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EXAMINATION IN
-
TSEK37/TEN1
ANALOG CMOS INTEGRATED CIRCUITS

Date:	2013-03-27
Time:	8-12
Location:	U7-U10
Aids:	Calculator, Dictionary
Teachers:	Behzad Mesgarzadeh (5719)
	Daniel Svärd (8946)

8 points are required to pass.

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

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1) Figure 1 shows a differential amplifier. The amplifier is completely symmetric, i.e. M_1=M_2, M_3=M_4 and M_5=M_6. Assume $\lambda \neq 0$ and $\gamma = 0$.

(a) Draw the low-frequency small-signal model of the circuit. (1 p)

(b) Derive an expression for the DC gain. (1 p)

(c) What kind of circuit element do M_5 and M_6 realize? (1 p)

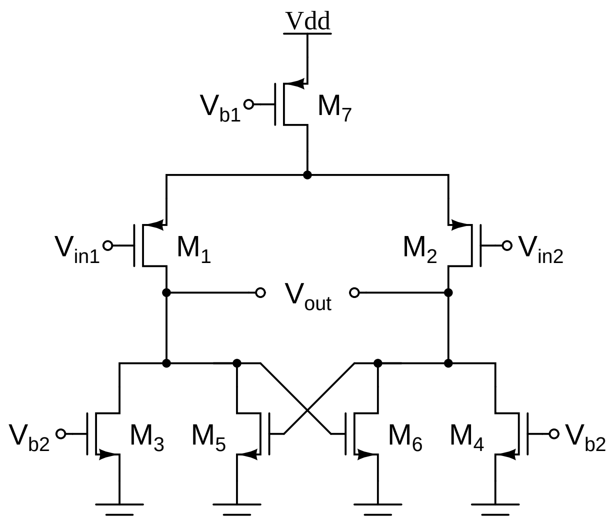

Fig. 1. Differential amplifier.

2) A cascode current mirror is shown in Fig. 2. If V_Y=1 V, determine V_b to have a perfect mirror (I_{out}=I_{ref}). Assume that all transistors are long channel transistors. (3 p)

$\mu_n C_{ox} = 250\ \mu A/V^2$
$\lambda_n = 0.1\ V^{-1}$
$\gamma_n = 0$
$V_{t0n} = 0.5$ V
$V_{dd} = 2$ V

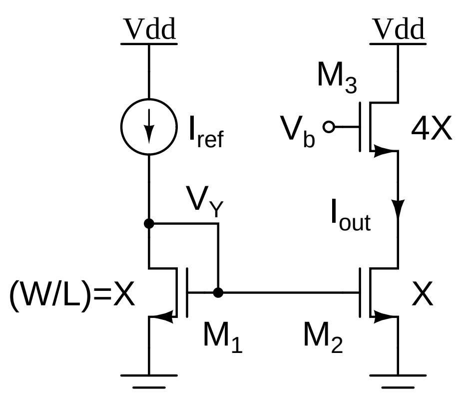

Fig. 2. Cascode current mirror.

3) Transimpedance amplifiers are commonly used in optical receiver circuits. This type of amplifier converts an input current, i_{in}, into a voltage, v_{out}. Figure 3 shows an example circuit implementation of such an amplifier. For all subproblems, neglect all capacitances except C_X and C_L; and assume $\lambda \neq 0$ and $\gamma \neq 0$.

(a) Draw the small-signal model of the amplifier. (1 p)

(b) Derive an expression for the transfer function, $R(s) = v_{out}/i_{in}$, of the amplifier. Identify the DC transimpedance and the two poles. (2 p)

(c) Calculate the DC transimpedance and the location of the poles given the bias conditions in Fig. 3. (2 p)

$\mu_n C_{ox} = 160\ \mu A/V^2$
$L = 0.35\ \mu m$
$W_1 = W_2 = 35\ \mu m$
$\lambda_n = 0.1\ V^{-1}$
$\gamma_n = 0.4\ V^{1/2}$
$V_{t0n} = 0.5\ V$
$2\Phi_F = 0.9\ V$
$V_{dd} = 3.3\ V$

$I_1 = 500\ \mu A$
$I_2 = 2\ mA$
$R_{D1} = 2\ k\Omega$
$R_{D2} = 500\ \Omega$
$R_S = 2\ k\Omega$
$C_X = 0.25\ pF$
$C_L = 2\ pF$

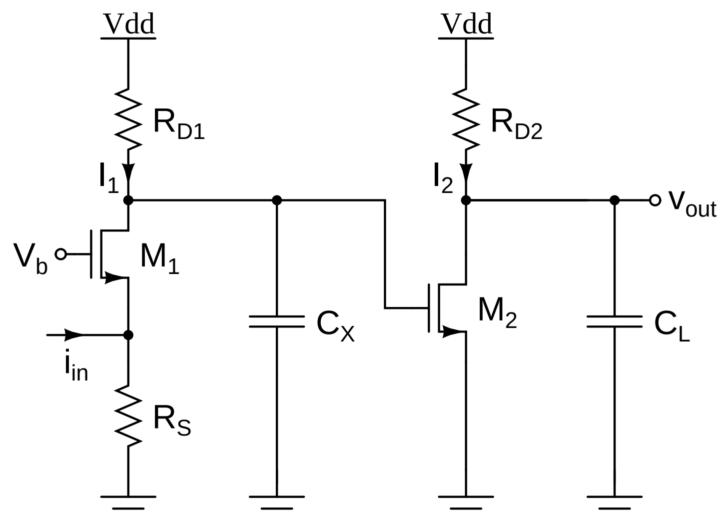

Fig. 3. Transimpedance amplifier.

4) Estimate the propagation delay of a 2-mm wire with a high-frequency characteristic impedance of 50 Ω and resistance per length of r=5 KΩ/m and dielectric constant ε_r=4. (3 p)

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5) A 3-stage ring oscillator is shown in Fig. 4. Assume that all of the transistors are identical and ignore their parasitics. Calculate the phase margin of this circuit. Assume R= 3.5 KΩ, C=1 pF, g_m=1 mA/V, and r_o= 10 KΩ. (4 p)

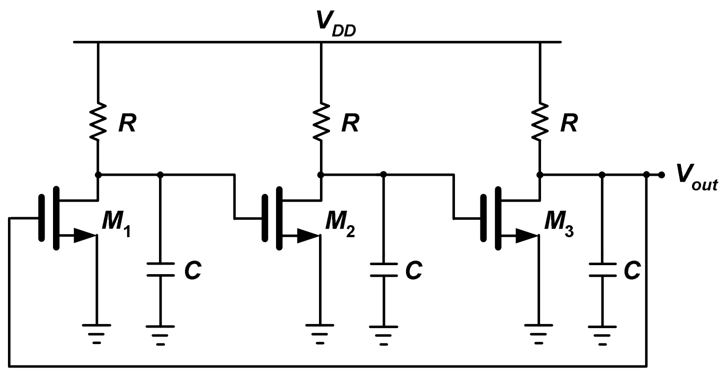

Fig. 4. A three-stage ring oscillator.

6) Assume you have access to the following components:

- An *ideal* Phase-Detector (PD), shown in Fig. 5(a).
- Many *ideal* Voltage-Controlled Delay elements (VCD), such as the one shown in Fig. 5(b).

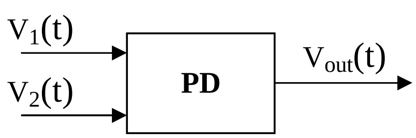

Fig. 5(a)

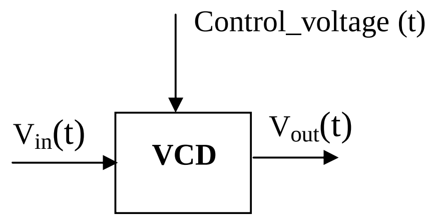

Fig. 5(b)

Use the abovementioned components and design a clock phase generator (Fig. 5(c)) which receives a periodic clock signal (Clk_{in}) with an arbitrary frequency, and generates a clock signal (Clk_{out}) with the same frequency but with 90 degree phase shift.

(2 p)

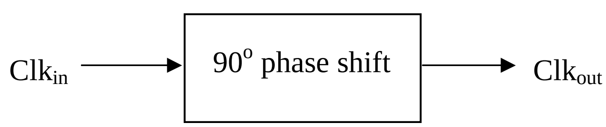

Fig. 5(c)

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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

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

- Characteristic impedance for lossless TL:

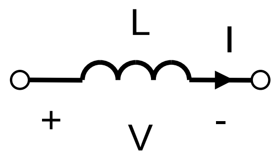
$$Z_0 = \sqrt{\frac{L}{C}}$$

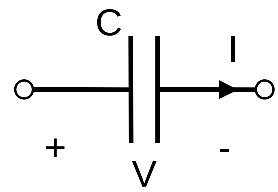
- Inductance voltage-current relation:

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

- Capacitance voltage-current relation:

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



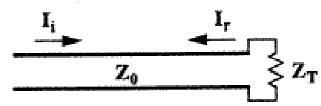


- Mutual inductance:

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

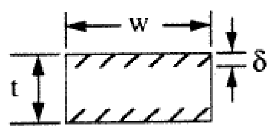
Telegrapher's Equation

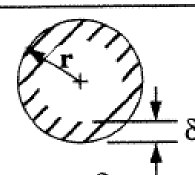
Reflection Coefficient $\quad k_r = \frac{V_r}{V_i} = \frac{I_r}{I_i} = \frac{Z_T - Z_0}{Z_T + Z_0}$



Skin Effect

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

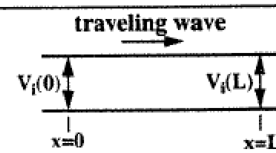




Skin Depth Frequency $\quad f_s = \frac{\rho}{\pi\mu(t/2)^2} \qquad f_s = \frac{\rho}{\pi\mu r^2}$

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

Attenuation in Lossy Line



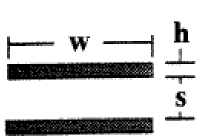
Attenuation $\quad \frac{V_i(L)}{V_i(0)} = \exp[-(\alpha_R + \alpha_D)L] = \exp\left[-\left(\frac{R}{2Z_0} + \frac{GZ_0}{2}\right)L\right]$

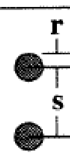
Conductor Loss $\quad \alpha_R(f) = \frac{R_{DC}}{4Z_0}\left(\frac{f}{f_s}\right)^{1/2}$ **(Round)** $\qquad \alpha_R(f) = \frac{R_{DC}}{2Z_0}\left(\frac{f}{f_s}\right)^{1/2}$ **(Strip)**

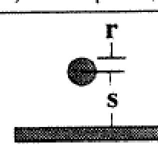
Dielectric Loss (Homogeneous) $\quad \alpha_D(f) = \frac{\pi\sqrt{\varepsilon_r}\tan\delta}{c}f$

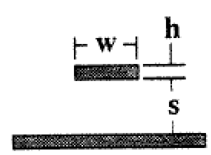
Dielectric Loss Tangent $\quad \tan\delta = \frac{G}{\omega C} = \frac{\sigma_{Diel}}{\omega\varepsilon_r}$

R, C, Z_0 for Various Geometries (Homogeneous Dielectric, $L = \varepsilon\mu/C$)









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