Lecture 6 : ECG (Part 2)

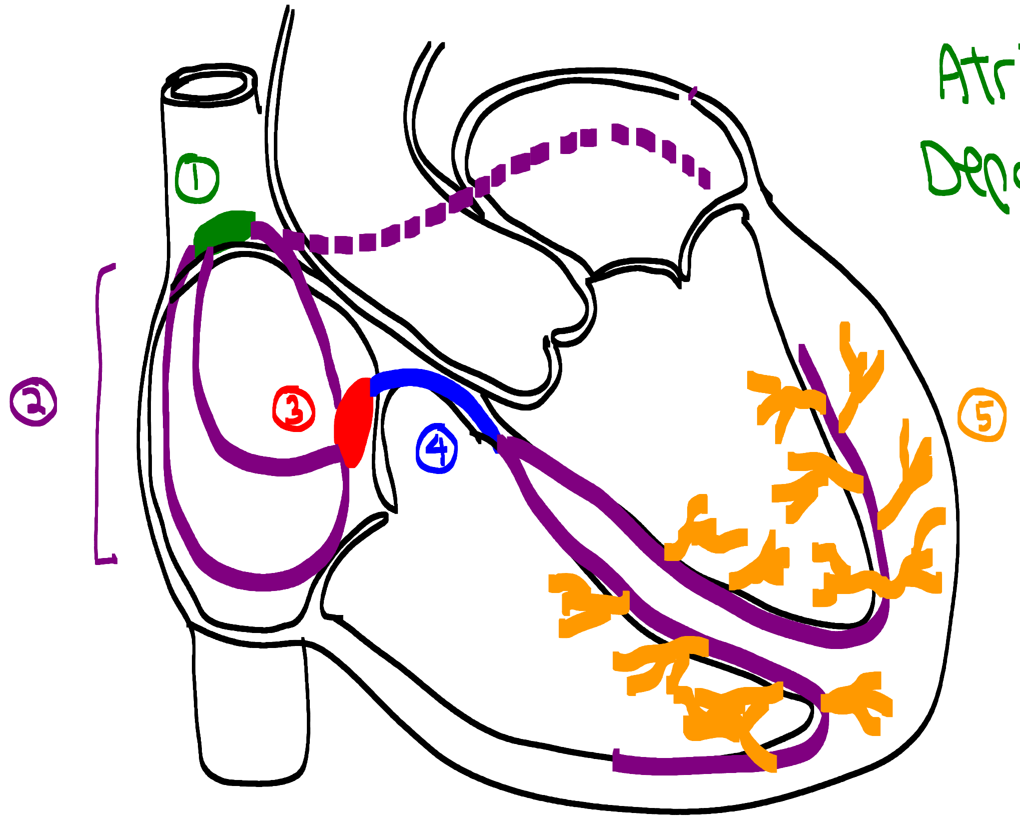
0. Review
1. 12-Lead ECG
2. ECG System
3. Mini Lab

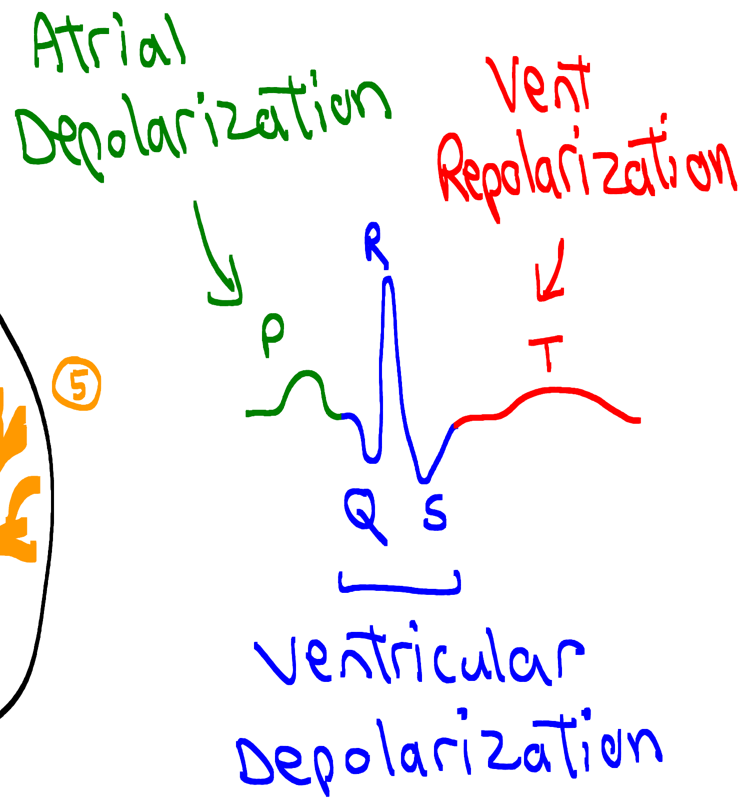
- Today : HW2 due
- Fri (Jan 24) : Lab 1 report due
- Next week : Quiz (Jan 28) ← HW2 material
  PreLab 3 (due at lab session)
  HW 3 (due Jan 30)
  Lab2 report (due Jan 31)
  ↑ see course website for template
- Exam #1 (Feb 6) !
  → Course website will have sample exam + solutions

0. Review

A. Electrical network of the heart

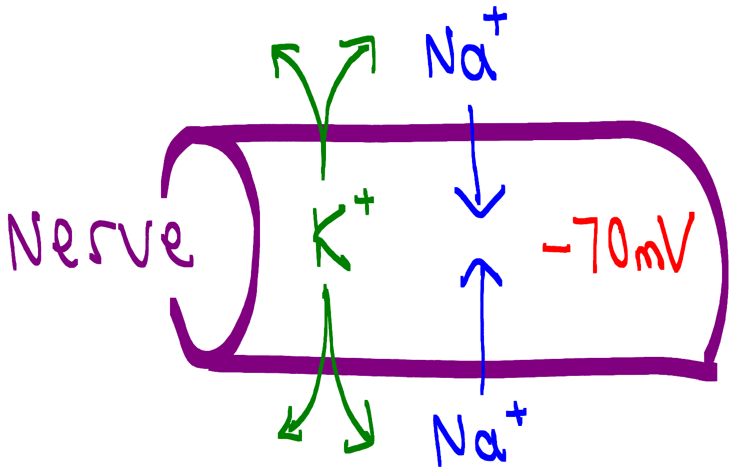
1. SA node
2. Internodal Tracts + Bachmann's Bundle
3. AV node
4. His, left + right bundles
5. Purkinje fibers

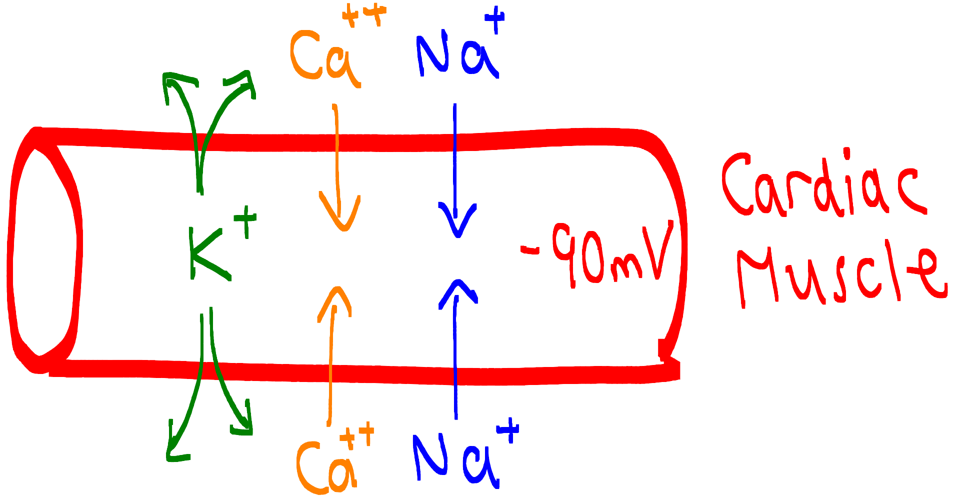




B. Action Potentials

Rest potential
Depolarization
Repolarization





1. 12-Lead ECG ← standard method

3 Einthoven's Triangle

+ 3 Augmented Leads ← ?

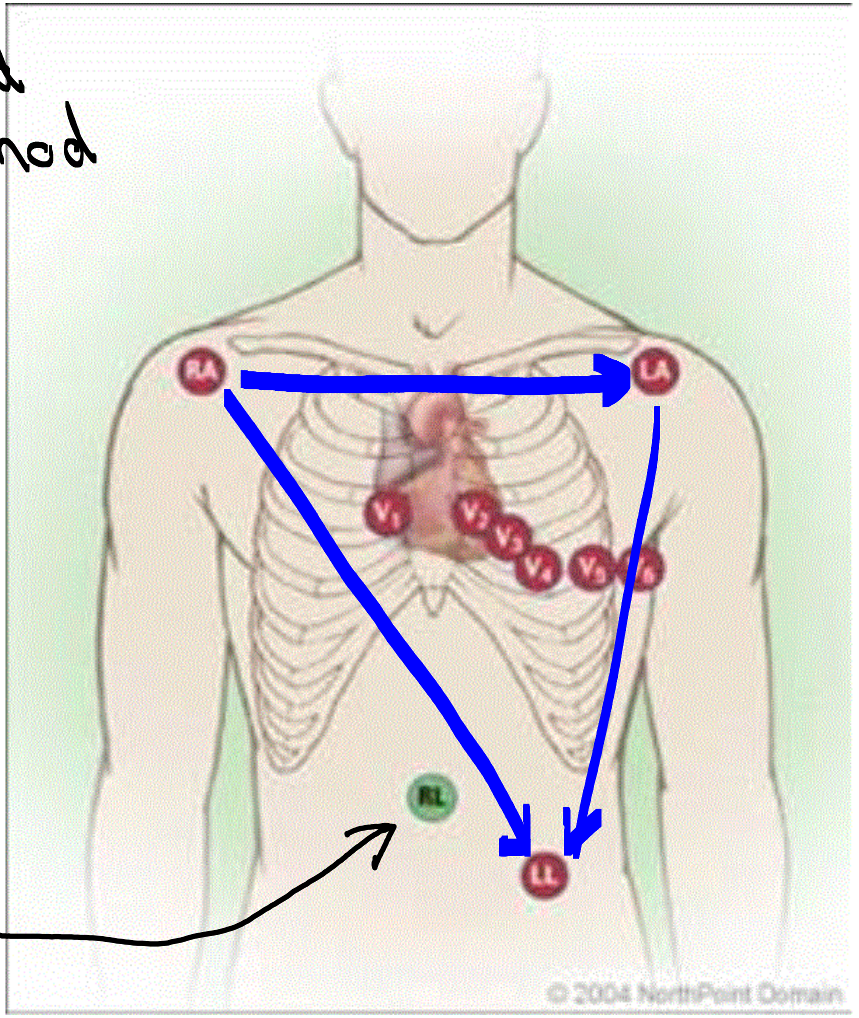
+ 6 Precordial Leads ← ?

12 Leads

NOTE: Only 9 electrodes

+ Right Leg electrode

For electrical grounding



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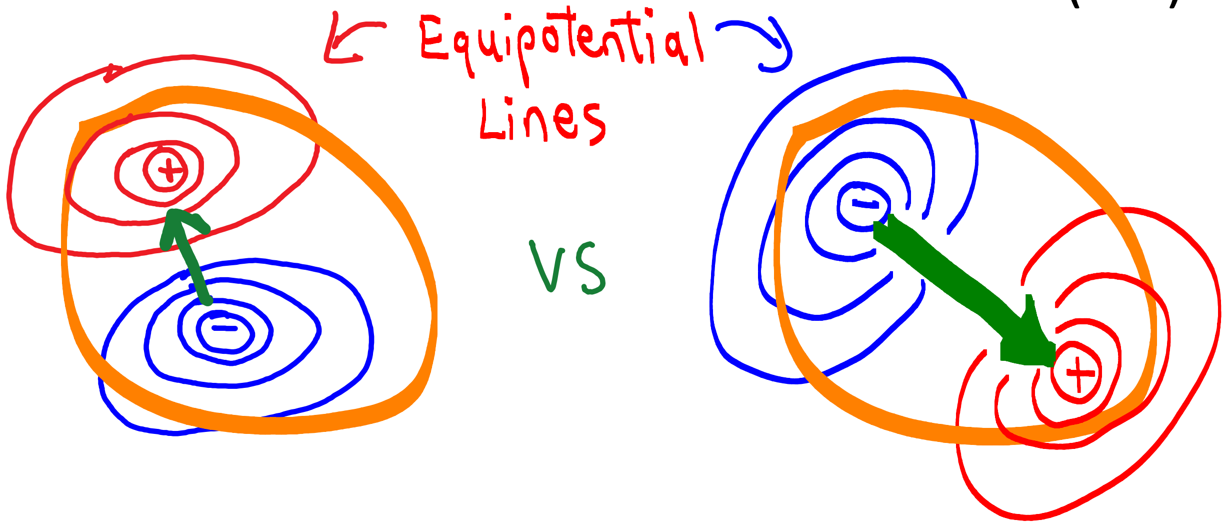
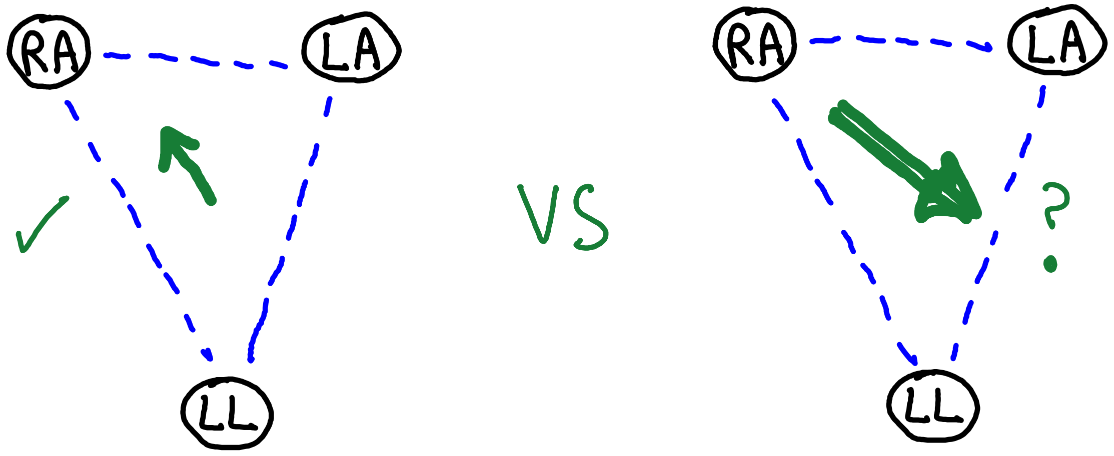




Q: Why so many leads?

- Cardiac vector provides useful diagnostic info.

} Mag + direction change during cardiac cycle ← Need multiple ECG leads to easily visualize

- Augmented Leads

The RA, LA, and LL electrodes also define three equivalent (augmented) leads

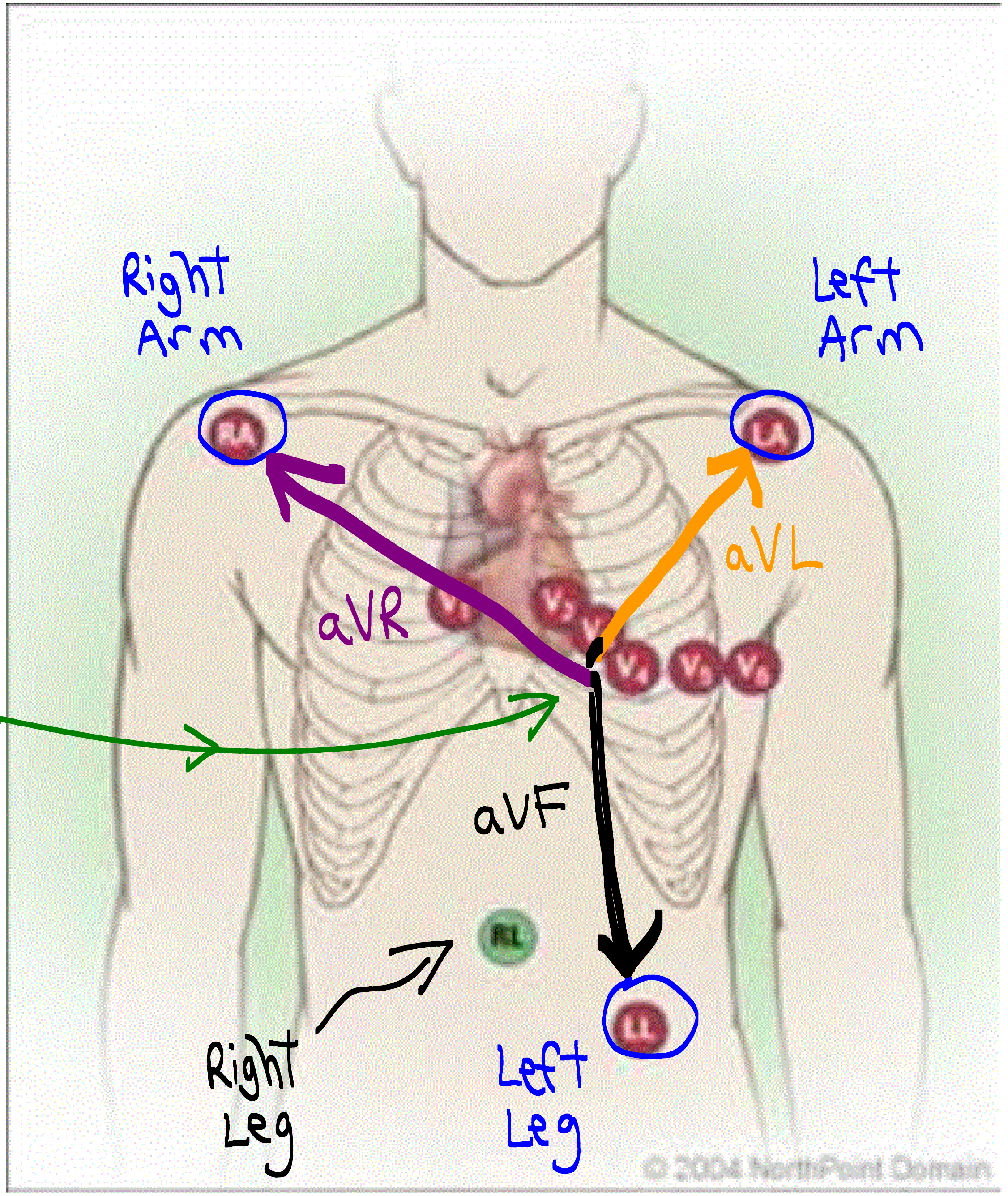
Potential difference between electrode and an equivalent reference electrode

↳ Wilson's Central Terminal

(1) aVR ≡ [Wilson] → [Right Arm]

(2) aVL ≡ [Wilson] → [Left Arm]

(3) aVF ≡ [Wilson] → [Left Leg]



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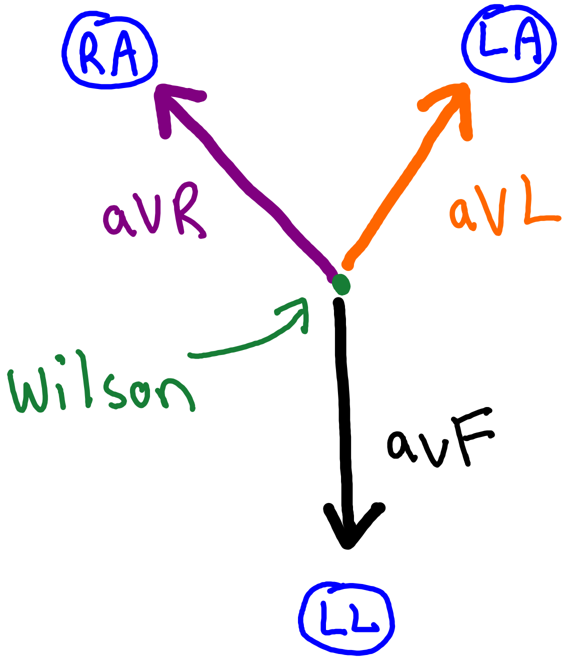
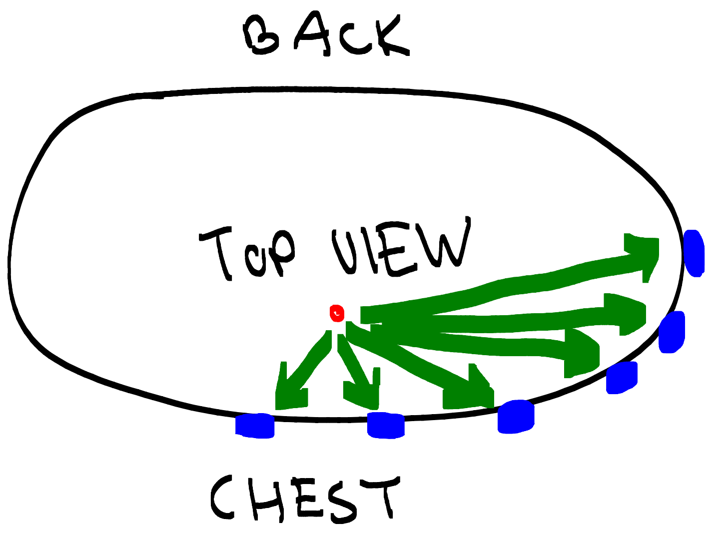


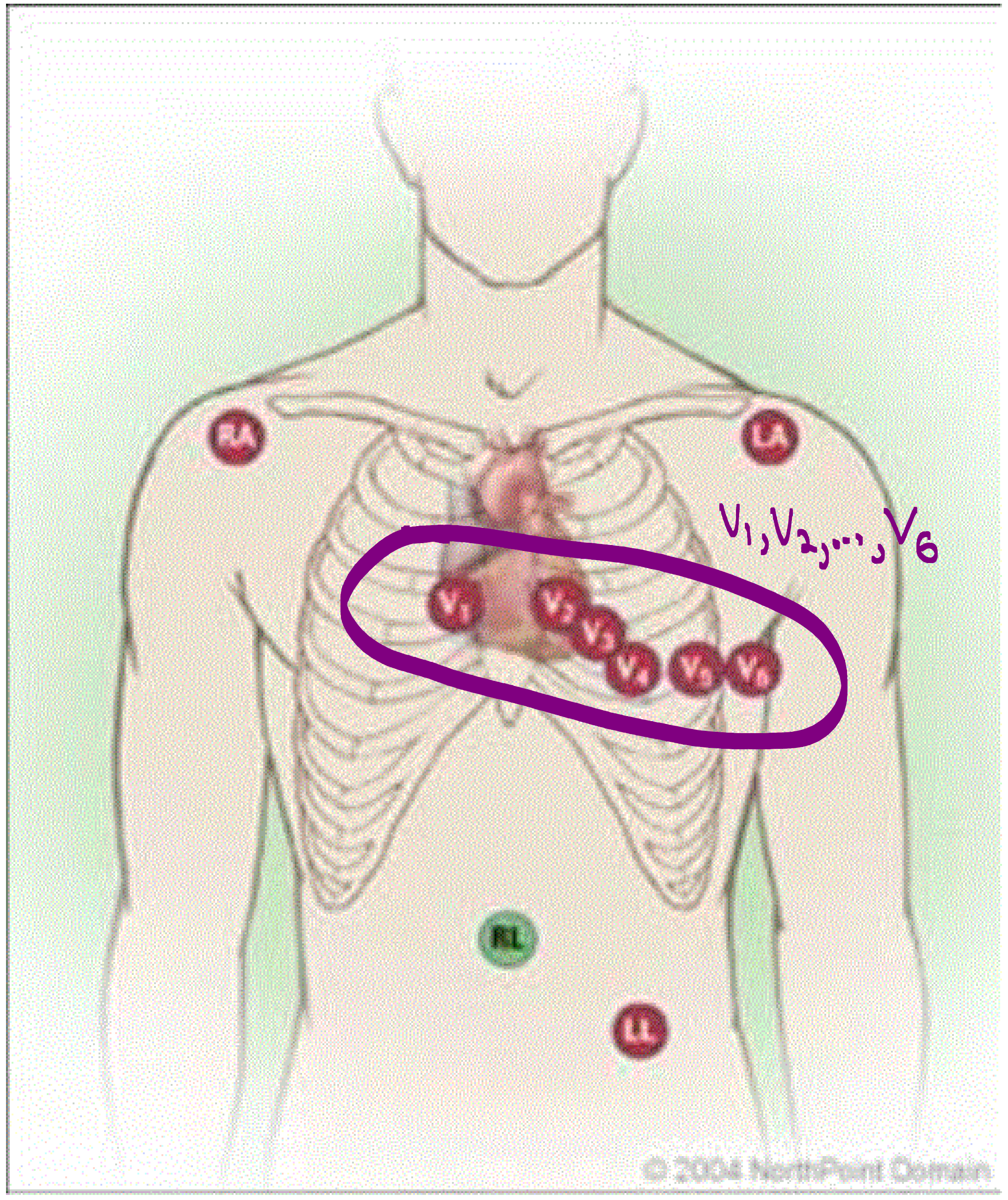
(6.3)

- Precordial Leads

→ Six more electrodes placed on the chest wall.



Provide info about cardiac vector along transverse plane!



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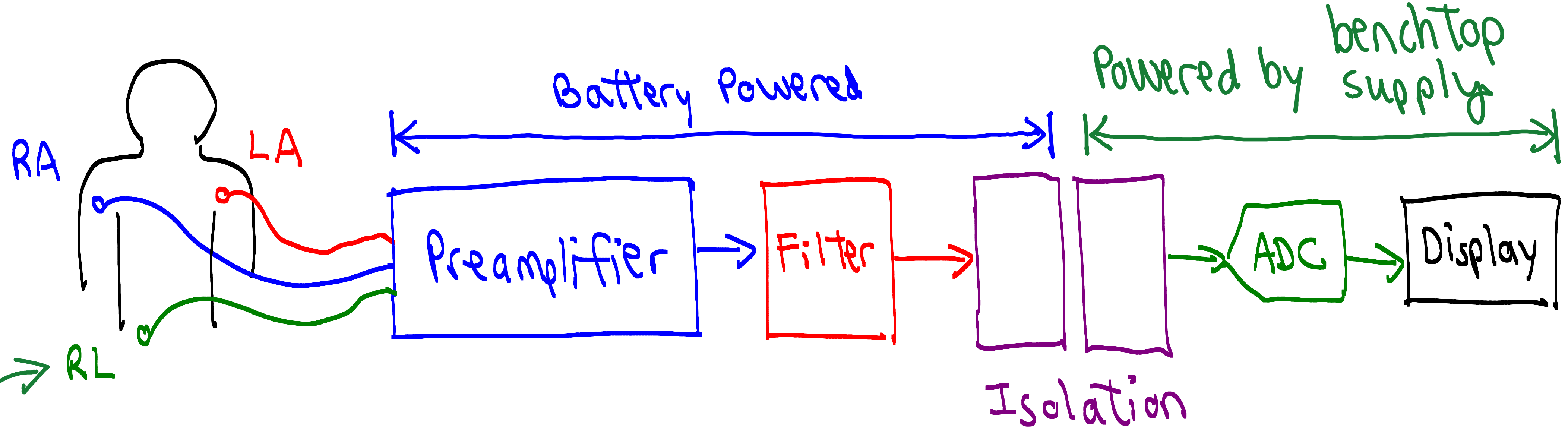
Precordial Leads are measured by:

[Wilson Central Terminal] → [Precordial Electrode]

2. ECG System

Lab3 is the simplest ECG case: ONE lead! Need 3 electrodes.

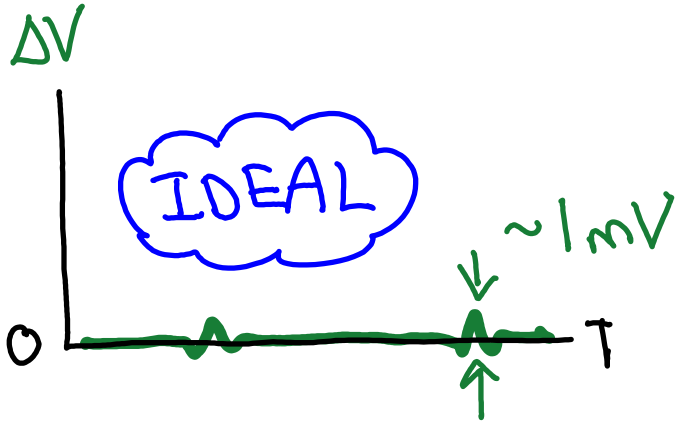
Defines electrical ground of patient → RL



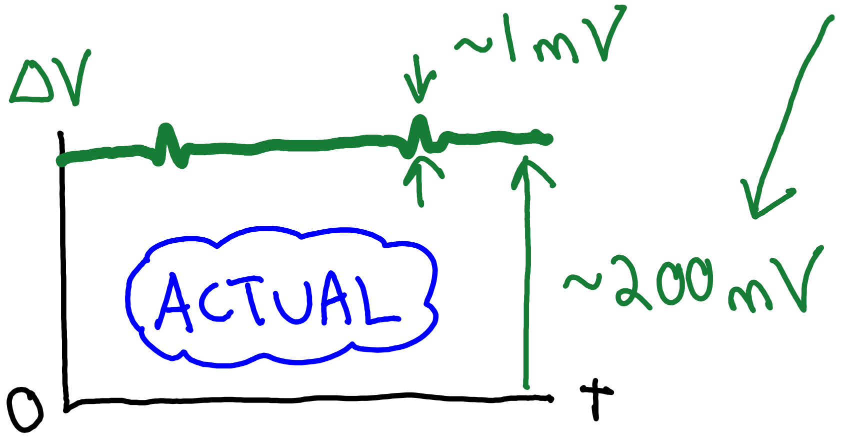
A. Preamplifier

- Instrumentation amplifier amplifies $\Delta V = V_{RA} - V_{LA}$

In reality, skin-electrode interface can produce up to ~200 mV offset!



vs.



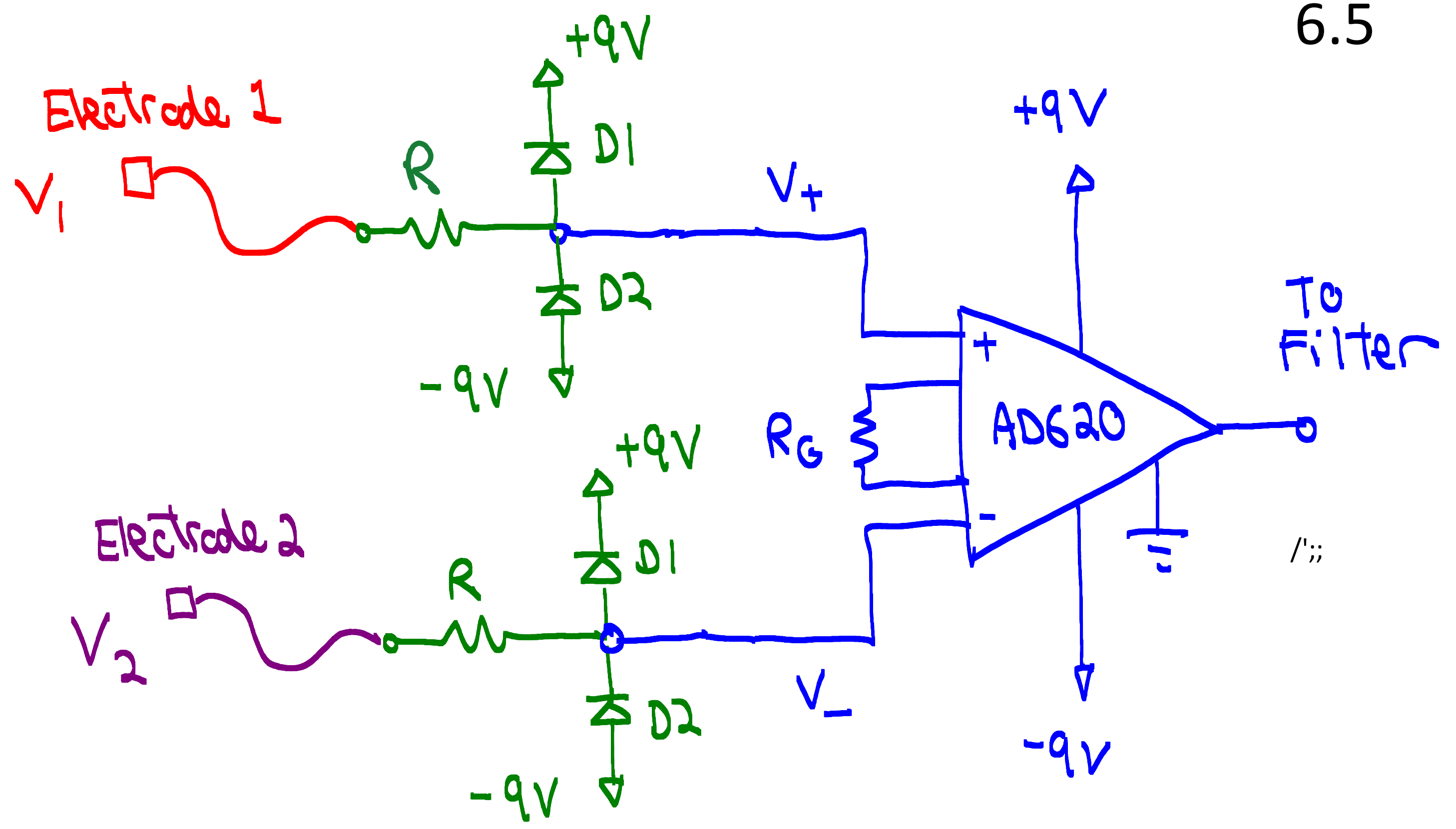
∴ A_d cannot be too high!

Typically $A_d \sim 30$.

- <u>Input protection</u>

ECG amplifier inputs usually have <u>protection diodes</u>.

→ Act as <u>voltage clamps</u> to prevent high voltages (static electricity, line voltage leakage, etc)

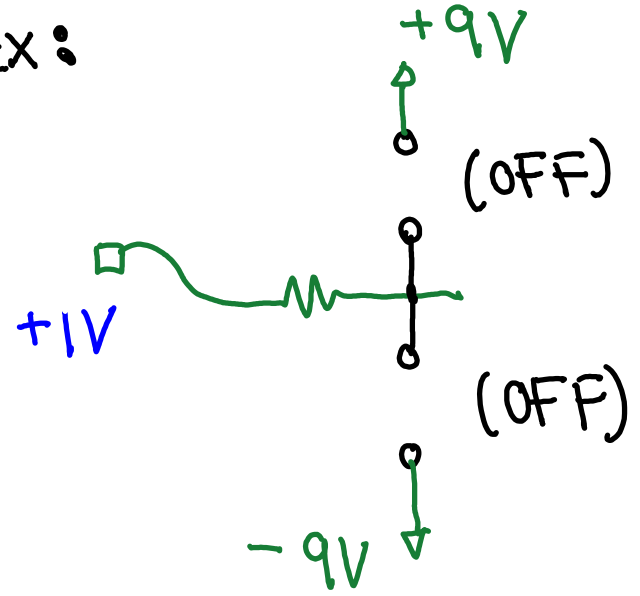


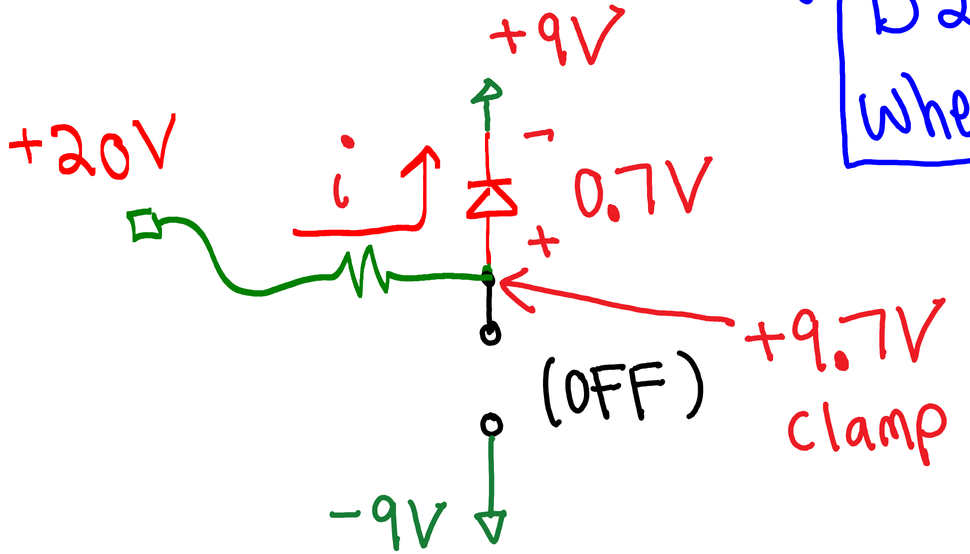
- Both Diodes are OFF when $|V_i| < 9V$

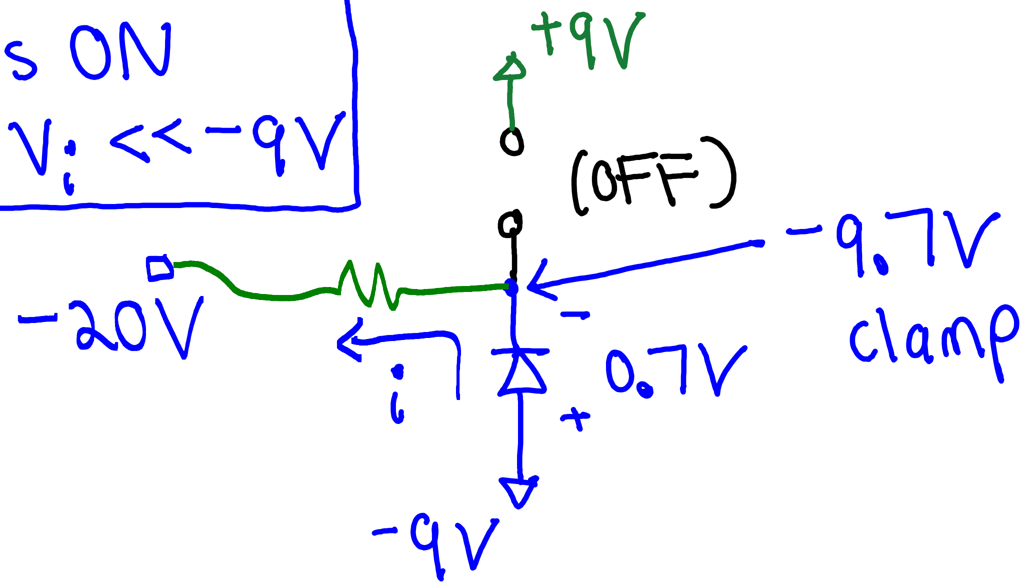
- D1 is ON when $V_i \gg +9V$

- D2 is ON when $V_i \ll -9V$

Ex:







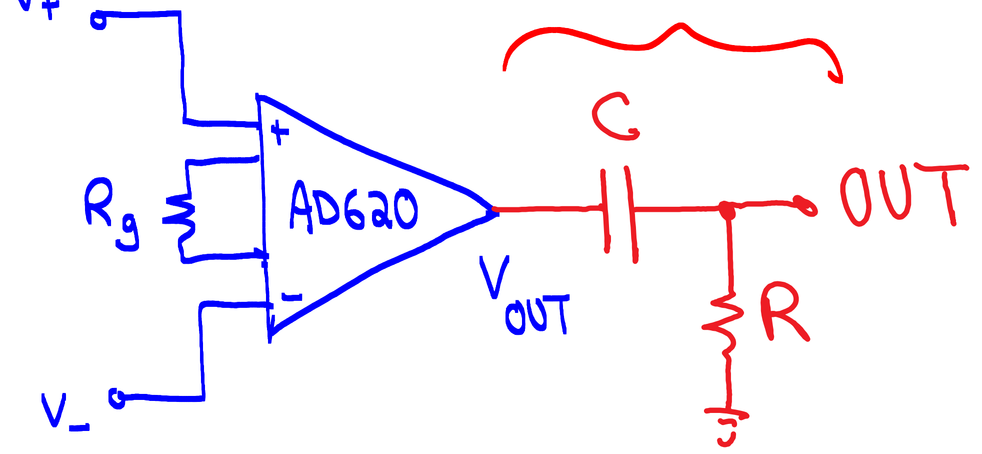
(6.6)

B. Filter

- Mismatch in skin-electrode contact potential creates an input DC offset voltage (up to ~200 mV)

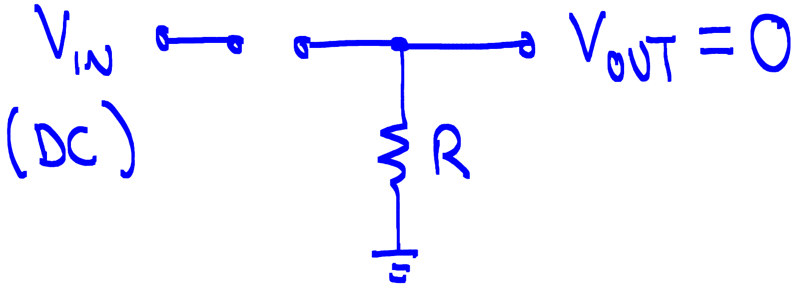
→ amplified by inst amp

Simple RC circuit

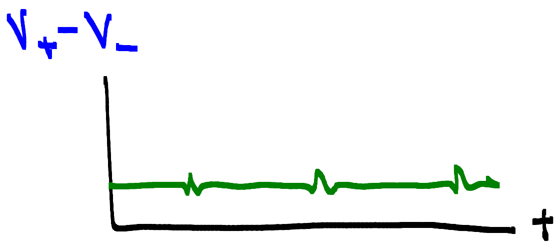


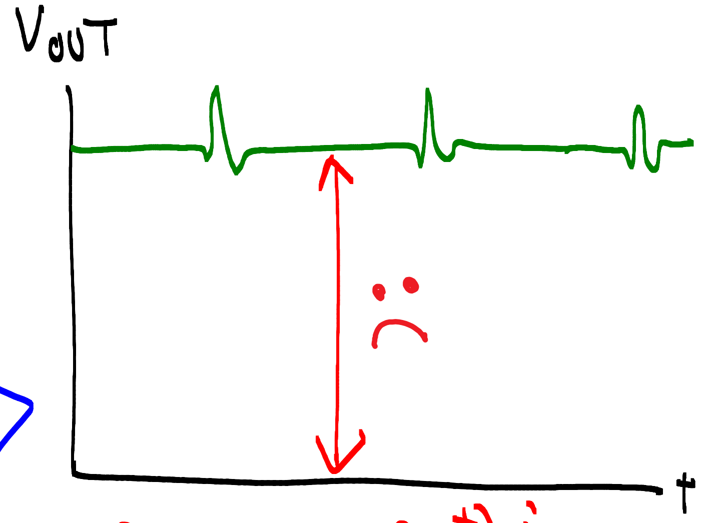
For capacitor, $Z = \frac{1}{j\omega C}$

- At DC (f=0), Capacitor is an OPEN

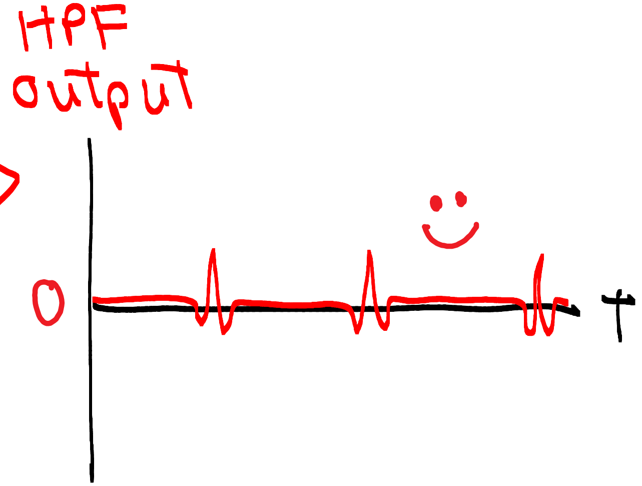


Ex:

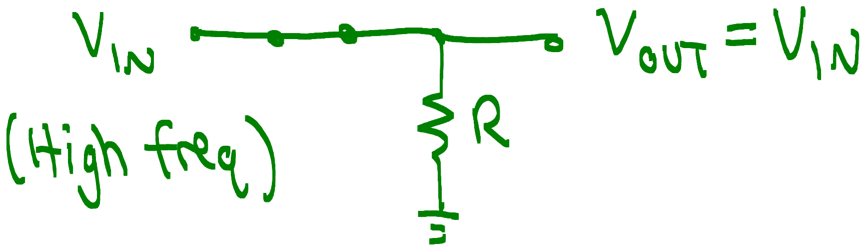




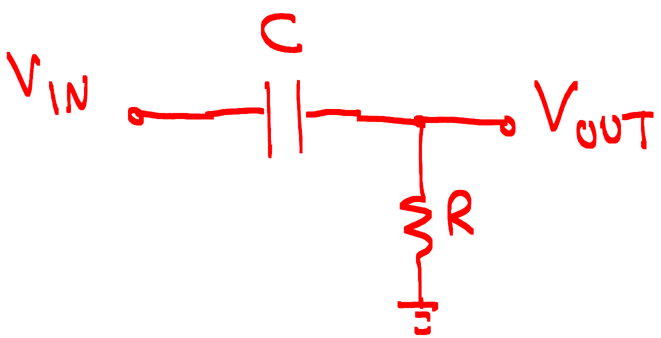
can remove this DC offset with a <u>high pass filter</u>!



- At high freq, capacitor is a SHORT



• HPF Frequency Response



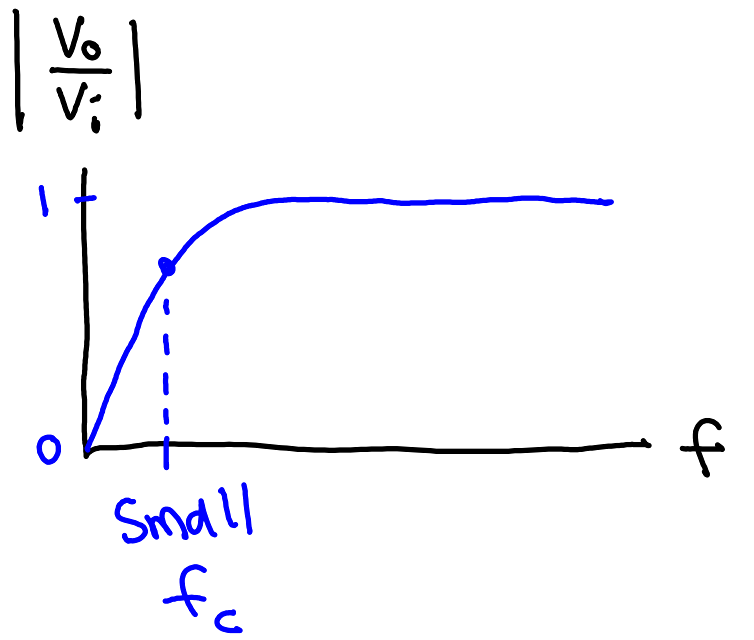
Straightforward to show that:

$$\frac{V_{OUT}}{V_{IN}} = \frac{j f/f_c}{1 + j f/f_c}$$

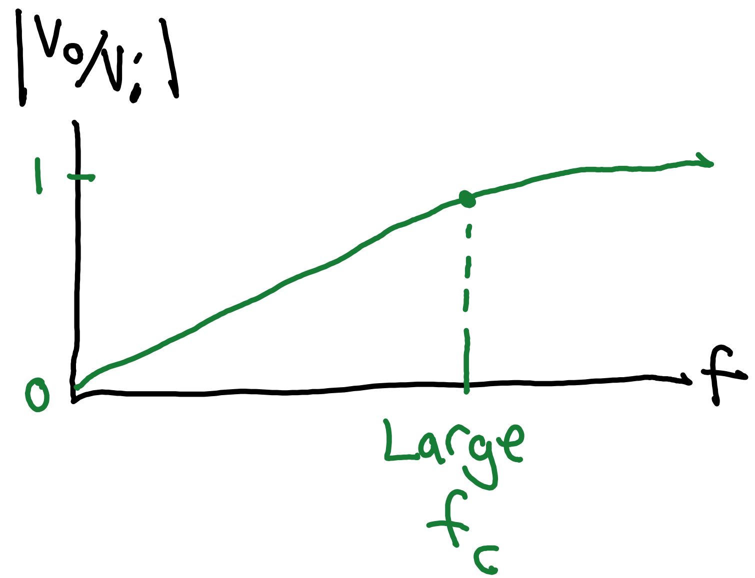
$$f_c = \frac{1}{2\pi RC}$$

NOTE:

$\boxed{\text{Large RC}}$



$\boxed{\text{Small RC}}$

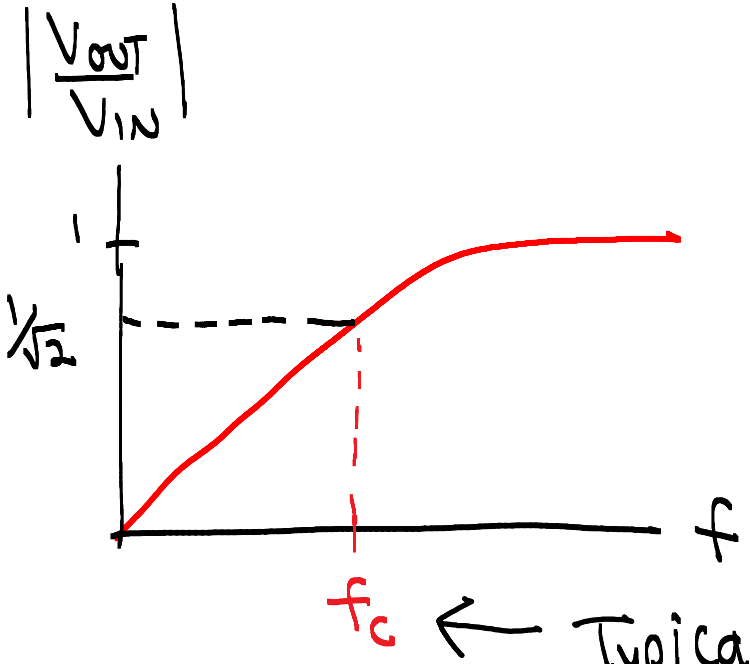


Can easily show that

$$\left|\frac{V_{OUT}}{V_{IN}}\right| = \frac{f/f_c}{\sqrt{1+(f/f_c)^2}}$$

PreLab 3 Problem

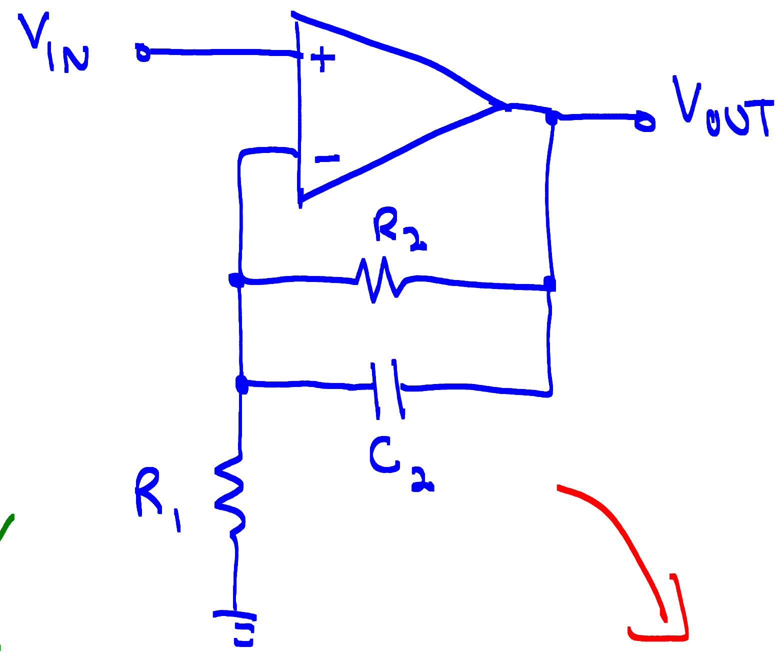
$$f_c = \frac{1}{2\pi RC}$$



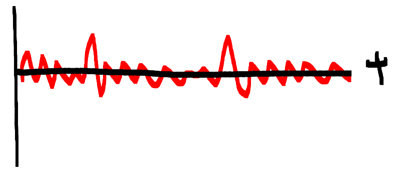
← Typically ~1 Hz for ECG

- After the HPF, the ECG signal is pretty small (~ 5 mV) and very noisy.
  1. Need more gain
  2. Need a low pass filter

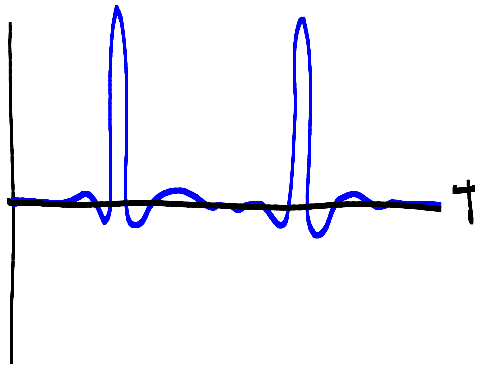
Can combine a non-inverting amplifier with a low pass filter



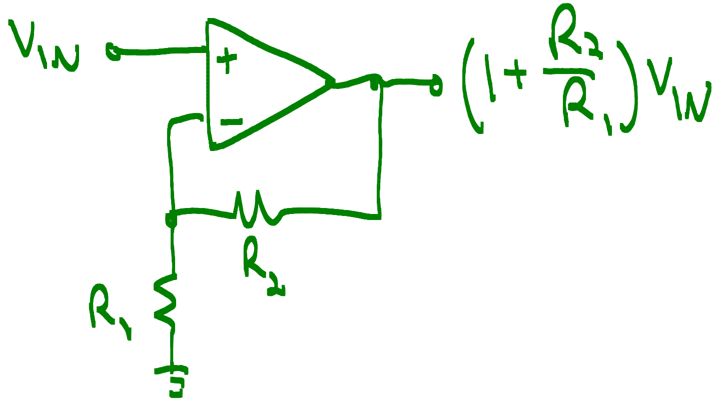
After HPF

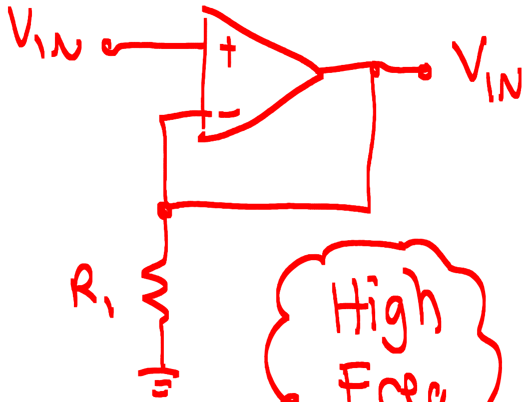


After gain + LPF



Low Freq





High Freq

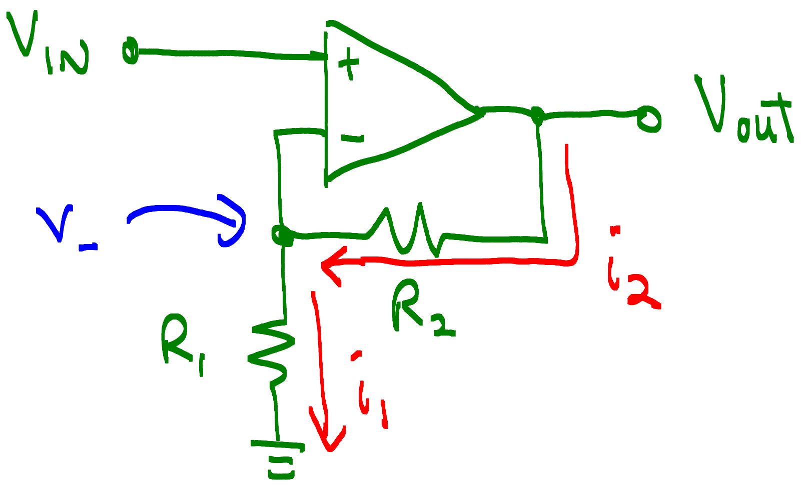
How to derive V_{OUT}/V_{IN}?

Recall the Op Amp **Golden Rules**:

1. The two input terminals are at the <u>same voltage</u>.
2. The two input terminals draw <u>no current</u>.

NOTE: These golden rules assume an ideal op amp used with negative feedback!

Ex:



Golden Rule #2 → KCL at node V_-: $i_2 = i_1$

$$\frac{V_{OUT} - V_-}{R_2} = \frac{V_- - 0}{R_1}$$

Golden Rule #1 → V_{IN}

$$V_{OUT} = \left(1 + \frac{R_2}{R_1}\right) V_-$$

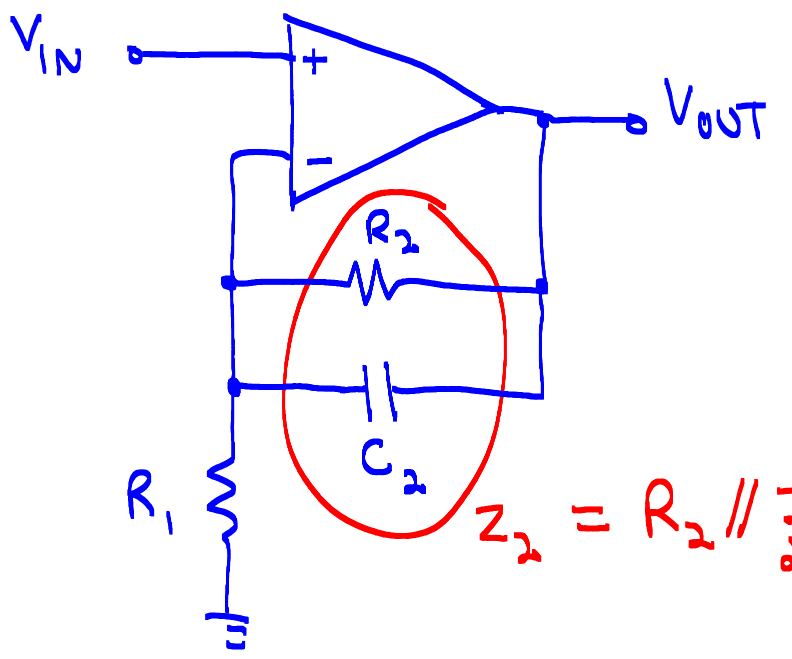
$$\Rightarrow \boxed{\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1}}$$

:)

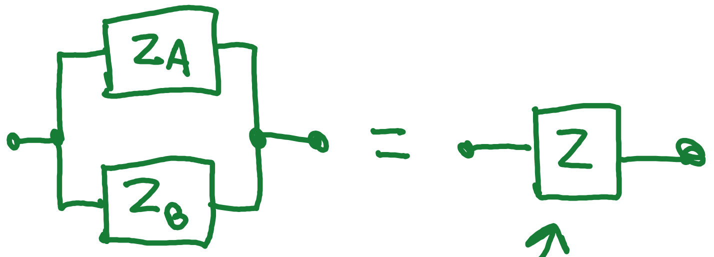
Adding a capacitor in parallel with R_2 causes the gain to <u>decrease</u> at high freq!

$$\Rightarrow \quad \frac{V_{OUT}}{V_{IN}} = 1 + \left[\frac{R_2}{R_1} \cdot \frac{1}{1 + jf/f_c}\right]$$

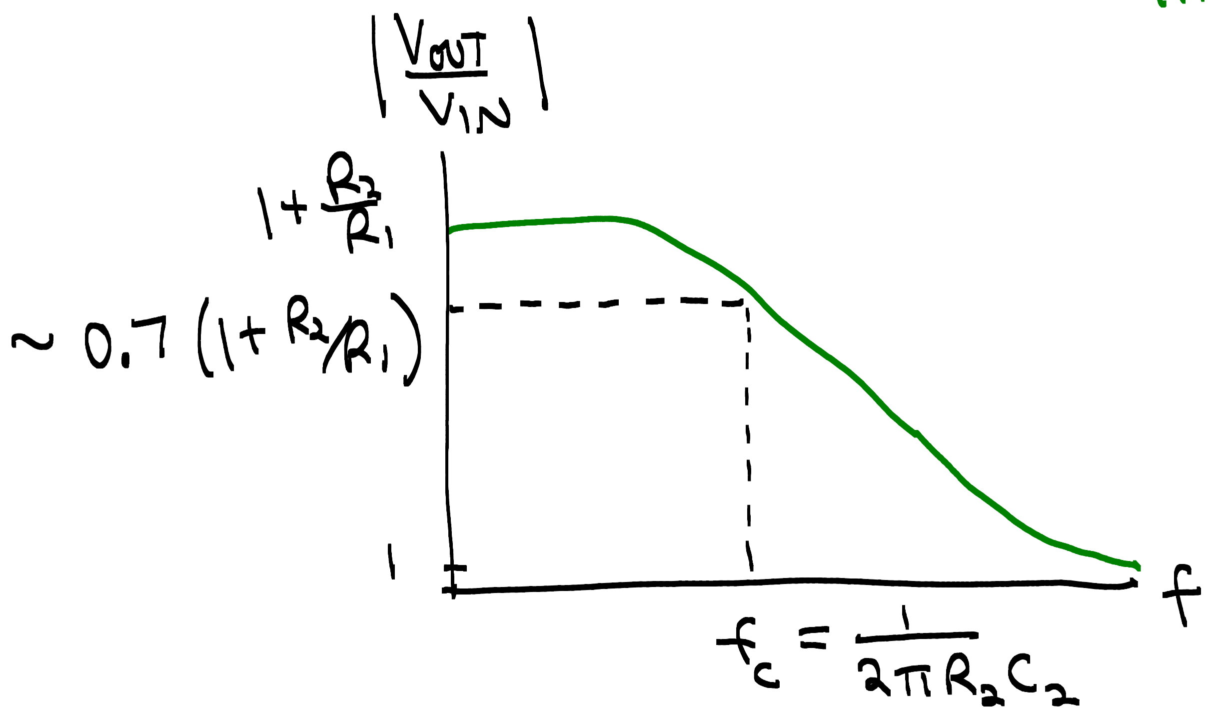
$$f_c = \frac{1}{2\pi R_2 C_2}$$

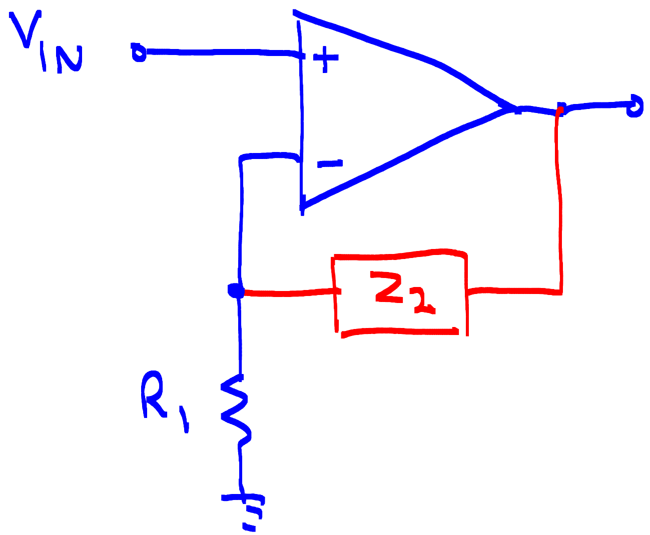


$$Z_2 = R_2 \,//\, \frac{1}{j\omega C_2}$$



$$\frac{Z_A \cdot Z_B}{Z_A + Z_B}$$

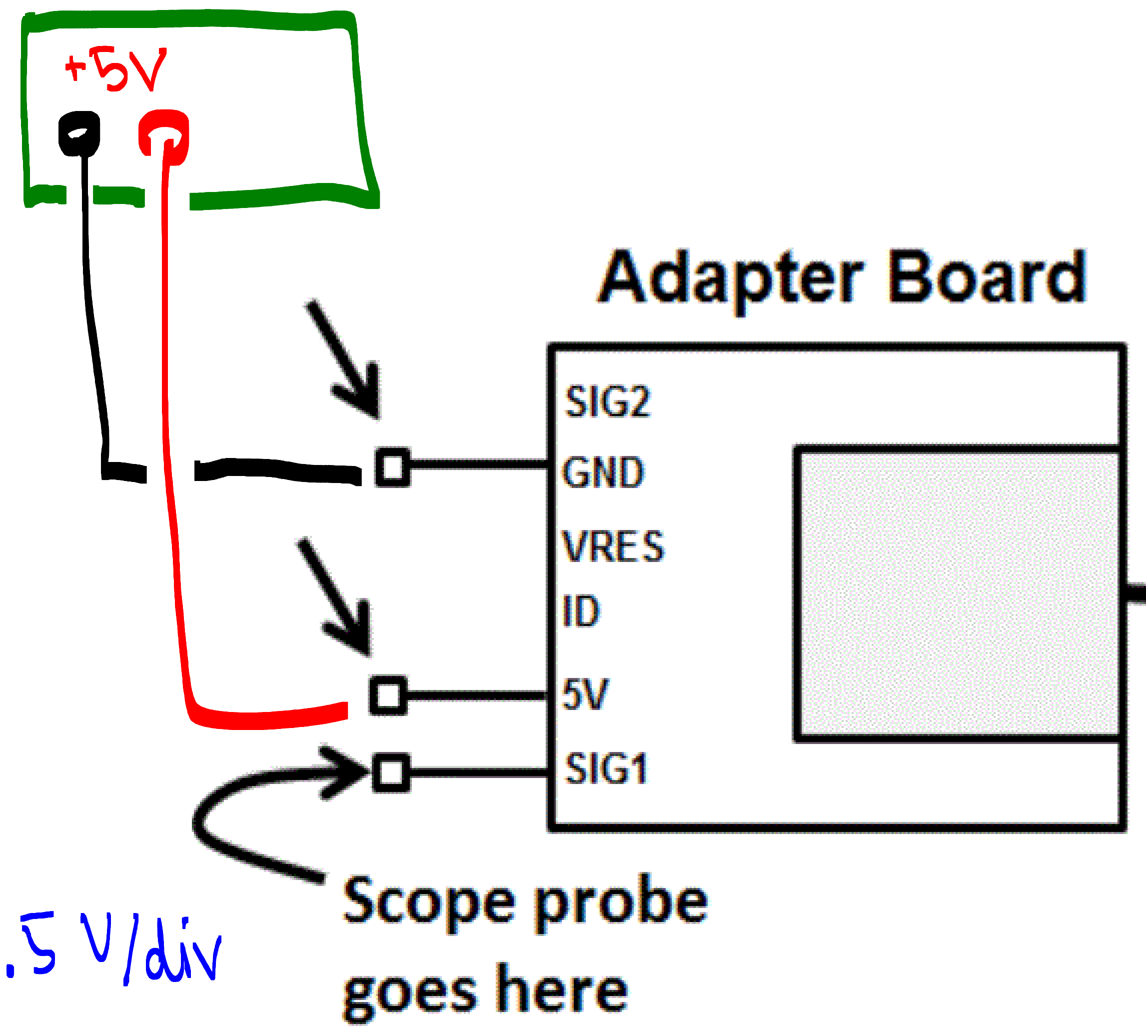


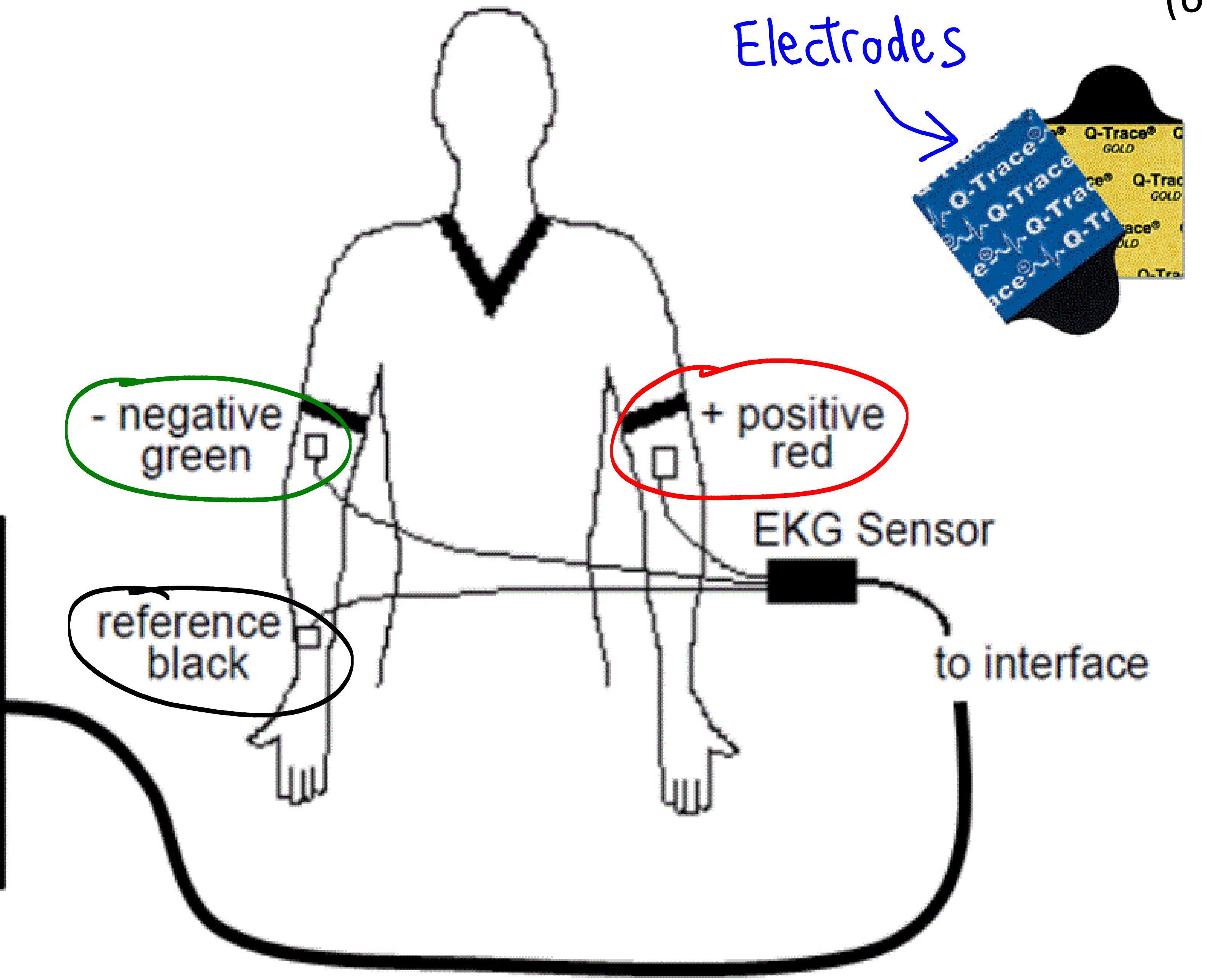


$$V_{OUT} = 1 + \frac{Z_2}{R_1}$$

3. MiniLab

GOAL: Use a commercial ECG sensor to detect PQRST waveform!





Scope:

Vertical = 0.5 V/div

Horizontal = 200 ms/div