EE-517: Bio-Nano-Chip Design

Exercises 11: Current-to-frequency converters, Amperometric detection, Temperature measurement

November 24, 2020

Problem 1

A *Current-to-Frequency Converter* (I-to-F converter) is implemented for the amperometric detection of a glucose biosensor. An electrochemical cell in a three-electrodes configuration is used, where the *Working Electrode* (WE) is functionalized with glucose oxidase enzyme. Fig. 1 represents the front-end circuit, including the potentiostat that controls the electrochemical cell potentials, and the I-to-F converter that readouts the faradaic current encoded as a pulse width-modulated signal.

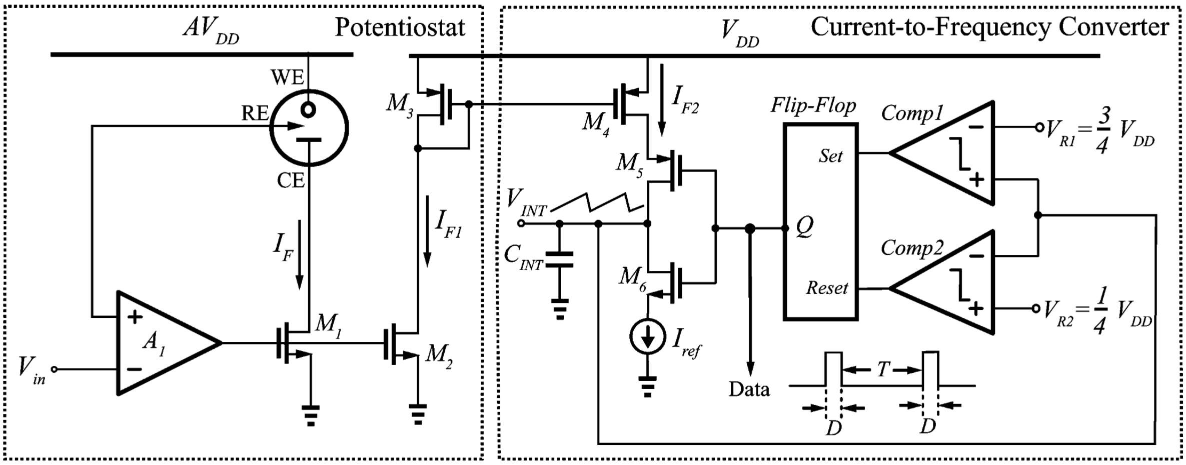

Figure 1: Simplified schematic of potentiostat and current-to-frequency conversion of oxidation currents.

The design specifications are listed hereunder:

- *Oxidation currents:* $I_f \in [1\,nA; 1\,\mu A]$
- *Supply voltages:* $AV_{dd} = 1.8\,V$, $V_{dd} = 1.8\,V$
- *Reference current:* $I_{ref} = 1\,\mu A$
- *Maximum resolvable frequency of the pulsed signal:* $f_{max} = 100\,kHz$

(a) Describe the functional blocks of the front-end circuitry. Explain how the faradaic current is encoded.
(b) Size the capacitor C_{INT} to comply with the design specifications.
(c) Implement circuit modifications to measure reduction currents.

Problem 2

The amperometric measurement of *Cyclophosphamide* and *Dextromethorphan* is considered. These exogenous metabolytes are sensed with two *Working Electrodes* (WEs), both functionalized with carbon nanotubes and cytochrome P450 enzyme. An additional WE is functionalized only with carbon nanotubes in order to remove the common-mode capacitive current.

Design a circuit that monitors selectively the two metabolites. Use a three-electrodes electrochemical cell in a grounded-WE configuration. Classical current-to-voltage converters are used. Justify your design choices.

Problem 3

A glucometer usually comprises a temperature sensor for calibration purposes. We consider a *Proportional To Absolute Temperature* (PTAT) circuit implemented with a beta-multiplier topology (see Fig. 2) . Size the transistors operating in weak inversion such that they comply with the design constraints listed hereunder:

- *Operating temperature:* $\mathrm{T} = 300\,\mathrm{K}$
- *Sensing resistor:* $\mathrm{R_s} = 100\,\mathrm{k\Omega}$ at $\mathrm{T} = 300\,\mathrm{K}$
- *Reference bias current:* $\mathrm{I_{ref}} = 1\,\mu\mathrm{A}$

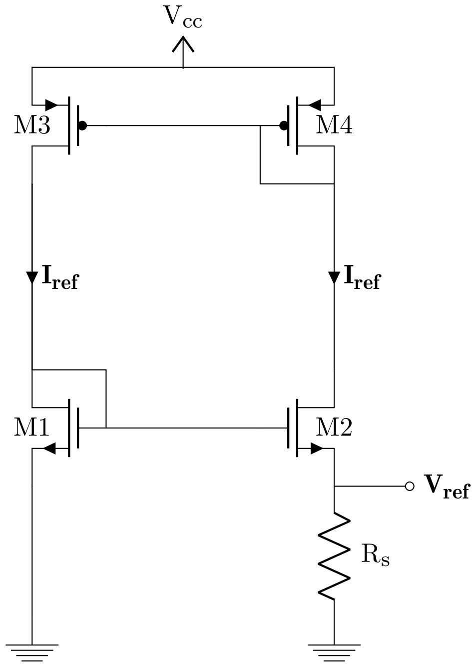

Figure 2: Beta-multiplier implemented for temperature measurement.