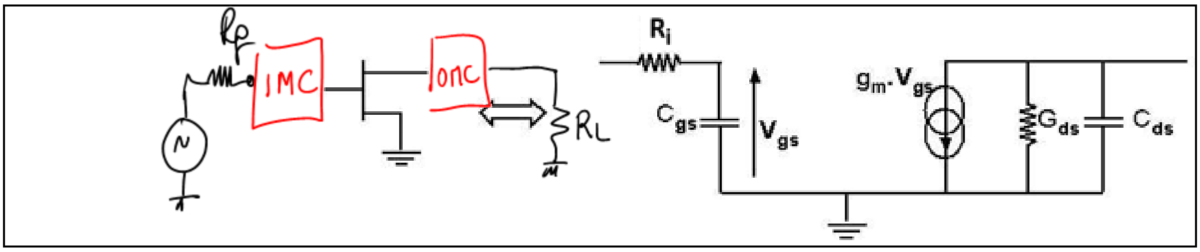
Basics of Active and Nonlinear HF Electronics – Tutorial 2

A) Power gain matching of a single-stage narrow-band amplifier

This figure represents the simplified electrical model of an FET.

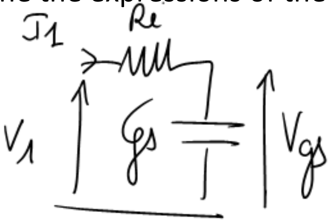


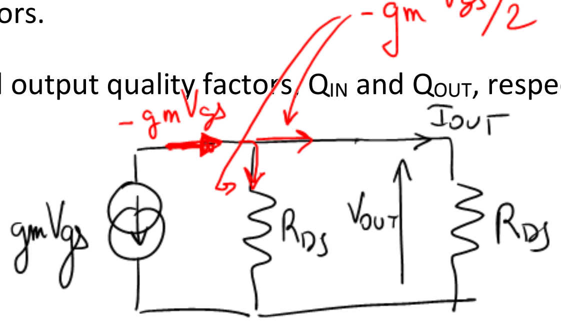
The model parameters are given at a bias point of (V_{GS0} = -2 V and V_{DS0} = 20 V)

Ri = 5 Ω ; C_{GS} = 0.5 pF ; g_m = 100 ms ; R_{DS} = 200 Ω ; C_{DS} = 0.15 pF

The amplifier environment is : R_G = 50 Ω ; R_L = 50 Ω ; f_0 = 10 GHz

1) Determine the expression of G_{MAX} : maximum power gain of the transistor as a function of frequency
2) We consider the design of a linear amplifier, which is loaded by a resistor R_L, while the input generator has an internal resistor R_G.
   a) Draw the ideal input and output matching circuits of a narrow-band amplifier which is matched to its maximum power gain G_{MAX} at f_0.
   b) Determine the expressions of each passive matching elements as a function of f_0, the model parameters and the R_G and R_L resistors.
3) Determine the expressions of the input and output quality factors, Q_{IN} and Q_{OUT}, respectively.





$$P_{IN} = \frac{1}{2} Re\left(V_1 I_1^*\right)$$

$$= \frac{1}{2} Re\left(\underbrace{\left(R_i - j\frac{1}{C_{gs}\omega}\right) I_1}_{V_1} I_1^*\right) = \frac{1}{2} R_i \underbrace{|I_1|^2}$$

$$I_1 = j C_{gs}\omega V_{gs} \rightarrow |I_1| = C_{gs}\,\omega |V_{gs}|$$

$$\boxed{P_{IN} = \frac{1}{2} R_i C_{gs}^2 \omega^2 |V_{gs}|^2}$$

$$P_{OUT} = \frac{1}{2} Re\left(V_{OUT} I_{OUT}^*\right)$$

$$= \frac{1}{2} Re\left(R_{DS} I_{OUT} I_{OUT}^*\right)$$

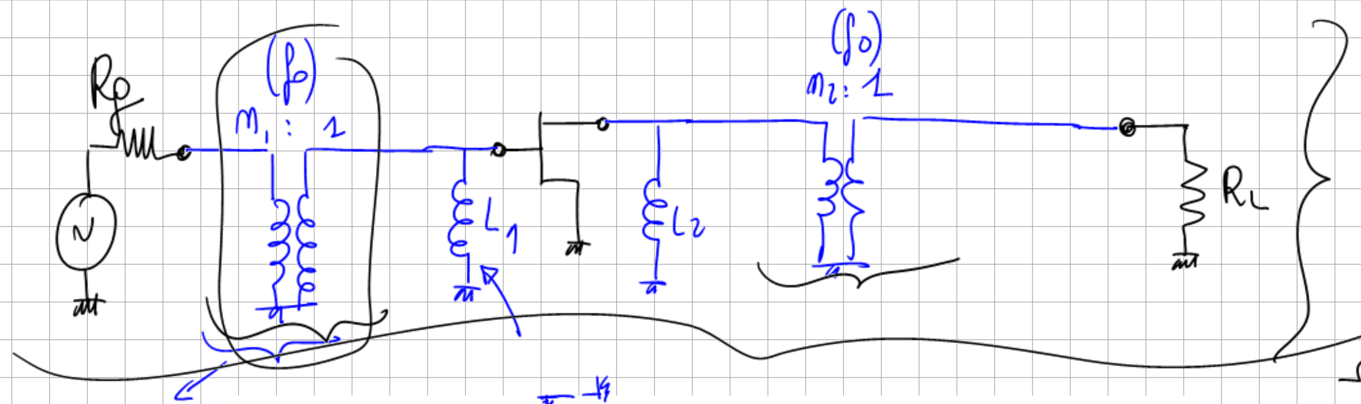
$$= \frac{1}{2} R_{DS} |I_{OUT}|^2$$

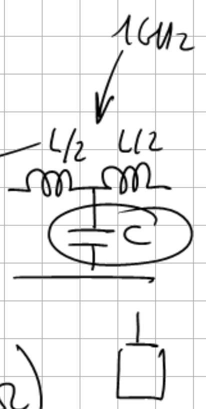
$$= \frac{1}{2} R_{DS} \left|-g_m \frac{V_{gs}}{2}\right|^2$$

$$\boxed{P_{OUT} = \frac{1}{8} R_{DS} g_m^2 |V_{gs}|^2}$$

max gain

$$\boxed{G_{MAX} = \frac{1}{4} \frac{R_{DS} g_m^2}{R_i C_{gs}^2 \omega^2}}$$





Ri = 5 Ω ; C_{GS} = 0.5 pF ; g_m = 100 ms ; R_{DS} = 200 Ω ; C_{DS} = 0.15 pF

The amplifier environment is : R_G = 50 Ω ; R_L = 50 Ω ; f_0 = 10 GHz

1) INPUT MATCHING

(R_i series or R_{IN} parallel ? to transform to $R_G \simeq 50\,\Omega$)

$$R_{IN}(10\,GHz) = \frac{1}{R_i C_{gs}^2 \omega^2} = \frac{1}{5\,(0{,}5\,10^{-12}\;2\pi\;10^{10})^2} = \frac{1}{5 \times \pi^2\;10^{-4}} = \frac{10000}{5\pi^2}$$

$$= 202\,\Omega$$

$$\frac{R_{IN}}{R_G} = \frac{202}{50} \simeq 4 \quad \text{and} \quad \frac{R_G}{R_i} = \frac{50}{5} = 10 \rightarrow$$ Best choice // matching $\boxed{m_1 = \sqrt{\frac{202}{50}} = 2}$

$$\boxed{L1 = \frac{1}{C_{gs}\,\omega^2} = 0{,}5\,nH}$$

• OUTPUT MATCHING

$$\boxed{L_2 = \frac{1}{C_{DS}\,\omega^2} = 1{,}7\,nH} \qquad \boxed{m_2 = \sqrt{\frac{R_{DS}}{R_L}} = \sqrt{\frac{200}{50}} = 2}$$

2) Quality factors

• INPUT

$$Q_S = \frac{1}{RC\omega_0} \qquad \boxed{Q_{IN}} = \frac{1}{R_i C_{gs} \omega_0} = \frac{1}{5\,(0{,}5\,10^{-12}\;2\pi\;10^{10})} = \frac{100}{5\pi} = \boxed{6{,}4}\,*$$

$$Q_{//} = RC\omega_0$$

in our case (matching to R_{DS})

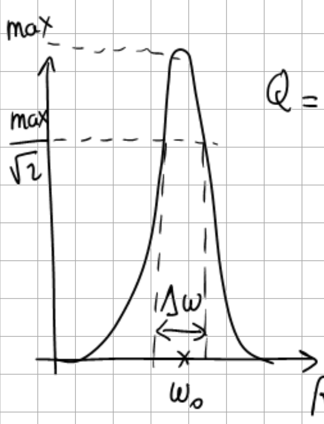
• OUTPUT

$$\boxed{Q_{OUT}} = R_{DS}\, C_{DS}\, \omega_0 = 200 \times 0{,}15\,10^{-12}\;2\pi\;10^{10} = \boxed{1{,}9}$$

or

$$= R_{opt}\, C_{DS}\, \omega_0$$

if you match to R_{opt}



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

$$\Delta\omega = \frac{\omega_0}{Q}\,* \qquad \Delta f_{max}^{\,?} \; \frac{f_0}{Q_{max}} = \frac{10\,GHz}{6{,}4} = 1{,}6\,GHz$$

2GHz

$R_{IN}(9GHz)$ $R_{IN}(11GHz)$

B) Power gain matching of a two stage narrow-band amplifier

Techno logical Data

Main pecifications of the narrow-band amplifier:

Output Power P_{OUT}> 1 W ; Center frequency f_0 = 15 GHz ; Power Gain G_P > 15 dB

Selected MMIC foundry (0.15 µm GaAs HEMT) :

Power Density PD = 1 W/mm ; Measured Gain $G_{MAX(@10GHz)}$ = 16 dB

Saturated Drain Current I_{DSS} = 800 mA/mm ; Drain Voltage range (V_{DSmin}=1V and V_{DSmax}=11V)

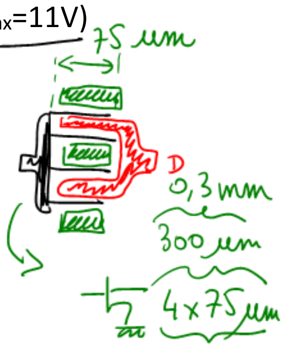
Pinch-off Voltage : V_P = -4 V

Optimum load impedance R_{OPT} = 12.5 Ω.mm

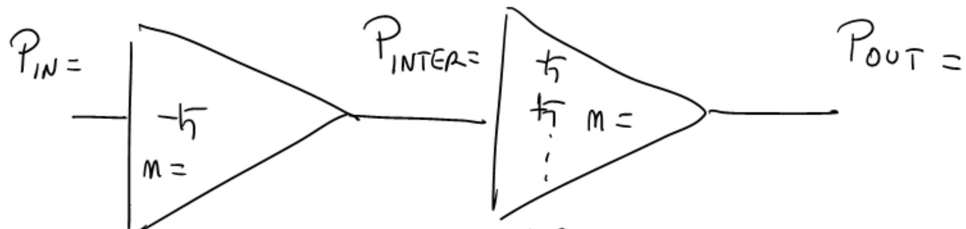
Small-signal model: C_{GS} = 2.7 pF/mm ; Ri =1 Ω.mm ; g_m = 200 mS/mm ;

R_{DS} = 125 Ω.mm ; C_{DS} = 0.6 pF/mm

Selected device size @ 15 GHz = 4x75 µm GaAs HEMT



1) Given the required specifications and the selected transistor technology, determine the initial sizing of the power amplifier (number of stages, number of amplifying cells per stage, power gain and input/output powers of each stage) using the selected device size (4x75 µm) as the unitary amplifying cell.
2) Given that only the last stage should be matched to its optimum output power while all the preceding stages should be matched to their maximum power gain, draw the input and output matching circuits of this two-stage narrow-band amplifier and calculate the values of each matching elements.
3) Calculate the input and output quality factors of each stage to assess what will be the bandwidth behavior.
4) Can you comment on the power limitations and the power added efficiency of this two-stage amplifier?



You have only to know how to find the Gmax value

$$g_m^2 \rightarrow \frac{4\,G_{max}}{R_{DS}}$$

$$G_p(R_{opt}) = \frac{\frac{G_{opt}}{(G_{opt}+G_{DS})^2}\, g_m^2}{R_i\, C_{GS}^2\, \omega^2} = \frac{G_{opt}}{(G_{opt}+G_{DS})^2} \times \frac{4\,G_{max}}{R_{DS}}$$

$$\boxed{G_{max} = \frac{1}{4}\,\frac{R_{DS}\, g_m^2}{R_i\, C_{GS}^2\, \omega^2}} \; * \qquad = \frac{1/R_{opt}}{(1/R_{opt}+1/R_{DS})^2} \times \frac{4\,G_{max}}{R_{DS}}$$

$$\left(\frac{R_{opt}+R_{DS}}{R_{opt}\,R_{DS}}\right)^2$$

$$G_P = \frac{\frac{G_2}{[G_2+g_{DS}]^2}\, g_m^2}{R_i\, C_{GS}^2\, \omega^2} \; *$$

$$\boxed{G_p(R_{opt}) = 4\,\frac{R_{opt}\,R_{DS}}{(R_{opt}+R_{DS})^2}\, G_{max}}$$