Semester S1 –Basics of active and non linear electronics

RF Power amplifiers (JM Nebus)

TUTORIAL N° 6

Let us consider the Doherty equivalent circuit at the fundamental frequency represented in figure 1 :

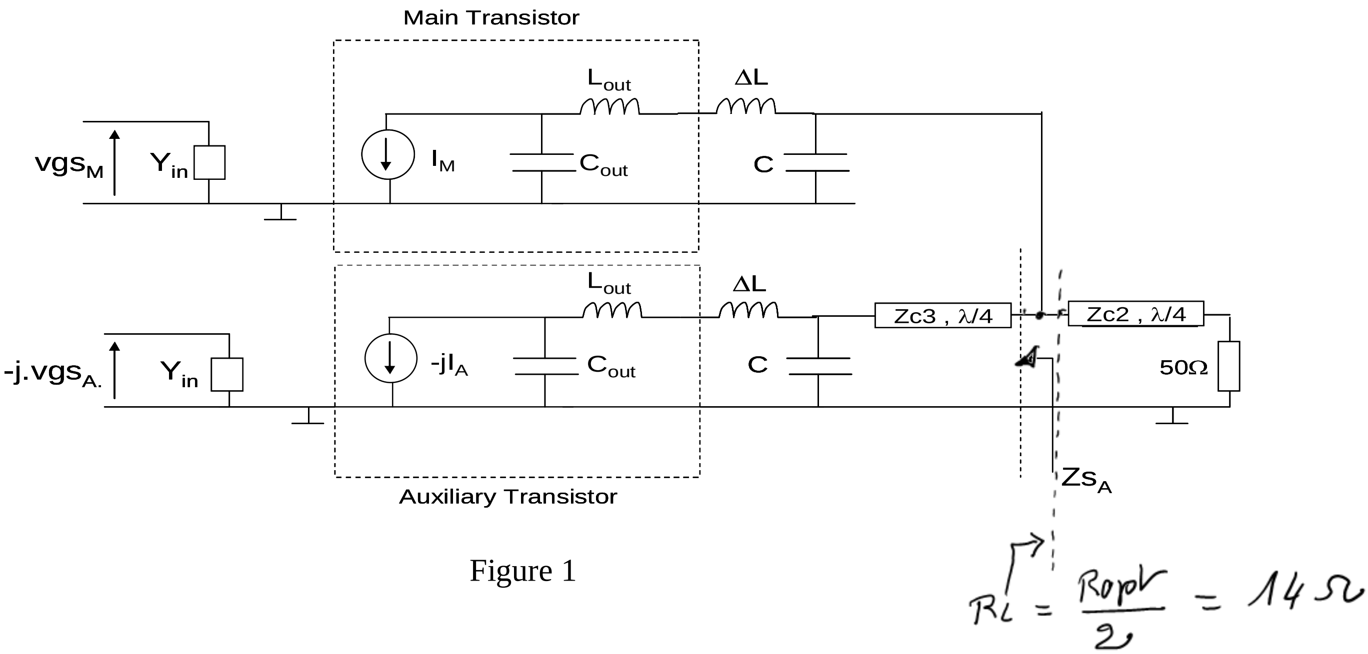


Figure 1

The variations of the drain currents I_M and I_A versus Vgs are similar to the those given in the course .

The operating frequency is 4 Ghz

Transistor's parameters are the following

Idss= 1,2 A , Vds0 = 20V , Vdsmin=Vk= 3V

Cout = 1,4 pF et Lout = 0,7 nH

1) Determine the values of Ropt and 2Ropt for a suitable Doherty load modulation operation

$$\begin{cases} 1 - L C_{out}\omega^2 = 0 \\ \text{AND} \\ jC_{out}\omega = \dfrac{j}{Z_c} \end{cases} \longrightarrow jL\omega = jZ_c$$

$$\to Z_c = \frac{1}{C_{out}\,\omega} \quad ?? \quad \frac{1}{1.4\,10^{-12}\times 2\pi\times 4\,10^{9}} = \boxed{28\,\Omega}$$

$$\to L\,C_{out}\,\omega^2 = 1$$

$$L = \frac{1}{1.4\,10^{-12}\times 4\pi^2\, 4^2\, 10^{18}} = 1.13\,\text{mH}$$

$$\Delta L = 1.13 - 0.7 = 0.43\,\text{mH}$$

$$C = C_{out} = 1.4\,\text{pF}$$

5) $\to$ Z_c high, θ small $\to$  $\to$

$Z_c = 80\,\Omega$

$\cos\theta \simeq 1$

$\sin\theta \simeq \theta$

$$\begin{pmatrix} \cos\theta & jZ_c\sin\theta \\ j\dfrac{\sin\theta}{Z_c} & \cos\theta \end{pmatrix} = \begin{pmatrix} 1 & jL\omega \\ 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & jZ_c\theta \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & jL\omega \\ 0 & 1 \end{pmatrix} \to \quad L\omega = Z_c\theta, \quad \theta = \frac{L\omega}{Z_c}$$

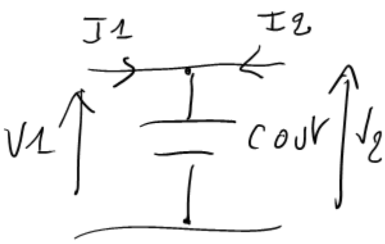
For example we choose $Z_c = 80\,\Omega$

$\to \theta = 0.135\,\text{rd}$

$\theta = 7.8°$

$\cos(0.135) = 0.99 \simeq 1$

$\sin(0.135) = 0.134$



$$\to \begin{pmatrix} 1 & 0 \\ jC\omega & 1 \end{pmatrix} = \begin{pmatrix} \cos\theta & \underbrace{jZ_c\sin\theta}_{\simeq 0} \\ j\dfrac{\sin\theta}{Z_c} & \cos\theta \end{pmatrix}$$

$C_{out} = \dfrac{\theta}{Z_c\omega} \xrightarrow{(20°)} \theta = 0.352\,\text{rd}$

θ small $\to \cos\theta = 1$

Z_c small. For example $Z_c = 10\,\Omega$

↳ Verification : $\cos(\underbrace{0.352}_{\theta}) = 0.94$ $\sin(0.352) = 0.342$

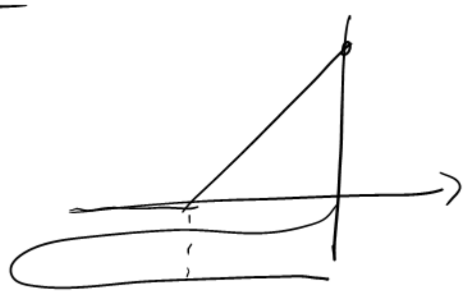
2) Determine the values of ΔL and C required to have an equivalent impedance inverting function (λ/4 , Zc1=Ropt) realized by the (Cout ; Lout +ΔL ; C) network connected at the output of drain current sources I_M and I_A .

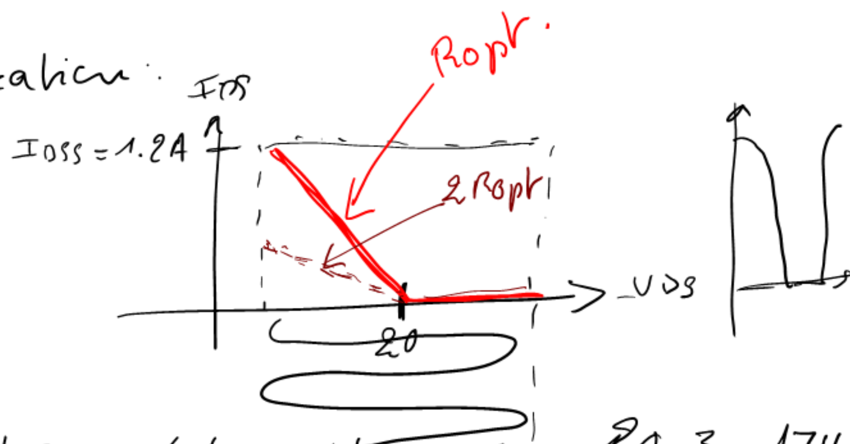
3) What is the value of Zc2 → $R_L = 14 = \dfrac{Zc_2^2}{50} \Rightarrow Zc_2 = 26.5\,\Omega$

4) When the auxiliary transistor is OFF , what is the value of Zs_A impedance. $ZS_A = \infty$ open circuit

5) Propose a realisation of ΔL and C with distributed components

Correction : 1) class B operation :



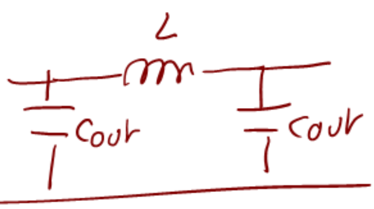


$$I_{DS1} = \frac{I_P}{2} = 0.6\ A.$$

$$V_{DS1} = (V_{DS0} - \cancel{V_{DSmin}}) = 20 - 3 = 17\,V$$

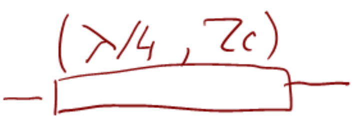
$$R_{opt} = \frac{V_{DS1}}{I_{DS1}} = \frac{17}{0{,}6} = 28\ \Omega \Rightarrow 2\,R_{opt} = 56\,\Omega$$

2)



$\xrightarrow{\text{chain}}$ Matrix

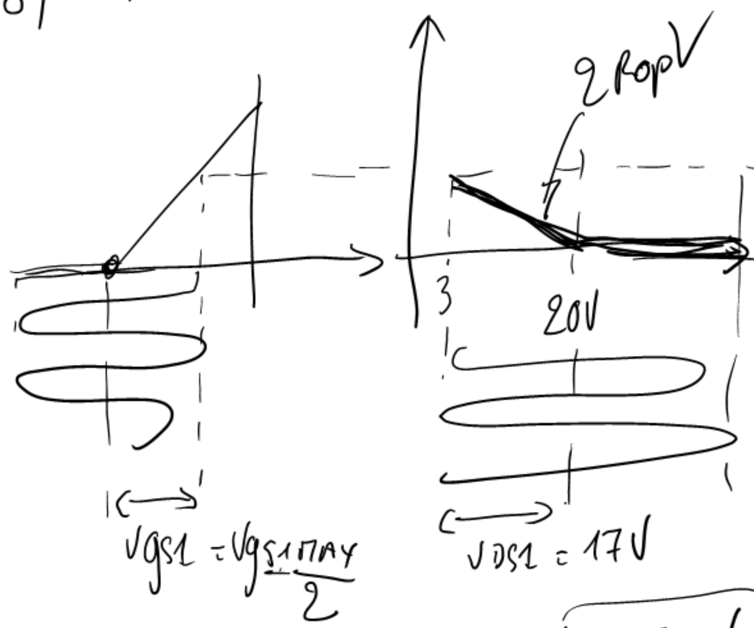
$$\begin{pmatrix} 1 - LC_{out}\omega^2 & jL\omega \\ jC_{out}\omega + jC_{out}\omega\left(1 + \frac{L\,C_{out}}{\omega^2}\right) & 1 - L\,\frac{C_{out}}{\omega^2} \end{pmatrix} =$$

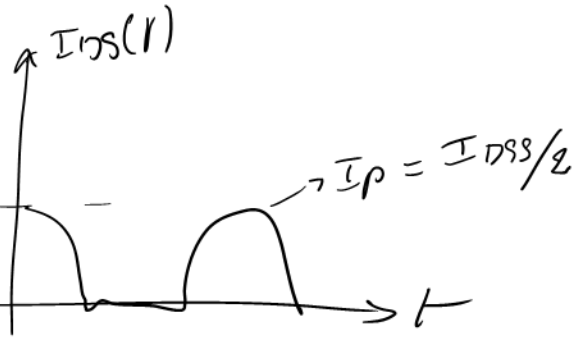


$\xrightarrow{\text{chain}}$ Matrix

$$\begin{pmatrix} 0 & jZc \\ \dfrac{j}{Zc} & 0 \end{pmatrix}$$

6) Pout = ?





$I_{DS1} = \frac{I_P}{2} = \frac{I_{DSS}}{4} = 0.3\,A$

$I_{DS0} = \frac{I_P}{\pi} = \frac{I_{DSS}/2}{\pi} = 0.19\,A$

$P_{out} = \frac{1}{2} \times 17V \times 0{,}3A = \boxed{2.55W} \rightarrow \eta_D = \frac{2.55W}{20 \times 0.19} = \boxed{67\%}$

7) $V_{gs1} = V_{gs1_{MAX}}$ for both transistors.

$P_M = \frac{1}{2} \times V_{DS1} I_{DS1} = \frac{1}{2} \times 17 \times 0.6 = 5.1W$

$P_A = \frac{1}{2} \times V_{DS1} I_{DS1} = \frac{1}{2} \times 17 \times 0.6 = 5.1W$

$P_{Amplifier} = 10.2W$

$P_{DC_{Amplifier}} = P_{DC_{main}} + P_{DC_{Aux}} = 20 \times \left(\frac{1.2}{\pi}\right) + 20\left(\frac{1.2}{\pi}\right)$

V_{DS0} $\quad$ I_{DS0} for $I_p = I_{DSS}$

$P_{DC} = 15.28W$

$\eta_D = \frac{10.2}{15.28} \simeq 67\%$