EE 538B CMOS RF IC DESIGN

Midterm Examination No. 1: April 28, 2004

Time Allowed: 110 Minutes

Student Name: Solutions

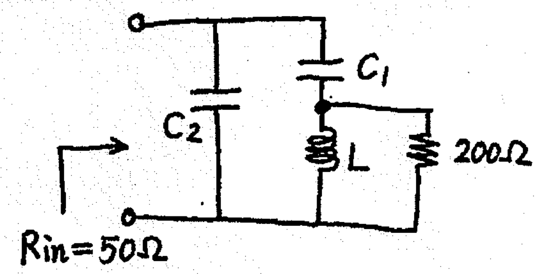
UW Student ID #: 1234567

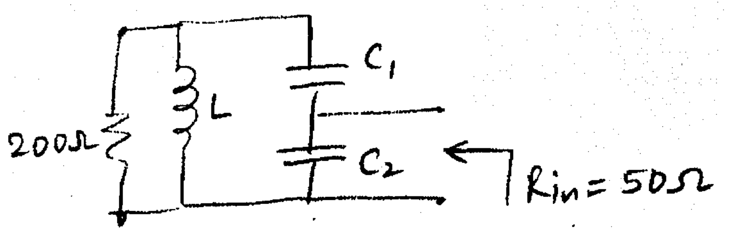
You are allowed one sheet of notes. Write legibly. Show all work. State assumptions.

Problem #	Points Possible	Points
1	10	10
2	20	20
3	25	25
4	25	25
5	20	20
		100

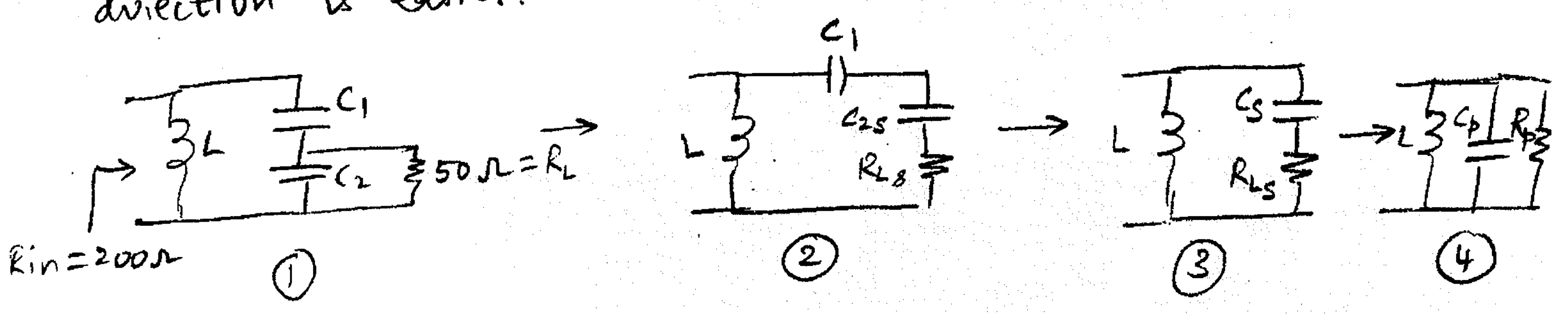
1. (10 points) With Q=10, the matching circuit below is used to convert $R_L = 200\Omega$ to $R_{IN} = 50\Omega$ at $f_O = 2.4\text{GHz}$. Determine the required component values. (Sorry Jeff, No Smith Charts are provided☺)

The ckt can be redrawn as a tapped capacitor match.





The ckt is reciprocal, and analysing the reverse direction is easier.



④ : $R_p = 200\Omega$, $Q = 10$ ⇒ $L = \dfrac{R_p}{Q\,\omega_o} = \underline{1.326\text{nH}}$

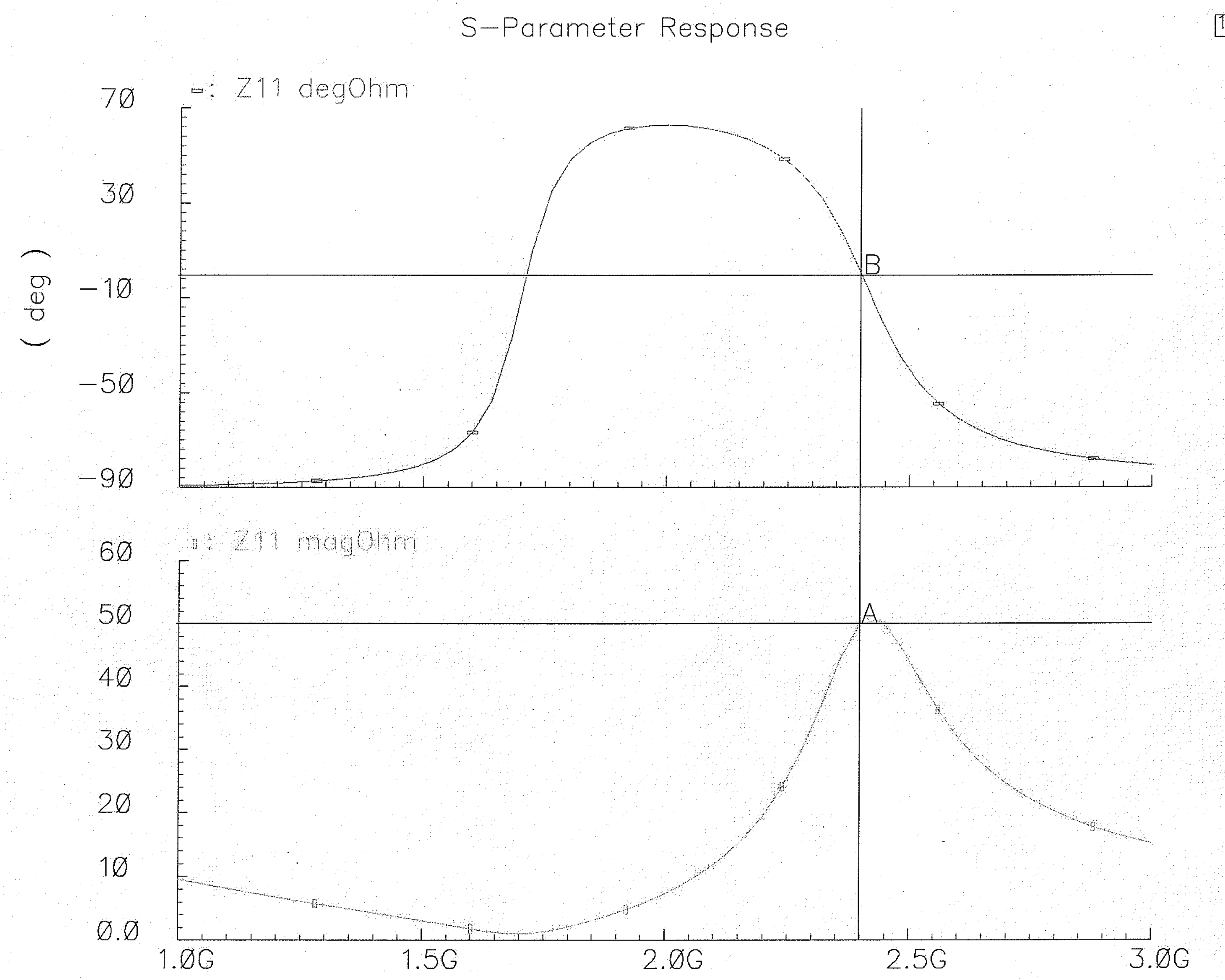
$$C_p = \frac{Q}{\omega_o R_p} = 3.316\text{pF} \Rightarrow C_s = 3.35\text{pF}$$

$$R_{Ls} = \frac{R_p}{1+Q^2} = 1.98\Omega$$

② : $Q_R = \sqrt{\dfrac{R_L}{R_{Ls}} - 1} = 4.925$

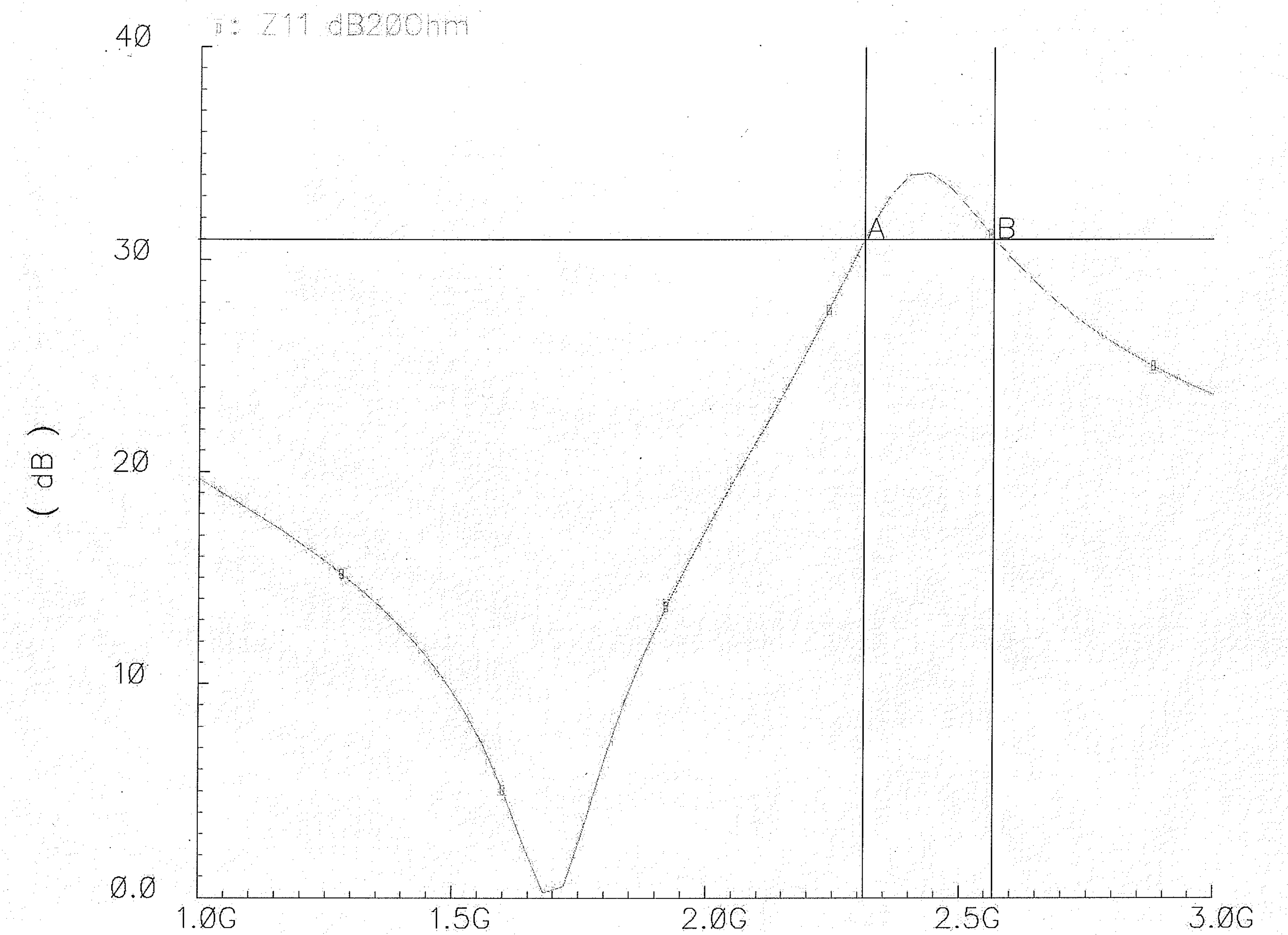
$$C_2 = \frac{Q_R}{\omega_o R_L} = \underline{6.53\text{pF}} \Rightarrow C_{2s} = 6.8\text{pF}$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_{2S}} \Rightarrow \underline{C_1 = 6.60\text{pF}}$$



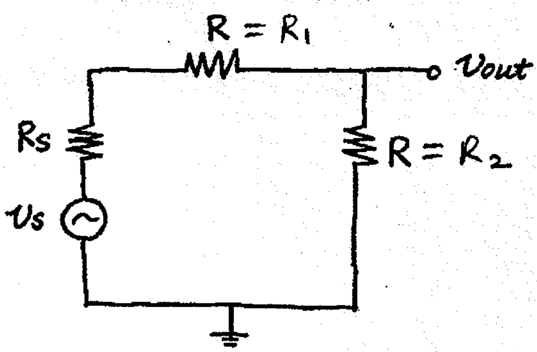
A: (2.4G 50.0522) delta: (0 −50.1634)
B: (2.4G −111.149m) slope: undefined

S–Parameter Response



A: (2.31187G 30.9885) delta: (256.069M −2.02521u)
B: (2.56794G 30.9885) slope: −7.90885f

2. (20 points) A resistive network is show below:



(a) What is the noise factor of the above circuit with respect to source resistance R_S?

$$\overline{V_{n,R_S}^2} = 4kTR_S\Delta f \cdot \left(\frac{R}{2R+R_S}\right)^2 ; \quad \overline{V_{n,R_1}^2} = 4kTR\Delta f \left(\frac{R}{2R+R_S}\right)^2$$

$$\overline{V_{n,R_2}^2} = 4kTR\Delta f \cdot \left(\frac{R+R_S}{2R+R_S}\right)^2$$

$$NF = \frac{\overline{V_{n,tot}^2}}{\overline{V_{n,R_S}^2}} = 1 + \frac{\overline{V_{n,R_1}^2} + \overline{V_{n,R_2}^2}}{\overline{V_{n,R_S}^2}}$$

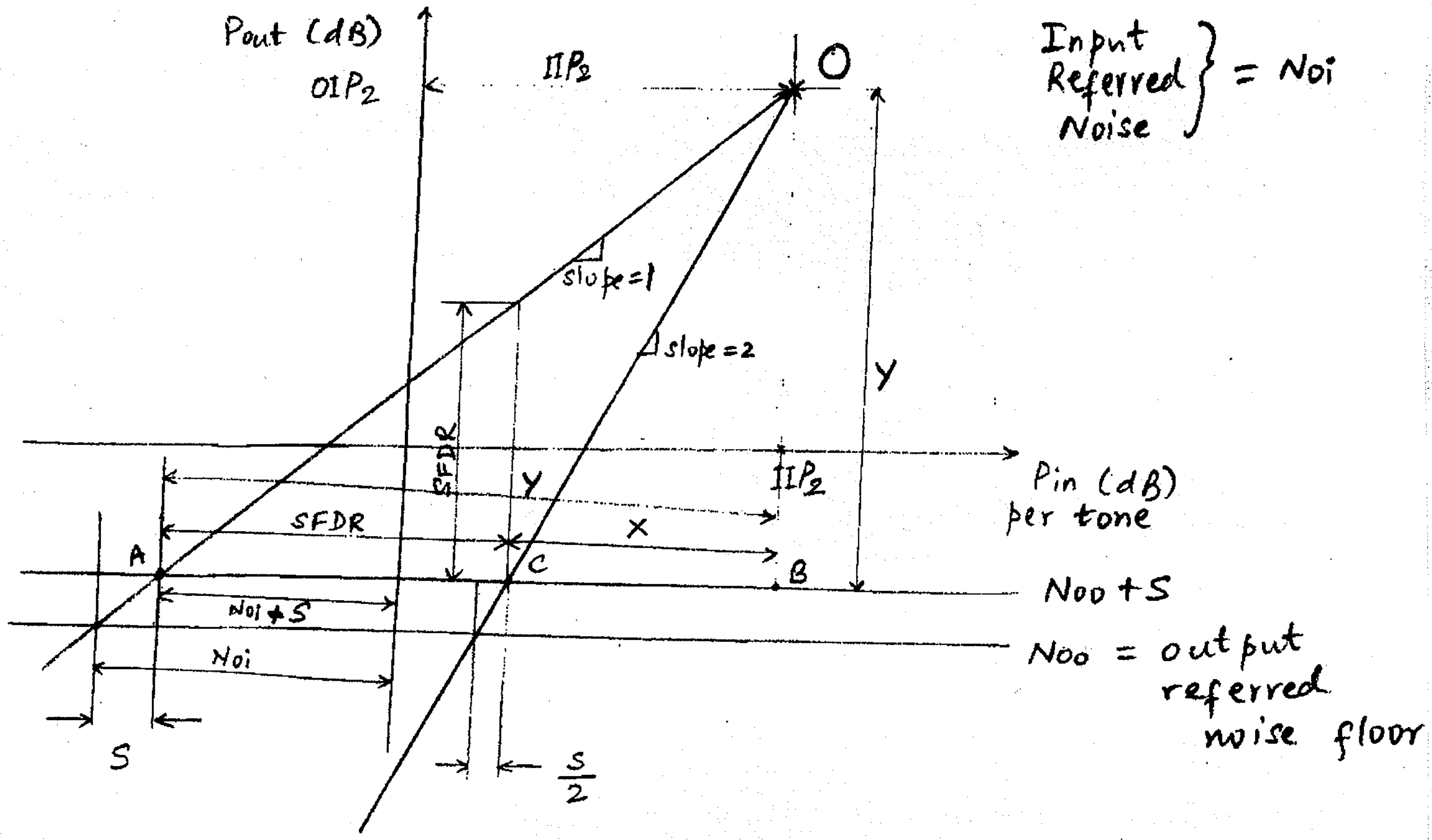
$$= 1 + \frac{4kTR\Delta f\left\{\frac{R^2}{(2R+R_S)^2} + \frac{(R+R_S)^2}{(2R+R_S)^2}\right\}}{4kTR_S\Delta f \cdot \frac{R^2}{(2R+R_S)^2}} = 1 + \frac{2R^2 + 2RR_S + R_S^2}{RR_S}$$

$$= \underline{3 + \frac{2R}{R_S} + \frac{R_S}{R}}$$

(b) What value of R minimizes the noise factor F?

$$\frac{dNF}{dR} = 0 \Rightarrow \frac{2}{R_S} - \frac{R_S}{R^2} = 0 \Rightarrow \boxed{R = \frac{R_S}{\sqrt{2}}}$$

3. (25 points) Assume that in a Direct Conversion Receiver (DCR), IIP2 (2^{nd} order intermodulation) is the dominant non-linearity component in the system. Determine the relation between SFDR, IIP2 and Input-Referred Noise of the system, using a graphical method. Assume that the system requires a minimum Input SNR 'S' to work properly.



The IM2 curve has a slope of 2; X is the distance between points B & C.

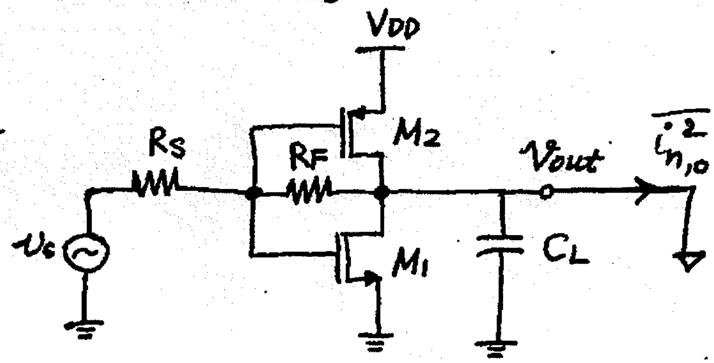
$$\frac{X}{Y} = \frac{1}{2} \; ; \qquad \frac{X + SFDR}{Y} = 1 \quad \text{(slope of fundamental curve is 1)}$$

$$\therefore \; X = SFDR = \frac{Y}{2}.$$

$$\begin{aligned} Y &= X \text{ co-ord } (B) - X \text{ co-ord } (A) \\ &= IIP_2 - (N_{oi} + S) \end{aligned}$$

$$\therefore \; SFDR = \frac{1}{2}\left[IIP_2 - N_{oi} - S\right]$$

4. (25 points) Determine the noise factor of the circuit shown below with respect to the source resistance R_S. Neglect channel length modulation effects, all parasitic capacitors and induced gate noise of the MOSFETs. Assume that all the MOSFETs work in saturation region.



$\underline{R_S}$

$$\overline{i^2_{out_{R_S}}} = 4kTR_S\Delta f\left[\frac{1}{R_S+R_F} - (g_{m1}+g_{m2})\frac{R_F}{R_S+R_F}\right]^2$$

$\underline{R_F}$

$$\overline{i^2_{out_{R_F}}} = 4kTR_F\Delta f\left[\frac{-1}{R_S+R_F} - (g_{m1}+g_{m2})\frac{R_S}{R_S+R_F}\right]^2$$

$\underline{M_1}$

$$\overline{i^2_{out_{M_1}}} = 4kT\gamma g_{do_1}\Delta f$$

$\underline{M_2}$

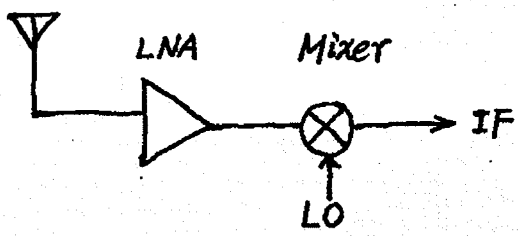
$$\overline{i^2_{out_{M_2}}} = 4kT\gamma g_{do_2}\Delta f$$

$$F = 1 + \frac{\overline{i^2_{R_F}} + \overline{i^2_{M_1}} + \overline{i^2_{M_2}}}{\overline{i^2_{R_S}}}$$

$$= 1 + \frac{4kT\Delta f\left[\gamma(g_{do_1}+g_{do_2}) + \frac{R_F}{(R_S+R_F)^2}\{1+(g_{m1}+g_{m2})R_S\}^2\right]}{4kT\Delta f\left[\frac{R_S}{(R_S+R_F)^2}\{1-(g_{m1}+g_{m2})R_F\}^2\right]}$$

$$= 1 + \frac{\gamma(g_{do_1}+g_{do_2})(R_S+R_F)^2 + R_F\left[1+(g_{m1}+g_{m2})R_S\right]^2}{R_S\left[1-(g_{m1}+g_{m2})R_F\right]^2}$$

5. (20 points) Calculate the overall Noise Figure and IIP3 for the RF front end shown below.



$A_p = 18dB$ 20dB
$NF = 2.5dB$ 12dB
$IIP3 = -15dBm$ +5dBm

$F_1 = 1.78$; $F_2 = 15.85$; $A_{p_1} = 63.1$;

$$F_{tot.} = F_1 + \frac{F_2 - 1}{A_{p_1}} = 1.78 + \frac{14.85}{63.1} = 2.02$$

$$NF_{tot.} = 10 \log F_{tot.} = 3.04 \text{ dB}$$

$$\frac{1}{IIP_{3_{tot}}^2} = \frac{1}{IIP_{3_1}^2} + \frac{A_p}{IIP_{3_2}^2} \; ; \quad IIP_{3_1}^2 = 3.16 \times 10^{-5}, \quad IIP_{3_2}^2 = 3.16 \times 10^{-3}$$

$$\frac{1}{IIP_{3,tot}^2} = \frac{1}{3.16 \times 10^{-5}} + \frac{63.1}{3.16 \times 10^{-3}} = 51613.92$$

$$IIP_{3,tot}^2 = 1.94 \times 10^{-5} = \underline{-17.12 \text{ dBm}}$$