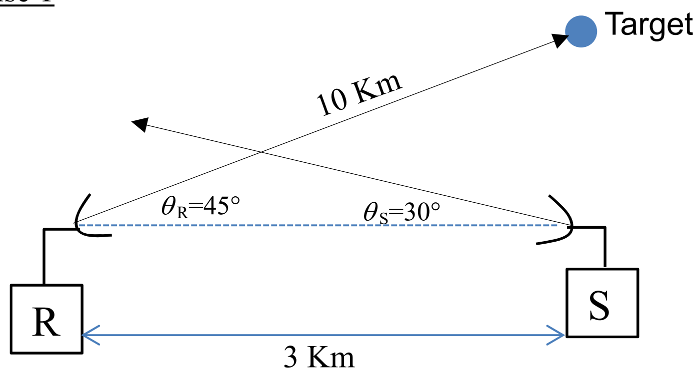
RF SYSTEMS
Written Test of February 25th, 2016

Surname & Name
Identification Number
Signature

Exercise 1



A discovery radar (R) operating at 4 GHz must be able to reveal a target at 10 Km and 45° elevation. The antenna used is a paraboloid dish with 1 m diameter (aperture efficiency e_a=0.6; efficiency η=0.8); the target is characterized by the radar cross section σ=1m^2. The transmitted power must be however limited by the presence, at the distance L=3 Km, of a satellite ground station (S) operating in the same frequency band. Also the antenna of S is a dish presenting a gain G_S=40 dB with efficiency η=0.9, directed at 30° elevation (see the figure). Both antennas exhibit the same directivity function:

$$f(\theta)=\left[\frac{\sin\left(1.3915\cdot\theta/\theta_{3dB}\right)}{\left(1.3915\cdot\theta/\theta_{3dB}\right)}\right]^2$$

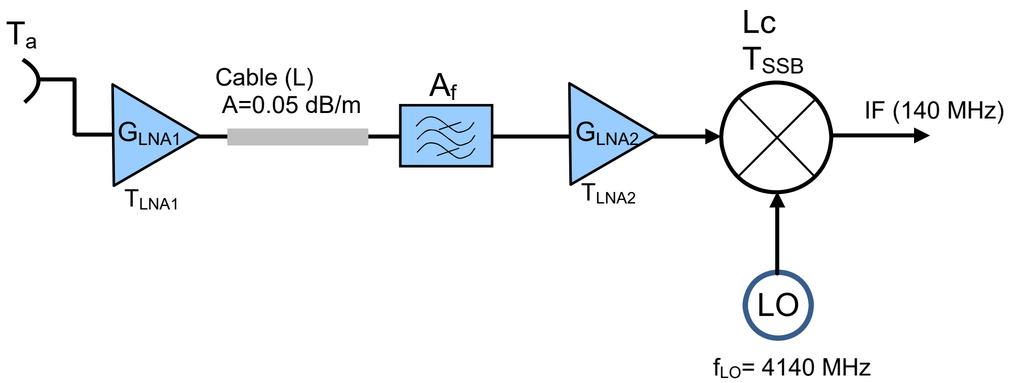
(θ is the angle with respect the maximum of G).

θ_{3dB} is the angle where f=0.5 (remember that θ_{3dB} can be expressed, in a first approximation, as a function of D_{max})

1) Evaluate the gain G and the directivity gain D_{MAX} of the radar antenna
2) Evaluate θ_{3dB} for both antennas (R and S)
3) Compute the maximum transmitted power P_T from R in order that the received power by S don't exceed -50 dBm (note that R antenna is pointing in the direction of target)
4) Evaluate the sensitivity of the radar receiver (i.e. the received power generated by the considered target)

<u>Exercise 2</u>

Consider the RF front-end of the satellite receiving station of the previous exercise:



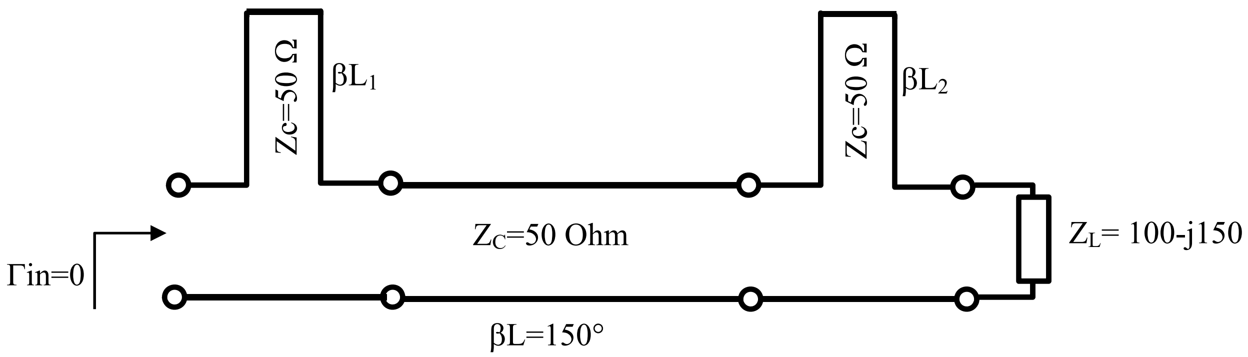
T_a=100°K
T_{LNA1}= ?
G_{LNA1}=10 dB
A_f=0.2 dB
NF_{LNA2}=1 dB
G_{LNA1}=15 dB
L_c=6 dB
T_{SSB}= 220 °K
L=10 m

Assume for the received signal: P_R=-60 dBm, f_0=4.28 GHz, B=32 MHz.

1) Evaluate the signal power P_{IF} at IF output.
2) Write the expression of the equivalent noise temperature T_{eq} referred at the input of the RF front-end
3) Imposing $SNR=P_R/KT_{eq}B \geq 40$ dB evaluate the maximum value of T_{LNA1}.
4) Evaluate the noise power $P_{N,IF}$ at IF output: $P_{N,IF} = KT_{IF}B$, with T_{IF} the equivalent noise temperature at IF
5) Consider the disturbing signal at 4 GHz produced by the radar station at the antenna input (P_{RAD}=-50 dBm). Evaluate the power $P_{RAD,IF}$ produced at IF output assuming the attenuation of the filter at the image frequency equal to 40 dB.
6) Assuming the disturbing signal at IF as noise, evaluate the overall signal-to-noise ratio at IF: $SNR_{IF} = P_{IF}/(P_{N,IF}+P_{RAD,IF})$

Exercise 3

Consider the matching network in the following figure.



Evaluate the electrical lengths βL_1 and βL_2 (choose the shortest lengths). Note that the stubs are connected in series and are terminated with a short circuit.

SOLUTION

Exercise 1

1) Gain of antenna R:

$$G = A_e \frac{4\pi}{\lambda^2} = e_a \left(\frac{\pi d}{\lambda}\right)^2$$

$\lambda = 300/4 = 75\text{mm}\ \ (0.075\text{m}) \rightarrow G_R = 1050\ (30.22\text{ dB})$

$D_{MAX} = G_R / \eta_R = 31.19\text{ dB}$

2) Evaluation of θ_{3dB} of the two antennas:

$$\theta_{3dB}^R = \frac{180}{\pi}\sqrt{\frac{4\pi}{D_{MAX}}} = 5.6°$$

$$\theta_{3dB}^S = \frac{180}{\pi}\sqrt{\frac{\eta_S 4\pi}{G_S}} = 1.93°$$

3) Link budget R→S:

$$P_{R,sat} = P_{T,\text{rad}} - 20\log\left(\frac{4\pi\cdot 3Km}{\lambda}\right) + G_R + G_S + 10\log\left(f_R(45°)\right) + 10\log\left(f_S(30°)\right) = -50\text{ dBm}$$

$P_{T,\text{rad}} = 50.63\text{ dBm}$

4) Evaluation of the received power by R:

$$P_{R,\text{rad}} = P_{T,\text{rad}} - 2\cdot 20\log\left(\frac{4\pi\cdot 10Km}{\lambda}\right) + 2G_R + 10\log\left(\frac{4\pi\cdot\sigma}{\lambda^2}\right) = -104.4\text{ dBm}$$

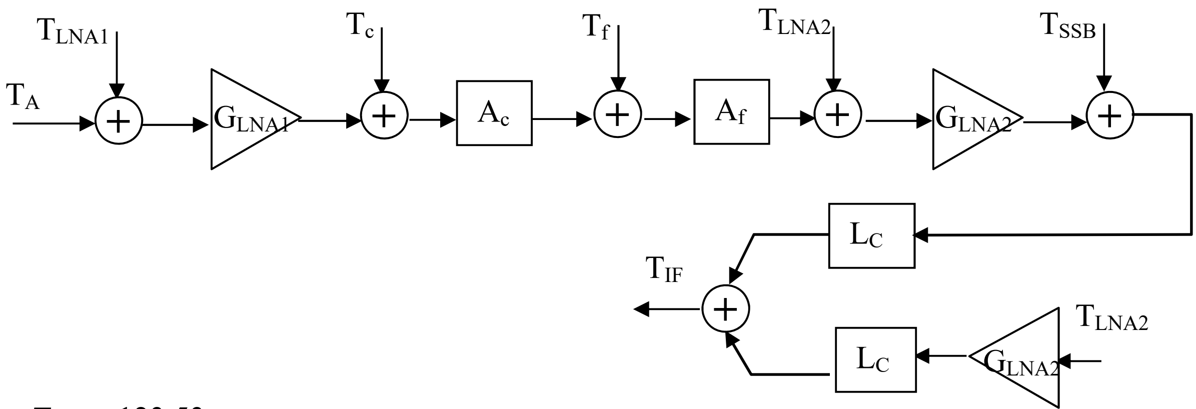
Exercise 2

1) Evaluation of Signal power at IF:

$P_{R,IF} = P_R + G_{LNA1} - A\cdot 10 - A_f + G_{LNA2} - L_c = -41.7\text{ dBm}$

2) Expression of Teq:

$$T_{eq} = T_a + T_{LNA1} + \frac{T_c}{G_{LNA1}} + \frac{T_f A_c}{G_{LNA1}} + 2\frac{T_{LNA2} A_c A_f}{G_{LNA1}} + \frac{T_{SSB} A_c A_f}{G_{LNA1} G_{LNA2}}$$



$T_{eq} = T_{LNA1} + 123.53$

3) Evaluation of T_{LNA1}:

$$SNR = P_R - \left(KT_{eq}B\right)_{dB} = 40$$

$$\left(KT_{eq}B\right)_{dB} = -60 - 40 = -100 \text{ dBm} \;\rightarrow\; 10^{-13}W$$

$$T_{eq} = \frac{10^{-13}}{KB} = 226.45 \text{ °K}$$

$$T_{LNA1} = T_{eq} - 123.53 = 102.92 \text{ °K}$$

4) Evaluation of $P_{N,IF}$:

$$T_{IF} = T_{eq}\frac{G_{LNA1}G_{LNA2}}{A_C A_f L_C} = 1.524 \cdot 10^{4}$$

$$P_{N,IF} = KT_{IF}B = 6.729 \cdot 10^{-12}W \rightarrow -81.72 \text{ dBm}$$

5) Evaluation of $P_{RAD,IF}$:

$$P_{RAD,IF} = P_{RAD} + G_{LNA1} - A \cdot 10 - A_f\left(f_{IM}\right) + G_{LNA2} - L_c = -50 + 10 - 0.5 - 40 + 15 - 6 = -71.5 \text{ dBm}$$

6) Evaluation of SNR_{IF}:

$$P_{N,tot} = P_{N,IF} + P_{RAD,IF} = 10^{-81.72/10} + 10^{-71.5/10} = 7.752 \cdot 10^{-11} \rightarrow 71.1 \text{ dBm}$$

$$SNR_{IF} = P_{IF} - P_{N,tot} = -41.7 + 71.1 = 29.4 \text{ dBm}$$

<u>Exercise 3</u>

Using the electronic Smith Chart we get the reactances requested by the two stubs:

$$x_1 = -0.73$$

$$x_2 = 3.27$$

Using the expression $\phi = \tan^{-1}\left(x\right)$ we get the electrical lengths of the stubs:

$$\phi_1 = 143.72°$$

$$\phi_2 = 73°$$