Application Report

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Basic RF Testing of CCxxxx Devices

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ABSTRACT

This document presents users of Texas Instruments' low-power RF products with an overview of the different characterization tests (conducted, not radiated) that are performed during the device verification process. The document covers the basic setup of the test system and gives procedural information about each test.

Throughout this document, the term *CCxxxx* refers to the low-power CC25xx, CC11xx, CC10XX, and CC24xx RF device families.

Keywords:

- RF Testing
- RX Test
- Conformance Testing
- Output Power
- SmartRF Studio
- TX Test
- Characterization Test
- Sensitivity

Contents

List of Figures

List of Tables

1 Introduction

This document provides the user of Texas Instruments' low-power RF products with an overview of the different characterization tests (conducted, not radiated) that are performed during the device verification process. This descriptive document enables users to have a better understanding of the systems and functions, and also presents general information about device testing under various conditions and parameters. The document covers the basic setup of the test system and gives procedural information about each test.

Texas Instruments' low-power RF products make it easier to build wireless links for remote control, metering, and sensing applications. In most cases, they are used inside unlicensed, or license-free, wireless products. *Unlicensed* means only that the user of these products does not need an individual license from the telecommunication regulatory authorities. Unlicensed does ***not*** mean unregulated; the wireless product itself must usually meet strict regulations and be certified by the appropriate regulatory authorities. The different international regulatory authorities such as the FCC, ETSI, and ARIB regulate the use of radio receivers and transmitters. These bodies maintain specifications that must be met by all devices for each of the tests mentioned in the application report. Refer to the respective standards document (see Section 2.1).

1.1 Abbreviations

Table 1 lists many of the terms and abbreviations used in this document.

Table 1. Terms and Abbreviations

Abbreviation/Acronym	Definition/Meaning
ARIB	Association of Radio Industries and Businesses
CEBAL	Chipcon Evaluation Board Access Layer
dBm	Power ratio in decibels (dB) of the measured power referenced to 1 mW
DUT	Device under test
EB	Evaluation board
EM	Evaluation module
ETSI	European Telecommunications Standards Institute
EVM	Error vector magnitude
FCC	Federal Communications Commission
FSQ	Full spectrum quantization
GUI	Graphical user interface
IEEE	Institute of Electrical and Electronics Engineer
INT	Interference source, interference signal
ISM	Industrial, scientific, medical
MSK	Minimum shift keying
PER	Packet error rate
PSD	Power spectral density
RSSI	Received signal strength indicator
RX	Receive, receiver
SMA	Sub Miniature version A connector
SoC	System on chip
SPI	Serial parallel interface
TX	Transmit, transmission, transmitter

2 Standards and System Requirements

2.1 Standards

The following standards serve as references for the tests described in this document. All electronic links are current at the time of document publication.

- Bluetooth® Low Energy RF PHY Standard
- ZigBee® RF4CE Standard
- Zigbee Standard
- FCC, Section 47CFR15 – Part 15 Standard
- ETSI EN 300 440 Standard
- ETSI EN 300 220 Standard
- IEEE 802.15.4 Standard
- ARIB T-66 Standard

2.2 Test Equipment Suppliers

The different test equipment used to perform the various procedures described in this document can be procured from the following suppliers. Obtaining some of this equipment may require going through an agent. All electronic links are current at the time of document publication.

- Rohde & Schwarz
- Agilent
- Anritsu
- Tektronix
- Test Equity
- National Instruments

2.3 Test System Requirements

Any characterization test system has some generic components and additional specialty engineering customization. A typical test system generally consists of these components and subsystems:

- **Signal analyzers (spectrum analyzers):** These tools are widely used to measure the frequency response, noise, and distortion characteristics of all types of RF circuitry. These devices compare the input and output spectra under a variety of conditions. A typical test system usually requires only one signal analyzer.
- **Signal generators:** These devices generate repeating or non-repeating electronic signals (in either the analog or digital domain). A typical system should have at least two signal generators: one to generate the primary signal, the second to generate an interference signal. The CC devices from TI can be used as a signal source in some lab setups. However, the power resolution may not be as good as that produced by a signal generator.
- **Temperature chamber:** An enclosure used to test the effects of specified temperature conditions on a series of test devices. A single temperature chamber should be sufficient for most test systems.
- **Connectors/cables/splitters:** These components connect different signals using coaxial cable from the test system to (and from) the device under test (DUT).
- **LabVIEW™:** LabVIEW, or Laboratory Virtual Instrumentation Engineering Workbench, is a software platform and development environment for a visual programming language from National Instruments. The graphical language is named *G*. Originally released for the Apple® Macintosh® in 1986, LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft® Windows®, various versions of Unix, Linux®, and Mac OS X. This software is used as a platform to automate the entire test system.
- **SmartRF™ Studio:** SmartRF Studio (see Ref. 10) is a Windows-based application that can be used to evaluate and configure low-power RF ICs from Texas Instruments. This tool helps RF system designers to quickly and easily evaluate the respective devices at an early stage in the design process. It is especially useful for generation of configuration register values, for practical testing of the RF

system, and for finding optimized external component values. SmartRF Studio can be used either as a standalone application or together with some evaluation boards that are shipped in RF IC development kits.

- **Network analyzer (vector network analyzer):** This tool is an instrument that measures the network parameters of electrical networks. Contemporary network analyzers usually measure *s*- parameters because reflection and transmission of electrical networks are easy to measure at high frequencies, but there are other network parameter sets such as *y*-parameters, *z*-parameters, and *h*-parameters. Network analyzers are often used to characterize two-port networks such as amplifiers and filters; they can also be used on networks with an arbitrary number of ports. It is useful to have one network analyzer available.
- **Oscilloscope:** This electronic test instrument allows users to observe constantly varying signal voltages, usually as a two-dimensional graph of one or more electrical potential differences with a vertical or *Y* axis, plotted as a function of time (horizontal or *x* axis). Although an oscilloscope displays voltage on the vertical axis, any other quantity that can be converted to a voltage can be displayed as well. In most instances, oscilloscopes show events that repeat with either no change or that change slowly. Having an oscilloscope is useful for a test system.

The more equipment one has in the test configuration, the greater need there is to automate the various testing processes. For an elaborate setup, then, one should use a platform such as LabVIEW and write specific application routines to enable the different test equipment to interface together.

Keep in mind that the capabilities of the available equipment used in a given test system will likely limit the types of testing that can be performed.

2.3.1 System Setup

This document describes two types of test system configurations: without LabVIEW and with LabVIEW. This section briefly describes each configuration.

2.3.1.1 Manual Test Systems (Without LabVIEW)

Systems not using LabVIEW use the following test equipment and resources:

1. CCxxxx Evaluation Module
2. SmartRF Evaluation Board (one)
3. Male to Male SMA RF cable
4. Variable attenuators (two)
5. PC with SmartRF Studio software installed
6. RF coupler (combiner)
7. RF signal generator (two)
8. Signal analyzer

2.3.1.2 Automatic Test Systems (Using LabVIEW)

Systems using LabVIEW use the following test equipment and resources:

1. CCxxxx Evaluation Module
2. SmartRF Evaluation Board (one)
3. Male to Male SMA RF cable
4. Signal analyzer
5. PC with SmartRF Studio and LabVIEW software installed
6. RF coupler (combiner)
7. RF signal generator (two)

2.3.2 Initial Conditions for Testing

The device under test (DUT) is connected to the tester via a 50-Ω connector. If there is no antenna interface, a temporary 50-Ω interface or a suitable coupling device (50-Ω load) should be used.

For RX testing, the input reference signal (both as the desired signal and the interference signal) should have certain characteristics that must be set according to the respective standards document.

Payload content of the desired signal should be a sequence specified by the relevant standard. It must be identical for all transmitted packets.

In test cases where an interference signal is used, the interference signal characteristics must be defined by the applicable standards for which the device is being evaluated.

2.3.3 System Communication Overview

The user can communicate with the DUT using SmartRF Studio 7/LabVIEW. These programs communicates with the evaluation board over the USB interface via the(Chipcon Evaluation Board Access Layer (CEBAL). This software library contains all the functions required to control the radio device on the EB. Figure 1 illustrates the connection between a PC and the SmartRF EB.

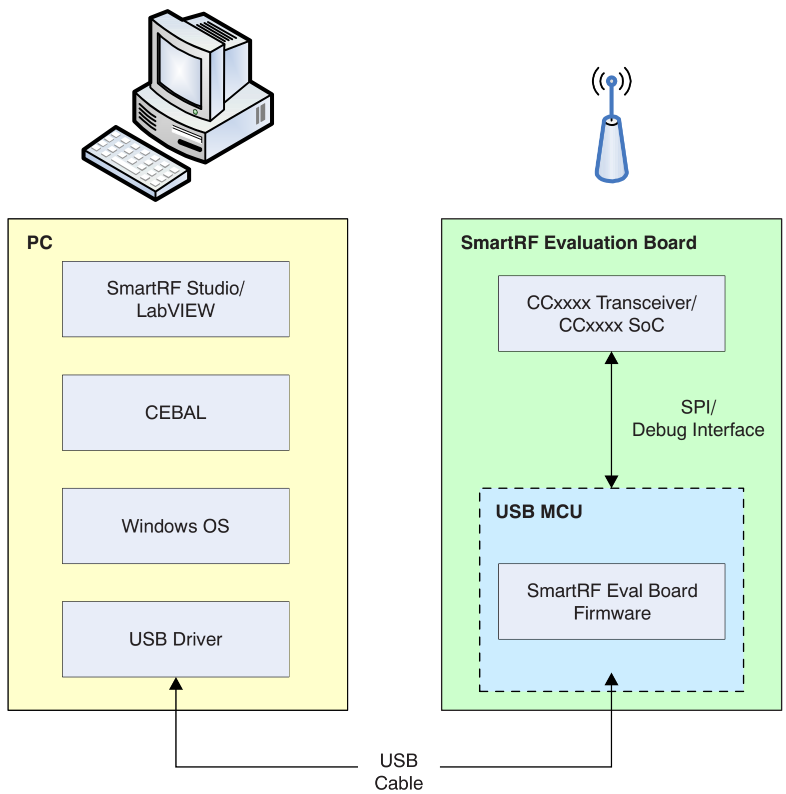
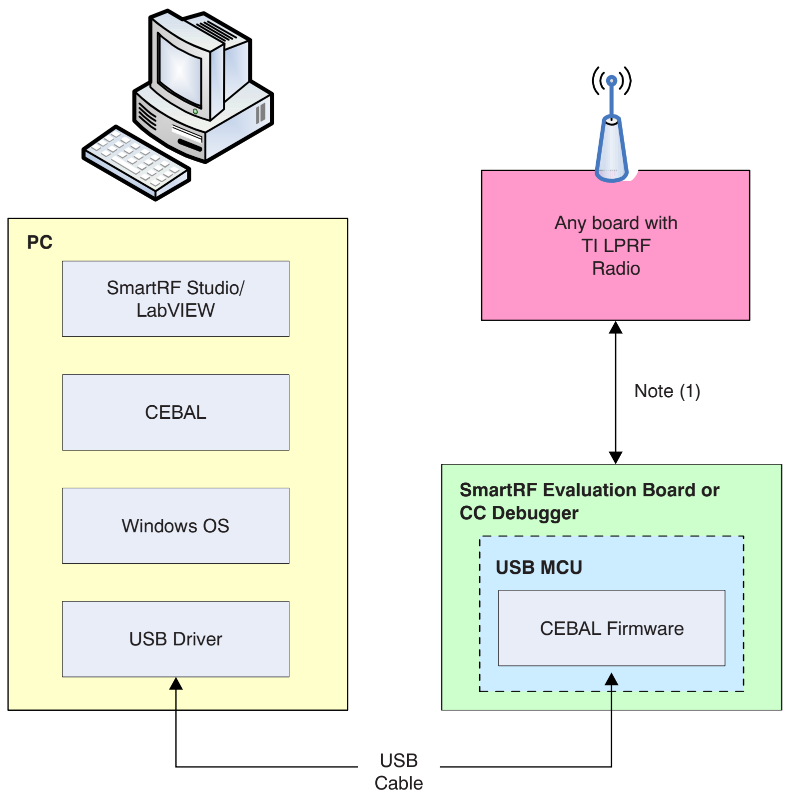


Figure 1. Interface Between PC and CCxxxx EMs

For proper operation of the applications that use CEBAL, the board must have compatible firmware that runs on the USB MCU. If the firmware is out-of-date, SmartRF Studio 7 proposes that the user update the firmware. The firmware update can be done directly in SmartRF Studio 7.

It is possible to connect your own hardware to the SmartRF Evaluation Board to test your own radio design with SmartRF Studio7/LabVIEW. Connect the board to the TI evaluation board via the breakout pins on the EB, or use the target connector on the CC Debugger. For SoCs, use the debug interface; for transceivers, use the serial peripheral interface (SPI). Figure 2 shows the connection between a PC and a generic evaluation board with a TI LPRF radio.



(1) Connect the board to the TI evaluation board via the break-out pins on the board, or user the target connector on the CC Debugger. For SoCs, use the debug interface; for transceivers, use the SPI interface. Refer to the evaluation board user guide for more details.

Figure 2. Interface Between PC and Any Board with TI LPRF Radio

In all cases, make sure that the boards are properly connected and that the voltage levels are correct. These cautions are especially relevant if you are not using level shifters and the voltage level on your board is different from the voltage level on the EB (usually 3.3 V). For more information, see Ref. 11 and Ref. 12.

CAUTION

The CC Debugger operates internally at 3.3 V. However, it has level converters that will detect the voltage on the target board and ensure that the debug control lines are set to a voltage that corresponds to the target I/O voltage.

2.3.4 Test System Operation

Use these general parameters to perform tests in TX mode when using LabVIEW:

- Set the DUT to TX mode using SmartRF Studio 7.
- Supply and temperature are set by LabVIEW.
- The signal analyzer is configured by LabVIEW to measure the transmitted data.
- LabVIEW captures the data from the signal analyzer.
- The collected information then can be interpreted either in LabVIEW or other PC-based software.

Use these general parameters to perform tests in RX mode when using LabVIEW:

- Set the DUT to RX mode using SmartRF Studio 7.
- Supply/temperature are set by LabVIEW.
- The signal analyzer is configured by LabVIEW to transmit data continuously or in packets that adhere to standards.
- SmartRF Studio 7/LabVIEW captures the data from the DUT.
- This collected information then can be interpreted either in LabVIEW or exported to other PC-based software.

3 Frequency Correction

Electronic circuits often use the mechanical resonance of a vibrating piezoelectric crystal to create an electrical signal with a very precise frequency. This frequency is commonly used to provide a stable clock signal for digital integrated circuits and to stabilize frequencies for radio transmitters and receivers.

Environmental changes in temperature, humidity, pressure, and external vibration can change the resonant frequency of a crystal. The age of a crystal also adds inaccuracies to the crystal over time.

Because there is always some inaccuracy in the crystals used with radios, one way to correct for this error is required in order to obtain an accurate measurement of sensitivity and other parameters.

The carrier frequency in the chip is mathematically related to the crystal frequency. For example, for the CC2500 the carrier frequency is calculated as shown by Equation 1:

$$f_{CARRIER} = \left(\frac{f_{XOSC}}{2^{16}}\right) \cdot FREQ[23:0] \tag{1}$$

Where FREQ[23:0] is the base frequency for the frequency synthesizer in increments of $\frac{f_{XOSC}}{2^{16}}$

However, the actual crystal frequency is not the same as the stated crystal frequency as a result of the inaccuracies noted earlier. Consequently, we must calculate the actual crystal frequency.

After putting the device into unmodulated, continuous TX mode with the settings found using SmartRF Studio, use a spectrum analyzer to measure the exact carrier frequency coming out of the chip.

This measured frequency is then put into Equation 1 from the product data sheet, and one solves for f_{XOSC}. This result is the actual crystal frequency for the specific DUT that can then be used to determine the exact carrier frequency across the band.

In the CC253x/CC254x devices, the FREQTUNE register is used to tune the crystal oscillator. The default setting '1111' leaves the XOSC not tuned. Changing the setting from default switches in extra capacitance to the oscillator, effectively lowering the XOSC frequency. As a result, the final crystal frequency can be controlled by adjusting the value of the FREQTUNE register in these devices.

Example 1.

Calculate the actual crystal frequency for a particular carrier frequency based on the known crystal frequency. Assume a 26-MHz crystal for a CC2500 device. The carrier frequency is set to 2.4 GHz using these register settings:

- FREQ2 [23:16] = 0x5C
- FREQ1 [15:8] = 0x4E
- FREQ0 [7:0] = 0xC4
- FREQ [23:0] = 0x5C4EC4
- FREQ = 6049476 [hex to dec conversion]

If the measured carrier frequency is 2.41 GHz, then the actual crystal frequency can be calculated using Equation 1.

Solving for f_{XOSC} produces these results:

$$f_{XOSC} = \left(\frac{f_{CARRIER} \cdot 2^{16}}{FREQ[23:0]}\right)$$

$$f_{XOSC} = \left(\frac{2.41\text{ GHz} \cdot 2^{16}}{6049476}\right)$$

$$f_{XOSC} = 26.108\text{ MHz}$$

Even though the crystal is rated at 26 MHz, as a result of inaccuracies the actual crystal frequency is 26.108 MHz. Therefore, the signal generator and signal analyzer must be set to frequencies calibrated from the true crystal frequency.

4 DUT and Test Instrument Information

This page (and subsequent pages) can be printed and used as a record for the details of the respective test setup.

4.1 DUT

Table 2 shows the generic DUT information.

Table 2. DUT Information

Product	
Model Name	
Hardware Version	
Host Interface Type	
Module SN	

4.2 Test Instruments

Table 3 lists the general test instrument data. (See Section 2.3 for more information.)

Table 3. Test Instrument Information

Item	Vendor	Model Name	Quantity
Signal generator			
Power combiner			
Spectrum analyzer			
Power meter			
Attenuator			
Temperature chamber			
Oscilloscope			
Network analyzer			

5 Transmission Tests

Refer to Table 4 for a summary of the various transmission tests.

Table 4. Transmission Test Summary

Section No	Item	Result
5.1	Transmission Power	
5.2	Power Spectral Density Mask	
5.3	Error Vector Magnitude	
5.4	Transmission Center Frequency Offset	
5.5	Spurious Emissions on Transmission	

5.1 Transmission Power

Purpose: To verify that the transmitted output power of the DUT conforms to the standards limit.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 3 illustrates the transmission power test setup.

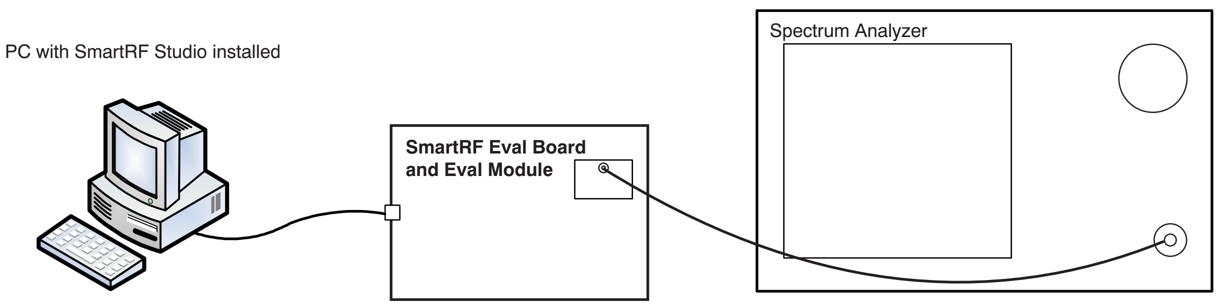


Figure 3. Transmission Power Test Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 3.

Step 2. Set the EM to unmodulated, continuous TX mode with the appropriate output power level through SmartRF Studio (see Ref. 10).

Step 3. Measure the output power level on the spectrum analyzer to confirm the output power programmed on the EM.

Table 5. Transmission Power Test Results

Output Power (dBm)			Design Specification (dBm)	Pass/Fail?
Freq 1 (MHz)	Freq 2 (MHz)	Freq 3 (MHz)		

Test Results:

5.2 Power Spectral Density Mask

Purpose: To verify that the PSD of the DUT is able to conform to stated conformance limits.

Pass Condition: Refer to the respective standards document. Table 6 shows an example for the IEEE 802.15.4 standards requirements. Figure 4 illustrates the requirements.

Table 6. IEEE 802.15.4 Standards Requirements (Example)

Frequency	Relative Limit	Absolute Limit
$\|f - f_C\| > 3.5$ MHz	–20 dB	–30 dBm

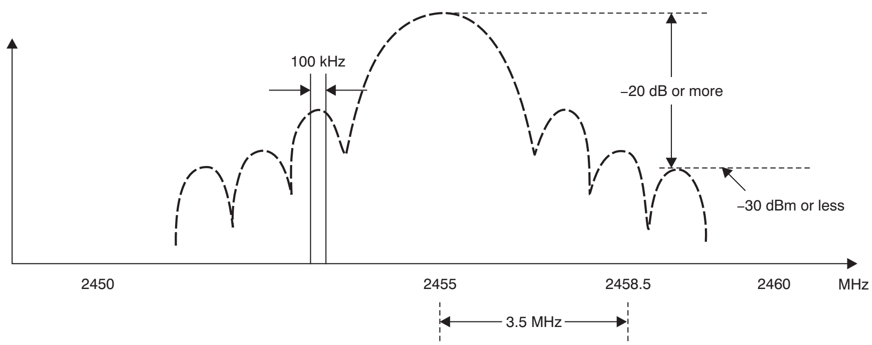


Figure 4. Power Spectral Density Mask Requirements

Test Environment: Figure 5 shows the test setup.

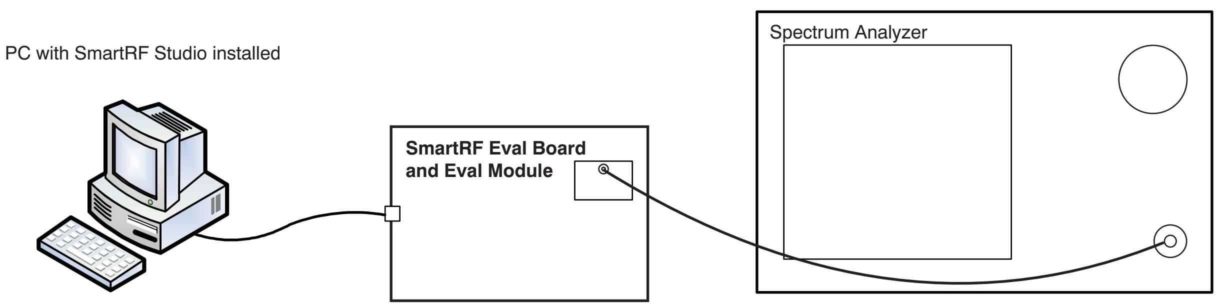


Figure 5. Power Spectral Density Mask Test Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 5.

Step 2. Set the EM to continuous TX mode through SmartRF Studio.

Step 3. Verify that the PSD mask conforms to the given standard on the spectrum analyzer.

Table 7. Power Spectral Density Mask Test Results

PSD Relative Limit (%)			Design Specification (%)	Pass/Fail?
Freq 1 (MHz)	Freq 2 (MHz)	Freq 3 (MHz)		

Test Results:

5.3 *Error Vector Magnitude*

Purpose: Transmission modulation accuracy is measured using error vector magnitude (EVM). EVM, as illustrated in Figure 6 and Figure 7, is the magnitude of the phase difference as a function of time between an ideal reference signal and the measured transmitted signal.

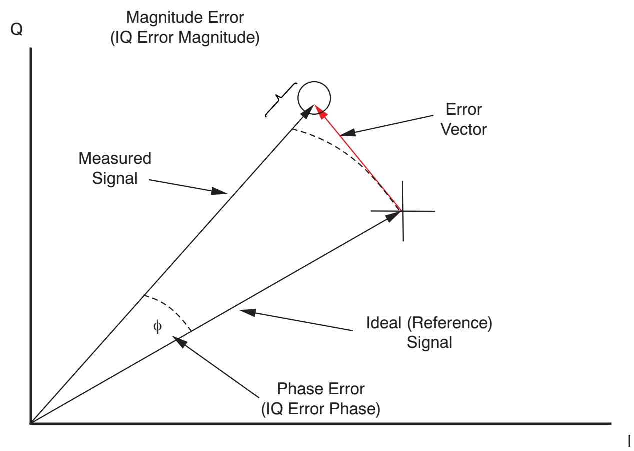


Figure 6. Error Vector Magnitude

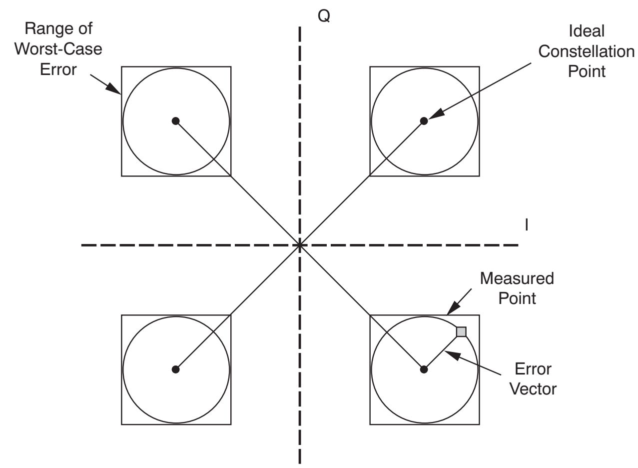


Figure 7. EVM and Related Quantities

Pass Condition: See the respective standards document for specifications and pass conditions.

Test Environment: Figure 8 illustrates the setup for the EVM test.

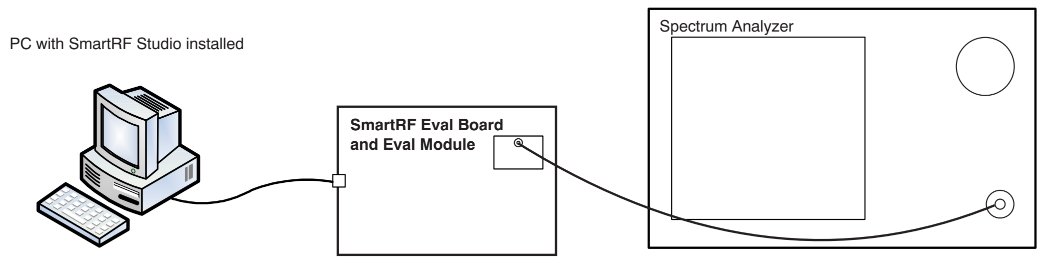


Figure 8. Error Vector Magnitude Test Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 8.

Step 2. Set the EM to continuous TX mode with random modulated data through SmartRF Studio.

Step 3. Measure EVM with the spectrum analyzer after setting up the instrument by following the steps described in the tool user manual. (See Appendix A for more information.)

Example: EVM measurements on ZigBee signals using a Rohde & Schwarz FSQ can be set up following the instructions in Ref. 2.

Table 8. Error Vector Magnitude Test Results

EVM (%) at ____ kbp/s			Design Specification (%)	Pass/Fail?
Freq 1 (MHz)	**Freq 2 (MHz)**	**Freq 3 (MHz)**		

Test Results:

5.4 *Transmission Center Frequency Offset*

Purpose: To verify that the center frequency offset is within limits.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 9 shows the setup for center frequency offset transmission testing.

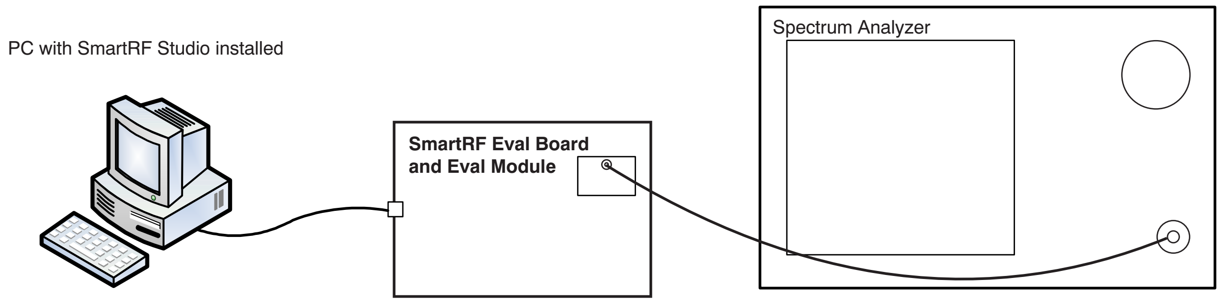


Figure 9. Transmission Center Frequency Offset Test Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 9.

Step 2. Set the EM to continuous TX mode through SmartRF Studio.

Step 3. Set the center frequency to the desired channel frequency; ensure that the signal is not modulated.

Step 4. Measure the actual frequency on the spectrum analyzer. The difference between the actual frequency and the center frequency is the frequency offset.

Table 9. Transmission Center Frequency Offset Test Results

Channel	Frequency	Frequency Offset	Design Specification (ppm)	Pass/Fail?

Test Results:

5.5 Spurious Emissions

Purpose: To verify that the conducted spurious emissions are within limits.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 10 illustrates the spurious emissions test setup.

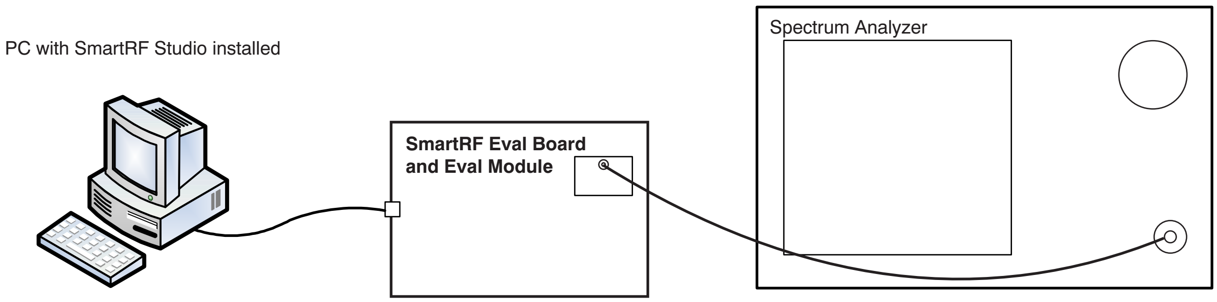


Figure 10. Spurious Emissions Test Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 10.

Step 2. Set the EM to continuous TX mode with random modulated data through SmartRF Studio. Set the center frequency to the desired channel frequency.

Step 3. Measure spurs from the minimum limit to the maximum limit of the spectrum analyzer.

Note that different spectrum analyzers have different maximum frequencies. Up to 25 GHz is more than sufficient.

Table 10. Spurious Emission Test Results

Channel	Frequency	Measured Spur	Design Specification	Pass/Fail?

Test Results:

6 Receive Testing Without LabVIEW

Refer to Table 11 for a summary of the various receiver tests to be performed without using LabVIEW.

Table 11. Receive Test (without LabVIEW) Summary

Section No	Item	Result
6.1	Receiver Sensitivity	
6.2	Interference Testing	
6.3	Interference Testing with Signal Generator	

6.1 Receiver Sensitivity

CAUTION

One issue to remember with the configuration described here is that RF power can reach the receiver outside the path through the coaxial cable and attenuators. This issue is of greater concern if the two boards are placed very close together and the receiver is operated with very good sensitivity (that is, low data rate and receiver bandwidth). This problem is observed if the receiver can decode packets even with very high attenuation, and it is not possible to find the sensitivity threshold correctly. To avoid this problem, one of the boards should be placed in a shielded box where the shield is grounded, and the only opening in the box is a small hole for cables to exit. This configuration reduces radiation to a minimum.

Purpose: To verify that the receiver sensitivity conforms to performance standards.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 11 illustrates the test setup for receiver sensitivity.

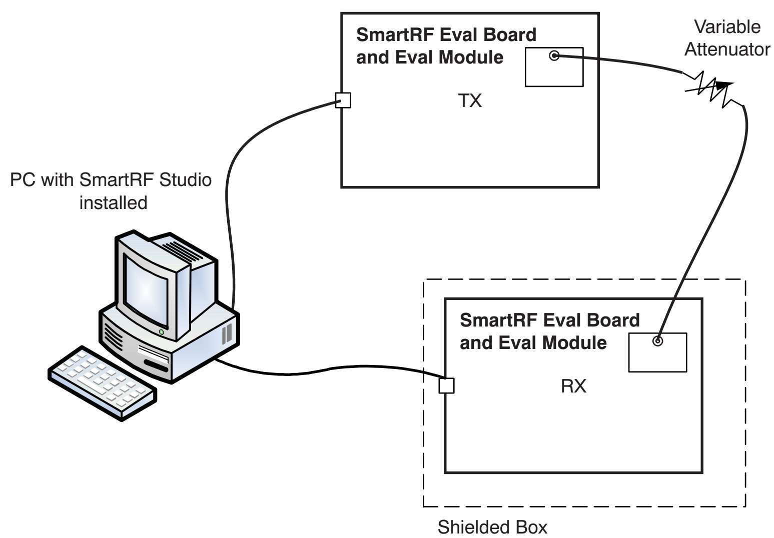


Figure 11. Receiver Sensitivity Test Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 11.

Step 2. Configure both the TX side and the RX side with the appropriate RF settings. Select the *packet TX* or *packet RX* tab, and select an appropriate packet format.

Step 3. Start up the receivers first. Ensure that the *Seq number included in payload* box is checked (enabled).

Step 4. Start the transmitter by clicking **Start**.

Step 5. The RSSI readout on the RX side provides a relative indicator of the signal strength

Step 6. The PER is calculated using this formula:

PER % = (No of packets lost/Total number of packets) x 100

Step 7. Increase the attenuation until the PER reaches 1%. This level defines the sensitivity threshold.

Table 12. Receiver Sensitivity Test Results

Sensitivity (dBm), PER < 1%			Design Specification (dBm)	Pass/Fail?
Freq 1 (MHz)	Freq 2 (MHz)	Freq 3 (MHz)		

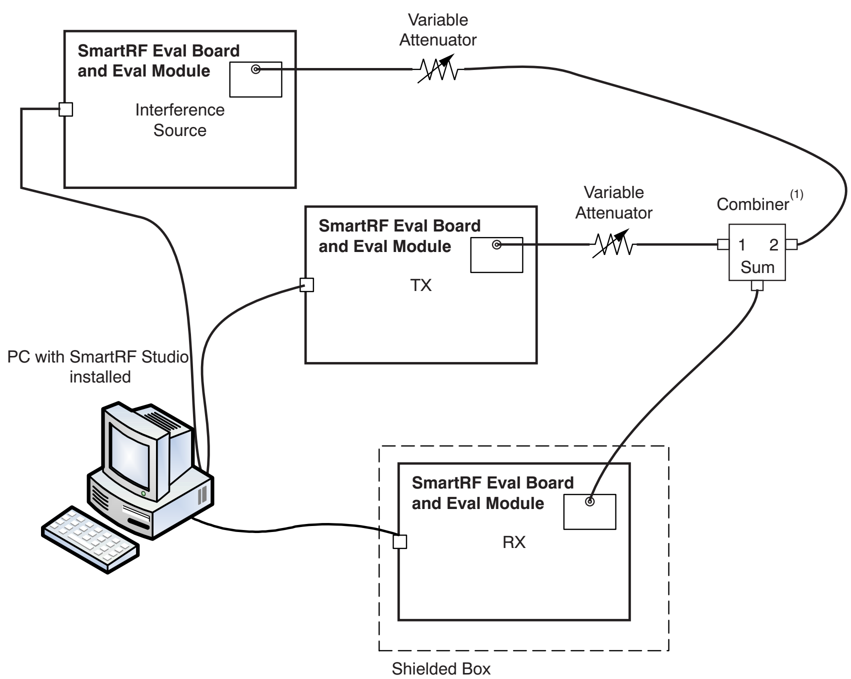
Test Results:

6.2 Interference Testing

Purpose: To verify that the receiver sensitivity conforms to the published standards.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 12 illustrates the interference test setup.



(1) 3-dB loss in signal on each input path through the combiner.

Figure 12. Interference Testing Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 12.

Step 2. The TX and RX boards must be set up as for the sensitivity test.

Step 3. The INT (interference) signal is set up as for TX; however, the frequency can be different than that of either the TX and RX signals, unless testing for co-channel interference. Furthermore, unlike the TX that transmits packets, the INT transmits continuously (that is, it is a continuous modulated signal).

Step 4. Set the output power of the TX such that the received power at the RX end is 10 dB above the sensitivity threshold obtained from sensitivity testing. (Remove 10 dB of attenuation from the attenuators after completing the sensitivity test.)

Step 5. Set the output power low for the INT initially, and perform the sensitivity test at the RX.

Step 6. Continue to increase the output power of the INT until the PER is greater than 1%. The difference between the TX and INT power measured on the RX side indicates the ability of the CCxxxx device to overcome interference.

Table 13. Adjacent Channel Test Results

Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?

Table 14. Alternate Channel Test Results

Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?

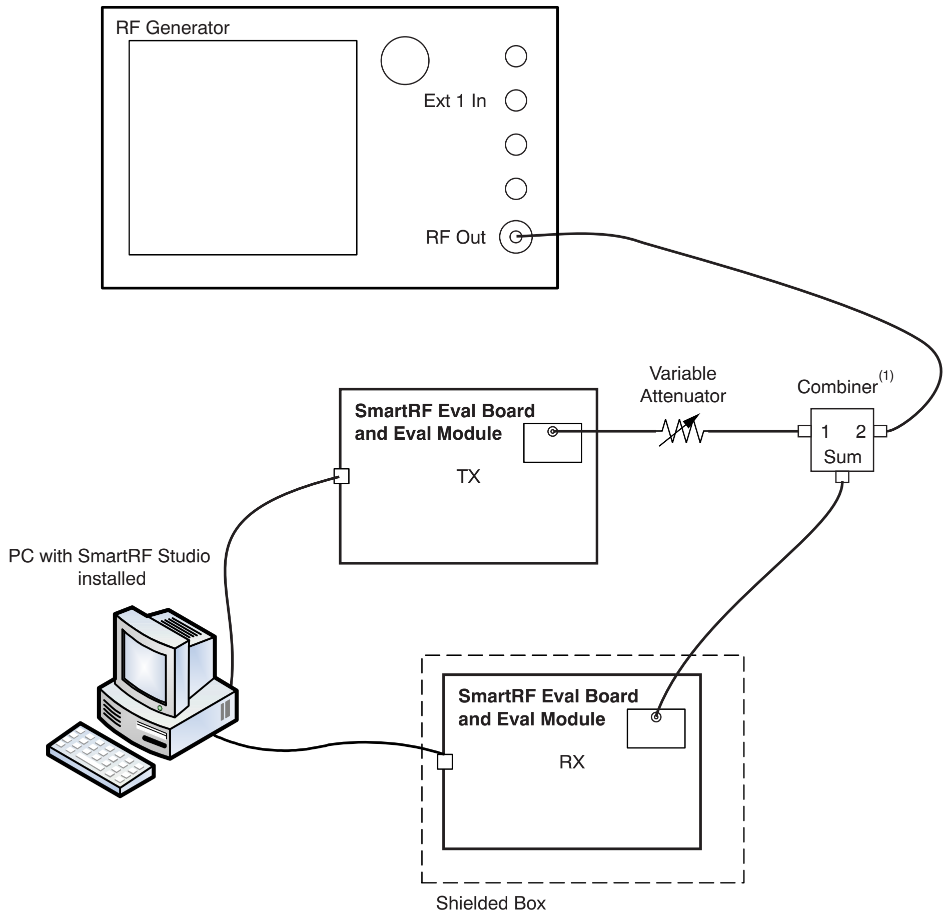
Test Results:

6.3 Interference Testing with RF Generator

Purpose: To verify that the receiver sensitivity conforms to the published standards.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 13 illustrates the test setup for interference testing with an RF generator.



(1) 3-dB loss in signal on each input path through the combiner.

Figure 13. Interference Testing with RF Generator Setup

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 13.

Step 2. The TX and RX boards must be set up as for the sensitivity test.

Step 3. The interference signal is set up by using a continuous, unmodulated signal where the frequency can be different from TX and RX unless testing for co-channel interference.

Step 4. Set the output power of the TX such that the received power at the RX end is 10 dB above the sensitivity threshold obtained from sensitivity testing. (Remove 10 dB of attenuation from the attenuators after completing the sensitivity test.)

Step 5. Set the output power low for the interference signal initially, and perform the sensitivity test at the RX.

Step 6. Continue to increase the output power of the interference signal until the PER is greater than 1%. The difference between the TX and INT power measured at the RX side indicates the ability of the CCxxxx device to overcome interference.

Table 15. Adjacent Channel Test Results

Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?

Table 16. Alternate Channel Test Results

Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?

Test Results:

7 Receive Testing with LabVIEW

Refer to Table 17 for a summary of the various receiver tests performed with LabVIEW.

Table 17. Receive Test with LabVIEW Summary

Section No	Item	Result
7.1	Receiver Sensitivity	
7.2	Maximum Input Power	
7.3	Adjacent/Alternate Channel	
7.4	Energy Detect	

7.1 Receiver Sensitivity

Purpose: To verify that the receiver sensitivity conforms to the published standards.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 14 illustrates the test setup for receiver sensitivity with LabVIEW.

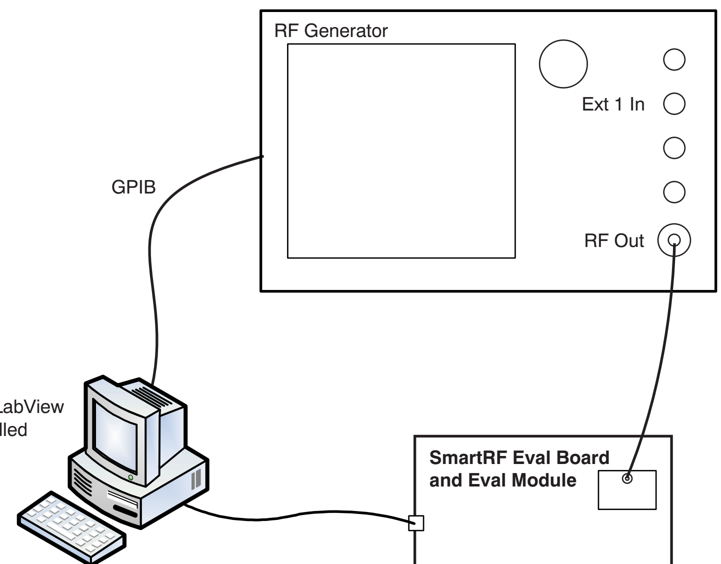


Figure 14. Receiver Sensitivity Test Setup for LabVIEW

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 14.

Step 2. Set the EM in Packet RX mode through SmartRF Studio.

Step 3. Using LabVIEW, send 1000 packets at a specified data rate and modulation format from the RF generator, while controlling the generator power. (Start 10 dB over the stated sensitivity of the device.)

Step 4. Measure the actual number of packets received.

Step 5. Calculate the PER. If the PER is less than 1%, repeat the test with a reduced signal power. When the PER ≥ 1%, the previous signal power with a PER less than 1% indicates the sensitivity.

NOTE: See Ref. 3 for more detailed techniques to test TI CCxxxx devices for sensitivity.

Table 18. Receiver Sensitivity with LabVIEW Test Results

Sensitivity (dBm), PER < 1%			Design Specification (dBm)	Pass/Fail?
Freq 1 (MHz)	Freq 2 (MHz)	Freq 3 (MHz)		

Test Results:

7.2 Maximum Input Power

Purpose: To verify that the receiver maximum input power level conforms to the published data sheet specifications.

Pass Condition: See respective standards document for specifications and pass conditions.

Test Environment: Figure 15 illustrates the test setup.

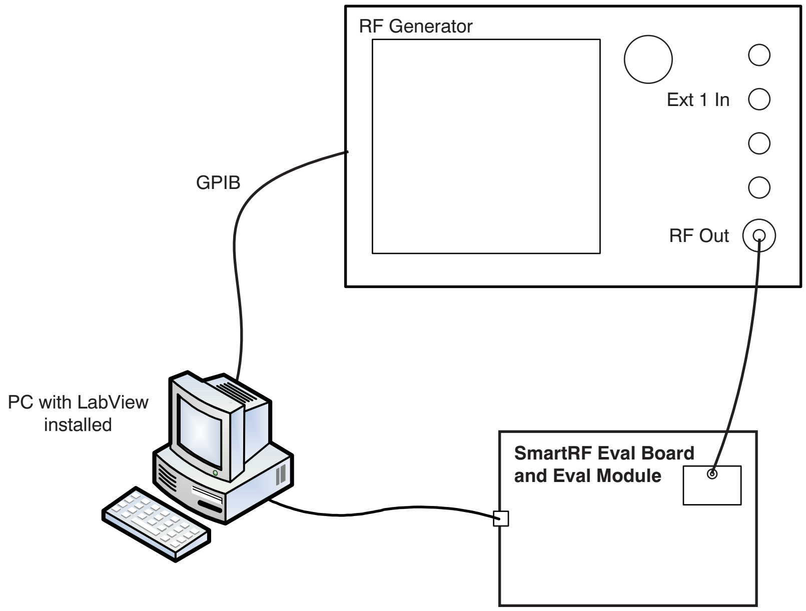


Figure 15. Maximum Input Power Test Setup for LabVIEW

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 15.

Step 2. Set the EM in Packet RX mode through SmartRF Studio.

Step 3. Using LabVIEW, send 1000 packets at a specified data rate from the RF generator, controlling the received signal power. (Start 10 dB below the stated saturation level of the device.).

Step 4. Measure the actual number of packets received.

Step 5. Calculate the PER. If the PER is less than 1%, repeat the test with reduced signal power. When the PER ≥ 1%, the previous signal power with a PER less than 1% indicates the sensitivity.

Table 19. Maximum Input Power with LabVIEW Test Results

Maximum Input Power (dBm), PER < 1%			Design Specification (dBm)	Pass/Fail?
Freq 1 (MHz)	Freq 2 (MHz)	Freq 3 (MHz)		

Test Results:

7.3 Adjacent/Alternate Channel

Purpose: This test verifies that the minimum jamming resistance levels conforms to the published standard.

Example 2.

Consider the 802.15.4 standards. The adjacent channel (Figure 16**a**) is one on either side of the desired channel that is closest in frequency to the desired channel, and the alternate channel (Figure 16**b**) is one channel removed from the adjacent channel.

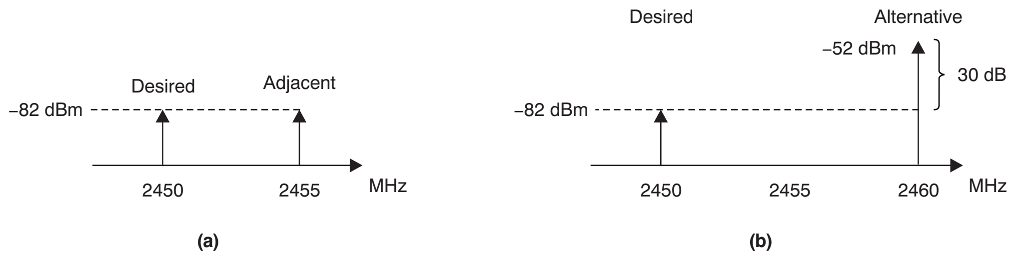
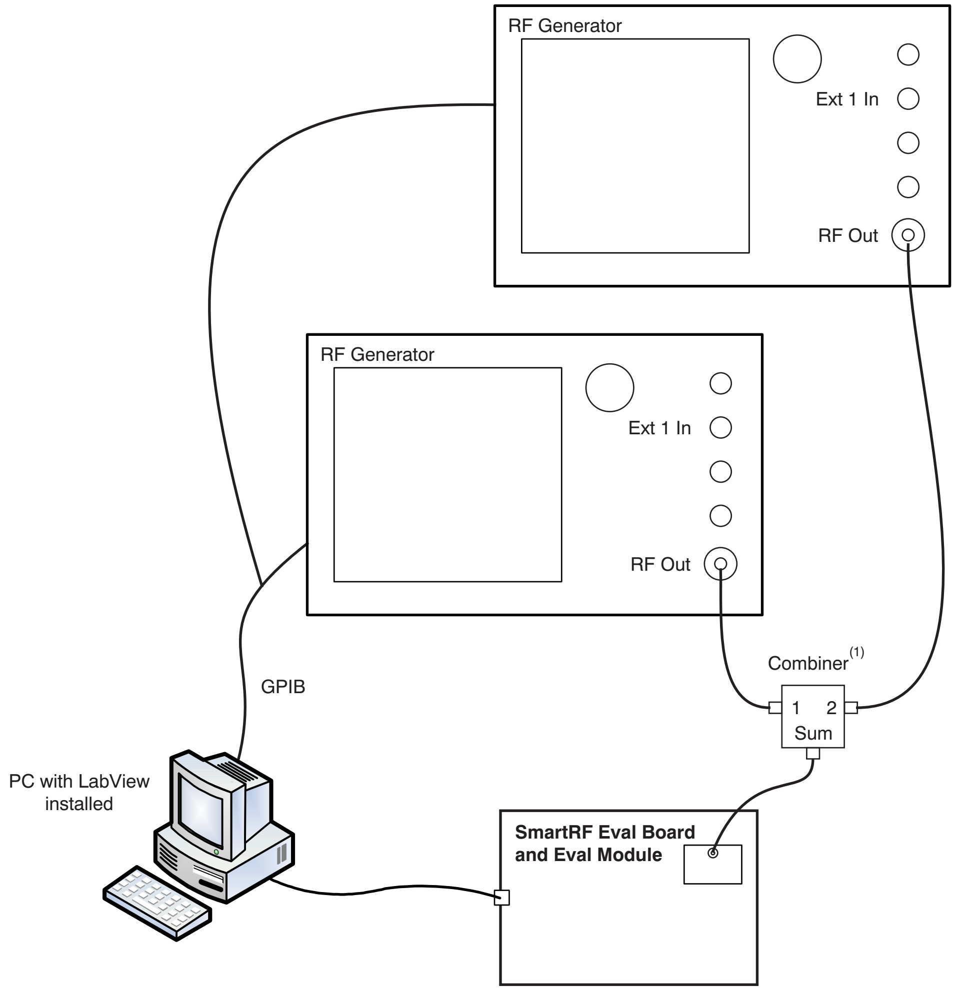


Figure 16. IEEE 802.15.4 Standard for Adjacent/Alternate Channels

Pass Condition:

Adjacent Channel Rejection	Alternate Channel Rejection
0 dB	30 dB

Test Environment: Figure 17 illustrates the adjacent/alternate channel test setup for LabVIEW.



(1) 3-dB loss in signal on each input path through the combiner.

Figure 17. Adjacent/Alternate Channels Test Setup for LabVIEW

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 17.

Step 2. Set the EM in Packet RX mode through SmartRF Studio.

Step 3. Set the output power of the first generator such that the received power at the EM end is at 3 dB greater than the minimum sensitivity obtained from sensitivity testing for LabVIEW.

Step 4. Using LabVIEW, send 1000 packets at a specified data rate from one of the RF generators, controlling the received signal power.

Step 5. Using LabVIEW, set the frequency and power of the interference signal on the second generator to the adjacent/alternate channel.

Step 6. Set the output power *low* for the interference signal (second generator) initially, then perform the sensitivity test at the EM.

Step 7. Continue to increase the output power of the interference signal until the PER is greater than 1%. The difference in the first and second generator power (as seen on the EM side) indicates the ability of the device to overcome interference, and is the adjacent/alternate channel rejection.

Table 20. Adjacent Channel with LabVIEW Test Results

Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?

Table 21. Alternate Channel with LabVIEW Test Results

Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?

Test Results:

7.4 Energy Detection/RSSI

Purpose: To verify that the energy detection conforms to the published data sheet specifications.

Pass Condition: The mapping from the received power in decibels to energy detection value must be linear, with a stated accuracy given in the standard.

Test Environment: Figure 18 illustrates the energy detection test setup.

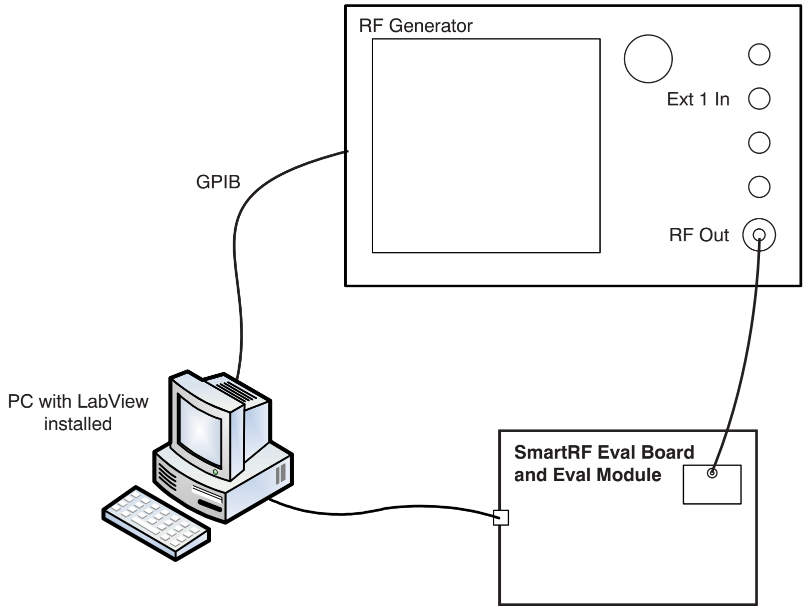


Figure 18. Energy Detection/RSSI Test Setup for LabVIEW

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 18.

Step 2. Set the EM in Packet RX mode through SmartRF Studio.

Step 3. Using LabVIEW, send 1000 packets at a specified data rate from the RF generator and set the generator signal power.

Step 4. Read the RSSI value from the SmartRF Studio software interface. This value should correlate to the sent signal strength.

Table 22. Energy Detection/RSSI with LabVIEW Test Results

Power Detection (dB) | Signal Strength = ____ (dBm)			Design Specification (dBm)	Pass/Fail?
Freq 1 (MHz)	Freq 2 (MHz)	Freq 3 (MHz)		

Test Results:

8 Electrical Tests

Table 23 summarizes the various electrical tests performed with LabVIEW.

Table 23. Hardware Tests with LabVIEW Summary

Section No	Item
8.1	Standby mode / RF disable mode
8.2	Idle mode
8.3	Power Down mode
8.4	TX mode
8.5	RX mode

Test Environment: Figure 19 illustrates the test setup for all hardware tests.

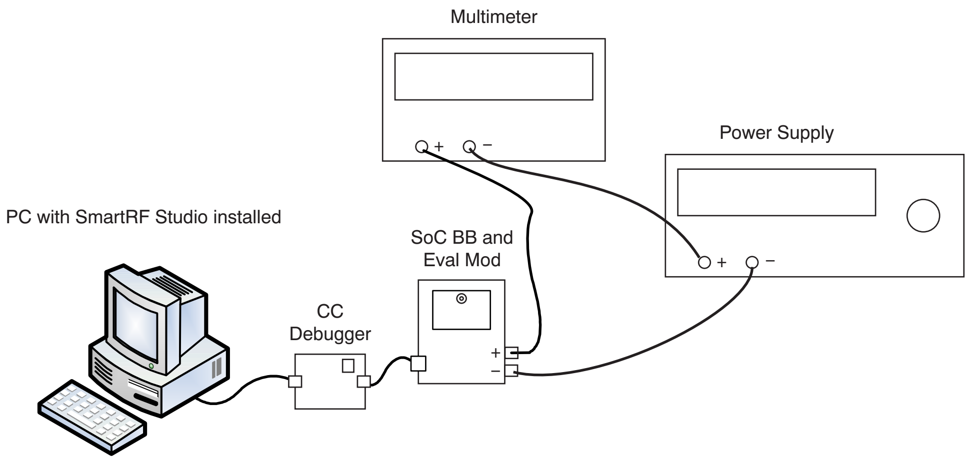


Figure 19. Hardware Test Setup for LabVIEW

Procedure:

Step 1. Connect the instruments and test board as shown in Figure 19.

Step 2. The test requires the use of a SoC BB for accurate measurement; see Ref. 14.

Step 3. Mount the CCxxxx EM on the SoC BB.

Step 4. Supply power to the board from an external supply rather than AA battery cells..

Step 5. Connect a multimeter in series with the supply line.

Step 6. Connect the CCDebugger (see Ref. 13) to the SoC BB to enable communication with the CCxxxx EM.

Step 7. Use SmartRF Studio to set the device to the proper modes.

Step 8. Set the supply to 3.3 V.

Step 9. Measure the current on the multimeter for each mode.

> **CAUTION**
>
> The CC Debugger influences the measurements. The debugger consumes some current and increases the measured current going into the EM.
>
> In particular, this device influences the sleep current measurements.
>
> The debugger can be disconnected from the SoC BB after the device has been set to the desired mode using SmartRF Studio. The radio device remains in the active/sleep state, and it is possible to perform more accurate measurements. A *hot disconnect* should not normally cause any damage to the devices.

8.1 Standby Mode

Table 24 lists the outcomes of the standby mode test.

Table 24. Standby Mode Test Results with LabVIEW

Voltage	Current (mA)
3.3 V	

8.2 Idle Mode

Table 25 lists the outcomes of the idle mode test.

Table 25. Idle Mode Test Results with LabVIEW

Voltage	Current (mA)
3.3 V	

8.3 Power-Down Mode

Table 26 lists the outcomes of the power-down mode test.

Table 26. Power-Down Mode Test Results with LabVIEW

Voltage	Current (mA)
3.3 V	

8.4 TX Mode

Table 27 lists the outcomes of the TX mode test.

Table 27. TX Mode Test Results with LabVIEW

Mode	Voltage	Current (mA)
At 2.440 GHz (0 dBm)	3.3 V	

8.5 RX Mode

Table 28 lists the outcomes of the RX mode test.

Table 28. RX Mode Test Results with LabVIEW

Mode	Voltage	Current (mA)
At 2.440 GHz (HG)	3.3 V	
At 2.440 GHz (LG)		

9 Testing Reminders

These reminders are presented as general considerations for all users, regardless of the testing setup used in a given situation.

1. The SMA cable connecting the EM to the signal analyzer should have a 50-Ω termination so it matches with the 50 Ω of the SMA port from the EM.
2. The RX board must be shielded.
3. Good tests for the shielding while executing the sensitivity test are to increase the attenuation by 20 dB to 40dB beyond the sensitivity stated in the product data sheet. If the RX is able to pick up the TX signal, the shielding must be improved.
4. When performing these tests, it is better to keep the output power of the TX and INT radios at approximately 0 dBm, and use attenuation provided by different attenuators.
5. In the interference signal setup, it is better to correlate the TX and INT outputs by simply turning off the other output and checking the RSSI at the RX end. These tests should be performed with the transmitters in continuous transmit mode.
6. RF couplers are asymmetric. The attenuation associated with the *lossy* path should be factored in. If a splitter (that is, a combiner) is used, it should be symmetric with equal attenuation on both paths.
7. The interference signal should be in continuous transmit mode.
8. If the carrier is unmodulated, the resulting difference in output power between the TX and INT indicates the blocking.
9. If the carrier is modulated, the resulting difference in output power between the TX and INT indicates the selectivity.
10. The shielded box can be a biscuit tin box with a small hole for the cable.
11. SmartRF Studio can be used to change the frequency for running the different interference tests.
12. When testing interference on IEEE 802.15.4 systems using an RF generator, if a modulated carrier is used, use a continuous MSK, 2-Mbps modulated carrier.
13. The adjacent channel rejection (ACR) measurement on IEEE 802.15.4 systems is described in Ref. 1.
14. Keep the cables/attenuators/connectors clean. Otherwise, losses in the cables can be excessive.

10 References

Unless otherwise indicated, the following references are available for download at the Texas Instruments website (www.ti.com).

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14. Battery Board for Systems-on-Chip. Product folder at www.ti.com.
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Appendix A Offset EVM vs. EVM

Offset EVM and EVM are both measurements of error vector magnitude; in other words, how far from the ideal position the actual signal position is.

The difference between offset EVM and EVM is when to obtain these measurements. In offset EVM measurements, calculate the EVM for the in-phase (I) portion of the signal at the start of the symbol, and the quadrature-phase (Q) portion at the middle of the symbol. Using this approach, users can obtain the EVM at the actual decision points that the demodulator makes when trying to decode it. This method is the correct way to measure EVM because it reflects the actual demodulator in the CCxxxx devices.

For a perfect signal, it does not matter if you use offset EVM or EVM. For spectrums where the I and Q phases are more noisy in the respective transitions than at the decision points, performing a regular EVM measurement gives you a poorer result, but does not affect the ability to receive the signal.