Solutions exercise 6 (oscillators and phase-noise)

1. Colpitts oscillator

$$L(\Delta f) = 10 \cdot \log\left[\frac{2FkT}{P_{sig}} \cdot \left(\frac{f_0}{2Q\Delta f}\right)^2\right] = -140 \text{ dBc/Hz @ 3MHz } \Delta f \Rightarrow P_{sig} = 2.2 \text{ mW}$$

$$P_{sig} = \frac{V_o^2}{2R_p} = \frac{V_o^2}{2Q \cdot \omega_0 \cdot L} \Rightarrow L = \frac{V_o^2}{2Q \cdot \omega_0 \cdot P_{sig}} = \frac{1.5^2}{2 \cdot 10 \cdot 2\pi \cdot 1.8 \cdot 10^9 \cdot 2.2 \cdot 10^{-3}} = 4.4 \text{ nH}$$

$$R_p = Q \cdot \omega_0 \cdot L = 500\ \Omega$$

Choose n=0.2 for high performance (see footnote on page 497)

$$\text{eq. 16.24} \Rightarrow V_o \approx 2 \cdot I_{bias} \cdot R_p \cdot (1-n) \Rightarrow I_{bias} = 1.9 \text{ mA},\ \eta = \frac{2.2 \text{ mW}}{1.9 \text{ mA} \cdot 2 \text{ V}} = 58\ \%$$

$$A_{loop} = g_m R_p (n - n^2) = 3 \Rightarrow g_m = 38 \text{ mS}$$

$$g_m = \frac{2I_D}{V_{od}} \Rightarrow V_{od} = \frac{2I_D}{g_m} = 100 \text{ mV}$$

$$g_m = \mu C_{ox} \frac{W}{L} V_{od} \Rightarrow \frac{W}{L} = 3500 \Rightarrow L = 0.4\ \mu\text{m},\ W = 1400\ \mu\text{m}$$

$$\text{finger layout} \Rightarrow C_{db} = C_{sb} = \frac{1}{2} \cdot W \cdot L_{diffusion} \cdot C_{jn} = 700 \cdot 0.8 \cdot 0.93 \text{ fF} = 0.5 \text{ pF}$$

$$C_{gd} = W \cdot C_{gd0} = 0.3 \text{ pF} \qquad C_{gs} = \frac{2}{3} \cdot WLC_{ox} = 1.7 \text{ pF}$$

$$C_{tank} = \frac{1}{\omega_0^2 \cdot L} = 2.44 \text{ pF} = C_{db} + C_{dg} + C_1 \parallel (C_2 + C_{sb} + C_{gs}) = C_{db} + C_{dg} + C_x \Rightarrow C_x = 1.6 \text{ pF}$$

$$n = 0.2 \Rightarrow C_1 = (C_2 + C_{sb} + C_{gs})/4 \Rightarrow C_x = (C_2 + C_{sb} + C_{gs})/5 \Rightarrow C_2 + C_{sb} + C_{gs} = 8 \text{ pF}$$

$$\Rightarrow C_2 = 5.8 \text{ pF},\ C_1 = 2 \text{ pF}$$

(The output capacitance of the current source must be subtracted from C_2)

Comment: $A_{loop} = \frac{V_o \cdot n}{V_{od}}$ makes the required overdrive very low to guarantee start-up

The Q must therefore be high not to get too large devices and thereby too low a frequency.

2. Differential oscillator

$$L(\Delta f) = 10 \cdot \log\left[\frac{2FkT}{P_{sig}} \cdot \left(\frac{f_0}{2Q\Delta f}\right)^2\right] = -140 \text{ dBc/Hz @ 3MHz } \Delta f \Rightarrow P_{sig} = 2.2 \text{ mW}$$

two inductors ↘

$$P_{sig} = \frac{2 \cdot V_o^2}{2R_p} = \frac{V_o^2}{Q \cdot \omega_0 \cdot L} \Rightarrow L = \frac{V_o^2}{Q \cdot \omega_0 \cdot P_{sig}} = \frac{1.5^2}{10 \cdot 2\pi \cdot 1.8 \cdot 10^9 \cdot 2.2 \cdot 10^{-3}} = 8.8 \text{ nH}$$

$$R_p = Q \cdot \omega_0 \cdot L = 1 \text{ k}\Omega$$

$$V_o \approx \frac{2}{\pi} \cdot I_{bias} \cdot R_p \Rightarrow I_{bias} = 2.4 \text{ mA}, \ \eta = \frac{2.2 \text{ mW}}{2.4 \text{ mA} \cdot 2 \text{ V}} = 46\ \%$$

$$A_{loop} = g_m R_p > 3 \Rightarrow g_m > 3 \text{ mS}$$

$$A_{loop} = g_m R_p = \frac{2I_D}{V_{od}} \cdot R_p = \frac{I_{bias}}{V_{od}} \cdot R_p = \frac{\pi}{2} \cdot \frac{V_o}{V_{od}}$$

(compare $A_{loop} = \frac{V_o \cdot n}{V_{od}}$ for Colpitts)

$V_{od} < \frac{\pi}{2} \cdot \frac{V_o}{A_{loop}} = 780 \text{ mV}$ choose V_{od} smaller = 0.25 V for fast switching => A_{loop}=9.4

The startup loop-gain is of no concern here!

$$\frac{W}{L} = \frac{2I_D}{\mu C_{ox} V_{od}^2} = 350 \Rightarrow W = 140\ \mu\text{m}, \ L = 0.4\ \mu\text{m}$$

finger layout $\Rightarrow C_{db} = C_{sb} = \frac{1}{2} \cdot W \cdot L_{diffusion} \cdot C_{jn} = 50 \text{ fF}$

$C_{gd} = W \cdot C_{gd0} = 30 \text{ fF}$ $\qquad C_{gs} = \frac{2}{3} \cdot WLC_{ox} = 170 \text{ fF}$

$$C_{\tan k,\, side} = 1.22 \text{ pF} = C_{add} + C_{gs} + C_{db} + 4 \cdot C_{gd} = C_{add} = 0.88 \text{ pF}$$

One can either put the 0.88 pF / side as a fixed capacitance or a varactor

Conclusion: The Colpitts oscillator has a slightly larger efficiency η, but has more parasitics that limit the tuning range and operating frequency, and it does not give a differential signal that is often needed in integrated circuits.