American University of Beirut
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
EECE 311 – Electronic Circuits (Sections 1 & 2)
Spring 2008

HOMEWORK 1
Due Friday February 29, 2008 at 1:00 PM

Problem 1.

Refer to Figure 6.4 in the textbook.

Using V_{DD} = 1.8 V and a pair of identical MOSFETs, design the current source in the figure to provide an output current of 50 μA, nominal. The nominal output current is obtained when the $V_O = V_{GS}$.
The output voltage is required to operate in the range 0.3 V to 1.8 V, and it is also required that the change in the output current over this range be limited to 3% of the nominal value.

a) Find the required values of *R* and all device dimensions (*W* and *L*). The technology parameters are: k'_n = 360 μA/V^2, V'_{An} = 20 V/μm, and V_{tn} = 0.55 V.

Do *not* neglect channel-length modulation in your design.

b) Using PSpice, verify that the nominal value of I_O is obtained at $V_O = V_{GS}$, and that the change in I_O is limited to 3% of its nominal value, when V_O changes from 0.3 V to V_{DD}.

Problem 2.

Refer to Figure 6.18 (a) in the textbook.
A common-source CMOS amplifier similar to the one shown in Fig. 6.18 (a) in the textbook uses a supply voltage V_{DD} of 1.8 Volts, and a bias current I_{REF} of 15 μA. The MOSFET parameters are: W/L = 40 for Q_2, W/L = 5 for Q_3, k'_n = 360 μA/V^2, k'_p = 90 μA/V^2, $V_{An} = 1/\lambda_n = |V_{Ap}| = 1/|\lambda_p|$ = 6 V, V_{tn} = 0.55 V, and V_{tp} = –0.5 V.

Do *not* neglect channel-length modulation in DC analysis.

a) Find the value of V_{SG} of Q_2.

b) Find the drain current of Q_1 when $v_O = V_{DD}/2$.

c) Find *W/L* for Q_1 if the drain current found in part (b) corresponds to $v_I = V_{DD}/2$ and $v_O = V_{DD}/2$.

d) Find the value of v_O and the corresponding value of v_I at which Q_2 leaves the saturation region.

e) Find the value of v_O and the corresponding value of v_I at which Q_1 leaves the saturation region.

f) Find the value of the small-signal voltage gain v_o/v_i around the DC bias point ($V_I = V_{DD}/2$, $V_O = V_{DD}/2$)

g) Find the value of the output resistance R_o.

h) Simulate the circuit in PSpice to derive the voltage transfer curve (v_O versus v_I) when v_I varies between 0 V and 1.8 V. This is done as follows:

```
vi input_node 0 DC 0V
.DC vi 0V 1.8V 0.001V
```

where `input_node` is the number you assigned to the input node. The `.DC` statement sweeps v_I from 0 V to 1.8 V in 1 mV steps.

Using the Probe trace of `V(output_node)`, where `output_node` is the number you assigned to the output node, note that for a range of values of v_I, the gain $|dv_O/dv_I|$ is large and approximately constant. What is this range of values of v_I? What is the corresponding range of values of v_O? How do the values compare with the results of parts (d) and (e)?

i) Bias the transistor at ($V_I = V_{DD}/2$, $V_O = V_{DD}/2$), and apply a sinusoidal input with an amplitude equal to 10 mV. Run a transient analysis using such a sinusoidal source (at a frequency of 1 KHz):

```
vi input_node 0 SIN(DC_bias Amplitude 1KHz)
.Tran 5us 8ms 5ms 5us
```

`DC_bias` is $V_{DD}/2$ and `Amplitude` is 10 mV.

i.1) Verify, from the Probe plots of v_O and v_I, that the AC gain is close to the value calculated in part (f).

i.2) Now change `Amplitude` to 50mV, and run the transient analysis. How do you explain the shape of the output waveform?

j) Find the output resistance of the amplifier. This is done in SPICE as follows: Set the input source v_I to $V_{DD}/2$ (this is a zero-volt AC input source!), and connect an AC voltage source v_x to the output node via a 1 F capacitor (this capacitance is needed in order not to disrupt the DC bias, and results in a negligible impedance of 0.16 mΩ at the AC frequency of 1 KHz):

```
vx test_node 0 AC 1
cx test_node output_node 1
```

where `test_node` is the number you assigned to the test node to which v_x is connected.

Run an AC analysis at 1KHz using:

```
.AC LIN 1 1KHz 1KHz
.PRINT AC i(vx)
```

The `.PRINT` statement will print the value of i_x. After running PSpice, click on
View -> Output File
then scroll down to "`****          AC ANALYSIS`   " to read the value of i_x = `I(vx)`.

Calculate the value of the output resistance from this value of i_x. Compare with the value calculated in part (g).

Problem 3.

a) A direct-coupled amplifier has a low-frequency gain of 32 dB, poles at 11 KHz, 48 KHz, and 220 KHz, a zero at 96 KHz, and two more zeros at infinity. Express the amplifier gain function in the form:

$$A_M \frac{(1+\frac{s}{\omega_{z1}})(1+\frac{s}{\omega_{z2}})\cdots(1+\frac{s}{\omega_{zn}})}{(1+\frac{s}{\omega_{p1}})(1+\frac{s}{\omega_{p2}})\cdots(1+\frac{s}{\omega_{pn}})}.$$

b) Sketch the Bode plot for the magnitude of the gain.

c) Calculate the 3-dB frequency f_H for this amplifier using:
 i) the dominant pole approximation
 ii) the definition of the 3-dB frequency (i.e. find the exact value of f_H).
 What is the error (in %) in the value of f_H due to the dominant pole approximation?

d) Calculate the frequency f_t at which the gain of the amplifier becomes unity (or 0 dB) using:
 i) the dominant pole approximation
 ii) the definition of f_t. Comment on the usefulness of the dominant pole approximation in estimating f_t.

e) Verify using PSpice the values of f_H and f_t calculated above. Use

```
Homework 1 Problem 3
.PARAM pi=3.141593
Vin 1 0 AC 1
Rin 1 0 1
Eamp 2 0 Laplace {V(1)}={ your gain function here }
Rout 2 0 1
.AC DEC 20 1Hz 1000KHz
.Probe
.End
```

and plot `dB(v(2))`.