User's Guide

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 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 CC11xx, CC12xx, CC13xx, CC23xx, CC24xx, CC25xx, CC26xx, and CC27xx RF device families.

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Trademarks

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1 Introduction

This document provides the user of Texas Instruments' low-power RF products with an overview of the different characterization tests 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, the products 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 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 Acronyms

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

Table 1-1. Terms and Abbreviations

Acronym	Definition/Meaning
ARIB	Association of Radio Industries and Businesses
dBm	Power ratio in decibels (dB) of the measured power dBm referenced to 1mW
DUT	Device Under Test
ETSI	European Telecommunications Standards Institute
EVM	Error Vector Magnitude
FCC	Federal Communications Commission
FSQ	Full Spectrum Quantization
GUI	Graphical User Interface
HF	High Frequency
IEEE	Institute of Electrical and Electronics Engineer
INT	Interference Source; Interference Signal
ISM	Industrial, Scientific, Medical
LF	Low Frequency
MSK	Minimum Shift Keying
PER	Packet Error Rate
PSD	Power Spectral Density
RBW	Resolution Bandwidth
RSSI	Received Signal Strength Indicator
RX	Received, Receiver
SMA	Sub Miniature version A connector
SoC	System on Chip
SPI	System Parallel Interference
TX	Transmit, Transmission, Transmitter
VBW	Video Bandwidth

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
- FCC Section 47 CFR15 - Part 15 Standard
- ETSI EN 300 220-Part 1, Part 2, Part 3-1, Part 3-2, and Part 4 Standard
- ETSI EN 300 328 Standard
- ETSI EN 300 440 Standard
- IEEE 802.15.4 Standard
- ARIB T-66 Standard
- ANSI C63.10 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 and Schwarz
- Keysight
- Anritsu
- Tektronix
- National Instruments

2.3 Radio Certification URLs

CC26xx: https://www.ti.com/tool/CC26XX-CERTIFICATION

CC23xx: https://www.ti.com/tool/download/CC23XX-REPORTS/7.20.00.00 (there is no hot site as for CC26xx above).

3 Test Equipment 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).
- **SmartRF™ Studio:** SmartRF Studio (see Ref. 5) 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 all Simplelink LaunchPad evaluation boards.
- **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.

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

3.1 System Setup

This document describes two types of test system configurations: conducted and radiated testing. This section briefly describes each configuration. The actual setup can vary per test and is depicted in the beginning of each test. All tests will be conducted unless specified that the test can be radiated.

3.1.1 Conducted Test Systems

Systems used for conducted tests use the following test equipment and resources.

1. CCxxxx Launchpad™ Development Kit
2. LaunchPad™ Development Kit Debugger (LP-XDS110 or LP-XDS110ET, needed if CCxxxx LaunchPad has no onboard debug device)
3. RF Cable
4. Variable attenuators (two needed, can be substituted with fixed attenuators)
5. PC with SmartRF Studio software installed
6. RF coupler (combiner)
7. RF signal generator

8. Spectrum analyzer

3.1.2 Radiated Test Systems

Systems used for radiated tests use the following test equipment and resources.

1. CCxxxx Launchpad™ Development Kit
2. LaunchPad™ Development Kit Debugger (LP-XDS110 or LP-XDS110ET, needed if CCxxxx LaunchPad has no onboard debug device)
3. Antenna
4. Variable attenuators (two needed, can be substituted with fixed attenuators)
5. PC with SmartRF Studio software installed
6. RF coupler (combiner)
7. RF signal generator
8. Spectrum analyzer

3.2 Initial Considerations for Testing

- For conducted measurements, the device under test (DUT) is connected to the tester via a 50Ω RF cable with SMA connectors. The LaunchPad comes by default with the RF signal path routed to its PCB antenna. To re-route the signal path to its SMA connector, a capacitor near this connector must be rotated by 90° on the board. This requires de-soldering it from its original position, rotating and re-soldering it in the new position. Consult the LaunchPad user' s guide for details.
- For radiated measurements, the device under test (DUT) must be connected to an antenna. Correspondingly, the spectrum analyzer must have an antenna attached to its input. The LaunchPad comes by default with the RF signal path routed to its PCB antenna and therefore does not require any modifications. If an external antenna must be connected to the SMA connector, follow the procedure to rotate the capacitor shown in the previous paragraph. Please note that radiated measurements are typically taken within an anecoic chamber to prevent interference, and signal reflections, which can cause inconsistent or inaccurate readings.
- 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. They 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.

3.3 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 DUT to the signal analyzer has to have a 50Ω characteristic impedance so it matches with the 50Ω of the SMA port from the DUT.
2. The RX board must be shielded when performing sensitivity measurements.
3. Good tests for the shielding while executing the sensitivity test are to increase the attenuation by 20dB 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 0dBm, 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. SmartRF Studio can be used to control either the DUT, the tester or both if they are compatible LaunchPads. By setting its transmit and receive parameters across the band being tested (Sub-1GHz or 2.4GHz), this tool allows for various testing procedures such as BER/PER Rx sensitivity, Tx output power and others.
11. If a modulated carrier is used when testing interference on IEEE 802.15.4 systems using an RF generator, use a continuous MSK, 2-Mbps modulated carrier.
12. Keep the cables/attenuators/connectors clean. Otherwise, losses in the cables can be excessive.
13. When using antennas for radiated measurements, refer to SWRA726 before testing.

4 Software Setup

All the tests in this document use SmartRF Studio, and depending on the device, the device will use SmartRF Studio 7 or SmartRF Studio 8. This section briefly describes setting up the software after connecting the device to the PC with SmartRF Studio installed.

Note that some options in the software do not appear depending on the capability of the EM or launchpad being tested.

4.1 SmartRF Studio 7

4.1.1 SmartRF Studio 7 Start-Up Window

After the LaunchPad is connected to the PC, on the SmartRF Studio 7 start-up window, double-click the device name on the List of Connected Devices to open up the Device Control Panel.

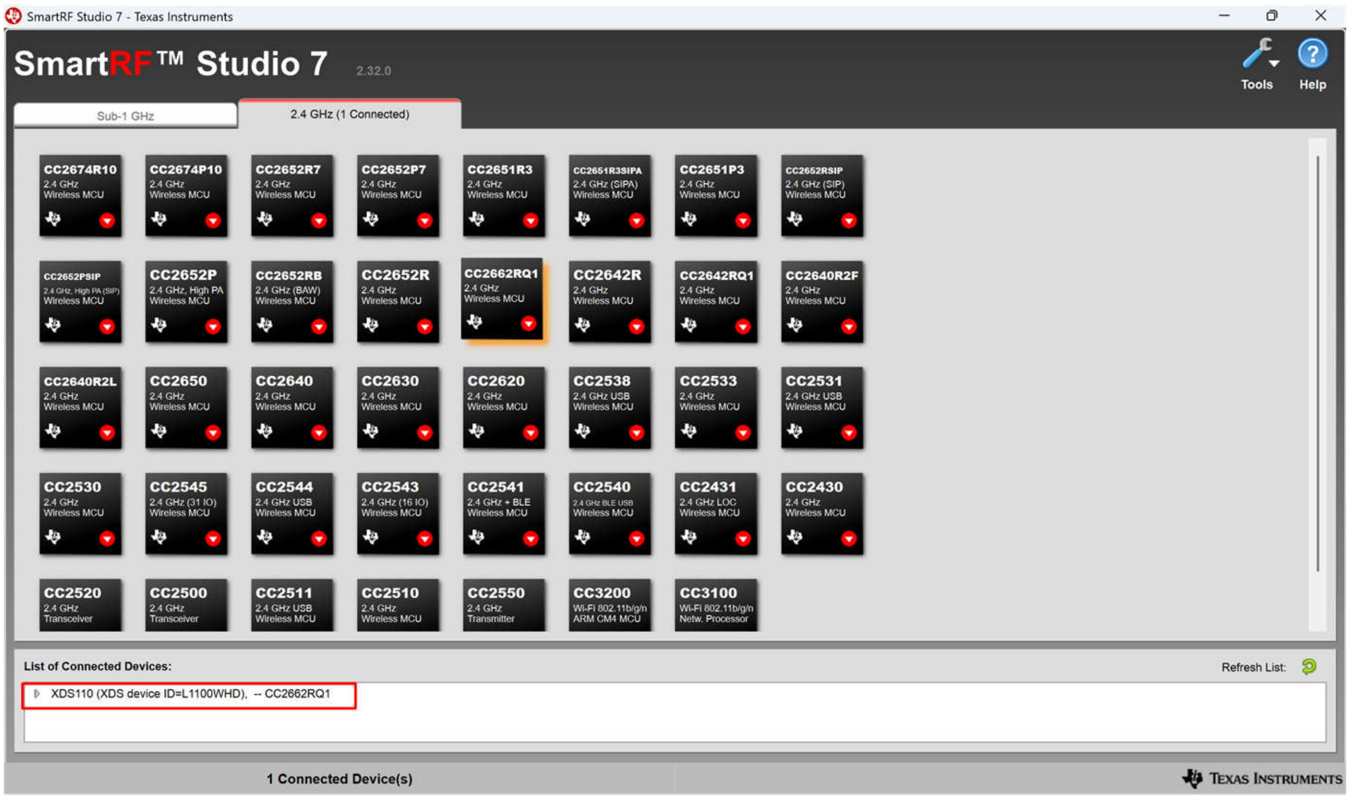


Figure 4-1. SmartRF Studio 7 Device Screen

4.1.2 SmartRF Studio 7 Modes

Depending on the device, there can be multiple modes/PHYs available, i.e. BLE mode, Proprietary mode, and IEEE 802.15.4. Select the mode that best fits needs of the test. If there is only one mode, no options will appear and the Device Control Panel will pop-up with that corresponding mode.

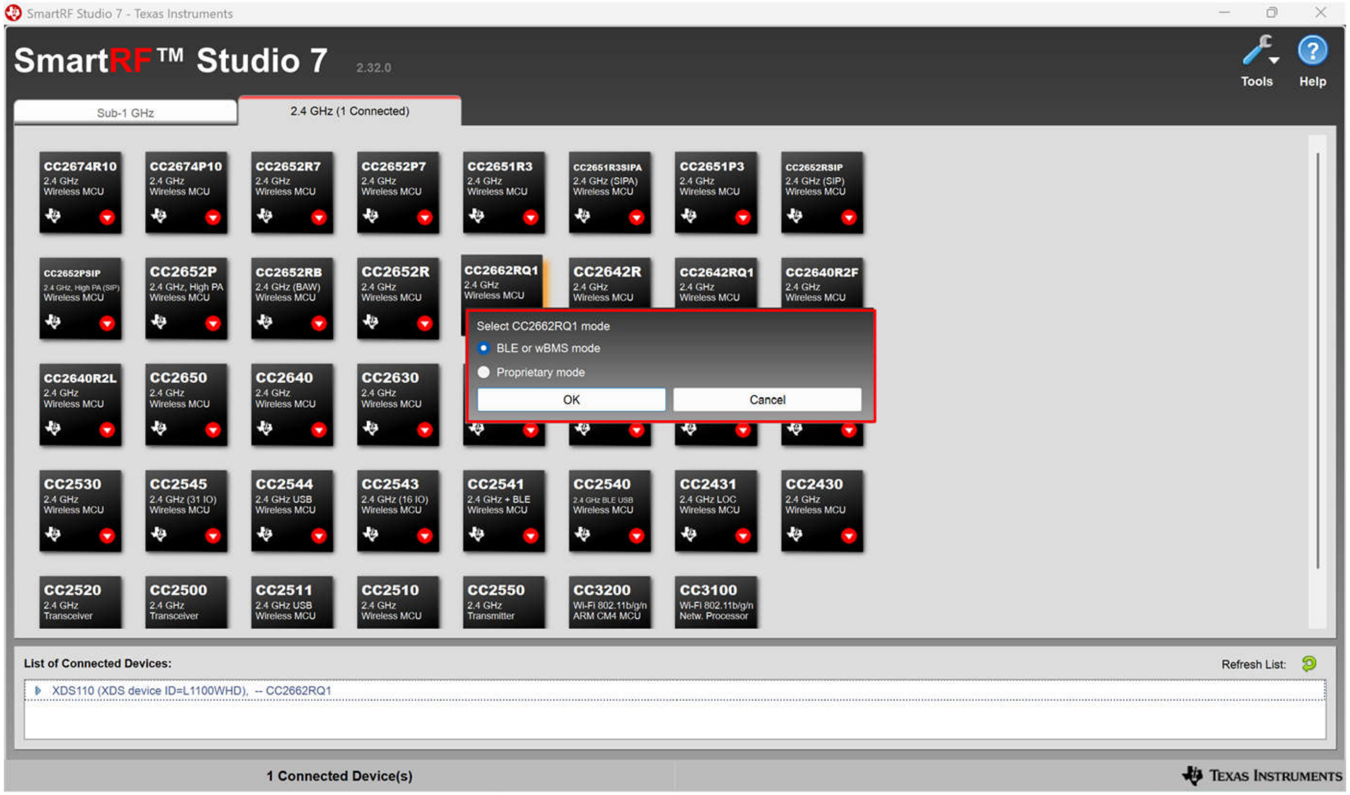


Figure 4-2. SmartRF Studio 7 Device Modes

4.1.3 SmartRF Studio 7 Device Control Panel

On the Device Control Panel, set up the device with the appropriate settings and RF parameters as needed. Some important settings for the characterization tests are the RF Test Modes, Modulation Setting, and Cap-Array Tuning. For IEEE 802.15.4 (Zigbee) mode, EVM testing is required. Certain devices also have Easy Mode and Expert Mode. Those are selected on the Device Control Panel, in which Expert Mode is needed to cover the characterization tests in this document. The data format also changes depending on the characterization test.

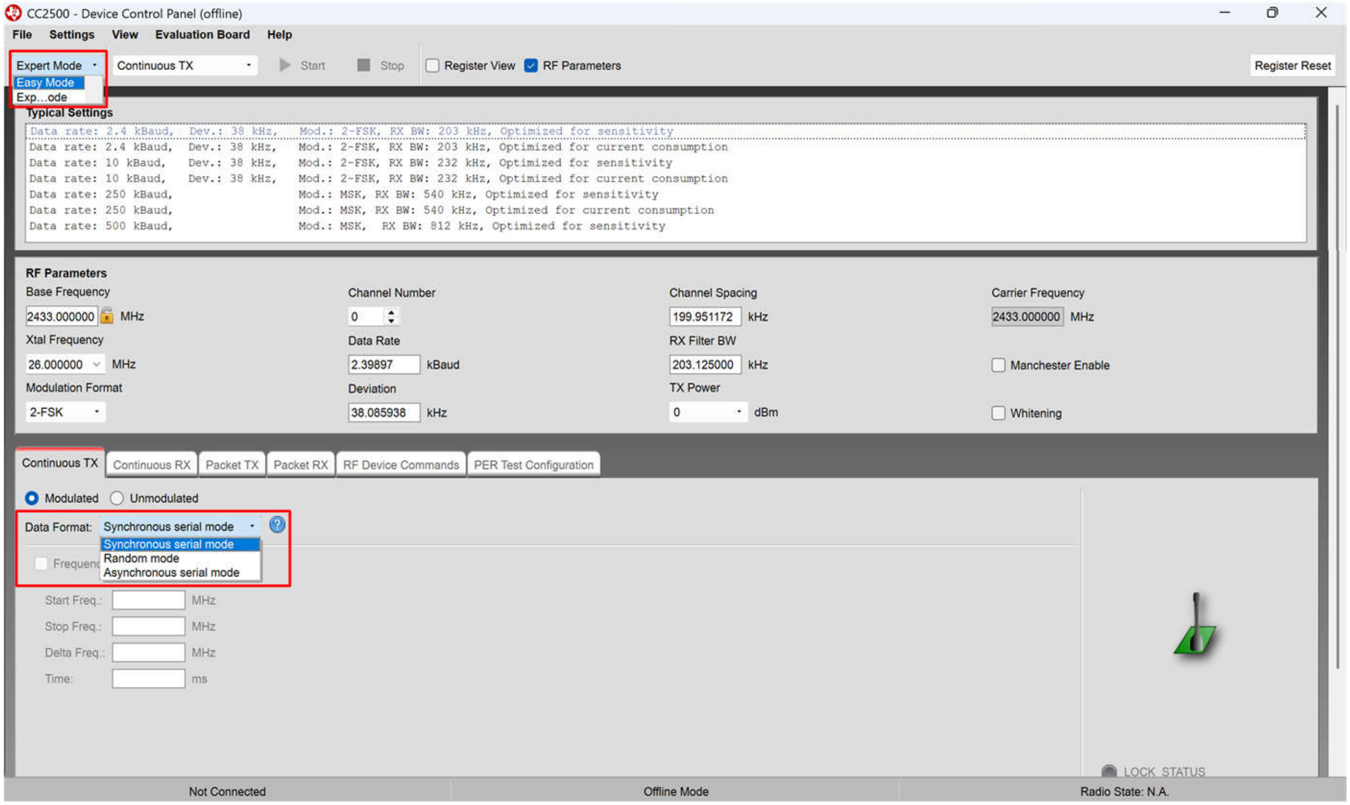


Figure 4-3. SmartRF Studio 7 Radio Control Panel - operation modes

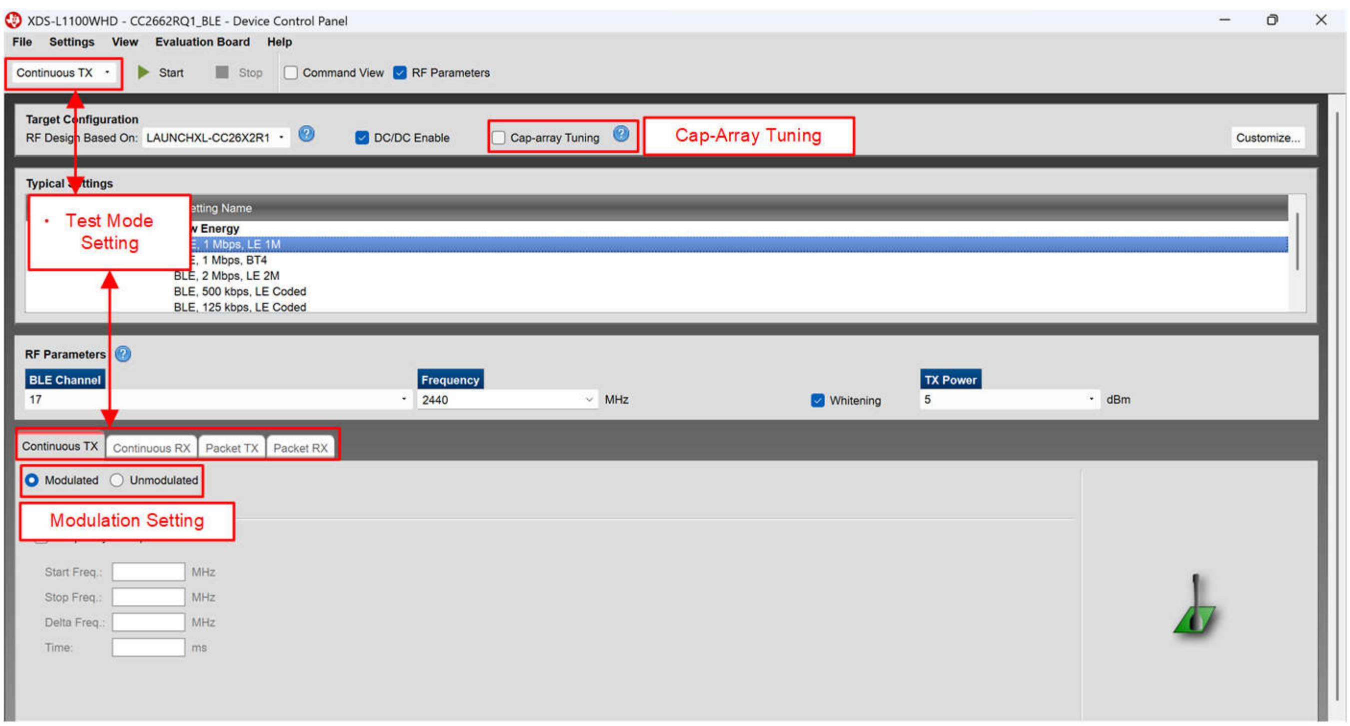


Figure 4-4. SmartRF Studio 7 Radio Control Panel – radio and device settings

4.1.4 SmartRF Studio 7 Software User Manual

For more advanced help, at the start-up window, click the help button on the upper right corner. After the SmartRF Studio Help window appears, click "Browse Complete Help Document...," to open the SmartRF Studio v7 User Manual.

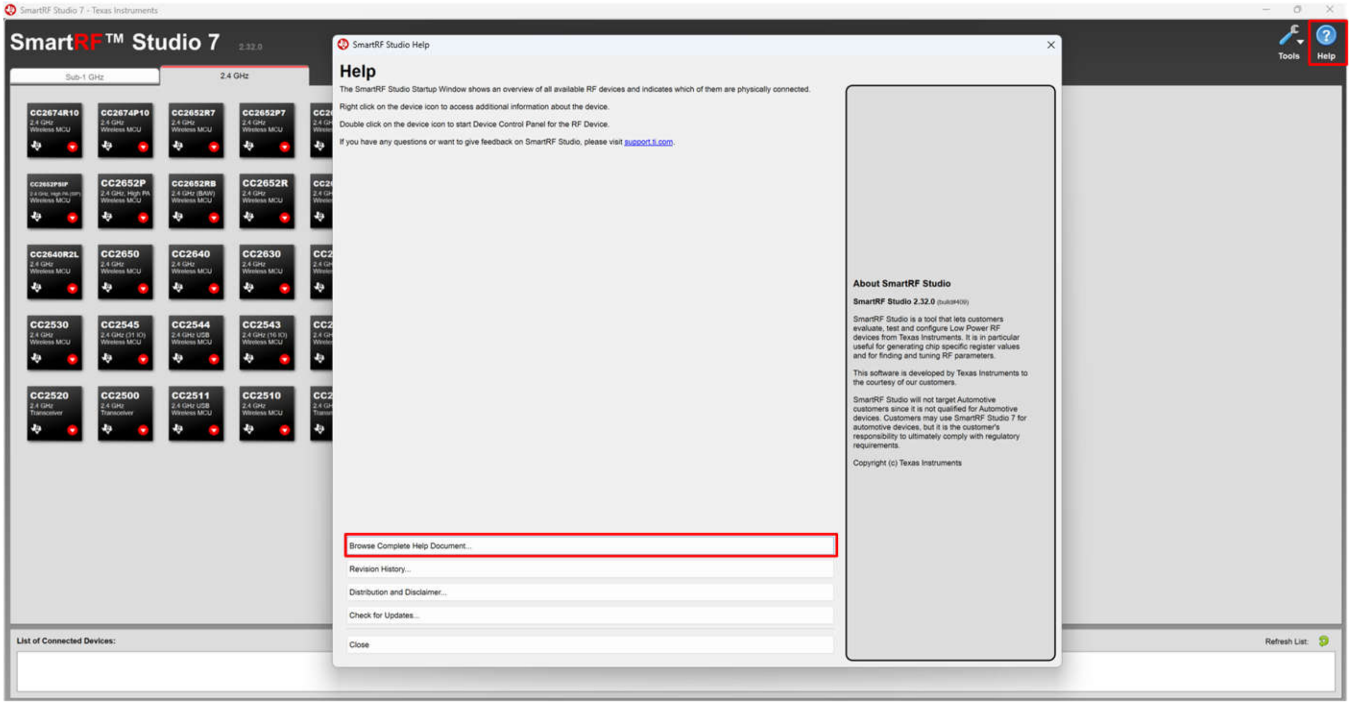


Figure 4-5. SmartRF Studio 7 Help Guide

4.2 SmartRF Studio 8

4.2.1 SmartRF Studio 8 Start-Up Window

After connecting the LaunchPad to the PC, in the SmartRF Studio 8 start-up window, double-click the device name on the Device Selection List to open up the Radio Control Window. The serial number of the debug probe appears under the device name if connected properly.

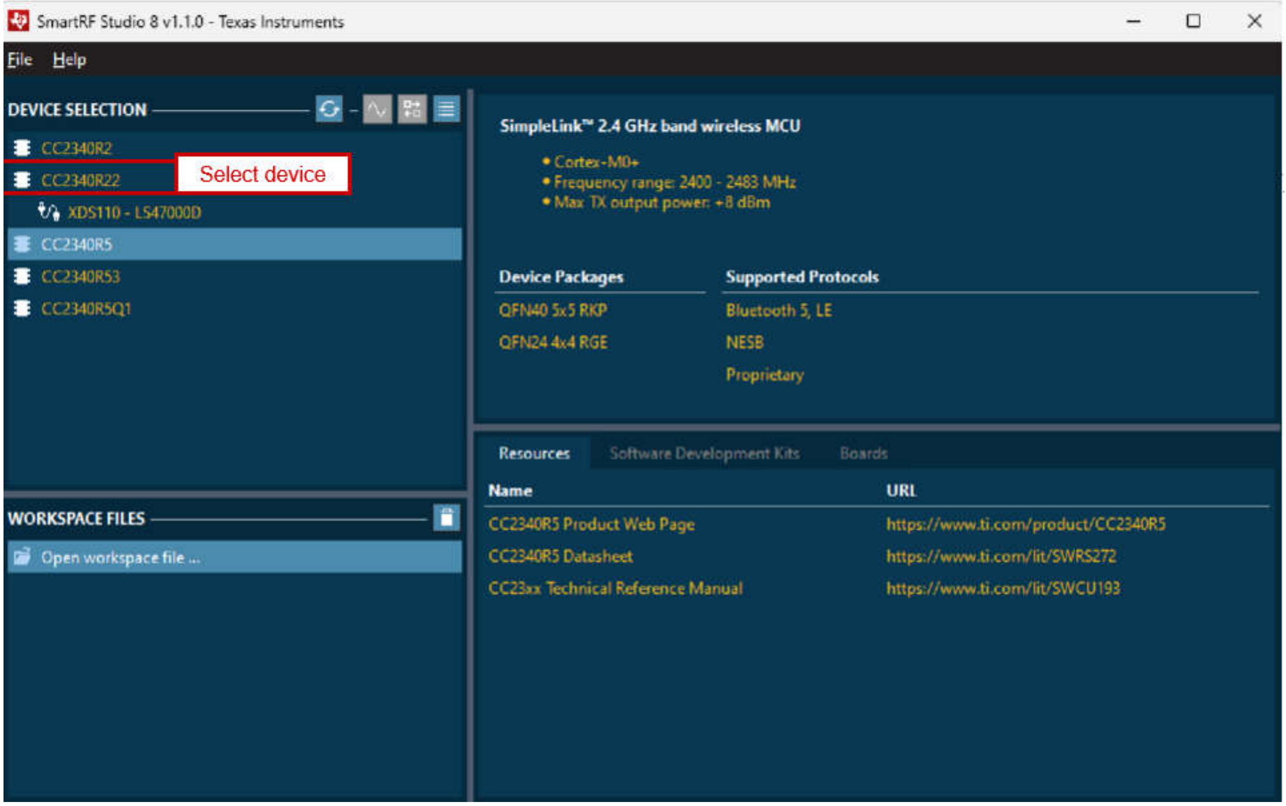


Figure 4-6. SmartRF Studio 8 Start-Up Window

4.2.2 SmartRF Studio 8 Radio Control Window

When the Radio Control Window appears, configure the device according to testing needs. Some important settings for the characterization tests are the RF Test Modes, PHY Selection, PHY Properties, Signal Type, and HFXT Cap-Array Tuning.

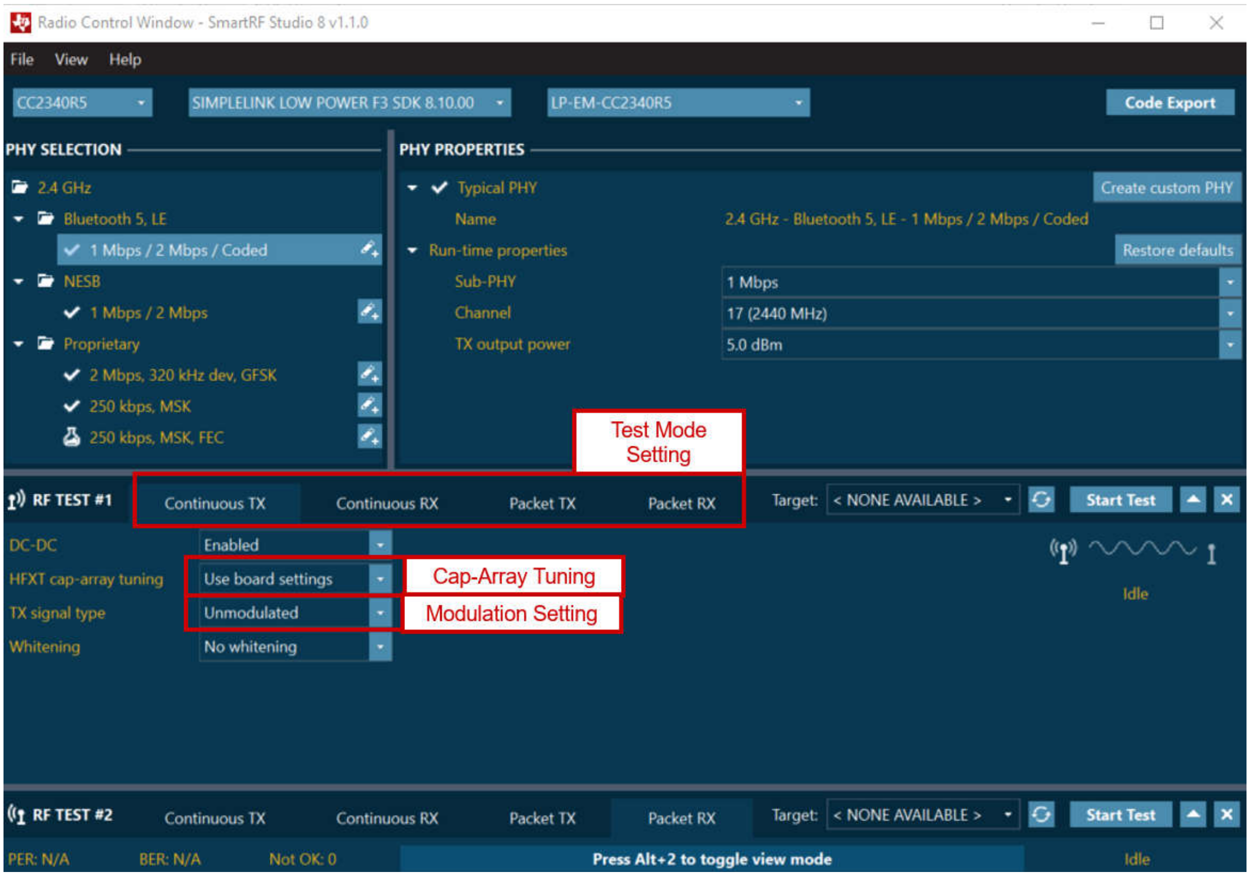


Figure 4-7. SmartRF Studio 8 Radio Control Window

4.2.3 SmartRF Studio 8 Software User Guide

For more advanced information, either click the F1 key when using the software or select "Help" on the upper left window ribbon and then "User Guide..." to open up the Help Viewer for SmartRF Studio 8.

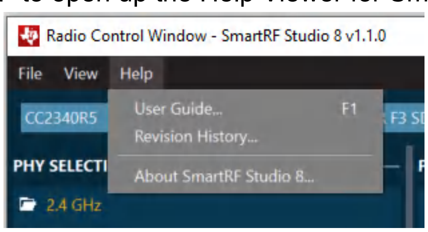


Figure 4-8. SmartRF Studio 8 Help Guide

5 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.

5.1 DUT

Table 5-1 shows the generic DUT information.

Table 5-1. DUT Information

Product	
Model Name	
Hardware Version	
Host Interface Type	
Modules SN	

5.2 Test Instruments

Table 5-2 lists the general test instrument data. (See Section 3 for more information.)

Table 5-2. Test Instrument Information

Item	Vendor	Model Name	Quantity
Signal Generator			
Power Combiner			
Spectrum Analyzer			
Power Meter			
Attenuator			
Temperature Chamber			
Oscilliscope			
Network Analyzer			

6 Clock Frequency Tuning

Refer to Table 6-1 for a summary of the oscillator frequency tuning.

Table 6-1. Clock Frequency Tuning

Section No.	Item	Result
Section 6.1	HF Clock Tuning	
Section 6.2	LF Clock Tuning	

6.1 HF Clock Tuning Utilizing the Internal Cap Array

Purpose: Adjusts the device's internal cap array setting for tuning the HF crystal clock accuracy to meet the crystal clock accuracy spec.

Pass Condition: Commanded RF output frequency is within crystal data sheet's specified tolerances with final cap array setting.

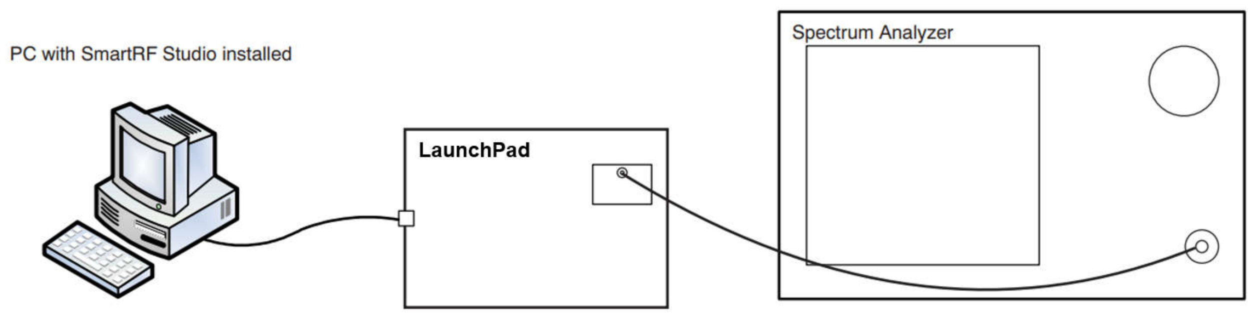


Figure 6-1. High Frequency Clock Tuning Setup Diagram

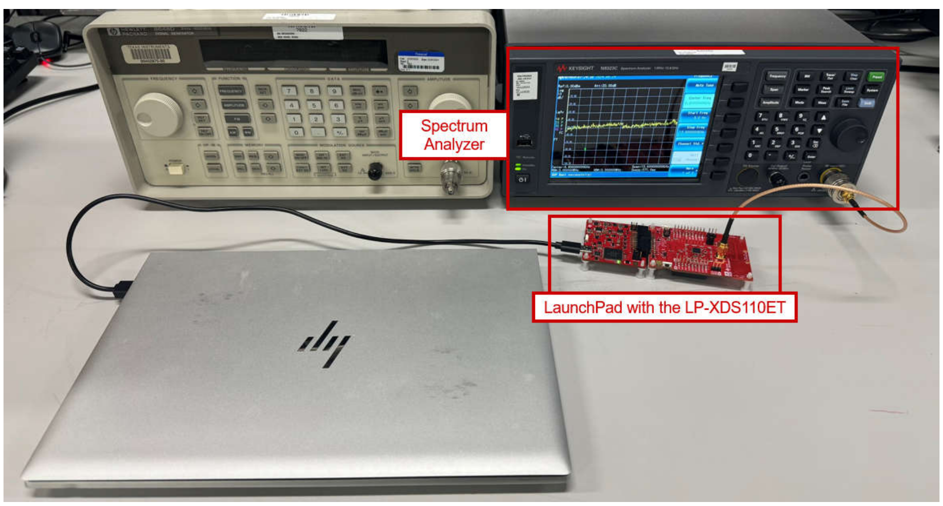


Figure 6-2. High Frequency Clock Tuning Bench Setup

Procedure:

- Step 1: Connect the instruments as shown in Figure 6-1 and Figure 6-2.
- Step 2: Open SmartRF Studio and select the desired frequency on RF Parameters.
- Step 3: Checkmark (enable) the Cap-Array Tuning. Start with the Cap-Array at 0.
- Step 4: At the Continous TX tab, make sure the TX is unmodulated and click start.
- Step 5: Measure the output frequency on the spectrum analyzer.
- Step 6: If the measured frequency is out of tolerance for the frequency commanded, stop the output signal and then change the Cap-Array (Delta) value depending on required adjustment. If the measured frequency

is above the commanded frequency, increase the Cap-Array Setting. If measured frequency is below the commanded frequency, decrease the Cap-Array Setting.

- Step 7: Enable the RF output and remeasure the output frequency.
- Step 8: Repeat Steps 6-7 until a Cap-Array Delta value which generates a measured frequency that is as close to the commanded frequency as possible is found.

Note

Ensure the RBW and frequency span of the spectrum analyzer are reduced to ensure the measured frequency resolution is at least within the hundreds of Hz. Also, it is recommended to use a spectrum analyzer with a precision frequency reference for best accuracy. For custom applications, please refer to SWRA495 for help with crystal selection and implementation.

Table 6-2. HF Oscillator Results

	Cap-Array Value	Chosen Frequency	Output Frequency	Frequency Delta	PPM
1					
2					
3					
4					

6.2 LF Clock Tuning

Purpose: To adjust the LF crystal's load capacitance to tune the LF crystal clock accuracy to meet the crystal clock accuracy spec.

Pass Condition: The LF clock output frequency is within crystal data sheet specified tolerances with the final load capacitor values installed.

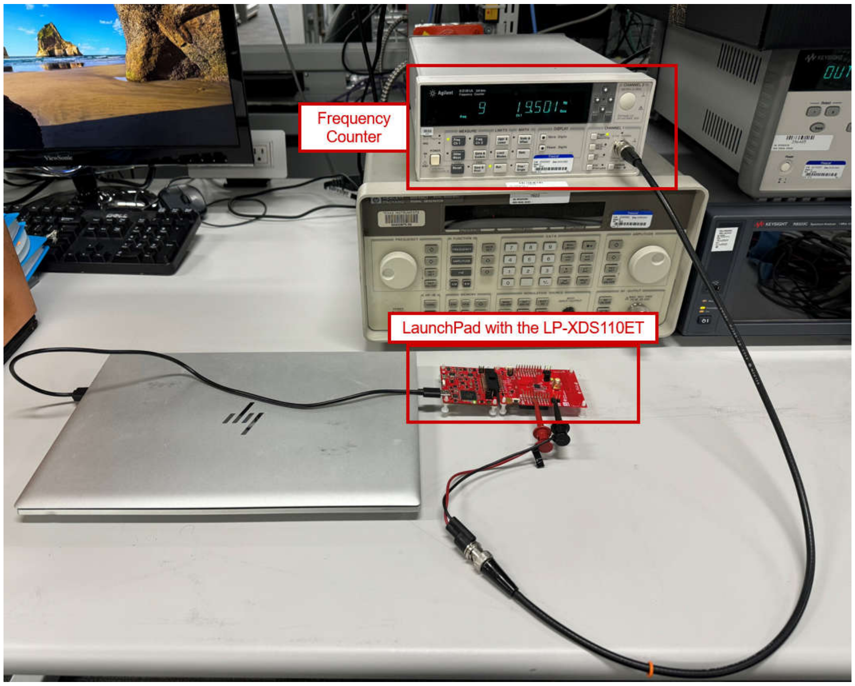


Figure 6-3. Low Frequency Clock Tuning Bench Setup

Procedure:

- Step 1: Generate a software load using Code Composer that outputs the LF clock to a GPIO that can easily be probed.
- Step 2: Using your preferred programming tool (Uniflash or SmartRF Flash Programmer), program the device with the software load.
- Step 3: Connect the instruments as shown on Figure 6-3.

- Step 4: Power up the device and measure the frequency of the GPIO pin assigned to output the LF clock.
- Step 5: If the LF clock frequency is out of tolerance or is not as close to the rated frequency as desired, adjust the load capacitance to shift the frequency appropriately. In general, increasing load capacitance reduces the frequency and reducing load capacitance increases the frequency.
- Step 6: Once the load capacitance is adjusted, repeat Steps 4 and 5 until the desired frequency clock accuracy is achieved.

Table 6-3. LF Oscillator Results

	Capacitor 1 Value	Capacitor 2 Value	Output Frequency	PPM
1				
2				
3				

7 Transmission Tests

Refer to Table 7-1 for a summary of the various transmission tests.

Table 7-1. Transmission Test Summary

Section No.	Item	Result
Section 7.1	Transmission Power	
Section 7.2	Power Spectral Density Mask	
Section 7.3	Error Vector Magnitude	
Section 7.4	Transmission Center Frequency Offset	
Section 7.5	Spurious Emissions on Transmission	

7.1 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 7-1 illustrates the transmission power test setup.

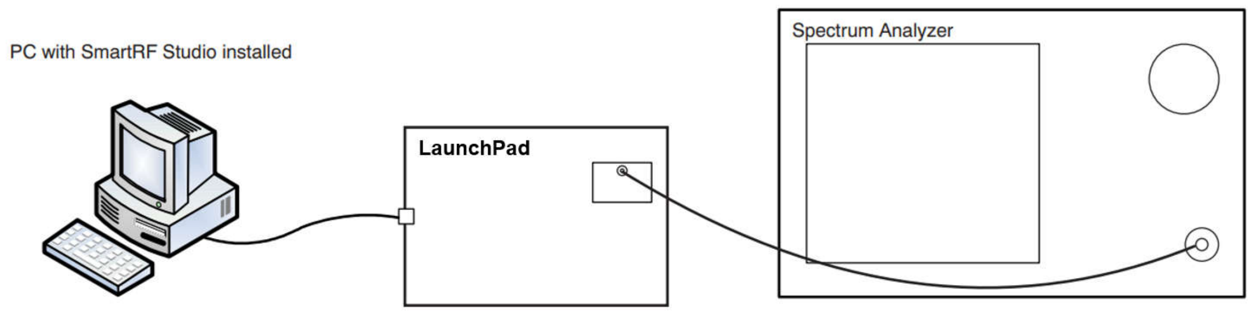


Figure 7-1. Transmission Power Test Setup Diagram

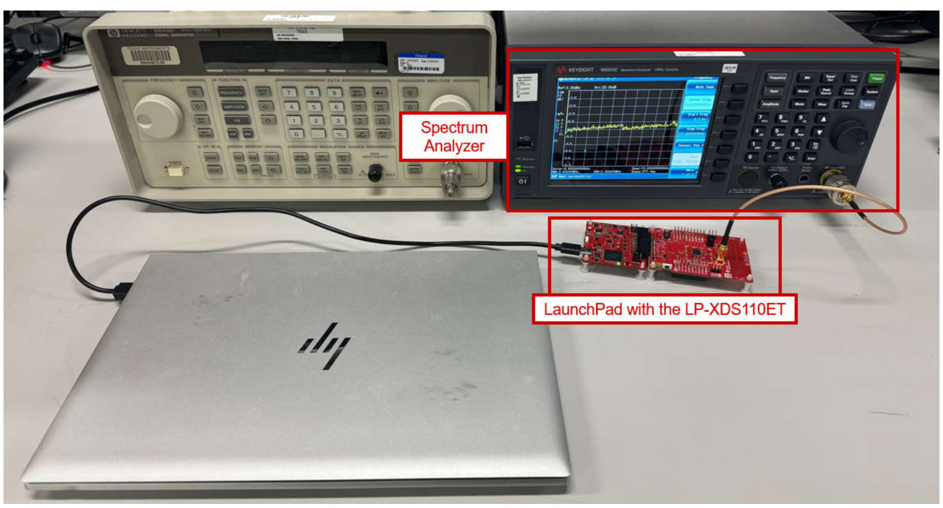


Figure 7-2. Transmission Power Test Bench Setup

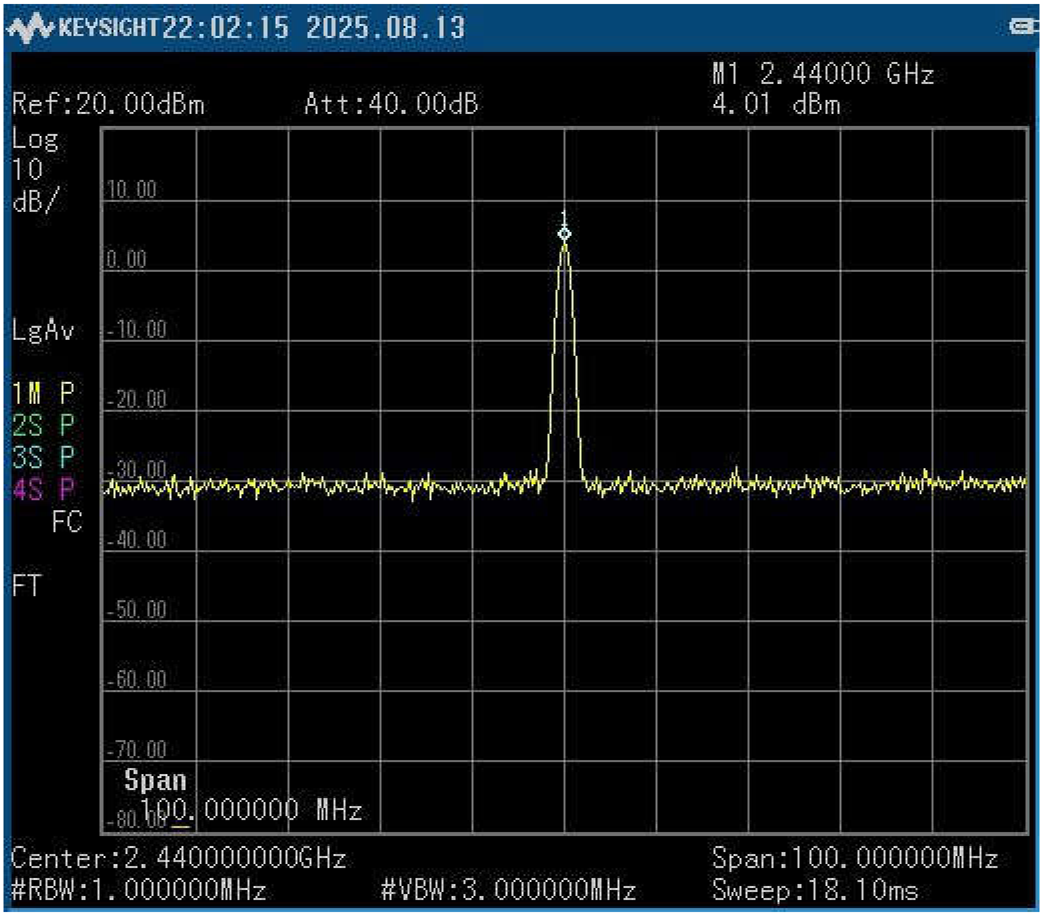


Figure 7-3. Spectrum Analyzer Output from Transmission Power Test

Procedure:

- Step 1: Connect the instruments as shown on Figure 7-1 and Figure 7-2.
- Step 2: Through SmartRF Studio, set the EM to unmodulated, continuous TX mode with the appropriate output power level and then click Start.
- Step 3: Measure the output power level on the spectrum analyzer to confirm the output power programmed on the EM. (Reference Figure 7-3 for an example of the results on the spectrum analyzer)

Note

To obtain true output power of the unit, add back cable loss to the measured output power.

Note

Transmission power for your products must comply with the limits established by regional regulatory authorities where the products are sold. For example:

ETSI (European Telecommunications Standards Institute) EN 300 328: Governs the 2.4GHz band.

- EIRP (Effective Isotropic Radiated Power) maximum is 20dBm.

FCC (Federal Communications Commission)

- EIRP (Effective Isotropic Radiated Power) maximum is 36dBm.

Verify your product design adheres to the specific maximum transmission power limits for the 2.4GHz band mandated by the appropriate regulatory authority for each target market.

Table 7-2. Transmission Power Results

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

Test Results:

7.2 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 7-3 shows an example for the IEEE 802.15.4 standards requirements. Figure 7-4 illustrates the requirements.

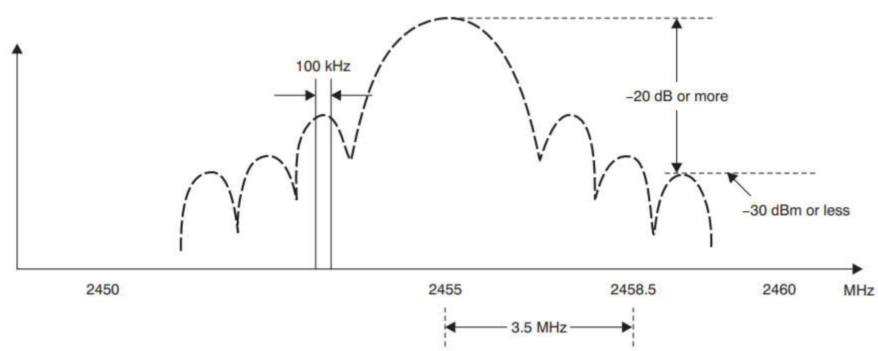


Figure 7-4. Power Spectral Density Mask Requirements

Table 7-3. IEEE 802.15.4 Standards Requirements (Example)

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

Test Environment: Figure 7-5 shows the test setup.

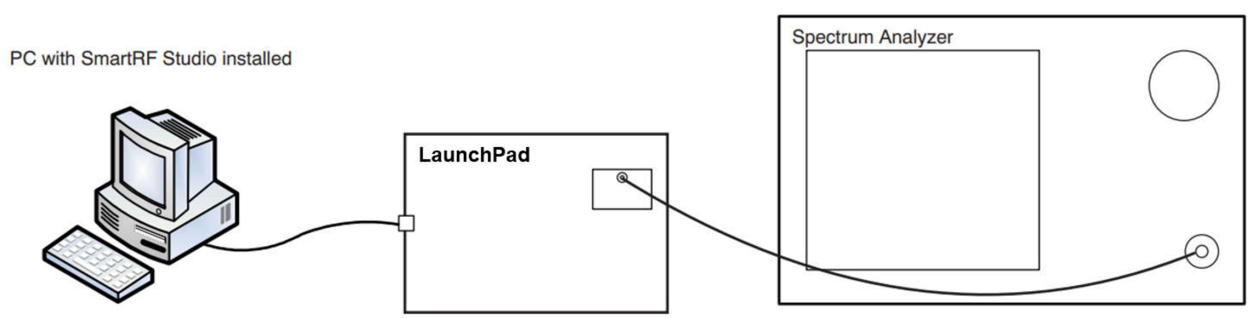


Figure 7-5. Power Spectral Density Mask Test Setup Diagram

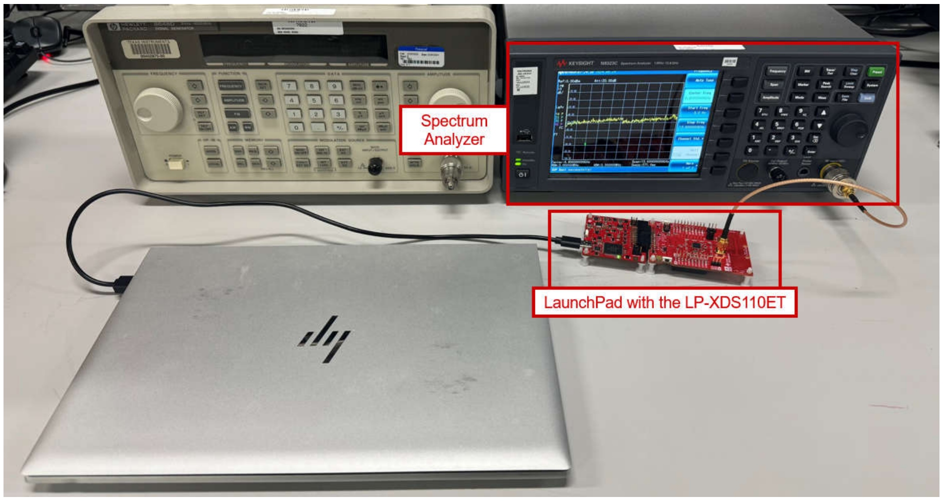


Figure 7-6. Power Spectral Density Mask Test Bench Setup

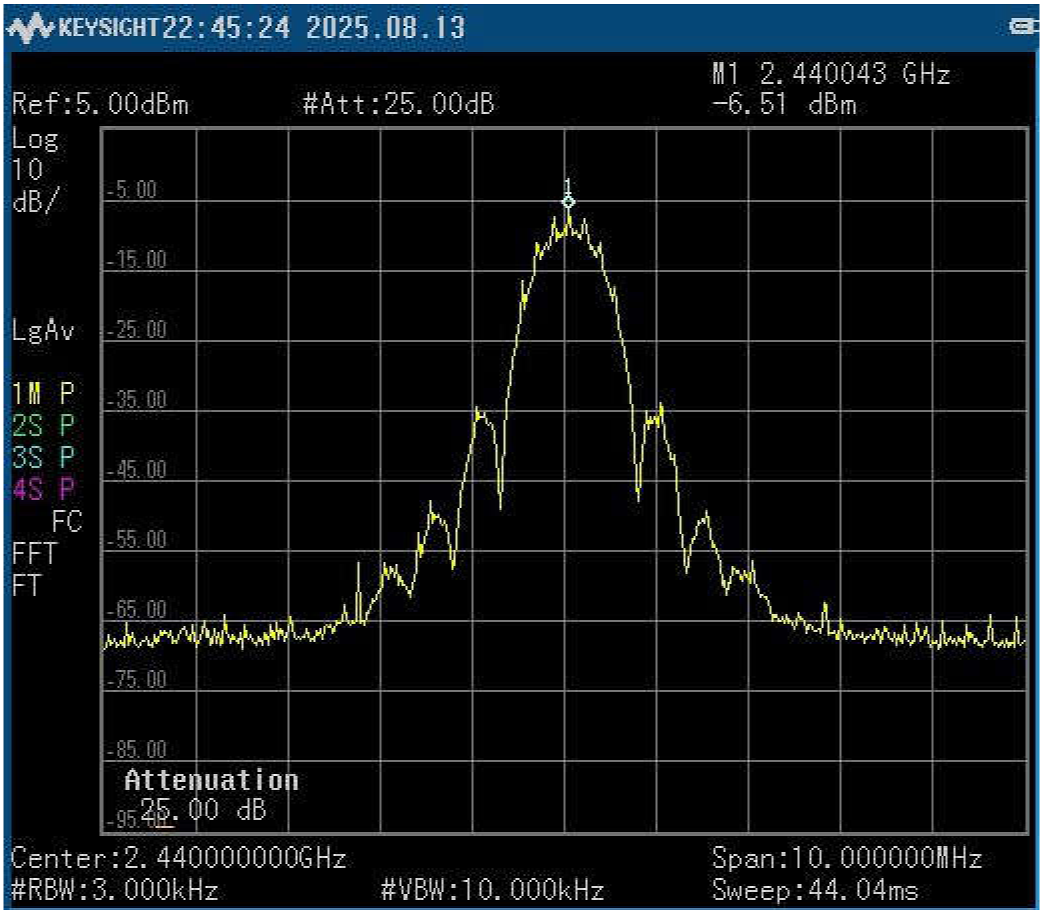


Figure 7-7. Spectrum Analyzer Output from Power Spectral Density Mask Test

Procedure:

- Step 1: Connect the instruments as shown on Figure 7-5and Figure 7-6.
- Step 2: Open SmartRF Studio and select the desired frequency on RF Parameters.
- Step 3: Through SmartRF Studio, set the EM to modulated, continuous TX mode and click start.
- Step 4: Verify that the PSD mask conforms to the given standard on the spectrum analyzer. (Reference Figure 7-7 for an example of the results on the spectrum analyzer)

Note

To obtain true output power of the unit, add back cable loss to the measured output power.

Table 7-4. Power Spectral Sensity Mask Results

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

Test Results:

7.3 Error Vector Magnitude

Purpose: Transmission modulation accuracy is measured using error vector magnitude (EVM). EVM, as illustrated in Figure 7-8 and Figure 7-9, is the magnitude of the phase difference as a function of time between an ideal reference signal and the measured transmitted signal.

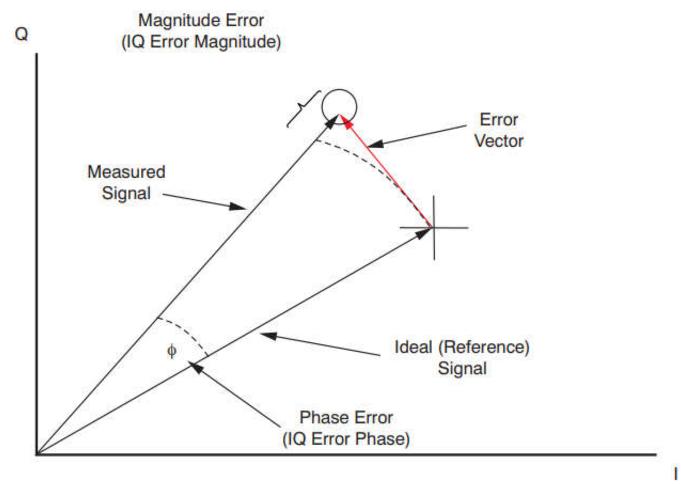


Figure 7-8. Error Vector Magnitude

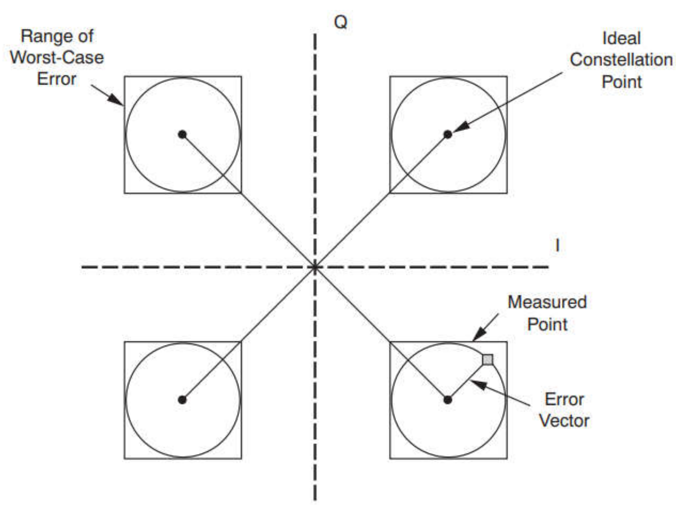


Figure 7-9. EVM and Related Quantities

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

Test Environment: Figure 7-10 illustrates the setup for the EVM test. Figure 7-10

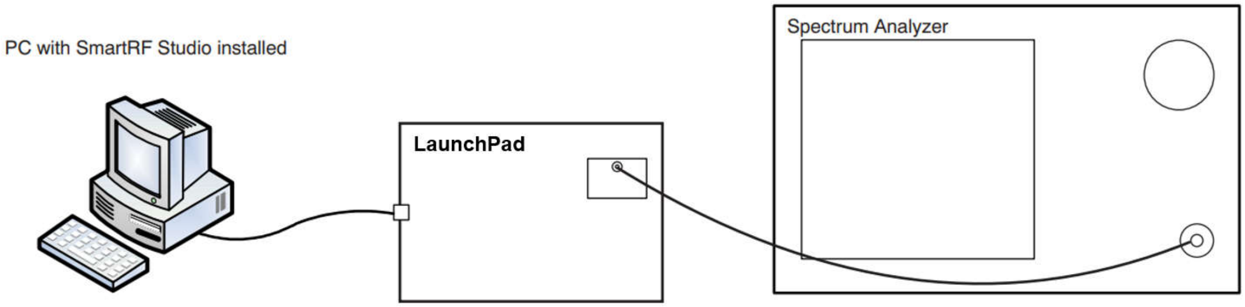


Figure 7-10. Error Vector Magnitude Test Setup Diagram

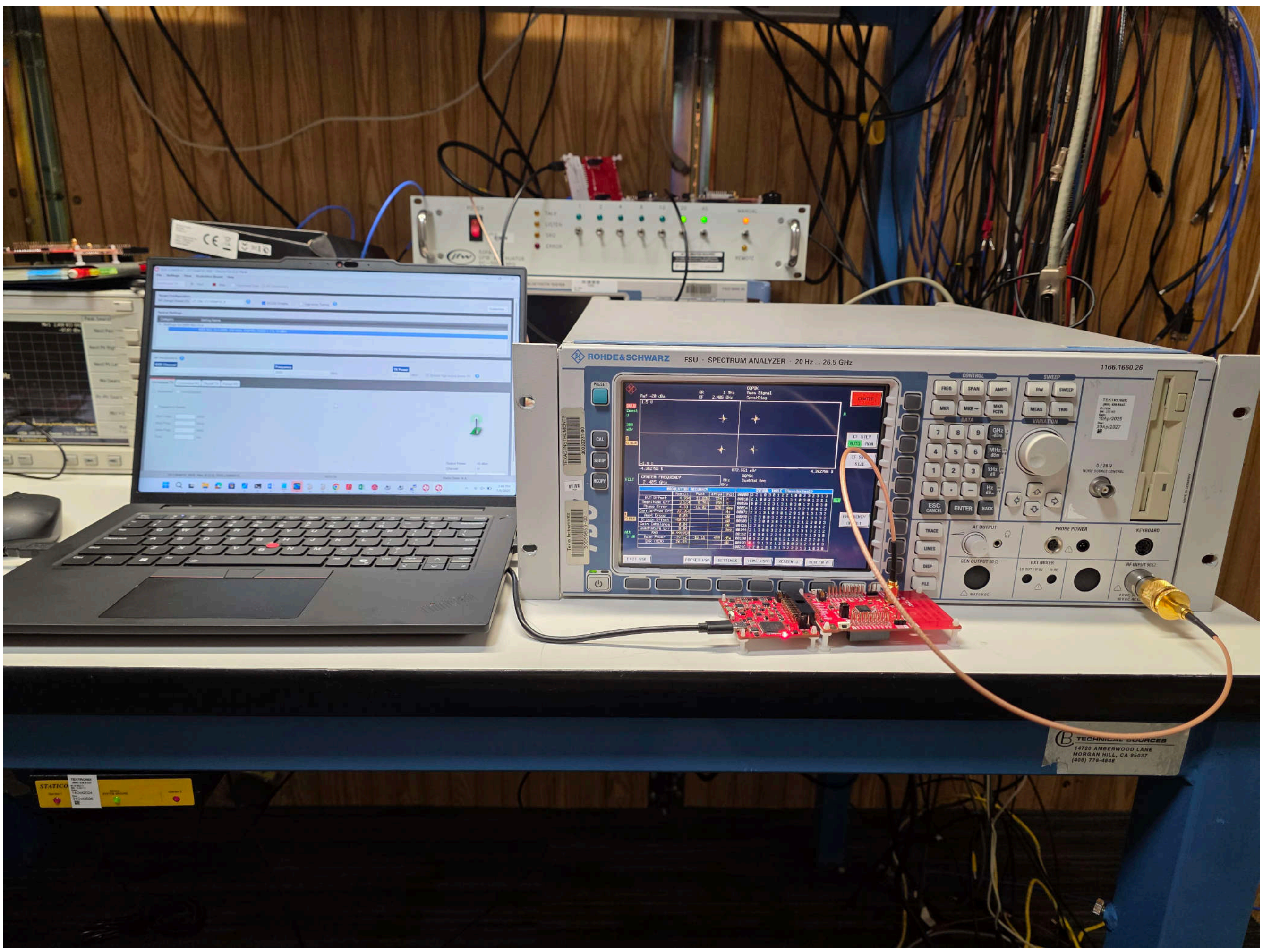


Figure 7-11. Error Vector Magnitude Test Bench Setup Using An SMA Connector

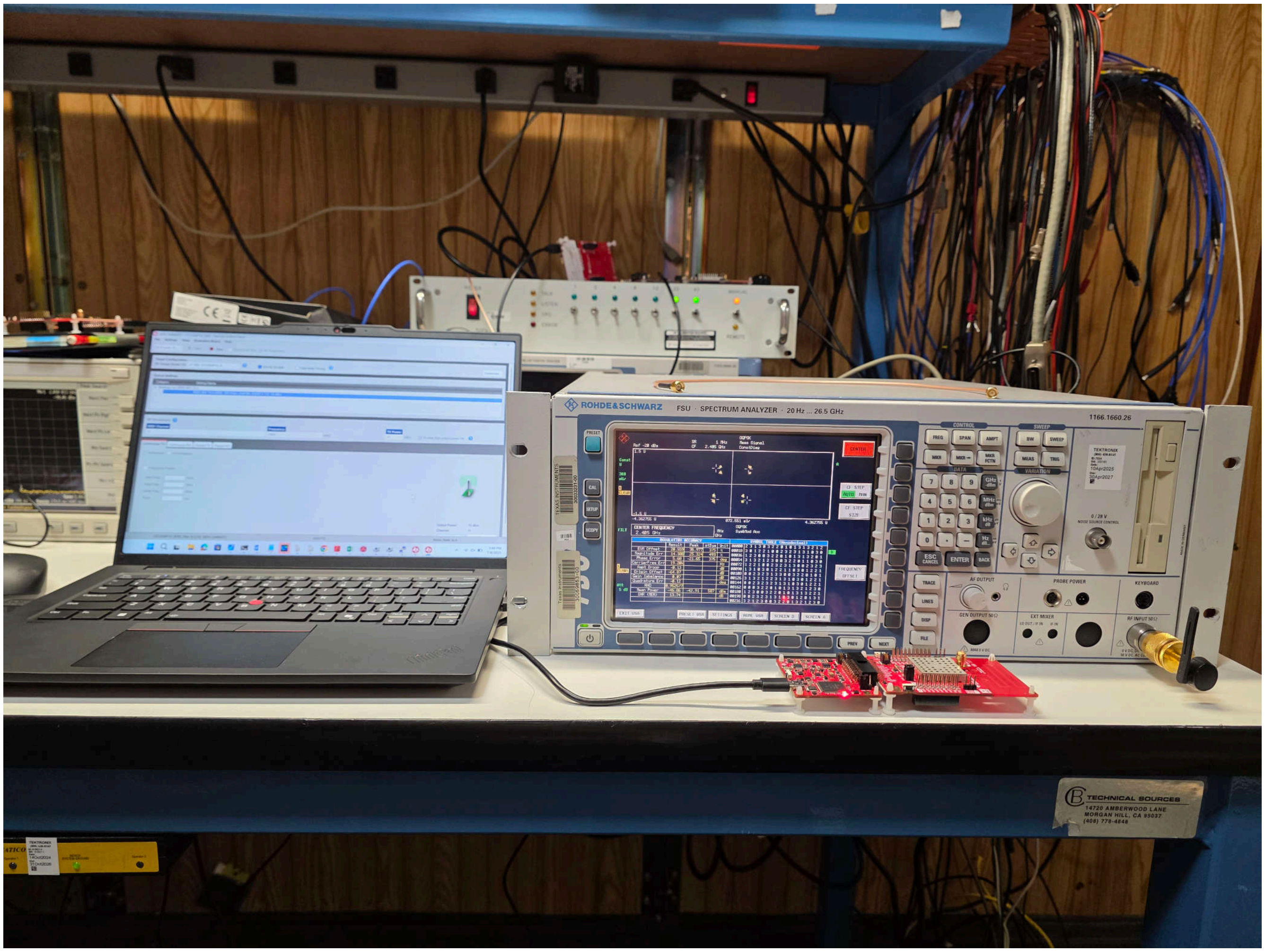


Figure 7-12. Error Vector Magnitude Test Bench Setup Using An Antenna

Procedure:

- Step 1: Connect the instruments as shown on Figure 7-10 and Figure 7-11, or with Figure 7-12, if using an antenna.
- Step 2: Set the EM to modulated, continuous TX mode (with random modulated data, if applicable) through SmartRF Studio.
- Step 3: Measure EVM with the spectrum analyzer after setting up the instrument by following the steps described in the tool's 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. 1.

Note that not all spectrum analyzers will work on this test, they must have the capability and be configured to do EVM measurements to do so.

Table 7-5. Error Vector Magnitude Test Results

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

Test Results:

7.4 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 Condition: Figure 7-13 shows the setup for transmission center frequency offset testing.

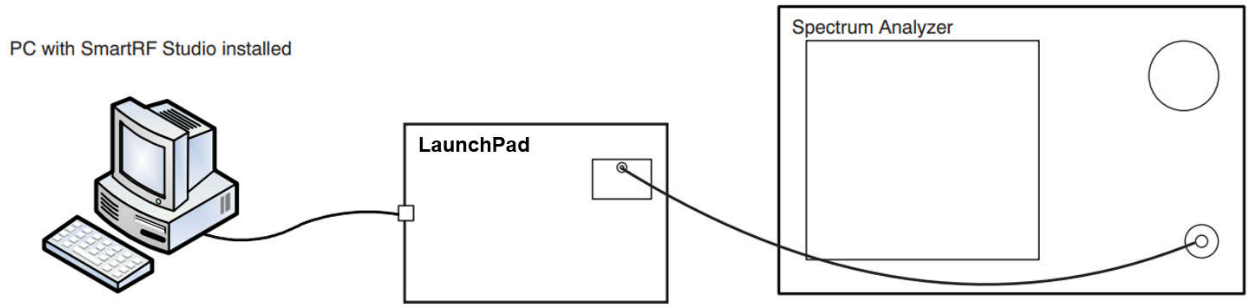


Figure 7-13. Transmission Center Frequency Offset Test Setup Diagram

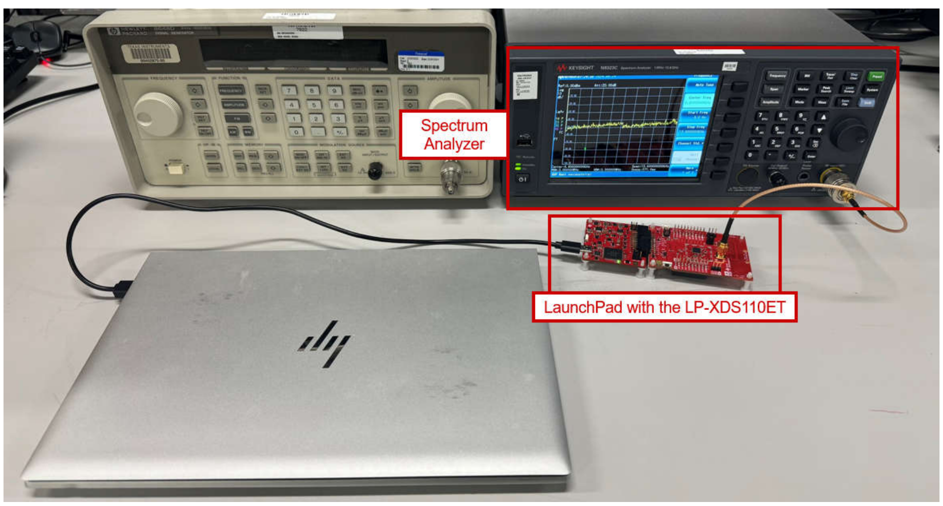


Figure 7-14. Transmission Center Frequency Offset Test Bench Setup With A SMA Connector

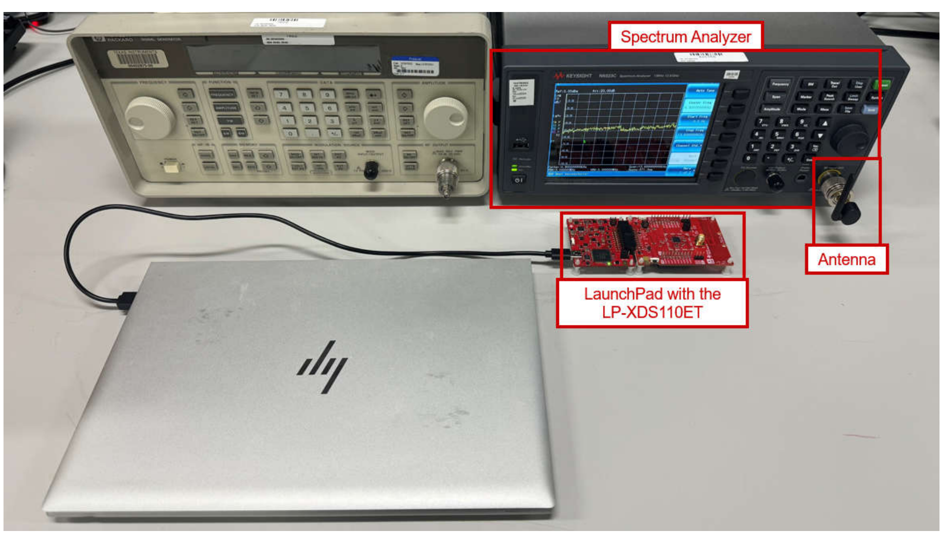


Figure 7-15. Transmission Center Frequency Offset Test Bench Setup With An Antenna

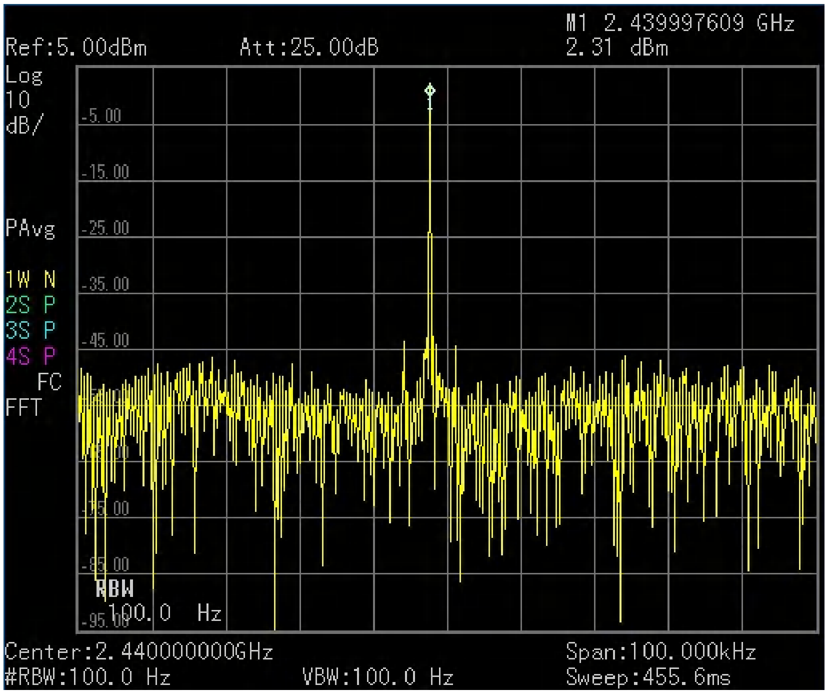


Figure 7-16. Spectrum Analyzer Output from Transmission Center Frequency Offset Test

Procedure:

- Step 1: Connect the instruments as shown on Figure 7-13 and Figure 7-14, or with Figure 7-15 if using an antenna.
- Step 2: Set the EM to continuous, unmodulated TX mode through SmartRF Studio.
- Step 3: Set the center frequency to the desired channel frequency.
- Step 4: Measure the actual frequency on the spectrum analyzer. The difference between the actual frequency and the center frequency is the frequency offset. (Reference Figure 7-16 for an example of the results on the spectrum analyzer, the lower the RBW and VBW, the more precise the frequency measurement)

Table 7-6. Transmission Center Frequency Offset Test Results

	Channel	Frequency	Frequency Offset	Design Specification (ppm)	Pass/Fail?
1					
2					
3					

Test Results:

7.5 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 Condition: Figure 7-17 shows the setup for spurious emissions test setup.

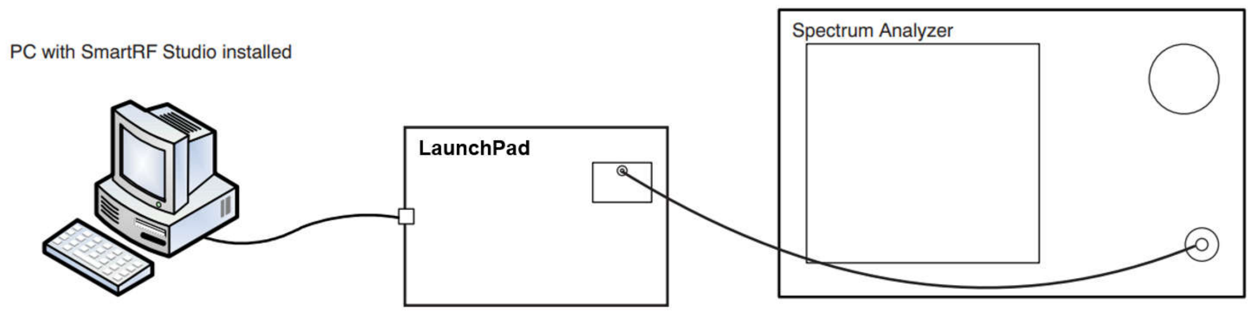


Figure 7-17. Spurious Emissions Test Setup Diagram

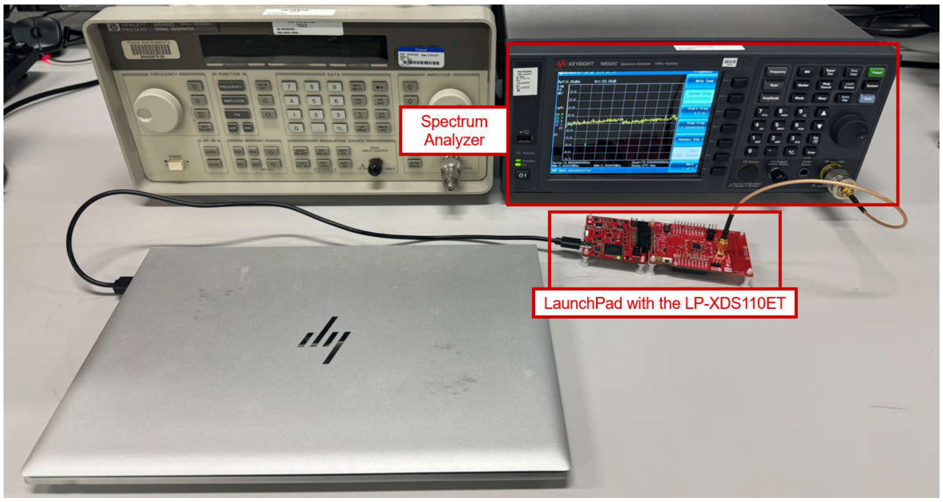


Figure 7-18. Spurious Emissions Test Bench Setup

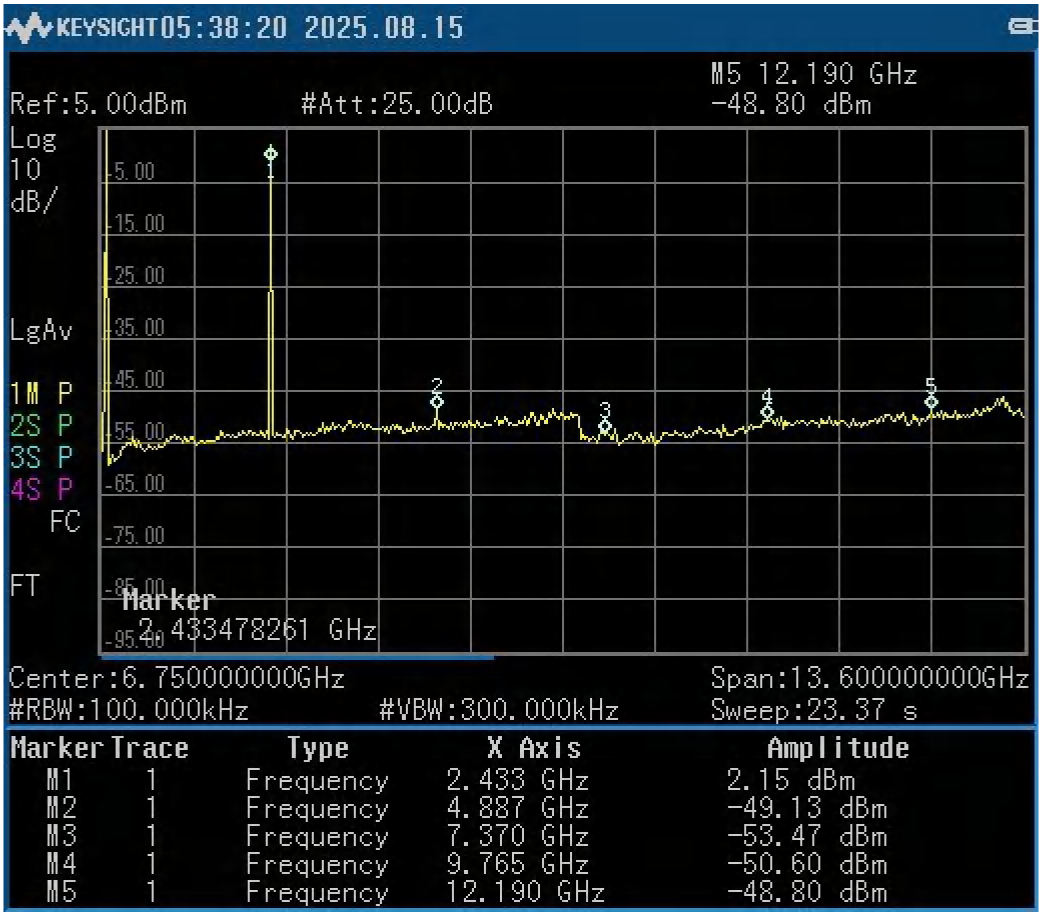


Figure 7-19. Spectrum Analyzer Output from Spurious Emissions Test

Procedure:

- Step 1: Connect the instruments as shown on Figure 7-17 and Figure 7-18.
- Step 2: Set the EM to continuous, modulated TX mode in 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. (Reference Figure 7-19 for an example of the results on the spectrum analyzer, spurs shown are harmonics)

Note

To obtain true output power of the unit, add back cable loss to the measured output power. Additionally, different spectrum analyzers have different maximum frequencies. Up to 25GHz is more than sufficient.

Note

Regulatory Compliance for Spurious Emissions

Spurious emissions are subject to regulatory limits specific to your operational region. Your product must comply with all applicable regional standards and regulations. For reference, below are common harmonic emission limits for 2.4GHz frequency operations.

ETSI (European Telecommunications Standards Institute) EN 300 328: Governs the 2.4GHz band.

- Field Strength: Cannot exceed 54dBuV/m.
- Spurious Emissions: EIRP (Effective Isotropic Radiated Power) must be below -30dBm at a distance of 3 meters.

FCC (Federal Communications Commission) §15.209 General emission limits.

- Field strength: Cannot exceed 500uV/m at a distance of 3 meters. This is equivalent to 54dBuV/m.
- Spurious Emissions: EIRP (Effective Isotropic Radiated Power) must be below -41.3dBm at a distance of 3 meters.

Table 7-7. Spurious Emission Test Results

	Channel Frequency	Spur Frequency	Measured Spur (dBm)	Design Specification (dBm)	Pass/Fail?
1					
2					
3					

Test Results:

8 Receive Testing

Refer to Table 8-1 for a summary of the various receiver tests.

Table 8-1. Receive Test Summary

Section No.	Item	Result
Section 8.1	Receiver Sensitivity	
Section 8.2	Interference Testing	
Section 8.3	Interference Testing with an RF Signal Generator	

8.1 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 8-1 illustrates the test setup for receiver sensitivity.

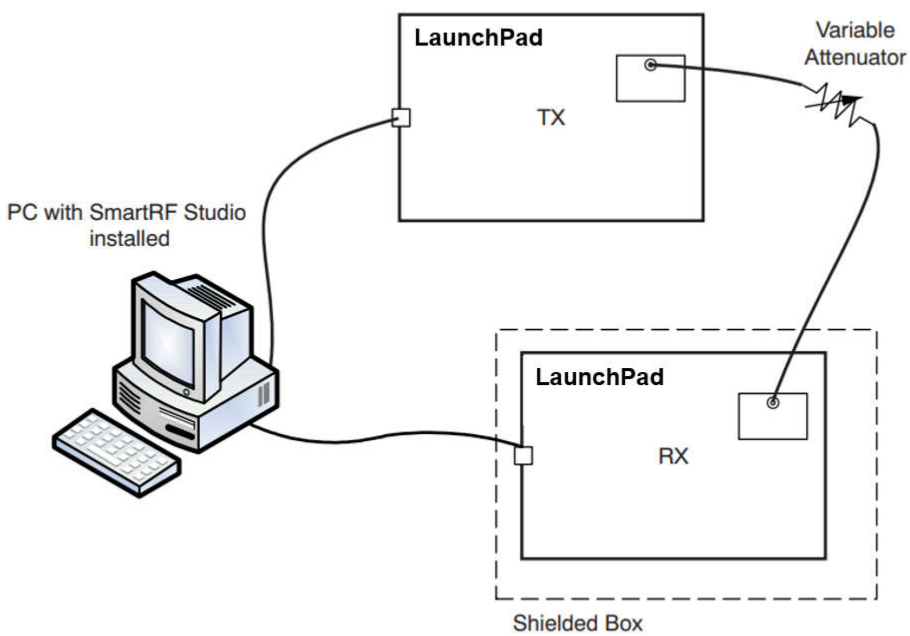


Figure 8-1. Receiver Sensitivity Test Setup Diagram

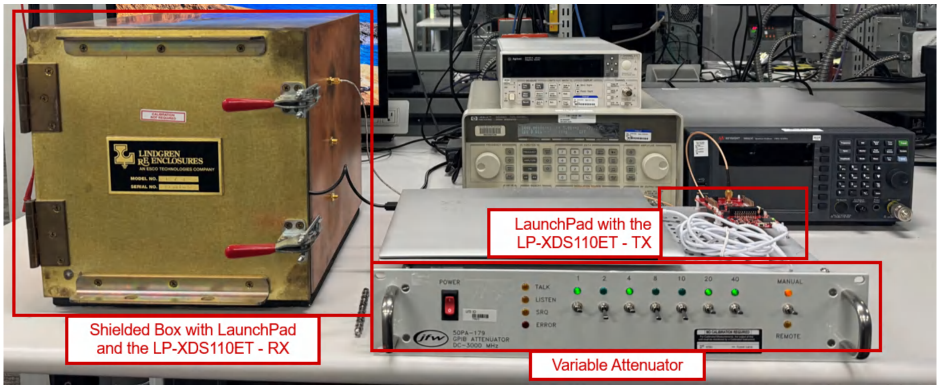


Figure 8-2. Receiver Sensitivity Test Bench Setup - Front

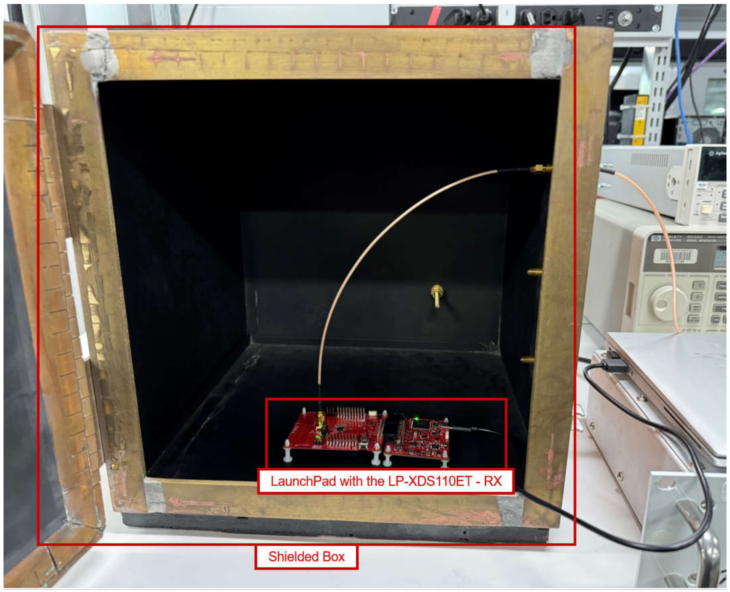


Figure 8-3. Receiver Sensitivity Test Bench Setup - Shielded Box

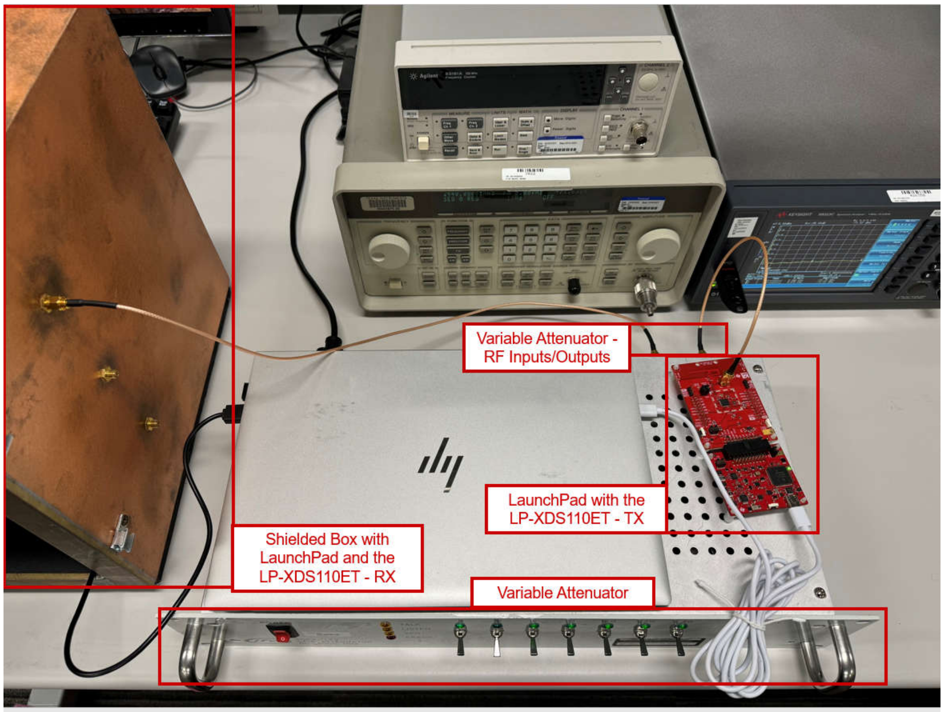


Figure 8-4. Receiver Sensitivity Test Bench Setup - Top

Procedure:

- Step 1: Connect the instruments as shown on Figure 8-1, Figure 8-2, Figure 8-3, and Figure 8-3.
- Step 2: Configure both the TX side and the RX side with the appropriate RF settings. Select the packet TX or packet RX tab for the corresponding devices, and select an appropriate packet format.
- Step 3: Start up the receiver first. Make sure 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 shown on the RX side reaches 1%. This level defines the sensitivity threshold. This is not always the case. It is dependent on the standard/packet size, etc

Table 8-2. Receiver Sensitivity Test Results

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

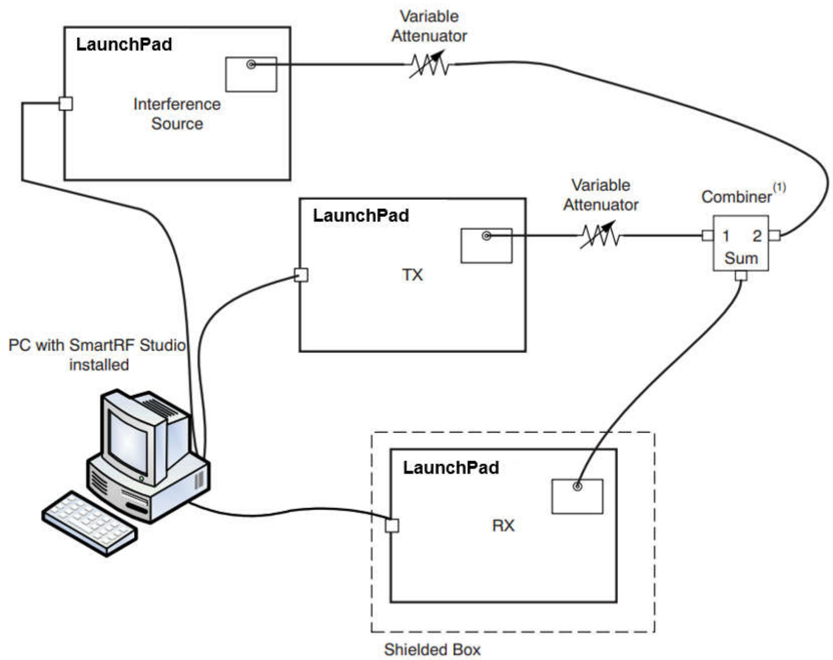
Test Results:

8.2 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 8-5 illustrates the interference test setup.



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

Figure 8-5. Interference Testing Setup Diagram

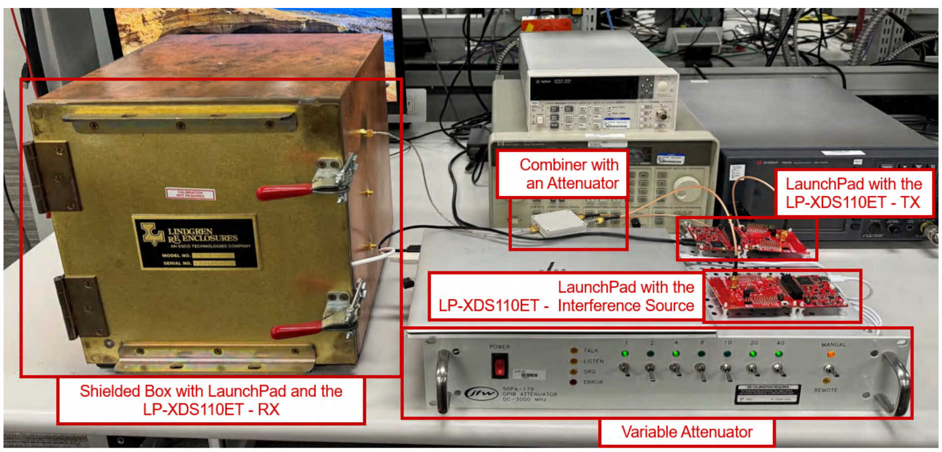


Figure 8-6. Interference Testing Bench Setup - Overview

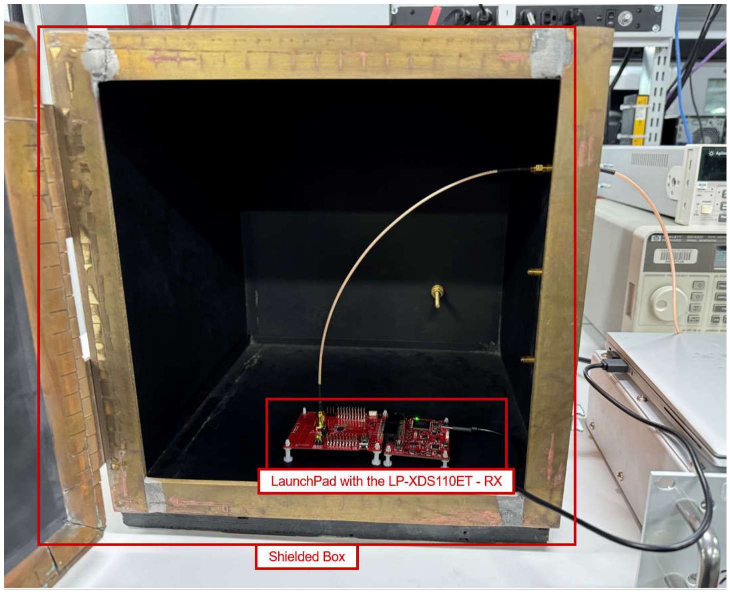


Figure 8-7. Interference Testing Bench Setup - Shielded Box

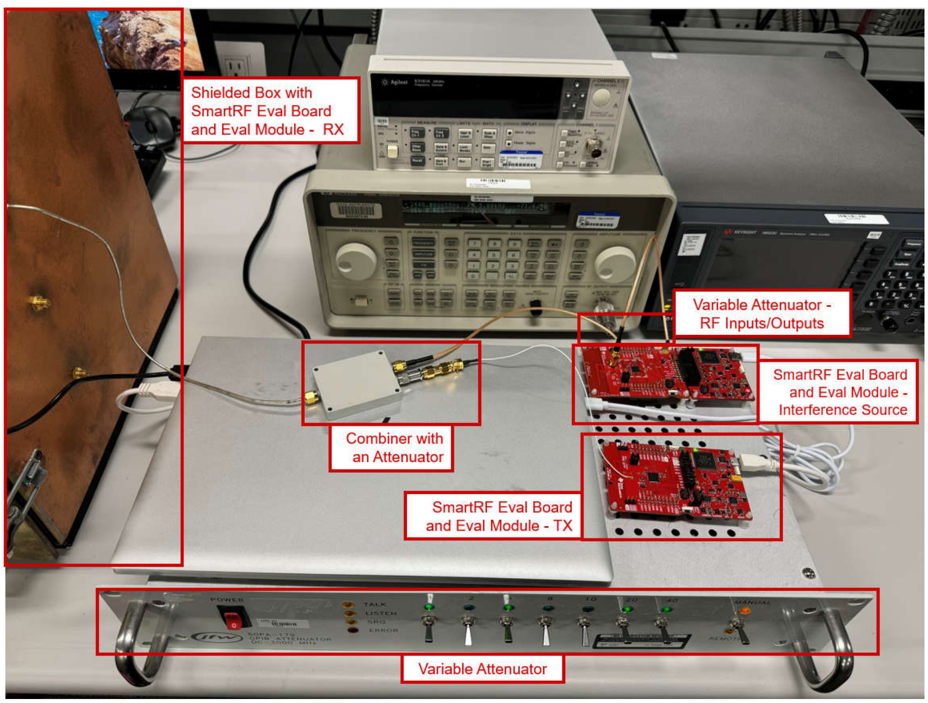


Figure 8-8. Interference Testing Bench Setup - TX and interferer connections

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Note

If there is no variable attenuator available, a series of fixed attenuators can be used instead. Also, a combination of variable and fixed attenuators can be used to increase the attenuation factor, as depicted in Figure 8-8. Figure 8-8.

Procedure:

- Step 1: Connect the instruments as shown on Figure 8-5, Figure 8-6, Figure 8-7, and Figure 8-8.
- Step 2: Use the same configuration from the sensitivity test 8.1, for the TX and RX boards.
- Step 3: Setup the INT (interference) board as a transmitter; however, the frequency can be different than that of either the TX and RX signals. If testing for co-channel interference, the frequency should be the

same, otherwise, frequency should vary. 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 10dB above the sensitivity threshold obtained from sensitivity testing. This is also dependent on the standard. (Remove 10dB of attenuation from the attenuators after completing the sensitivity test.)
- Step 5: Initially, set the output power of the INT board to the lowesr output power setting possible and start transmitting.
- Step 6: Perform the sensitivity test between the RX and TX board and notate the PER. Continue to increase the output power of the INT until the PER, displayed on the RX side, 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 8-3. Adjacent Channel Test Results

	Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?
1					
2					
3					

Table 8-4. Alternate Channel Test Results

	Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?
1					
2					
3					

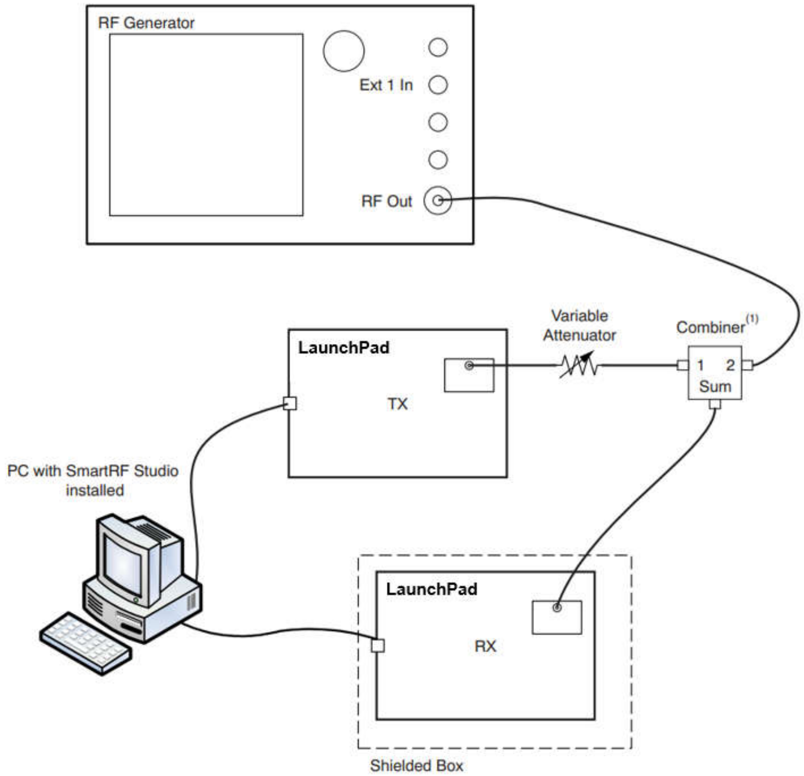
Test Results:

8.3 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 8-9 illustrates the interference test setup with a RF generator.



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

Figure 8-9. Interference Testing with a RF Generator Setup Diagram

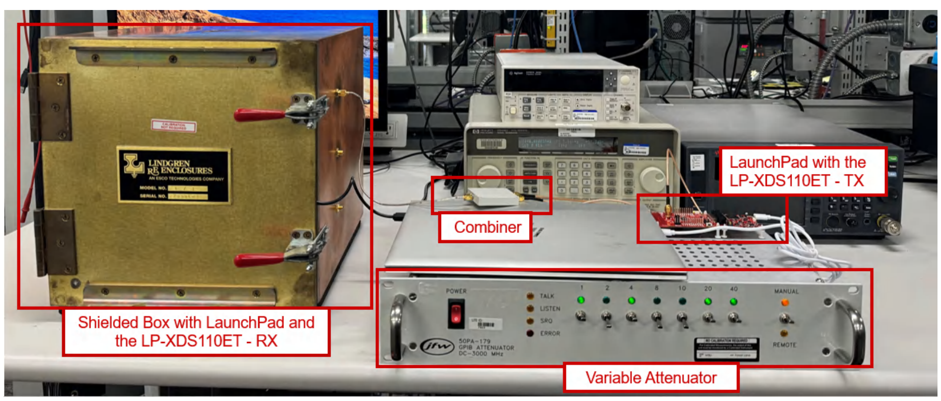


Figure 8-10. Interference Testing with a RF Generator Bench Setup - Overview

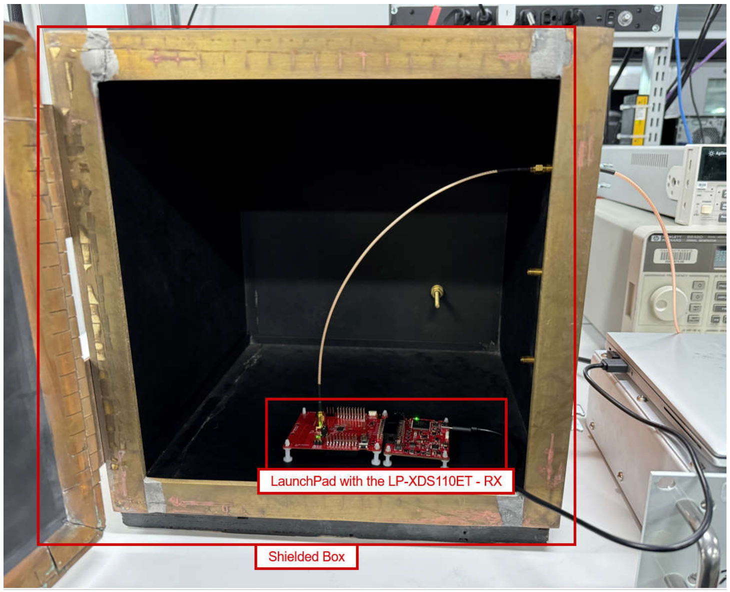


Figure 8-11. Interference Testing with a RF Generator Bench Setup - Shielded Box

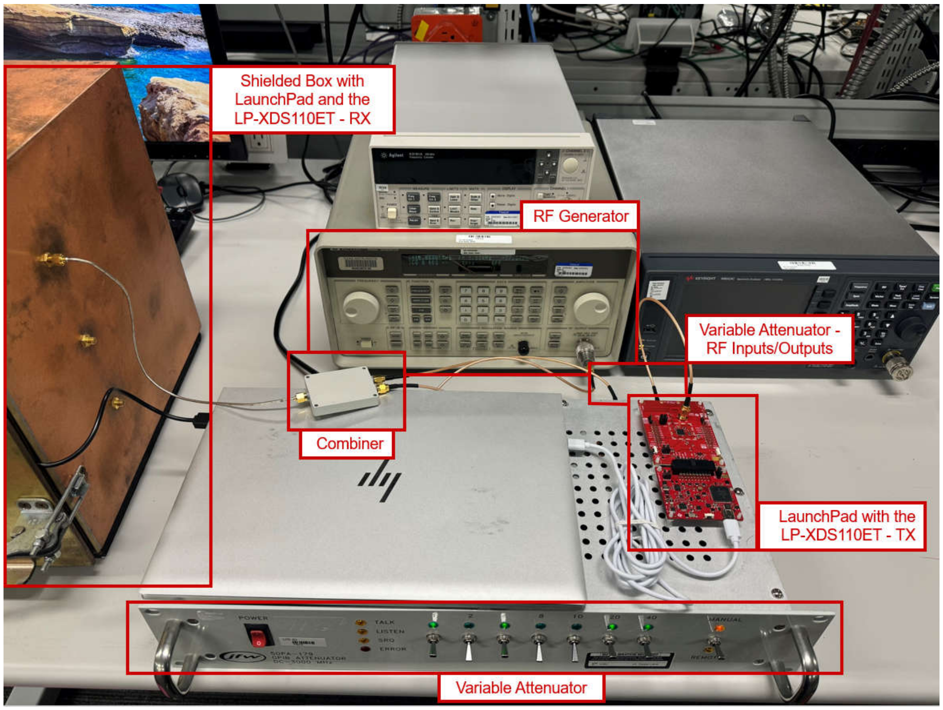


Figure 8-12. Interference Testing with a RF Generator Bench Setup - TX connections.

Procedure:

- Step 1: Connect the instruments as shown on Figure 8-9, Figure 8-10, Figure 8-11, and Figure 8-12.
- Step 2: The TX and RX boards must be set up 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 10dB above the sensitivity threshold obtained from sensitivity testing. (Remove 10dB of attenuation from the attenuators after completing the sensitivity test.)
- Step 5: Initially, set the output power of the INT board to the lowesr output power setting possible and start transmitting.

- Step 6: Perform the sensitivity test between the RX and TX board and notate the PER. Continue to increase the output power of the INT until the PER, displayed on the RX side, 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 8-5. Adjacent Channel Test Results

	Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?
1					
2					
3					

Table 8-6. Alternate Channel Test Results

	Channel	Frequency (MHz)	Difference (dB)	Design Specification (dB)	Pass/Fail?
1					
2					
3					

Test Results:

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.

9 References

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

1. Rohde and Schwarz. (2005). News from Rohde & Schwarz, 185:1. Product information bulletin.
2. European Telecommunications Standards Institute. European government regulatory commission.
3. Federal Communications Commission. U.S. government regalatory commission.
4. Association of Radio Industries and Businesses. Trade association website.
5. SmartRF Studio. Product folder at www.ti.com

10 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (September 2011) to Revision A (December 2025)	Page
• Updated links, added clock tuning section, removed references to LabView, added more detailed instructions and pictures, and added radiated measurement references.	1