# ECE 4880 RF Systems Fall 2016
# Homework 9

Due 11/18 5pm in the Phillips Dropbox

**Reading:** Chaps. 8 and 9 of lecture notes

1. (**Classical AM radio**) AM bands are between 530kHz – 1610kHz with the base band $BW_{bb}$ = 20kHz. Conventionally there are 27 stations within the same region, each separated by additional 20kHz.
   (a) When we choose $f_{IF}$ = 455 kHz as a high-side conversion, what is the range of $f_{LO}$ for selecting all channel by high side injection? What is the ratio of the highest $f_{LO}$ to lowest $f_{LO}$? Repeat for low-side injection. Can one station be the image interference of the other station? (**6 pts**)
   (b) Work out the superheterodyne up-conversion scheme with $f_{IF}$ = 5.1MHz for both the transmitter modulation and recevier demodulation. Show the block diagrams for the transmitter and the receiver. Give the range of $f_{LO}$ to receive all AM stations under the FCC regulation. (**8 pts**)
   (c) If the transmitter has the classical choice of $f_{IF}$ = 455kHz (as it is difficult to change the old radio tower) with high-side injection, present the radio receiver design in homodyne and superheterodyne architectures when you have an analog-to-digital converter (ADC) of 1MHz sampling with 12 bits per sample, followed by a .wav player. We will assume that if you need to sample a $BW_{bb}$ = 20kHz, you will need to sample at least at 200kHz. You are free to use mixers, but no analog filters as they would be costly and bulky in this frequency range. You can assume that all digital functions such as filtering can be performed easily after ADC. (**8 pts**)

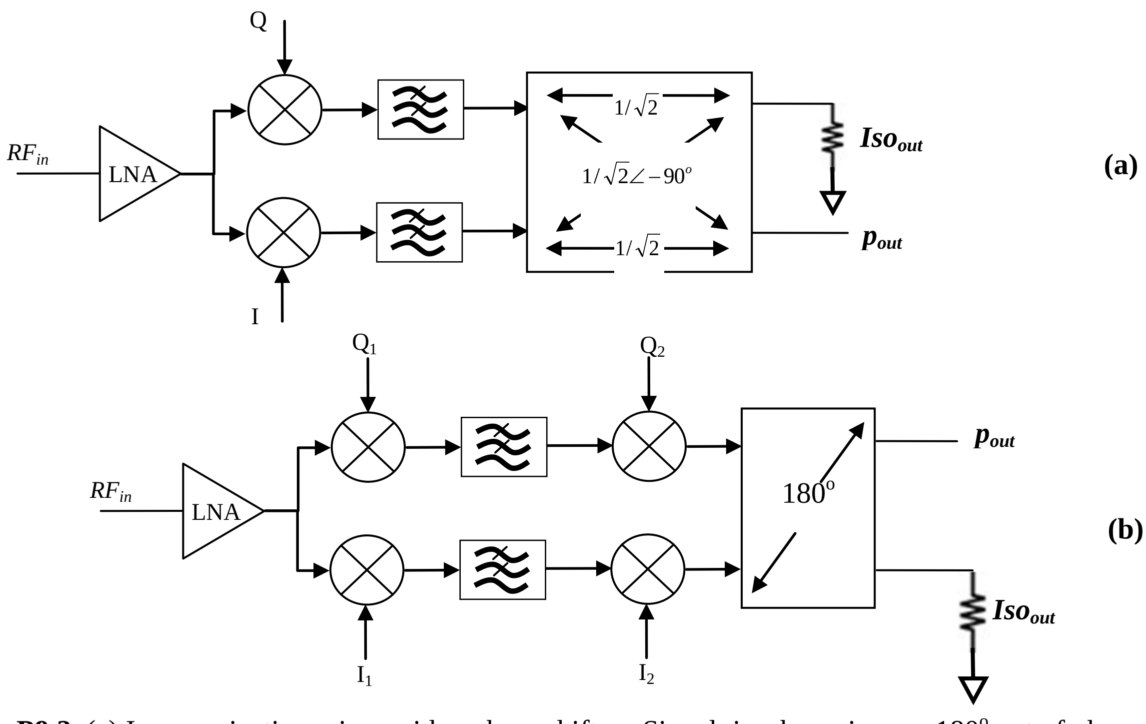



**Fig. P9.2.** (a) Image rejection mixer with a phase shifter. Signal: in-phase; image: 180$^o$ out of phase. (b) Weaver architecture for image rejection.

2. (**Parallel image cancellation**) For the two quadrature image rejection architectures as shown in Fig. P9.2, $RF_{in}$ = $A\cos(\varphi_{LO} - \varphi_{IF})$ + $B\cos(\varphi_{LO} + \varphi_{IF})$, i.e., $B$ is the image interference for $A$ in the high-side injection. The final hybrid combiner is for the intermediate frequency. Assume LNA has sufficient gain to just cancel the splitter loss. We will need to use the following trigonometry identities:

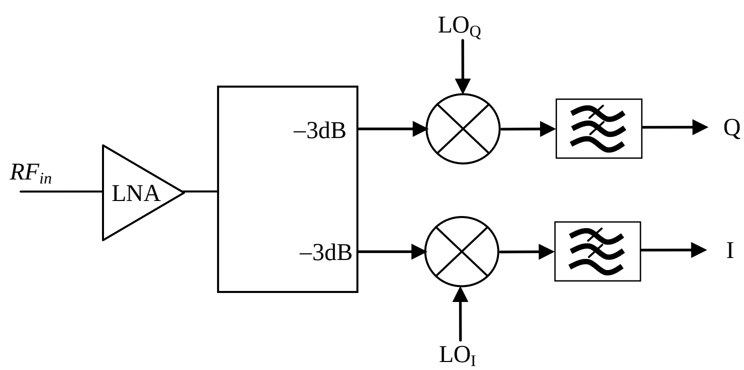
$$\cos a \cos b = \frac{1}{2}[\cos(a-b)+\cos(a+b)]; \qquad \sin a \sin b = \frac{1}{2}[\cos(a-b)-\cos(a+b)]$$

$$\sin a \cos b = \frac{1}{2}[\sin(a+b)+\sin(a+b)]; \qquad \cos a \sin b = \frac{1}{2}[\sin(a+b)-\sin(a-b)]$$

(a) For the architecture in Fig. P9.2(a), assume $I_1$ and $Q_1$ are synchronized to the frequency $\varphi_{LO}$ in the coming signal. Show the wave functions immediately after the mixers and at $p_{out}$ and $Iso_{out}$. (**10 pts**)

(b) For the architecture in Fig. P9.2(b), assume $\varphi_1 = \varphi_{LO}$ in $I_1$ and $Q_1$. Will $I_1/Q_1$ be different from $I_2/Q_2$? Show the wave functions immediately after the mixers and at $p_{out}$ and $Iso_{out}$. (**10 pts**)

3. (**Direct conversion transceivers**) One of the main problems of direct-conversion homodyne is the excessive DC shift and drift. Owing to $f_{IF} = 0$, there is already a DC component after the mixer. A high-pass filter with very low frequency is very difficult to make (very large LC), unless we can do digital filtering without saturating the data converter. Moreover, there can be additional DC factors in the direct conversion receiver below. Assume that $RF_{in}$ has a carrier at an angular frequency of $\omega$ = 1GHz and the power of the carrier is at –10dBm. All RF parts have impedance matched at 50Ω. LNA has a gain of 15dB with negligible phase delay and $IIP_{H2}$=30dBm. The power splitter has –3dB loss at each terminal with negligible phase delay. $LO_I$ has 0dBm power at 1GHz and in phase with $RF_{in}$. $LO_Q$ is the ideal quadrature of $LO_I$. The low pass filter is at 5MHz and is ideal.




(a) What is the output of the $LO_I$ and $LO_Q$ mixers? What is the output of I and Q after the LPF? Write the voltage waveforms at each stage. (**8 pts**) *Hint: Express known signals in the general form of $A\cos(\omega t + \theta)$ and work out the functional forms.*

(b) Now we will consider the nonlinearity of LNA. Find $a_2$ (still assume negative) from $IIP_{H2}$ and the resulting DC term after the LNA when $RF_{in}$ = –10dBm. What is the DC level shift before the mixer? (**8 pts**)

(c) Assume $LO_I$ leaks to its own RF port with –30dB loss. What is the resulting DC level from this self leakage at I? (**8 pts**)

4. (**Spurious DC resolution in direct conversion**) For the direct conversion demodulator in Q. 3, assume I and Q will be directly fed into the ADC (analog-to-digital converter) and the spurious DC shift is mainly caused by (1) the LO coupling to $RF_{in}$ and (2) the second-order nonlinearity of the LNA.

(a) Will the feedthrough technique in Fig. 7.7 be helpful for the DC drift condition caused by LO coupling? By $2^{nd}$-order nonlinearity in LNA? Give a brief explanation. Assume that you can subtract a nearly DC signal by a functional block of "subtractor" (which is typically a diff pair, but you do not need to give details). (**6 pts**)

(b) If a "zero" signal can be provided (such as the ground plane in a patch antenna), will that help the DC drift caused by LO coupling? By 2nd-order nonlinearity of LNA? (**6 pts**)

(c) If the data rate is at 5 million symbols per second, for a typical microcontroller of 200MHz clock cycle, is reset to zero on I and Q between symbols a practical technique to do? Assume that the original modulation has a "return-to-zero" (RTZ) scheme. (**6 pts**)

5. (**Phase noise in LO**) Assume that we use a LO with a phase noise profile as shown below:

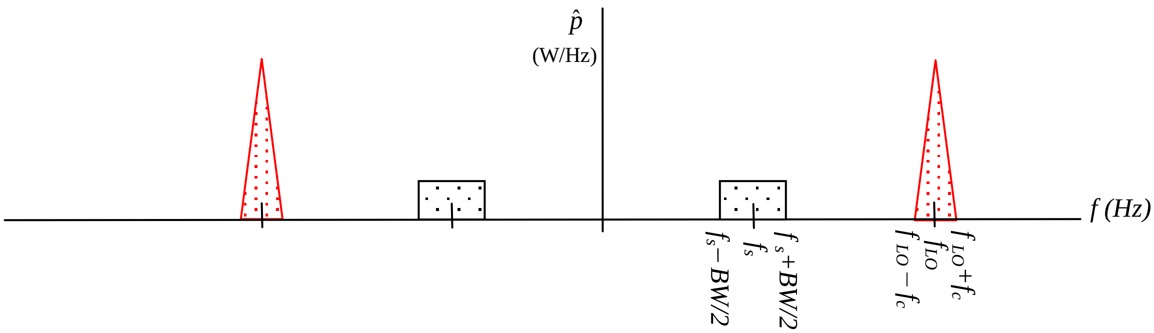



**Fig. P9.5.** Signals multiplied by LO with phase noise.

The phase noise of LO can be approximated with a $1/|f - f_{LO}|$ profile for the frequency of interest. Assume that the phase noise spectral power density will be equal to that of the background thermal noise at $f_{LO} \pm f_c$ (corner frequency). Surely the phase noise expression is not valid for $f \cong f_{LO}$, but we will not consider the information carried very close $f_{LO}$.

(a) Draw the spectral profile for an $f_s$ with a $BW$ bandwidth ($f_s < f_{LO}$ as high-side injection, and also assume $f_c < BW/2$) that is multiplied by $f_{LO}$ with the above phase noise. Denote the frequency ranges for the multiplication product. (**8 pts**)

(b) Assume the thermal noise floor has a spectral density of $N_0 = -174$dBm/Hz, for $f_c = 10$kHz, calculate the total noise power in dBm (thermal + phase) when $BW = 200$kHz and 2MHz. Assume all phase noise within 1Hz of LO can be discarded. (**8 pts**)