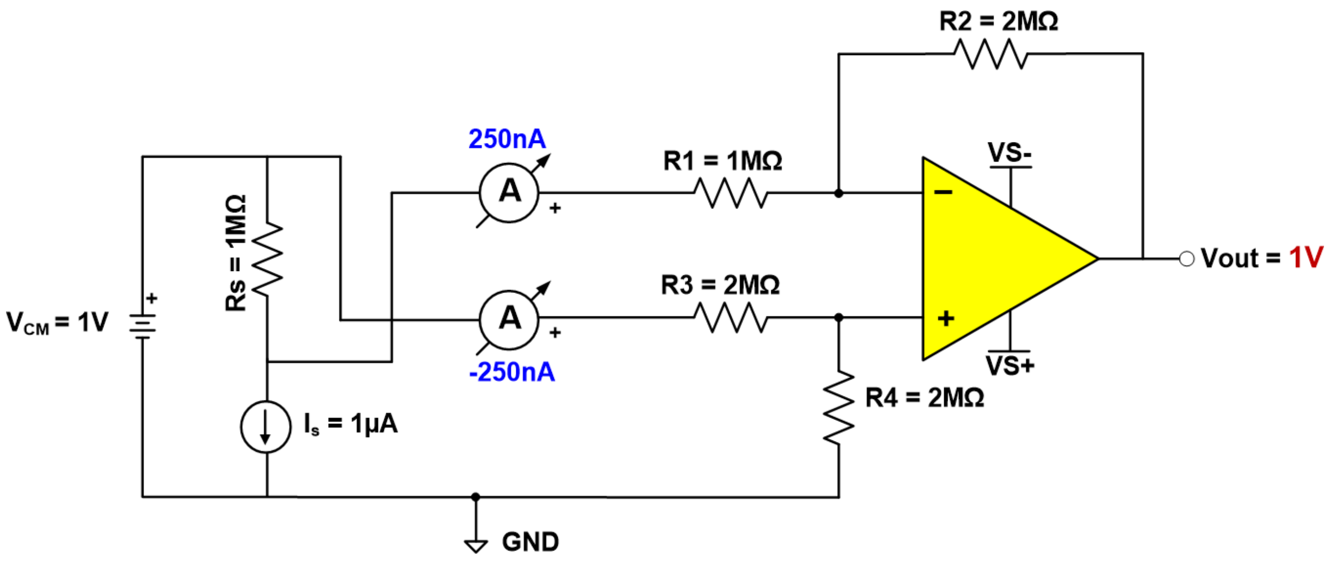
Input impedance – Current sensing



Rule-of-thumb: $RIN_{DA} \geq 100 \times ROUT_{Source}$

Input impedance – Current sensing cont'd





Differential input impedance: Rdiff = R1 + R3

Rdiff = Rs + R1 + R3 = 3MΩ

Rdiff- = Rs + R1 = 2MΩ

Rdiff+ = R3 = 1MΩ

Common mode input impedance: Rcm+ and Rcm– = (R3+R4)||(R1+R2+Rs)

Rcm = 1.2MΩ

Differential input impedance: Rdiff = R1 + R3

Rdiff = Rs + R1 + R3 = 4MΩ

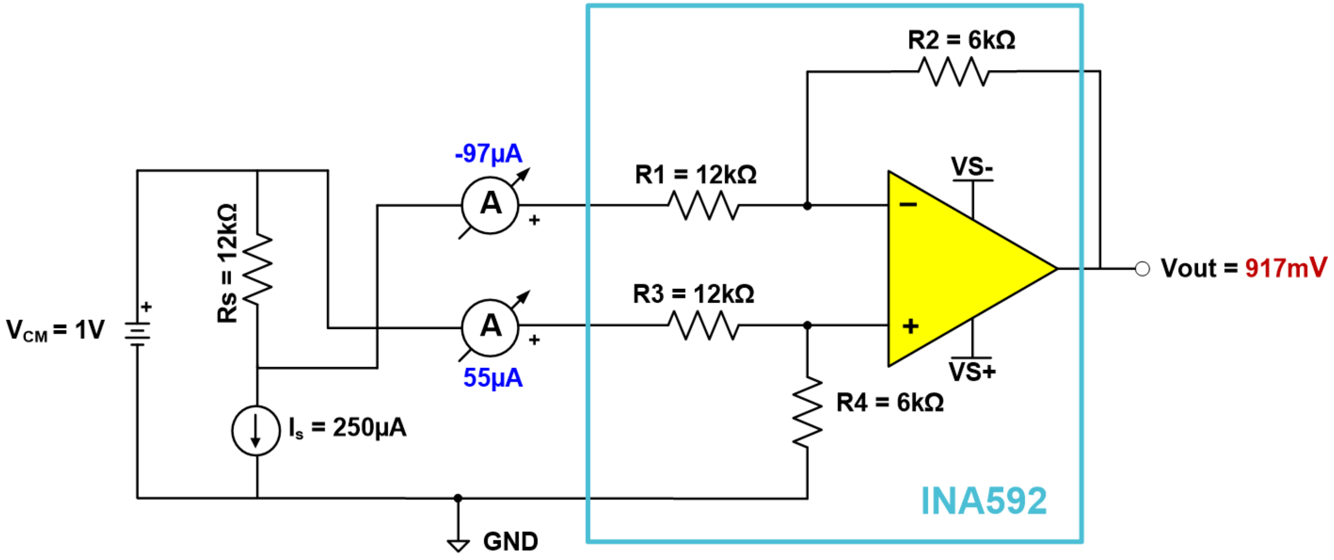
Rdiff- = Rs + R1 = 2MΩ

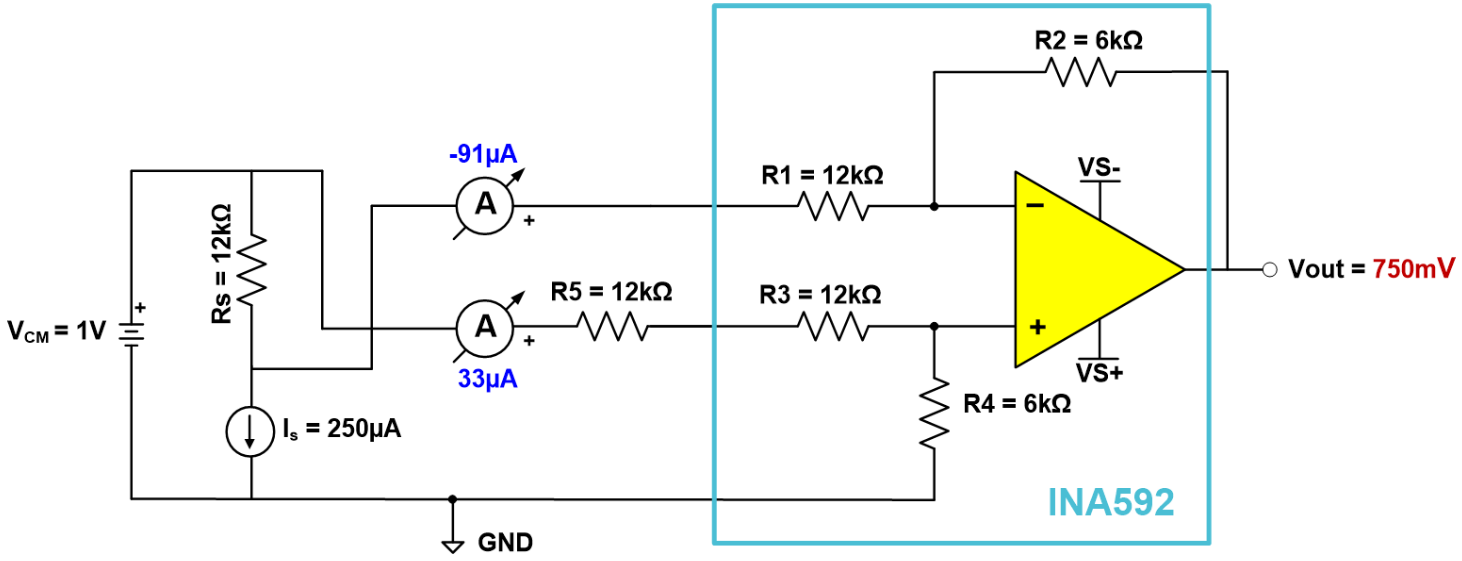
Rdiff+ = R3 = 2MΩ

Common mode input impedance: Rcm+ and Rcm– = (R3+R4)||(R1+R2+Rs)

Rcm = 2MΩ

Input impedance – Current sensing cont'd





Differential input impedance:

Rdiff = Rs + R1 + R3 = 36kΩ

Rdiff- = Rs + R1 = 24kΩ

Rdiff+ = R3 = 12kΩ

Common mode input impedance: Rcm+ and Rcm– = (R3+R4)||(R1+R2+Rs)

Rcm = 11.25kΩ

Differential input impedance:

Rdiff = Rs + R1 + R3 = 36kΩ

Rdiff- = Rs + R1 = 24kΩ

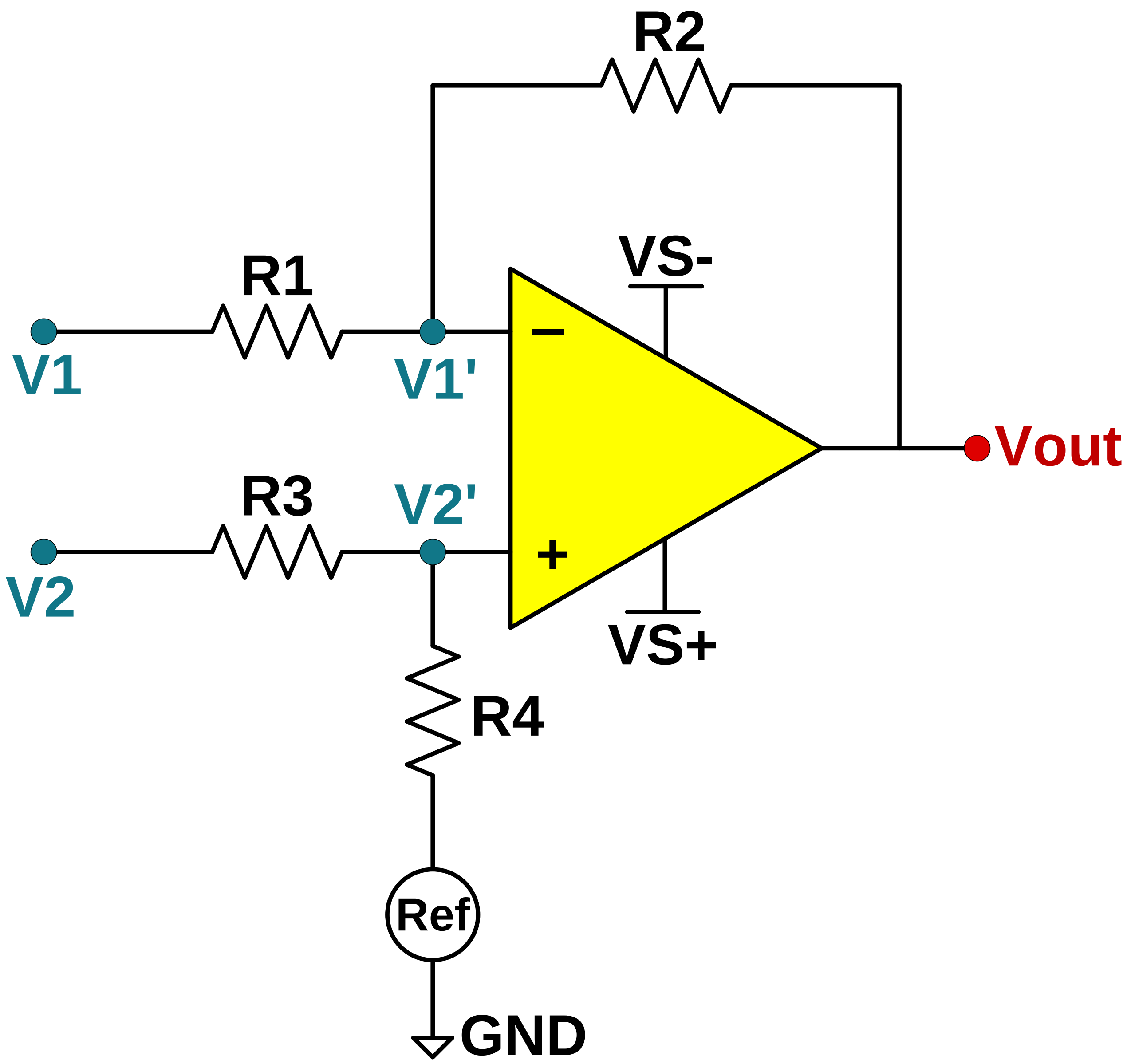
Rdiff+ = R3 + R5 = 24kΩ

Common mode input impedance: Rcm+ and Rcm– = (R3+R4+R5)||(R1+R2+Rs)

Rcm = 15kΩ

Vout = Vd × Ad = 3V × ¼ V/V = 750mV

One amp IA topology – Design summary



Design challenges:

- Low input impedance
- Challenge to match resistances

Summary:

If you have an application where you have low impedance sources and high common mode voltages, consider a one-amp IA (difference amplifier) topology

Thanks for your time!
Please try the quiz.

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TI Precision Labs – Instrumentation Amplifiers

Presented by Tamara Alani

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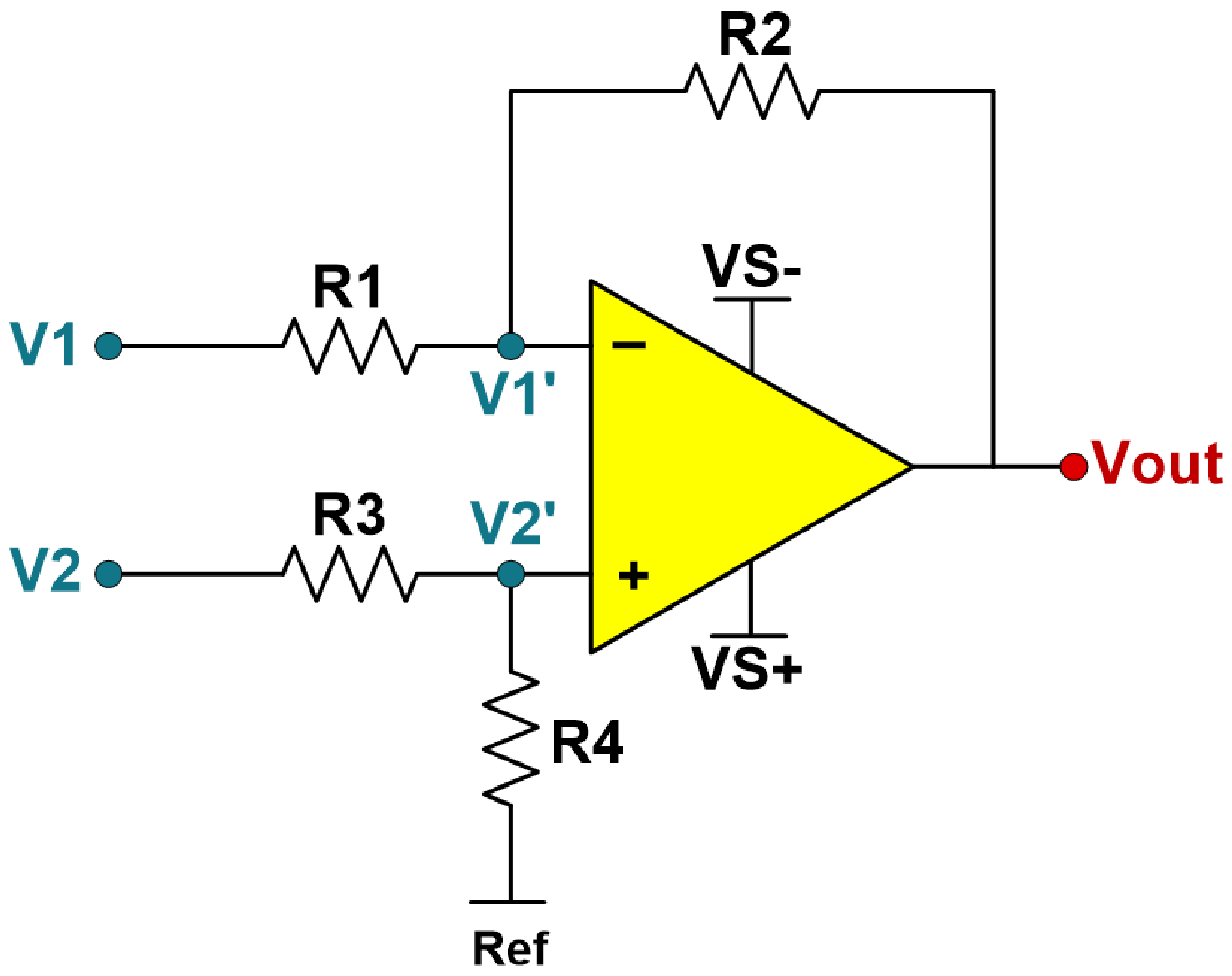
Quiz: (IA) topologies: one-amp || Question

1. What is the output equation of a one-amp IA assuming all resistances are equal to each other?

   a) Vout = V2 × V1
   b) Vout = V2 – V1 + Ref
   c) Vout = Ref × (V2 – V1)
   d) Vout = V1 × V2 × Ref



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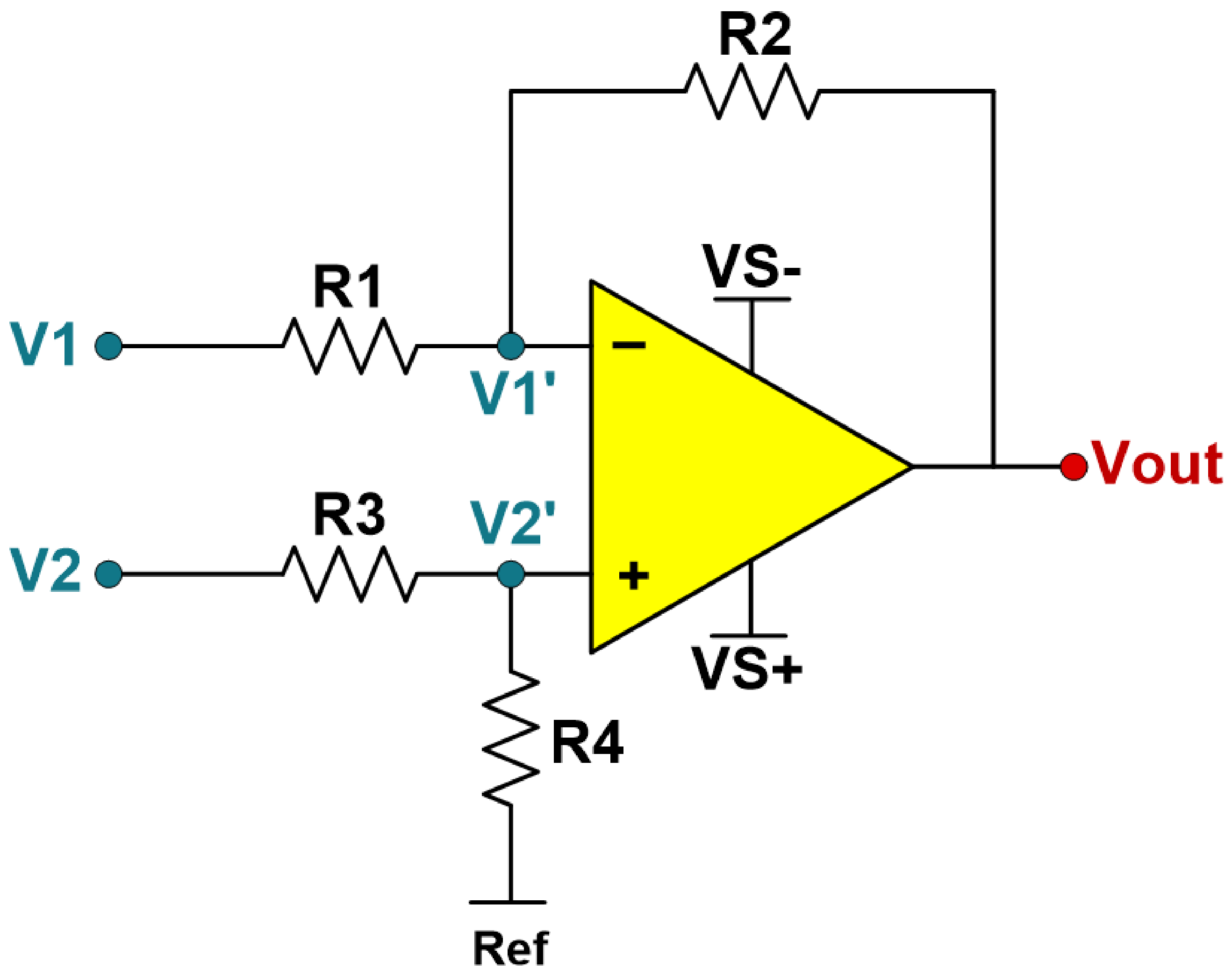
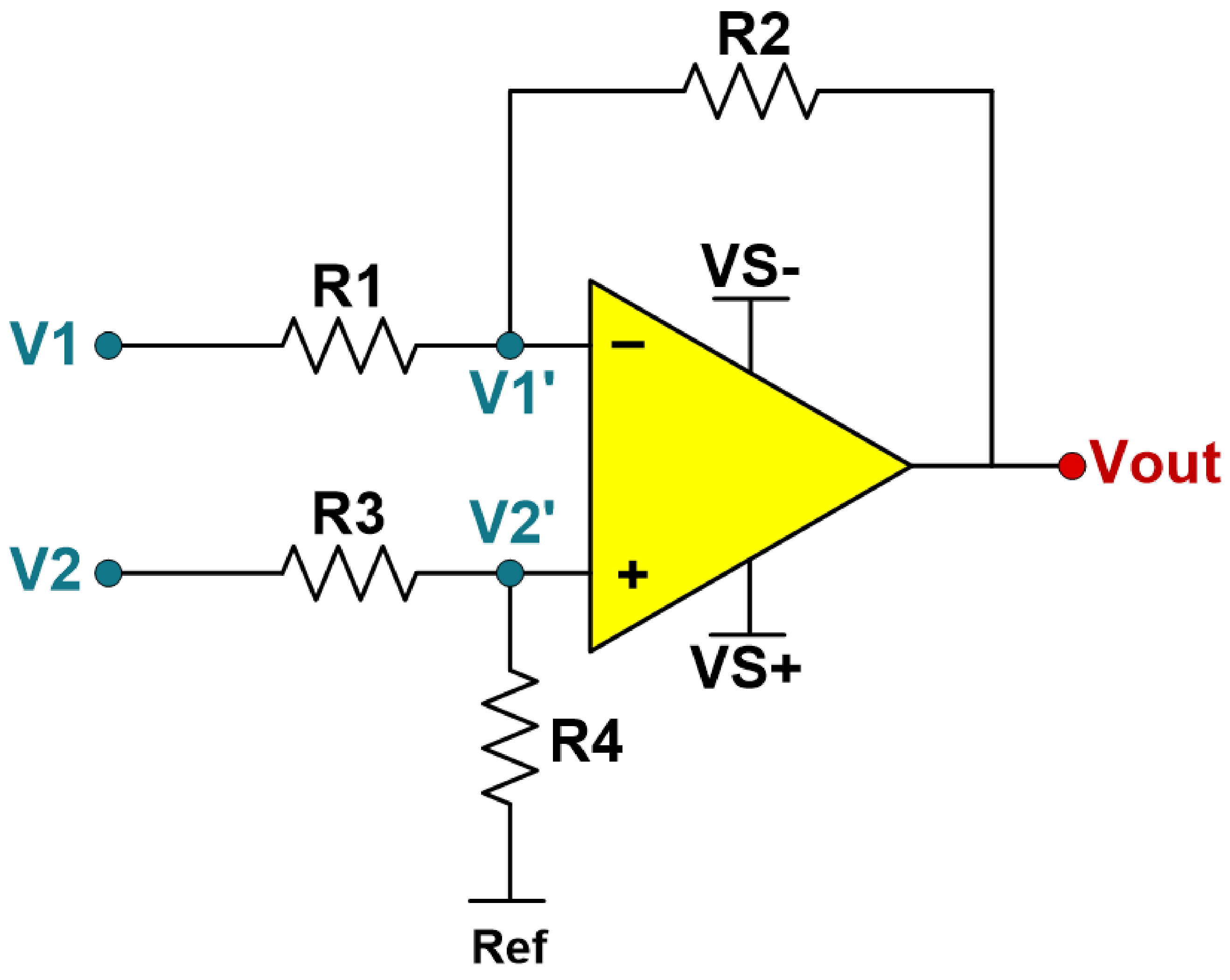


Quiz: (IA) topologies: one-amp || Question

2. If we match R1 to R3 and R2 to R4, what is the differential gain (A_d) of the following circuit?

a) A_d = R2 / R1
b) A_d = R1 × R2
c) A_d = R1 / R2
d) A_d = R3 / R4



Quiz: (IA) topologies: one-amp || Answer

2. If we match R1 to R3 and R2 to R4, what is the differential gain (A_d) of the following circuit?

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   c) A_d = R1 / R2
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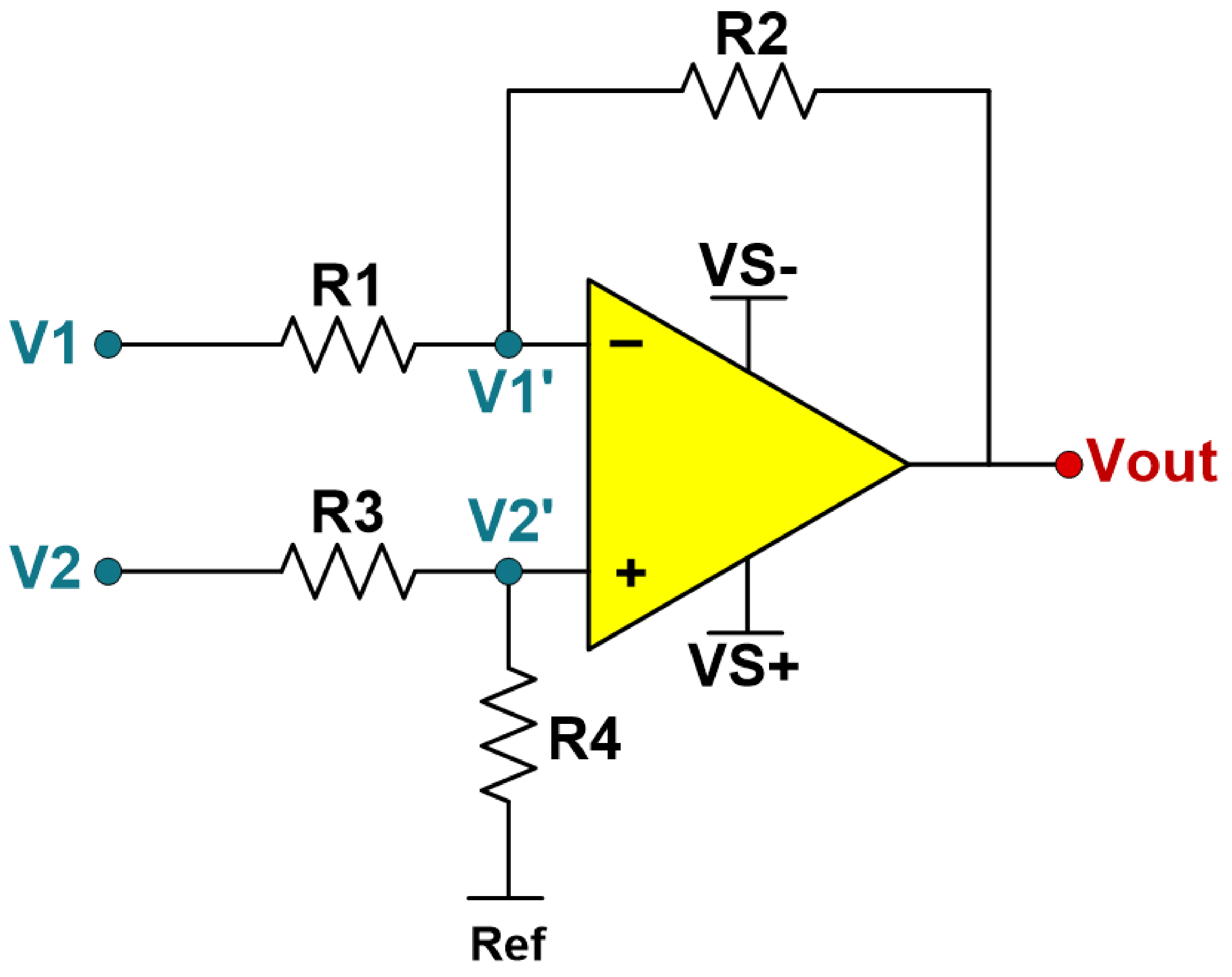

Quiz: (IA) topologies: one-amp || Question

3. Which of the following statements is true of signal gain and noise gain?

   a) Signal gain determines the bandwidth of the circuit, and noise gain is the non-inverting gain of the amplifier
   b) Signal gain is dependent on the amplifier's configuration and determines the input-output relationship.
   c) The noise gain of a circuit determines many features of the amplifier, including bandwidth and stability, and is defined as the non-inverting gain.
   d) For a difference amplifier, noise gain is defined as A_d and signal gain is defined as $A_d + 1$
   e) B & C

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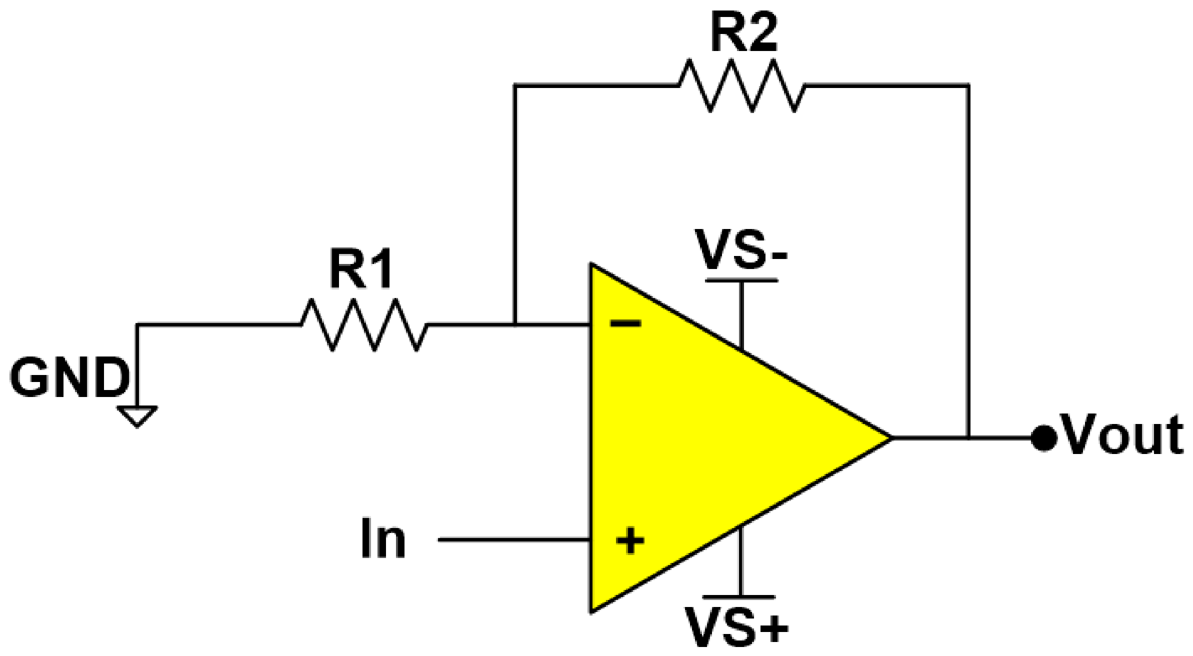
   d) For a difference amplifier, noise gain is defined as A_d and signal gain is defined as $A_d + 1$
   e) **B & C**

Quiz: (IA) topologies: one-amp || Question

4. What is the signal gain and noise gain of the following circuit?

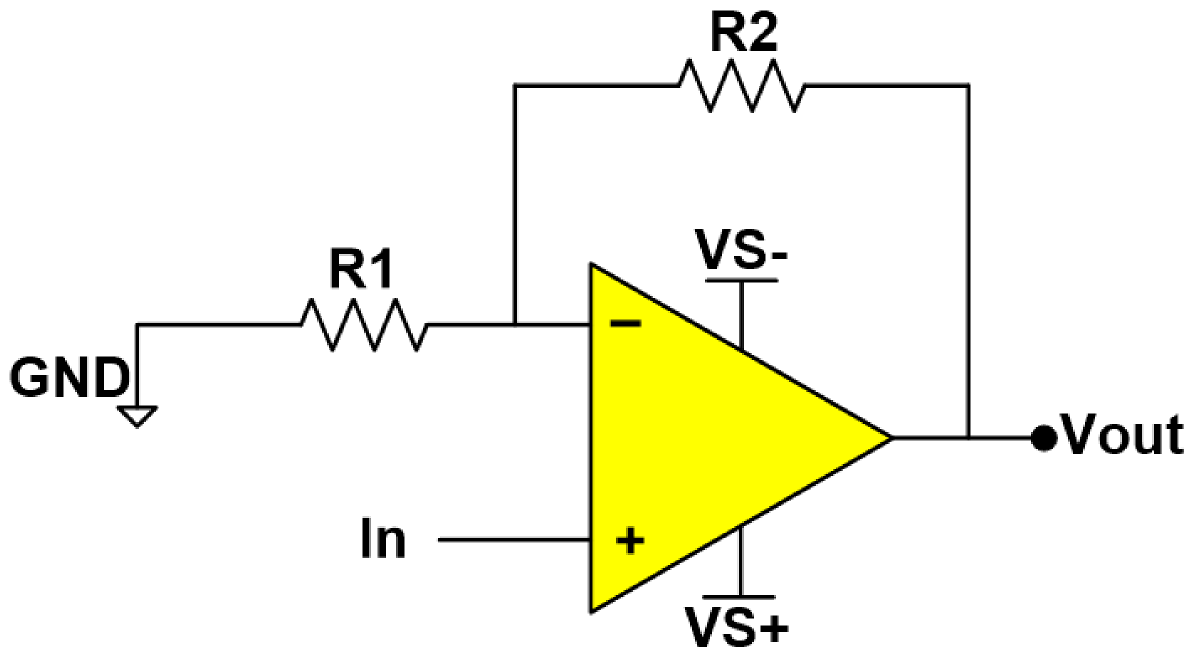
a) Signal gain = -R2 / R1
   Noise gain = 1 – (R2 / R1)
b) Signal gain = 1 + (R2 / R1)
   Noise gain = R2 / R1
c) Signal gain = 1 + (R2 / R1)
   Noise gain = 1 + (R2 / R1)
d) None of the above



Quiz: (IA) topologies: one-amp || Answer

4. What is the signal gain and noise gain of the following circuit?

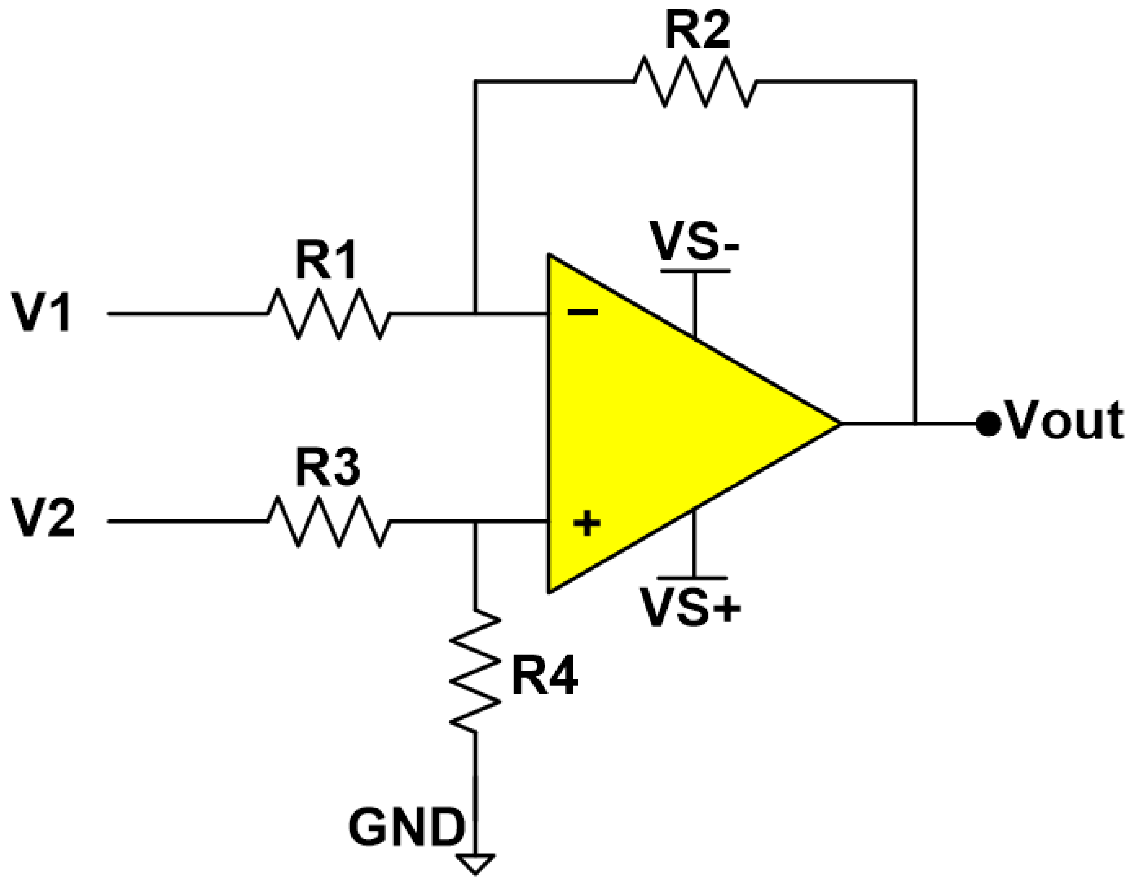
a) Signal gain = -R2 / R1
   Noise gain = 1 – (R2 / R1)
b) Signal gain = 1 + (R2 / R1)
   Noise gain = R2 / R1
c) **Signal gain = 1 + (R2 / R1)**
   Noise gain = 1 + (R2 / R1)
d) None of the above



Quiz: (IA) topologies: one-amp || Question

5. What is the signal gain and noise gain of the following circuit?

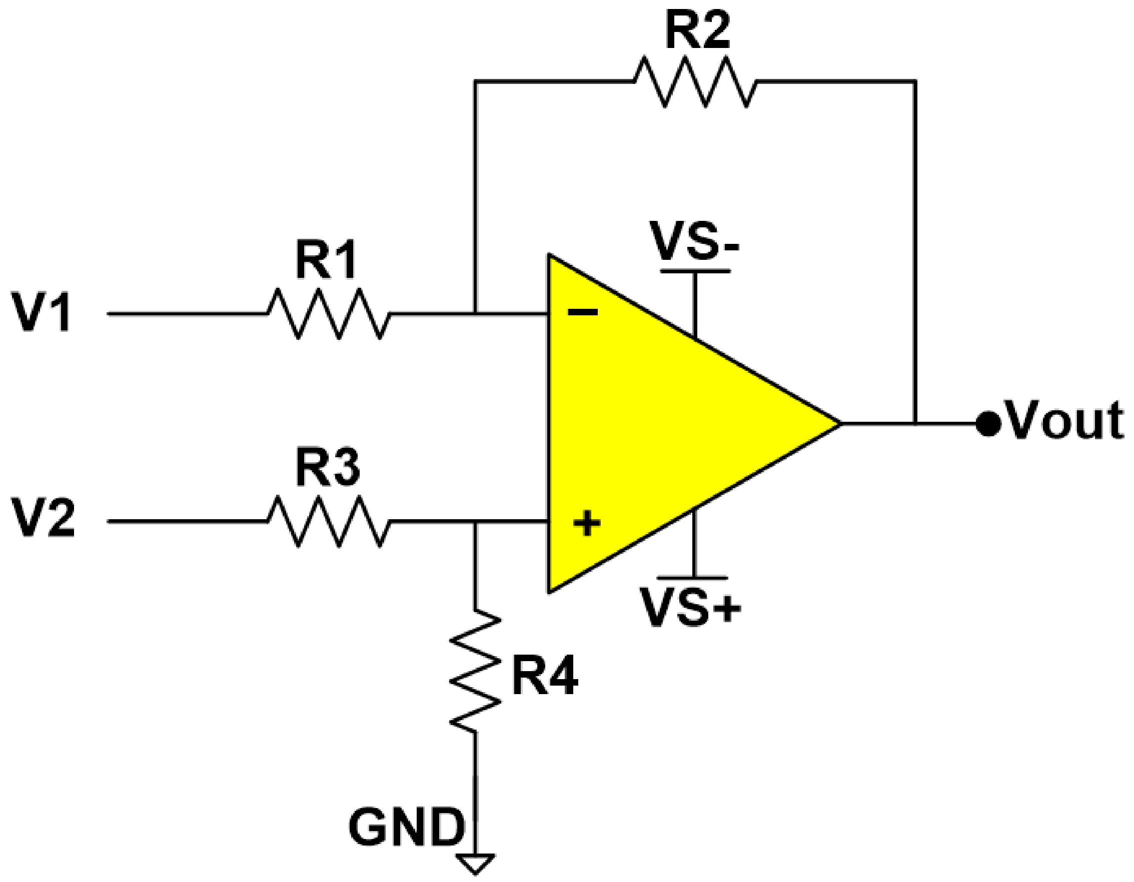
a) Signal gain = -R2 / R1
   Noise gain = 1 – (R2 / R1)
b) Signal gain = 1 + (R2 / R1)
   Noise gain = R2 / R1
c) Signal gain = R2 / R1
   Noise gain = 1 + (R2 / R1)
d) None of the above



Quiz: (IA) topologies: one-amp || Answer

5. What is the signal gain and noise gain of the following circuit?

a) Signal gain = -R2 / R1
   Noise gain = 1 – (R2 / R1)
b) Signal gain = 1 + (R2 / R1)
   Noise gain = R2 / R1
c) **Signal gain = R2 / R1**
   Noise gain = 1 + (R2 / R1)
d) None of the above



Quiz: (IA) topologies: one-amp || Question

6. Which of the following is true of resistor CMRR performance?

   a) CMRR performance due to resistor mismatch is improved in low gain or attenuated circuits
   b) CMRR performance due to resistor mismatch is independent of gain
   c) CMRR performance due to resistor mismatch is improved for higher gain circuits
   d) None of the above

Quiz: (IA) topologies: one-amp || Answer

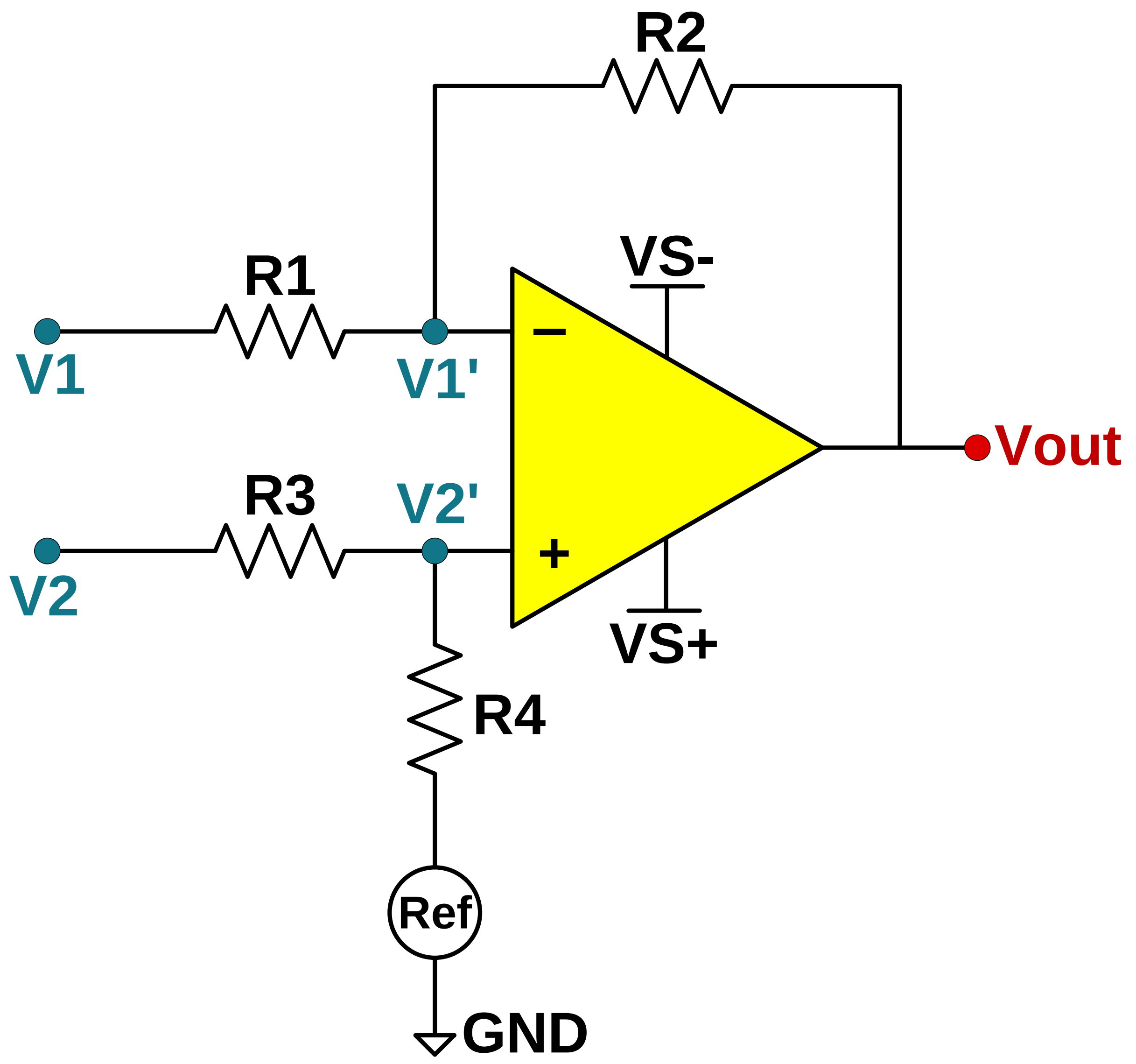
6. Which of the following is true of resistor CMRR performance?

   a) CMRR performance due to resistor mismatch is improved in low gain or attenuated circuits
   b) CMRR performance due to resistor mismatch is independent of gain
   c) **CMRR performance due to resistor mismatch is improved for higher gain circuits**
   d) None of the above

Quiz: (IA) topologies: one-amp || Question

7. Which of the following is true of one-amp IAs?

a) Resistor matching is not crucial, as long as the value of the resistors are high
b) One-amp IAs exhibit low input impedance. If paired with a non-zero output impedance source, accuracy will be degraded.
c) The precision of a one-amp IA relies heavily on resistor matching
d) B & C



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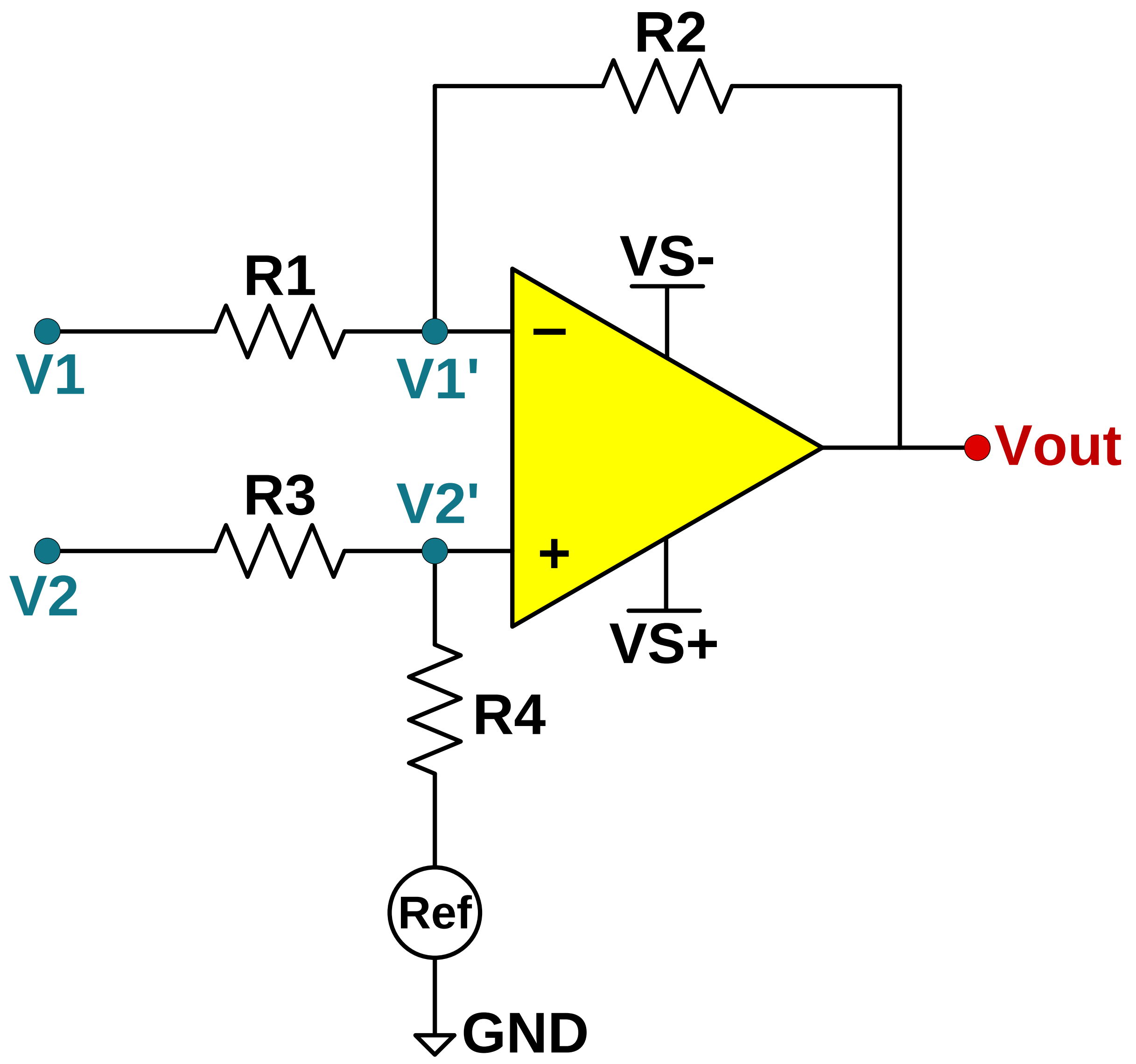
c) The precision of a one-amp IA relies heavily on resistor matching
d) **B & C**



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