5XCC0 Biopotential and Neural Interface Circuits

Assignment 1

System model in Matlab

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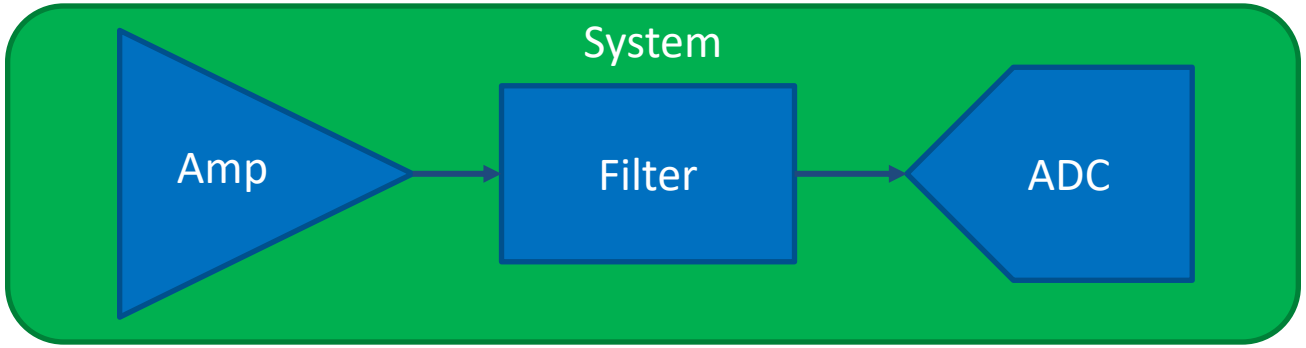
Overall Assignment

- In 6 steps (spread out over 6 weeks), we will design a neural recording interface for AP & LFP recording. The system is composed of an amplifier, a filter, and an ADC.
  - This week, we will focus on step 1: Requirements → Specifications



- In a separate design assignment (week 6), we will also design a neural stimulation circuit.

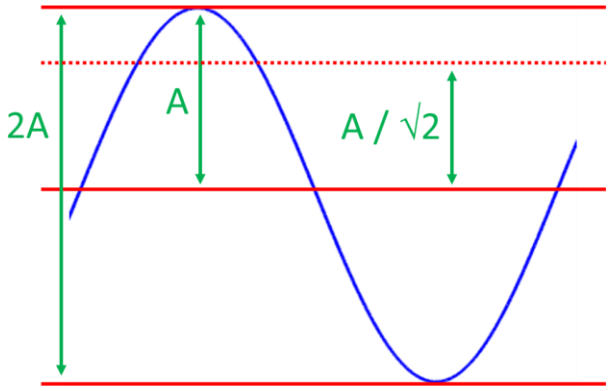
Instructions

- First, do the practicing exercises (slide 4 to slide 8)
- After that, do the main assignment (slide 9 to slide 12)
- The final answers need to be entered in CANVAS
  - Carefully check the unit that is asked on CANVAS (e.g.: V, mV, V_{rms}, dB)
  - This will determine your score for this assignment
  - You can enter results twice
  - The deadline (on CANVAS) is a hard deadline!

Part 1: Practicing Exercises

Peak-Peak, RMS, and Regular Amplitude

- Sinewave $x(t) = A \sin(2\pi ft)$
  - Amplitude: A [V]
  - Peak-peak amplitude: 2A [V_{pp}]
  - RMS amplitude: $A / \sqrt{2}$ [V_{rms}]



- Note: the biopotential amplitudes given in the lecture are peak-peak amplitudes, e.g.:

Measurement	Amplitude Range
Electrocardiography (ECG)	0.5 – 4mV_{pp}

This is the peak-peak amplitude

- Question 1: What should the input range (in mV_{pp}) of our system be if we want to record the above ECG signal and we also expect a disturbance sinusoid with an RMS amplitude of 3mV?

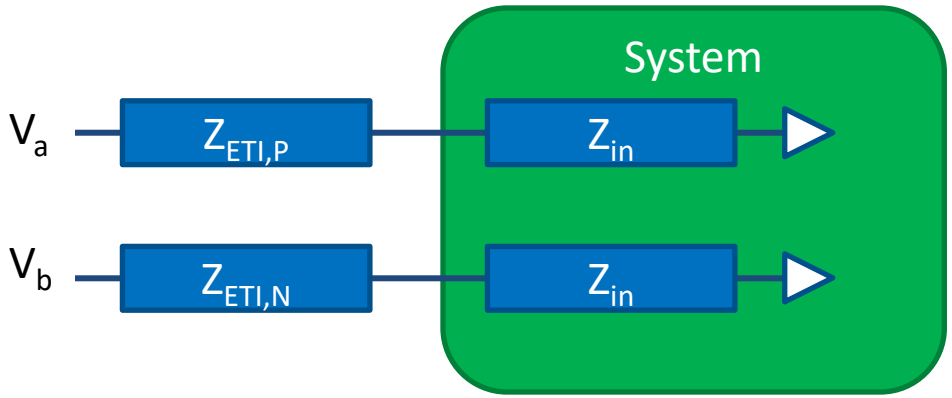
Dynamic Range

- A biopotential interface has:
  - An input range of $0.1V_{pp}$
  - An input-referred noise level of $10\mu V_{rms}$

- Question 2: What is the Dynamic Range of this interface (in dB)?

Z_{ETI}, Z_{in}, CMRR

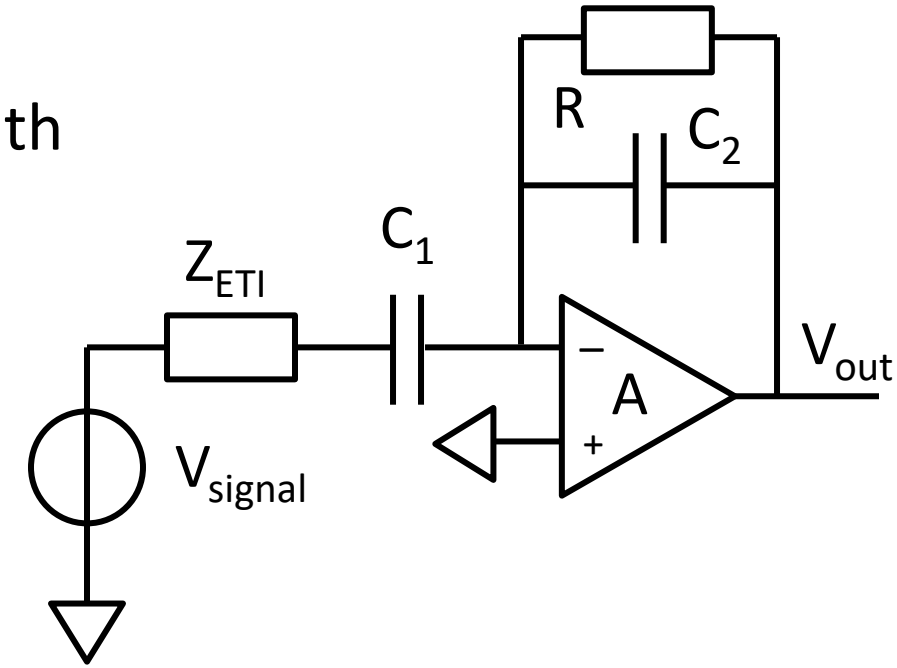
- Given the system in the figure where we like to record $V_a - V_b$.
- Assume that $Z_{ETI,P}$ and $Z_{ETI,N}$ are in the range between 10kΩ and 100kΩ, but we don't know their actual value, and they might be different from each other.
- Assume that Z_{in} is 10MΩ.



- Question 3: What is the CMRR (in dB) of this interface (in the worst case)?
- Question 4: What is the signal attenuation (in dB) due to the finite value of Z_{in} (in the worst case)?

AC Coupled Amplification

- Given the AC coupled amplifier in the figure below
- Suppose the following requirements are given:
  - We'd like to use this amplifier to record ECG
  - Z_{in} should be ≥10MΩ in the entire ECG bandwidth
  - R should be no greater than 500GΩ
  - The amplifier is ideal, and A is very high (∞)



- Question 5: What is the maximum in-band gain (in V/V) that we can achieve with these requirements?
  - Tip: ECG specifications can be found in Lecture 1

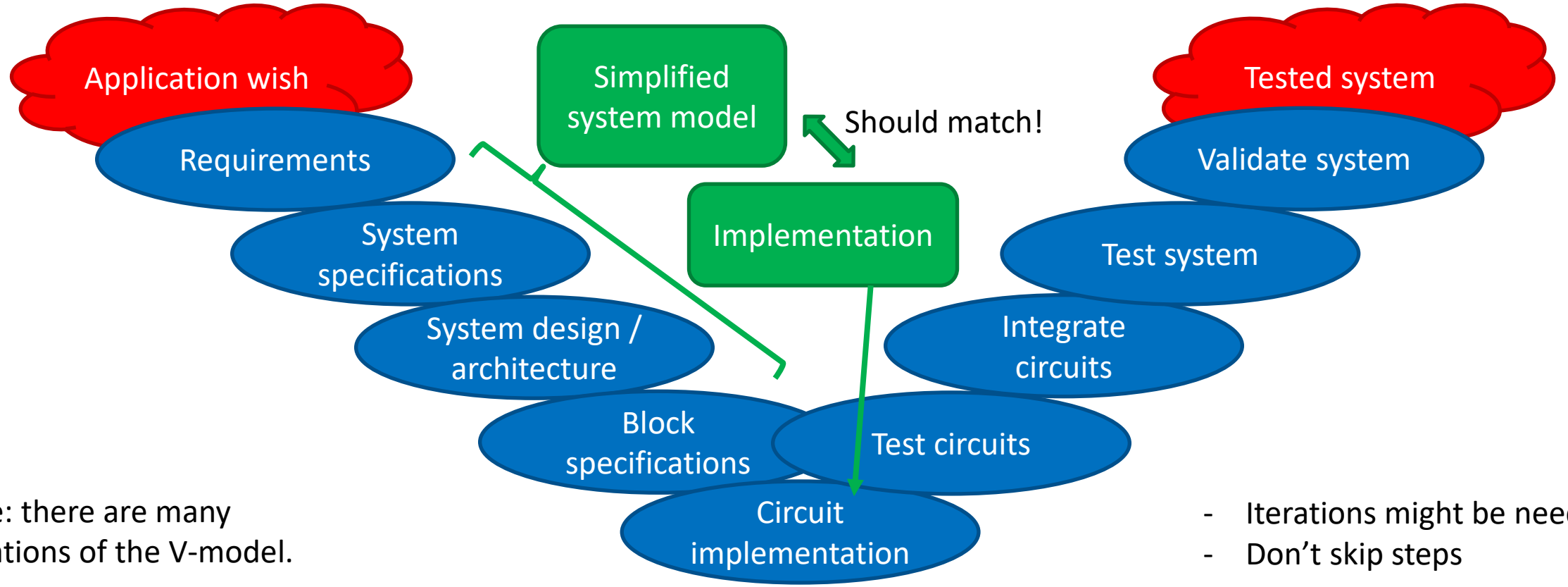
Part 2: Main Assignment

- According to the V-model (slide 10), we will start the design task with translating application requirements (slide 12) to system specifications (slide 11)
  1. Calculate the specifications based on the given requirements
     - Note: the noise level cannot be calculated, so decide this based on simulations
  2. Use the provided Matlab system model (systemmodel.m) and the example AP recording (1551.mat [1]) to verify your calculations
     - First familiarize yourself with the provided Matlab code
     - Enter your calculated specifications in the Matlab script
     - Use the Matlab script to confirm that your chosen specifications can meet the requirements (for as much as possible)
  3. Enter your answers in CANVAS

[1] Benjamin Metcalfe, “Action potentials recorded from the L5 dorsal rootlet of rat using a multiple electrode array,” Mendeley Data, Version 1, June 12, 2020, CC BY 4.0 License, doi: 10.17632/ybhwtngzmm.1

V-model

- Systematic design methodology to go from an application wish down to a circuit implementation, and up to a tested system

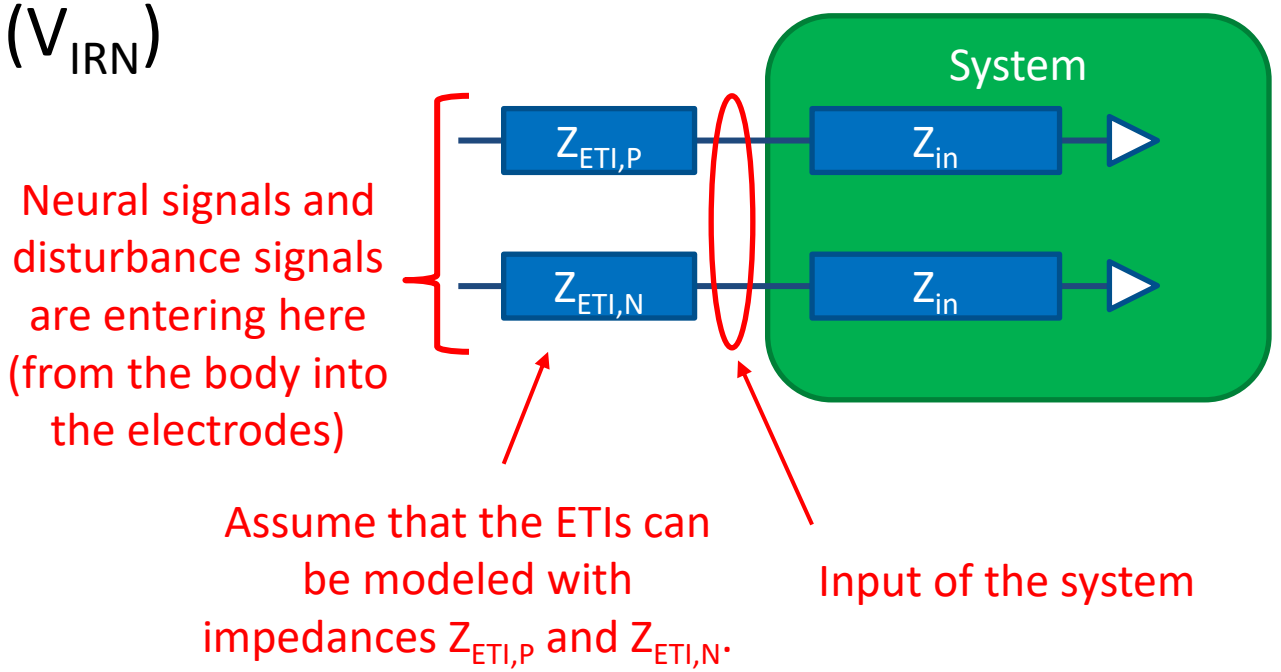


Note: there are many variations of the V-model.

- Iterations might be needed
- Don't skip steps

System View

- In this assignment, you will derive 5 specifications for the system, based on the requirements given on the next slide:
  - Bandwidth (from f_{low} to f_{high})
  - Input-referred noise level, RMS (V_{IRN})
  - Input range, peak-peak (V_{inpp})
    - Note: this relates to the differential input only, not to the common-mode input range
  - Input impedance (Z_{in})
- These specifications are all related to the input (signal) of the system



Requirements

- The goal of this interface is to record both APs and LFPs.
  - Bandwidth, signal range, and noise level should be chosen accordingly.
  - Note: you may use the amplitude/frequency values from lecture #1, slide 46.
- Z_{ETI} can be anywhere between 100kΩ and 200kΩ and can be different for the 2 electrodes.
- For all possible combinations of Z_{ETI}, Z_{in} should be chosen such that the resulting CMRR is at least 50dB, to deal with common-mode disturbances.
- A common-mode disturbance of max. $300mV_{pp}$ and a differential disturbance of max. $12mV_{pp}$ are expected at the input of the system.
- The combination of AP, LFP, common-mode disturbance and differential disturbance should not exceed the differential input range of the system.
  - Note: you only need to check the differential range, not the common-mode range.
- The provided exemplary AP recording should be recorded such that:
  - The spikes remain (somewhat) recognizable within the noise.
  - The spikes, together with the disturbances, should not saturate the system.