"Guidelines to low cost wireless system design"

Frank Karlsen - RF Designer, Wireless Communications, Nordic VLSI ASA

The recent availability of radio components operating in the license free Low Power Radio Device (LPRD) bands, has made implementation of systems with wireless data transmission easier. Design of such systems was earlier a closely guarded secret, reserved for RF-designers with years of experience.
Today, a multitude of vendors offer components ranging from simple single ON/OFF-keying transmitters to advanced multi-channel GMSK-transceivers.

Although the availability of off-the-shelf components has made wireless system design easier, the system designer still needs some fundamental knowledge of which radio-related parameters influence the overall system performance.

A key issue is transmission reliability; how will parameters such as sensitivity, output power, adjacent channel selectivity, operating frequency etc. influence system performance? That is; the probability to transmit/receive an error free data package with the presence of other noise sources.
Reliable transmission range is also of utmost importance when designing a wireless system. Once output power and sensitivity is known, what other parameters are of importance? Environmental factors such as air humidity, range of sight, building materials, metal film sun-screened windows etc. limit maximum useful range in addition to the choice of antenna implementation. The system designer must make his choice of the wireless solution mainly based upon the overall system environmental scene.

The large number of wireless component vendors has led to the need of caution when reading and interpreting datasheets. Some knowledge of "the not-so-fine art of creative RF-datasheet writing" may be in order. Why should you investigate closer if sensitivity is measured for a lower data-rate than the stated maximum? Is the *effective* data-rate stated for systems that require Manchester encoding? Checking just a few fundamental parameters may save time and frustration when realising that the circuit chosen does not comply with your system specifications.

The session covers;

- fundamental parameters and their definitions for integrated one-chip wireless components
- system design guidelines based upon environmental factors, cost and reliability requirements
- what to look for in RF-circuit data-sheet interpretation

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Scope

This article discusses some fundamental issues and device parameters related to the use of a wireless link. Typical non-idealities and rules of thumb are presented to help gain insight into what limits the practical transmission range of a system.
Included are also a few hints and tips of what to look for in RF-circuit data-sheets when comparing product specifications. Checking just a few fundamental parameters may save time and frustration when realising that the circuit chosen does not comply with your system specifications.

Introduction: The free haven of the LPRD bands

The recent availability of one-chip RF-IC's operating in the license free Low Power Radio Device (LPRD) bands, has made implementation of systems with wireless data transmission easier. In Europe, the 433MHz- and 868MHz bands have been available for the electronic system designer for the last few years.

Design of such systems was earlier a closely guarded secret, reserved for RF-designers with years of experience. Today, a multitude of vendors offer components ranging from simple single ON/OFF-keying transmitters to advanced multi-channel GMSK-transceivers.

Figure 1 - Single-chip RF-circuits has resulted in a wide range of ingenious wireless systems (Photo courtesy of Jan Meyer)

License free transmission: Where, what & how?

Figure 2 shows the position of the most prominent European license free LPRD bands. The beauty of these two frequency oasis is that systems operating in these bands do not need a telecommunations authority approval. The only requirement being that the wireless system producer must guarantee that the product does not violate the regulations for these bands. These regulations are described in the document *CEPT/ERC recommendation 70-03*. CEPT is the 'European Conference of Postal and Telecommunications Administrations' which issue the regulations that are valid for European countries (www.ero.dk).

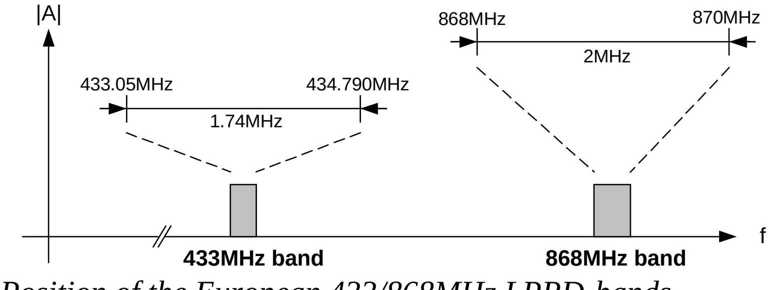


Figure 2 - Position of the European 433/868MHz LPRD-bands

Most available components on the market satisfy the requirements if used according to data-sheet recommendations (i.e. use correct antenna impedance and external components according to specifications). However, there are a few important regulatory parameters that are controlled by the user:

- **Application**
  The 868MHz band are divided into sub-bands in which some are designated for alarm applications, these sub-bands cannot be used for products that does not fall into this category
- **Output power**
  Maximum allowed output power differ in the frequency bands
- **Channel bandwidth**
  Some frequency sub-bands are only allowed for very narrow-band channels, whilst others have optional bandwith
- **Transmit duty-cycle**
  In order to reduce the risk of jamming by other devices operating at the same frequency, a maximum allowed transmit duty-cycle has been defined. This is the transmit-time percentage of the system over an hour period. The maximum allowed transmit time pr. hour for the 433MHz band is thus 6 minutes. The transmit time may be spread out over multiple time slots

Table 1 lists the European LPRD sub-band frequencies and their respective regulations.

Frequency range [MHz]	Output power [mW]	Channel bandwidth	Duty cycle
433.050 - 434.790	<10	Optional	High, <10%
868.000 - 868.600	<25	Optional	Low, <1%
868.600 - 868.700	<10	25kHz	Very low, <0.1%
868.700 - 869.200	<25	Optional	Very low, <0.1%
869.200 - 869.250	<10	25kHz	Very low, <0.1%
869.250 - 869.300	<10	25kHz	Very low, <0.1%
869.400 - 869.650	<500	25kHz	Very low, <0.1%
869.650 - 869.700	<25	25kHz	High, <10%
869.700 - 870.000	<5	Optional	Very high, up to 100%

Shaded bands: Non-Specific SRD's, Others: (Social)Alarms
Source: CEPT/ERC Recommendation 70-03, March 2001

Table 1 - European LPRD-bands, frequency allocation and user restrictions

Although the availability of off-the-shelf components has made wireless system design easier, the system designer still needs some fundamental knowledge of the radio-related parameters which influence overall system performance.

The wireless link: Fundamentals
The wireless link consists of a transmitter with antenna, a transmission path and the receiver with antenna. Parameters of interest are the *output power* of the transmitter and the *sensitivity* of the receiver. Figure 3 illustrates the link principle.

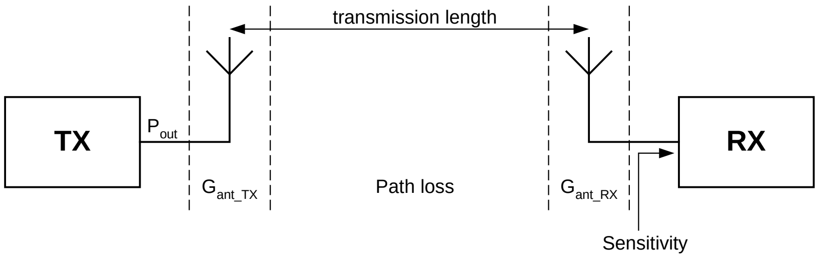


Figure 3 - Wireless link

Sensitivity is the minimum received power that results in a satisfactory Bit Error Rate (BER, usually $1 \cdot 10^{-3}$) at the received data output (i.e. correct demodulation).
The difference between received signal power and sensitivity, is the transmission link margin also known as *'headroom'*. Headroom is reduced by a number of factors; such as transmission path length, antenna efficiency, carrier frequency and physical characteristics of obstructions in the transmission path.

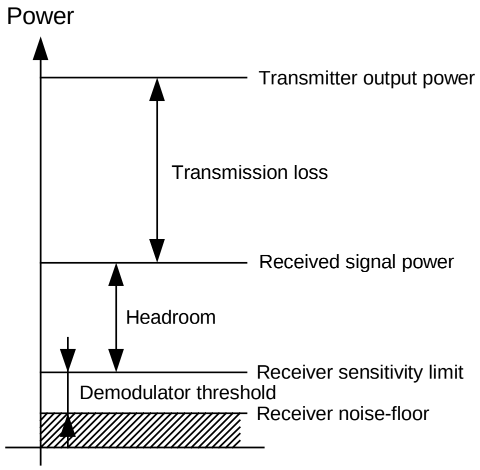


Figure 4 - Transmission link budget

Sensitivity and Output power given in the RF-circuit datasheets are given for the load impedance which is optimal for the input LNA and the output power amplifier. This means that the impedance of the antenna used must be equal to the load stated in the datasheet, otherwise mismatch and loss of headroom occur. A typical matching network introduces in the order of 1-3dB of attenuation.

The antenna: Shouting out your message
The antenna transforms the transmitter output power into electromagnetic energy, which radiates from the antenna depending on the given radiation pattern. For the LPRD bands, the maximum output power is given as *Effective Isotropic Radiated Power* (EIRP). An isotropic radiator is defined as a hypothetical lossless antenna having equal radiation in all directions. This means that it is not allowed to boost transmission range by using a directive antenna. If the antenna gain is larger than 1 (0dB) in any given direction, the output power has to be decreased accordingly.

For example, for the lower portion of the 868MHz band, it is allowed to transmit maximum 25mW (14dBm) EIRP. For a directive antenna that has 10dB gain in a given direction, it would seem as if it was transmitting 24dBm for a receiver positioned in this direction. Thus, the output power would have to be reduced to

4dBm to fulfil the ETSI requirements. Note that this type of directive antenna may be used for receivers without any penalty.

Calculating antenna gain and radiation pattern is generally quite complex, and the resulting radiation pattern is heavily influenced by surrounding elements.
Placing the antenna close to conducting surfaces is likely to distort your antennas radiation pattern and efficiency, but is in most practical applications unavoidable.

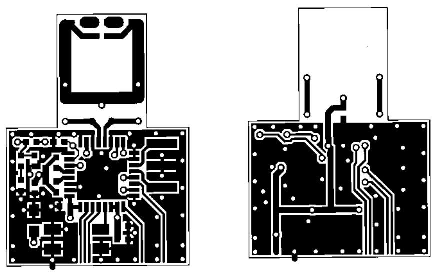
Antenna gain: Correlate expectations with size and frequency...
In the transmission budget the antenna is included as the parameter *antenna gain* (G_{ant}). This may be interpreted as the antenna's ability to transform the output power into radiated energy. Antenna gain is generally proportional to physical size, as a fundamental relation in antenna theory is

$$G_{ant} = \frac{4 \cdot \pi \cdot A_e}{\lambda^2} \tag{1}$$

where A_e is the effective area of the antenna and λ is the wavelength of the carrier frequency. For the 433MHz LPRD band, the wavelength is approx. 0.69m and approx. 0.35m for the 868MHz band.

To put things into perspective; the necessary effective area to achieve an antenna gain of 1 (0dB) is 0.038m^2 (0.19m x 0.19m) for the 433MHz band and 0.001m^2 (0.1m x 0.1m) for the 868MHz band. As most practical applications would be most unpractical with such a voluminous and cumbersome antenna, one usually settles for a much smaller antenna. This means that the antenna actually introduce loss in the transmission budget.

A popular small low cost antenna for LPRD-applications is the loop-antenna. These antennas may be etched on the actual PCB and do not represent a significant cost other than PCB-area. Figure 5 shows the PCB of a LPRD transceiver for 868MHz with a 9.5mm x 9.5mm antenna. This antenna has a typical effectivity (or gain) of approx. -20dB to -25dB.



c) Top view d) Bottom view

Figure 5 - PCB layout of 868MHz transceiver IC (nRF903)

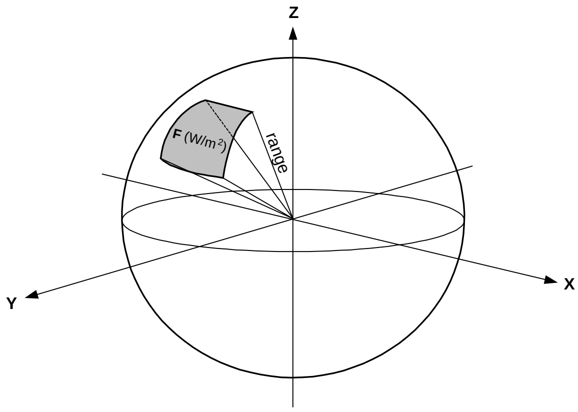


Figure 6 - Path loss / energy spread

Consider the transmitter in Figure 3 radiating power uniformly in all directions (assuming the antenna is isotropic). At a distance *r* from the antenna, the Flux density crossing the surface of the sphere at that distance is given by

$$F = \frac{P_{out} \cdot G_{ant\_TX}}{4 \cdot \pi \cdot r^2} \quad [\text{W/m}^2] \qquad (2)$$

This illustrates that the power density decrease with 1/range^2 as the energy spreads out over an increasingly larger area.

It can be shown that the received power in the receiver in Figure 3 can be expressed as

$$P_{rec} = \frac{P_{out\_TX} \cdot G_{ant\_TX} \cdot G_{ant\_RX}}{Path\_loss} = \frac{P_{out\_TX} \cdot G_{ant\_TX} \cdot G_{ant\_RX}}{\left(\frac{4 \cdot \pi \cdot r}{\lambda}\right)^2} \quad [\text{W}] \qquad (3)$$

From this equation it is interesting to note that range and transmission frequency decide what is defined as *Path loss*. For the receiver to demodulate, the received power must be equal to, or larger than the sensitivity limit. Figure 7 illustrates the theoretical range as function of range.
As can be seen, a 6dB (fourfold) increase in output power (or receiver sensitivity) corresponds to a doubling of the effective range.

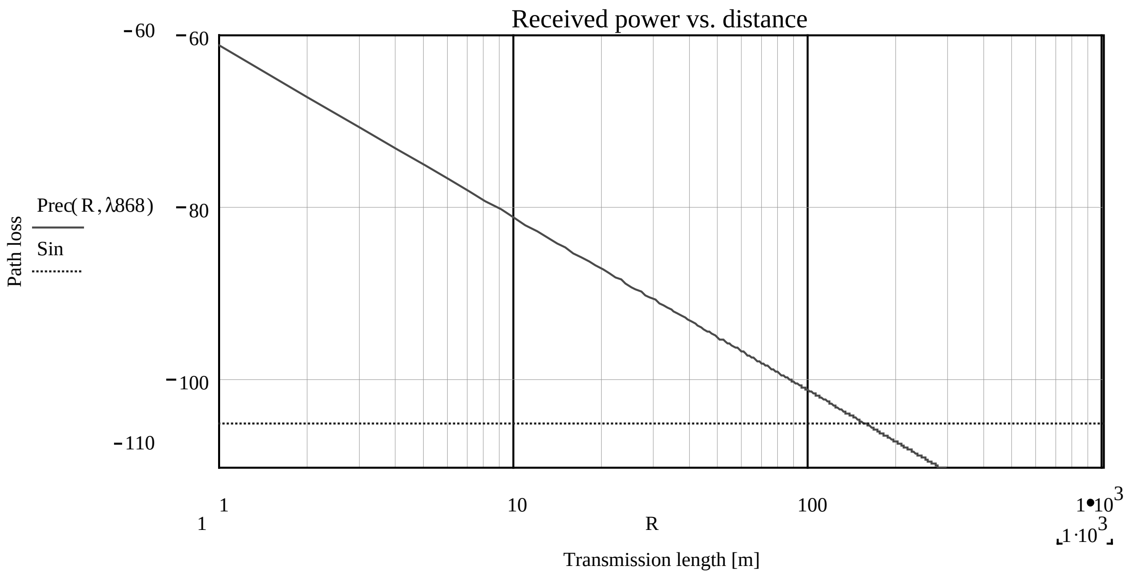


Figure 7 - Received power vs. transmission range

Transmitting electromagnetic energy: What can possibly go wrong?
Headroom decrease with range, and as headroom is reduced, the probability of communication loss due to *multipath phenomenon* and environmental obstacles increase. For the 868MHz link illustrated in Figure 7, the headroom is less than 15dB if the range is 10 meters. This means that if additional attenuation in the signal path exceed 15dB, communication is lost. Additional attenuation is caused by multipath phenomenon and environmental obstacles.

An non-ideal transmission path cause signal fading at the receiver if the transmitted signal travels multiple paths to the receiver antenna. As different paths have different lengths, the combined signals may arrive at the receiver out of phase, with the result of signal attenuation and also 'smearing' of the received signal in the time-domain, causing inter-symbol interference.
As the wavelengths at 434MHz and 868MHz are 0.69meters and 0.35meters respectively, fading may fluctuate on a short-term basis if one or both radio units are mobile. Remember that fading may also occur due to moving objects in the proximity (people, furniture or machinery) even if the radio units are stationary.

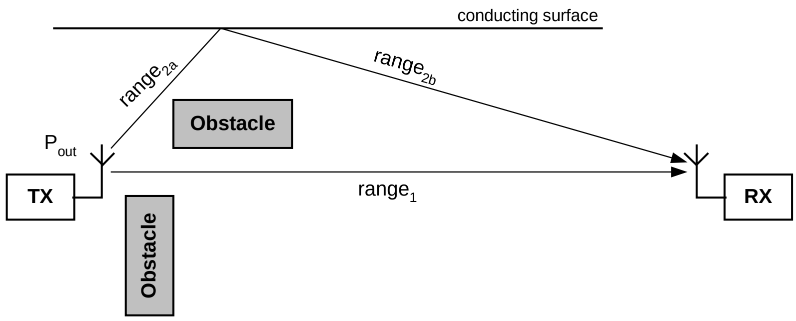


Figure 8 - Multiple paths; transmitted waves arrive at antenna with different phase

Multipath phenomenon are caused by reflection, diffraction and scattering. *Reflection* results when the transmitted energy 'bounce' off the surface of an object that is large compared to the carrier wavelength (e.g. walls, buildings, the ground etc.).
Diffraction is the term used to describe 'wave-bending' around sharp irregular edges of an object in the transmission path. *Scattering* is equivalent of energy dispersion, caused by objects that are small compared to the wavelength of the propagating wave.

An important factor to account for (or rather, be prepared for) is the loss caused by environmental obstacles such as floors, walls, buildings and windows. The amount of loss depends heavily on the physical characteristics of the object. For example, reinforced concrete walls introduce a much higher loss than a wooden or plaster wall. Metal tinted windows are high loss barriers compared to 'normal' windows.

For the most interesting frequency bands (433MHz and 868MHz), typical losses are shown in Table 2.

Object causing path loss	Typical loss [dB]
Wall (indoor)	10-15
Wall (exterior)	2-38 (percentage of windows and height important)
Floor	12-27
Window	2-30 (metal tinted windows cause high loss)

Table 2 - Typical losses caused by transmission obstacles

Consider the 868MHz system with 10dBm output power, antenna efficiency (gain) of -20dB and -105dBm sensitivity (shown in Figure 3). This system may have a theoretical range of more than 100 meters, but in a typical application with all the aforementioned non-idealities, the effective range may drop to just a few meters. This is why it one should take caution when accepting what often is referred to as ’free-line-of-sight range.
Also keep in mind that the headroom also varies with time due to multipath phenomenon.

Radio system parameters of interest: What You should know
Designing a radio system requires knowledge to a few fundamental parameters in order to comprehend what will influence link performance and reliability. We have already discussed the obvious parameters; output power and receiver sensitivity.
Others are;

- Receiver dynamic range
- Co-channel rejection
- Adjacent channel selectivity
- Reference frequency stability
- Blocking performance
- Mirror image attenuation
- Modulation principle

These are all important parameters which do not enter the transmission link budget directly, but are closely related to transmission reliability in a system where multiple transmitters exist. The key question is: "How does my system behave when an unwanted transmitter radiates energy in my system environment?".

Dynamic range is the maximum received power variation at the receiver input pins which result in a correct demodulated signal. This means that the signal of interest may vary between the sensitivity limit and the sensitivity limit *plus* the dynamic range.

Co-channel rejection is a measure of the capability of the receiver to demodulate a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted modulated signal, both signals being at the nominal frequency of the receiver. This parameter is given in dB (i.e. 10dB). 10dB would in this instance mean that if the wanted signal is 10dB or higher in magnitude than the unwanted signal, correct demodulation is performed (typ. $BER<1\cdot10^{-3}$).
If this parameter is not given in the datasheet, one can safely assume approx. 12-14dB co-channel rejection (typical FSK demodulator threshold).

Figure 9 illustrates a typical system setting. Let’s consider a system with multiple transmitters operating at the same frequency. How far away must the unwanted transmitter be, for the receiver to demodulate the correct signal?

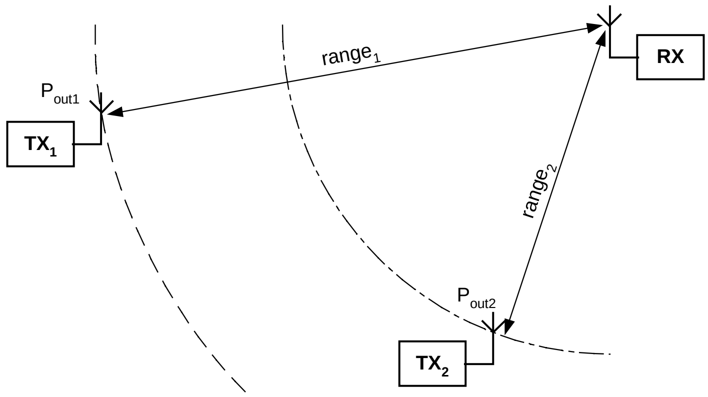


Figure 9 - Range and power illustration; multi-transmitter environment

The equation for the received power is as follows

$$\frac{P_{out1} \cdot G_{ant1} \cdot G_{ant\_RX}}{Path\_loss_1} \geq \frac{P_{out2} \cdot G_{ant2} \cdot G_{ant\_RX}}{Path\_loss_2} \cdot CCR \quad [\mathrm{W}] \tag{4}$$

in dB's

$$P_{out1} + G_{ant1} + G_{ant\_RX} - Path\_loss_1 \geq P_{out2} + G_{ant2} + G_{ant\_RX} - Path\_loss_2 + CCR \tag{5}$$

reducing yields

$$P_{out1} + G_{ant1} - 20 \cdot \log(range_1) \geq P_{out2} + G_{ant2} - 20 \cdot \log(range_2) + CCR \tag{6}$$

assuming identical antennas for both transmitters

$$P_{out1} - 20 \cdot \log(range_1) \geq P_{out2} - 20 \cdot \log(range_2) + CCR \tag{7}$$

reducing

$$P_{out1} - P_{out2} + 20 \cdot \log\left(\frac{range_2}{range_1}\right) \geq CCR \tag{8}$$

This equation illustrate an important relation in a multi-transmitter environment. Assuming a co-channel rejection of 12dB, and that the transmitters have equal output power and antenna gain, the distance-relation is shown in Figure 10. As can be seen, the ratio between $range_2$ and $range_1$ must be at least 4 in order for the receiver to demodulate the wanted TX_1 signal correctly without interference from TX_2.

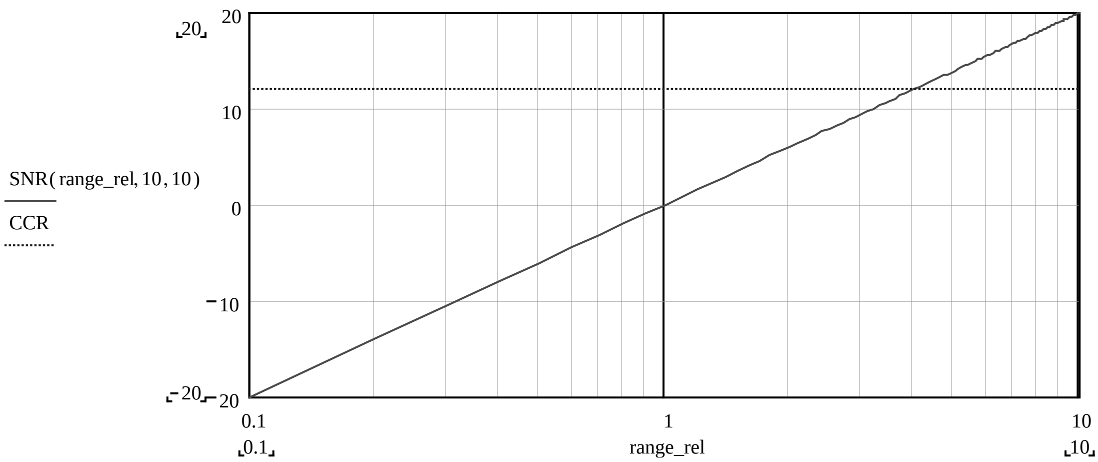


Figure 10 - Necessary distance relation for demodulation with presence of interfering signal (spotted line; co-channel rejection limit)

The *adjacent channel selectivity* (ACS) of the receiver is defined by ETSI as the ability to demodulate a received signal at the sensitivity limit, with the presence of a sine component centered in the adjacent channel (see Figure 11). I.e. if the ACS for a 25kHz channel system is given as 30dB, demodulation of the wanted signal at the sensitivity limit may be performed with a sine component with 30dB higher power than the received signal present in the adjacent channel.

Note that the ETSI definition is merely meant as a comparative figure. The *system* ACS is always lower, as the adjacent channel is not likely to be a sine component, but a modulated spectrum.

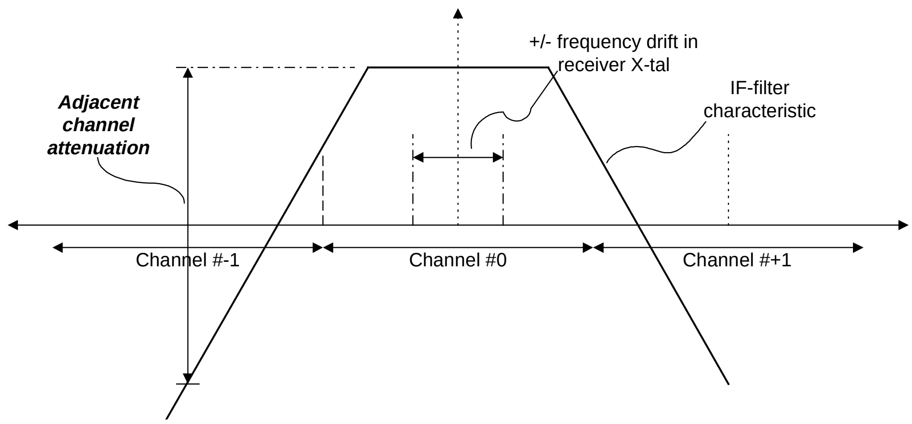


Figure 11 - Adjacent channel power attenuation obtained due to IF-filter passband characteristic (ETSI-def.)

Reference frequency stability is a parameter that influences on the resulting ACS. Deviation from the ideal crystal reference frequency will result in a corresponding deviation of the transmitted frequency, and an IF offset/deviation for the receiver. This will appear as an offset in the IF-filter centre frequency (see Figure 11).

Blocking performance is the term used to describe the receivers ability to function under the influence of a very strong interfering RF-signal. It is closely related to ACS, but the scenario of interest is an high power RF interference in a frequency band relatively close to the signal of interest (typically 10-200MHz from the received

channel). For example; how will a 900MHz GSM-signal interfere with my 868MHz application?
There are numerous parameters that are related to blocking performance, most of them describe linearity and gain of the first stages in the receiver. Imagine a high powered interferer driving the front end amplifier into saturation. A low power signal superimposed on this signal will not be visible to the receiver as phase and/or amplitude information is lost due to the front being driven into saturation by the interfering signal. Due to the inherent nonlinearity of the receiver amplifiers and mixers, the actual effect on demodulation varies both with frequency and amplitude of the interfering signal. Traditionally, blocking has been avoided by introducing narrow-band SAW-filters between the receiver and the antenna, but is regrettably an expensive way to avoid trouble. The antenna and matching network have a limited bandpass effect, but is usually too wide-band to have much effect.
A good approach is to identify any potential high power interference sources for your application and check the receiver blocking-characteristics for this particular frequency.

For example; in the 433MHz band, a potential problem may be the Tetra communications system (410MHz-430MHz) which allows output power as high as 25W (44dBm). Measuring the sensitivity as a function of interference source frequency offset and output power gives valuable information. Figure 12 shows such a measurement for a one-chip RF-IC nRF401. The curve shows the maximum power difference between the interference source and the received signal at the normalised sensitivity level (0dB).

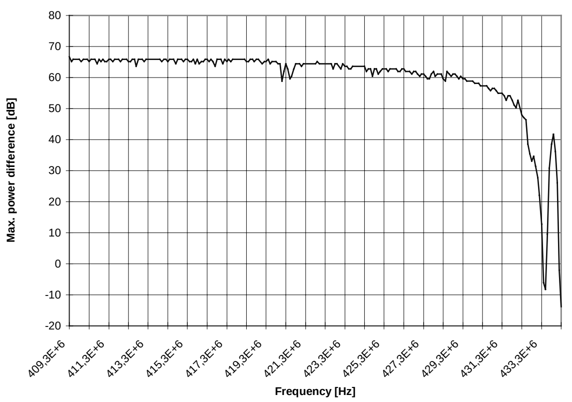


Figure 12 - Blocking characteristics of the nRF401 receiver (no pre-filtering)

The receiver centre frequency is positioned at 433.92MHz. As can be seen, an interfering signal at 420MHz may be 65dB higher than the received signal before transmission is lost. With a sensitivity of -110dBm, the interfering signal may not exceed -45dBm at the antenna input. At the centre frequency, the interferer must be -9dB *lower* than the received signal, which corresponds to the *co-channel rejection* parameter.

Mirror image attenuation (MIA) is a measure of to which extent the mirror image frequency for superheterodyne receivers (receivers with IF) is suppressed. The superheterodyne principle is often chosen for its excellent channel filtering performance, but care should be taken to avoid mirror image interference. All heterodyne receivers have a mirror image frequency for a given channel, which may cause in-band interference.
Figure 13 illustrates the principle. The Mirror image positioned at IF-Hz lower than the LO-frequency will also appear at the intermediate frequency as well as the wanted signal. This mirror image frequency must be attenuated to avoid destructive disturbance or loss of sensitivity.

MIA has traditionally been performed with an external filter at the antenna input, or more recently, with on-chip cancellation techniques.
As the mirror image appear inside the IF-filter bandwidth after mixing, the mirror image attenuation minus the co-channel rejection is the maximum power difference between the two signals to ensure demodulation.

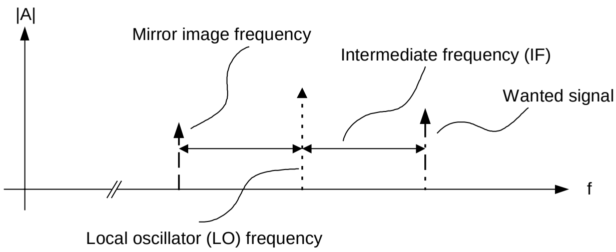


Figure 13 - Mirror image frequency in super-heterodyne mixing

I.e. If the mirror image attenuation is 35dB and the co-channel rejection is 12dB, the received mirror image frequency power may not be higher than 23dB (35dB-12dB) compared to the wanted signal.

Modulation principle should also be considered when choosing the transceiver solution for the system. Until recently, amplitude shift keying (ASK, also known as on-off keying, OOK) dominated the license free LPRD bands. Although these solutions are simple and reasonable priced, they suffer from poor reliability when under influence from in-band interference. In ASK/OOK systems, a logic '1' is represented with a carrier frequency, logic '0' is represented by no carrier. Needless to say, the presence of a very weak unwanted signal in the channel may still be interpreted as a logic '1' depending on the receiver sensitivity. As described in the CCR section, a FSK system will demodulate the wanted signal eventually if the correct transmitter comes close enough to the receiver. This is not the case for ASK/OOK systems.
The LPRD bands still suffer from a dodgy reputation due to numerous problems related to high density of keyless-entry systems based on ASK/OOK solutions. This has in some instances led to the rather hasty conclusion that these bands, 433MHz in particular, are 'full' and that the only sane solution is to go for either 868MHz or 2.4GHz.

Frequency Shift Keying (FSK) is a completely different approach in which each of the two logic levels corresponds to a frequency value;

$$DATA_{FSK} = \text{“1”} \rightarrow f_{\text{'1'}} = f_{centre} + \Delta f \quad (9)$$
$$DATA_{FSK} = \text{“0”} \rightarrow f_{\text{'0'}} = f_{centre} - \Delta f \quad (10)$$

GMSK and GFSK modulation are enhanced versions of FSK implemented to optimise modulation bandwidth efficiency, i.e. the maximum transmitted number of bits pr. Hz of channel bandwidth.

In Gaussian Frequency Shift Keying (GFSK), the data is filtered through a gaussian filter before modulating the carrier. Figure 14 shows the general principle. This results in a narrower power spectrum of the modulated signal, which in turn allows a higher bitrate to be transfered in the same channel bandwidth. Figure 15 shows the difference between a 76.8kbit/s GMSK- and FSK-spectrum.
Gaussian Minimum Shift Keying (GMSK) is the term used for a GFSK signal in which the bitrate is four times the frequency deviation.

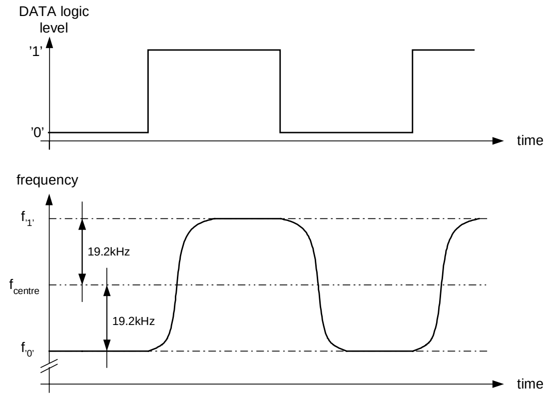
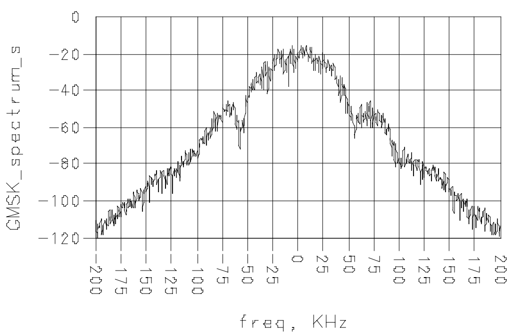
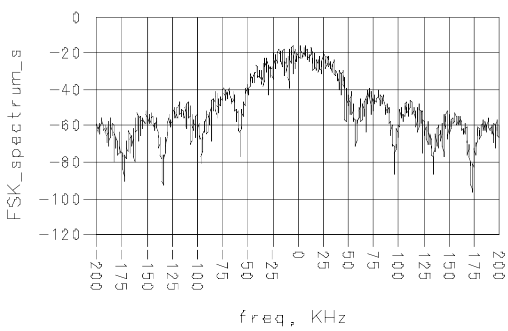


Figure 14 - Principle of Gaussian filtering of transmitted data



a) GMSK spectrum



b) FSK spectrum

Figure 15 - Power Density Spectrum (PDS) of a GMSK- and FSK-signal (Δf = 19.2kHz, BR = 76.8kbit/s, BT_{GMSK} = 0.5)

The fine art of RF-IC datasheet interpretation

Although datasheets are supposed to accurately describe the performance of a device, this is regrettably not necessarily the case. A highly competitive market has led to some ingenious ways of rewriting parameter definitions in order to make circuit performance look better than it actually is.

As a systems designer, a key requirement is to have information about circuit performance that may be used to make comparative assessments between the various RF-IC alternatives.

The large number of wireless component vendors has led to the need of caution when reading and using parameters given in datasheets. Some knowledge of "the not-so-fine art of creative RF-datasheet writing" may be in order. If the measurement conditions of one or more of the key parameters are not given, there might be a reason for this. Checking just a few fundamental parameters may save time and frustration when realising that the circuit chosen does not comply with your system specifications.

Some important things to verify are:

Datarate
The datarate listed should be the effective datarate of the data you wish to transfer in your system protocol. Some systems have Manchester coding as a presupposition when transmitting data. Make sure that the stated datarate does not include the extra transitions resulting from Manchester encoding (See Figure 16).

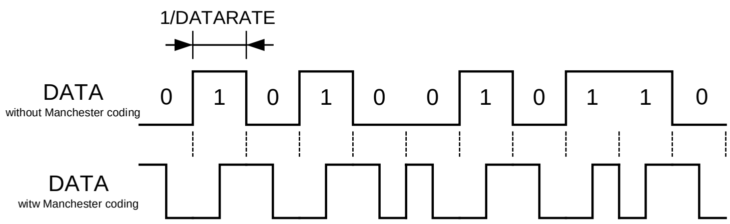


Figure 16 - Difference between data and Manchester encoded data stream

Terms such as datarate, chiprate and baudrate are all used to describe the amount of data that may be transferred per time unit of the RF-IC. Make sure you understand how the RF-IC vendor defines this parameter.

Sensitivity
Sensitivity is an important parameter when calculating the transmission link budget. In systems where multiple datarates and IF-filter bandwidths exist, make sure that the sensitivity given is for the maximum datarate (or the datarate you wish to use).
Generally, sensitivity drops with IF-filter bandwidth.

Adjacent channel selectivity
Make sure that the ACS is given for the adjacent channel and not spaced further away from the received channel than the channel spacing. Stating the 'ACS' for a frequency further away from the received channel make the ACS seem better than it actually is.
Some vendors state adjacent channel attenuation (ACA) which is not the same as ACS. ACA does only state the attenuation of a signal at a given spacing from the received channel, not how large this signal may be before demodulation is inhibited.
Generally ACS is lower than the ACA.

Current consumption
Be sure that the current consumption is given for the frequency band in which you intend to use the device. Also, what is the continuos current drain of the device in any given mode. Often power duty-cycling current drain is given to catch attention.

Blocking
Whilst parameters like IP3, two-tone 3rd order intermodulation and compression point give useful information to the experienced RF-designer, their direct effect on functionality is not that easy to comprehend or foresee.
If in doubt, ask your component vendor to supply blocking characteristics for your channel and nearby frequency bands (see Figure 12).

Crystal reference requirement
X-tal requirement is usually given as maximum allowed offset from the nominal frequency in ppm. Make sure that the requirement stated in the datasheet is valid for the channel bandwidth and frequency deviation used.
Some transceiver solutions are based upon receiver tracking of the received signal in order to reduce crystal reference requirements. In other words, that the receiving frequency is adjusted actively in order to 'find' the transmitted signal. Note that the transmitted frequency will still drift according to the transmitter crystal offset. Although this approach will ensure communication between two units, transmitter frequency drift must still comply with the channel spacing of the system. I.e. trying to use a ±30ppm crystal for a 868MHz system with 25kHz channel spacing will result in a worst case transmitter frequency drift of 26kHz ($868\text{MHz} \cdot 30^{-6}$).
Generally the crystal reference is a significant part of the total system cost. Also note that crystal cost is proportional to the temperature range of which required performance is guaranteed.

Switching time
Switching time between different operational modes should be stated in the datasheet (i.e. transmit to receive mode, power-down to receive mode etc.). Remember to add the duration time of 'training'- or preamble sequences. Some receiver topologies require lengthy '10101010...'-sequences in order to initialise or syncronise the demodulator. Also, receiver frequency tuning sequences described in the X-tal reference requirement section, is generally time-consuming compared the given switching time.

Summary
This article has covered the following topics;

- system design guidelines based upon environmental factors, cost and reliability requirements
- fundamental parameters and their definitions for integrated one-chip wireless components
- what to look for in RF-circuit data-sheet interpretation

The intention has been to provide an introduction to the use of typical off-the-shelf integrated RF-IC's. Often the first step to knowledge is just to find out what to ask for. Hopefully the article has opened the door, just ever so slightly, to the exiting world of wireless communication.