RF SYSTEMS
Written Test of February 23th, 2015

Surname & Name	
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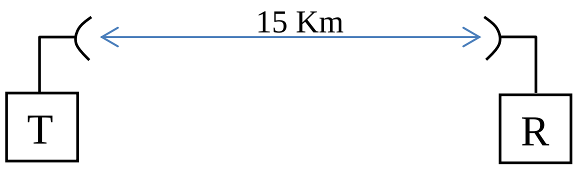
Exercise 1

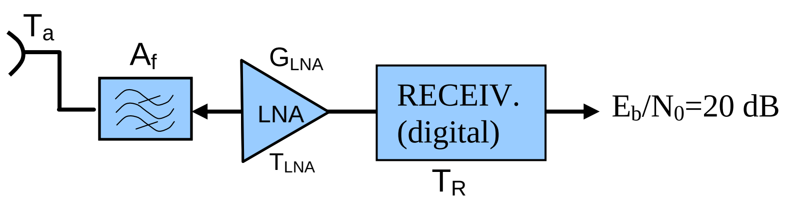


The figure shows a terrestrial link operating at 12 GHz with bandwidth B=10 MHz. The two stations are located 15 Km away and the antennas are identical with the following features:

Efficiency η=0.8. Directivity function $f(\theta)=1$ for $0< \theta <20°$, $=0$ elsewhere.

1) Evaluate the gain G of the antennas
2) It is known the system noise temperature Tsys=1000 °K of the station R. What it the power to be transmitted from T in order to get the system SNR equal to 30 dB? Assume the antennas pointed for the maximum gain.

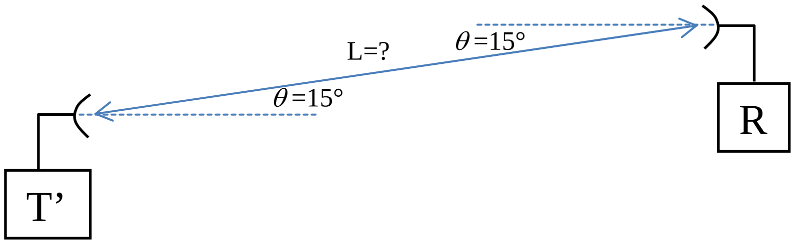
Consider the following scheme for the receiving station R:



T_{LNA}=150°K
T_a=500°K
G_{LNA}=10 dB
A_f=1 dB
T_R=? °K

3) Evaluate the equivalent noise temperature of the receiver (T_R) compatible with the imposed system SNR .
4) Assuming E_b/N_0=20 dB at the receiver output, what is the maximum data rate R?

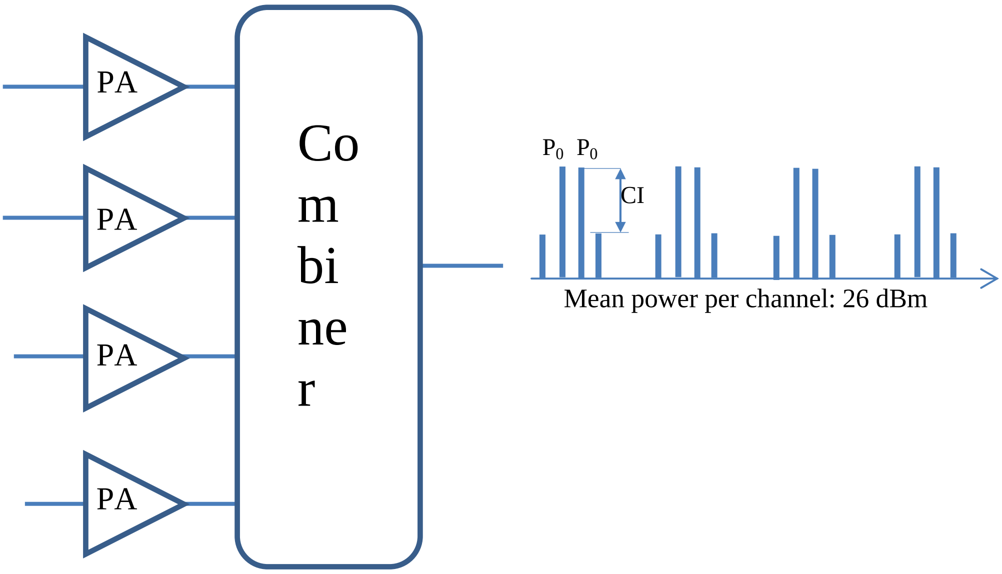
Consider now another transmitting station located as in the following figure, transmitting a power P=10W at the same frequency of T (12 GHz). The antenna of this station is characterized by G=10 dB and $g(\theta)=\cos(5.7\cdot\theta)$. The signal received by R represents in this case an interference and should be treated as noise which is added to the thermal noise of the receiving station.



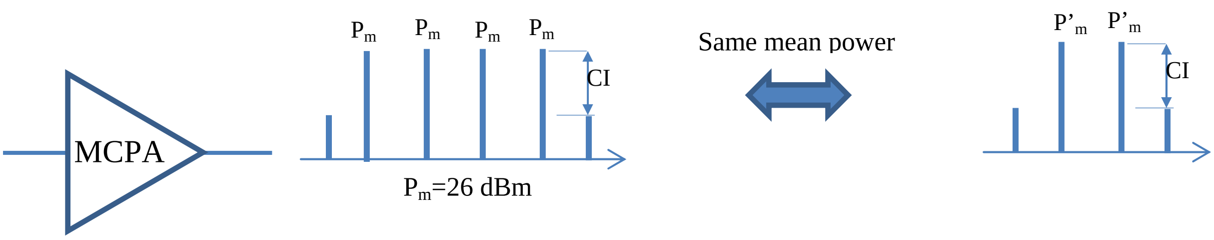
5) Evaluate the minimum distance L so that the overall system SNR of R is not lower than 20 dB.

Exercise 2

A base station transmitter generates a signal constituted by 4 channels 5 MHz spaced, each with bandwidth 1 MHz. The first channel starts at 1.8 GHz. This signal is produced by 4 amplifiers (PA) followed by a selective combiner (producing a loss of 1 dB for each channel).
Assume that the signal in each channel can be represented by 2 tones 1 MHz apart. If the mean power per channel must be 26 dBm (at the output of the combiner), find the P_{1dB} of the amplifiers which determine the minimum carrier-to-intermodulation (CI) equal to 30 dB (see the figure).



Consider now the use of a single PA (MCPA). Assume that the signal in each channel is represented by a single tone with the assigned mean power (26 dBm). We ask to determine the P_{1dB} of the MCPA which still determine CI=30 dB. For performing this computation, assume that the 4-tone signal at the output of the MCPA is equivalent (for the IM3 generation) to a 2-tone signal with the same mean power:

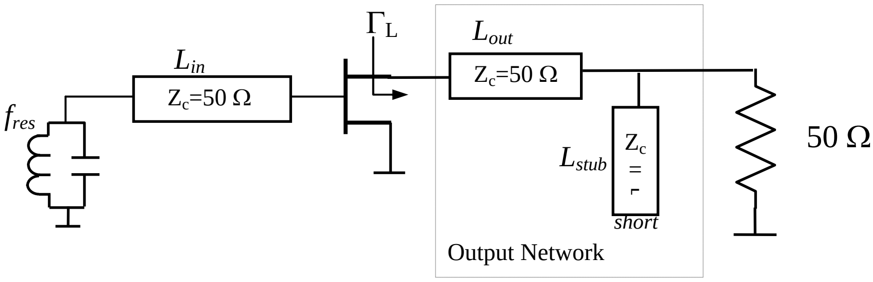


The gain of the MCPA is not sufficient to get the requested power at the output. A driver is then used before the MCPA. Knowing that G_{MCPA}=10 dB, $P_{in,m}$=6 dBm, find the gain G_{drv} and P_{1dB} of the driver in order to get the requested output power and the overall P_{1dB} reduced by 1 dB with respect that of the MCPA.

In what way is it possible to reduce the requested P_{1dB} of the MCPA still maintaining the same CI (and not resorting to a linearizer)?

Exercise 3

We want to design the oscillator in the figure operating at 2 GHz:



The S parameters of the active device at 2 GHz are given in the following table as function of the bias current:

Ibias	S11	S12	S21	S22
10 mA	0.745 ∠ -162.9°	0.063∠-7.1°	1.875∠25.1°	0.602∠-119.6°
20 mA	0.76∠-145°	0.06∠-1.2°	1.92∠43.6°	0.603∠-105.3°
30 mA	0.864∠-93.4°	0.064∠27.4°	2.545∠93.8°	0.627∠-64.2°

1) Select the bias current (imposing the necessary oscillation condition)
2) Assign a suitable value to the resonant frequency f_{res}
3) Assuming the relative dielectric constant of the lines ε_r=2.2, evaluate the length L_{in} of the input line
4) Evaluate the reflection coefficient Γ_L to be presented at the transistor output and design the output network (i.e. evaluate the lengths L_{out} and L_{stub})

Solution

Exercise 1

The antenna gain is obtained from the formula:

$$G = \eta 4\pi \left[\int_0^{2\pi} d\varphi \int_0^{\pi} g(\theta) \sin\theta d\theta \right]^{-1} = 2\eta \int_0^{20°} \sin\theta d\theta = \frac{2\eta}{1-\cos(20°)} = 26.53 \ \text{(14.24 dB)}$$

The system SNR is defined as:

$$SNR_{sys} = \frac{P_{rec}}{KT_{sys}B} = 30 \text{ dB}$$

Then the received power must be $Pr=30+KT|_{dBm}+10\log(B)=30-168.6+70=-68.6$ dBm

The Friis equation for the given link is:

$$P_{rec} = P_{tr} + 2G - L_f$$

with: $L_f = 20 \cdot \log\left(\frac{4\pi R}{\lambda}\right) = 137.55$ dB, (λ=3e8/12e9=0.025m)

Then the transmitted power results:

$$P_{tr} = P_{rec} - 2G + L_f = -68.6 - 2G + L_f = 40.45 \text{ dBm}$$

From the scheme of the receiving system it has:

$$T_{sys} = T_a + T_f + 290 \cdot \left(10^{A_f/10} - 1\right) + T_{LNA} \cdot 10^{A_f/10} + T_R \cdot 10^{(A_f - G_{LNA})/10} = 1000 \text{ °K}$$

from which: T_R=1875.2 °K

The SNR_{sys} is related to E_b/N_0 as follows:

$$SNR_{sys} = \frac{E_b}{N_0}\frac{R}{B}$$

The value of R is then given by: $R=B \cdot 10^{(30-20)/10}$=100 Mbit/sec

From the Friis equation for the second link the received power at R is expressed as:

$P'_{rec}=P't+G_T+G_R+f(15°)+g(15°)-Lf'=40+10+14.24+0+10 \cdot \log(\cos(5.7 \cdot 15°))-Lf'=53.19 \text{ dBm}-L'_f$

The received power is imposed by the minimum system SNR=20dB (100):

$$SNR'_{sys} = \frac{P_{rec}}{KT_{sys}B + P'_{rec}} = \frac{1}{\frac{KT_{sys}B}{P_{rec}} + \frac{P'_{rec}}{P_{rec}}} = \frac{1}{\frac{1}{SNR_{sys}} + \frac{P'_{rec}}{P_{rec}}} = 100$$

It has then:

$$\frac{P'_{rec}}{P_{rec}} = \frac{1}{SNR'_{sys}} - \frac{1}{SNR_{sys}} = 0.01 - 0.001 = 0.009,$$

$$P'_{rec}\big|_{dBm} = P_{rec}\big|_{dBm} + 10 \cdot \log(0.009) = -68.6 - 20.46 = -89.06$$

The link attenuation can be obtained as follows:

L'_f=53.18+89.06=142.24

The minimum distance L is then given by:

$$L = 10^{142.24/20} \cdot \frac{0.025}{4\pi} = 25.75 \text{ Km}$$

Exercise 2

With the mean power per channel at output equal to 26 dBm, each amplifier must exhibit an output power in each tone given by P_0=26+1-3=24 dBm. It has then:

CI=2(IP3-P_0) → IP3=CI/2+P_0=15+24=39 dBm → P_{1dB}=39-10=29 dBm

In the case of using a MCPA, the mean power of the equivalent 2-tone signal is given by P'mean=4Pm=26+6=32 dBm. The power per tone is P'm=32-3=29 dBm, so the new IP3 is given by:

IP3'=CI/2+P'_m=15+29=44 dBm → P'_{1dB}=44-10=34 dBm

With Pin=6 dBm and G_{MCPA}=10 dB, in order to get Pout=32 dB we need G_{drv}=16 dB.

The P_{1dB} of the driver is obtained from this equation:

$$\frac{1}{IP3_{tot}^2} = \frac{1}{IP3_{MCPA}^2} + \frac{1}{G_{MCPA}^2 \cdot IP3_{drv}^2} \rightarrow IP3_{drv} = \frac{1}{G_{MCPA}} \sqrt{\frac{1}{\left(\frac{1}{10^{0.2 \cdot IP3_{tot}}} - \frac{1}{10^{0.2 \cdot IP3_{MCPA}}}\right)}} = 3284.4 \text{ (35.16 dB)}$$

$P_{1dB,drv}$=35.16-10=25.16 dBm

The P_{1dB} of the MCPA can be reduced by 3 dB without affecting the CI by using a balanced configuration (two identical amplifiers + two 90° hybrids).

Exercise 3

Using the electronic Smith Chart it can be observed that the active device is potentially instable ($k<1$) only with Ibias=30 mA.

The resonant frequency of the resonator is assigned equal to the oscillation frequency. The input line is then an open stub with $b_s=\tan(\beta \cdot L_{in})$. For choosing bs the mapping circle of the source is drawn with $|\Gamma_{out}|=1.2$. The chosen point must be also on the outer circle (two choices); we have selected bs=-1.39. The electrical length of the input stub is then given by:

$(\beta \cdot L_{in})=\tan^{-1}(-1.2)=129.8°$

It has:

$Z_{out}=-0.27-j1.386 \rightarrow Z_L=0.09+j1.386$.

The single-stub matching network transforms Z_L into 50 Ohm. We get:

$(\beta \cdot L_{out})=44.4°$, $b_{stub}=-5.55 \rightarrow (\beta \cdot L_{stub})=\tan^{-1}(1/5.55)=10.21°$

Lengths computations:

$$\lambda = \frac{300}{f_0\sqrt{\varepsilon_r}} = 101.13 \text{ mm}, \qquad \beta = \frac{360}{\lambda} = 3.56 \text{ °/mm}$$

$L_{in}=129.8/\beta=36.46$ mm, $L_{out}=44.4/\beta=12.47$ mm, $L_{stub}=10.21/\beta=2.87$ mm