CC11xx Sensitivity Versus Frequency Offset and Crystal Accuracy

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ABSTRACT

This design note provides plots of CC11xx (CC1100, CC1100E, CC1101, CC1110, and CC1111) sensitivity versus frequency offset for different data rates. The required crystal accuracy is calculated from these plots. The results are also applicable for CC430.

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Trademarks

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1 Abbreviations

FSK	Frequency shift keying
IF	Intermediate frequency
MSK	Minimum shift keying
PER	Packet error rate
PLL	Phase locked loop
ppm	parts per million
SoC	System-on-chip

2 Receiver Channel Filter Bandwidth and Crystal Inaccuracies

A phase locked loop (PLL) is used to generate the RF frequency in the CC1100, CC1101, and CC1100E transceivers and the CC1110, CC1111, and CC430 SoCs. The PLL reference frequency is derived from an external crystal. If the crystal frequency is incorrect, the transmitter carrier frequency and the receiver LO frequency will also be incorrect. The crystal frequency error is due to initial tolerance, capacitive loading errors, ageing, and temperature drift.

Example: If the crystal frequency has an error of ±X ppm (parts per million) the RF frequency also has an error of ±X ppm. As an example, if the crystal error is +10 ppm and the CC11xx is programmed for a carrier frequency of 868 MHz, there will be an error in the carrier frequency of 868 MHz×10/1E^6 = 8.68 kHz.

The transmitted signal will have a certain signal bandwidth (BW_{signal}), which depends on the data rate and modulation format. On the receiver side there is a channel filter, which is centered on the down-converted received RF frequency; that is, the intermediate frequency (IF). The channel filter has a programmable bandwidth $BW_{channel}$. The signal bandwidth has to be less than the receiver channel filter bandwidth, but we also have to take the frequency error of the transmitter and receiver into account.

If there is an error in the transmitter carrier frequency and the receiver LO frequency, there will also be an error in the IF frequency. For simplicity assume the frequency error in the transmitter and receiver is equal (same type of crystal). If the receiver has an error of –X ppm and the transmitter has an error of +X ppm the IF frequency will have an error of +2 × X ppm (CC11xx uses low side LO injection). Conversely, if the receiver has an error of +X ppm and the transmitter an error of –X ppm the IF frequency will have an error of –2 × X ppm.

Example: If the transmitter crystal error is +10 ppm and the CC11xx is programmed for a carrier frequency of 868 MHz, there will be an error in the carrier frequency of 8.68 kHz. If the receiver crystal error is -10 ppm and the CC11xx is programmed for an LO frequency of 867.7 MHz (300-kHz IF frequency) there will be an error in the LO frequency of –8.677 kHz (approximately the same as the error in the carrier frequency due to the low IF frequency used). The total error in the IF frequency, after down conversion from RF, will be 2 × 8.68 kHz = 17.4 kHz.

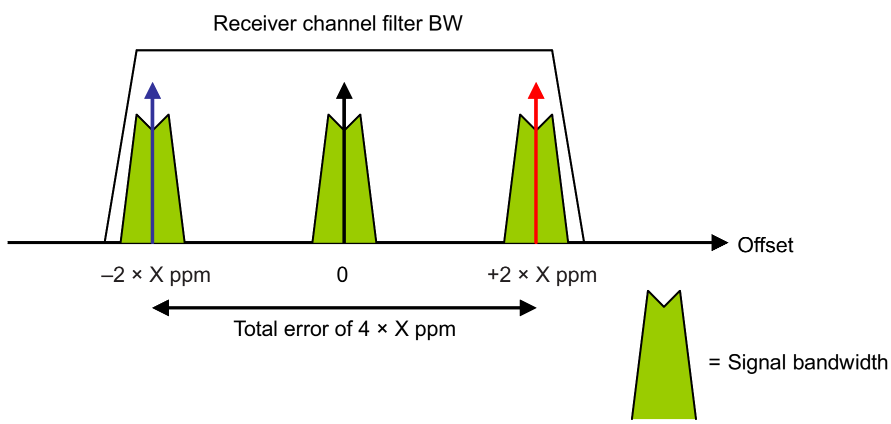

Figure 1. Plot of IF Versus Frequency Error

Figure 1 shows the required minimum channel filter bandwidth $BW_{channel}$ to account for crystal errors of opposite signs, which is a worst case scenario. $BW_{channel}$ has to be larger than the maximum signal bandwidth BW_{signal} plus the maximum frequency error due to crystal inaccuracies.

$$BW_{channel} > BW_{signal} + 4 \times XTAL_{ppm} \times f_{RF} \quad (1)$$

where

- $XTAL_{ppm}$ is the total accuracy of the crystal including initial tolerance, temperature drift, loading, and aging.
- f_{RF} is the RF operating frequency.

Example: If both the transmitter and receiver crystal accuracy is ±10 ppm and the CC11xx is programmed for a carrier frequency of 868 MHz with an IF frequency of 300 kHz, $BW_{channel}$ must be larger than $BW_{signal} + 4 \times XTAL_{ppm} \times f_{RF} = BW_{signal} + 4 \times 8.68$ kHz.

3 PER Versus Frequency Offset

Figure 6 to Figure 12 plot the 1% PER for different data rates and modulation formats. Register FOCCFG.FOC_LIMIT[1:0] = 11_b and the RF frequency is 868 MHz in the measurements. Because the signal bandwidth is given, the plots can be used to estimate the maximum frequency offset and hence the required crystal accuracy.

Assuming a 3-dB loss in sensitivity is acceptable, the total frequency offset is estimated as 2 times the frequency offset where a 3-dB degradation in PER is first measured (see Figure 2). In the ideal case the 3-dB degradation in PER should occur at the same positive and negative frequency offsets (see Figure 3). Because the IF frequency is programmed in steps of 25 kHz, this is not always possible.

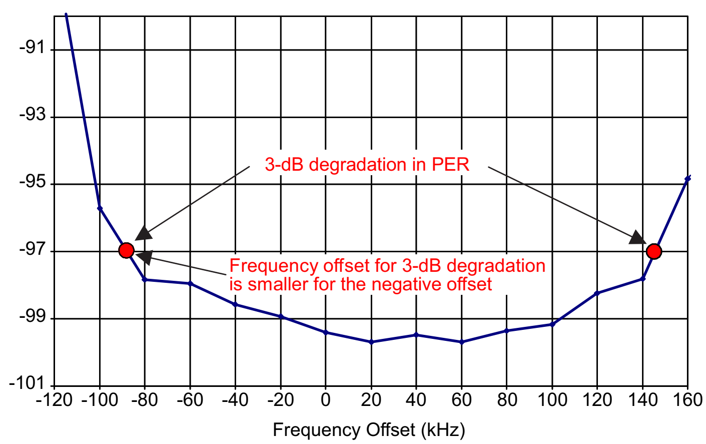

Figure 2. Definition of Frequency Offset That Gives 3-dB Degradation on PER (Unsymmetrical Frequency Offset)

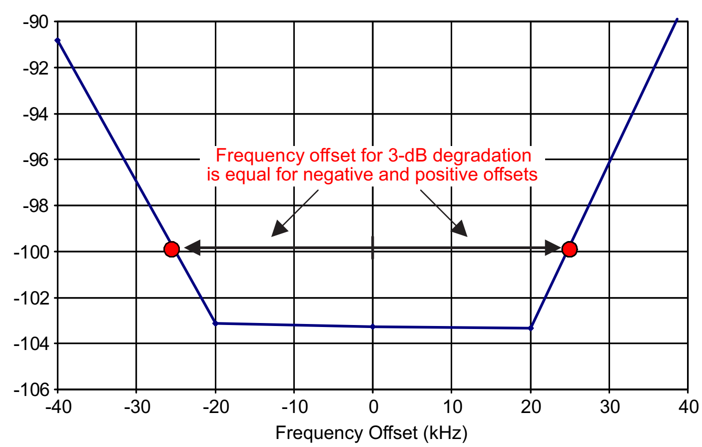

Figure 3. Definition of Frequency Offset That Gives 3-dB Degradation on PER (Symmetrical Frequency Offset)

4 Crystal Accuracy

Section 5 shows plots of sensitivity versus frequency offset for different data rates. The required crystal accuracy is calculated from the total frequency offset as

$$\text{Total frequency offset} = 4 \times XTAL_{ppm} \times f_{RF} \quad (2)$$

$$\text{Crystal accuracy (in ppm)} = \text{Total frequency offset} \times 1E^{6} / (4 \times f_{RF}) \quad (3)$$

Table 1. Crystal Accuracy Requirement for Selected Data Rates and Modulation Formats With FOCCFG.FOC_LIMIT[1:0] = 11_b

Case	Figure	3-dB Bandwidth (Total Frequency Offset)	Crystal Accuracy (868 MHz)
4.8 kbps, 2FSK, 25 kHz deviation, DC filter, RX filter bandwidth = 101 kHz	Figure 4	50 kHz	±14 ppm
4.8 kbps, 2FSK, 25 kHz deviation, no DC filter, RX filter bandwidth = 101 kHz	Figure 5	50 kHz	±14 ppm
10 kbps, 2FSK, 19 kHz deviation, DC filter, RX filter bandwidth = 101 kHz	Figure 6	70 kHz	±20 ppm
10 kbps, 2FSK, 19 kHz deviation, no DC filter, RX filter bandwidth = 101 kHz	Figure 7	70 kHz	±20 ppm
38.4 kbps, 2FSK, 20 kHz deviation, DC filter, RX filter bandwidth = 101 kHz	Figure 8	110 kHz	±32 ppm
38.4 kbps, 2FSK, 20 kHz deviation, no DC filter, RX filter bandwidth = 101 kHz	Figure 9	120 kHz	±35 ppm
76.8 kbps, 2FSK, 32 kHz deviation, DC filter, RX filter bandwidth = 232 kHz	–	230 kHz	±66 ppm
76.8 kbps, 2FSK, 32 kHz deviation, no DC filter, RX filter bandwidth = 232 kHz	–	260 kHz	±75 ppm
100 kbps, 2FSK, 47 kHz deviation, DC filter, RX filter bandwidth = 325 kHz	–	220 kHz	±63 ppm
100 kbps, 2FSK, 47 kHz deviation, no DC filter, RX filter bandwidth = 325 kHz	–	180 kHz	±52 ppm
250 kbps, MSK, DC filter, RX filter bandwidth = 541 kHz	Figure 10	200 kHz	±58 ppm
250 kbps, MSK, no DC filter, RX filter bandwidth = 541 kHz	Figure 11	220 kHz	±63 ppm
500 kbps, MSK, DC filter, RX filter bandwidth = 812 kHz	Figure 12	120 kHz	±35 ppm

NOTE: The ADC spectrum in the RX chain consists of a significant DC component. This puts a lower limit on the IF frequency that can be used. For optimum sensitivity, a digital DC filter can be enabled (MDMCFG2.DEM_DCFILT_OFF =0), and the ADC DC output is attenuated. This opens for selection of lower IF frequencies thereby lower noise floor and improved sensitivity. As an example, for 868 MHz, 250 kbps 2-FSK, enabling the DC filter gives 2 dB better sensitivity, at the expense of an increased current consumption of 2.3 mA.

5 Sensitivity Versus Frequency Offset

5.1 4.8 kbps

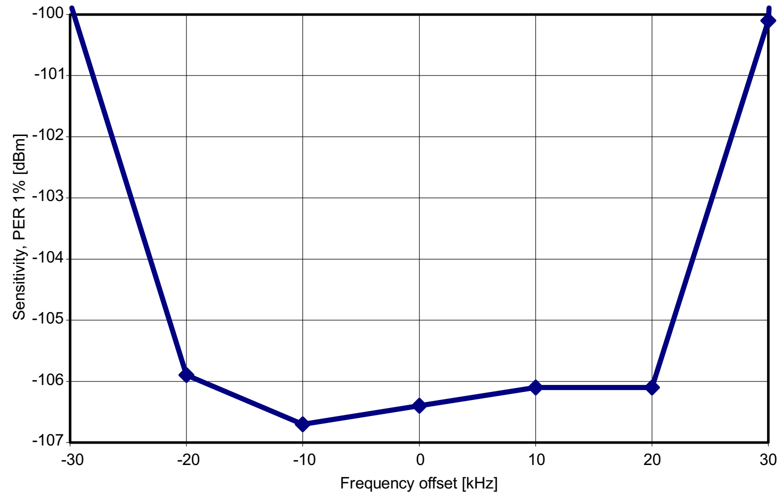

Figure 4. 4.8 kbps, MDMCFG2.DEM_DCFILT_OFF = 0

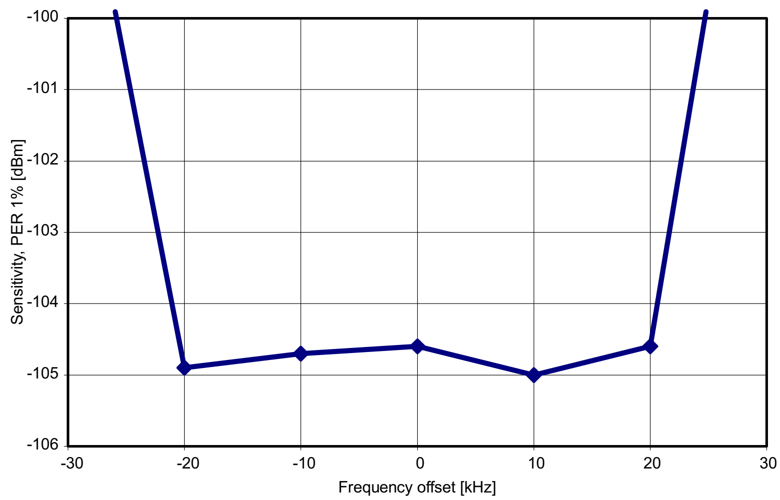

Figure 5. 4.8 kbps, MDMCFG2.DEM_DCFILT_OFF = 1

5.2 10 kbps

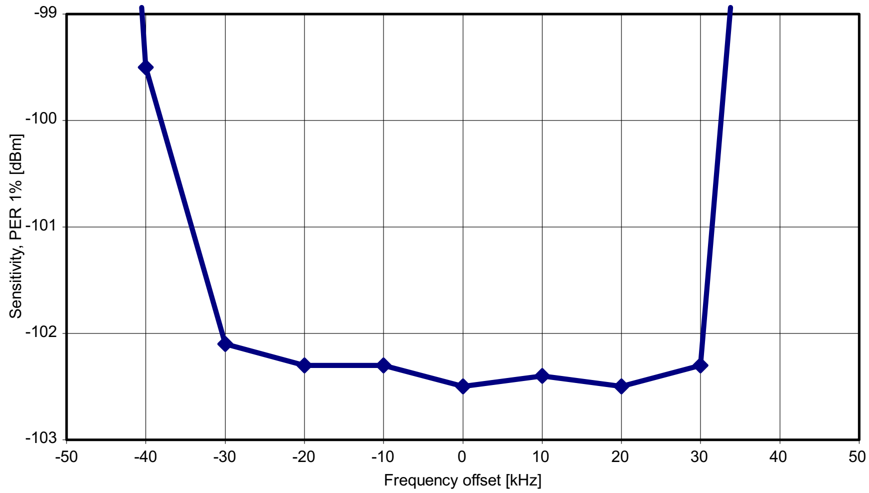

Figure 6. 10 kbps, MDMCFG2.DEM_DCFILT_OFF = 0

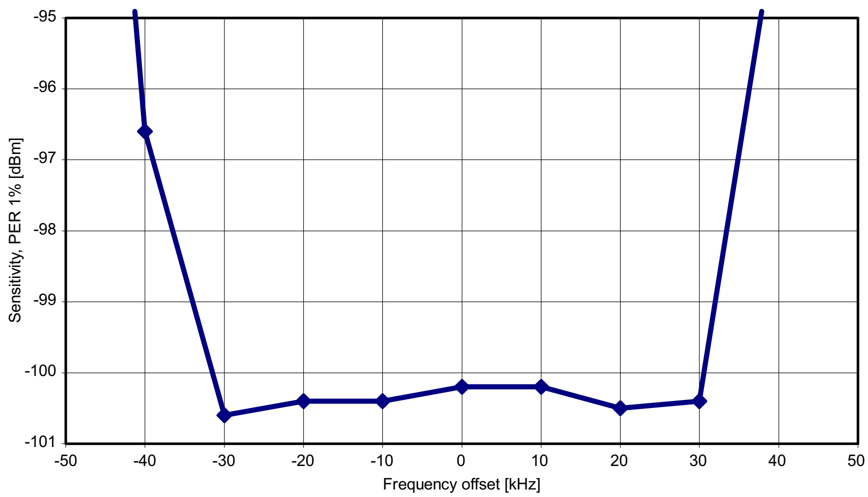

Figure 7. 10 kbps, MDMCFG2.DEM_DCFILT_OFF = 1

5.3 38.4 kbps

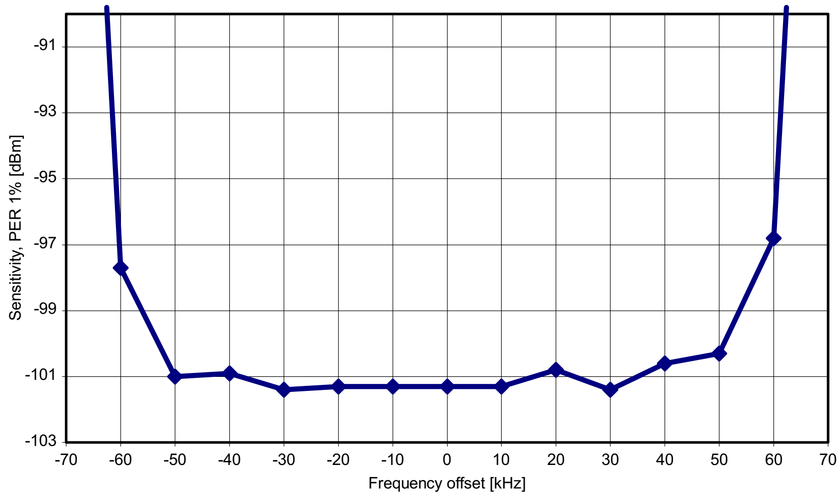

Figure 8. 38.4 kbps, MDMCFG2.DEM_DCFILT_OFF = 0

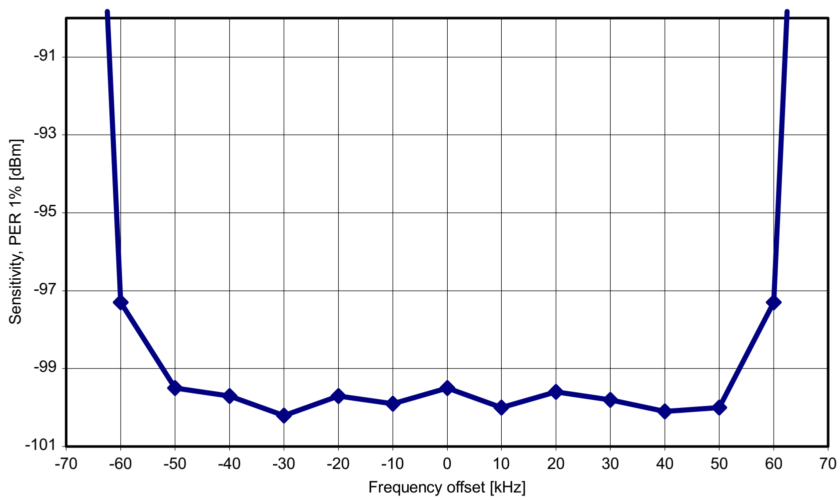

Figure 9. 38.4 kbps, MDMCFG2.DEM_DCFILT_OFF = 1

5.4 250 kbps

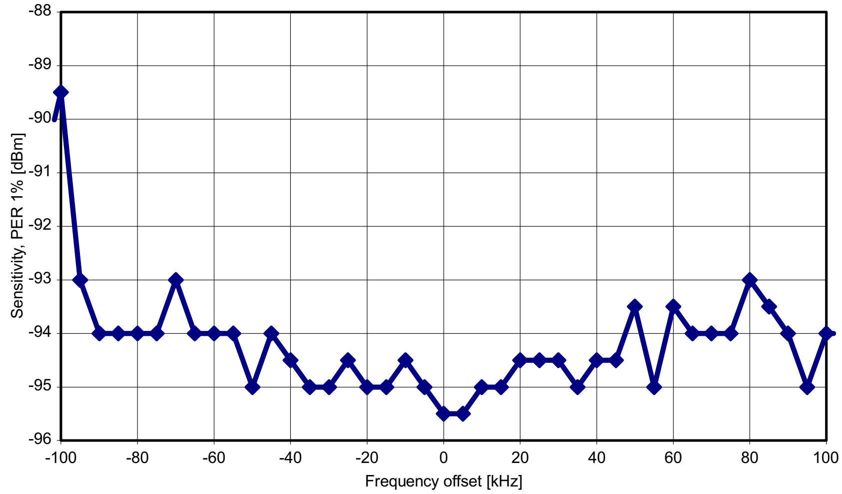

Figure 10. 250 kbps, MDMCFG2.DEM_DCFILT_OFF = 0

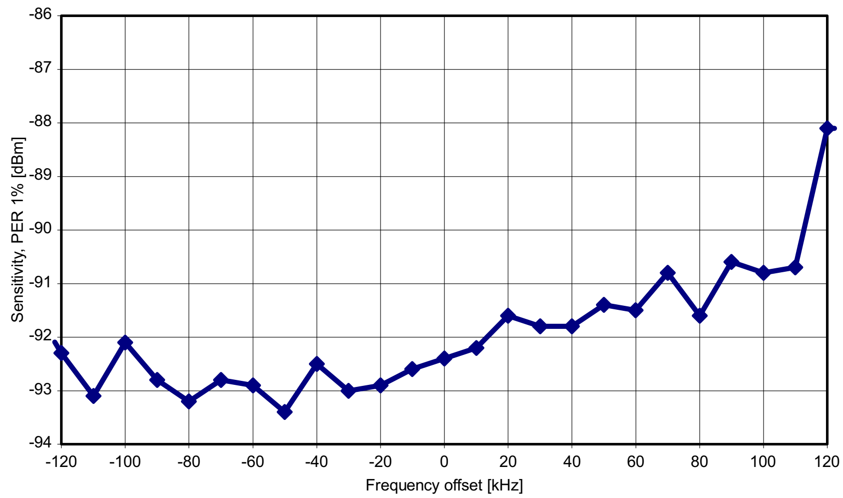

Figure 11. 250 kbps, MDMCFG2.DEM_DCFILT_OFF = 1

5.5 500 kbps

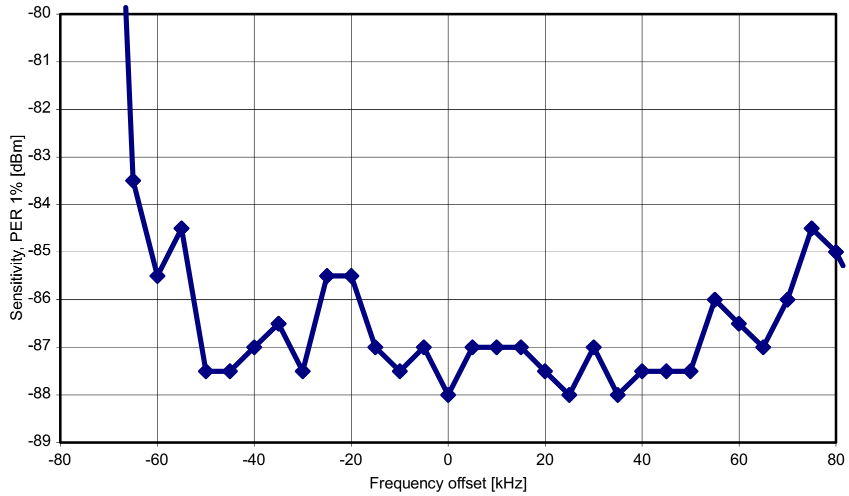

Figure 12. 500 kbps, MDMCFG2.DEM_DCFILT_OFF = 0

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from August 20, 2009 to September 27, 2018	**Page**
• Formatting and editorial changes throughout document	1

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