Electronics –II (ELEC 312), Winter 2009 class

Mid-term test (March 6, 2009)

(Time: 45 minutes Instructor: Dr. R. Raut)

Student ID# Name:

Q.1: Consider the amplifier in Figure 1, built with MOS transistors. The transistor M3 functions as an active load for the transistors M1 and M2. M1 is a common source stage while M2 is a common gate stage.

(a) Draw the small signal ac equivalent circuit for the system. Ignore the *body effect* for M2.

(b) Set up the nodal admittance matrix for the system with a goal to find the small signal voltage gain v_o/v_i. You DO NOT have to find the voltage gain.

Setting up of nodal admittance matrix (Say $g = \frac{1}{r}$)

$$\begin{array}{cc} ① & ② \\ \end{array}$$

$$\begin{bmatrix} g_{o1}+g_{o2} & -g_{o2} \\ -g_{o2} & g_{o2}+g_{o3} \end{bmatrix} \begin{bmatrix} v_{①} \\ v_{②} \end{bmatrix} = \begin{bmatrix} -g_{m1}v_i - g_{m2}v_x \\ g_{m2}v_x \end{bmatrix}$$

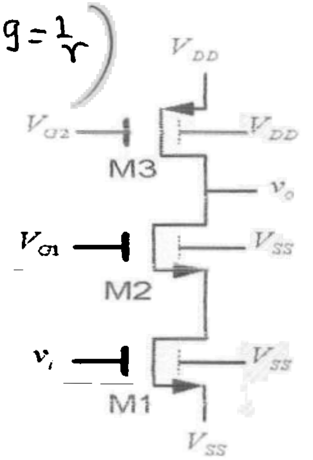


Figure 1:

But $v_x = v_{①}$, $v_{②} = v_o$

So $-g_{m2}v_x = -g_{m2}v_{①}$

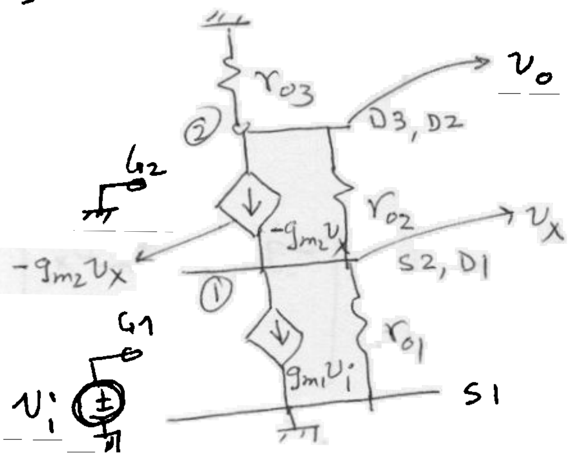
Transferring sides

$$\begin{bmatrix} g_{m2}+g_{o1}+g_{o2} & -g_{o2} \\ -g_{m2}-g_{o2} & g_{o2}+g_{o3} \end{bmatrix} \begin{bmatrix} v_{①} \\ v_o \end{bmatrix} = \begin{bmatrix} -g_{m1}v_i \\ 0 \end{bmatrix}$$

Ans (b)

M3 has source and gate at DC, drain connected to drain of M2 M3 functions as r_{o3} for ac signal The ac equivalent of Fig 1 is

$\therefore$ $v_{gs2} = v_{g2} - v_{s2} = 0 - v_x$

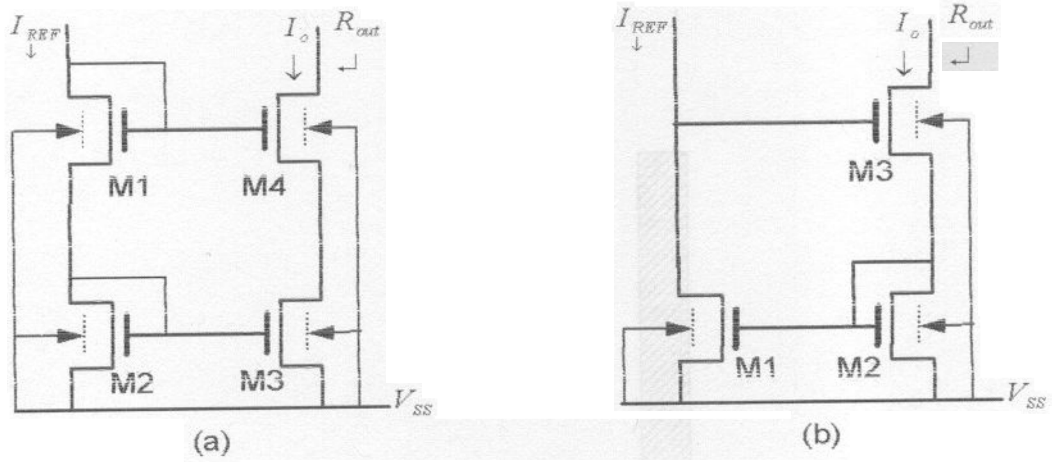


Ans (a)

Q.2: Figures 2(a)-(b) show the Cascode and the Wilson current mirror respectively, using NMOS transistors. The bias currents are set as $I_{REF} = I_o = 20$ micro amp. Given that V_A=20 volts, K_n=100 micro amp./V^2, W/L=10, $g_m = \sqrt{\dfrac{2K_n I_{BIAS} W}{L}}$, $g_{mb} = 0.2 g_m$ for all the transistors, compare the output resistances that the two mirrors present to an outside circuit. The expressions for the output resistances are (approximately):

(Cascode) $R_{out} = (g_{m4} + g_{mb4}) r_{o3} r_{o4}$,

(Wilson) $R_{out} = \dfrac{g_{m1} g_{m3}}{g_{m2}} r_{o1} r_{o3}$



(a) (b)

Figure 2:

Using $g_m = \sqrt{\dfrac{2K_n I_{BIAS} W}{L}}$, for M4 in Fig (a) $I_{BIAS} = I_o = 20\times10^{-6}$

$g_{m4} = \sqrt{2\times100\times10^{-6}\times20\times10^{-6}\times10} = 0.0002$ mho

$g_{mb4} = 0.2\, g_{m4} = 0.00004$ mho

$r_{o3} = \dfrac{V_A}{I_{BIAS}} = \dfrac{20}{20\times10^{-6}} = 1\times10^{6} \cong r_{o4}$ ($\because$ same I_{BIAS})

So $R_{out}\big|_{Cascode} = (.0002 + .00004) \times 1\times10^{6} \times 1\times10^{6} =$
$= 240\ M\Omega$

For Fig (b)

$r_{o1} = r_{o3} = 1\times10^{6}$ (All transistors are matched)

$g_{m1} = g_{m3} = g_{m2} = 0.0002$

$R_{out}\big|_{Wilson} = \dfrac{0.0002\times0.0002}{0.0002} \times10^{6}\times10^{6} = 200\ M\Omega$

So $R_{out}\big|_{Cascode}$ is $>$ $R_{out}\big|_{Wilson}$

Q.3 The BJT differential amplifier is supplied with a differential ac signal $v_D = v_1 - v_2$. The differential output signal is given by the expression

$$v_{o1} - v_{o2} = R_c I\left[\frac{\exp(-v_D/V_T)}{1+\exp(-v_D/V_T)} - \frac{\exp(v_D/V_T)}{1+\exp(v_D/V_T)}\right]$$

Where V_T is the thermal voltage (~ 25 mV). The bias current I is arranged to be 2 mA, and R_C= 2000 ohms.

Determine the voltage gain $(v_{o1}-v_{o2})/v_D$, when (i) v_D=20 mV and (ii) v_D= 2 mV. How do these compare with the theoretical small signal voltage gain value of $|g_mR_C|$, where g_m is the trans-conductance of each BJT device.

ii) For $v_D = 2\text{mV}$

$\exp\left(\frac{v_D}{V_T}\right) = 1{\cdot}083$

$\exp\left(-v_D/V_T\right) = 0{\cdot}923$

So $v_{01} - v_{02}$

$= 4\left[\frac{\cdot 923}{1{\cdot}923} - \frac{1{\cdot}083}{2{\cdot}083}\right]$

$= -0{\cdot}1598$

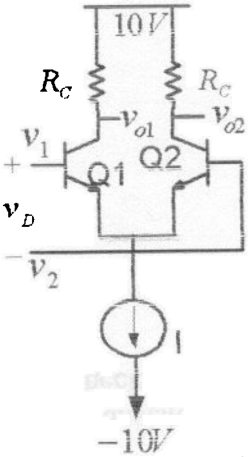


Figure 3

(ii)

Voltage gain $= \frac{v_{01}-v_{02}}{v_D}$

$= -\frac{\cdot 1598}{2\times10^{-3}}$

$= -79{\cdot}89 \text{ V/V}$

Small Signal voltage gain $= |g_m R_c|$ where

$g_m = \frac{1\text{mA}}{25\text{mV}} = {\cdot}04$

Small Signal gain $= {\cdot}04 \times 2\times10^{3} = 80$

i) For $v_D = 20\text{mV}$, $\exp(v_D/V_T) = \exp\left(\frac{20}{25}\right) = 2{\cdot}225$

So $\exp(-v_D/V_T) = 1/2{\cdot}225 = 0{\cdot}449$

$\frac{\exp(-v_D/V_T)}{1+\exp(-v_D/V_T)} = \frac{0{\cdot}449}{1{\cdot}449} = 0{\cdot}31$

$\frac{\exp(v_D/V_T)}{1+\exp(v_D/V_T)} = \frac{2{\cdot}225}{3{\cdot}225} = 0{\cdot}689$

$v_{01} - v_{02} = 2\times10^{3} \times 2\times10^{-3} \times [\cdot 31 \; \cdot 689] = -1{\cdot}516$

Voltage gain $= \frac{v_{01}-v_{02}}{v_D} = \frac{-1{\cdot}516}{20\times10^{-3}} = -75{\cdot}8 \text{ V/V}$

Comparison: $|\text{Small signal gain}| = 80$ V/V

$|\text{gain for } v_D = 2\text{mV}| = 79{\cdot}89$ V/V

$|\text{gain for } v_D = 20\text{mV}| = 75{\cdot}8$ V/V