CC2500 and CC2510/CC2511 Sensitivity versus Frequency Offset and Crystal Accuracy

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Keywords

- *Sensitivity*
- *Frequency Offset*
- *Crystal Accuracy*
- *PER (Packet Error Rate)*
- *CC2500*
- *CC2510*
- *CC2511*

1 Introduction

This design note provides plots of CC2500 sensitivity versus frequency offset for different data rates. The results are also applicable for CC2510/CC2511.

The required crystal accuracy is calculated from these plots. Throughout this document, CC25xx is used to refer to both CC2500 and CC2510/CC2511.

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2 Abbreviations

2-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

3 Receiver Channel Filter Bandwidth and Crystal Inaccuracies

A phase locked loop (PLL) is used to generate the RF frequency in the CC2500 transceiver and CC2510/CC2511 SoC. 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 1.

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 CC25xx is programmed for a carrier frequency of 2440 MHz, there will be an error in the carrier frequency of $2440\ \text{MHz} \cdot 10/1 \cdot 10^6 = 24.4\ \text{kHz}$.

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, i.e. 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 (CC25xx 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 2.

If the transmitter crystal error is +10 ppm and the CC2500/10 is programmed for a carrier frequency of 2440 MHz, there will be an error in the carrier frequency of 24.4 kHz. If the receiver crystal error is -10 ppm and the CC25xx is programmed for an LO frequency of 2439.7 MHz (300 kHz IF frequency) there will be an error in the LO frequency of –24.397 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 2·24.4 kHz = 48.8 kHz.

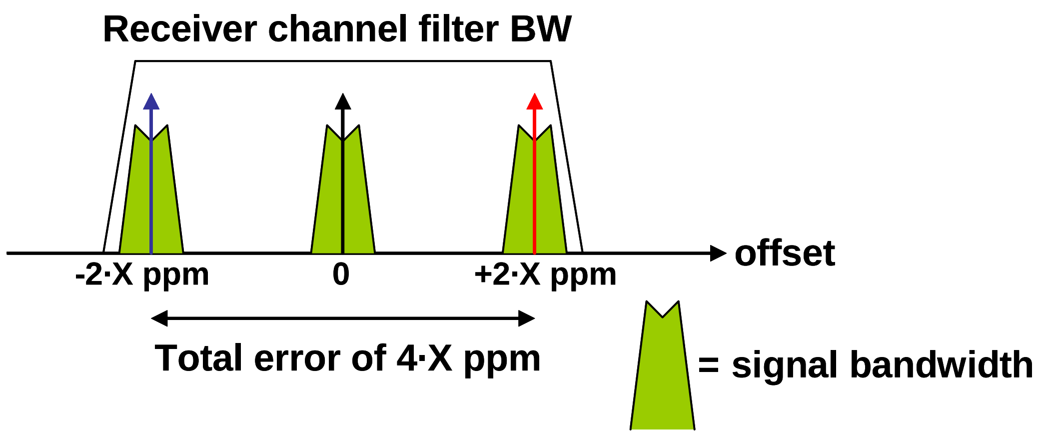


Figure 1. Plot of IF versus Frequency Error

Figure 1 shows the required minimum receiver 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.

$$BW_{channel} > BW_{signal} + 4 \cdot XTAL_{ppm} \cdot f_{RF}$$

where

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

Example 3.

If both the transmitter and receiver crystal accuracy is ±10 ppm and the CC25xx is programmed for a carrier frequency of 2440 MHz with an IF frequency of 300 kHz, $BW_{channel}$ must be larger than $BW_{signal} + 4 \cdot XTAL_{ppm} \cdot f_{RF} = BW_{signal} + 4 \cdot 24.4$ kHz $= BW_{signal} + 97.6$ kHz.

4 PER versus Frequency Offset

Figure 4 to Figure 10 plots the 1% PER for different data rates and modulation formats. The RF frequency is 2440 MHz in the measurements. Since 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). Since the IF frequency is programmed in steps of 25 kHz this is not always possible.

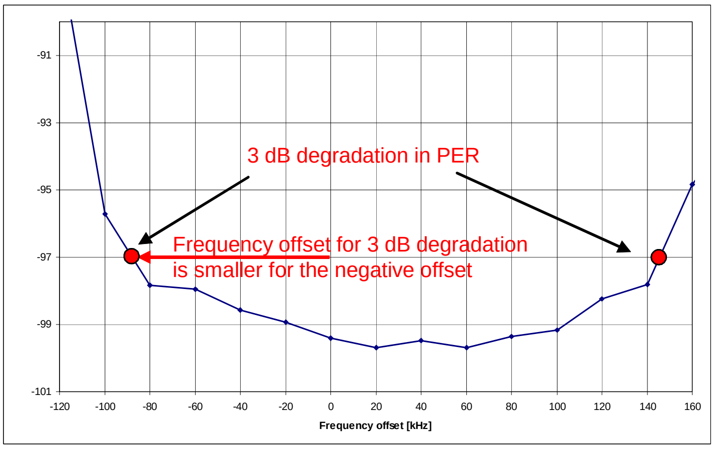


Figure 2. Definition of Frequency Offset which gives 3 dB Degradation in PER (unsymmetrical frequency offset)

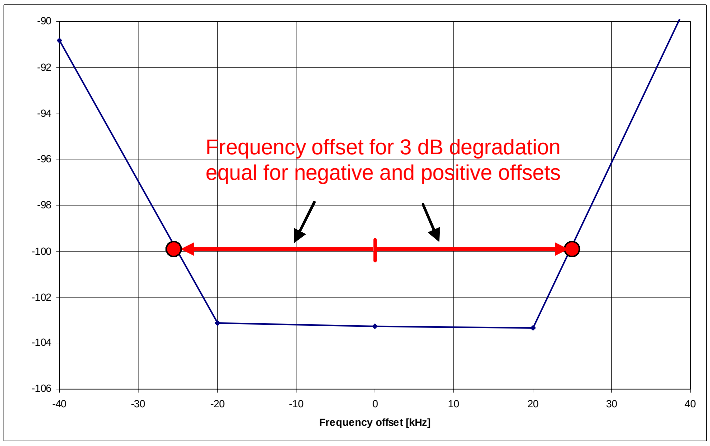


Figure 3. Definition of Frequency Offset which gives 3 dB Degradation in PER (symmetrical frequency offset)

5 Crystal Accuracy

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

$$\text{Total frequency offset} = 4 \cdot XTAL_{ppm} \cdot f_{RF}$$

$$\Rightarrow \text{Crystal accuracy (in ppm)} = \text{Total frequency offset} \cdot 10^6 / (4 \cdot f_{RF})$$

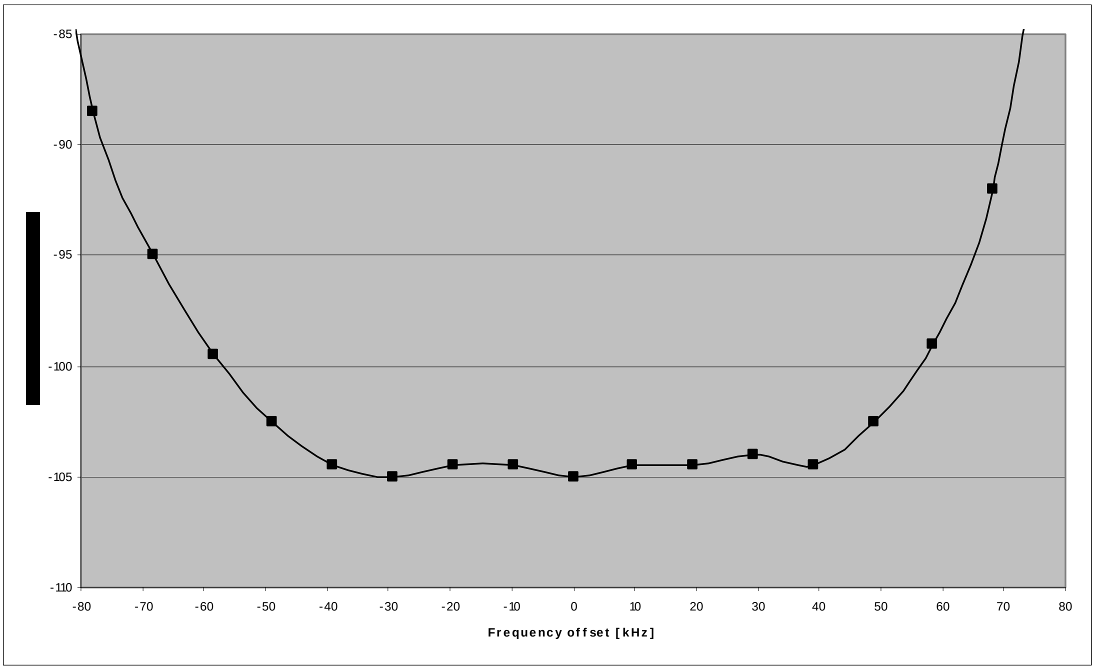
Case	Figure	3 dB Bandwidth (total frequency offset)	Crystal Accuracy (@ 2440 MHz)
2.4 kBaud, 2-FSK, 38 kHz deviation, DC filter. RX filter bandwidth = 203 kHz.	Figure 4	100 kHz	±10 ppm
2.4 kBaud, 2-FSK, 38 kHz deviation, no DC filter. RX filter bandwidth = 203 kHz.	Figure 5	100 kHz	±10 ppm
10 kBaud, 2-FSK, 38 kHz deviation, DC filter. RX filter bandwidth = 232 kHz.	Figure 6	130 kHz	±13 ppm
10 kBaud, 2-FSK, 38 kHz deviation, no DC filter. RX filter bandwidth = 232 kHz.	Figure 7	150 kHz	±15 ppm
250 kBaud, MSK, DC filter. RX filter bandwidth = 541 kHz.	Figure 8	140 kHz	±14 ppm
250 kBaud, MSK, no DC filter. RX filter bandwidth = 541 kHz.	Figure 9	140 kHz	±14 ppm
500 kBaud, MSK, DC filter. RX filter bandwidth = 812 kHz.	Figure 10	200 kHz	±20 ppm

Table 1. Crystal Accuracy Requirement for Selected Data Rates and Modulation Formats

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 a lower IF frequency and thereby lower noise floor and improved sensitivity. As an example, for 2440 MHz, 250 kBaud MSK, enabling the DC filter gives 2 dB better sensitivity at the expense of an increased current consumption of 2.2 mA.

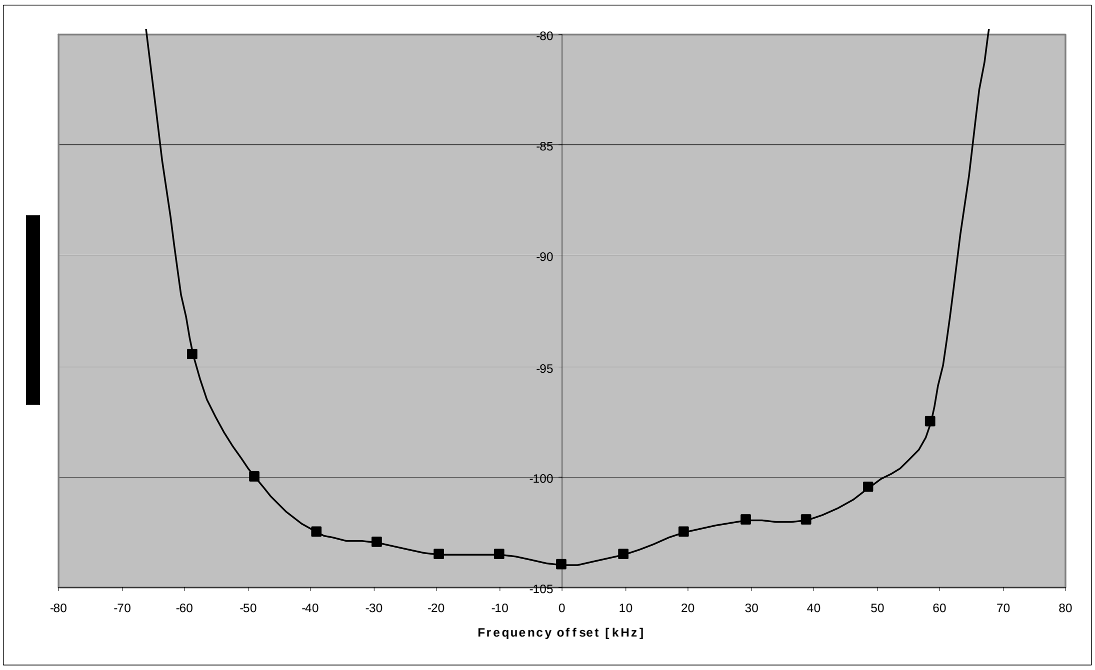
Appendix A: Sensitivity versus Frequency Offset

5.1 2.4 kBaud



FOCCFG.FOC_LIMIT[1:0]	10_b
FSCTRL1	0x08

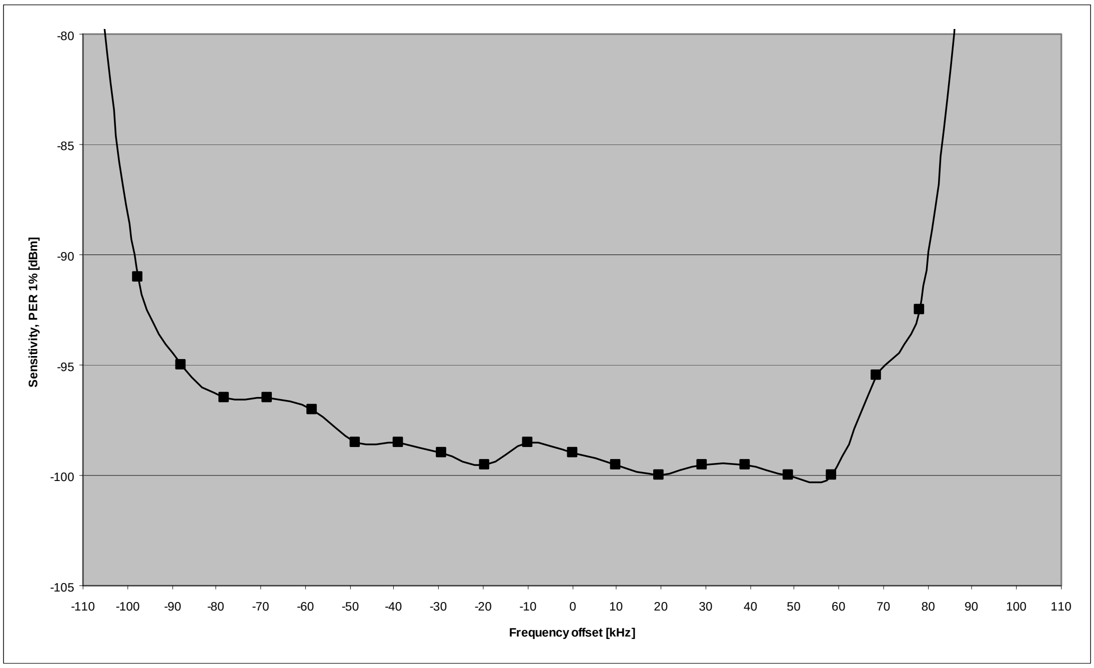
Figure 4. 2.4 kBaud, MDMCFG2.DEM_DCFILT_OFF = 0



FOCCFG.FOC_LIMIT[1:0]	11_b
FSCTRL1	0x0B

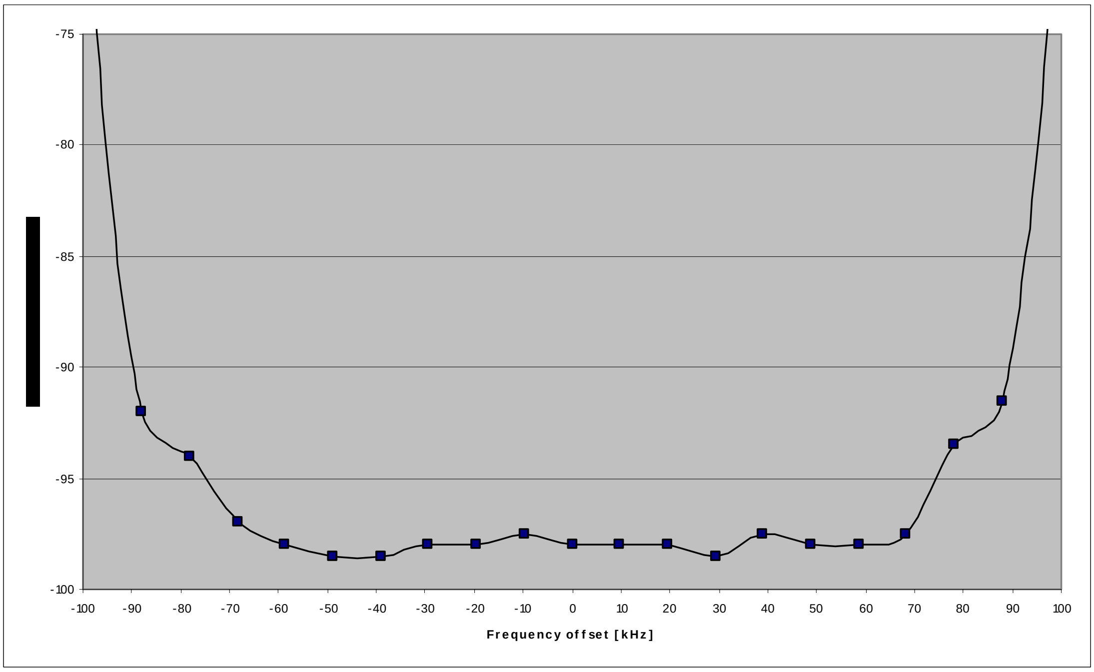
Figure 5. 2.4 kBaud, MDMCFG2.DEM_DCFILT_OFF = 1

5.2 10 kBaud



FOCCFG.FOC_LIMIT[1:0]	10_b
FSCTRL1	0x06

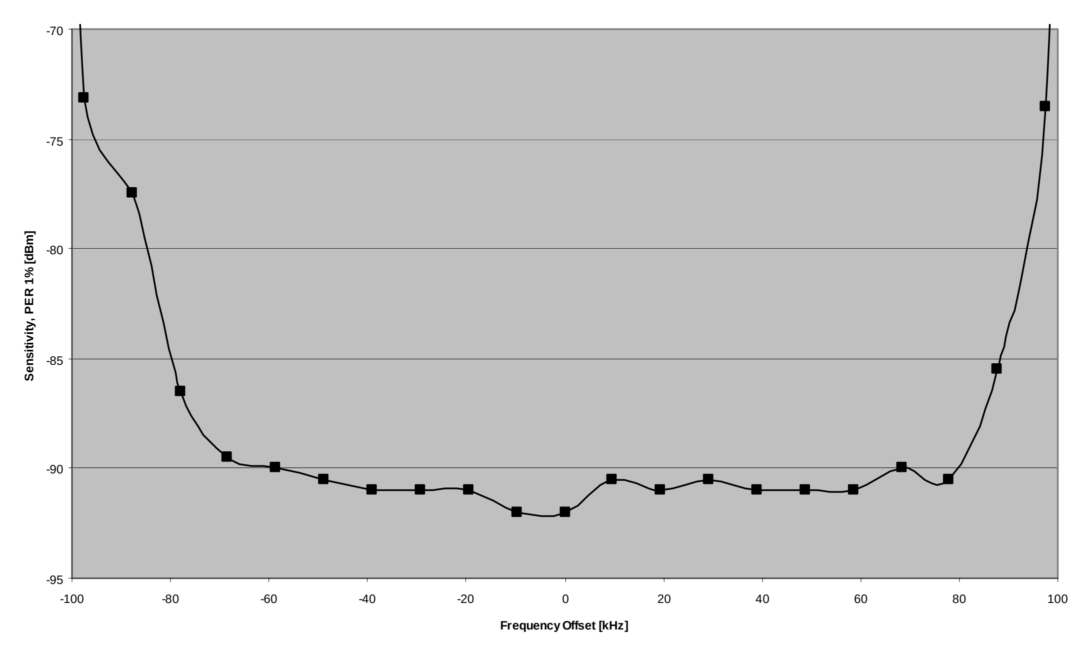
Figure 6. 10 kBaud, MDMCFG2.DEM_DCFILT_OFF = 0



FOCCFG.FOC_LIMIT[1:0]	10_b
FSCTRL1	0x0B

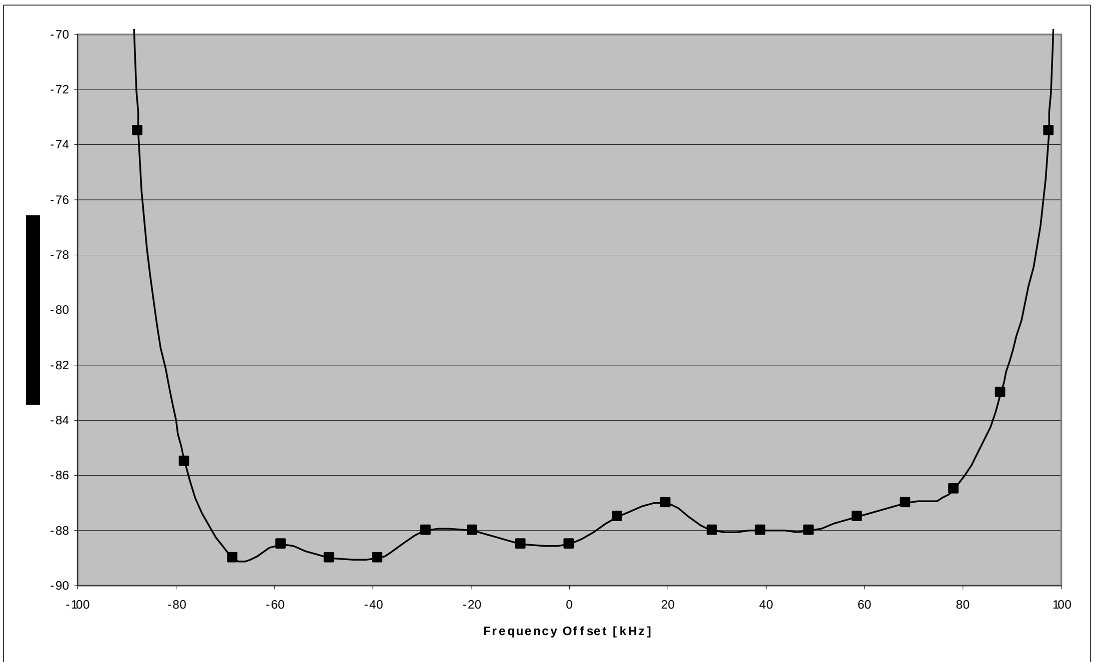
Figure 7. 10 kBaud, MDMCFG2.DEM_DCFILT_OFF = 1

5.3 250 kBaud



FOCCFG.FOC_LIMIT[1:0]	01_b
FSCTRL1	0x0A

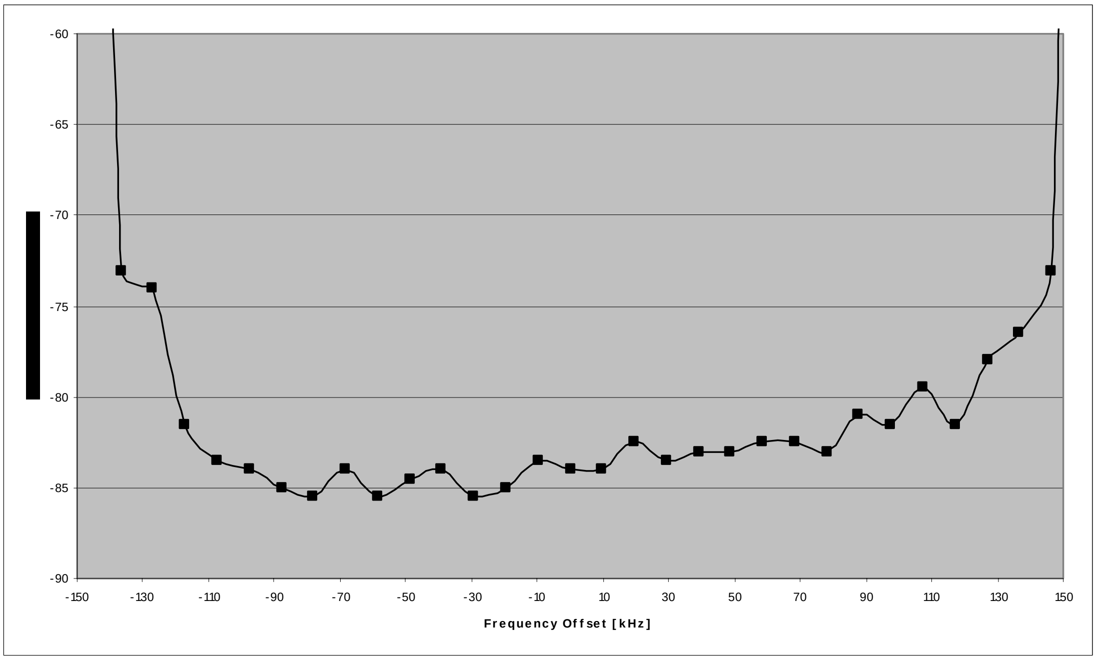
Figure 8. 250 kBaud, MDMCFG2.DEM_DCFILT_OFF = 0



FOCCFG.FOC_LIMIT[1:0]	01_b
FSCTRL1	0x12

Figure 9. 250 kBaud, MDMCFG2.DEM_DCFILT_OFF = 1

5.4 500 kBaud



FOCCFG.FOC_LIMIT[1:0]	01_b
FSCTRL1	0x10

Figure 10. 500 kBaud, MDMCFG2.DEM_DECFILT_OFF = 0

6 General Information

6.1 Document History

Revision	Date	Description/Changes
SWRA181	2008-03-10	Initial release

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