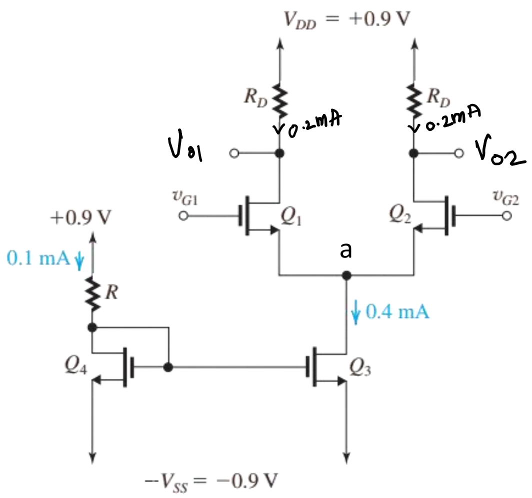
Tutorial 8 solutions
EE204: Analog Circuits

Dept of Electrical Engineering, IITB
Autumn Semester 2023

Q1.

Design the diff pair circuit in Fig. 1 to obtain a dc voltage of +0.1 V at each of the drains of Q1 and Q2 when $v_{G1} = v_{G2} = 0$ V. Operate all transistors at $V_{OV} = 0.15$ V and assume that for the process technology in which the circuit is fabricated, $V_{Th} = 0.4$ V and $\mu_n C_{ox} = 400\ \mu A/V^2$. Neglect channel-length modulation. Determine the values of R, R_D, and the W/L ratios of Q1, Q2, Q3, and Q4. What is the input common-mode voltage range for the design?



Given Vo1=0.1V then,
Rd= (Vdd-vo1)/I_{DQ1} = **4K ohm**.
I_{DQ1}= I_{DQ2}=0.2mA. The transistors should be in the saturation region for the diff pair operation, given all transistors are Operated at $V_{OV} = 0.15$ V so, by using saturation current equation of the transistors,

$$\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{1,2} V_{ov}^2 = 0.2mA$$

$$\left(\frac{W}{L}\right)_{1,2} = \frac{400}{9}$$

$$\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{3} V_{ov}^2 = 0.4mA$$

$$\left(\frac{W}{L}\right)_{3} = \frac{800}{9}$$

$$\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{4} V_{ov}^2 = 0.1mA$$

$$\left(\frac{W}{L}\right)_{4} = \frac{200}{9}$$

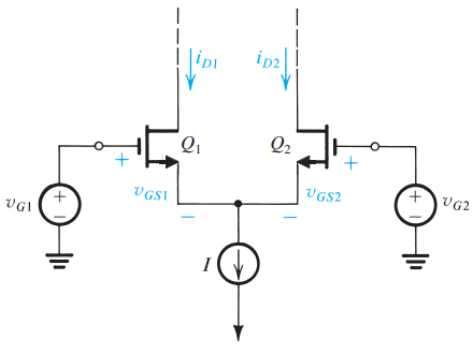
V_{ovQ4}=0.15
V_{GSQ4}=0.15+Vth=0.55
V_{GQ4}= -Vss+0.55=-0.35
R=(Vdd- V_{GQ4})/0.1mA =**12.5K ohm**
As Vcm goes up the voltage at node a goes up to maintain the same current through Q1 and Q2 decreasing VDS across them
For Q1,Q2 to be in saturation

$$V_{DS1,2} \geq V_{GS1,2} - V_{TH}$$
$$V_{D1,2} \geq V_{G1,2} - 0.4$$
$$0.1 \geq V_{G1,2} - 0.4$$
$$V_{G1,2} \leq 0.5V$$
$$V_{G1,2} = V_{CM} \leq 0.5V$$

As Vcm goes down the voltage at node a goes down to maintain the same current through Q1 and Q2 decreasing VDS across Q4

$$V_{DS3} \geq V_{GS3} - V_{TH}$$
$$V_{DS3} = V_{G1,2} - V_{GS1,2} - VSS \geq 0.15$$
$$V_{G1,2} \geq 0.15 + 0.55 - 0.9$$
$$V_{G1,2} = V_{CM} \geq -0.2$$
$$-0.2V \leq V_{CM} \leq 0.5V$$

Q2.
Design the MOS differential amplifier shown in the figure below to operate at V_{ov} =0.25V and to provide a transconductance gm of 1 mA/V. Specify the W/L ratios and the bias current. The technology available provides V_{Th} =0.5 V and µnCox =400 µA/V^2 .

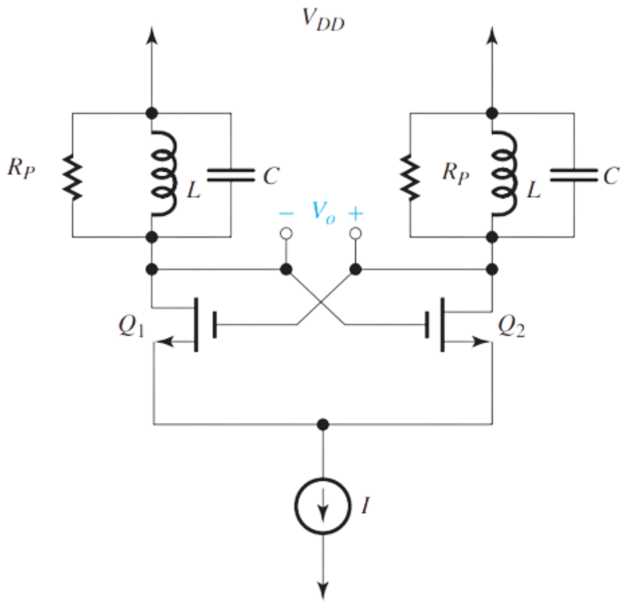


Given g_m =1mA/V then the bias current I_D is related to gm as, g_m=2I_D/Vov
1mA/V=2I_D/0.25
I_D=0.125mA
Also from the mosfet current equation ,

$$\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{1,2} V_{ov}^2 = 0.125\text{mA}$$
$$\left(\boldsymbol{\frac{W}{L}}\right)_{\mathbf{1,2}} = \mathbf{10}$$

Q3.

Design the cross-coupled oscillator to operate at ω_o = 10 G rad/s. The IC inductors available have L = 10 nH and Q = 10. If the transistor r_o = 10 k, find the required value of C and the minimum required value of gm at which Q1 and Q2 are to be operated.



$$frequency\ of\ oscillation\ of\ LC\ tank\ circuit = \ \omega_0 = \frac{1}{\sqrt{LC}}$$

$C = \omega_0^2 * L$

$\boldsymbol{C = 1pF}$

R_P can be evaluated from the Q factor of inductance

Q=$R_P/(\omega_0 L)$

R_P=10*10n*10G =1000=1K

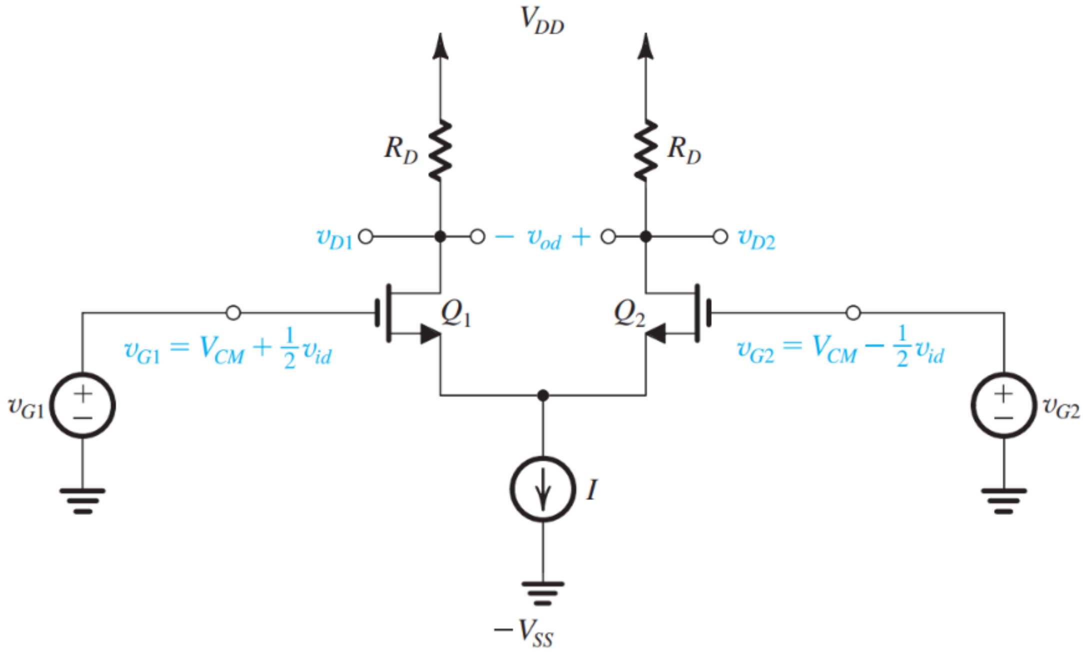
at ω_0 , the gains A1=A2=-g_m (Rp||r_o)

from barkhausen's criterion for sustained oscillations , |A1*A2|=1

$$A_1^2 = 1$$
$$-g_m(R_p||r_o) = -1$$
$$g_m(R_p||r_o) = 1$$
$$\boldsymbol{g_m = 1.1\ mA/V}$$

Q4.

Design a MOS differential amplifier to operate from a 2V supply and dissipate no more than 1 mW in its equilibrium state. Select the value of V_{ov} so that the value of V_{id} that steers the current from one side of the pair to the other is 0.25 V. The differential voltage gain A_d is to be 10 V/V. Assume k_n = 400 μA/V^2 and neglect the Early effect. Specify the required values of I, RD, and W/L.



The power consumed by the circuit = 2*IW <1mW => **I < 0.5mA**

Given value of Vid that steers the current from one side to other is 0.25V this means for Vid of 0.25 v one branch carries 0 current while other carries all the current of the current source

Assume initial overdrive voltage = Vov1 , now a differential input of 0.25V is applied then , on positive side , V_{ovQ1}= Vov1+0.125
on the negative side V_{ovQ2}= Vov1-0.125

The negative branch has no current flowing through it so **Vov1= 0.125V**

Id= I /2 < 0.25mA

$$\frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_{1,2} V_{ov1}^2 < 0.25\text{mA}$$
$$\boldsymbol{\left(\frac{W}{L}\right)_{1,2} < 80}$$

Also, given Ad= 10v/v => $g_m R_D$=10
$g_m R_D = 2I_D R_D$ /Vov1= I *R_D/Vov1=10
I=10*Vov1/R_D < 0.5mA
10*0.125/0.5<R_D
R_D>2.5K ohm