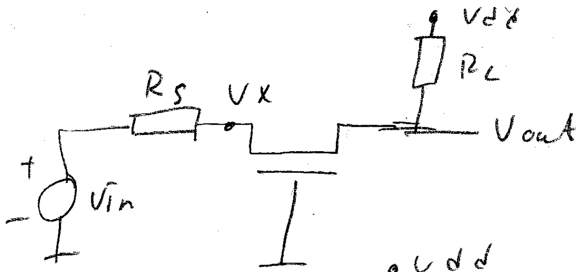
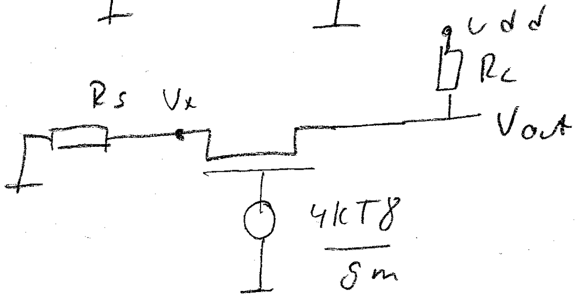
Solutions

1 a) Circuit:



For noise



i) Gain? $\frac{V_{out}}{V_x} = g_m \cdot R_L$

$$A_v = \frac{V_{out}}{V_{in}} = g_m \cdot R_L \left(\frac{\frac{1}{g_m}}{\frac{1}{g_m} + R_s} \right) = g_m \cdot R_L \left(\frac{1}{1 + g_m \cdot R_s} \right)$$

When used as an LNA, select $g_m = \frac{1}{R_s}$ ⇒

$$A_v = \frac{R_L}{2R_s}$$

ii) Noise from M1: $\overline{V^2_{n,out M1}} = \frac{4kT\gamma}{g_m} \cdot \left(\frac{R_L}{R_s + \frac{1}{g_m}} \right)^2 = kT\gamma \frac{R_L^2}{R_s}$

Noise from R_L = $\overline{V^2_{n,out,RL}} = 4kTR_L$

iii) NF: $1 + \frac{\overline{V^2_{n,out,M1}} + \overline{V^2_{n,out,RL}}}{A_v^2 \cdot \overline{V^2_{n,Rs}}} =$

1 a) cont.

$$= 1 + \frac{kT\gamma \frac{R_L^2}{R_s} + 4kTR_L}{\left(\frac{R_L}{2R_s}\right)^2 \cdot 4kTR_s} = 1 + \frac{}{kT\frac{R_L^2}{R_s}} =$$

$$= \boxed{1 + \gamma + 4\frac{R_s}{R_L}} \quad NF$$

1 b) For gate noise, add another voltage source on the gate: $\overline{V_{n}^2 out, M_{1g}} = \frac{4kTR_G}{3} \cdot \left(\frac{R_L}{2R_s}\right)^2 =$

$$= \frac{kT \cdot R_G \cdot R_L^2}{3R_s^2}$$

$$\Rightarrow NF = 1 + \frac{kT\gamma\frac{R_L^2}{R_s} + \frac{kTR_G \cdot R_L^2}{3R_s^2} + 4kTR_L}{kT\frac{R_L^2}{R_s}} =$$

$$\boxed{1 + \gamma + \frac{R_G}{3R_s} + 4\frac{R_s}{R_L}} \quad NF$$

2.

a. See Example 5.3 in Razavi. New value for Q = 2450/(2550-2350) = 12.5

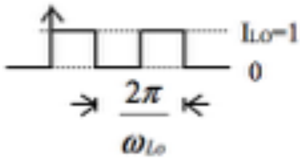
b. On-chip L are usually much more lossy than on-chip C.

c. In the L, the Q value is mainly limited by the series resistance in the metallization and, at higher frequencies, the losses in the substrate.

3.

a.

LO-IF feedthrough: measured level of the 900-MHz output component in the absence of an RF signal.



$$i_{LO}^{+}(t)=\frac{1}{2}+\frac{2}{\pi}\cos\omega_{LO}(t)-\frac{2}{3\pi}\cos 3\omega_{LO}(t)+\frac{2}{5\pi}\cos 5\omega_{LO}(t)-...$$
$$i_{LO}^{-}(t)=\frac{1}{2}-\frac{2}{\pi}\cos\omega_{LO}(t)+\frac{2}{3\pi}\cos 3\omega_{LO}(t)-\frac{2}{5\pi}\cos 5\omega_{LO}(t)+...$$

$$i_{RF}(t)=I_1+I_{RF}\cos\omega_{RF}t$$

No RF signal: $I_{RF}=0$ => $i_{RF}(t)=I_1$

The output current at IF is given by:

$$i_{IF}^{+}(t)=i_{LO}^{+}(t)\times i_{RF}(t)=\left[\frac{1}{2}+\frac{2}{\pi}\cos\omega_{LO}(t)-\frac{2}{3\pi}\cos 3\omega_{LO}(t)+\frac{2}{5\pi}\cos 5\omega_{LO}(t)-...\right]\cdot(I_1)$$
$$=\frac{I_1}{2}+\frac{2I_1}{\pi}\cos\omega_{LO}(t)$$
$$i_{IF}^{-}(t)=i_{LO}^{-}(t)\times i_{RF}(t)=\left[\frac{1}{2}-\frac{2}{\pi}\cos\omega_{LO}(t)+\frac{2}{3\pi}\cos 3\omega_{LO}(t)-\frac{2}{5\pi}\cos 5\omega_{LO}(t)+...\right]\cdot(I_1)$$
$$=\frac{I_1}{2}-\frac{2I_1}{\pi}\cos\omega_{LO}(t)$$

$$i_{IF}(t)=i_{IF}^{+}(t)-i_{IF}^{-}(t)=\frac{4I_1}{\pi}\cos\omega_{LO}(t)$$

$$v_{IF}(t)=i_{IF}(t)\times R_p=\frac{4}{\pi}I_1R_p\cdot\cos\omega_{LO}(t)$$
where R_p is the parallel resistance, which models the inductor loss.

$R_p=Q\omega_oL_p$ => LO-IF feedthrough $=\frac{4}{\pi}I_1R_p=\frac{4}{\pi}I_1Q\omega_{LO}L_p$

b. The noise figure of a noiseless mixer is 3 dB (SSB), Razavi 6.1.2.

4.

a. See Razavi Example 8.14 and Figure 8.26. Here instead we have Q=5 @ 2.45 GHz => Q*(L1+L2)*ω = 154 Ω. (L1 = L2 = 1 nH each!)

g_m for the transistors > 154/2 = 77 Ω^{-1}.

b. See Razavi, Example 8.23: -98 dBc/Hz.

5.

a.

$$H(s) = \frac{\phi_{out}}{\phi_{in}}(s) = \frac{K_{PD}K_{VCO}}{R_1C_1s^2 + s + K_{PD}K_{VCO}}$$

b. Type I.

c. For slow variations, s ≈ 0 and then H(s) = 1. The output phase tracks the input.

6.

a.

Maximum drain efficiency [%]	50	78.5	100	100	100
Peak drain voltage [*V_{DD}]	2	2	1	2	3.6
Normalized power output capability [Pout/(max V and I)]	0.125	0.125	0.32	0.125	0.098
Power Amplifer Class	A	B	D	C	E

b. You don't! :-)

A Doherty amplifier (Razavi section 12.9) consists of (at least) two amplifiers: a main amplifier (carrier PA) and an auxiliary amplifiers (peaking PA).