Department of EEE, BITS PILANI K. K. BIRLA GOA CAMPUS

Mid-Semester Question Paper – Analog IC Design (MEL G 632)

Date: 18-03-2023 | **Time: 11:00 hours to 12:30 hours**

Duration: 90 minutes | **Closed Book** | **Full-Marks: 25**

Attempt All Questions. Please use the Table given at the end to select appropriate values wherever they are not given in the question.

1. **(a) Assume that V_{DD} varies from 4V to 6V and V_{SS} = 0 in Fig. 1(a). Assume due to process variation, $k'_{n/p}$, V_{thn} and | V_{thp}| also vary and can be estimated by k'_n =110±10%, k'_p =50+10%, V_{thn}=| V_{thp}|=(0.7±0.15) V. If I_{SS} = 100 μA, $\left(\frac{W}{L}\right)_{1,2} = 5$, $\left(\frac{W}{L}\right)_{3,4} = 1$ and drop across $V_{DS\text{-}M5}$ = 0.2 V. Include worst case variation to calculate input common-mode range. Ignore L-diffusion, body effect and channel lengh modulation.**

   (b) In the Fig. 1(b), what is the value of I_1, I_2 and I_3? Given λ = $0.1V^{-1}$, threshold voltage = 0.5 V and overdrive = 0.2 V for all the devices, while V_{DD} = 1.8 V. Further V_x = 0.3V and I_0 = 1 mA. All the devices have same channel length. Assume λV_{DS} <<1 for all the devices and neglect 2nd and higher order terms of λ.

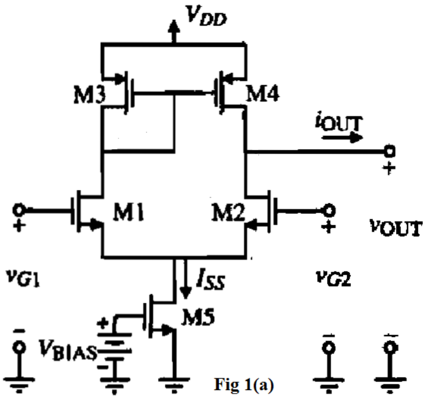

Fig 1(a)

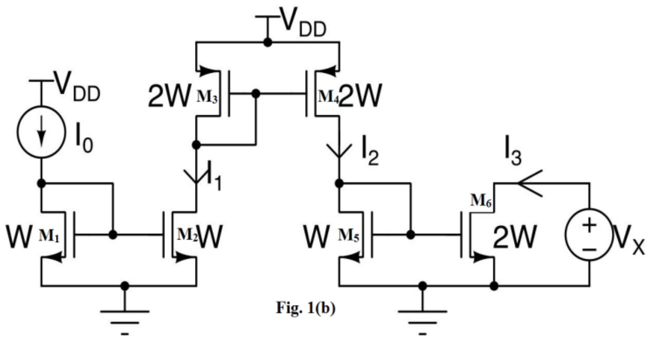

Fig. 1(b)

4(=1+1+2)+3×2 = 10-marks

2. **Design the circuit of Fig. 2 for a voltage gain of |20| and a power budget of 1 mW with V_{DD} = 1.8 V. Assume M_1 operates at the edge of saturation if the input common-mode level is 1 V. Also, $\mu_n C_{ox} = 2\mu_p C_{ox}$ = 100 μA/V², V_{THn} = 0.5 V, V_{THp} = -0:4 V, $\lambda_p = 2\lambda_n = 0.1V^{-1}$. Take L_{geo} = 1μm (neglect L-diffusion).**

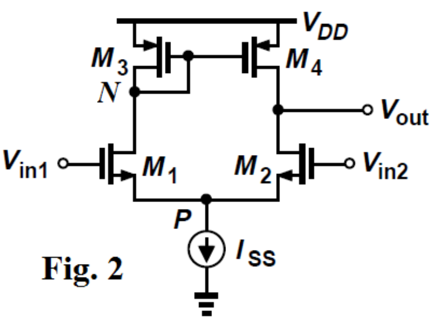

Fig. 2

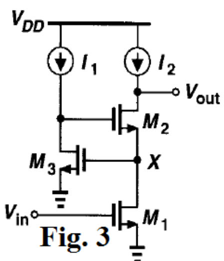

Fig. 3

3+3= 6-marks

3. **If I_1 = 1mA, I_2 = 750 µA, $2 \times \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_{1,2} = \frac{5\mu m}{0.5\mu m}$ in Fig. 3, find R_{out} and voltage gain without using any approximation. Consider channel length modulation, L-diffusion and assume $g_{mb} = 0.1g_m$.**

3+2= 5-marks

4. **Find RMS noise voltage of a *1/f* noise source with $\overline{V}_n(f)^2 = (50\ nV)^2/f$, over the range of frequency from 1 *hz* to 100 *Mhz*. What is the RMS noise voltage if the lower limit of the frequency is reduced to 10 *nHz*? Give your answer in μV in both cases.**

2+2= 4-marks

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[i] **Table of Values**

Parameters	V_{Th}(V)	$\gamma\ (\sqrt{V})$	ϕ_f(V)	L_D (m)	λ(V^{-1}) for L_{Geo}=0.5µm	$k'_{n/p} = \mu_{n/p}C_{OX}$(A/V^2)
NMOS	0.7	0.5	0.9	0.08×10^{-6}	0.1	134.26×10^{-6}
PMOS	-0.8	0.4	0.8	0.09×10^{-6}	0.2	38.36×10^{-6}
Common	$n_i = 1.45 \times 10^{10} cm^{-3}$, q= $1.6\times 10^{-19} C$; $k = 1.38\times 10^{-23} \frac{J}{K}$; V_{DD}= V_{Ck}= 3.0V; V_{SS}= 0 V; β_{NPN}=150, β_{PNP}=100, Room Temperature= 27^0C; ε_{Si}=11.68; ε_{SiO_2}=3.6; ε_0= $8.85 \times 10^{-12} \frac{F}{m}$; $C_{GDO_{NMOS}} = 0.4 \times 10^{-9} \frac{F}{m}$; C_{ox}=6.9 $fF/\mu m^2$ for t_{ox}= 50$\dot{A}$					

Table of Equations (*You might have seen in a distant galaxy....)*

1.	$I_D = \frac{1}{2}\mu_{n/p}C_{OX}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2$; $I_D = \frac{1}{2}\mu_{n/p}C_{OX}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2(1+\lambda V_{DS})$ when channel length is included
2.	$\phi_0 = \frac{kT}{q} ln\left(\frac{N_D N_A}{{n_i}^2}\right)$
3.	$Q_{B0} = -\left(1 - \frac{\Delta L_S + \Delta L_D}{2L}\right)\sqrt{2q\epsilon_{Si}N_A\lvert 2\Phi_F\rvert}$
4.	$C_{j0} = \sqrt{\frac{q\epsilon_{Si}}{2}\left(\frac{N_D N_A}{N_D+N_A}\right)\frac{1}{\Phi_0}}$
5.	$\Delta V_{T0} = \frac{1}{C_{ox}}\sqrt{2q\xi_{Si}N_A\lvert 2\Phi_F\rvert}.\frac{x_j}{2L}.\left[\left(\sqrt{1+\frac{2x_{dS}}{x_j}}-1\right)+\left(\sqrt{1+\frac{2x_{dD}}{x_j}}-1\right)\right]$
6.	$x_d = \sqrt{\frac{q\epsilon_{Si}}{2}\left(\frac{N_D N_A}{N_D+N_A}\right)(\Phi_0 - V)}$