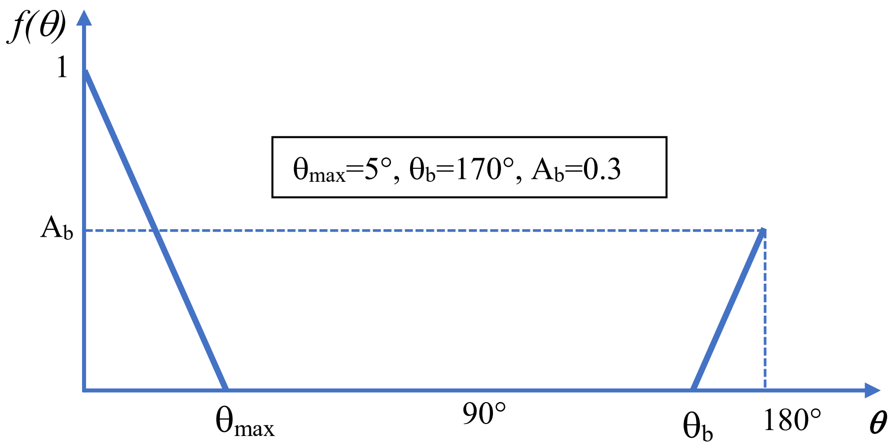
RF SYSTEMS – 1th Midterm test
8 November 2018

Surname & Name
Identification Number
Signature

Exercise 1



Consider the antenna exhibiting the directivity function $f(\theta)$ shown in the figure (f is constant along the φ coordinate). Note that the part of f up to θ_{max} represents the main lobe while that above 90° is the back lobe.

Analytically, f is expressed as follows:

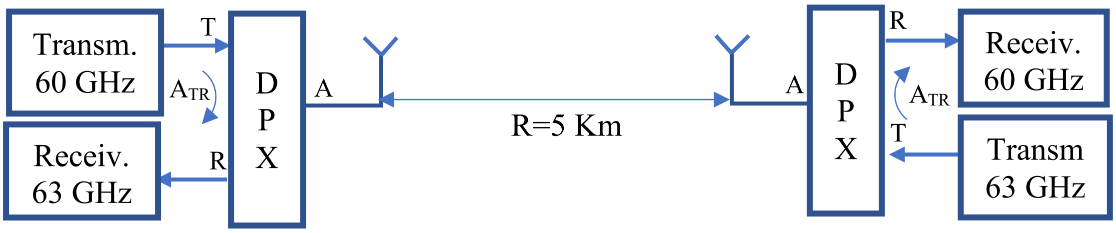
$f(\theta) = 1 - \theta/\theta_{\max}$ for $0<\theta<\theta_{\max}$, $\quad f(\theta) = A_b(\theta-\theta_b)/(\pi-\theta_b)$ for $\pi>\theta>\theta_b$

$f(\theta) = 0$ elsewhere

1) Draw qualitatively the directivity diagram in the polar plane (f, θ coordinate)
2) Compute the 3dB beam width $\Delta\theta_{3dB}$ of the antenna (main lobe).
3) Compute the directivity gain D_M of the antenna. Hint: $\int x \cdot \sin(x) \cdot dx = \sin(x) - x \cdot \cos(x)$
4) The beam efficiency B_E is defined as the ratio of the power emitted in the main lobe and the emitted overall power. Evaluate B_E for the considered antenna.

Exercise 2

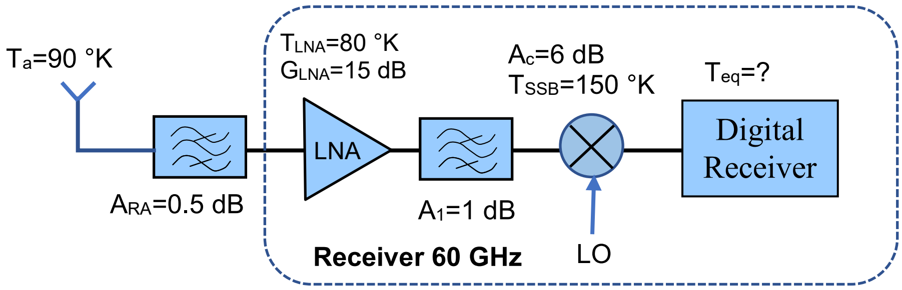
The full duplex communication system in the following figure operates at 60/63 GHz. The antennas are identical, with G=20 dB and T_a=90°K



The block DPX is a diplexer, which allows connecting transmitters and receivers to a single antenna. The attenuation (dissipative) from ports T and R to port A is $A_{TA}=A_{AR}$=0.5 dB. The rejection from port T to port R is A_{TR}=70 dB. The signal is 256-QAM with B=32 MHz and the transmitted mean power (transmitters output) is P_T=40 dBm. The transmitters produce intermodulation noise in the receiver band, determined by the ACPR=70 dB (which is the ratio between the power in the transmit band and the intermodulation power produced in the receiving band at the transmitters outputs).

In addition to the free space attenuation L_f determined by R, an additional attenuation L_{add}=15 dB must be included to account for meteorological events.

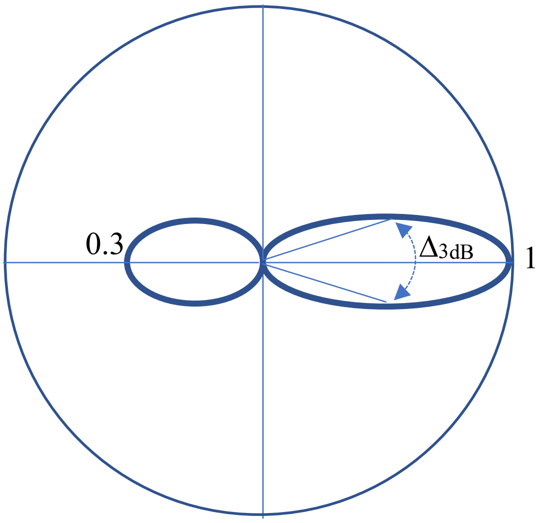
1) Evaluate the power at the input of the receiver at 60 GHz
2) Assuming that the receiving system temperature T_{sys} (antenna terminal) is 250 °K, evaluate SNR_{sys}, which is defined as $P_{ant}/(P_N+P_{int})$, with P_{ant} the received power at antenna output, P_N the thermal noise power and P_{int} the intermodulation power in the receiving band arriving from the transmitter through A_{TR} and reported at the antenna port.
3) With E_b/N_0=10 dB, what is the allowed data rate R?
4) Consider the receiving path described in the following scheme:



Imposing T_{sys}=250 °K evaluate the maximum value for T_{eq} of the digital receiver.
With the computed value of T_{eq}, is it possible, with a new value of T_{SSB}, to remove the LNA and the following filter, maintaining the overall T_{sys} unchanged?

Exercise 1

1)



2) $\Delta\theta_{3dB}$ is obtained by imposing $f(\theta_{0.5})=0.5$ → $\theta_{0.5} = \theta_{max}/2=2.5°$. Then $\Delta\theta_{3dB} = 2\theta_{0.5} = 5°$.

3) Computation of directivity gain D_m:

$$D_M = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} f(\theta)\sin(\theta)\,d\varphi\,d\theta} = \frac{2}{\int_0^{\theta_{max}} f_1(\theta)\sin(\theta)\,d\theta + \int_{\theta_b}^{\pi} f_2(\theta)\sin(\theta)\,d\theta} =$$

$$\int_0^{\theta_{max}} f_1(\theta)\sin(\theta)\,d\theta = \int_0^{\theta_{max}}\left(1-\frac{\theta}{\theta_{max}}\right)\sin(\theta)\,d\theta = 1-\frac{\sin(\theta_{max})}{\theta_{max}} = 1.2687\cdot 10^{-3}$$

$$\int_{\theta_b}^{\pi} f_2(\theta)\sin(\theta)\,d\theta = \frac{A_b}{\pi-\theta_b}\int_{\theta_b}^{\pi}(\theta-\theta_b)\sin(\theta)\,d\theta = \frac{A_b}{\pi-\theta_b}\left(\pi-\theta_b-\sin(\theta_b)\right) = 1.5208\cdot 10^{-3}$$

$$D_M = \frac{2}{2.79\cdot 10^{-3}} = 717 \quad (28.55\text{ dB})$$

3) B_E is given by:

$$B_E = \frac{\int_0^{2\pi}\int_0^{\theta_{max}} f_1(\theta)\sin(\theta)\,d\varphi\,d\theta}{\int_0^{2\pi}\int_0^{\pi} f(\theta)\sin(\theta)\,d\varphi\,d\theta} = \frac{1.2687\cdot 10^{-3}}{2.79\cdot 10^{-3}} = 0.455$$

Exercise 2

1) Applying the Friis equation we get the received power at the receiver input (60 GHz):

$$P_r = P_t - A_{TA} + 2G - L_f - L_{add} - A_{AR} = 40 - 0.5 + 40 - 20\log\left(\frac{4\pi\cdot 5000}{3\cdot 10^8/60\cdot 10^9}\right) - 15 - 0.5 = -77.98 \text{ dBm}$$

2) The received power at antenna terminal is $P'_r = P_r + A_{AR} = -77.48$ dBn ($1.7848\cdot 10^{-11}$ W). The thermal noise is $P_N = KT_{sys}B = 1.104\cdot 10^{-13}$ W. The intermodulation power at transmitter output is $P_{int1} = P_t - ACPR = -30$ dBm. The intermodulation at the receiver input results: $P_{int2} = P_{int1} - A_{TR} = -100$ dBm. This power, reported at the antenna terminal: Pint=Pint2+A_{TA}=-99.5 dBm ($1.122\cdot 10^{-13}$ W)
Finally:

$$SNR_{sys} = \frac{P'_r}{P_N + P_{int}} = \frac{1.7848\cdot 10^{-11}}{1.104\cdot 10^{-13} + 1.122\cdot 10^{-13}} = 80.1797 \ \ (19.04 \text{ dB})$$

3) It has:

$$SNR_{sys} = \frac{E_b}{N_0}\frac{R}{B} \Rightarrow R = B\frac{SNR_{sys}}{E_b/N_0} = 32\cdot\frac{80.18}{10} = 256.58 \text{ Mbit/sec}$$

4) Expression of Tsys:

$$T_{sys} = T_a + T_{RA} + T_{LNA}A_{RA} + \frac{A_{RA}}{G_{LNA}}\left(T_1 + A_1 T_{SSB} + T_{eq}A_1 A_c\right) = 250$$

$$A_{RA} = 10^{0.05} = 1.122,\ A_1 = 10^{0.1} = 1.259,\ A_c = 10^{0.6} = 3.98$$

$$T_{RA} = T_0\left(A_{RA} - 1\right) = 35.75\ °K,\quad T_1 = T_0\left(A_1 - 1\right) = 75.865\ °K$$

$$0.1778\cdot T_{eq} = 25.0951$$

$$T_{eq} = 141.12\ °K$$

If the LNA and filter 2 are removed Tsys is expressed as:

$$T_{sys} = T_a + T_{RA} + A_{RA}T_{SSB} + T_{eq}A_{RA}A_c$$

Replacing the assigned parameters, even with $T_{SSB}=0$, we get Tsys=756.1 °K. Then it is not possible to eliminate the LNA maintaining Tsys=250 °K.