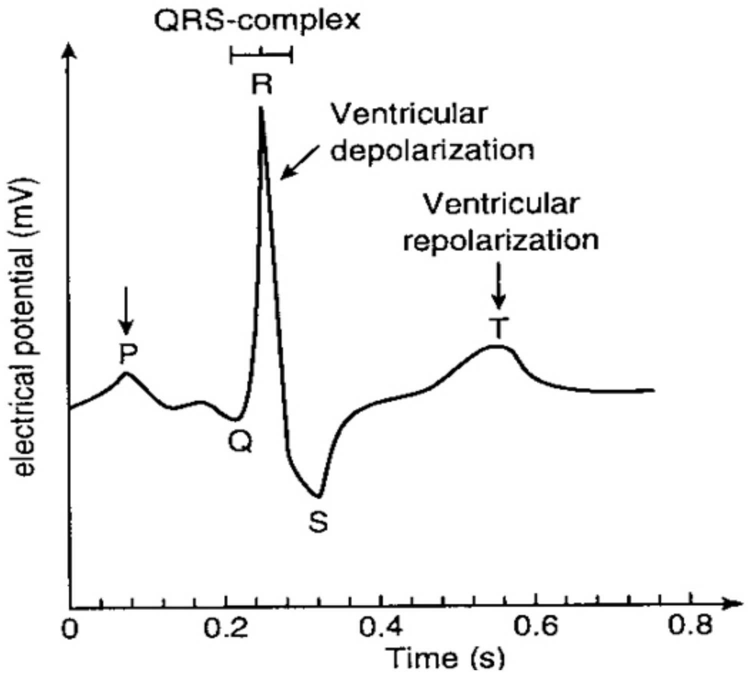
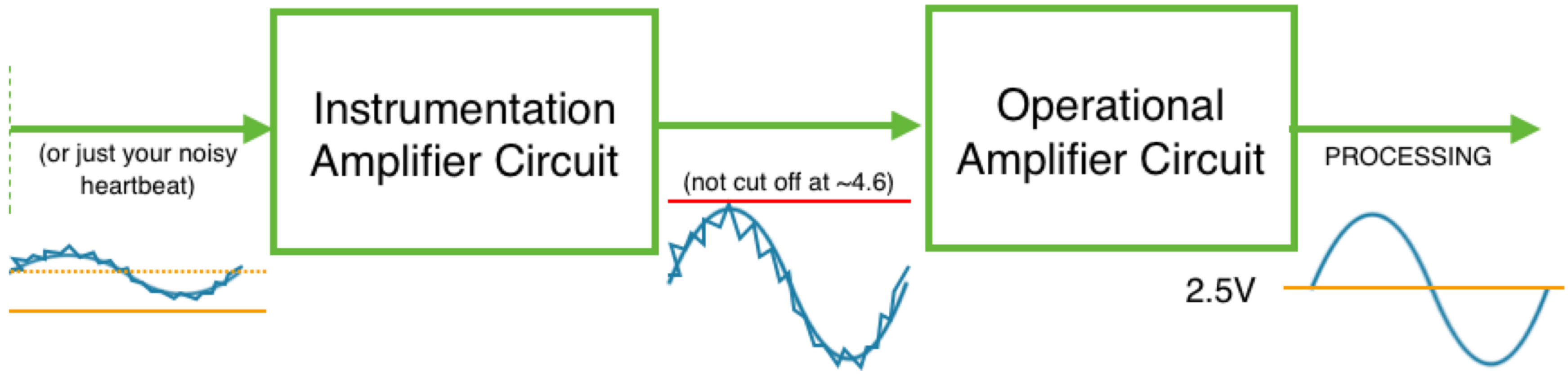
E40M

Instrumentation Amps and Noise 2

ECG Lab - Electrical Picture

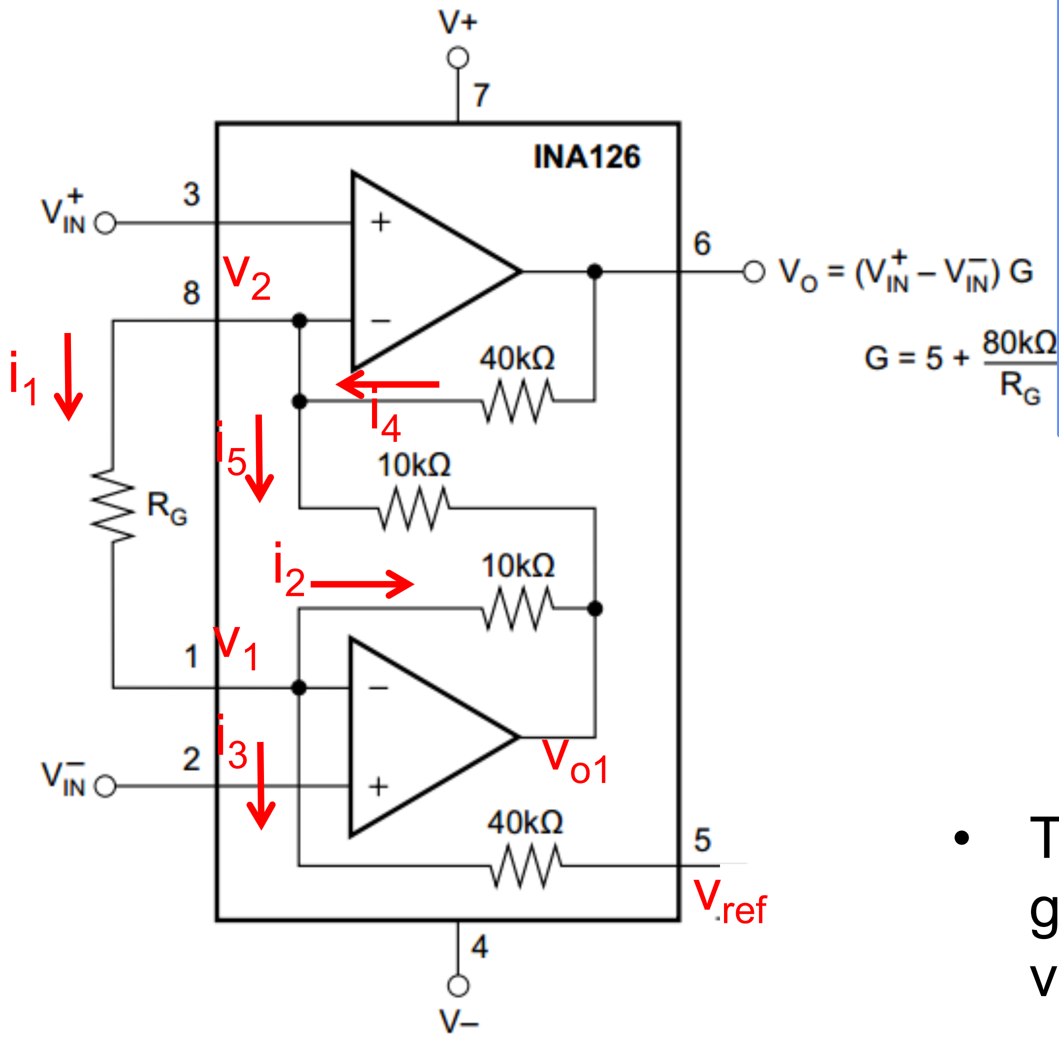


- Signal amplitude ≈ 1 mV
- Noise level will be significant
- ∴ will need to amplify and filter
- We'll use filtering ideas from the last set of lecture notes



Last Time: we found $v_o = f(v_{IN+} - v_{IN-}, v_{ref})$ for the INA126 using the Golden Rules!

Simplified Schematic: INA126



$$v_{o1} = \frac{5v_{IN}^{-}}{4} - \frac{v_{ref}}{4} - \frac{10k\Omega\left(v_{IN}^{+} - v_{IN}^{-}\right)}{R_G}$$

$$v_o = 5v_{IN}^{+} + \frac{40k\Omega\left(v_{IN}^{+} - v_{IN}^{-}\right)}{R_G} - 4v_{o1}$$

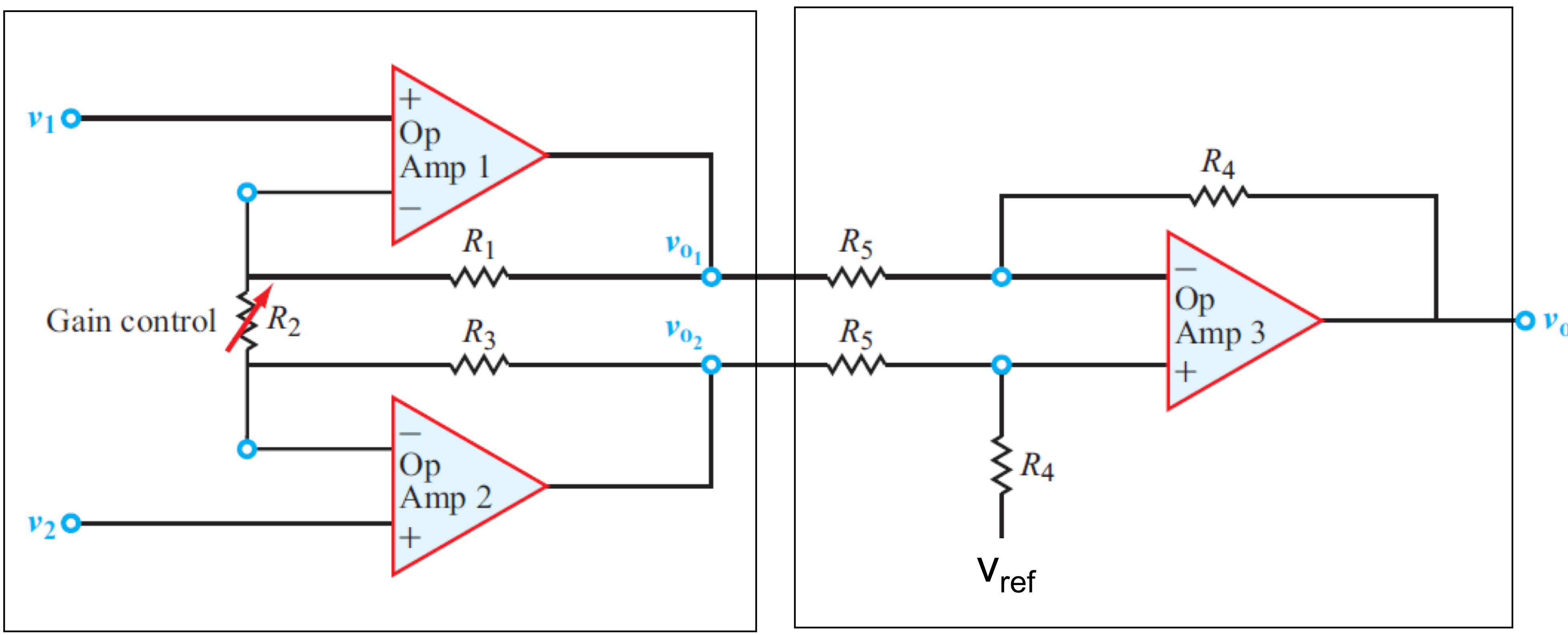
$$\boxed{v_o = \left(\frac{80k\Omega}{R_G} + 5\right)\left(v_{IN}^{+} - v_{IN}^{-}\right) + v_{ref}}$$

- This is exactly the gain expression given in the 1NA126 data sheet for $v_{ref} = 0$!

Another Instrumentation Amplifier

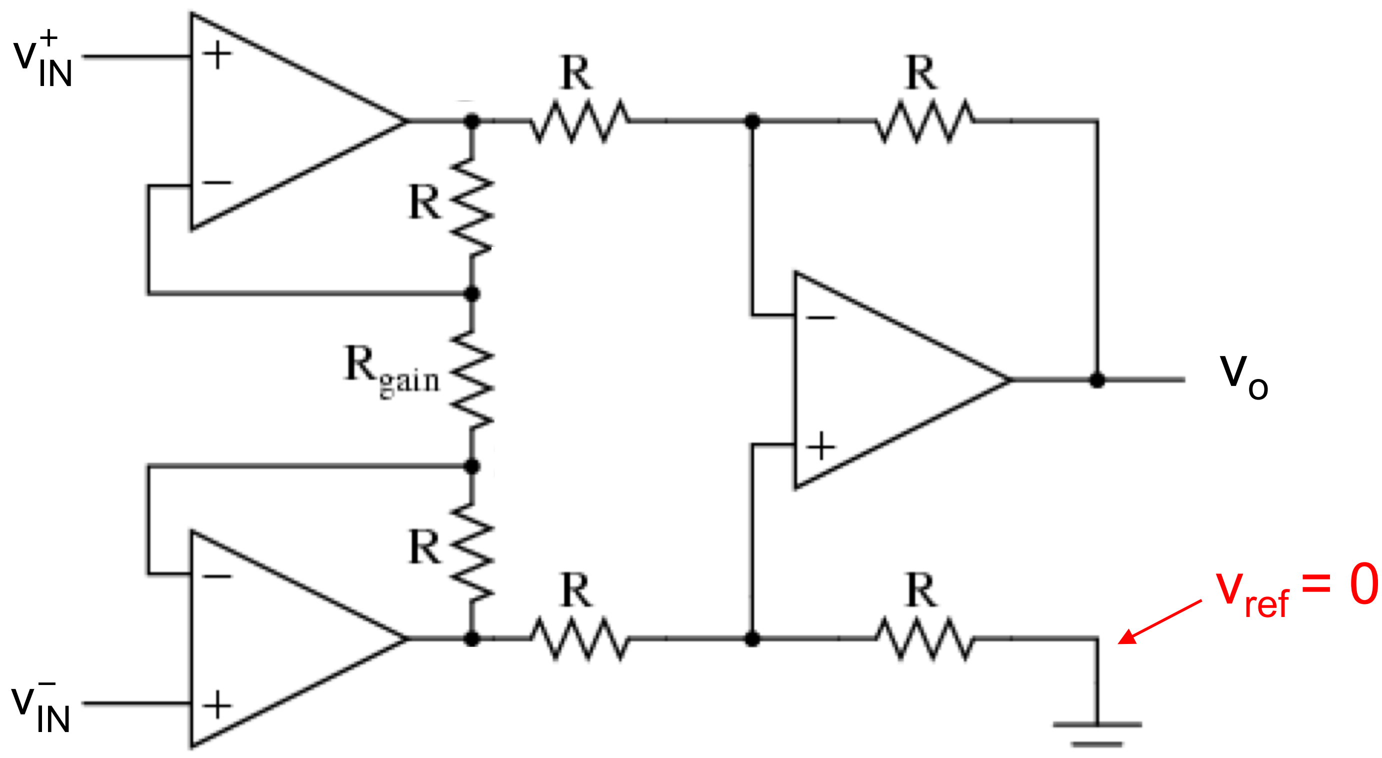
(Note: we are not using this architecture in Lab 4)

- Most instrumentation amplifiers are actually built with 3 op amps.
- The analysis is quite similar to the past few pages

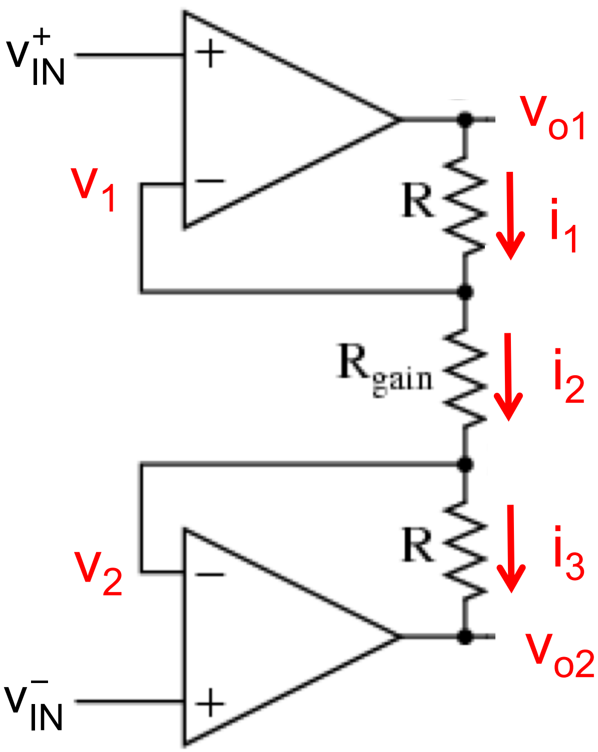


Another Instrumentation Amplifier (More Practice)

- Consider a simplified case in which all resistors are the same (except R_{gain}) and $v_{ref} = 0$.
- We won't cover this in class – try it yourself, you should be able to analyze this! Try it to test your understanding.



Front End (First Stage) of this Instrumentation Amplifier



- G.R. #1: $v_{IN}^{+} = v_1$ and $v_{IN}^{-} = v_2$
- KCL + G.R. #2: $i_1 = i_2 = i_3$

$$\frac{v_{o1} - v_{IN}^{+}}{R} = \frac{v_{IN}^{+} - v_{IN}^{-}}{R_{gain}} = \frac{v_{IN}^{-} - v_{o2}}{R}$$

$$\therefore \frac{v_{o1}}{R} = \frac{v_{IN}^{+}}{R} + \frac{v_{IN}^{+}}{R_{gain}} - \frac{v_{IN}^{-}}{R_{gain}}$$

$$\therefore v_{o1} = \frac{R}{R_{gain}}\left(v_{IN}^{+} - v_{IN}^{-}\right) + v_{IN}^{+}$$

Similarly, $v_{o2} = \dfrac{R}{R_{gain}}\left(v_{IN}^{-} - v_{IN}^{+}\right) + v_{IN}^{-}$

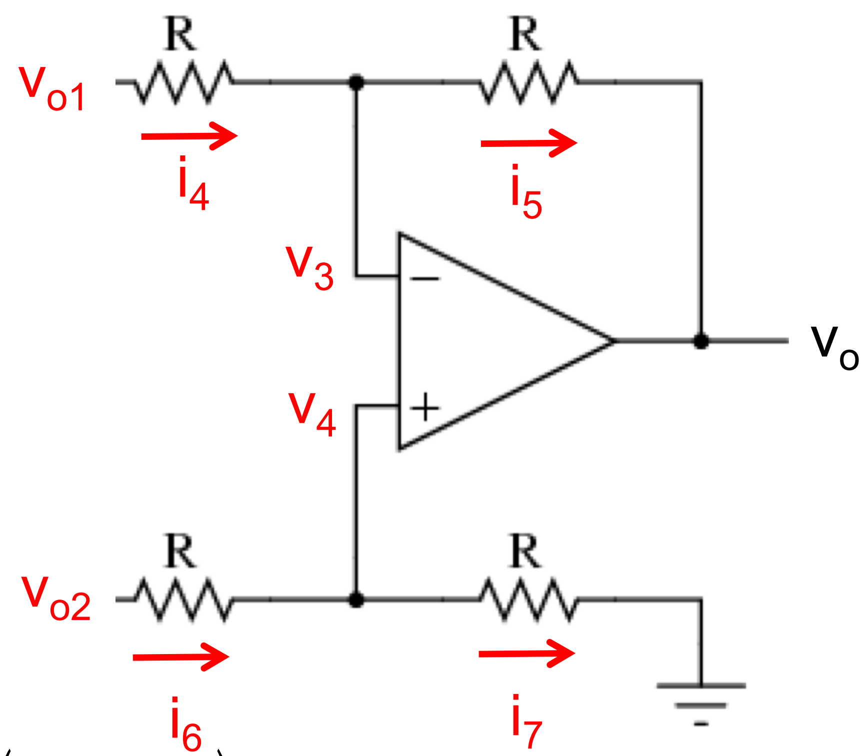
Back End (Second Stage) of this Instrumentation Amplifier

G.R. #2: $i_4 = i_5$ and $i_6 = i_7$

$$\frac{v_{o1} - v_3}{R} = \frac{v_3 - v_o}{R} \quad \text{so that} \quad v_o = 2v_3 - v_{o1}$$

$$\frac{v_{o2} - v_4}{R} = \frac{v_4}{R} \quad \text{so that} \quad v_4 = \frac{v_{o2}}{2} = v_3$$

Combining, $v_o = v_{o2} - v_{o1}$



Using the results from the previous page,

$$v_o = v_{o2} - v_{o1} = \frac{R}{R_{gain}}\left(v_{IN}^- - v_{IN}^+\right) + v_{IN}^- - \frac{R}{R_{gain}}\left(v_{IN}^+ - v_{IN}^-\right) - v_{IN}^+$$

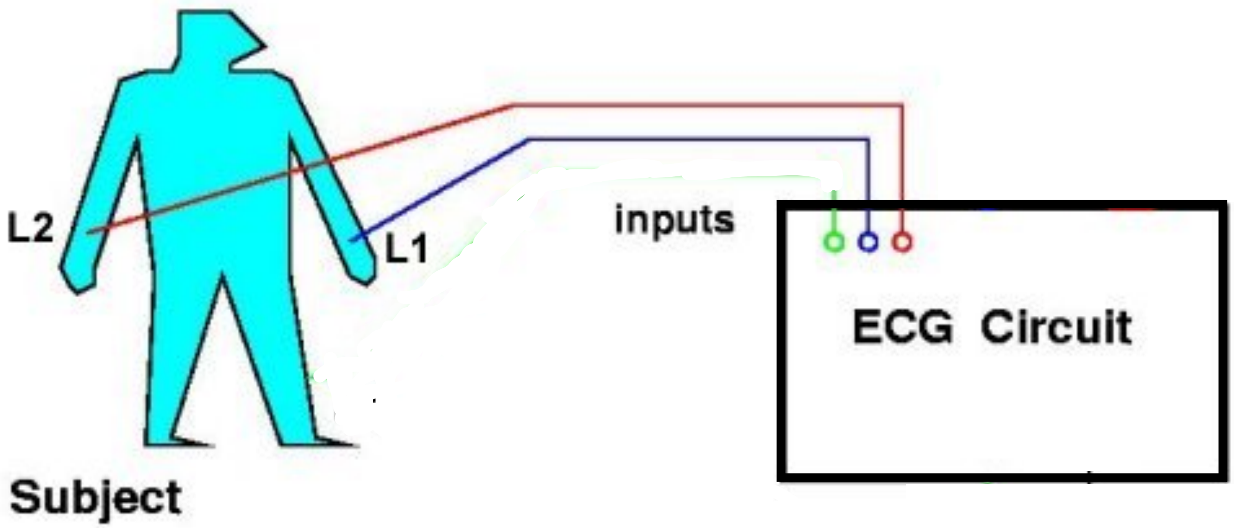
$$\therefore v_o = \left(v_{IN}^- - v_{IN}^+\right)\left(2\frac{R}{R_{gain}} + 1\right)$$

Why do we need the second stage?

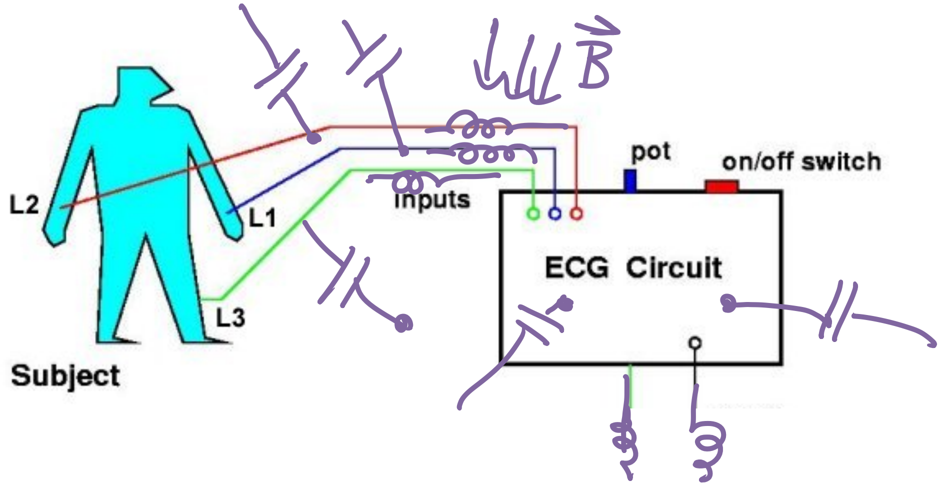
NOISE

ECG Measurement

- Need to measure the difference between L1 and L2
  - We think the circuit looks like



The Circuit Really Looks Like This:

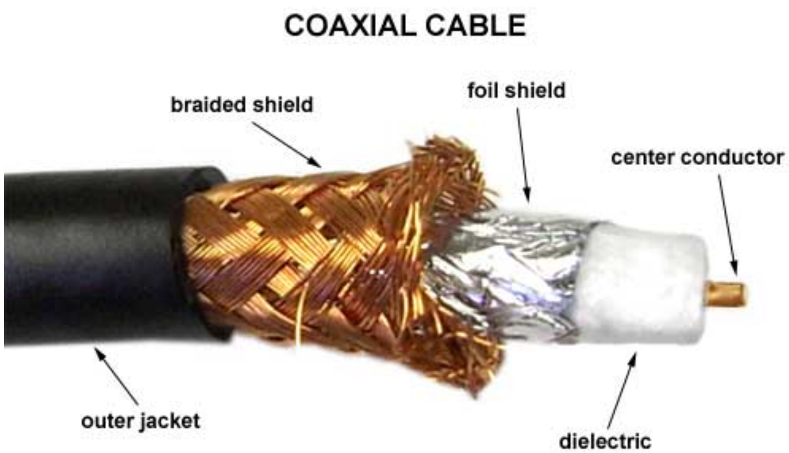


- There are many unwanted signals coupling into our circuit
  - Both capacitive (stray electric fields) and inductive (magnetic fields)
  - These signals can be larger than what we want to measure!

- How to prevent them from obscuring our signal?

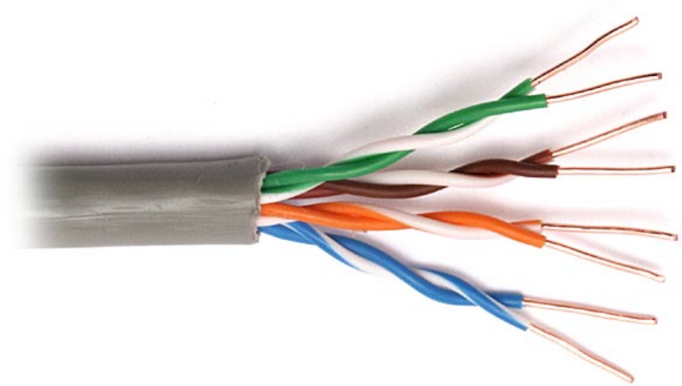
Noise Protection For Wires

- Shield the signal (literally cover it with metal)

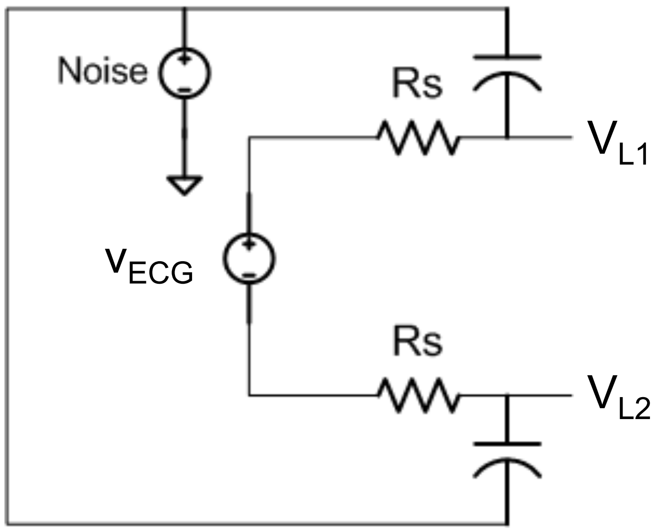


http://www.cablewholesale.com/support/technical_articles/coaxial_cables.php

- Try to make the noise common mode
  … meaning the same voltage on each of the inputs
  – Twist wires to each other



Model of the Capacitive Noise
(if it is common to both wires)

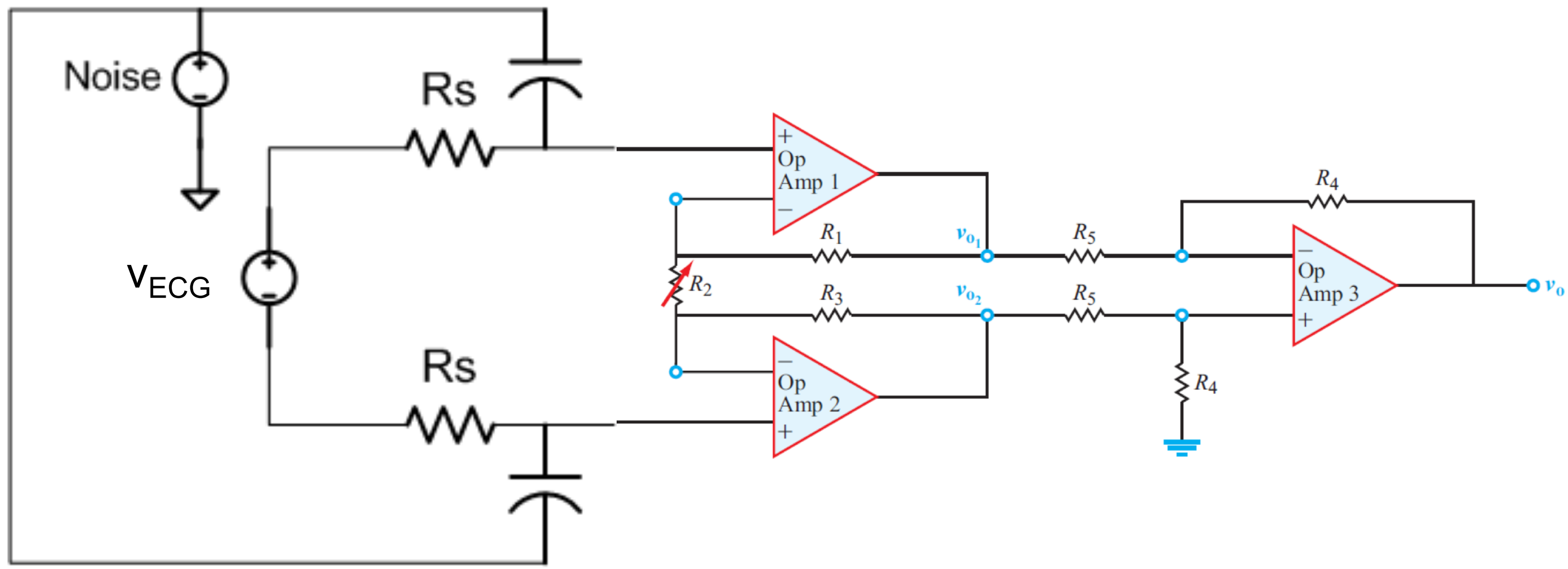


- The voltage at the two outputs will depend on ECG and Noise

  But if the capacitors and resistors are exactly the same

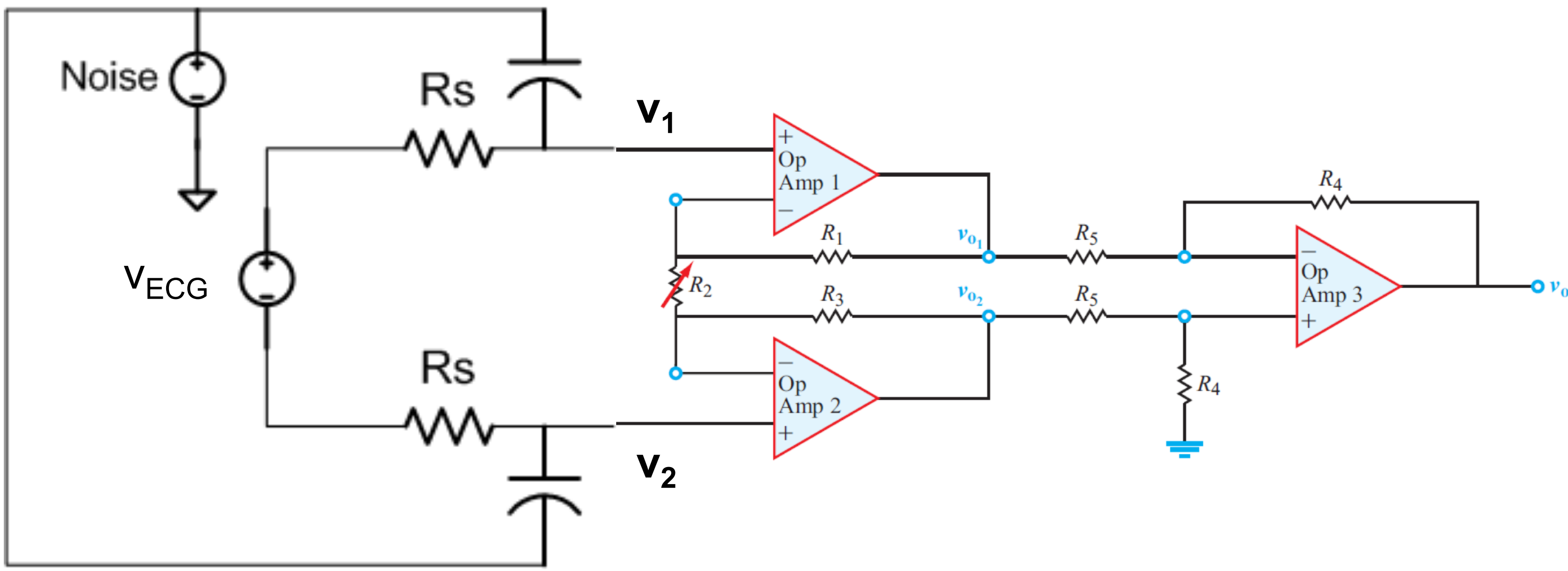
  $(V_{L1} - V_{L2})$ will not depend on noise – only on v_{ECG}
- This is only true if the capacitance on both wires is identical
  - Which means we need a balanced differential amplifier

Balanced Amplifier



- This is a completely differential system
  - Good for reducing noise coupling

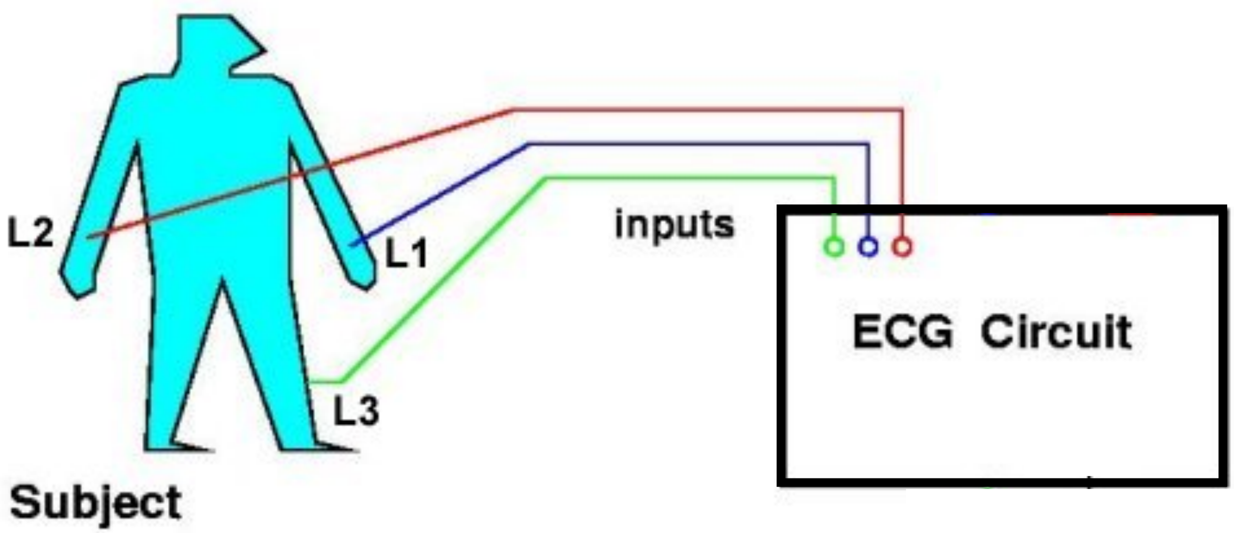
New Problem in Our Balanced Amplifier



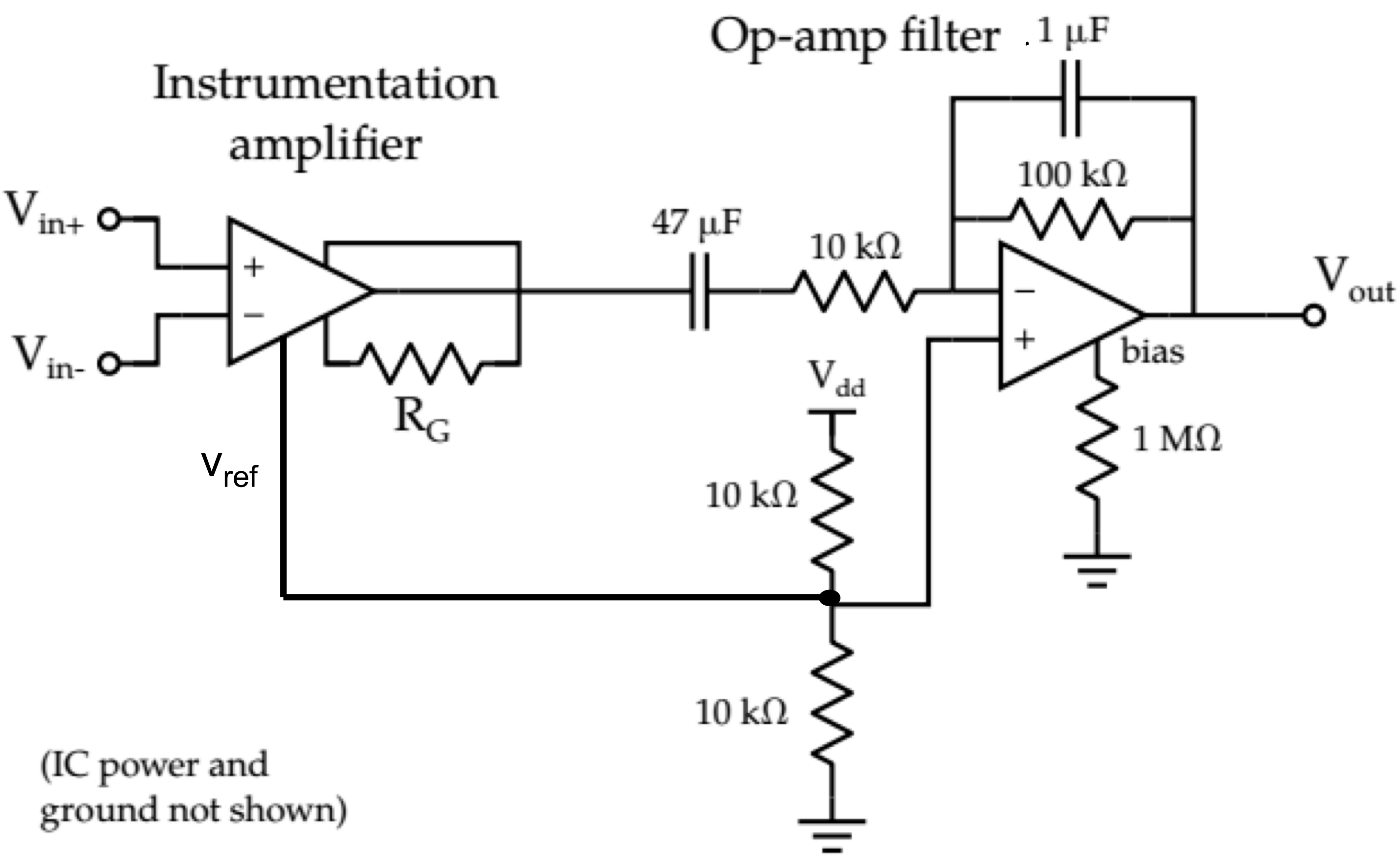
- What sets the voltage at v_1, v_2 ?
  - v_{ECG} only sets $v_1 - v_2$
  - They are not referenced to our chip's reference (Gnd)!
  - Chip won't work unless inputs are between +/- supply voltage.

The Reason for the Third Wire

- Need to measure the difference between L1 and L2
  - L3 is used to set the common-mode of the person



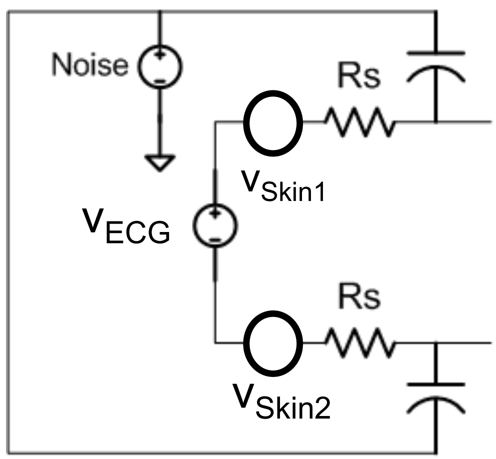
Why Does the ECG Circuit Look Like This?

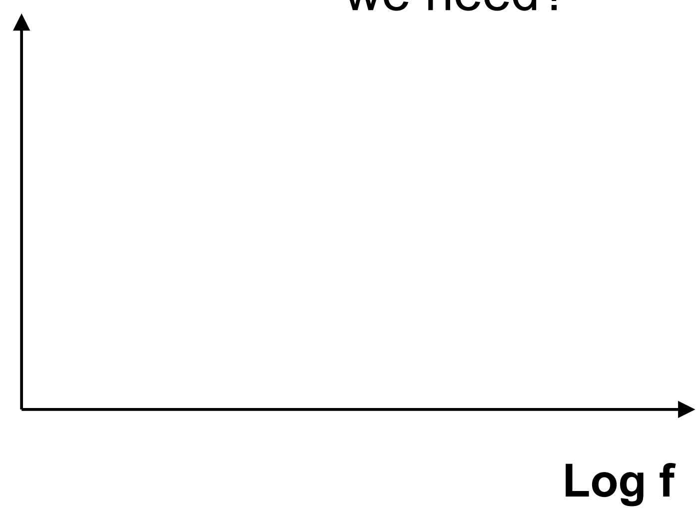


Noise: Skin Voltage

- A voltage forms when metal contacts skin
  - The size of the voltage depends on the skin condition

- This means if the conditions at the two electrodes differ
  - You can generate a voltage
    - This voltage will change very slowly with time … what kind of filter do we need?





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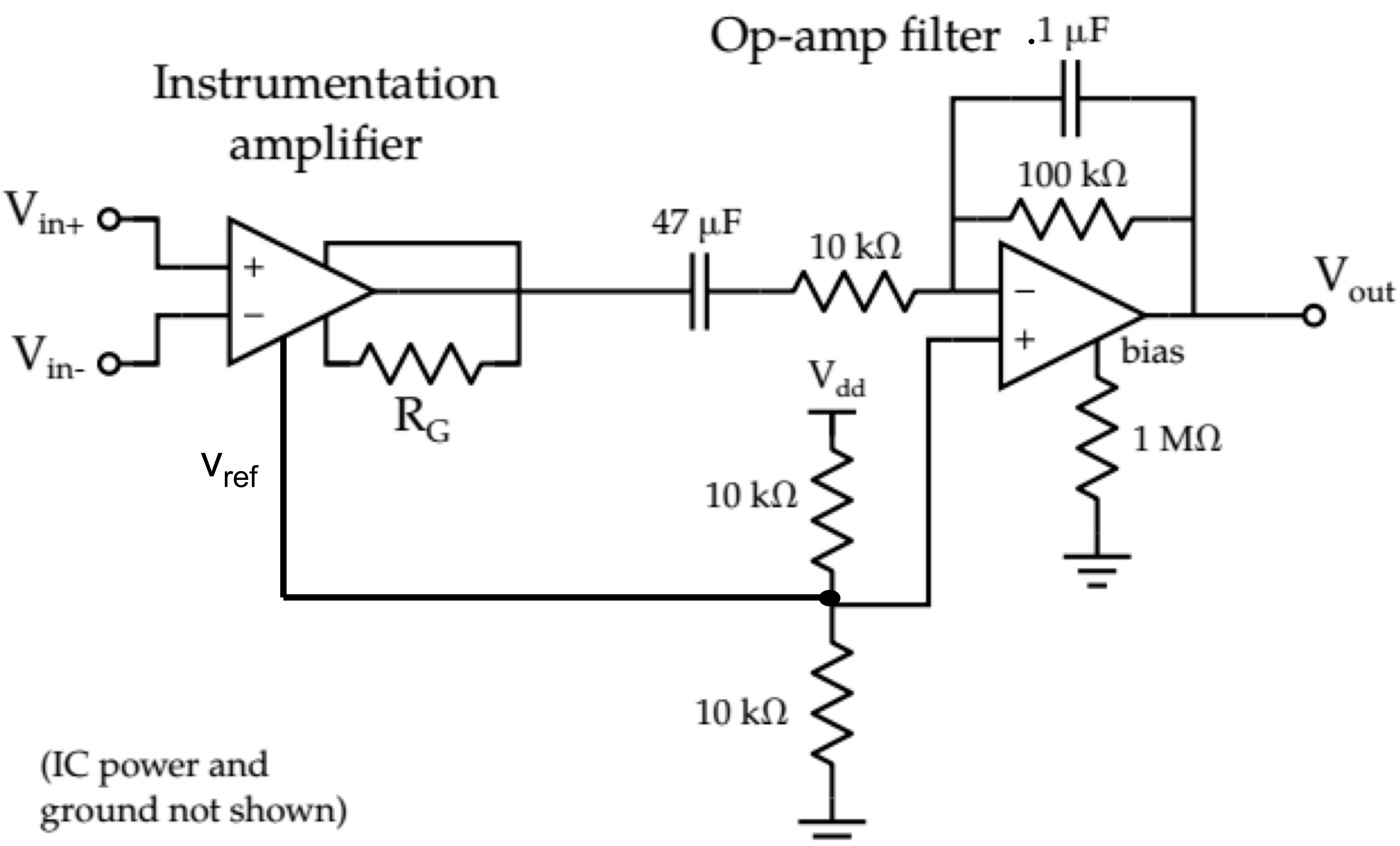
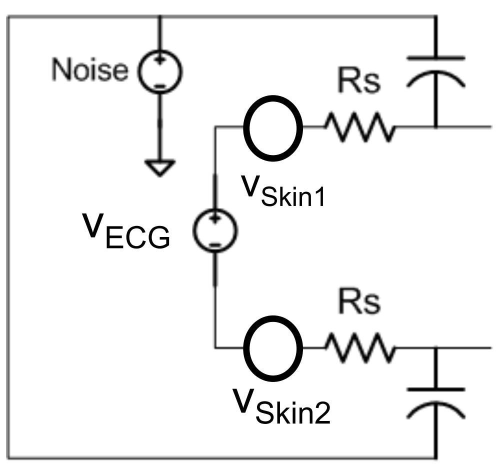
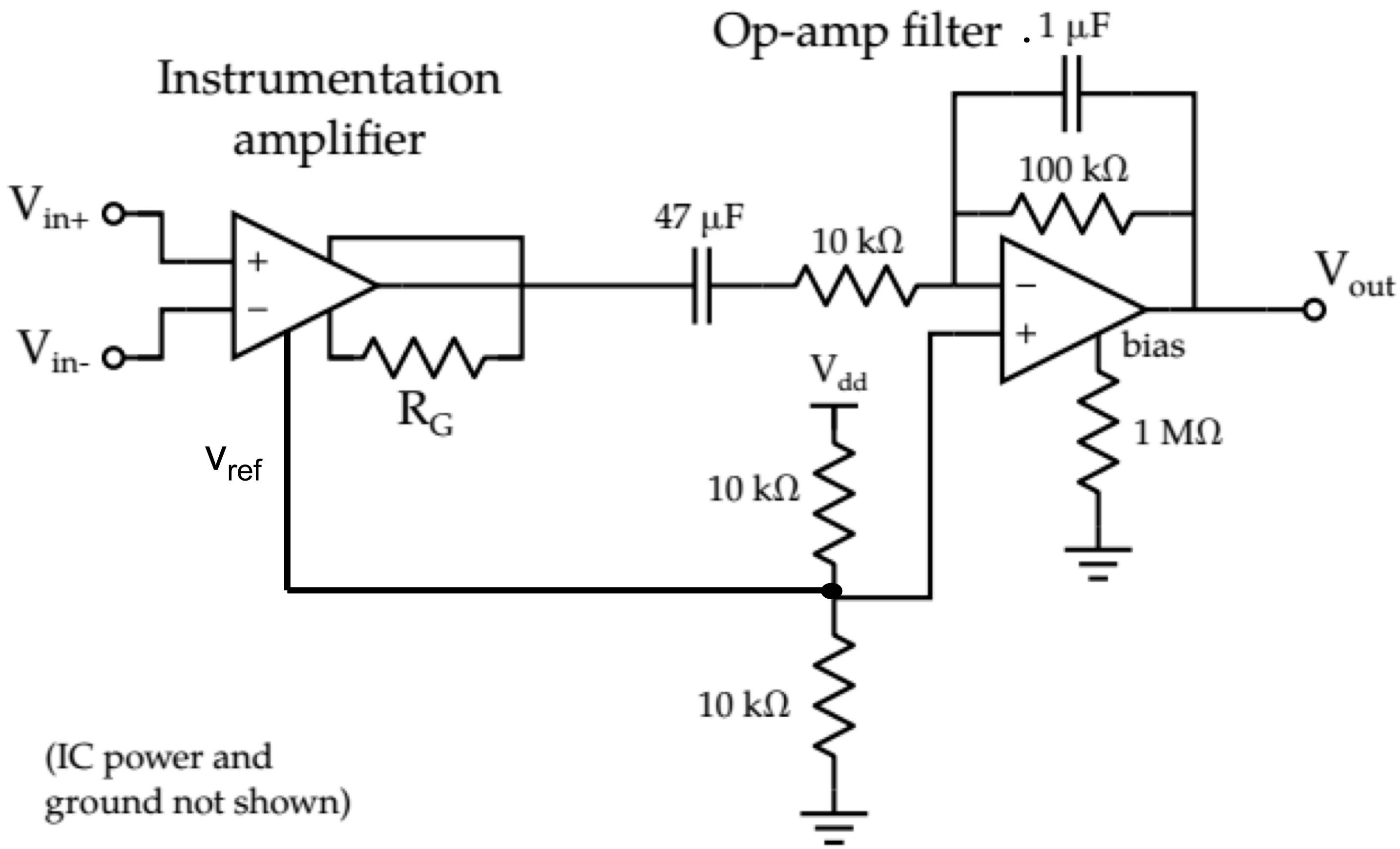


Noise: 60 Hz Wall Voltage

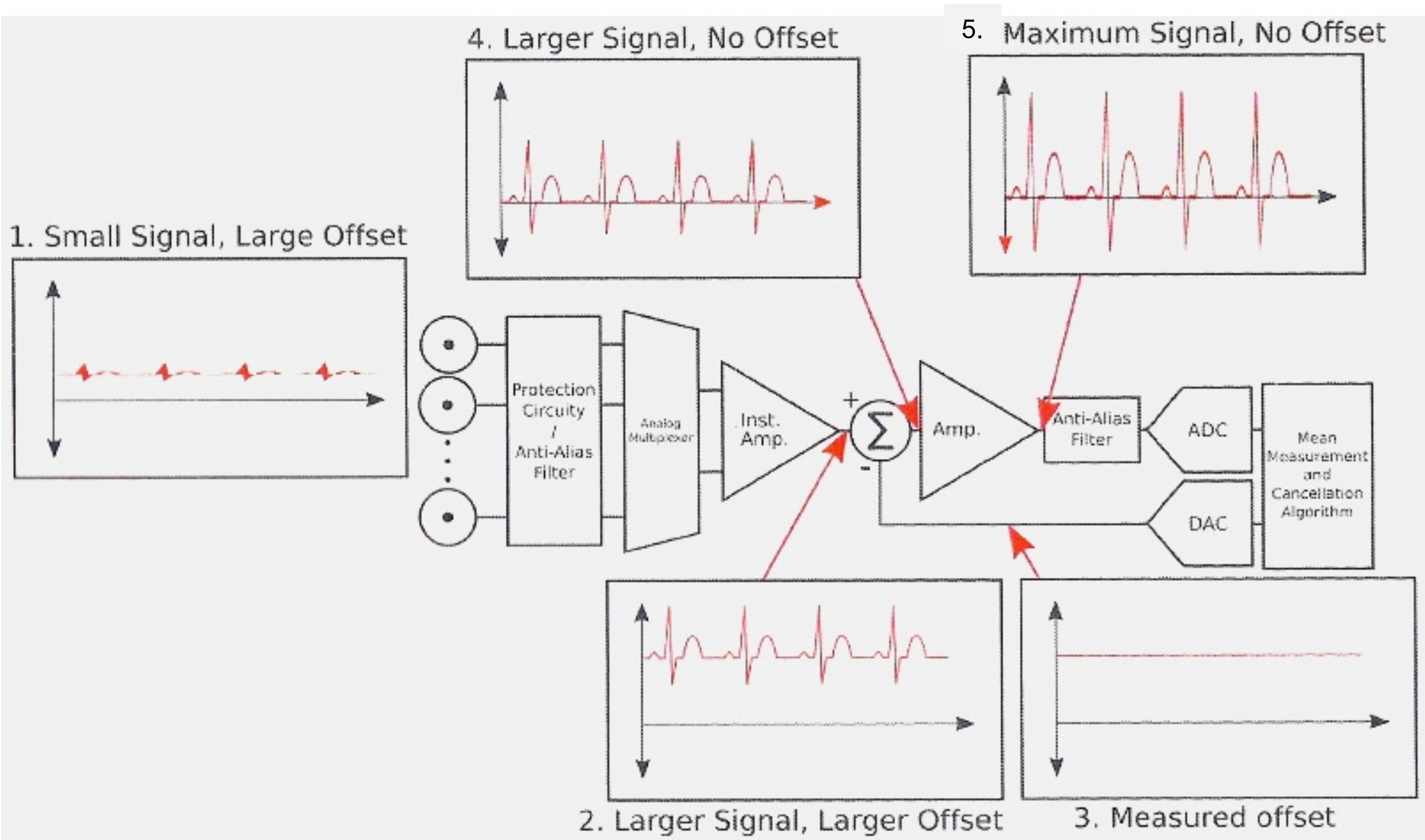
- The main capacitive noise comes from AC power
  - 120 to 240V, 60 Hz and harmonics, especially 120 Hz
  - This signal can be quite large (Volts!)
    - 1000x your signal!
- Differential circuit cancels most of it out
  - But some will still get through due to imperfect matching. What kind of filter do we need?



Why Does the ECG Circuit Look Like This?



Alternative ECG Architecture



Bill Esposito, Ph.D. Defense, Dept. of Electrical Engineering, Stanford University, May 21, 2018

Learning Objectives

- Understand how an instrumentation amplifier works
  - And how to set its gain through resistor selection
- Understand what noise is
  - Other electrical signals that you don't want on your wires
  - And how to minimize their effects on your circuit through differential amplifiers and filtering
- Understand the design philosophy behind our E40M ECG circuit