ECE 145b Homework #4 Solutions

#1

a) $f_{IF} + f_{RF} = f_{LO} \Rightarrow 98.7\,MHz$

$f_{LO} + f_{IF} = f_{image} = 109.4\,MHz$

b) $f_{LO} = 118.7\,MHz$

$f_{image} = 129.4\,MHz$

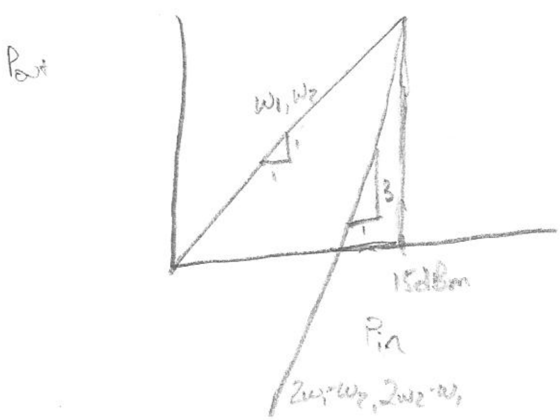
c) Yes, $f_{IF,min} > f_{RF,max}$. Needs a steep BPF for 88–108 MHz

#2

a) $f_1 = 99.8\,MHz$

$f_2 = 99.6\,MHz$ $2f_1 - f_2 = 100\,MHz = f_{RF}$

$IIP3 = -15\,dBm$ ↙ hard to see on problem set



ω_1, ω_2	$2\omega_1 - \omega_2, 2\omega_2 - \omega_1$
-15 dBm	-15 dBm
-16 dBm	-18 dBm
-17 dBm	-21 dBm
⋮	
-30 dBm	-60 dBm

$P_{int} = -60\,dBm$ $SNR = \frac{P_{sig}}{P_{int}} = 20\,dB \Rightarrow \underline{P_{sig} = -40\,dBm}$

b) For $P_{sig} = -40\,dBm$ & $P_{noise} = -135\,dBm$, $SNR = 95\,dB$, much higher

or $P_{sig} = -115\,dBm$ for required $SNR = 20\,dB$

#3

$I = I_s e^{-qV_{be}/KT}$ $\qquad V_{be} = V_b + \delta V_{in}$

$V_{ac} = V_0 \cos(\omega_1 t) + V_0 \cos(\omega_2 t)$

$I = I_s e^{qV_b/KT} \cdot e^{-q\delta V_{in}/KT} = I_{dc}\, e^{-\frac{\delta V_{in}}{V_T}} \approx I_{dc}\left[1 + \left(\frac{\delta V_{in}}{V_T}\right) + \frac{1}{2!}\left(\frac{\delta V_{in}}{V_T}\right)^2 + \frac{1}{3!}\left(\frac{\delta V_{in}}{V_T}\right)^3 + \dots\right]$

$I_{dc} + I_{AC} =$

$\delta V_{in} = \frac{V_0}{2}\left((z_1 + z_1^{-1})(z_2 + z_2^{-1})\right)$ from notes

$$(\delta V_{in})^3 = \frac{V_0^3}{8}\Big(15\cos(\omega_1 t) + 15\cos(\omega_2 t) + 2\cos(3\omega_1 t) + 2\cos(3\omega_2 t) + 6\cos((2\omega_1 + \omega_2)t) + 6\cos((2\omega_2 + \omega_1)t) + \underbrace{6\cos((2\omega_1 - \omega_2)t) + 6\cos((2\omega_2 - \omega_1)t)}_{\text{what we're concerned with}}\Big)$$

3rd order int. @ $\frac{\delta V_{in}}{V_T} = \frac{1}{3!}\left(\frac{\delta V_{in}}{V_T}\right)^3$

$$\frac{\cancel{V_0}\left[\cos(\omega_1 t) + \cos(\omega_2 t)\right]}{\cancel{V_T}} = \frac{\frac{V_0^{\cancel{3}\,2}}{8}\cancel{6}\left[\cos((2\omega_1 - \omega_2)t) + \cos((2\omega_2 - \omega_1)t)\right]}{\cancel{6}\, V_T^{\cancel{3}\,2}}$$

$1 = \frac{V_0^2}{8V_T^2}$ $\qquad V_0 = 2\sqrt{2}\, V_T \approx \underline{73.5\,mV}$

$I_{AC} = g_m V_{AC}$ $\qquad I_{AC} = \frac{I_C}{V_T} \cdot (2\sqrt{2}\, \cancel{V_T}) = 2\sqrt{2}\,(1mA) \approx \underline{2.83\,mA}$

$g_m = \frac{I_C}{V_T}$

#4

$$I_d = K(V_{gs} - V_{th})^2 \qquad K = 10mA/V^2 \qquad V_{th} = 0.3V$$

$$I_d = 3mA$$

$$(V_{gs_{dc}} - 0.3V) = \sqrt{\frac{3mA}{10mA/V^2}}$$

$$V_{gs_{dc}} = 0.848V$$

$$I_{AC} + I_{dc} = K\left(V_{gs_{dc}} + V_{AC} - V_{th}\right)^2$$

$$V_{gs_{dc}} - V_{th} = V_{dc}$$

$$I_{AC} + 3mA = K(V_{AC} + V_{dc})^2$$

$$I_{AC} + \cancel{3mA} = K(V_{AC}^2 + 2V_{AC}V_{dc} + \cancel{V_{dc}^2})$$

from notes:

$$I_{AC} = K\left(\frac{V_0}{2}\right)^2\left[2 + 2\cos(2\omega_1 t) + 2\cos(2\omega_2 t) + 4\cos(2(\omega_1+\omega_2)t) + 4\cos(2(\omega_1-\omega_2)t)\right]$$

$$+ K \cdot 2 \cdot V_0 \cdot V_{dc}\left[\cos(\omega_1 t) + \cos(\omega_2 t)\right]$$

additional DC — 5nA

$\pm$ ω_1/ω_2 — 10.96μA

$\pm$ $2\omega_1/2\omega_2$ — 5nA

$\pm$ $2(\omega_1+\omega_2)/2(\omega_1-\omega_2)$ — 10nA