M1 EMIMEO Tutorial N°6

Let us consider a transistor having the following I / V characteristics (Figure 1)

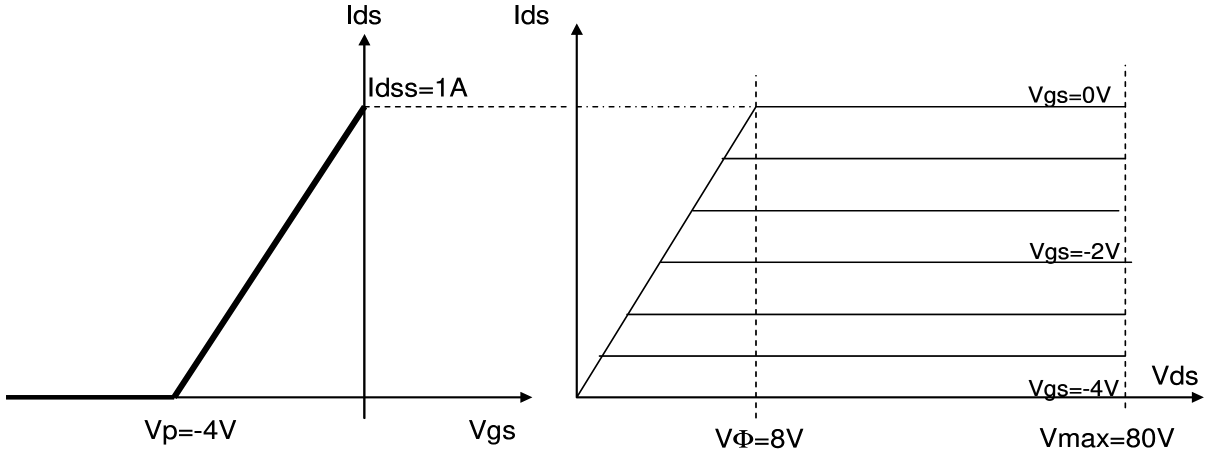


Figure 1

We consider also the following parameters:

$R_g = 4\Omega$, C_{gs}=5pF , Fo=3.6 Ghz , C_{ds} = 0.76 pF

The gate source bias voltage V_{gs0} is chosen in order to have an aperture angle φ= 110° when V_{gs1} is at its maximum value . ($V_{gs}(t)_{max} = 0V$)

I] In this first part we want to obtain the maximum output RF power

1) Determine the values of Vgs0 and Vds0

2) Determine the corresponding optimal load impedance (Real part and Imaginary part)

3) Calculate the output power and the power added efficiency

4) We want to design the output RF matching Network with distributed elements as represented in Figure 2

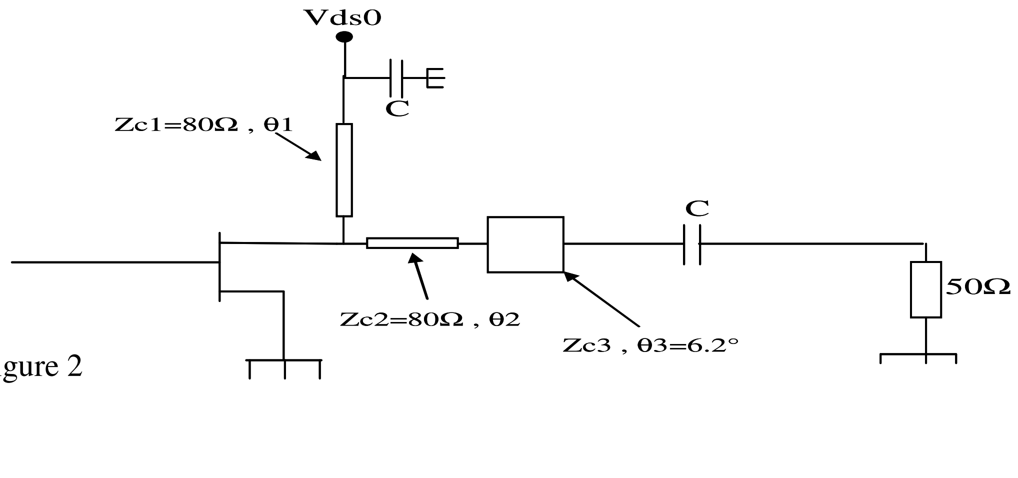


Figure 2

Determine the values of the electrical lengths θ1 and θ2 and the value of the characteristic impedance Zc3

II] In this second part we keep the same values for the load impedance , Vgs0 and Vds0 than the ones obtained in Part I but Vgs1 is decreased .
Vgs1 is now equal to +2V .

1) What are the corresponding values of the output RF power and the PAE .

III] In this third part we keep the same values of the load impedance and Vgs0 .
We keep also Vgs1 equal to +2V but we decrease the value of Vds0 .

1) What is the minimal value of Vds0 for which we reach the saturation regime of the transistor

2) What are the corresponding values of the output power and the PAE

IV] In this last part we take again the values of Vgs0 and Vds0 determined in part I
We keep Vgs1=+2V but we modify the value of the load impedance in order to have the maximum possible output RF power for Vgs1 = +2V.

1) Determine the required value of the load resistance as well as the corresponding values of the output RF power and the PAE .

I] 1) $V_{GS0} - V_{GS0}\cos\varphi = V_P$ $\quad V_{GS1} = -V_{GS0} = |V_{GS0}|$ $\quad V_{DS0} = \frac{80+8}{2} = 44V$

$V_{GS0} = \frac{V_P}{1-\cos\varphi} = -3V \rightarrow V_{GS1} = +3V$ $\quad V_{DS1} = 44 - 8 = 36V$

2) $I_{DS0} = \frac{I_P}{\pi}\frac{\sin\varphi - \varphi\cos\varphi}{1-\cos\varphi} = 378\,mA \quad (I_P = 1A)$

$I_{DS1} = \frac{I_P}{\pi}\frac{\varphi - \sin\varphi\cos\varphi}{1-\cos\varphi} = 532\,mA$ $\quad R_{opt} = \frac{V_{DS1}}{I_{DS1}} = \frac{36}{0.532} = 68\,\Omega$

$Y_{opt} = \frac{1}{R_{opt}} + \frac{1}{jL\omega}$ with $LC_{ds}\omega^2 = 1 \rightarrow \frac{1}{jL\omega} = -jC_{ds}\omega$

$Y_{opt} = \frac{1}{R_{opt}} - jC_{ds}\omega = (14{,}8 - j17{,}2)\,mS \rightarrow Z_{opt} = \frac{1}{Y_{opt}} = (28{,}7 + j33{,}4)\,\Omega \simeq (29 + j33)\,\Omega$

3) $P_{out} = \frac{1}{2} V_{DS1} I_{DS1} = 9576\,mW$ $\quad P_{in} = \frac{1}{2} g_{in} (v_{gs1})^2 = 230\,mW$

$g_{in} = R_g C_{gs}^2 \omega^2 = 51\,mS$

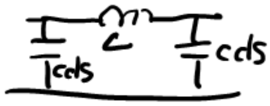
$PAE = \frac{9576 - 230}{44 \times 378} = 56.2\,\%$

4) $\theta_1 = 90°$ (corresponding to a $\lambda/4$ line)

For the output RF matching network we want to have. The following equivalence

$\Rightarrow Z_c = 58\,\Omega$

The chain matrix of the C,L,C Network is



$\boxed{Z_c\,,\ \lambda/4}$

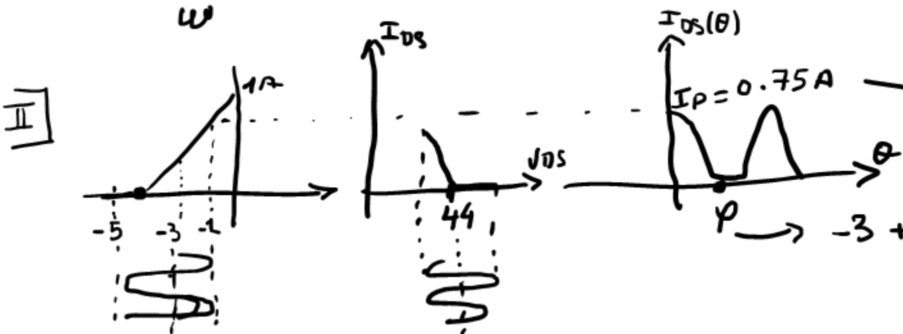
$$\begin{pmatrix} 1-LC_{ds}\omega^2 & jL\omega \\ jC_{ds}\omega + jC_{ds}\omega(1-LC_{ds}\omega^2) & 1-LC_{ds}\omega^2 \end{pmatrix} = \begin{pmatrix} 0 & jZ_c \\ \frac{j}{Z_c} & 0 \end{pmatrix}$$

$\rightarrow LC_{ds}\omega^2 = 1 \rightarrow L = 2.57\,mH$

$\frac{1}{C_{ds}\omega} = Z_c \rightarrow$ ok $Z_c = 58\,\Omega.$

$L = \frac{Z_{c2}\,\theta_2}{\omega} \rightarrow \theta_2 = 0{,}727\,rd$ $\quad C = C_{ds} = \frac{\theta_3}{Z_{c3}\,\omega} \rightarrow Z_{c3} = \frac{\theta_3}{C_{ds}\,\omega} = 6\,\Omega$

II



$I_{DS0} = 305\,mA$

$I_{DS1} = 403\,mA$

$\varphi \rightarrow -3 + 2\cos\varphi = -4 \rightarrow \cos\varphi = -0{,}5$

$\varphi = 2.1\,rd$

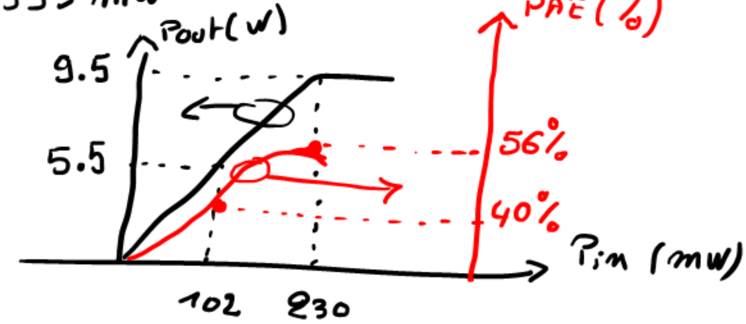
$\sin\varphi = 0.87$

$V_{GS1} = 2V$ $\quad V_{DS1} = R_{opt}\,I_{DS1} = 68 \times 0{,}403 = 27.4\,V$

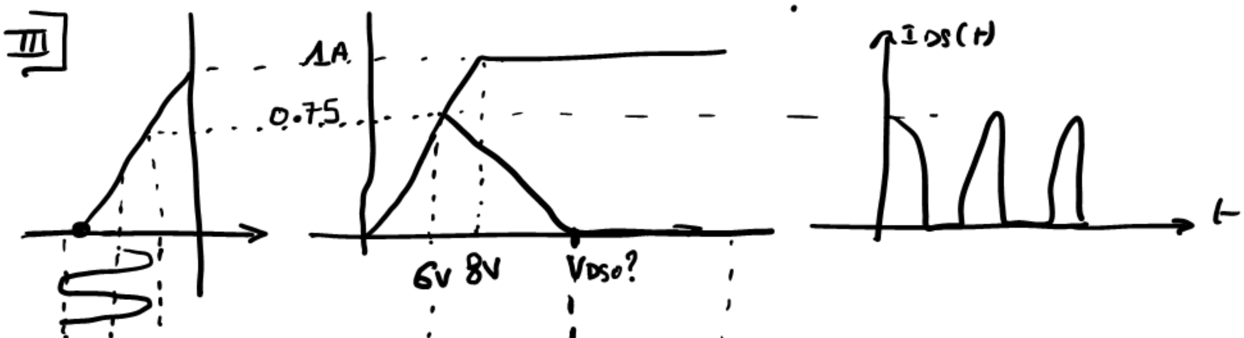
$P_{in} = \frac{1}{2}\,g_{in}\,V_{gs1}^2 = \frac{1}{2} \times 51\,10^{-3} \times (2)^2 = 102\,mW$

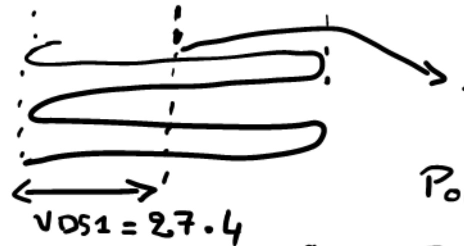
$P_{out} = \frac{1}{2}\,V_{DS1} \cdot I_{DS1} = \frac{1}{2}\,R_{opt}\,I_{DS1}^2 = 5533\,mW$

$PAE = \frac{5533 - 102}{44 \times 305} = 40.4\%$



III



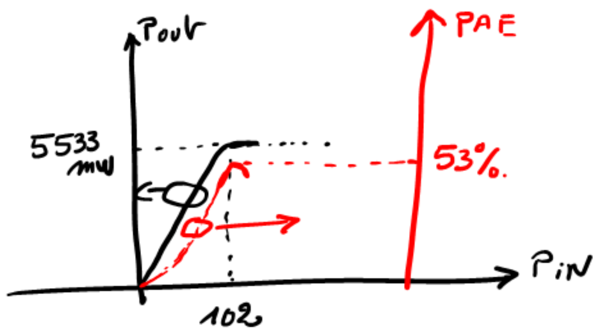


So : $V_{DS0_{min}} = 6V + 27.4V = 33.4V$

$P_{out} = \frac{1}{2}\,V_{DS1}\,I_{DS1} = 5533\,mW$

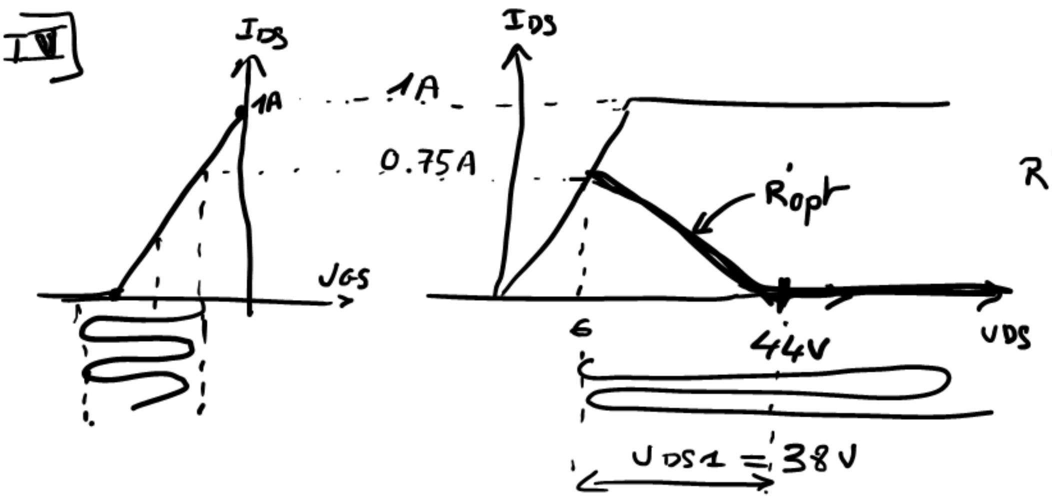
$P_{DC} = 305\,mA \times 33.4V = 10187\,mW$

$PAE = \frac{5533 - 102}{10187} = 53.2\%$



PAE $\nearrow$ 40% → 53% because V_{DS0} $\searrow$ 44V → 33,4V

$\boxed{IV}$



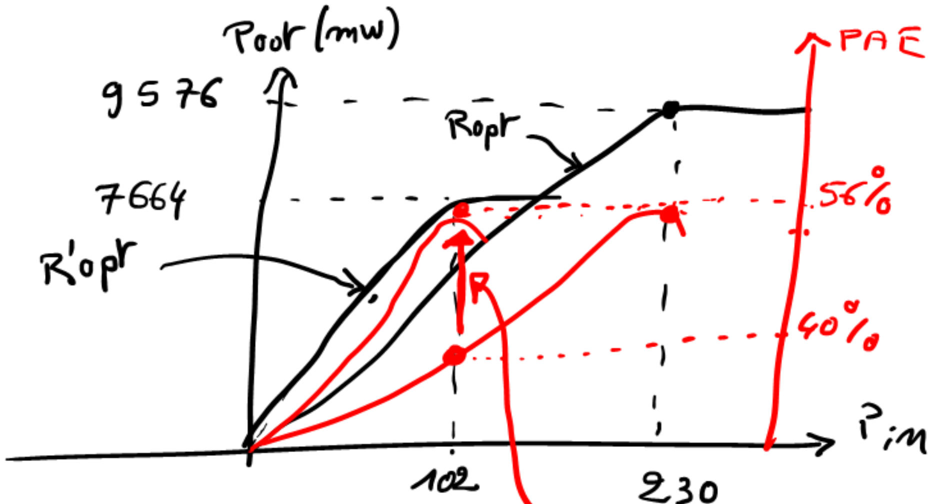
$$R'_{opt} = \frac{V_{DS1}}{I_{DS1}} = \frac{38}{0.403} = 94\,\Omega$$

$$P_{out} = \frac{1}{2} \times 38V \times 403\,mA = 7664\,mW$$

$$P_{in} = 102\,mW$$

$$PAE = \frac{7664 - 102}{44 \times 305} = 56\%$$

PAE $\nearrow$ 40% → 56% because V_{DS1} $\nearrow$ 27.4V → 38V



PAE improvement if (Ropt → R'opt)

Principle used in Load Modulated power amplifiers