

## **CC13xx Combined WMBUS C-Mode and T-Mode**

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### **ABSTRACT**

This application note describes a combined WMBUS C-Mode and T-Mode patch for the CC13xx SimpleLink™ Sub-1 GHz ultra-low power wireless microcontroller.

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## 1 Introduction

This application note provides a brief description of the patch, relevant status and configuration registers, and required overrides. The performance figures for the CC1310 device when using the patch are included in [Section 4](#) and [Section 5](#).

All measurements were performed on the CC13xxEM-7793\_4L reference design (see [\[1\]](#)).

Measurements show that the CC13xx device meets EN13757-4:2012 (see [\[2\]](#)) specifications with margin.

## 2 Combined WMBUS C-Mode and T-Mode Patch

The WMBUS PHY T-Mode and C-Mode are not available in ROM code, and a WMBUS patch is needed to support these physical layers. The WMBUS stack must use Proprietary API commands together with WMBUS related overrides. The patch and recommended register settings are found in [\[3\]](#).

### 2.1 RX

The WMBUS T-Mode and C-Mode patch can receive both T-Mode and C-Mode packets.

For C-Mode, the first 16 chips of the sync word (=0x543D) are equal to the preamble and sync word of T-Mode. The next 8 chips in C-Mode are the bit pattern 01010100. This pattern will never occur in a 3-out-of-6 encoded T-Mode frame.

When the CC1310 wakes up into RX, it will start to search for a valid sync word (=0x543D). Because it is not known whether it is a T-Mode or a C-Mode packet, 8 chips following the sync word will also be checked.

- If 01010100 is *not* detected, a T-Mode packet will be received and the patch will handle the 3-out-of-6 decoding. No CRC check is done by the patch. Automatic CC1310 CRC check must be disabled. CRC check must be handled by the application software.
- If 01010100 is detected, a C-Mode packet will be received. The patch automatically removes the 01010100 signaling byte. No CRC check is done by the patch. Automatic CC1310 CRC check must be disabled. CRC check must be handled by the application software.

After setting the CC13xx device into RX, a search for valid sync word will only take place if one of the following conditions is fulfilled:

- (16 bit preamble detection with 0 bit errors) && CS
- (12 bit preamble detection with up to 2 bit errors) && CS over 20 symbols.

The carrier sense (CS) threshold is set to -107 dBm. In an environment with a noise floor above -107 dBm, it is advantageous to increase the CS threshold to reduce the likelihood of processing a false packet. If the CC13xx device is preoccupied processing a false packet, there is a finite possibility that a true packet will be missed.

The CS threshold is set by bits [7-0] in register 0x4004609 (see [Table 1](#)).

**Table 1. Carrier Sense Threshold**

Register	Bit	Field Name	Description
0x4004 6090	7-0	CS_THR	Carrier Sense Threshold CS_THR_dBm = CS_THR-256 [dBm]

As an example, the following register write sets the carrier sense threshold to -107 dBm:

HW\_REG\_OVERRIDE (0x6090, 0x0A95)

Increasing the carrier threshold to -104 dBm (for example) gives HW\_REG\_OVERRIDE (0x6090, 0x0A98).

## 2.2 TX

The WMBUS T-Mode and C-Mode patch can transmit both T-Mode and C-Mode packets.

- In T-Mode, the patch does the 3-out-of-6 encoding of data.
- In C-Mode, the patch automatically inserts 01010100 signaling byte after the preamble and sync word. The patch does not do any encoding of data in C-Mode.
- Automatic CC1310 CRC calculation must be disabled. CRC calculation must be handled by the application software.

WMBUS must be run with WMBUS T-Mode and C-Mode MCE patch and may run RFE from ROM.

## 2.3 Recommended Operating Limits

The patch is only designed for WMBUS T-Mode and C-Mode. This means that the patch has many values that are hard coded (for example, data rate and packet format). The user needs to set the following to make the patch work properly:

- Set the data rate to 100 kbps
- Set the number of preambles to  $\geq 4$  bytes
- Set the sync word to 0x0000543D
- Set the number of sync word bits to 16
- Enable the MSB first
- Set the RF frequency to 868.95 MHz
- Do not change the correlator setting through the Prop API. Use override (uint32\_t)0x00048103 to let the patch control the correlator setting.
- The maximum sync search time is 6 minutes. If sync is not found within this time limit, RX should be restarted.

### 2.3.1 API Configuration

Table 2 lists the required changes to the recommended 50 kbps, 2-GFSK radio operation commands from SmartRF™ Studio (see [4]) to be compliant with recommended operation limits in Section 2.3.

**Table 2. API Settings Required for the Patch**

Radio Operation Command	Field Name	Value
CMD_PROP_RADIO_DIV_SETUP	modulation.modType	0
	modulation.deviation	0xC8 (T-Mode), 0xB4 (C-Mode)
	symbolRate.preScale	12
	symbolRate.rateWord	52429
	rxBw	39
	preamConf.nPreamBytes	4
	preamConf.preamMode	0
	formatConf.nSwBits	16
	formatConf.bMsbFirst	1
	centerFreq	0x0364
	intFreq	0x8000
	loDivider	5
CMD_FS	frequency	0x0364
	fractFreq	0xF333
CMD_PROP_TX	syncWord	0x0000543D
CMD_PROP_RX	syncWord	0x0000543D

### 2.3.2 Register Overrides

Table 3 lists the overrides needed *in addition* to the recommended 50 kbps, 2-GFSK radio register settings from SmartRF Studio (see [4]) to be compliant with recommended operation limits in Section 2.3.

A complete smartrf\_settings.c file is included in the zip file containing the patch (see [3]).

**Table 3. Additional Register Overrides Required for the Patch**

Override	Comment
MCE_RFE_OVERRIDE(1, 0, 0, 0, 4, 0)	Run the MCE patch
HW_REG_OVERRIDE(0x6064, 0x1101)	AGC winsize 2 samples
HW_REG_OVERRIDE(0x608C, 0x0007)	AGC settle wait = 18 samples
HW_REG_OVERRIDE(0x6090, 0xA095)	CS threshold to -107 dBm
HW_REG_OVERRIDE(0x6084, 0x37F1)	Freeze RSSI on sync found
(uint32_t)0x00048103	Let the patch control the correlator setting
HW_REG_OVERRIDE(0x51F8, 0x0000)	Clear state in internal radio register due to frequency change

One of the 50 kbps, 2-GFSK radio register settings from SmartRF Studio must be removed (see Table 4).

**Table 4. Register Overrides to be Removed from 50 kbps, 2-GFSK Radio Register Settings**

Override	Comment
HW_REG_OVERRIDE(0x6088, 0xFFFF)	Remove from SmartRF Studio code export

## 2.4 Configuration and Status Registers

Table 5 lists the configuration register available in the WMBUS patch.

**Table 5. Configuration Registers**

Register	Bit	Field Name	Description	Default
0x4004 52B4	14	TxPacketType	0: Transmit T mode packet 1: Transmit C mode packet	0x00
	13	Invert Data	0: No invert T-Mode data 1: Invert T-Mode Data	0x00
	12	DisablePQT	0: Preamble qualifier enabled 1: Preamble qualifier disabled	0x00
	11–0	Not in use		0x00

This register can only be changed through static overrides of the following format:

HW\_REG\_OVERRIDE(0x52B4, 0xFFFF)

Table 6 lists the status registers available in the WMBUS patch.

**Table 6. Status Registers**

Register	Bit	Field Name	Description	Default
0x4004 5178	15–0	RxPacketType	0: Received T-Mode packet 1: Received C-Mode packet	0x00
0x4004 5180	15–0	SyncTimCnt	Sync search timeout counter	0x00
0x4004 5184	15–0	SymRateEst	Symbol rate estimation	0x00

The registers can be read using the CMD\_READ\_RFREG API command.

### 2.4.1 T-Mode Packets

The patch is default transmitting T-Mode packets. T-Mode packets are transmitted as long as Bit 14 of the hardware register 0x400452B4 is zero.

The patch automatically does the 3-out-of-6 coding. The 3-out-of-6 coding is according to EN13757-4 (see [4]).

The application software needs to read the *RxPacketType* (see Table 6) in order to know which packet type is received.

### 2.4.2 C-Mode Packets

The patch is transmitting C-Mode packets when the *TxPacketType* (see Table 5) is set to 1. The C-Mode packet has no coding.

The patch automatically inserts and removes the C-Mode signaling byte 01010100 following the preamble and sync word.

The application software needs to read the *RxPacketType* (see Table 6) in order to know which packet type is received.

## 3 Building a Software Example

To test the RF performance of the patch, the user can refer to the rfPacketRX and rfPacketTX example available when downloading the TI-RTOS for CC13xx and CC26xx devices [5]. Refer to the *Getting Started Guide\_cc13xx\_cc26xx* after installing TI-RTOS to the default location. The *Getting Started Guide* will be located in the following folder:

C:\ti\rtos\_cc13xx\_cc26xx\_x\_xx\_xx\_xx\docs

The smartrf\_settings.c file must be replaced with the file included with the document in [3]. The patch, rf\_patch\_mce\_wmbus\_ctmode.h in [3], must be stored in the same folder on the user's hard drive as the smartrf\_settings.c.

**NOTE:** When using the rfPacketRX/TX examples, the correct packet format will not be transmitting (with respect to CRC and length information).

The example and settings use variable packet-length mode and the default CRC from the CC13xx device, so the packets sent will appear as shown in Figure 1.

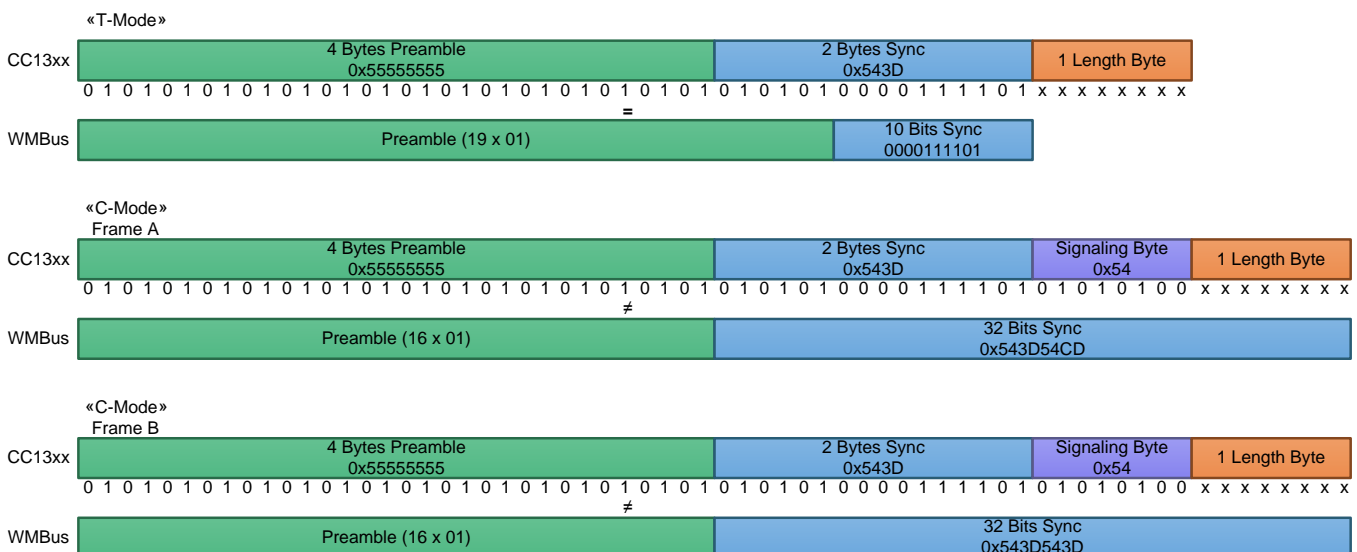


Figure 1. Packets Sent When Using rfPacketTx (Not Showing Payload and CRC)

The receiver will be set up to look for a 2-byte sync word (0x543D) and then to interpret the next byte received as the length byte.

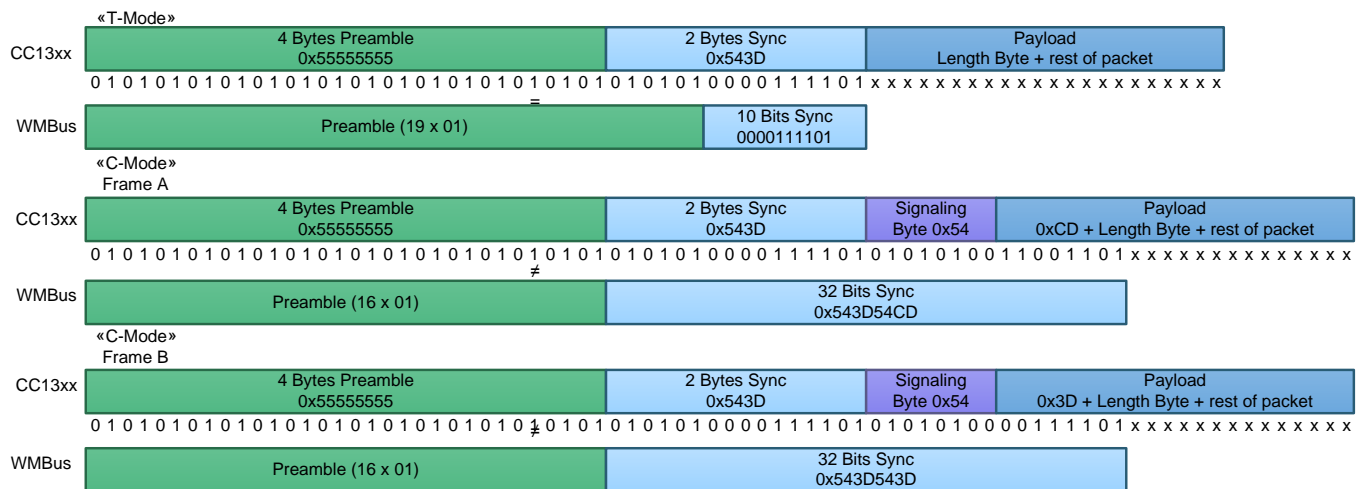
**NOTE:** Remember that the signaling byte is removed by the patch.

Figure 1 shows that for C-Mode packets, the CC13xx device will not send the last byte of the sync word (the byte containing info regarding frame format [A or B]).

To make an example that uses the correct packet format, the following actions must be taken:

### TX:

In TX mode, the user should use fixed packet length and disable CRC. For T-Mode, the length info should be the first byte, while for C-Mode, the byte containing the frame format information should be the first byte and the length byte should be the second byte (see Figure 2).



**Figure 2. TX When Using Fixed Packet Length**

### RX:

Because the patch is supporting both C-Mode and T-Mode and the receiver is unaware which packets will be received, the receiver is only searching for a 16-bit sync word (0x543D) because this is common for both modes. If a T-Mode packet is received, the length information will be the first byte the RF Core writes to the data entry used to store the received packet. If a C-Mode packet is received, the byte containing the frame format information is the first byte put in the data entry and the length byte is the second byte (the signaling byte is removed by the patch). This means that it is not possible to configure the radio in variable packet length mode because the length information is located at different byte indexes with respect to the 16-bit sync word. Fixed packet length cannot be used either because the length is not known by the receiver.

The solution is to configure the receiver for unlimited length and then use the CMD\_PROP\_SET\_LEN to set the proper length after the length information has been received.

**NOTE:** When using unlimited length mode, partial read entries must be used.

### Pseudo Code:

Use the following steps for pseudo code:

1. Enter RX and wait for the Rx\_N\_Data\_Written interrupt.
2. When interrupt is received, read RxPacketType (see [Table 6](#)) to determine if the packet is T-Mode or C-Mode.
3. If T-Mode, interpret the first byte in the entry as the length byte.
4. If C-Mode, interpret the second byte as the length byte.
5. Use the length information to set the proper length using CMD\_PROP\_SET\_LEN.

## 4 C-Mode Measurement Summary

All measurements performed with 4-byte preamble except PER versus Input Power Level (see [Section 4.3](#)).

### 4.1 Sensitivity vs Frequency Deviation

C-Mode allows the frequency deviation parameter to vary from  $\pm 33.75$  kHz to  $\pm 56.25$  kHz, where  $\pm 45$  kHz is the nominal value. [Table 7](#) lists the measurement results.

**Table 7. C-Mode 1% BER Sensitivity (55% PER, 10 Bytes Payload)**

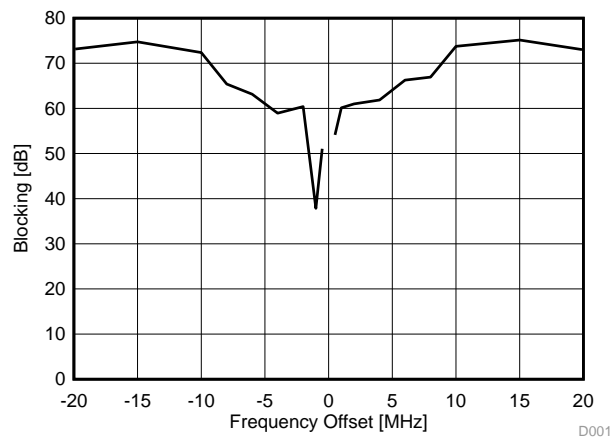
Frequency [MHz]	Typical Sensitivity [dBm]	Deviation [kHz]
868.95	-105.6	33.75
	-106.3	45 (nominal)
	-105.9	56.25

### 4.2 C-Mode Blocking

[Table 8](#) and [Figure 3](#) show the C-Mode blocking performance.

**Table 8. C-Mode Blocking**

Frequency Offset [MHz]	Blocking [dB]
$\pm 20$	73.0 / 73.1
$\pm 15$	75.1 / 74.7
$\pm 10$	73.7 / 72.4
$\pm 8$	66.9 / 65.4
$\pm 6$	66.3 / 63.1
$\pm 4$	61.9 / 58.9
$\pm 2$	61.0 / 60.4
$\pm 1$	60.1 / 37.9
$\pm 0.5$	54.1 / 51.1



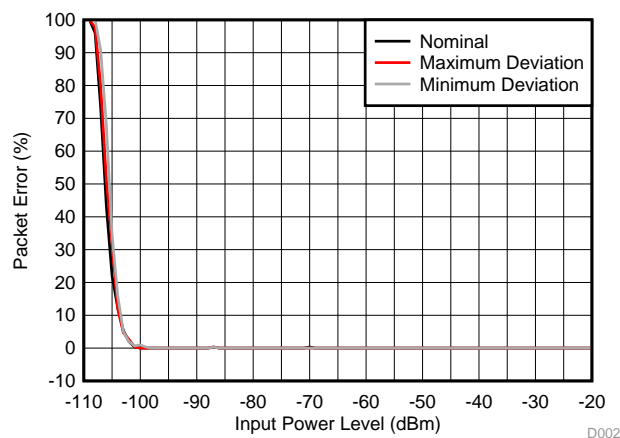
**Figure 3. C-Mode Blocking**

### 4.3 PER versus Input Power Level

The following lists PER versus Input Power Level parameters:

- 100 bps,  $\pm 45$ -kHz deviation (nominal)
- 100 bps,  $\pm 33.75$ -kHz deviation (minimum deviation)
- 100 bps,  $\pm 56.25$ -kHz deviation (maximum deviation)
- 200 packets were transmitted at each power level
- 55% PER (packet error rate) corresponds to 1% BER (bit error rate)

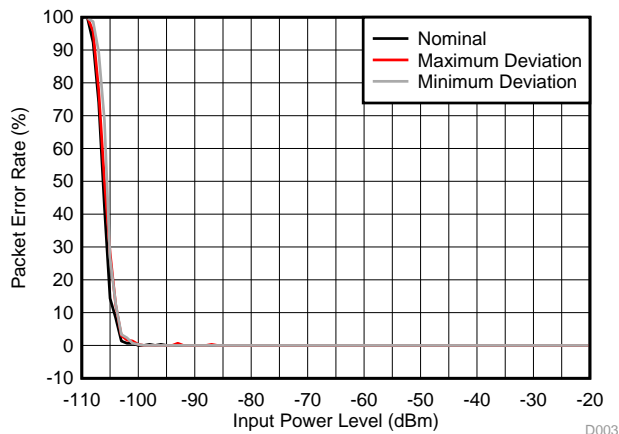
#### 4.3.1 4-Byte Preamble



**Figure 4. C-Mode PER vs Input Power Level, 4-Byte Preamble, 10-Byte Payload. Nominal, Minimum, and Maximum Deviation**

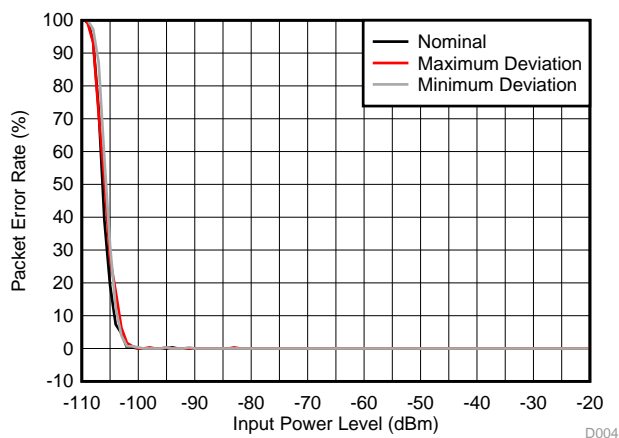


### 4.3.2 5-Byte Preamble



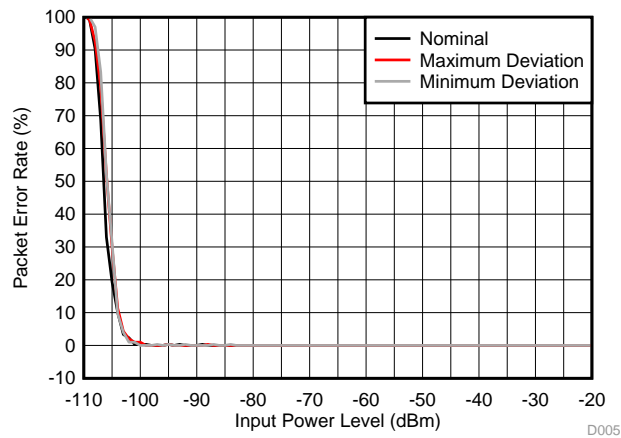
**Figure 5. C-Mode PER vs Input Power Level, 5-Byte Preamble, 10-Byte Payload. Nominal, Minimum, and Maximum Deviation**

### 4.3.3 6-Byte Preamble



**Figure 6. C-Mode PER vs Input Power Level, 6-Byte Preamble, 10-Byte Payload. Nominal, Minimum, and Maximum Deviation**

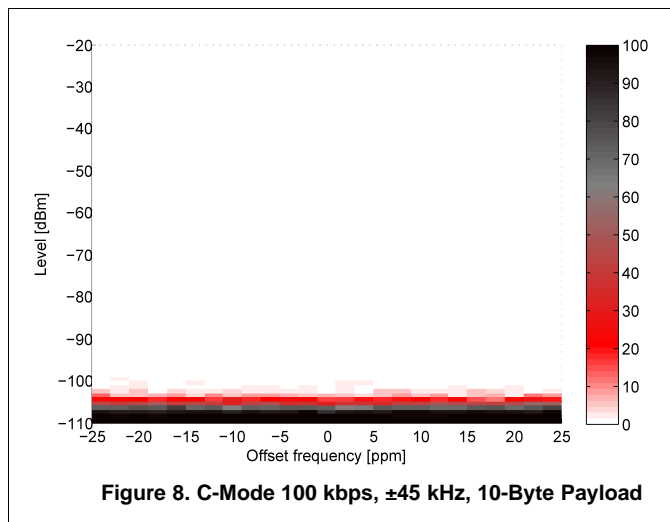
#### 4.3.4 10-Byte Preamble



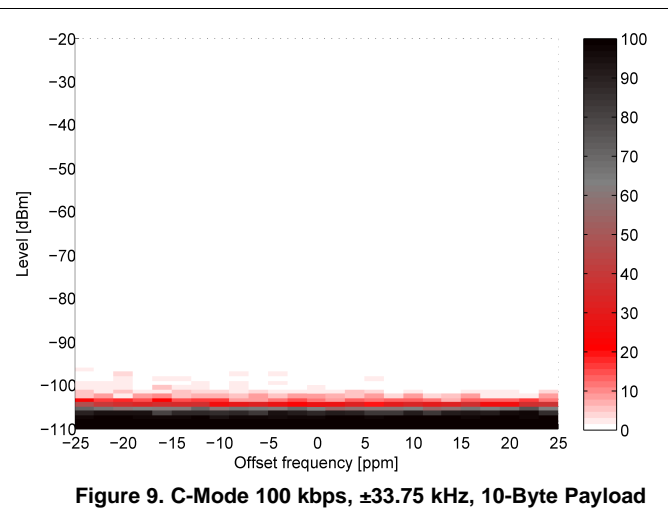
**Figure 7. C-Mode PER vs Input Power Level, 10-Byte Preamble, 10-Byte Payload. Nominal, Minimum, and Maximum Deviation**

#### 4.4 PER versus Frequency Offset

The frequency offset can be up to  $\pm 25$  ppm in C-Mode. In [Figure 8](#) through [Figure 10](#), 55% PER corresponds to 1% BER.



**Figure 8. C-Mode 100 kbps,  $\pm 45$  kHz, 10-Byte Payload**



**Figure 9. C-Mode 100 kbps,  $\pm 33.75$  kHz, 10-Byte Payload**

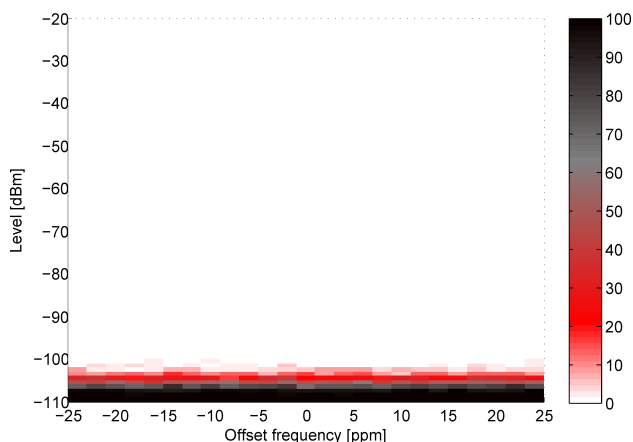


Figure 10. C-Mode 100 kbps,  $\pm 56.25$  kHz, 10-Byte Payload

## 5 T-Mode Measurement Summary

All measurements are performed with 4-byte preamble except PER versus input power level (see [Section 5.4](#)).

### 5.1 Sensitivity versus Frequency Deviation

T-Mode allows the frequency deviation parameter to vary from  $\pm 40$  kHz to  $\pm 80$  kHz, where  $\pm 50$  kHz is the nominal value. [Table 9](#) lists the measurement results.

Table 9. T-Mode Typical 1% BER Sensitivity (70% PER, 15 Bytes Payload)

Frequency [MHz]	Typical Sensitivity [dBm]	Deviation [kHz]
868.95	-105.4	40
	-105.4	50 (nominal)
	-102.3	80

### 5.2 Sensitivity versus Data Rate Offset

The chip transmit rate for *meter to other* in T-Mode is between 90 kcps and 110 kcps, where 100 kcps is the nominal value. [Table 10](#) lists the measurement results.

Table 10. T-Mode Typical 1% BER Sensitivity (70% PER, 15-Byte Payload)

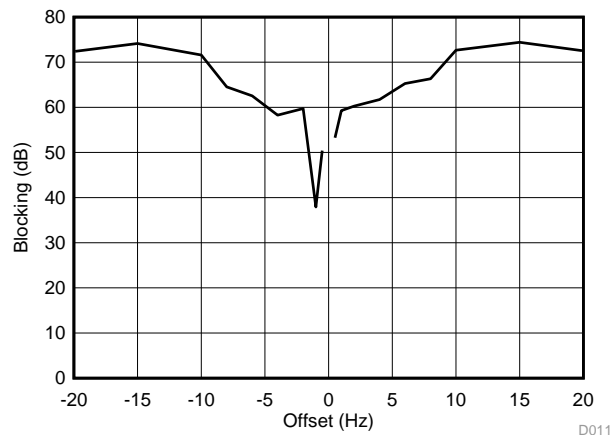
Frequency [MHz]	Typical Sensitivity [dBm]	Chip Rate [kcps]
868.95	-105.6	90
	-105.4	100 (nominal)
	-104.7	110

### 5.3 T-Mode Blocking

Table 11 and Figure 11 show the T-Mode blocking performance.

**Table 11. T-Mode Blocking**

Frequency Offset [MHz]	Blocking [dB]
±20	72.5 / 72.4
±15	74.4 / 74.1
±10	72.7 / 71.6
±8	66.3 / 64.5
±6	65.3 / 62.5
±4	61.7 / 58.3
±2	60.3 / 59.7
±1	59.3 / 37.9
±0.5	53.3 / 50.4

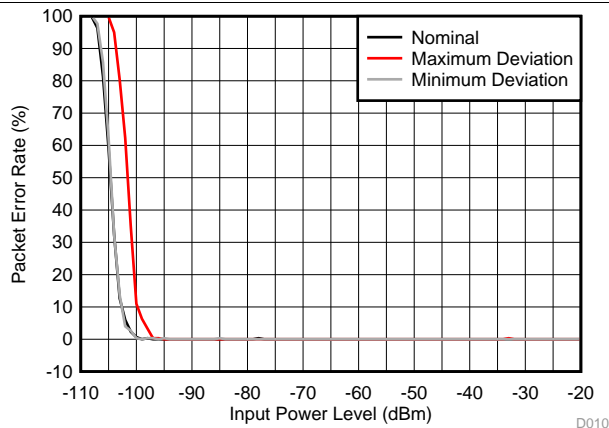


**Figure 11. T-Mode Blocking**

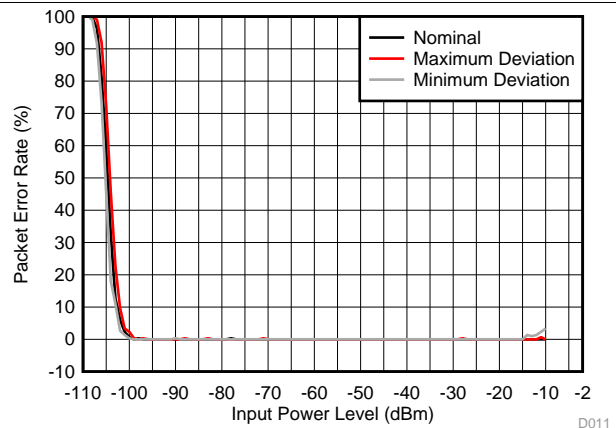
### 5.4 PER versus Input Power Level

- 100 kcps, ±50-kHz deviation (nominal)
- 100 kcps, ±40-kHz deviation (minimum deviation)
- 100 kcbps, ±80-kHz deviation (maximum deviation)
- 90 kcps, ±50-kHz deviation (minimum data rate)
- 110 kcps, ±50-kHz deviation (maximum data rate)
- 200 packets were transmitted at each power level
- 70% PER (packet error rate) corresponds to 1% BER (bit error rate)

### 5.4.1 4-Byte Preamble

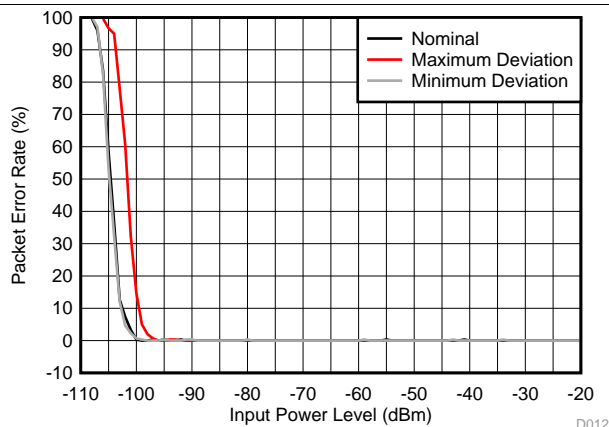


**Figure 12. T-Mode PER vs Input Power Level,  
4-Byte Preamble, 15-Byte Payload.  
Nominal, Minimum, and Maximum Deviation**

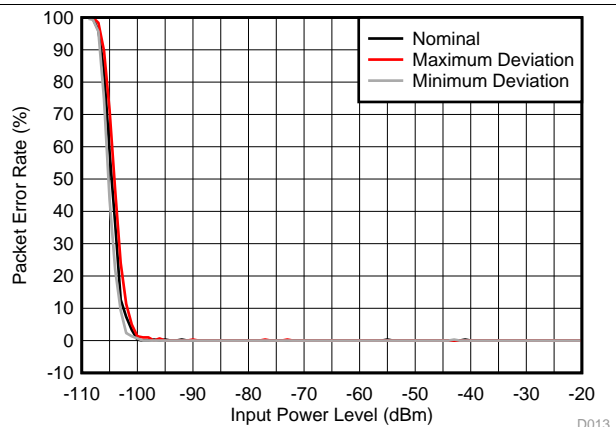


**Figure 13. T-Mode PER vs Input Power Level,  
4-Byte Preamble, 15-Byte Payload.  
Nominal, Minimum, and Maximum Data Rate**

### 5.4.2 5-Byte Preamble

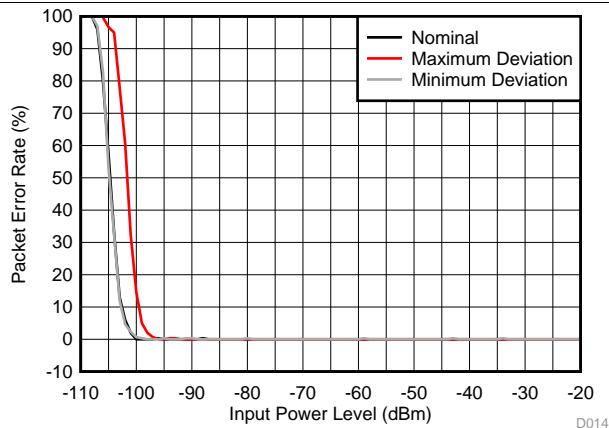


**Figure 14. T-Mode PER vs Input Power Level,  
5-Byte Preamble, 15-Byte Payload.  
Nominal, Minimum, and Maximum Deviation**

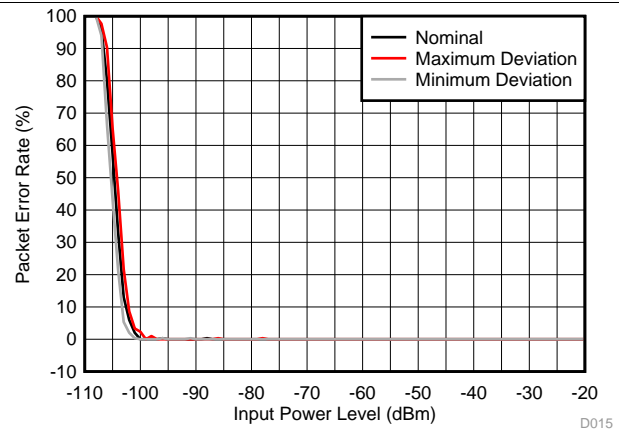


**Figure 15. T-Mode PER vs Input Power Level,  
5-Byte Preamble, 15-Byte Payload.  
Nominal, Minimum, and Maximum Data Rate**

### 5.4.3 6-Byte Preamble

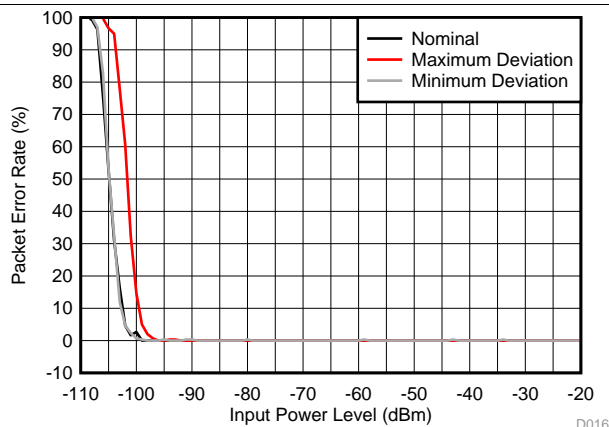


**Figure 16. T-Mode PER vs Input Power Level, 6-Byte Preamble, 15-Byte Payload. Nominal, Minimum, and Maximum Deviation**

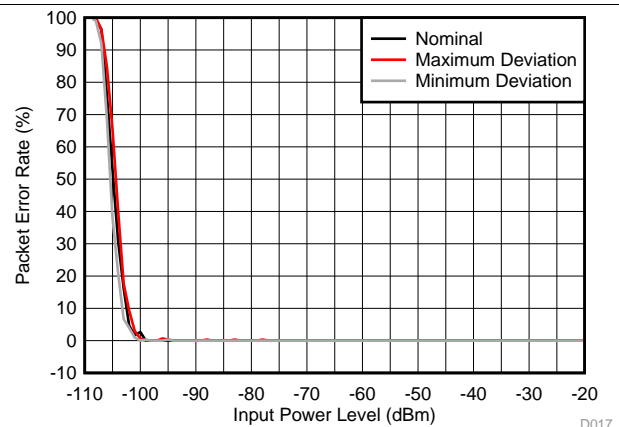


**Figure 17. T-Mode PER vs Input Power Level, 6-Byte Preamble, 15-Byte Payload. Nominal, Minimum, and Maximum Data Rate**

### 5.4.4 10-Byte Preamble



**Figure 18. T-Mode PER vs Input Power Level, 10-Byte Preamble, 15-Byte Payload. Nominal, Minimum, and Maximum Deviation**



**Figure 19. T-Mode PER vs Input Power Level, 10-Byte Preamble, 15-Byte Payload. Nominal, Minimum, and Maximum Data Rate**

#### 5.4.4.1 PER versus Frequency Offset

The frequency offset can be up to  $\pm 60$  ppm in T-Mode. In Figure 20 through Figure 24, 70% PER corresponds to 1% BER.

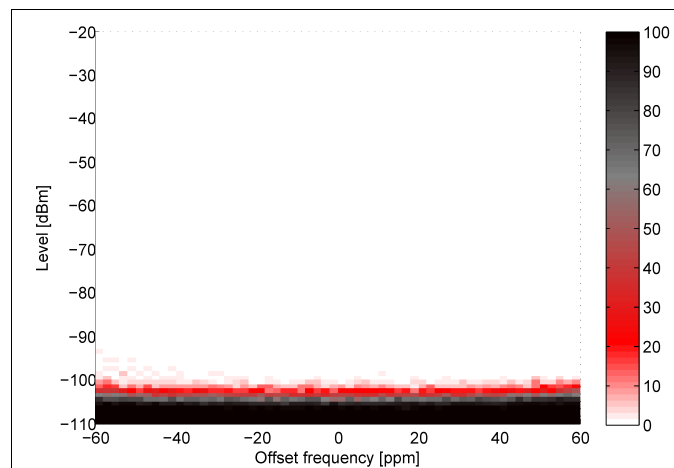


Figure 20. T-Mode 100 kcps,  $\pm 50$  kHz, 15-Byte Payload

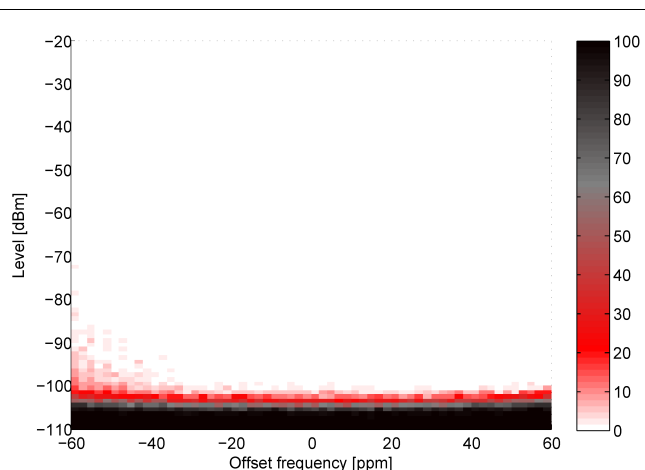


Figure 21. T-Mode 100 kcps,  $\pm 40$  kHz, 15-Byte Payload

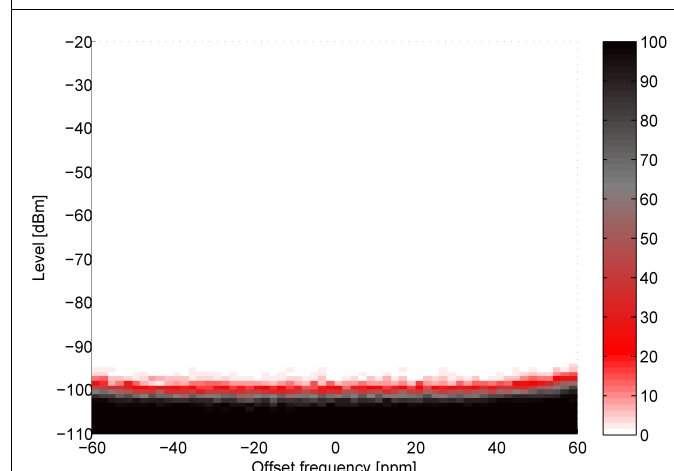


Figure 22. T-Mode 100 kcps,  $\pm 80$  kHz, 15-Byte Payload

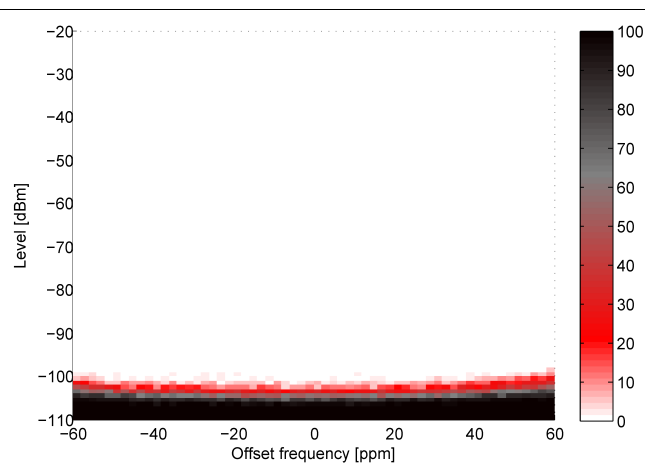


Figure 23. T-Mode 90 kcps,  $\pm 50$  kHz, 15-Byte Payload

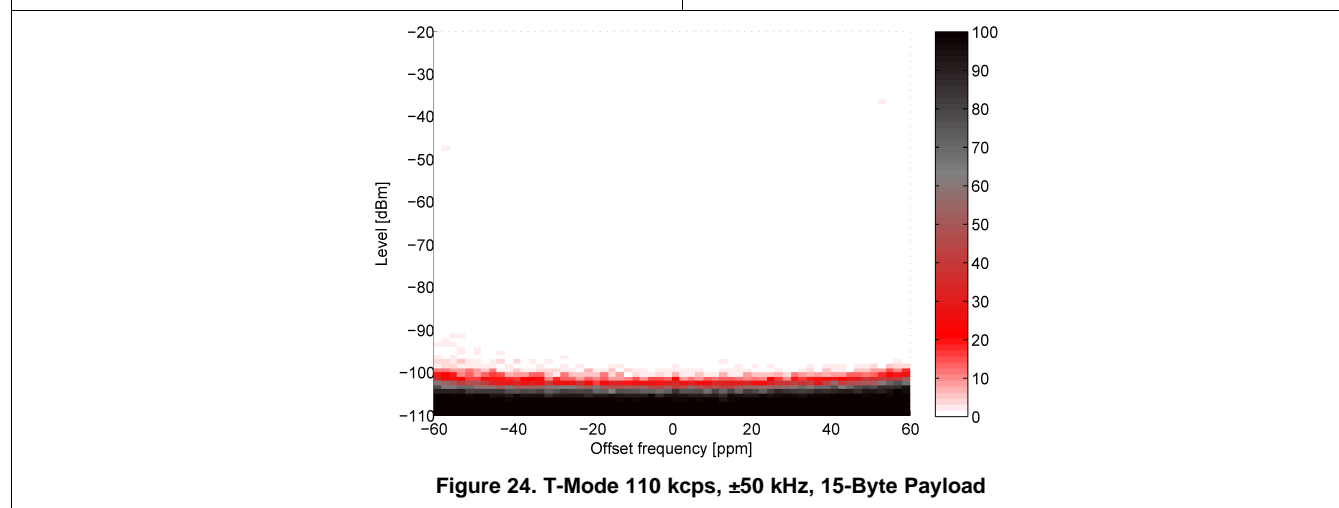
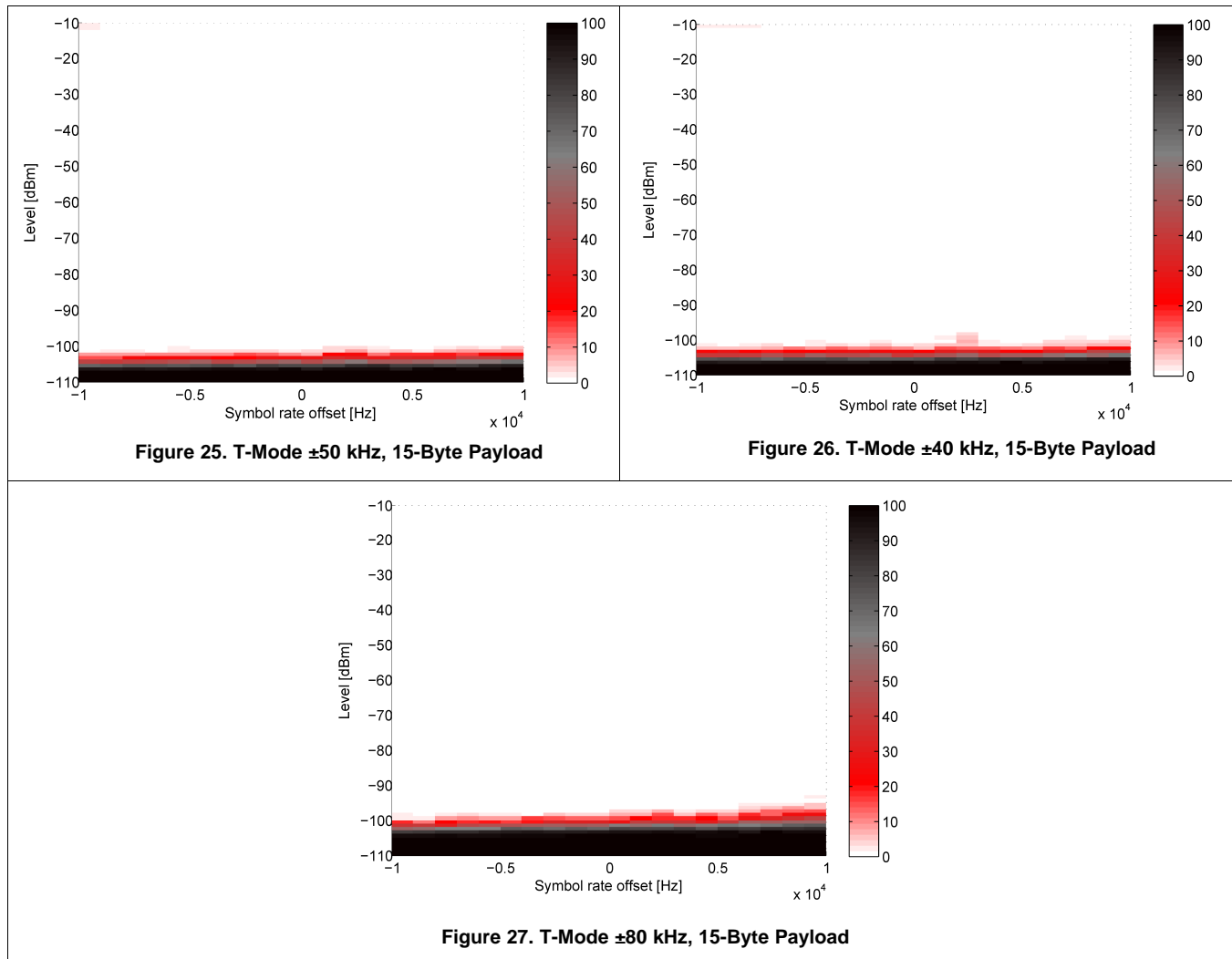


Figure 24. T-Mode 110 kcps,  $\pm 50$  kHz, 15-Byte Payload

## 5.5 PER versus Symbol Rate Offset

PER versus symbol rate offset was measured for nominal, minimum, and maximum deviation.

Figure 25 through Figure 27, 70% PER corresponds to 1% BER.





## 6 References

See the following resources for more information:

- [1] [CC13xxEM-7793\\_4L reference design](#)
- [2] European standard EN 13757-4:2012 Draft "Communication system for meters and remote reading of meters"
- [3] Zip-file with patch and recommended settings ([SWRC323](#))
- [4] [SmartRF Studio 7](#)
- [5] [TI-RTOS for Microcontrollers](#) and Wireless Connectivity devices

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