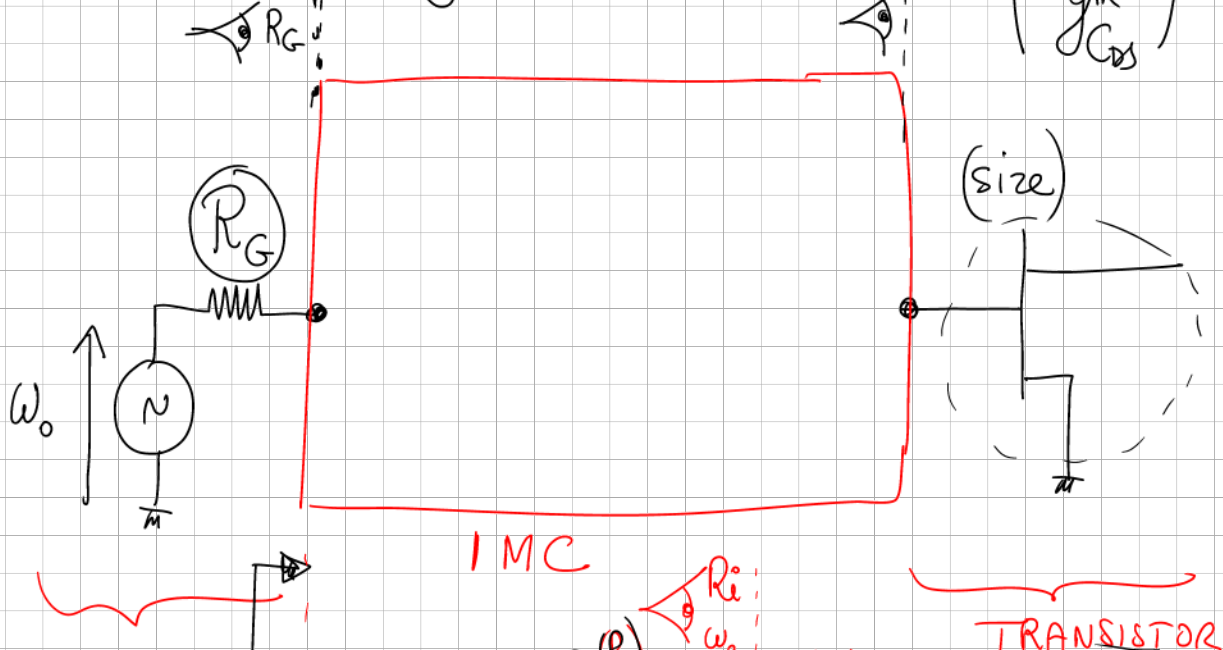
Matching principles of narrow-band amplifiers At high frequencies

Université de Limoges
UNIVERSITÀ DEGLI STUDI DI BRESCIA
Aston University
Universidad del País Vasco Euskal Herriko Unibertsitatea The University of the Basque Country
UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA

1 Input matching circuit @ ω_0

$$\begin{pmatrix} R_i \\ C_{GS} \\ R_{DS} \\ g_m \\ C_{DS} \end{pmatrix}$$

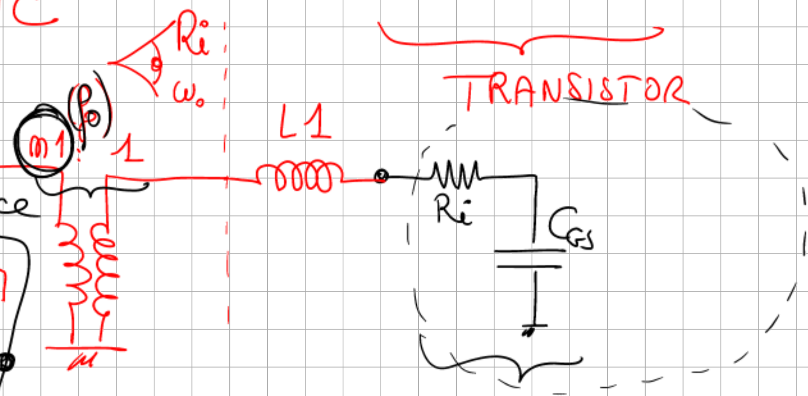
$$Z_{LC} = jL\omega + \frac{1}{jC\omega} = j\left(L\omega - \frac{1}{C\omega}\right)$$



Power Matching of source

$R_G^* = R_G$

$$\boxed{m_1 = \sqrt{\frac{R_G}{R_i}}}$$



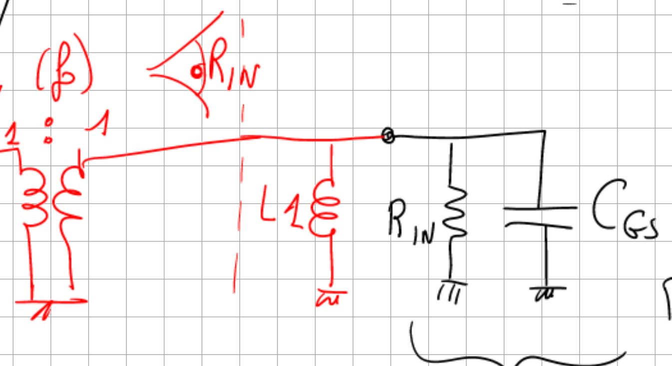
$$\boxed{L_1\omega_0 = \frac{1}{C_{GS}\omega_0}}$$

1st solution

narrowband

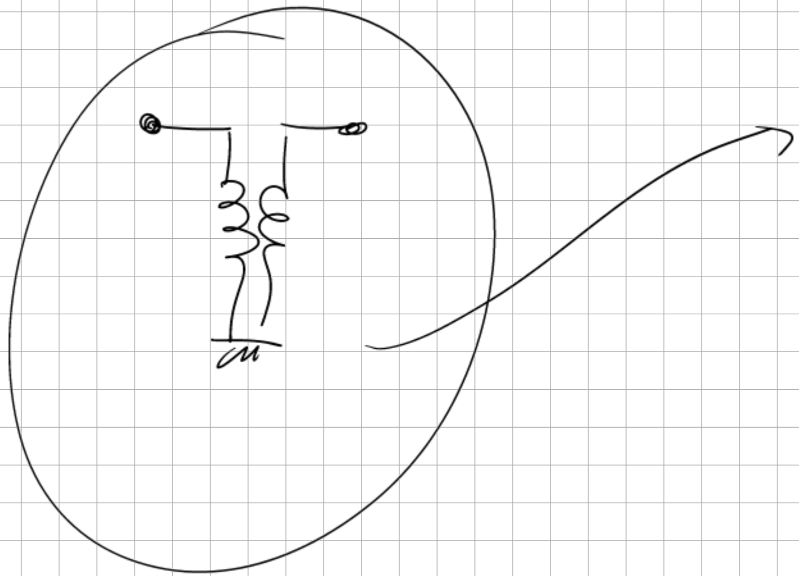
selection criterion

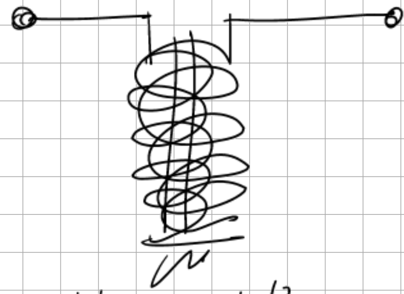
$$\boxed{m_1' = \sqrt{\frac{R_G}{R_{IN}}}}$$



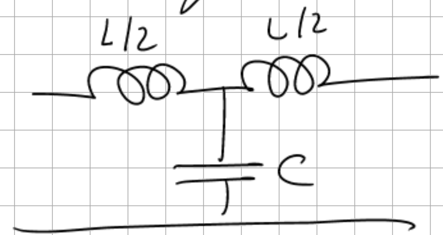
2nd solution

$$R_{IN} = \frac{1}{R_i C_{GS}^2 \omega^2}$$

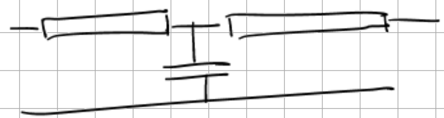




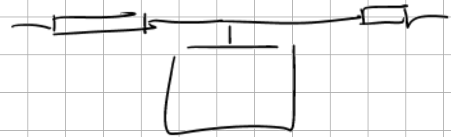
10 MHz



1GHz *



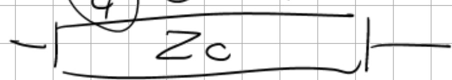
10 GHz



30 GHz

$$\lambda = \frac{v}{f}$$

$\frac{\lambda}{4}$ $\theta = \pi/2$



40 G

$$Z_C = \sqrt{R_G R_i}$$

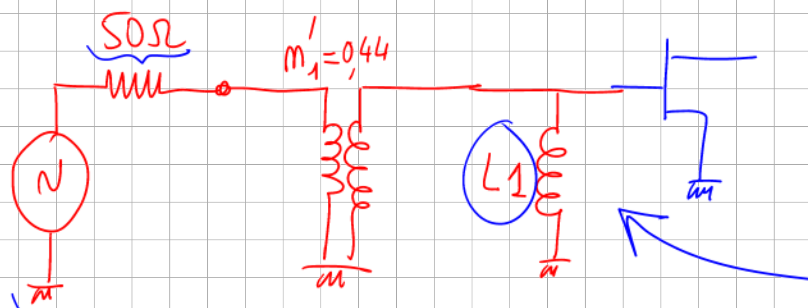
examples

$f_0 = 10\,GHz$

$R_i = 4\,\Omega$

$C_{gs} = 0.5\,pF$

$$\longrightarrow R_{IN}(10\,GHz) = \frac{1}{R_i\, C_{gs}^2\, \omega_0^2} = \frac{1}{4 \times (0{,}5\,10^{-12} \times 2\pi \times 10^{10})^2} = 253\,\Omega$$



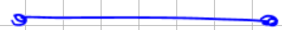
$$L_1 = \frac{1}{C_{gs}\, \omega_0^2} = \frac{1}{0{,}5\,10^{-12} \times (2\pi\, 10^{10})^2}$$

$$= 0{,}5\ mH$$

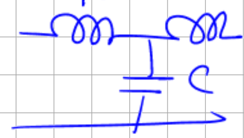
$m_1 \qquad \frac{1}{m_1}$

- 1st solution R_i: $\quad m_1 = \sqrt{\frac{50}{R_{i0}}} = \sqrt{\frac{50}{4}} = \cancel{3{,}53} \rightarrow \frac{1}{3{,}53} = \cancel{0{,}28}$
- 2nd solution R_{IN0}: $\quad m'_1 = \sqrt{\frac{50}{R_{IN0}}} = \sqrt{\frac{50}{253}} = 0{,}44 \rightarrow \frac{1}{0{,}44} = 2{,}27 \Longrightarrow$ Best choice

$m = 1$

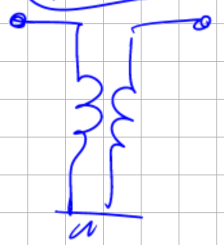


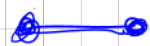
$m = 0{,}8$



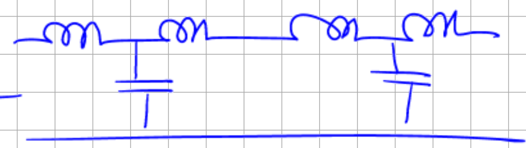
$\cancel{m = 0}$

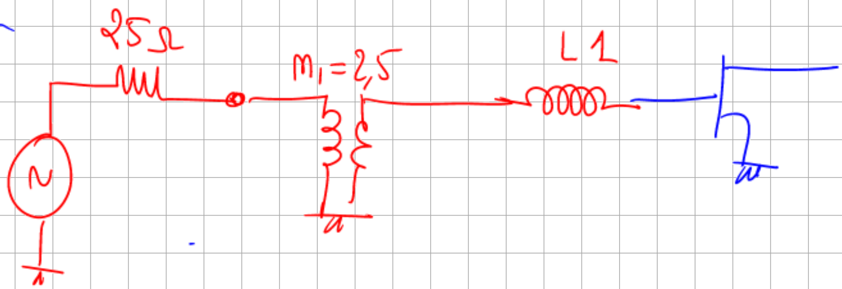
$m = 1$





$m = 0{,}4 \Longleftarrow$





$R_L \Rightarrow m_1 = \sqrt{\frac{25}{4}} = 2,5 \rightarrow \frac{1}{2,5} = 0,4 \rightarrow$ Best choice

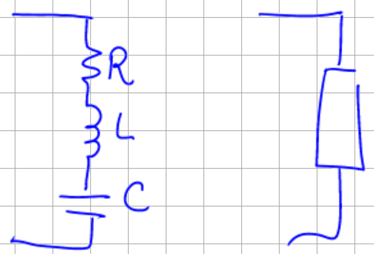
$R_{IN} \Rightarrow m'_1 = \sqrt{\frac{25}{253}} = 0,3$

Digression

$\Downarrow$

Quality factors of series and parallel resonant circuits

1 Series RLC circuit

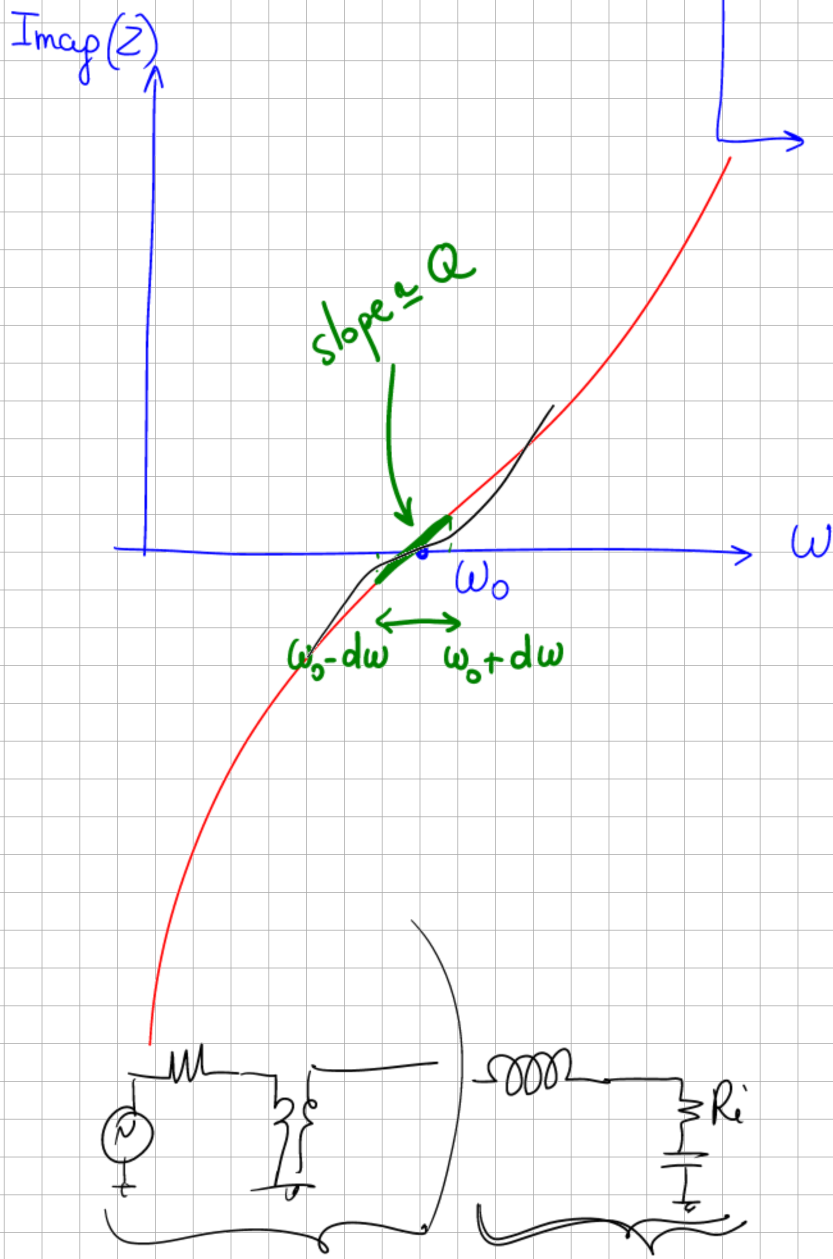


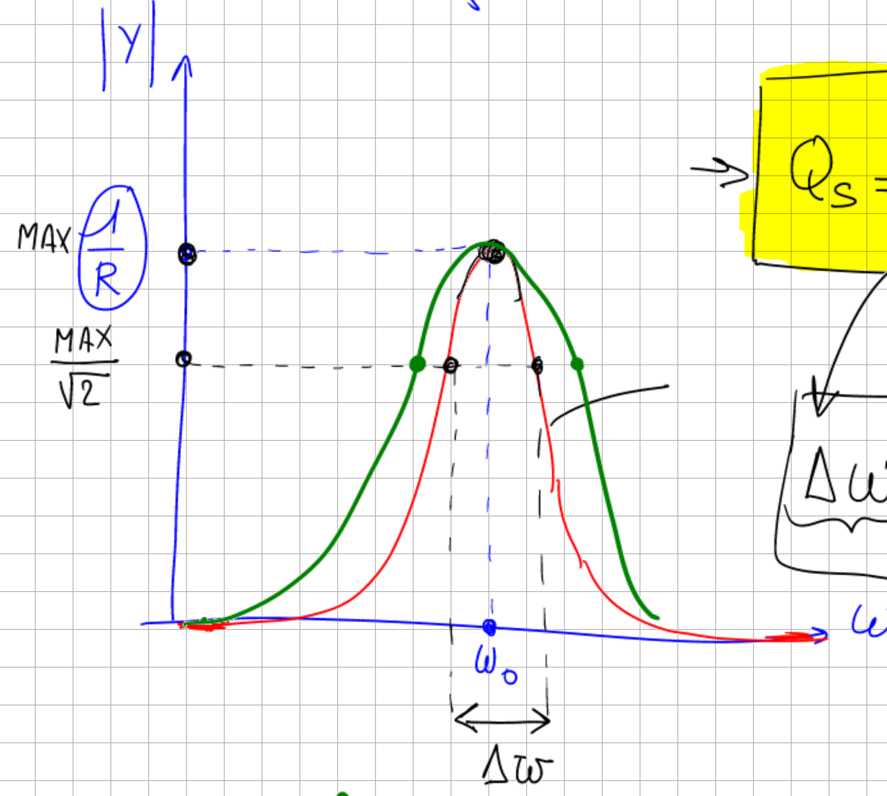
$$Z = R + j\left(L\omega - \frac{1}{C\omega}\right)$$

→ resonant frequency f_0: $\boxed{\mathrm{Imag}(Z(\omega_0)) = 0}$ $\boxed{Z(\omega_0) = R + j0}$

$$\rightarrow L\omega_0 = \frac{1}{C\omega_0} \rightarrow \omega_0 = \frac{1}{\sqrt{LC}} \rightarrow \boxed{f_0 = \frac{1}{2\pi\sqrt{LC}}}$$

→ quality factor → $\boxed{Q_s = \frac{L\omega_0}{R} = \frac{1}{RC\omega_0}}$





$$\boxed{Q_s = \frac{\omega_0}{\Delta\omega}}$$

$$\boxed{\underbrace{\Delta\omega\uparrow}_{} = \frac{\omega_0}{Q_s\downarrow}}$$

if $Q_s \downarrow$

$$Z = R + j\left(L\omega - \frac{1}{C\omega}\right) = R\left[1 + j\,\frac{1}{R}\left(L\omega - \frac{1}{C\omega}\right)\right]$$

$$= R\left[1 + j\,\frac{L\omega_0}{R}\left(\frac{L\omega}{L\omega_0} - \frac{1}{L\omega_0 C\omega}\right)\right]$$

$$= R\left[1 + j\,Q_s\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right]$$

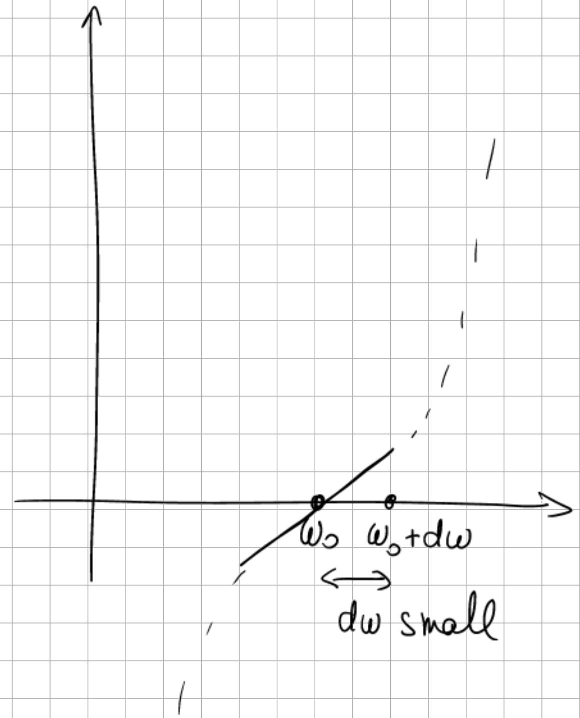
$$= R\left[1 + j\,Q_s\,\frac{\omega^2 - \omega_0^2}{\omega\,\omega_0}\right]$$

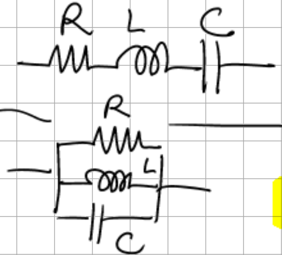
$$LC\omega_0^2 = 1 \;\longrightarrow\; \frac{1}{LC\omega_0} = \omega_0$$

$$\lim_{\omega \to \omega_0} Z = R\left[1 + j\,Q_s\,\frac{\overset{2\omega_0}{(\omega+\omega_0)}\,\overset{d\omega}{(\omega-\omega_0)}}{\underbrace{\omega\,\omega_0}_{\omega_0^2}}\right]$$

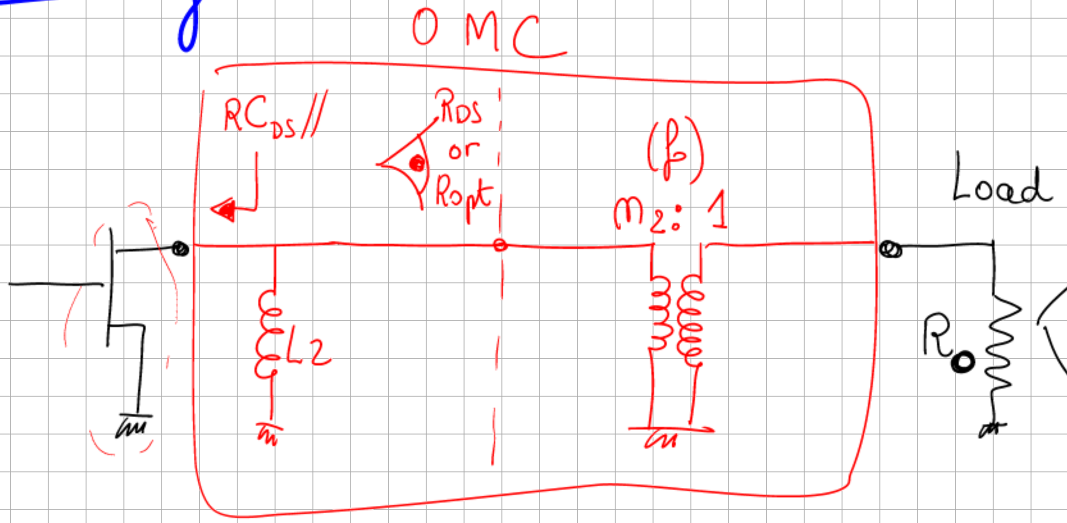
$$\omega = \omega_0 + d\omega$$

$$= R\left[1 + j\,\underbrace{2Q_s\,\frac{d\omega}{\omega_0}}\right]$$



Series		$f_0 = \frac{1}{2\pi\sqrt{LC}}$	$Q_S = \frac{L\omega_0}{R} = \frac{1}{RC\omega_0}$
Parallel resonant circuit			$Q_P = \frac{R}{L\omega_0} = RC\omega_0$

2) Output matching circuit



1st solution

$R_L = R_{DS} \Rightarrow \begin{cases} G_{max} \\ \text{Reduced Power} \end{cases}$

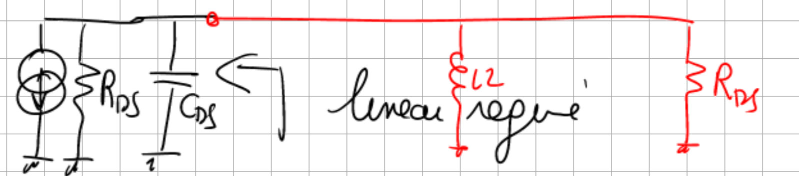
$m_2 = \sqrt{\dfrac{R_{DS}}{R_0}}$

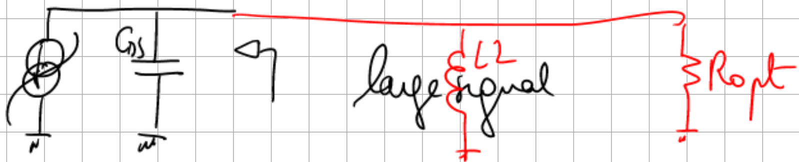
2nd solution $\rightarrow \begin{cases} P_{OUT\,MAX} \\ \text{reduced gain} \end{cases}$

$R_L = R_{opt}$

$m_2 = \sqrt{\dfrac{R_{opt}}{R_0}}$

$$\boxed{L_2 = \frac{1}{C_{DS}\,\omega_0^2}}$$





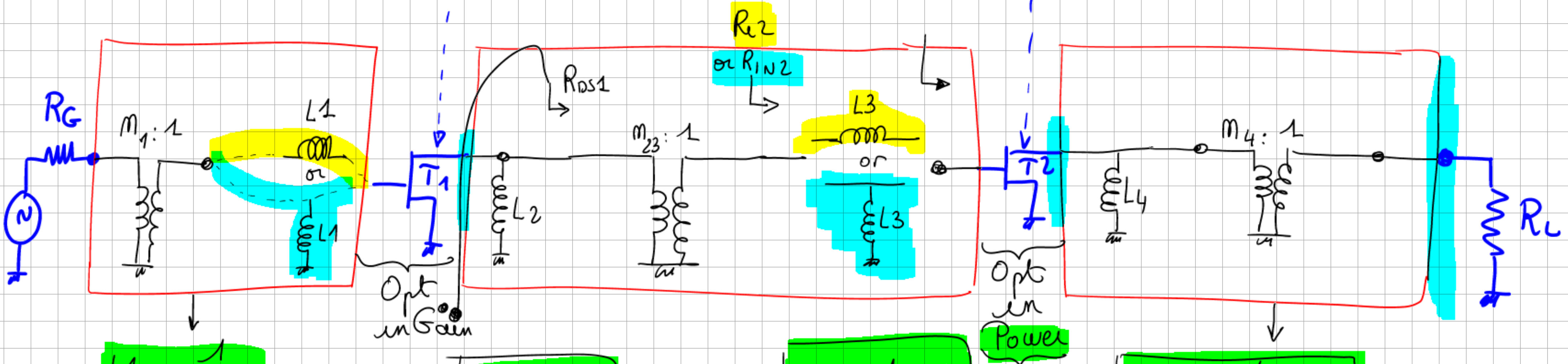
③ Interstage matching

C_{gs1}, C_{DS1}, g_{m1} ; R_{i1}

$\hookrightarrow R_{IN1} = \dfrac{1}{R_{i1} C_{gs1}^2 \omega_0^2}$

C_{gs2} ; R_{i2}

$\hookrightarrow R_{IN2} = \dfrac{1}{R_{i2} C_{gs2}^2 \omega_0^2}$



$$L1 = \frac{1}{C_{gs1}\,\omega_0^2}$$

$$\boxed{L_2 = \frac{1}{C_{DS1}\,\omega_0^2}}$$

$$\boxed{L_3 = \frac{1}{C_{gs2}\,\omega_0^2}}$$

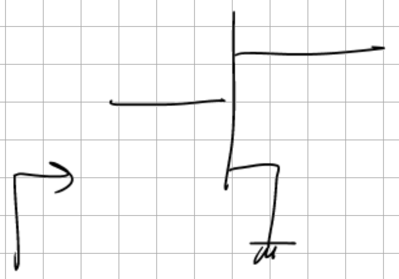
$$\boxed{L4 = \frac{1}{C_{DS2}\,\omega_0^2}}$$

$$m_4 = \sqrt{\frac{R_{opt_2}}{R_L}}$$

$$R_{IN1} = \frac{1}{R_{i1}\; C_{gs1}^2\; \omega_0^2}$$

$$m_1 = \sqrt{\frac{R_G}{R_{i_1}}} \quad \text{or} \quad m_1 = \sqrt{\frac{R_G}{R_{IN1}}}$$

$$m_{23} = \sqrt{\frac{R_{DS1}}{R_{i2}}} \quad \text{or} \quad m_{23} = \sqrt{\frac{R_{DS1}}{R_{IN2}}}$$



@ the input

$R_i \; L_1 \; C_{gs}$ series circuit $\longrightarrow$ $\boxed{Q_{IN} = \dfrac{1}{R_i \, C_{gs} \, \omega_0}}$ whatever the size!

or whatever the matching // or series

$R_i \rightarrow \dfrac{R_i}{n}$, $C_{gs} \rightarrow n\,C_{gs}$

$R_{IN} \; L1 \; C_{gs}$ // circuit $\longrightarrow$

$$Q_{//} = R_{IN} \, C_{gs} \, \omega_0 = \frac{1}{R_i \, C_{gs}^{\cancel{2}} \, \omega_0^{\cancel{2}}} \times \cancel{C_{gs}} \, \cancel{\omega_0} = \frac{1}{R_i \, C_{gs} \, \omega_0} = Q_{IN}$$

@ the output

$\hookrightarrow$ $R \; L2 \; C_{DS}$ // circuit

$\hookrightarrow$ R_{DS} or R_{opt}

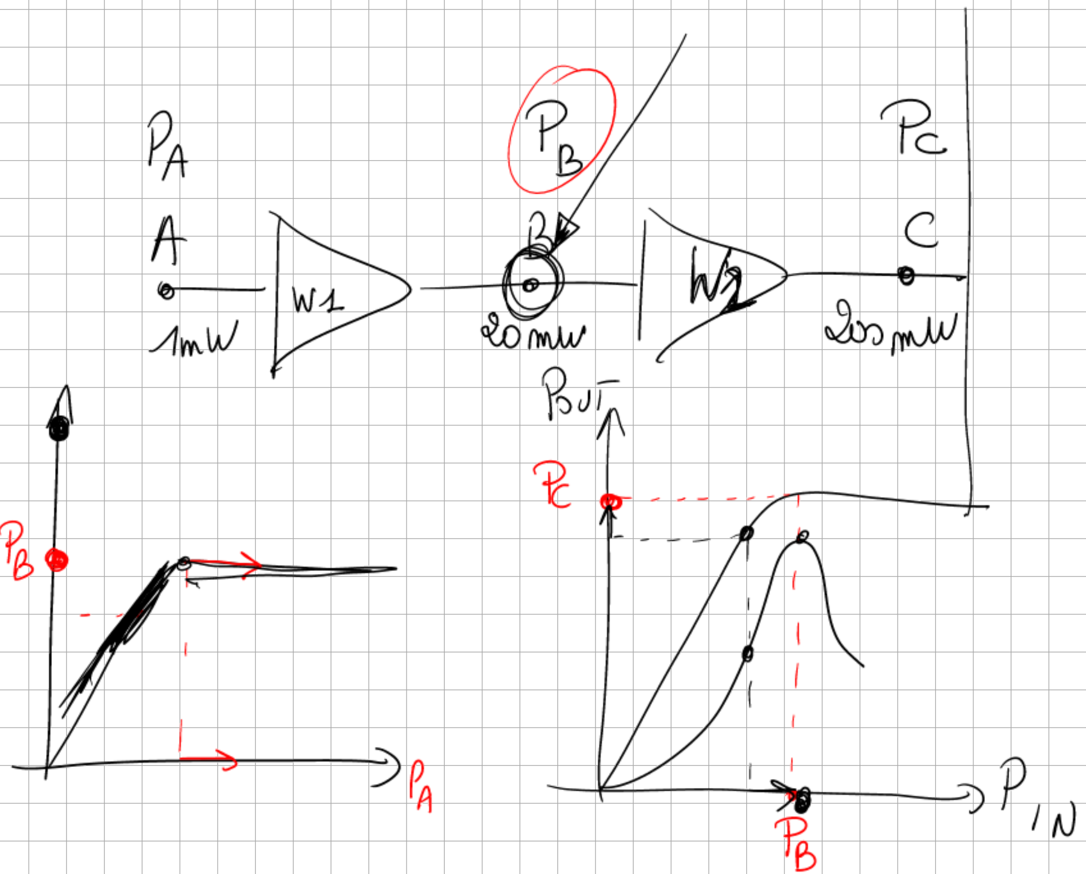
$$\boxed{Q_{OUT\,(R_{DS})} = R_{DS} \, C_{DS} \, \omega_0}$$

$R_{DS} \rightarrow \dfrac{R_{DS}}{n}$, $C_{DS} \rightarrow n\,C_{DS}$

$$\boxed{Q_{OUT}\,(R_{opt}) = R_{opt} \, C_{DS} \, \omega_0}$$

whatever the size

$$\Rightarrow \boxed{\Delta\omega_{actual} = \frac{\omega_0}{Q_{max}}}$$



PA
A
1mW
W1
PB
B
20mW
W2
PC
C
200mW
PB
PA
POUT
PC
PIN
PB