RF circuit design techniques

Link budget and Friis formula

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1 Recall: Friis equation and sensitivity

The Friis equation relates the power received to the power sent, the gains of the antennas and the path losses. In [W], which are linear, it is given by:

$$P_{rx} = P_{tx} \cdot G_{tx} \cdot G_{rx} \cdot \left(\frac{4\pi \cdot d}{\lambda}\right)^n \tag{1}$$

To convert a power P form W to dBm, which is unitless, $P|_{dBm} = 10log\left(\frac{P}{1mW}\right)$

To calculate the sensitivity, often used in dBm:

$$\begin{aligned} P_{sensitivity}|_{dBm} &= 10log(\frac{KTB}{1mW}) + NF + SNR \\ &= 10log(\frac{KT}{1mW}) + 10log(B) + NF + SNR \\ &= -174dBm/Hz + 10log(B) + NF + SNR \end{aligned} \tag{2}$$

2 Bluetooth receiver

Suppose you have to plan a bluetooth communication system. The carrier frequency is $f_c = 2.4GHz$, the bandwidth needed is $B = 1MHz$ and you are not allowed to exceed a transmitted power greater than $20dBm$. The GMSK modulation use for bluetooth requires a minimal SNR of 10dB. Assume that we want to keep a margin of 10 dB in order to make sure that we have a reliable link (received power must remain 10 dB above the sensitivity level). The gain of the transmitter and receiver antenna is 0dB. At the input of the receiver, the maximum available power of the thermal noise is given by $P_n = KTB$. The power attenuation in dB when transmitting a signal with wavelength λ over a distance d is given by:

$$L_{path} = 10log\left(\left(\frac{4\pi \cdot d}{\lambda}\right)^n\right) \tag{3}$$

Where n is the path loss exponent, which can be picked as follows:

Environment	n
Free space	2
Urban	2.7 to 3.5
Urban (without line of sight)	3 to 5
Indoor (line of sight)	1.6 to 1.8
Indoor (without line of sight)	4 to 6
Industrial (without line of sight)	2 to 3

1. Find the sensitivity of the transceiver if you want to transmit at 1km range. What is the maximum noise figure need to achieve this sensitivity?

2. What is the NF for a 100m range link?

3. Now the NF of the receiver is 10dB. What is the maximum range you can expect? Compare different environments

4. Due to your system going to battery save mode, your power is reduced to 0dBm. How the range is reduced?

5. Let's consider now that you want to extend the range to 10km. Your system is already build, so the only parameter that you can change in software is the bandwidth. Will it be reduced or increased? Buy how much? Imagine that you want to transmit audio, what is the consequence?

You've seen that Bluetooth is quite fast mainly for short range communication. You basically see that you have a trade-off between speed and range.

3 RF Rocket Science

1. Imagine that you have to plan for the link between the rocket and the ground station (GS). LoRa is a good candidate given it's a sensitivity down to -148 dBm depending on the radio configuration. Let's say with a bandwidth of 500kHz and a spreading factor of 12, you have a sensitivity of -130dBm. What is the power margin, given the figure below and that: $P_{tx} = 15dBm$, the gain of the GS is 15dB, the gain of antenna on the rocket is 0dB, but loose 0.06dB per degree with respect the the horizon, and you have -3dB form polarization mismatch.

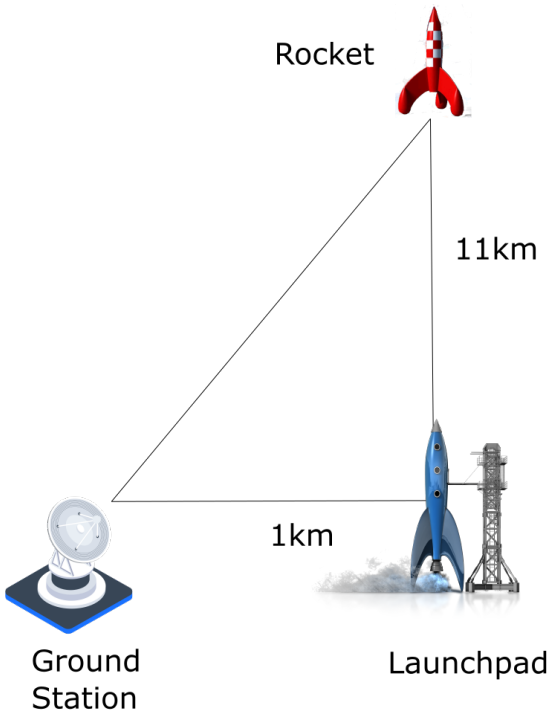

Figure 1: Rocket flight scenario

2. A team member has the great idea to put a camera inside the rocket and to live-stream the launch. Explain why it can not be done with the 868MHz channel.

3. We choose to do it with a Wifi module, but we have to choose between 2.45GHz and 5GHz. What would you object against the 5GHz?

4. You then have to know what is the transmitted power needed, to see if you need to add a power amplifier to the system. You have the following info: Sensitivity is -80dBm, a gain of 24dB for the receiver antenna (GS), 0dB for the transmitter antenna (recall that the gain is changing depending on the angle of transmission), same distance as previously, -3dB form polarization mismatch, and you need to account for 15dB margin.

5. Now the judges of the competition are using an illegal radio emitter to communicate, with the central frequency at $f_c = 434MHz$. While the fundamental is emitted at a power of 8W, the 2nd harmonic is only 30dB lower [1] due to the absence of output filter. The emitter is at 50m from the GS, and this time the cumulated gain of the parasitic radio and the GS antenna is -20dB. Explain quantitatively why is could be an issue while the rocket is still on the ground.

4 GSM vs LAN (From Razavi's RF microelectronics)

A GSM receiver requires a minimum SNR of 12 dB and has a channel bandwidth of 200 kHz. A wireless LAN receiver, on the other hand, specifies a minimum SNR of 23 dB and has a channel bandwidth of 20 MHz. Compare the sensitivities of these two systems if both have an NF of 7 dB

5 Long range communication

You want to include a GPS tracker on a given project. At first, you don't know any about it. Google is your precious friend. Try to find the info that you need to estimate the link budget (typical antenna gain for GNSS, SNR needed for GPS modulation, typical power available, etc), and establish specifications that you will give to your design engineers (NF, bandwidth, sensitivity, etc).

[1] https://youtu.be/rgHl9MRAgYQ?si=j_XeDAsACnG2gcx4&t=243