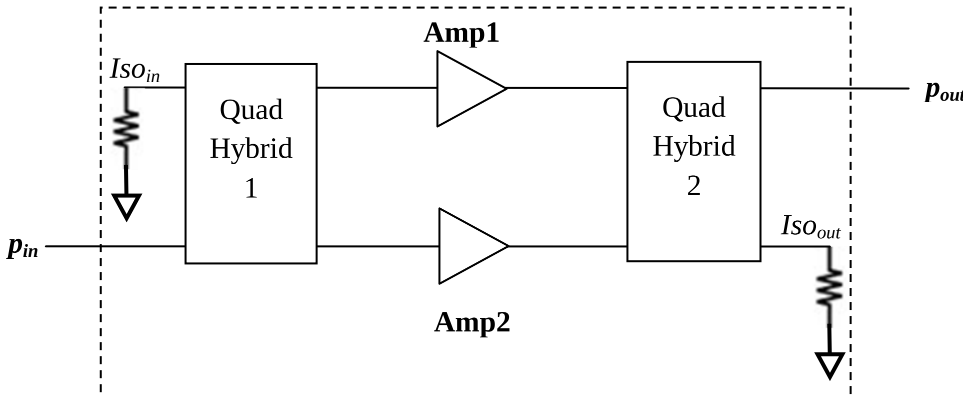
ECE 4880 RF Systems Fall 2016
Homework 8 (Due on 11/4/2016 5pm in the Phillips Hall Dropbox)

Reading before homework:

- Lecture summary on Signal Splitting and Combining
- Egan's book, Chaps 6 and 7

1. (**Quadrature hybrid amplifier**) To improve the linearity and signal reflection of LNA, a quadrature hybrid architecture is used, as shown below. You measure the S parameters for Amp1 with 50Ω cables and obtain:

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}_{amp1} = \begin{bmatrix} 0.1 & 0 \\ 8 & 0.05 \end{bmatrix}$$



(a) What are the input and output impedance of Amp1 in Ω? What is the amplifier gain in dB? Notice that S parameters are voltage ratios. (**6 pts**)

(b) First assume that Amp1 and Amp2 are identical in every aspect. What are the S parameters for the block in the dash-line box? Remember that S parameters are complex numbers. (**6 pts**)

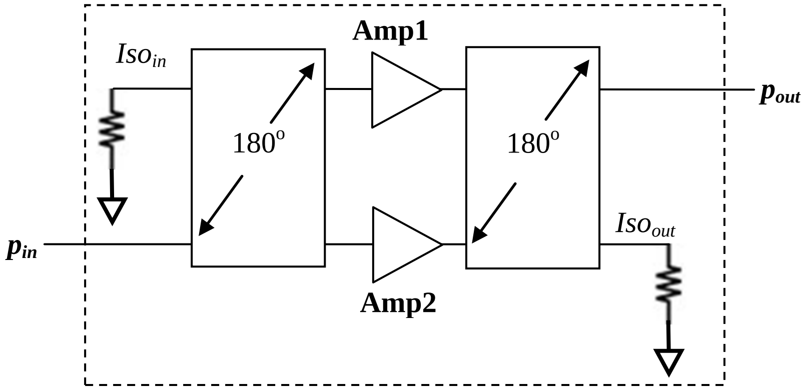
(c) If you measure the S parameters for Amp2 and find that they are slightly different as below.

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}_{amp2} = \begin{bmatrix} 0.1 & 0 \\ 7 & 0.1 \end{bmatrix}$$

Estimate the S parameters for the block in the dash-line box now? Assume the quadrature hybrid is still ideal. (**8 pts**) For p_{in} = 0dBm, estimate the power dissipated in Iso_{in} and Iso_{out}. (**8 pts**) **Hint**: when you calculate the voltage through the hybrid, the path without phase shift is $1/\sqrt{2}$, and the one with 90° shift is $-j/\sqrt{2}$.

(d) If both Amp1 and Amp2 have IIP_{H2} = 20dBm (but their S parameters are slightly different like in part (c)), for p_{in} = 0dBm, estimate the 2nd harmonic power at p_{out}. Assume that H2 will make the total output voltage at Amp1 and Amp2 smaller (i.e., a_2 is negative). (**8 pts**) Compare your answer of the H2 power if p_{in} = 0dBm is just fed into Amp1. (**8 pts**)

2. (**180^o hybrid amplifier**) For the 180^o hybrid amplifier shown below, we will use the same amplifier in Prob. 1. Basically repeat part (b), (c) and (d) of Prob. 1 in the three sub-problems below.



(a) First assume that Amp1 and Amp2 are identical in every aspect as described below.

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}_{amp1} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}_{amp2} = \begin{bmatrix} 0.1 & 0 \\ 8 & 0.05 \end{bmatrix}$$

What are the S parameters for the block in the dash-line box? Remember that S parameters are complex numbers. (**6 pts**) **Hint**: when you calculate the voltage through the hybrid, the path without phase shift is $1/\sqrt{2}$, and the one with 180^o shift is $-1/\sqrt{2}$.

(b) Now the S parameters for Amp2 is slightly different as shown below.

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}_{amp2} = \begin{bmatrix} 0.1 & 0 \\ 7 & 0.1 \end{bmatrix}$$

Estimate the S parameters for the block in the dash-line box now? Assume the 180^o hybrid is still ideal. (**6 pts**) For p_{in} = 0dBm, estimate the power dissipated in Iso_{in} and Iso_{out}. (**6 pts**)

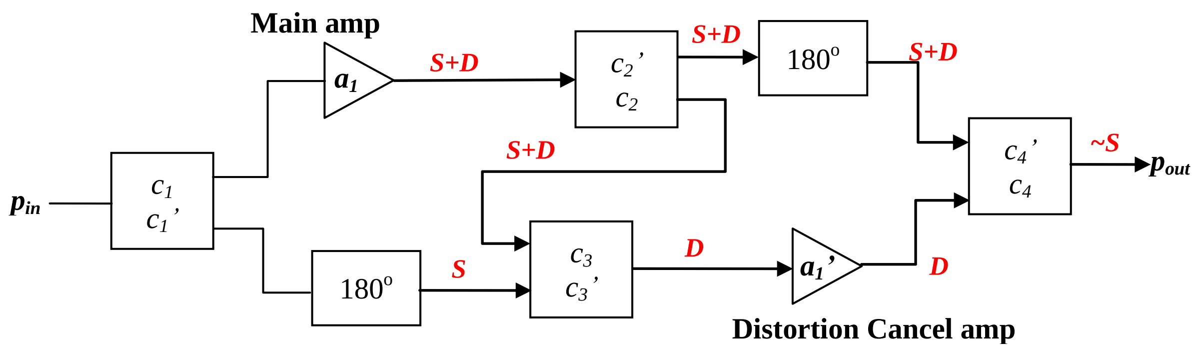
(c) If both Amp1 and Amp2 have IIP_{H2} = 20dBm (but their S parameters are slightly different), for p_{in} = 0dBm, estimate the 2nd harmonic power at p_{out}. Assume that H2 will make the total output voltage at Amp1 and Amp2 smaller (i.e., a_2 is negative). (**8 pts**)

Notice that this is a lot lower, and only result from the Amp1 and Amp2 mismatch. If Amp1 and Amp2 match well, p_{outH2} will be 0!!! This is the unique advantage of 180^o hybrid over quadrature hybrid.

(d) Assume that we are implementing amplifiers in monolithic microwave integrated circuits (MMIC) where device matching can be done almost perfectly and good passive elements can be constructed. Answer the following design needs with "quad", "180^o" or "both" for the scenarios given. (**6 pts**)

- Need to improve the overall linearity.
- Need to have minimal IM2 and H2.
- Need to relax the input impedance match without the penalty of signal reflection.

3. (**Feedthrough distortion cancellation**) For the feedthrough distortion compensation, assume the main amplifier a_1 has a gain of 20dB and $I_{1dBcomp}$ = 20dBm. All couplers have $c_i + c_i' = 1$ with no added noise or nonlinearity (passive lossless). We will assume $c_1 = c_2' = c_4' = 0.9$.



(a) What is the final gain of the amplifier in dB with respect to p_{in}? Assume only IM3 is important for distortion, what is IIP_{IM3} for a_1 in dBm? (**6 pts**)

(b) What are the required values for c_3 ,c_3', and a_1' to cancel the distortion? (**6 pts**)

(c) As the coupler design is to minimize the degradation of the signal gain, you may have obtained a VERY large a_1' required to cancel the distortion. Let's see if that is achievable. Assume you have p_{in} at 10dBm (which is lower than $I_{1dBcomp}$ so you know distortion is still small), and the major distortion is from IM3. Estimate the input power level at a_1 and a_1'. (**6 pts**) You should observe that because the input at a_1' is so small, the large gain will not saturate or cause severe distortion.

(d) Assume that the compensation a_1' has a very low $I_{1dBcomp}$ = –20dBm due to the large gain (as an amplifier with large gain can easily get saturated, and hence a very low $I_{1dBcomp}$). Estimate the reduction (in dB) for the signal distortion power. (**6 pts**)