5XCC0 Biopotential and Neural Interface Circuits

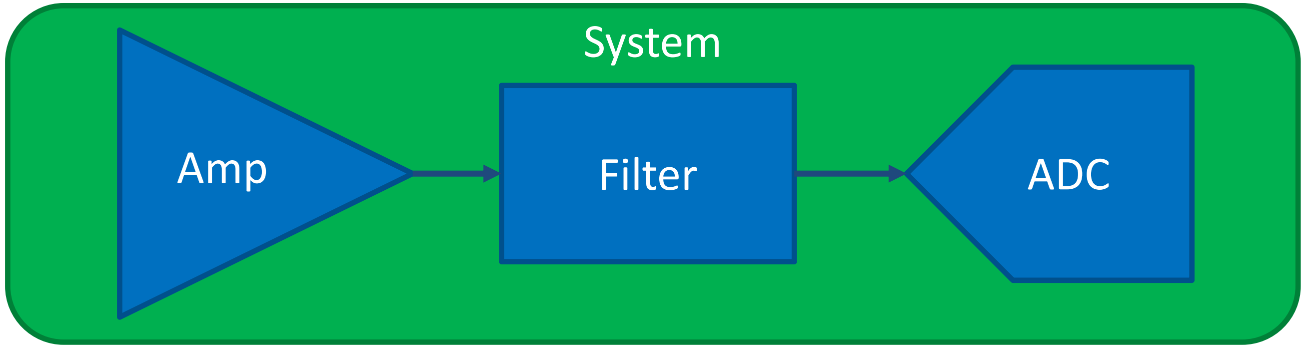
Assignment 2

Determine block specifications

Pieter Harpe

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 2: we will translate system-level specifications to block-level 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 19)
- 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!

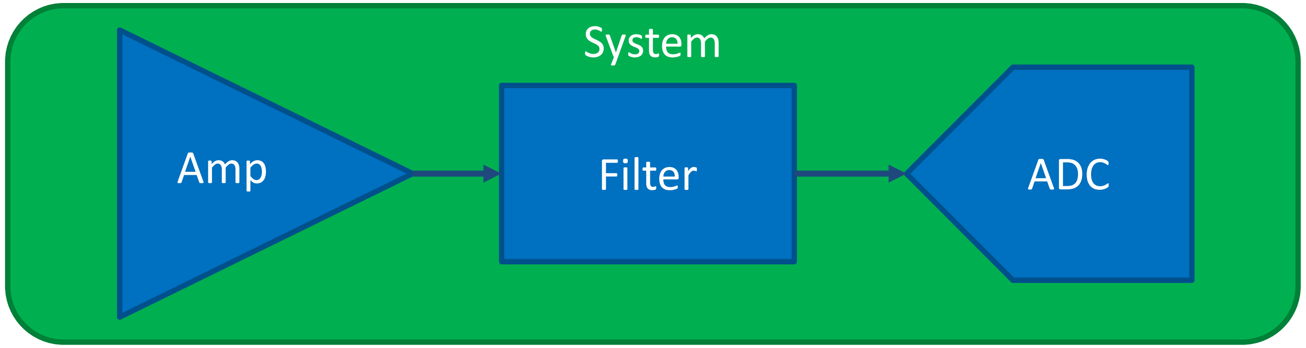
Part 1: Practicing Exercises

Input-Referred Noise of a System

Given the system below, you may assume that:

- The voltage gain of the amplifier is 20dB. The filter has 0dB gain.
- The IRN of the amplifier is 10μV_{rms}, the IRN of the filter is 70μV_{rms}, and the IRN of the ADC is 120μV_{rms}.

- Question 1: Calculate the IRN of the total system (in μV_{rms}).



Quantization Noise in an ADC

An ADC has the following properties:

- The resolution (of the digital codes) is N = 10bit.
- The full-scale input range is $1.4V_{pp}$.
- You may assume the ADC has only quantization noise, and no other noise sources.

- Question 2: What is the IRN (in μV_{rms}) of this ADC?

Amplifier NEF

- Question 3: Use the NEF equation to estimate the power consumption of an amplifier with an IRN of $10\mu V_{rms}$, a bandwidth of 1kHz, a supply voltage of 1.2V, and an NEF value of 2. Give your answer in nW.

ADC FOMS

- Question 4: Use the FOMS equation to estimate the power consumption of an ADC with an ENOB of 11bit, a bandwidth of 1kHz, and a FOMS value of 182dB. Give your answer in nW.

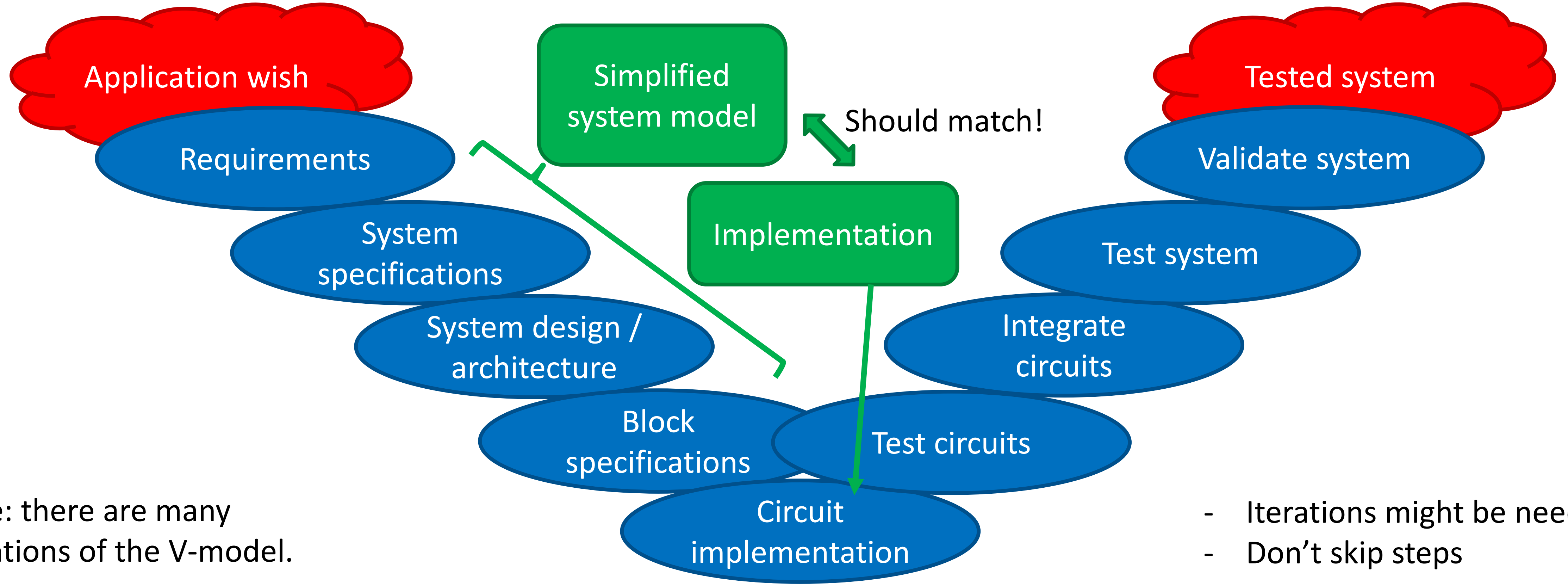
Part 2: Main Assignment

- According to the V-model (slide 10), this second assignment will focus on deciding the system architecture and translating the system level specifications to block level specifications.
  1. Follow the steps on slides 11 to 19 to decide the block level specifications one by one.
  2. Use the provided Matlab system model (systemmodel2.m) and the example AP recording (1551.mat [1]) to verify your choices
     - 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

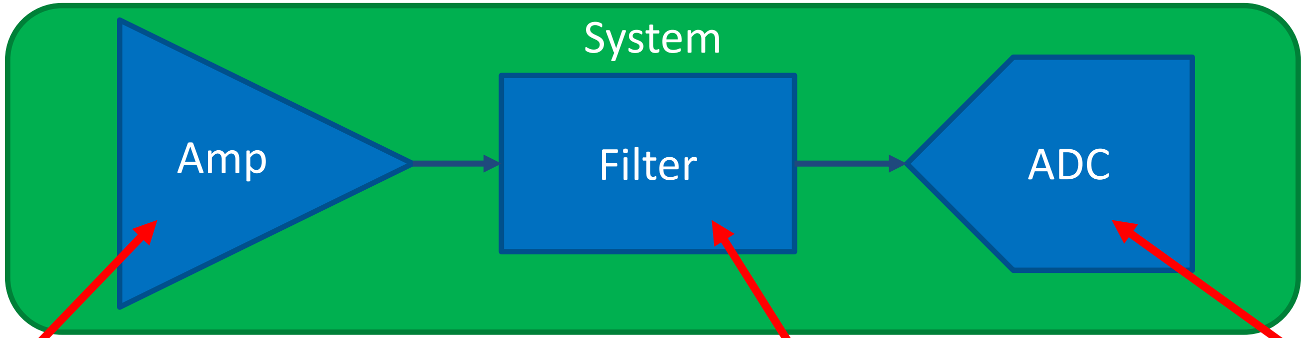


Note: there are many variations of the V-model.

- Iterations might be needed
- Don't skip steps

Deciding the Architecture

- Actually, the architecture of our system was already pre-defined, but why does it make sense?



Why do we start with an amplifier?

- Because the input signal is small
- Gain relaxes noise and power consumption of later blocks

Why do we use a filter?

- To remove interference and noise that is out of the BW of interest
- To meet Nyquist: Signal BW < ½ f_{sample}

Why do we have an ADC?

- Input is analog, output is digital (easier for storage, processing, communication)

System Level Specifications

- Regardless of your results from assignment 1, from now on you may assume the following system level specifications:
  - Bandwidth (BW): from 0.5Hz (f_{low}) until 6kHz (f_{high})
  - Input-referred noise level (V_{IRN}): 3.5μV_{rms}
  - Input range (V_{inpp}): 18mV_{pp}
  - Input impedance (Z_{in}): 32MΩ

Specifications: System → Block

- The table below summarizes the system specifications (blue) and the block-level specifications (red) that are to be determined.
  - One block specification is already given: the ADC input range is $1V_{pp}$
  - One system specification (Dynamic Range, DR) is still to be determined

System	Amplifier	Filter	ADC
IRN = $3.5\mu V_{rms}$	IRN	IRN	IRN
BW = 0.5Hz – 6kHz	BW	BW	f_{sample}
Input range = $18mV_{pp}$	Input range	Input range	Input range = $1V_{pp}$
Z_{in} = $32M\Omega$	Z_{in}		
	Gain		
DR			ENOB
			N

Step 1: Bandwidth (BW) and Sample Rate (f_{sample})

- The system-level bandwidth is from 0.5Hz to 6kHz. Because 0.5Hz is very small, we can ignore that and say that the bandwidth is approximately equal to f_{max} = 6kHz.

- Question 5: What is the <u>minimum</u> bandwidth for the amplifier and (low-pass) filter? (You may assume they have an identical bandwidth.) Give your answer in Hz.
- Question 6: Given that bandwidth, what is then the minimum sample rate and why? Give your answer in Hz (or samples/s).

Step 2: Input Range and Gain

- Assume that only the amplifier has a certain gain (Gain), and that the filter and ADC do not have any amplification (Gain of 1 V/V).

- Question 7: Determine the required Gain of the amplifier (in V/V).
- Question 8: Determine the Input range for the amplifier (in mV_{pp}).
- Question 9: Determine the Input range for the filter (in mV_{pp}).

Step 3: Input Impedance

- Question 10: Determine the minimum input impedance of the amplifier (Z_{in}), give your answer in MΩ.

Step 4: Dynamic range, N, ENOB, IRN

- Question 11: What is the DR (in dB) of the entire <u>system</u>?

An ADC resolution (N) of 6, 8, 10, 12, 14, or 16 bits can be chosen.

- Question 12: What is the minimum value of N (in bit) that is sufficient?

Assume that the ENOB is 0.5bit less than the resolution N. (E.g.:if you chose N = 6bit, the ENOB becomes 5.5bit.)

- Question 13: What is than the actual DR (in dB) of the ADC?
- Question 14: What is thus the IRN of the ADC (in μV_{rms})?

Step 5: IRN

Assume that the filter has the same IRN as the ADC. This makes sense because there is no gain between filter and ADC, and thus their noise counts ‘equally’ for the total noise. Therefore, as a first target, it is ‘fair’ to give them an equal ‘noise budget’.

- Write down for yourself the equation that expresses the IRN of the entire system as function of the IRN of the amplifier, the IRN of the filter, the IRN of the ADC, and the Gain in the system.
- Question 15: Determine the unknown in this equation, the IRN of the amplifier. Give your answer in μV_{rms}.

Step 6: Final check

- Great, you're almost done!
- Next is the <u>verification</u>: put all numbers in the Matlab system model #2, and check that the requirements (of week 1) are met
- If successful, enter the values of the specifications in CANVAS

System	Amplifier	Filter	ADC
IRN = $10\mu V_{rms}$	IRN	IRN	IRN
BW = 250Hz	BW	BW	f_{sample}
Input range = $10mV_{pp}$	Input range	Input range	Input range = $1V_{pp}$
$Z_{in} \geq 10M\Omega$	Z_{in}		
	Gain		
DR			ENOB
			N