Using the CC1100/CC1150 in the European 433 and 868 MHz ISM bands

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Keywords

- *Modulation bandwidth*
- *Occupied bandwidth*
- *ETSI EN 300 220*
- *OOK/ASK*
- *GFSK*

1 Introduction

The CC1100 is a truly low-cost, highly integrated and very flexible RF transceiver. The CC1100 is primarily designed for use in low-power applications in the 315, 433, 868 and 915MHz ISM bands. The CC1150 is the transmitter version of the CC1100, and is also covered in this document.

This application note describes how to use the CC1100 and CC1150 in the European 433 and 868 MHz ISM bands and comply with relevant regulations.

The limiting factors caused by the ETSI regulations are discussed, and different sets of transmit data rate, output power and other transceiver parameters are given.

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2 Abbreviations

ASK	Amplitude Shift Keying (In this document the term ASK refers to a special ASK case, i.e. OOK with pulse shaping)
EM	Evaluation module
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
GFSK	Gaussian Frequency Shift Keying
ISM	Industrial, Scientific, Medical
MBW	Modulation Bandwidth
OBW	Occupied Bandwidth
OOK	On Off Keying
PLL	Phase Locked Loop
RBW	Resolution Bandwidth

3 Selection of operating frequency and crystal

The CC1100/CC1150 will, as any transceiver or transmitter using a frequency synthesizer with high resolution, show some variation in performance across the usable frequency range.

The CC1100/CC1150 does allow selection of virtually any channel/frequency within the 400 to 464 MHz and 800 to 928 MHz operating ranges, but some variations in TX spurious levels and RX sensitivity must be expected. Therefore it is necessary to select TX and RX frequencies with care to optimize performance.

Alternatively it is possible to use a different crystal than the 26 MHz crystal used on the CC1100EM/CC1150EM. When changing from 26 MHz to another crystal frequency within the 26 to 27 MHz range, spurious components generated by the CC1100/CC1150 will move along the frequency axis. Thus a specified channel/frequency will have slightly different performance for different crystal frequencies, i.e. selection of crystal frequency can be used as a tool to improve the CC1100/CC1150 performance for a given channel.

The channels suggested in this document are mainly based on usage of a 26 MHz crystal frequency. When selecting other crystal frequencies it is necessary to ensure TX and RX performance for the selected channels. This is required to ensure compliance with regulations, and confirm performance in line with specifications.

4 Limiting factors towards regulatory requirements

4.1 Spurious emissions

Regulatory limits specify the allowed RF level of spurious emissions (spurs) produced by a transmitter or receiver. The spurs are defined as frequency components outside the intended operating range.

In short the applicable TX limits are -36 and -54dBm in the European ISM bands. The spur level is measured with the transmitter outputting an unmodulated carrier (if possible). The resolution bandwidth (RBW) used on the spectrum analyzer is 100 kHz for frequencies below 1 GHz, and 1 MHz for frequencies above 1 GHz.

For the specific details on spurious limits and measurement methods, please refer to the ETSI EN 300 220 standard.

4.2 Phase noise

The phase noise produced by the transceiver will in some cases be a limiting factor for the transmitted output power, even if there is no specific regulatory limit to phase noise. If a transmitter is operating close to the frequency band edge, or in a narrow frequency band, the power level measured at the band edge will to some degree be determined by the transmitter phase noise.

In a sufficiently wide band this is simply solved by selecting frequencies away from the band edges. In a narrow frequency band, it may however be necessary to transmit with an output power below the maximum limit to comply with the regulatory limits.

4.3 Occupied bandwidth and modulation bandwidth

The occupied bandwidth or modulation bandwidth is to a certain degree a function of the phase noise.

In Europe ETSI EN 300 220 specifies a limit for modulation bandwidth (MBW). Note that the ETSI requirement is ambiguous as it specifies the measurement to be done with “wide enough” resolution bandwidth (RBW) on the spectrum analyzer. And the used RBW has a strong impact on the measured MBW. There are indications that this requirement will be relaxed and more clearly defined in the new version of EN 300 220 that is expected early 2006.

The conducted MBW measurements presented in this document are carried out using an R&S FSIQ7 spectrum analyzer, with the RBW mainly set to 3 kHz. The spectrum analyzer is set to maximum hold mode as specified in ETSI EN 300 220. The transmitter is modulated with a PN sequence.

As mentioned above the ETSI EN 300 220 standard does not specify the exact RBW to be used when performing the MBW measurement. The exact term given in the standard is “The test laboratory shall ensure that the spectrum analyser’s span and bandwidth is sufficiently wide enough and scan time slow enough, to ensure that the emission and all its major modulation side bands are captured”.

Outside the modulated spectrum the power level measured by such a MBW measurement will scale with the spectrum analyzer‘s RBW. This is the case since a spectrum analyzer will receive a higher amount of random noise when measuring in a larger bandwidth, and thus accumulate a higher power level due to the maximum hold detection. The definition within the standard indicates that the RBW should be decreased as much as possible while still retaining the level of the modulated signal and modulation sidebands. As mentioned above using a 3 kHz RBW should be sufficient for measuring the modulation bandwidth.

4.4 Other considerations

The results presented in this document are based on conducted measurements performed on CC1100EM modules that are tuned to zero frequency offset.

Using conducted measurements will in some cases give results that can be seen as conservative. For instance does a typical CC1100 application use antennas with less than 0dBi gain, e.g. PCB antennas. In this case the output power from the CC1100 can be increased when doing radiated measurements, while still meeting the regulatory limits due to the antenna losses.

For a practical application it is necessary to include the expected frequency drift of the transmitter, i.e. the crystal tolerances. The measurements presented in this document are given for 0 crystal offset.

5 Suggested settings

In this section settings related to different sets of radio parameters are presented. These settings are included to show examples of settings that meet the relevant regulatory limits in the different frequency bands. Different modulation methods, data rates and output powers are used. For all measurements the CC1100EM and CC1150EM reference designs are used.

In general the lowest MBW is achieved with GFSK modulation for data rates below 100 kbps. The settings given in the tables in this chapter are therefore mainly GFSK instead of other frequency- or phase modulation formats.

For the exact regulatory limits in the 433/868 MHz ISM bands, please refer to the ETSI EN 300 220 standard and ERC recommendation 70-03. These can be downloaded from www.etsi.org and www.ero.dk .

In addition to the tables containing suggested frequencies and settings, several spectrum plots are shown. The spectrum plots are measured according to the ETSI EN 300 220 requirements for modulation bandwidth and show compliance with the regulations.

5.1 European 433 MHz band

In Europe the CC1100/CC1150 can be used in the 433.050-434.790 MHz ISM band. This band is 1.74 MHz wide, and the main limitation will be spurious emissions. In addition it is necessary with a certain distance between the selected channel and the band edges to meet the power limit at the band edge. Below are Chipcon's recommended settings for use of CC1100/CC1150 in the European 433 MHz ISM band. All measurements are performed conducted, and thus an antenna with loss will allow higher output power.

Frequency band [MHz]	Carrier Frequency [MHz] [1]	Modulation format [2]	Data Rate [kbps]	Output Power [dBm] [3]	Modulation Bandwidth [kHz]
433.050-434.790	433.75-434.3	GFSK	1.2	10	600 [4]
	433.75-434.3	GFSK	10	10	600
	433.75-434.3	GFSK	38.4	10	600
	433.75-434.3	GFSK	100	10	600
	433.75-434.3	ASK	1.2	0	100
	433.75-434.3	ASK	10	0	200
	433.75-434.3	ASK	38.4	0	150
	433.92	GFSK	250	10	1000
	433.92	FSK	250	10	1300
	433.92	OOK	38.4	10	1000
	433.92	ASK	1.2	0	100
	433.92	ASK	10	0	200
	433.92	ASK	38.4	0	150
	433.92	ASK	76.8	0	250
	433.92	ASK	100	0	300

Table 1: Suggested radio parameters for use in the European 433.05-434.79 MHz band.

The 433.05 - 434.79 MHz band allows an output power of 10dBm (10mW). CC1100/CC1150 are able to transmit with 10dBm in this band, while meeting regulatory limits to spurious emissions, power level at band edge and modulation bandwidth. As shown in Table 1 GFSK modulation is more bandwidth efficient than FSK modulation.

[1] Frequencies in the range 433.75-434.3 MHz are suggested. The widely used 433.92 MHz frequency is included as a specific example. (If possible avoiding the 433.92 MHz channel can be advantageous due to interference).

[2] GFSK modulation is recommended for best bandwidth efficiency at low data rates.
ASK is in this document referred to the special ASK case of OOK with pulse shaping. This is the ASK form supported by CC1100/CC1150, using the on-chip shaping features. On CC1100/CC1150 the maximum output power with ASK modulation (shaping) is 0 dBm. The shaping sequence used for optimal ASK shaping is 00 32 34 36 38 3A 3C 3F.
For higher output powers the shaping is turned off (OOK modulation) and hence the MBW will increase. OOK is pure un-shaped on-off-keying.

[3] GFSK and OOK can be used with the maximum allowed output power offered by the CC1100/CC1150 within the stated band. When using ASK the output power must be 0 dBm or lower to retain the spectral efficiency offered by the shaping feature of the CC1100/CC1150.

[4] For data rates below 100 kbps the MBW is to a large degree decided by phase noise, and thus it is not reduced for lower data rates. MBW is measured with a 10 kHz RBW.

The ASK option is limited to 0dBm due to technical limitations in the CC1100/CC1150, but pure OOK can be used with 10dBm output power while still having margin to regulatory limits. If the spectral efficiency of ASK modulation is required, it is possible to use the CC1100/CC1150 with 0dBm output power and increase the transmitted power to 10dBm using external amplification.

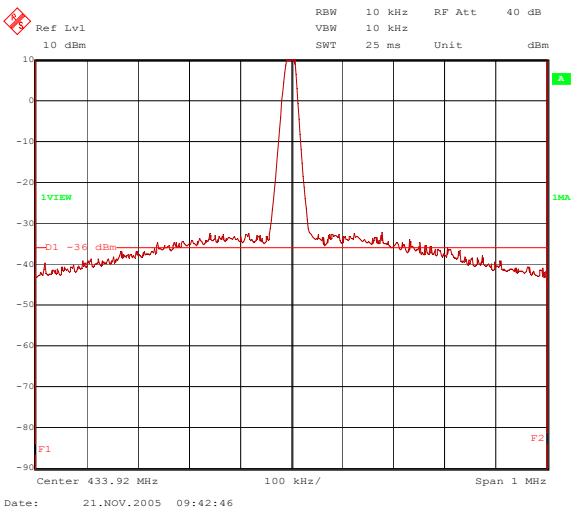

Figure 1 : Transmitted spectrum, 433.92 MHz, GFSK, 1.2 kbps, 5.2 kHz deviation, 10dBm.

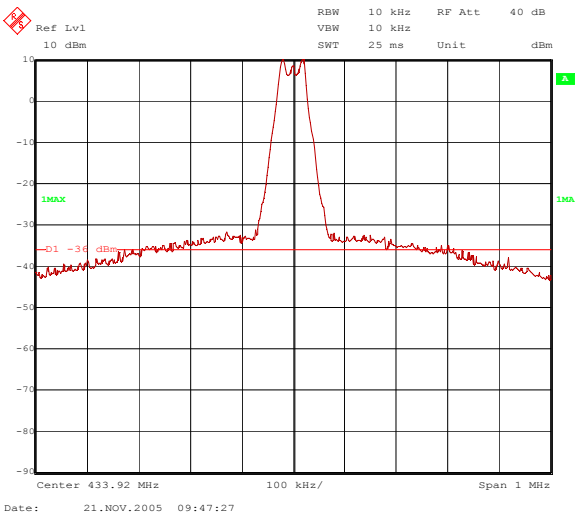

Figure 2 : Transmitted spectrum, 433.92 MHz, GFSK, 38.4 kbps, 20 kHz deviation, 10dBm.

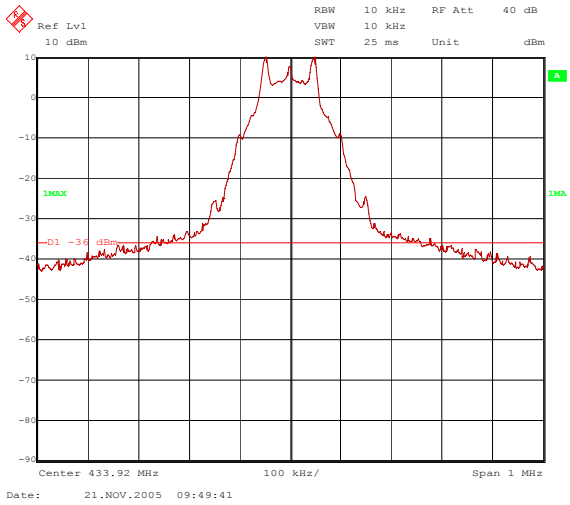

Figure 3 : Transmitted spectrum, 433.92 MHz, GFSK, 100kbps, 47 kHz deviation, 10dBm.

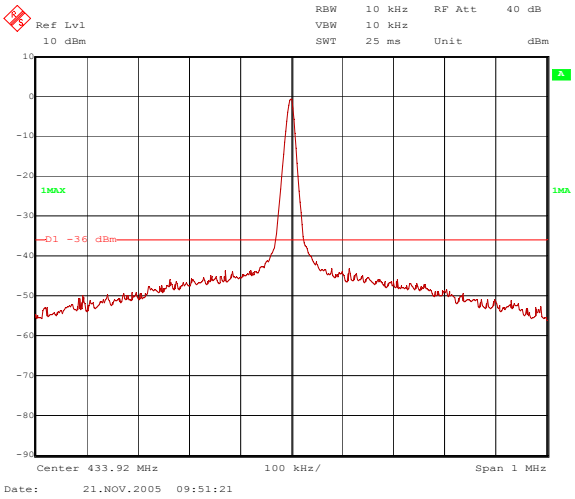

Figure 4 : Transmitted spectrum, 433.92 MHz, ASK, 1.2 kbps, 0dBm.

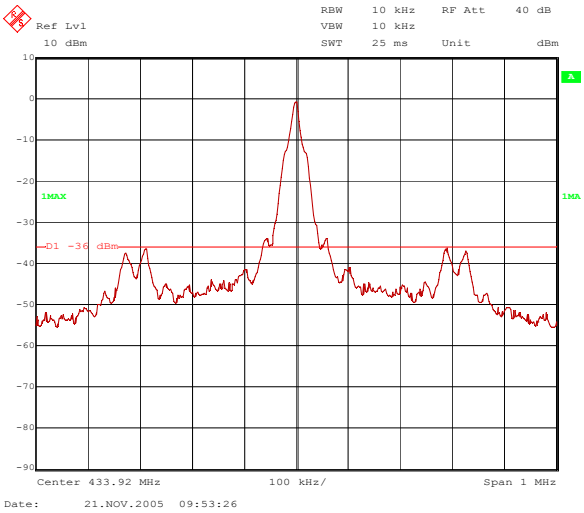

Figure 5 : Transmitted spectrum, 433.92 MHz, ASK, 38.4 kbps, 0dBm.

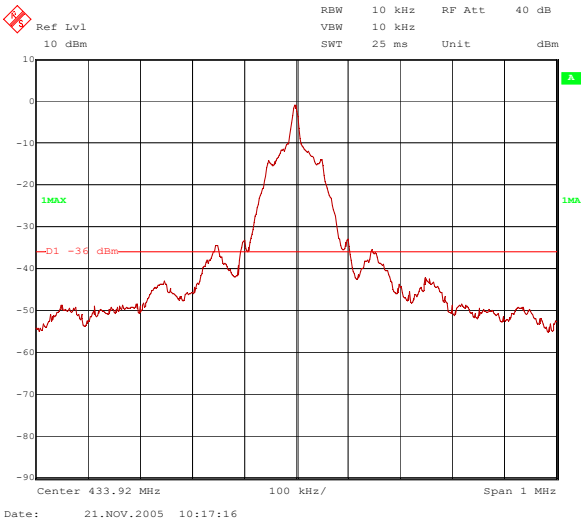

Figure 6 : Transmitted spectrum, 433.92 MHz, ASK, 100 kbps, 0dBm.

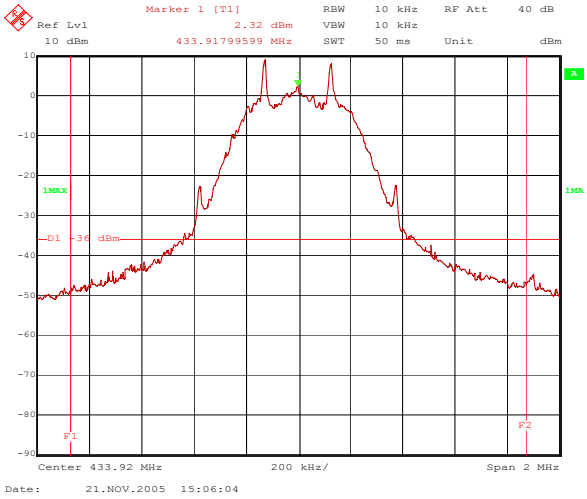

Figure 7 : Transmitted spectrum, 433.92 MHz, GFSK, 250 kbps, 127 kHz deviation, 10dBm.

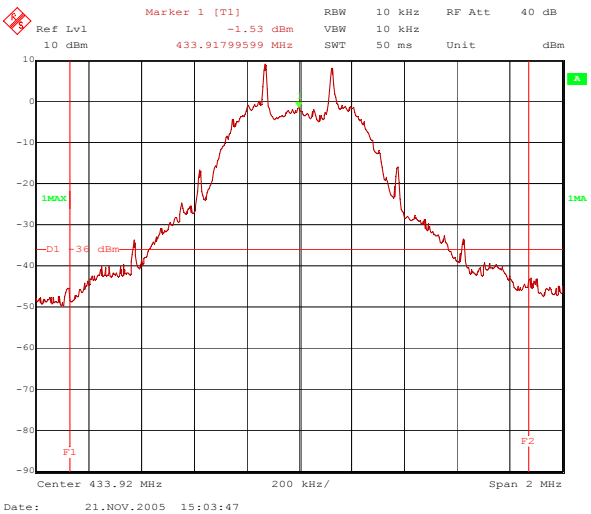

Figure 8 : Transmitted spectrum, 433.92 MHz, FSK, 250 kbps, 127 kHz deviation, 10dBm.

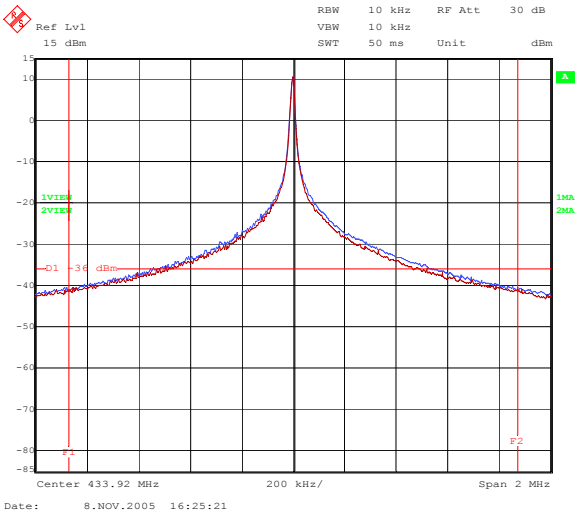

Figure 9 : Transmitted spectrum, 433.92 MHz, OOK, 1.2 kbps (red), 10 kbps (blue), 10dBm.

5.2 European 868MHz band

In Europe the 868 MHz ISM band is divided into several sub-bands. Since these sub-bands are relatively narrow the MBW requirement of EN 300 220 will to some extent limit the possible data rates, modulation formats and output powers.

The sub-bands covered in this document are the 868.0-868.6 MHz, 868.7-869.2 MHz and 869.7-870.0 MHz sub-bands. The CC1100EM and CC1150EM reference designs are used for the measurements. Chipcon's recommended settings for use in the different bands are given below. All measurements are performed conducted, and thus an antenna with loss will allow higher output power.

Frequency band [MHz]	Carrier Frequency [MHz]	Modulation format [5]	Data Rate [kbps]	Output Power [dBm] [6]	Modulation Bandwidth [kHz]
868-868.6	868.3	GFSK	1.2	7	600 [7]
		GFSK	2.4	7	600
		GFSK	10	7	600
		GFSK	38.4	7	600
		ASK	1.2	0	100
		ASK	2.4	0	100
		ASK	10	0	200
		ASK	38.4	0	150

Table 2: Suggested radio parameters for use in the European 868-868.6 MHz band.

The 868-868.6 MHz band specifies a maximum output power of 25mW (14dBm). CC1100/CC1150 are capable of transmitting 10dBm, but a 3dBm back-off is necessary to meet regulatory limits to spurious emissions and modulation bandwidth.

Frequency band [MHz]	Carrier Frequency [MHz]	Modulation format [5]	Data Rate [kbps]	Output Power [dBm] [6]	Modulation Bandwidth [kHz]
868.7-869.2	868.95	GFSK	1.2	7	500 [7]
		GFSK	2.4	7	500
		GFSK	10	7	500
		GFSK	38.4	7	500
		ASK	1.2	0	100
		ASK	2.4	0	100
		ASK	10	0	200
		ASK	38.4	0	150

Table 3: Suggested radio parameters for use in the European 868.7-869.2 MHz band.

The maximum allowed output power in the 868.7-869.2 MHz is 25mW (14dBm). CC1100/CC1150 are capable of transmitting 10dBm, but it is necessary to use a 3dBm back-off to meet regulatory limits to modulation bandwidth.
The measurements conducted for the 868.7-869.2 MHz band are performed with a 27MHz crystal.

Frequency band [MHz]	Carrier Frequency [MHz]	Modulation format [5]	Data Rate [kbps]	Output Power [dBm] [6]	Modulation Bandwidth [kHz]
869.7-870	869.85	GFSK	1.2	6	300 [7]
		GFSK	2.4	6	300
		GFSK	10	6	300
		GFSK	38.4	6	300
		ASK/OOK	1.2	0	100
		ASK/OOK	2.4	0	100
		ASK/OOK	10	0	200
		ASK/OOK	38.4	0	150

Table 4: Suggested set of radio parameters for use in the European 868MHz band.

The 869.7-870 MHz frequency band specifies a maximum output power of 5mW (7dBm). CC1100/CC1150 are capable of transmitting the maximum 7 dBm, but due to spurious emissions a small back-off is necessary to meet the MBW regulatory limits.
Note that the 869.7-870.0 MHz sub-band is not affected by duty cycle limitations; see ERC Recommendation 70-03 for details.

[5] GFSK modulation is recommended for best bandwidth efficiency at low data rates.
ASK is in this document referred to the special ASK case of OOK with pulse shaping. This is the ASK form supported by CC1100/CC1150, using the on-chip shaping features. On CC1100/CC1150 the maximum output power with ASK modulation (shaping) is 0 dB. For higher output power the shaping is turned off (OOK modulation) and hence the MBW will increase.
OOK is pure un-shaped on-off-keying.

[6] When using GFSK in the mentioned band, the output power is backed off from the maximum allowed limits of 14dBm (868-868.6 and 868.7-869.2 MHz) or 7dBm (869.7-870).
For ASK modulation the max output power is limited by the shaping feature on the CC1100/CC1150, which supports output powers up to 0dBm. The shaping sequence used in our measurements is 00 32 34 36 38 3A 3C 3F. When using on-chip ASK shaping is possible to increase the output power with external amplification to an output power giving max allowed MBW.

[7] For data rates below 38.4 kbps the MBW is to a large degree decided by phase noise, and thus it is not reduced for lower data rates.

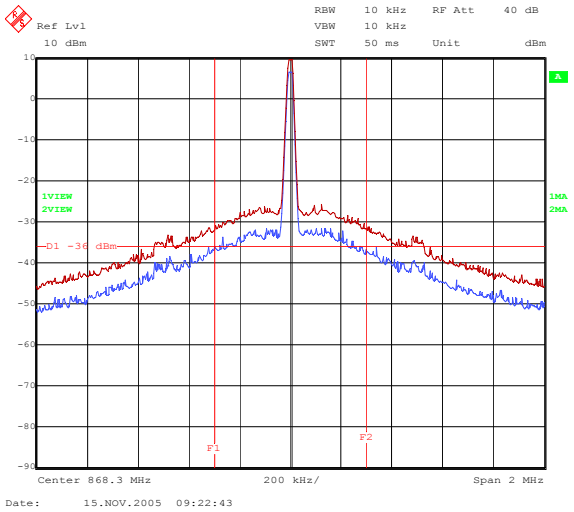

Figure 10 : Transmitted spectrum, 868.3 MHz, GFSK, 1.2 kbps, 5.2 kHz deviation, 10dBm (red), 7 dBm (blue).

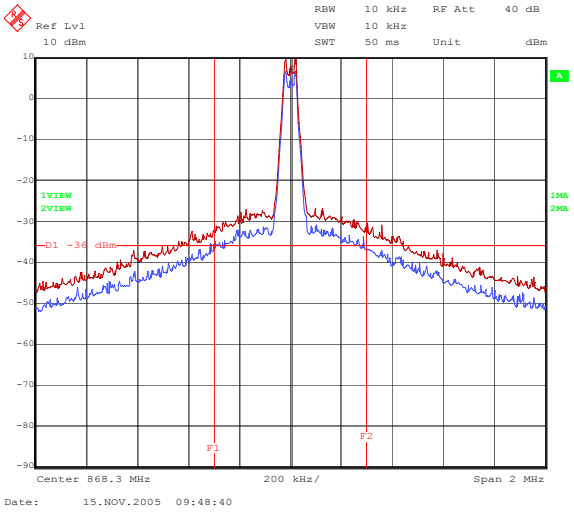

Figure 11 : Transmitted spectrum, 868.3 MHz, GFSK, 38.4 kbps, 20 kHz deviation, 10dBm (red), 7 dBm (blue).

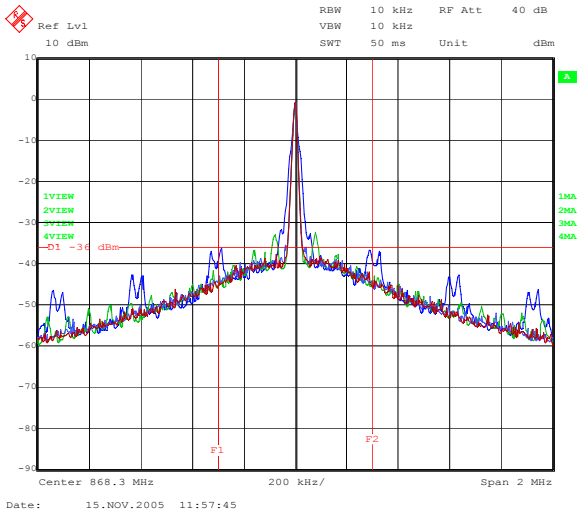

Figure 12 : Transmitted spectrum, 868.3 MHz, ASK, 0dBm
1.2 kbps (red), 2.4 kbps (light blue), 10 kbps (green), 38.4 kbps (dark blue)

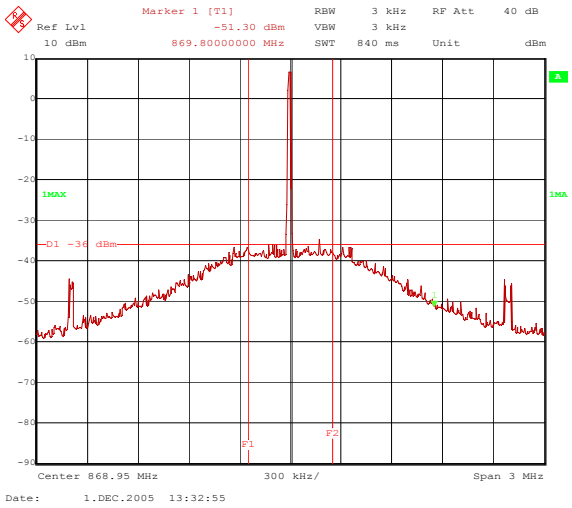

Figure 13 : Transmitted spectrum, 868.95 MHz, GFSK, 1.2 kbps, 5.2 kHz deviation, 7dBm. (27MHz crystal used)

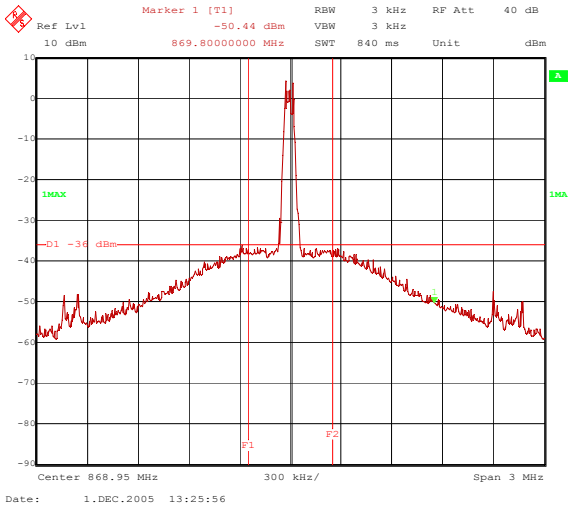

Figure 14 : Transmitted spectrum, 868.95 MHz, GFSK, 38.4 kbps, 20 kHz deviation, 7dBm. (27MHz crystal used)

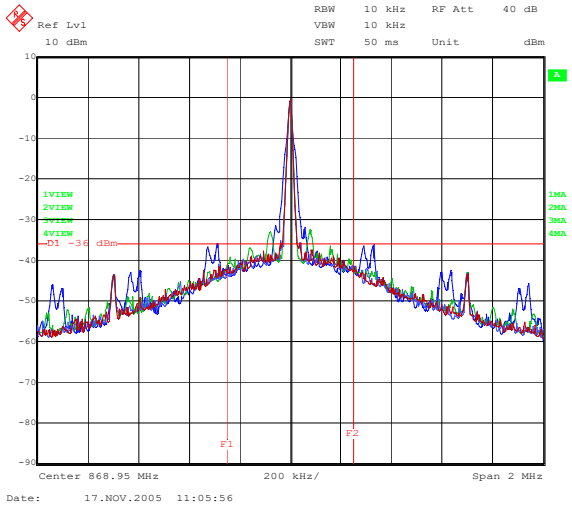

Figure 15 : Transmitted spectrum, 868.95 MHz, ASK, 0 dBm.
1.2 kbps (red), 2.4 kbps (light blue), 10 kbps (green), 38.4 kbps (dark blue)

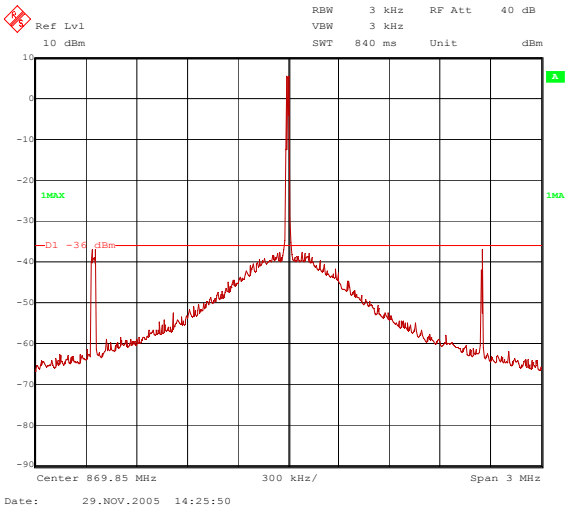

Figure 16 : Transmitted spectrum, 869.85 MHz, GFSK, 1.2 kbps, 5.2 kHz deviation, 7dBm.

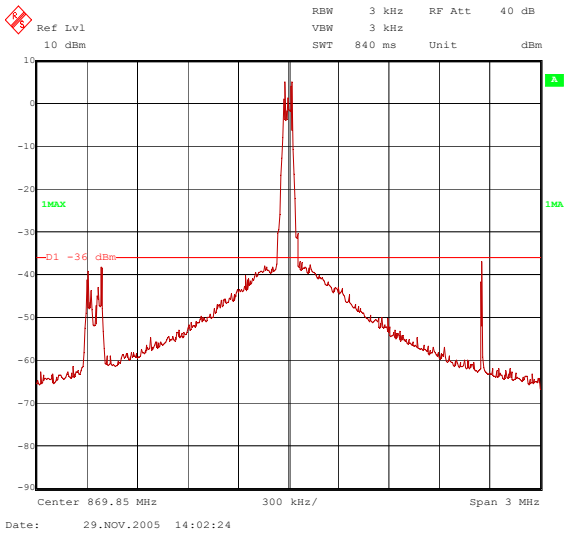

Figure 17 : Transmitted spectrum, 869.85 MHz, GFSK, 38.4 kbps, 20 kHz deviation, 7dBm.

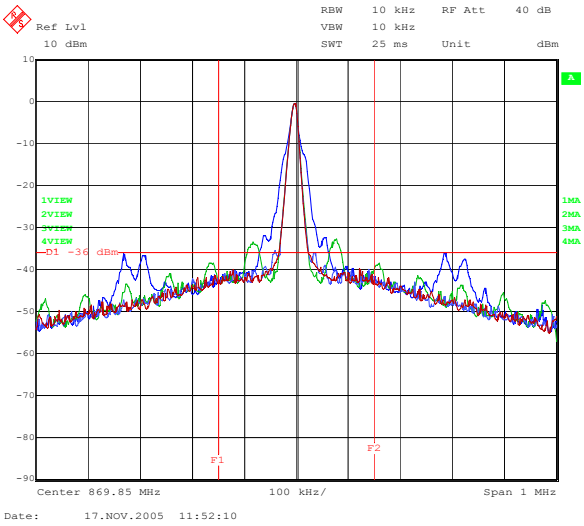

Figure 18 : Transmitted spectrum, 869.85 MHz, ASK, 0dBm.
1.2 kbps (red), 2.4 kbps (light blue), 10kbps (green), 38.4 kbps (dark blue)

6 Conclusions

The CC1100 and CC1150 are suitable for use in the European 433 MHz and 868 MHz ISM bands under the provisions of ETSI EN 300 220. This application note focuses on use in the 433.05-434.79 MHz ISM band, and the following sub-bands within the 868-870 MHz ISM band; 868-868.6 MHz, 868.7-869.2 MHz and 869.7-870 MHz.

This document suggests a set of channels and corresponding radio parameters to be used with the CC1100/CC1150 in the mentioned bands, while meeting all regulatory limits. The measurements are performed using the CC1100EM and CC1150EM reference designs. The document does also discuss the regulatory limitations, and considerations to be made when selecting operating frequency and crystal frequency.

7 General Information

7.1 Document History

Revision	Date	Description/Changes
1.0	2005-12-22	Initial release.

7.2 Disclaimer

Chipcon AS believes that the information contained in this Application Note is correct and accurate at the time of this printing. However, this Application Note may contain inaccuracies, typographical errors or other mistakes, and Chipcon assumes no liability as a result of any such error.

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