Link Budget Calculation: Wireless Link Project

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1 Introduction

In the course Wireless link project (MCC125) the task is to design and construct a wireless communication system that can communicate over 100 m. This document explains the link budget for the project.

2 Software Design

The system is designed to operate at QPSK and 16-QAM. The transmitted message is a text message using a bit rate (R_b) of 80 Kbps. The symbol rate (R_s) is 40 KHz for QPSK and 20 KHz when using 16-QAM. The sampling rate (f_s) is 800 KHz and the bandwidth (B) is 400 KHz. Assuming a maximum bit error rate is $BER = 10^{-5}$ which requires a $SNR = 15.6$ dB for QPSK and a $SNR = 25.4$ dB for 16-QAM respectively according to equation below

$$SNR = \frac{E_b}{N_0} \cdot \frac{R_b}{B}. \tag{1}$$

Where E_b is bit energy, N_0 is noise power.

Table 1

Modulation	**Eb/N0**	**Rb/B**	**SNR (dB)**
QPSK	9.6	2	15.6
16-QAM	13.4	4	25.4

3 Hardware Design

3.1 Transmitter

The transmitter is designed as shown in the figure 1.
The specifications of the transmitter elements @2.4 GHz@+25C are shown in the table 2. The calculated gain delivered by the transmitter is 19.2 dB with an output power of 16.4 dBm.

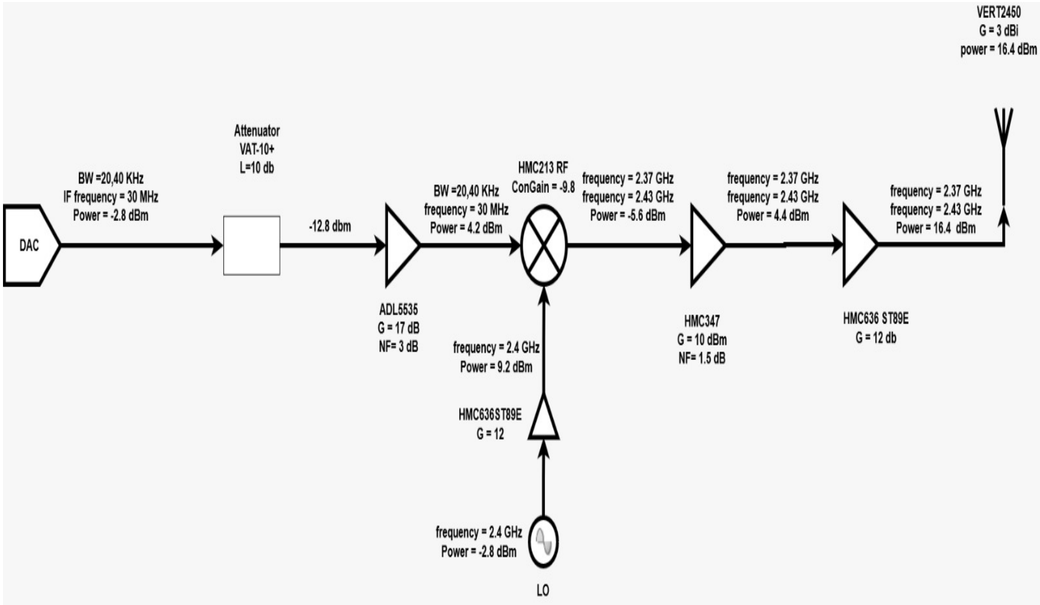

Figure 1: Transmitter Block Diagram

Table 2: Transmitter Block Elements

Elements	Input Power (dBm)	Output Power (dBm)	Gain (dB)	Noise Figure (dB)	Input P1dB (dBm)
USRP Transm (N210)	-	-2.8	-	-	-
Attenuator: (VAT-10+)	-2.8	-12.8	-10	-	-
Power Amplifier -1: (ADL5535)	-12.8	4.2	17	3	8
Mixer: (HMC213 RF)	4.2	-4.6	-9.8	5	9
Power Amplifier - 2: (HMC347)	-5.6	4.4	10	3	8
Power Amplifier - 3: (HMC636ST89E)	4.4	16.4	12	3	22

3.2 Free space propagation

The distance (d) is 100 meters, it is considered a short distance, we can neglect attenuation and we will only have free space loss which according to equation is depends on the frequency and antennas gain Gt, Gr, for both Tx and Rx we will use VERT2450 antenna with 3 dBi gain.

$$\begin{aligned} &FSPL = 20 \cdot log_{10}\left(d\right) + 20 \cdot log_{10}\left(f\right) + 20 \cdot log_{10}\left(\frac{4\pi}{C}\right) - G_{Tx} - G_{Rx} \\ &FSPL = 74 \quad dB \end{aligned} \tag{2}$$

3.3 Receiver

The specifications of the Receiver elements @2.4 GHz@+25C are shown in the table 3.

Table 3: Receiver Block Elements

Elements	**Input Power (dBm)**	**Output Power (dBm)**	**Gain (dB)**	**Noise figure (dB)**
Bandpass filter: VBF2435+	-57.6	-59.5	-1.9	-
Low Noise Amplifier: HMC374E	-59.5	-49.5	10	1.5
Mixer HMC213 IF	-49.5	-59.5	-10	5
Power Amplifier ADL5535	-59.5	-42.5	17	3
Power Amplifier ADL5535	-44.5	-25.5	17	3
Low-pass Filter SBLP-39+	-29.5	-27.5	-2	2

The receiver is designed as shown in the figure 2. The noise figure of receiver is 4 dB, calculated in Eq.(3) with a total gain of 30.1 dB.

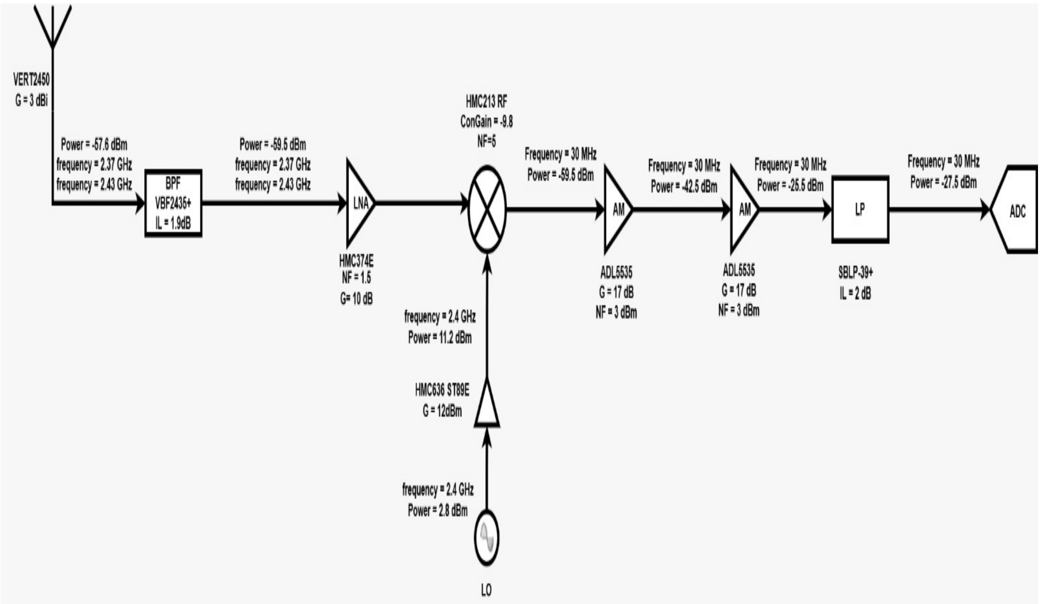

Figure 2: Receiver Block Diagram

3.4 Receiver calculation

Noise figure (NF), gain (Gain) and 1 dB compression point(P1dB) are calculated as the equations below:

$$\begin{aligned} NF &= 10 \cdot log_{10}\Big(nf1 + \frac{nf2-1}{Gain1} + \frac{nf3-1}{Gain1 \cdot Gain2}\Big) \\ NF &= 4 \quad dB\ (for\ first\ 3\ stages) \end{aligned} \tag{3}$$

Where $nf1$, $nf2$ and $nf3$ are the noise figures and $Gain1$, $Gain2$ and $Gain3$ are the gains of the first three blocks in the receiver.

$$\begin{aligned} Gain &= Gain1 + Gain2 + Gain3 \\ Gain &= 28.3 \quad dB \end{aligned} \tag{4}$$

$$\begin{aligned} P1dB &= 10 \cdot log_{10}\Big(\frac{1}{p1dB1 \cdot Gain2 \cdot Gain3} + \frac{1}{p1dB2 \cdot Gain3} + \frac{1}{p1dB3^{-1}}\Big) \\ P1dB &= 4.8 \quad dBm \end{aligned} \tag{5}$$

Where P1dB is the 1 dB compression point of the first three blocks of the receiver.

4 Frequency

The frequency of the local oscillator (F_{lo}) is set to 2.4 GHz. The intermediate frequency (F_{IF}) is set to 30 MHz. The transmitted frequency can be calculated as Eq.(6).

$$F_{RF} = F_{lo} \pm F_{IF} \tag{6}$$

Hence, the $F_{RF} = 2.4 \pm 0.03$.

5 Noise Performance

The noise figure (NF) of the receiver is calculated to be 4 dB. The system input thermal noise depends on the antenna temperature which can be calculated from Eq.(7).

$$T_a = e_r \cdot T_b + (1 - e_r) \cdot T_p \tag{7}$$

where e_r is antenna radiation efficiency = 0.9, T_b is brightness temperature = 300 K and T_p is physical temperature = 300 K. Hence, T_a = 300 K

Receiver sensitivity can be calculated according to the equation:

$$P_r = SNR \cdot (T_a + (F_{sys} - 1) \cdot T_0) \cdot K \cdot B \tag{8}$$

Where F_{sys} is the receiver noise figure, T_0 is room temperature in kelvin, K is Boltzmann constant and B is Bandwidth.

The table below shows the targeted SNR for 16QAM and QPSK, the related receiver sensitivity and SNR margin for our case (-2.8 dbm from USRP and -57.6 dbm at the receiver input).

Table 4

Modulation	**SNR (dB)**	**Receiver Sensitivity (dBm)**	**SNR Margin (dB)**
QPSK	15.6	-108	50.4
16-QAM	25.4	-101	43.4