Matching principles of narrow-band amplifiers At high frequencies

Université de Limoges

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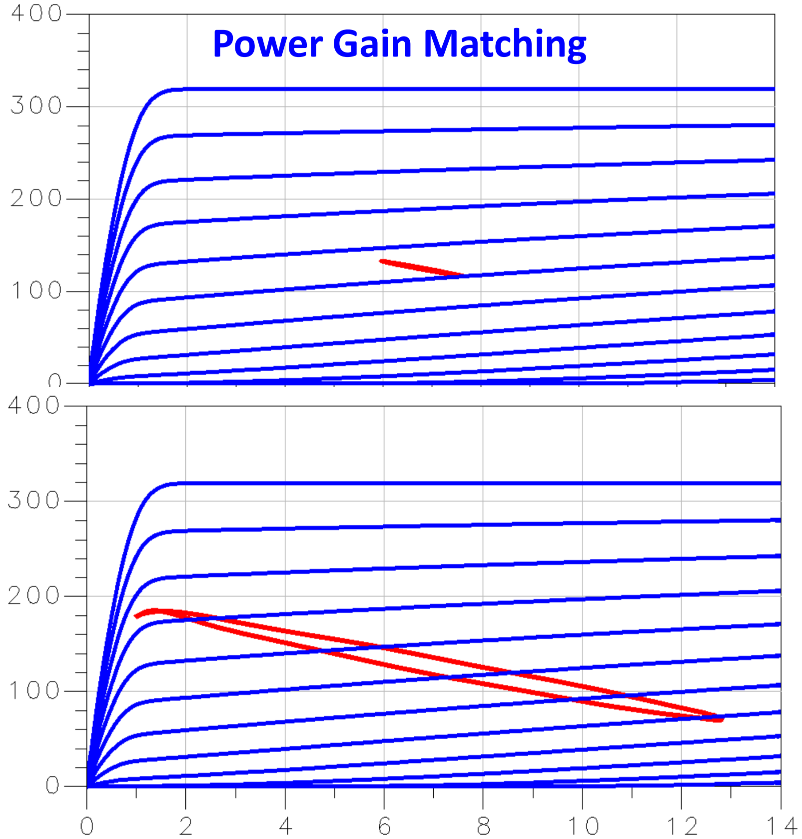
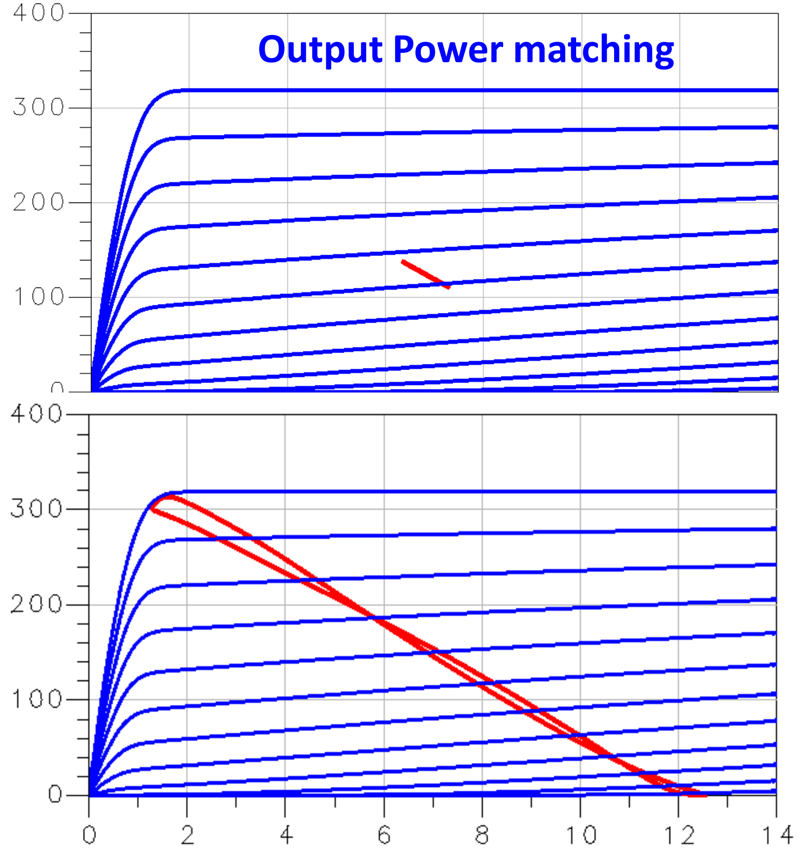
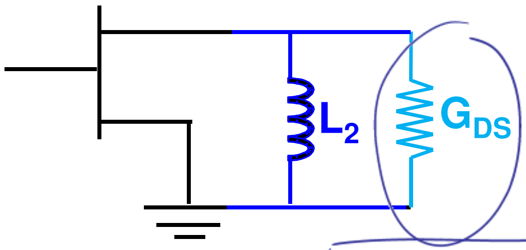
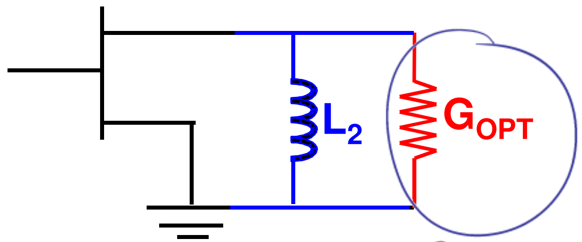
UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA







R_{DS}



G_{max} ∘

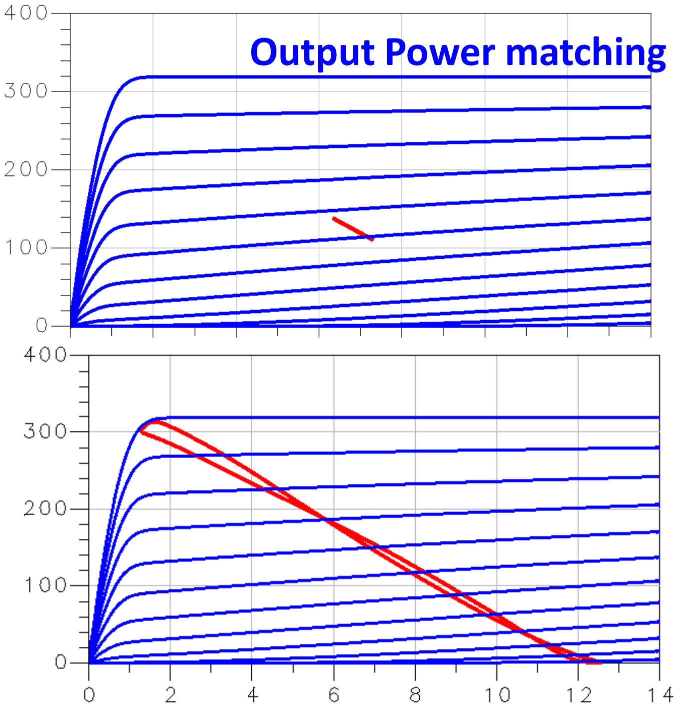
$$\boxed{P_{OUT}(R_{DS}) = \frac{R_{opt}}{R_{DS}} P_{OUT_{MAX}}}$$

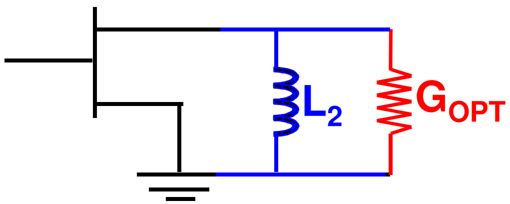
$P_{OUT_{MAX}}$

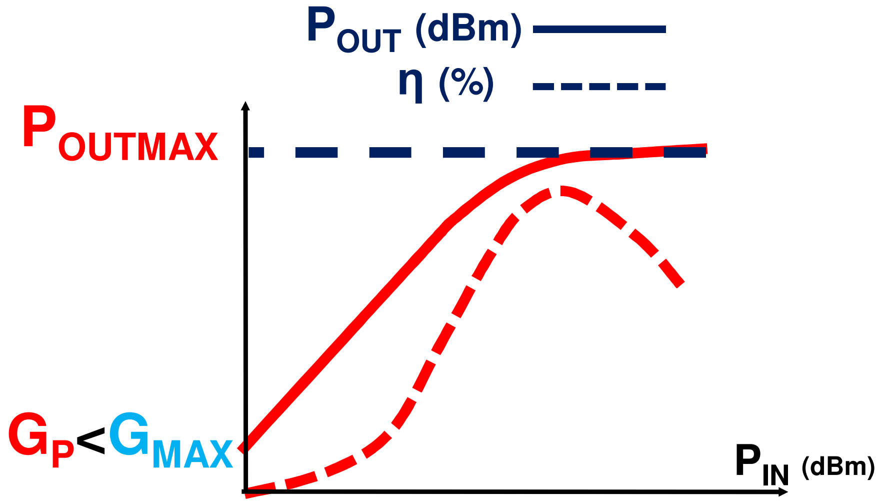
$G_p < G_{max}$ ∘

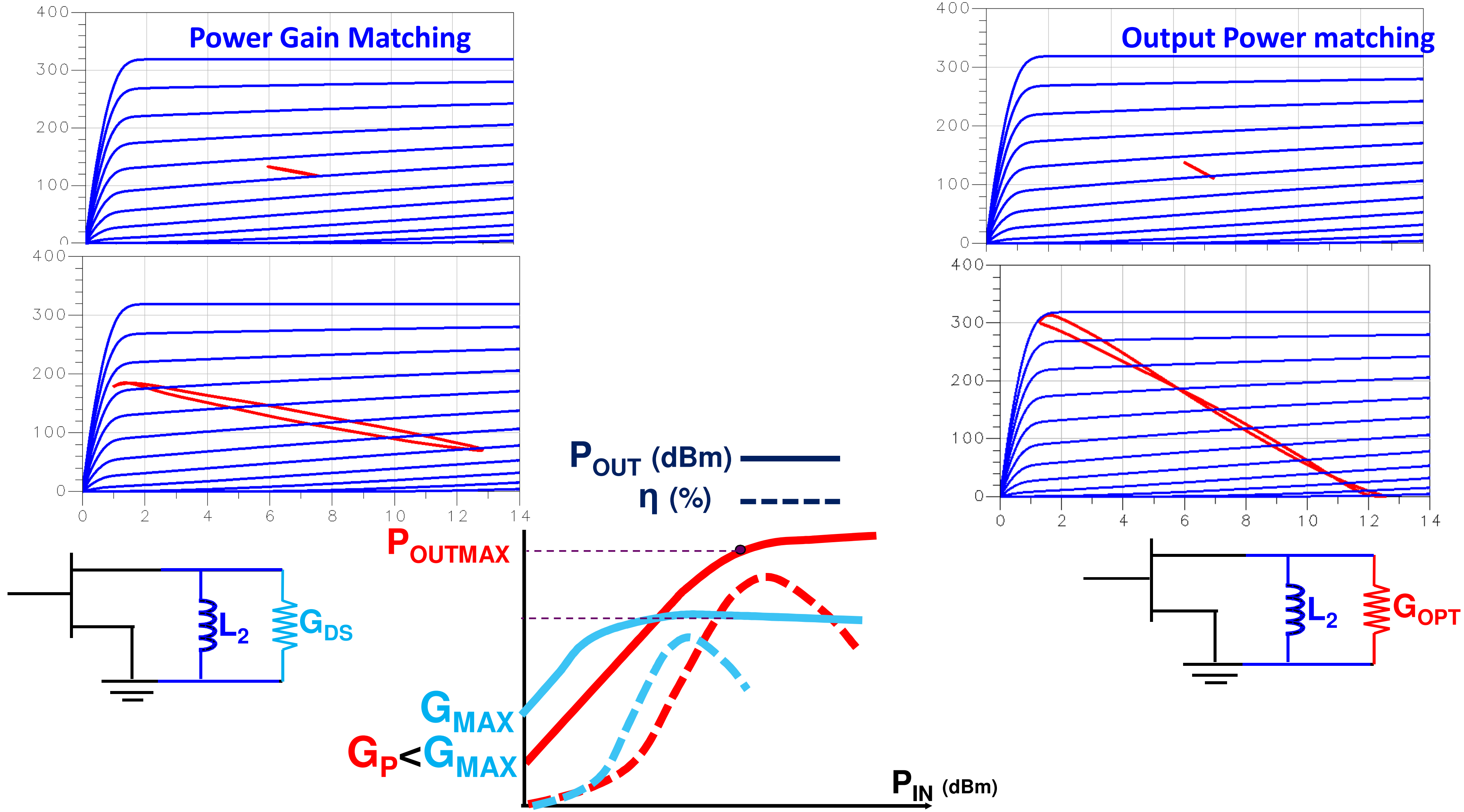
R_{opt}

$$P_{OUT}(R_{DS}) = \frac{1}{2}\,\frac{\left[\frac{1}{2}\left(V_{DSMAX} - V_{DSMIN}\right)\right]^2}{R_{DS}} \longleftrightarrow P_{OUT}(R_{opt}) = \frac{1}{2}\,\frac{\left[\frac{1}{2}\left(V_{DSMAX} - V_{DSMIN}\right)\right]^2}{R_{opt}}$$



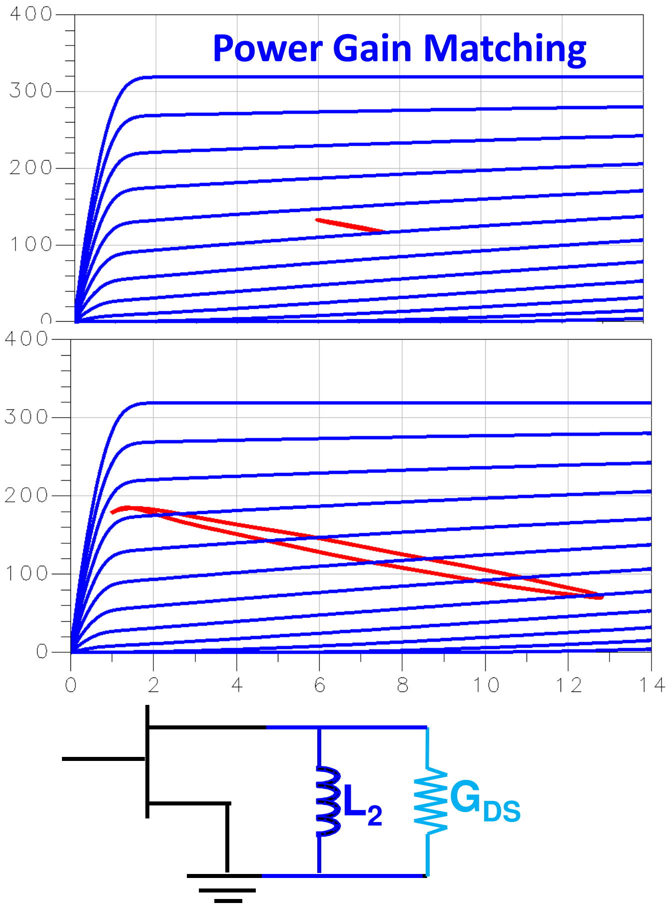


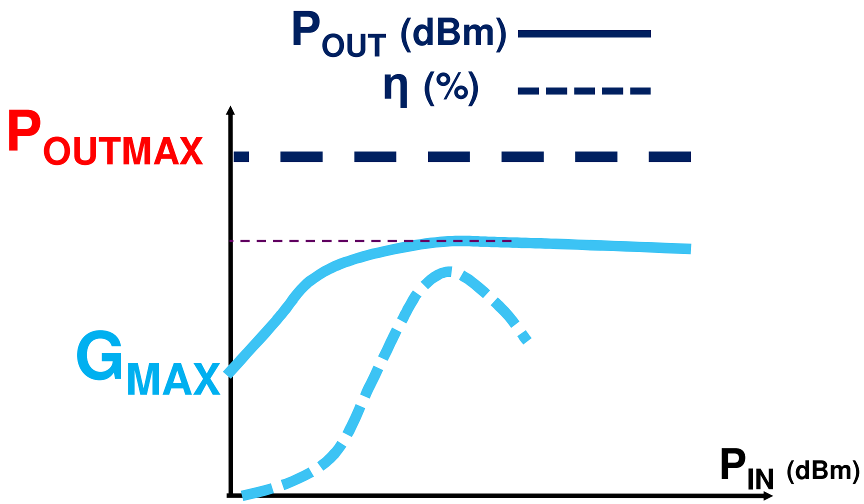



Power Gain Matching
Output Power matching
400
300
200
100
0
0 2 4 6 8 10 12 14
P_OUT (dBm)
η (%)
P_OUTMAX
G_MAX
G_P<G_MAX
P_IN (dBm)
L_2
G_DS
G_OPT

EMIMEO

E(rasmus) Mundus on Innovative Microwave Electronics and Optics

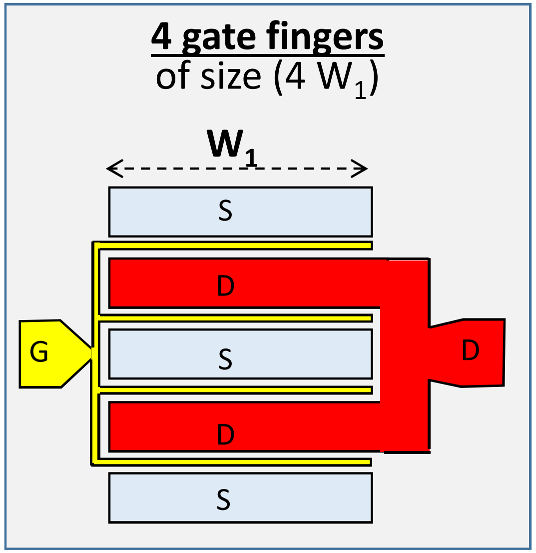


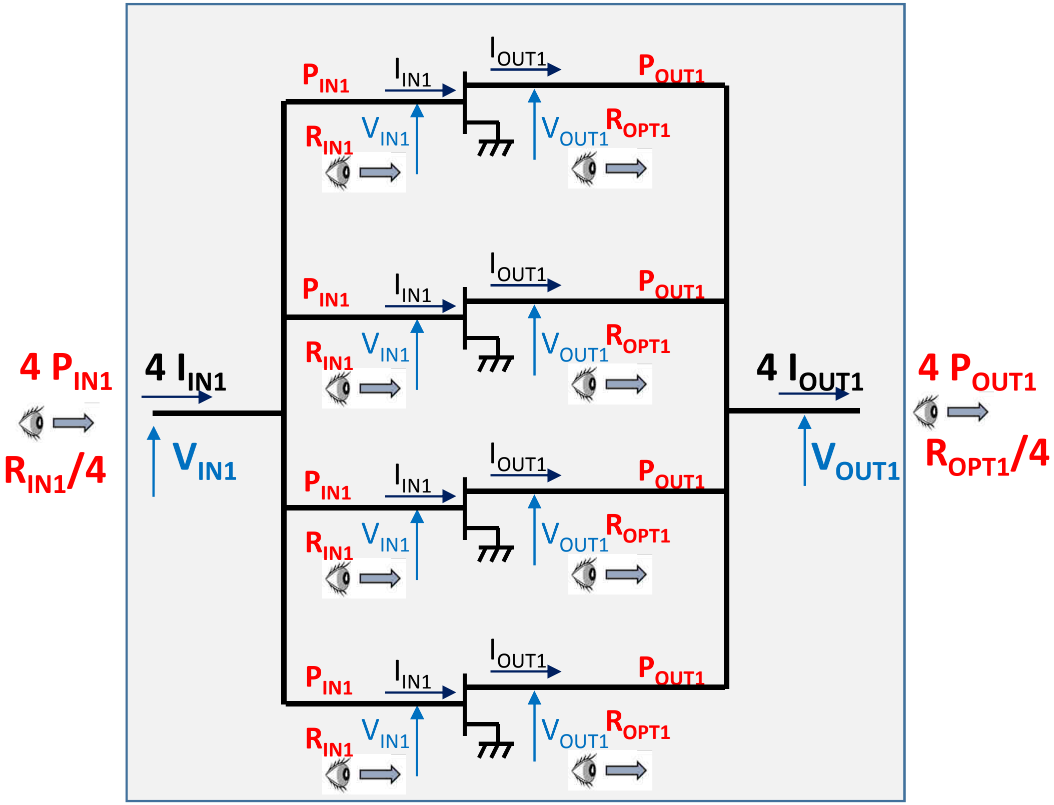


EMIMEO
E(rasmus) Mundus on Innovative Microwave Electronics and Optics

Power combination (Power Bars) and power matching

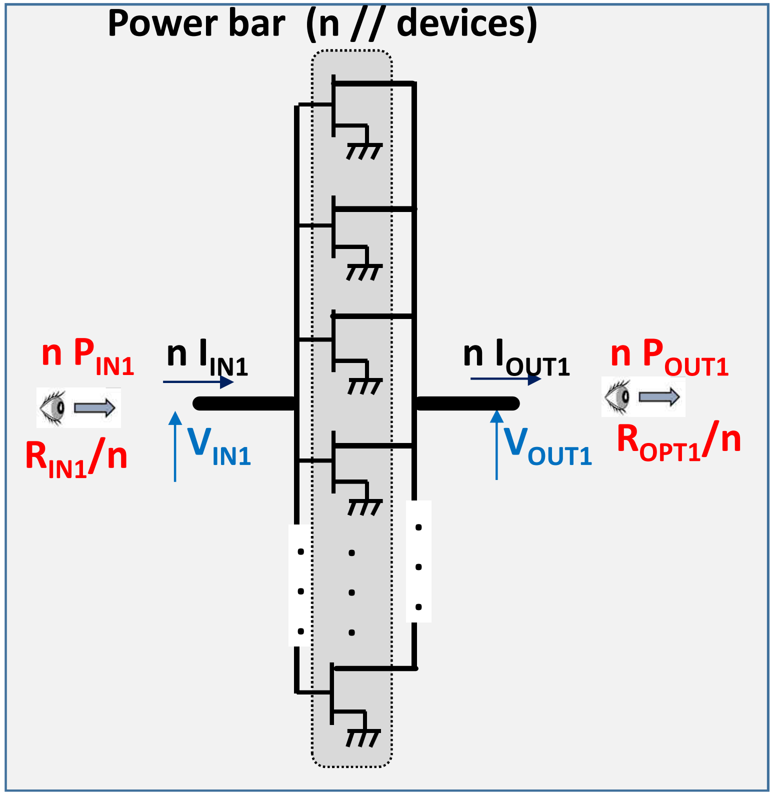
- Illustration of critical issues in power matching



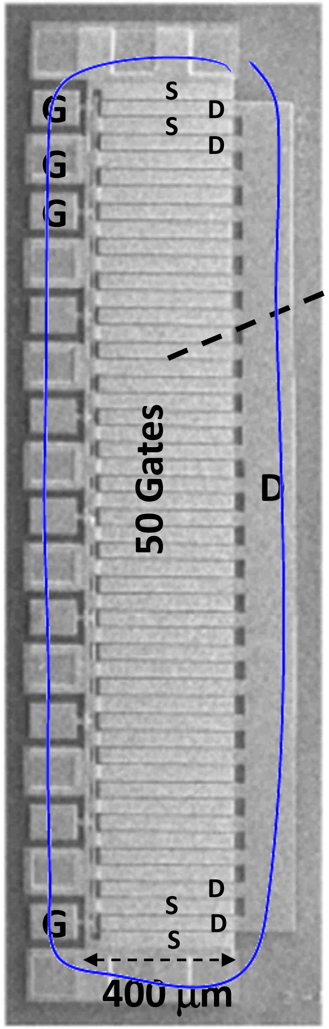


Power combination (Power Bars) and power matching

- Illustration of critical issues in power matching



20 mm GaN HEMT die

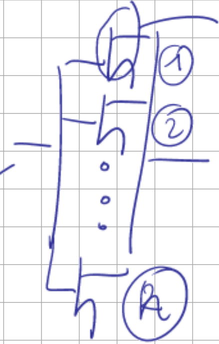


Device Size
=
Total Gate Width
=
(N° of // gates) x (Gate width)
=
50 x 400 µm = **20 mm**

Scaling Rules:

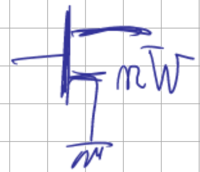
- **Drain Current** I_{DS} (mA/mm)
- **Voltages** V_{GS} and V_{DS} (V)
- **Output Power** P_{OUT} (W/mm)
- **Optimum Output Load** R_{OPT} (Ω . mm)

Tutorial 1



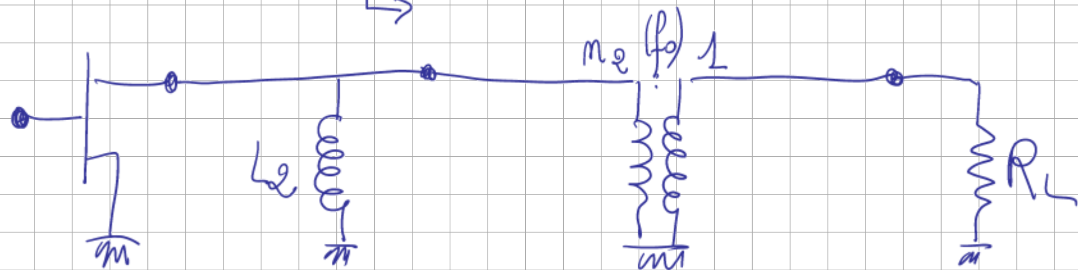
$\overline{W} \left(\begin{matrix} R_{i1} \\ C_{gs1} \\ \vdots \end{matrix} \right)$

scaling rules



$\left(\begin{matrix} R_{in} = R_{i1}/n \\ C_{gsn} = n\, C_{gs1} \\ \vdots \end{matrix} \right.$

R_{opt} or R_{DS}

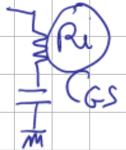


$$L_2 = \frac{1}{C_{DS}\, \omega_0^2}$$

Center angular frequency

$$n_2 = \sqrt{\frac{R_{opt}}{R_L}} \text{ or } \sqrt{\frac{R_{DS}}{R_L}}$$

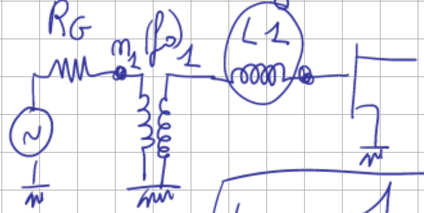
R_i C_{gs} in series

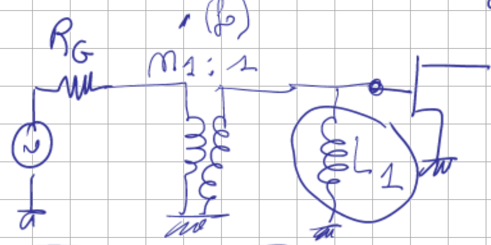


INPUT matching

OR

$R_{IN}(\omega_0)$ C_{gs} in //





$$R_{IN}(\omega_0) = \frac{1}{R_i C_{GS}^2 \omega_0^2}$$

$$\boxed{L_1 = \frac{1}{C_{GS}\,\omega_0^2}}$$

$$\boxed{n_1 = \sqrt{\frac{R_G}{R_i}}}$$

$$\boxed{n_1' = \sqrt{\frac{R_G}{R_{IN}}}}$$

$n \qquad \frac{1}{n}$

0.3

0.35

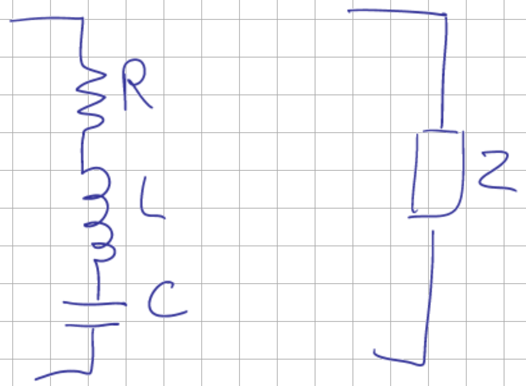
$n = 1$

$n_1 = 0.7$ $\qquad \frac{1}{0.7} \neq 1.4$

$n_1' = 1.35$

$Q_{IN} =$

RLC series resonant circuit



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

$$\mathrm{Imag}(Z)_{(\omega_0)} = 0$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$\infty \quad 0 \qquad 0 \quad -\infty$

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

$$= R\left[1 + j\,\frac{L\omega}{R}\left(1 - \frac{1}{LC\omega^2}\right)\right]$$

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

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

because $LC = \frac{1}{\omega_0^2}$

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

Quality factor Q_s of resonant circuit

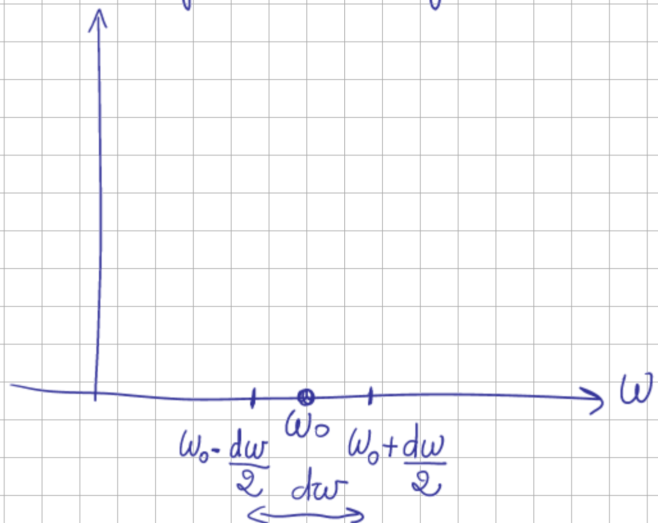
$$\lim_{\omega \to \omega_0} Z_s = \lim R\left[1 + j\,Q_s\,\frac{\omega^2 - \omega_0^2}{\omega\,\omega_0}\right]$$

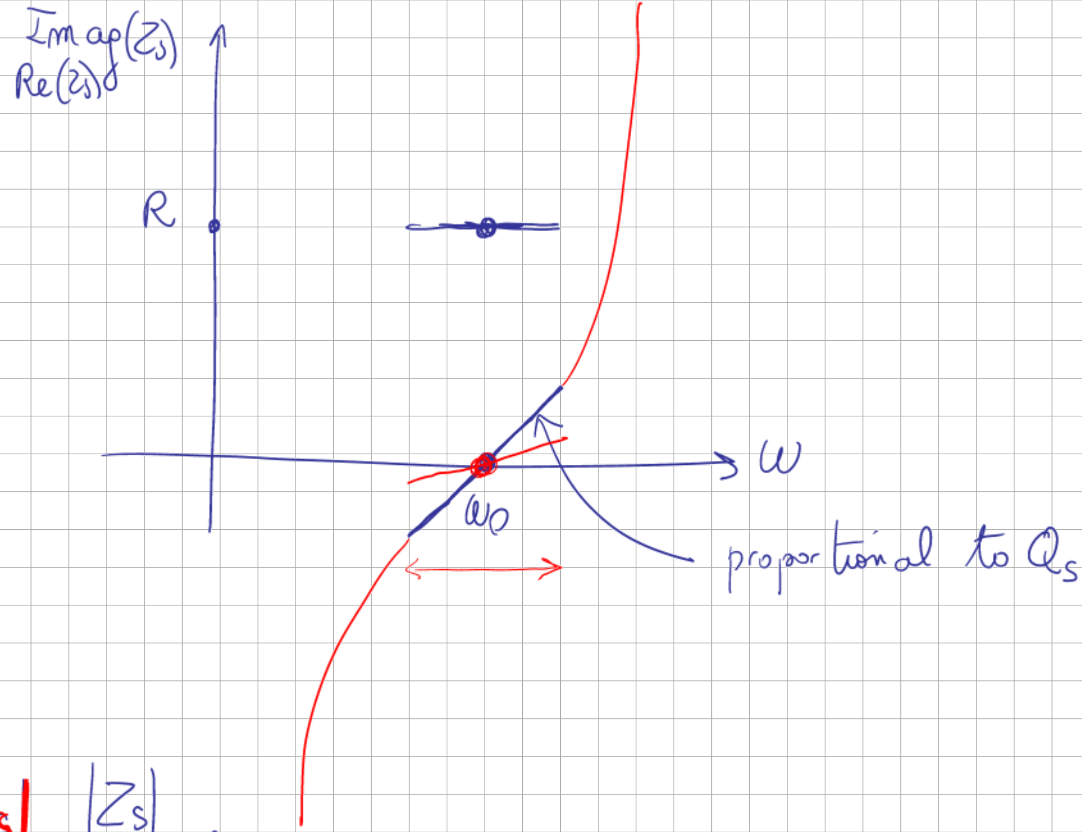
$$\underbrace{\omega = \omega_0 + \frac{d\omega}{2}}_{d\omega \ll} \qquad = \lim R\left[1 + j\,Q_s\,\frac{(\omega+\omega_0)(\omega-\omega_0)}{\underbrace{\omega\,\omega_0}_{\omega_0^2}}\right]$$

$2\omega_0 + \frac{d\omega}{2} \approx \cancel{2}\omega_0$

$\frac{d\omega}{\cancel{2}}$

$$\lim_{\omega \to \omega_0} Z_s = R\left[1 + j\,\frac{Q_s}{\omega_0}\,d\omega\right]$$

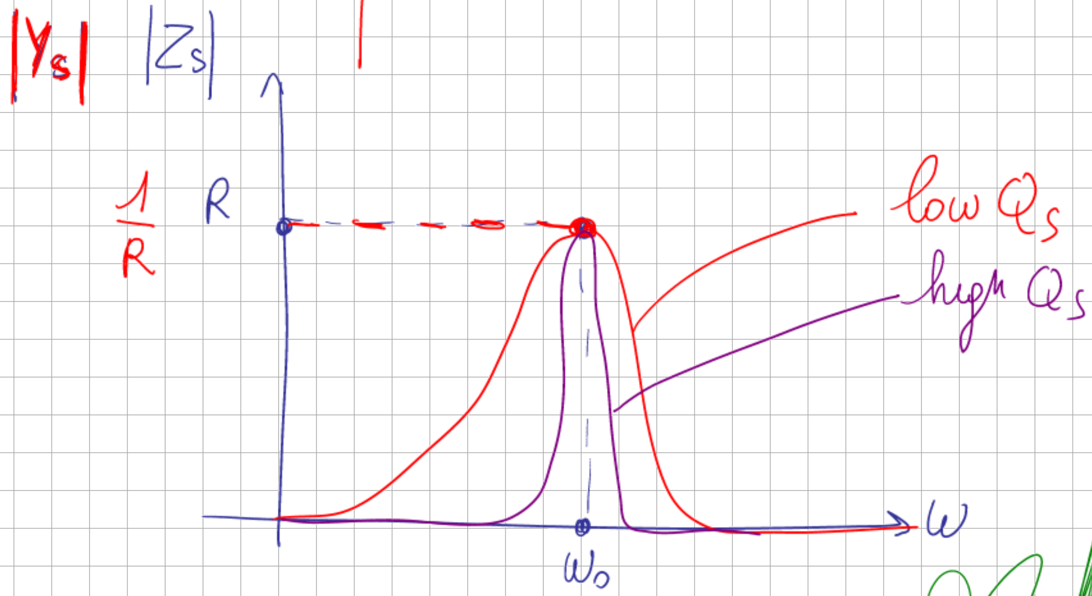


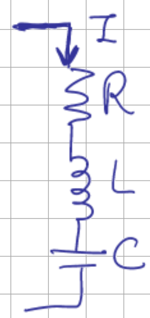


$$\begin{cases} Q_s = \dfrac{L\omega_0}{R} = \dfrac{1}{RC\omega_0} \\[2ex] \dfrac{Q_s}{\omega_0} = \dfrac{L}{R} \end{cases}$$

if $Q_s \gg$ ⇒ highly resonant
⇒ Bandwidth $\ll$

if $Q_s \ll$ ⇒ low resonant factor
⇒ Bandwidth $\gg$

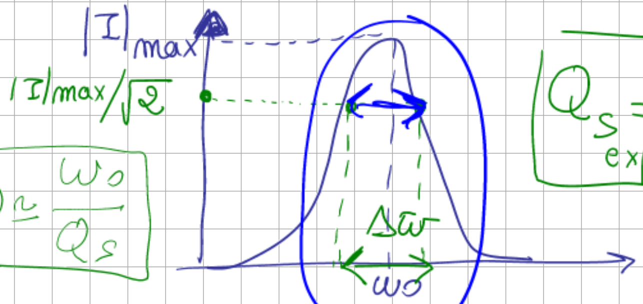




$$Q_S = \frac{L\omega_0}{R} = \frac{1}{RC\omega_0}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

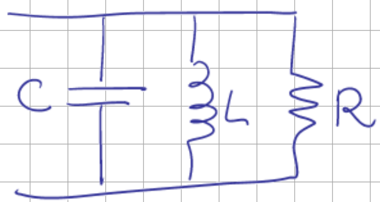
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

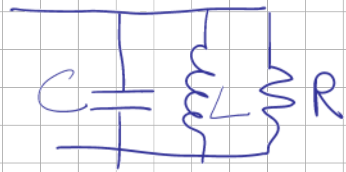


$$\boxed{\Delta\omega \simeq \frac{\omega_0}{Q_s}}$$

$$\boxed{Q_{s_{exp}} = \frac{\omega_0}{\Delta\omega}}$$

$$Y_p \approx \frac{1}{R}\left[1 + jQ_p\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right]$$



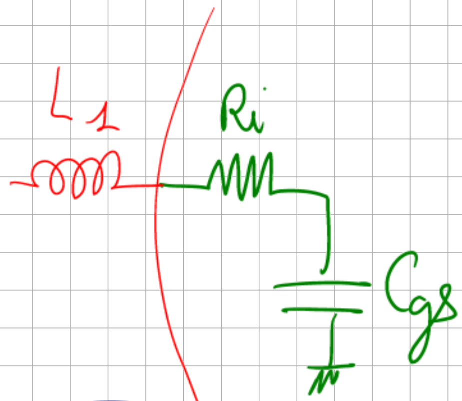


$$Q_p = \frac{R}{L\omega_0} = RC\omega_0$$

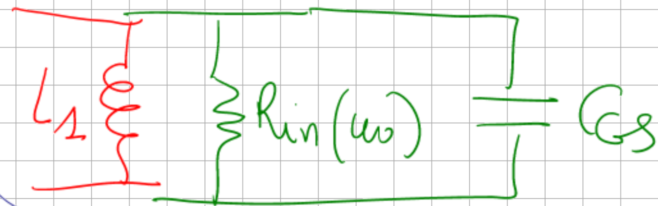
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$\Delta\omega = \frac{\omega_0}{Q_p}$$



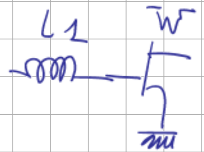
$$Q_s = \frac{L_1\omega_0}{R_i}$$



$$Q_p = \frac{R_{IN}}{L_1\omega_0} = \frac{\left(1/[R_i C_{gs}^2\omega_0^2]\right)}{\underbrace{L_1\omega_0}_{\frac{1}{C_{gs}\omega_0^2}}}$$

$$= \frac{1}{R_i C_{gs}^{\cancel{2}}\cancel{\omega_0^2}\ \frac{1}{C_{GS}\cancel{\omega_0^2}}\ \omega_0}$$

$$= \frac{1}{R_i C_{gs}\omega_0} = \frac{L_1\omega_0}{R_i}$$



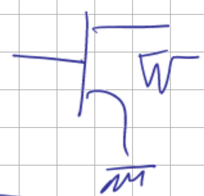
$$L_1 = \frac{1}{C_{GS1}\omega_0^2}$$

$$Q_s = \frac{L_1\omega_0}{R_{i1}}$$

$$L = \frac{1}{C_{gs2}\omega_0^2} = \frac{1}{2C_{GS1}\omega_0^2} = \frac{L_1}{2}$$

$$Q_s' = \frac{L\omega_0}{R_{i2}} = \frac{(L_1/2)\,\omega_0}{\left(\frac{R_{i1}}{2}\right)} = \frac{L_1\omega_0}{R_{i1}}$$

$= Q_s$ (does not depend on transistor's size

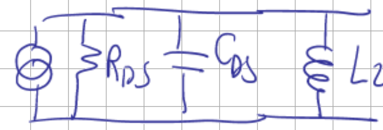


$$\boxed{Q_{IN} = \frac{L_1 \omega_0}{R_i} = \frac{1}{R_i C_{gs} \omega_0}}$$

$$\boxed{Q_{IN}(\omega_0) = \frac{1}{R_i C_{GS} \omega_0}}$$

$$\Delta\omega \leq \frac{\omega_0}{Q_{IN}(\omega_0)}$$

$$Q_{IN} = 10$$



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

$$\boxed{Q_{OUT} = \frac{R_{DS}}{L_2 \omega_0} = R_{DS} C_{DS} \omega_0}$$

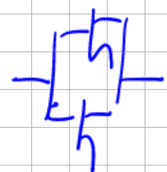
$$\boxed{Q_{OUT}(\omega_0) = R_{DS} C_{DS} \omega_0}$$

$$\Delta\omega \leq \frac{\omega_0}{Q_{OUT}(\omega_0)}$$

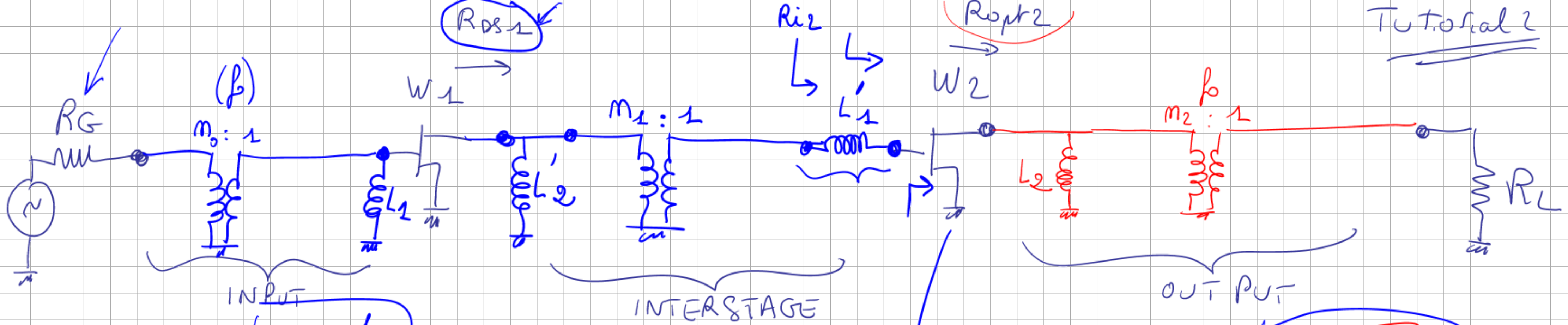
$$Q_{OUT} = 5$$

2^n devices placed in parallel

1
2
4
8
16



Tutorial 2



$$L_1 = \frac{1}{C_{GS1}\,\omega_0^2}$$

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

$$m_0 = \sqrt{\frac{R_G}{R_{IN1}}}$$

R_{i1}

Chosen

$$\frac{R_G}{R_{i1}} \qquad \frac{R_{IN1}}{R_G}$$

$$L_1' = \frac{1}{C_{GS2}\,\omega_0^2}$$

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

$$m_1 = \sqrt{\frac{R_{DS1}}{R_{i2}}}$$

$$L_2 = \frac{1}{C_{DS2}\,\omega_0^2}$$

$$m_2 = \sqrt{\frac{R_{optr2}}{R_L}}$$

$$R_{IN2} = \frac{1}{R_{i2}\,C_{gs2}^2\,\omega_0^2}$$

$\frac{R_{DS1}}{R_{i2}}$ and $\frac{R_{DS1}}{R_{IN2}}$?

R_{in}