

# Homework 4

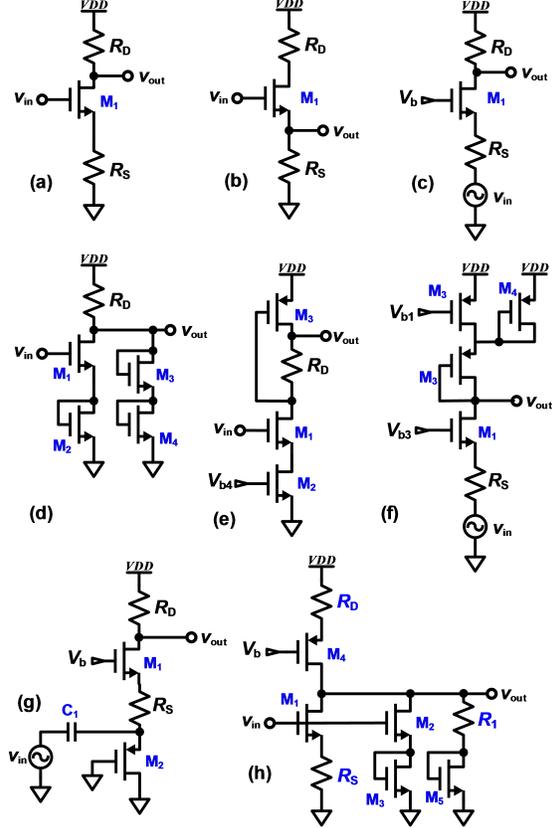
ECE 5/415 – Analog IC Design

**Note:**

1. Use Cadence schematic capture, layout and Spectre simulation tools, available on the servers for the homework problems.
2. Unless otherwise stated, use the following MOSFET parameters for hand-calculations. Use the  $1\ \mu\text{m}$  CMOS models on the servers for corresponding simulations.

**Table 1:** Long-channel MOSFET parameters.

Parameter	NMOS	PMOS
Scale factor ( $L_{min}$ )	$1\ \mu\text{m}$	
$V_{DD}$	5 V	
$V_{THN}$ and $ V_{THP} $	0.8	0.9
$KP_n$ and $KP_p$	$120\ \frac{\mu\text{A}}{\text{V}^2}$	$40\ \frac{\mu\text{A}}{\text{V}^2}$
Bias Current, $I_D$	$20\ \mu\text{A}$	$20\ \mu\text{A}$
$g_{mn}$ and $g_{mp}$	$150\ \frac{\mu\text{A}}{\text{V}}$	$150\ \frac{\mu\text{A}}{\text{V}}$
$V_{ov} \cong \frac{2I_D}{g_m}$	250mV	250mV
$W/L$	10/2	30/2
$V_{GS}$ and $V_{SG}$	1.05V	1.15V
$r_{on}$ and $r_{op}$	$5\text{M}\Omega$	$4\text{M}\Omega$
$C'_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$	$1.75\ \frac{\text{fF}}{\mu\text{m}^2}$	
$C_{oxn}$ and $C_{oxp}$	35 fF	105 fF
$C_{gsn}$ and $C_{gsp}$	23.3 fF	70 fF
$C_{gdn}$ and $C_{gdp}$	2 fF	6 fF
$f_{Tn}$ and $f_{Tp}$	900 MHz	300 MHz



**Figure 1**

**Problem 1:** Assuming all transistors are in saturation, find expressions for small-signal voltage gain ( $A_v = G_m R_{out}$ ),  $R_{in}$  and  $R_{out}$  for each of the circuits shown in Fig. 1 below. Use variables  $g_{m1}$ ,  $r_{o1}$ ,  $g_{m2}$ ,  $r_{o2}$ , etc. Assume that  $r_o = \infty$ , unless you must have a finite value, and use  $\gamma = 0$ .

**Problem 2:** Read the amplifier frequency response analysis examples posted on the course site. Fig. 2 shows amplifier circuits with wide-swing cascoded bias voltages ( $V_{bias1}$  to  $V_{bias4}$ ) generated for the current and overdrive parameters from Table 1 above. For each of these three amplifiers:

(a) Determine the frequency response (perform numerical calculations for DC gain

and pole-zero locations, and provide hand-sketched Bode magnitude and phase responses).

(b) Estimate the unity-gain frequency ( $f_{un}$ ), and phase-margin ( $\Phi_M$ ) for the amplifiers. Use  $R_s = 1\text{k}\Omega$  in 2 (c). Note that  $f_{un} = \frac{\omega_{un}}{2\pi}$  and  $\Phi_M$  is defined as the margin before the total phase-shift is  $180^\circ$  at the gain-crossover (or the unity-gain frequency).

(c) Create circuit schematics and verify/compare your calculations with Spectre simulations using *AC analysis*. You will need to use a BMR with  $I_{ref} = 20\ \mu\text{A}$ , and then use wide-swing cascode bias circuits to generate DC reference  $V_{bias1-4}$ . The  $R_{big}$  and  $C_{big}$  are sufficiently large to bias the amplifiers,

i.e.  $\omega_x = \frac{1}{R_{big}C_{big}} = \frac{\omega_{in}}{10}$ .

(d) Apply a small transient input,  $v_{in}$ , say 1mV amplitude at a low-frequency (say  $\omega_{in} = 2\pi \cdot 10kHz$ ) and show the output response for all circuits. Verify the gain.

(d) Modify the circuit in Fig. 2 (c) to cancel the RHP zero. Verify using Spectre simulations.

**Extra work:** Use/modify the provided MATLAB scripts (e.g. *CommonSourceFreqResp1.m* or *TwoStageFreqResp1.m*) to generate frequency response and pole-zero plots to augment your understanding.

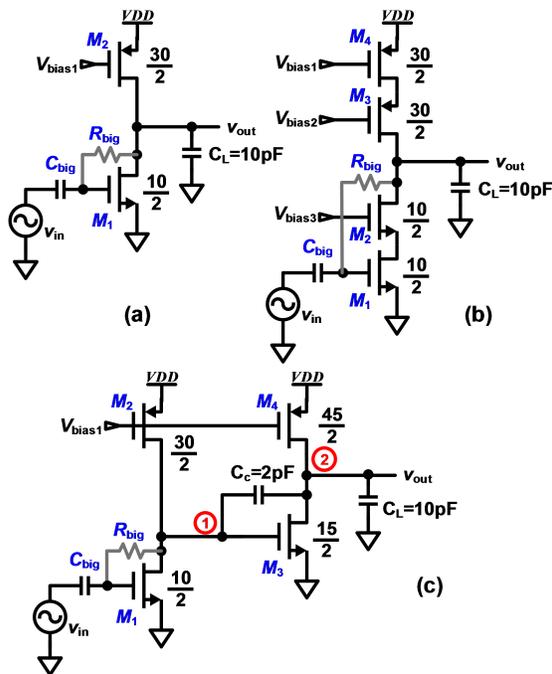


Figure 2

**Problem 3:** Figure 3 shows a source follower (SF) designed using parameters from Table 1.

(a) Determine the frequency response for Fig. 3 (a). Create circuit schematics and compare your calculations with Spectre simulations.

(b) Assuming  $R_s = 0$ , derive the input AC impedance  $Z_{in}$  of the SF. Show that the overall input capacitance contributed by  $M_1$  is the sum of  $C_{gd1}$  and a fraction of  $C_{gs1}$ .

Plot  $|Z_{in}(f)|$  using Spectre and verify your results.

(c) Figure 3 (b) shows the SF driving a large load with a pulsed source. It can be shown that the equivalent output impedance of the SF can be expressed as an inductive combination  $Z_{out} = (sL || R_1) + R_2$ . Here,  $R_2 = \frac{1}{g_{m1}}$ ,  $R_1 = R_s - \frac{1}{g_{m1}}$  and  $L = \frac{C_{gs1}}{g_{m1}} \left( R_s - \frac{1}{g_m} \right)$ . Using Spectre, plot  $|Z_{out}(f)|$  for the cases including  $R_s \gg \frac{1}{g_{m1}}$  and  $R_s \ll \frac{1}{g_{m1}}$  to demonstrate this behavior.

(d) In Figure 3 (b), use a 10 MHz clock source as the input to the SF, and plot output response for  $R_s = 0, 50\Omega, 1k\Omega, \text{ and } 10k\Omega$ . Explain the results.

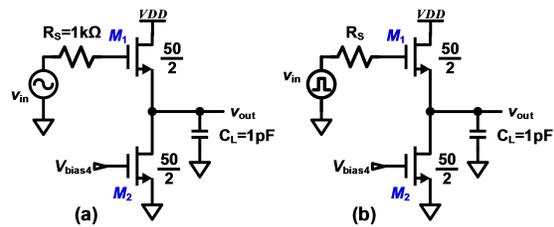


Figure 3