Solutions to

Written Exam in

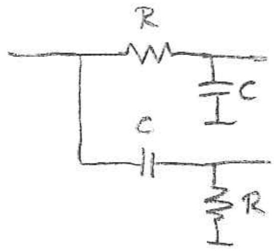
Integrated Radio Electronics (ETI170)

2009-03-11

Henrik Sjöland

1.

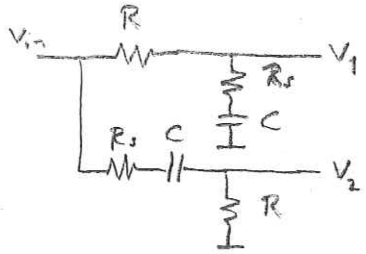
a)



$R = 200\,\Omega$

$$C = \frac{1}{2\pi f R} = \frac{1}{2\pi \cdot 5\cdot 10^9 \cdot 200} = 159 \text{ fF}$$

b)



$$V_1 = \frac{R_s + \frac{1}{sC}}{R + R_s + \frac{1}{sC}}$$

$$V_2 = \frac{R}{R + R_s + \frac{1}{sC}}$$

$$\frac{V_1}{V_2} = \frac{R_s + \frac{1}{sC}}{R} = \frac{10 + \frac{1}{j2\pi \cdot 5 \cdot 10^9 \cdot 159 \cdot 10^{-12}}}{200} = \frac{10 - j200}{200} = -j + 0{,}05 =$$

$$\left|\frac{V_1}{V_2}\right| = \sqrt{1^2 + 0{,}05^2} = 1{,}00125 \Rightarrow \text{amplitude error} = 0{,}125\,\%$$

$$\arg\left(\frac{V_1}{V_2}\right) = -90^\circ + \arctan(0{,}05) = -90^\circ + 2{,}86^\circ \Rightarrow \text{phase error} = 2{,}86^\circ$$

c) $\varepsilon = 0{,}00125$ before $\Rightarrow$ $\varepsilon = 0{,}00025$ after suppression

$\Delta\phi = 2{,}86^\circ = 0{,}050$ rad

$$IRR = \frac{4}{\varepsilon^2 + (\Delta\phi)^2} = \frac{4}{(0{,}00025)^2 + (0{,}050)^2} = 1{,}6 \cdot 10^3 = 32 \text{ dB}$$

2.

a. $R_g = \frac{1}{3} \cdot R_D \cdot \frac{W_{tot}}{L} \cdot \frac{1}{(\#fingers)^2} = \frac{1}{3} \cdot 6 \cdot \frac{100}{0,4} \cdot \frac{1}{64} = 7,8\,\Omega$

b. $R_{met} = \frac{l}{W \cdot \sigma \cdot \delta(1 - e^{-t/\delta})}$, $\delta = \sqrt{\frac{2}{\omega \mu_0 \sigma}}$

$$\delta = \sqrt{\frac{2 \cdot 2,7\ 10^{-8}}{2\pi \cdot 1,575\ 10^{9} \cdot 4\pi \cdot 10^{-7}}} = 2,08\ \mu m$$

$$R_{met} = \frac{150 \cdot 10^{-6} \cdot 2,7\ 10^{-8}}{10 \cdot 10^{-6} \cdot 2,08 \cdot 10^{-6} \cdot (1 - e^{-0,925/2,08})} = 0,54\ \Omega$$

c. $NF_{no,par} = 2\ dB \Rightarrow F_{no,par} = 1,585$

With parasitics:

$$F_{par} \approx F_{no,par} + \frac{R_{met} + R_g}{50\Omega} = 1,585 + \frac{8,3}{50} = 1,747$$

$NF_{par} = 10 \cdot \log F_{par} = 2,43\ dB < 2,5\ dB \Rightarrow$

<u>It still meets the specification</u>

3. a Capacitances/side:

$$C_{trans} = C_{gs1} + 4C_{gd1} + C_{db1} = \frac{2}{3}WLC_{ox} + 5WC_{gdo} +$$

$$+ \frac{W}{2}\cdot 1{,}2\mu m \cdot C_{jn} \cdot \frac{1}{\left(1+V_{dd}/V_j\right)^{m_j}} + 1{,}2\mu m \cdot 8 \cdot C_{jsp} \cdot \frac{1}{\left(1+V_{dd}/V_{sw}\right)^{m_{jsw}}} =$$

$$= 98\,fF + 84\,fF + 29\,fF + 2\,fF = 213\,fF$$

$$C_{ind} = \frac{1}{\omega_s^2 \cdot L} = \frac{1}{(2\pi\, 8\cdot 10^9)^2 \cdot 5\cdot 10^{-9}} = 79\,fF$$

$$C_{var,max} = WLC_{ox} + 2C_{sv} = 300\cdot 0{,}5\cdot 4{,}60 + 2\cdot 300\cdot 0{,}21\,fF = 816\,fF$$

$$C_{var,min} = C_{var,max}/2{,}5 = 326\,fF$$

$$C_{tot,max} = C_{trans} + C_{ind} + C_{load} + C_{var,max} = 213 + 79 + 100 + 816\,fF = 1{,}2\,pF$$

$$C_{tot,min} = C_{trans} + C_{ind} + C_{load} + C_{var,min} = 718\,fF$$

Tuning range:

$$f_{min} = \frac{1}{2\pi\sqrt{L\cdot C_{tot,max}}} = 2{,}05\,GHz \quad , \quad f_{max} = \frac{1}{2\pi\sqrt{L\cdot C_{tot,min}}} = 2{,}66\,GHz$$

b. First calculate parallel resistances:

$$R_{p,ind} = \omega L\cdot Q_{ind} = 644\,\Omega \;@ f_{min} \quad , \quad 836\,\Omega \;@ f_{max}$$

$$R_{p,trans} = \frac{Q_{trans}}{\omega C_{trans}} = \frac{20}{2\pi f\cdot 213\cdot 10^{-15}} = 7{,}3\,k\Omega \;@ f_{min} \quad , \quad 5{,}6\,k\Omega \;@ f_{max}$$

$$R_{p,var} = \frac{Q_{var}}{\omega C_{var}} = \frac{30}{\omega_{min}\cdot C_{var,max}} = 2{,}85\,k\Omega \;@ f_{min} \quad , \quad 5{,}5\,k\Omega \;@ f_{max}$$

$$R_{p,load} : Q_{load} = \frac{1}{\omega R_{load} C_{load}} = 155 \;@ f_{min} \quad , \quad 120 \;@ f_{max}$$

$$R_{p,load} = \frac{Q_{load}}{\omega C_{load}} = 120\,k\Omega \;@ f_{min} \quad , \quad 72\,k\Omega \;@ f_{max}$$

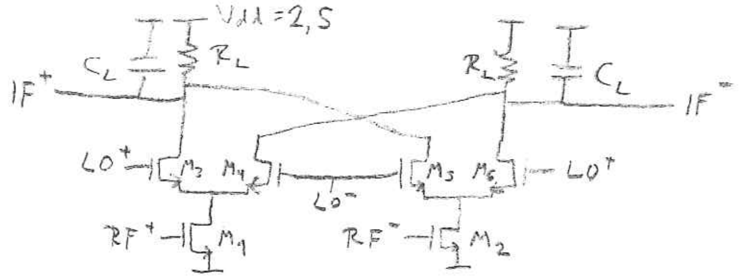
$$R_{p,tot} = \frac{1}{\frac{1}{R_{p,ind}} + \frac{1}{R_{p,trans}} + \frac{1}{R_{p,var}} + \frac{1}{R_{p,load}}} = 488\,\Omega \;@ f_{min} \quad , \quad 637\,\Omega \;@ f_{max}$$

$$Q_{tot} = \frac{R_{p,tot}}{\omega L} = 7{,}58 \;@ f_{min} \quad , \quad 7{,}62 \;@ f_{max}$$

c. $V_o = I_{BIAS}\cdot\frac{2}{\pi}\cdot R_{p,tot} = 2\cdot 10^{-3}\cdot\frac{2}{\pi}\cdot 488 = 0{,}62\,V_{pk}$ /side @ f_{min}

— " — $= 2\cdot 10^{-3}\cdot\frac{2}{\pi}\cdot 637 = 0{,}81\,V_{pk}$ /side @ f_{max}

4.



$ICP \geq 200\,mV/side \Rightarrow V_{ov1,2} \geq 200\,mV$, set $V_{ov1,2} = 250\,mV$

$I_{DC} \leq 5\,mA$, set $I_{D1} = I_{D2} = 2,5\,mA$

$g_{m1} = \frac{2 I_{D1}}{V_{ov1}} = \frac{5m}{0,25} = 20\,mS$

$A_{cv} = g_{m1} \cdot \frac{2}{\pi} \cdot R_L = 6\,dB = 2 \Rightarrow \underline{R_L = 157\,\Omega}$

$F = 1 + \frac{\gamma}{g_m\, 50\Omega} \cdot 2 = 1 + \frac{1,5}{20m \cdot 50} \cdot 2 = 4 = 6\,dB < 8\,dB$ <u>ok</u>

$V_{ov,sw,bal} = \frac{1}{\sqrt{2}} \cdot \hat{V}_{LO(diff)} \cdot \sin(90^\circ \cdot 0,25) = 216\,mV$ (with $\hat{V}_{LO(diff)} = 0,8\,V$)

$W_{3,4,5,6} = W_{sw} = L_{sw} \cdot \frac{2 I_d}{\mu C_{ox} V_{ov,sw,bal}^2} = 0,4\mu m \frac{2,5m}{115\mu \cdot 0,108^2} = \underline{186\,\mu m}$

$W_{1,2} = L_{1,2} \cdot \frac{2 I_d}{\mu C_{ox} V_{ov1,2}^2} = 0,4\mu m \frac{5m}{115 \cdot 10^{-6} \cdot 0,25^2} = \underline{278\,\mu m}$

$V_{G1,2} = V_{tn0} + V_{ov1,2} = 0,48 + 0,25 = \underline{0,73\,V}$

$V_{s,sw,min} = V_{G,sw} - V_t - 2 \cdot V_{ov,sw,bal} > V_{ov1,2} + V_{in,max} \Rightarrow M_{1,2}$ i saturation.

$V_{G,sw} > V_{ov1,2} + V_{in,max} + V_t + 2 \cdot V_{ov,sw,bal} = 0,25 + 0,2 + 0,48 + 2 \cdot 0,216 =$

$= 1,36\,V$, choose $\underline{1,5V}$ to give margin for body effect

M_{sw} in saturation $\Rightarrow V_{out} > V_{G,sw} + \hat{V}_{LO} - V_t = 1,42V$

$V_{out,min} = V_{dd} - \frac{I_{DC}}{2} \cdot R_L - A_{cv} \cdot V_{in,max} = 2,5 - 2,5 \cdot 157 - 2 \cdot 0,2 = 1,7V$

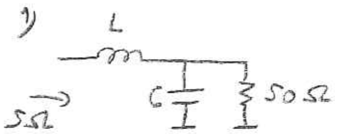
$\Rightarrow$ OK

$C_{L,trans} < 2 \cdot \frac{1}{2} W_{sw} \cdot 1,2\mu m \cdot C_{jn} = 0,2\,pF$ (almost negligable)

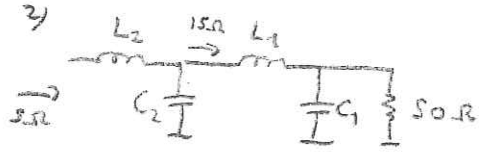
$C_{L,tot} = \frac{1}{2\pi \cdot BW \cdot R_L} = 6,75\,pF$

Choose $\underline{C_L = 6,6\,pF}$

5) a) 1)



2)



1: $Q = \sqrt{\frac{50}{5} - 1} = 3$ $\quad L = \frac{Q R_{in}}{\omega_0} = \frac{3 \cdot 5}{2\pi\, 2 \cdot 10^9} = 1{,}19\,nH$

$C = \frac{Q}{\omega_0 R_L} = \frac{3}{2\pi \cdot 2 \cdot 10^9 \cdot 50} = 4{,}78\ pF$

2: $Q_1 = \sqrt{\frac{50}{15} - 1} = 1{,}53$ $\quad L_1 = \frac{Q_1 \cdot R_I}{\omega_0} = \frac{1{,}53 \cdot 15}{2\pi \cdot 2\, 10^9} = 1{,}83\ nH$

$C_1 = \frac{Q_1}{\omega_0 R_L} = \frac{1{,}53}{2\pi \cdot 2\, 10^9 \cdot 50} = 2{,}44\ pF$

$Q_2 = \sqrt{\frac{15}{5} - 1} = 1{,}41$ $\quad L_2 = \frac{Q_2 R_{in}}{\omega_0} = \frac{1{,}41 \cdot 5}{2\pi \cdot 2 \cdot 10^9} = 0{,}56\ nH$

$C_2 = \frac{Q_2}{\omega_0 R_I} = \frac{1{,}41}{2\pi\, 2 \cdot 10^9 \cdot 15} = 7{,}5\ pF$

b) 1: $Z_{in} = j\omega L + R_L \,//\, \frac{1}{j\omega C}$

2: $Z_{in} = j\omega L_2 + \frac{1}{j\omega C_2} \,//\, \left(j\omega L_1 + \left(\frac{1}{j\omega C_1} \,//\, R_L\right)\right) = j\omega L_2 + \cfrac{1}{j\omega C_2 + \cfrac{1}{j\omega L_1 + \cfrac{1}{j\omega C_1 + 1/R}}}$

	$f = 1{,}6\ GHz$	$f = 2{,}5\ GHz$
1:	$Z_{in} = 7{,}4 - j5{,}8\,\Omega$	$3{,}3 + j6{,}3\,\Omega$
2:	$Z_{in} = 4{,}5 - j3{,}2\,\Omega$	$6{,}7 + j0{,}5\,\Omega$

Result: Matching circuit 2 is closer to 5Ω, best.

c) Voltage limit $2V_{rms}$ $\Rightarrow i_{max} = \min\left(\frac{V_{limit}}{|Z_{in}|},\ i_{max}\right)$

$P_{max} = i_{max}^2 \cdot Re(Z_{in})$ $\quad$ (ideal: $i_{max} = 0{,}4\,A_{rms} \Rightarrow P_{max} = 5 \cdot 0{,}4^2 = 0{,}8\,W_{rms}$)

	$f = 1{,}6\ GHz$	$f = 2{,}5\ GHz$
1:	$\lvert Z_{in}\rvert = 9{,}4\,\Omega$	$\lvert Z_{in}\rvert = 7{,}1\,\Omega$
	$i_{max} = 0{,}21\ A_{rms}$	$i_{max} = 0{,}28\,A_{rms}$
	$P_{max} = 0{,}34\ W_{rms}$	$P_{max} = 0{,}26\ W_{rms}$
2:	$\lvert Z_{in}\rvert = 5{,}5\,\Omega$	$\lvert Z_{in}\rvert = 6{,}72\,\Omega$
	$i_{max} = 0{,}36\ A_{rms}$	$i_{max} = 0{,}30\ A_{rms}$
	$P_{max} = 0{,}59\ W_{rms}$	$P_{max} = 0{,}59\ W_{rms}$

} Circuit 2 is superior, about 2 times more power!