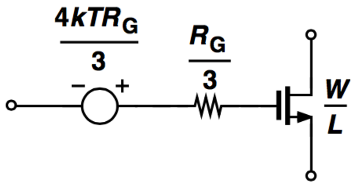
1.

(a). The problem is very similar to Noise Tutorial Problem 1, but here we shall not neglect the gate noise which can be modelled using an additional voltage source at the transistor's input (Razavi, Fig. 2.40c):



The solution without the gate source (check course page for the Tutorial 1, Problem 1 solution at page 3), which includes the two noise source from the transistor channel and load resistor is:

$$\overline{V_{n,in}^2} = \frac{\overline{V_{n,out}^2}}{A_v^2} = \frac{4kT}{g_m^2}(\gamma g_{d0} + \frac{1}{R_L})$$

Then we add the noise contribution from the gate resistance (which is at the input, so not divided by the gain) and get:

$$\overline{V_{n,in}^2} = \frac{4kT}{g_m^2}\left(\gamma g_{d0} + \frac{1}{R_L}\right) + 4kT\frac{R_G}{3}$$

(b). The flicker noise can either be modelled by a current source parallel to the channel noise source, or transferred to a voltage source at the gate input (in series with the gate resistance noise source). The net effect is the same, of course, and the result input-referred noise becomes:

$$\overline{V_{n,in}^2} = \frac{4kT}{g_m^2}\left(\gamma g_{d0} + \frac{1}{R_L}\right) + 4kT\frac{R_G}{3} + \frac{K}{WLC_{ox}}\frac{1}{f}$$

(c). The *corner frequency* is the frequency where the 1/f noise intercepts the thermal noise. Equation (2.98) and Figure 2.43 in the in Razavi course book.

2.

a. See LNA Tutorial Problem 2, pp. 5-6:

$$Z_{in} = \frac{V_{in}}{i_{in}} = j\omega(L_g + L_s) + \frac{1}{j\omega C_{gs}} + \frac{g_m L_s}{C_{gs}}$$

b. See LNA Tutorial Problem 2, p. 6:

For input matching purpose, the imaginary part of (3) should be zero, which means that $L_g + L_s$, should be canceled out by C_{gs}. Therefore, at frequency of interest, we have:

$$\omega_o(L_g + L_s) = \frac{1}{\omega_o C_{gs}} \Rightarrow \omega_o^2 = \frac{1}{(L_g + L_s)C_{gs}}$$

And $\frac{g_m L_s}{C_{gs}} = R_S = 50\Omega$

3.

See Mixer Tutorial Problem 1, p. 2:

Eq. (6.54) from the course book:

Writing the Fourier series for LO waveform having a duty cycle of *d*, the RF current entering each switch generates an IF current given by:

$$I_{IF}(t) = \frac{2}{\pi}\frac{\sin \pi d}{2d} I_{RF0} \cos \omega_{IF} t$$

$$V_{IF}(t)\Big|_{Differential} = \frac{2}{\pi}\frac{\sin \pi d}{2d} I_{RF0} \cos \omega_{IF} t \times 2 \times Z_{BB}$$

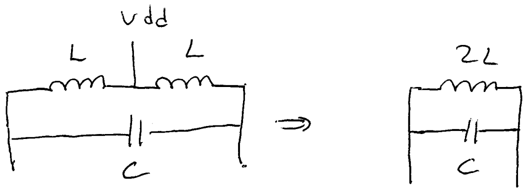
$$\text{voltage conversion gain} = G_c = \left|\frac{V_{IF}}{V_{RF}}\right| = \frac{\frac{2}{\pi}\frac{\sin \pi d}{2d} I_{RF0} \times 2 \times Z_{BB}}{I_{RF0} \times Z_{BB}} = \frac{2}{\pi}\frac{\sin \pi d}{2d} \times 2$$

$$\lim_{d \to 0} G_c = \lim_{d \to 0} \frac{2}{\pi}\frac{\sin \pi d}{2d} \times 2 = 2$$

$$20\log_{10}(2) = 6 \quad dB$$

4.

a. Equivalent circuits of the tank with no losses:



It has oscillation frequency:

$$\omega_{osc} = \frac{1}{\sqrt{2L_{tank}C_{tank}}}$$

For a center frequency of (960-925)/2 + 925 = 942.5 MHz, the following C is required:

$$C_{tank} = \frac{1}{2L_{tank}(2\pi f)^2}$$

Using L_{tank} = 1.25 nH, f = 942.5 MHz => C_{tank} = 11.4 pF

b. Tuning range = Cmax-Cmin:

$$\Delta\omega_{osc} \approx \frac{1}{\sqrt{LC}}\frac{C_{max} - C_{min}}{2C}$$

$$C_{tank} = \frac{1}{2L_{tank}(2\pi f)^2}$$

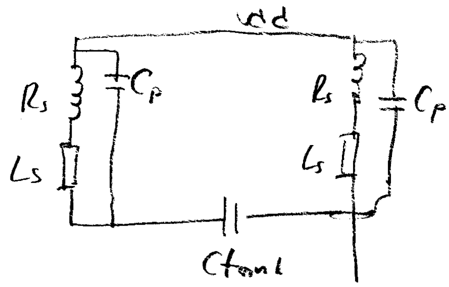
Using 925-960 MHz frequency interval, C = 11.4 pF and L = 2*L_{tank} = 2 * 1.25 nH =>

Cmax - Cmin = 0.83 pF or 7.3 % of C_{tank}.

This should pose no problem to achieve in CMOS technology (cf. Example 7.34).

(The problem is actually ”reversed”, i.e. it is so small that if using a single varactor, the voltage vs. capacitance sensitivity may be too high. The C_{tank} should therefore be realized with a fixed C and a variable C (e.g. in parallel) to achieve a robust solution.)

c. New tank:



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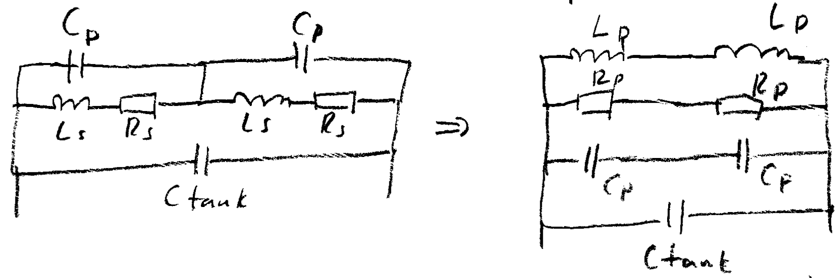

$$\text{Resonance} = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{L_p \cdot C_{tot}}} = \frac{1}{\sqrt{L_p \left(C_{tank} + C_p/2\right)}} = \omega$$

L_p, R_p ?

$$Q = \frac{\omega L_s}{R_s} = \begin{cases} f = 942.5\ MHz \\ \omega = 2\pi f \\ L_s = 1.25\ nH \\ R_s = 1\ \Omega \end{cases} \Rightarrow Q = 7.4$$

$$L_p = \left(1 + \frac{1}{Q^2}\right) \cdot L_s \Rightarrow L_p = 1.2728\ nH$$

$$R_p = (Q^2 + 1) \cdot R_s \Rightarrow R_p = 55.7952\ \Omega$$

New fosc = 932.6 MHz

M1/M2 circuit must provide $2R_p = 111.59\ \Omega$ of negative resistance

5.

a. closed-loop transfer function

$$F(s) = \frac{\frac{1}{sC_1}}{\frac{1}{sC_1} + R_1} = \frac{1}{sR_1C_1 + 1}$$

The close loop Transfer Function:

$$\varphi_{out} = \frac{K_{VCO}K_{PD}}{s}\left(\varphi_{in} - \frac{\varphi_{out}}{M}\right)\left(\frac{1}{sR_1C_1 + 1}\right)$$

$$\frac{\varphi_{out}}{\varphi_{in}}(s) = \frac{K_{VCO}K_{PD}M}{s(sR_1C_1 + 1)M + K_{VCO}K_{PD}}$$

$$= \frac{K_{VCO}K_{PD}M}{s^2R_1C_1M + sM + K_{VCO}K_{PD}} = \frac{\frac{K_{VCO}K_{PD}}{R_1C_1}}{s^2 + s\frac{1}{R_1C_1} + \frac{K_{VCO}K_{PD}}{R_1C_1M}} = \frac{\frac{K_{VCO}K_{PD}}{R_1C_1}}{s^2 + 2\xi\omega_n s + \omega_n^{\ 2}}$$

b. damping factor ζ

$$\xi = \frac{1}{2}\sqrt{\frac{\omega_{LPF}M}{K_{VCO}K_{PD}}}$$

c. natural frequency ω_n

$$\omega_n = \sqrt{\frac{K_{VCO}K_{PD}\omega_{LPF}}{M}}$$

d. loop bandwidth = $\zeta * \omega_n = 1/2 * \omega_{LPF} = 1 / (2RC)$.

6.

D C B A E