30.04.2019

Name:

EHB 262E – MIDTERM 2

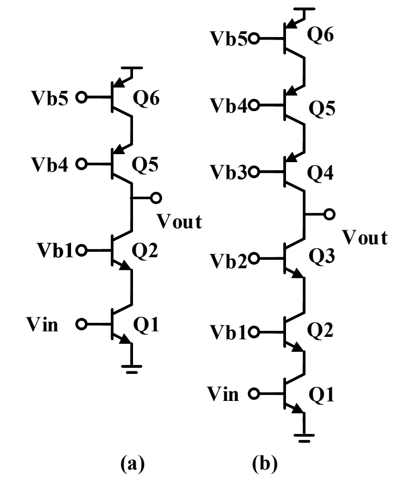


Figure 1. BJT Cascode Amp

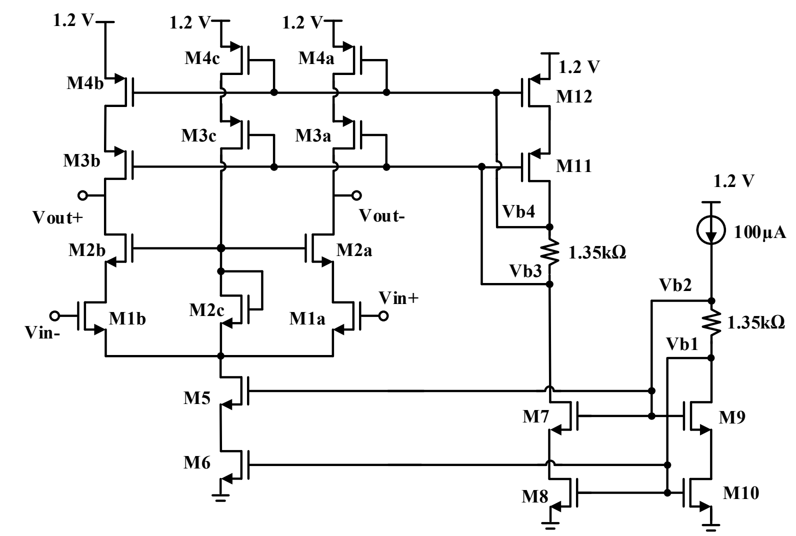


Figure 2. MOSFET Differential AMP

1) Collector current of input transistor is 1mA in each of the amplifiers in figure 1. Early voltage is 50V and β is 100 for NPNs. Early voltage is 25V and β is 50 for PNP transistors. V_T is 25mV.
   a) Calculate I_c, g_m, r_π and r_o values for all transistors.
   b) Calculate G_m of the input cascode, resistance of input and load cascodes.
   c) Briefly explain why adding Q3 and Q4 does not increase the gain in BJT amplifiers.

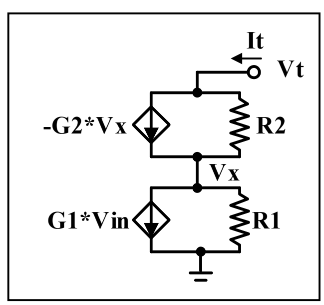
2) μ_n= 500 $cm^2V^{-1}s^{-1}$, μ_p= 200 $cm^2V^{-1}s^{-1}$, C_{ox}= 12.5 fF/μm^2, V_{thn}=0.3V, V_{thp}= -0.3V, λ_n=0,25 V^{-1}, λ_p=0,5 V^{-1}
   Overdrive voltage ($|V_{GS}|-|V_{TH}|$) is 100mV for all transistors except for M2c.
   $V_{DS1a} = V_{GS1a} - V_{TH1a} + 35mV$ and $V_{DS1b} = V_{GS1b} - V_{TH1b} + 35mV$
   $W_{1a}= W_{1b}=W_{2a}=W_{2b}$; $W_{11}=W_{12}=W_{3a}= W_{3b}= W_{4a}= W_{4b}=2W_{3c}=2W_{4c}$; $W_7=W_8= W_9=W_{10}$

a. L=0.5μm for all transistors. Calculate W for all transistors, currents through all transistors and V_{b1}, V_{b2}, V_{b3} and V_{b4}.
b. Calculate the minimum value of $V_{in,CM}$. (M5-M6 must be in saturation)
c. Calculate the maximum value of $V_{in,CM}$ which will keep M3c in SAT. Show that all M1, M2, M3, M4 transistors on both sides will be in SAT under this condition.
d. Calculate Max and Min voltages at output
Hint: Calculate minimum output voltage for minimum $V_{in,cm}$.
e. Use Half circuit method to split the amplifier into 2 half circuits. Calculate Gm of the input cascode, resistances of input and load cascodes.
f. Calculate the Voltage Gain of the circuit.

Hint: If a circuit can be represented wit the equivalent circuit on the left, its output resistance and transconductance is given by:

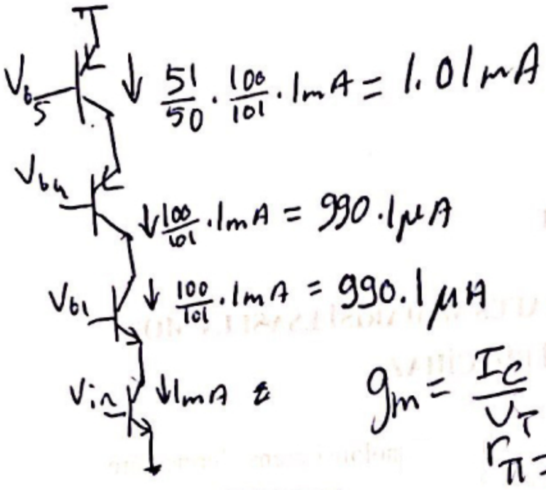
$$R_{out} = \left(G_2 R_2 + 1\right) R_1 + R_2$$

$$G_m = G1 \frac{R_{out} - R_2}{R_{out}}$$



1)

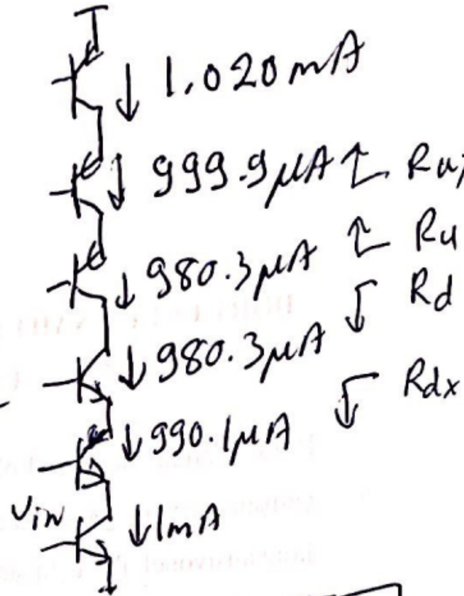
a)



$g_m = \frac{I_C}{V_T}$

$r_o = \frac{V_A}{I_C}$

$r_\pi = \beta / g_m$



g_m	40m	39.6m	39.6m	4.04m
r_o	50k	50.5k	25.25k	24.75k
r_π	2500	2525	1262.5	1238

g_m	40m	39.6m	39.2m	39.2m	40m	40.8m
r_o	50k	50.5k	51k	25.5k	25k	24.5k
r_π	2500	2525	2550	1275	1250	1226

b) 1st

$R_d = (g_{m2} r_{o2} + 1)(r_{o1} \| r_{\pi 2}) + r_{o2}$

$= 4.86\ M\Omega$

$R_u = (g_{m5} r_{o5} + 1)(r_{o6} \| r_{\pi 5}) + r_{o5}$

$= 1.21\ m\Omega$

$G_m = g_{m1} \frac{R_d - r_{o2}}{R_d} = 39.6\ mS$

2nd

$R_{dx} = (g_{m2} r_{o2} + 1)(r_{o1} \| r_{\pi 2}) + r_{o2}$

$= 4.86\ M\Omega$

$R_d = (g_{m3} r_{o3} + 1)(R_{dx} \| r_{\pi 3}) + r_{o3}$

$= 5.15\ M\Omega$

$R_{ux} = (g_{m5} r_{o5} + 1)(r_{o6} \| r_{\pi 5}) + r_{o5}$

$= 1.19\ M\Omega$

$R_u = (g_{m3} r_{o3} + 1)(R_{ux} \| r_{\pi 3}) + r_{o3}$

$= 1.275\ M\Omega$

$G_{mx} = \frac{R_{dx} - r_{o2}}{R_{dx}} \cdot g_{m1} = 39.6\ mS$

$G_m = G_{mx} \cdot \frac{R_d - r_{o3}}{R_d} = 39.2\ mS$

c) Adding more than 2 transistors into cascode configuration does not increase output resistance significantly. Main reason is r_π resistance.
As long as emitter resistance is larger than r_π, their parallel combination is approximately r_π.
Therefore, $\boxed{R_{casc} \cong (g_{m2} r_{o2} + 1) r_{\pi 2} + r_{o2} \text{ or } (g_{m3} r_{o3} + 1) r_{\pi 3} + r_{o3}}$

2) a) $I_{D9} = I_{D10} = I_{D7} = I_{D8} = 100\mu A = I_{D11} = I_{D12} = I_{D3a} = I_{D3b} = I_{D4a} = I_{D4b}$

$I_{D4c} = I_{D3c} = \quad \frac{I_{D12}}{2} = 50\mu A = I_{D2C}$

$I_{D5} = I_{D6} = I_{D4b} + I_{D4a} + I_{D4c} = 250\mu A$

$I_{D1a} = I_{D1b} = I_{D2a} = I_{D2b} = 100\mu A$

$100\times10^{-6} = \frac{1}{2}(500\times10^{-4})(12.5\times10^{-3})\left(\frac{W}{L}\right)_{10} \cdot (V_{GS10} - V_{TH})^2$

$V_{GS} - V_{TH} = 100mV$ for all M_x

$\left(\frac{W}{L}\right)_{10} = \left(\frac{W}{L}\right)_9 = \left(\frac{W}{L}\right)_8 = \left(\frac{W}{L}\right)_7 = \left(\frac{W}{L}\right)_{1a} = \left(\frac{W}{L}\right)_{1b} = \left(\frac{W}{L}\right)_{2a} = \left(\frac{W}{L}\right)_{2b}$

$\left(\frac{W}{L}\right)_{10} = \frac{2\times10^{-4}}{62.5\times10^{-5}\times10^{-2}} = 32$ $\quad W_{10} = 16\mu m$

$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6 = \frac{2\times(250\times10^{-6})}{\mu_n C_{ox} V_{OD}} = 80$ $\quad W_5 = 40\mu m$

$\left(\frac{W}{L}\right)_{12} = \left(\frac{W}{L}\right)_{11} = \left(\frac{W}{L}\right)_{3a} = \left(\frac{W}{L}\right)_{3b} = \left(\frac{W}{L}\right)_{4a} = \left(\frac{W}{L}\right)_{4b} = \frac{2\times10^{-4}}{\mu_n C_{ox} V_{OD}} = 80$

$W_{12} = 40\mu m$

$W_{4c} = W_{3c} = \frac{W_{12}}{2} = 20\mu m$

$V_{b1} = V_{OD} + V_{TH} = 0.4V$ $\qquad V_{b2} = V_{b1} + 1350(10^{-4}) = 0.535V$

$V_{DD} - V_{b4} = V_{OD} + |V_{THP}| = 0.4V$ $\qquad V_{b4} = 0.8V$

$V_{b4} - V_{b3} = 1350(10^{-4}) = 0.135V$ $\qquad V_{b3} = 0.665V$

$V_{DS1a} = V_{DS1b} = 0.135V$ $\quad V_{D1a} = V_{D1b} = V_{S1a} + 0.135V$

$V_{G2a} = V_{G2b} = V_{D1a} + V_{GS2a} = V_{S1a} + 0.135 + 0.4$

$V_{GS2c} = V_{G2a} - V_{S1a} = 0.535V$ $\quad = V_{S1a} + 0.535V$ mS

$$\left(\frac{W}{L}\right)_{2c} = \frac{2 \times 5\times10^{-5}}{\mu_n C_{ox} (V_{GS2c} - V_{TH})} = 2.9$$

15

$\underline{W_{2c}} = 1.45\ \mu m$

b) $V_{DS_{min}} = V_{G2} - V_{TH} = 0.235\ V = V_{S1a_{min}}$ 7,5

$V_{in_{cm}\,min} = V_{DS_{min}} + V_{GS1a} = 0.635V$

c) $V_{D2c} = V_{G2c} = V_{S1a} + 0.535V = V_{G1a} - V_{GS1a} + 0.535$

$= V_{G1a} + 0.135V$

7,5

$V_{D2c_{max}} = V_{D3c_{max}} = V_{G3} + |V_{THP}| = 0.965V$

$V_{G1a_{max}} = V_{D3c_{max}} - 0.135 = 0.830V$

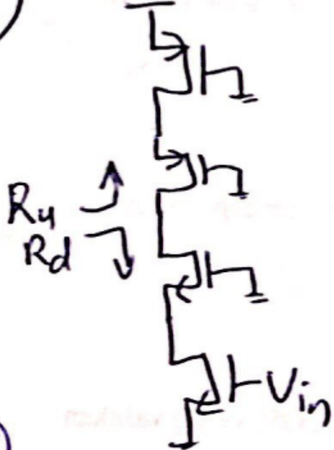
2 d) $V_{O_{max}} = V_{b3} + |V_{THP}| = 0.965\,V$

(10)

$V_{G2a_{min}} = V_{G2C_{min}} = V_{S1a_{min}} + V_{GS_{2C}} = 0.235 + 0.535 = 0.77\,V$

$V_{O_{min}} = V_{G2a_{min}} - V_{TH} = 0.47\,V$

e)



Since $I_{D4C} = I_{D2C}$ is DC, $V_{GS_{2C}}$ is constant. when a diff input is applied, V_{S1a} is AC ground, Thus, V_{G2a} is also AC ground

(15)

$R_d = (g_{m2a} r_{o2a} + 1) r_{o1a} + r_{o2a}$
$= 81(40k) + 40k = 3.28\,M\Omega$

$R_u = (g_{m3a} r_{o3a} + 1) r_{o4a} + r_{o3a}$
$= 840\,k\Omega$

$G_m = g_{m1a} \cdot \frac{R_d - r_{o2a}}{R_d} = 1.98\,mS$

$g_m = \frac{2I_D}{V_{OD}}$

$g_{m1} = g_{m2} = g_{m3} = g_{m4} = 2mS$

$r_o = \frac{1}{\lambda I_D}$

$r_{o1} = r_{o2} = \frac{1}{0.25(10^{-4})} = 40\,k\Omega$

$r_{o3} = r_{o4} = \frac{1}{0.5(10^{-4})} = 20\,k\Omega$

f) $A_v = -G_m(R_d // R_u) = 1320\,V/V$

(10)