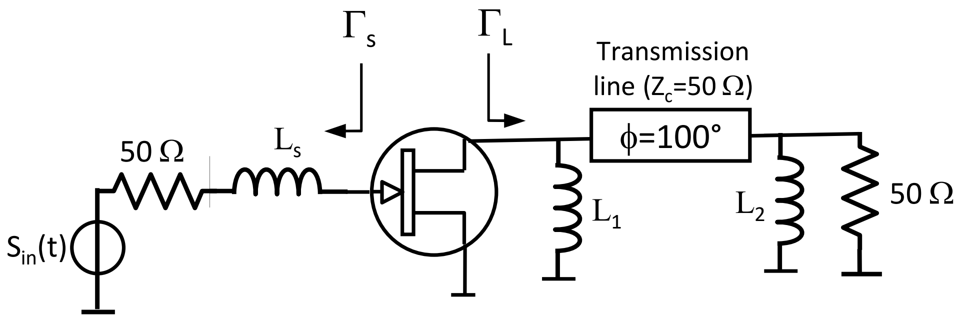
RF SYSTEMS
End Test on 21 January 2022

Surname & Name	
Identification Number	
Signature	

Exercise 1

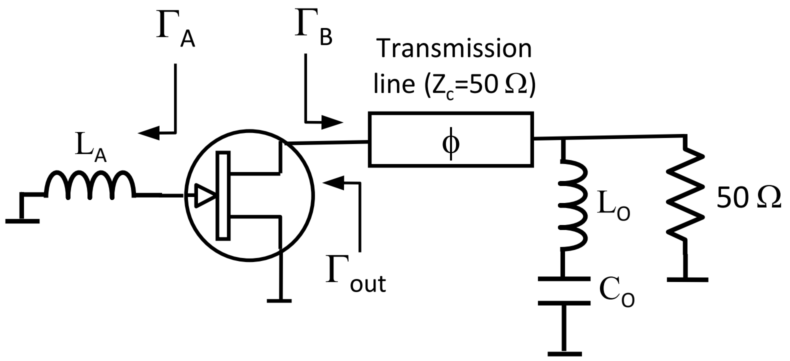
A power amplifier operating at 1.2 GHz with the scheme in the figure must be designed. The active device is characterized by the following S parameters: $S_{11}=0.37\angle{-160.8°}$, $S_{21}=3.3\angle\ 23.68°$, $S_{12}=0.091\angle 22.9°$, $S_{22}=0.25\angle{-91.7°}$. The IP3 parameter of the device is also assigned: IP3=22 dBm.



1) Assume $S_{in}(t)$ a 2-tone signal with average power P_{in}=0 dBm. Evaluate the average output power that determines the carrier-to-intermodulation (CI) of the output signal not smaller than 30 dB. Compute then the required transducer gain G_T (Note that this gain cannot exceed the maximum gain of the transistor).
2) The conjugate matching at the transistor output is assumed. Evaluate Γ_S and Γ_L so that the previously computed G_T is obtained. Note that Γ_S must be selected so that it can be realized with the assigned input network (Hint: the impedance Z_S corresponding to Γ_S is the series of 50 Ω with a positive reactance. Then, on the Smith Chart, Γ_S must be on a specific circle).
3) Compute the value of L_S, L_1 and L_2 of the input and output networks. Note that only positive values are meaningful.

Exercise 2

An oscillator working at f_0=1 GHz must be designed with the scheme in the figure (the S parameters of the active device are also reported).



S_{11}=0.73∠ -102°
S_{12}=0.1∠42°
S_{21}=4.27∠ 96°
S_{22}=0.54∠ -49°

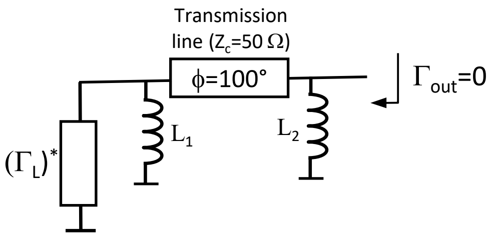
1) Imposing $|\Gamma_{out}|$=1.2 evaluate Γ_A and Γ_B that allow the start of the oscillation (choose Γ_A so that it can be implemented with the largest value of the inductor L_A). After Γ_A and Γ_B are obtained, check that the oscillation can actually starts.
2) Compute the value of the inductor L_A
3) The output network transforms the load (50 Ω) into Γ_B. Assuming that the series resonator resonates at $f_r=2f_0$, compute the electrical length ϕ and the values of L_O and C_O of the output network. Hint: The resonator at f_0 is represented by a susceptance whose value B is obtained by the design of the transforming network. To find L_O and C_O use the following expression: $B = \frac{1}{2\pi f_r L_O \left(\frac{f_r}{f_0} - \frac{f_0}{f_r} \right)} > 0$, with $f_r = \frac{1}{2\pi\sqrt{L_O C_O}} = 2 f_0$. Being $B>0$, this constraint must be taken into account during the design of the output network.
4) What is the advantage of using the series resonators in the output network?

Solutions

Exercise 1

From the S parameter we know that the device is unconditionally stable with G_{TMAX}=11.6 dB.

1) The following equation should be used: $CI_{dB} \simeq 2IP_3 - 2P_m + 6$, from which we get P_m=10 dBm. Being the input power 0 dBm, the required transducer gain is G_T=10 dB (admissible because < G_{TMAX}).
2) Being the matching at output imposed, we design the amplifier using the Available Power Gain. First, we draw the circle with G_{AV}=10 dB and select a point on this circle (this point represents Γ_S). The selection is not free because the input network imposes that the impedance z_S (corresponding to Γ_S) must be in the form (1+jx_S), with x_S>0. Then the selected point must be on the intersection of the G_{AV} circle with upper part of the circle r=1: $\Gamma_S=0.314\angle 71.68°$ (corresponding to z_S=1+j0.662).
To have the G_{AV} equal to G_T we must then impose the conjugate matching at output. With the S.C. we get $\Gamma_L=0.168\angle 104.49°$.
3) The inductance L_S is determined from $X_S=50\cdot x_S=50\cdot 0.662=33.1\ \Omega$: $L_S = X_S/(2\pi f) = 4.39$ nH.
To design the double stub network at output is convenient to consider the dual problem (matching $\Gamma_{out} = (\Gamma_L)^*$ to 50 Ohm):



$(\Gamma_L)^*$= 0.168∠-104.49° →

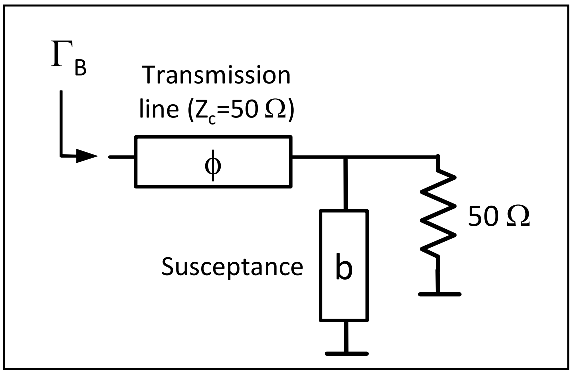
y=1.029+j0.345

We start by inserting $(\Gamma_L)^*$ in the S.C., store this value in memory and draw the circle g=1 rotated by 200° in the load direction. Then select one of the two intersections of this circle with the circle g=const passing for the load (g=1.029). The imaginary part of Delta Y represents the susceptance b_1=-0.477. Note that this value is acceptable being the susceptance implemented by an inductor. The value of L_1 is obtained from: $L_1 = -50/(2\pi f b_1) = 13.9$ nH. Now we give and increment of -200° to the current point to arrive at the input of the transmission line. This point must be on the circle g=1. In fact, from the S.C. we obtain y_2=1+j0.133. To arrive to the center of the S.C. the susceptance b_2=-0.133 must then be added, which is realized by the inductance $L_2 = -50/(2\pi f b_2) = 49.86$ nH.

Exercise 2

From the S parameter we get K=0.473 <1 then the device is potentially instable and suitable for the oscillator design.

1) We draw the Γ_S mapping circle with $|\Gamma_{out}|$=1.2, which intersects the outer circle of the Smith Chart in two points. We select the one with the largest normalized reactance: $\Gamma_A = 1\angle 89.4°$. The output reflection coefficient results $1.2\angle -137.03°$, to which correspond the impedance z_{out}=-0.105-0.39i. To ensure the start of oscillation we assign z_B=0.035+0.39i, corresponding to $\Gamma_B = 0.941\angle 137.35°$. To check the oscillation condition at the input of the transistor we determine the input reflection coefficient with the S.C. determined by Γ_B : $|\Gamma_{in}|$=1.02. Being >1 both $|\Gamma_{in}|$ and $|\Gamma_{out}|$ the start of the oscillation is confirmed.
2) From Γ_A we derive with the S.C. x_A=1.011 and then $X_A = 50 \cdot x_A = 50.55\ \Omega$. The inductance LA is then given by: $L_A = \dfrac{X_A}{2\pi f_0} = 8.0453$ nH
3) The transforming network has the single stub topology. Assume the series resonator represented by its normalized susceptance *b*. As explained in the text, this susceptance must be positive. Starting from Γ_B we move on the circle with constant gamma in the load direction until arrive at the intersection with the circle *g*=1 where the imaginary part of Y is positive. The variation of the phase of gamma ($\Delta\phi$=62.43°) defines the electrical length of the line: $\phi = \Delta\phi/2 = 31.21°$. The admittance in the direction of the load observed at the intersection is 1+jb=1+j5.56, then *b*=5.56.



Imposing:

$$B = \frac{1}{2\pi f_r L_O \left(\dfrac{f_r}{f_0} - \dfrac{f_0}{f_r} \right)} = 0.02 \cdot 5.56 = 0.1112\,,$$

we get: $L_O = \dfrac{1}{2\pi \cdot 2 \cdot 0.1668 \cdot 10^9} = 0.48$ nH. From the resonance condition at f_r=2GHz we obtain $C_O = \dfrac{1}{(2\pi \cdot f_r)^2 L_0} = 13.19$ pF.

4) The presence of the series resonator introduces a short circuit at the second harmonic frequency. In this way this harmonic is removed from the load voltage, improving the spectral purity of the oscillator.