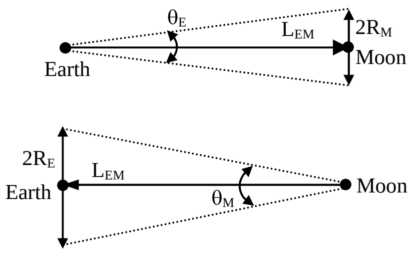
RF SYSTEMS
Written Test of February 9th, 2015

Surname & Name
Identification Number
Signature

Exercise 1

A bi-directional communication link must be established between Earth and Moon. Each station employs a single antenna for transmitting and receiving. The link Earth→ Moon operates at f_{TE}=6 GHz and the opposite (Moon→Earth) at f_{TM}=4 GHz. The antennas must be dimensioned in order that their beam width correspond to the solid angle under which the moon is seen by the earth (earth antenna) and the earth is seen by the moon (moon antenna). The following picture defines the geometry and the parameters of the links.



L_{EM} (Earth-Moon distance): 384400 Km
R_E (Earth radius): 6371 Km
R_M (Moon radius): 1378 Km
θ_E Beam width of the earth antenna
θ_M Beam width of the moon antenna

a) Evaluate the beam width of the two antennas and the corresponding directivity gain (use the approximate formulas). Assuming that dish antennas are employed, evaluate their diameter. Dimension the antennas at the transmitting frequencies(f_{TE}, f_{TM}); assume the aperture efficiency e_a= 0.65 and the efficiency factor η=0.7 for both antennas.

b) Assuming that the power transmitted from the Earth is 500W and that transmitted from the Moon is 50W evaluate the power of the received signals at the two stations

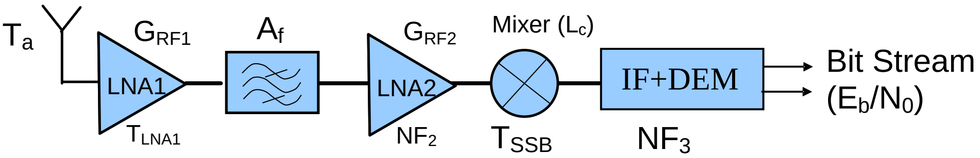
c) The SNR (signal-to-noise ratio) at the input of the receivers must be at least 20 dB. The signal bandwidth is 100 MHz and the noise temperature of the antennas is 50 °K (the transmitted powers are the same as in previous point). Compute the maximum values of the equivalent noise temperature at input of the receivers in order to meet the SNR requirement.

Use K=-228.6 dBW/(Hz·°K) (Boltzmann Constant)

Exercise 2

The scheme in the figure represents the RF front-end of a receiver for a satellite earth station operating at 4 GHz with signal bandwidth 100 MHz.

The goal is to get the system SNR equal to 20 dB with the power of the received signal equal to -109.2 dBW



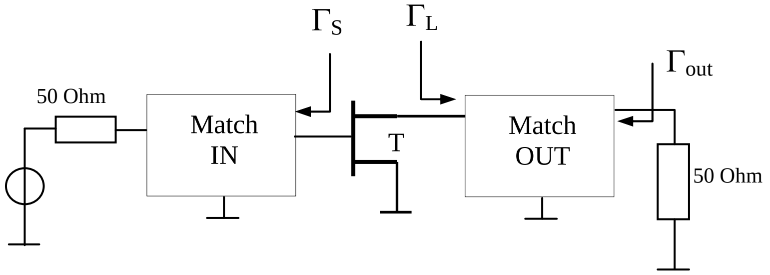
T_A=25°K
G_{RF1}=? dB
T_{LNA1}=20 °K
A_f=0.1 dB
G_{RF2}=20 dB
NF_2=1 dB
L_c=4 dB
T_{SSB}=200 °K
NF_3=2 dB

a) Evaluate the gain G_{RF1} of LNA1 in order to meet the goal
b) What is the maximum data rate R of the demodulated bit stream with (E_b/N_0) =15 dB?
   Hint: Use the expression relating the system SNR to E_b/N_0

Use K=-228.6 dBW/(Hz·°K) (Boltzmann Constant)

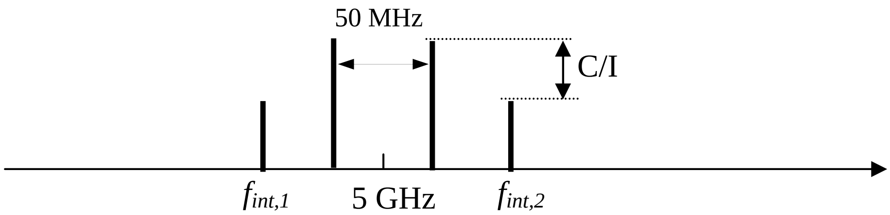
<u>Exercise 3</u>

The following figure is the scheme of a single stage amplifier to be designed at 5 GHz. The design goal is to get the largest value for the transducer gain compatible with the stability condition. Moreover we also require that the output is matched (Γ_{out}=0)



S_{11}=0.772∠ 6.17°
S_{12}=0.2∠-82.08°
S_{21}=2.224∠ -137.15°
S_{22}=0.508∠ 37.07°

1) Choose Γ_S e Γ_L in order to meet the requirements. Specify the corresponding transducer gain
2) Design the Match OUT network (single-stub configuration)
3) Assume a 2-tone driving signal with f_0=5 GHz and Δf=50 MHz. Assuming the 3th order intercept point of the device IP_3=40 dBm, compute the output peak power for which the ratio C/I is equal to 30 dB. What is the power in each intermodulation line? What are the frequencies ($f_{int,1}$, $f_{int,2}$) of the intermodulation lines?



<u>Solution</u>

<u>Exercise 1</u>

The beam width angles are immediately derived from the figures:

$$\theta_E = 2\tan^{-1}\left(\frac{R_M}{L_{EM}}\right) = 0.411°, \qquad \theta_M = 2\tan^{-1}\left(\frac{R_E}{L_{EM}}\right) = 1.9°$$

The directivity gain of the antennas is obtained with the following formula: $\cos(\theta/2) = 1 - 2/D$:

$$D_{ET} = \frac{2}{1-\cos(\theta_E/2)} = 3.113\cdot10^5\,(54.93\text{ dB}), \qquad D_{MT} = \frac{2}{1-\cos(\theta_M/2)} = 1.4565\cdot10^4\,(41.63\text{ dB})$$

The dishes radius is then obtained from:

$$\left(\frac{d}{\lambda}\right)^2 = \frac{D\cdot\eta}{\pi^2\cdot e_a}$$

For the earth antenna $\lambda_E=3\cdot10^8/6\cdot10^9=0.05$m while for the moon antenna $\lambda_M=3\cdot10^8/4\cdot10^9=0.075$m.

Then:

$$d_E = \frac{\lambda_E}{\pi}\sqrt{\frac{\eta D_{ET}}{e_a}} = 9.21\text{m}, \qquad d_M = \frac{\lambda_M}{\pi}\sqrt{\frac{\eta D_{MT}}{e_a}} = 2.99\text{m}$$

The gain of the antennas (transmission):

$G_{ET}=D_{ET}+10\cdot\log(\eta)=53.38$ dB, $G_{MT}=D_{MT}+10\cdot\log(\eta)=40.08$ dB

The gain of antenna in reception is computed from the dish formulas:

$$G_{ER} = e_a\left(\frac{\pi d_E}{\lambda_M}\right)^2 = 49.86\text{ dB}, \qquad G_{MR} = e_a\left(\frac{\pi d_M}{\lambda_E}\right)^2 = 43.6\text{ dB}$$

Computation of the links attenuation:

Earth→Moon (6Hz): $A_{EM}=20\cdot\log(4\pi L_{EM}/\lambda_E)=219.7$ dB

Moon→ Earth (4Hz): $A_{ME}=20\cdot\log(4\pi L_{EM}/\lambda_M)=216.2$ dB

The received power at the two receiving stations is obtained with the Friis Equation:

$P_{RM}=P_{TE}-A_{EM}+G_{ET}+G_{MR}=-95.72$ dBW, $P_{RE}=P_{TM}-A_{EM}+G_{MT}+G_{ER}=-109.24$ dBW

The noise at the antennas output is determined by the SNR (20 dB) and the received signals power:

$N_E=P_{RE}-SNR=-129.24$ dBW, $N_M=P_{RM}-SNR=-115.72$ dBW.

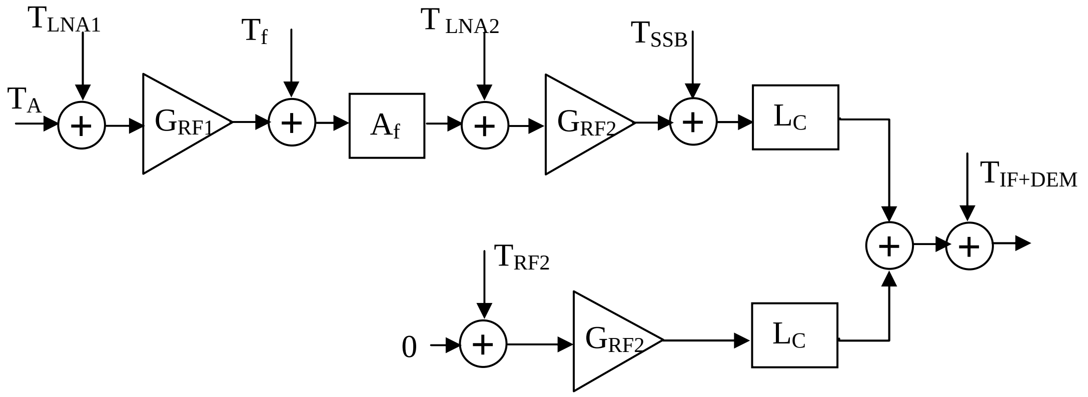
The noise power can be expressed as $N=KT_{sys}B$, with $T_{sys}=T_a+T_{rec}$. It is then obtained:

$T_{eq,E}=86.22$ °K → $T_{rec,E}=36.2$ °K

$T_{eq,M}=1939.7$ °K → $T_{rec,M}=1889.7$ °K

Exercise 2

Equivalent noise scheme :



Where:

$$T_{LNA2} = 290\left(10^{\frac{NF_2}{10}} - 1\right) = 75.088\ °\text{K}, \quad T_f = 290\left(10^{\frac{A_f}{10}} - 1\right)T_0 = 6.755\ °\text{K}$$

$$T_{IF+DEM} = 290\left(10^{\frac{NF_3}{10}} - 1\right) = 169.62\ °\text{K}$$

The equivalent noise temperature at the input of the receiver is then given by:

$$T_{sys} = T_A + T_{LNA1} + \frac{T_f}{G_{RF1}} + 2\frac{T_{LNA2}A_f}{G_{RF1}} + \frac{T_{SSB}A_f}{G_{RF1}G_{RF2}} + \frac{T_{IF+DEM}L_c A_f}{G_{RF1}G_{RF2}}$$

$$= 45 + \frac{166.83}{G_{RF1}}$$

Imposing the SNR it results: $N=KT_{sys}B=P_{rec}$-SNR=-129.2 dBW. The equivalent temperature is then given by:

$10\cdot\log(T_{sys})=-129.2-(KT_{sys})_{dB}=19.4$ → $T_{sys}=87.1$ °K

Finally the gain is obtained:

$$G_{RF1} = \frac{166.83}{T_{eq} - 45} = 3.96\ (6\ \text{dB})$$

The system SNR is equal to 20 dB and is expressed as:

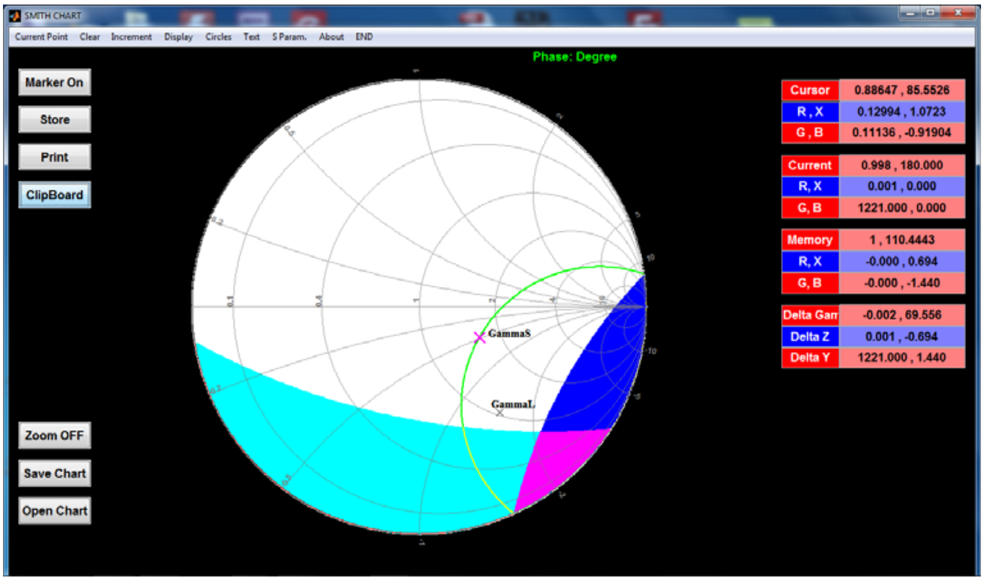
$$SNR = \frac{P}{N_0 \cdot B} = \frac{E_B}{N_0}\left(\frac{R}{B}\right) = 20\ \text{dB}$$

then: $(R/B)_{dB}=20-15=5$ → $R=3.16\cdot B=316$ Mbit/sec

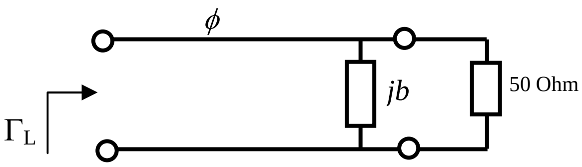
Exercise 3

After inserting on the electronic S.C. the S parameters, we get the transistor information (potentially instable, MGS=10.46 dB). The we draw the stability circles for source and load.

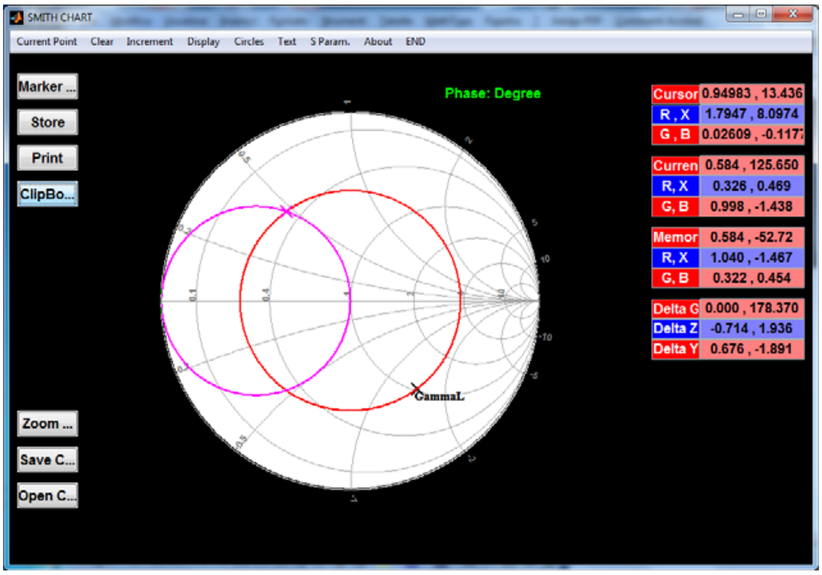
Being the output matched required, we draw the circle with available power gain equal to 10.4 and select Γ_S=0.3∠-26.85°. The conjugate match at the transistor output determine Γ_L=0.884∠-52.72 and G_T=G_{AV}=10.4 dB



The OUT network is implemented as a single stub matching network:



Using the S.C. we enter Γ_L , store it, and draw the circle with const | Γ |. Then draw the circle g=1 and select one of the intersection between the two circles.



The angle of "DeltaG" tab gives 2ϕ=178.37 → ϕ=89.18°.

The imaginary part of Y (current point tabs) gives b=-1.438.

The susceptance *b* is implemented as a short-circuited stub with:

$$\phi_s = \tan^{-1}\left(\frac{1}{1.438}\right) = 34.78°$$

It has CI=2(IP3-P_0), with P_0 power per line at f0. Then P_0=IP3-CI/2=25 dBm.
Moreover PEP=P_0+6=31 dBm.
The power in each intermod. line is P_0-CI=-5 dBm.
The frequencies of intermod. line are 5±0.075=(4.925,5.075) GHz