CC1125 Operating in 25 kHz Channels at 869 MHz, ETSI Category 1

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Keywords

- *ESTI category 1*
- *EN 300 220*
- *Optimized close in phase noise*
- *ACS - Adjacent Channel Selectivity*
- *Blocking*
- *Spurious response rejection*
- *Crystal specification*
- *TCXO*
- *CC1125*

1 Introduction

The CC112x family of devices is fully integrated single-chip radio transceivers designed for high performance at very low power in cost effective wireless systems. All filters are integrated, removing the need for costly external IF filters.

CC1125 is the highest performing member in the performance line family and provides the lowest phase noise and the best selectivity and blocking performance. CC1125 has the option to set narrower receiver filter bandwidth than the rest of the family – down to 3 kHz - and is therefore suitable for 6.25 kHz channel spacing solutions and below.

This application note outlines the expected performance when operating CC1125 under ETSI category 1 EN 300 220-1 V2.3.1 [5] in the 869 MHz frequency band. It also discusses trade-offs in terms of data rate, sensitivity and frequency accuracy for narrowband (25 kHz) systems.

Lab measurements show that CC1125 meets category 1 requirements with good margins. In addition, CC1125 has features that enables relaxed frequency accuracy requirement, which make designs with a regular crystal, as opposed to a TCXO, possible. Using Sniff Mode the CC1125 can operate in receive with as low as 1.8 mA (4 byte preamble) average current consumption with no degradation in RF performance. The fast receiver with the Wavematch feature makes it possible to reduce the number of preamble bytes to below 1 byte. This, combined with the high data rate (19.2 kbit/s using 4GFSK), reduces the TX consumption to a fraction of what previously has been possible for category 1 solution.

The CC1125 Development Kit [1] is certified for category 1.

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2 Abbreviations

ACS	Adjacent Channel Selectivity
Cat 1	Category 1
CW	Continuous Wave
EB	Evaluation Board
EM	Evaluation Module
FB2PLL	Feedback to PLL
PCB	Printed Circuit Board
PER	Packet Error Rate
PLL	Phase Locked Loop
RF	Radio Frequency
RSSI	Receive Signal Strength Indicator
RX	Receive, Receive Mode
RX_BW	Receiver Bandwidth
SRD	Short Range Device
TCXO	Temperature Compensated Crystal Oscillator
TrxEB	SmartRF Transceiver EB
TX	Transmit, Transmit Mode

3 ETSI Category 1

ETSI Category 1 is a receiver specification under EN 300 200 for *"Highly reliable SRD communication media; e.g. serving human life inherent systems (may result in a physical risk to a person)…".* The classification is for sub-1 GHz frequency RF systems in general, but in this application note frequencies in the 863-870 MHz range are assumed. The most relevant application for category 1 is social alarm in the 869.200 to 869.250 MHz band where 25 kHz channel spacing is defined. For details on regulatory limits in the 863-870 MHz SRD frequency bands, refer to the ETSI EN 300 220-1 V2.3.1 [5] and ERC Recommendation 70-03 [6]. These can be downloaded from www.etsi.org and www.ero.dk.

The most challenging category 1 requirement is the adjacent channel selectivity, which is a measure of how robust the receiver is against an interferer that is only ±25 kHz away. Since the interferer differs in frequency from the wanted signal by 25 kHz it is not possible to filter this signal out with an external filter (e.g. SAW filter).

The main requirements for category 1 are explained in Sections 3.1 - 3.5. The requirements depend on the receiver bandwidth (RX_BW) and the bandwidth therefore has to be stated in the certification test report. The definition of "receiver bandwidth" is unfortunately missing in the standard. In this application note we have chosen to use the 6 dB bandwidth as this is relatively common definition of a receiver bandwidth. Some manufacturers use the 20 dB receiver bandwidth, and it should be noted that such a definition makes it easier for a *poorer* receiver to pass the regulation.

The "bathtub" plots (e.g. Figure 1), which show packet error rate (PER) vs. frequency offset vs. input signal, is a good way to visualize the actual receiver bandwidth. Note that it is possible to pass category 1 regulations with higher bandwidths than 25 kHz. In cases where the receiver bandwidth is larger than 25 kHz, then 25 kHz is used in the calculations for the ETSI limit.

3.1 Usable Sensitivity

The minimum useable sensitivity is specified as a function of receiver bandwidth. The requirement is rather relaxed and poses no challenge for CC1125. The sensitivity numbers presented in this application note are measured through a SAW filter with a 3-4 dB insertion loss – thus reducing the actual CC1125 sensitivity by 3-4 dB. Note that the *calculated* useable sensitivity is used as a basis for the wanted signal strength in the selectivity and blocking measurements and not the CC1125 actual sensitivity.

$$\text{Usable sensitivity} = 10 * \log_{10}\left(\frac{RX\_BW[kHz]}{16[kHz]}\right) - 107dBm$$

As an example, for a 16 kHz receiver bandwidth the limit is -107 dBm.

Table 1 shows the useable sensitivity limits for different receiver bandwidths.

RX_BW [kHz]	Usable Sensitivity [dBm]
5	-112.05
10	-109.04
15	-107.28
20	-106.03
25	-105.06

Table 1. Usable Sensitivity Limit vs. RX_BW

3.2 Adjacent Channel Selectivity (ACS)

The ETSI definition is: "*The adjacent channel selectivity is a measure of the capability of the receiver to operate satisfactorily in the presence of an unwanted signal, which differs in frequency from the wanted signal by an amount equal to the adjacent channel separation for which the equipment is intended.*"

As for sensitivity, the requirement depends on the receiver bandwidth and a lower bandwidth will give a tougher requirement. The test is done with a continuous wave (CW) as a jammer and a wanted signal that is 3 dB higher than the calculated usable sensitivity (see Section 3.1). For channel spacing ≤ 25 kHz the following equation applies:

$$\text{Adjacent Channel Selectivity} = 54dB - 10 * \log_{10}\left(\frac{RX\_BW[kHz]}{16[kHz]}\right)$$

As an example, for a 16 kHz receiver bandwidth the limit is 54 dB. The limit is relative, and assuming a wanted signal of -104 dBm (i.e. -107 dBm + 3 dB), the absolute level is -104 dBm + 54 dB = -50 dBm.

Table 2 shows the selectivity limits (relative and absolute) for different receiver bandwidths.

RX_BW [kHz]	Wanted Signal [dBm]	Relative Selectivity [dB]	Absolute Selectivity [dBm]
5	-109.05	59.05	-50.0
10	-106.04	56.04	-50.0
15	-104.28	54.28	-50.0
16	-104.00	54.00	-50.0
20	-103.03	53.03	-50.0
25	-102.06	52.06	-50.0

Table 2. Adjacent Channel Selectivity Requirement vs. RX_BW

3.3 Receiver Saturation at Adjacent Channel

The receiver saturation at adjacent channel is very similar to the selectivity test, but the wanted signal is 43 dB stronger than the usable sensitivity as opposed to 3 dB for ACS measurements. The limit is 87 dB above the useable sensitivity limit.

Table 3 shows the receiver saturation at adjacent channel requirement for different receiver bandwidths.

RX_BW [kHz]	Usable Sensitivity [dBm]	Wanted Signal [dBm]	Relative Selectivity [dB]	Absolute Selectivity [dBm]
5	-112.05	-69.05	87	-25.05
10	-109.04	-66.04	87	-22.04
15	-107.28	-64.28	87	-20.28
20	-106.03	-63.03	87	-19.03
25	-105.06	-62.06	87	-18.06

Table 3. Receiver Saturation at Adjacent Channel Requirement vs. RX_BW

3.4 Blocking

Blocking is defined in EN 300 220 as: "*a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted input signal at any frequencies other than those of the spurious responses or the adjacent channels or bands…"*. It is measured very much like ACS (selectivity), but further away from the wanted signal in frequency.

The limit depends on the receiver bandwidth and is specified for ±2 MHz and ±10 MHz offsets. For category 2 and 3, the limits are different for 2 and 10 MHz, but for category 1 the limit is the same at both frequency offsets.

$$\text{Minimum Blocking (2 and 10MHz)} = 84dB - 10 * \log_{10}\left(\frac{RX\_BW[kHz]}{16[kHz]}\right)$$

Table 4 shows the category 1 blocking requirements for different receiver bandwidths.

RX_BW [kHz]	Usable Sensitivity [dBm]	Wanted Signal [dBm]	Relative Blocking [dB]	Absolute Blocking [dBm]
5	-112.1	-109.1	89.1	-20.0
10	-109.0	-106.0	86.0	-20.0
15	-107.3	-104.3	84.3	-20.0
20	-106.0	-103.0	83,0	-20.0
25	-105.1	-102.1	82.1	-20.0

Table 4. Blocking Requirement vs. RX_BW

In order to comply with the 2 MHz blocking requirement, CC1125 needs a standard narrowband SAW filter made for the 869 MHz frequency band.

3.5 Spurious Response Rejection

Spurious response rejection is defined in EN 300 220 as: "*a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted modulated signal at any other frequency, at which a response is obtained."*

The spurious response rejection is measured similar to ACS – not with a modulated carrier as indicated by the definition, but with a CW jammer (the standard is not very clear on this). The frequency range used in this test depends on the IF frequency, which has to be stated when doing compliance testing. For CC1125 the default IF frequency is 62 kHz (the IF frequency is programmable). In order to limit the test scope, the standard defines a "limited frequency range" where the spurious response rejection has to be measured and the range should be calculated as following:

a) the limited frequency range is defined as the frequency of the local oscillator signal (f_{LO}) applied to the first mixer of the receiver plus or minus the Intermediate Frequency (IF) or where more than 1 IF is involved, at the image frequency of the first and subsequent frequency conversions;
b) at frequency separation corresponding to half of the first IF from the wanted receive frequency.

In a) above, the CC1125 local oscillator (f_{LO}) is RF - IF and since CC1125 only has one IF and one mixer, the range is f_{LO} ± IF = RF - IF ± IF. That is, from RF frequency to -2*IF = -124 kHz, where -124 kHz is the image frequency.

The limit for spurious response rejection is 60 dB, but is relaxed by 25 dB for frequencies that are separated from the wanted signal by less than ±0.1% of the centre frequency. At 869

MHz, this is ±869 kHz. The relaxation is to allow low IF receivers to have poorer performance at the image frequency, since it is not feasible to use a SAW filter to improve blocking this close to the carrier.

CC1125 has an on-chip automatic image removal feature and does not need such a relaxation. Note that many receivers in the market have poor image rejection solutions that need calibration. In these cases the image rejection will typically degrade with temperature, aging and voltage variations. Although this can be acceptable in terms of regulatory requirements (particular when the image frequency falls below 0.1% of the RF frequency), it is still a weakness that lowers the robustness of the product.

Table 5 shows the spurious response rejection requirements for different receiver bandwidths.
.

RX_BW [kHz]	Wanted Signal [dBm]	Relative Rejection [dB] 1)	Absolute Rejection [dBm] 1)	Relative Rejection [dB] 2)	Absolute Rejection [dBm] 2)
5	-109.1	60.0	-49.1	35.0	-74.1
10	-106.0	60.0	-46.0	35.0	-71.0
15	-104.3	60.0	-44.3	35.0	-69.1
16	-104.0	60.0	-44.0	35.0	-69.0
20	-103.0	60.0	-43.0	35.0	-68.0
25	-102.1	60.0	-42.1	35.0	-67.1

Table 5. Spurious Response Rejection Requirement vs. RX_BW
1) Jammer >0.1% of Wanted. 2) Jammer <0.1% of Wanted

4 System Design – Data Rate, RX Bandwidth and Crystal Accuracy

4.1 Data Rate

Data rate [kbit/s] will influence the current consumption since the "on" time, for the same data payload, is shorter for a higher data rate. On the other hand, a higher data rate means less energy per bit and therefore the need for a higher signal to noise ratio in the demodulator resulting in degraded sensitivity, shorter RF range and less margin to the ETSI regulatory requirements. A higher data rate will also "fill up" the channel more such that there is less room for crystal frequency errors/drift.

GFSK is the preferred modulation for narrowband communication. CC1125 also supports 4GFSK and can, in a 25 kHz channel, support up to 19.2 kbit/s (9.6 ksymbols/s).

4.2 Receiver Bandwidth

Receiver sensitivity and selectivity/blocking depend on the receiver filter bandwidth. CC1125 has a very sharp digital receiver filter with fine resolution and several filter bandwidths are possible in a 25 kHz channel. In addition, CC1125 has a digital feature called "feedback to the PLL" (FB2PLL), which is described in more detail in Section 5. FB2PLL makes it possible to track and correct the frequency error of the incoming signal. Using FB2PLL, the *effective* receiver bandwidth appears wider than the configured filter bandwidth. In this application note, the term *filter bandwidth* is the bandwidth configured in the CC1125 while *receiver bandwidth* (RX_BW) is used for the effective bandwidth that includes the effect of FB2PLL and is also the 6 dB receiver bandwidth used to calculate the ETSI category 1 regulatory limits.

Using a 40 MHz crystal/TCXO the lowest filter bandwidth possible is 3.5 kHz. Some RF IC manufactures state 869 MHz performance with filter bandwidth in the 5 kHz range. This low bandwidth will give very good sensitivity and selectivity performance figures, but is not all that useful as the maximum data rate will be very limited and the crystal accuracy requirements will be challenging even for a very expensive high performance TCXO. For CC1125, a filter bandwidth in the 10-25 kHz range allows for some crystal frequency inaccuracies and still gives excellent sensitivity and selectivity/blocking performance. Keeping good frequency control is vital for a narrowband solution, drifting outside the wanted channel will cause significant reduction in RF range.

4.3 Crystal Accuracy and Specification

25 kHz at 869 MHz is only 28 ppm (the whole channel), so frequency accuracy is challenging for narrowband communication in the 869.200 to 869.250 band. How tight the crystal or TCXO specification needs to be depends on data rate, deviation/separation and effective receiver bandwidth. Plotting PER vs. frequency offset vs. input power yields a "bathtub" figure, which can be used to determine the crystal accuracy needed for the application. CC1125 has a very fast way of detecting the frequency error of an incoming RF signal and using the FB2PLL feature greatly reduces the required crystal accuracy compared to many competing solutions.

In many cases, it is easier/better to use a TCXO instead of a crystal. The disadvantage is that a TCXO is more expensive, draws more current and has longer start-up time than a crystal. A rough price estimate of a quality RF crystal (100k per year) is $0.2 and a TCXO (2.5 ppm) is in the range of $0.7. It is also possible to make software TCXO by using a good quality crystal and performing a temperature measurement. This is not covered in this application note.

4.3.1 Initial Tolerance

This is the initial crystal frequency error at room temperature when using the specified crystal loading. If the application uses an MCU with flash/FRAM memory (e.g. MSP430) the initial error can be removed in production by adjusting the RF frequency. This is possible since the CC1125 has a fractional-N PLL with very fine resolution.

4.3.2 Crystal Loading

The crystal is designed for a specific crystal load. The two external capacitors from the crystal terminals to ground and parasitic capacitances define the crystal capacitive load. If the capacitive load is too low (high) compared to the specified capacitive load the crystal and RF frequencies will be higher (lower) than specified. CC1125 data sheet [2] specifies the crystal load as 10 pF.

4.3.3 Temperature Drift

A regular AT-cut high frequency crystal for RF communication will drift with temperature. The drift is typically in the 10 ppm to 20 ppm range depending on the temperature range. 6-8 ppm in a -20^{o}C to 70 ^{o}C temperature range is about the best a crystal can do. If the application requires less temperature drift, use a TCXO or make your own by measuring the temperature and adjust the RF frequency accordingly by changing the frequency word. The CC1125 has an on-chip temperature sensor as described in [7].

The required crystal temperature drift specification depends on data rate, frequency deviation and receiver bandwidth. The "bathtub" plots as discussed in Section 5 are useful in determining the required crystal accuracy. Note that the temperature range of interest needs to be specified to the crystal/TCXO manufacturer.

4.3.4 Aging

Due to stresses in the packet, the crystal frequency will change somewhat over time. The rate of change decays exponentially. It is common to state aging as first year aging and then a maximum drift. Specification for a 25 kHz system at 869 MHz will typically be maximum 1 ppm first year, 2 ppm total.

4.3.5 Crystal Frequency

CC1125 has best phase noise performance at 40 MHz so always use this for category 1 designs.

4.3.6 Size

Due to the need for small size components in portable electronics like Smartphones, small size crystals and TCXOs are now readily available. Initially, smaller size came with a bigger price tag, but this is no longer the case and 2.0 mm x 1.6 mm is recommended by many crystal manufactures. However, somewhat bigger size crystals often have lower losses (ESR) and faster start-up times.

4.3.7 Crystal and TCXO manufactures

There are many crystal and TCXO manufactures. For the Low Power RF product range, TI is working with Epson and NDK for our development kits. These manufactures will also keep a stock of products such that lead time for samples can be kept low.

Manufacturer	Crystal	TCXO
EPSON	FA-128 TSX-3225 FA-20H	TG-5021CG series TG-5021CE series
NDK	NX2016SA 40MHz EXS00A-CS03875	NT2016SA 40 MHz TEE3016A

Table 6. Crystal and TCXO for Category 1 Design

5 Feedback to the PLL

The CC112x family of high performance transceivers include a feature called Feedback to the PLL (F2PLL). This is a feature that allows for maximum frequency error and thereby as low cost crystal as possible.

The receiver consists of dedicated DSP hardware capable of finding the frequency of the signal in the preamble and synchronisation word. The frequency error is then fed back to the PLL (the Local Oscillator - LO) and compensated for such that the signal is centred in the middle of the CC112x filter bandwidth. If you have a choice in terms of synchronisation word make sure the last byte in the sync word is dc balanced (same number of 0’s and 1’s) as this gives the best working condition for the FB2PLL algorithm.

The FB2PLL feature is controlled by the FREQ_IF_CFG register. FREQ_IF_CFG = 0x33 is used for most test cases and will give a medium gain in the feedback loop. One can also set how much the loop is allowed to track and two register settings are available: ±1/4 or ±1/8 of the programmed filter bandwidth. FREQ_IF_CFG = 0x33 uses the ±1/4 setting for maximum “tuning”.

Figure 1 and Figure 2 show plots of PER vs. frequency offset vs. input signal (“bathtub” plots) with and without FB2PLL enabled respectively. As can be seen in the figures the sensitivity remains the same, but in the case where FB2PLL is enabled a larger frequency error is acceptable without degradation in sensitivity. +13 ppm and -12 ppm error is acceptable in the case with FB2PLL enabled, while in the case with FB2PLL disabled +8 ppm and -7 ppm is the maximum error. Note that the transmitter and the receiver can have frequency errors at opposite extremes (worst case) so the specification for the crystal/TCXO needs to be half of this – in the range of ± 6 ppm with FB2PLL enabled and ± 3.5 ppm with FB2PLL disabled.

FB2PLL needs some time to correct frequency errors, so for 4.8 kbit/s 3-4 bytes of preambles are needed. When FB2PLL is not used, CC1125 can handle 9.6 kbit/s with only 1 byte of preamble.

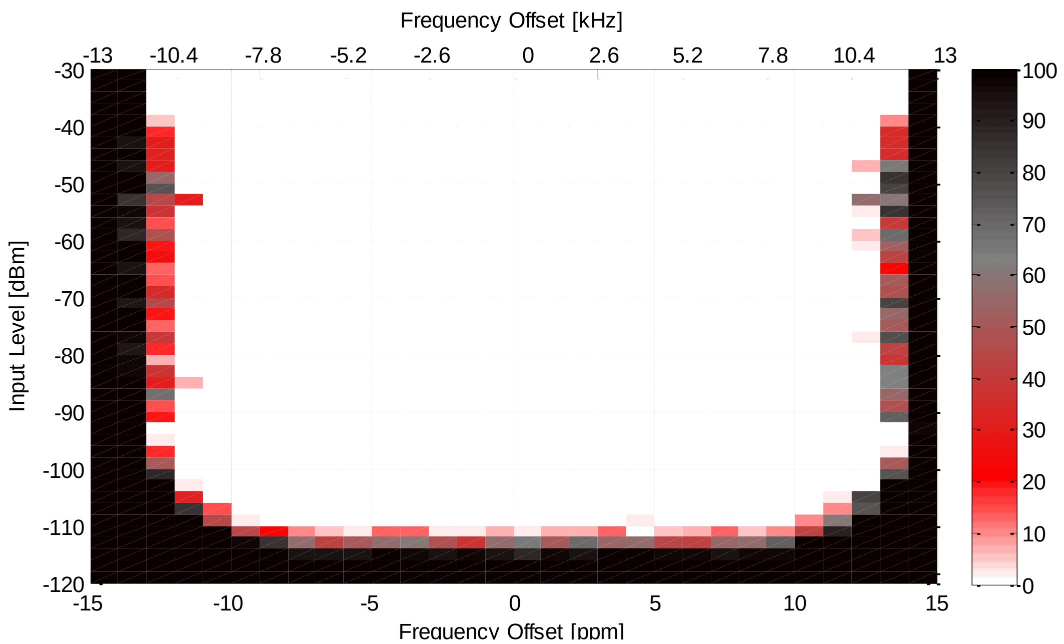


Figure 1. FB2PLL Enabled, 4 byte Preamble (4.8 kbit/s, 16.6 kHz Filter Bandwidth)

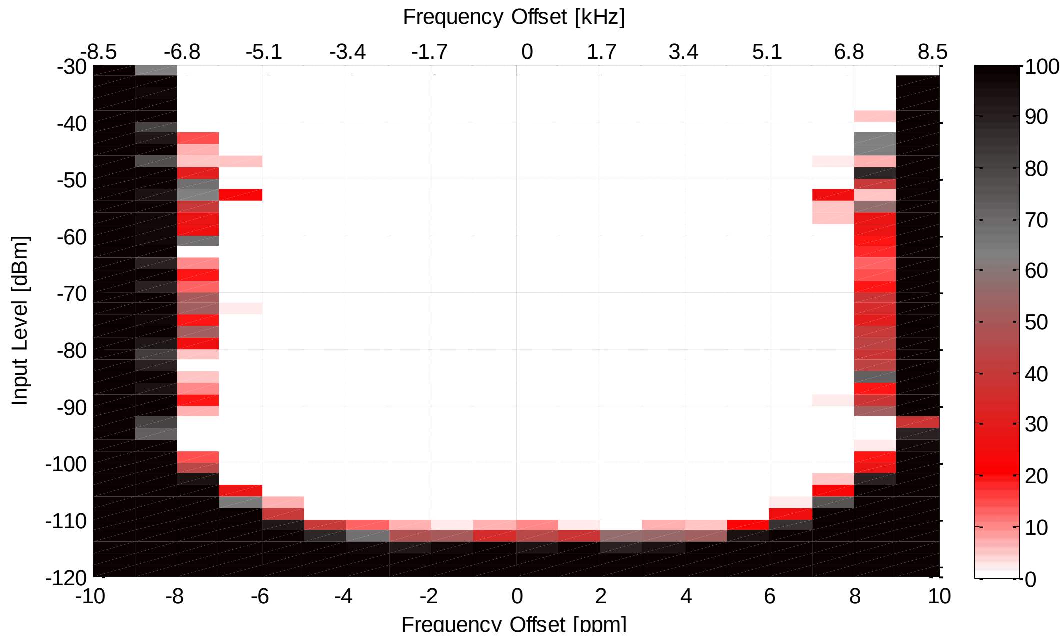


Figure 2. FB2PLL Disabled, 1 byte Preamble (4.8 kbit/s, 16.6 kHz Filter Bandwidth)

6 CC1125 25 kHz Narrowband ETSI Category 1 Performance

CC1125 has been tested against ETSI category 1 regulatory requirements for various data rate and receiver bandwidths. The data presented in subsequent sections is average performance measured over 6 CC1125 869 cat 1 EMs, which includes a SAW filter in the receiver path. The register settings have been optimized for close-in phase noise.

T_C = 25°C, VDD = 3.0 V, f = 869.225 MHz if nothing else is stated. All parameters are measured conducted on the CC1125EM 868 ETSI Cat1 reference design [4] with a 50 Ω load.

6.1 GFSK, 1.2 kbit/s, ±1.2 kHz Deviation

1.2 kbit/s is the lowest data rate tested. Low data rate gives the best sensitivity/range and margin towards regulatory requirements. On the other hand, low data rate increases the "on-time" and will not be the lowest power solution. 2 byte preamble and 2 byte sync word are used for the testing as this is sufficient for error free reception including the FB2PLL feature.

6.1.1 Performance Overview @1.2 kbit/s for Various Receiver Bandwidths

Filter Bandwidth [kHz]	5	10	16.6	19.2
RX_BW with FB2PLL [kHz]	7.5	15	24.9	28.8
Sensitivity [dBm]	-118.0	-114.8	-112.9	-112.0
ETSI Limit [dBm]	-110.3	-107.3	-105.1	-105.1
ACS [dB]	62.5/62.5	58.7/58.1	56.1/55.6	55.5/55.0
ETSI Limit [dB]	57.3	54.3	52.1	52.1
Receiver Saturation at Adjacent Channel [dB]	101.3/101.0	99.6/99.4	98.5/98.5	98.6/98
ETSI Limit [dB]	87	87	87	87
Blocking 2 MHz [dB]	105.3/100.3	102.3/97.3	100.0/95.2	99.1/94.6
ETSI Limit [dB]	87.3	84.3	82.1	82.1
Spurious Response Rejection @±0.1%RF [dB]	80.9/71.3	78.0/68.2	77.0/66.0	75.5/65.0
ETSI Limit [dB]	60	60	60	60

Table 7. Performance Overview @1.2 kbit/s vs. RX_BW

10 MHz blocking is better than 105 dB and is higher than what can be accurately measured by our automatic test system. The limit is the same as for 2 MHz blocking.

For receiver bandwidths above 25 kHz (as for 19.2 kHz RX filter with FB2PLL), 25 kHz is used to calculate the ETSI limit.

6.1.2 Register Settings

Use Smart RF Studio 1.2 kbit/s ETSI category 1 default settings and adjust the filter bandwidth through the CHAN_BW register as desired.

For the best close-in phase noise performance, set the phase pump current to maximum by configuring FS_CHP register to 0x3F **after** calibrating the PLL.

In addition, for the 16.6 kHz and 19.2 kHz filter bandwidths, the "extra" data filter is enabled by selecting DATA_FILTER_EN = 1 in the MDMCFG0 register. Use this setting when the data rate is less than 1/10 of the filter bandwidth.

6.1.3 Crystal Accuracy Needed @1.2 kbit/s for Various Receiver Bandwidths

Figure 3 to Figure 6 show plots of PER vs. frequency offset vs. input power level for 5, 10, 16.6 and 19.2 kHz filter bandwidth with feedback to PLL feature enabled. With FB2PLL enabled the receiver bandwidth (RX_BW) is 7.5, 15, 24.9 and 28.8 kHz.

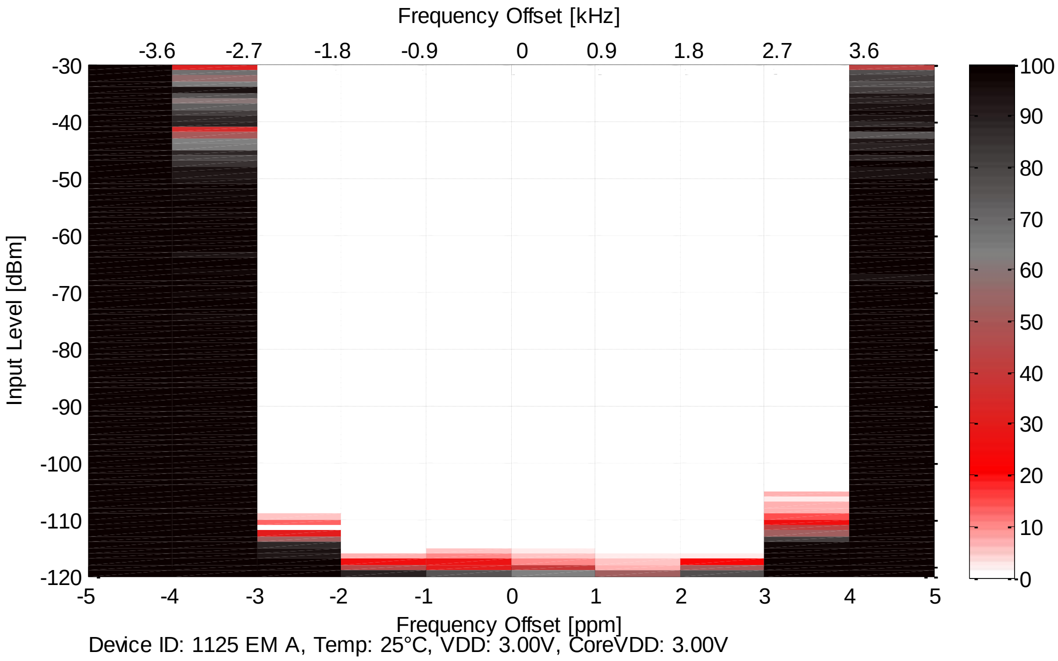
The required crystal accuracy can be estimated from the plots. The receiver and transmitter can drift in opposite directions and the crystal accuracy requirement is therefore half of what is indicated in Figure 3 to Figure 6. As an example, in Figure 3 the crystal accuracy must be in the range of -1.5 ppm to +2 ppm.

Table 8 gives a summary of the required crystal accuracy.

RX_BW [kHz]	Crystal Accuracy [ppm]	Plot	Comment
7.5	-1.5 / +2	Figure 3	This tight tolerance crystal is only possible with a very high quality TCXO. Due to the frequency accuracy needed, 1.2 kbit/s data rate and 5 kHz filter bandwidth with FB2PLL enabled is not a recommended setting for a “regular” category 1 system even though it gives the best performance numbers.
15	±3.5	Figure 4	This can be achieved with a low cost TCXO 1.2 kbit/s and 10 kHz filter bandwidth with FB2PLL enabled is the setting that will give best range/robustness.
24.9	±7.0	Figure 5	This can be achieved with a regular crystal with a limited temperature range or a low cost TCXO.
28.8	±8.0	Figure 6	This can be achieved with a regular crystal with a limited temperature range or a low cost TCXO.

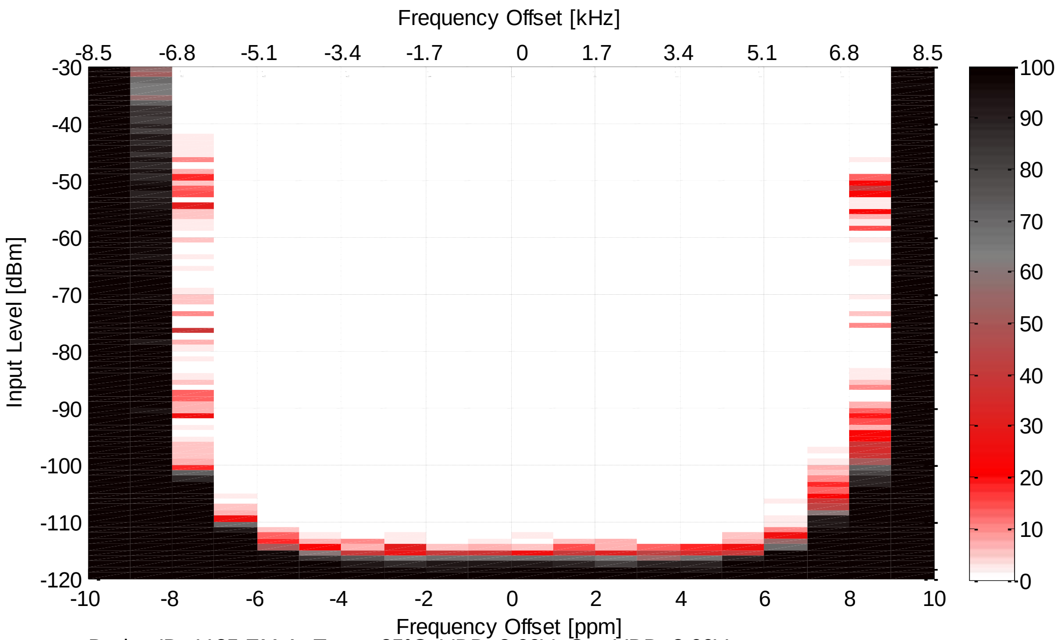
Table 8. Crystal Accuracy vs. RX_BW

The crystal accuracy in Table 8 includes initial tolerance, temperature drift and aging. The initial tolerance can be compensated for in production by measuring the RF frequency in TX and then adjusting the frequency by changing the CC1125 frequency word (the correction must be stored in an MCU).



Device ID: 1125 EM A, Temp: 25°C, VDD: 3.00V, CoreVDD: 3.00V
ChipSetup: Register sheet= combine#CC1125;PKT;MCAL;TC1_2k;CHPabsolute
RegWrite= CHAN_BW;5F
Operating Frequency:869.225000MHz

Figure 3. "Bathtub Plot". 1.2 kbit/s, ±1.2 kHz, 5 kHz Filter Bandwidth with FB2PLL



Device ID: 1125 EM A, Temp: 25°C, VDD: 3.00V, CoreVDD: 3.00V
ChipSetup: Register sheet= combine#CC1125;PKT;MCAL;TC1_2k;CHPabsolute
RegWrite= MDMCFG0;D
Operating Frequency:869.225000MHz

Figure 4. "Bathtub Plot". 1.2 kbit/s, ±1.2 kHz, 10 kHz Filter Bandwidth with FB2PLL

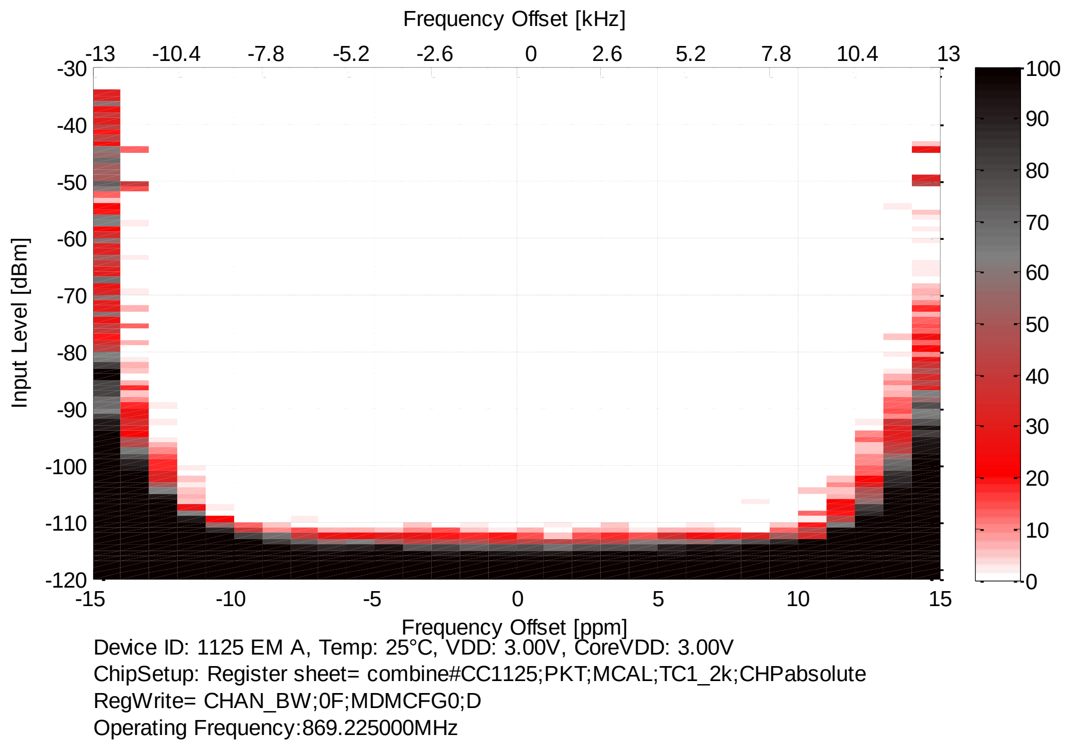


Figure 5. "Bathtub Plot". 1.2 kbit/s, ±1.2 kHz, 16.6 kHz Filter Bandwidth with FB2PLL

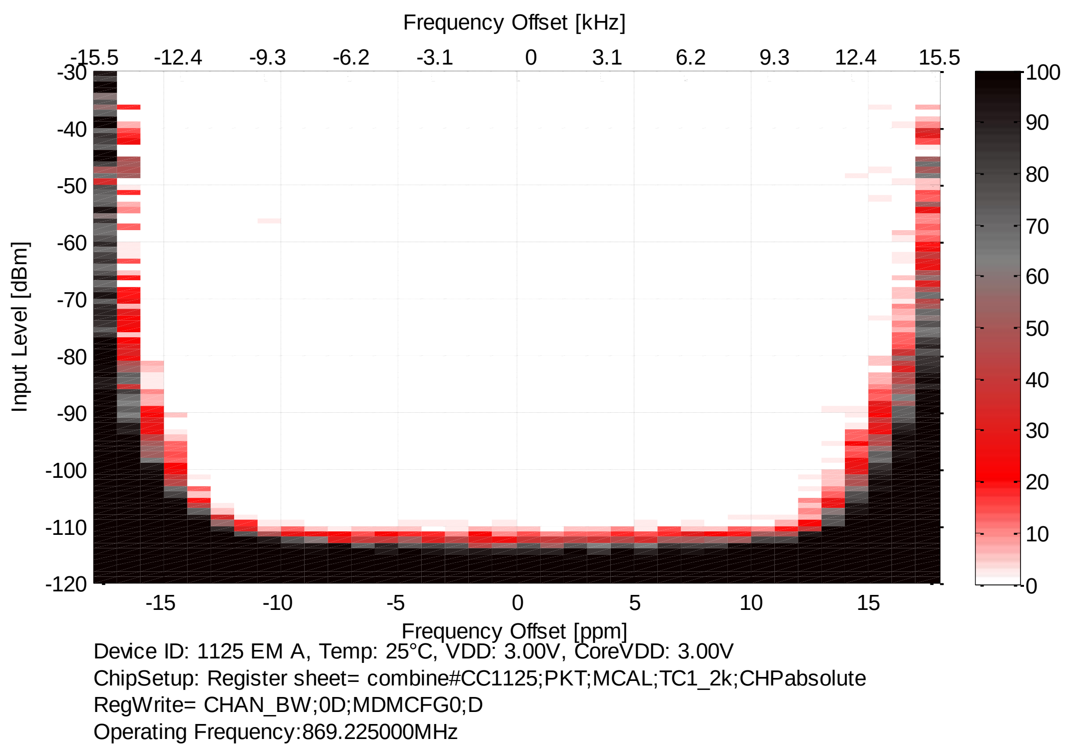


Figure 6. "Bathtub Plot". 1.2 kbit/s, ±1.2 kHz, 19.2 kHz Filter Bandwidth with FB2PLL

6.1.4 Spurious Response Rejection @1.2 kbit/s

Figure 7 and Figure 8 show the spurious response rejection performance for 1.2 kbit/s data rate with 10 kHz and 19.2 kHz filter bandwidth respectively for ±1 MHz offset in 25 kHz steps. Average performance from 3 samples is used. The limit is 60 dB for frequencies that are separated from the wanted signal by more than ±0.1% of the centre frequency (±869 kHz) and 35 dB closer to the carrier. CC1125 passes this requirement with good margin. Note that the image at -124 kHz offset is completely removed. This is done by the CC1125 modem autonomously without any need for calibration.

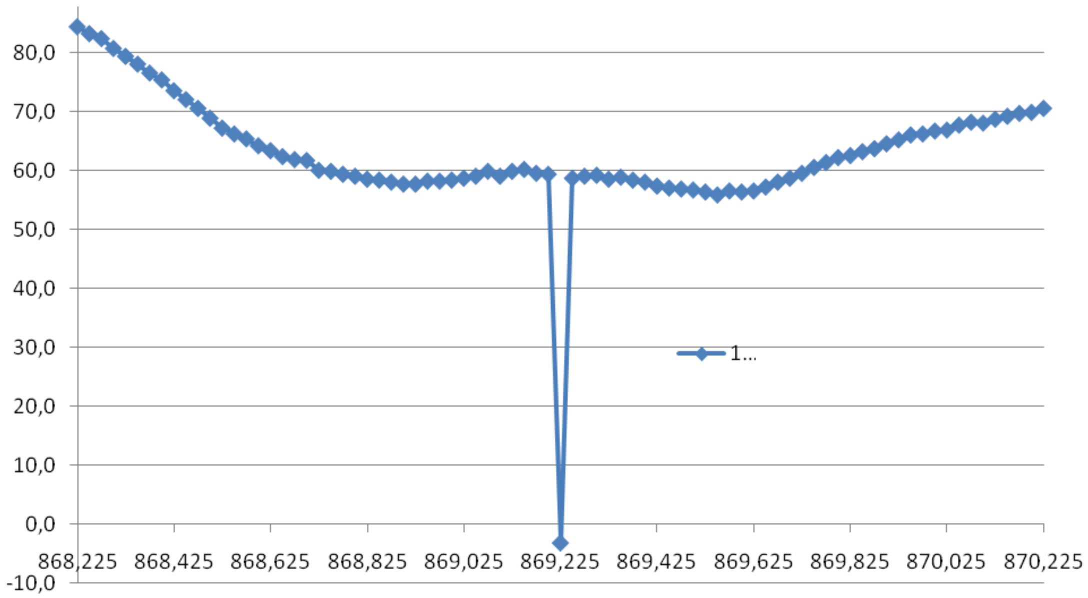


Figure 7. Spurious Response Rejection @1.2 kbit/s, 10 kHz Filter Bandwidth with FB2PLL

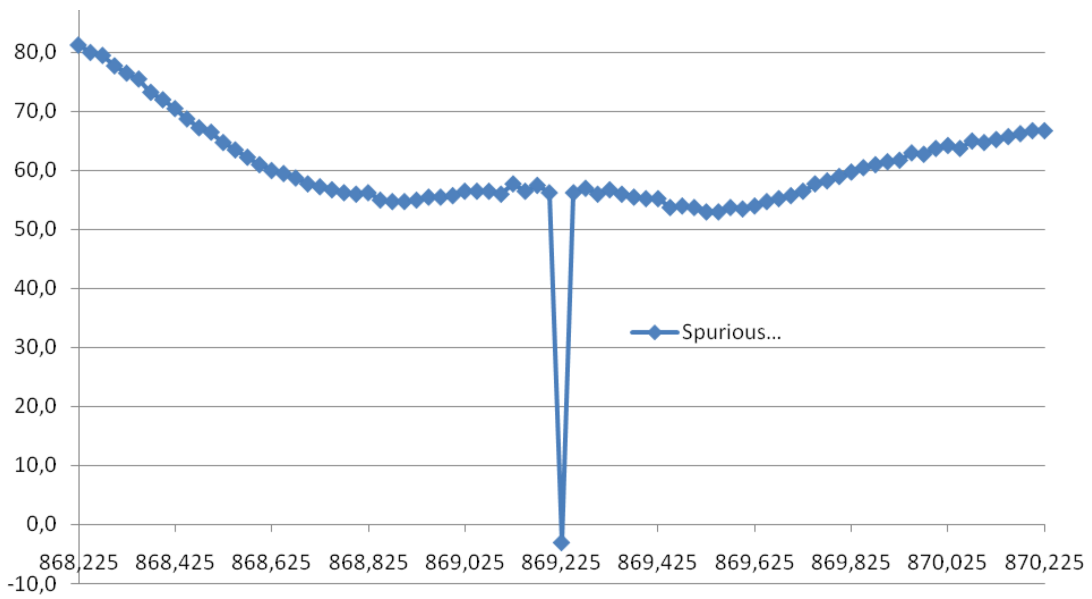


Figure 8. Spurious Response Rejection @1.2 kbit/s, 19.2 kHz Filter Bandwidth with FB2PLL

6.2 GFSK, 4.8 kbit/s, ±2.4 kHz Deviation

4.8 kbit/s data rate is a good trade-off between data rate and sensitivity/range. 3 byte preamble is used for the testing as this allows the FB2PLL feature to correct for the frequency offset in the incoming signal. If FB2PLL is not used 1 byte of preamble is enough.

6.2.1 Performance Overview @4.8 kbit/s for Various Receiver Bandwidths

Filter Bandwidth [kHz]	10	16.6	19.2
RX_BW with FB2PLL [kHz]	15	24.9	28.8
Sensitivity [dBm]	-115.1	-111.9	-111.2
ETSI Limit [dBm]	-107.3	-105.1	-105.1
ACS [dB]	58.5/58.0	56.1/55.8	55,1/54.8
ETSI Limit [dB]	54.3	52.1	52.1
Receiver Saturation at Adjacent Channel [dB]	97.4/96.9	95.6/98.3	95.4/98.0
ETSI Limit [dB]	87	87	87
Blocking 2 MHz [dB]	102.0/98.0	100.0/95.5	99.5/94.9
ETSI Limit [dB]	84.3	82.1	82.1
Spurious Response Rejection @±0.1%RF [dB]	76.8/67.0	74.8/65.0	74.3/64.3
ETSI Limit [dB]	60	60	60

Table 9. Performance Overview @4.8 kbit/s vs. RX_BW

10 MHz blocking is better than 105 dB and is higher than what can be accurately measured by our automatic test system. The limit is the same as for 2 MHz blocking.

For receiver bandwidths above 25 kHz (as for 19.2 kHz RX filter with FB2PLL), 25 kHz is used to calculate the ETSI limit.

6.2.2 Register Settings

Use Smart RF Studio 4.8 kbit/s ETSI category 1 default settings and adjust the filter bandwidth through the CHAN_BW register as desired.

For the best close-in phase noise performance set the phase pump current to maximum by configuring FS_CHP register to 0x3F **after** calibrating the PLL.

6.2.3 Crystal Accuracy Needed @4.8kbit/s for Various Receiver Bandwidths

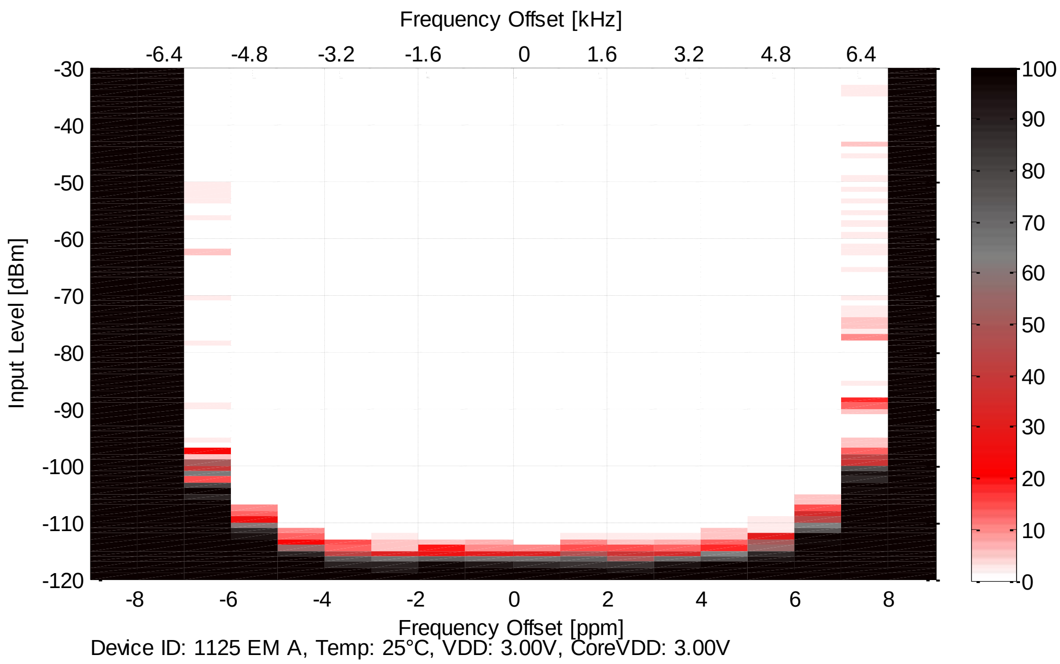
Figure 9 to Figure 11 show plots of PER vs. frequency offset vs. input power level for 10, 16.6 and 19.2 kHz filter bandwidths with feedback to PLL feature enabled. With FB2PLL enabled the receiver bandwidth (RX_BW) is 15, 24.9 and 28.8 kHz.

The required crystal accuracy can be estimated from the plots. The receiver and transmitter can drift in opposite directions and the crystal accuracy requirement is therefore half of what is indicated in Figure 9 to Figure 11. As an example, in Figure 9 the crystal accuracy must be in the range of -3.0 ppm to +3.0 ppm.

Table 10 gives a summary of the required crystal accuracy.

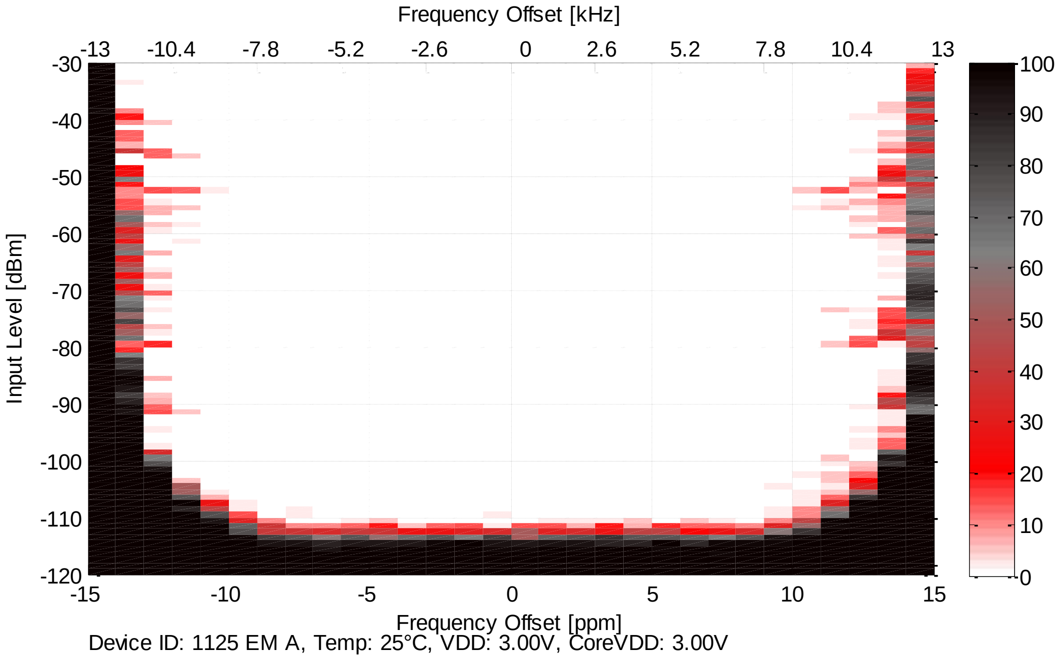
RX_BW [kHz]	Frequency Accuracy [ppm]	Plot	Comment
15	±3.0	Figure 9	This can be achieved with a TCXO. 4.8 kbit/s and 10 kHz filter bandwidth with FB2PLL enabled is the setting that will give best range/robustness.
24.9	±6.0	Figure 10	This can be achieved with a regular crystal with a limited temperature range or a low cost TCXO.
28.8	±7.0	Figure 11	This can be achieved with a regular crystal with a limited temperature range or a low cost TCXO.

Table 10. Crystal Accuracy vs. RX_BW



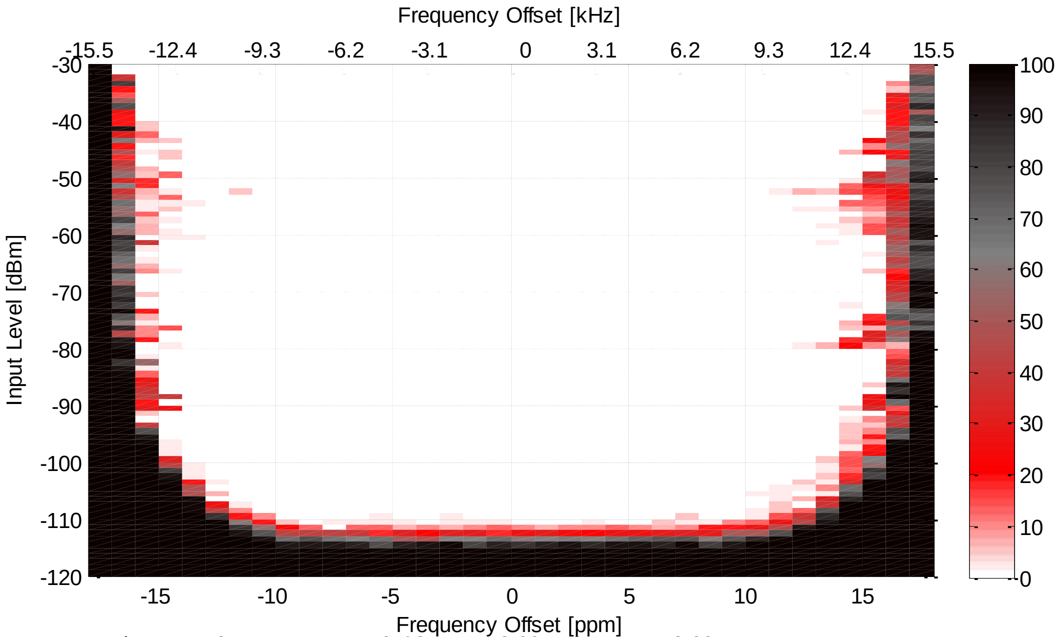
Device ID: 1125 EM A, Temp: 25°C, VDD: 3.00V, CoreVDD: 3.00V
ChipSetup: Register sheet= combine#CC1125;PKT;MCAL;TC4_8k;CHPabsolute
RegWrite=
Operating Frequency:869.225000MHz

Figure 9. "Bathtub Plot". 4.8 kbit/s, ±2.4 kHz, 10 kHz Filter Bandwidth with FB2PLL



Device ID: 1125 EM A, Temp: 25°C, VDD: 3.00V, CoreVDD: 3.00V
ChipSetup: Register sheet= combine#CC1125;PKT;MCAL;TC4_8k;CHPabsolute
RegWrite= CHAN_BW;0F
Operating Frequency:869.225000MHz

Figure 10. "Bathtub Plot". 4.8 kbit/s, ±2.4 kHz, 16.6 kHz Filter Bandwidth with FB2PLL



Device ID: 1125 EM A, Temp: 25°C, VDD: 3.00V, CoreVDD: 3.00V
ChipSetup: Register sheet= combine#CC1125;PKT;MCAL;TC4_8k;CHPabsolute
RegWrite= CHAN_BW;0D;MDMCFG0;D
Operating Frequency:869.225000MHz

Figure 11. "Bathtub Plot". 4.8 kbit/s, ±2.4 kHz, 19.2 kHz Filter Bandwidth with FB2PLL

6.2.4 Spurious Response Rejection @4.8kbit/s

Figure 12 shows the spurious response rejection performance for 4.8 kbit/s data rate with 16.6 kHz filter bandwidth for ±1 MHz offset in 25 kHz steps. Average performance from 3 samples is used. The limit is 60 dB for frequencies that are separated from the wanted signal by more than ±0.1% of the centre frequency (±869 kHz) and 35 dB closer to the carrier. CC1125 passes this requirement with good margin. Note that the image at -124 kHz offset is completely removed. This is done by the CC1125 modem autonomously without any need for calibration.

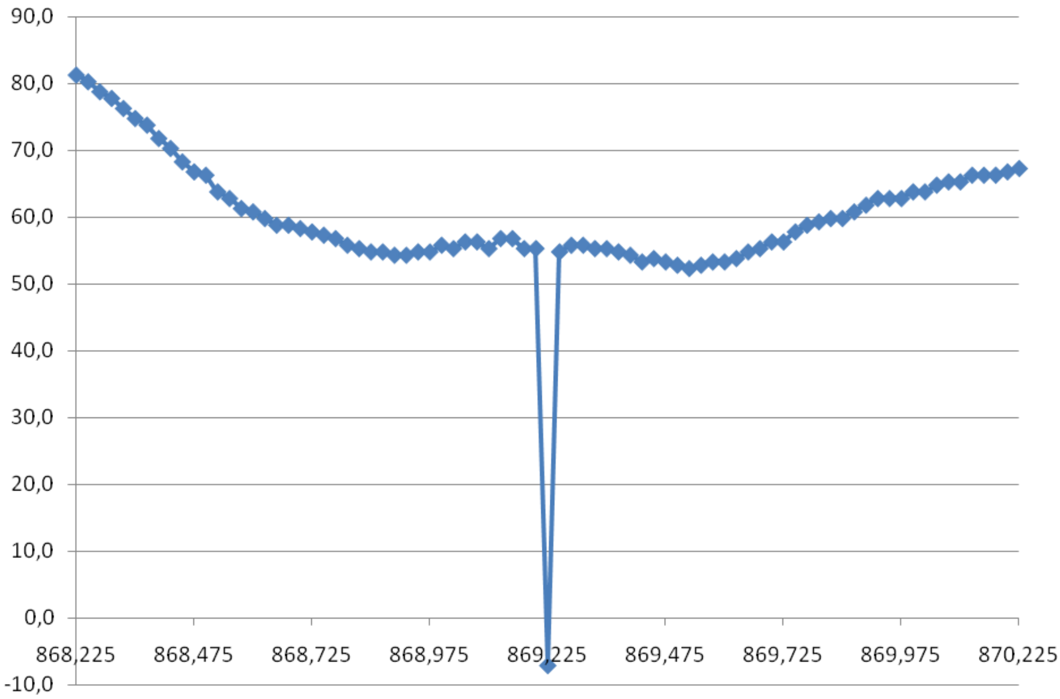


Figure 12. Spurious Response Rejection @4.8kbit/s, 16.6 kHz Filter Bandwidth with FB2PLL

6.3 GFSK, 9.6 kbit/s, ±4.8 kHz Deviation

9.6 kbit/s data rate can be used for systems where low power consumption is important. 4 byte preamble is used for the testing to allow time to track frequency errors for maximum relaxed crystal requirements.

6.3.1 Performance Overview @9.6 kbit/s

Filter Bandwidth [kHz]	19.2
RX_BW with FB2PLL [kHz]	24
Sensitivity [dBm]	-112.1
ETSI Limit [dBm]	-105.2
ACS [dB]	54.7/54.1
ETSI Limit [dB]	52.2
Receiver Saturation at Adjacent Channel [dB]	88.8/94.6
ETSI Limit [dB]	87
Blocking 2 MHz [dB]	99.1/94.4
ETSI Limit [dB]	82.2
Spurious Response Rejection @±0.1%RF [dB]	74.0/65.2
ETSI Limit [dB]	60

Table 11. Performance Overview @9.6 kbit/s

10 MHz blocking is better than 105 dB and is higher than what can be accurately measured by our automatic test system. The limit is the same as for 2 MHz blocking.

6.3.2 Register Settings

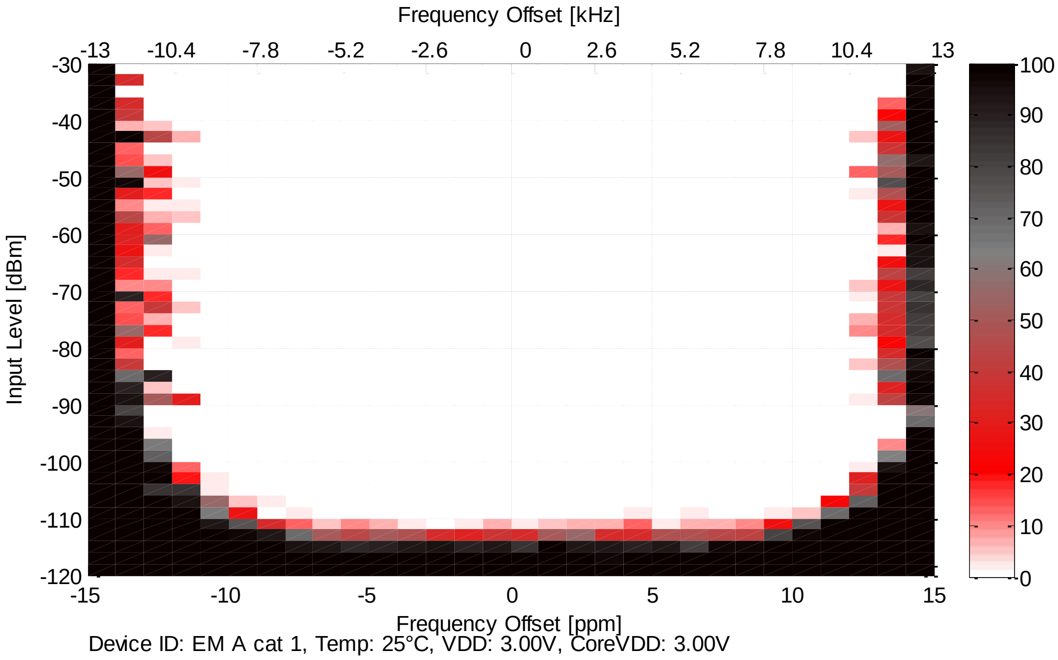
Use Smart RF Studio 9.6 kbit/s ETSI category 1 default settings.

For the best close-in phase noise performance set the phase pump current to maximum by configuring FS_CHP register to 0x3F **after** calibrating the PLL

Note that for this case, the FB2PLL register setting used is ±1/8 of the configured filter bandwidth (the 1.2 kbit/s and 4.8 kbit/s test cases use ±1/4)

6.3.3 Crystal Accuracy Needed @9.6 kbit/s, 19.2 kHz Receiver Filter

Figure 13 shows the PER vs. frequency offset vs. input power level for a 19.2 kHz filter bandwidth with feedback to PLL feature enabled (i.e. RX_BW = 24 kHz). Since the receiver and transmitter can drift in opposite directions the crystal accuracy requirement is therefore half of what is indicated in Figure 13, i.e. in the range of ±6.0 ppm- This can be achieved with a regular crystal with a limited temperature range (assuming initial tolerance is compensated for in production), or a low cost TCXO.



Device ID: EM A cat 1, Temp: 25°C, VDD: 3.00V, CoreVDD: 3.00V
ChipSetup: Register sheet= combine#CC1125;PKT;MCAL;TC9_6k;CHPabsolute
RegWrite= AGC_CFG1;A0;AGC_CFG0;C3
Operating Frequency:869.225000MHz

Figure 13. "Bathtub Plot". 9.6 kbit/s, ±4.8 kHz, 19.2 kHz Filter Bandwidth with FB2PLL

6.3.4 Spurious Response Rejection @9.6 kbit/s

Figure 14 shows the spurious response rejection performance for 9.6 kbit/s data rate with 19.2 kHz filter bandwidth for ±1 MHz offset in 25 kHz steps. Average performance from 3 samples is used. The limit is 60 dB for frequencies that are separated from the wanted signal by more than ±0.1% of the centre frequency (±869 kHz) and 35 dB closer to the carrier. CC1125 passes this requirement with good margin. Note that the image at -124 kHz offset is completely removed. This is done by the CC1125 modem autonomously without any need for calibration.

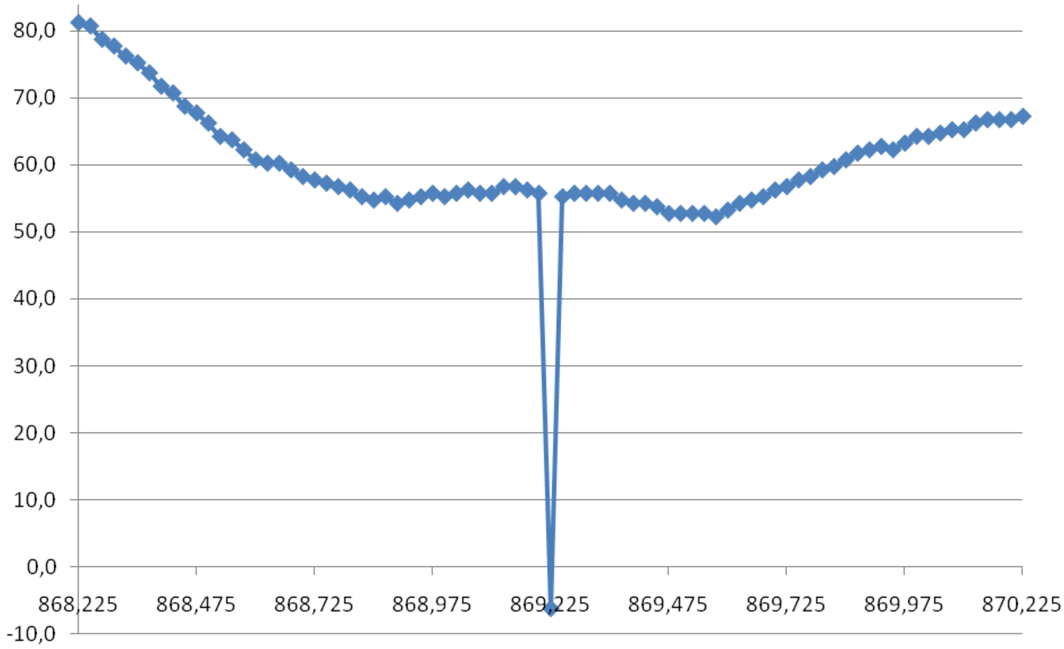


Figure 14. Spurious Response Rejection @9.6kbit/s, 19.2 kHz Filter Bandwidth with FB2PLL

6.4 4GFSK, 19.6 kbit/s, ±7.2 kHz Deviation

19.2 kbit/s 4GFSK can be used for systems where power consumption and high throughput is important. 4 byte preamble is used for the testing.

6.4.1 Performance Overview 4GFSK 19.6 kbit/s ±7.2 kHz

Filter Bandwidth [kHz]	25
RX_BW [kHz]	25
Sensitivity [dBm]	-110.2
ETSI Limit [dBm]	-105.1
ACS [dB]	53.3/53.0
ETSI Limit [dB]	52.1
Receiver Saturation at Adjacent Channel [dB]	93.7/94.2
ETSI Limit [dB]	87
Blocking 2 MHz [dB]	93.8/91.1
ETSI Limit [dB]	82.1
Spurious Response Rejection @±0.1%RF [dB]	71.3/62.1
ETSI Limit [dB]	60

Table 12. Performance Overview @19.2 kbit/s

10 MHz blocking is better than 105 dB and is higher than what can be accurately measured by our automatic test system. The limit is the same as for 2 MHz blocking.

6.4.2 Register Settings

Use Smart RF Studio 19.2 4GFSK kbit/s ETSI category 1 setting.

For the best close-in phase noise performance set the phase pump current to maximum by configuring FS_CHP register to 0x3F **after** calibrating the PLL

Feedback to PLL feature is not used.

6.4.3 Crystal Accuracy Needed @19.2 kbit/s ± 7.2 kHz, 25 kHz Receiver Filter

Figure 15 shows the PER vs. frequency offset vs. input power level for a 25 kHz filter bandwidth *without* feedback to PLL feature enabled (i.e. programmed filter bandwidth = RX_BW). Since the receiver and transmitter can drift in opposite directions the crystal accuracy requirement is therefore half of what is indicated in Figure 15, i.e. in the range of ±4.0 ppm. This can be achieved with a low cost TCXO.

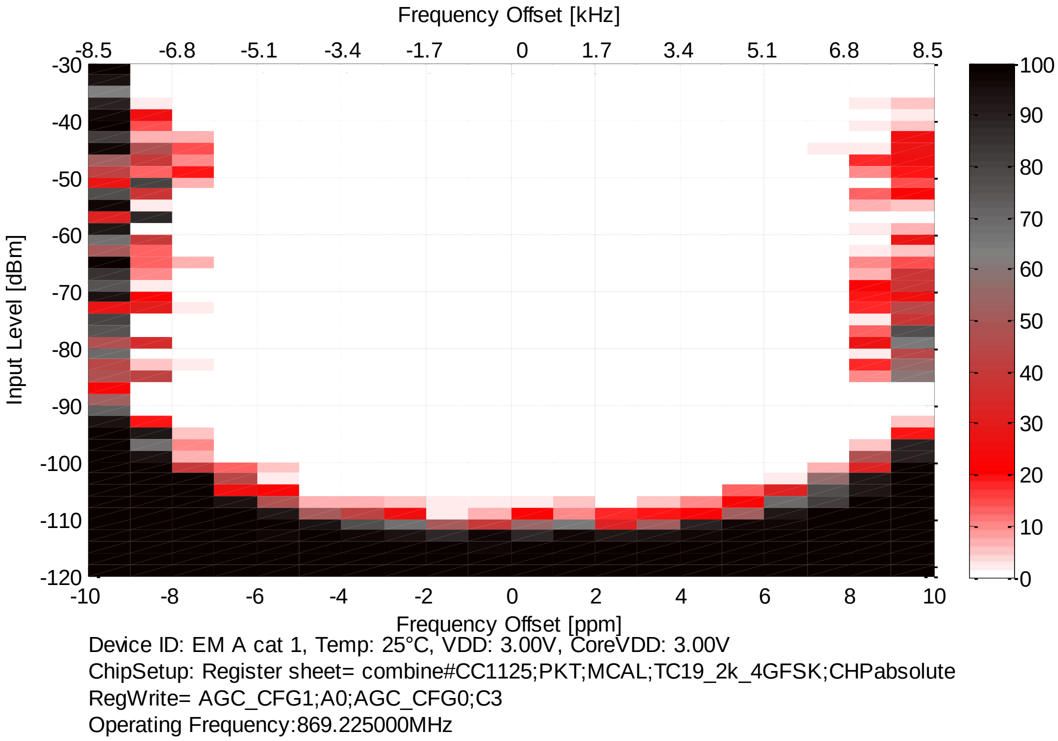


Figure 15. "Bathtub Plot". 19.2 kbit/s, 4GFSK, 25 kHz Filter Bandwidth

6.4.4 Spurious Response Rejection @19.2 kbit/s 4GFSK

Figure 16 shows the spurious response rejection performance for 19.2 kbit/s data rate with 25 kHz filter bandwidth for ±1 MHz offset in 25 kHz steps. Average performance from 3 samples is used. The limit is 60 dB for frequencies that are separated from the wanted signal by more than ±0.1% of the centre frequency (±869 kHz) and 35 dB closer to the carrier. CC1125 passes this requirement with good margin. Note that the image at -124 kHz offset is completely removed. This is done by the CC1125 modem autonomously without any need for calibration.

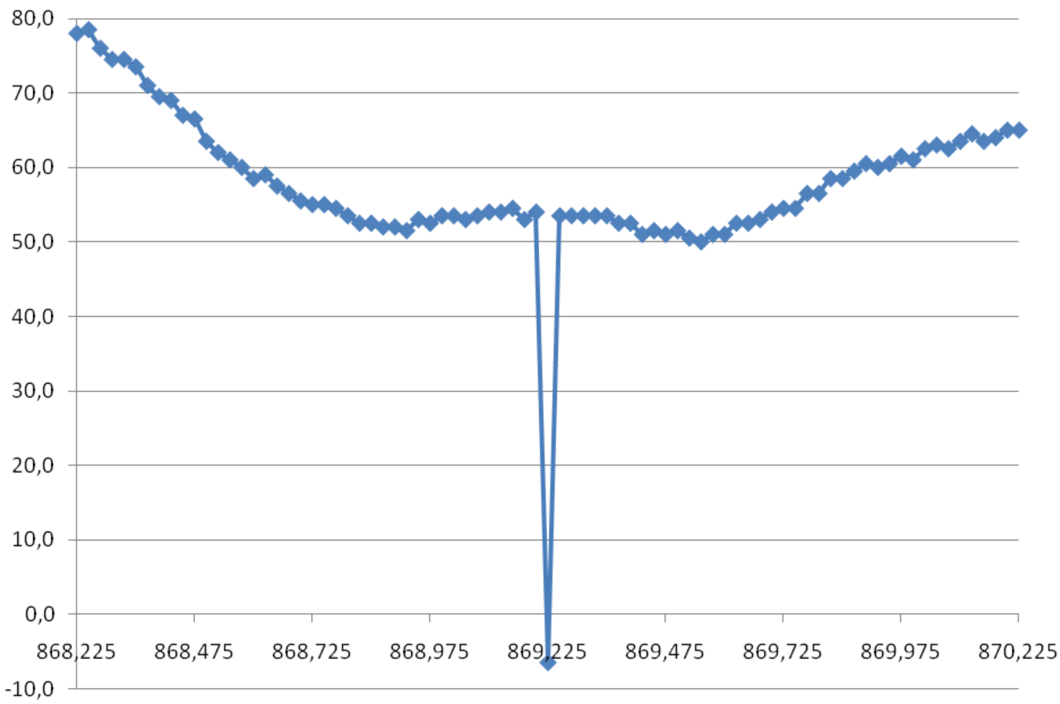


Figure 16. Spurious Response Rejection @19.2kbit/s, 25 kHz Filter Bandwidth

6.5 Measurement Equipment

The following equipment was used for the measurements.

Measurement	Instrument Type	Instrument Model
RX	Signal Generator	Rohde & Schwarz SMU
TX	Spectrum Analyzer	Rohde & Schwarz FSG
RX/TX	Power Supply	Agilent E3631A
	Multimeter	Keithley 2000

Table 13. Measurement Equipment

6.6 SmartRF Studio

The CC1125 can be configured using the SmartRF Studio 7 software [8]. The SmartRF Studio software is highly recommended for obtaining optimum register settings.

7 Current Consumption – Sniff Mode, Short Preambles

The CC1125 current consumption in continuous receive mode is 26 mA, but taking advantage of the CC1125 sniff mode feature the *average* current consumption can be reduced significantly without degrading RF performance.

7.1 Sniff Mode

Sniff mode is a feature that automatically duty cycles the receiver and quickly triggers on either RSSI (Received Signal Strength Indication) or preamble of the incoming signal. Triggering on preamble is the most robust method of detecting a valid incoming signal, but RSSI is faster and gives the lowest current consumption. *Sniff mode does not degrade the RF performance of the device – the same RF performance is achieved, but at a much lower average receiver current consumption.*

Sniff mode uses a feature in CC1125 called “Wavematch”, which utilizes the on-chip DSP circuitry to lock on to the incoming waveform. The advantage is much faster settling receiver and thereby lower current consumption.

See the Table 14 for current consumption estimates for various data rates and preamble lengths.

Data rate	Preamble bytes	Trigging on RSSI [mA]	Trigging on Preamble [mA]
1.2 kbit/s, GFSK	2	4.0	Not possible
	4	1.8	18.9
4.8 kbit/s, GFSK	4	9.6	Not possible
	8	4.0	10.0
9.6 kbit/s, GFSK	4	14.6	Not possible
	8	5.6	10.9
19.2 kbit/s, 4GFSK	4	14.6	Not possible
	8	5.6	10.9

Table 14. Average RX Current Consumption During Sniff Mode

7.2 TX Consumption, Short Preambles and “High” Data Rate

Alarm buttons and sensors with batteries need to have special focus on low power. Using CC1125, one can transmit with relatively high (for a 25 kHz channel) data rate and still comply with ETSI category 1 regulatory requirements. This will give significant improvements in power consumption. Using 9.6 kbit/s compared to 1.2 kbit/s gives 8 times less active TX time for the same packet length. This also makes it easier to buffer current in a capacitor when small coin cell batteries are used.

7.3 Trade-offs for Alarm Solutions

CC1125 can handle very low packet overhead in terms of number of preamble bytes, and also use sniff mode for very low average RX consumption. These two features can be combined in an alarm system for optimum power consumption.

In an alarm system the battery powered alarm button or sensor is the most power sensitive device. Very often the alarm panel (the central node in a star network) can, during normal operation, operate in continuous receive (powered by the mains). The best solution for low power is then to use short preambles and high data rate – for example 9.6 kbit/s with 1 byte of preamble. In the case of power failure for the alarm panel (with battery backup), one can switch to sniff mode and reduce the power consumption down to below 6 mA (average). The button then needs to send 8 bytes of preamble (this can be implemented in the retry function). With the above suggestion, one can extend the battery life on an alarm button and reduce the size of the backup battery in the alarm panel.

8 Reference Design

The CC1125DK [1] is designed and certified for category 1. The CC1125 evaluation module (EM) includes a narrowband 869 MHz SAW filter. The EM is also the reference design available from TI web [4] and includes schematic and gerber files. It is highly recommended to follow the reference design for optimum performance. The reference design also includes bill of materials with manufacturers and part numbers.

8.1 SAW Filter

A narrowband SAW is needed to comply with the blocking requirements. The SAW filter used in the reference design is a standard EPCOS filter (EPCOS B3749). Other SAW filters with a similar specification can be used.

9 References

[1] CC1125 Development Kit

[2] CC1125 Datasheet (SWRS120.pdf)

[3] CC112x User Guide (SWRU295.pdf)

[4] CC1125EM 868MHz ETSI Cat 1 Reference Design (SWRR097.zip)

[5] ETSI EN 300 220 V2.3.1: Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1000 MHz frequency range with power levels ranging up to 500 mW"

[6] CEPT/ERC/Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)"

[7] CC112X/CC1200 On-Chip Temperature Sensor (SWRA415)

[8] SmartRF™ Studio 7 (SWRC176.zip)

10 General Information

10.1 Document History

Revision	Date	Description/Changes
SWRA424	2013.03.21	Initial release

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