Biopotential Amplifiers

Biopotentials arise from movement of ions in cells and organs. Signal Levels are small + noise levels are large

Electrodes are the biosensor which converts from voltage (as ion potential energy – in tissue)
→
voltage (as electron potential energy – in wires)

Biopotential **amplifiers** are required to

- Amplify signal levels while rejecting interference
- Maintain patient electrical safety

Amplifiers

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Amplitude of biomedical signals

Measurement-+	Range	Frequency, Hz	Method
Blood flow	1 to 300 mL/s	0 to 20	Electromagnetic or ultrasonic
Blood pressure	0 to 400 mmHg	0 to 50	Cuff or strain gage
Cardiac output	4 to 25 L/min	0 to 20	Fick, dye dilution
Electrocardiography	0.5 to 4 mV	0.05 to 150	Skin electrodes
Electroencephalography	5 to 300 μV	0.5 to 150	Scalp electrodes
Electromyography	0.1 to 5 mV	0 to 10000	Needle electrodes
Electroretinography	0 to 900 μV	0 to 50	Contact lens electrodes
pH	3 to 13 pH units	0 to 1	pH electrode
pCO_2	40 to 100 mmHg	0 to 2	pCO_2 electrode
pO_2	30 to 100 mmHg	0 to 2	pO_2 electrode
Pneumotachography	0 to 600 L/min	0 to 40	Pneumotachometer
Respiratory rate	2 to 50 breaths/min	0.1 to 10	Impedance
Temperature	32 to 40 °C	0 to 0.1	Thermistor

Biopotential Amplifier requirements

Signals are small

Signals are low frequency

- Generally amplifiers should be limited to signal range

Voltage amplifiers required with high input impedance

Electrical shock protection of patient

Common mode (CM voltages are high)

- Active ground required
- High CMRR required

Quick calibration required

Lots of electrical interference in clinical milieu

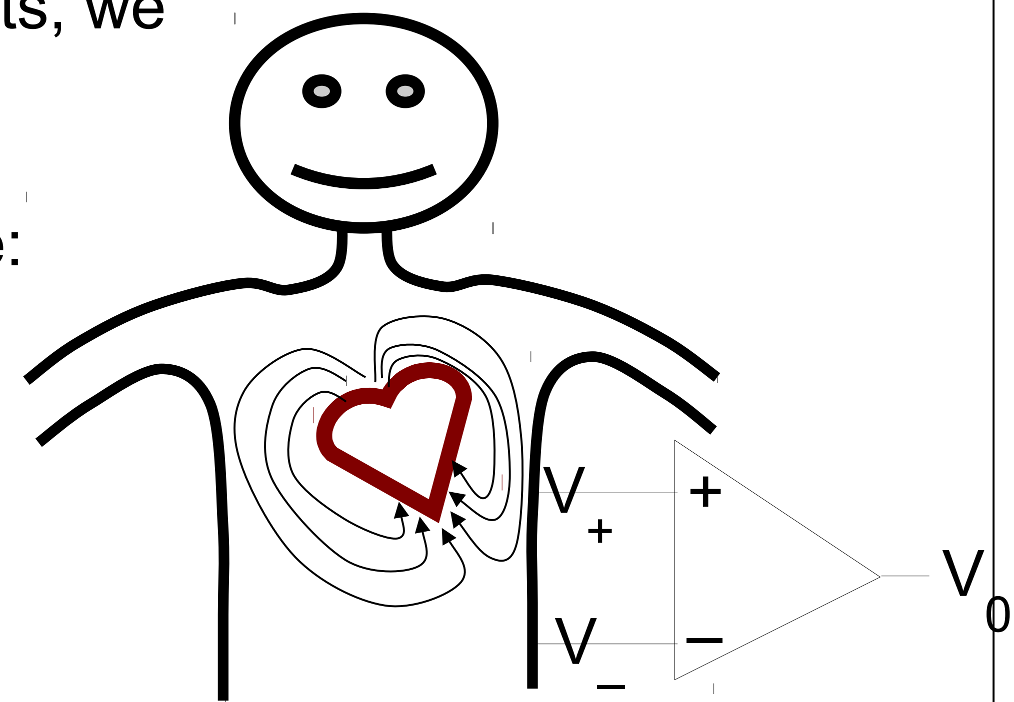
Adjustable gain (signal levels vary significantly between patients)

Gain: differential and common mode

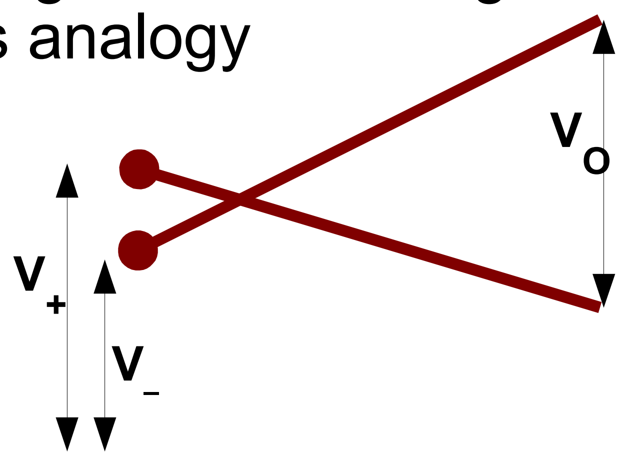
In most biomedical measurements, we want to make difference measurements: $v_+ - v_-$

For biopotentials, this is because:

- The signals are inherently differential
- Differential measurements reduce noise



Differential gain works using a scissors analogy



Gain: differential and common mode

Based on difference measurements: $v_+ - v_-$

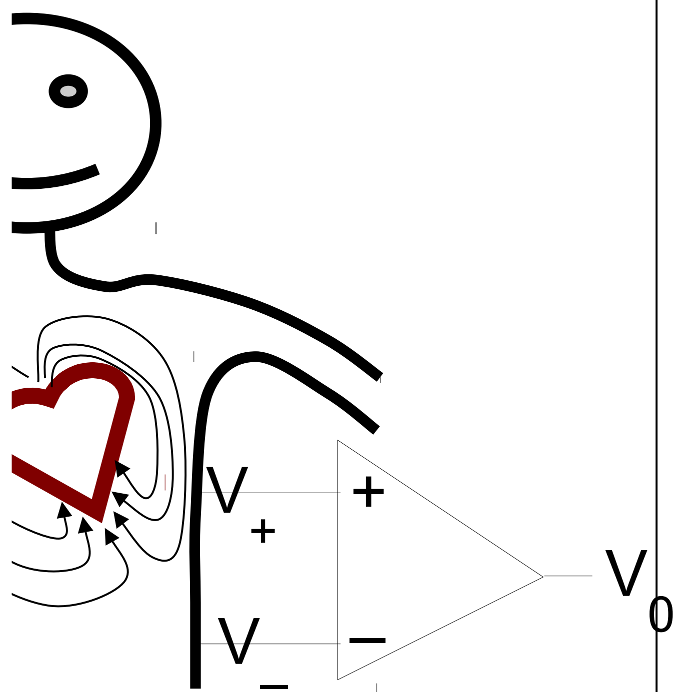
the output is:

$$V_O = A_d(V_+ - V_-) + A_{cm} V_{cm}$$

where:

$$\text{where } V_{cm} = \frac{V_+ + V_-}{2}$$

- A_d: Differential Gain
- A_{cm}: Common-mode Gain
- CMRR = A_d/A_{cm}



Example:

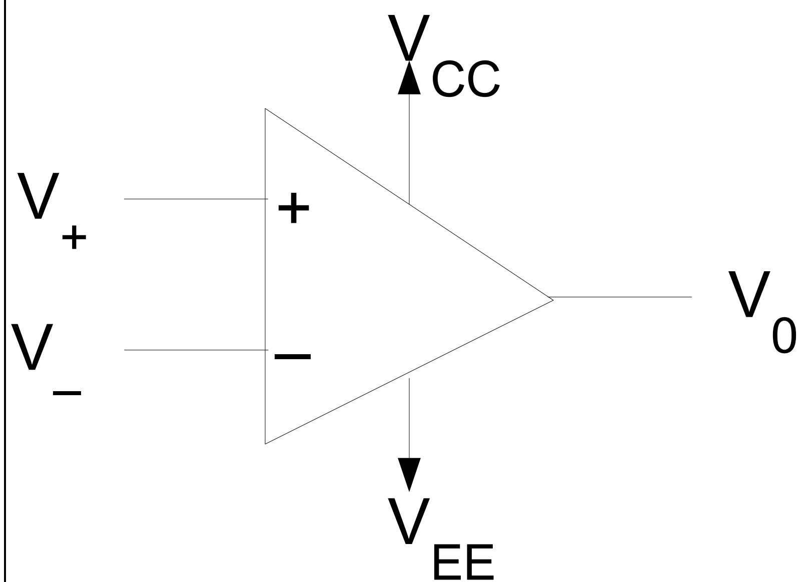
- V_O= 0.01V when V_-=V_+=1V
- V_O= 0.02V when V_-=1V & V_+= 1V+1μV
- A_{cm} = 0.01→ A_d = 0.01V/1μV = 10000
- CMRR= A_d/A_{cm} = 10^6 10000 → $20\log_{10}10^6$ = 120dB

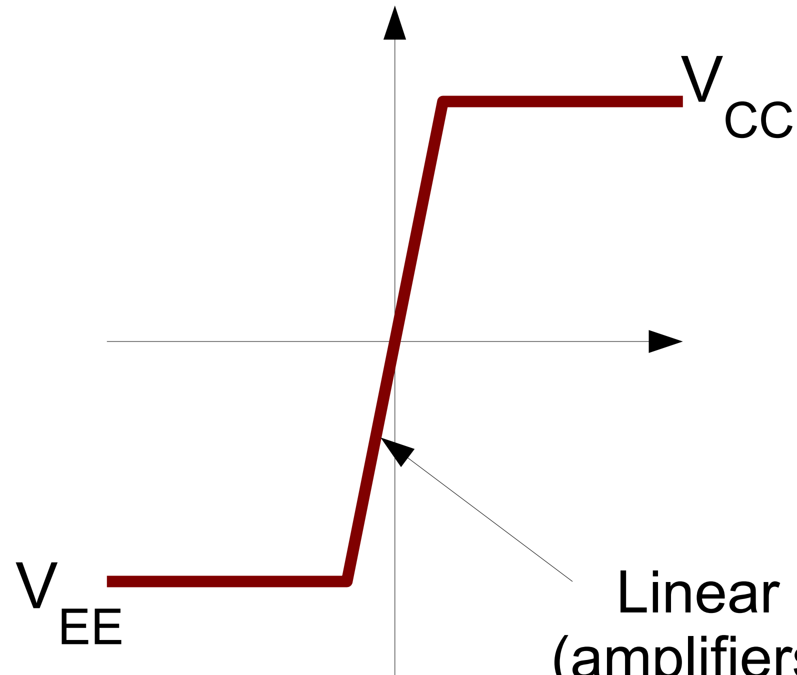
Amplifiers

Slide 03B.6

Amplifiers: Ideal Op-amp

The ideal op-amp is the building block for most precision analog circuits





Linear behaviour (amplifiers designed to operate here)

$V_0 = A(V_+ - V_-)$

very large $A \approx 100k$

Ideal Op-amp

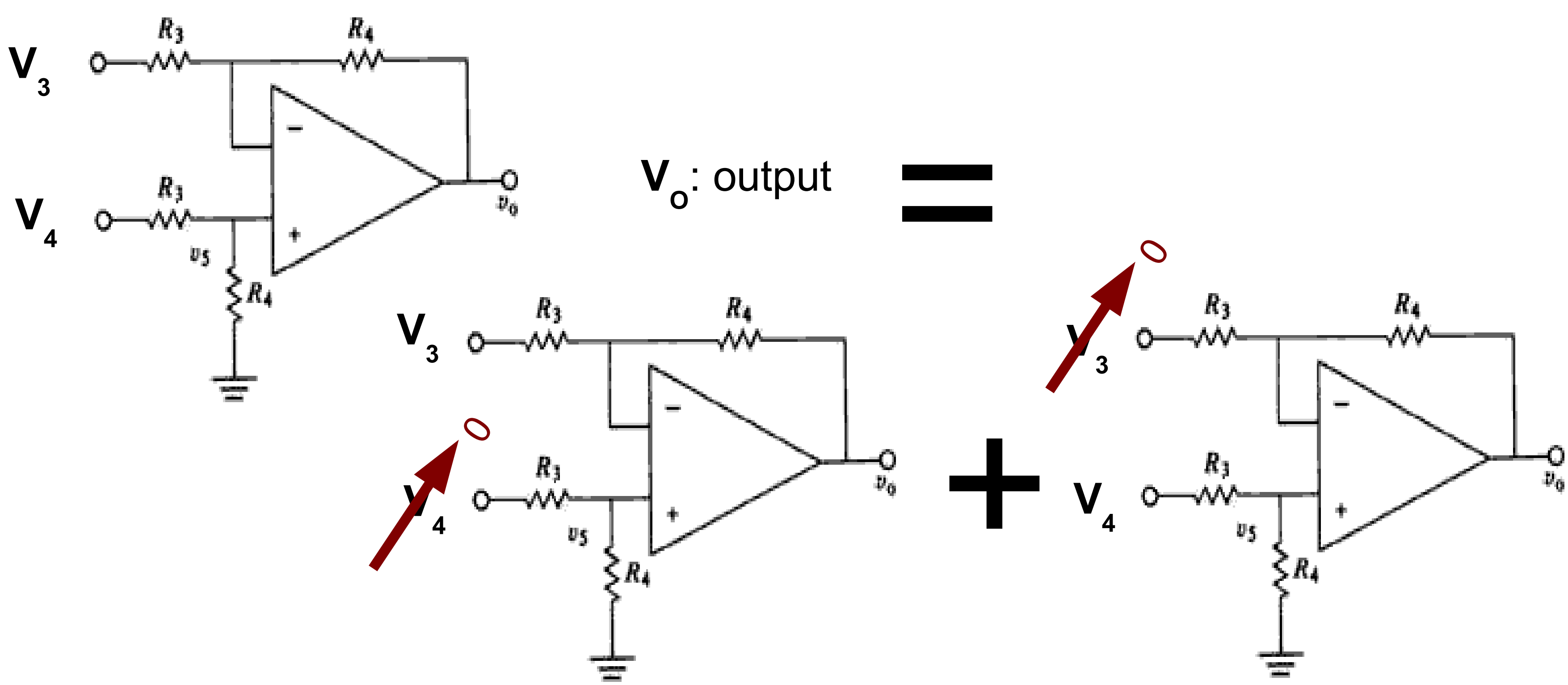
- Inputs V_+, V_- draw no current
- Output V_O can source any current
- When you have negative feedback, V_o "tries" to make $V_- = V_+$

Amplifier Building Blocks: The difference Amplifier

In most biomedical measurements, we want to make difference measurements ($v_+ - v_-$).

We can use a *difference amplifier*

Because the circuits are linear we decompose the difference amp:



Amplifiers

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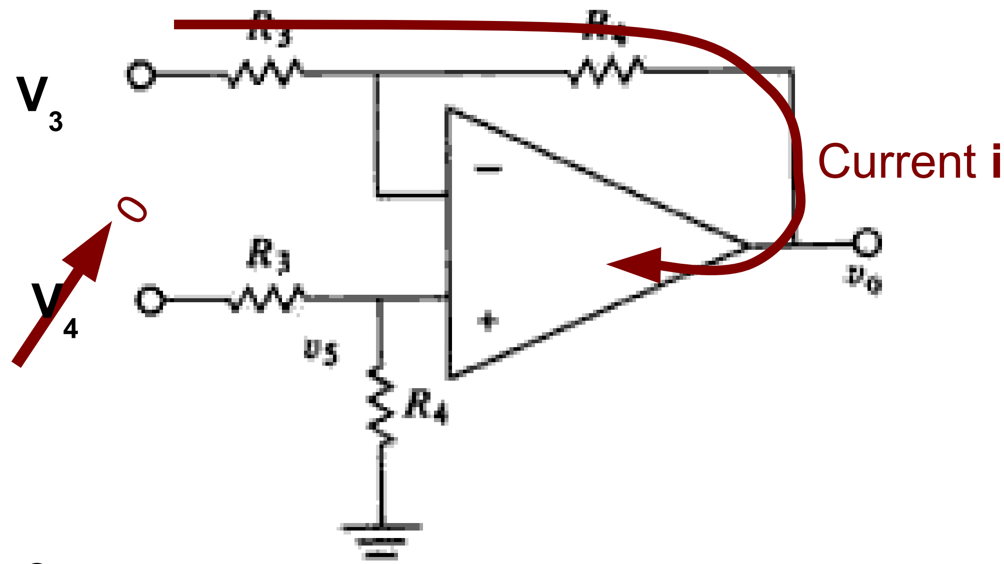
Amplifier Building Blocks: the inverting amplifier



Because $V_4 = 0$, $V_+ = 0$

Because V_- draws no current, **i** flows from V_3 to V_O

We have negative feedback, therefore V_O does what it can to get $V_- = V_+$.

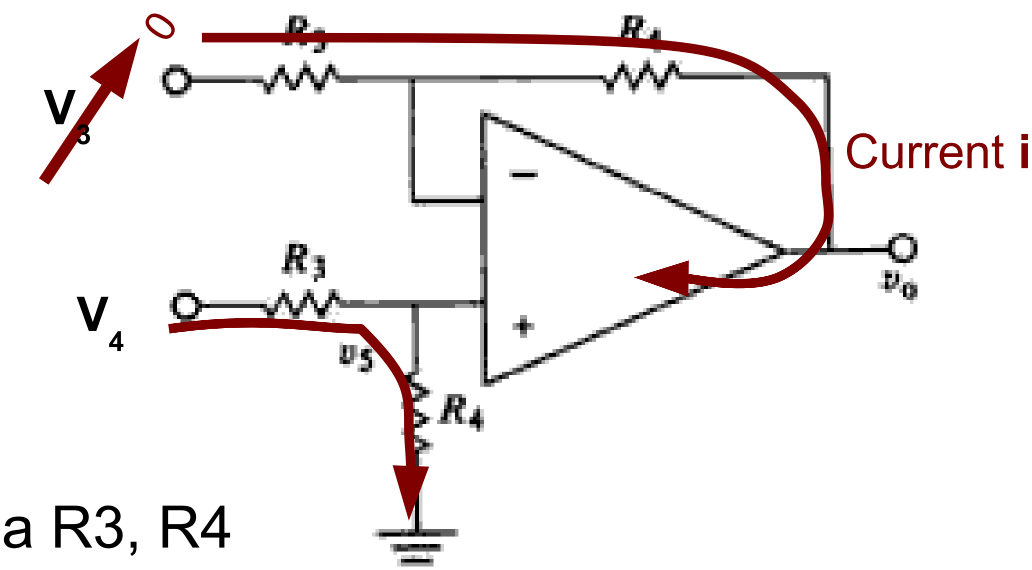
Since $V_+ = 0$, $V_- = 0$.

Current **i**: ($V_3 - V_+ = R_3\, i$) → $i = V_3/R_3$

Output Voltage: $V_- - V_O = R_4\, i$ →

$$V_O = -R_4 \frac{V_3}{R_3} = -V_3 \frac{R_4}{R_3}$$

Amplifier Building Blocks: the non-inverting amplifier



Current flows from V_4 to ground via R3, R4 acting like a voltage divider.

$$V_+ = \frac{R_4}{R_3+R_4} V_4$$

We have negative feedback, therefore V_O does what it can to get $V_- = V_+$.

Current **i**:

$$V_3 - V_+ = R_3 i \quad \rightarrow \quad i = \frac{-R_4}{R_3(R_3+R_4)} V_4$$

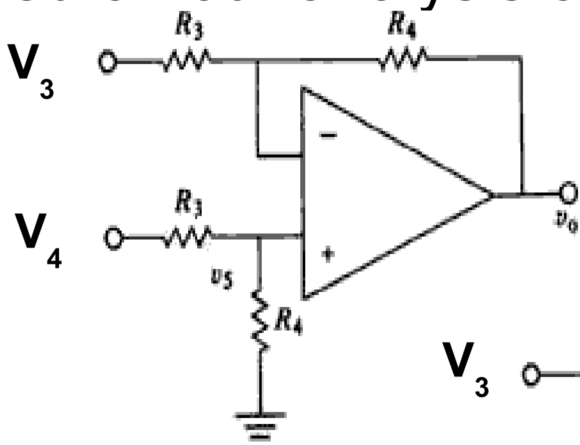
Output Voltage: $V_- - V_O = R_4 i$

$$\frac{R_4}{R_3+R_4} V_4 - V_O = \frac{-R_4^2}{R_3(R_3+R_4)} V_4$$

$$V_O = \left(\frac{R_4}{R_3+R_4}\right)\left(1+\frac{R_4}{R_3}\right) V_4 = \frac{R_4}{R_3} V_4$$

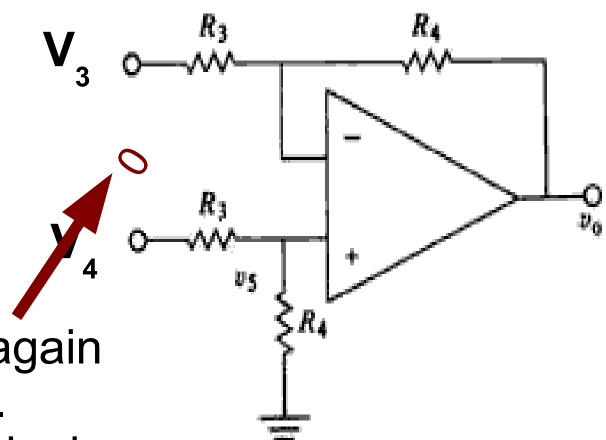
The difference Amplifier

Based on our analysis of each part of the difference amplifier,



V_o: output

=



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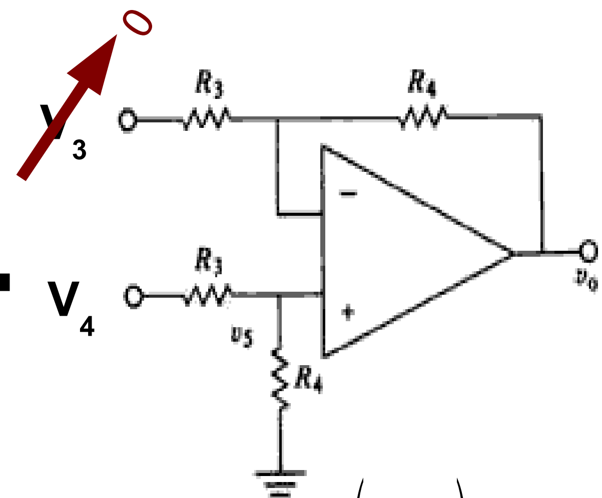


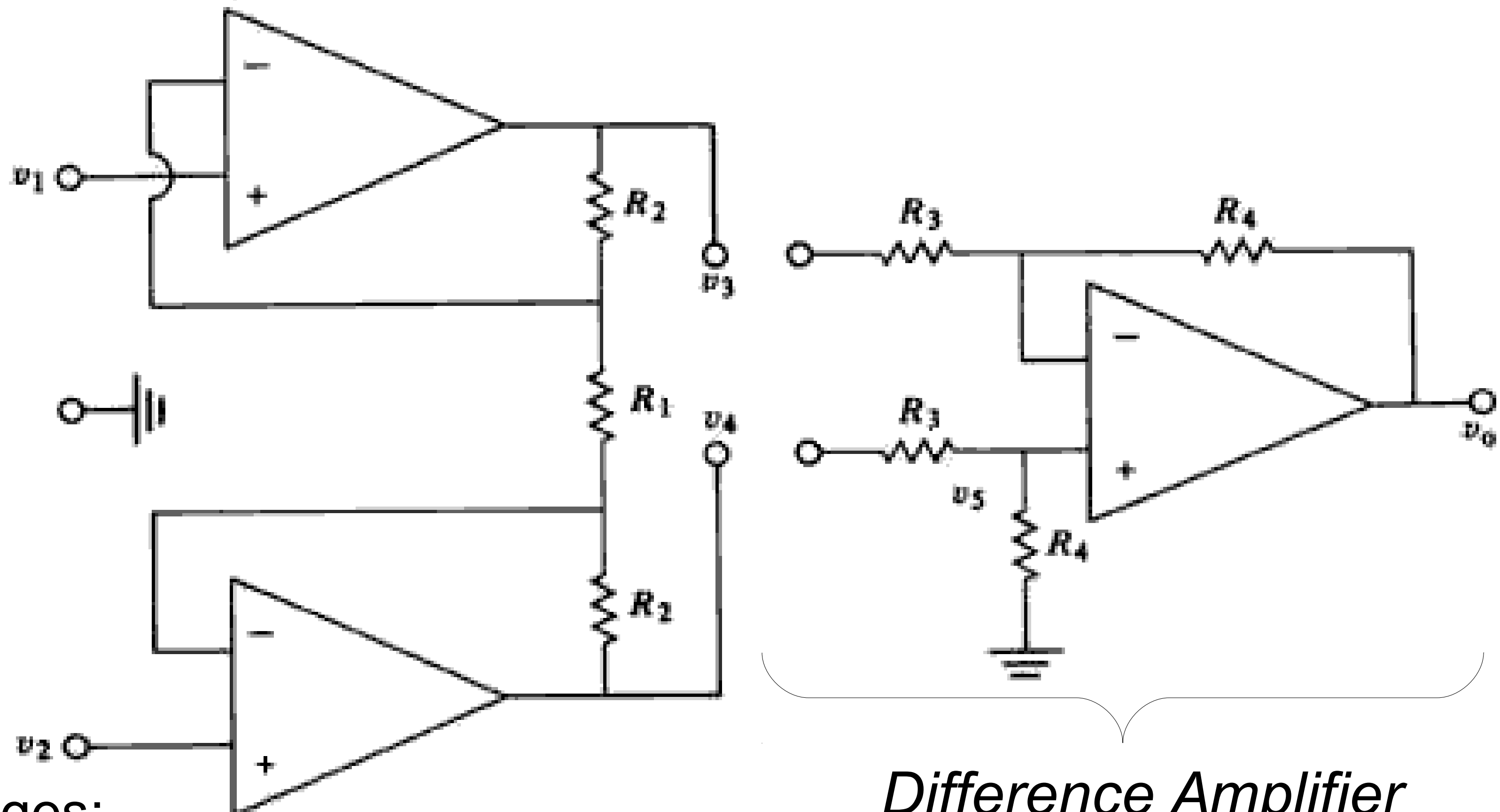
$$V_O = -\left(\frac{R_4}{R_3}\right) V_3 + \left(\frac{R_4}{R_3}\right) V_4$$

$$V_O = \left(\frac{R_4}{R_3}\right)(V_4 - V_3)$$

Good circuit, balanced again various op-amp defects.
Ampli has differential gain, but no common mode gain.

Disadvantages:
- need good matching R_3, R_4
- input impedance is low ($=R_3$)

The instrumentation amplifier



Difference Amplifier

Advantages:

- High input impedance
- Matched components (available in chip form). Stable time/temp/freq
- Gain controlled by selection of R_1

The instrumentation amplifier

In both input op-amps, $V_- = V_+$, since we have negative feedback.

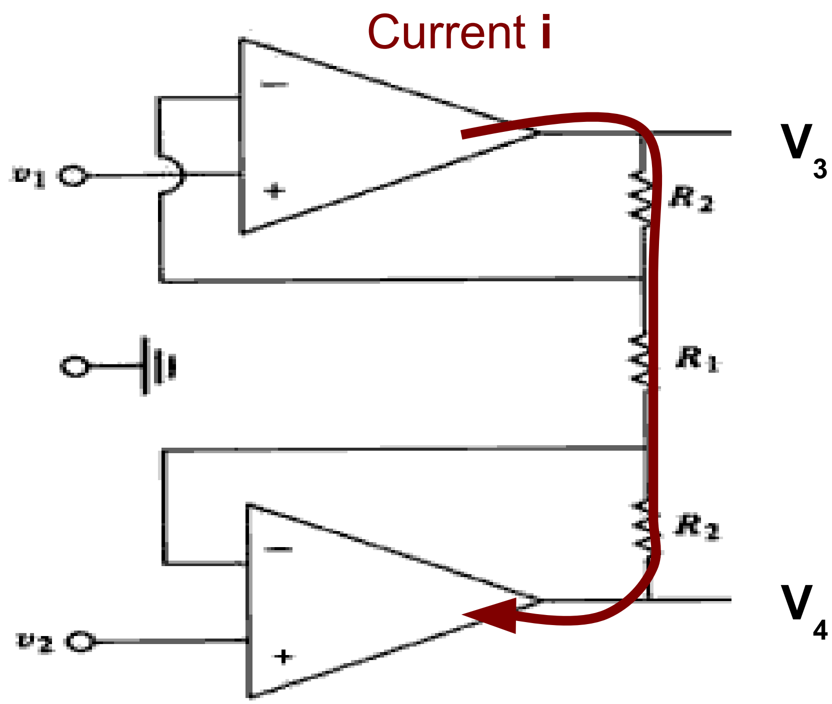
Thus, we can analyse current **i**

$$i=\frac{V_+-V_-}{R_G}$$

$$V_3-V_4=(R_G+2R_2)i$$

$$V_3-V_4=\frac{R_G+2R_2}{R_G}(V_+-V_-)$$

$$V_3-V_4=(1+2\frac{R_2}{R_G})(V_+-V_-)$$



Using the equation for the difference amplifier, we have

$$V_O=\frac{R_4}{R_3}(V_3-V_4)$$

$$V_O=(1+2\frac{R_2}{R_G})(\frac{R_4}{R_3})(V_+-V_-)$$

Instrumentation Amplifiers

ANALOG DEVICES

Low Cost, Low Power Instrumentation Amplifier

AD620

FEATURES

EASY TO USE

Gain Set with One External Resistor
(Gain Range 1 to 1000)
Wide Power Supply Range (±2.3 V to ±18 V)
Higher Performance than Three Op Amp IA Designs
Available in 8-Lead DIP and SOIC Packaging
Low Power, 1.3 mA max Supply Current

EXCELLENT DC PERFORMANCE ("B GRADE")

50 μV max, Input Offset Voltage
0.6 μV/°C max, Input Offset Drift
1.0 nA max, Input Bias Current
100 dB min Common-Mode Rejection Ratio (G = 10)

LOW NOISE

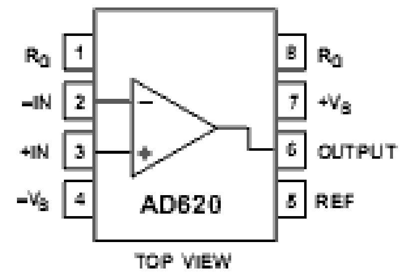
9 nV/√Hz, @ 1 kHz, Input Voltage Noise
0.28 μV p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS

120 kHz Bandwidth (G = 100)
15 μs Settling Time to 0.01%

CONNECTION DIAGRAM

8-Lead Plastic Mini-DIP (N), Cerdip (Q) and SOIC (R) Packages



Spec sheet from: analog devices

Questions

What are some requirements for medical amplifiers?

What is the CM signal? Why is it a problem?

Why are single chip instrumentation amplifiers better than 3 op-amp ones?

From the spec sheet: The internal gain resistors, R1 and R2, are trimmed to 24.7 kΩ, allowing the gain to be programmed with a single external resistor: G= 1+49.4kΩ/RG. What is R3, R4?

Exam 07f (1c) Because the scalp is an insulator, the EEG signal levels are small, and high amplification is required. Consider an EEG signal which causes a difference of 15μV between two electrodes. The neon interrogation lights cause a common mode signal of 1.8V on the scalp. Given an instrumentation amplifier with gain 10 and CMRR=80 dB, what level of common mode and difference signal will be measured?

Will twisting the EEG lead wires together help to reduce the interference from the lights?