TI Designs

wM-Bus Smart Meter Subsystem at 868 MHz

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Design Resources

TIDC-WMBUS-868MHZ	Design Folder
CC1200	Product Folder
TPS62740	Product Folder
CC120XEM-868-930-RD	Tool Folder
TPS62740EVM-186	Tool Folder

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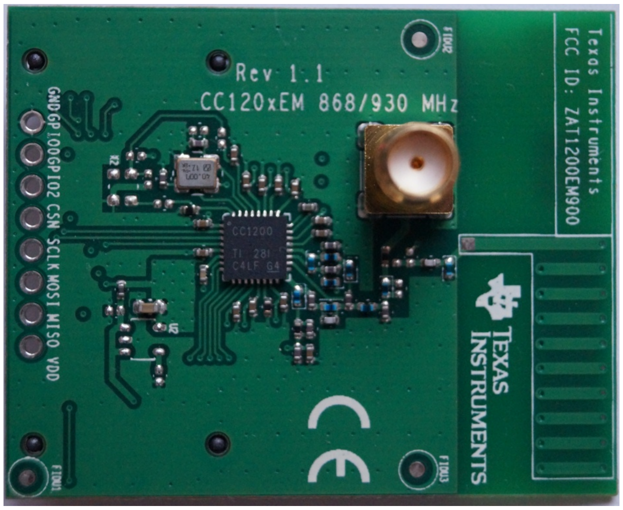
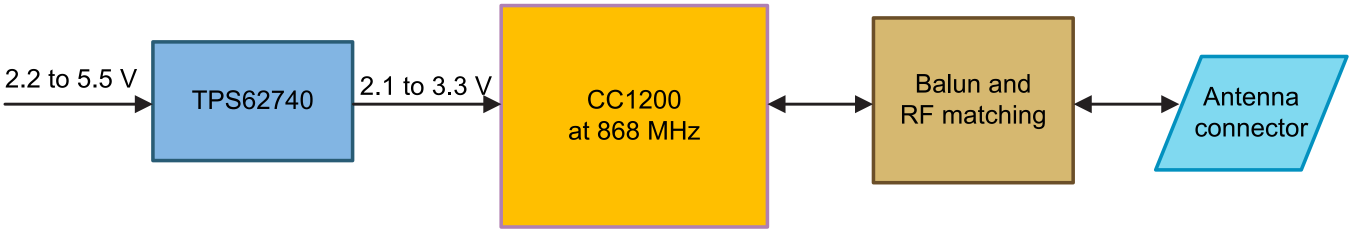
Design Features

- High-Performance and Low-Power 868-MHz wM-Bus RF Device
- Market Leading RF Blocking, Selectivity and RX Sensitivity Solution for 868 MHz
- ETSI Category 2 Receiver Capable RF System
- Supports Multiple Battery Technologies (For Example, LiSoCl2 and LiMnO2)

Featured Applications

- Smart Meters (Electricity, Gas, Water, and Heat)
- Heat Cost Allocators
- Alarm and Security Systems at 868 MHz and 915 MHz
- Alarms and Smoke Detectors
- Proprietary Sub-1-GHz Solutions





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1 Introduction

This reference design describes an ETSI Cat. 2 receiver-capable RF subsystem for smart meters and sub-meters, fully compliant with the most popular wM-Bus S-, T-, and C-Modes at 868 MHz as per EN13757-4:2014.

The CC1200 transceiver device delivers market leading blocking, selectivity, and RX sensitivity numbers in wM-Bus applications such as bi-directional flow meters, e-meters and heat cost allocators. This cost-optimized design handles the worst case frequency offset of ±60ppm in S2-Mode by utilizing a low-cost XTAL component. This design needs neither an external SAW filter nor a costly TCXO component to meet the specification of the wM-Bus modes at 868 MHz.

Adding TPS62740, an ultra-low Iq DC-DC device with dynamically adjustable output voltage, enables a new level of optimization of the design's power consumption, significantly extending the battery lifetime.

2 Key System Specifications

The CC1200 is a transceiver device with excellent blocking, selectivity, and receiver (RX) sensitivity in the supported ISM bands at 164 to 190 MHz, 410 to 475 MHz, and 820 to 950 MHz. This design has been optimized for operation in the ETSI ISM 868-MHz band, where the wM-Bus communication protocol is used. CC1200 radio operates from 2.0 to 3.6 V (up to 3.9 V as the absolute maximum are allowed), the transmit current for 14 dBm of transmitter (TX) power (conducted measurement) is typically 46 mA at a 3.0-V supply. The input supply voltage coming from the battery or power management system should be above 2.1 V to guarantee best RF performance of the CC1200 radio. Supported data rates are from 0 to 1250 kbps, and 2-FSK, 2-GFSK, 4-FSK, 4-GFSK, MSK, and OOK modulation formats are available. Either 2-FSK or 2-GFSK modulation formats are required to comply with the most popular wM-Bus modes at 868 MHz, called S2, T2, and C2.

The CC1200EM-868-930 has been optimized for the 868-MHz band: this design has no SAW filter and no TCXO components used. Still, adding an external SAW component is possible and a good practice in many applications.

In addition to low-cost XTAL devices, the CC1200 also supports TCXO components for applications that mandate the highest-possible frequency accuracy over temperature and lifetime, such as smart utility meters.

The TPS62740 is the industry's first step-down converter featuring a 360-nA quiescent current (typical) and operating with a tiny 2.2-µH inductor and a 10-µF output capacitor with user selectable output voltage. Four VSEL pins that can be connected to a microcontroller (MCU) device allow dynamic voltage adjustment in the range from 1.8 to 3.3 V in 100-mV steps. The maximum input voltage of up to 5.5 V enables operation from a USB port and thin-film solar modules. The TPS62740 is available in a small 12-pin 2×3 mm^2 WSON package and supports a total solutions size of 31 mm^2.

For highest power efficiency and lowest energy consumption, the TPS62740 output voltage is set to 2.1 V with the help of the VSEL pins.

Table 1. TPS6274x Device Options

T_A	PART NUMBER	OUTPUT VOLTAGE SETTING VSEL 1 TO 4	OUTPUT CURRENT (mA)	PACKAGE MARKING
–40°C to 85°C	TPS62740	1.8 to 3.3 V in 100-mV steps	300 mA	62740
	TPS62741(1)	1.3 to 2.8 V in 100-mV steps	300 mA	-/-
	TPS62742	1.8 to 3.3 V in 100-mV steps	400 mA	62742

(1) Device option, contact TI for more details

The operating ambient temperature for both CC1200 and TPS62740 is T_A = –40°C to 85°C.

3 System Description

The CC1200 device is optimized towards wideband applications but can also cover narrowband solutions down to 12.5-kHz channels.

Using a supply voltage of up to 3.6 V delivers excellent RF results. However, the drawback is increased power loss in the internal LDOs of the CC1120. To reduce these losses and extend the battery life in such an RF system, TI recommends using the lowest-possible supply voltage for each operation mode. So the supply voltage can vary between receive, transmit and sleep (power-down) operation of CC1200 and the MCU (such as MSP430). Another constraint is that the supply voltage must be the same for both MCUs running the RF communication protocol (for example, the wM-Bus S2-, T2-, or C2-Mode RF stack) and the CC1200 radio. This constraint helps avoid voltage level issues on the SPI and on the control signals between the radio and the MCU.

All these considerations lead to the choice of TPS62740 with its dynamic output voltage selection capability and ultra-low Iq current of only 360 nA.

Depending on the application’s duty cycle (for example, how often a system must transmit or receive data per day, for how long, and at which transmit power level) a different power scheme will be most efficient. In wM-Bus 868-MHz applications, such as smart utility meters and heat cost allocators, the transmit operations may occur from six times per day up to over several hundred times per day with a maximum ERP of 14 dBm (or 25 mW).

Knowing the duty cycle of the transmission and reception activity, it is easy to calculate the full system power budget (current consumed by CC1200 × operational time × voltage level as well as the energy drawn in sleep mode) and find out the most energy efficient option.

This option could be either to shut down (power-off) completely the CC1200 or put it into low-power (sleep state) with data retention. The power-up and initialization procedure of the CC1200 takes just a few milliseconds and has to be repeated every time the device starts from shut-down. Alternatively, using the sleep mode with retention (typical value is 120 nA) might be the more effective when a transmission or reception activity happens more often.

The combination of the TPS62740+CC1200 radio delivers a RF solution, which is market leading in terms of both wM-Bus 868-MHz performance and very low-power consumption. This design has been developed to meet and exceed the requirements of all wM-Bus systems at 868 MHz, which are already very popular in Europe for smart flow and electricity meters as well as for heat cost allocators.

3.1 CC1200 — High-Performance RF Transceiver for Narrow- and Wideband Systems

The CC1200 transceiver features adjacent channel selectivity of 60 dB at 12.5 kHz offset and a blocking performance of 86 dB at 10 MHz offset in combination of excellent receiver sensitivity of –123 dBm at 1.2 kbps.

In transmit mode, the CC1200 transforms the data packets, created in the MCU, into RF signal and passes it to the antenna. In receive mode, the CC1200 processes the RF signal coming from the antenna, detects the bit stream and converts the bits into data bytes, which are passed to the MCU for further processing. The CC1200 device provides extensive hardware support for packet handling and data buffering, using its 2×128-byte FIFO (separate for transmit and receive operations). Burst transmissions with an auto-acknowledgment or auto-retransmit are supported as well as clear channel assessment, link quality indication, and enhanced wake-on-radio modes.

All operating parameters of the CC1200 can be controlled by a MCU such as the TI MSP430 family through an SPI. A typical wM-Bus 868-MHz system consists of the CC1200, an MCU, and only a few external passive components.

The CC1200 contains an AES accelerator module, which supports AES-128 CBC and CTR mode operations. AES CTR mode operations are possible on the content of each of the TX and RX FIFOs, which offload encoding and decoding of the wM-Bus data packets from the MCU.

The RX Sniff Mode is a novel feature enabled by the TI Performance Line WaveMatch technology. The receiver only needs a few bits of preamble for settling, as opposed to legacy receivers that often need three to four bytes of preamble.

Using discrete passive components for the Balun+Matching delivers the best possible RF performance. Alternatively, for lowest system cost and complexity the eighteen discrete parts, used for the Balun and matching, can be replaced by a single integrated device (called an integrated passive component, or IPC) with negligibly lower RX sensitivity and transmit power.[5]

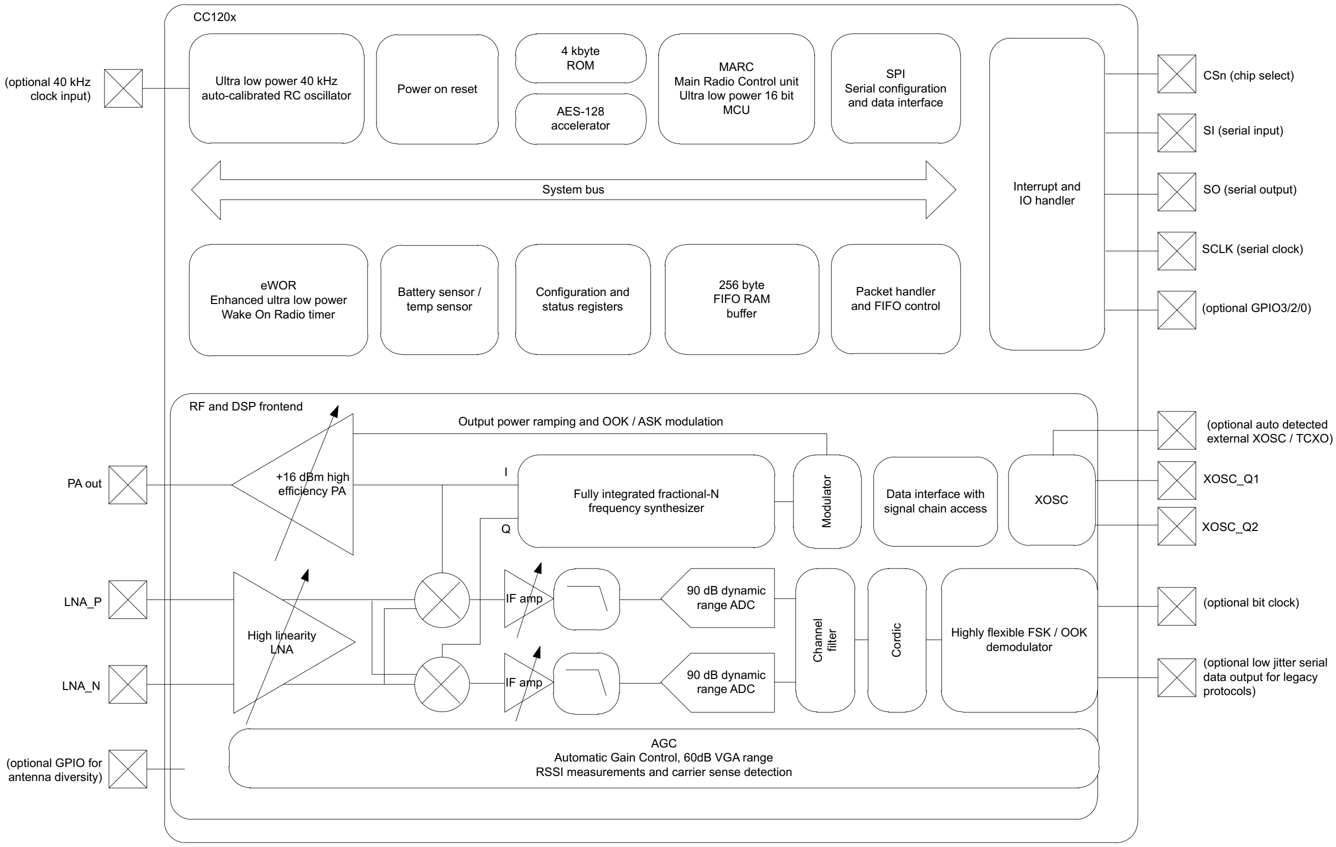


Figure 1. Functional Block Diagram of CC1200

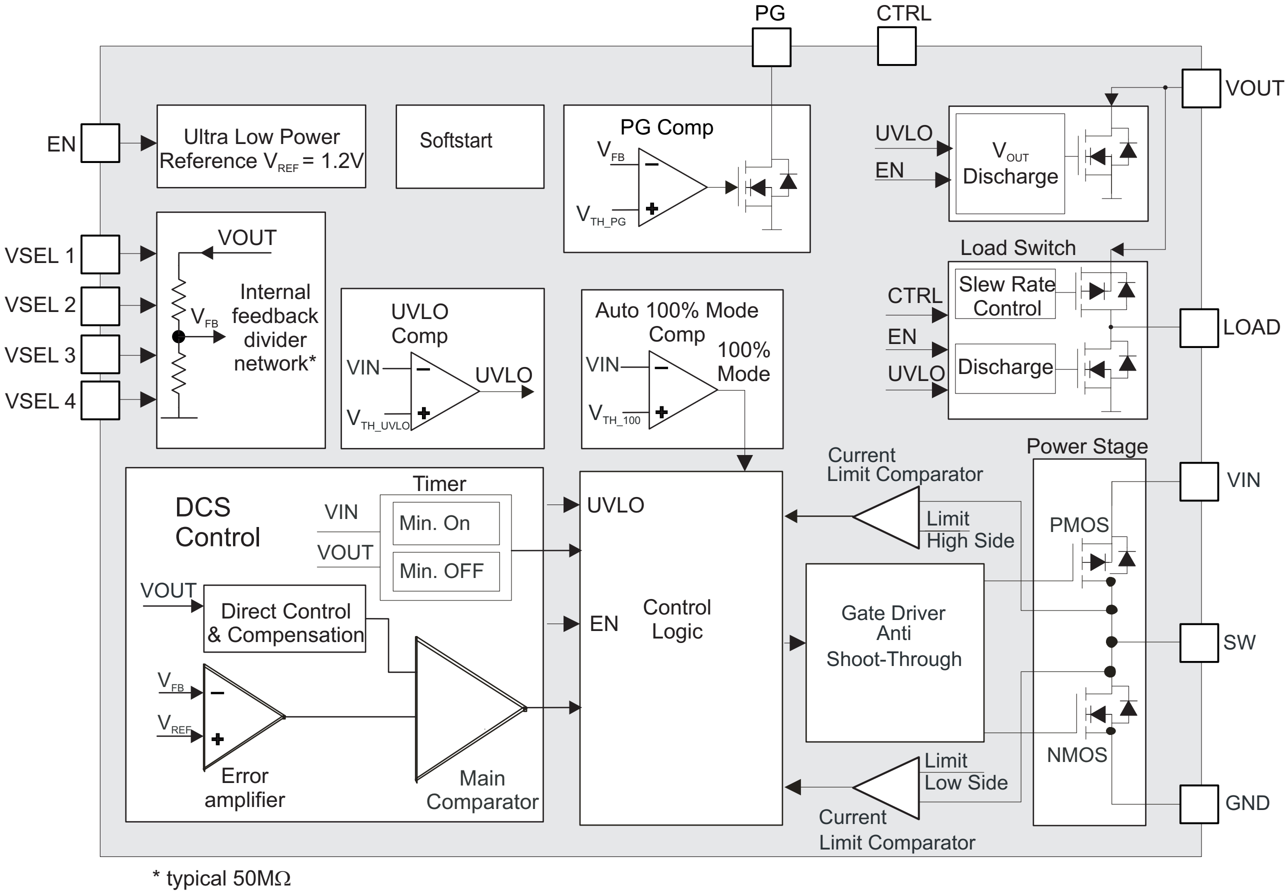
3.2 TPS62740 - 360-nA Iq DC-DC with Integrated Load Switch and 4-Pin Voltage Select

The TPS6274x DC-DC devices have several unique features that make them a perfect fit for low-power RF applications such as wM-Bus systems. The device operates from rechargeable Li-Ion batteries, Li-primary battery chemistries such as Li-SOCl2, Li-MnO2, and two or three cell alkaline batteries.

TPS6274x device family features low output ripple voltage and low noise with a small output capacitor. Once the battery voltage comes close to the output voltage (close to 100% duty cycle) the DC-DC enters a no ripple, 100% mode operation to prevent an increase of output ripple voltage. The device then stops switching and the output is connected to the input voltage.

This outcome is helpful in RF applications, where supply voltage ripple can negatively influence the radio performance. The integrated slew rate controlled load switch provides a typical 0.6-Ω on-resistance and can distribute the selected output voltage to a temporarily used RF sub-system, consisting of both an MCU and the CC1200, saving an external FET device.

The 16 selectable voltage levels enable the optimization of the supply voltage for each operating mode. For example, during a receive operation, a 2.1-V supply voltage is sufficient to achieve best sensitivity while in transmit mode, the supply voltage can be dynamically increased to 2.7 or even 3.0 V to obtain 14 dBm or higher output power levels, if required.



* typical 50MΩ

Figure 2. Block Diagram of TPS62740

4 Block Diagram

The system's block diagram is quite simple: the DC-DC is connected to the power supply (usually a battery or a SuperCap device) down-converting the supply voltage to 2.1 or 3.0 V, for example, depending on the CC1200 operational mode.

The radio has its Balun and Matching network, build up with discrete 0402-sized passive components, and there is the antenna connector (which is a 50-Ω RF feeding point).

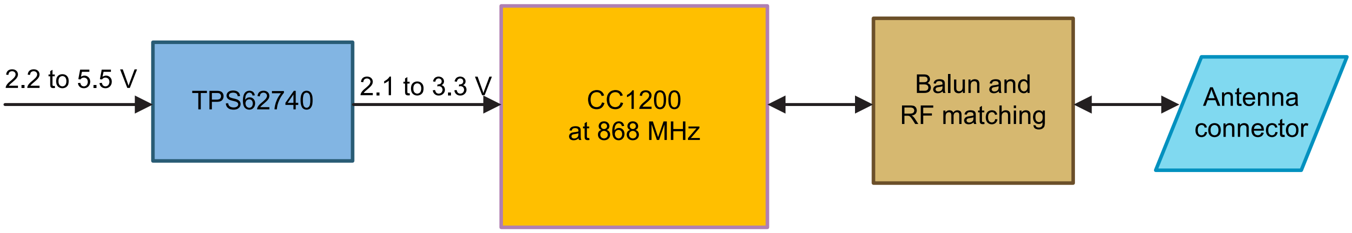


Figure 3. Block Diagram of CC1200 wM-Bus RF Subsystem at 868 MHz

4.1 Highlighted Products

4.1.1 CC1200

The CC1200 device is a fully integrated single-chip radio transceiver designed for high performance at very low-power and low-voltage operation in cost-effective wireless systems. All filters are integrated, thus removing the need for costly external SAW and IF filters. The device is mainly intended for the industrial, scientific, and medical (ISM) and short-range device (SRD) frequency bands at 164 to 190 MHz, 274 to 316.6 MHz, 410 to 475 MHz, and 820 to 950 MHz.

The CC1200 is suitable for RF systems targeting ETSI Category 1 receiver compliance in 169 MHz and ETSI Category 2 systems in 433- and 868-MHz bands. Some unique and very handy features of CC1200 are:

- WaveMatch: Advanced digital signal processing for improved sync detect performance
- RX Sniff Mode: Autonomously checking for preamble and reducing current consumption - supports in S2-Modes (Other and Meter), T2-Mode (Meter) and C2-Mode (Meter)
- ImageExtinct: Compensation algorithm that digitally compensates for an I/Q mismatch by removing the image component and thus any issues at the system image frequency.
- Feedback to PLL: A capability to "increase the RX filter bandwidth" without increasing the noise bandwidth and hence improving receive sensitivity (used in wM-Bus 868-MHz Modes)
- AES-128 hardware accelerator (can be used for wM-Bus AES-128 encryption and decryption)
- IEEE 802.15.4g compliant packet processing engine (not used in wM-Bus protocol)

4.1.2 TPS62740

The TPS62740 achieves up to 90% efficiency at 10-µA output current, which opens new applications, where DC-DC converters were not used before. Many systems, especially in metering and sub-metering, do achieve average current over lifetime in the range of 10 to 15 µA, which makes them suitable for using a DC-DC device, instead of a low current LDO.

The buck converter includes TI's DCS-Control™, an advanced regulation topology, that combines the advantages of hysteretic and voltage mode control architectures. While a comparator stage provides excellent load transient response, an additional voltage feedback loop ensures high DC accuracy as well. The DCSControl enables switch frequencies up to 2 MHz, and the device integrates an automatic transition to a no ripple, 100% mode as well as a slew rate controlled load switch, which can save an external FET device. In addition, a discharge function on VOUT / LOAD is provided and a dedicated power good output pin is available.

5 System Design Theory

Several considerations were taken into account when defining this RF subsystem. The main focus was to get the best RF performance (RX sensitivity and blocking parameters) for wM-Bus 868-MHz modes, lowest system cost, and highest power efficiency. As the TX power level of CC1200 depends on the supply voltage, it is a good practice to use different voltage levels for RX and TX operations, which is possible with TPS62740. While optimal receive performance requires only a 2.1-V supply voltage, transmit operation at 14 dBm needs a 2.7-V or higher voltage supply.

5.1 Power Efficiency

TPS62740 has been selected as it can dynamically adjust the output voltage level, making it a perfect fit for low-power metering systems (for example wM-Bus enabled smart utility meters) or sub-metering devices (such as a heat cost allocator, or HCA). The optimal supply range for CC1200 between 2.1 V (highest energy savings) and 3.3 V (highest TX power levels) can be now fully supported with a single DC-DC component, the TPS62740, and controlled through signal lines by the host MCU (such as MSP430).

5.2 RF Performance at 868 MHz (ETSI Cat. 2 Receiver Capable)

CC1200 easily achieves ETSI Category 2 receiver category compliance; optimized register settings for best RX sensitivity for each of the wM-Bus modes S2 (same as T2 for a Meter device) and C2 (for a Meter device) are provided with this design. Main focus is on the receive performance under all possible parameter variations (or worst case), as this is the most challenging part for any wM-Bus system.

In this design guide, Meter Mode means the wM-Bus RX performance that needs to be supported by a wM-Bus Meter device (for example, a smart utility Meter or HCA). The wM-Bus Other Mode, or the functionality required to implement a data collector system, is not analyzed here. Nevertheless, the CC1200 radio is also supporting C2-Other and T2-Other Modes and can be used in wM-Bus enabled data collectors or mobile reader devices collecting metering data.

The CC1200 has been tested in the same RF test setup as CC1120EM-868 boards, documented in TI's wM-Bus application note.[4] The results for CC1200 RX sensitivity and the PER plots in Section 8.3 are in-line with that application note, proving also that the CC1200 is an equally capable wM-Bus device with market leading RF performance.

The transmit parameters for all wM-Bus Modes in 169-, 433-, or 868-MHz ISM bands, are derived using the SmartRF™ 7 Studio and the specific wM-Bus transmitter RF parameters as defined in the wM-Bus Standard Document.[3]

5.3 System Cost

In high-volume rollouts of 868-MHz RF systems in Europe, the full system cost as well as the bill of materials (BOM) cost are of utmost importance. CC1200-based designs are leading not only in RF performance but also in terms of system cost, as they can use any of two pin-compatible IPC products for a single-chip Balun+Matching, reducing handling and logistics costs and drastically simplifying the system layout.[5]

The “Feedback-to-PLL” is a powerful feature in the CC1200, which eases the XTAL specifications and tolerates larger frequency offset between transmitter and receiver units in the field deployment.

6 Getting Started Hardware

The test hardware comprises three different hardware boards: one TRXEB board from the CC1200DK, the CC1200EM868-930 Rev1.1 board, and the TPS62740EVM-186. For the RF performance tests, two CC1200EM868-930 Rev1.1 boards were measured by connecting a cable from the R&S® RF signal generator to the SMA antenna connector. All three boards together were used to measure currents in dependence of the TX output power under control of the TI SmartRF 7 Studio software.[11]

The RX Sniff Mode code example requires IAR Workbench for MSP430; the reported current measurements apply for the combination of the TRXEB+CC1200EM868-930 board with and without TPS62740. The C-code examples can be easily ported to any other code development tools, such as TI's Code Composer Studio™ (CCS) or GCC.

6.1 Setting Up the Hardware System

The E3631A power unit delivers to the TRXEB adjustable voltage levels and connects straight to GND (blue circle) and voltage to EXT pin (brown circle) of the TRXEB in Figure 4 and Figure 6.The left side pin of the RF Core header (the Jumper is removed), is the “yellow” circle in Figure 5 and is connected to the multimeter unit, measuring current consumption. The second cable of this multimeter is connected to the Vin pin TPS (shown as a black circle on Figure 4. Ground connection between P7.20 (GND) and any TPS62740EVM-186 GND Pin is shown with the red circles in Figure 4, while Vout pin (light blue) is connected to the right side of the RF Core header on Figure 5.

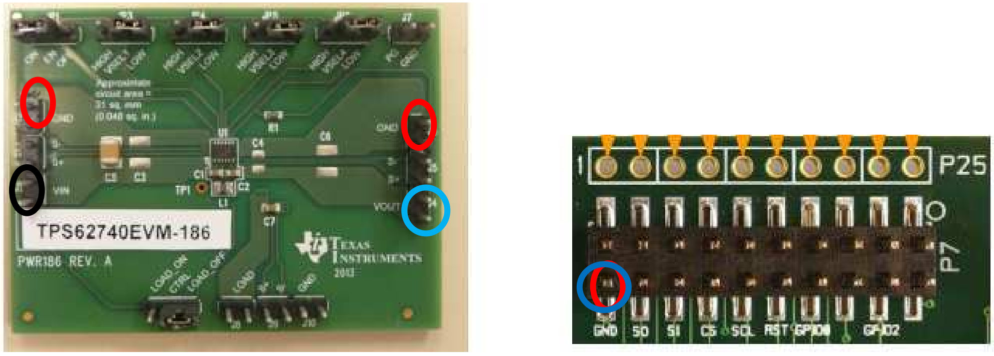


Figure 4. P7 and P17 Ports of TRXEB
(Blue and Red Circles Show GND Connections)

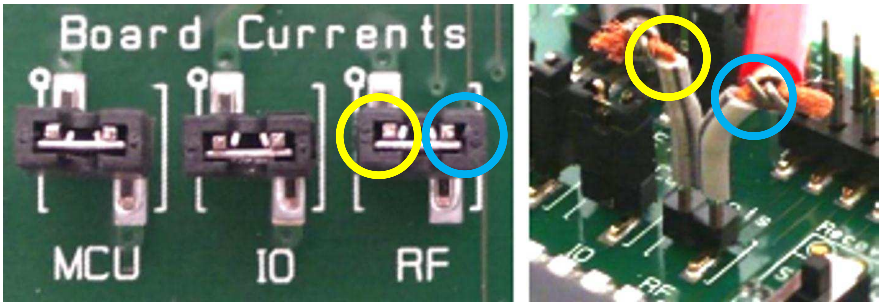


Figure 5. RF Jumper for Measuring Currents to CC1200EM868-930 Rev1.1

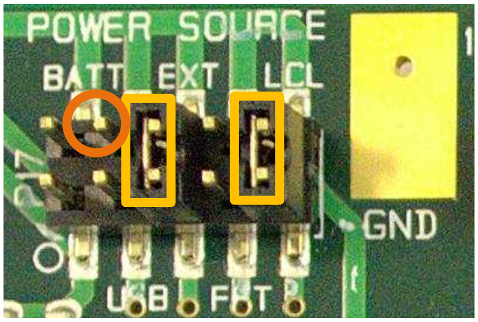


Figure 6. Power Selector for TRXEB

On TRXEB, connect jumpers EXT and LCL at P17 as shown in orange in Figure 6 to enable external power supply source. A second multi-meter unit is measuring the voltage Vout of TPS62740; the readings of both multi-meters have been documented in Section 8.2.

The SmartRF 7 Studio uses special XML files, which deliver the optimized RF settings for the CC1200 high-performance radio. Two XML files for each of the wM-Bus Modes S2 (equals T2-Meter) and C2-Meter are provided for both TX and RX direction.

6.2 Testing Conditions

Two test setups were used:

- Test 1: One signal generator and one spectrum analyzer (both from R&S) for measuring RX sensitivity and PER plots within an automated RF test system.
- Test 2: Current measurements with RX Sniff Mode enabled and TPS62740 (room temperature, Vin = 3.6 V to TPS62740 (from E3631); Vout from TPS62740 = VCC of CC1200 = 2.3 V.

For Test 1, a special packet configuration file for R&S signal generators have been created, such that the same known transmit packet is sent out multiple times, with an additional CRC16 field (2 bytes) added. The CRC16 field is automatically checked by the receiving CC1200 CRC block engine and an error is indicated if at least one bit in the received packet is wrong or a full packet is missed.

The optimized CC1200 register settings from the Test 1 were incorporated into the XML configuration files for Test 2. Test 2 uses the wM-Bus packet format (as defined in the wM-Bus standard document) with a 20-byte payload.[3]

7 Getting Started Firmware

There are two different options to test the CC1200EM performance: the TRXEB embedded firmware for SmartRF 7 or a “custom” code for S2- and C2-Meter Modes with RX Sniff functionality support, created based on the RX Sniff Mode application report.[7]

Additionally, Excel files for calculating the RX Sniff current consumption are provided for S2-and C2-Modes, using the corresponding optimized wM-Bus register settings.

7.1 *SmartRF 7 Studio Files*

The DUT board is controlled through SmartRF 7 with specific configuration files for S2 and C2-Modes, running on a Windows® PC and connected thru a USB cable to the TRXEB. The SmartRF 7 Studio GUI reports correct and missing or wrong packets and calculates the packet error rate (PER) automatically. The embedded TRXEB firmware is enabled by setting the DIP switch to “USB Mode Smart RF”.

7.2 *Test Frames*

The wM-Bus data packet is created according to the different RF parameters for S2- and C2-Meter Modes, as in Table 2:

Table 2. Definition of S2- and C2-Meter Packet Formats[3]

PREAMBLE	n	SYNC WORD	POSTAMBLE	N	LINK
n*(01)	15 ≤ n	00 0111 0110 1001 0110	n*(01)	2 ≤ n ≤ 4	S-Mode, short preamble
n*(01)	16 = n	0101010000111101 0101010011001101 (frame format A) 0101010000111101 0101010000111101 (frame format B)	NA	NA	C2-Mode Meter

The conversion into text format (hexadecimal):

PREAMBLE	SYNC	PACKET DATA	COMMENT	
0x55 55 55	54 76 96	20 bytes of payload	FF	if S2-Mode (=T2-Mode Meter)
0x55 55 55	54 3D 54 3D	21 bytes of payload	--	if C2-Mode Meter

7.3 Signal Generator Settings

The SMU200A generates a test frame with a random data payload for each measurement using the correct wM-Bus C2-Meter or S2 packet format and RF parameters such as data rate, frequency and modulation, and the packet format as in Table 2.

As S2-Mode and C2-Modes allow some RF parameter variations, the automated test were run also with:

- the minimal and maximal deviation for each mode (see definitions in the wM-Bus Standard Document)[3]
- the minimal and maximal frequency offset (S2 = ±60 ppm for the data collector and ±25 ppm for a Meter, and C2-Meter = ±25 ppm)

In each test the correct preamble length, SYNC word sequence, modulation format, and data packet length of 20 bytes were used.

The transmit power level and the frequency offset to the DUT are being automatically stepped through: for example, a test packet is sent out 100 times at a –110-dBm TX power level at a –15-ppm frequency offset (note that the frequency offset is automatically removed in the RF test system at the beginning of the test). The data packet stays the same, until either the frequency offset or the TX power level setting is changed.

PER plot explanation:

Step for RF input signal level = 2 dB;
Signal input range = 90 dB (from –110 to –20 dBm)

- 90-dB range / 2 = 45 signal levels per test point

Step for ppm = 2; Frequency offset limits: ±70 ppm

- 140 / 2 = 70 frequency test points

Number of packets per test point = 100

Total packets tested for one PER Plot: 45 × 70 × 100 = 315,000 packets

By automatically running hundreds of thousands of packet transmissions, a complex PER plot is created using a color coding scheme for the PER levels. These PER plots showing the combination of frequency offset variation and the different input signal levels are often referred to as a “bathtub” plot, see Figure 7.

8 Test Data

The automated performance numbers was tested on two regular CC1200EM868-930Rev1.1 boards, no hardware modifications have been done. The boards have no SAW filter and no TCXO; instead, a low-cost 10-ppm XTAL is used as a reference clock source for the CC1200 device. The TPS62740 DC-DC device was not used in the RX sensitivity tests and PER plots. RF signals are always measured at the antenna connector at room temperature.

8.1 TX Current

For this test, unmodulated TX carrier has been generated through SmartRF 7 at 868.3 MHz, TPS62740 Vin = 3.6 V, and Vout = 2.1 V.

Table 3. TX Current (Unmodulated Carrier) at 868.3 MHz (S2-Mode Frequency) and 3.6 Vin

SMARTRF 7 STUDIO TX SETTING (dBm)	R&S FSIQ7 READING (dBm)	Vin TO TPS62740 = 3.6 V, Vout = 2.1 V; TPS INPUT CURRENT (mA)
14	11.93	25.82
13	11.33	23.88
10	9.29	20.38
6	5.44	16.76
0	–0.41	15.87
–6	–6.4	12.32
–12	–12.31	11.43
–24	–25.02	10.35
–40	–43.01	9.58

Comparison: CC1200EM uses 36 mA at 10 dBm TX power and a 3-V supply (see the CC1200 datasheet; no TPS62740 used).[1]

The TX current has additional current consumption numbers for 3.3-V and 3.0-V external power supplies, and TPS62740 Vout = 2.1 V.

Table 4. TX Current versus Vin Level versus TX Power Level for Unmodulated TX Carrier (at 868.3 MHz)

SMARTRF 7 STUDIO TX SETTING (dBm)	R&S FSIQ7 READING (dBm)	Vin to TPS62740 = 3.3 V; TPS INPUT CURRENT (mA)	Vin to TPS62740 = 3.0 V; TPS INPUT CURRENT (mA)
14	11.93	28.89	32.36
13	11.33	26.78	30.05
10	9.29	23	25.89
6	5.44	19.03	21.56
0	–0.41	15.89	18.12
–6	–6.4	14.21	16.28
–12	–12.31	13.24	15.22
–24	–25.02	12.07	13.95
–40	–43.01	11.23	13.03

Summary: Due to the >90% DC-DC conversion efficiency, the higher the Vin voltage the lower the current consumption of the CC1200 is.

Best results are achieved for 3.6-V voltage, being typical for LiSoCL2 primary batteries, which are quite often used in Metering applications. But also with 3.0-V input voltage, common for LiMnO2 batteries, the TPS62740 can deliver power savings, as shown in the far-right column of Table 4.

8.2 RX Current

External power supply is 3.6 V. The boards used are TPS62740EVM-186, TRXEB, and CC1200EM868-930Rev1.1; TPS62740 Vin = 3.6 V and Vout = 2.3 V. The carrier sense is 1 dB below the sensitivity limit (CS = –109 dB) for both S2 and C2-Mode (Meter).

Table 5. RX Current versus Vin

DATA RATE	MEASURED CURRENT IN mA	COMMENT
S2-Mode and T2-Mode (Meter)	8.52 mA	998 of 1000 data packets
S2-Mode and T2-Mode (Meter)	7.45 mA	No data packets
C2-Mode (Meter)	6.43 mA	1000 of 1000 data packets
C2-Mode (Meter)	7.42 mA	No data packets

Comparison: RX current = 23 mA at 3.3 V (USB power to TRXEB)

NOTE: The RX Sniff Mode current is highly dependant on the RF noise in the channel (wM-Bus frequency) used. The measured current also depends on the inactivity time period between each wM-Bus packet (bursts of 250 packets were used).

8.3 RX Performance in S2- and T2-Modes for Meter Device

The wM-Bus S2-Mode with 30 bits of preamble (which is also used in T2-Mode response to the Meter) has sufficient time for CC1200 to autonomously duty cycle the receiver while searching for a preamble. Therefore, the RX Sniff Mode can be used, offering dramatically reduced average current without compromising the RF performance. The RX Sniff Mode is enabled by using the eWOR timer together with the RX termination based on carrier sense (CS).

Packet format: preamble (n = 15) × (01) + sync word “000111011010010110” + P byte payload + CRC16; with n ≥ 15 for the sub-Mode S2 (short header).

Table 6 summarizes the test conditions used:

Table 6. S-Mode Test Conditions

PARAMETER	VALUE
TX/RX centre frequency (MHz)	868.3
Modulation	2-FSK
Frequency deviation (kHz)	±50 (min. ±40; max. ±80)
Chip rate (kcps)	32.768 ±2%
RX filter bandwidth (kHz)	208.333

NOTE: The long preamble used in S1 Mode is supported by CC1200 but not analyzed in this design guide (S2-Mode with the short preamble is much more challenging to support). Typically, numbers for S1-Mode will be a bit better than for S2-Mode because of the very long preamble of 69.75 bytes, which allows a very reliable SYNC detection in the receiver and reduces the PER.

8.3.1 S2-Mode RX Sensitivity

The summary of S2-Mode sensitivity performance of CC1200 under all conditions is in Table 7, achieving market leading –109 dBm at 80% PER and –107.5 dBm at 20% PER.

Table 7. S2-Mode and T2-Meter Typical RX Sensitivity Numbers for CC1200

FREQUENCY (MHz)	TYPICAL SENSITIVITY (dBm)	PER (%)	P = PAYLOAD BYTES	PARAMETER IN EN13757-4
868.3	–109	80	20	
	–107.5	20	20	
	–106.25	1	20	
	–107	20	20	Max Deviation = 80 kHz
	–106.75	20	20	Min Deviation = 40 kHz
	–107.5	20	20	Max. data rate = 32.768 +2%
	–107.5	20	20	Min. data rate = 32.768 –2%

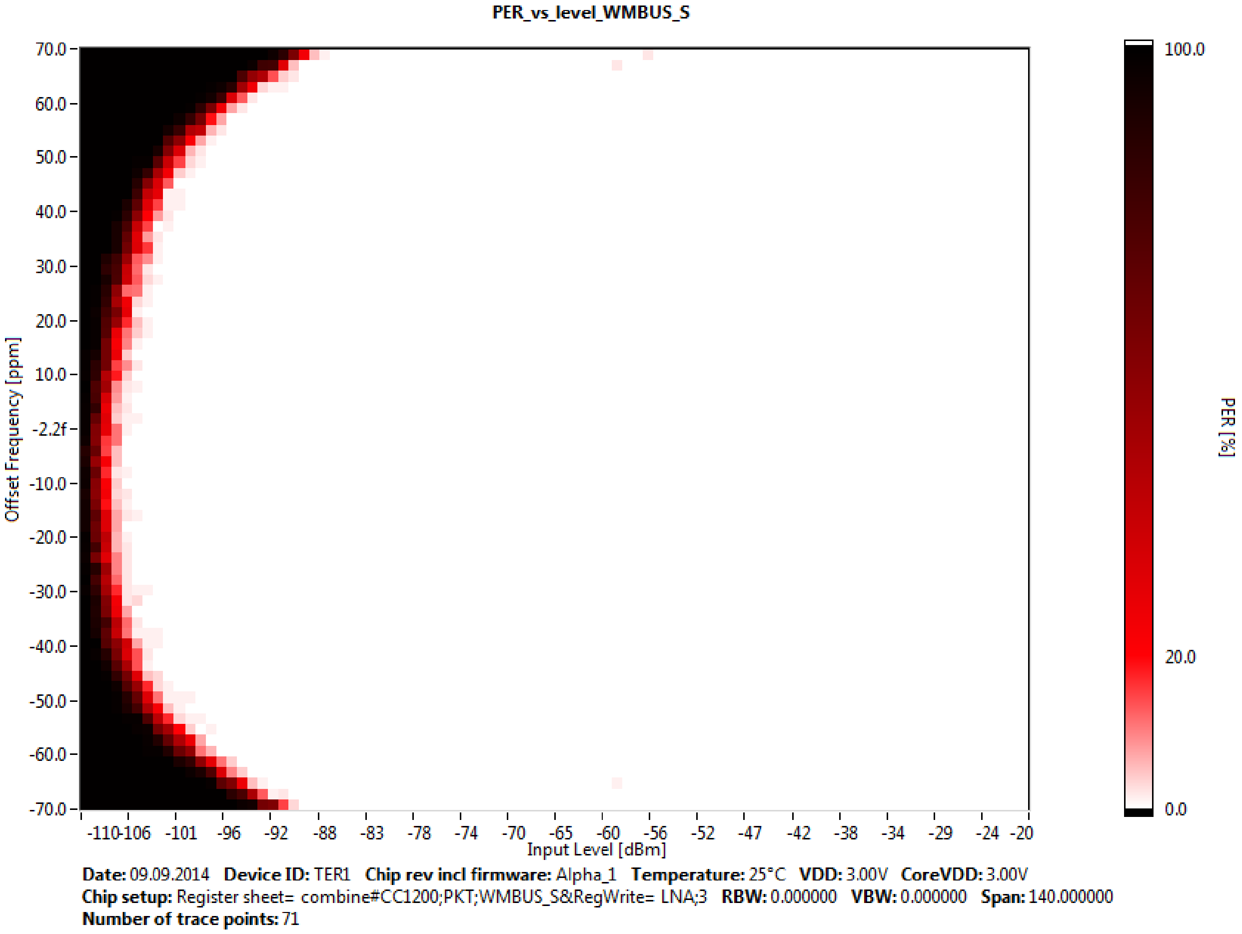
NOTE: RX sensitivity numbers are measured conducted at the single antenna port with combined TX/RX matching (and not at the CC1200 chip pin).

Summary: CC1200 exceeds the S2-, S1-m, and T2-Meter Mode (32.768 kcps) requirements, achieving market leading sensitivity of –109 dBm at 80% PER, which is 1.5 dB better than the nearest competitor solution.

8.3.2 S2-Mode PER Plot (Applies Also for T2-Meter and S1-Modes)

The full RF performance of any transceiver can be best shown using the so-called packet error rate (PER) plots versus the frequency offset versus input signal power level. Note that the ±60-ppm offset (shown on the left side in Figure 7) are the maximum tolerance allowed in S2-Mode for data collector units, while the PER plot shows data up to ±70 ppm. For a smart meter in S2-Mode, when that meter is receiving data from other devices (such as a data collector unit), only the ±25-ppm worst case frequency offset applies.

In short, the PER plot in Figure 7 proves that the RF register settings enable error-free (PER = 0%) over the full ±60-ppm frequency offset for RF input levels with a range of 90 dB. The signal strength begins at the RX sensitivity level around –110 dBm and goes up to very strong RF signal levels of –20 dBm (horizontal axis). There are only three packets lost out of 315,000 packets in total (each pink point at around –58-dBm input signal level represents one packet lost out of 100) and these packets are not counted as they are at irregular frequency offset greater than the ±60 ppm limit.


PER_vs_level_WMBUS_S

Date: 09.09.2014 **Device ID:** TER1 **Chip rev incl firmware:** Alpha_1 **Temperature:** 25°C **VDD:** 3.00V **CoreVDD:** 3.00V
Chip setup: Register sheet= combine#CC1200;PKT;WMBUS_S&RegWrite= LNA;3 **RBW:** 0.000000 **VBW:** 0.000000 **Span:** 140.000000
Number of trace points: 71

Figure 7. PER Plot for wM-Bus S2-Mode with CC1200EM868-930 Rev1.1

8.3.3 S2-Mode RX Sniff Mode

For the measurements in Table 8, both TPS62740EVM-186 and CC1200EM868-930 Rev1.1 were used (as described in Section 6.1) together with the TRXEB. The RX Sniff software example has been flashed onto one TRXEB, which is used as the receive unit. A second TRXEB board is programmed with the RX Sniff code and is used as a wM-Bus packet generator, transmitting single or bursts of 250 wM-Bus compliant data packets. A CC1200EM868-930Rev1.0 board was used on the second TRXEB to implement this transmitter function.

Table 8. Average RX Current Consumption in RX Sniff Mode in S2-Mode and T2-Mode Meter (Short Preamble)

DATA RATE	PREAMBLE BYTES	TRIGGERING ON RSSI (SMARTRF 7 ESTIMATED VALUE)	TRIGGERING ON RSSI, NO DC-DC	TRIGGERING ON RSSI WITH TPS62740 (MEASURED)
32.768 kcps 2FSK = S2-Mode (Meter and Data Collector) = T2-Mode (Meter)	3.75	7.93 mA (assumes noise-free channel)	8.37 mA (measured in office environment)	Vout = 2.3 V 8.61 mA (3.0 Vin) 6.83 mA (3.6 Vin)

8.4 RX Performance in C2-Mode for Meter Device

In C2-Mode, a data collector unit uses a 50-kbps data rate to transmit data to a wM-Bus Meter device, with four bytes preamble and four bytes of sync word. Therefore, the RX Sniff Mode can also be used in a meter while waiting for a wM-Bus data packet from the Other device.

Table 9. C2-Meter Mode Test Conditions

PARAMETER	VALUE
TX and RX center frequency (MHz)	869.525
Modulation	2-GFSK
Frequency deviation (kHz)	±25 (min.±18.75; max. ±31.25)
Chip rate (kcps)	50 ±100 ppm
RX filter bandwidth (kHz)	104.167

8.4.1 C2-Mode RX Sensitivity

The summary of C2-Mode sensitivity performance of CC1200 under all conditions is in Table 10:

Table 10. C2-Meter Mode Typical Sensitivity Numbers for CC1200

FREQUENCY (MHz)	TYPICAL SENSITIVITY (dBm)	PER (%)	P = PAYLOAD BYTES	PARAMETER IN EN13757-4
869.525	–110	80	20	
	–108	20	20	
	–106.5	1	20	
	–109.5	20	20	Max deviation = ±31.25 kHz
	–110.25	20	20	Min deviation = ±18.25 kHz

NOTE: RX sensitivity numbers are measured conducted at the single antenna port with combined TX and RX matching (and not at the CC1200 chip pin).

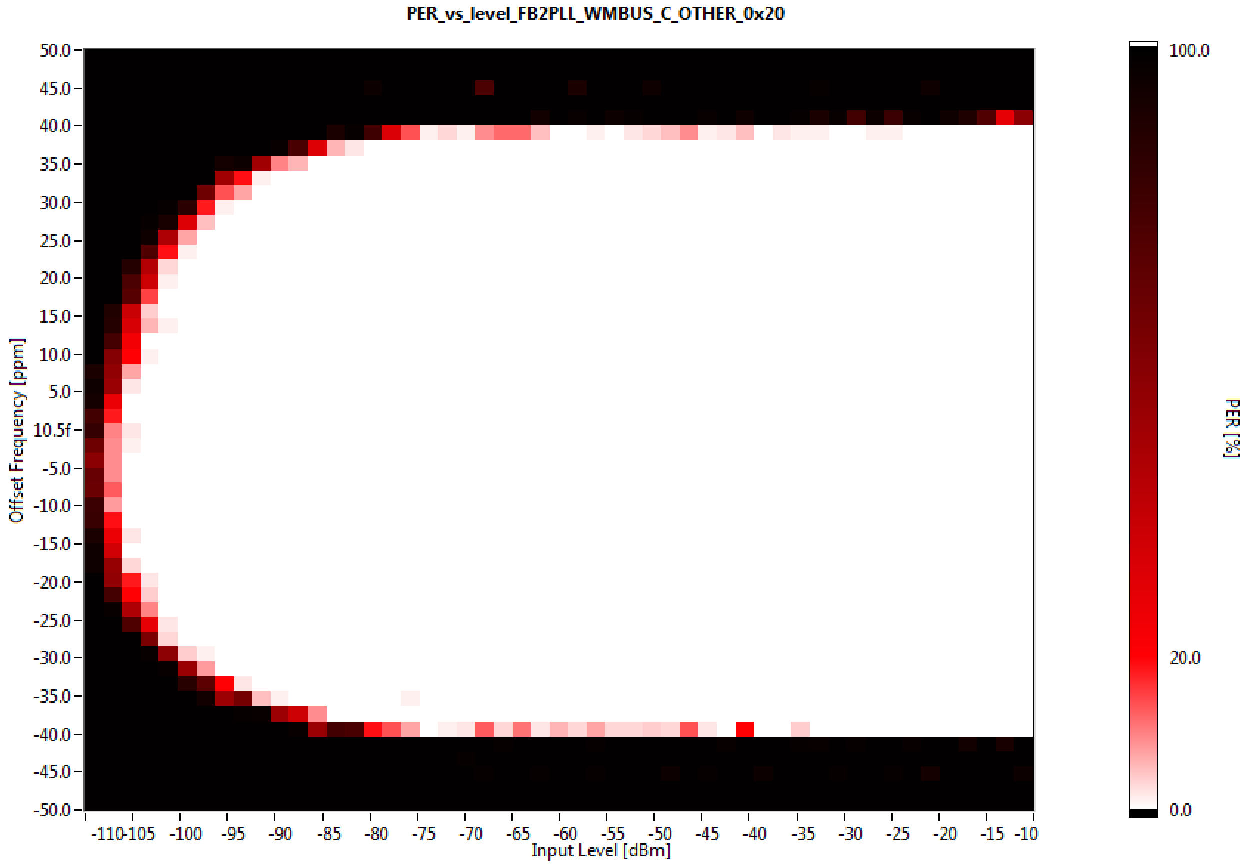
Summary: CC1200 exceeds the C2-Meter Mode (50 kbps) requirements, achieving market leading sensitivity of –110 dBm at 80% PER, which is 2 dB better than the nearest competitor solution.

8.4.2 C2-Mode PER Plot (with and without “Feedback-to-PLL”)

The C2-Meter Mode allows a relatively small variation of deviation and the data rate, which makes things easier for the RF demodulator in the CC1200. Therefore, the CC1200 can handle C2-Meter Mode even without using its “Feedback-to-PLL” feature, as shown in Figure 8.

The worst case frequency offset of ±25 ppm has close to a 5-dB loss in RX sensitivity compared to the optimum result at zero frequency offset. This offset is where the FB2PLL feature in the CC1200 comes in and helps achieve a significantly better C2-Meter Mode performance (see Figure 9).

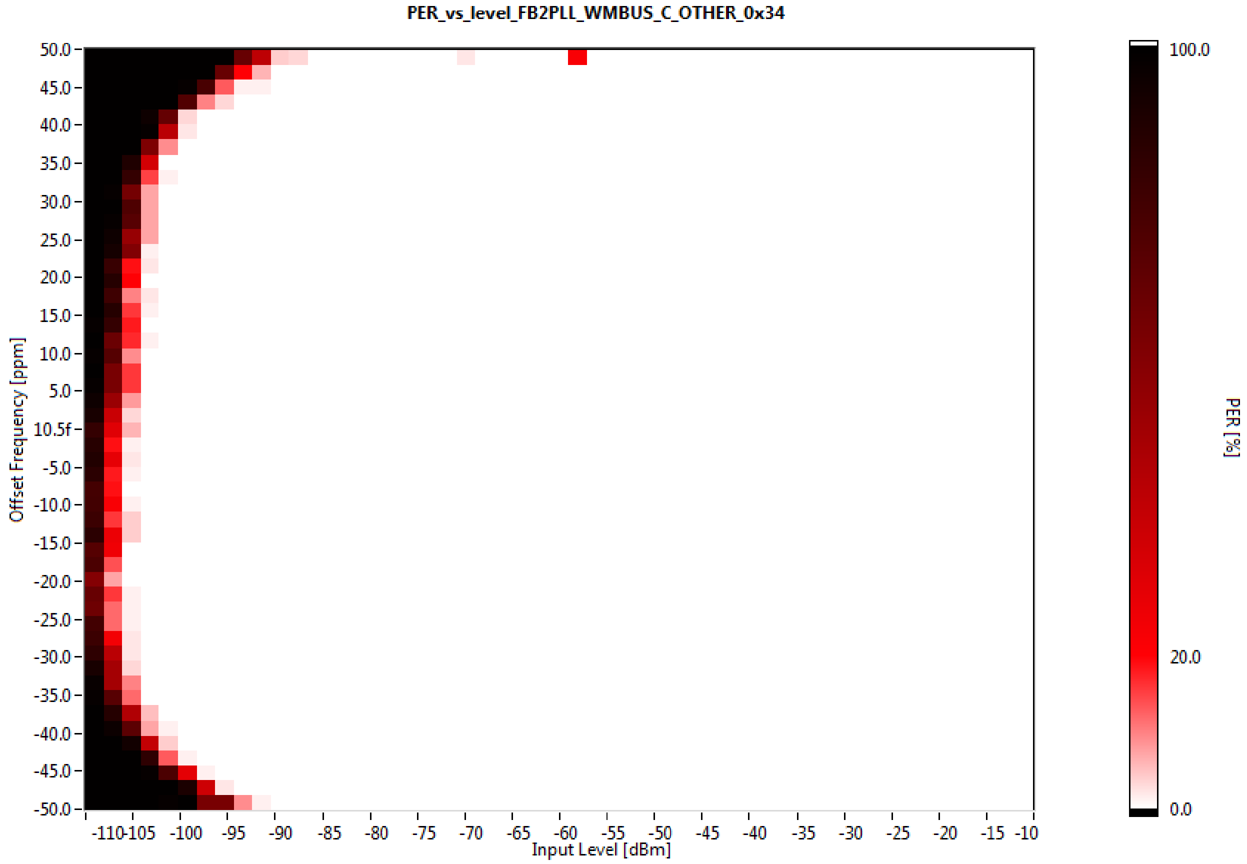
Using the register setting (FREQOFF_CFG = 0x34) the RX sensitivity numbers at ±25 ppm offset are now around 2 dB less that at the center frequency. In addition, even at frequency offsets of ±30 ppm the RX sensitivity is better than –100 dBm, which is the minimum requirement for an Hr class receiver device (Hr is the highest receiver category).[3] The improved tolerance of frequency offset beyond the ±25-ppm requirement eases the RF frequency precision requirements; low-cost XTAL devices can be used and significantly less effort for frequency calibration per wM-Bus system is needed.



PER_vs_level_FB2PLL_WMBUS_C_OTHER_0x20

Date: 16.09.2014 **Device ID:** TER1 **Chip rev incl firmware:** Alpha_1 **Temperature:** 25°C **VDD:** 3.00V **CoreVDD:** 3.00V
Chip setup: Register sheet= combine#CC1200;PKT;WMBUS_C_OTHER&RegWrite= LNA;3;FREQOFF_CFG;20 **RBW:** 0.000000 **VBW:** 0.000000
Span: 100.000000 **Number of trace points:** 51

Figure 8. PER Plot for wM-Bus C2-Meter Mode with CC1200EM868-930 Rev1.1 (No FB2PLL Enabled)



Date: 17.09.2014 **Device ID:** TER1 **Chip rev incl firmware:** Alpha_1 **Temperature:** 25°C **VDD:** 3.00V **CoreVDD:** 3.00V
Chip setup: Register sheet= combine#CC1200;PKT;WMBUS_C_OTHER&RegWrite= LNA;3;FREQOFF_CFG;34 **RBW:** 0.000000 **VBW:** 0.000000
Span: 100.000000 **Number of trace points:** 51

Figure 9. PER Plot for wM-Bus C2-Meter Mode with CC1200EM868-930 Rev1.1 (FB2PLL Enabled, ±25-ppm Frequency Offset Required; TI Recommended Settings)

Enabling the “Feedback-to-PLL” features delivers market leading RX sensitivity and frequency offset tolerance of the CC1200 in C2-Meter Mode with power levels from –110 dBm up to –10 dBm (a very strong RF signal) at 0% PER (equal to the white area in the plot).

8.4.3 C2-Mode RX Sniff Mode

The test setup used here is identical to Section 8.3.3, the only difference being that C2-Mode Meter has been selected using the RIGHT key on the TRXEB while running the RX Sniff software example (TPS62740 Vin = 3.6 V or 3.0 V, and Vout = 2.3 V).

Table 11. Average RX Current Consumption in RX Sniff Mode in C2-Meter

DATA RATE	PREAMBLE BYTES	TRIGGERING ON RSSI (SMARTRF 7 ESTIMATED VALUE)	TRIGGERING ON RSSI, NO DC-DC	TRIGGERING ON RSSI WITH TPS62740 (MEASURED)
50 kbps 2-GFSK (C2-Meter Mode)	5	10.7 mA (assumes noise-free channel)	13.20 mA (measured in an office environment)	7.41 mA (3.6 V) 11.42 mA (3.0 V)

Summary:

1. RX Sniff Mode can be used for in S2-Mode (in both Meter and Other wM-Bus systems), T2-Mode (in the Meter only), and C2-Meter Mode (Meter receiving data from Other). The RX Sniff Mode current is highly dependant on noise in the RF channel. For more details, see Chapter 3.9 "RX Termination" of *CC112x/CC120x RX Sniff Mode*.[7]
2. Adding the new TPS62740 DC-DC device with Iq of 360 nA reduces the energy consumption of 30% to 40% of the CC1200 and extends significantly the battery lifetime of such RF system. The cost of the TPS62740 device can be offset by using a lower capacity battery and a much smaller sized buffer cap required to support the transmit current peaks of the CC1200.

NOTE: The RF influence of TPS62740 switching noise on the CC1200 sensitivity and blocking has not been evaluated. When using DC-DC devices in RF devices, such as wM-Bus 868-MHz enabled systems, measure the RF performance with the DC-DC active under different conditions and ensure that system RF performance is not degraded. This measurement is best done by generating a PER plot for the DC-DC wM-Bus system under the relevant input and output DC-DC voltage levels.

9 Design Files

9.1 Schematics

To download the schematics, see the design files at TIDC-WMBUS-868MHZ.

L1 is a Bead to be mounted if the regulator U2 and capacitors C12 and C41 are not mounted. By default the regulator is not mounted

CC120x using XTAL: do not mount X2, C321, C322 R321, R322
CC120x using TCXO: do not mount R12, R321, C311, X1, C301: mount 0 Ohm resistor

R12 is a 0 Ohms shunt resistor that ground the EXT_OSC pin when TCXO is not mounted

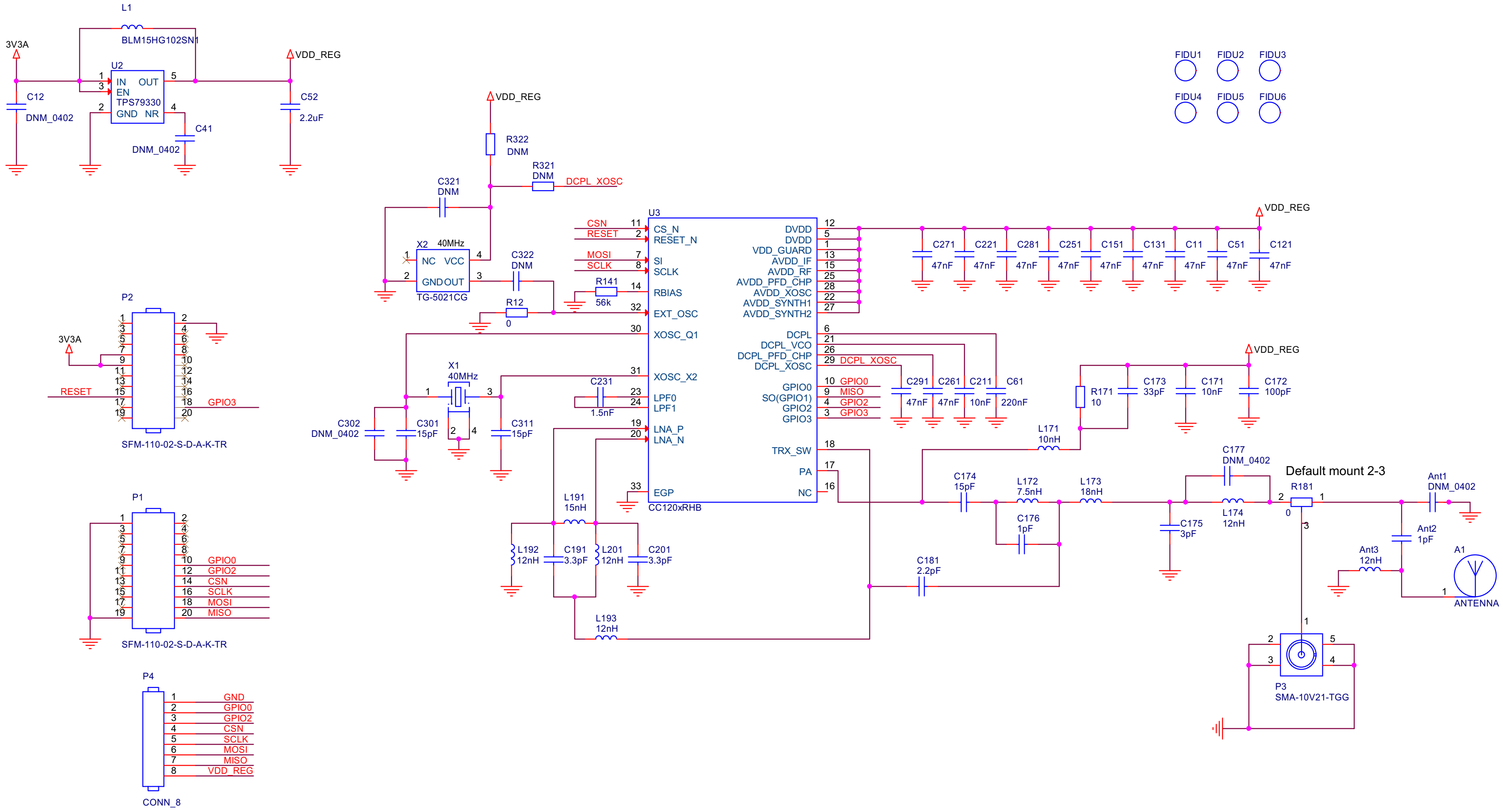


Figure 10. TIDC-WMBUS-868MHZ Schematic

9.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDC-WMBUS-868MHZ.

Table 12. BOM

ITEM	QTY	VALUE	DESCRIPTION	PARTNUMBER	PART REFERENCE	MPN	NOTE STATUS	MANUFACTURER	PCB PACKAGE
1	0	DNM	Capacitor, Ceramic, N/A Value, –55°C/125°C, 0402, SMD	02-04164	ANT1 C12 C41 C177 C302	CAPACITOR_0402_DNM_N/A_M	Preferred	Manufacturer selection	402
2	2	1 pF	Capacitor, Ceramic C0G/NP0, 1 pF, 50 V, –0.1 pF/0.1 pF, –55°C/125°C, 0402, SMD	02-04367	ANT2 C176	GRM1555C1H1R0BA01D	Preferred	Murata	402
3	5	12 nH	Inductor, Chip, 12 nH, ±5%, 0.5 A, –55°C/125°C, 0402, SMD	03-06556	ANT3 L174 L192 L193 L201	LQW15AN12NJ00D	Preferred	Murata	402
4	11	47 nF	Capacitor, Ceramic, X7R, 47 nF, 25 V, ±10%, –55°C/125°C, 0402, SMD	02-04324	C11 C51 C121 C131 C151 C221 C251 C261 C271 C281 C291	GRM155R71E473KA88D	Preferred	Murata	402
5	1	2.2 µF	Capacitor, Ceramic X5R, 2.2 µF, 10 V, ±10%, –55°C/85°C, 0603, SMD	02-02405	C52	GRM188R61A225KE34D	Preferred	Murata	603
6	1	220 nF	Capacitor, Ceramic X5R, 220 nF, 10 V, ±15%, –55°C/85°C, 0402, SMD	02-04353	C61	GRM155R61A224KE19D	Preferred	Murata	402
7	2	10 nF	Capacitor, Ceramic X7R, 10 nF, 25 V, ±10%, –55°C/125°C, 0402, SMD	02-02314	C171 C211	GRM155R71E103KA01D	Preferred	Murata	402
8	1	100 pF	Capacitor, Ceramic C0G/NP0, 100 pF, 50 V, ±5%, –55°C/125°C, 0402, SMD	02-04365	C172	GRM1555C1H101JA01D	Preferred	Murata	402
9	1	33 pF	Capacitor, Ceramic C0G/NP0, 33 pF, 50 V, ±5%, –55°C/125°C, 0402, SMD	02-04354	C173	GRM1555C1H330JA01D	Preferred	Murata	402
10	3	15 pF	Capacitor, Ceramic C0G/NP0, 15 pF, 50 V, ±5%, –55°C/125°C, 0402, SMD	02-04372	C174 C301 C311	GRM1555C1H150JA01D	Preferred	Murata	402
11	1	3 pF	Capacitor, Ceramic C0G/NP0, 3 pF, 50 V, ±0.25 pF, –55°C/125°C, 0402, SMD	02-04606	C175	GRM1555C1H3R0CA01D	Preferred	Murata	402
12	1	2.2 pF	Capacitor, Ceramic C0G/NP0, 2.2 pF, 50 V, ±0.25pF, –55°C/125°C, 0402, SMD	02-04605	C181	GRM1555C1H2R2CA01D	Preferred	Murata	402
13	2	3.3 pF	Capacitor, Ceramic C0G/NP0, 3.3 pF, 50 V,±0.25pF, –55°C/125°C, 0402, SMD	02-04369	C191 C201	GRM1555C1H3R3CA01D	Preferred	Murata	402
14	1	1.5 nF	Capacitor, Ceramic U2J, 1.5 nF, 10 V, ±5%, –55°C/125°C, 0402, SMD	02-04545	C231	GRM1557U1A152JA01D	Preferred	Murata	402
15	0	DNM	Capacitor, Ceramic X7R, 100 nF, 10 V, ±10%, –55°C/125°C, 0402, SMD	02-00760	C321	GRM155R71A104KA01D	Preferred	Murata	402
16	0	DNM	Capacitor, Ceramic C0G/NP0, 22 pF, 50 V, ±5%, –55°C/125°C, 0402, SMD	02-04373	C322	GRM1555C1H220JA01D	Preferred	Murata	402
17	1	BLM15HG102SN1	Filter, Inductor Type, 1000Ω at 100 MHZ, 25%, 250 mA, 0402, SMD	04-00032	L1	BLM15HG102SN1D	Preferred	Murata	402

Table 12. BOM (continued)

ITEM	QTY	VALUE	DESCRIPTION	PARTNUMBER	PART REFERENCE	MPN	NOTE STATUS	MANUFACTURER	PCB PACKAGE
18	1	10 nH	Inductor, Chip, 10 nH, ±5%, 0.5 A, –55°C/125°C, 0402, SMD	03-06552	L171	LQW15AN10NJ00D	Preferred	Murata	402
19	1	7.5 nH	Inductor, Chip, 7.5 nH, ±2%, 0.57 A, –55°C/125°C, 0402, SMD	03-06551	L172	LQW15AN7N5G00D	Preferred	Murata	402
20	1	18 nH	Inductor, Chip, 18 nH, ±5%, 0.37 A, –55°C/125°C, 0402, SMD	03-06593	L173	LQW15AN18NJ00D	Preferred	Murata	402
21	1	15 nH	Inductor, Chip, 15 nH, ±5%, 0.46 A, –55°C/125°C, 0402, SMD	03-06555	L191	LQW15AN15NJ00D	Preferred	Murata	402
22	2	SFM-110-02-S-D-A-K-TR	Connector, Header, Female, Straight, 2 Rows, 20 Pins, Pitch 1.27 mm, SMD	06-02251	P1 P2	SFM-110-02-SM-D-A-K-TR	Preferred	SAMTEC	
23	1	SMA-10V21-TGG	Connector, Coax RF, Straight, Female, 1 PIN, SMD	06-02188	P3	SMA-10V21-TGG	Preferred	HUS-TSAN	
24	1	0	Resistor, Jumper, –55°C/155°C, 0402, SMD	01-01784	R12	RK73Z1ETTP	Preferred	KOA SPEER	402
25	1	56 k	Resistor, Thick Film, 56 k, ±1%, 0.063 W, 50 V, –55°C/155°C, 0402, SMD	01-16848	R141	RK73H1ETTP5602F	Preferred	KOA SPEER	402
26	1	10	Resistor, Thick Film, 10, ±5%, 0.063 W, 50 V, –55°C/155°C, 0402, SMD	01-11612	R171	RESISTOR_0402_10_+/-5%_50V_0.063W_M_+/-200PPM	Preferred	Manufacturer selection	402
27	1	0	Resistor, Jumper, 3 Ports, –55°C/155°C, 0402, SMD	01-16574	R181	RK73Z1ETTP	Preferred	KOA SPEER	402
28	0	DNM	Resistor, Do Not Mount, 0402, SMD	01-02472	R321 R322	DNM	Preferred	Do Not Mount	402
29	0	DNM	IC, Analog, High PSRR Fast Rf Low Dropout Regulator in Wafer Chip Scale, VIN: 2.7 to 5.5 V, VOUT: 3 V, SOT23-5, SMD	18-01358	U2	TPS79330DBVR	Not Preferred	Texas Instruments	SOT23-5
30	1	CC120xRHB	IC, Analog RF, CC120xRHB, N/A, QFN32, SMD	18-28112	U3	CC120xRHB	Preferred	Texas Instruments	QFN32
31	1	40 MHz	Crystal, Oscillator, 40 MHz, –15 PPM/°C/15 PPM/°C, 100 V, –20°C/75°C, SMD	12-00469	X1	NX3225SA 40MHz EXS00A-CS03880	Preferred	NIHON DEMPA KOGYO CO., LTD	
32	0	DNM	Crystal, Oscillator, TBD, 2.3 to 3.6 V, –30°C/85°C, , SMD	12-00451	X2	TG_5021CG	Preferred	Epson Toyocom	

9.3 Layer Plots

To download the layer plots, see the design files at TIDC-WMBUS-868MHZ.

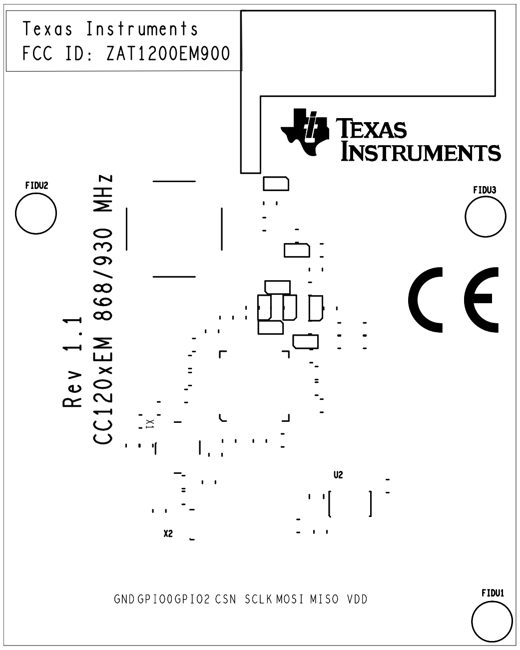


Figure 11. Top Silkscreen

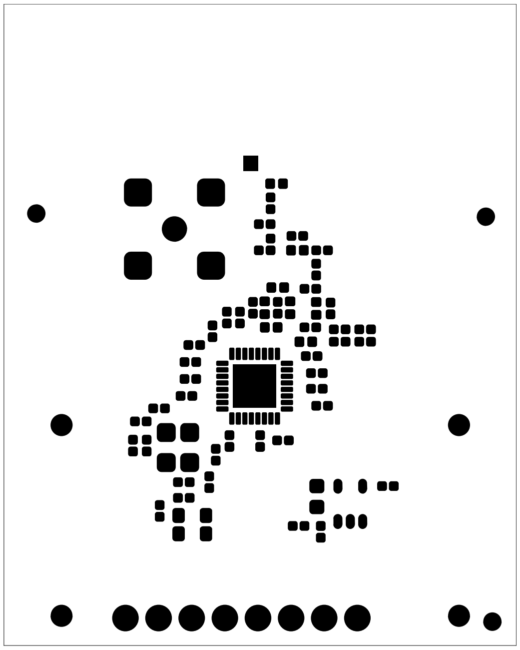


Figure 12. Top Solder Mask

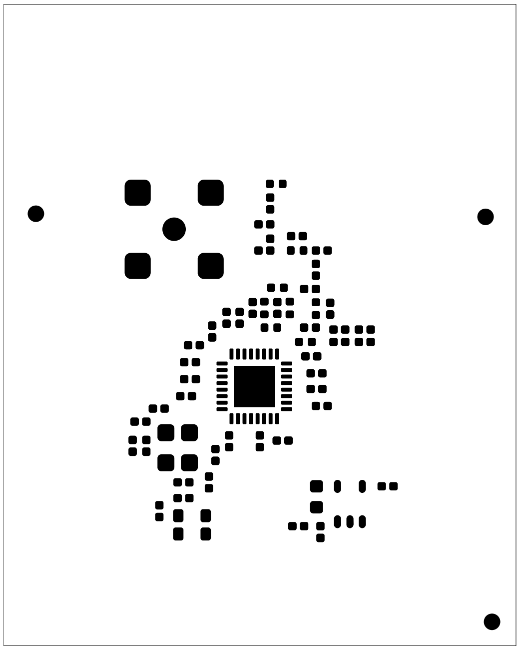


Figure 13. Top Paste

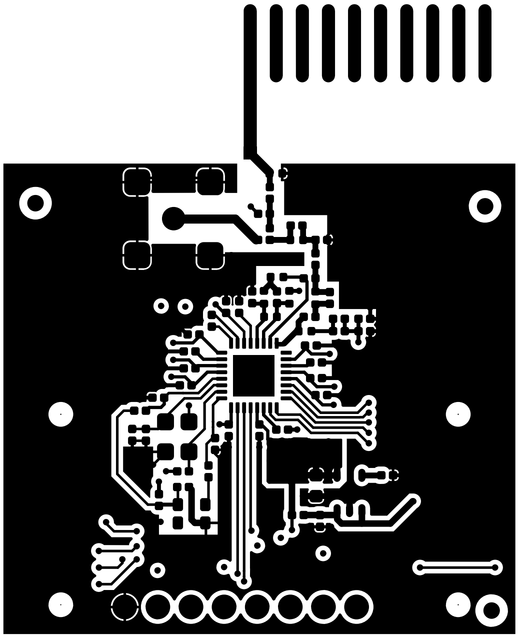
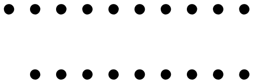
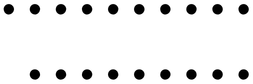


Figure 14. Top Layer





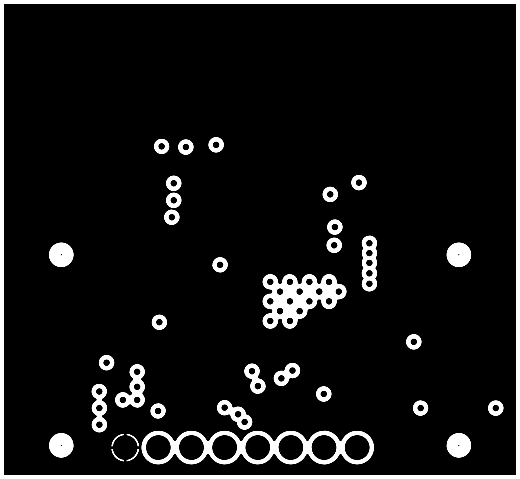


Figure 15. Ground Plane Layer 2

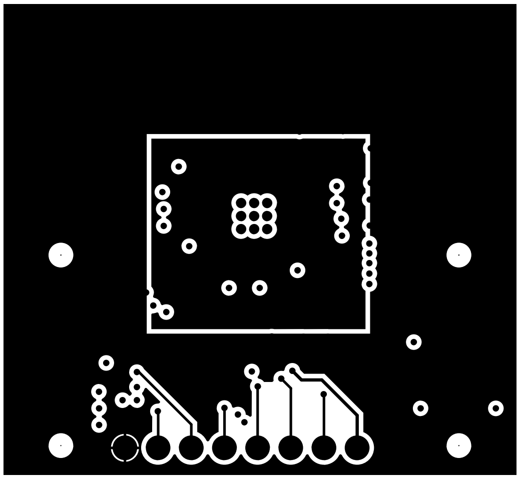
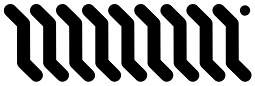


Figure 16. PWR Plane Layer 3



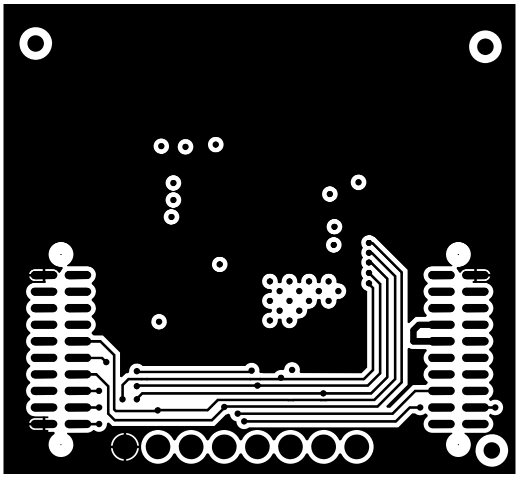


Figure 17. Bottom Layer

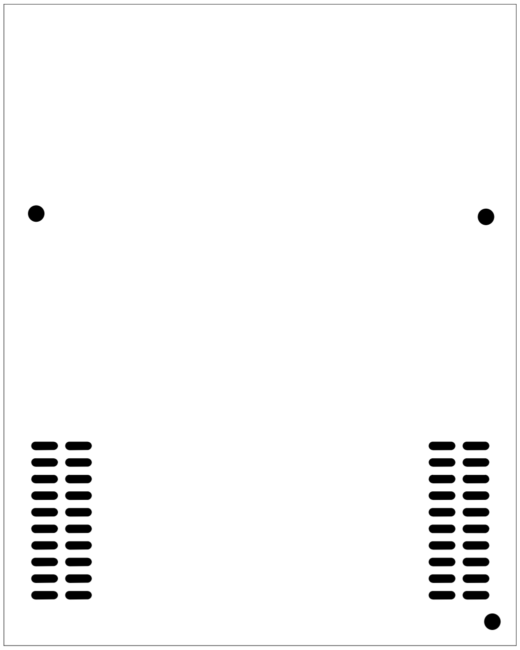


Figure 18. Bottom Paste

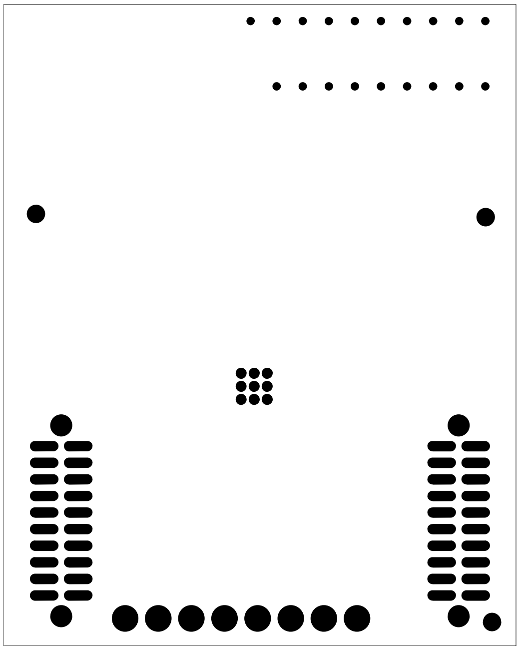


Figure 19. Bottom Solder Mask

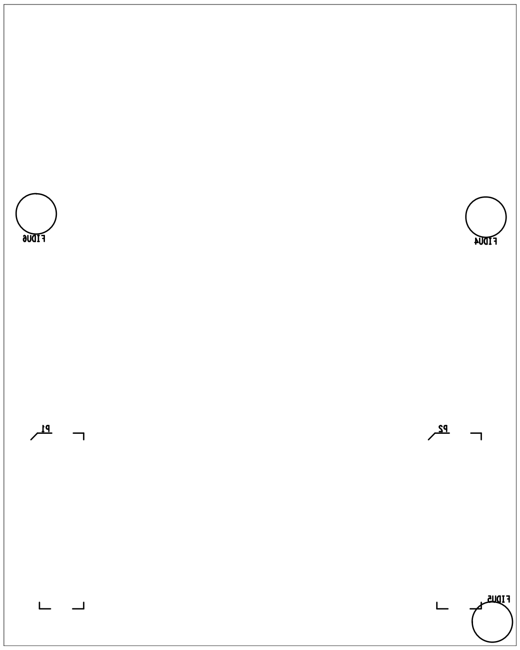


Figure 20. Bottom Silkscreen

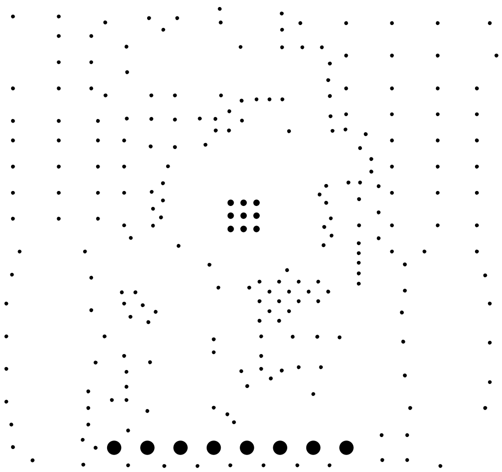


Figure 21. Drill Drawing

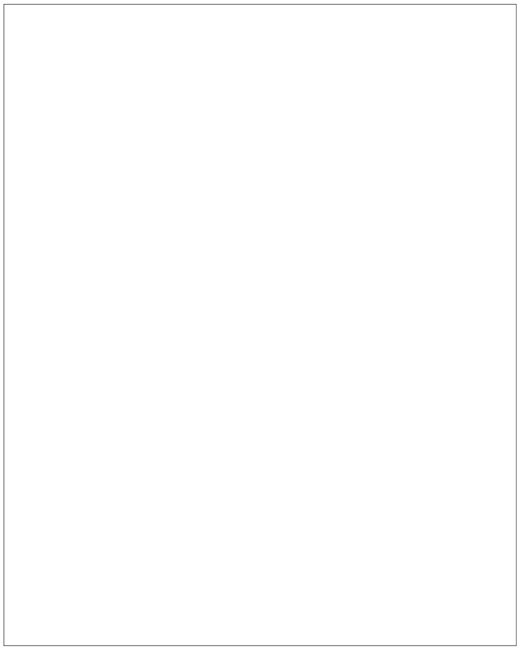


Figure 22. Board Outline

9.4 CAD Project

To download the CAD project files, see the design files at TIDC-WMBUS-868MHZ.

9.5 Gerber Files

To download the Gerber files, see the design files at TIDC-WMBUS-868MHZ.

9.6 Assembly Drawings

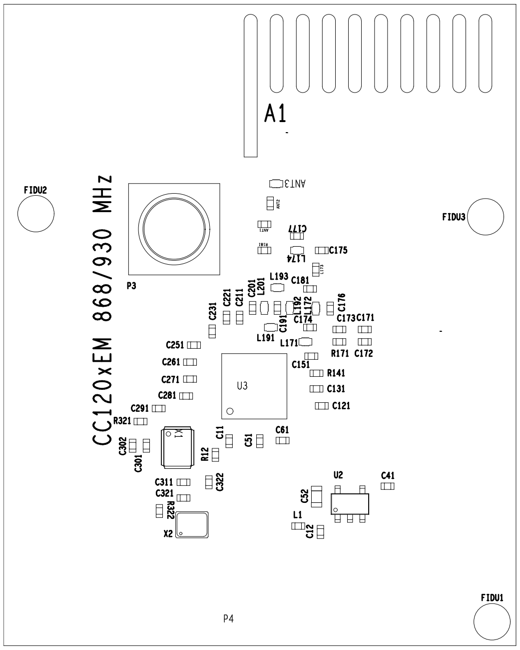


Figure 23. Top Assembly Drawing

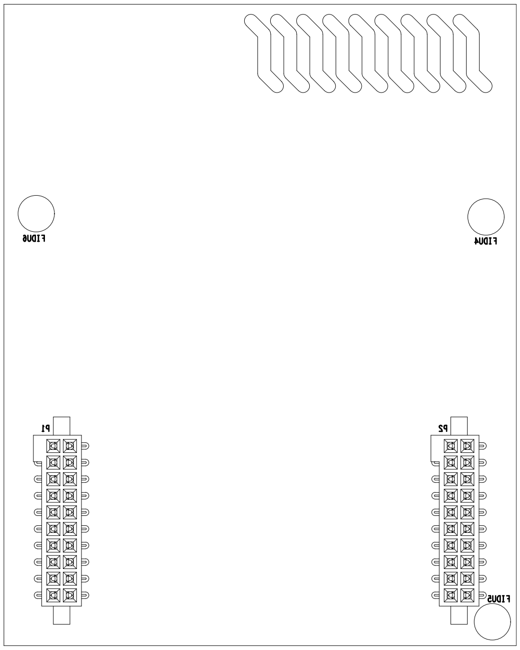


Figure 24. Bottom Assembly Drawing

9.7 Software Files

To download the software files, see the design files at TIDC-WMBUS-868MHZ.

10 References

1. Texas Instruments, CC1200 Datasheet (SWRS123D)
2. Texas Instruments, TPS62740 Datasheet (SLVSAC3C)
3. Beuth, EN13757-4:2014-02 (wM-Bus Standard Document)
4. Texas Instruments, Application Note AN121, *Wireless M-Bus Implementation with CC112x / CC120x High Performance Transceiver Family* (SWRA423)
5. Texas Instruments, Design Note DN039, *Matched Integrated Passive Component for 868 / 915 MHz operation with the CC112x, CC117x & CC12xx high performance radio series* (SWRA407)
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8. ETSI 300220 v2.4.1 (Web)
9. Texas Instruments, Application Note AN098, *Layout Review Techniques for Low Power RF Designs* (SWRA367)
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11 Terminology

wM-Bus— The European RF Metering standard, providing solutions for 169-, 433-, and 868-MHz bands

ETSI Cat. 2 Receiver—The definition for a set of RF parameters in EN300 220 v2.4.1, representing the minimum requirement in wM-Bus capable RF systems at 868 MHz

S-Mode— wM-Bus Mode at 868 MHz at 32.768 kcps (net of 16.384 kbps), mandated in Germany

T-Mode— wM-Bus Mode at 868 MHz at 100 kcps (net of 66.667 kbps), mandated in Germany and Netherlands

C-Mode— The “new” or improved "T-Mode" at 868 MHz at 100 kcps (net of 100 kbps), mandated in Germany

12 About the Author

MILEN STEFANOV is a system applications engineer at Texas Instruments, where he is responsible for Sub-1 GHz RF communications solutions for Smart Meters. Milen has significantly contributed to delivering TI’s full wM-Bus system solution, consisting of an MCU+RF chipset, a complete wM-Bus protocol stack, and a dedicated power management solution. Milen has a system-level expertise on smart metering and RF communications and over 15 years of experience working with customers. He has published several technical articles on wM-Bus related topics in the past four years. He earned his master of science in electrical engineering (MSEE) from Technical University in Chemnitz, Germany.

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