Problems for Chapter 6 of 'Ultra Low Power Bioelectronics'

<u>Problem 6.1</u>
Assuming that Equations (6.53) and (6.54) apply,

a) How large (in μm units) do the W and L of a transistor need to be to achieve a threshold-voltage variance of 2 mV, assuming that $W = L$ in a 1 μm process.
b) Repeat a) for a 0.1 μm process.

<u>Problem 6.2</u>
A saturated transistor in a deep submicron process has parameters $L_{eff} = 0.25$ μm,
$\mu_0 C_{ox} \dfrac{W}{L_{eff}} = 150\, \mu\mathrm{A}/\mathrm{V}^2$, $V_{TS} = 0.4\ V$, $V_{DS} = 2\ V$, $\kappa_S = 0.75$, $E_c = 2 \times 10^6\ \mathrm{Vm}^{-1}$.

a) Find the saturation current, and saturation voltage, assuming that velocity saturation is absent.
b) Find the saturation current and saturation voltage assuming that velocity saturation is present.
c) What is the loop-gain of the velocity-saturation feedback loop? How does the ratio of your answers in a) and b) relate to this loop gain?

<u>Problem 6.3</u>
If $\kappa = 0.7$ for both the NMOS and PMOS transistor in a symmetric subthreshold (small V_{DD}) CMOS inverter (see Figure 21.1(a) in Chapter 21), and the Early voltage = 2 V for both these transistors, find the small-signal gain of this CMOS inverter at its switching point $V_{DD}/2$ (see Figure 21.2(b)) when

a) We assume that DIBL effects are negligible (DIBL coefficient is 0) and that both transistors are saturated.
b) We assume that the DIBL coefficient is 0.1V/V and that both transistors are saturated.

<u>Problem 6.4</u>
Derive Equation (6.6) from Equation (6.4) and (6.5). Use asymptotic approximations that are valid in weak inversion or strong inversion.

<u>Problem 6.5</u>
Derive Equation (6.8).

<u>Problem 6.6</u>
Derive the dimensional forms of velocity-saturation equations {Equations (6.25) and (6.26) respectively} from the dimensionless forms {Equations (6.13), (6.18), (6.19) and (6.20)}.

<u>Problem 6.7</u>
Convert the dimensionless feedback loop of Figure 6.2 (b) into a dimensional feedback loop that depicts Equations (6.25) and (6.26).

Problem 6.8
Using elementary relations between thermal energy, electrical energy, and the kinetic energy of electrons, intuitively explain the plausibility of Equation (6.27).

Problem 6.9
Map the voltage diagrams of Figures 6.3 (a) and 6.3 (b) into equivalent energy diagrams for electrons in a short-channel transistor. How do these energy diagrams differ from those in long-channel transistors?

Problem 6.10
Redraw the intuitive transistor model of Figure 3.4 to incorporate the effects of velocity saturation, DIBL, VMR, poly-gate depletion, and bandgap widening.