Name: Thong Thach

LNA DESIGN PROJECT

Based on this schematic of the biasing cascode CG stage LNA from the textbook

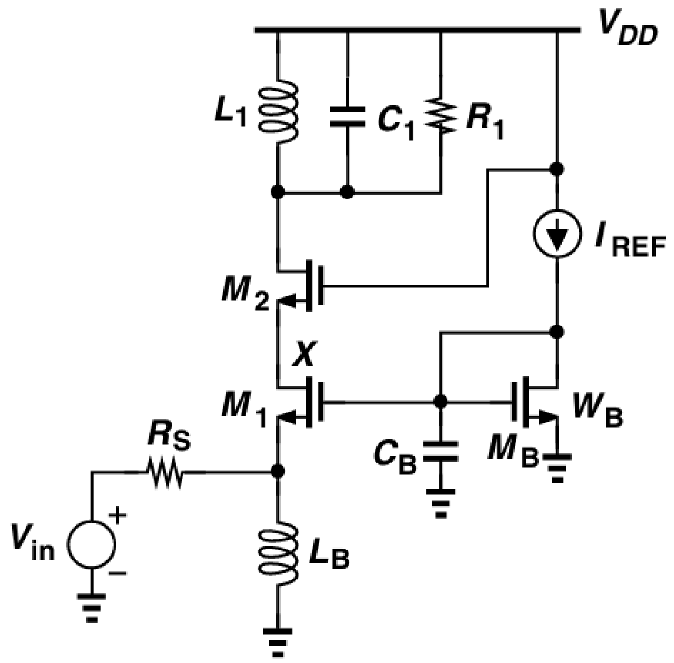
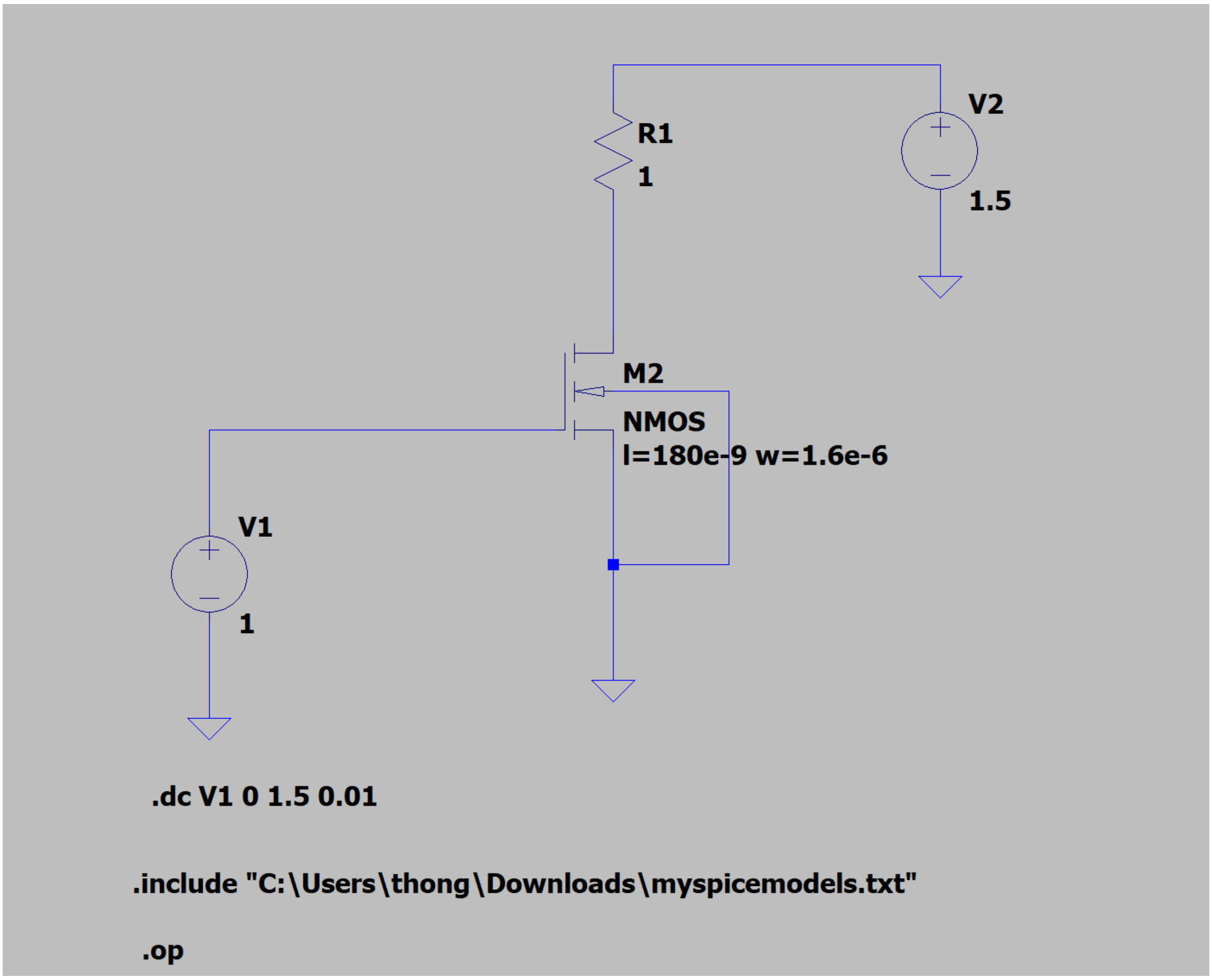


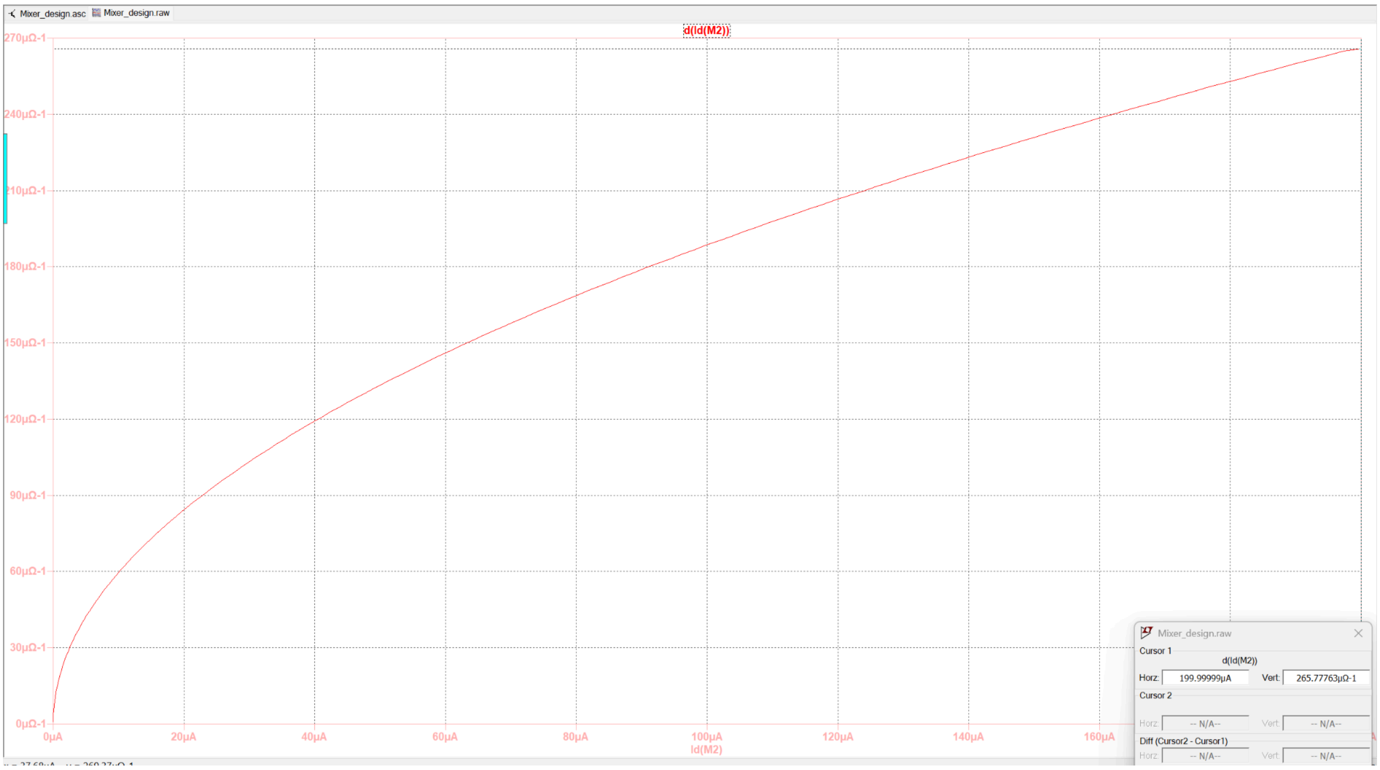
Figure 5.24 *Biasing of cascode CG stage.*

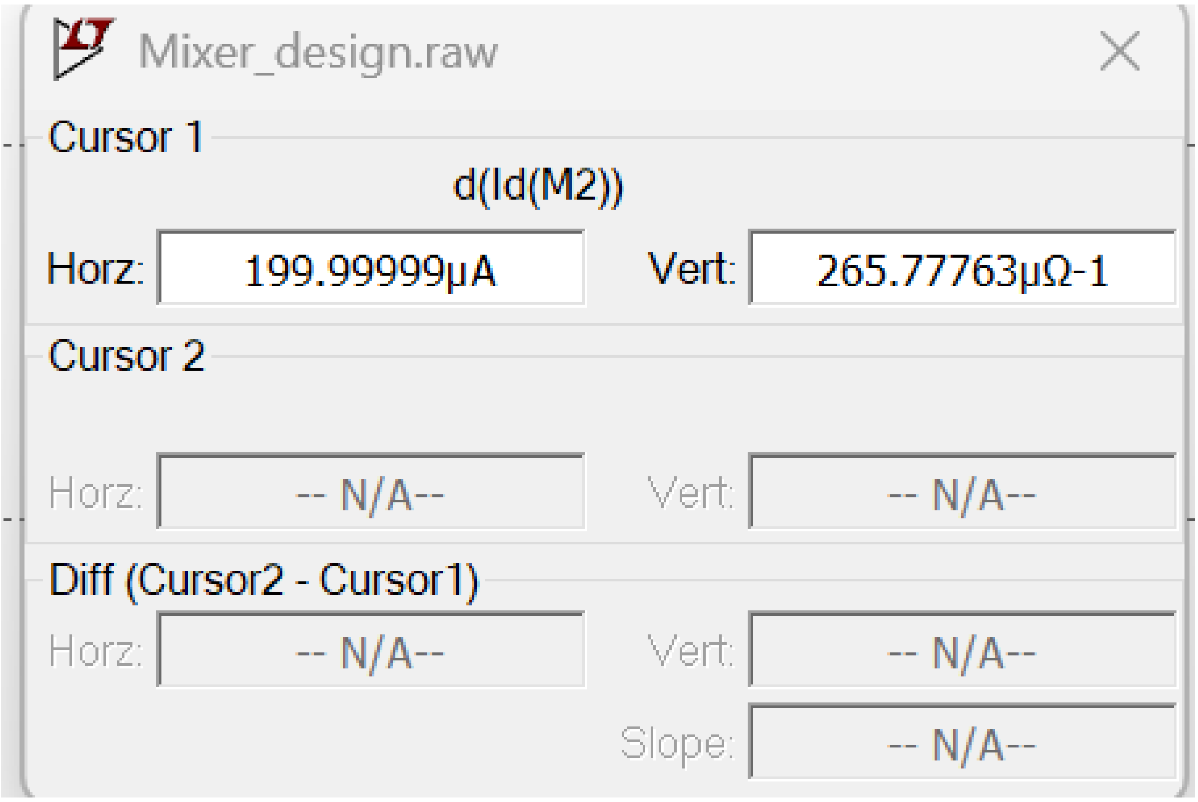
Design all the parameters will be followed below:

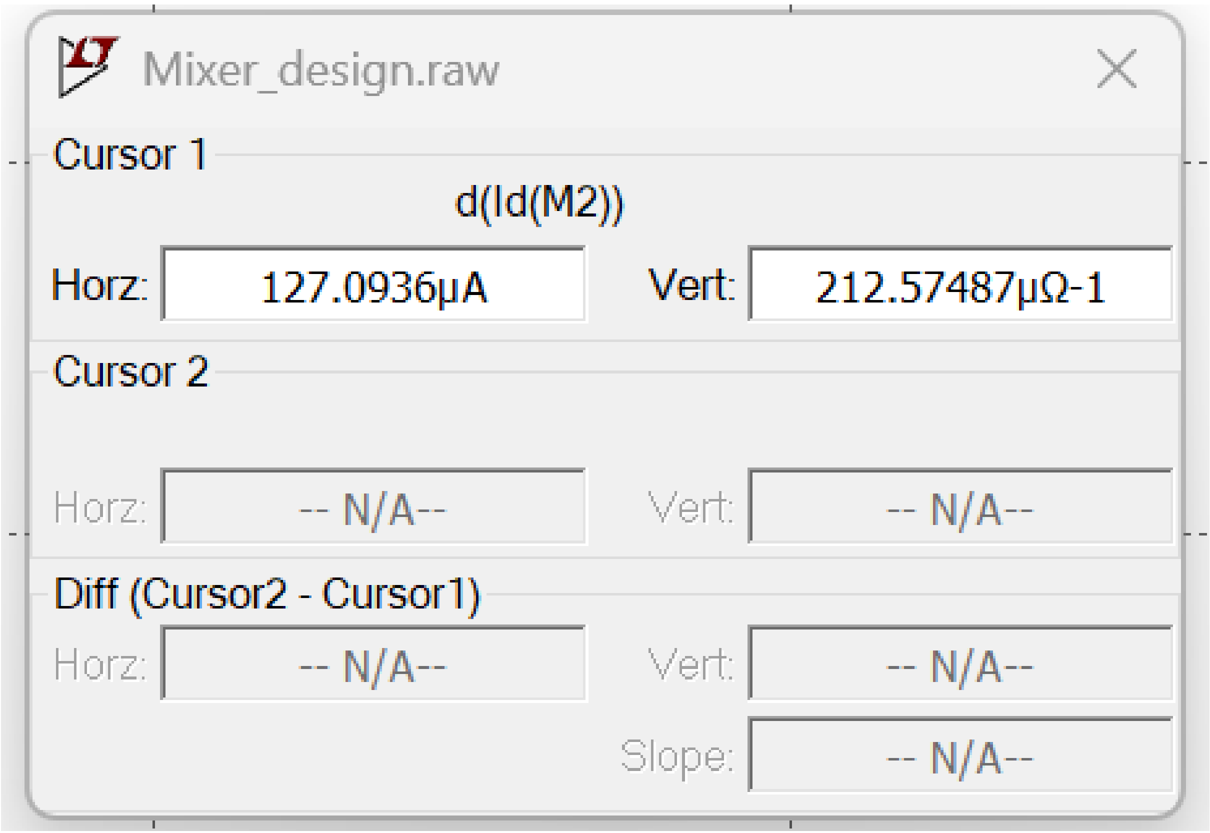
Step 1: Sizing and biasing of cascode M1



Plot between Id(M2) and the gm


Mixer_design.asc
Mixer_design.raw
d(Id(M2))
270μΩ-1
240μΩ-1
210μΩ-1
180μΩ-1
150μΩ-1
120μΩ-1
90μΩ-1
60μΩ-1
30μΩ-1
0μΩ-1
0μA
20μA
40μA
60μA
80μA
100μA
120μA
140μA
160μA
Id(M2)
Cursor 1
Horz: 199.99999μA
Vert: 265.77763μΩ-1
Cursor 2
Diff (Cursor2 - Cursor1)


Mixer_design.raw
Cursor 1
d(Id(M2))
Horz: 199.99999μA
Vert: 265.77763μΩ-1
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Slope: -- N/A--


Mixer_design.raw
Cursor 1
d(Id(M2))
Horz: 127.0936μA
Vert: 212.57487μΩ-1
Cursor 2
Horz: -- N/A--
Vert: -- N/A--
Diff (Cursor2 - Cursor1)
Horz: -- N/A--
Vert: -- N/A--
Slope: -- N/A--

1

$g_{m,max} = 265.78\,\mu S$

$\Rightarrow 80\%\, g_{m,max} = \dfrac{265.78\,(80)}{100} = \boxed{212.6} \Rightarrow I_{do} = 126.6\,\mu A$

Scaling factor $\alpha = \dfrac{g_{m1}}{g_{mo}} = \dfrac{0.025}{212.6\,\mu S} = \boxed{94}$

$\Rightarrow W_1 = 94\, W_0 = 94\,(1.6) = \boxed{150.4\,\mu m.}$

$I_d = 94\, I_{d_0} = 94\,(126.6\,\mu A) = 11900.4$

$= \boxed{1.2\ mA}$

Calculating L_B and R_B

$C_{total} = C_{pad} + C_{SB_1} + C_{GS1}$

Since $C_{GS_1} = \frac{2}{3} W_1 L_1 C_{ox} + W_1 C_{ov}.$

$\Rightarrow C_{GS_1} = \frac{2}{3}\,(150.4\,\mu m)\,(180.10^{-9})\,(0.508) + (150.4\,\mu m)\,(2.8.10^{-10})$

$\Rightarrow C_{GS_1} = 91.6\,fF^{12} + 42\,fF^{-14}$

$\Rightarrow \boxed{C_{GS_1} = 133.6\,fF^{-12}}$

②

$C_{SB_1} = W_1 E C_j + 2(W_1 + E) C_{jsw}$

$\Rightarrow C_{SB_1} = 150.4\mu m\,(1\mu m)\left(3.82 \cdot 10^{-4}\right) + 2\left(150.4\mu m + 1\mu m\right)\left(0.78 \cdot 10^{-10}\right)$

$\Rightarrow C_{SB_1} = 575 \cdot 10^{-16} + 236 \cdot 10^{-16}$

$\Rightarrow \boxed{C_{SB_1} = 811 \cdot 10^{-16}}$

$\Rightarrow \boxed{C_{SB_1} = 81.1 fF}$

$\Rightarrow C_{total} = C_{GS_1} + C_{SB_1} + C_{pad}$

$\Rightarrow C_{total} = 133.6 fF + 81.1 fF + 50 fF$

$\Rightarrow \boxed{C_{total} = 264.7 fF}$

$\omega = \frac{1}{\sqrt{LC}} \Rightarrow L = \frac{1}{\omega^2 C}$

$\Rightarrow L = \frac{1}{\left(2\pi(2.4 \cdot 10^9)\right)^2 (264.7 fF)}$

$\Rightarrow \boxed{L_B = 16.6 nH}$

$R_B = Q L_B \omega$

$\Rightarrow R_B = 10\left(16.6 \cdot 10^{-9}\right)\left(2\pi(2.4 \cdot 10^9)\right)$

$\Rightarrow \boxed{R_B = 2503 \text{ ohms.}}$

Calculating M_1 and M_B. (3)

$W_B = 0.2 W_1$

$\Rightarrow W_B = 0.2(150.4\ \mu m) = \boxed{30.08\ \mu m}$

$\Rightarrow I_{ref} = 0.2 I_{d_1} = 0.2(1.2\ mA) = \boxed{0.24\ mA}$

The width of $M_1 = M_2 = \boxed{150.4\ \mu m}$

$\Rightarrow$ Finding L_1 and R_1

$\Rightarrow C_{out} = C_1 = C_{load} + C_{GD_2} + C_{DB_2}$

$\Rightarrow C_1 = 40fF + W_1 C_{ov} + C_{SB_1}$

$\Rightarrow C_1 = 40fF + 42fF + 91.6fF$

$\Rightarrow \boxed{C_1 = 173\ fF}$

$\Rightarrow L_1 = \frac{1}{\omega^2 C}$

$\Rightarrow L_1 = \frac{1}{(2\pi(2.4 \cdot 10^9))^2 (173 fF)}$

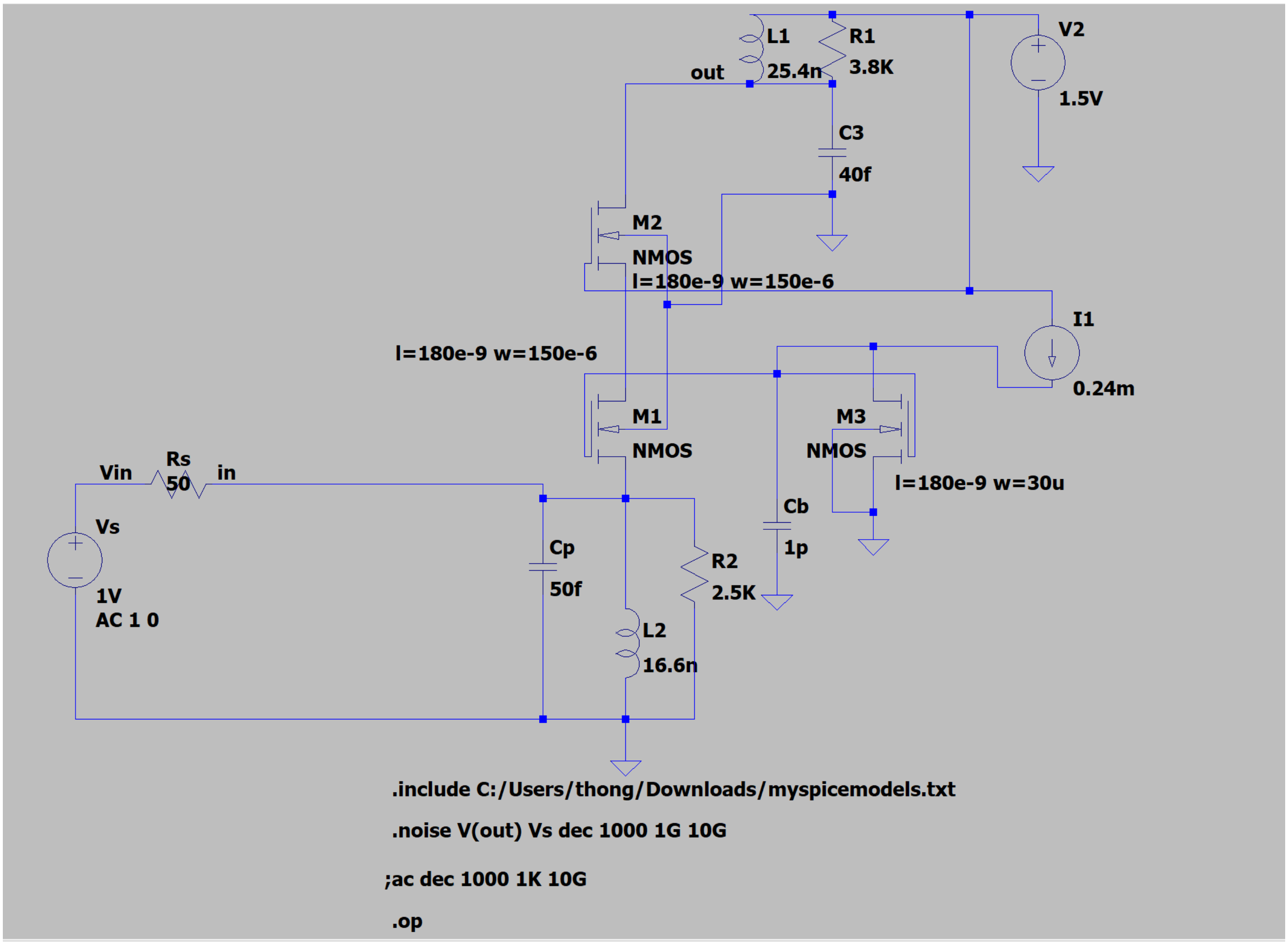
$\Rightarrow \boxed{L_1 = 25.4\ nH.}$

$\Rightarrow R_1 = Q L_1 \omega$

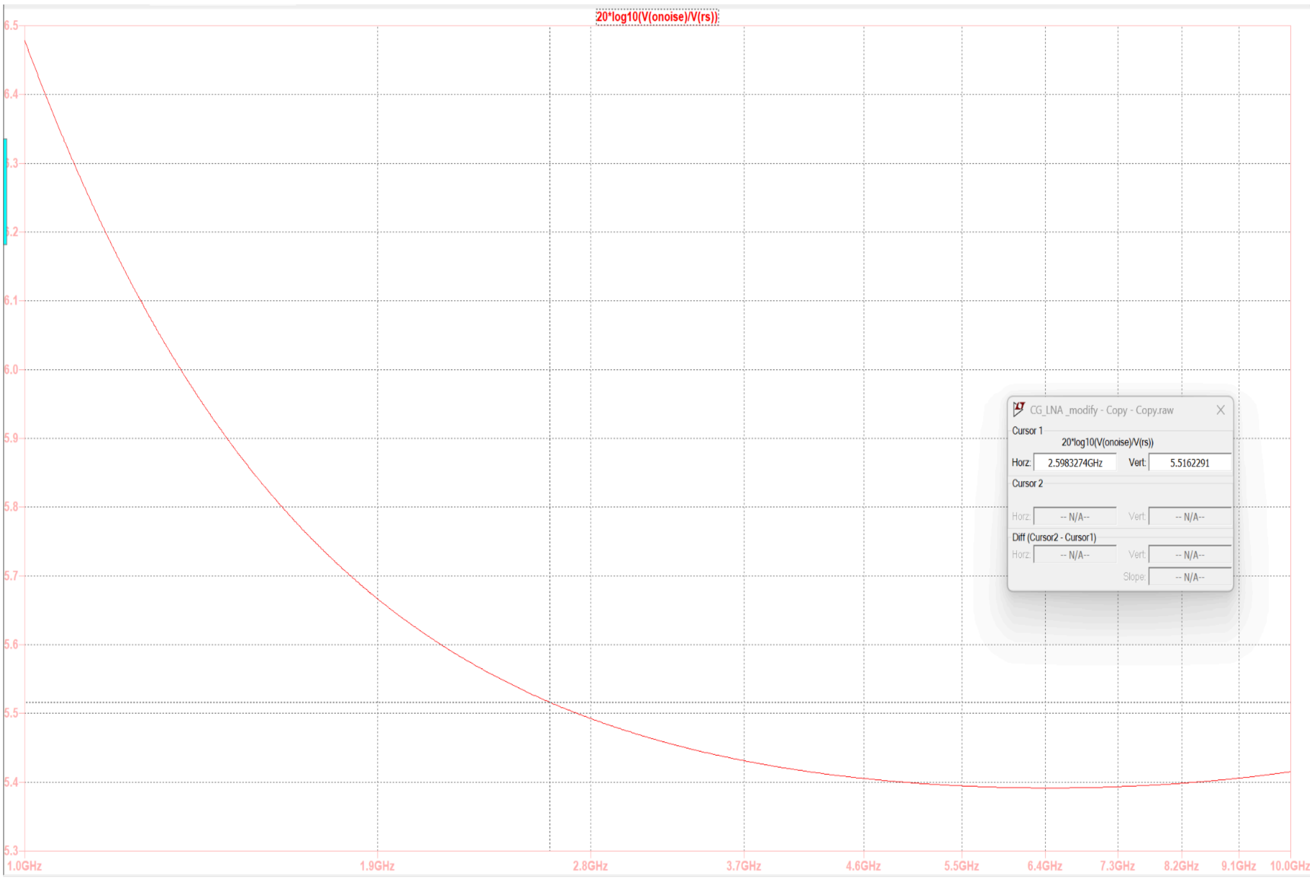
$\Rightarrow R_1 = 10(25.4 \cdot 10^{-9})(2\pi(2.4 \cdot 10^9))$

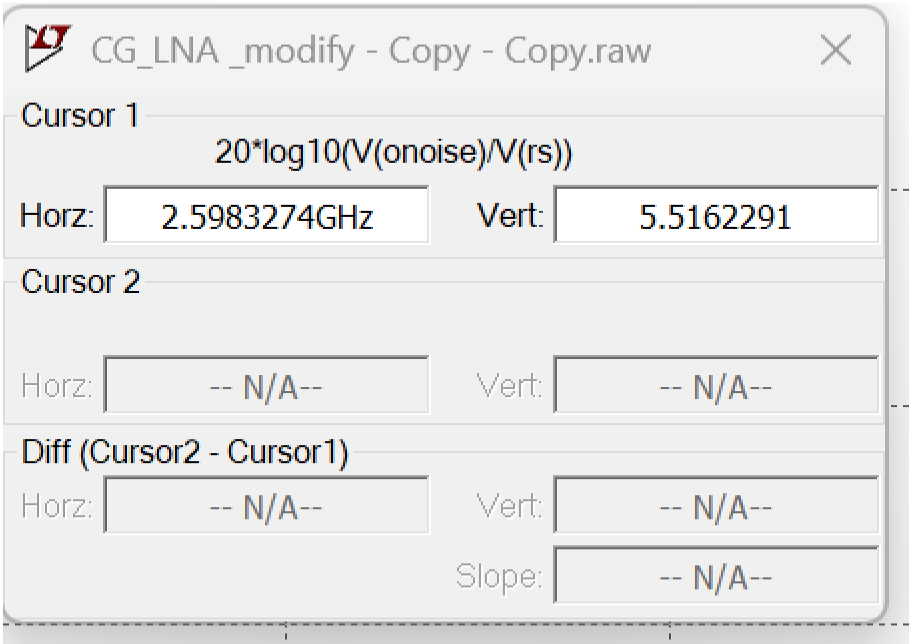
$\Rightarrow \boxed{R_1 = 3830\ \text{ohms.}}$

CG STAGE LNA DESIGN without ro effect:



NF from the simulation:





NF = 5.5

NF calculation from the theory:

without r_o chanel length.

1

$NF\ M_1 = 4KT\gamma/g_{m_1}\ A_v^2 / 4KTR_s A_v^2 = \boxed{\gamma}$

$NF_{M_2} = 4KT\gamma/g_{m_2} A_v^2$ but since r_o is large $\Rightarrow$ M_2 is negligible.

$NF_{R_1} = 4KTR_1 / 4KTR_s (A_v)^2 = \boxed{\dfrac{R_1}{R_s (A_v)^2}}$

$NF_{R_B} = 4KTR_B (A_v)^2 (R_s/2R_B)^2 / 4KTR_s (A_v)^2$

$$= \boxed{\frac{R_B}{R_s} (R_s/2R_B)^2}$$

Gain. (based on testbook p. 282) $\left(\dfrac{V_{out}}{V_{in}} = \dfrac{R_1}{2R_s} \right)$

$\rightarrow \dfrac{R_1}{2R_s} = \dfrac{6.3 \cdot 10^3}{2(50)} = 63 \leftarrow$ gain is too large.

$\Rightarrow NF_{M_1} = \boxed{\gamma}$

$$NF_{R_1} = \frac{R_1}{R_s\left(\frac{R_1}{2R_s}\right)^2} = \frac{R_1}{R_s\left(\frac{R_1^2}{4R_s^2}\right)} = \frac{R_1}{\frac{R_s R_1^2}{4R_s^2}} = \frac{1}{\frac{R_1}{4R_s}} = \boxed{\frac{4R_s}{R_1}}$$

$$NF_{R_B} = \frac{R_B}{R_s} \frac{R_s^2}{4R_B^2}$$

$$\Rightarrow \boxed{NF_{R_B} = \frac{R_s}{4R_B}}$$

$$\rightarrow NF_{total} = 1 + \gamma + \frac{4R_s}{R_1} + \frac{R_s}{4R_B}$$

$$NF_{total} = 1 + \frac{2}{3} + \frac{4(50)}{3.8 \cdot 10^3} + \frac{50}{4(25 \cdot 10^3)} \quad (2)$$

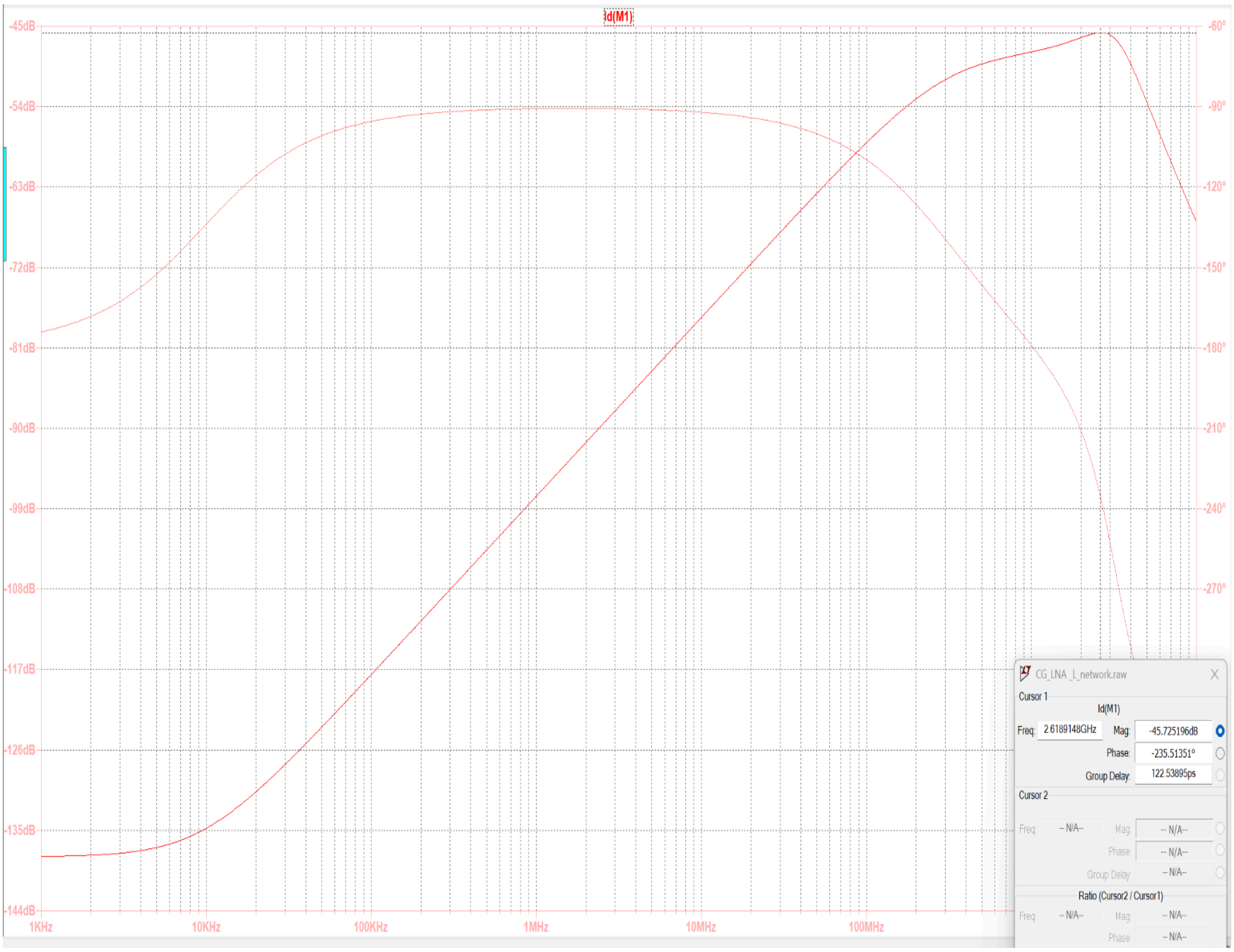
$$\Rightarrow NF_{total} = 1.72 \simeq \boxed{2.4\,dB}$$

NF = 2.4

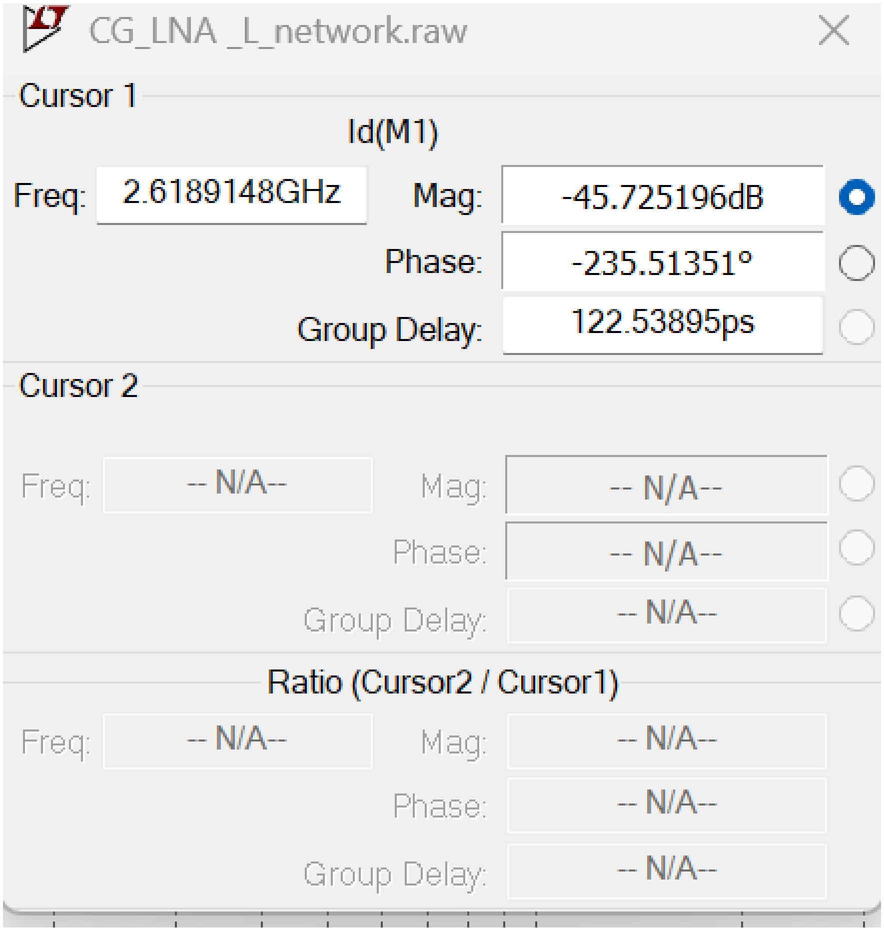
Since the NF from the simulation is too high (5.5 and 2.4), the difference is **3.1 dB.**
-> considered adding the L-matching network will reduce the noise figure of the LNA circuit
-> LNA CG stage design with the ro effect

CG STAGE LNA DESIGN with ro effect:

Finding ro:



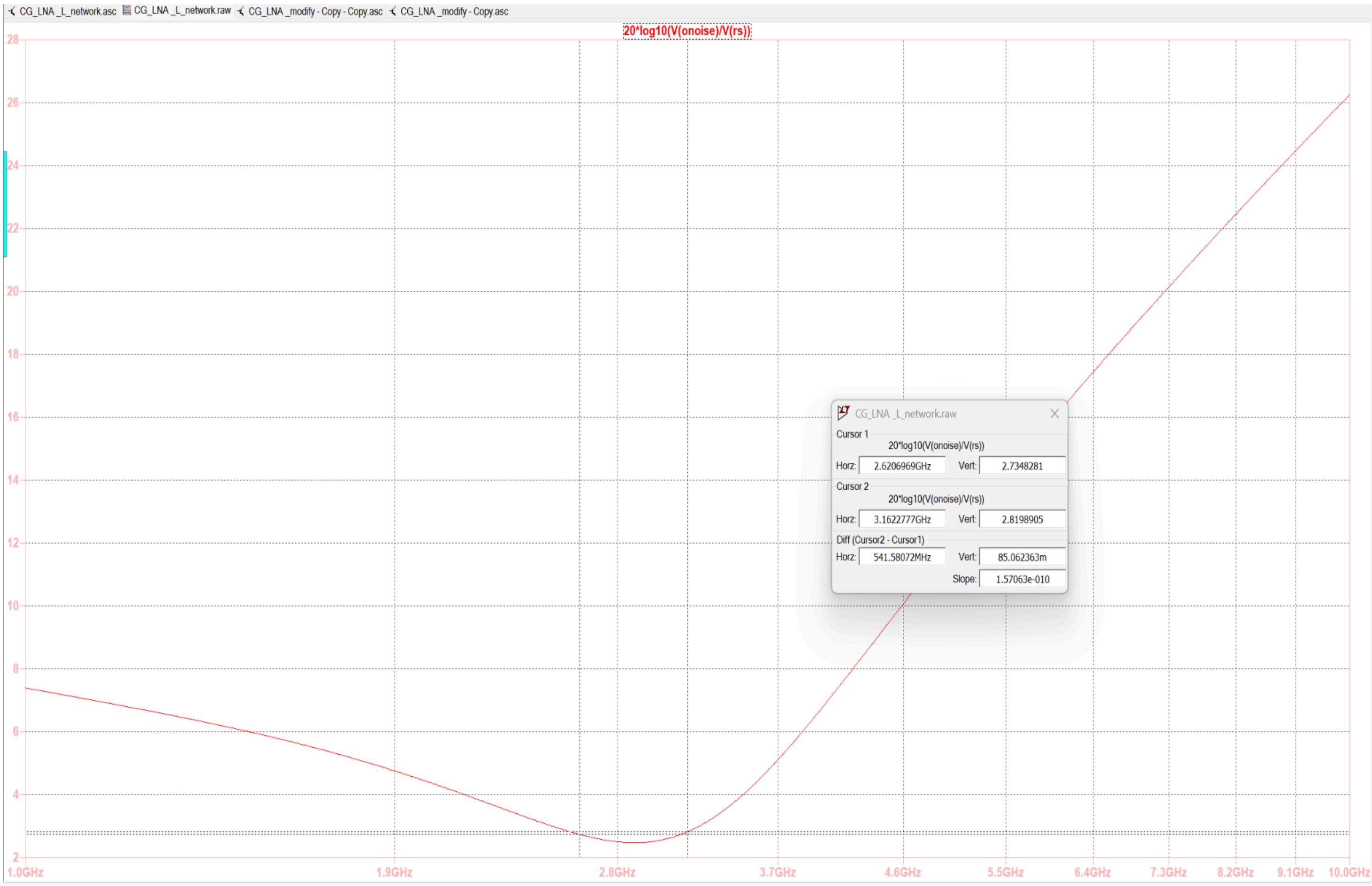
Id(M1)
-45dB
-54dB
-63dB
-72dB
-81dB
-90dB
-99dB
-108dB
-117dB
-126dB
-135dB
-144dB
-60°
-90°
-120°
-150°
-180°
-210°
-240°
-270°
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz
CG_LNA_L_network.raw
Cursor 1
Id(M1)
Freq: 2.6189148GHz
Mag: -45.725196dB
Phase: -235.51351°
Group Delay: 122.53895ps
Cursor 2
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--
Group Delay: --N/A--
Ratio (Cursor2 / Cursor1)
Freq: --N/A--
Mag: --N/A--
Phase: --N/A--

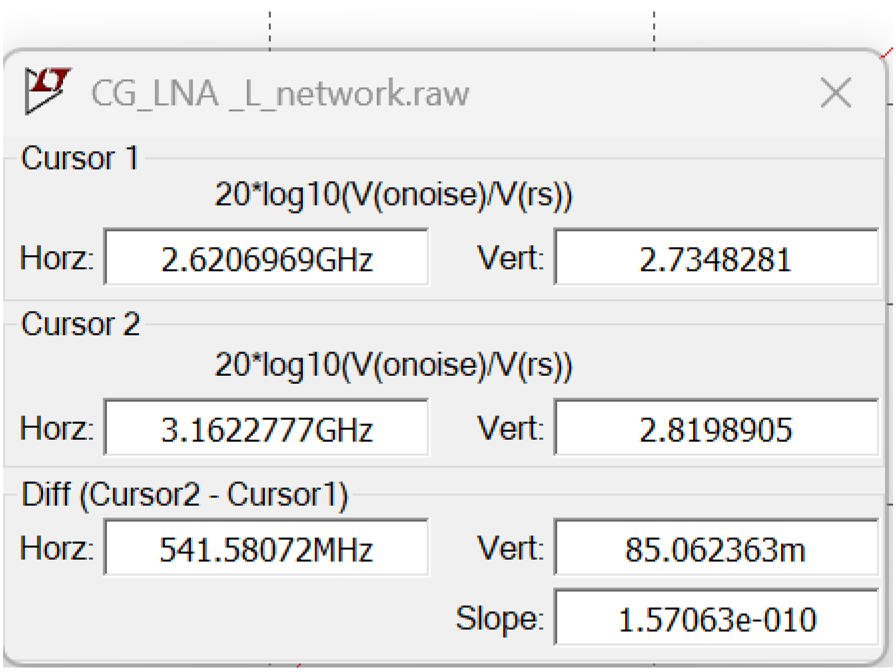


-45.8 = 20 *log(Id)
-> Id= 10^(-45/20) = **5.1*10^(-3)**

Finding the gain of the LNA from the simulation:

NF from the simulation:





NF = 2.73

NF from the theory:

Noise Figure

NF

①

For the NF of M1:

Thermal noise output $(4KT\varphi/gm_1)A_v^2$

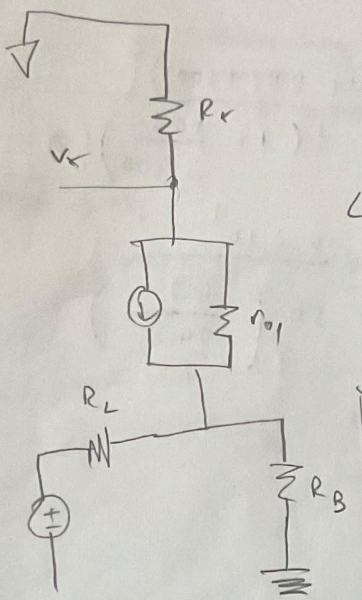
$$\Rightarrow \frac{\frac{4\cancel{KT}\varphi/gm_1\left(\frac{A_v}{2}\right)^2}{2}}{4\cancel{KT}R_S\,\cancel{A_v^2}}$$

$\langle V_{n,out,M}\rangle$

$R_S = \frac{1}{gm}$

$$\Rightarrow \frac{\varphi/gm}{4R_S} = \frac{\varphi}{4R_S\,gm} = \boxed{\frac{\varphi}{4}}$$

M1

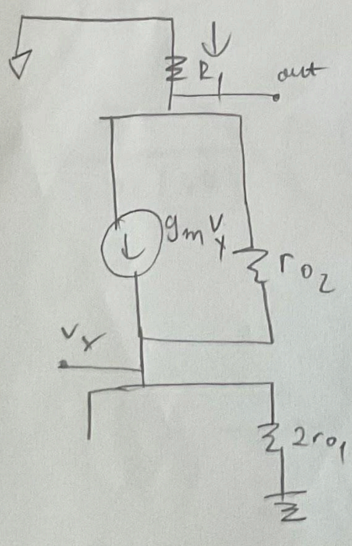


Since $R_B >> R_L \Rightarrow G_m = G_m(R_{in}/2R_B)$

$$\Rightarrow \langle V_{n,out,R_B}\rangle^2 = \frac{4KTR_B\left(G_m\frac{R_{in}}{2R_B}\right)^2}{4KTR_S\,G_m^2}$$

$$= \frac{R_B\,R_{in}^2}{4R_S R_B^2} = \boxed{\frac{R^2_{in}}{4R_S R_B}}$$

M2



$$\langle V_{n,out,r_{o2}}\rangle^2 = \boxed{4KT\varphi/gm_2\,A_v^2}$$

Since $v_x = 2.6\,GHz > 2.4\,GHz$

$\Rightarrow$ Source degeneration CS stage

$\Rightarrow V_{out} = V_x + I_2\,r_{o2}$

$I_{out} = gm\,v_{GS} + I_2$

$\Rightarrow I_2 = gm\,V_{GS} - I_{out}$

$\Rightarrow V_{out} = V_S + (gm\,V_{GS})\,r_{o2}$

$\Rightarrow V_{out} = (V_{in} - V_{GS}) + (gm\,V_{GS})\,r_{o2}$

$$\Rightarrow V_{out} = V_{in} - V_{GS} + g_m V_{GS}\, r_{o2}$$ (2)

$$\Rightarrow V_{out} = V_{in} - V_{GS}(1 + g_{m2} r_{o2}).$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{g_{m2} r_{o2} R_1}{R_1 + 2r_{o1} + r_{o2} + g_{m2} r_{o2} 2r_{o1}} = A_V$$

$\rightarrow$ NF of M_2:

$$\Rightarrow \frac{4KT\gamma/g_{m2}\left(\dfrac{g_{m2} r_{o2} R_1}{R_1 + 2r_{o1} + r_{o2} + g_{m2} r_{o2} 2r_{o1}}\right)^2}{4KTR_S\left(\dfrac{(1+g_{m2} r_{o2})(1+g_{m1} r_{o1})}{\left(1+\dfrac{r_{o2}}{R_{out}}\right)\left(2+\dfrac{2r_{o1}}{R_X}\right)}\right)^2}.$$

$$\Rightarrow \frac{\gamma}{g_{m2} R_S}\left(\frac{A_V}{G_m}\right)^2. \qquad R_X = \frac{R_1 + r_{o2}}{1 + g_{m2} r_{o2}} \approx \frac{R_1}{g_{m2} r_{o2}}$$

$$\cancel{\Rightarrow \frac{\frac{2}{3}}{0.02(50)}\left(\frac{(1+0.02.(300))(1+0.02.300)}{\left(1+\frac{300}{2(300)}\right)\left(2+\frac{2(300)}{\frac{6.3.10^3}{0.02(300)}}\right)}\right)^2}$$

$$\cancel{= \frac{2}{3}\left(\frac{49}{\frac{3}{2}\left(2+\frac{2.300}{1050}\right)}\right) = \frac{2}{3}\left(\frac{49}{\frac{3}{2}\left(\frac{18}{7}\right)}\right)}$$

$$\cancel{= \frac{2}{3}\left(\frac{49}{\frac{27}{7}}\right)^2 = 107.59.}$$

(3)

$$NF_{R_1} = \frac{4KTR_1}{4KTR_S(G_m)^2} = \frac{R_1}{R_S(G_m)^2}$$

$$= \frac{3.8.10^3}{50(15.1)^2}$$

$$= \boxed{0.33}$$

$$NF_{M_1} = \frac{4}{4} = \frac{\frac{2}{3}}{4} = \boxed{\frac{1}{6}}$$

$$NF_{R_B} = \frac{163.9^2}{4(50)(2.5.10^3)}$$

$$\Rightarrow \boxed{NF_{R_B}} = \boxed{0.054}$$

$$R_{in} = \frac{1}{g_{m_1}} + \frac{R_1}{g_{m_1}r_{o_1}g_{m_2}r_{o_2}} + \frac{1}{g_{m_1}r_{o_1}g_{m_2}}$$

$$\Rightarrow R_{in} = \frac{1}{0.02} + \frac{3.8.10^3}{0.02(300)(0.02)(300)}$$

$$+ \frac{1}{0.02(300)(0.02)}$$

$$\Rightarrow R_{in} = 50 + 105.56 + 8.33.$$

$$\Rightarrow R_{in} = 163.9.$$

$$NF_{M_2} = \frac{4}{g_{m_2}R_S}\left(\frac{A_v}{G_m}\right)^2$$

$$A_v = \frac{g_{m_2} r_{o_2} R_1}{R_1 + 2r_{o_1} + r_{o_2} + g_{m_2}r_{o_2}2r_{o_1}}.$$

$$\Rightarrow A_v = \frac{0.02(300)(3.8.10^3)}{3.8.10^3 + 2(300) + 300 + 0.05(300)2(300)}$$

$$\Rightarrow A_v = \frac{22800}{13700} = \boxed{1.66}$$

4

$$\Rightarrow NF_{M_2} = \frac{\frac{2}{3}}{0.02(50)} \left(\frac{1.66}{15.1}\right)^2$$

$$\Rightarrow NF_{M_2} = \frac{2}{3} \cdot 0.012$$

$$\Rightarrow \boxed{NF_{M_2} = 8 \cdot 10^{-3}}$$

$$NF_{total} = 1 + NF_{M_1} + NF_{M_2} + NF_{R_B} + NF_{R_1}$$

$$= 1 + \frac{1}{6} + 8 \cdot 10^{-3} + 0.054 + 0.33$$

$$= \boxed{1.56}$$

NF= 1.56

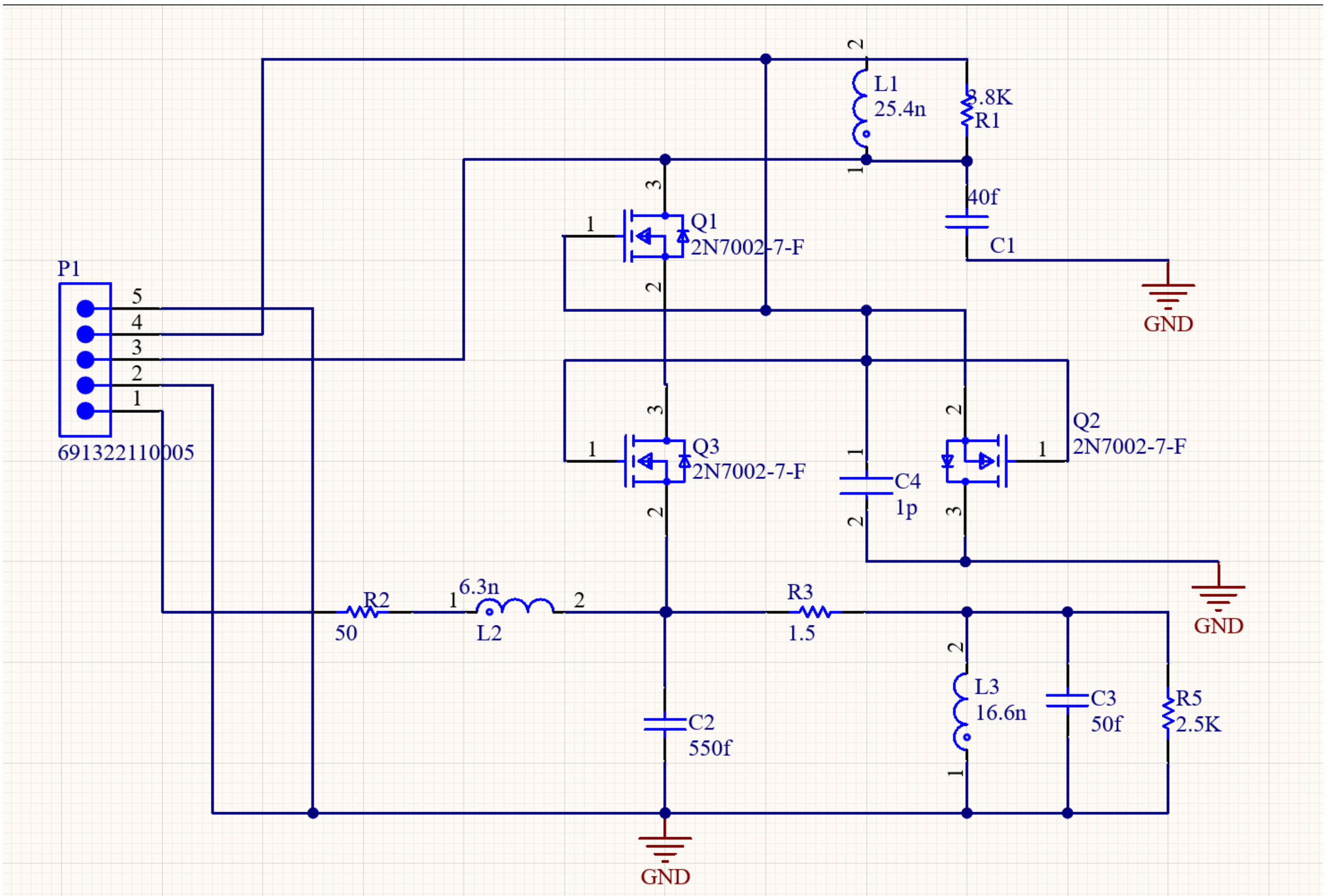
-> The difference between the NF from the simulation and the theory:

2.73-1.56 = **1.17 dB**

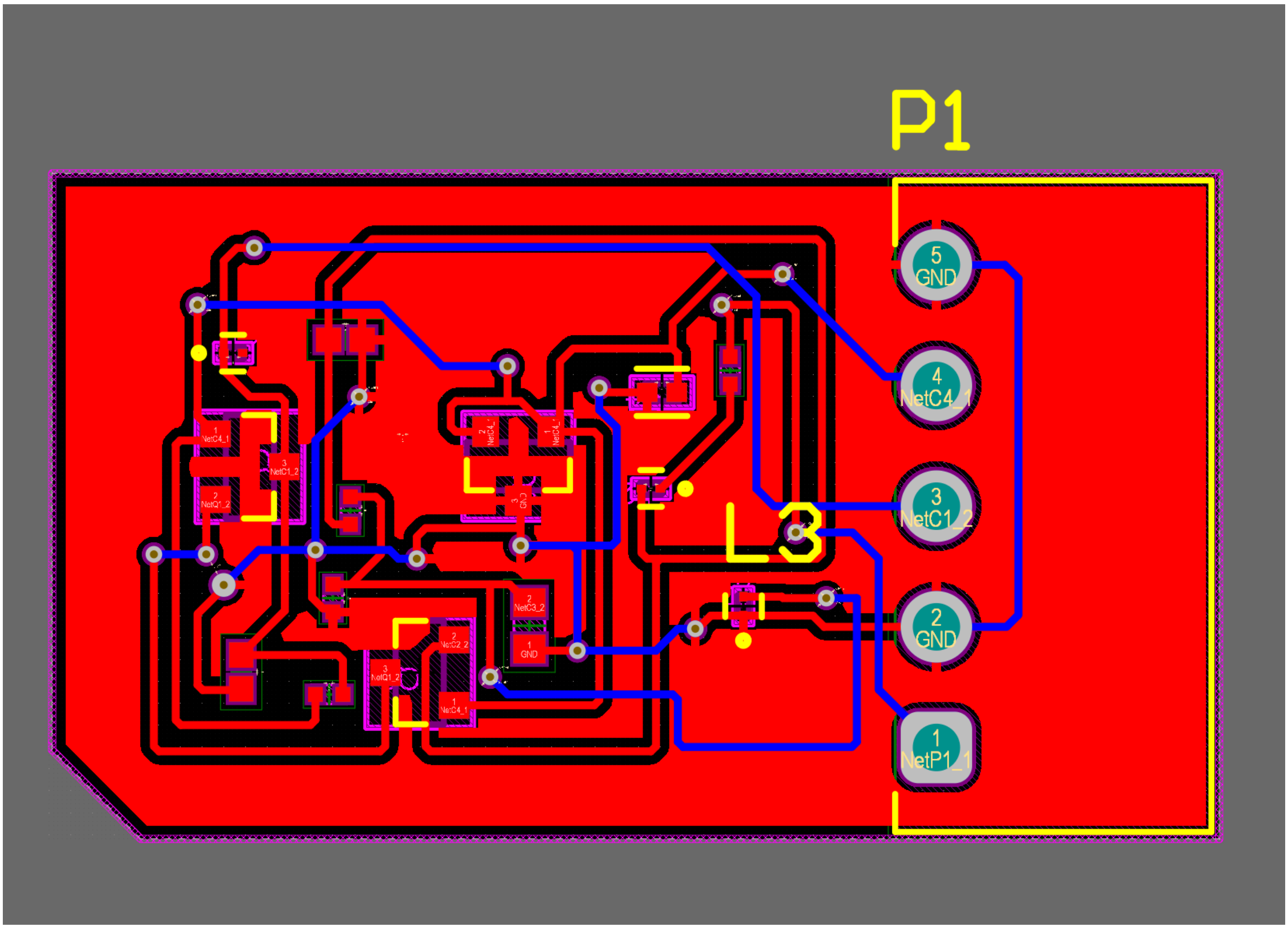
As the observation between the NF of CG Cascode LNA with ro effect and without ro effect, the ro effect will reduce the noise figure significantly compares to CG Cascode LNA without ro effect.

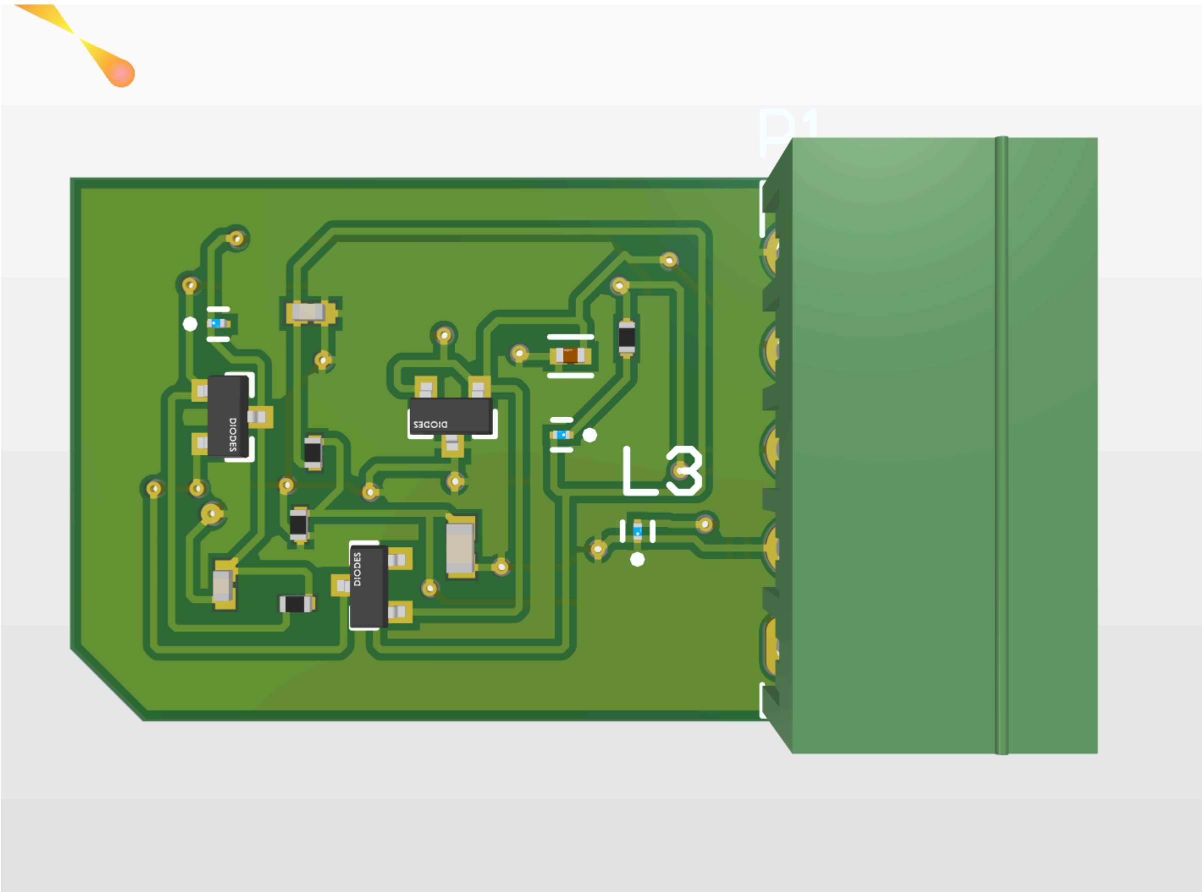
Altium design for LNA CG Stage

For the schematic design:



For the PCB Design:


P1
L3
5
GND
4
NetC4_1
3
NetC1_2
2
GND
1
NetP1_1


P1
L3
DIODES
DIODES
DIODES

HANDS-DRAWING LAYOUT:

FOR THE WIDTH AND LENGTH:

Based on RF Microelectric textbook reference from Behzad Razavi

$W_1 = W_2$, such a structure can be expanded to one with multiple gate fingers.

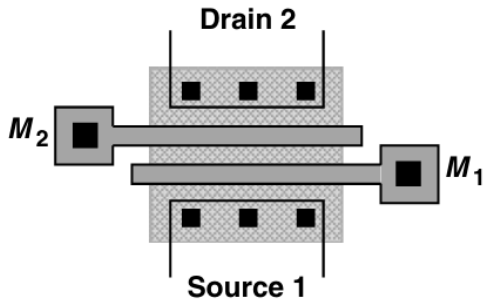


Figure 5.27 *Layout of cascode devices.*

L= 180e-9
W= 81e-6

FOR THE INDUCTOR:

Chap. 7.

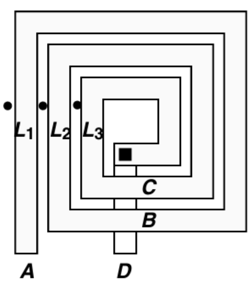
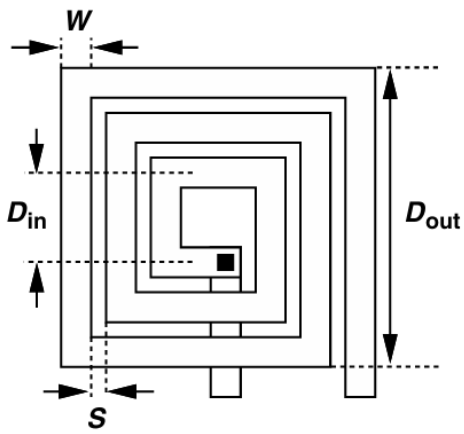


Figure 7.4 *Simple spiral inductor.*



$$l_{tot} \approx 4N[D_{out} - W - (N-1)(W+S)]. \qquad (7.12)$$

$$L \approx 1.3 \times 10^{-7} \frac{l_{tot}^{5/3}}{\left[\frac{l_{tot}}{4N} + W + (N-1)(W+S)\right]^{1/3} W^{0.083}(W+S)^{0.25}}. \qquad (7.15)$$

For the optimal width of M_2.

$\Rightarrow$ L and w of M_2 equals to L and w of M_1

For the inductor design: $D_{out} \simeq 200\mu m$ as the pitch with $N = 3$, $w = 4\mu m$, and $S = 0.5\mu m$.

$$l_{total} = 4N\left[D_{out} - w - (N-1)(w+s)\right]$$

$$= 4(3)\left[200\mu m - 4\mu m - (3-1)(4\mu m + 0.5\mu m)\right]$$

$$= 2244\mu m$$

$$\Rightarrow L = 1.3.10^{-7} \frac{l_{total}^{5/3}}{\left(\frac{l_{total}}{4N} + w + (N-1)(w+s)\right) w^{0.083} (w+s)^{0.25}}$$

$$\Rightarrow L = 1.3.10^{-7} \frac{(2244\mu m)^{\frac{5}{3}}}{\left(\frac{2244\mu m}{4(3)} + 4\mu m + (3-1)(4\mu m + 0.5\mu m)\right)(4\mu m)^{0.083}(4\mu m + 0.5\mu m)^{0.25}}$$

$$\Rightarrow L = 1.3.10^{-7} \frac{(2244\mu m)^{\frac{5}{3}}}{(187\mu m + 13\mu m)(4\mu m)^{0.083}(4.5\mu m)^{0.25}}$$

$$\Rightarrow L = 1.3.10^{-7} \frac{(2244\mu m)^{\frac{5}{3}}}{326\mu m}$$

$$\Rightarrow L = 1.3.10^{-7} \frac{2224.4\mu m}{143.47\mu m} = (1.3.10^{-7})\, 0.118$$

$$= 1.53\, 10^{-8}\ H$$

Increase N = 4 will give the L, closed to the simulation (41nH).

$N = 4$

$\Rightarrow l_{total} = 2920\,\mu m.$

$$L = 1.3\,(10^{-7})\,\frac{(2920\,\mu m)^{\frac{5}{3}}}{200\,(4)^{0.083}\,(4.5)^{0.25}\,(\mu m)}.$$

$$\Rightarrow L = (1.3 \cdot 10^{-7})\left(\frac{5.66 \cdot 10^{-5}}{327 \cdot 10^{-6}}\right)$$

$$\Rightarrow L = 2.4 \cdot 10^{-8}$$

$\Rightarrow$ with $n = 4$, the result of L_1 is very closed to the simulation.

$(2.4 \cdot 10^{-8} \sim 4.1 \cdot 10^{-8})$

Since using the same width, spacing, and metal layers,
assuming $L_1 = L_B = 2.4 \cdot 10^{-8}$ with $N = 4$

->L= 2.4*10^-8 H

FOR CAPACITOR:

oxide thickness of **200nm** and dielectric constant **3.9**

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

For the capacitor:

$100\mu m \times 100\mu m =$

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}.$$

$$\Rightarrow C = \frac{(8.854 \cdot 10^{-12})(3.9)(100\mu m)^2}{200\,(10^{-9})}$$

$$\Rightarrow \boxed{C = 1.72 \cdot 10^{-12}} = 17.2 \cdot 10^{-13} \simeq 17.2f \rightarrow C_3.$$

For the current I_{ref}:

$$I_{ref} = R = V_{dd} - V_{gs\,bias}.$$

$$= 1.5 - 0.814709.$$

$$= 0.685 = R$$

C= 17.2fF

FOR BOND-WIRE PADS:

100um x 100um squares placed at 200um pitch (center to center)

FOR THE DIE SIZE:

allow a minimum of 2mm long bond wire;

FOR Iref current using resistor instead:

Iref = R = 0.685

(Vdd - Vgs of bias transistor).

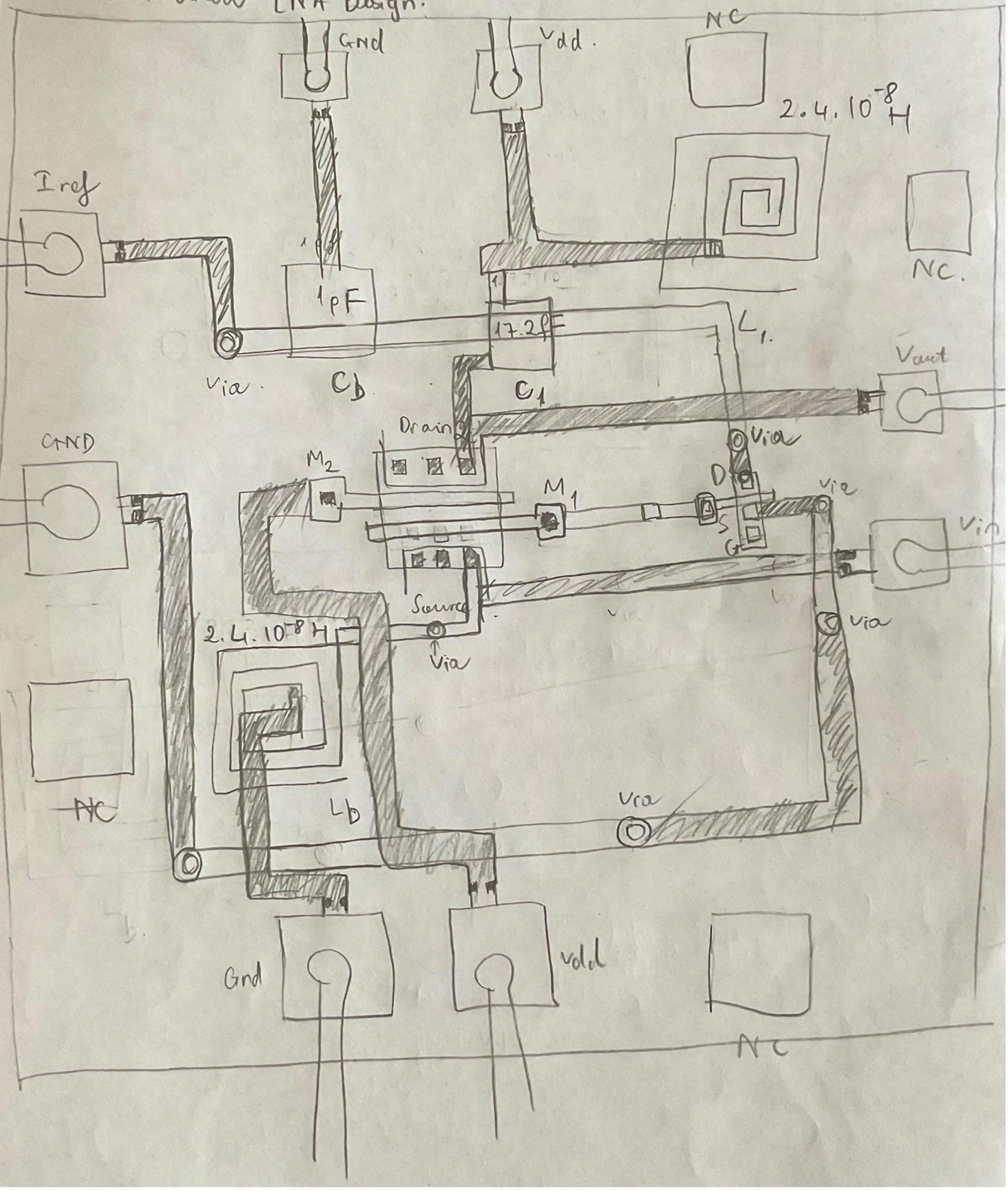
FOR DECOUPLING CAPACITOR:

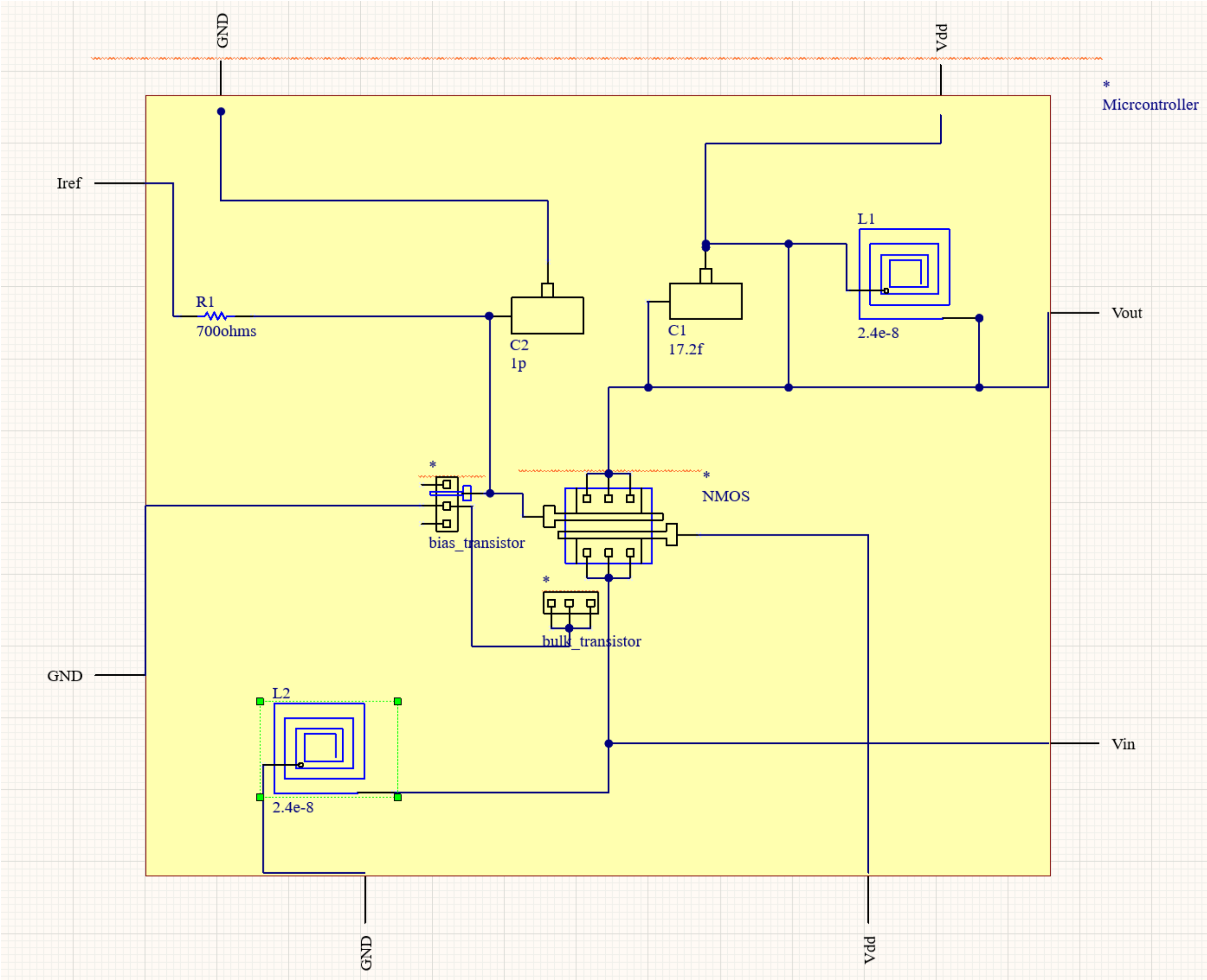
1-3pF capacitor is used for decoupling of bias line;

Cb= 1pF

Schematic:

Hand-draw LNA Design.




GND
Vdd
*
Micrcontroller
Iref
L1
R1
700ohms
C2
1p
C1
17.2f
2.4e-8
Vout
*
*
NMOS
bias_transistor
*
bulk_transistor
GND
L2
2.4e-8
Vin
GND
Vdd