Solutions exercise 7 (mixers)

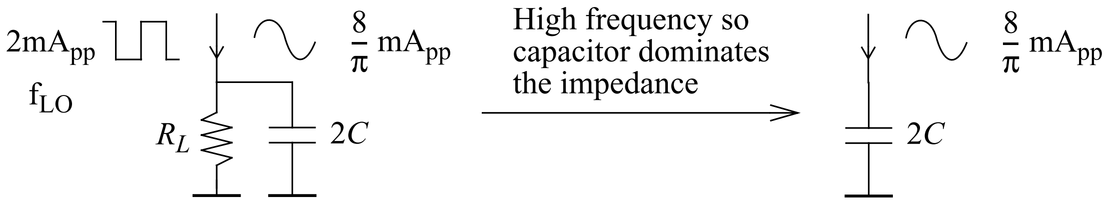
1. Problem 5 from exam 01-03-06

a.

$$2\text{V}_{pp}\ \text{out} \Rightarrow V_{R_L} = 1\ \text{V} \Rightarrow R_L = \frac{1\ \text{V}}{1\ \text{mA}} = 1\ \text{k}\Omega$$

$$G_c = g_m \cdot \frac{2}{\pi} \cdot R_L = 20\ \text{dB} = 10 \Rightarrow g_m = 16\ \text{mS}$$

LO leakage to IF:



$$V_{LOatIF} = \frac{8}{\pi} \cdot 10^{-3} \cdot \frac{1}{2\pi \cdot 2.4 \cdot 10^{9} \cdot 2C} \le 10 \cdot 10^{-3}\ \text{V} \Rightarrow C \ge 8.4\ \text{pF}$$

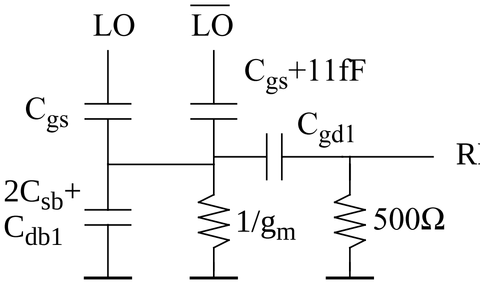
$$BW = \frac{1}{2\pi \cdot R_L \cdot 2C} = 9.5\ \text{MHz} > 8\ \text{MHz} \Rightarrow \text{OK}$$

Furthermore: $C_{gds,switch} < \frac{V_{LOatIF}}{V_{LO}} \cdot 2C = 170\ \text{fF}$ to keep LO to IF leakage within bounds

$$g_m = \frac{2I_d}{V_{od}} \Rightarrow V_{od} = \frac{2I_d}{g_m} = \frac{4\ \text{mA}}{16\ \text{mS}} = 0.25\ \text{V} \qquad V_{G1} = V_T + V_{od} = 0.77\ \text{V}$$

$$I_d = \frac{1}{2} \cdot \mu C_{ox} \cdot \frac{W}{L} \cdot V_{od}^2 \Rightarrow W = L \cdot \frac{2I_d}{\mu C_{ox} V_{od}^2} = 230\mu\text{m}$$

b. $I_{d,sw} = 1\ \text{mA}$ $\qquad W_{sw} = L \cdot \frac{2I_d}{\mu C_{ox} V_{od}^2} = 180\mu\text{m}$ $\qquad C_{gs,sw} = \frac{2}{3} \cdot WLC_{ox} = 0.22\ \text{pF}$

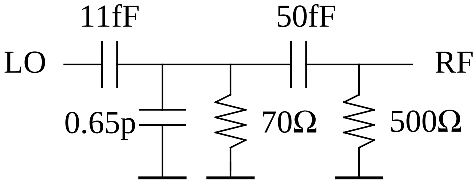


$$C_{sb} \approx 0.93 \cdot \frac{W}{2} \cdot 0.7\ \text{fF} = 60\ \text{fF}$$

$$2C_{sb} + C_{db} \approx 0.2\ \text{pF}$$

$$C_{gd1} = 0.21 \cdot W\ \text{fF} = 50\ \text{fF}$$

$$g_m = \frac{2 \cdot 2I_d}{V_{od,max}} = \frac{4\ \text{mA}}{0.2 \cdot \sqrt{2}} = 14\ \text{mS} = \frac{1}{70\Omega}$$



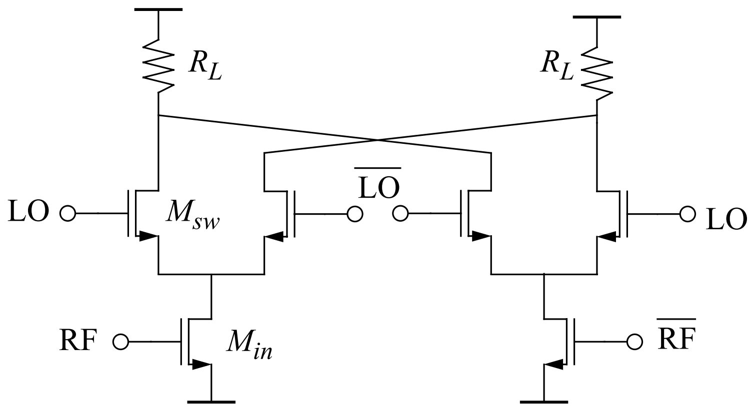
$$Z_1 = \left|\frac{1}{j\omega \cdot 11\ \text{fF}}\right| \approx 6\ \text{k}\Omega$$

$$Z_2 = 0.65\ \text{pF} \parallel 70\Omega \approx 60\Omega$$

$$Z_3 = \frac{1}{j\omega \cdot 50\ \text{fF}} \approx -j1.3\ \text{k}\Omega$$

$$V_{LO} = 1\text{V}_{pp} \Rightarrow V_{RF} \approx V_{LO} \cdot \frac{Z_2}{Z_1 + Z_2} \cdot \left|\frac{500}{500 + Z_3}\right| = 4\ \text{mV}_{pp}$$

2. Design problem double-balanced mixer



$$A_{cv} = \frac{2}{\pi} \cdot g_{m,in} R_L \Rightarrow g_{m,in} = \frac{A_{cv}}{R_L} \cdot \frac{\pi}{2} = \frac{5}{1000} \cdot \frac{\pi}{2} = 7.9 \text{ mS}$$

400 mV_{pp} max input per side $\Rightarrow V_{od,in} \geq 200$ mV and max output = 2V_{pp} per side

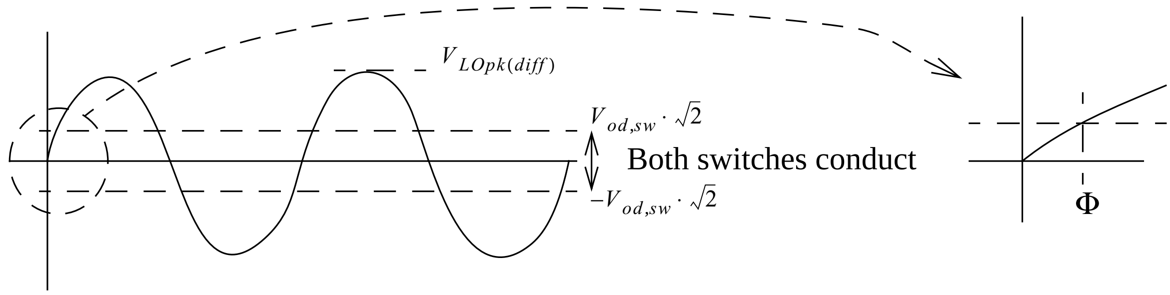
$$V_{R_L} \geq \frac{V_{out,max}}{2} = 1 \text{ V}$$

$$V_{dd} - V_{R_L} - \frac{V_{out,max}}{2} \geq 1 \text{ V (where switches enter triode)} \Rightarrow V_{R_L} \geq 1 \text{ V}$$

V_{R_L} must thus be chosen to 1V $\Rightarrow I_{R_L} = \frac{V_{R_L}}{R_L} = 1 \text{ mA} = I_{d,in}$

$$g_{m,in} = \frac{2I_{d,in}}{V_{od,in}} \Rightarrow V_{od,in} = \frac{2I_{d,in}}{g_{m,in}} = \frac{2 \text{ mA}}{7.9 \text{ mS}} = 0.25 \text{ V} \geq 200 \text{ mV} \Rightarrow \text{OK}$$

$$I_d = \frac{1}{2} \cdot \mu C_{ox} \cdot \frac{W}{L} \cdot V_{od}^2 \Rightarrow \left(\frac{W}{L}\right)_{in} = \frac{2I_{d,\,in}}{\mu C_{ox} V_{od,\,in}^2} = 290 \qquad L = 0.4\mu\text{m} \Rightarrow W = 120 \ \mu\text{m}$$

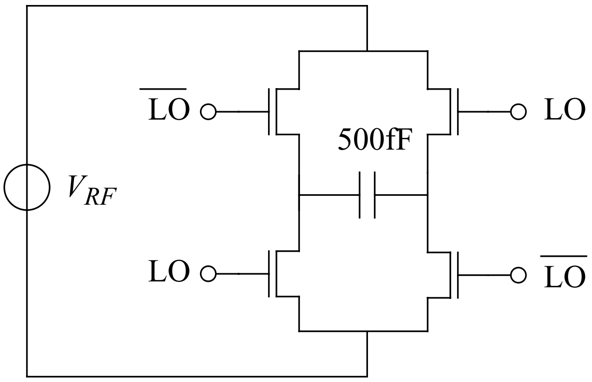


20% of the time $\Rightarrow \Phi = 90° \cdot 0.20 = 18°$ $\qquad$ $\sin\Phi = 0.31$

$$V_{LOpk(diff)} \cdot 0.31 = V_{od,sw} \cdot \sqrt{2} \Rightarrow V_{od,sw} = 0.22 \text{ V}$$

$$\left(\frac{W}{L}\right)_{sw} = \frac{2I_{d,\,sw}}{\mu C_{ox} V_{od,\,sw}^2} = 188 \Rightarrow W = 75\mu\text{m},\ L = 0.4\mu\text{m}$$

3. Design problem passive mixer



$f_{RF} = f_{LO} = 2.1$ GHz

$F < 10$ dB (related to 50Ω)

$BW > 20$ MHz

$V_{LO} = 2V_{pk}/\text{side}$ (very large)

$A_{cv} > -5$ dB

Assume the LO to be a square wave giving an overdrive of 1.5V at conduction at a 50% duty cycle to simplify the calculations.

50% duty cycle $\Rightarrow A_{cv} \approx \frac{2}{\pi} = -4$ dB

$$BW = \frac{1}{2\pi \cdot \frac{2}{g_{ds0}} \cdot C_L} > 20 \text{ MHz} \Rightarrow g_{ds0} > 0.125 \text{ mS} = \frac{1}{8\text{k}\Omega}$$

$$F \approx 1 + \frac{2r_{ds0}}{50\Omega} \cdot \frac{1}{A_{cv}} < 10 \Rightarrow r_{ds0} < 140\Omega < 8\text{k}\Omega \Rightarrow \text{The noise determines the dimensions}$$

$$g_{ds} = \mu C_{ox}\frac{W}{L}V_{od} \Rightarrow \frac{W}{L} = \frac{g_{ds}}{\mu C_{ox}V_{od}} = \frac{1}{140 \cdot 110 \cdot 10^{-6} \cdot 1.5} = 44$$

$$L = 0.4\mu\text{m} \Rightarrow W = 18\mu\text{m}$$

Problem 12.5 a

voltage division ↙

$$G_c = \frac{2}{\pi} \cdot \frac{R_s}{2R_s} = \frac{1}{\pi} = -10\text{dB}$$

Problem 12.6

a. $$\frac{G_c}{G_{c,\,ideal}} = \frac{R_s/(2R_s + R_{switch})}{R_s/(2R_s)} = \frac{2R_s}{2R_s + R_{switch}} > 10^{-\frac{1}{20}} = 0.89 \Rightarrow R_{switch} < 0.25 \cdot R_s$$

b. $$R_{switch} = \frac{1}{\mu C_{ox}\frac{W}{L}V_{od}} \Rightarrow W = L \cdot \frac{1}{\mu C_{ox}R_{switch}V_{od}} = L \cdot \frac{4}{\mu C_{ox}R_s V_{od}}$$

c. $$P = CV^2 f = 4WLC_{ox}V_{od}^2 f = 4\frac{4L}{\mu C_{ox}R_s V_{od}} \cdot LC_{ox}V_{od}^2 f = \frac{16L^2 V_{od} f}{\mu R_s}$$

The LO power can be reduced (by Q) by resonating the capacitances with coils.