Problems for Chapter 24 of 'Ultra Low Power Bioelectronics'

Problem 24.1

a) Find differential equations that correspond to the acid dissociation reaction of Equation (24.4) and show that Figure 24.2 (b) is a circuit representation of them.
b) Draw a dissociation feedback loop analogous to the association feedback loop of Figure 24.3.

Problem 24.2

Show that the variance in the number of heads obtained after N_t tosses of a coin with a probability of heads = p is given by Equation (24.7).

Problem 24.3

The circuit shown in Figure 24.4 is a current-mode implementation of the forward half of the chemical reaction $A+B \rightleftharpoons C$. Draw a circuit that is a current-mode implementation of the backward half of the reaction $\left(C \rightarrow A+B\right)$.

Problem 24.4

Show how to modify the circuit of Figure 24.8 such that the transcription binding subcircuit has a programmable Hill coefficient.

Problem 24.5

If [S] may not be assumed constant, modify Figure 24.3 into a nonlinear interacting set of feedback loops that model changes in dynamics in [E] and [S].

Problem 24.6

If the "logic circuit" of Figure 24.11 is described by the following truth table for mRNA production rates

$u\left(X_1^*/K_D-1\right)$	$u\left(X_2^*/K_D-1\right)$	β_{MRNA}
0	0	β_0
0	1	$10\beta_0$
1	0	$10\beta_0$
1	1	$100\beta_0$

plot the output mRNA concentration if X_1^* and X_2^* are both described by the symmetric triangle wave shown below. You may assume that $R_\alpha^{mRNA}C \approx 0$ because C is small but that R_α^{mRNA} is finite.

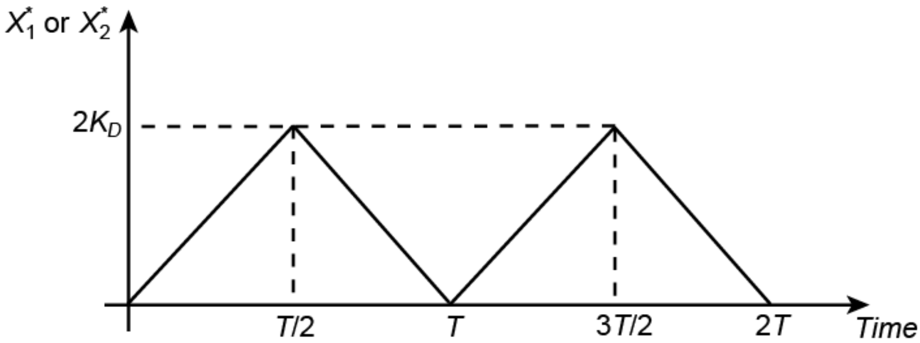

Figure P24.6: X_1^* and X_2^* waveforms.

Problem 24.7

Repeat Problem 24.6 for $R_\alpha^{mRNA}C = \frac{T}{10}$. Justify any approximations.

Problem 24.8

Modify Figure 24.10 to implement an analog AND function.

Problem 24.9

Derive Equation (24.33) from Figure 24.17 (c) and the discussion of chemical-reaction noise in the chapter.

Problem 24.10

Can you guess why the power consumption per neuron (~0.66 nW) is much higher than the average power consumption per cell (~1 pW)?