Instrumentation Amplifier (IA) topologies: one-amp use cases

TI Precision Labs – Instrumentation Amplifiers

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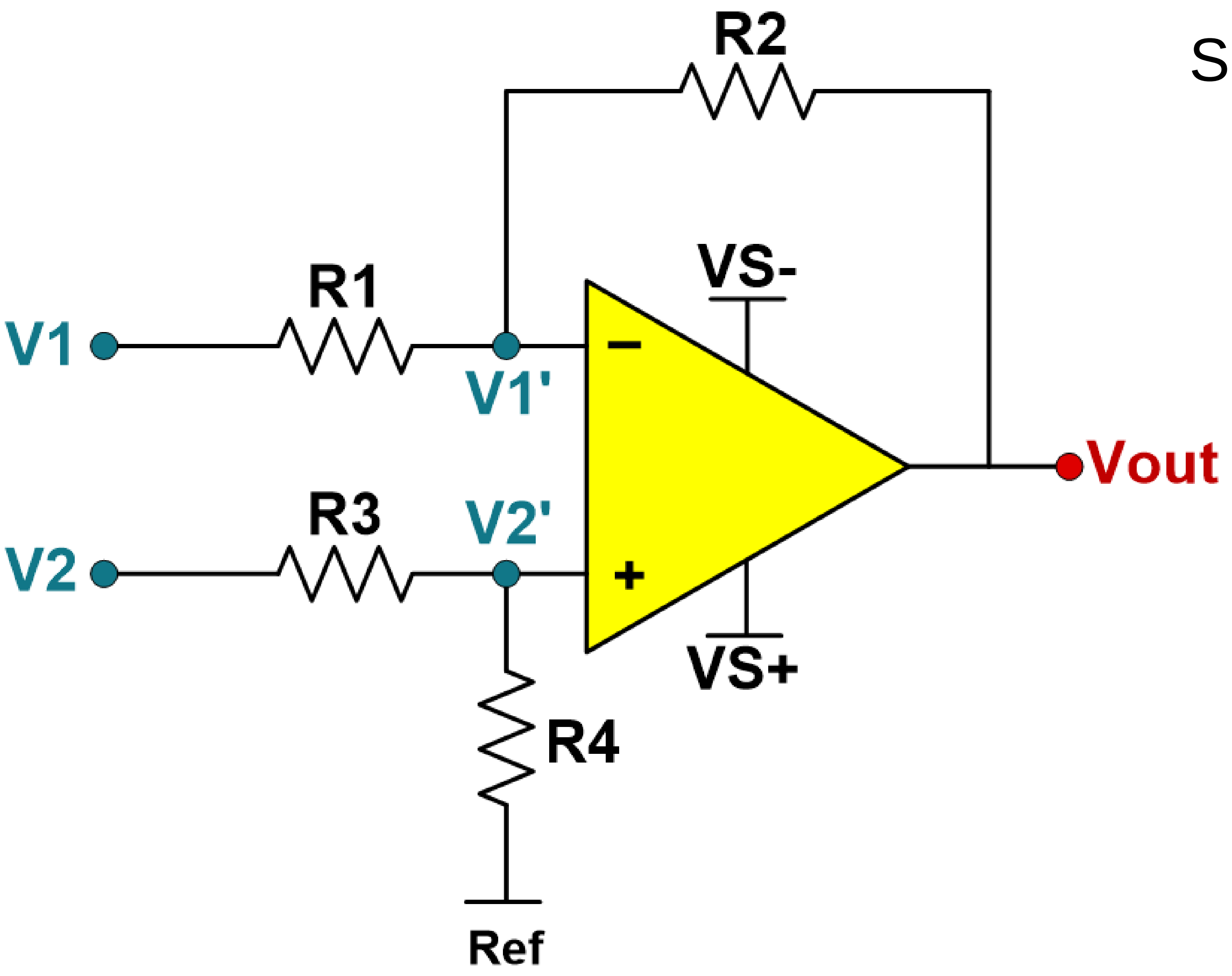
One-amp IA topology – Simplified equation



Simplified equation:

"Differential gain, Ad"

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

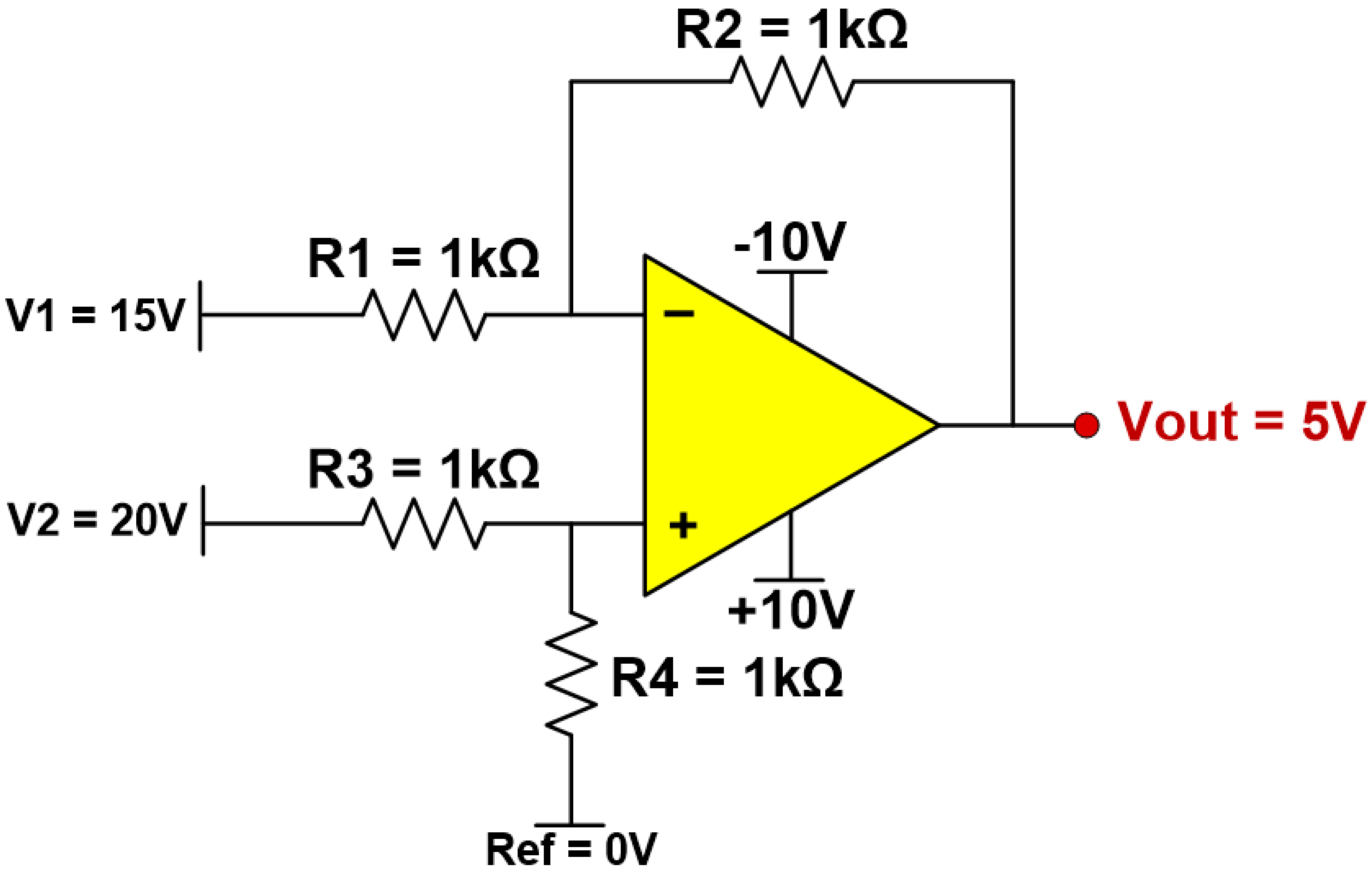
"Differential input voltage, V_d"

$$Vout = Ad \times Vd + Ref$$

Difference amplifier – Use case examples

- **High input voltages in unity gain**
  - Input voltages that exceed the supply rails
- **High gain**
  - Amplifying a very small differential input voltage
- **Attenuation and high input voltages**
  - How to attenuate signals in the presence of large common mode voltages
- **Level-shifting**
  - Adding a reference voltage to level-shift the output

Difference amplifier – High differential voltages

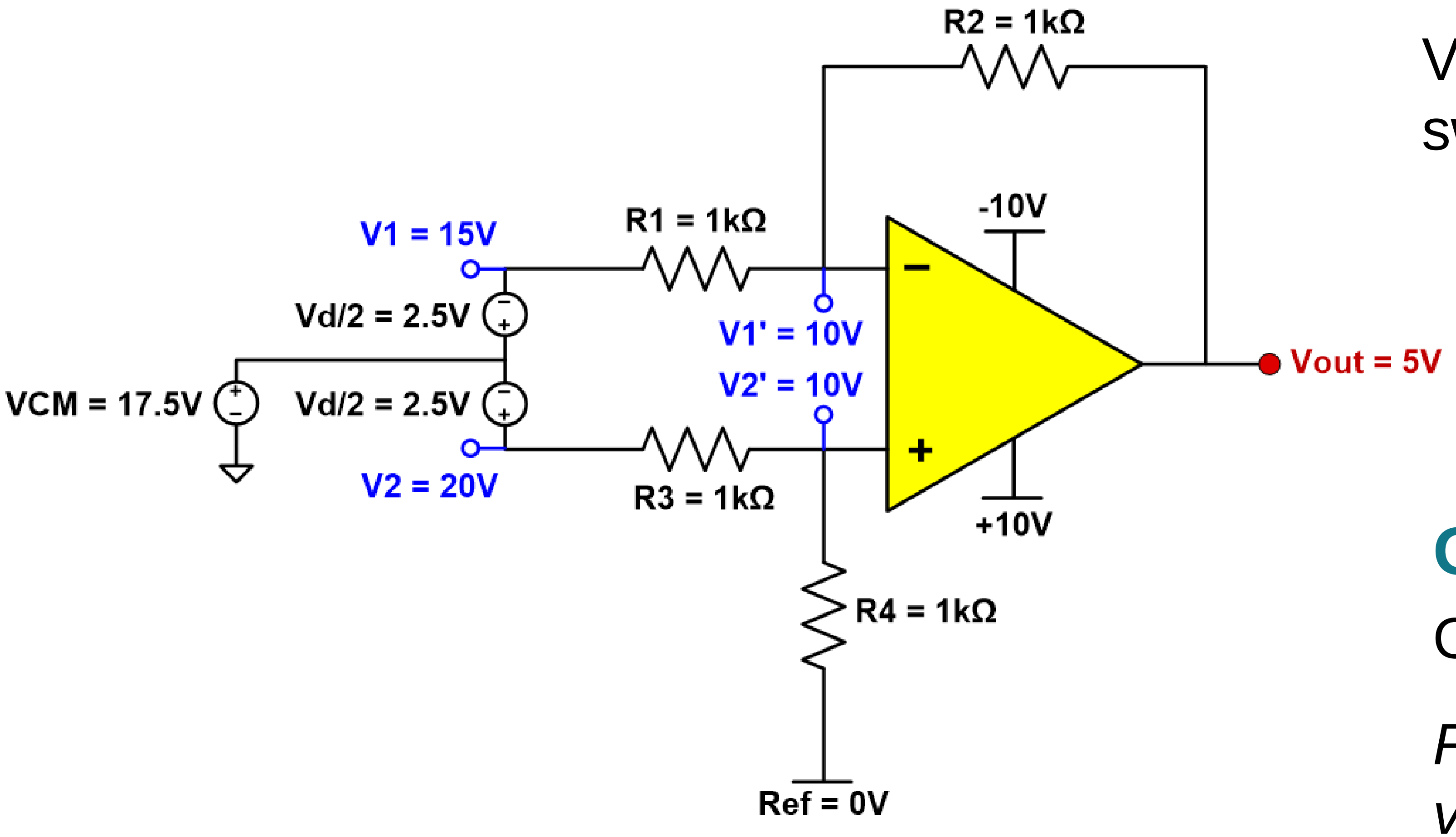


Input and output – Voltage swing limitations

- Common mode input voltage range = **input voltage range**
  - Relative to the positive and negative power supplies
  - Exceeding the input range leads to non-linear behavior
- **Output voltage swing**
  - Relative to the positive and negative power supplies
  - Exceeding the linear output range of the amplifier leads to non-linear behavior
- **Rail-to-Rail input and output amplifiers**
  - Rail-to-Rail input (RRI) amplifiers have input ranges which extend *to* and sometimes *beyond* the rail
  - Rail-to-Rail output (RRO) amplifiers have output swings *near* the rails

For more information on op amp input / output limitations: watch this TIPL video:
3.1 TI Precision Labs - Op Amps: Input and Output Limitations

Difference amplifier – High differential voltages



Input analysis:

Input voltage range: **-10V ≤ Vin ≤ +10V**

V1' and V2' must be between the input voltage swing (as high as 10V, and as low as -10V)

$$V2' = \frac{R4}{R3 + R4} \times V2 = \frac{V2}{2}$$

$$\text{V1' tracks V2', so } V1' = \frac{V2}{2}$$

Output analysis:

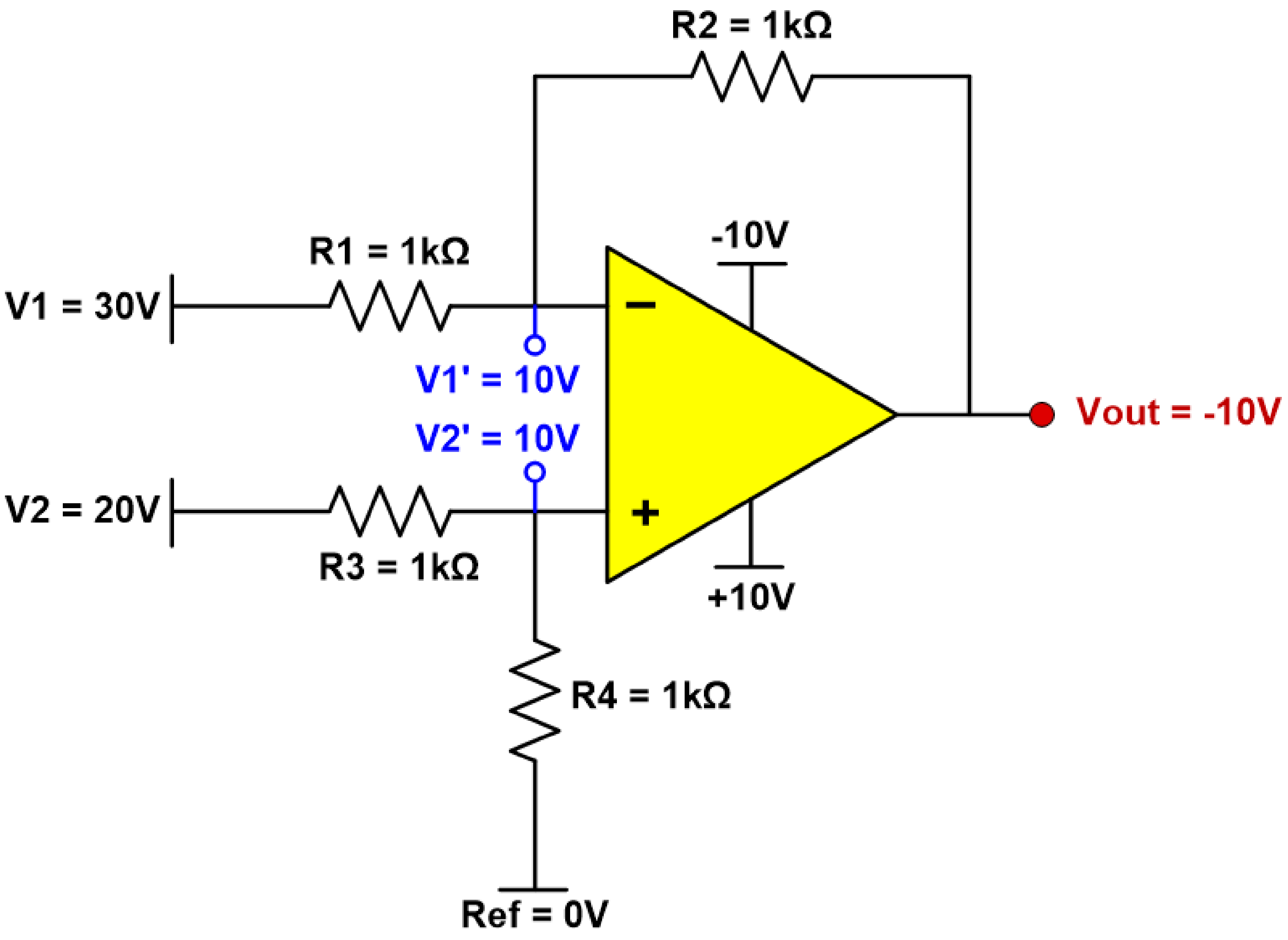
Output voltage swing: **-9.9V ≤ Vout ≤ +9.9V**

For simplicity, let us assume the output voltage swing is: ***-10V ≤ Vout ≤ +10V***

Output equation: Vout = Ad × Vd + Ref

Vout = Vd

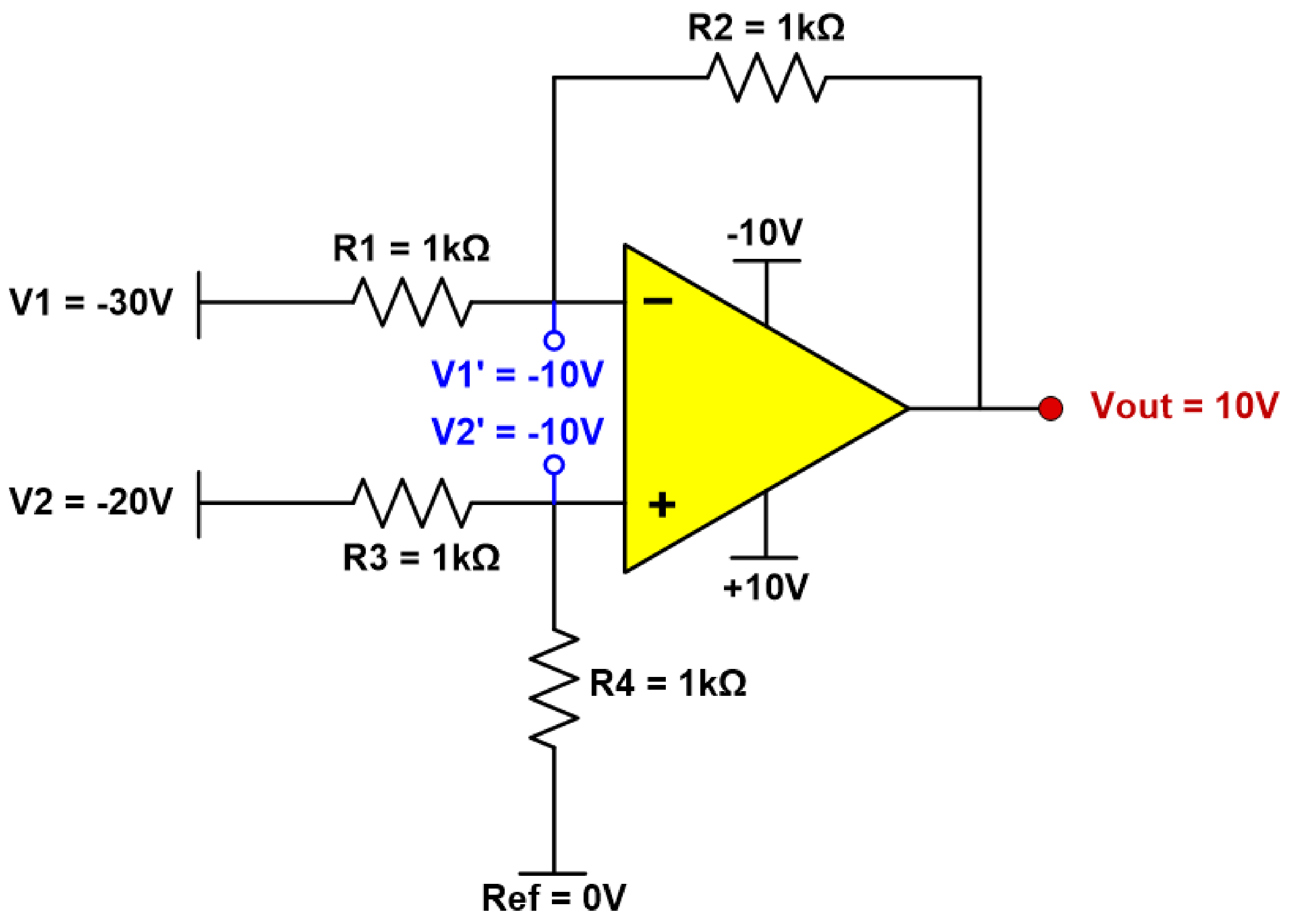
Difference amplifier – Maximum voltage ranges



Question:

If V2 can be as high as 20V and as low as -20V and Vout can be as high as 10V and as low as -10V, what range can V1 be?

Difference amplifier – Defining VCM



Answer:

- When V2 = -20V, V1 can be -30V to yield a linear output of 10V
- When V2 = +20V, V1 can be +30V to yield a linear output of -10V

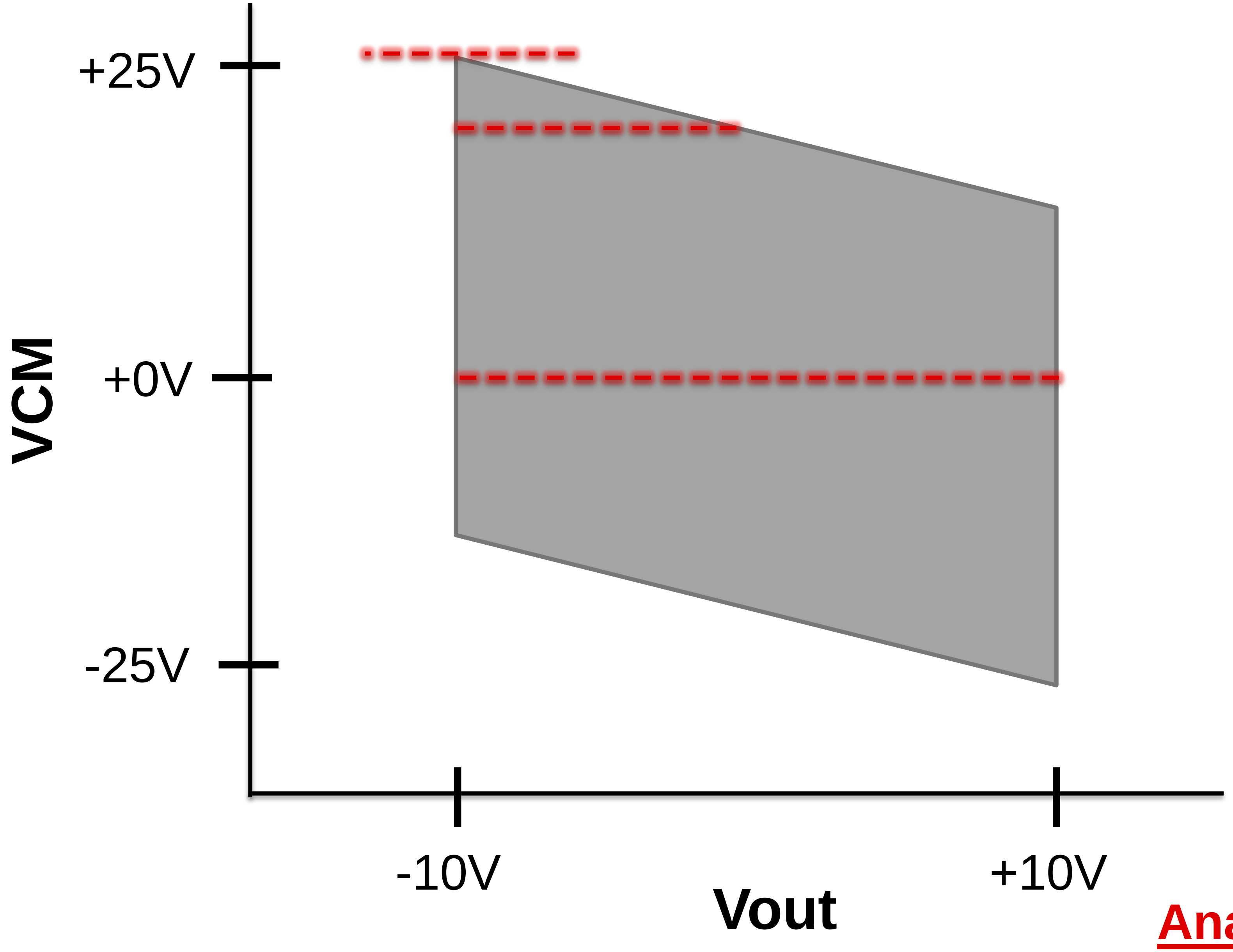
VCM is defined as:

$$VCM = \frac{V1 + V2}{2}$$

When V1 = 30V and V2 = 20V, **VCM = 25V**

When V1 = -30V and V2 = -20V, **VCM = -25V**

Linear behavior – VCM vs Vout Boundary plot



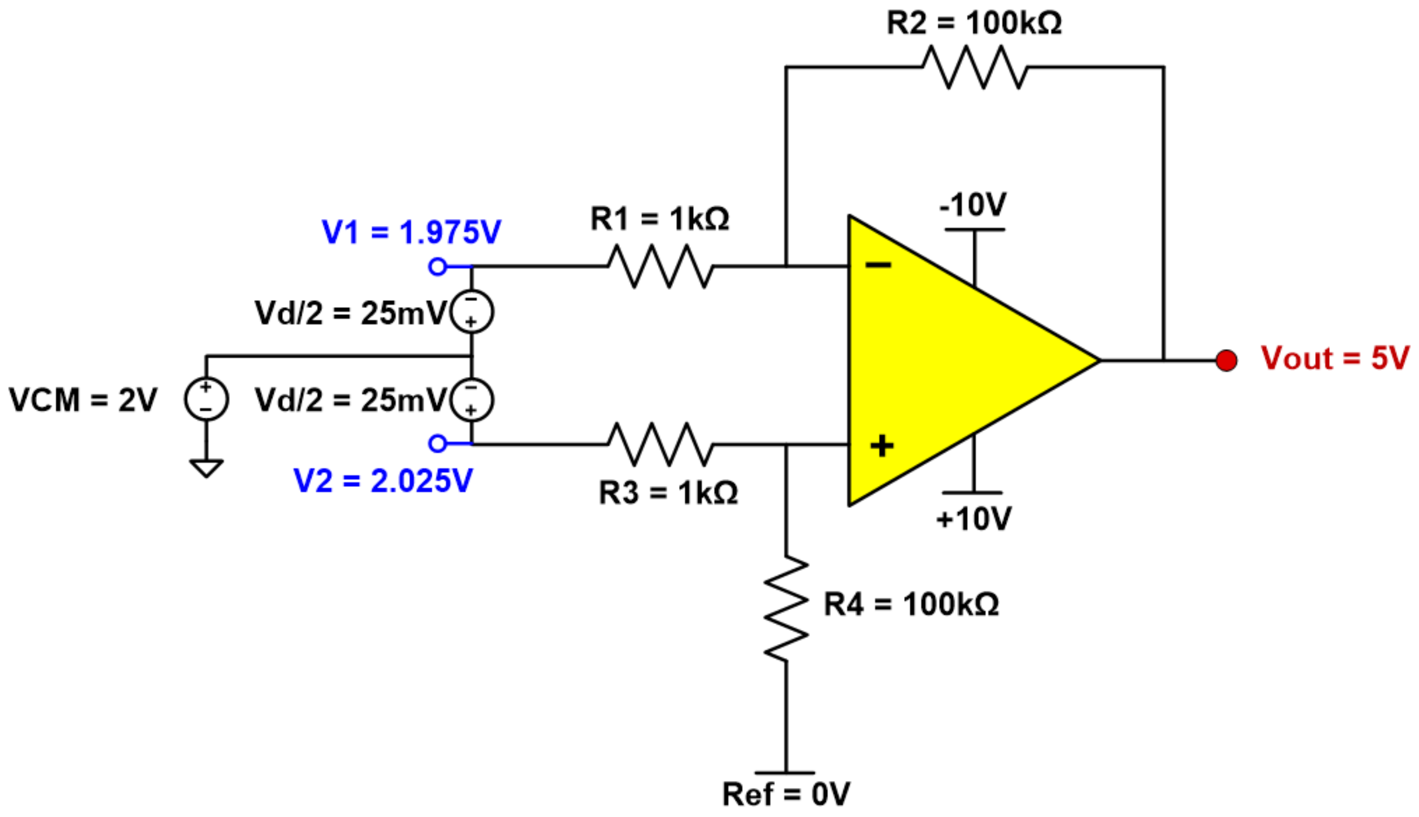
Boundary plots graphically show a designer the usable range of an IA by analyzing the internal nodes.

- Y-axis: **VCM** = -25V to +25V
- X-axis: **Vout** = Vd = -10V to +10V

VCM	Vout = Vd
25V	-10V
20V	-10V to 0V
0V	-10V to +10V

Analog engineer's calculator → INA Vout vs VCM

Difference amplifier – High gain



Remember, we can match R1 to R3 and R2 to R4 to arrive at the general equation:

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

Ad = signal gain = R2/R1

Assume we have an input differential voltage (Vd) of 50mV and want to gain this up to 5V at the output.

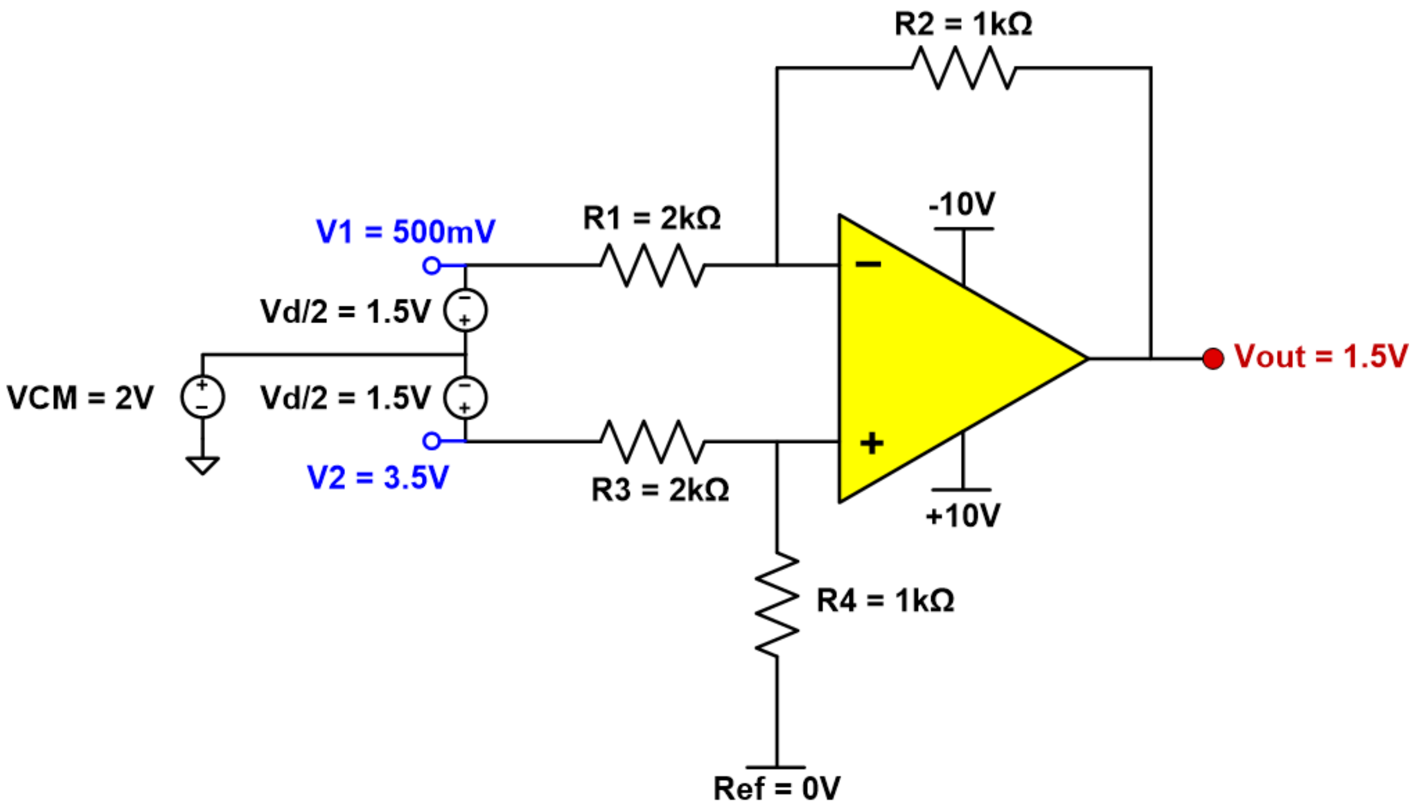
Calculate gain: $\text{Ad} = \frac{Vout}{Vin} = \frac{5V}{50mV} = 100V/V$

Choose R2 and R1 such that $\frac{R2}{R1} = 100$

We can choose:

R2 = R4 = 100kΩ and **R1 = R3 = 1kΩ**

Difference amplifier – Attenuation



$$Vout = Ad \times Vd + Ref$$

$$Ad = signal\ gain = \frac{R2}{R1}$$

Need: R2 = R4 and R1 = R3

Assume we have Vd = 3V and we want to attenuate this to 1.5V at the output.

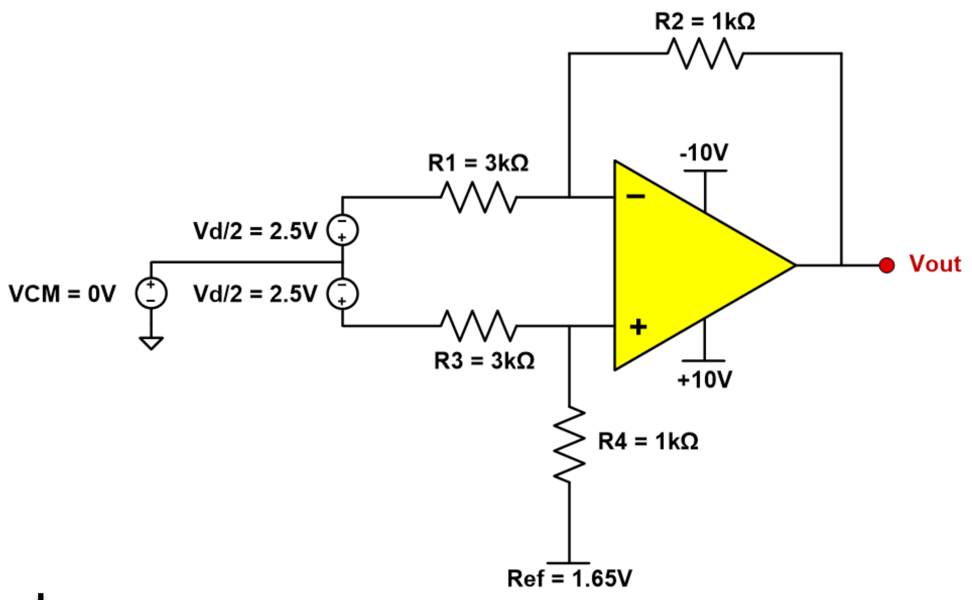
Calculate gain: $Ad = \frac{Vout}{Vin} = \frac{1.5V}{3V} = 0.5V/V$

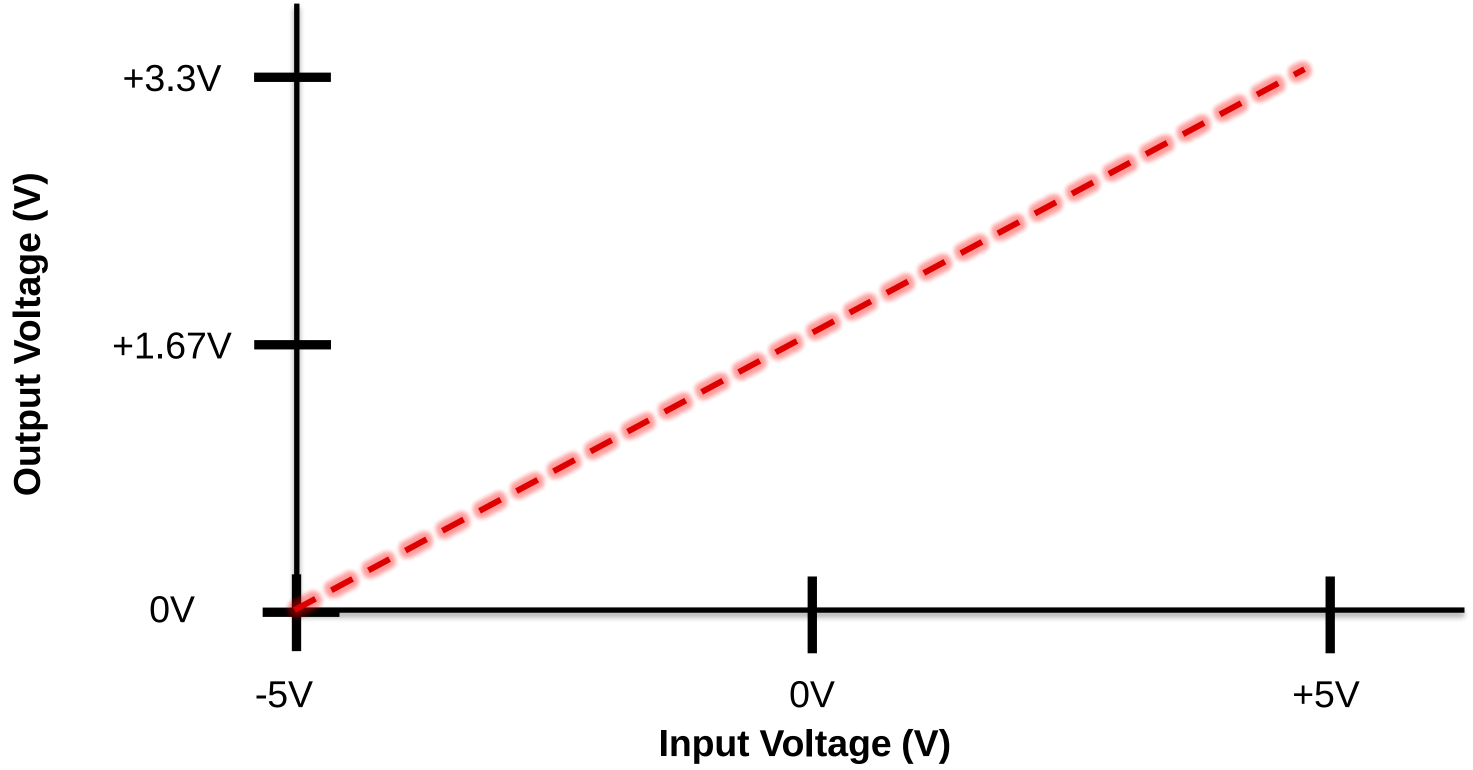
Choose R2 and R1 such that $\frac{R2}{R1} = 0.5$

We can choose:

R2 = R4 = 1kΩ and **R1 = R3 = 2kΩ**

Difference amplifier – Level shifting





Example:

Vd: -5V to 5V

Vout: 0V to 3.3V

- Solve for Gain:

$$\text{Gain} = \frac{\Delta \text{Vout}}{\Delta \text{Vd}} = \frac{3.3}{10} = \frac{1}{3} = \frac{Voutmax - Voutmin}{Vinmax - Vinmin}$$

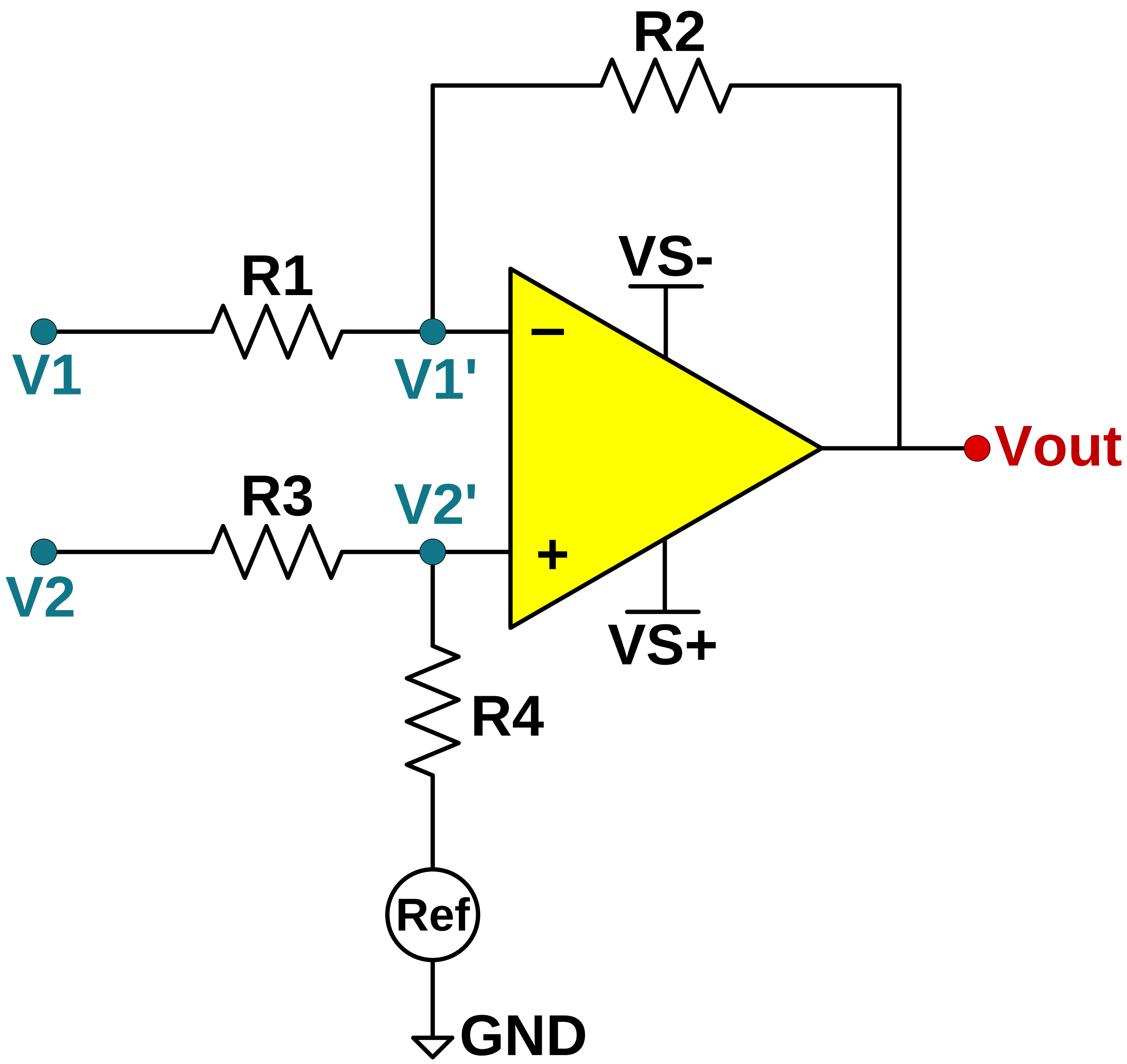
Choose R2=R4=1kΩ, R1=R3=3kΩ

- Solve for Ref:

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

$$0 = \frac{1}{3} \times (-5) + \text{Ref} \rightarrow \text{Ref} = 1.67\text{V}$$

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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