Wireless MBUS Implementation with CC1101 and MSP430

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Keywords

- *Wireless MBUS*
- *KNX-RF*
- *Meter reading*
- *Data rate offset and drift*
- *Frequency offset and drift*
- *MSP430*
- *Synchronization word*
- *Packet length modes*
- *CRC*
- *Data coding and encoding*
- *CC1101*

1 Introduction

This application note describes how the CC1101 and MSP430 combined can be configured to a modem that complies with the Wireless MBUS standard [1]. The wireless MBUS standard is a communication standard for meters and wireless readout of meters, and specifies the physical and the data link layer. Power consumption is a critical parameter for the meter side, since the communication link shall be operative for the full lifetime of the meter, without changing the battery. CC1101 combined with MSP430 is an excellent choice for the Wireless MBUS standard. CC1101 is a truly low cost, low power and flexible transceiver, and MSP430 a high performance and ultra low power MCU. The source code discussed in this application note can be downloaded from http://www.ti.com/lit/zip/SWRA234.

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2 Abbreviations

EM	Evaluation module
ISM	Industrial, Scientific, Medical
MBUS	Metering Bus
CRC	Cyclic Redundancy Check
TX	Transmit
RX	Receive
MSB	Most Significant Bit
LSB	Least Significant Bit
FIFO	First In First Out
MCU	Micro Controller Unit
FSK	Frequency Shift Keying
NRZ	Non Return to Zero
IF	Intermediate Frequency
PER	Packet Error Rate
BER	Bit Error Rate
KNX	Konnex
LCD	Liquid Crystal Display
SoC	System on Chip, used in this document to reference CC111x
LPM	Low Power Mode

3 Wireless MBUS

The wireless MBUS standard specifies the communication between a *meter and an "other"* system component, e.g. mobile/stationary readout devices, data collectors. See Figure 1 for a simple overview of a wireless MBUS system.

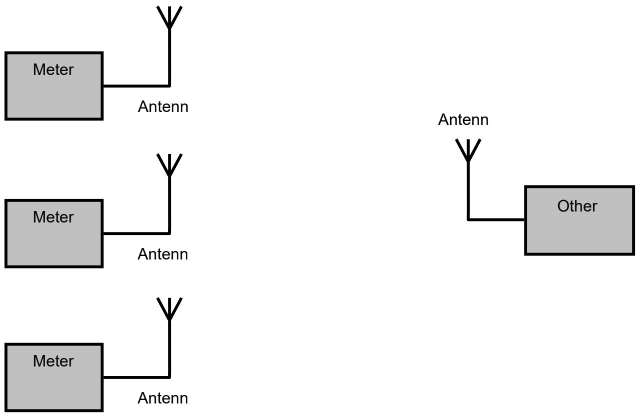


Figure 1. Wireless MBUS Communication System

Three different *meter* modes with sub-modes are defined, for the communication between a meter and an "*other*".

- S-mode, Stationary Mode
  - S1-mode, one-way communication from *meter* to *"other"*
  - S1m-mode, one-way communication from *meter* to *"other"*
  - S2-mode, two-way communication between *meter* and *"other"*
- T-mode, Frequent Transmit Mode
  - T1-mode, one-way communication from *meter* to *"other"*
  - T2-mode, two-way communication between *meter* and *"other"*
- R-mode, Frequent Receive Mode
  - R2-mode, two-way communication between *meter* and *"other"*

R2-mode is out of the scope for this application note.

3.1 KNX-RF

The physical layer and the data link layer of KNX-RF were defined jointly with the wireless MBUS standard, and S-mode complies with the KNX-RF standard.

4 Physical Layer

All of the presented radio requirements are taken from the wireless MBUS specification [1]. Only two different radio links are defined, which will be named radio link A and B in this application note. Table 1 shows the mapping between the different wireless MBUS modes and the two radio links.

Mode	Link
S-mode Meter -> Other	Radio Link A
S-mode Other -> Meter	Radio Link A
T-mode Meter -> Other	Radio Link B
T-mode Other -> Meter	Radio Link A

Table 1. RF Link Mapping

Since the Wireless MBUS standard operates in the 868-870 ISM band, the radio requirements must also comply with the ETSI EN 300 220 [2] and CEPT/ERC/REC 70-03 E [3] standards. An introduction to these requirements, and how CC1101 complies with these requirements, can be found in application note AN050 [4].

Requirements that are applicable for the application layer are not considered in this application note, e.g.

- Duty cycle
- Response delay

The implementation should still ensure that the transceiver is configured to terminate TX and RX automatically when a packet is transmitted or received.

Three different performance classes of transceivers are defined in the wireless MBUS standard, and the radio requirements presented comply with the highest performance class.

4.1 Radio Link A Requirements

The requirements are summarized in Table 2, Table 3 and Table 4.

Common Radio Parameter	Min	Typical	Max	Unit	Comment
Frequency Band	868.0	868.3	868.6	MHz	600 kHz channel
Modulation		2-FSK			

Table 2. RF Requirements RF Link A

Transmit Radio Parameter	Min	Typical	Max	Unit	Comment
Carrier Frequency (other)	868.278	868.3	868.322	MHz	± 25 ppm
Carrier Frequency (meter)	868.25	868.3	868.35	MHz	± 60 ppm
Frequency deviation	± 40	± 50	± 80	kHz	
Baud rate		32.768		kbaud	
Baud rate drift			± 1.5%		

Table 3. TX Requirements RF Link A

Receive Radio Parameter	Min	Typical	Max	Unit	Comment
Sensitivity (BER < 10^{-2})	-100	-105		dBm	
Baud rate		32.768		kbaud	
Baud rate drift			± 2%		

Table 4. RX Requirements RF Link A

4.2 Radio Link B Requirements

The requirements are summarized in Table 5, Table 6 and Table 7.

Common Radio Parameter	Min	Typical	Max	Unit	Comment
Frequency Band	868.700	868.950	869.200	MHz	500 kHz channel
Modulation		2-FSK			

Table 5. RF Requirements RF Link B

Transmit Radio Parameter	Min	Typical	Max	Unit	Comment
Carrier Frequency	868.90	868.95	869.00	MHz	± 60 ppm
Frequency deviation	± 40	± 50	± 80	kHz	
Baud rate	90	100	110	kbaud	
Baud rate drift			± 1 %		

Table 6. TX Requirements RF Link B

Receive Radio Parameter	Min	Typical	Max	Unit	Comment
Sensitivity (BER < 10^{-2})	-100	-105		dBm	
Baud rate	88	100	112	kbaud	
Baud rate drift			± 2 %		

Table 7. RX Requirements RF Link B

5 Data Link layer

All of the presented data link requirements are taken from the wireless MBUS specification [1]. For detailed explanation of the different fields in a packet and the data coding, see the wireless MBUS specification.

5.1 Data Coding

Data coding used for the different radio links are shown in Table 8.

Data coding	Data / baud rate	Link
Manchester	1 / 2	Radio Link A
3 out of 6 coding	2 / 3	Radio Link B

Table 8. Wireless MBUS Data Coding

5.2 Preamble and Synchronization Word

Preamble and synchronization word for the different radio links are shown in Table 9.

Preamble	n	Sync word	Postamble	n	Link
n*(01)	279 ≤ n	00 0111 0110 1001 0110	n*(01)	2 ≤ n ≤ 4	Radio Link A, long preamble
n*(01)	15 ≤ n	00 0111 0110 1001 0110	n*(01)	2 ≤ n ≤ 4	Radio Link A, short preamble
n*(01)	19 ≤ n	00 0011 1101	n*(01)	2 ≤ n ≤ 4	Radio Link B

Table 9. Pre/postamble and Synchronization Word

The long preamble sequence for radio link A is used for the S1-mode, and optionally for the S2-mode.

Note that the preamble, synchronization word and postamble sequences are not data coded.

5.3 Packet Format

A packet will consist of

- A preamble sequence and a synchronization word
- Block 1 and block 2 as shown in Table 10 and Table 11 respectively
- Optionally n blocks, determined by the packet length, as shown in Table 12
- Postamble sequence

L-Field	C-field	M-field	A-field	CRC–field
1 byte	1 byte	2 bytes	6 bytes	2 bytes

Table 10. Block 1 Format

CI-field	Data field	CRC field
1 byte	15 bytes or (((L-9) mod 16) -1) bytes	2 bytes

Table 11. Block 2 Format

Data field	CRC field
16 bytes or ((L-9) mod 16) bytes	2 bytes

Table 12. Optional block(s) format

The length field excludes the following fields

- CRC fields
- L-Field

5.4 CRC - field

The CRC polynomial is $x^{16} + x^{13} + x^{12} + x^{11} + x^{10} + x^{8} + x^{6} + x^{5} + x^{2} + 1$, with 0 as initial value. The final CRC is complemented

6 Radio Implementation

Both Radio Link A and Radio Link B radio register configurations are based on the following preferred setting from SmartRF® studio:

- 325 kHz RX filter bandwidth
- GFSK with 47 kHz frequency deviation
- 100 kbaud data rate
- Sensitivity optimized

The radio register configuration for the 2 radio links can be found in appendix C and D.

6.1 Crystal Tolerance

Frequency drift in the transceiver is due to the crystal inaccuracy. E.g. A crystal inaccuracy of ± 40 ppm, will give a frequency drift of ± 40 ppm. A more detailed description on frequency drift and crystal tolerance can be found in design note DN005 [6]. For the implementation to comply with the strictest TX radio link requirement, the maximum crystal tolerance is ± 25 ppm.

6.2 Receiver Filter Bandwidth

The bandwidth of the RX filter is an important parameter. If the bandwidth is set too small the wanted RX signal is filtered out. If the bandwidth is set too large it will degrade the sensitivity. Carlson's rule is used to estimate the bandwidth of the FSK modulated signal, where Δf is the frequency deviation and f_{mod} is frequency of the modulation signal.

$$BW_{FSK} = 2 * (\Delta f + f_{\mathrm{mod}})$$

For an NRZ signal, $2 * f_{\mathrm{mod}}$ equals the baud rate.

Following parameters must be taken into account when determining the bandwidth of the received RX signal.

- Frequency drift in the receiver and transmitter
- Baud rate drift
- Frequency deviation drift

The RX filter bandwidth, BW_{RX}, should be selected so that the RX signal occupies at most 80% of the signal RX filter bandwidth. If frequency offset compensation is disabled, the RX filter bandwidth can be calculated by the following equation.

$$BW_{RX} = {(BW_{FSK,MAX} + 2 * f_{drift,MAX})} \big/ {0,8}$$

When frequency offset compensation is enabled, the IF is continuously adjusted so that the RX signal is aligned with the RX filter. This implies that the frequency offset/drift can be ignored from the RX filter bandwidth calculation, but note that the frequency error is estimated after the RX filter. Hence the modulation index to the RX signal is one of the main parameters that will determine how much frequency offset/drift can be ignored.

$$h = \Delta f \big/ f_{\mathrm{mod}}$$

For a FSK signal with a large modulation index the RF spectrum will have two distinct peaks, e.g. the signal effect is not centered. This implies that the frequency offset/drift cannot be totally ignored from RX filter bandwidth calculation. On the other hand, for a FSK signal with a small modulation index the frequency offset/drift can be ignored from the RX filter bandwidth calculation.

6.2.1 Radio Link A

Maximum bandwidth of the FSK signal is

$$BW_{FSK} = 2 * 80kHz + 33kHz = 193kHz$$

This will give the following RX filter bandwidth when ignoring frequency offset/drift from the calculation.

$$BW_{RX} = {}^{193}\!/_{0,8} = 242kHz$$

Since the modulation index is large for an RX signal with maximum frequency deviation, frequency offset/drift should not be totally ignored from the calculation. Hence a BW_{RX} of 270 kHz is selected for radio link A.

6.2.2 Radio Link B

Maximum bandwidth of the FSK signal is

$$BW_{FSK} = 2 * 80kHz + 112kHz = 272kHz$$

This will give the following RX filter bandwidth when ignoring frequency offset/drift from the calculation.

$$BW_{RX} = {}^{272}\!/_{0,8} = 340Hz$$

Since the modulation index is low, even for an RX signal with maximum frequency deviation, frequency offset/drift can be ignored from the calculation. Hence a BW_{RX} of 325 kHz is selected for radio link B.

6.3 Frequency Offset and Drift Compensation

Frequency offset compensation is controlled from the FOCCFG register, and not compensating for frequency drift will degrade the receiver sensitivity. The RX bandwidth selection also requires that frequency offset compensation is enabled.

Maximum frequency offset for both links, given the requirements, is

$$\pm 25\ ppm + \pm 60\ ppm = \pm 85\ ppm$$
$$f_{drift} = f_{carrier} * \pm 85\ ppm \approx \pm 74kHz$$

Hence the saturation limit for the frequency offset compensation loop (FOC_LIMIT) should be set to ± BW_{RX} / 4.

The pre gain factor determines the frequency offset tracking. The post gain factor determines the frequency drift tracking. The post gain factor can be reduced, since the frequency drift is often limited.

6.4 Data Rate Offset and Drift Compensation

Data rate offset compensation is controlled from the BSCFG register. Failing to compensate for data rate offset will give a packet error rate of 100 % in synchronous mode when the data rate offset is large. This is because the bit synchronization is lost, independently of the strength of the received signal.

For radio link A, the maximum data rate drift in the system is ± 2 %, and hence the saturation limit for the data rate offset compensation loop (BC_LIMIT) must be set to ±3.125 %.

For radio link B, the maximum data rate drift in the system is ± 12 %, and hence the saturation limit for the data rate offset compensation loop (BC_LIMIT) must be set to ±12.5 %. Setting the FOC_BS_CS_GATE bit ensures that noise does not make the data rate drift algorithm drift away to the limit before the carrier is sensed. Given the short preamble sequence of only 4-5 bytes and the large data rate offset, it is important that the FOC_BS_CS_GATE bit is set.

When given a short preamble the data rate compensation loop is not perfectly symmetrical, and it can be problems with locking at data rate offsets above +7 %. Hence several packets can be lost even with strong signal inputs, since the synchronization word is not detected. To get minimum degradation in performance in the ± 12 % range, the data rate setting for the receiver should be set to 102-103 kbaud. Note also that the wireless MBUS standard limits the transmitter data rate offset to ± 10 %.

The pre gain factors, pre Ki and pre Kp, determine the data rate offset tracking. The post gain factors, post Ki and post Kp, determine the data rate drift tracking.

The pre gain factors for the algorithms should be increased from the default value. This will decrease the lock time and degrade the noise immunity. The post gain factors are reduced compared to the pre gain factors; since the data rate drift in the package is limited to 2 %.

6.5 Frequency Deviation Offset

Frequency deviation is controlled from the DEVIATN register. The frequency deviation setting is not only used during transmit, but is also used during receive. Preferably the receiver frequency deviation should be set close to the minimum frequency deviation in the wireless MBUS standard. Note that the receiver frequency deviation should also take into account that the maximum offset should not be larger than twice the receiver frequency deviation. Since the frequency deviation is 40 - 80 kHz for both radio links, the frequency deviation in the receiver should be in the 40 - 50 kHz range.

For Radio Link A the frequency deviation is set to 47 kHz. This allows for fast response delay in S-mode, since the communication between the meter and the *other* is done on the same link.

For Radio Link B the frequency deviation is set close to 40 kHz. This is because the data rate offset is larger, and the receiver performance is more dependent on the frequency deviation setting. Note that an offset from the receiver frequency deviation setting affects the gain in the frequency and data rate offset compensation loops.

6.6 Carrier Sense

The absolute carrier sense level is controlled through the AGCCTRL registers. Preferably the CARRIER_SENSE_ABS_THR bits should be used for fine adjustments over the MAGN_TARGET bits. The carrier sense limit should be set as close as possible to the sensitivity limit, to avoid degradation in sensitivity. The given radio implementations give approximately the following carrier sense limits:

- Radio Link A: -107 dBm
- Radio Link B: -104 dBm

7 Data Link Layer Implementation

The inbuilt packet engine on the CC1101 transceiver does not directly support the packet format specified in the Wireless MBUS standard. Yet, the most critical functionality is supported and will significantly reduce the MCU load.

In RX mode the most critical parameters for MCU load are bit and byte synchronization. Failing to perform bit synchronization, will require that the radio is set in asynchronous (transparent) mode and leave the bit synchronization to the MCU. The given radio implementation takes into account the data rate offset and drift, e.g. the bit synchronization. Bit synchronization will also enable the use of the RX FIFO. This combined with byte synchronization will reduce the MCU load since the MCU only will be interrupted when valid data has been received.

7.1 Data Encoding

The CC1101 transceiver supports Manchester encoding and decoding, but this requires that the complete packet sequence, including preamble and synchronization word, to be Manchester coded both in TX and RX. The CC1101 transceiver does not support “3 out of 6” encoding or decoding. For these reasons the CC1101 transceiver must be configured in NRZ mode and the data encoding and decoding must be performed by the MCU.

7.2 Preamble, Synchronization Word in Transmit Mode

The CC1101 transceiver supports maximum a 16 bit unique synchronization word, since the 32 bit synchronization word mode requires that the synchronization word is repeated. A postamble sequence is also not supported by the packet engine included on the CC1101, and this requires the MCU to append a postamble byte into the TX FIFO.

7.2.1 Radio Link A

The short preamble sequence is directly supported by the packet engine on the CC1101 transceiver, and hence the MCU can start to load the TX FIFO immediately. The long preamble sequence requires on the other hand that the TX FIFO is not loaded immediately after enabling TX. In this case the transmitter will transmit a preamble sequence until the TX FIFO is loaded.

The 18-bit long synchronization word requires that a part of the synchronization word must be inserted by the MCU before the Wireless MBUS packet bytes. Since the TX FIFO is byte organized, adding the last byte of the synchronization word will minimize the MCU load, since the wireless MBUS packet bytes can be added directly into the TX FIFO (un-shifted). The 10-bit left of the synchronization word is easily extended to a 16 bit synchronization word by including 6 bits of the preamble sequence.

7.2.2 Radio Link B

The preamble sequence is directly supported by the packet engine included on the CC1101, and hence the MCU can start to load the TX buffer in CC1101 immediately.

The synchronization word, which is 10 bits long, is easily extended to a 16 bit synchronization word by including 6 bits of the preamble sequence.

7.3 Synchronization Word in Receive Mode

False synchronization word matches, due to noise, can be limited by using one or both of the following features

- Carrier Sense Qualification
- Preamble Quality Threshold

In the radio implementation carrier sense qualification is used for both radio link A and B. For radio link A, there is an option to use preamble quality threshold instead of carrier sense. For radio link B, preamble quality threshold will not be a good solution, since most of the preamble sequence is used by the receiver to lock the compensation loops.

7.3.1 Radio Link A

The CC1101 packet handler engine can be used to get byte synchronization on the synchronization word. Applying only the 16 LSB of the synchronization word, and hence ignoring the 2 MSB of the synchronization word, is the simplest solution and the one implemented. Alternatively the same synchronization word as in transmit mode can be used and the last byte of the synchronization word is manually checked by the MCU.

7.3.2 Radio Link B

The same solution as in transmit mode is used.

7.4 Packet Length Control

The length field in a wireless MBUS packet is not supported by the CC1101 packet engine, since

- The length field is data coded
- The length field does not includes all fields in the packet
- The total size of the packet can be larger than 255 bytes

The inbuilt packet engine on the CC1101 transceiver supports on the other hand that length mode is re-configured during transmit and receive. For packets that contain more than 255 bytes, the length mode is initialized to infinite mode, and changed to fixed mode when less than 256 bytes to transmit or receive. Hence TX and RX mode is automatically terminated after a packet transmission and a packet reception, with no interaction from the MCU.

7.5 CRC

The CRC polynomial and CRC-fields placement in the packet is not supported by the CC1101 packet engine. Hence the CRC must be calculated and checked by MCU.

8 Radio Performance

All the sensitivity measurements are done with PER, and not with BER. The correlation between PER and BER is

$$PER = 1 - (1 - BER)^{packet\_length}$$

The reason for selecting PER instead of BER is that PER gives a more accurate picture of the performance. Measuring BER on one continuous packet / data stream will be optimistic, since the gain is reduced in the compensation loops when a synchronization word is found. With a packet payload of 20 bytes the PER can be calculated.

$$PER = 1 - (1 - 0.01)^{20*8} \approx 0.80 = 80\%$$

Note that formula above is not totally accurate, since there can be several bit errors in an erroneous packet.

All measurements are performed against two CC1101EMs, version 2.1 [5]. In version 2.1 the inductors are replaced with wired-wound inductors. The difference in performance is measured to be around 1 dB increase in

- Output power
- Receiver sensitivity

All measurements are performed under the following conditions, if not stated otherwise.

- 25º Celsius
- Packet payload of 20 bytes
- Wireless MBUS Synchronization Word
- 4 Byte Preamble

8.1 Radio Link A

All measurements are done for a typical wireless MBUS signal if not stated otherwise, e.g.

- 32.768 kbaud data rate
- 2-FSK modulation
- 868.3 MHz carrier frequency
- 50 kHz frequency deviation

Appendix A shows more diagrams of performance versus temperature and frequency deviation variation.

8.1.1 Receiver Sensitivity

The measured sensitivity is shown in Table 13.

EM	PER 20 %	PER 1 %
EM2	-104.8 dBm	-103.0 dBm
EM3	-103.8 dBm	-102.2 dBm

Table 13. Sensitivity

The following diagrams show

- Packet error rate versus input level
- Sensitivity versus frequency offset at PER 20 % and PER 1 %
- Sensitivity versus data rate offset at PER 20 % and PER 1 %

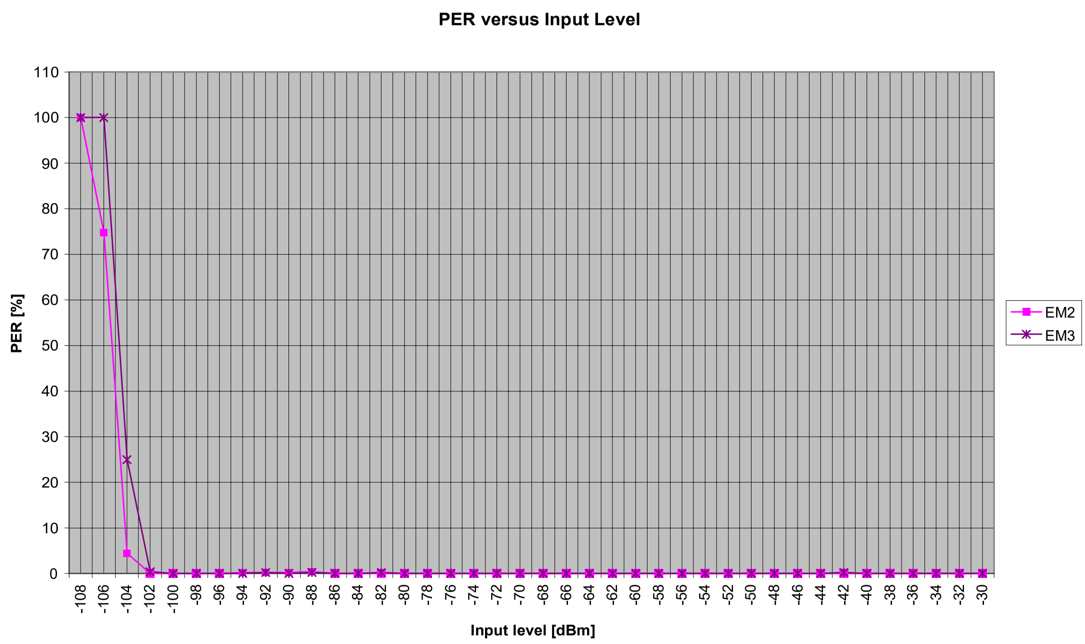


Figure 2. Sensitivity Curve

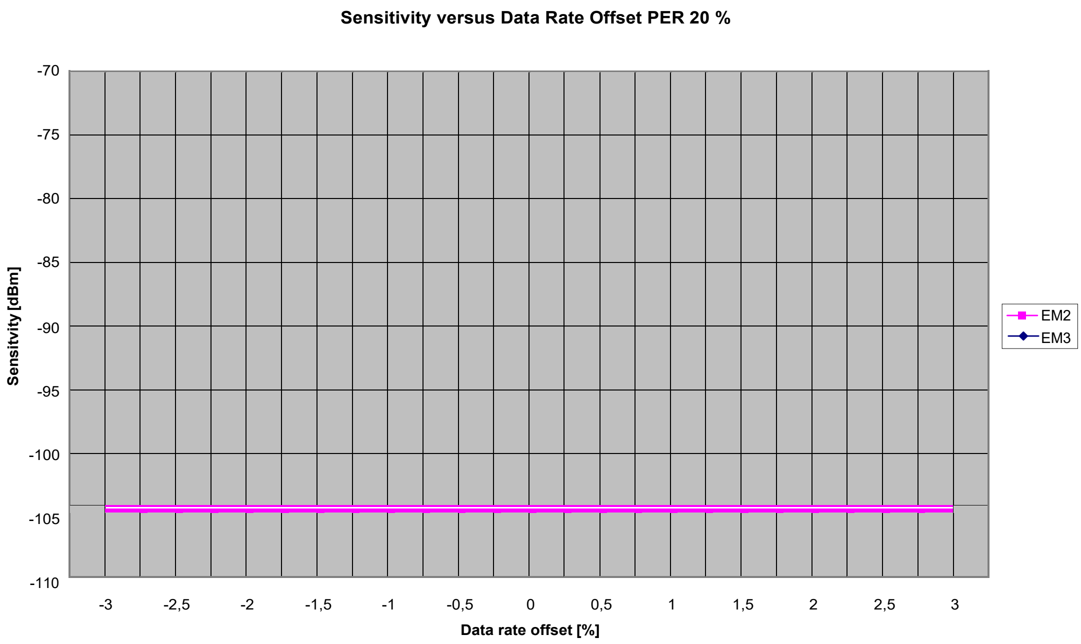


Figure 3. Sensitivity at PER 20 % versus Data Rate Offset

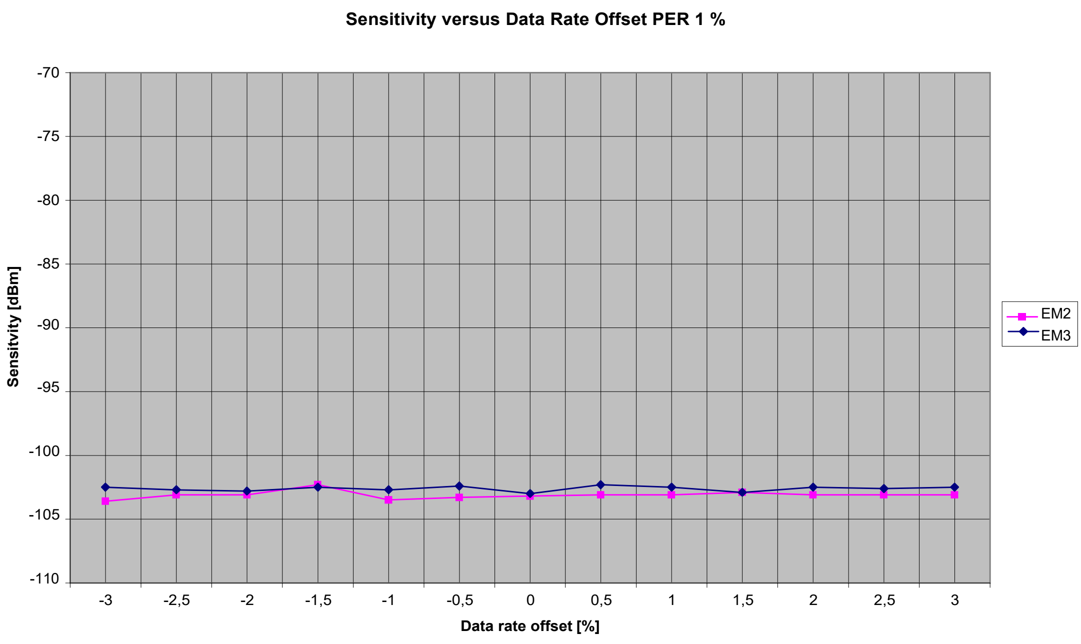


Figure 4. Sensitivity at PER 1% versus Data Rate Offset

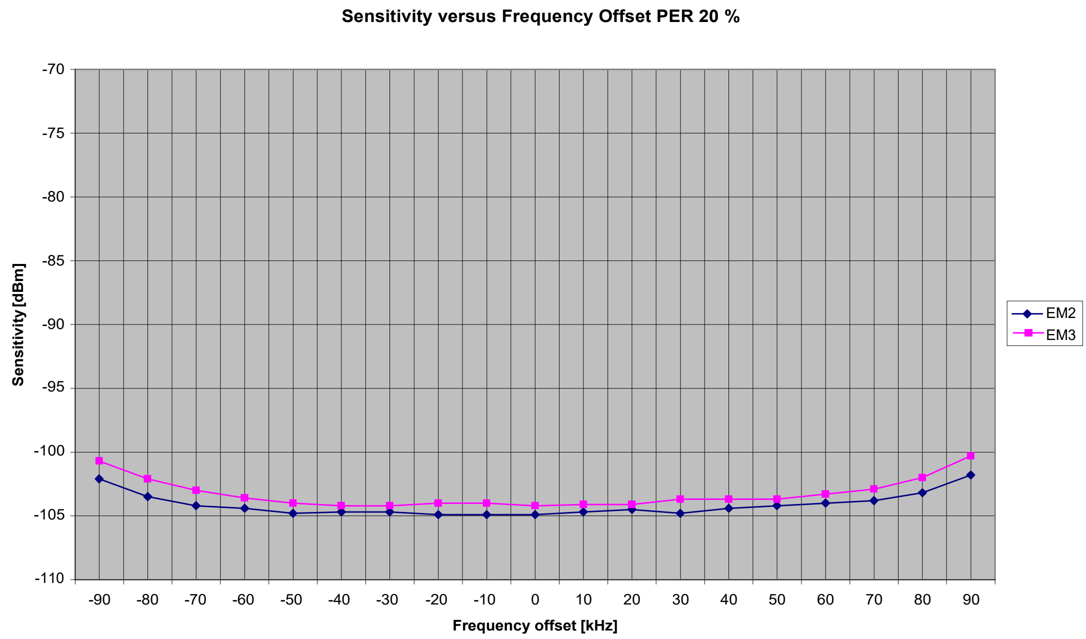


Figure 5. Sensitivity at PER 20 % versus Frequency Offset

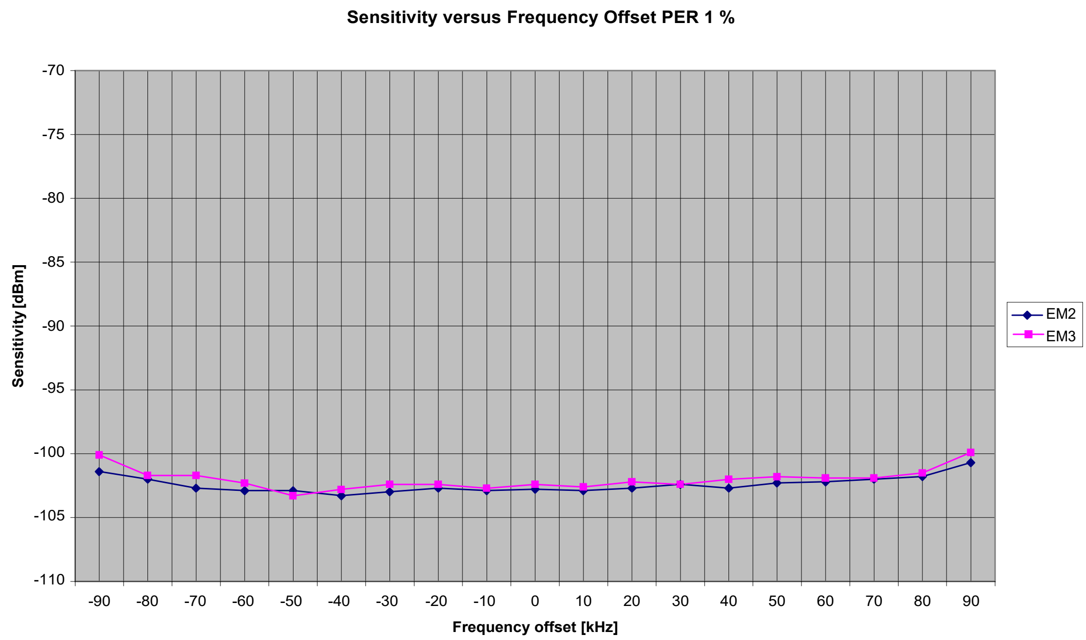


Figure 6. Sensitivity at PER 1 % versus Frequency Offset

8.1.2 Summary

As seen from appendix A, a 270 kHz RX filter bandwidth is the minimum bandwidth required to get minimum degradation in performance for the complete range of valid input signals. The sensitivity for a typical wireless MBUS signal can be improved by narrowing the RX filter bandwidth. Narrowing the RX filter bandwidth will give a higher degradation in performance for a wireless MBUS signal with maximum frequency offset and frequency deviation.

Measurements with a 232 kHz RX filter bandwidth have been performed, and the improvement in sensitivity at PER 1% for a nominal wireless MBUS signal was around 0.5

dB. The same measurements also show a high degradation in performance for wireless MBUS signals with high frequency deviation and frequency offset.

8.2 Radio Link B

The receiver measurements are done with a typical signal if not stated other ways, e.g.

- 100 kbaud data rate
- 2-FSK modulation
- 868.95 MHz carrier frequency
- 50 kHz frequency deviation

Appendix B shows diagrams of performance versus temperature and frequency deviation variation. For sensitivity at PER 1 % there have been done measurements for two different receiver frequency deviation configurations:

- 41 kHz
- 38 kHz

8.2.1 Receiver Sensitivity

The receiver sensitivity is shown in Table 14.

EM	PER 20%	PER 1%
EM2	-101 dBm	-96.9 dBm
EM3	-100 dBm	-95.6 dBm

Table 14. Sensitivity

The following diagrams shows

- Packet error rate versus input level
- Sensitivity versus frequency offset at PER 20 % and PER 1 %
- Sensitivity versus data rate offset at PER 20 % and PER 1 %

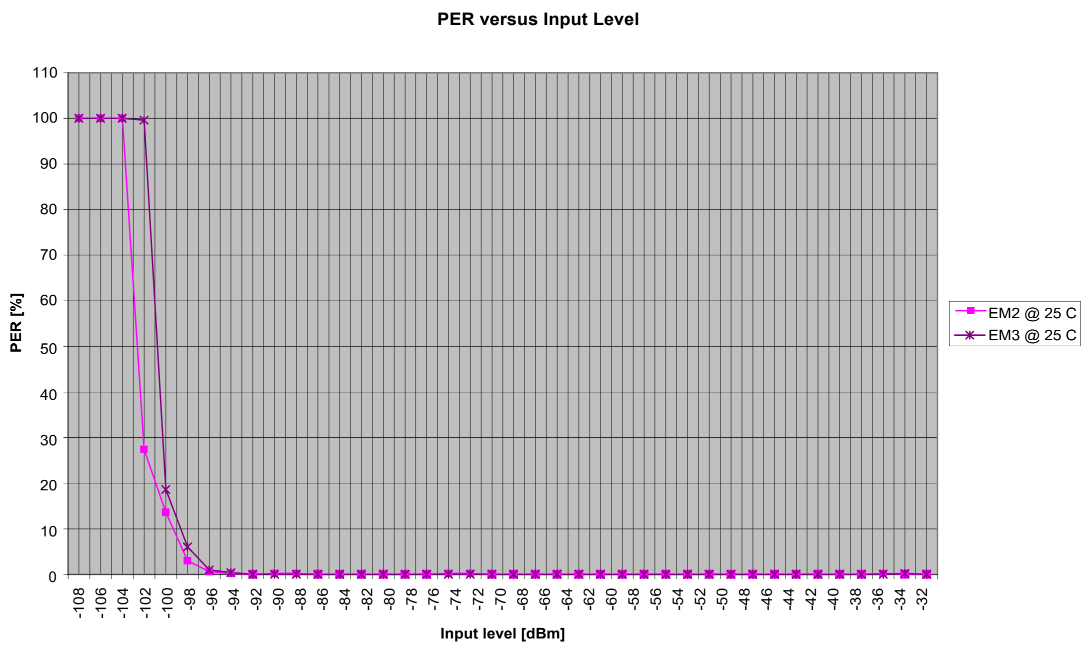


Figure 7. Sensitivity Curve

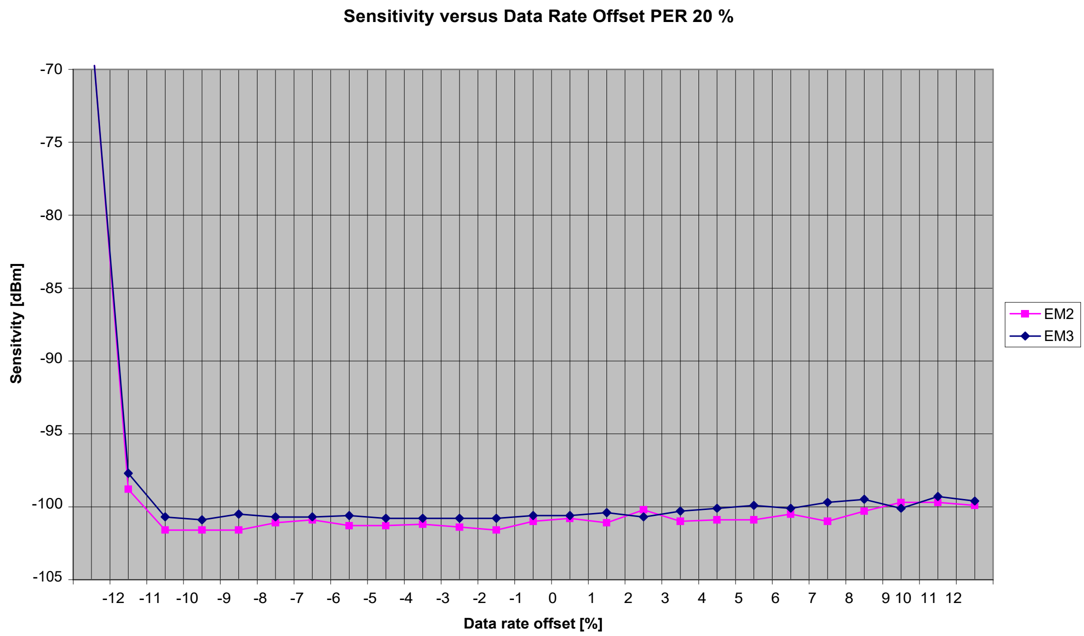


Figure 8. Sensitivity at PER 20% versus Data Rate Offset

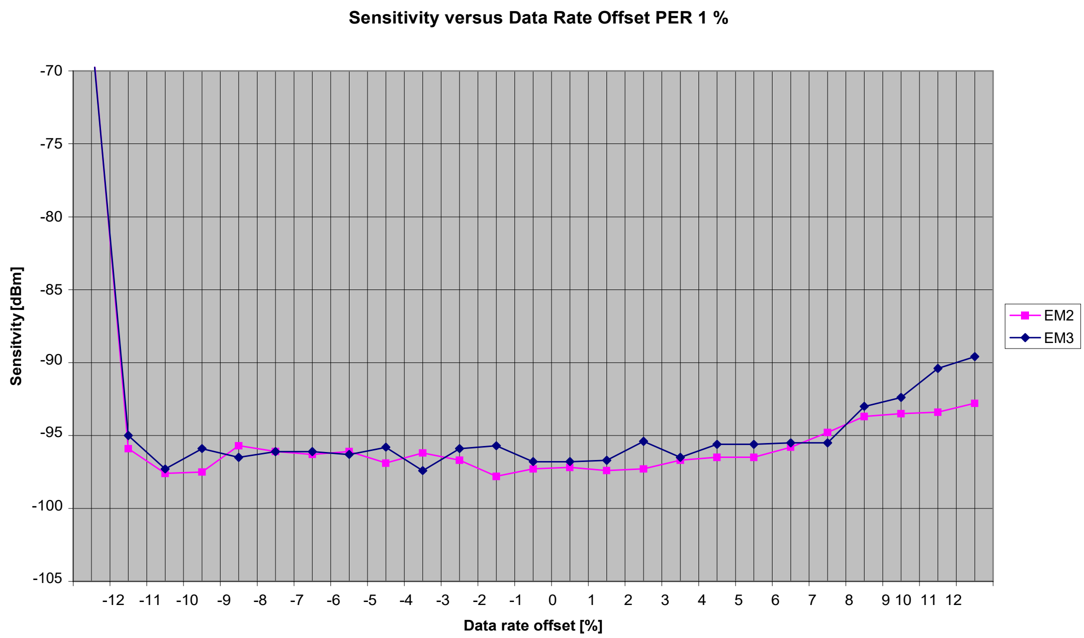


Figure 9. Sensitivity at PER 1% versus Data Rate Offset

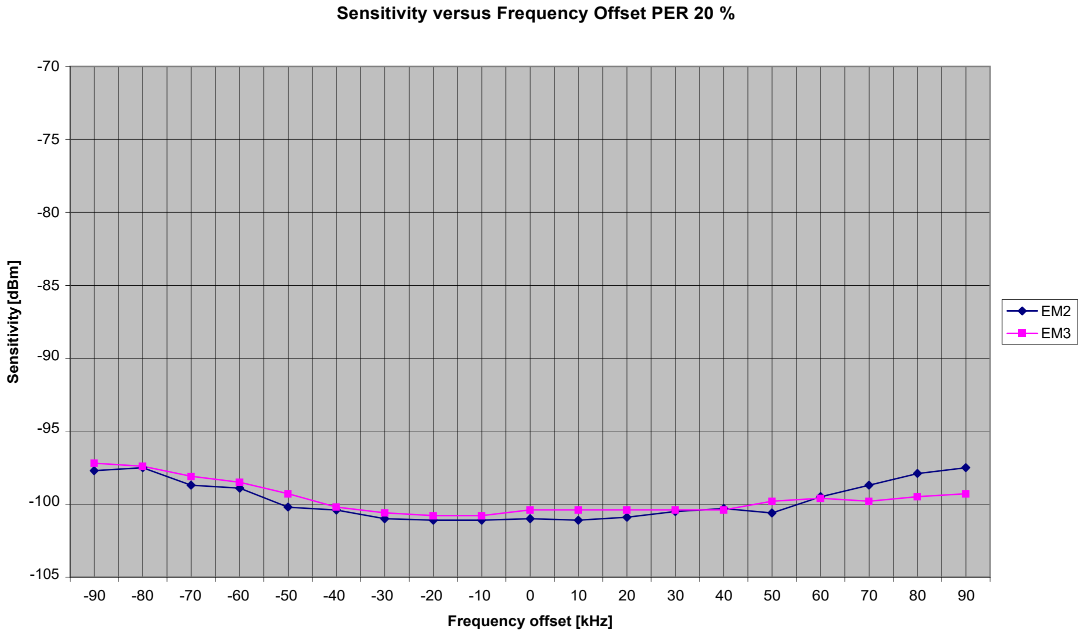


Figure 10. Sensitivity at PER 20% versus Frequency Offset

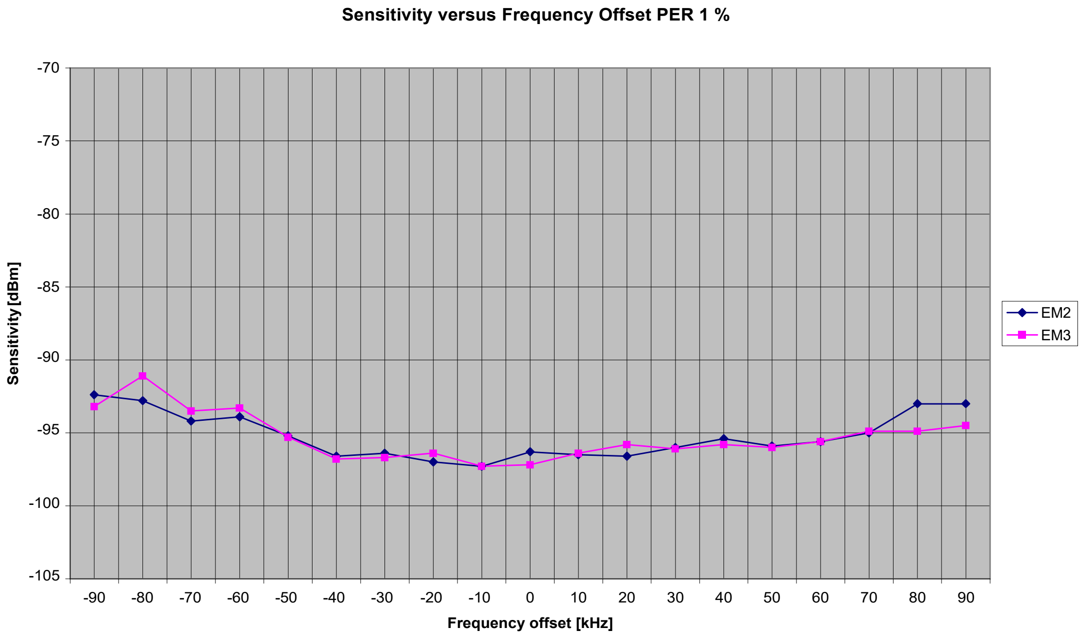


Figure 11. Sensitivity at PER 1% versus Frequency Offset

8.2.2 Summary

As seen from appendix B, a 325 kHz RX filter bandwidth is the minimum bandwidth required to get minimum degradation in performance for the complete range of valid input signals. The sensitivity for a typical wireless MBUS signal can be improved by narrowing the RX filter bandwidth. Narrowing the RX filter bandwidth will give a higher degradation in performance for a wireless MBUS signal with maximum frequency offset and frequency deviation.

Enabling both the data rate offset and frequency offset compensation loop with high saturation limit and high gain factors, degrades the noise immunity, and the sensitivity curve becomes less steep. Measurements with the data rate offset compensation loop disabled, gives sensitivity at -100 dBm measured for PER 1 %.

As seen from appendix B, the sensitivity at PER 1 % versus date rate offset with 40 kHz and 80 kHz frequency deviation, shows the difference in performance between the two different receiver configurations. For best overall performance a receiver setting with 38 kHz deviation is preferred. Measurements with 60 and 70 kHz frequency deviation has been performed for the 38 kHz deviation receiver setting, and shows no degradation for high data rate offsets.

9 Application Software Documentation

Attached in this application note is a simple application, for the MSP430 experimenter's board, which transmits and receives wireless MBUS packets. The application is not a full wireless MBUS application, but exemplifies how the basic transmit, receive, encoding and decoding routines/drivers can be performed.

For people new to using MSP430 and CC1101 in a combination the application note AN049 [7] gives an introduction. The wireless MBUS application code is based on the HAL drivers that are included in the application note AN049. Using CC111x, which is SoC containing an 8051 core and the same radio modem as CC1101, is also fully possible.

9.1 Application User Guide

First transmit mode or receive mode is selected by pushing either the S1 button (RX) or the S2 (TX) button on the MSP430 experimenter's board. Secondly radio link A or radio link B is selected by pushing either the S1 button (radio link A) or the S2 button (radio B).

In RX mode the LCD will display the number of successfully received packets. If an error occurred during reception a LED will blink. If the packet reception was successful the received packet will also be converted to ASCII characters and transmitted over the UART. This enables the possibility to view the received packet in a HyperTerminal. The UART on the MSP430 is configured with the following configuration.

- 15200 kbaud
- 8-bit data
- No parity bit
- 1 stop bit

In TX mode a new packet will be transmitted each time a button is pushed. The LCD is updated to display the number of packets transmitted, or a LED will blink if an error occurred during transmission.

9.2 Transmit Mode

The main stages for the transmit routine are:

- Encode Packet
    - Calculate the length of bytes to transmit
    - Packet data coding
- Initialize TX
    - Upload data to the TX FIFO
    - Enable TX
- TX Active
    - If not all data bytes are written to the TX FIFO the MCU is set in low power mode
- TX FIFO threshold interrupt – Upload data to the TX FIFO.
    - Fill the TX FIFO
    - Fixed length mode set when less than 255 bytes left to transmit
    - Signalize complete when all bytes are written

Flow diagram for the transmit routine is shown in Figure 12.

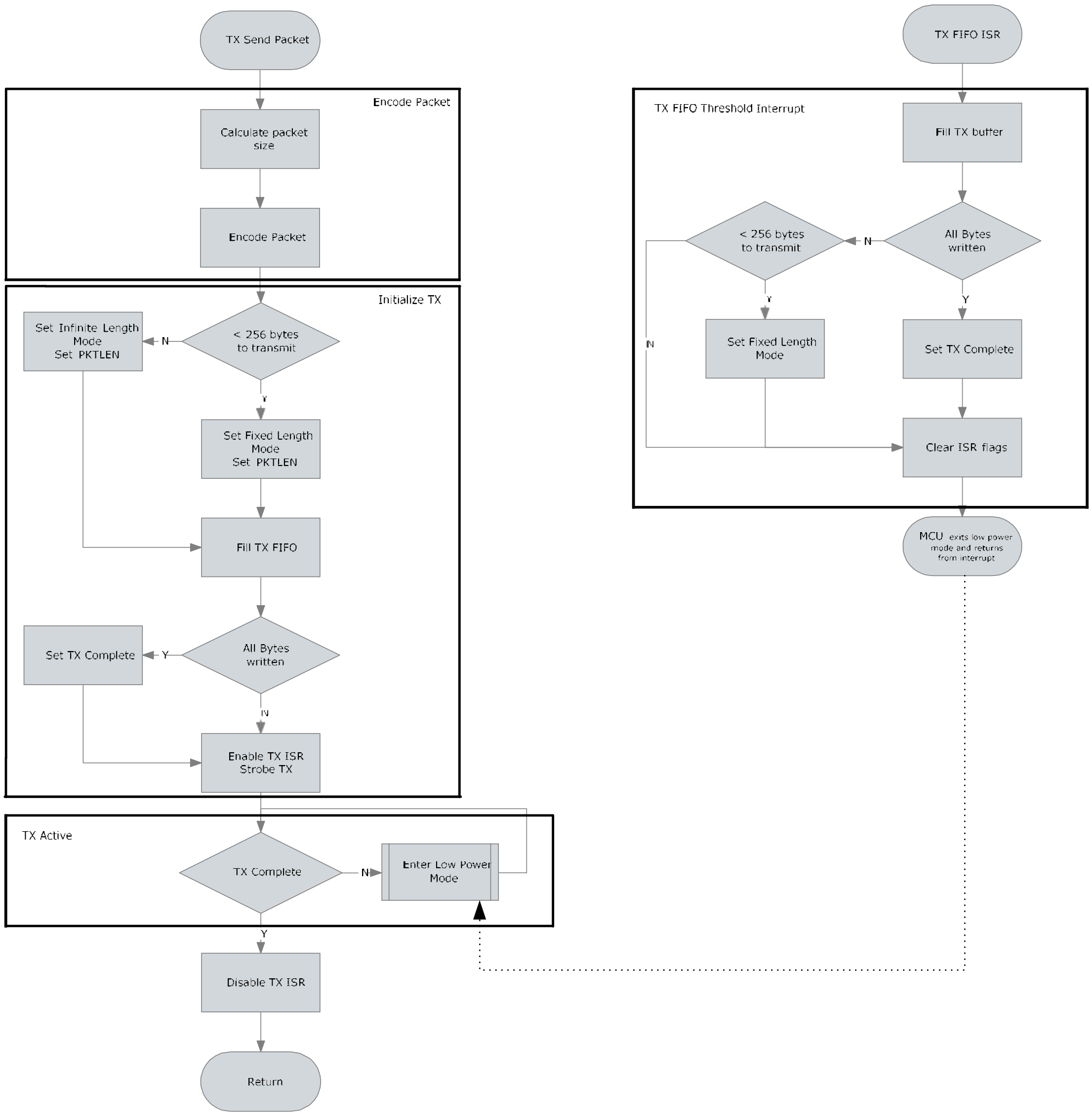


Figure 12. TX Flow Diagram

9.2.1 MCU Load

The plot shown in Figure 13 displays the LPM mode versus active mode during TX of a wireless MBUS packet with radio link A. System Clock at 4 MHz, SPI clock at 2 MHz, and TX FIFO threshold at 32 bytes.

- LPM -> 1 : Active mode
- LPM -> 0 : Low Power mode

- GD0 -> 1: TX FIFO above threshold
- GD0 -> 0: TX FIFO bellow threshold

During the first active mode the wireless MBUS packet is data encoded, and the TX FIFO filled. In the subsequent active mode the TX FIFO threshold interrupt has triggered, and the TX FIFO is filled.

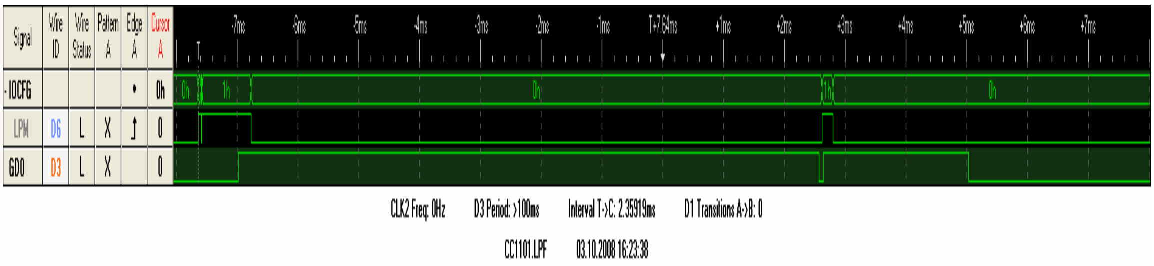


Figure 13: TX Active versus LPM

The time between the TX enabled and the first TX FIFO Threshold interrupt can also be calculated as shown bellow.

$$\frac{1}{32768} * (32 * 8 + 2 * 8 + 4 * 8) = 9.3ms$$

The packet engine will automatically insert the preamble sequence and the synchronization word, before data from the TX FIFO is transmitted. Timing between consecutive FIFO thresholds interrupt can be calculated as shown bellow.

$$\frac{1}{32768} * (32 * 8) = 7.8ms$$

9.3 Receive Mode

The main stages for the receive routine are:

- Initialize RX
  - Set infinite length mode
  - Set FIFO Threshold to 4 bytes
- RX Active
  - If not all data bytes are read from the RX FIFO the MCU is set in low power mode
- RX FIFO 4 Bytes Threshold Interrupt – Start of packet
  - The length field is read out from the RX FIFO
  - Total length of bytes to receive is calculated
  - Length mode is set to fixed length mode if less than 255 bytes left to receive
  - PKTLEN is calculated and set
- RX FIFO 32 Bytes Threshold Interrupt: - Read RX FIFO
  - The RX FIFO is read
  - Length mode is set to fixed length mode if less than 255 bytes left to receive
- RX Packet Received – Packet complete
  - The remaining bytes are read out
  - Signalize complete when all bytes are read
- Decoding
  - The data packed decoding and CRC checking

Flow diagram for the receive routine is shown in Figure 14.

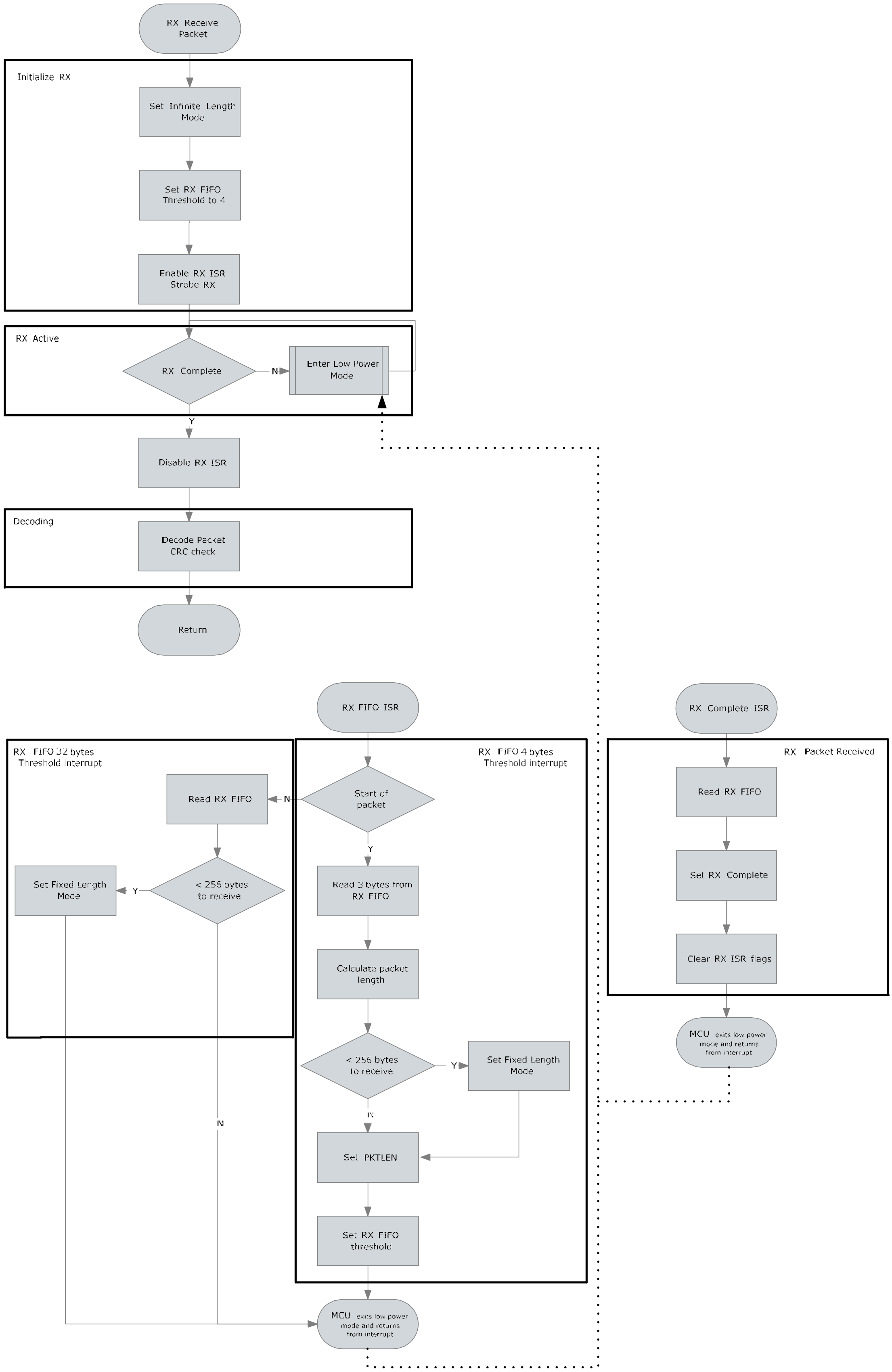


Figure 14. RX Flow Diagram

9.3.1 MCU Load

The plot shown in Figure 15 displays the LPM mode versus active mode during RX of a wireless MBUS packet with radio link A.

System Clock at 4 MHz, SPI clock at 2 MHz and FIFO threshold at 32 bytes

- LPM -> 1 : Active mode
- LPM -> 0 : Low Power mode

- GD0 -> 1: RX FIFO above threshold
- GD0 -> 0: RX FIFO bellow threshold

- GD2 -> 1: Packet reception active
- GD2 -> 0: Packet reception inactive

During the first active modes the RX FIFO ISR are triggered and received data read out. During the last active mode, the RX FIFO is emptied, and the received data is decoded into a wireless MBUS packet, with CRC verification.

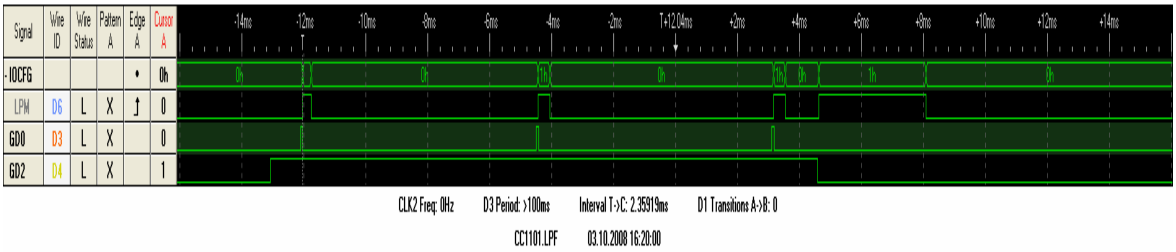


Figure 15: RX Active versus LPM

Timing between consecutive RX FIFO threshold interrupts can also be calculated as shown bellow.

$$\frac{1}{32768} * 32 * 8 = 7.8ms$$

9.4 Improvements

The C code is written to be easily understandable, and not optimized for speed or size. Hence there are several improvements that can be done to optimize the code, based on the final user application.

The active mode versus low power mode ratio can easily be reduced by increasing the system clock speed and/or increasing the SPI clock speed.

CRC can be implemented by using look-up tables, which will speed up the code. There is already an application note that describes this using the MSP430 [8].

Data encoding and decoding performance is dependent on the look-up table sizes.

Packet encoding and decoding can be performed during transmit and receive, if the MCU has enough recourses, dependent on the full application on the MSP430.

If the user wants the MCU to execute other tasks during active TX/RX mode, then the TX/RX routine must be slightly changed, such that the TX/RX state monitoring is done in the main application routine.

10 References

[1] European standard EN 13757-4:2005 "Communication system for meters and remote reading of meters".

[2] ETSI EN 300 220 V2.1.1: 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"

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

[4] Application Note AN050 Using the CC1101 in the European 868 MHz SRD band (swra146a.pdf)

[5] CC1101EM 868 and 915MHz Reference Design (swrr045.zip)

[6] Design Note DN005 CC11xx Sensitivity versus Frequency Offset and Crystal Accuracy (swra122a.pdf)

[7] Application Note AN049 Software for CC1100/CC2500 and MSP430 – Examples and Function Library (swra141.pdf)

[8] Application Note CRC Implementation with MSP430 (slaa221.pdf)

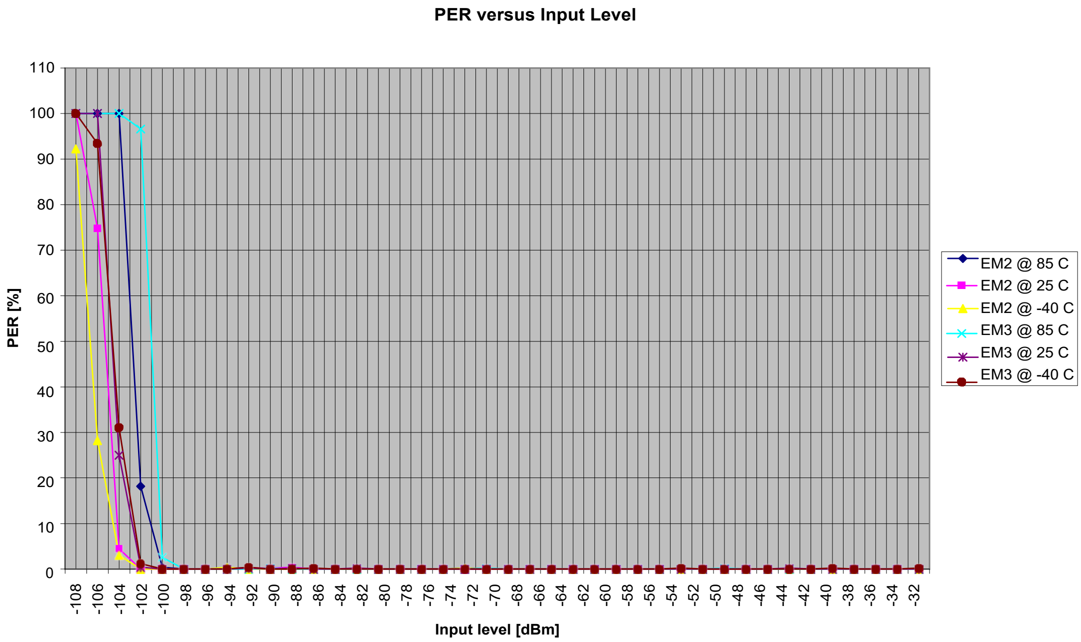
11 Document History

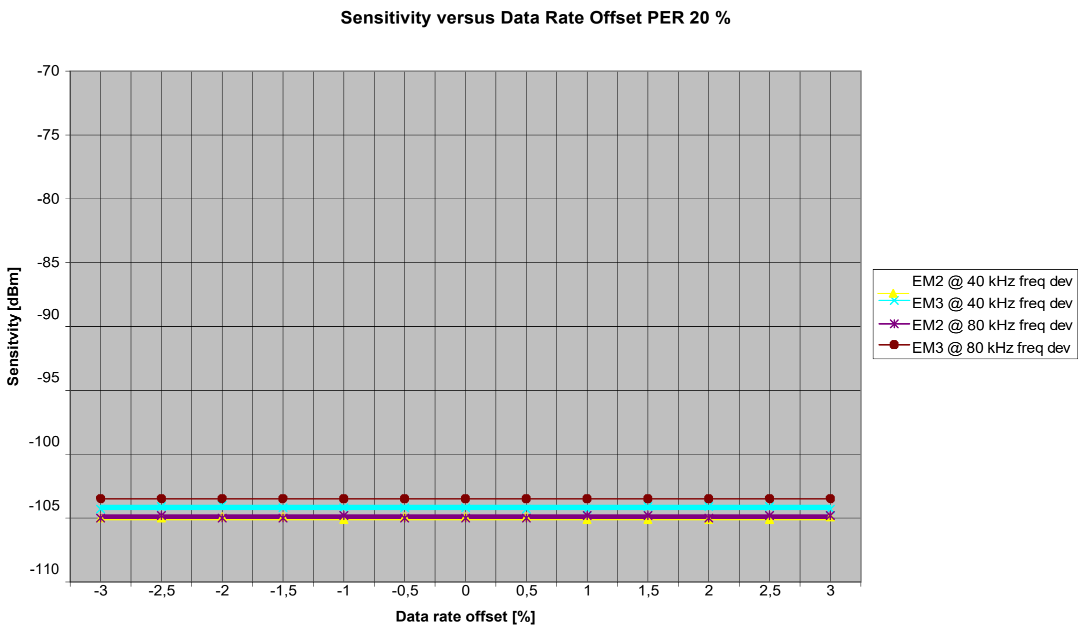
Revision	Date	Description/Changes
SWRA234	2008.10.23	Initial release.

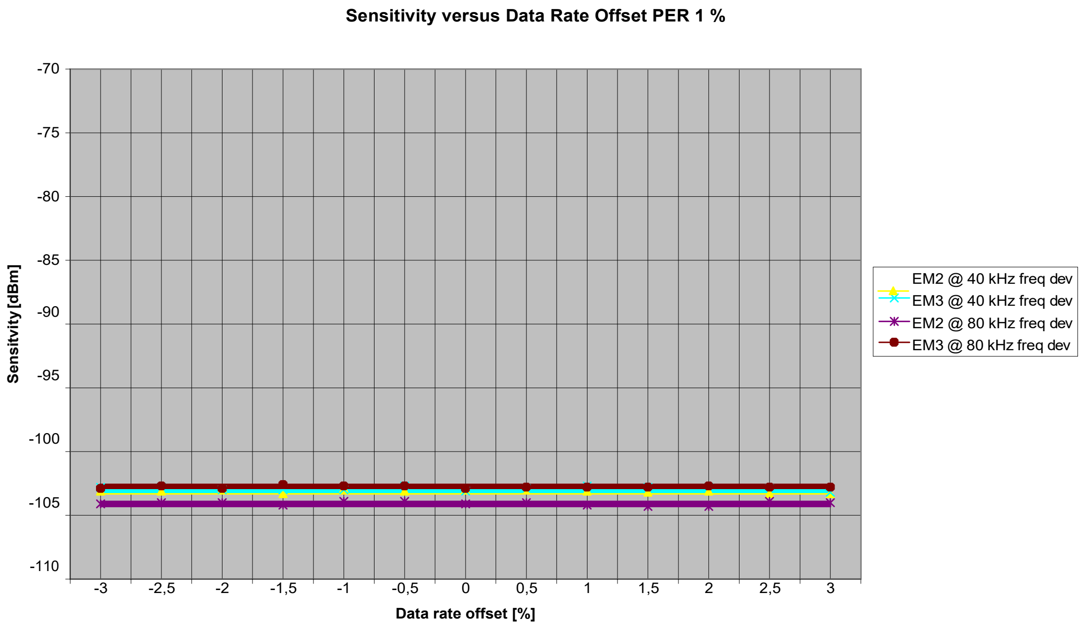
Appendix A

The following diagrams for Radio link A show

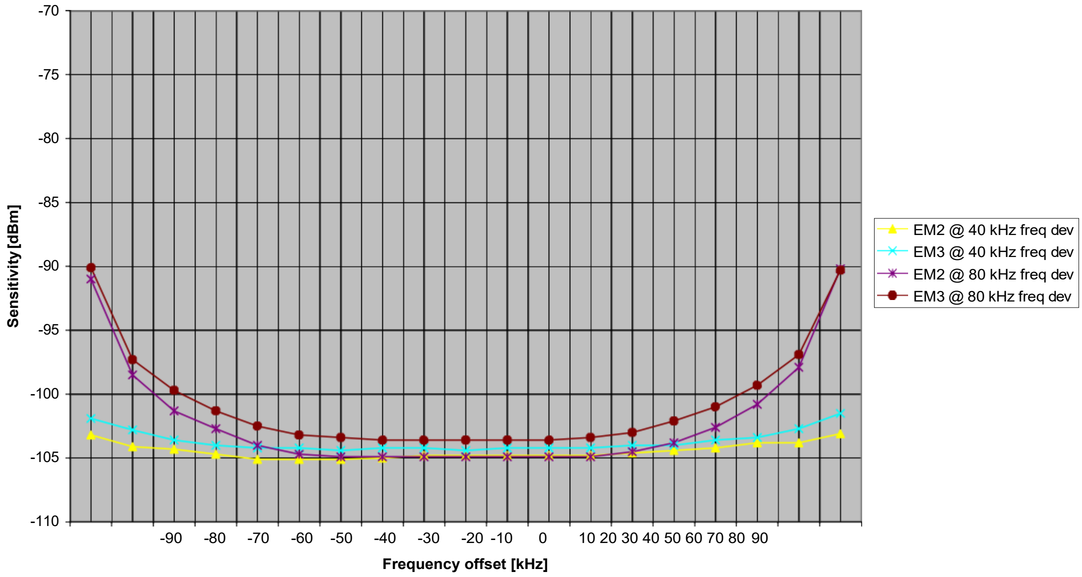
- Packet error rate versus input level over temperature
- Sensitivity versus frequency offset with different frequency deviation
- Sensitivity versus data rate offset with different frequency deviation



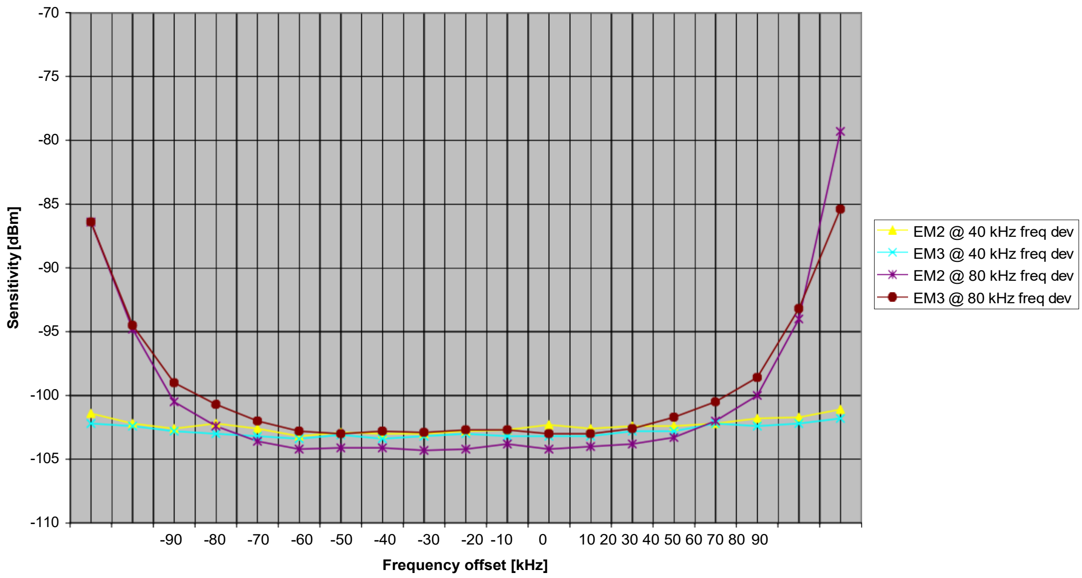

Sensitivity versus Data Rate Offset PER 20 %
Sensitivity [dBm]
-70
-75
-80
-85
-90
-95
-100
-105
-110
-3
-2,5
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
2,5
3
Data rate offset [%]
EM2 @ 40 kHz freq dev
EM3 @ 40 kHz freq dev
EM2 @ 80 kHz freq dev
EM3 @ 80 kHz freq dev


Sensitivity versus Data Rate Offset PER 1 %
Sensitivty [dBm]
-70
-75
-80
-85
-90
-95
-100
-105
-110
-3
-2,5
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
2,5
3
Data rate offset [%]
EM2 @ 40 kHz freq dev
EM3 @ 40 kHz freq dev
EM2 @ 80 kHz freq dev
EM3 @ 80 kHz freq dev

Sensitivity versus Frequency Offset PER 20 %



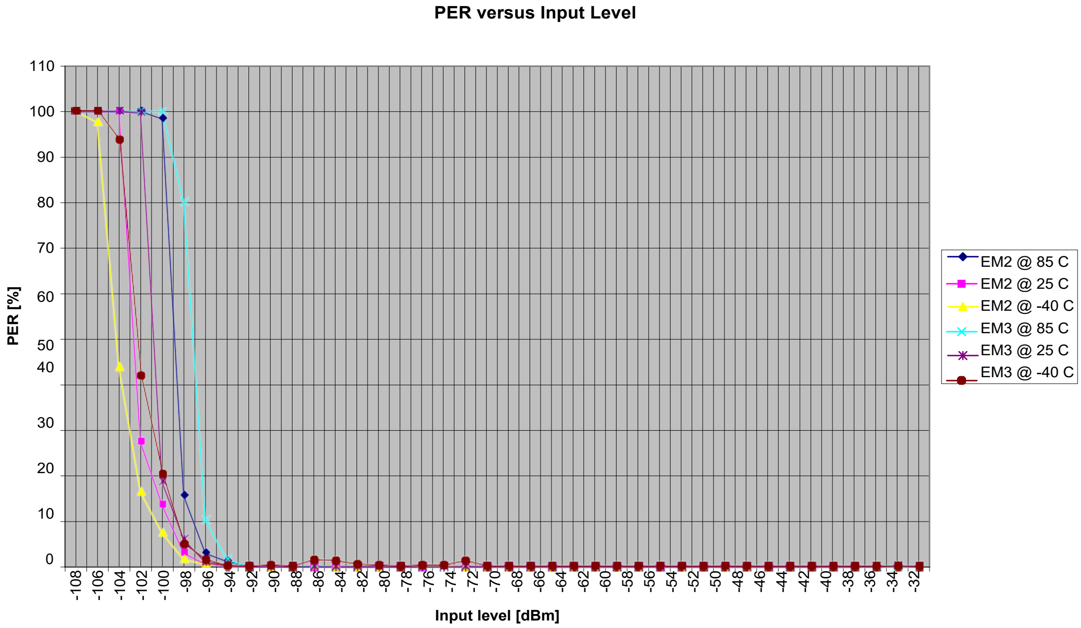
Sensitivity versus Frequency Offset PER 1 %

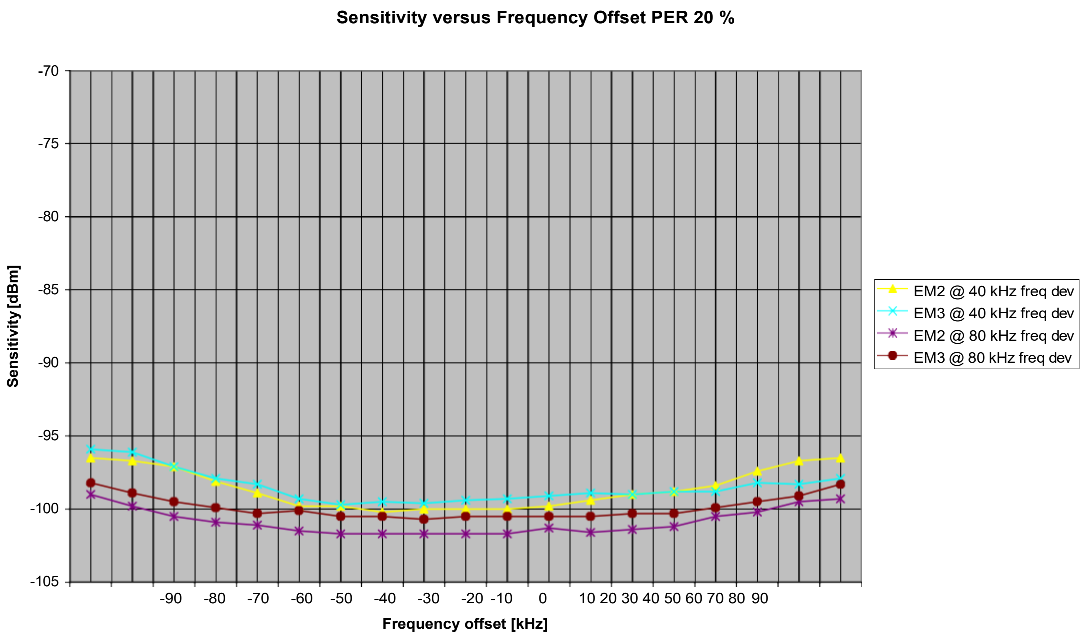


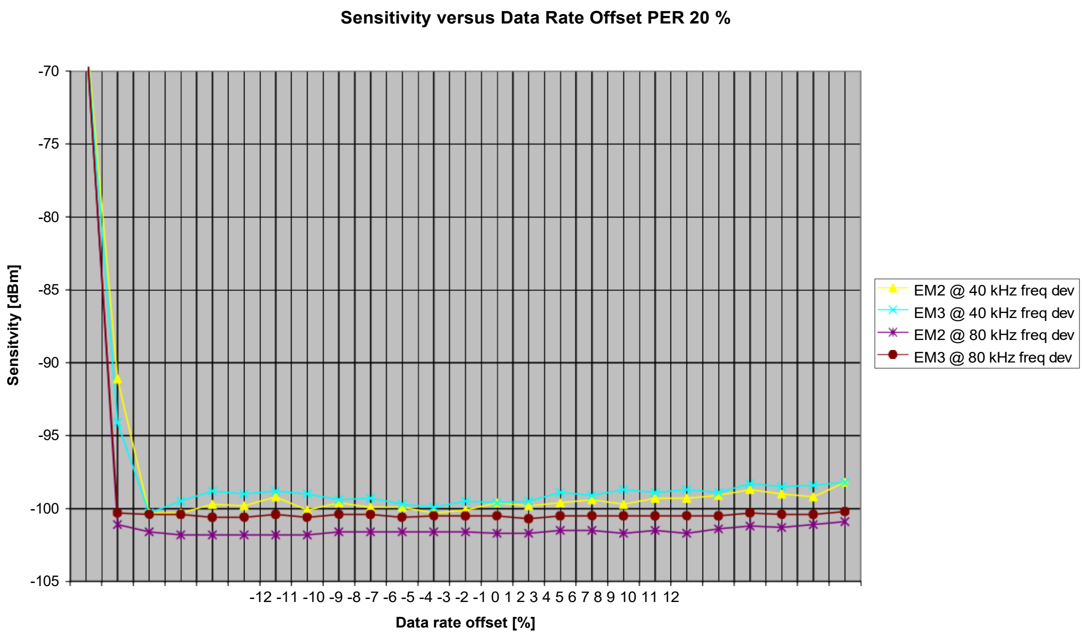
Appendix B

The following diagrams for Radio link B show

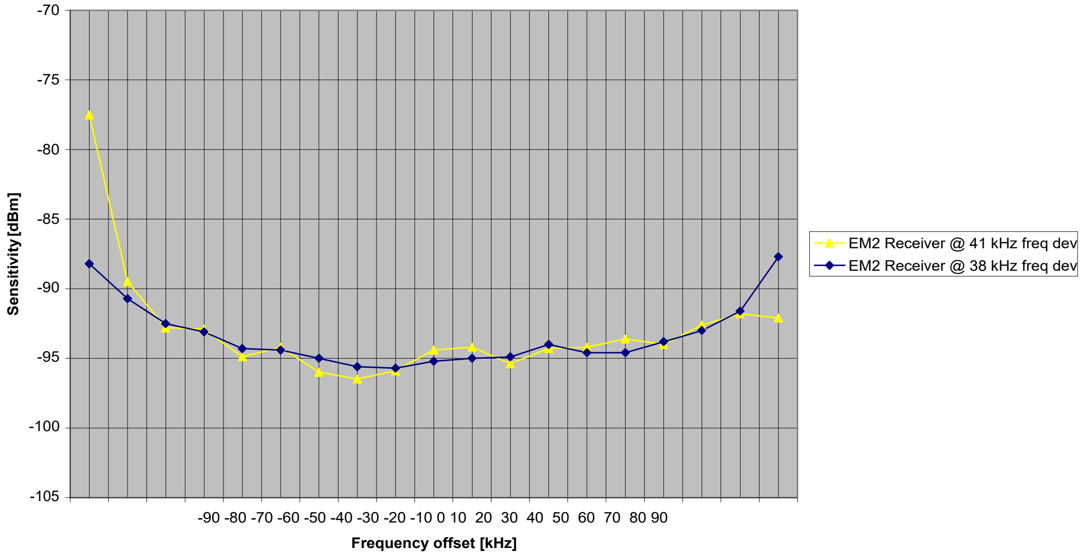
- Packet error rate versus input level over temperature
- Sensitivity versus frequency offset with different frequency deviation
- Sensitivity versus data rate offset with different frequency deviation



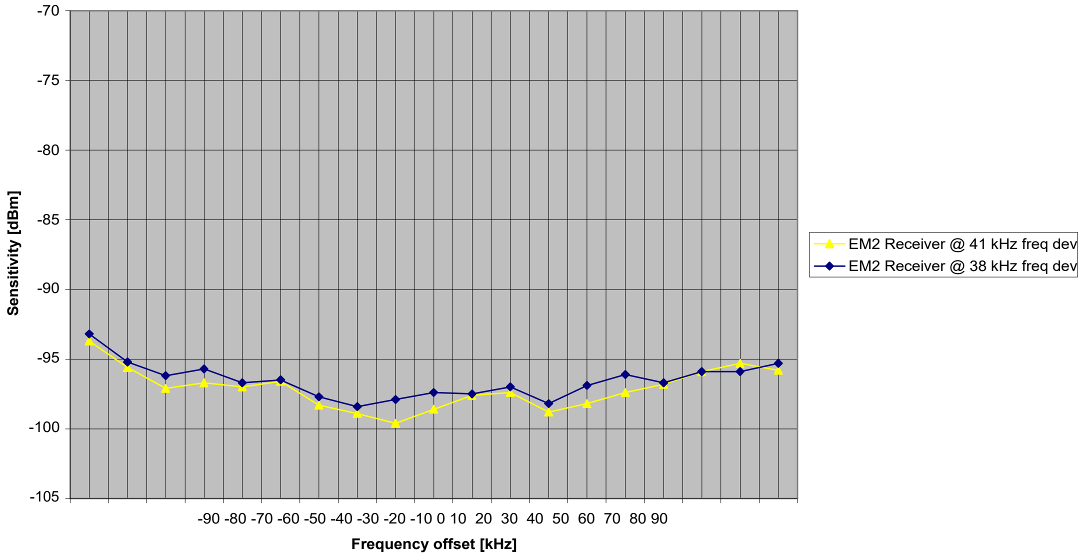

Sensitivity versus Frequency Offset PER 20 %
-70
-75
-80
-85
-90
-95
-100
-105
Sensitivity [dBm]
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Frequency offset [kHz]
EM2 @ 40 kHz freq dev
EM3 @ 40 kHz freq dev
EM2 @ 80 kHz freq dev
EM3 @ 80 kHz freq dev

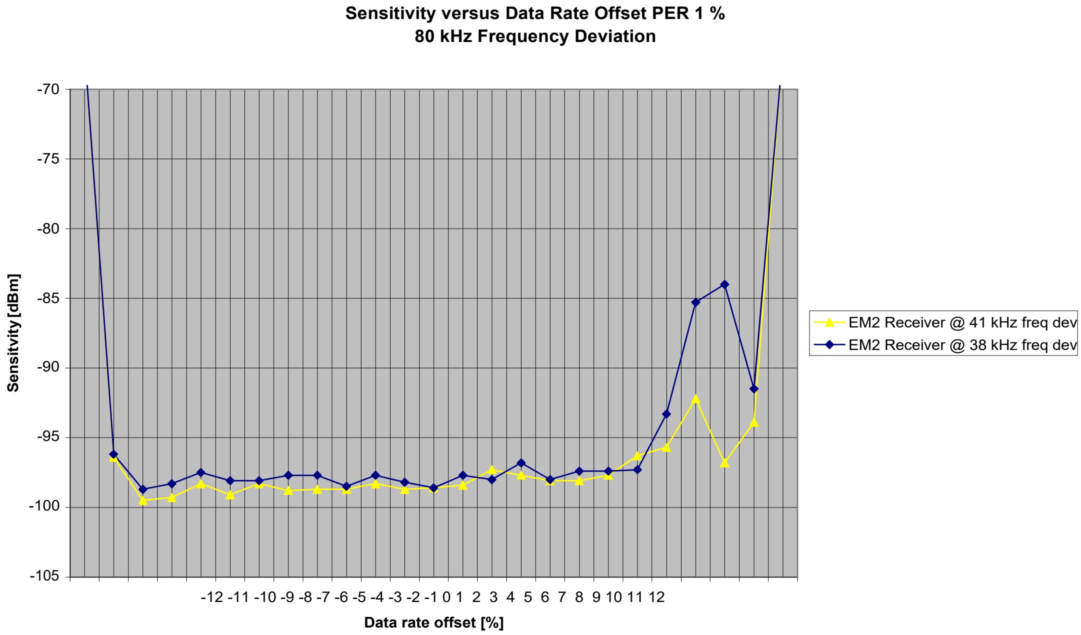

Sensitivity versus Data Rate Offset PER 20 %
-70
-75
-80
-85
-90
-95
-100
-105
Sensitivity [dBm]
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12
Data rate offset [%]
EM2 @ 40 kHz freq dev
EM3 @ 40 kHz freq dev
EM2 @ 80 kHz freq dev
EM3 @ 80 kHz freq dev

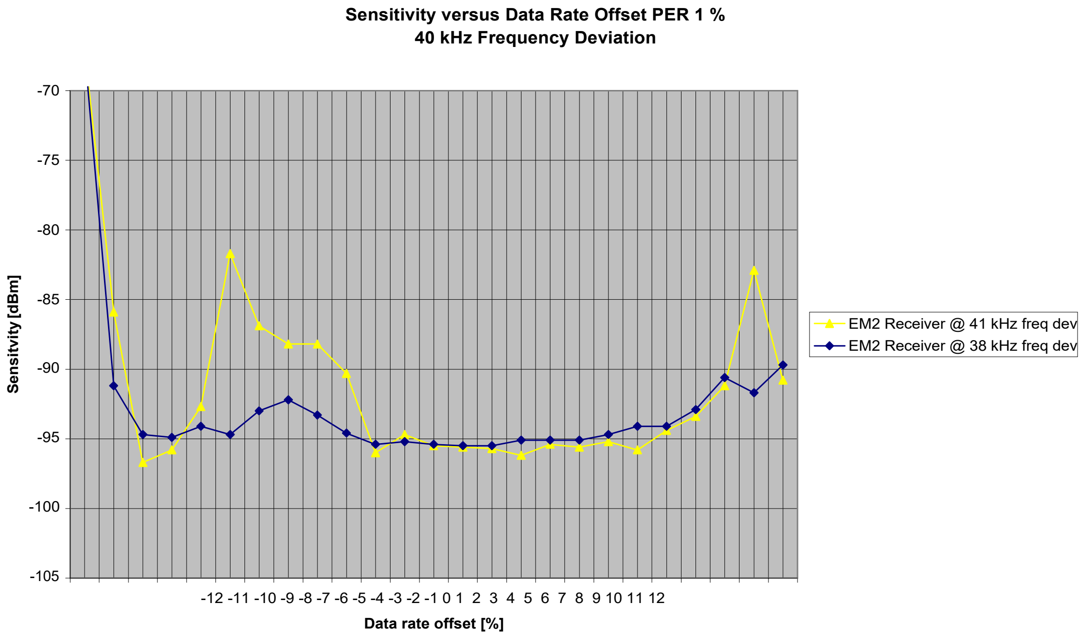
Sensitivity versus Frequency Offset PER 1 %
40 kHz Frequency Deviation



Sensitivity versus Frequency Offset PER 1 %
80 kHz Frequency Deviation




Sensitivity versus Data Rate Offset PER 1 %
80 kHz Frequency Deviation
Sensitvity [dBm]
-70
-75
-80
-85
-90
-95
-100
-105
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12
Data rate offset [%]
EM2 Receiver @ 41 kHz freq dev
EM2 Receiver @ 38 kHz freq dev


Sensitivity versus Data Rate Offset PER 1 %
40 kHz Frequency Deviation
Sensitvity [dBm]
-70
-75
-80
-85
-90
-95
-100
-105
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12
Data rate offset [%]
EM2 Receiver @ 41 kHz freq dev
EM2 Receiver @ 38 kHz freq dev

Appendix C

CC1101 Register Settings for Radio Link A:

IOCFG2=0x06
IOCFG1=0x2E
IOCFG0=0x02 (TX) or 0x00 (RX)
FIFOTHR=0x7
SYNC1=0x76 (RX) or 0x54 (TX)
SYNC0=0x96 (RX) or 0x76 (TX)
PKTLEN=0xFF
PKTCTRL1=0x0
PKTCTRL0=0x0
ADDR=0x0
CHANNR=0x0
FSCTRL1=0x8
FSCTRL0=0x0
FREQ2=0x21
FREQ1=0x65
FREQ0=0x6A
MDMCFG4=0x6A
MDMCFG3=0x4A
MDMCFG2=0x5
MDMCFG1=0x22
MDMCFG0=0xF8
DEVIATN=0x47
MCSM2=0x7
MCSM1=0x30
MCSM0=0x18
FOCCFG=0x2E
BSCFG=0x6D
AGCCTRL2=0x4
AGCCTRL1=0x9
AGCCTRL0=0xB2
WOREVT1=0x87
WOREVT0=0x6B
WORCTRL=0xFB
FREND1=0xB6
FREND0=0x10
FSCAL3=0xEA
FSCAL2=0x2A
FSCAL1=0x0
FSCAL0=0x1F
RCCTRL1=0x41
RCCTRL0=0x0
FSTEST=0x59
PTEST=0x7F
AGCTEST=0x3F
TEST2=0x81
TEST1=0x35
TEST0=0x9

Appendix D

CC1101 Register Settings for Radio Link B:

IOCFG2=0x06
IOCFG1=0x2E
IOCFG0=0x02 (TX) or 0x00 (RX)
FIFOTHR=0x7
SYNC1=0x54
SYNC0=0x3D
PKTLEN=0xFF
PKTCTRL1=0x4
PKTCTRL0=0x0
ADDR=0x0
CHANNR=0x0
FSCTRL1=0x8
FSCTRL0=0x0
FREQ2=0x21
FREQ1=0x6B
FREQ0=0xD0
MDMCFG4=0x5C (RX:103 kbaud) or 0x5B (TX:100 kbaud)
MDMCFG3=0x4 (RX:103 kbaud) or 0xF8 (TX:100 kbaud)
MDMCFG2=0x5
MDMCFG1=0x22
MDMCFG0=0xF8
DEVIATN= 0x44 (RX: 38 kHz) or 0x50 (TX: 50 kHz)
MCSM2=0x7
MCSM1=0x00
MCSM0=0x18
FOCCFG=0x2E
BSCFG=0xBF
AGCCTRL2=0x43
AGCCTRL1=0x9
AGCCTRL0=0xB5
WOREVT1=0x87
WOREVT0=0x6B
WORCTRL=0xFB
FREND1=0xB6
FREND0=0x10
FSCAL3=0xEA
FSCAL2=0x2A
FSCAL1=0x0
FSCAL0=0x1F
RCCTRL1=0x41
RCCTRL0=0x0
FSTEST=0x59
PTEST=0x7F
AGCTEST=0x3F
TEST2=0x81
TEST1=0x35
TEST0=0x9

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