SAN JOSE STATE UNIVERSITY
Electrical Engineering Department

EE220 RFIC I

Spring 2019

Final Exam

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Problem	Score	Max Score
1		10
2		10
3		20
4		20
5		20
6		20
Total		**100**

CID #: ____

NAME: ____

1. (**10 point**) A GSM receiver senses a narrowband (modulated) signal having a level of -100 dBm. If the front-end amplifier provides a voltage gain of 15 dB, calculate the peak-to-peak voltage swing at the output of the amplifier.

$$Power = \frac{V_{rms}{}^2}{R}$$

$$dBm = 10\log\frac{Power}{1mW} = 10\log\frac{V_{rms}{}^2}{(50)(1mW)} = 10\log\frac{V_{rms}{}^2}{0.05}$$

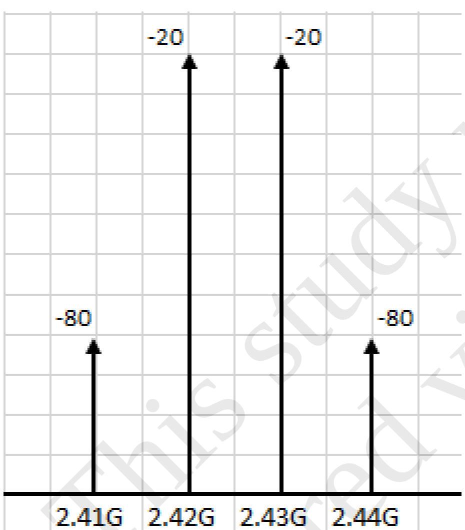
$$-100\ dBm = 10\log\frac{V_{rms}{}^2}{0.05} \ \rightarrow\ V_{rms}{}^2 = (0.05)(10^{10}) = (5)(10^{12})$$

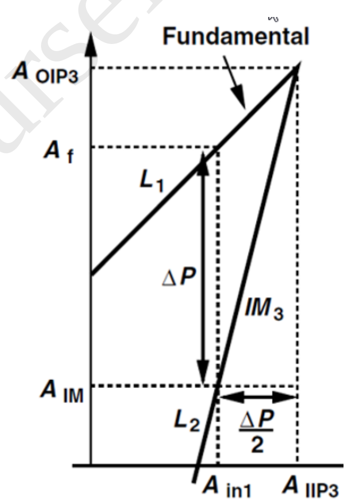
$$V_{rms} = \sqrt{5}\,uV \ \rightarrow\ V_{pp} = 2\sqrt{2}\,V_{rms} = 2\sqrt{2}\sqrt{5}\,uV = 2\sqrt{10}\,uV = 6.324\ uV$$

$$20\log(A_V) = 15\ dB \ \rightarrow\ A_V = 10^{0.75} = 5.62$$

$$V_{outpp} = (6.324\ uV)(5.62) = 35.5uV$$

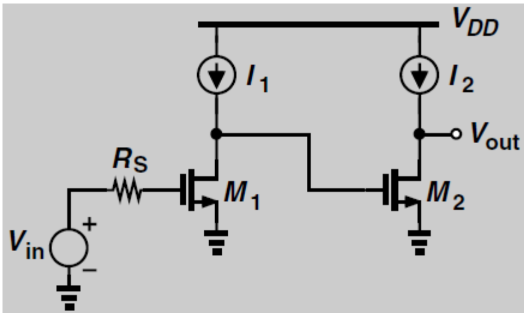
2. (**10 point**) A low-noise amplifier senses a -80-dBm signal at 2.410 GHz and two -20-dBm interferers at 2.420 GHz and 2.430 GHz. Using the method outlined in the right plot, what IIP3 is required if the IM products must remain 20 dB below the signal? For simplicity, assume 50-ohm interfaces at the input and output.





IIP3 = ΔP / 2 + Pin = [-20 –(-100)] / 2 + (-20) = 40 – 20 = 20 dBm

3. (**20 point**) Determine the *NF* of the cascade of common-source stages shown here. Neglect the transistor capacitances and flicker noise.



Which approach is simpler to use here, the direct method or Friis' equation? Since $R_{in1} = R_{in2} = \infty$, Eq. (2.126) reduces to

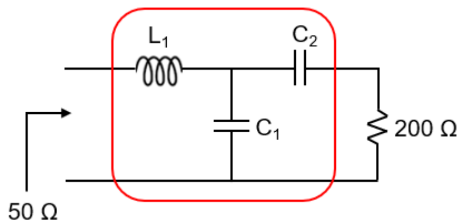
$$NF = 1 + \frac{\overline{V_{n1}^2}}{A_{v1}^2}\frac{1}{4kTR_S} + \frac{\overline{V_{n2}^2}}{A_{v1}^2 A_{v2}^2}\frac{1}{4kTR_S}, \qquad (2.133)$$

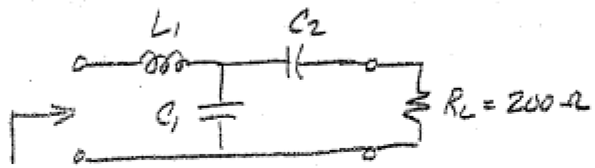
where $\overline{V_{n1}^2} = 4kT\gamma g_{m1} r_{O1}^2$, $\overline{V_{n2}^2} = 4kT\gamma g_{m2} r_{O2}^2$, $A_{v1} = g_{m1} r_{O1}$, and $A_{v2} = g_{m2} r_{O2}$. With all of these quantities readily available, we simply substitute for their values in (2.133), obtaining

$$NF = 1 + \frac{\gamma}{g_{m1} R_S} + \frac{\gamma}{g_{m1}^2 r_{O1}^2 g_{m2} R_S}. \qquad (2.134)$$

On the other hand, Friis' equation requires the calculation of the available power gain of the first stage and the *NF* of the second stage with respect to a source impedance of r_{O1}, leading to lengthy algebra.

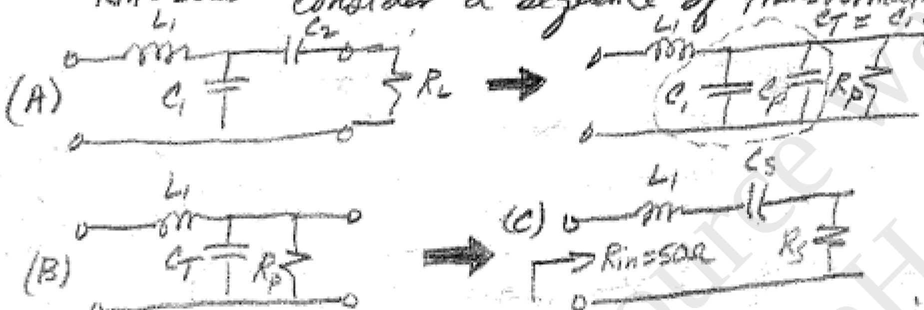
4. (**20 point**) The matching circuit below inside the red box is used to convert $R_L = 200\Omega$ to $R_{in} = 50\ \Omega$ at $f_o = 5.6$ GHz. Determine the required component values to achieve Q = 10 for the final series RLC circuit.





(This is a band pass matching network.)

$R_{in} = 50\Omega$ consider a sequence of transformations:



- The final circuit is pure series RLC circuit with:

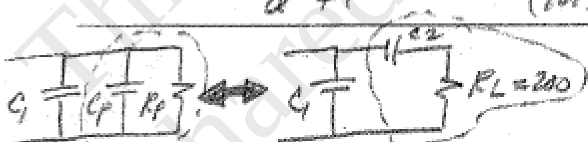
$Q = 10$; $R_S = R_{in} = 50\Omega$; $f_0 = 5.6$ GHz

For (C): $Q = 10 = \frac{\omega_0 L_1}{R_S}$ ⇒ $L_1 = \frac{Q R_S}{\omega_0} = $ **14.2 nH** ← L_1

$Q = 10 = \frac{1}{\omega_0 R_S C_S}$ ⇒ $C_S = \frac{1}{Q R_S \omega_0} = $ **56.8 fF**

For (B): $R_P = R_S (Q^2+1) = 50(101) = $ **5050 Ω**

$C_T = \frac{C_S Q^2}{Q^2+1} = \frac{(56.8\text{ fF})(100)}{(101)} = $ **56.3 fF**



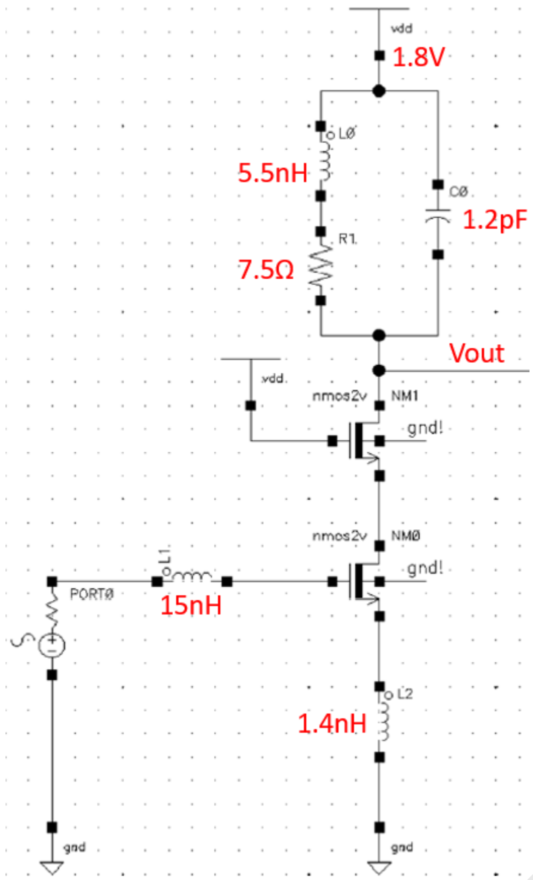
$Q_2 = \sqrt{\frac{R_P}{R_L} - 1} = $ **4.92**

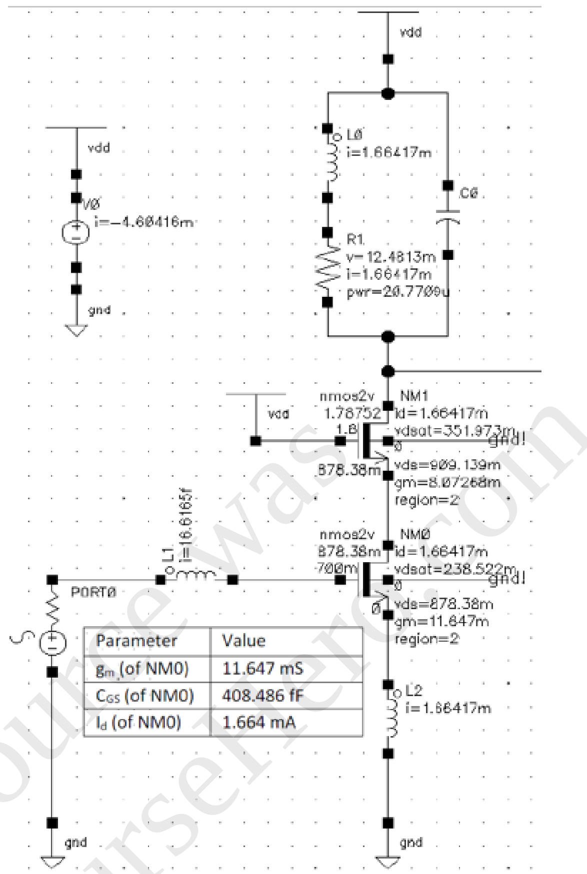
$Q_2 = \frac{1}{\omega_0 R_L C_2}$ ⇒ $C_2 = \frac{1}{Q_2 \omega_0 R_L} = $ **28.9 fF** ← C_2

$Q_2 = \omega_0 R_P C_P$ ⇒ $C_P = \frac{Q_2}{\omega_0 R_P} = $ **27.7 fF**

Finally, $C_1 = C_T - C_P = $ **28.6 fF** ← C_1

5. (**20 point**) For the LNA circuit shown below, we want to match the input impedance to a 50 Ω source impedance at the resonance frequency of f_o = 1.9 GHz. Neglect all parasitic capacitors and the channel length modulation effect (λ=0) and solve the followings using the DC results below.





Parameter	Value
g_m (of NM0)	11.647 mS
C_{GS} (of NM0)	408.486 fF
I_d (of NM0)	1.664 mA

(a) Calculate the Q of the input matching circuit.

$$Q_i = \frac{1}{\omega_0 C_{gs} R_s} = \frac{1}{(2\pi)(1.9x10^9)(408.486x10^{-15})(50)} = 4.1$$

(b) Calculate the gain (dB) of the amplifier.

$$Q_L = \frac{\omega_0 L_o}{R} = \frac{(2\pi)(1.9x10^9)(5.5x10^{-9})}{7.5} = 8.755$$

$$R_p = R_s(1 + Q_L{}^2) = 7.5(1 + 8.755^2) = 582.3\Omega$$

$$A_V = \frac{1}{2} Q_i g_m R_p = \frac{(4.1)(0.011647)(582.3)}{2} = 13.9$$

$$A_V = 20\log(13.9) = 22.87\ dB$$

(c) Calculate the input impedance at resonance.

$$R_{in} = \frac{g_m L_2}{C_{GS}} = \frac{(0.011647)(1.4x10^{-9})}{408.486x10^{-15}} = 39.9\Omega$$

(d) Calculate the noise figure assuming $\gamma = 1$.

$$NF = 1 + \frac{\gamma}{{Q_i}^2 g_m R_S} = 1 + \frac{1}{(4.1^2)\ (0.011647)(50)} = 1.102$$

$$NF(dB) = 10\log(1.102) = 0.422\ dB$$

6. (**20 point**) Design a high-pass L-section matching network to match a series RC load with an impedance Z_L=200-j100 ohm to a 100ohm line at a frequency of 500 MHz. Use the ZY Smith Chart to find the component values of the lumped elements and clearly draw the path from the load to the matching points in the Smith Chart.

$$L:\ \frac{1}{0.7} = 1.428 \quad \leftarrow Normalized$$

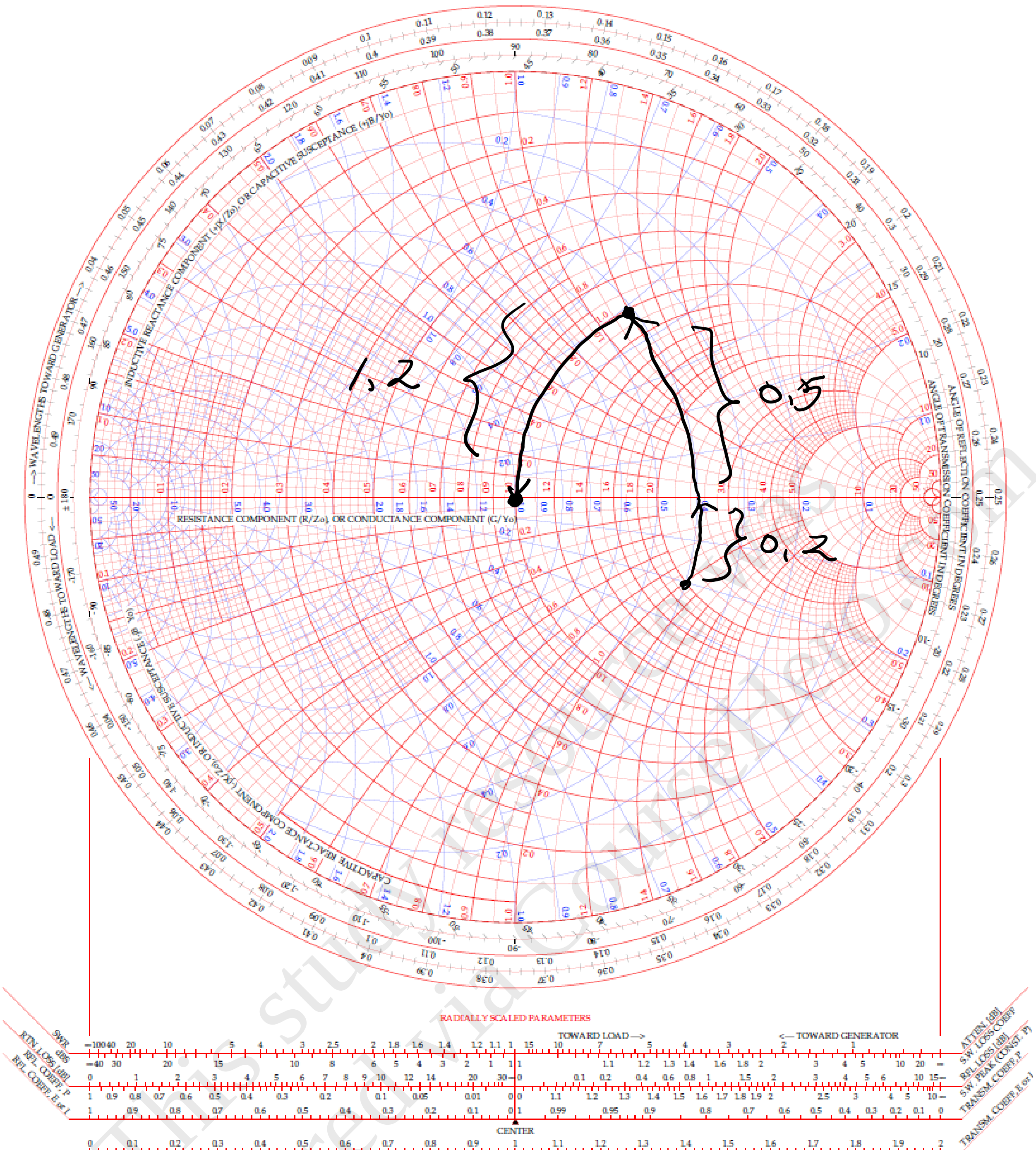
$$\omega L = (1.428)(100) \leftarrow Denormalize$$

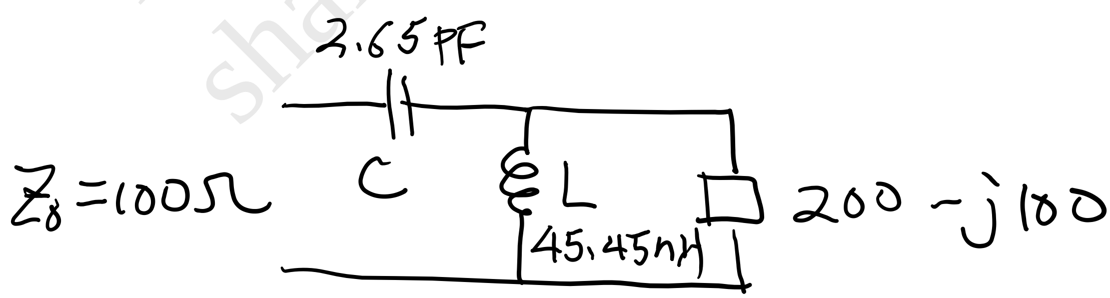
$$L = \frac{142.8}{(2\pi)(500x10^6)} = 45.45\ nH$$

$$C:\ 1.2 \ \leftarrow Normalized$$

$$\frac{1}{\omega C} = (1.2)(100) \leftarrow Denormalize$$

$$C = \frac{1}{(2\pi)(500x10^6)(120)} = 2.65\ pF$$


1,2
0,5
0,2
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
RADIALLY SCALED PARAMETERS
TOWARD LOAD —>
<— TOWARD GENERATOR
CENTER


2.65 pF
$Z_0 = 100\Omega$
C
L
45.45nH
200 - j100