TI Designs
Long-Range Mode with Ultra-Narrowband RF Design Guide

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Design Resources

[TIDC-CC112X-LRM-410-480MHZ] [TIDC-CC112X-LRM-820-960MHZ]	Tool Folders Containing Design Files
[CC1120]	Product Folder
[CC1125]	Product Folder
[MSP430F5438A]	Product Folder

TI E2E™ Community

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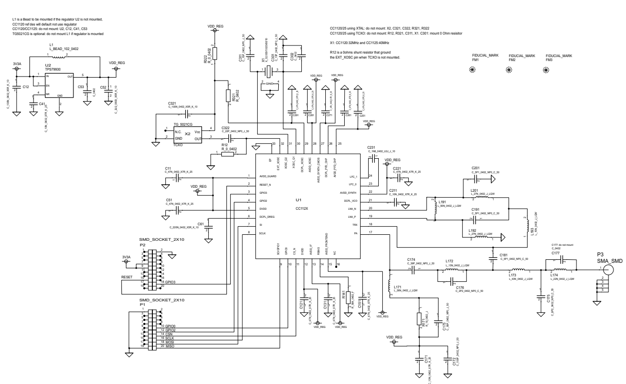
[WEBENCH® Calculator Tools]

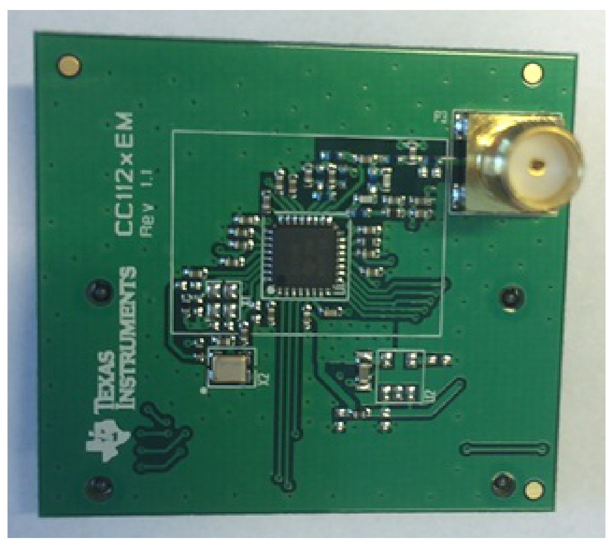
Design Features

- Ultra-Narrowband, Long-Range RF Communication
- Range of More Than 100 km Possible
- Range of More Than 2 km in Dense Urban Environment
- –125 dBm Sensitivity @433 MHz, 14 dBm Output Power
- High Spectrum Efficiency

Featured Applications

- City-Wide Star Network
- Metering Systems
- Alarm and Security Systems





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1 System Description

Long-range mode (LRM) allows several kilometers of RF transmission range in both rural and urban areas with minimal use of RF frequency bandwidth. In this TI design, the CC1120 ultra-narrowband transceiver is used with a TCXO, which allows a very narrow RX filter bandwidth and improves RF sensitivity, selectivity, and blocking.

LRM uses 600-bps symbol rate, ±1.5 kHz frequency deviation, and GFSK modulation. The CC1120 evaluation module includes a 32-MHz TCXO.

This TI design shows how to use a standard CC1120DK device with a CC1120EM device modified to use a TCXO. There are two versions of the CC1120EM device—433 MHz and 868 MHz. Test software for packet error rates demonstrates LRM.

1.1 CC1120

The CC1120 device is a fully integrated, single-chip radio transceiver designed for high-performance operation at very low power and low voltages. All filters are integrated to operate free of costly external SAW and IF filters. The device is intended for the industrial, scientific, and medical (ISM) fields and short-range device (SRD) frequency bands at 164 MHz to 192 MHz, 274 MHz to 320 MHz, 410 MHz to 480 MHz, and 820 MHz to 960 MHz.

The CC1120 device provides hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and RX sniff mode. The main operating parameters of the CC1120 device can be controlled through an SPI interface. In a typical system, the CC1120 device can be used with a microcontroller and a few external passive components.

To learn more about TI's 169-MHz, 315-MHz, 433-MHz, 433-MHz, 868-MHz, 915-MHz, and 920-MHz solutions, visit the sub-1 GHz overview page.

1.2 MSP430F5438A

The TI MSP430™ family of ultra low-power microcontrollers consists of devices that feature sets of peripherals targeted for various applications. Combined with low-power modes, the architecture is optimized to extend battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows the device to wake up from low-power modes to active mode in 3.5 µs.

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Symbol Rate	600 bps	
Frequency Deviation	±1.5 kHz	
Modulation	GFSK	
Carrier Frequency	433 MHz	Two versions of this design
	868 MHz	
1% BER Sensitivity	433 MHz: –125 dBm, 7.8-kHz RX filter bandwidth	
	868 MHz: –124 dBm, 12.5-kHz RX filter bandwidth used for frequency compensation and 7.8 kHz for packet reception	
Crystal	32-MHz TCXO	

2 Block Diagram

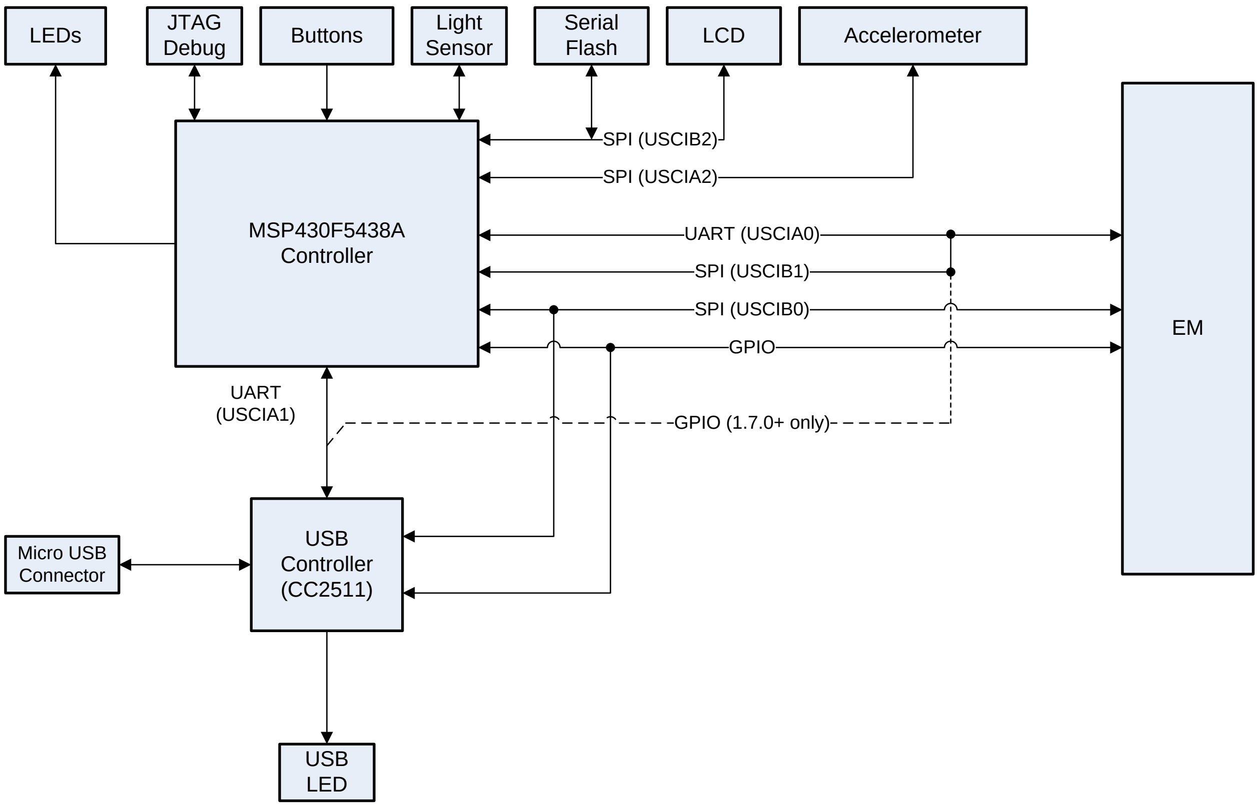

Figure 1. TrxEB Block Diagram With Connections to EM

NOTE: The CC1120DK kit includes a TrxEB with connectors for the CC1120EM device. The long-range packet error rate test runs on the MSP5438A, which controls the CC1120 device through an SPI interface.

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3 System Design Theory

This section discusses how to enable an ultra-narrowband solution with the CC1120 device to achieve better RF range and improved coexistence with RF interference. A narrowband solution has two main benefits. The narrowband solution has more RF channels than in wideband solutions. Also, the RF receive filters in a narrowband solution pick up less noise than wide RF recieve filters used in wideband solutions. A narrowband is the best choice for RF solutions in urban and industrial areas. For more details, check out the whitepaper titled *Long-range RF Communication: Why narrowband is the de facto standard*.

3.1 RF System Parameters

Settings: 600-bps symbol rate, ±1.5 kHz frequency deviation, GFSK modulation gives a 99% occupied bandwidth (OBW) of 3.4 kHz.

A channel filter is on the receiver side, which is centered on the down-converted received RF (that is, the intermediate frequency [IF]). The channel filter has a programmable bandwidth "RX filter BW". The OBW of the transmitted signal must be less than the RX filter bandwidth but should also consider the frequency error of the transmitter and receiver.

If the frequencies of the transmitter carrier and the receiver LO contain errors, the IF will also contain an error. Assume the frequency errors in the transmitter and receiver are equal (same type of crystal). For example, if the receiver has an error of –x ppm and the transmitter has an error of +x ppm, the IF will have an error of +2 × x ppm (assuming low-side LO injection). If the receiver has an error of +x ppm and the transmitter has an error of –x ppm, the IF will have an error of –2 × x ppm.

The RX filter bandwidth must be larger than the OBW plus the maximum frequency error due to crystal inaccuracies. The worst case scenario is if the crystal TX and RX errors have opposite signs.

$$\text{RX filter BW} > \text{OBW} + 4 \times \text{XTAL}_{ppm} \times f_{RF} \tag{1}$$

$XTAL_{ppm}$— the total accuracy of the crystal including initial tolerance and temperature drift

f_{RF}— the RF operating frequency

For 433-MHz operation, a 7.8-kHz RX filter bandwidth and the use of FB2PLL allow a frequency error up to ±8 ppm.

From Equation 1:

$$3.4\text{-kHz} + 4 \times 4 \times 433 = 11\text{-kHz} < 7.8 \times 1.5\text{-kHz (RX filter bandwidth} \pm \text{RX filter bandwidth} \div 4\text{)} \tag{2}$$

See Figure 11 for a plot of packet error rate (PER) vs frequency offset at 433 MHz.

For 868-MHz operation, a 12.5-kHz RX filter bandwidth and the use of FB2PLL allow a frequency error of up to ±8 ppm.

From Equation 1:

$$34\text{-kHz} + 4 \times 4 \times 868 = 17.3\text{ kHz} < 12.5. \times 1.5\text{ kHz (RX filter bandwidth} \pm \text{RX filter bandwidth} \div 4) \tag{3}$$

See Figure 12 for a plot of PER vs frequency offset at 868 MHz.

When the RX filter bandwidth increases from 7.8 kHz to 12.5 kHz, it gives a theoretical degradation in sensitivity of 2.0 dB. The sync word detection algorithm is more sensitive than the data demodulation algorithms in CC1120. A wider receive bandwidth can be used for sync word detection compared to data demodulation. This condition enables estimating and compensating for the frequency offset on the sync word before demodulating the actual data payload.

3.2 Frequency Compensation

Frequency compensation uses a wide RX filter bandwidth to measure the frequency offset. Frequency offset compensation aligns the RX and TX units and then programs a lower RX filter bandwidth to improve sensitivity, selectivity, and blocking.

To achieve frequency compensation, a dummy packet is sent before the real packet. The dummy packet must contain a preamble and a sync word (for example, SYNC_1), while the real packet consists of a preamble, a sync word (SYNC_2), and the payload.

In Figure 2, the dummy packet and the real packet have the same format to simplify the code and minimize reconfigurations between packets. Figure 2 shows the packet format sent from the transmitter.

3-byte PREAMBLE	4-byte SYNC_1	1-byte payload	3-byte PREAMBLE	4-byte SYNC_2	Data payload

indent: SYNC_1 = 0x2633D9CC

indent: SYNC_2 = 0x930B51DE

Figure 2. Packet Format Used for Frequency Compensation

The following procedure is for frequency offset compensation.

1. Start the RX with a 12.5-kHz RX filter bandwidth
2. Enable FB2PLL (that is, wide enough to account for maximum frequency error caused by temperature drift and initial tolerance) (After SYNC_1 is detected, register FREQOFF_EST gives the frequency offset between RX and TX units.)
3. Put the RX unit is put in idle mode.
4. Reduce the RX filter bandwidth to 7.8 kHz.
5. Write the error in FREQOFF_EST to register FREQOFF.
6. Write SYNC_2 to the chip.
7. Restart RX mode. For example, setting FREQOFF_CFG.FOC_LIMIT = 0 the programmed RX filter bandwidth is extended by ±RX_BW ÷ 4. If the RX filter bandwidth is programmed to 50 kHz and FREQOFF_CFG.FOC_LIMIT = 0, the noise bandwidth is 50 kHz (that is, the bandwidth sets the noise floor) but the effective RX filter bandwidth is 75 kHz. The TX unit transmits PREAMBLE, SYNC_1, and 1-byte payload (2 bytes CRC) then goes to idle mode.
8. Restart the TX unit with a 3-byte PREAMBLE, SYNC_2, and data payload (Alternatively, write the second preamble and SYNC_2 to TX FIFO and do not restart TX after SYNC_1 and a 1-byte payload, but then calculate CRC in the software on the receiver side).

NOTE: FREQOFF and SYNC_2 cannot be updated in RX mode and must be updated with the chip in idle mode. If the two packets have different formats, reconfigure the necessary registers . In Figure 2, change the PKT_LEN registers from 1 to 3.

Feedback to PLL (FB2PLL) extends the RX filter bandwidth (RX_BW) without increasing the noise bandwidth.

4 Getting Started

4.1 Hardware Setup

To test the long-range mode with the CC1120 device, standard TI development hardware and two TCXO crystals are needed. Desolder the crystal on the CC1120EM device and replace it with a TCXO crystal. See Table 4 (433 MHz) and Table 5 (868 MHz).

Most cell phones use TCXO crystals; TCXO crystal prices are now in the range of twice the price of a crystal.

4.1.1 Long-Range Mode–433 MHz

This mode needs TI EVMs CC1120DK and CC1120EMK-420-433.

4.1.2 Long-Range Mode–868 MHz

This mode needs TI EVM CC1120DK (includes CC1120EMK-868-915).

4.2 Firmware

The LRM PER test software is one of the CC1120 software examples (SWRC253). In the zip archive, complete project files for IAR and the precompiled hex image used for the test exist (*ide\iar\cc1120_long_range_mode\LRM\Exe\cc1120_long_range_mode.hex*). The hex image can be programmed to the TrxEB board using the SmartRF™ Flash programmer. For more details, see the *TrxEB PER Software User Guide* (SWRU296).

The demo software implements frequency offset compensation to operate at 868 MHz. To operate at 433-MHz, the RX filter bandwidth is fixed at 7.8 kHz. If frequency offset compensation is also implemented at a frequency of 7.8 kHz, it is possible to use a less accurate and less expensive TCXO crystal than the one used on the CC1120EM device to operate at 433 MHz.

5 Test Data

5.1 Setting Up the Board

The SmartRF™ TrxEB device includes a battery holder for two 1.5-V AA batteries. The jumpers for selecting the power source should short-circuit pin 1-2 (BATT) and 9-10 (LCL) of header P17 (see Figure 3).

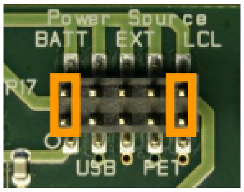

Figure 3. Power Selection

To run the software application from the MSP430 device, set the correct mode of the TrxEB device by setting switch S1 to UART then setting switch S2 to Enable. Setting these switches enables the MCU (see Figure 4).

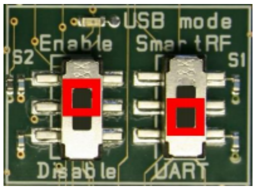

Figure 4. Select Operation Mode

Set the main power supply switch (S5 in top-left corner of the TrxEB device) to ON (see Figure 5).

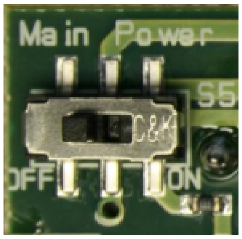

Figure 5. Power Switch

The arrows on the LCD screen will show ways to navigate the menu when the board is powered up (see Figure 6).

Figure 6. Frequency Selection

5.2 Navigating the Menu

To navigate the menu, start RX on one board and TX on the other. See Figure 7.

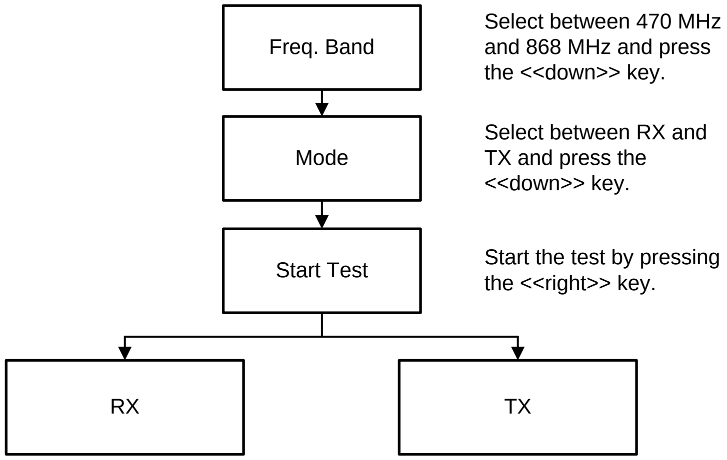

Figure 7. Navigating the Menu

5.3 Operating TX Mode

In TX mode, packet1 and packet2 are transmitted (at 433 MHz or at 868 MHz).

See packet1 (containing SYNC_1 and a dummy byte).

0xAA 0xAA 0xAA	0x26 0x33 0xD9 0xCC	0x55	CRC CRC

Figure 8. Packet1

See packet2 (containing SYNC_2, a 16-bit sequence number, and a dummy byte).

0xAA 0xAA 0xAA	0x93 0x0B 0x51 0xDE	Seq. Seq. 0x55	CRC CRC

Figure 9. Packet2

Press any key to stop or restart TX mode.

5.4 Operating RX Mode

In RX mode, the radio runs two algorithms based on the frequency band.

433 MHz

- No frequency offset compensation
- The radio searches for packet2 only.

868 MHz

- Frequency offset compensation
- The radio searches for packet1, performs frequency offset compensation, and reconfigures to look for packet2 using an RX filter bandwidth of 7.8 kHz (compared to 12.5 kHz for packet1).

When starting RX mode, the LCD displays the number of received packets, the number of lost packets, and the RSSI packets received. See Figure 10 for an example of the display. Press any key to stop or restart RX mode.

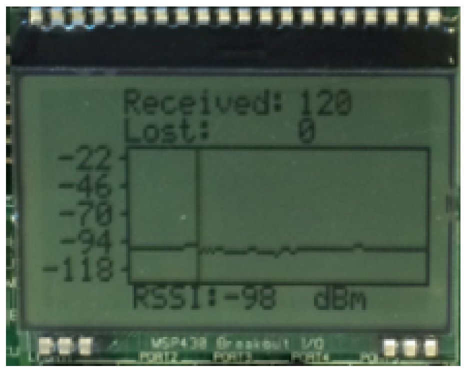

Figure 10. RSSI View

5.5 Sensitivity

Table 2 gives 1% BER sensitivity figures. The sensitivity is the average of 12 evaluation modules.

Table 2. Sensitivity for 600 bps Symbol Rate, ±1.5 kHz Frequency Deviation

RF FREQUENCY [MHz]	SENSITIVITY [dBm]	COMMENTS
433	–125	RX filter bandwidth of 7.8 kHz
868	–124	RX filter bandwidth of 12.5 kHz RX filter bandwidth used for frequency compensation and 7.8 kHz for packet reception

5.6 PER Versus Frequency Offset Versus Input Power Level

Operating at 433-MHz, Figure 11 shows a 7.8 kHz RX filter bandwidth and the use of feedback to PLL (FB2PLL) allows up to ±8 ppm frequency error.

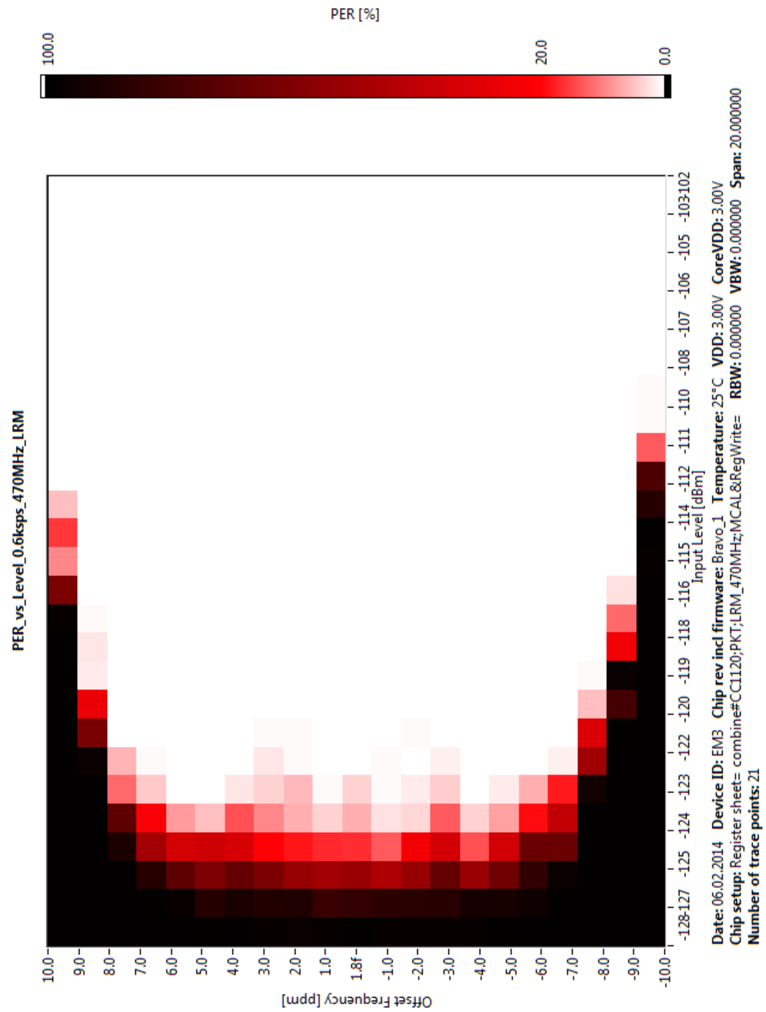

Figure 11. PER Versus Offset Versus Input Power Level: 433 MHz, 7.8-kHz RX Filter Bandwidth

Operating at 868-MHz, Figure 12 shows a 12.5 kHz RX filter bandwidth and the use of FB2PLL allows up to ±8 ppm frequency error.

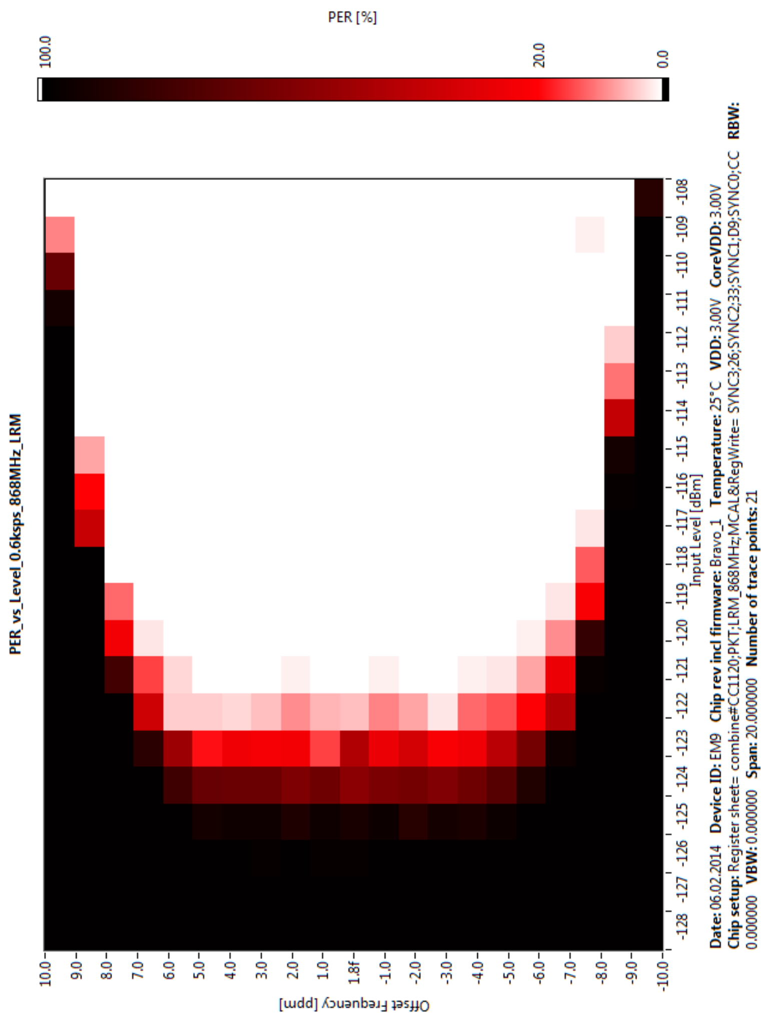

Figure 12. PER vs Offset vs Input Power Level: 868 MHz, 12.5-kHz RX Filter Bandwidth

20% PER in Figure 11 and Figure 12 corresponds to 1% BER. See the *CC1120 User Guide* (SWRU295) and Sub-1 GHz Wiki for details on FB2PLL.

5.7 Range Testing

This section presents range measurements using the LRW software with the CC1120EM hardware in a high rise building located in a dense urban environment and a 114-km range measurement using LRM demo software with the CC1120 transceiver and the CC1190 range extender hardware. This section also includes a link to a wiki page for more results of range measurement.

5.7.1 High Rise Building

Wireless metering for water, gas, and electric has become more common. A challenge with these applications is achieving a wireless link through floors of a high rise building. To test in this type of environment, we chose the TI office in Stockholm, Sweden on the 26th floor in the Kista Science Tower.

Test Parameters:

- Hardware: CC1120EM 420 to 433 MHz modified with 32-MHz TCXO and TrxEB
- Frequency: 430 MHz
- Antenna: Tuned to 430-MHz to 510-MHz operation
- Software: PER software running on TrxEB MSP430
- Output power: 14 dBm
- 99% OBW: 3.4 kHz
- Data payload: 30 bytes (excluding preamble, sync word, CRC)
- TX unit placed at floor 26 in the stairway
- Register settings: LNA = 0x03, extended data filter enabled
- Link budget = 14 + 2.1 + 2.1 – 125 = 143 dB (The antenna gain is 2 dBi)

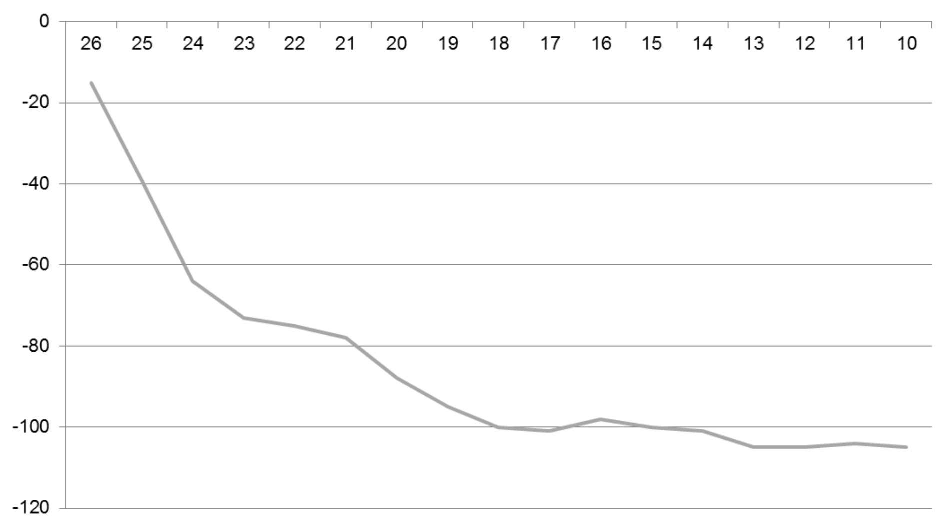

Figure 13. RSSI Levels at Different Floors Through the High Rise Building

Figure 14. An Indoor Radio Link Through a High Rise Building

The TX unit transmitted data through 12 to 16 floors.

NOTE: The maximum number of floors through which the radio signal can pass is dependent on the construction material of the building. Refer to the *Application Report Achieving Optimum Radio Range* (SWRA479) for more details on radio range.

A link budget of 143 dB approximately 6 floors would be expected if the RF signal only traveled through the concrete floors because eight inches of concrete at 500 MHz has an attenuation of 21 dB. The attenuation between each floor was a mixture of free space and concrete attenuation because the TX unit was placed in the stairway. Assume 10 dB per floor (average of 21 and 1 dB). An average of 10 dB attenuation per floor correlates to the measured results that the signal recorded at 12 to 16 floors lower in the building. With a link budget of 143 dB and 10 dB attenuation per floor, we expected the RF signal to be transmitted through 14 floors.

The radio link was established outside the high rise building (see Figure 15). The signal strength was –78 dBm, leaving 40 dB for the link budget.

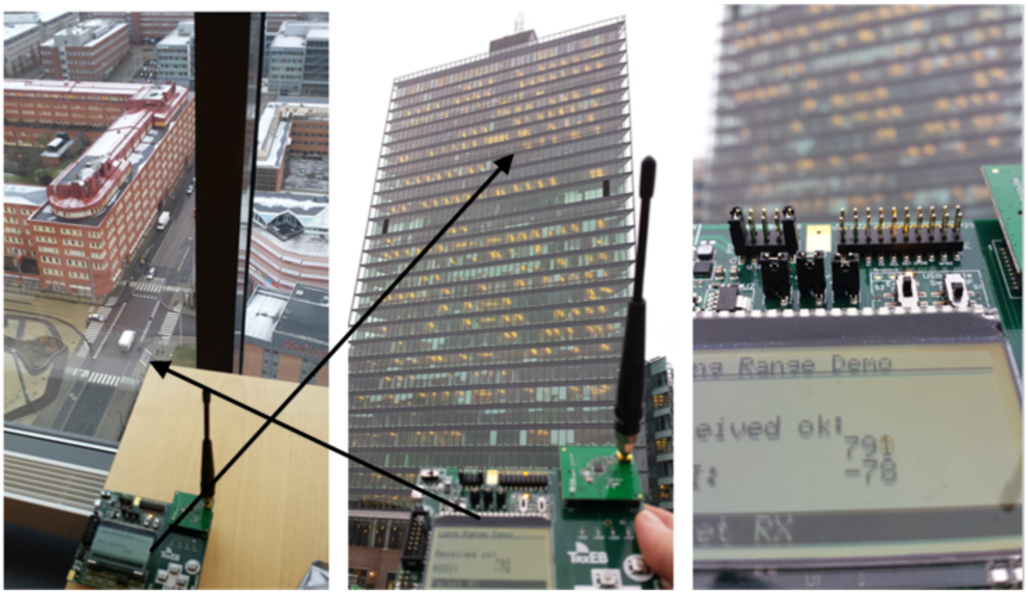

Figure 15. Testing Outside the Building

5.7.2 Dense Urban Environment

Test setup:

- A CC1120EM device with TCXO using long-range demo software with 600 bps, ±1.5 kHz deviation, 7.8-kHz RX filter bandwidth, and frequency offset compensation on each packet for to operate at 868-MHz.
- Output power: 14 dBm
- Frequency: 868 MHz and 433 MHz
- Location: Oslo, Norway

The range distance measured at 433 MHz was 2 km (see Figure 16) and at 868 MHz the range was 1.3 km (see Figure 17). The range was greater at the lower frequency due to the attenuation difference of the construction materials in an urban environment.

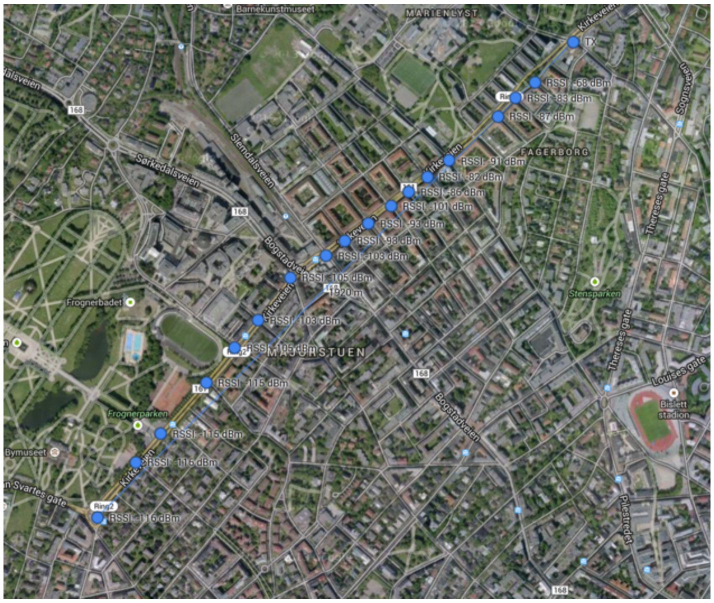

Figure 16. CC1120 433 MHz 2-km Range

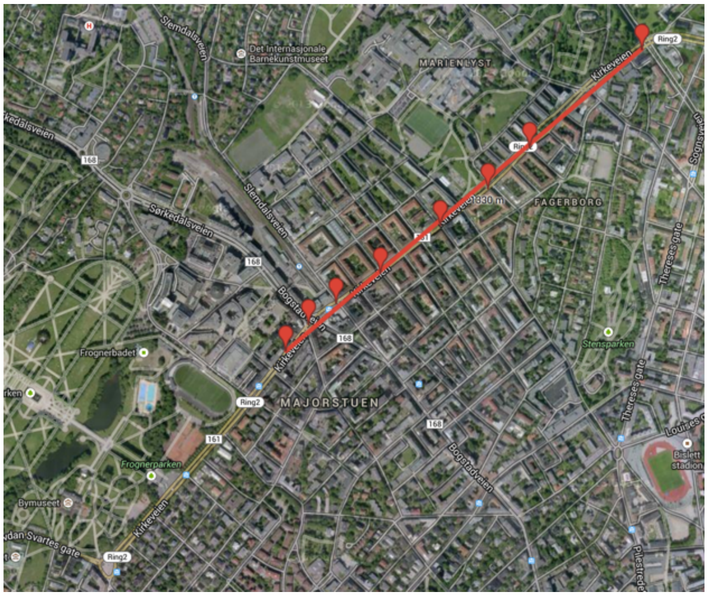

Figure 17. CC1120 868 MHz 1.3-km Range

5.7.3 Extremely Long Range

We measured the range when running LRM demo software with the CC1120 transceiver and with the CC1190 range extender hardware.

Table 3. Sensitivity for 600-bps Symbol Rate, ±1.5 kHz Frequency Deviation

RF Frequency [MHz]	Sensitivity [dBm]	Comments
868	–126.5	RX filter bandwidth of 12.5 kHz. RX filter bandwidth is used for frequency compensation and 7.8 kHz for packet reception.

Test Parameters:

- CC1120 + CC1190 at 868 MHz, LRM, +27 dBm and standard kit antennas
- Location: Table Mountain in Cape Town, South Africa
- Antenna positioning: H1 = 1000 m, H2 = 1 m for 78 – 98-km tests and 91 m for 114-km test
- Frequency: 868 MHz
- CC1120 + CC1190 evaluation module includes a 32-MHz TCXO
- Register settings: LNA = 0x03, extended data filter enables
- Link budget = 27 + 2.1 + 2.1 – (–126.5) = 158 dB (The antenna gain is 2 dBi)
- Three tests performed at these distances: 71 km, 98 km, and 114 km

Figure 18. Road Sign Showing the Same Distance Covered With the Range Test Range

More than 600 data packets were sent with just 2 packets lost at 71 km; 1000 data packets were sent with just 2 packets lost at 98 km; 1000 data packets were sent with no lost data packets at 114 km (see Figure 18).

More Range Test Results

This video shows the CC1120 device range with a jammer present in a dense urban environment. The video shows the CC1120 device and a competitor solution operating at the same time. The RF link using the competitor solution breaks down in the presence of the jammer.

See the range testing wiki for more test results.

6 Design Files

6.1 Gerber Schematics

The schematics are presented in the following order:

1. 433 MHz (see Figure 19)
2. 868 MHz (see Figure 20)

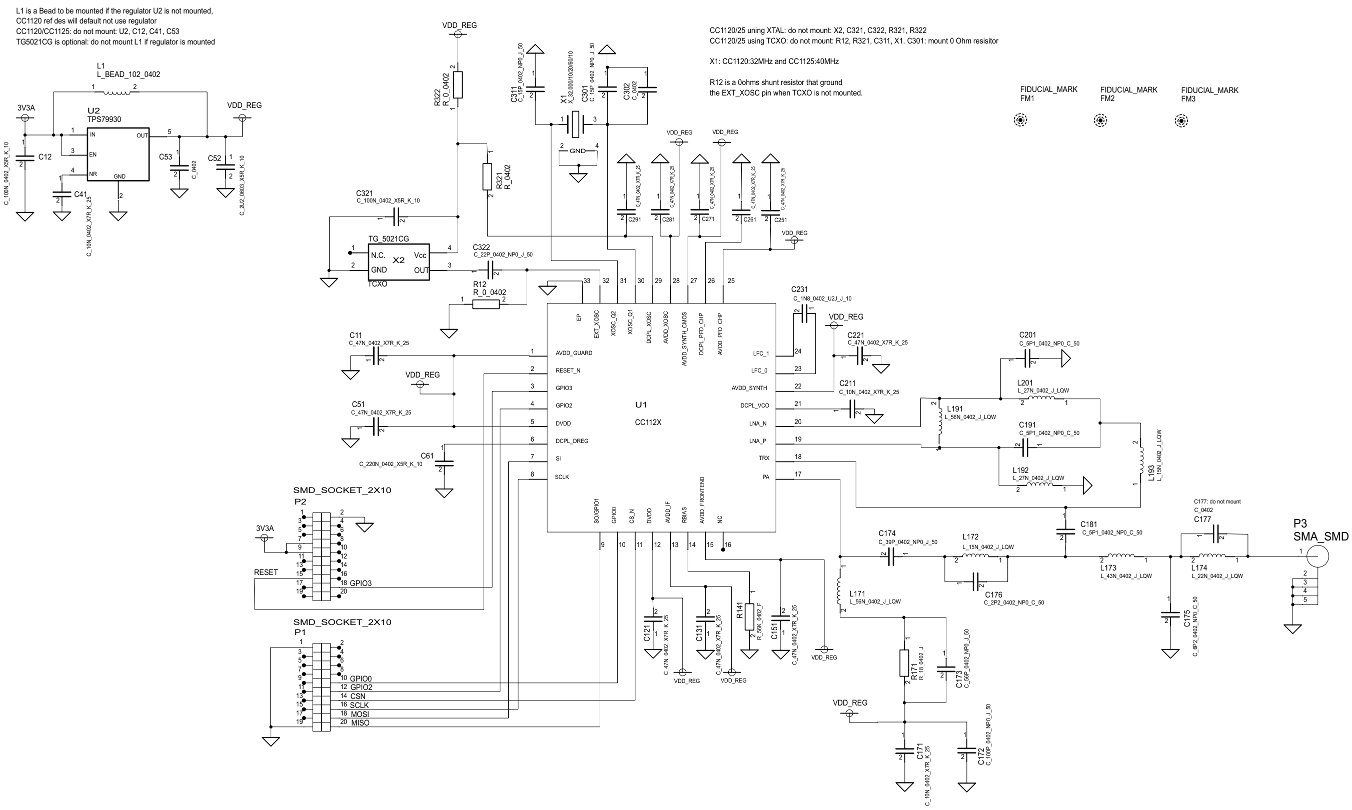

Figure 19. Schematics for 433 MHz

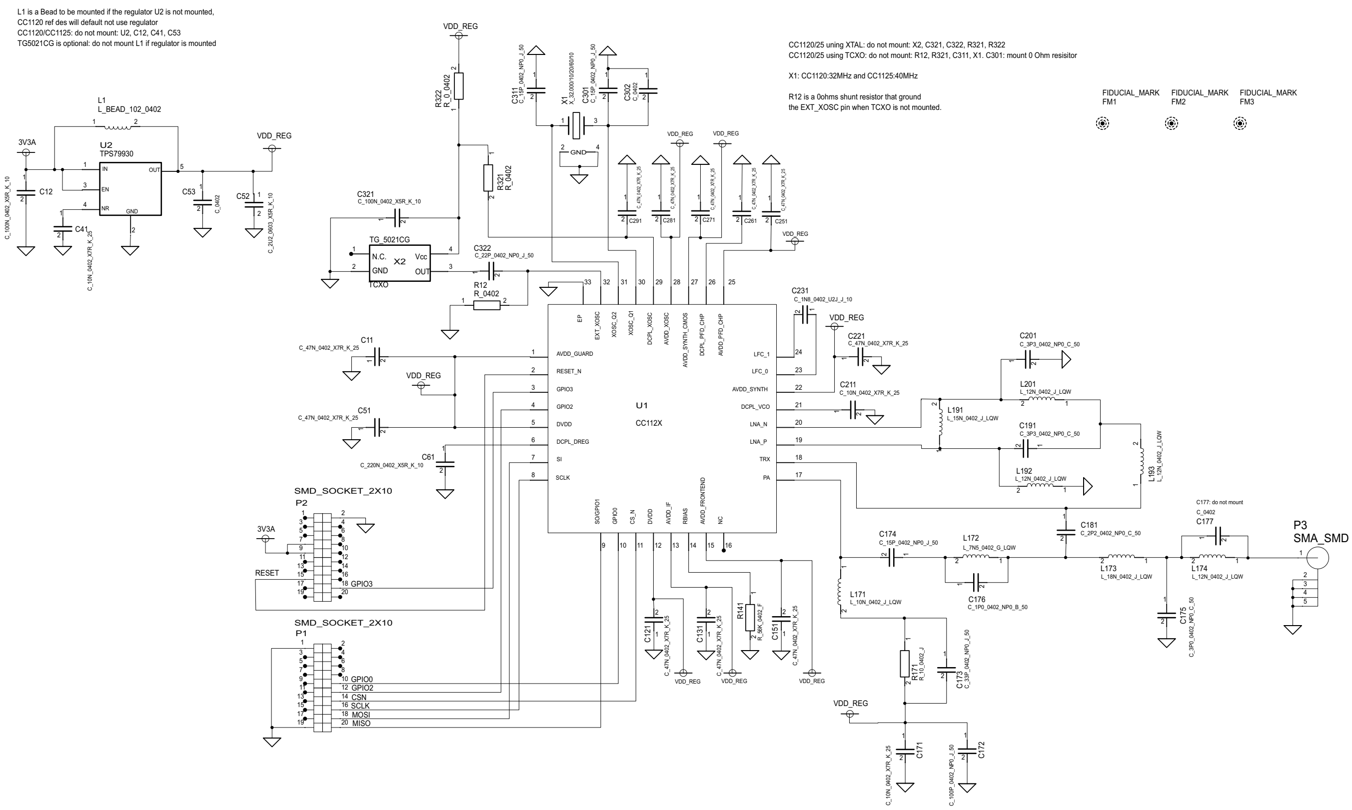

Figure 20. Schematics for 868 MHz

6.2 Bill of Materials–433 MHz

To download Table 4, see the design files at SWRC221.

Table 4. Bill of Materials

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
C11	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C12	0		Do not mount			
C41	0		Do not mount			
C51	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C52	1	2.2 µF	Capacitor, 2.2 µ, 0603, X5R, 10%, 10 V	603	GRM188R61A225KE34D	Murata
C53	0		Do not mount			
C61	1	220 nF	Capacitor, 220 n, 0402, X5R, 10%, 10 V	402	GRM155R61A224KE19D	Murata
C121	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C131	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C151	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C171	1	10 nF	Capacitor, 10 n, 0402, X7R, 10%, 25 V	402	GRM155R71E103KA01D	Murata
C172	1	100 pF	Capacitor, 100 p, 0402, NP0, 5%, 50 V	402	GRM1555C1H101JZ01D	Murata
C173	1		Do not mount			
C174	1	39 pF	Capacitor, 39 p, 0402, NP0, 5%, 50 V	402	GRM1555C1H390JZ01D	Murata
C175	1	6.2 pF	Capacitor, 6.2 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H6R2CZ01D	Murata
C176	1	2.2 pF	Capacitor, 2.2 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H2R2CZ01	Murata
C177	0		Do not mount			
C181	1	5.1 pF	Capacitor, 5.1 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H5R1CZ01D	Murata
C191	1	5.1 pF	Capacitor, 5.1 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H5R1CZ01D	Murata
C201	1	5.1 pF	Capacitor, 5.1 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H5R1CZ01D	Murata

Table 4. Bill of Materials (continued)

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
C211	1	10 nF	Capacitor, 10 n, 0402, X7R, 10%, 25 V	402	GRM155R71E103KA01D	Murata
C221	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C231	1	1.8 nF	Capacitor, 1.8 n, 0402, U2J, 5%, 10 V	402	GRM1557U1A182JA01D	Murata
C251	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C261	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C271	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C281	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C291	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C301	0		Do not mount			Murata
C302	1	0 Ω	Resistor, 0 Ω, 0402	402	RK73Z1ETTP	Koa
C311	0		Do not mount			Murata
C321	1	100 nF	Capacitor, 100 n, 0402, X5R, 10%, 10 V	402	GRM155R71A104KA01D	Murata
C322	1	22 pF	Capacitor, 22 p, 0402, NP0, 5%, 50 V	402	GRM1555C1H220JZ01D	Murata
L1	1		EMI filter bead, 0402, 1 kΩ, Tape GHz Band Gen Use	402	BLM15HG102SN1D	Murata
L171	1	56 nH	Inductor, 56 n, 0402, ±5%, wire-wound type	402	LQW15AN56NJ00	Murata
L172	1	15 nH	Inductor, 15 n, 0402, ±5%, wire-wound type	402	LQW15AN15NJ00D	Murata
L173	1	43 nH	Inductor, 43 n, 0402, ±5%, wire-wound type	402	LQW15AN43NJ00	Murata
L174	1	22 nH	Inductor, 22 n, 0402, ±5%, wire-wound type	402	LQW15AN22NJ00D	Murata
L191	1	56 nH	Inductor, 56 n, 0402, ±5%, wire-wound type	402	LQW15AN56NJ00	Murata
L192	1	27 nH	Inductor, 27 n, 0402, ±5%, wire-wound type	402	LQW15AN27NJ00D	Murata
L193	1	15 nH	Inductor, 15 n, 0402, ±5%, wire-wound type	402	LQW15AN15NJ00D	Murata

Table 4. Bill of Materials (continued)

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
L201	1	27 nH	Inductor, 27 n, 0402, ±5%, wire-wound type	402	LQW15AN27NJ00D	Murata
P1	1		SMD pinrow socket, .050 spacing, 2 × 10		SFM-110-02-SM-D-A-K-TR	Samtec
P2	1		SMD pinrow socket, .050 spacing, 2 × 10		SFM-110-02-SM-D-A-K-TR	Samtec
P3	1		SMA connector, straight SMD-mount		SMA-10V21-TGG	Hus-Tsan Group Taiwan
R12	0		Do not mount			Koa
R141	1	56 kΩ	Resistor, 56k Ω, 0402, ±1%	402	RK73H1ETTP5602F	Koa
R171	1	18 Ω	Resistor, 18 Ω, 0402, 5%	402	RK73H1ETTP18R0F (±1%)	Koa
R321	0		Do not mount			Koa
R322	1	0 Ω	Resistor, 0 Ω, 0402	402	RK73Z1ETTP	Koa
U1	1	CC112x	TI transceiver		CC112x	TI
U2	0		Do not mount			
X1	0		Do not mount		FA-128, 32 MHZ, 10 PPM, 10 PF, 2 × 1.6 mm, –40°C / +85°C, 60 Ω	Epson Toyocom
X2	1	32 MHz	TCXO 32.000000 MHz (2.5 × 2.0 × 0.9 mm)		TG_5021CG-28N	Epson Toyocom
			Supply voltage: 3.0 V			

6.3 *Bill of Materials–868 MHz*

To download Table 5, see the design files at SWRC222.

Table 5. Bill of Materials

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
C11	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C12	0		Do not mount			
C41	0		Do not mount			
C51	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata

Table 5. Bill of Materials (continued)

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
C52	1	2.2 µF	Capacitor, 2.2 µ, 0603, X5R, 10%, 10 V	603	GRM188R61A225KE34D	Murata
C53	0		Do not mount			
C61	1	220 nF	Capacitor, 220 n, 0402, X5R, 10%, 10 V	402	GRM155R61A224KE19D	Murata
C121	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C131	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C151	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C171	1	10 nF	Capacitor, 10 n, 0402, X7R, 10%, 25 V	402	GRM155R71E103KA01D	Murata
C172	1	100 pF	Capacitor, 100 p, 0402, NP0, 5% 50 V	402	GRM1555C1H101JZ01D	Murata
C173	1	33 pF	Capacitor, 33 p, 0402, NP0, 5%, 50 V	402	GRM1555C1H330JZ01D	Murata
C174	1	15 pF	Capacitor, 15 p, 0402, NP0, 5%, 50 V	402	GRM1555C1H150JA01D	Murata
C175	1	3.0 pF	Capacitor, 3.0 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H3R0CZ01D	Murata
C176	1	1.0 pF	Capacitor, 1 p, 0402, NP0, ±0.1 pF, 50 V	402	GRM1555C1H1R0BZ01D	Murata
C177	0		Do not mount			
C181	1	2.2 pF	Capacitor, 2.2 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H2R2CZ01	Murata
C191	1	3.3 pF	Capacitor, 3.3 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H3R3CZ01D	Murata
C201	1	3.3 pF	Capacitor, 3.3 p, 0402, NP0, ±0.25 pF, 50 V	402	GRM1555C1H3R3CZ01D	Murata
C211	1	10 nF	Capacitor, 10 n, 0402, X7R, 10%, 25 V	402	GRM155R71E103KA01D	Murata
C221	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C231	1	1.8 nF	Capacitor, 1.8 n, 0402, U2J, 5%, 10 V	402	GRM1557U1A182JA01D	Murata
C251	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata

Table 5. Bill of Materials (continued)

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
C261	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C271	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C281	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C291	1	47 nF	Capacitor, 47 n, 0402, X7R, 10%, 25 V	402	GRM155R71E473KA88D	Murata
C301	0		Do not mount			Murata
C302	1	0 Ω	Resistor, 0 Ω, 0402	402	RK73Z1ETTP	Koa
C311	0		Do not mount			Murata
C321	1	100 nF	Capacitor, 100 n, 0402, X5R, 10%, 10 V	402	GRM155R71A104KA01D	Murata
C322	1	22 pF	Capacitor, 22 p, 0402, NP0, 5%, 50 V	402	GRM1555C1H220JZ01D	Murata
L1	1		EMI filter bead, 0402, 1 kΩ, Tape GHz Band Gen Use	402	BLM15HG102SN1D	Murata
L171	1	10 nH	Inductor, 10 n, 0402, ±5%, wire-wound type	402	LQW15AN10NJ00D	Murata
L172	1	7.5 nH	Inductor, 7.5 n, 0402, ±2%, wire-wound type	402	LQW15AN7N5G00	Murata
L173	1	18 nH	Inductor, 18 n, 0402, ±5%, wire-wound type	402	LQW15AN18NJ00D	Murata
L174	1	12 nH	Inductor, 12 n, 0402, ±5%, wire-wound type	402	LQW15AN12NJ00D	Murata
L191	1	15 nH	Inductor, 15 n, 0402, ±5%, wire-wound type	402	LQW15AN15NJ00D	Murata
L192	1	12 nH	Inductor, 12 n, 0402, ±5%, wire-wound type	402	LQW15AN12NJ00D	Murata
L193	1	12 nH	Inductor, 12 n, 0402, ±5%, wire-wound type	402	LQW15AN12NJ00D	Murata
L201	1	12 nH	Inductor, 12 n, 0402, ±5%, wire-wound type	402	LQW15AN12NJ00D	Murata
P1	1		SMD pinrow socket, .050 spacing, 2 × 10		SFM-110-02-SM-D-A-K-TR	Samtec
P2	1		SMD pinrow socket, .050 spacing, 2 × 10		SFM-110-02-SM-D-A-K-TR	Samtec

Table 5. Bill of Materials (continued)

DESIGNATOR	QUANTITY	VALUE	DESCRIPTION	PACKAGE REFERENCE	PART NUMBER	MANUFACTURER
P3	1		SMA connector, straight SMD-mount		SMA-10V21-TGG	Hus-Tsan Group, Taiwan
R12	0		Do not mount			Koa
R141	1	56 kΩ	Resistor, 56 kΩ, 0402, ±1%	402	RK73H1ETTP5602F	Koa
R171	1	10 Ω	Resistor, 10 Ω, 0402, 5%	402	RK73H1ETTP10R0F (±1%)	Koa
R321	0		Do not mount			
R322	1	0 Ω	Resistor, 0 Ω, 0402	402	RK73Z1ETTP	Koa
U1	1	CC112x	TI transceiver		CC112x	TI
U2	0		Do not mount			
X1	0		Do not mount		FA-128, 32 MHZ, 10 PPM, 10 PF, 2 × 1.6 mm, –40 / +85°C, 60 Ω	Epson Toyocom
X2	1	32 MHz	TCXO 32.000000 MHz (2.5 × 2.0 × 0.9 mm) Supply voltage: 3.0 V		TG_5021CG-28N	Epson Toyocom

6.4 Software Files

To download the software files, see the design files at SWRC253.

7 References

1. Whitepaper: *Long-range RF communication: Why narrowband is the de facto standard* (SWRY006)
2. Long-Range Mode Wiki: Sub-1GHz Wiki
3. CC112x Software Examples: (SWRC253)
4. Generic PER test, SimpleLink™, and RX sniff mode: *TrxEB RF PER Test Software Example User's Guide*. (SWRU296)
5. Detailed information about the SmartRF™ TrxEB: *SmartRF™ Transceiver Evaluation Board TrxEB User's Guide*. (SWRU294)
6. The TrxEB and CC1120EM devices can also be used with SmartRF™ Studio to evaluate and configure the CC1120 device for testing in the lab. See SmartRF™ Studio, the software package, or the user's guide.
7. Application Report: *Achieving Optimum Radio Range* (SWRA479)

8 Terminology

- EVM—Evaluation Module
- DK—Development Kit
- LRM— Long-Range Mode
- PER—Packet Error Rate
- TCXO—Temperature-Compensated Crystal Oscillator
- TrxEB—Transceiver Evaluation Board

9 About the Author

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