ECE 4880 RF Systems Fall 2016
Prelim 2 Exam

Load reflection coefficient Γ_L at the load as: $\Gamma_L = \frac{V_-}{V_+} = \frac{Z_L/Z_o - 1}{Z_L/Z_o + 1}$

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \frac{1}{S_{21}} \begin{bmatrix} 1 & -S_{22} \\ S_{11} & S_{12}S_{21} - S_{11}S_{22} \end{bmatrix} \qquad \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \frac{1}{T_{11}} \begin{bmatrix} T_{21} & T_{11}T_{22} - T_{12}T_{21} \\ 1 & -T_{12} \end{bmatrix}$$

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \frac{Y_0}{(1+S_{11})(1+S_{22}) - S_{12}S_{21}} \begin{bmatrix} (1-S_{11})(1+S_{22}) + S_{12}S_{21} & -2S_{12} \\ -2S_{21} & (1+S_{11})(1-S_{22}) + S_{12}S_{21} \end{bmatrix}$$

Thermal noise at room temperature: –174dBm + 10log$_{10}$(BW/1Hz)

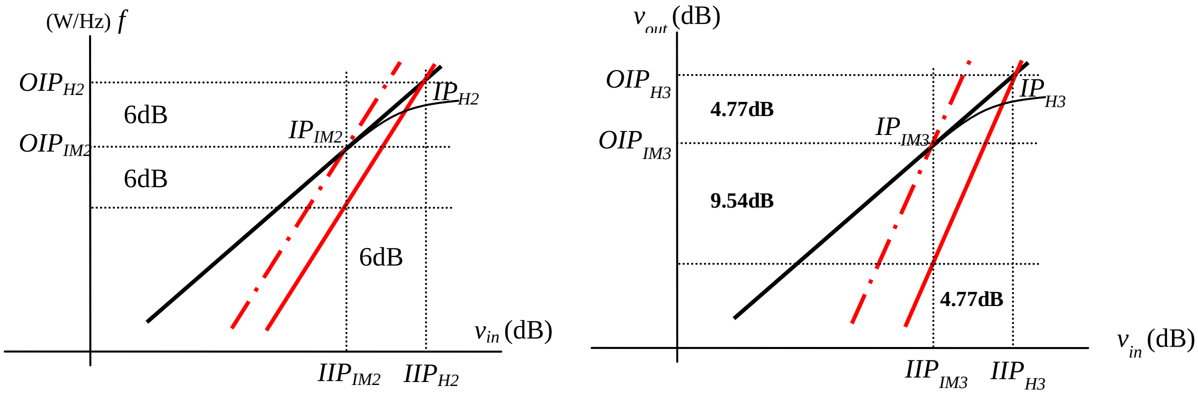


Fig. 1. Use of intercept points to represent nonlinearity from the quadratic and cubic terms.

$I_{1dBcomp} = IIP_{IM3}$ – 9.64dB when only IM3 is dominant.

Nonlinear Taylor coefficients: $A_{IIPIM\,2} = \left|\frac{a_1}{a_2}\right|$; $A^2_{IIPIM\,3} = \frac{4}{3}\left|\frac{a_1}{a_3}\right|$

$$\frac{1}{OIP_{IM\,3,cas}} = \frac{1}{g_2 \cdot OIP_{IM\,3,1}} + \frac{1}{OIP_{IM\,3,2}} \qquad \text{(IM3 adding coherently)}$$

The noise factor of the cascade: $f_{cas} = f_1 + \sum_{k=2}^{N} \frac{f_k - 1}{\prod_{i=1}^{k-1} g_i}$;

Instantaneous spur-free dynamic range: $ISFDR = P_{in\max} - P_{in\min} = \frac{2}{3}(IIP3 - P_{in\min})$

Desensitization signal level in V for two-tone signals: $B = \sqrt{\frac{1}{3}\left|\frac{a_1}{a_3}\right|} = \frac{1}{2} A_{IIPM\,3}$

Name: ______________________ NetID: __________________________

1. (**1dB gain compression, 6 pts**) To obtain an estimate of the input power at the 1dB gain compression point $I_{1dBcomp}$ of an RF amplifer, circle all statements that are true. There can be one or more correct answers. (**6 pts**) No explanation necessary.
   (A) If we know IIP_{H2}, then $I_{1dBcomp}$ can be uniquely determined.
   (B) If we know *ISFDR* (instantaneous spur-free dynamic range), then $I_{1dBcomp}$ can be uniquely determined.
   (C) $I_{1dBcomp}$ can be obtained from a single-tone carrier input testing.
   (D) $I_{1dBcomp}$ is well defined only if the dominant nonlinear term in the VTC Taylor expansion has a negative coefficient (such as a_2 or a_3).
   (E) $I_{1dBcomp}$ is an intrinsic property for the amplifier and will not depend on the testing frequency.
   (F) $I_{1dBcomp}$ can be extracted from the S parameter measurements under constant input power and sweeping frequency.

2. (**Signal cascade, 44 pts**) To achieve a desirable RF gain, we often have to cascade modules in a signal chain of the RF front end. Three components are available for the purpose of the RF frond end of an Wi-Fi receiver (2.4GHz – 2.5GHz), all with good input and output matching at 50Ω:

Module	Gain (dB)	*NF* (dB)	IIP_{H2} (dBm)	IIP_{H3} (dBm)	Bandwidth (GHz)
Amp1	15	2	40	30	2.3 – 2.6
Amp2	Variable: –20 to 10	10	60	15	1.9 – 3.0
Band-pass filter (BPF)	In-band: –1 Out-of-band: –40	5	80	80	2.35 – 2.55

a) Here you are designing to receive to the weakest input p_{in} = –100dBm with SNR_{in} = 10dB to extend the total operating range, and you will need a front-end with the least added noise. How will you arrange the three modules (all needed for the overall functions)? (**4 pts**) What are the noise figure and SNR_{out} of the entire block? (**4 pts**)

b) For the same configuration in a) and Amp2 at its highest gain of 10dB, when p_{in} = –20dBm, estimate the power of the 3rd-order intermodulation p_{outIM3} in each stage. (**6 pts**) Hint: You do not need to deal with modules with very high IIP.

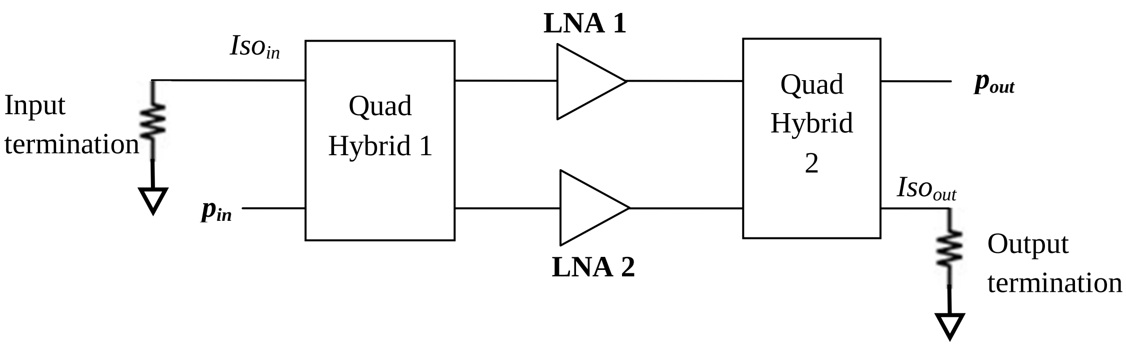
c) To accommodate the full range of p_{in} from –100dBm to –20dBm, Amp2 is set to the lowest gain of –20dB from a feedback when p_{in} = –20dBm is detected. Estimate p_{outIM3} in each stage now. (**4 pts**) This is the only sub-question that Amp2 has a gain of –20dB for gain control.

d) Here you are expecting a large interference signal at 2.6GHz in your ambient, but you still hope to provide the largest gain in the 2.4 – 2.5GHz band by setting Amp2 at 10dB gain. Due to the interference, IM3 consideration is more important than noise now. How will you arrange the three modules? Briefly justify your answers. (**4 pts**) What are the noise figure and SNR_{out} of the entire block now? (**6 pts**)

e) Here you are expecting a large jamming signal at 2.45GHz in your ambient as you are close to a microwave oven. How will you arrange the three modules in order to avoid jamming in all 20MHz channels not overlapped with 2.45GHz? (**4 pts**) What are the IIP_{IM3} and ISFDR of the RF front end now? (**6 pts**) The weakest input to be heard remains at –100dBm.

f) By using your configuration in e), what is the signal level in dBm of the 2.45GHz jamming signal that can desensitize any desirable signal within the Wi-Fi band? (**6 pts**) Use a simple estimate will be sufficient. No detailed calculation necessary.

3. (**Quad hybrid modules, 40 pts**) A quad hybrid architecture is used to implement an amplifier block out of two LNA. The overall system you design will have line impedance at 50Ω, and your quad hybrid unit is well matched to 50Ω. However, the individual LNA here has 75Ω Z_{in} and Z_{out}. The VTC of the individual LNA at matched input-output impedance conditions can be reasonably approximated by: $v_{out} = 20v_{in} - 2.5v_{in}^2 - 5v_{in}^3$ in volts and in a broad bandwidth.



a) By using a small testing p_{in} where the nonlinearity can be ignored, what is the S parameter matrix when the individual LNA is measured with a network analyzer with port impedance at 50Ω? (**6 pts**). Express your S parameters in dB.

b) Following a), when the quad-hybrid module is used with the small testing p_{in}, what is the expected S parameter matrix now? (**6 pts**) Express your S parameters in dB.

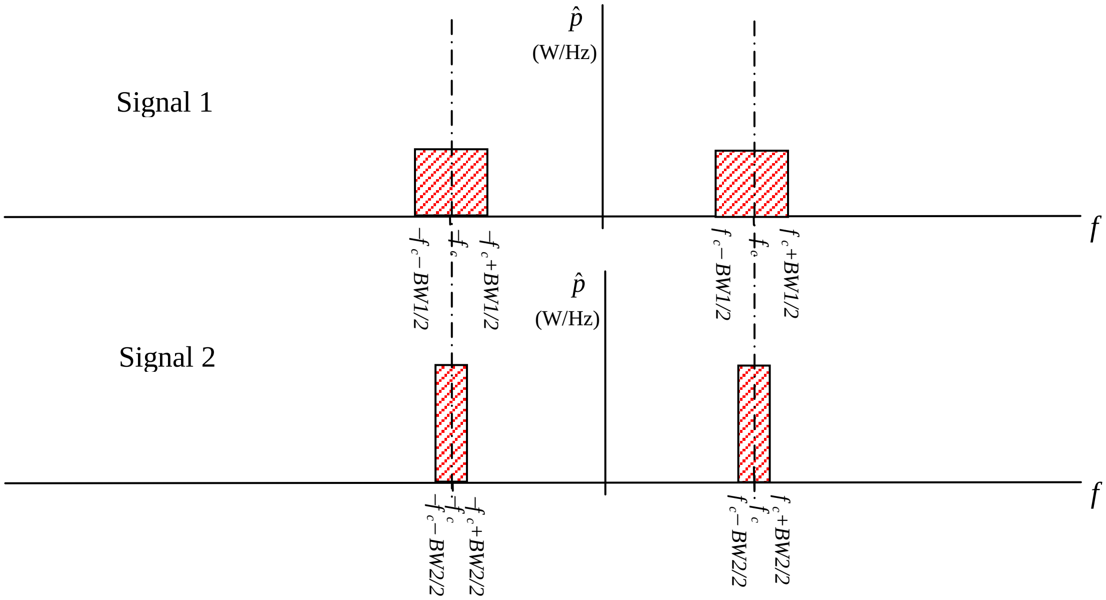
c) Following b) but now LNA1 has Z_{in} = Z_{out} = 75Ω but LNA2 has Z_{in} = Z_{out} = 50Ω, what is the expected S parameter matrix in dB for the quad-hybrid module? (**6 pts**)

d) Estimate the IIP_{H2} and IIP_{H3} of the individual LNA when Z_{in} = Z_{out}= 50Ω. (**6 pts**) Give your answers in dBm.

e) When both the quadratic and cubic terms are important, estimate $I_{1dBcomp}$ in dBm of the individual LNA. (**8 pts**) Hint: There is a quadratic equation to be solved.

f) Estimate IIP_{H2} and in-band IIP_{H3} in dBm of the quad hybrid module when Z_{in} = Z_{out}= 50Ω. (**8 pts**) Hint: Work out the voltage combination before converting to power in the harmonic frequency.

4. (**Intermodulation of two finite-bandwidth signals, 10 pts**) Two signals have the spectral components as shown below. They are received by the same antenna and fed into an amplifier low IIP_{IM2} and negligible IM3. Both Signals 1 and 2 are centered at f_c, and have bandwidths of $BW1$ and $BW2$, respectively. We will assume $BW2 < BW1 << f_c$. Signal 2 has stronger power but smaller bandwidth than Signal 1.



a) What is the appropriate noise description? Choose the most appropriate *one* answer below. (**5 pts**)
   (A) The shot noise is larger than the thermal noise.
   (B) If the flicker noise ($1/f^{\alpha}$) is dominant, then Signal 2 has larger total noise power than Signal 1.
   (C) If the thermal noise is dominant, then Signal 1 has larger total noise power than Signal 2.
   (D) If the AC power line noise is dominant, then Signal 1 has larger total noise power than Signal 2.
   (E) The blackbody radiation noise is strong around f_c.

b) For the intermodulation signal of Signals 1 and 2, which of the following statement is correct? Choose the most appropriate *one* answer below. (**5 pts**)
   (A) The intermodulation signal has an upper frequency bound of $2\times(f_c + BW1 + BW2)$.
   (B) The intermodulation signal has negligible component around f_c.
   (C) The intermodulation signal has negligible DC components.
   (D) The intermodulation signal has a square shape.
   (E) The intermodulation signal has a triangular shape.
   (F) The intermodulation signal has a quadratic shape.

(**Bonus question**) Which of the following actions by students in ECE 4880 is most detestable to Prof. Kan? (**0 pts**) Choose the most appropriate *one* answer below.
   (A) Eating in class.
   (B) Late for class.
   (C) Copy the number from calculator with much more significant digits than feasible.
   (D) Get the unit wrong for the final calculation results.
   (E) Late homework submission.