Problems for Chapter 25 of 'Ultra Low Power Bioelectronics'

<u>Problem 25.1</u>
Modify Figure 25.3 to include battery self-discharge. Assume that the self-discharge leads to an approximately 5% loss of battery capacity each month. You should specify the value of the components added in relation to the values of other components in Figure 25.3.

<u>Problem 25.2</u>
Prove Equation (25.14).

<u>Problem 25.3</u>
The Gouy-Chapman cosh-like capacitance (The C_{GC} term in Equation (25.22)) at a battery electrode is extremely similar to the MOS inversion capacitance of Problem P3.10: The inversion capacitance, C_{inv}, is the slope of the monotonically increasing curve in Figure 3.11 (d) where the straight line intersects it. The depth of the inversion layer in MOS device physics (part of Problem 3.10) is extremely similar to the Debye length.

By using Poisson-Boltzmann equations that we discussed in MOS device physics in Chapter 3, and the inversion capacitance, which we discussed in Problem 3.10, derive the C_{GC} term of Equation (25.22).

<u>Problem 25.4</u>
A Li-ion battery has a 750 mAh maximum rating. Assuming that Equation (25.18) with τ=0.2 h applies (as in Figure 25.6). Estimate

a) How long the battery lasts when it is discharged at 1C.
b) How long the battery lasts when it is discharged at 0.1C.

<u>Problem 25.5</u>
Show how a transmission-line circuit model of Equation (25.28) leads to Equation (25.29). Transmission lines are described in Chapter 17 in Section 17.2.

<u>Problem 25.6</u>
A particular cell phone houses a 3.7 V battery with a 1.44 Ah capacity.

a) If the cell phone receives no phone calls whatsoever, the cell-phone battery lasts for 12 days without requiring a recharge. From this information, estimate the standby power consumption of the cell phone, dominated by its radio-receiver function.
b) If the maximum 'continuous talk time' of the cell phone is 6 hours, estimate the active power consumption of the cell phone, dominated by its radio-transmitter function. You may assume that τ in Equation (25.18) is 0.
c) Estimate the weight of the battery if its gravimetric energy density is 300 J/g
d) Estimate the weight of an ultra capacitor with a gravimetric energy density of 10 J/g that would be needed in this cell phone to completely replace the current battery while preserving its standby and talk times. Would this solution be practical, even if weight were not a consideration?
e) The battery manufacturer tells you that if the cell phone battery were only

required to supply its standby power, its energy density could be doubled to 600 J/g. From the Ragone curve of Figure 25.9 and the discussion in this chapter, explain what the battery manufacturer might do to make this improvement possible.

f) Your boss proposes that an ultra capacitor with a 10 J/g energy density will solely power the cell phone during its 'talk time' while the battery of part e) will recharge the ultra capacitor and power the cell phone during its standby time. He states that the overall weight of the power source can't be altered, however, and must be the same as that computed for the battery in part c). If a hybrid battery-ultra-capacitor power source is created with a battery and ultra capacitor of equal weight, estimate the maximum talk time possible in the cell phone with the hybrid solution.

Problem 25.7

From the expected dependence of the Warburg impedance in Equation (25.32), and assuming that the anode and cathode have identical impedance parameters for all components in Figure 25.8, plot the expected small-signal frequency variation of the impedance of Figure 25.8. Plot your impedance in the complex plane showing both real and imaginary parts.

Problem 25.8

Figure P25.8 shown below illustrates the recommended charging profile of a Li-ion battery.

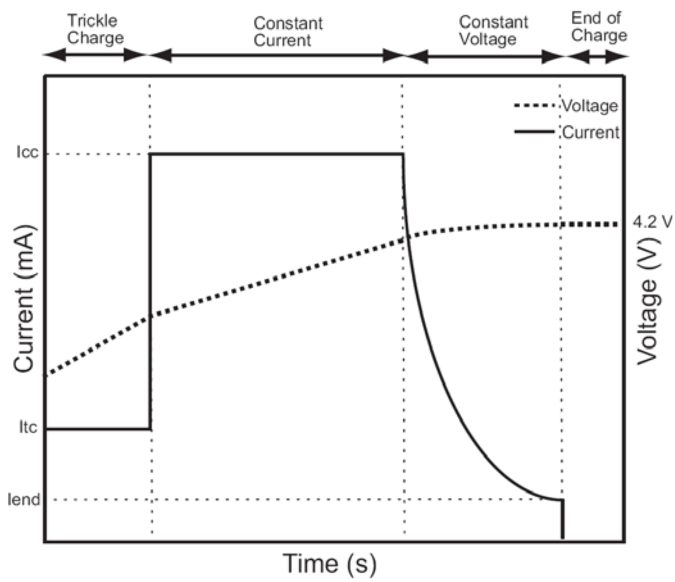

Figure P25.8 Li-ion charging profile

The charging profile is divided into three different regimes: In the trickle-charge regime, the battery is charged with a small amount of current until the battery voltage reaches approximately 3 V; then, the battery is charged with a larger amount of constant current in its constant-current regime; when the battery's voltage nears 4.2

V, the charging is performed by holding the charging voltage supplied to the battery constant in its constant-voltage regime. The charging current is shut off in the end-of-charge regime when the battery voltage is almost exactly 4.2 V.

a) Explain why the Li-ion battery requires a constant-voltage charging regime after its constant-current regime has terminated.
b) Explain why the current supplied to the Li-ion battery falls in its constant-voltage regime as the battery is charged.

<u>Problem 25.9</u>

Figure P25.9 shows a circuit proposed in the literature to charge a Li-ion battery.

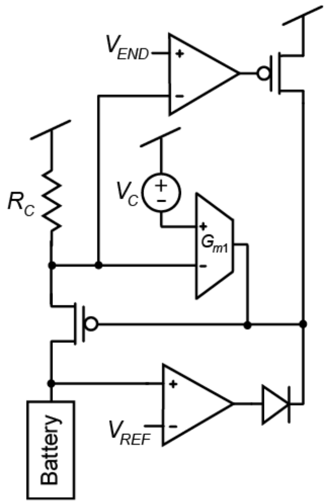

Figure P25.9 Li-ion charger circuit

Explain how the circuit shown in Figure P25.9 creates the required constant-current and constant-voltage charging profile shown in Figure P25.8.

<u>Problem 25.10</u>

In this problem we will study the normalized charge usage of a battery.

a) Explain why the normalized charge usage, shown in Figure 25.5 (b), when the battery is discharged at 750 mA is 0.8 instead of 1.
b) What is the normalized charge usage if we discharge the battery with 1,500 mA?
c) What battery discharge current gives a normalized charge usage of 0.5?