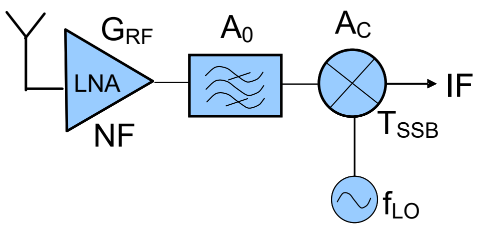
RF SYSTEMS
Written Test of 28 September 2015

Surname & Name	
Identification Number	
Signature	

Exercise 1

Consider the following receiver operating at 15 GHz (signal bandwidth B=70 MHz), with the specified parameters of the filter, mixer and antenna:



A_0=0.5 dB
A_c=4 dB
T_{SSB}=400 °K
T_A=40°K

It is now requested that:
- the minimum power of the received signal at the antenna port is -43 dBm
- the minimum power level of the signal at IF (P_{IF}) must be -30 dBm
- the S/N (power) ratio at IF must be at least 55 dB ($S/N=P_{IF}/N_{IF}$)

Compute the gain G_{RF} and the noise figure NF of the LNA so that the above requirements are satisfied (assume that the filter eliminates completely the image band)

Hint: The noise power at IF can be expressed as $N_{IF}=K \cdot T_{IF} \cdot B$, where K is the Boltzmann Constant ($1.38 \cdot 10^{-23}$ W/°K·Hz); T_{IF} is the equivalent temperature at IF; B is the signal bandwidth.

Exercise 2

A satellite earth station operates at 6 GHz with a geostationary satellite (distance: 36000 Km). The parameters of the employed antennas are the following:

Earth station:
Gain G_T =55 dB, directivity function $f_T=cos(110\cdot\theta_T)$

Satellite:
Gain G_s to compute, directivity function $f_S=cos(\theta_S)$

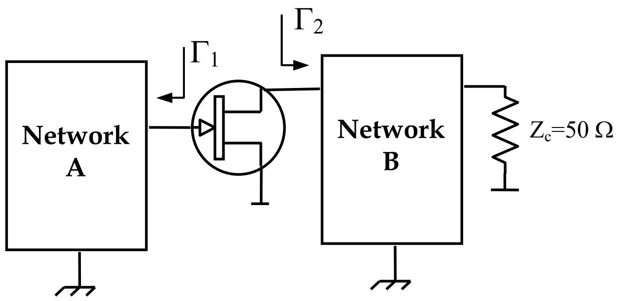
The transmitted power from the earth station is 5.5 kW.

a) Assuming initially the two antennas perfectly aligned ($\theta_{T,S}$=0), evaluate the gain G_s of the satellite antenna in order the received power (P_R) is ≥ -43 dBm.
b) Let assume now that the earth antenna is misaligned ($\theta_T \neq 0$). Evaluate the maximum value of θ_T that determines the received power to decrease by 3 dB (note that the satellite antenna remains optimally directed, so f_S=1)

Exercise 3

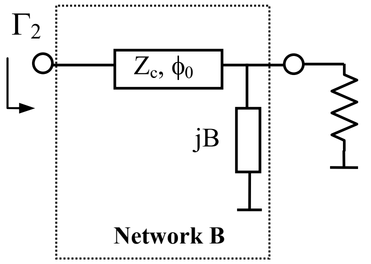
The following figure represents the general configuration of a microwave oscillator. Using the reported scattering parameters of the active device, evaluate the reflection coefficients Γ_1 and Γ_2 which ensure the start of oscillation (the magnitude of Γ_1 must be imposed equal to 1).

Hint: draw the mapping circle of the source with $|\Gamma_{out}|=1.2$ for determining Γ_1. For evaluating Γ_2 determine the value of Z_{out} corresponding to the selected Γ_1 and assign $Z_2=|R_{out}/3|-jX_{out}$.



$S_{11}=0.521\angle-52.6°$
$S_{12}=0.069\angle42.7°$
$S_{21}=14.44\angle 121.7°$
$S_{22}=0.844\angle -62.3°$

Then design the network B, using the scheme in the following figure (assume Z_c=50 Ohm and evaluate the electrical length ϕ_0 and the susceptance B):



Solution

Exercise 1

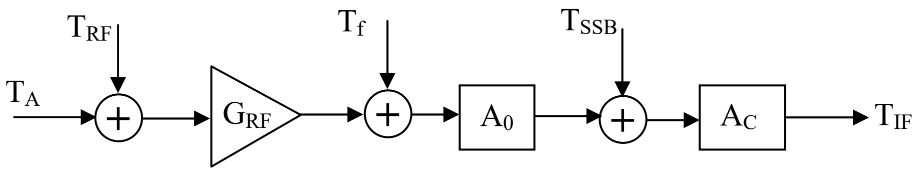
From the imposed signal power at IF the gain G_{RF} is obtained:

$$P_{IF} = P_{in}\frac{G_{RF}}{A_0 A_C} \Rightarrow G_{RF} = \frac{P_{IF}}{P_{in}} A_0 A_C = 17.5 \text{ dB}$$

The equivalent noise temperature at IF is obtained from the imposed S/N:

$$N_{IF} = \frac{P_{IF}}{S/N} = K \cdot T_{IF} \cdot B = 3.16 \cdot 10^{-12} W \Rightarrow T_{IF} = \frac{3.16 \cdot 10^{-12}}{K \cdot B} = 3273.6°\text{K}$$

T_{IF} results from the following equivalent representation:



$$T_{IF} = \frac{\left[\frac{\left[\left(T_{RF} + T_A\right) G_{RF} + T_f\right]}{A_0} + T_{SSB}\right]}{A_C}$$

where the parameter T_f is given by $T_f = T_0\left(A_0 - 1\right)$.

The unknown is represented by T_{RF}, which results:

$$T_{RF} = \frac{\left[\left(A_C T_{IF} - T_{SSB}\right) A_0 - T_f\right]}{G_{RF}} - T_A = 115.46 \text{ °K}$$

Finally the noise figure of the amplifier is given by:

$$NF = 10 \cdot \log_{10}\left(1 + \frac{T_{RF}}{T_0}\right) = 1.45 \text{ dB}$$

Esercizio 2

Link budget equation (in dB) with aligned antennas:

$$P_{S,dBm} = P_{T,dBm} + 20 \cdot \log(\lambda) - 20 \cdot \log(4\pi R) + G_{T,dB} + G_{S,dB}$$

Substituting: $P_{T,dBm}$=67.4 dBm, $P_{S,dBm}$=-43 dBm, λ=50 mm, R=36000 Km, G_T=55 dB we get:

$$G_{S,dBm} = -43 - 67.4 - 20 \cdot \log(0.05) + 20 \cdot \log\left(4\pi \cdot 36 \cdot 10^6\right) - 55 = 33.73 \text{ dB}$$

Evaluation of the misalignment angle of the earth antenna that determine 3 dB reduction of the received power:

$$P_{S,dBm} - 3 = P_{T,dBm} + 20 \cdot \log(\lambda) - 20 \cdot \log(4\pi R) + G_{T,dB} + G_{S,dB} + 10 \cdot \log\left(\cos(110 \cdot \theta)\right)$$

Then:

$$10 \cdot \log\left(\cos(110 \cdot \theta)\right) = -3$$

$$\theta = \frac{\text{acos}\left(10^{-0.3}\right)}{110} = 0.0095\text{rad} \ \ (0.545°)$$

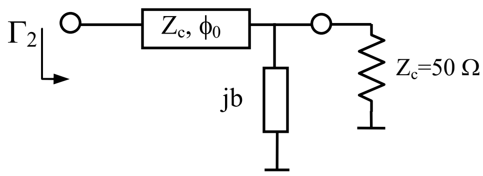
Exercise 3

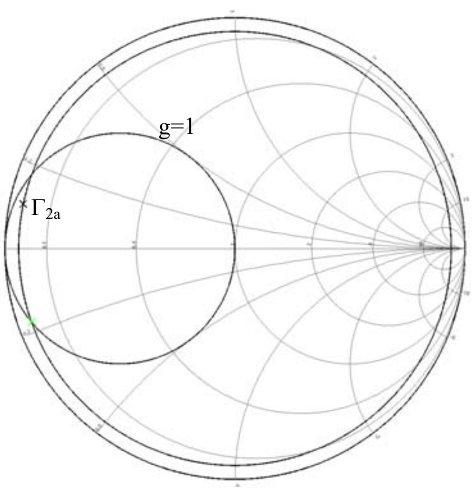
The assigned transistor is potentially instable (k=0.53), so it can be used for realizing an oscillator. Using the electronic Smith Chart, the mapping circle with $|\Gamma_{out}|=1.2$ is drawn. The two intersections with the outer circle are: $\Gamma_{1a}=1\angle 23°$ and $\Gamma_{1b}=1\angle -161.5°$

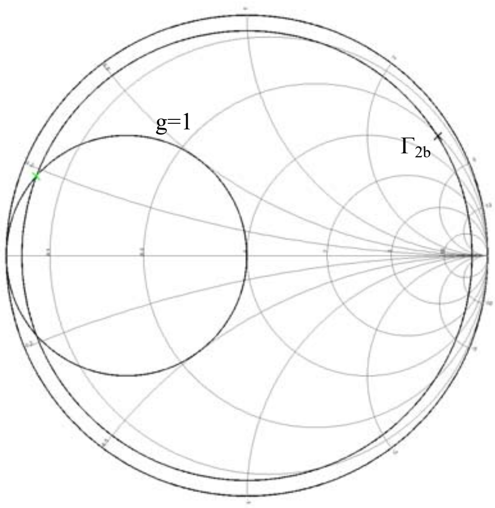
Selecting "S Param." → "Gamma OUT" the reflection coefficient at port 2 is obtained:
$\Gamma_{out,a}=1.2\angle -168°$ ($\Gamma_{out,a}=1.2\angle -28.7°$) The S. chart reports also the normalized impedance $Z_{out,a}=-0.092-j0.103$ ($Z_{out,b}=-1.31-j3.44$).

Imposing the condition suggested in the text, the values of Z_2 and Γ_2 are then obtained:
$Z_{2a} = 0.03+j0.103 \rightarrow \Gamma_{2a} =0.94\angle 168.2°$ ($Z_{2b} = 0.44+j3.44 \rightarrow \Gamma_{2b} =0.935\angle 32°$)

The matching network is designed according the well-known procedure:







$\phi_0=15.85°$, $b=5.5$

$\phi_0=63.7°$, $b=-5.3$