Problems for Chapter 22 of 'Ultra Low Power Bioelectronics'

Problem 22.1

The raw input image information into the eye over all intensities and conditions and over all of its pixels is an estimated 36 Gbs^{-1} (see Chapter 23). The retina in the eye performs analog preprocessing before sampling and discretization to reduce this information to ~20 Mbs^{-1}.

a) If the brain's power consumption scales linearly with its output information rate, and its power consumption for an average 65 kg male is 14.6 W, estimate the power consumption of the brain in a scenario where the retina does not use analog preprocessing to perform compression and simply uses a linear ADC to transmit all incoming information.
b) How much larger would our brains need to be to process this information?
c) Would the cooling and feeding of this brain be biologically feasible?

For parts a), b), and c), you may assume that half the brain's power consumption is due to visual information processing.

Problem 22.2

A single-transistor nFET common-source amplifier is built with a gate input, a grounded source, and a drain connected to an $R||C$ load originating from a power-supply V_{DD}. The output is at the drain of the nFET. The amplifier is designed to have a gain of 15. The output noise of the amplifier is denoted by $\overline{V_n^2}$ and may be assumed to be only due to thermal noise. Compute the noise-resource equation of the amplifier, $\overline{V_n^2}$ versus dc current consumption, if the output signal bandwidth is always architected to be fixed at Δf = 100 kHz in

a) subthreshold operation
b) above-threshold operation

You may assume that small-signal operation is valid in all of your calculations in the entire problem.

c) Show that the amplifier power assumption is related to the output signal-to-noise ratio and output bandwidth. Compute the power laws that govern this relationship in subthreshold and above-threshold operation.

Problem 22.3

An aircraft controller has different control strategies during takeoff, landing, cruising, ascending or descending for preserving efficiency and robustness (safety) during flight.

a) Discuss why the aircraft controller is a hybrid state machine and identify through your common sense and imagination three sensor variables that can lead to 'events' that trigger state transitions in the controller.
b) Identify the four modes of locomotion in a horse that are triggered when it moves at different speeds.
c) In both cases, what is the low-level circuit equivalent of a high-level 'behavior'?

Problem 22.4

a) If the instantaneous dynamic range of a sensor system is 60 dB but the overall dynamic range of this system is 120 dB (e.g. in audition and in several visual scenes), estimate the power-savings factor obtained through the use of an adaptive feedforward or feedback AGC versus that of a brute-force high-dynamic-range system.
b) How might this savings factor vary with technology, e.g., subthreshold vs. above-threshold implementation or in a thermal-noise-limited vs. non-thermal-noise limited system?

Problem 22.5

Derive Equations (22.6) and (22.8).

Problem 22.6

Your computer-science friend has discovered a clever bio-inspired algorithm for image compression. To perform N:1 compression on the information in the image, she has figured out a method that costs ($4x10^{-9}$) N.J/(input bit) {with $1 < N < 40$ and with sufficiently high-resolution images.} of energy. Your manager instructs you to make a wireless camera that uses her compressed output information and transmits it wirelessly for a short distance at a 30 μJ/bit of communication energy.

a) For a 1-million pixel camera operating with 8 bits/pixel and a 5 Hz frame rate, compute the power consumption needed for 1:1 and 40:1 compression respectively.
b) Compute the power consumption of wireless communication at 1:1 compression and 40:1 compression in a) respectively.
c) Find the optimum N, at which there is just enough compression at which the sum of the computation/compression power and the communication/wireless power is minimized. What is the optimum total computation and communication power at this N?
d) Draw similarities between the optimum computation/communication tradeoff and the optimum analog/digital tradeoff shown in Figures 22.5 (a) and (b).

Problem 22.7

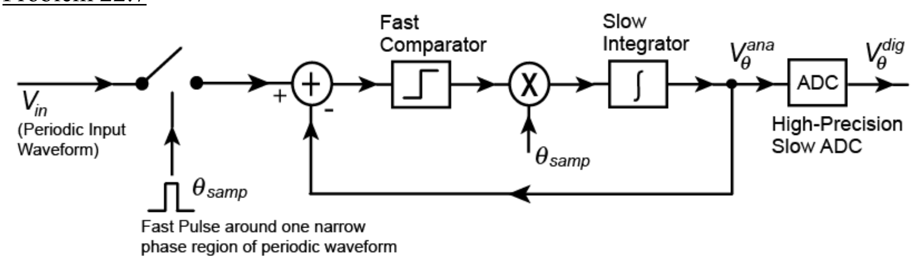

Figure P22.7 High-Speed Sampling Oscilloscope Block Diagram.

A high-speed sampling oscilloscope is constructed with the architecture of Figure P22.7 by separating the problem of speed from the problem of precision: You are told that 'the periodic input waveform is digitally reconstructed point by point by extracting a sample point at each phase over many periodic cycles, slowly digitizing the point, and then repeating the same procedure by changing the sample phase slowly from 0 to 2π.'

a) From this cryptic description and your knowledge of feedback loops, explain how such an oscilloscope works. Would it work if the signal were not periodic?
b) Why is the scheme shown in Figure P22.7 energy efficient and cost effective?

Problem 22.8

What is the key reason that several watches operate with 1-10 μW of power? To reduce the power consumption to 100 nW, what would a key technology development need to be?

Problem 22.9

For the ΣΔ, SAR and neuron-inspired ADCs of Chapter 15, create a formal mathematical description of the ADS, FSM, binary control vector, and events that illustrate that they are all special-purpose HSMs performing analog-to-digital conversion. Delineate what constitutes 'digital code' versus what constitutes a nonlinear analog dynamical system.

Problem 22.10

The power cost of an escalator that is constantly running is P_{esc}. The cost of a constantly running sensor that detects when any person steps on the escalator is P_{sens}. If the probability that the escalator is used is p_s find the value of p_s at which a constantly running escalator is more energy efficient than a gated escalator that only turns on when the sensor detects that it needs to be used.