5XCC0 Biopotential and Neural Interface Circuits

Assignment 6

Neural Recording and Stimulation

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Overall Assignment

- In this standalone design assignment (week 6), we will:
  - Take a look at cross-talk in neural recording arrays.
  - Check the impact of active electrodes in such arrays.
  - Design and simulate neural stimulation circuits based on constant current, constant voltage, and constant charge.
  - Look at charge balancing using biphasic pulses and using a blocking capacitor.

Instructions

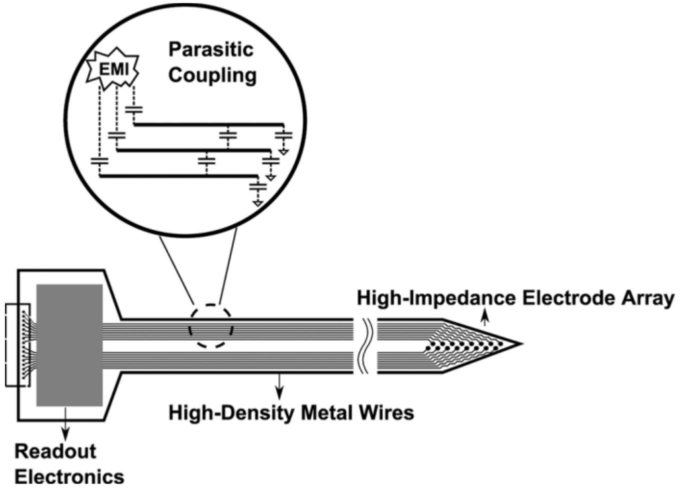
- First, do the various exercises in Cadence Virtuoso
- The final answers need to be entered in CANVAS
  - Carefully check the unit that is asked on CANVAS (e.g.: V, mV, V_{rms}, dB)
  - This will determine your score for this assignment
  - You can enter results twice
  - The correct results will be shown after the deadline

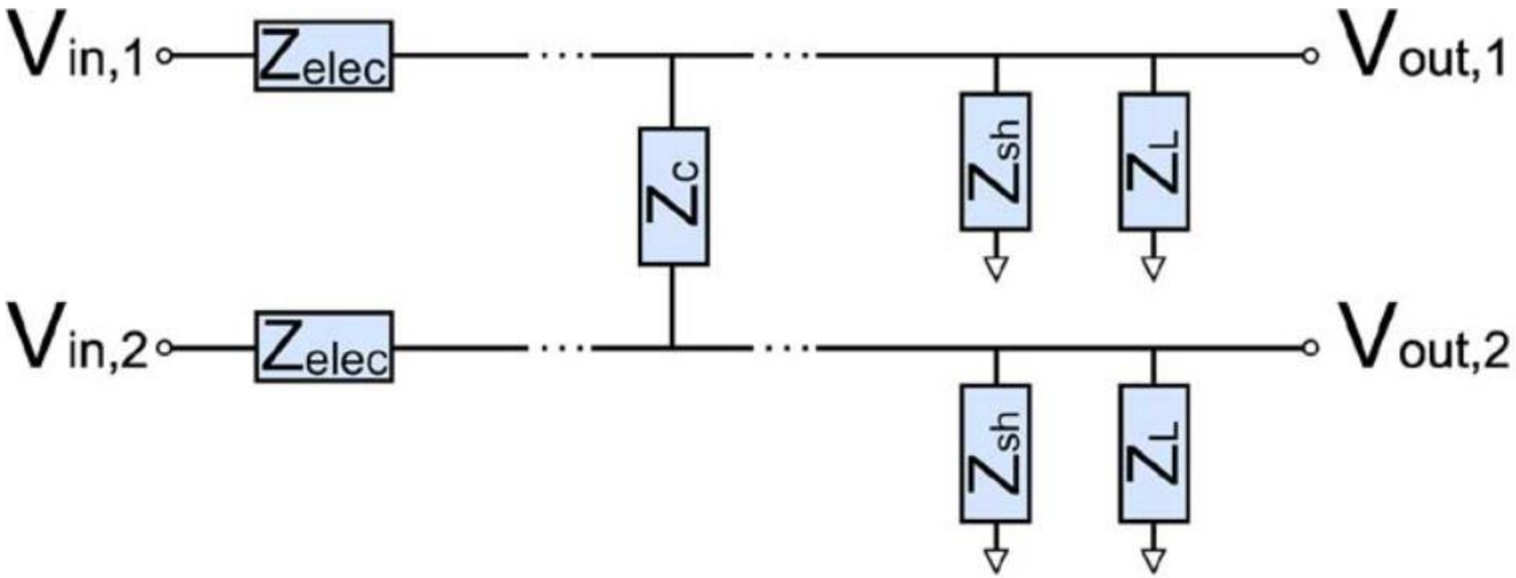
Before You Start: Create a New Design Library

- Create a new design library (from the menu in the library manager, or from the menu in the main virtuoso window)
  - You can give the library any name you like
  - Attach it to the gpdk045 technology library
  - In case of doubt how to do this, please check the Cadence tutorial

Cross-talk in Neural Recording Arrays

- Ideally V_{out1} only depends on V_{in1} and V_{out2} only depends on V_{in2}. In practice there is cross-talk (due to Z_c), which means V_{in1} also appears (with attenuation) at V_{out2} and V_{in2} appears at V_{out1}.
- If H_{ji} is the transfer function from input i to output j, the cross-talk C_{ba} from channel a to b can be calculated as: C_{ba} [dB] = $20 \log_{10} \{|H_{ba}| / |H_{aa}|\}$



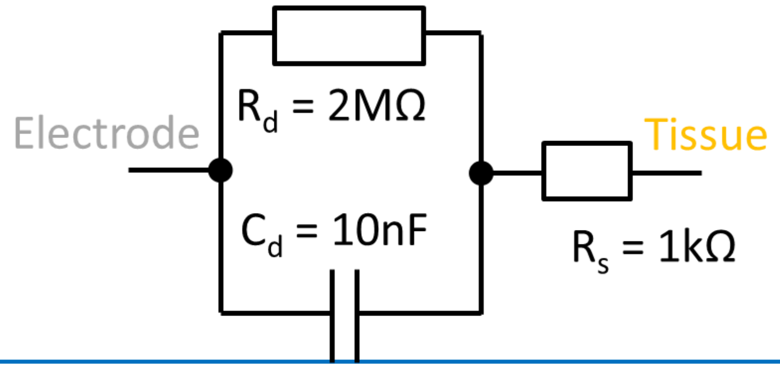


- Z_{elec}: electrode-tissue impedance
- Z_c: coupling impedance between adjacent traces
- Z_{sh}: impedance of each trace to ground
- Z_L: input impedance of the load (e.g. readout amplifier)

Cross-Talk Simulations

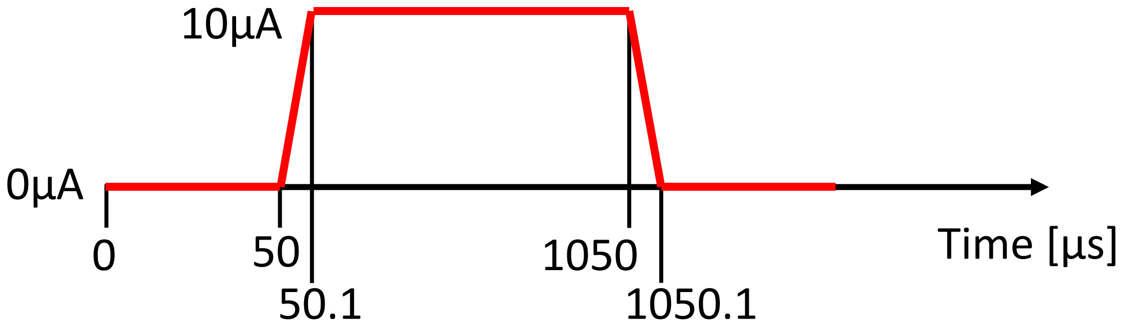
- Given the 2-channel setup on the previous slide, draw a model of the network in Cadence using ideal components:
  - Use components res, cap, gnd and vdc from the library analogLib for resistors, capacitors, ground connections, and the input signals (V_{in1} and V_{in2}), respectively.
  - We want to check the cross-talk from V_{in1} to V_{out2}, so set the “AC magnitude” of the vdc source for V_{in1} to 1V, while you keep all values for V_{in2} at 0.
- Run an AC simulation to determine $|H_{11}|$ and $|H_{21}|$.
- Question 1: Based on the simulated results, what is the cross-talk C_{21} (in dB) for a frequency of 1kHz?
- Question 2: Now assume we use active electrodes, which means Z_{elec} can be replaced by a single resistor representing the amplifier R_{out}. What is the required value for R_{out} (in Ω) to achieve a C_{21} of -80dB at 1kHz?

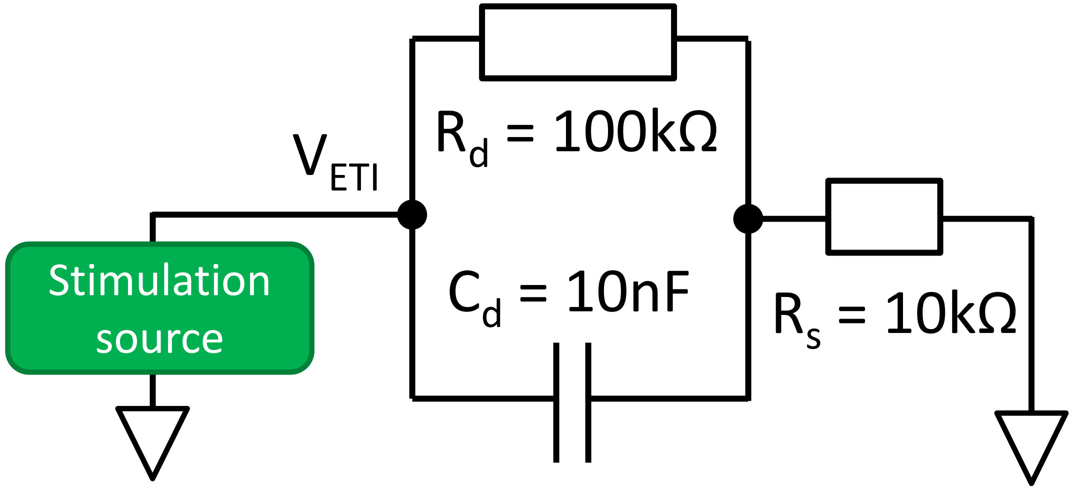
Impedance	**Value**
Z_{elec}	ETI model, as shown in the figure
Z_c	20pF
Z_{sh}	20pF
Z_L	1pF



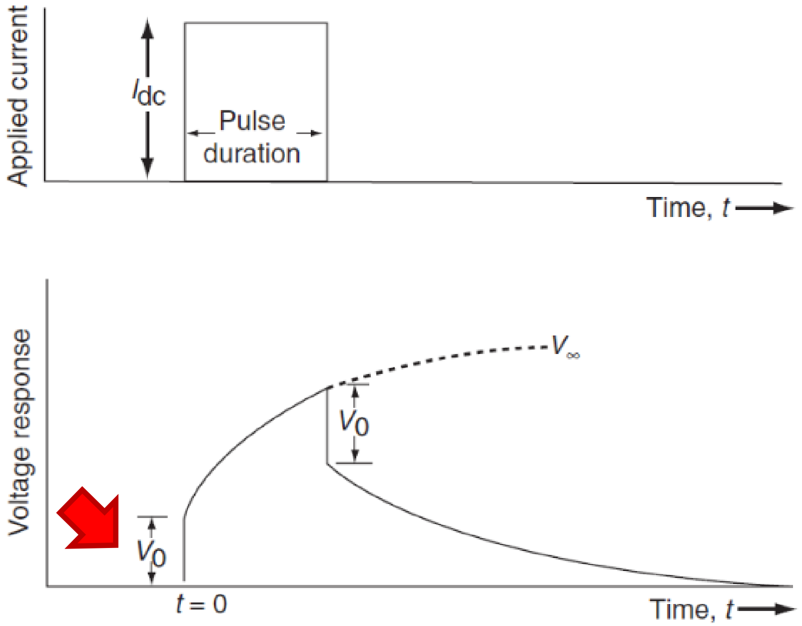
Constant Current Stimulation

- Build the ETI model as shown in the figure in Cadence.
- For the stimulation source, you can insert an ipwl component (a current source with a “programmable” waveform) and adjust its parameters so that it creates a single current pulse as sketched below



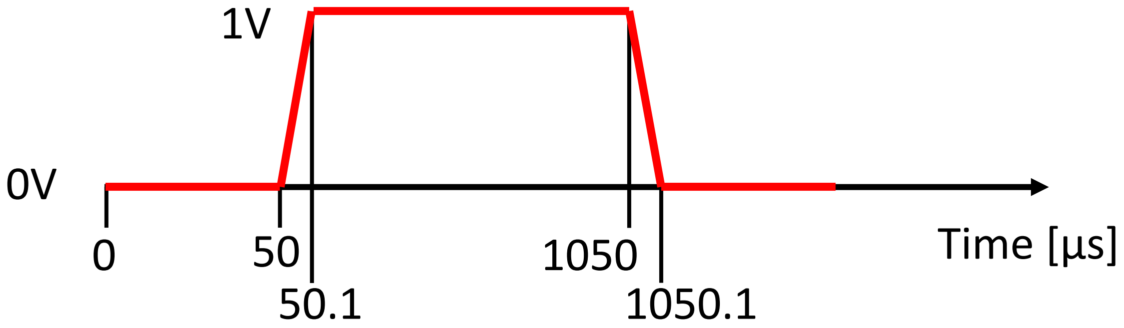


- Run a transient simulation (10ms total time) and confirm you get patterns for the source current and V_{ETI} voltage similar to the ones shown on the right (taken from the lecture)
- Question 3: Which component(s) is/are responsible for the initial voltage step (V_0) at the start of the stimulation pulse?
- Question 4: What is the total charge delivered to the body during the entire response (in nC)?

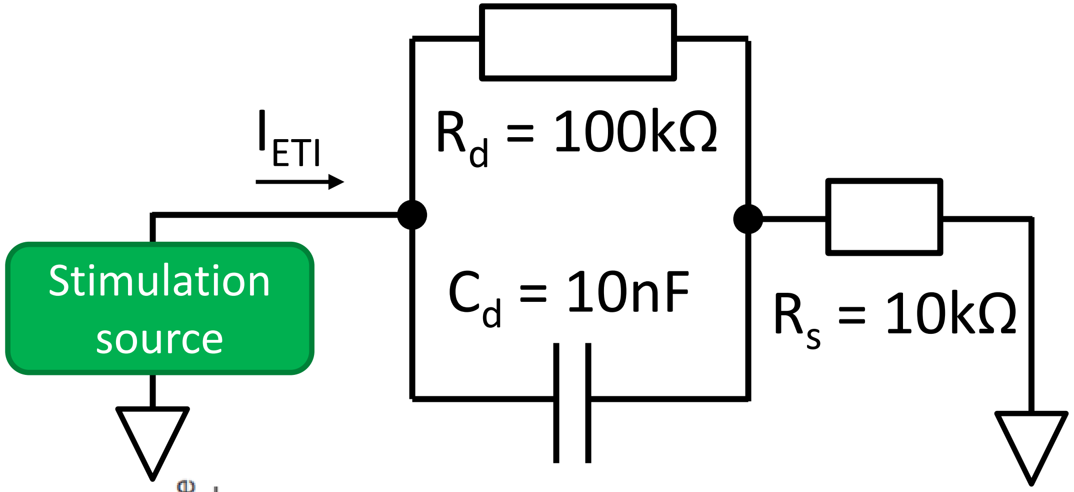


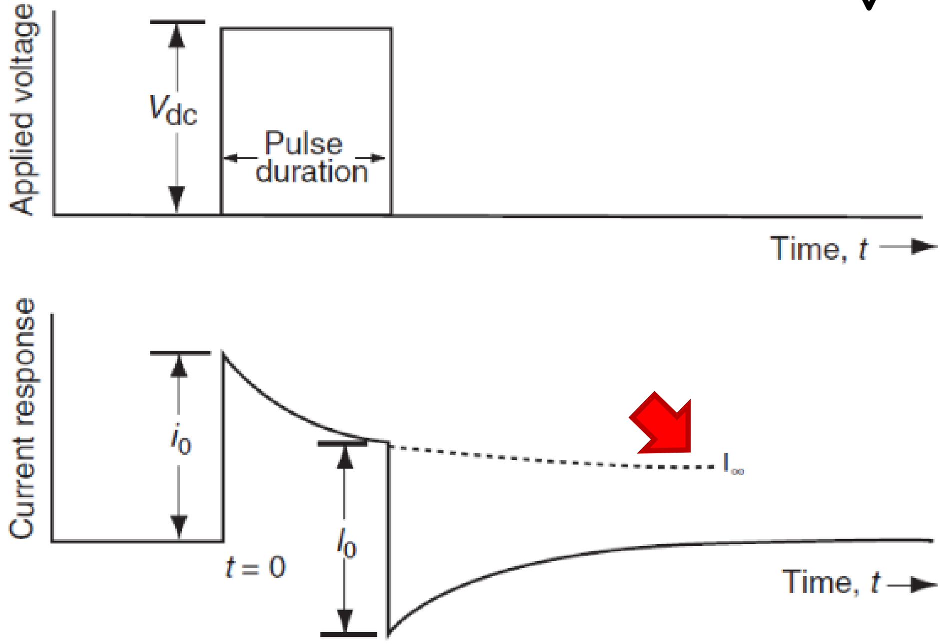
Constant Voltage Stimulation

- Build the ETI model as shown in the figure in Cadence.
- You now replace the stimulation source with a vpwl component (a voltage source with a "programmable" waveform) and adjust its parameters so that it creates a single voltage pulse as sketched below



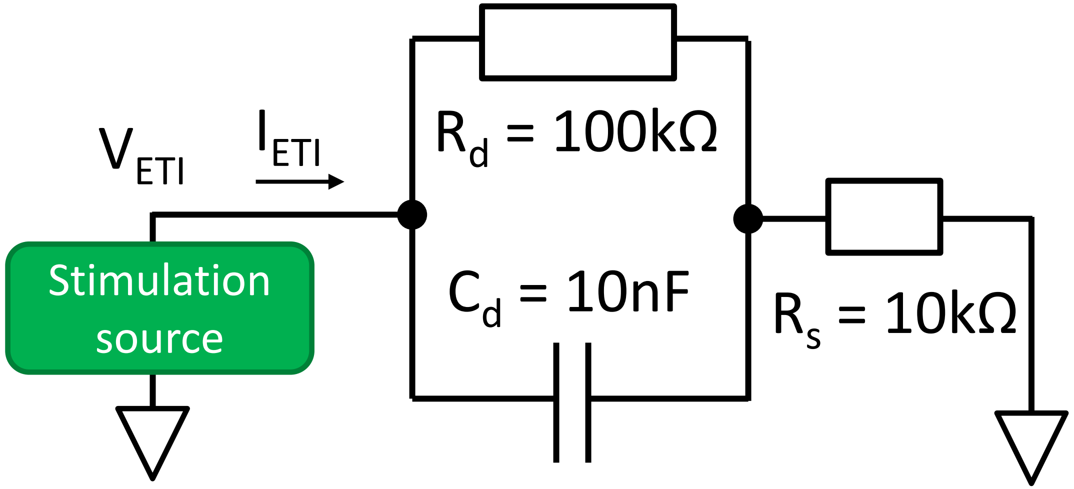
- Run a transient simulation (10ms total time) and confirm you get patterns for the source voltage and I_{ETI} current similar to the ones shown on the right (taken from the lecture)
- Question 5: Which component(s) is/are responsible for the I_{∞} current value once the stimulation is active long enough?
- Question 6: What is the total charge delivered to the body during the entire response (in nC)?





Constant Charge Stimulation

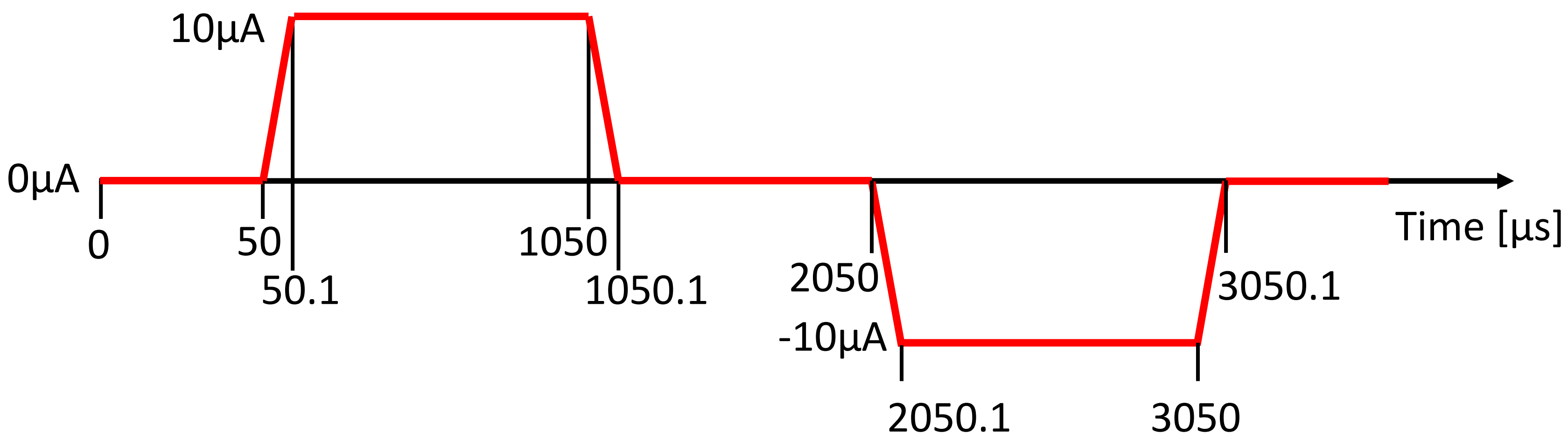
- Build the ETI model as shown in the figure in Cadence.
- You now replace the stimulation source with a capacitor of 10nF. If you set the initial condition to 1V, it will behave as a pre-charged capacitor that will immediately (at time t = 0) start to stimulate the body.



- Run a transient simulation (**<u>100ms</u>** total time) and confirm you get patterns a decaying current and voltage.
- Question 7: What is the total charge delivered to the body during the entire response (in nC)?

Biphasic Current Stimulation

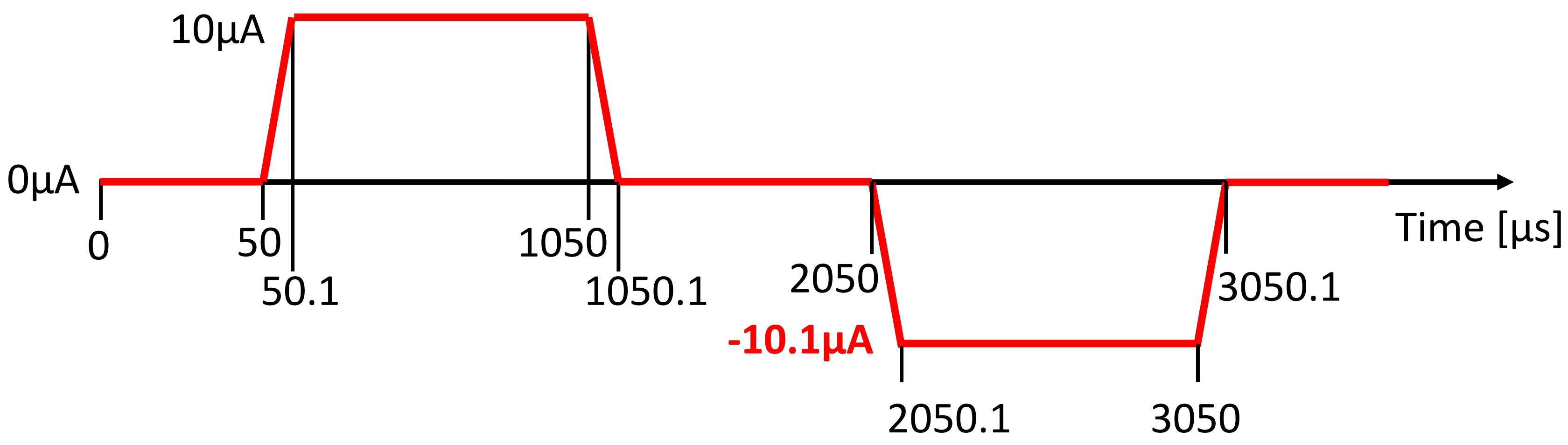
- Return to your test bench with the current source stimulation source (slide 7).
- Modify ipwl such that it creates a biphasic current as shown in the figure below.
- Also set the parameter “Period of the PWL” to 5ms. In that way, you get repetitive biphasic patterns.



- Run a transient simulation (**<u>1s</u>** total time)
- Question 8: What is the final charge (in nC) delivered to the body after 1s of stimulation time?

Biphasic Current Stimulation

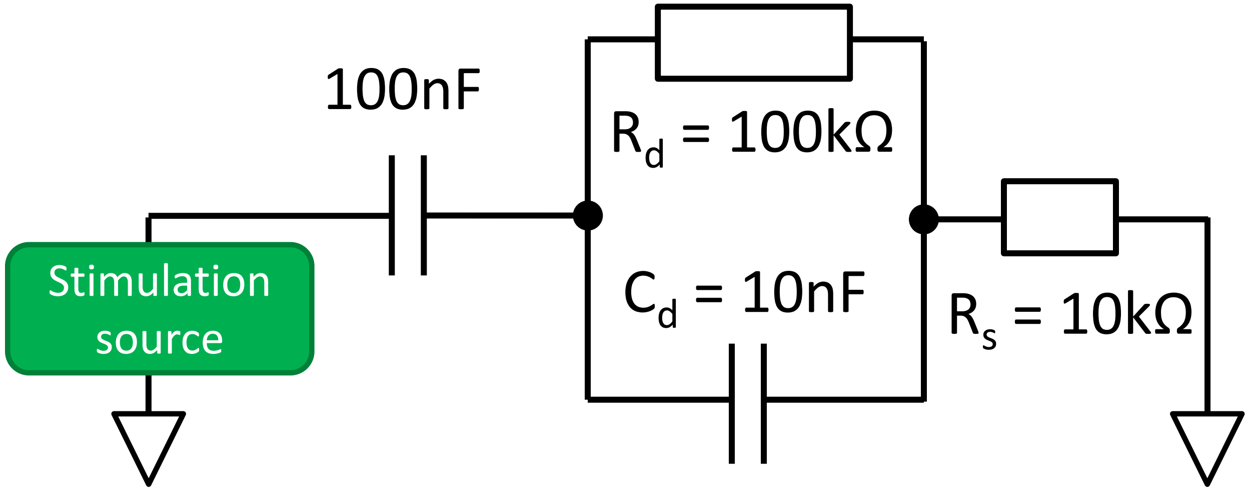
- Now generate some mismatch in the biphasic currents, by lowering the second pulse to -10.1μA.



- Run a transient simulation (**1s** total time)
- Question 9: What is the final charge (in nC) delivered to the body after 1s of stimulation time?

Biphasic Current Stimulation

- As a final step, keep the mismatch in the ipwl source, but add a series blocking capacitor of 100nF



- Run a transient simulation (**<u>1s</u>** total time)
- Question 10: Does this capacitor solve the charge accumulation problem in this particular case?