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EXAMINATION IN
-
TSEK37/TEN1
ANALOG CMOS INTEGRATED CIRCUITS

Date:	2012-04-13
Time:	14-18
Location:	TER2
Aids:	Calculator, Dictionary
Teachers:	Behzad Mesgarzadeh (5719)
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8 points are required to pass.

Please start each new problem at the top of a page!
Only use one side of each paper!

1) A current mirror circuit is shown in Fig. 1. If properly sized, this circuit can realize accurate mirroring with a high output impedance while consuming low voltage headroom.

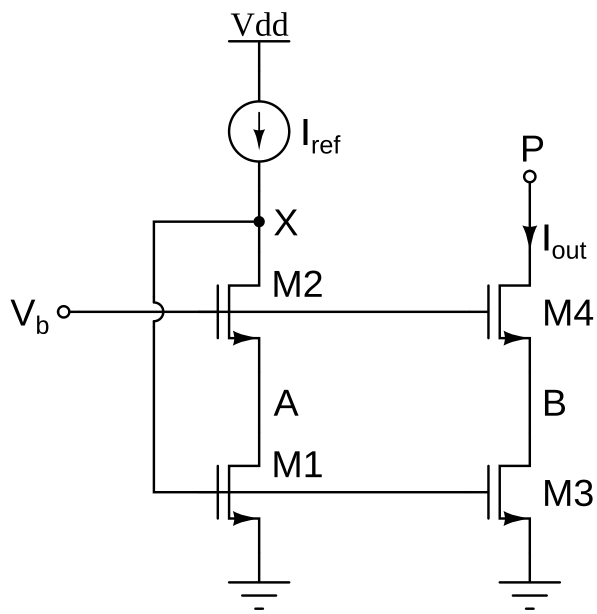

Fig. 1. Current mirror.

(a) Derive the bounds on V_b such that M_1 and M_2 are in the saturation region. Determine the restriction on the sizing of M_2 for this to be possible. Give the answers in terms of V_{GS1}, V_{GS2}, V_{TH1} and V_{TH2}. (2 p)

(b) Using the lowest value of V_b from (a), determine the minimum allowable voltage at node P to keep M_3 and M_4 in saturation. Assume that M_3=M_1 and that the transistors are sized such that V_{GS4}=V_{GS2}. Give the answer in terms of V_{GS3}, V_{GS4}, V_{TH3} and V_{TH4}. (1 p)

2) An amplifier with a DC gain of A_0 and poles at 1 MHz and 450 MHz is connected in a feedback loop with a gain of 4 (i.e. the feedback factor (β) is 1/4). Compute the value of A_0 such that the phase margin is 60°. (2 p)

Hint: $\arctan u + \arctan v = \arctan\left(\frac{u+v}{1-uv}\right)$ **(**mod π), $uv \neq 1$

3) A fully differential current-mirror amplifier is shown in Fig. 2. The bias current of the device M_4 is mirrored B times to the output stage, i.e. $I_{D4} = B \times I_{D2}$. A local positive feedback composed of transistors M_3 and M_{3b} is used to enhance the DC gain.

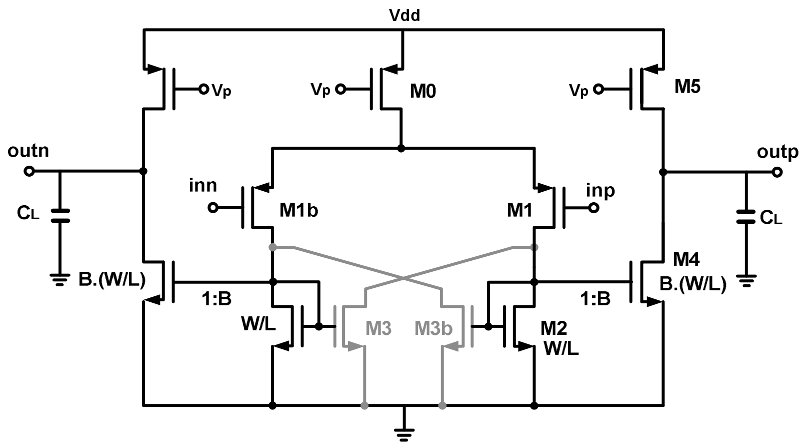

Fig. 2. Current mirror amplifier.

(a) Disregard the positive feedback containing M_3-M_{3b} devices and draw the small-signal model. Determine the DC gain in terms of the transconductance g_m, the conductance g_{ds}, and the mirroring ratio B. Assume that $\gamma = 0$. (2 p)

(b) Consider the positive feedback and derive the DC gain expression. How can the DC gain be enhanced by sizing of the transistors M_3 and M_{3b}? (2 p)

(c) Consider the current-mirror amplifier as a two-pole system and that it is frequency compensated by the load capacitor C_L, rather than miller capacitor. Also, assume that the second pole (non-dominate) occurs in the gate of the transistors M_2, M_{3b}, and M_4. Derive the approximate expressions for the two poles. (1 p)

4) A lossless interconnect is shown in Fig. 3. At time 0, the voltage step of V_0 drives a transmission line that is splitted into different sections, each driving an inverter with a high impedance input. With the impedance given below, calculate the voltage at A, B and C at the time instant 7.5 ns.

R_0 =75 Ω, Z_0 =75 Ω, Z_1 =150 Ω, and Z_2 =50. (4 p)

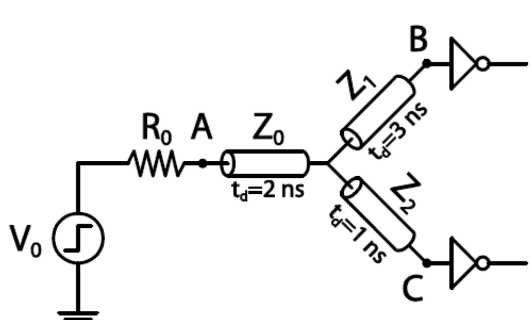

Fig. 3. A transmition-line circuit.

5) Assume that the output of a voltage-controlled oscillator (VCO) is a sinusoidal as it is shown in Fig. 4. In this figure, ω_0 is the output frequency when V_{cont}=0, K_{VCO} is the gain of the VCO, and V_{cont} is the control voltage of the VCO. Now Assume that we apply a small sinusoidal control voltage to this VCO (i.e., $V_{cont} = V_m \cos(\omega_m t)$). If V_m is small enough to satisfy $K_{VCO}V_m << \omega_m$ and $\omega_m < \omega_0$, draw the output spectrum of the VCO. Motivate your answer by presenting the details of your calculations. We can assume that the VCO characteristic is linear. (4 p)

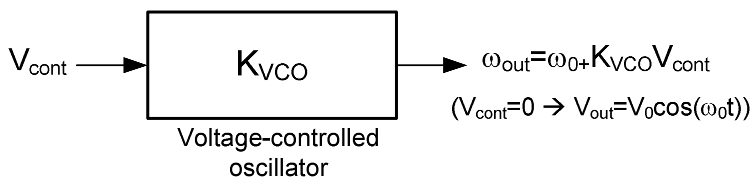

Fig. 4. A voltage-controlled oscillator.

6) A PLL type I with $\zeta = 0.1$ is utilized to generate a 200-MHz carrier frequency. If $\omega_{LPF} = 2\pi \times 28.6\ KHz$ and the output is to be changed from 201 MHz to 201.5 MHz, how long does it take in the worst-case for the PLL to settle within 100 Hz of its final value? (2 p)

Hint: The step response of a PLL type I with underdamped response is as:

$$\omega_{out}(t) = \left\{1 - \frac{1}{\sqrt{1-\zeta^2}} \cdot e^{-\zeta\omega_n t} \sin\left(\omega_n \sqrt{1-\zeta^2} t + \theta\right)\right\} \Delta\omega u(t)$$

where

$$2\zeta\omega_n = \omega_{LPF}$$

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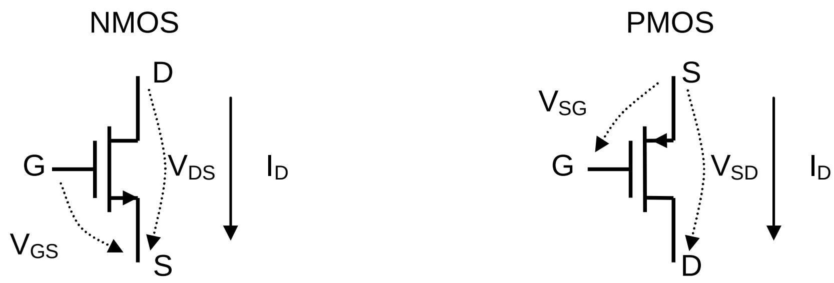
TRANSISTOR EQUATIONS



NMOS

- **Cutoff:** $I_D = 0$ $(V_{GS} < V_{TN})$
- **Linear mode:**

$$I_D = \mu_n C_{ox} \frac{W}{L}\left((V_{GS} - V_{TN})V_{DS} - \frac{V_{DS}^2}{2}\right)$$ $(V_{GS} > V_{TN})$ and $(V_{DS} < V_{GS} - V_{TN})$

- **Saturation mode:**

$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TN})^2(1 + \lambda V_{DS})$$ $(V_{GS} > V_{TN})$ and $(V_{DS} > V_{GS} - V_{TN})$

PMOS

- **Cutoff:** $I_D = 0$ $(V_{GS} < |V_{TP}|)$
- **Linear mode:**

$$I_D = \mu_p C_{ox} \frac{W}{L}\left((V_{SG} - |V_{TP}|)V_{SD} - \frac{V_{SD}^2}{2}\right)$$ $(V_{GS} > |V_{TP}|)$ and $(V_{SD} < V_{SG} - |V_{TP}|)$

- **Saturation mode:**

$$I_D = \frac{1}{2}\mu_p C_{ox} \frac{W}{L}(V_{SG} - |V_{TP}|)^2(1 + \lambda V_{SD})$$ $(V_{GS} > |V_{TP}|)$ and $(V_{SD} > V_{SG} - |V_{TP}|)$

TRANSMISSION LINE EQUATIONS

- Complex characteristic impedance

$$Z_c = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

- Inductance voltage-current relation:

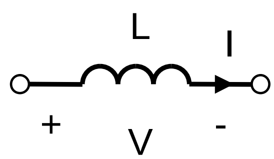
$$V = L\frac{dI}{dt}$$

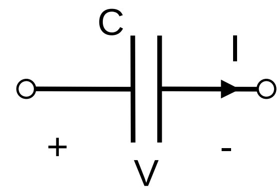
- Characteristic impedance for lossless TL:

$$Z_0 = \sqrt{\frac{L}{C}}$$

- Capacitance voltage-current relation:

$$I = C\frac{dV}{dt}$$



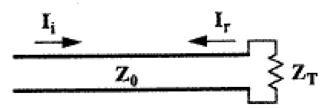


- Mutual inductance:

$$V_{mn} = L_{mn}\frac{dI_n}{dt} \quad \text{where } m \neq n$$

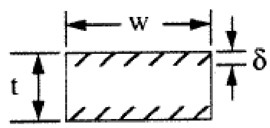
Telegrapher's Equation

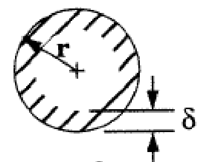
Reflection Coefficient $k_r = \frac{V_r}{V_i} = \frac{I_r}{I_i} = \frac{Z_T - Z_0}{Z_T + Z_0}$



Skin Effect

Skin Depth $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$



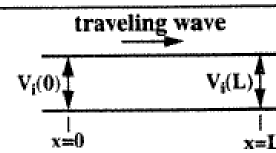


Skin Depth Frequency $f_s = \frac{\rho}{\pi\mu(t/2)^2}$ $\qquad f_s = \frac{\rho}{\pi\mu r^2}$

Skin Depth Resistance $R(f) = \frac{\sqrt{\pi f \mu \rho}}{2w} = R_{DC}\left(\frac{f}{f_s}\right)^{1/2}$ $\qquad R(f) = \frac{\sqrt{f\mu\rho/\pi}}{2r} = \frac{R_{DC}}{2}\left(\frac{f}{f_s}\right)^{1/2}$

Attenuation in Lossy Line

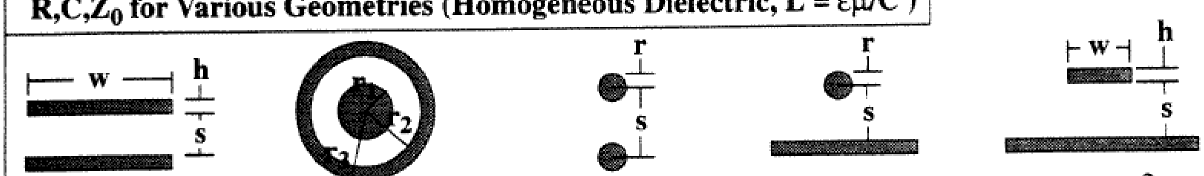
Attenuation $\frac{V_i(L)}{V_i(0)} = \exp[-(\alpha_R + \alpha_D)L] = \exp\left[-\left(\frac{R}{2Z_0} + \frac{GZ_0}{2}\right)L\right]$



Conductor Loss $\alpha_R(f) = \frac{R_{DC}}{4Z_0}\left(\frac{f}{f_s}\right)^{1/2}$ **(Round)** $\qquad \alpha_R(f) = \frac{R_{DC}}{2Z_0}\left(\frac{f}{f_s}\right)^{1/2}$ **(Strip)**

Dielectric Loss (Homogeneous) $\alpha_D(f) = \frac{\pi\sqrt{\varepsilon_r}\tan\delta}{c}f$ $\qquad$ **Dielectric Loss Tangent** $\tan\delta = \frac{G}{\omega C} = \frac{\sigma_{Diel}}{\omega\varepsilon_r}$

R,C,Z_0 for Various Geometries (Homogeneous Dielectric, L = εμ/C)



$R_{DC} = 2\frac{\rho}{wh}$	$R_{DC} = \frac{\rho}{\pi r_1^2} + \frac{\rho}{\pi(r_3^2 - r_2^2)}$	$R_{DC} = \frac{2\rho}{\pi r^2}$	$R_{DC} = \frac{\rho}{\pi r^2}$	$R_{DC} = \frac{\rho}{wh}$
$C = \frac{\varepsilon w}{s}$	$C = \frac{2\pi\varepsilon}{\log(r_2/r_1)}$	$C = \frac{\pi\varepsilon}{\log(s/r)}$	$C = \frac{\pi\varepsilon}{\log(2s/r)}$	$C \approx \frac{\varepsilon w}{s} + \frac{2\pi\varepsilon}{\log(s/w)}$
$Z_0 = \sqrt{\frac{\mu}{\varepsilon}}\frac{s}{W}$	$Z_0 = \sqrt{\frac{\mu}{\varepsilon}}\frac{\log(r_2/r_1)}{2\pi}$	$Z_0 = \sqrt{\frac{\mu}{\varepsilon}}\frac{\log(s/r)}{\pi}$	$Z_0 = \sqrt{\frac{\mu}{\varepsilon}}\frac{\log(2s/r)}{\pi}$	$Z_0 = \frac{\sqrt{\varepsilon\mu}}{C}$