ECE 441 Interfacing & Modulating the Nervous System

Fall 2023

Lecture 06 Electrical Neural Interface

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Today's Agenda

- Neural signals
- Neural Signal Amplification
- Model of Electrode Interface
- Noise and Interferences
- Instrumentation Amplifiers

About Me

- **Experience**
  - Assistant Professor – University of Toronto
  - Affiliated Scientist – University Health Network
  - Qualcomm Inc. (2016 – 2021)
  - Ph.D. University of Pennsylvania
- **Research Interests**
  - Integrated Circuits and Systems
  - Brain Machine Interfaces
  - Edge Artificial Intelligence

About Me

- **More about my research**

https://www.eecg.utoronto.ca/~xilinliu/

- **Contact**
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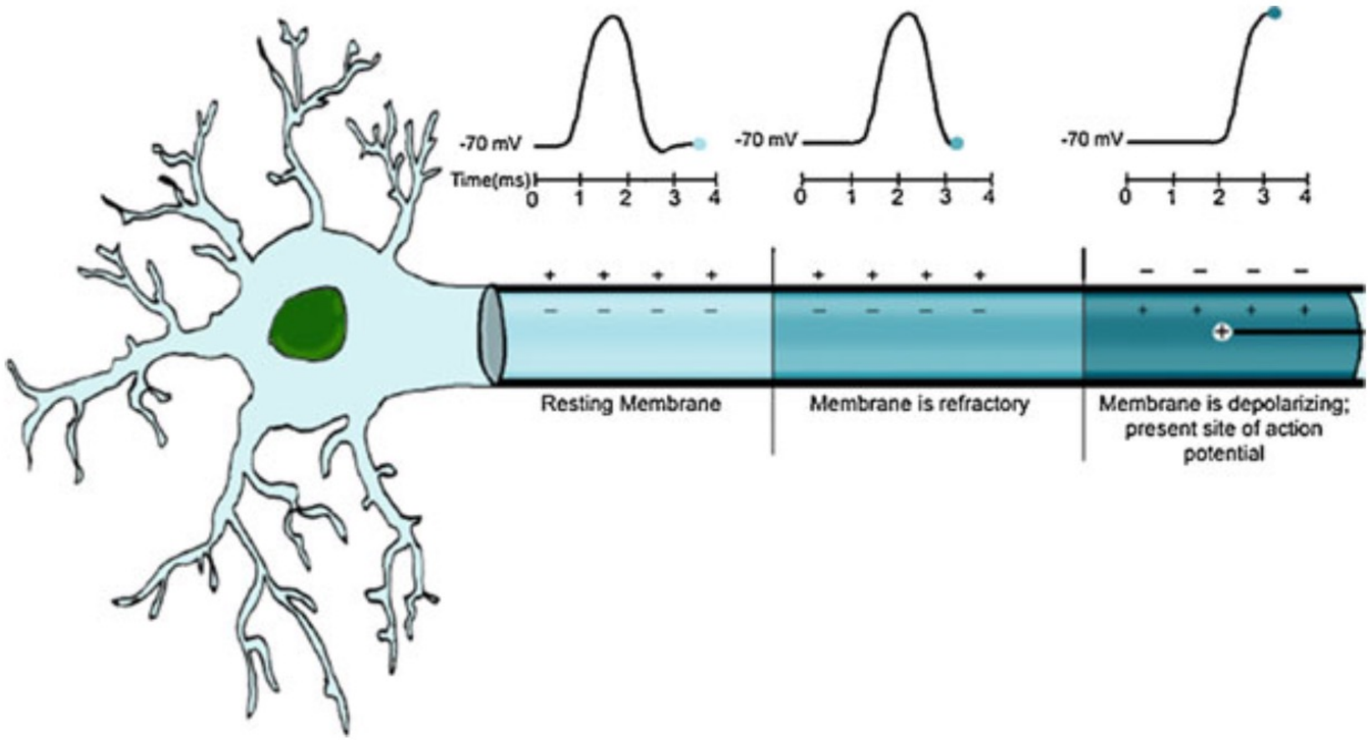
  - Office: BA5108

- **Office Hours**
  - After lecture or by appointment

Neural Signals

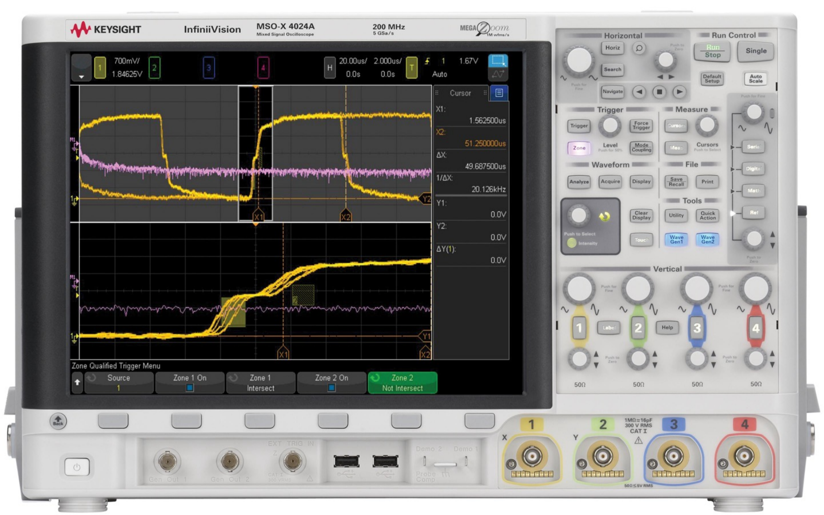
Neural signals are essentially electrical and electrochemical signals



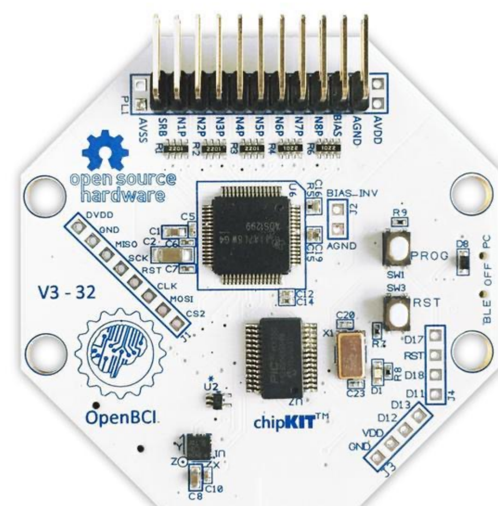
B. He, Neural Engineering, ch 1.1

Neural Signals

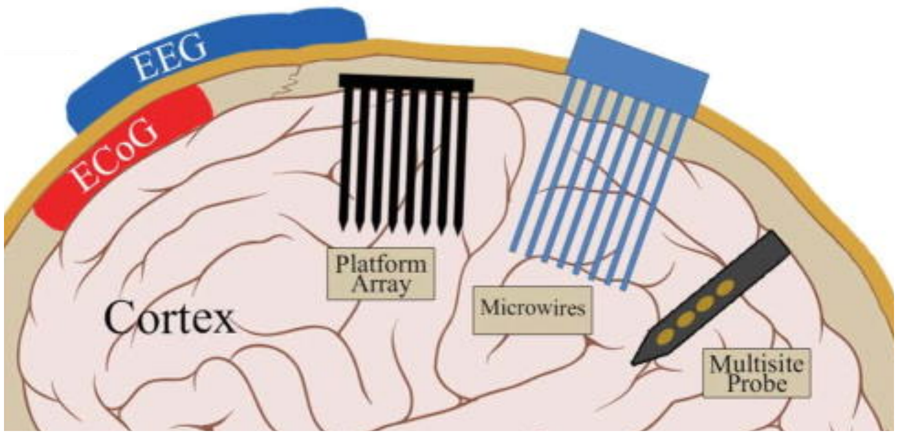
Can we use an oscilloscope to measure brain signals?



V.S.



Neural Signals: EEG

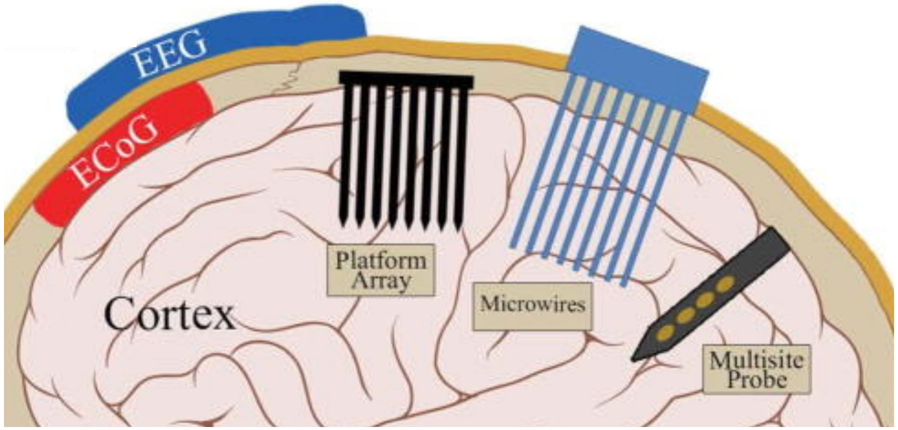


EEG
5-300uV
< 100Hz

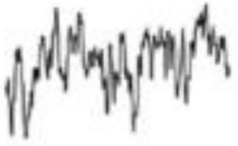
- **EEG**: Electroencephalogram

Nicolo Lago, et al., "Flexible and Organic Neural Interfaces: A Review", Applied Science

Neural Signals: ECoG



EEG
5-300uV
< 100Hz

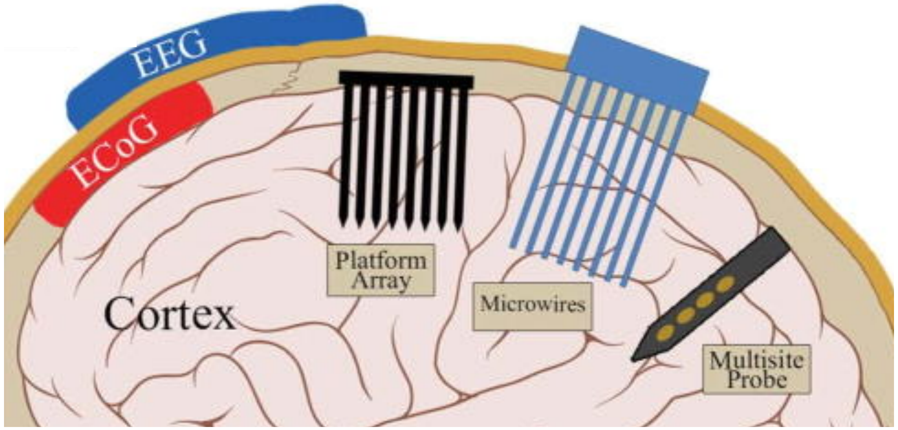


ECoG
10uV – 1mV
< 200Hz

- **EEG**: Electroencephalogram
- **ECoG**: Electrocorticography

Nicolo Lago, et al., “Flexible and Organic Neural Interfaces: A Review”, Applied Science

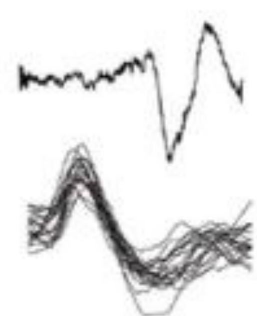
Neural Signals: LFP & AP



- **EEG**: Electroencephalogram
- **ECoG**: Electrocorticography
- **LFP**: Local Field Potential
- **AP**: Action Potential

EEG
5-300uV
< 100Hz

ECoG
10uV – 1mV
< 200Hz



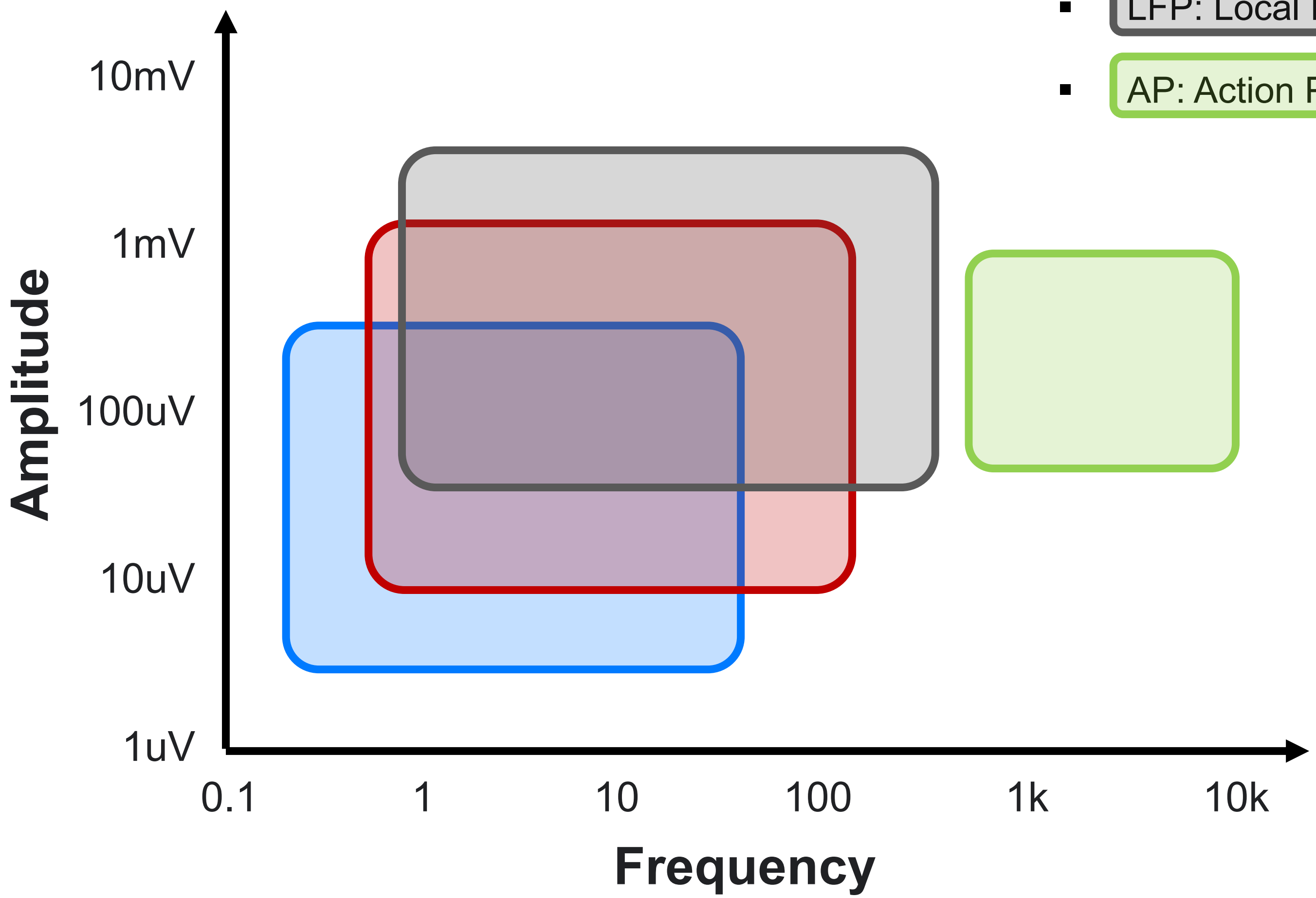
LFP
20uV – 2mV
< 500Hz

AP
100uV – 1mV
100 – 7kHz

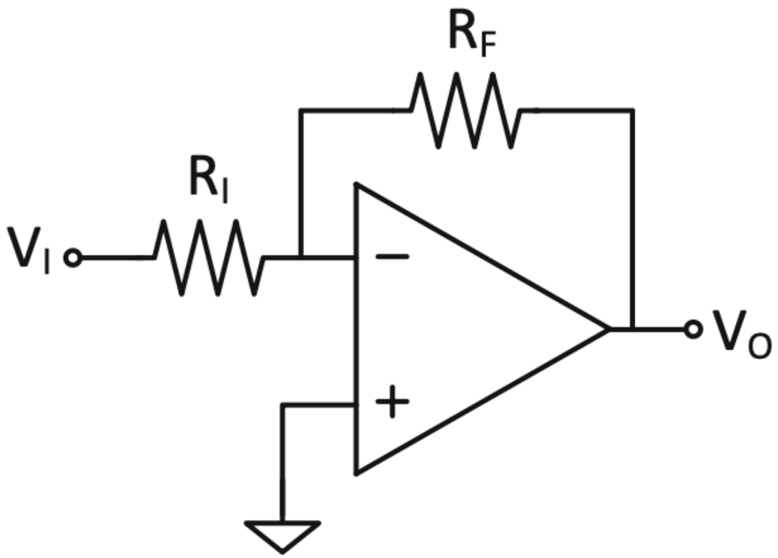
Nicolo Lago, et al., “Flexible and Organic Neural Interfaces: A Review”, Applied Science

Neural Signals

- EEG: Electroencephalogram
- ECoG: Electrocorticography
- LFP: Local Field Potential
- AP: Action Potential

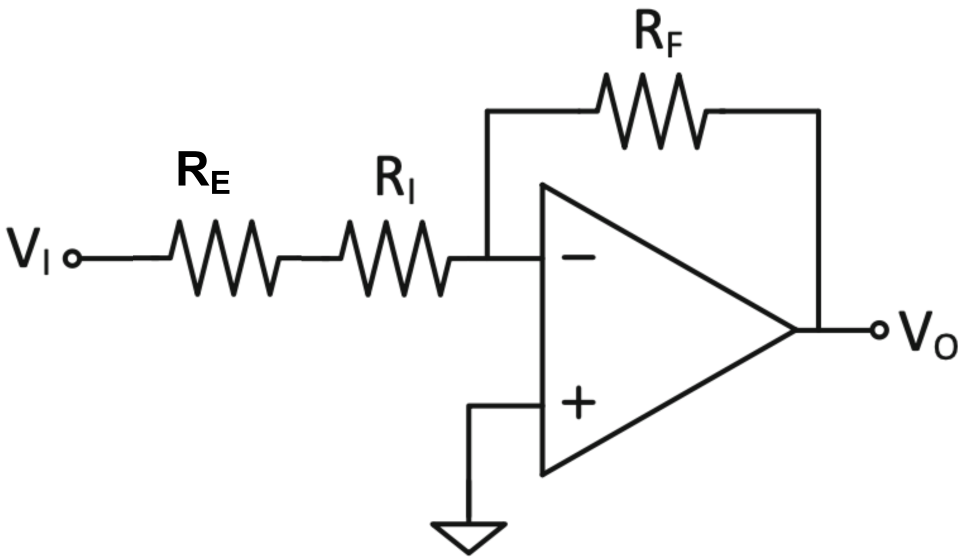


Neural Signal Amplification



B. He, Neural Engineering, ch 2.3

Neural Signal Amplification with Electrode

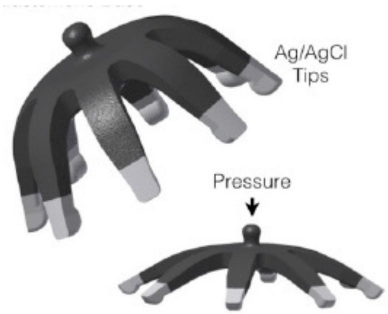


Neural Electrodes: EEG

Wet EEG Electrodes

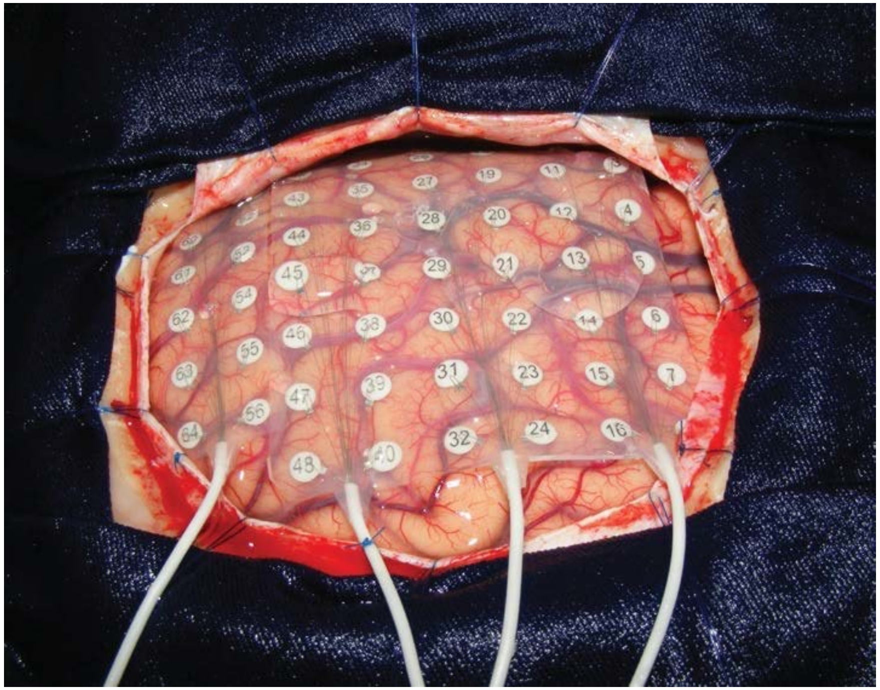
Impedance:
< 10kohm

Dry EEG Electrodes



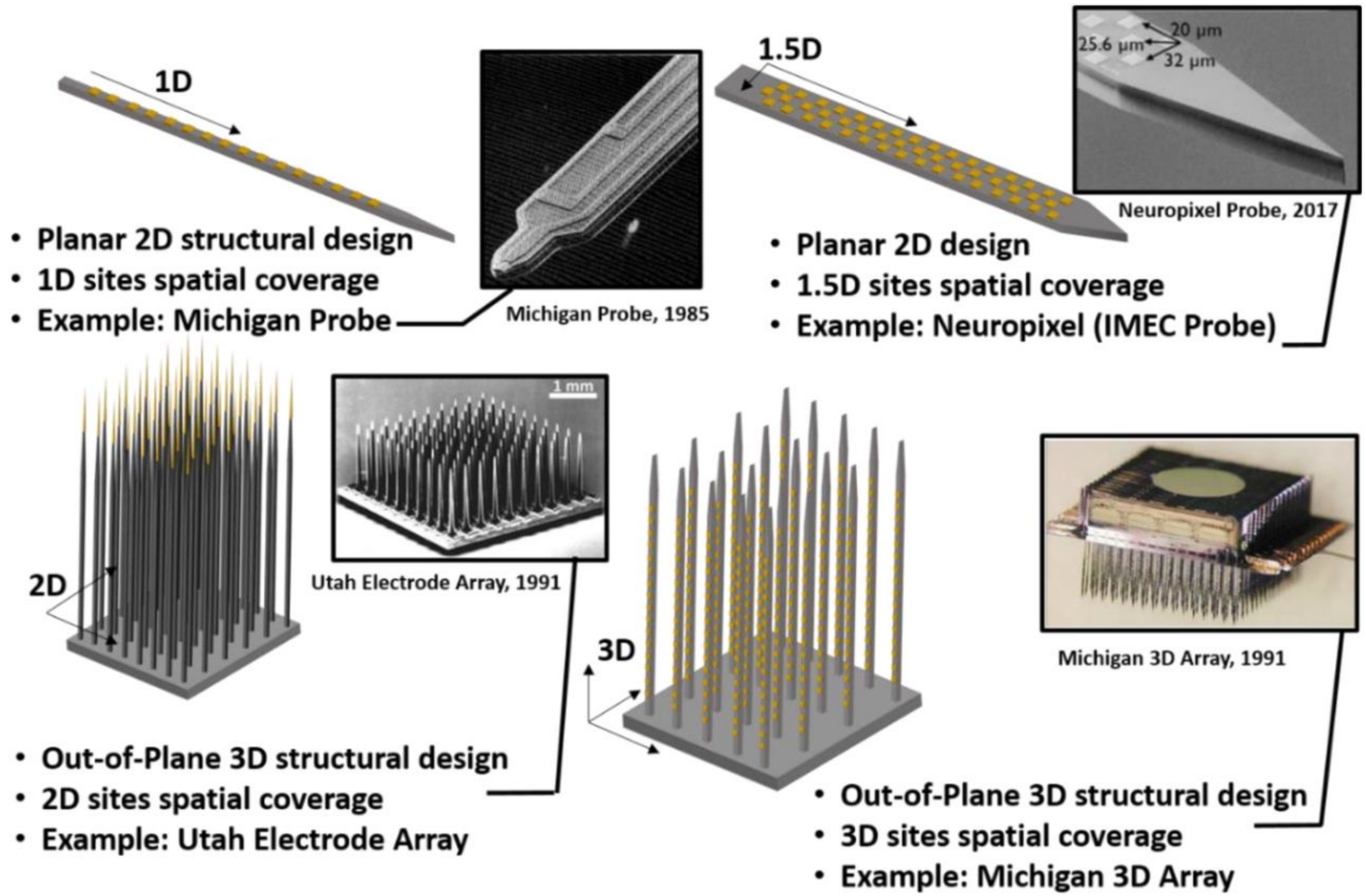
Impedance:
500kohm –
1Mohm

Neural Electrodes: ECoG



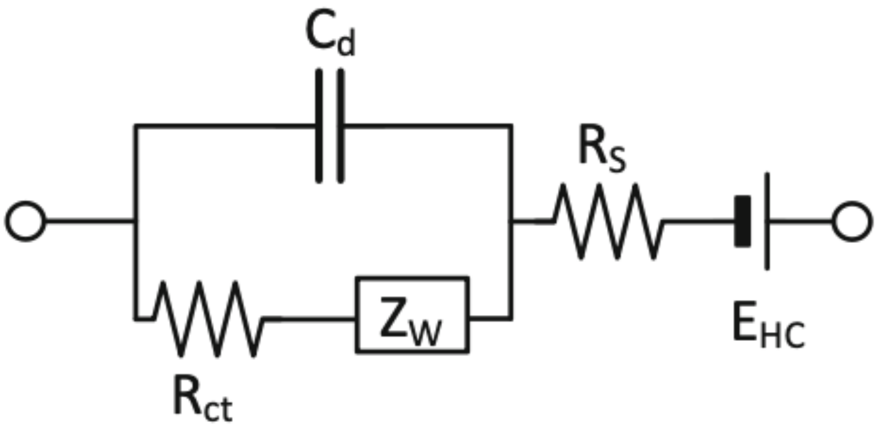
Impedance:
5-10kohm

Neural Electrodes: AP



Impedance: 300kohm – 5Mohm

Model of Electrode Interface

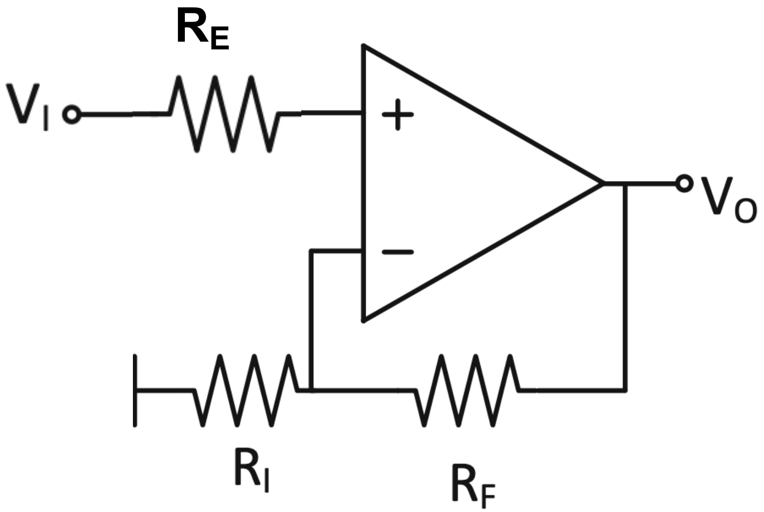


Metal and Reaction	Potential E^0 (V)
$Al \rightarrow Al^{3+} + 3e^-$	−1.706
$Zn \rightarrow Zn^{2+} + 2e^-$	−0.763
$Cr \rightarrow Cr^{3+} + 3e^-$	−0.744
$Fe \rightarrow Fe^{2+} + 2e^-$	−0.409
$Cd \rightarrow Cd^{2+} + 2e^-$	−0.401
$Ni \rightarrow Ni^{2+} + 2e^-$	−0.230
$Pb \rightarrow Pb^{2+} + 2e^-$	−0.126
$H_2 \rightarrow 2H^+ + 2e^-$	0.000 by definition
$Ag + Cl^- \rightarrow AgCl + e^-$	+0.223
$2Hg + 2Cl^- \rightarrow Hg_2Cl_2 + 2e^-$	+0.268
$Cu \rightarrow Cu^{2+} + 2e^-$	+0.340
$Cu \rightarrow Cu^+ + e^-$	+0.522
$Ag \rightarrow Ag^+ + e^-$	+0.799
$Au \rightarrow Au^{3+} + 3e^-$	+1.420
$Au \rightarrow Au^+ + e^-$	+1.680

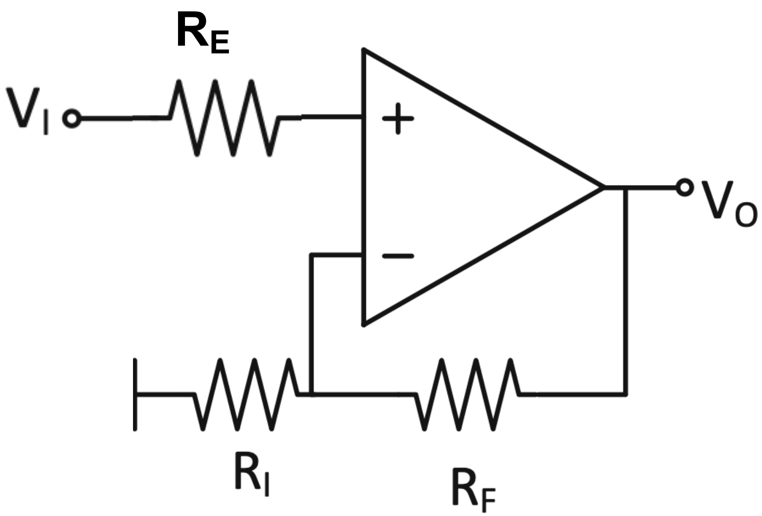
SOURCE: Data from *Handbook of Chemistry and Physics*, 55th ed., Cleveland, OH: CRC Press, 1974–1975, with permission.

B. He, Neural Engineering, ch 2.2

Neural Signal Amplification with Electrode

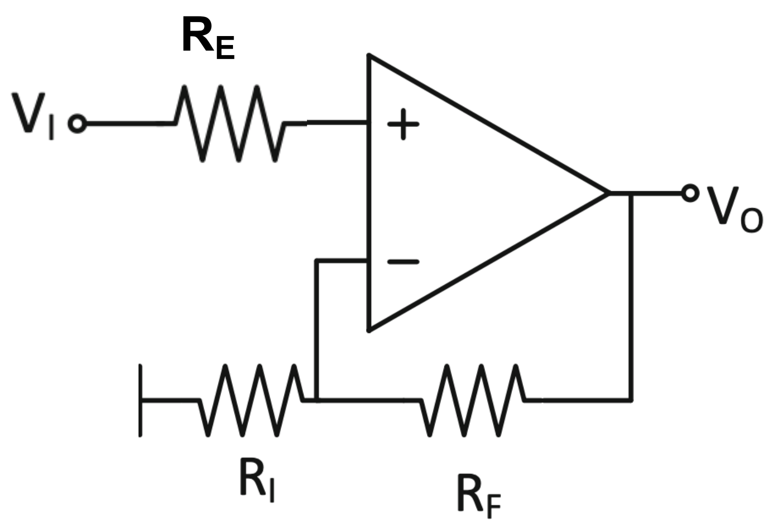


Neural Signal Amplification with Electrode



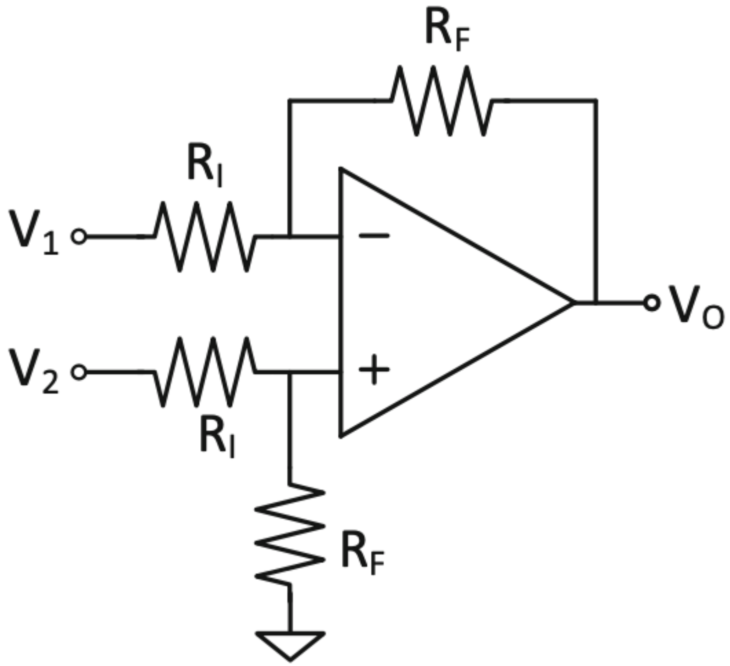
If we consider the non-idealities of the amplifier…

Noise and Interference

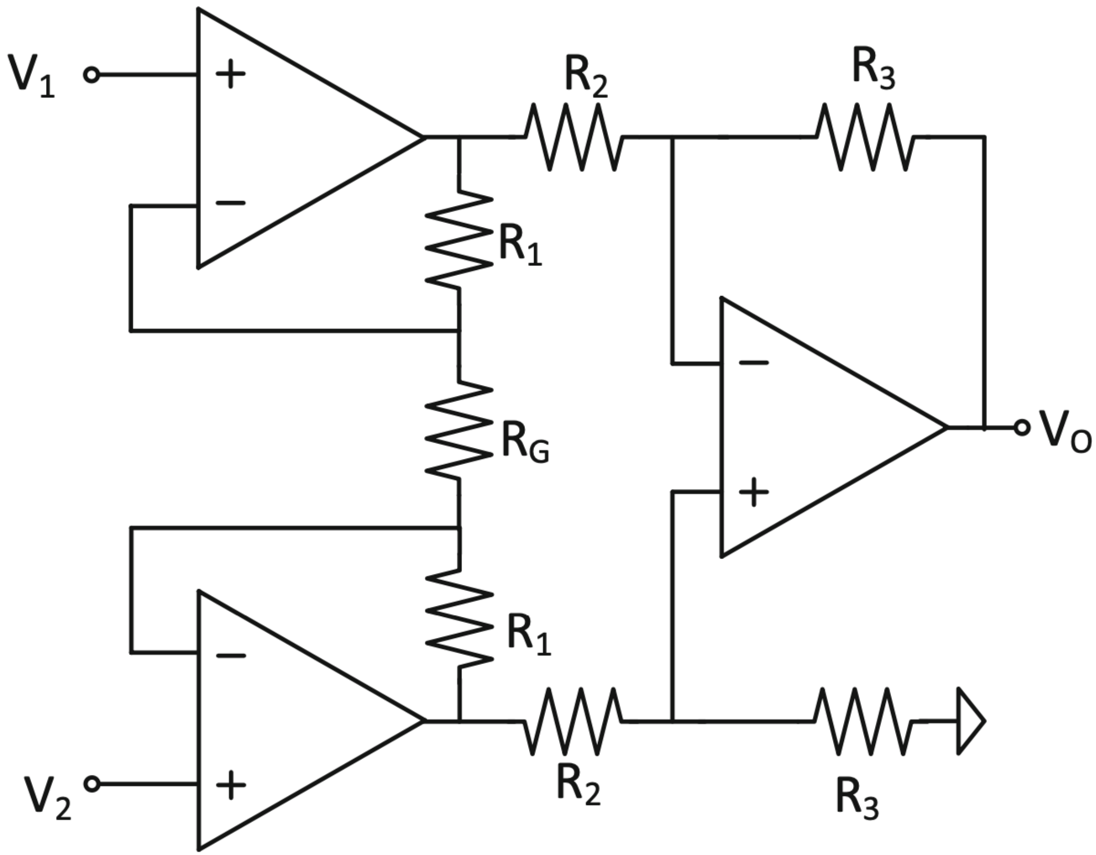


Common Mode Rejection

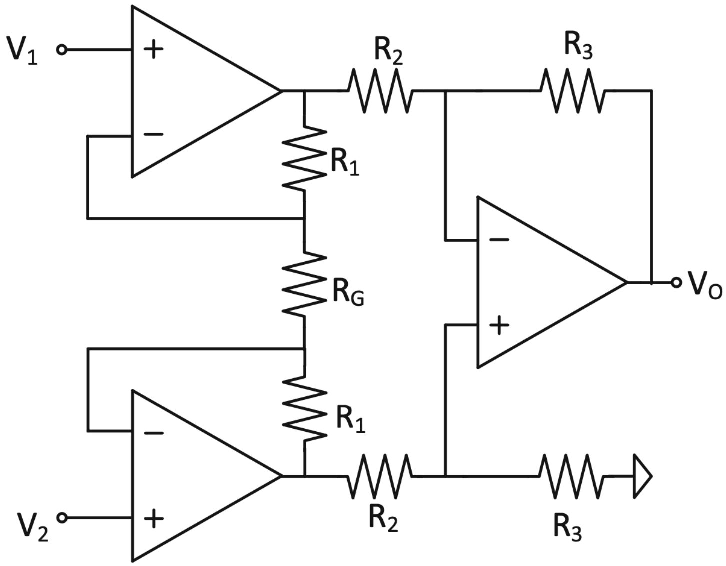
Differential Amplifier



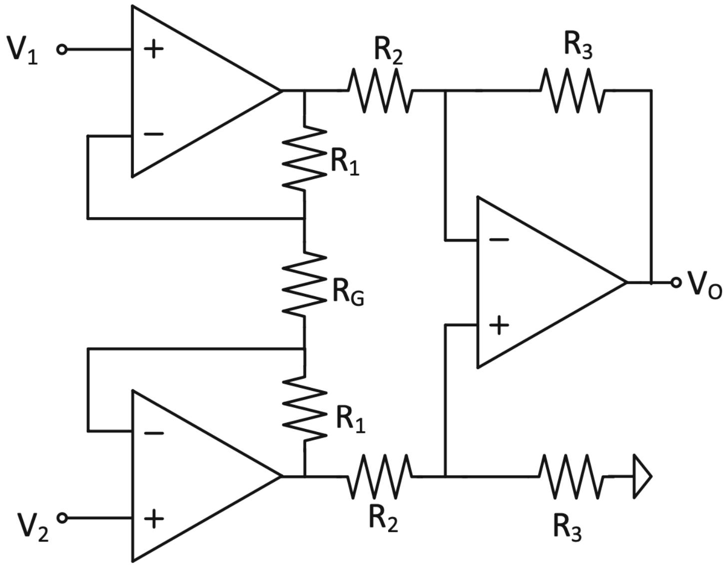
Instrumentation Amplifier (3 Op-amp Circuit)



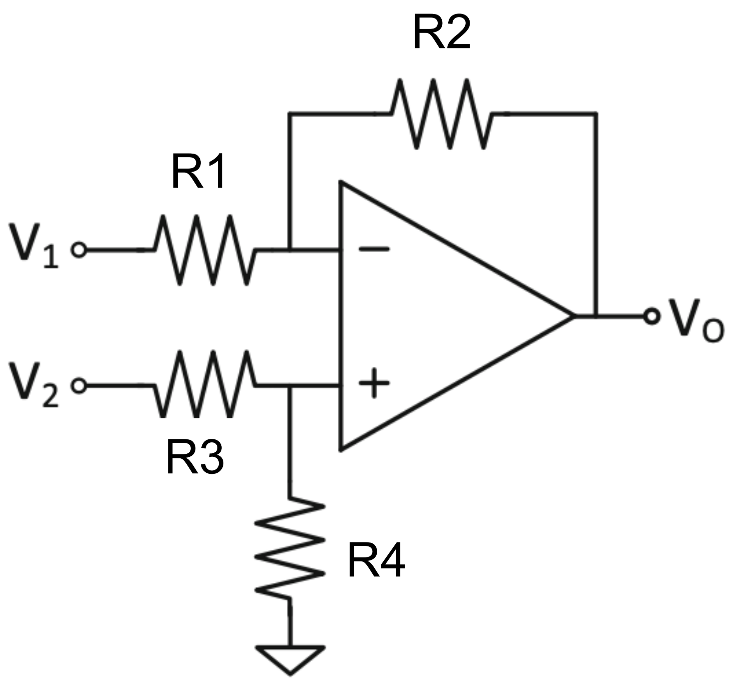
Instrumentation Amplifier (3 Op-amp Circuit)



Instrumentation Amplifier (3 Op-amp Circuit)



… with Resistor Mismatches

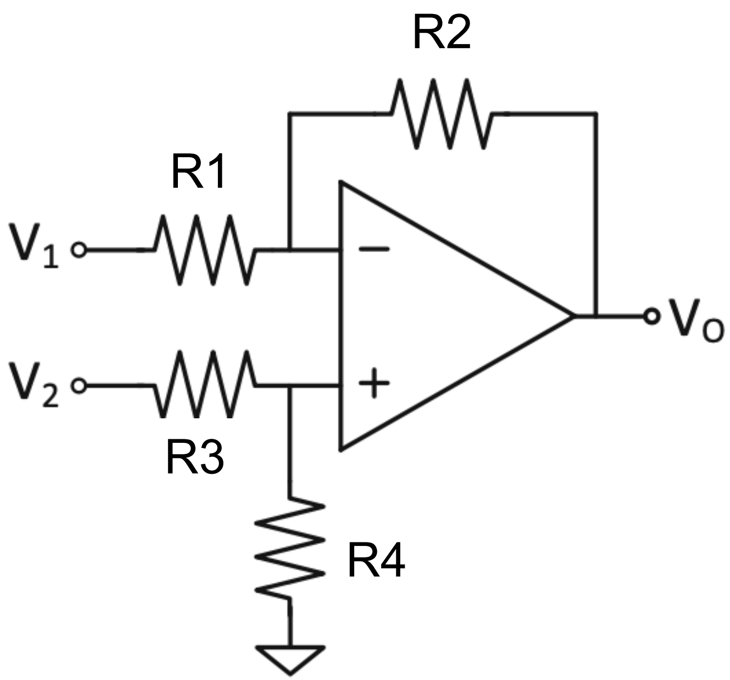


Let's assume resistors have 1% mismatch

R1 = 10.1kohm, R3 = 9.9kohm

R2 = 0.99Mohm, R4 = 1.01Mohm

… with Resistor Mismatches



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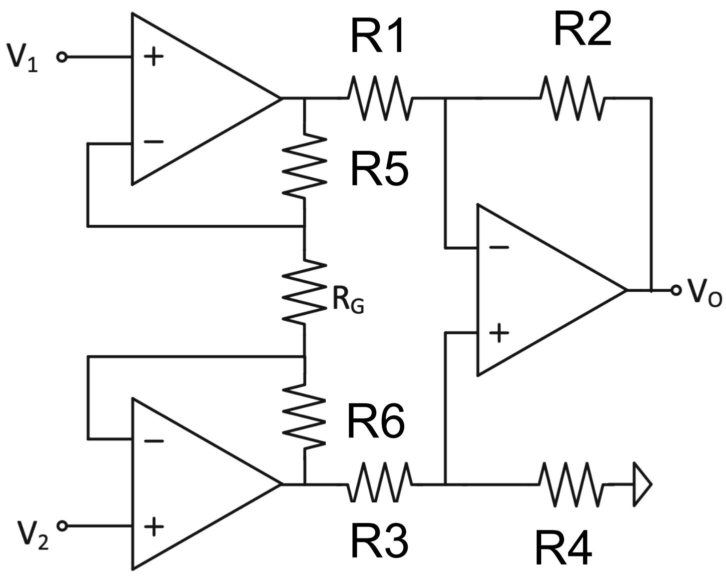


Let's assume resistors have 1% mismatch

R1 = 10.1kohm, R3 = 9.9kohm

R2 = 0.99Mohm, R4 = 1.01Mohm

R5 = 505kohm, R6 = 495kohm

RG = 10kohm

TEXAS INSTRUMENTS

ADS1299, ADS1299-4, ADS1299-6

SBAS499C – JULY 2012 – REVISED JANUARY 2017

ADS1299-x Low-Noise, 4-, 6-, 8-Channel, 24-Bit, Analog-to-Digital Converter for EEG and Biopotential Measurements

1 Features

- Up to Eight Low-Noise PGAs and Eight High-Resolution Simultaneous-Sampling ADCs
- Input-Referred Noise: 1 μV_{PP} (70-Hz BW)
- Input Bias Current: 300 pA
- Data Rate: 250 SPS to 16 kSPS
- CMRR: –110 dB

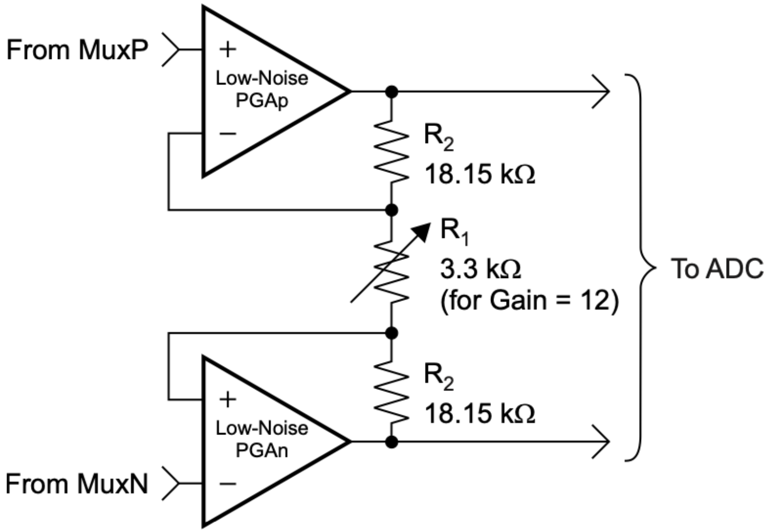
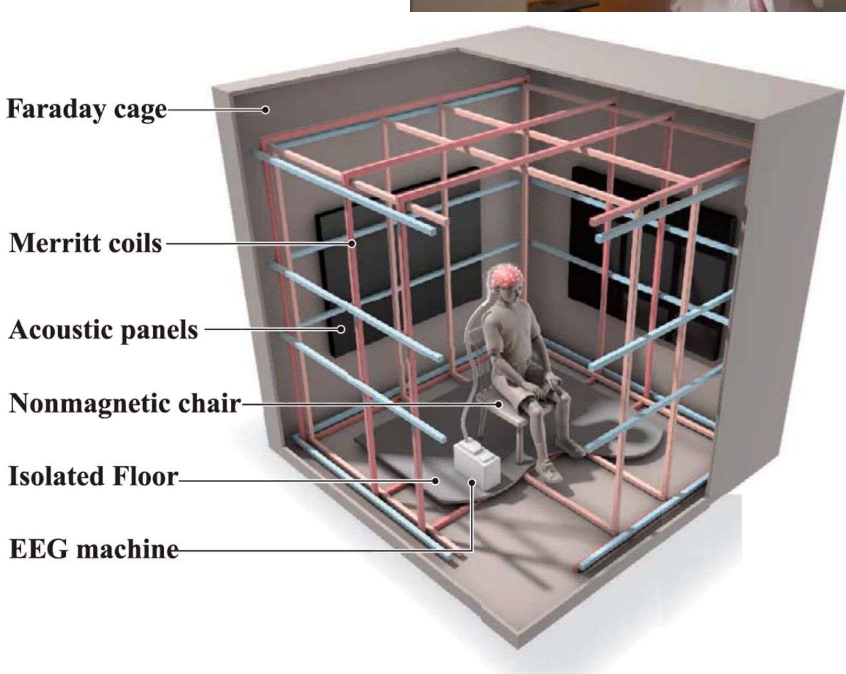
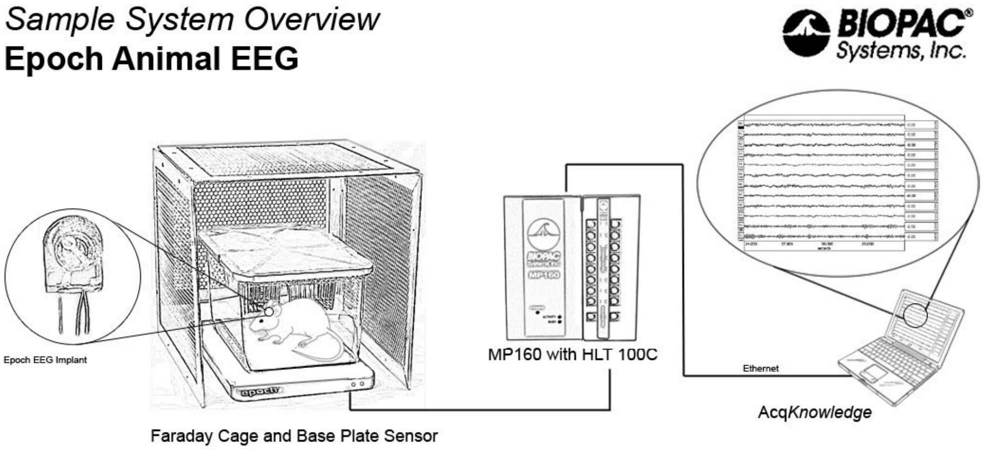


Figure 23. PGA Implementation

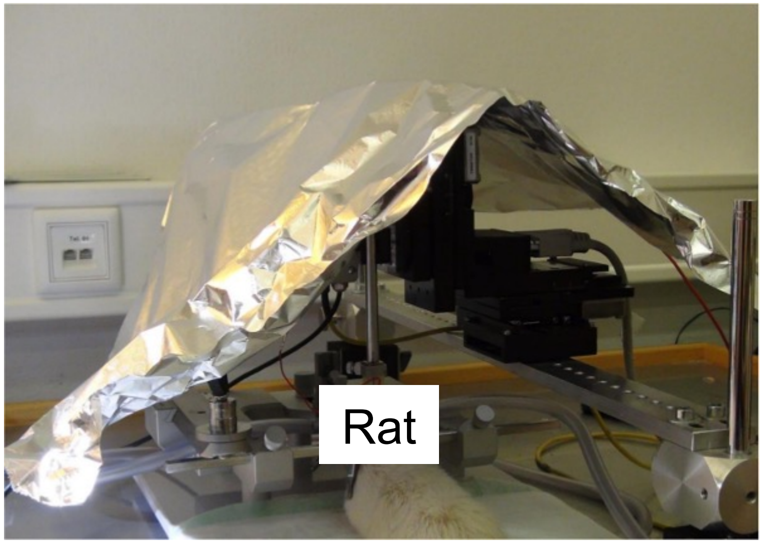
Faraday Cabin



Faraday Cabin for Animal Studies



or home-made…



Noise and Interference

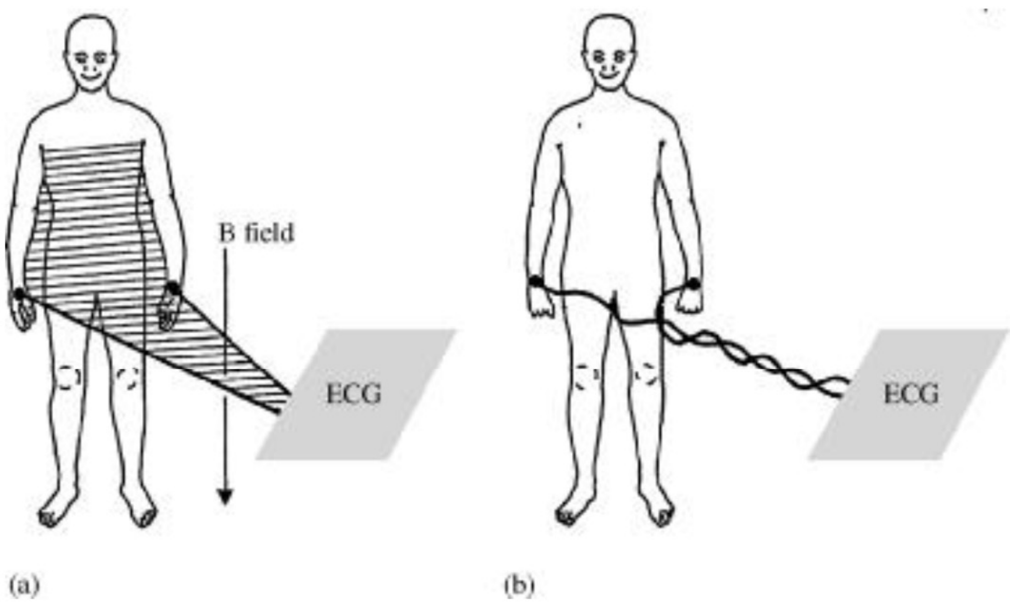
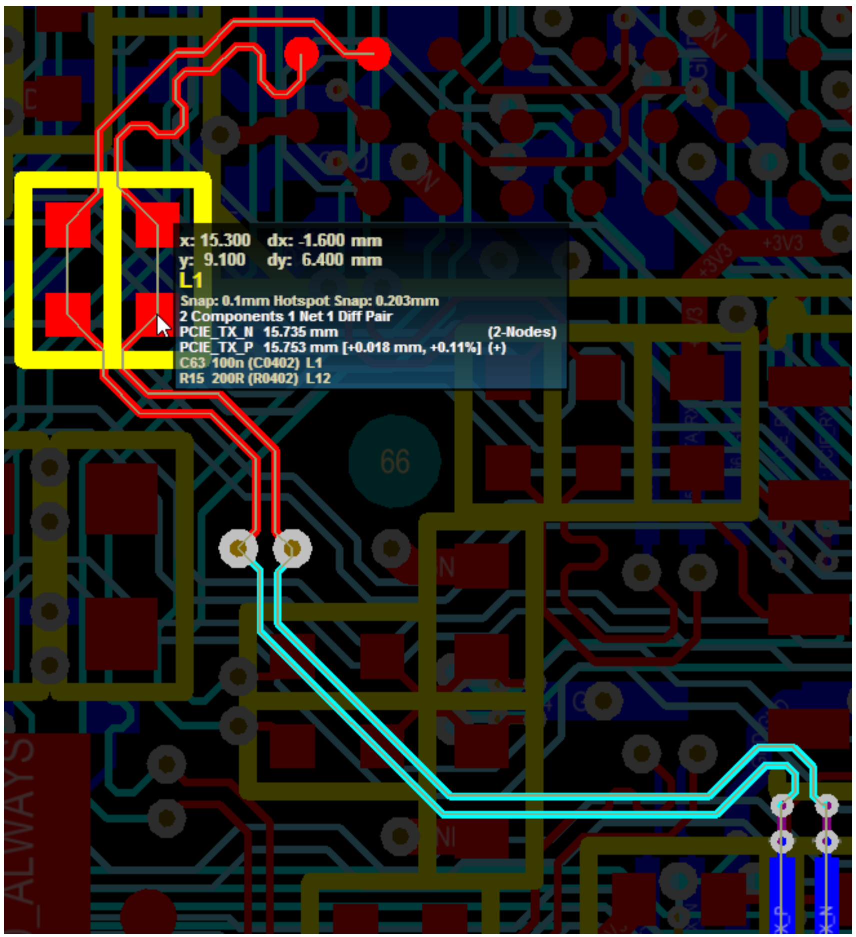


Figure 6.12 Magnetic-field pickup by the electrocardiograph (a) Lead wires for lead I make a closed loop (shaded area) when patient and electrocardiograph are considered in the circuit. The change in magnetic field passing through this area induces a current in the loop. (b) This effect can be minimized by twisting the lead wires together and keeping them close to the body in order to subtend a much smaller area.

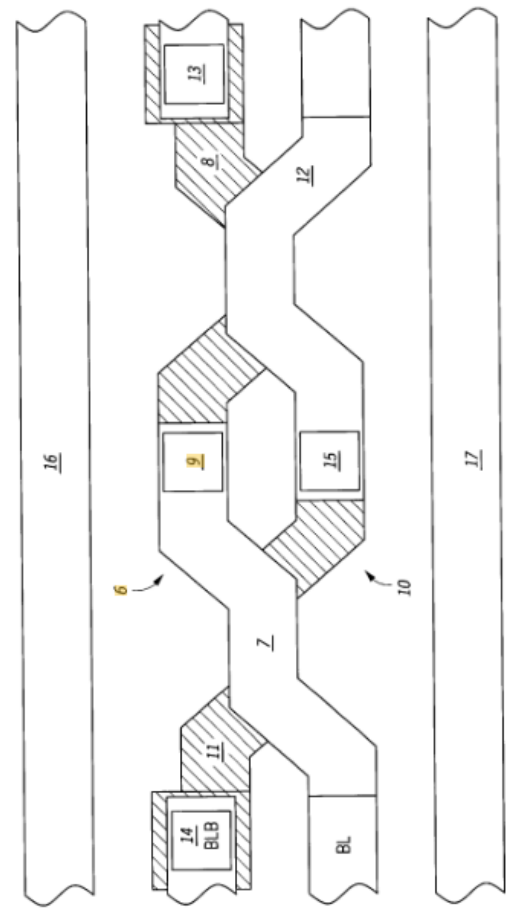
J. Webster, Medical Instrumentation, ch 6

Differential Signal Routing

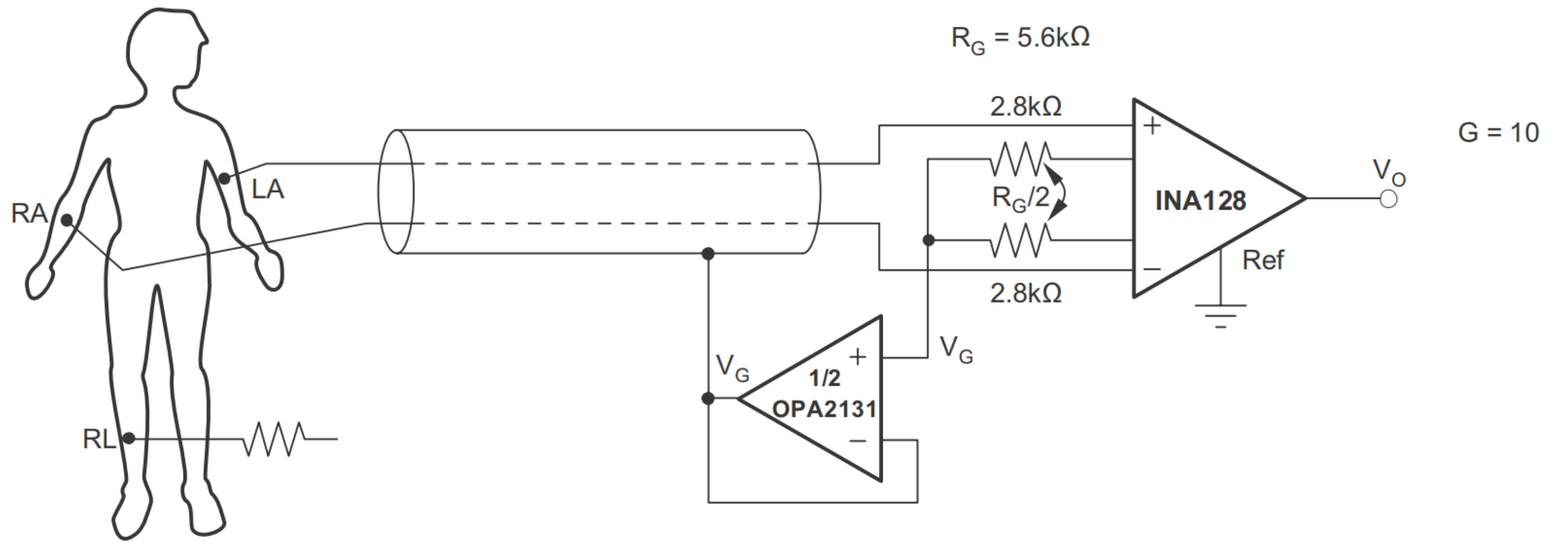
PCB routing for differential signal



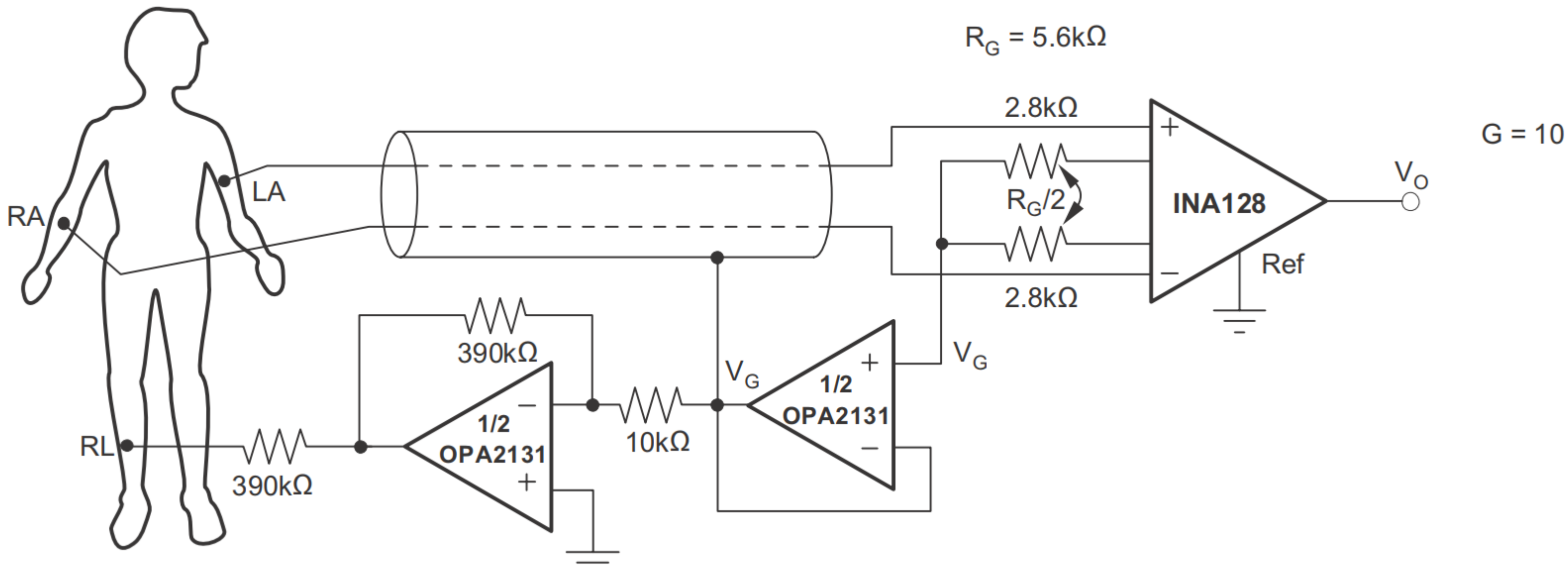
IC routing with “braiding”



Active Shielding



Active Shielding with DRL



Summary

- Neural recording is challenging because:
  - Signals are weak
  - Electrodes have high and complex impedance
  - Strong interference and noise in the environment
  - Non-idealities in amplifiers
- Challenges that we didn't discuss:
  - Channel scaling (there are sooooo many neurons…)
  - Noises and power of electronics, heating
  - Electrode drifting, degradation, foreign body rejection
  - etc.