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# Short-Range Devices, Indoor Radio Propagation

## 1. Signification of power, dBm, logarithms, range wide and their relation

Radio signals are electromagnetic waves. Their radiated power attenuates in free space as a logarithmic function, meaning the signal becomes weaker the further it travels. Radio frequency (RF) output power is measured in milliwatt (mW) or, more useful in a logarithmic scale of decibels (dB), or decibels referenced to 1 mW of power (dBm). Here are some examples of how these scales relate:

| | | | |
|---|---|---|---|
| 1 mW | = | 0 dBm | Relations: |
| 2 mW | = | 3 dBm | A 2-fold increase in power yields 3 dB of signal |
| 4 mW | = | 6 dBm | Every 6 dBm more power means a 2-fold range in free space |
| 10 mW | = | 10 dBm | A 10-fold increase in power yields 10 dB of signal |
| 100 mW | = | 20 dBm | A 100-fold increase in power yields 20 dB of signal |

## 2. General requirements and general limitations of specific radio signals.

Short-range wireless applications typically operate in license-free frequency bands, also known as ISM (Industrial, Scientific, Medical) with limited power. The allowed frequencies and powers in these bands vary from country to country. The most common license-free frequencies worldwide are:

* 2.4 GHz band - nearly worldwide

* 315/900 MHz bands - America, Japan and some other countries

* 868 MHz band – e.g. for Europe and some other countries

Independent of frequency and used technology, per definition, wireless “BER” (Bit Error Rates) are always orders of magnitude higher than for wired communications.

## 3. Basics about antennas (design, requirements, limitations)

See e.g. EnOcean AN102, AN103…

## 4. Specific of Indoor Radio Propagation / Attenuation

Indoor radio propagation is strongly determined by the specific building structure. Propagation indoors is therefore very difficult to predict and results are never as planned. Keep in mind that usually planned distances are based on ideal conditions, meaning “as long as possible” with link quality always close to its limit. Indoor installations often include many reflective obstacles leading to numerous propagation paths. The received signal is therefore (other as in free space) a mix of these reflexions. Depending on the singular phase of each signal, they can be added or subtracted. In multiple path environments, simply moving the antenna slightly can significantly change the received signal strength. Also remember, some obstacles are mobile, environment can change and metal is not your friend. Obstacles’ material, thickness and radio penetration angles (effective path length) are important. Their attenuation factor also depends on specific radio wave length, below only few usual listed, just as orientation for the 868/900 MHz bands (see EnOcean AN001)

| Material | Range reduction % | Attenuation up to (dB) |
|---|---|---|
| Wood, plaster, glass uncoated, w/o metal | 5 - 10 | 3-5 |
| Brick, press board | 10 - 30 | 6-10 |
| Ferro concrete 200 mm | 20 - 80 | 15-20 |
| Metal, aluminium lining | 80 - 95 | 90 |

In free space, 6 dB loss corresponds to half range. Indoor best case a near field up to 5 m around the antenna can be considered as "LoS", beyond this, paths tend to be more complex, so use more aggressive rules of thumb:

* To ensure fade margin requirements in a line of sight (LoS) application, never exceed 50% of the manufacturer's rated maximal range. This in itself yields a 6 dB fade margin (minimal requirements!)

* De-rate to 10% of the manufacture's free space specifications if you have multiple obstacles, obstacles located near the antennas, or the antennas are located indoors.

* Doubling the distance beyond a near field of about 5 m indoors increases path loss by 9…15 dB.

As a rough empiric rule, you can consider for typical indoors within about 30 m distance a path loss L:

L (dB) = $L_{FS}$ (dB) + 0.6 (dB/m) · D (m), where $L_{FS}$ = free space loss and D = distance

Below some orientation only values for indoors path loss in 900 MHz bands (in absence of massive walls located directly between transmitter and receiver):

D =  5 m: L = 46 + 0.6 x  5 = 49 dB
D = 10 m: L = 52 + 0.6 x 10 = 58 dB
D = 20 m: L = 58 + 0.6 x 20 = 70 dB

## 5. Long-range performance is not only a function of antenna and radio power

The more sensitive the radio receiver, the lower the power **S**ignal it can successfully receive, stretching right down to the **N**oise floor (**S/N**), also see EnOcean AN007, AN008. There is so much variety in specifications for radio sensitivity, that it is difficult to make a direct comparison between products. The most used specification refers to a particular bit error rate (BER) and is given for an ideal environment shielded from external noise. Because receiver sensitivity indicates how faint an input signal can be to be successfully received, the larger the absolute value, the better. Accordingly, when the signal power is expressed in dBm, the larger the absolute value of the (negative) number, the better the receiver sensitivity. For example, a receiver sensitivity of −98 dBm is better than a receiver sensitivity of −95 dBm by 3 dB, or a factor of two. In other words, at a specified data rate, a receiver with −98 dBm sensitivity can hear signals that are half the power of those heard by a receiver with −95 dBm receiver sensitivity. Another important factor, especially in a noisy environment, is its selectivity. Avoiding and filtering environmental radio interferences (noise suppression) induced by e.g. own power supply, heavy external load (ballasts, dimmers, motors) digital circuitry is an important factor to improve the receiver performance. Means, efficient antennas are mandatory for efficient transmitting (transmission is not affected by "noise floor"!) but not enough to guarantee an efficient reception.

## 6. Radio noise (interferences) recognizing and avoiding situations where the radio interferences may hamper the installation.

RF background noise comes from many sources, ranging from power supplies (see EnOcean AN101) and specific (heavy) loads to high frequency digital products and all forms of other interfering radio communications. That background noise establishes a noise floor which is the point where the desired, weak radio signals are lost in the background noise or in worst case affect the data integrity (see EnOcean AN104). The specific noise floor varies by frequency. Typically, the noise floor will be lower than the receiver sensitivity of your radio, so it will not be an important factor in your system design. If, however, you're in an environment where high degrees of RF noise may exist in your frequency band, then use the noise floor figures instead of radio receiver sensitivity in your calculations. If you suspect this is the case, a simple site survey (e.g. using a Spectrum Analyzer) to determine the noise floor value can be a high payoff investment. Antennas are everywhere nowadays - on the sides or top of buildings, traffic monitoring stations or even disguised. Some sources of interference may not be immediately obvious (e.g. even by own receiver / actuator).

## 7. Planning with enough reserve

Fade margin is a critical term to wireless success. Fade margin describes how many dB a received signal may be reduced by, without causing system performance to fall below an acceptable value. Walking away from a newly commissioned wireless installation without understanding how much fade margin exists is the number one cause of wireless issues.

Establishing a link budget reserve of > 6 dB will provide a high degree of assurance that the system will still continue to operate effectively even in a variety of changing environmental conditions.

There are a number of creative ways to estimate fade margin of a system without investing in specialty gear, e.g. using a small 6 dB attenuator (pick the correct one for your radio frequency!)
If you lose communication when you install the attenuator in-line with one of your antennas, you don't have enough fade margins.

## 8. Using simple mathematics and logics when planning wireless installations.

Contrary to popular opinions, no black magic is required to make a reasonable prediction of the range wide of a given radio path. Several simple concepts must be understood first, and then we can apply some simple rules of thumb. The rough equation for successful wireless system implementation is:

**TX power + TX antenna gain - Path loss - Cable loss + RX antenna gain – 6 dB fade margin > RX Radio sensitivity or (less commonly) RF noise floor**

Note that most of the equation's parameters are easily to be found in the manufacturer's specifications. That leaves only path loss and, in cases of heavy RF interference, RF noise floor as the two parameters to be estimated or with sufficient safety margin fulfilled by your installation. Also see EnOcean AN001…

## 9. Planning in advance with repeaters as possible additional fall back option in critical environmental conditions.

Also see EnOcean AN001.

## 10. Avoiding cable loss

The high frequencies don't propagate particularly well through cable and connectors. Use short, quality RF cable with the appropiate impedance (e.g. 50 Ω) between the receiver/transmitter and your antenna and ensure that all connectors are good quality and carefully installed. Calculate 0.3 dB loss per coaxial connector in addition to the cable attenuation/meter itself. Typical attenuation figures for two popular cable types are listed below. Also see EnOcean AN103.

Typical Loss in dB per 10 meter of cable length for three representative 50 Ω RF cable types:

| Frequency | RG-174 | RG-58 | LMR-400 |
|---|---|---|---|
| **900 MHz** | 10 | 3 | 1 |
| **2.4 GHz** | N.A. | 10 | 2 |

**Knowing and respecting these rules will help you make a reliable planning and avoid later range wide issues in field.**