

Using CC2592 Front End With CC2530

Farrukh Inam and Srividya Sundar

Embedded Processing Applications

ABSTRACT

This application report describes the pairing of the cost-effective SimpleLink™ ZigBee CC2530 wireless MCU with the SimpleLink CC2592 range extender to improve the receiver sensitivity and increase the total link budget, enabling up to four times the range of each node in the ZigBee network. The combination of these devices creates a system solution that is ideal for applications such as home and industrial automation, lighting, metering, and sensor networks. This document also describes the expected performance of the module and factors to consider with respect to the layout and regulatory requirements. The RF front end of the CC2530 has the same settings as the SimpleLink CC2531 wireless MCU with USB; therefore, the presented results are also valid for the CC2531.

Project collateral and source code discussed in this document can be downloaded from the following URL:
<http://www.ti.com/lit/zip/swra465>.

Contents

1	Introduction	1
2	Acronyms Used in This Documents	2
3	Absolute Maximum Ratings	2
4	Electrical Specifications	2
5	Application Circuit.....	9
6	PCB Layout Considerations.....	11
7	Regulatory Requirements	11
8	Controlling the CC2592.....	15
9	Integrating CC2592 With Z-Stack and TIMAC (spell out this acronym - TIMAC).....	16
10	References	16
Appendix A Marker - Delta Method.....		17

1 Introduction

The CC2530 is a system-on-chip (SoC) solution for IEEE 802.15.4, Zigbee, and RF4CE applications. The CC2530 combines the excellent performance of a leading RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable Flash memory, 8-KB RAM, and many other powerful features.

This chip enables industrial grade applications by offering state-of-the-art selectivity and co-existence, excellent link budget, and low-voltage operation.

The CC2592 is a range extender for 2.4 GHz RF transceivers, transmitters, and SoC products from Texas Instruments. The CC2592 increases the RF link budget by providing a Power Amplifier (PA) for higher output power and a Low Noise Amplifier (LNA) for improved receiver sensitivity. The CC2592 contains RF switches, RF matching, and an on-chip balun for a seamless interface with the CC2530. This allows for a simple design of high performance wireless applications.

Texas Instruments ZigBee SW solution, Z-Stack (www.ti.com/z-stack), includes the necessary software changes for using the CC2592.

2 Acronyms Used in This Documents

DSSS	Direct Sequence Spread Spectrum
EIRP	Equivalent Isotropically Radiated Power
EM	Evaluation Module
EVM	Error Vector Magnitude
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
GPIO	General-Purpose Input/Output
HGM	High Gain Mode
ISM	Industrial, Scientific, Medical
LGM	Low Gain Mode
LNA	Low Noise Amplifier
PA	Power Amplifier
PCB	Printed Circuit Board
PSD	Power Spectral Density
PM	Power Mode
RF	Radio Frequency
RSSI	Receive Signal Strength Indicator
RX	Receive, Receive Mode
SoC	System-on-Chip
TX	Transmit, Transmit Mode
VSWR	Voltage Standing Wave Ratio

3 Absolute Maximum Ratings

The absolute maximum ratings and operating conditions listed in the CC2530 data manual [1] and the CC2592 data manual [2] must be followed at all times. Stress exceeding one or more of these limiting values may cause permanent damage to any of the devices.

4 Electrical Specifications

These characteristics are only valid when using the recommended register settings presented in [Section 4.6](#) and the *SimpleLink™ ZigBee® Network Range Extender Reference Design* [3]. For further recommendations and regulatory requirements, see [Section 7](#).

4.1 Operating Conditions

Table 1. Recommended Operating Conditions

Parameter	Min	Max	Unit
Operating Frequency	2405	2483.5	MHz
Operating Supply Voltage	2.0	3.6	V
Operating Temperature	–40	125	°C

4.2 Current Consumption

$T_C = 25^\circ\text{C}$, $V_{DD} = 3.0\text{ V}$, $f = 2440\text{ MHz}$ if nothing else is stated. All parameters are measured on the SimpleLink™ ZigBee® Network Range Extender Reference Design [3] with a $50\ \Omega$ load.

Table 2. Current Consumption

Parameter	Condition	Typical	Unit
Receive Current	Wait for sync, -90 dBm input level Wait for sync, -50 dBm input level	28.8 25	mA
Transmit Current	TXPOWER = 0xF5 TXPOWER = 0xE5 TXPOWER = 0xD5 TXPOWER = 0xC5 TXPOWER = 0xB5 TXPOWER = 0xA5 TXPOWER = 0x95 TXPOWER = 0x85 TXPOWER = 0x75 TXPOWER = 0x65 TXPOWER = 0x55 TXPOWER = 0x45 TXPOWER = 0x35	172.3 155.7 143.1 133.8 124.8 115.2 102.7 95.0 847.5 82.3 77.9 75.1 73.6	mA

4.3 Receive Parameters

$T_C = 25^\circ\text{C}$, $V_{DD} = 3.0\text{ V}$, $f = 2440\text{ MHz}$ if nothing else is stated. All parameters are measured on the SimpleLink™ ZigBee® Network Range Extender Reference Design [3] with a $50\ \Omega$ load.

Table 3. Receive Parameters

Parameter	Condition	Typical	Unit
Receive Sensitivity HGM	1 % PER, IEEE 802.15.4 [7] requires -85 dBm	-100.3	dBm
Receive Sensitivity LGM	1 % PER, IEEE 802.15.4 [7] requires -85 dBm	-99.2	
Saturation HGM	IEEE 802.15.4 [7] requires -20 dBm	-2	
Saturation LGM	IEEE 802.15.4 [7] requires -20 dBm	-1	
Interferer Rejection	Wanted signal 3 dB above the sensitivity level, IEEE 802.15.4 modulated interferer at IEEE 802.15.4 channels		dB
	$\pm 5\text{ MHz}$ from wanted signal, IEEE 802.15.4 [7] requires 0 dB	35.5	
	$\pm 10\text{ MHz}$ from wanted signal, IEEE 802.15.4 [7] requires 30 dB	45.5	
	$\pm 20\text{ MHz}$ from wanted signal. Wanted signal at -82dBm	48.8	

4.4 Received Signal Strength Indicator (RSSI)

Due to the external LNA and the offset in the CC2530, the RSSI readouts from the CC2530 - CC2592 are different from RSSI offset values for a standalone CC2530 design. The offset values are shown in Table 4.

Table 4. RSSI Compensation

Gain Modes	RSSI Offset ⁽¹⁾
High Gain Mode	83
Low Gain Mode	78

⁽¹⁾ Real RSSI = Register value – RSSI offset

4.5 Transmit Parameters

$T_C = 25^\circ\text{C}$, $V_{DD} = 3.0\text{ V}$, $f = 2440\text{ MHz}$ if nothing else is stated. All parameters are measured on the *SimpleLink™ ZigBee® Network Range Extender Reference Design* [3] with a $50\ \Omega$ load.

Table 5. Transmit Parameters

Parameter	Condition	Typical	Unit
Emission with TXPOWER = 0xE5	Conducted 2•RF (FCC restricted band)	-46.4	dBm
	Conducted 3•RF (FCC restricted band)	-48.3	
	Radiated 2•RF (FCC restricted band)	-41.66	
	Radiated 3•RF (FCC restricted band)	-42.84	
Max Error Vector Magnitude (EVM)	IEEE 802.15.4 requires max. 35% Measured as defined by IEEE 802.15.4		%
	TXPOWER = 0xF5	31.6	
	TXPOWER = 0xE5	16.8	

4.6 Output Power Programming

The RF output power of the CC2530 - CC2592EM is controlled by the 8-bit value in the CC2530 TXPOWER register. [Table 6](#) shows the typical output power and current consumption for the recommended power settings. The results are given for $T_C = 25^\circ\text{C}$, $V_{DD} = 3.0\text{ V}$ and $f = 2440\text{ MHz}$, and are measured on the *SimpleLink™ ZigBee® Network Range Extender Reference Design* [3] with a $50\ \Omega$ load. For recommendations on the remaining CC2530 registers, see [Section 8](#).

Table 6. Power Table

TXPOWER	Power [dBm]	Current [mA]
0xF5	21.1	172.3
0xE5	20.4	155.7
0xD5	19.7	143.1
0xC5	18.9	133.8
0xB5	18.2	124.8
0xA5	17.2	115.2
0x95	15.7	102.7
0x85	14.8	95
0x75	13.4	87.5
0x65	11.8	82.3
0x55	9.9	77.9
0x45	7.7	75.1
0x35	5.4	73.6

Note that the recommended power settings given in [Table 6](#) are a subset of all the possible TXPOWER register settings. Using settings other than those recommended might result in sub-optimal performance in areas like current consumption, EVM, and spurious emission.

4.7 Typical Performance Curves

$T_C = 25^\circ\text{C}$, $V_{DD} = 3.0\text{ V}$, $f = 2440\text{ MHz}$, if nothing else is stated. All parameters are measured on the SimpleLink™ ZigBee® Network Range Extender Reference Design [3] with a $50\ \Omega$ load.

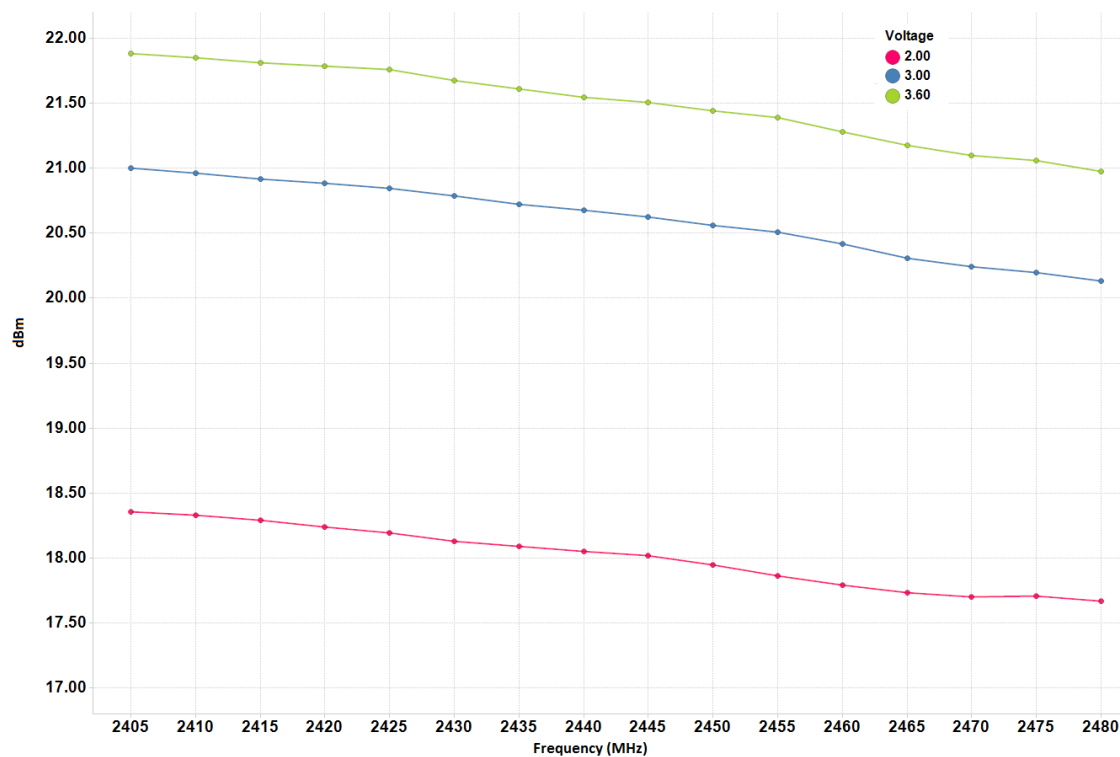


Figure 1. Output Power vs. Frequency and Power Supply Voltage, TXPOWER = 0xE5

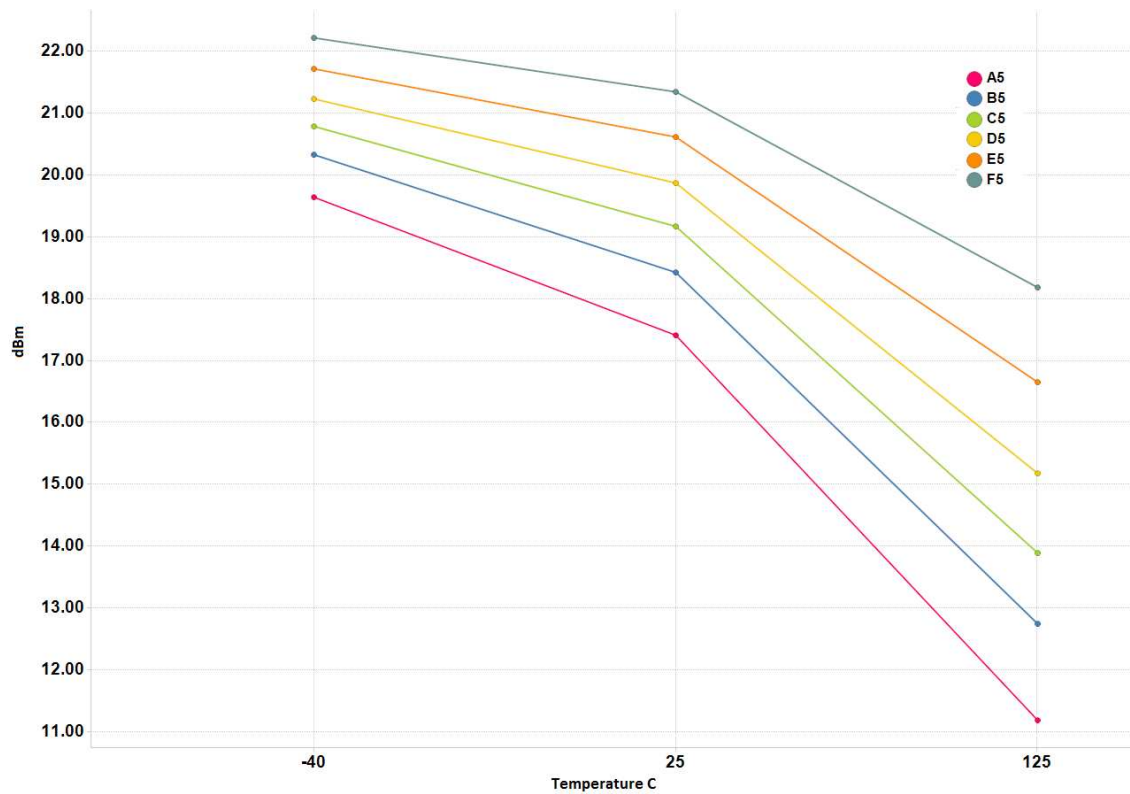


Figure 2. Output Power vs. Temperature



Figure 3. Sensitivity vs. Frequency and Power Supply Voltage

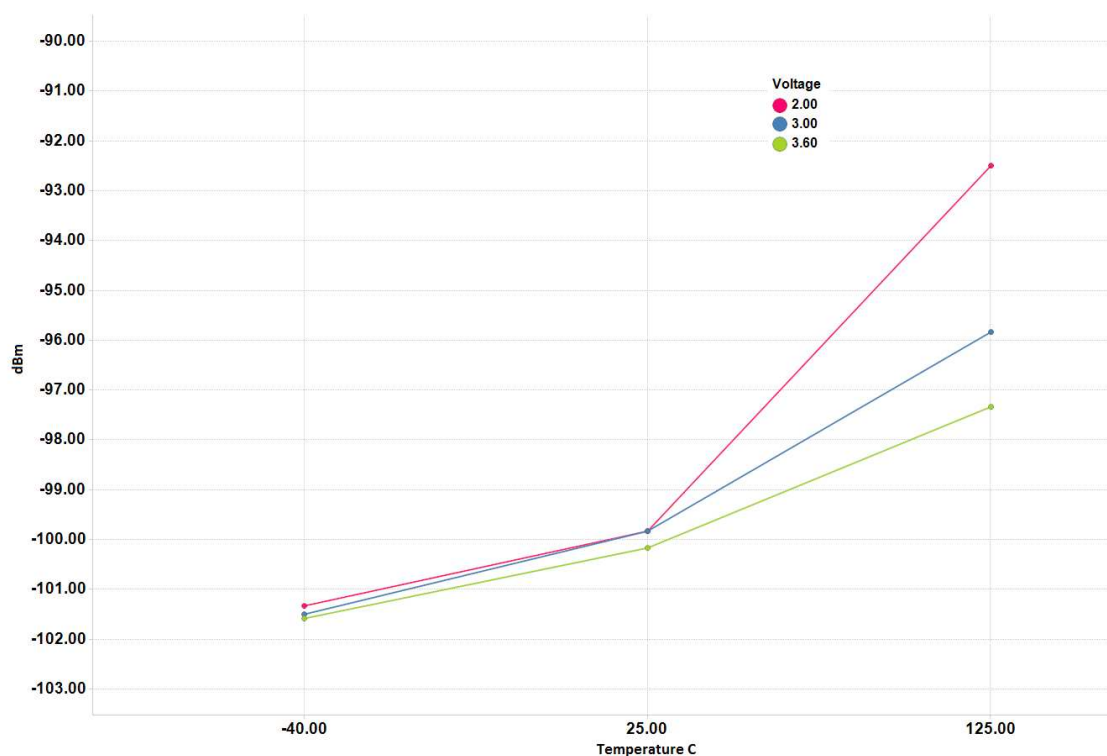


Figure 4. Sensitivity vs. Temperature and Power Supply Voltage

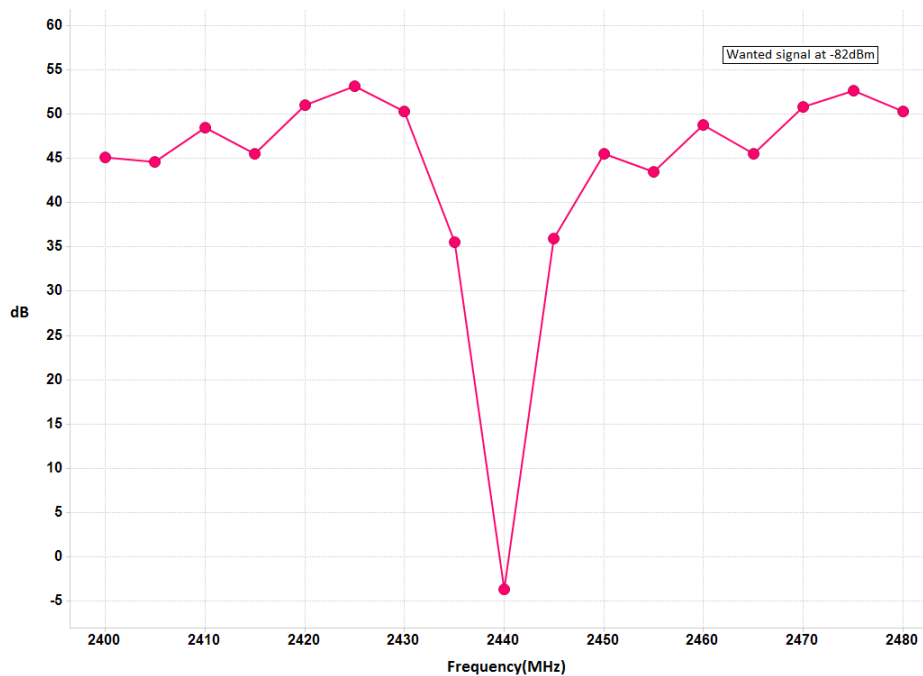


Figure 5. Selectivity Operating at Channel 18 (2440 MHz)

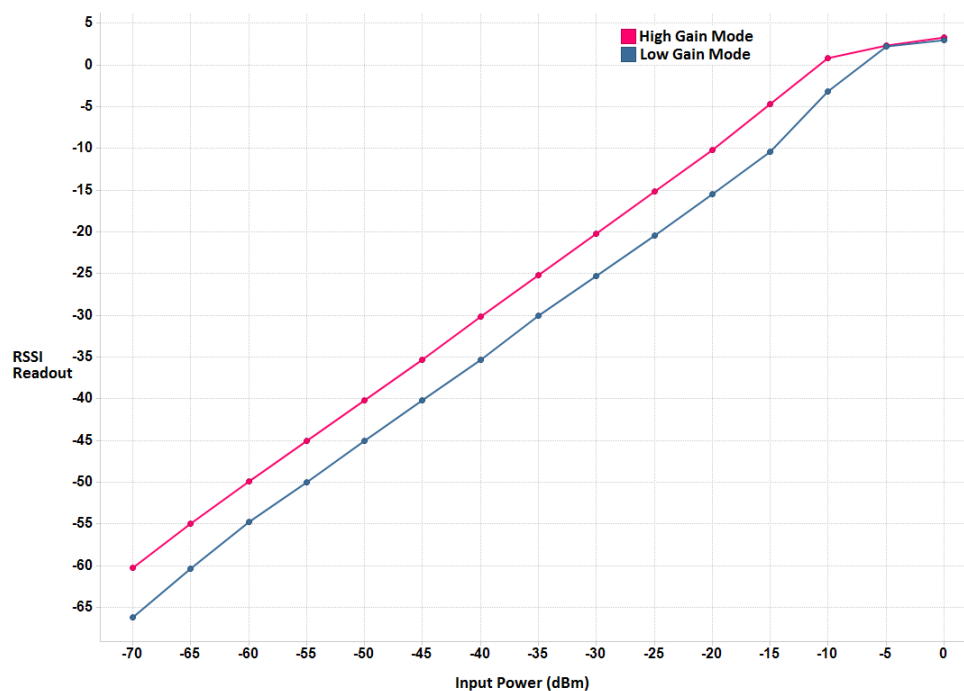


Figure 6. RSSI Readout vs. Input Power

4.8 IEEE - Transmit Power Spectral Density (PSD) Mask

The IEEE standard 802.15.4 requires the transmitted spectral power to be less than the limits specified in Table 7.

Table 7. Transmit PSD Limits

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

Figure 7 shows the transmitted PSD at $T_C = 25^\circ\text{C}$, $V_{DD} = 3.0 \text{ V}$ and $f = 2440 \text{ MHz}$, measured on the SimpleLink™ ZigBee® Network Range Extender Reference Design [3] with a 50Ω load.

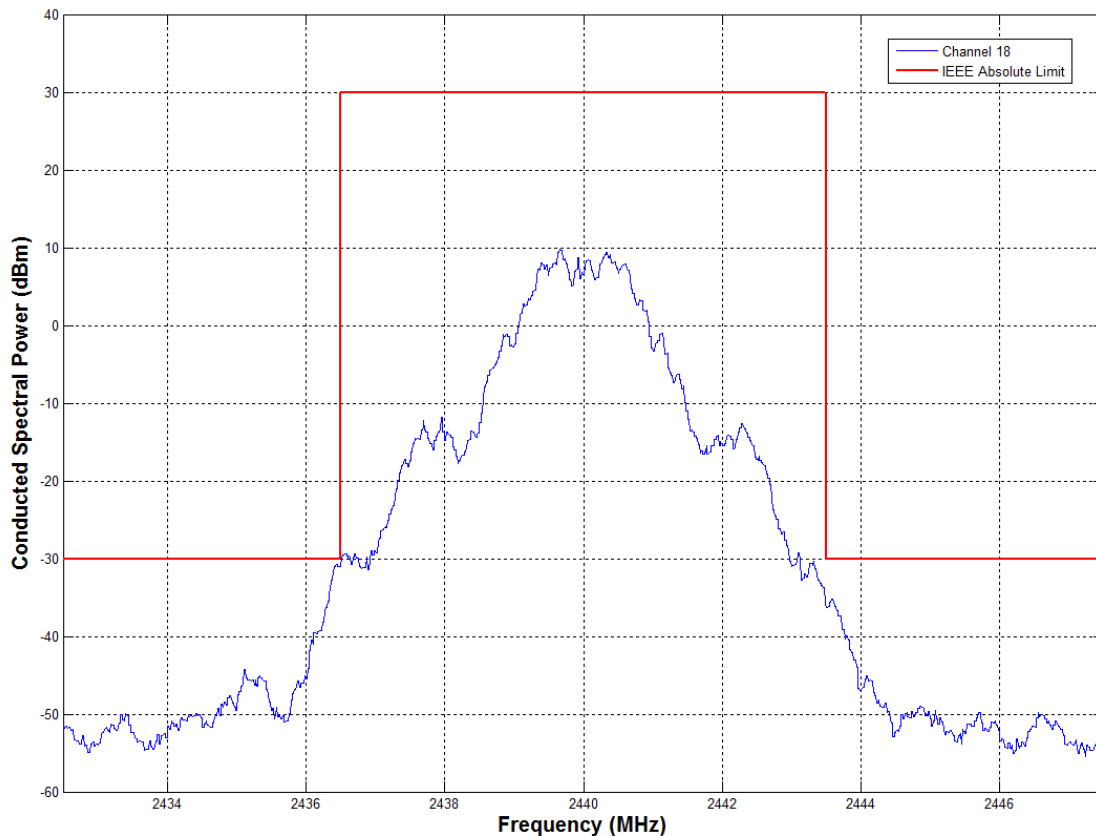


Figure 7. Conducted Power Spectral Density, TXPOWER = 0xE5

5 Application Circuit

Only a few external components are required for the SimpleLink™ ZigBee® Network Range Extender Reference Design [3]. A typical application circuit is shown in Figure 8. Note that the application circuit figure does not show the complete schematic or layout of the CC2530 - CC2592EM. The board layout will greatly influence the RF performance of the CC2530 - CC2592EM.

When using the CC2530 - CC2592EM at high power levels, an RF shield is required to be compliant with FCC harmonic emission regulations. TI provides a compact CC2530 - CC2592EM reference design incorporating shielding footprints that is highly recommended. The layout, stack-up, and schematic for the CC2592 should be copied as closely as possible to obtain optimum performance. The reference design also includes a bill of materials with manufacturer part numbers.

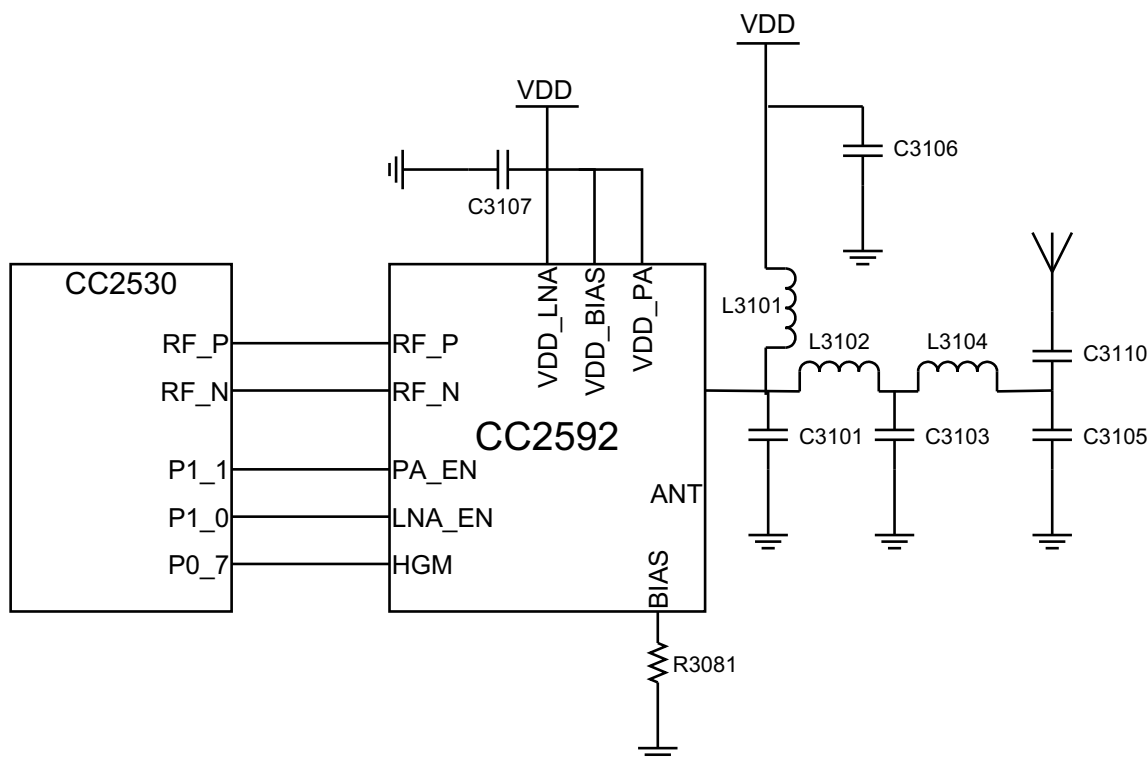


Figure 8. Application Circuit for the CC2530 With CC2592

5.1 Power Decoupling

Proper power supply decoupling must be used for optimum performance. [Figure 8](#) is a simplified schematic showing only the output matching and a reduced number of VDD decoupling components for the CC2592.

The placement and size of the decoupling components, the power supply filtering, and the PCB lines are important to achieve the best performance. Details about the importance of copying *SimpleLink™ ZigBee® Network Range Extender Reference Design* [3] exactly, and potential consequences of changes, are explained in [Section 6](#).

5.2 Input /Output Matching and Filtering

The CC2592 includes a balun and a matching network in addition to the PA, LNA and RF switches which makes the interface to the CC2530 seamless.

Note that the PCB lines that connect the two devices also are part of the RF matching. Copy the distance between the devices, the transmission lines, and the stack-up of the PCB according to the reference design to ensure optimum performance. The network between the CC2592 and the antenna (C3101, L3101, C3106, L3102, C3103, L3104, C3105 and C3110) matches the CC2592 to a 50 Ω load and provides filtering to pass regulatory demands. C3110 also works as a DC-block. Note: component names in [Figure 8](#) may be different from the design files in the [CC2530-CC2592 Reference Design](#).

5.3 Bias Resistor

R3081 is a bias resistor used to set an accurate bias current for internal use in the CC2592.

5.4 Antenna Considerations

The TI reference design contains two RF output options. A capacitor in the RF path can be rotated to route RF on either the SMA or the PCB antenna, which is a planar inverted F antenna (PIFA). All testing and characterisation has been completed using the SMA connector. Radiated measurements must be made with the PCB antenna to obtain FCC certification. For further details on the antenna solutions, see the Antenna Selection Guide ([SWRA161](#)) and the 2.4 GHz Inverted F Antenna ([SWRU120](#)).

6 PCB Layout Considerations

The *SimpleLink™ ZigBee® Network Range Extender Reference Design* [3] uses a 4-layer PCB solution with each layer having a different thickness.

The top layer is used for components and signal routing, and the open areas are filled with metallization connected to ground using several vias. The areas under the two chips are used for grounding and must be well connected to the ground plane with multiple vias. Footprint recommendation for the CC2592 is provided in the *CC2592: CC2592 2.4-GHz Range Extender Data Manual* ([SWRS159](#)) [2].

Layer two is a complete ground plane and is not used for routing. This ensures short return paths for RF currents. The low impedance of the ground plane prevents any unwanted signal coupling between any of the nodes that are decoupled to it. A dedicated ground plane is also needed to improve stability. Layer three is a power and signal routing plane. The power plane ensures low impedance traces at radio frequencies and prevents unwanted radiation from power traces. Layer four is used for routing, and like layer one, open areas are filled with metallization connected to ground using several vias.

NOTE: Changes in the PCB stack-up, component value, vendor sizes, or placements may affect the performance of the CC2530 and CC2592 solution. Any change may cause higher current consumption, unwanted spurious emissions, and generally degraded performance. Follow the reference design as closely as possible in order to obtain the best performance.

6.1 The Gain of the CC2592

Changing the layout or the stack-up of the reference design affects the RF performance of the CC2592. Due to all the contributors to the CC2592 performance, a few observations can be made on how changing layout and PCB stack-up affects the amplifier:

- Bad soldering of the ground paddle can reduce the gain significantly.
- Too few or too long vias reduce the gain significantly. Because of this, a checkered pattern of vias and solder paste, and a 4-layer PCB with the ground plane close to the top layer was chosen for the *SimpleLink™ ZigBee® Network Range Extender Reference Design* [3].

7 Regulatory Requirements

In the United States, the Federal Communications Commission (FCC) is responsible for the regulation of all RF devices. CFR 47, Part 15, regulates RF products intended for unlicensed operation. A product intended for unlicensed operation has to be subject to compliance testing. If the product is approved, the FCC will issue an identification number.

The specific frequency bands used for unlicensed radio equipment for the 2.4 GHz band are regulated by section 15.247 and 15.249. General rules for certification measurements are found in section 15.35. Restricted bands and general limits for spurious emissions are found in sections 15.205 and 15.209.

The FCC Part 15.247 compliance is generally a tougher requirement than ETSI compliance (EN 300 328) due to the restricted bands of operation. There are requirements with regards to ETSI compliance (EN 300 328) that prevent operation at maximum output power. The clause 4.3.2.2 Maximum Power Spectral Density requirement of EN 300 328 requires maximum +10 dBm/ 1 MHz. The output power must, therefore, be reduced to approximately +12 dBm in order to get CE approval. The final output power level depends on the antenna used.

FCC Part 15.247 limits the output power to 1W or +30 dBm when Direct Sequence Spread Spectrum (DSSS) modulation or Frequency Hopping Spread Spectrum (FHSS) with at least 75 hop channels is used. The spectral density of digital modulation systems (not including FHSS) should not exceed 8 dBm/ 3 kHz. The minimum 6 dB bandwidth of such systems is 500 kHz. Since the CC2530 is an IEEE 802.15.4 compliant transceiver, it uses DSSS modulation. The +30 dBm limit therefore applies for the CC2530 with the CC2592 combination.

When complying with Part 15.247, in any 100 kHz bandwidth outside the operating band, the power level should be at least 20 dB below the level in the 100 kHz bandwidth with the highest power level in the operating band. Attenuation below limits given in 15.209 is not required. Emission that fall within restricted bands (15.205) must meet general limits given in 15.209. This is summarized in [Table 8](#). More details about the 2.4 GHz FCC regulations can be found in *SRD Regulations for License-Free Transceiver Operation in the 2.4 GHz Band* ([SWRA060](#)) [8].

Table 8. Summarized FCC 15.247 Regulations for the 2.4 GHz Band

Standard	Relevant Frequency	Radiated Power (EIRP)	Conducted Power	Comment
FCC 15.247	2400 – 2483.5 MHz		+ 30 dBm	Maximum 6 dBi antenna gain
	Restricted bands defined by 15.205, including the 2 nd , 3 rd and 5 th harmonics	–41.2 dBm		
	All frequencies not covered in above cells		–20 dBc	

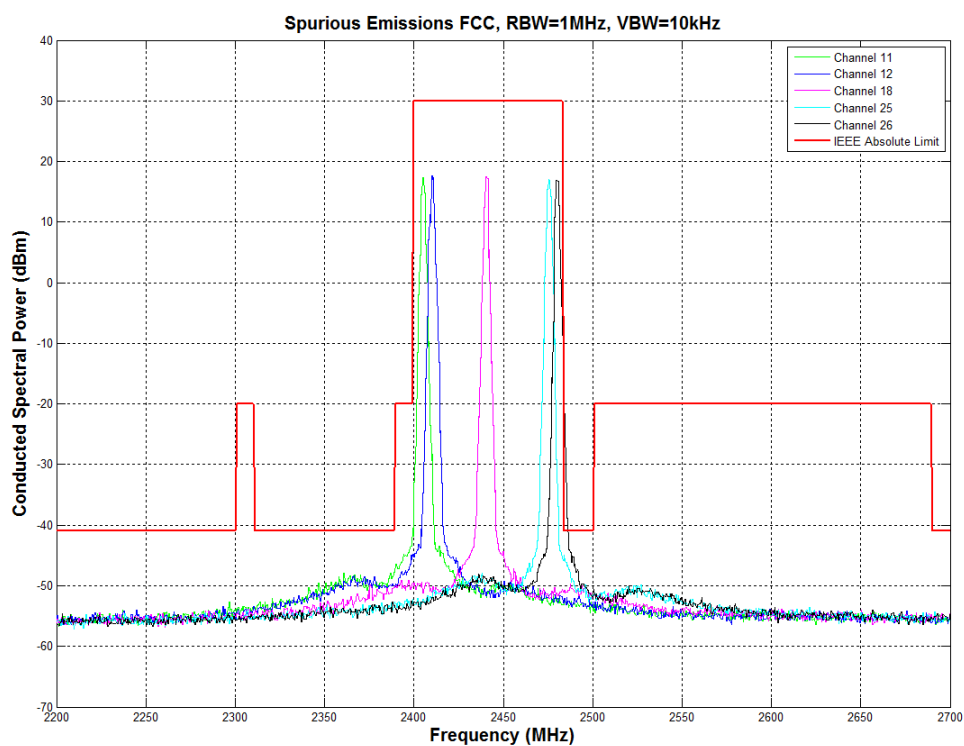
7.1 Compliance of FCC Part 15.247 When Using the CC2530 With the CC2592

When using CC2592 with the CC2530 a back-off is required for the highest IEEE 802.15.4 channel (channel 26) to comply with FCC. [Table 9](#) shows the back-off needed to comply with the FCC Part 15.247 limits at typical conditions. Note that the numbers in [Table 9](#) are based on conducted emission measurements from the CC2530 - CC2592EM reference design. The real required back-off may be different for applications with different antennas, plastic covers, or other factors that amplify or attenuate the radiated power.

[Figure 9](#) depicts the level of the conducted spurious emission and margins to the FCC Part 15.247 limits for the IEEE 802.15.4 channels under typical conditions ($T_C = 25^\circ\text{C}$, $V_{DD} = 3.0\text{ V}$) when transmitting at maximum recommended power (TXPOWER = 0xE5) using the CC2530 - CC2592EM. [Figure 10](#) and [Figure 11](#) show the margins versus the FCC 15.247 for the lowest frequency channels at the lower band edge and for the upper frequency channels at the upper band edge respectively. At the band edge the FCC allows for a Marker-delta method of measurement to determine the amount of back off or duty cycle required to comply with the FCC Part 15.247. This is necessary because when making radiated band-edge measurements, there can be an issue obtaining meaningful data since a measurement instrument that is tuned to a band-edge frequency may also capture some of the in-band signal when using the resolution bandwidth (RBW) required by measurement procedure ANSI C63.4-1992. [Appendix A](#) provides a step-by-step example of using the marker-delta method to calculate the required back off required.

Table 9. Back-Off Requirement for FCC Part 15.247 Compliance Under Typical Conditions

Frequency [MHz]	Back-Off [dB]
2405	0
2410	0
2415	0
2420	0
2425	0
2430	0
2435	0
2440	0
2445	0
2450	0
2455	0
2460	0
2465	0
2470	0
2475	0
2480	12


Figure 9. Conducted Spurious Emission vs. FCC Part 15.247 Limit (TXPOWER = 0xE5, RBW = 1 MHz, VBW = 10 kHz)

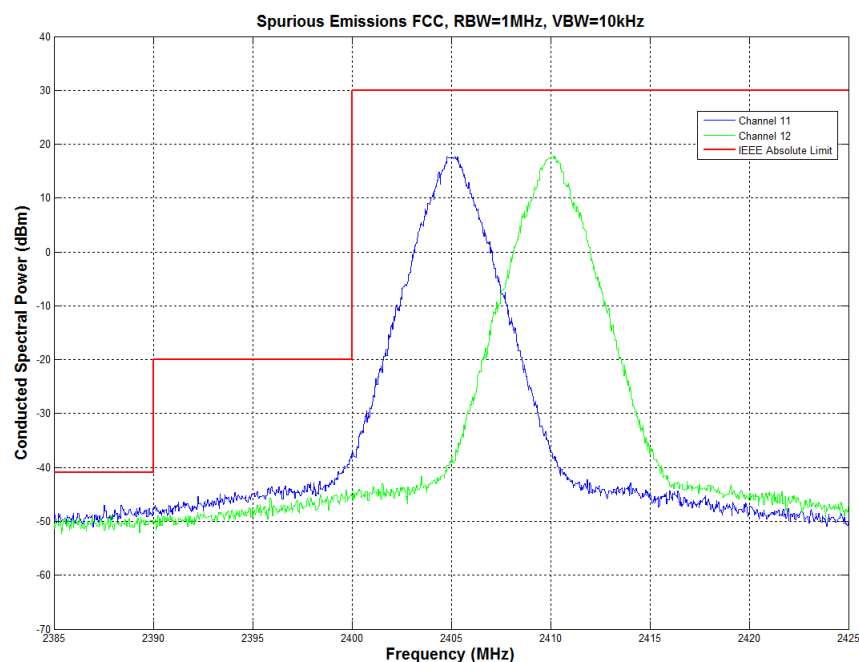


Figure 10. Conducted Spurious Emission, Lower Band Edge (TXPOWER = 0xE5, RBW = 1 MHz, VBW = 10 KHz)

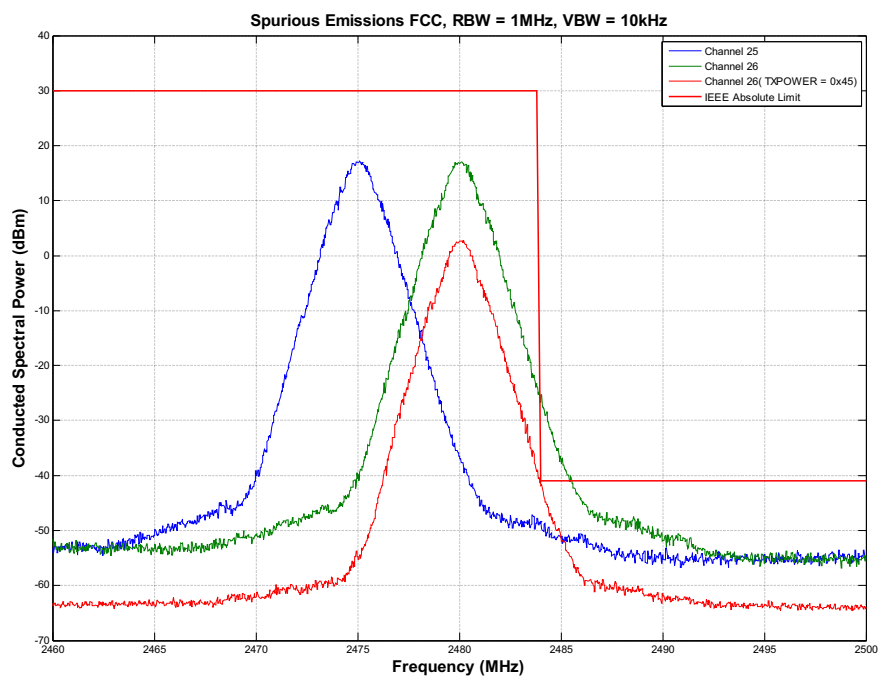


Figure 11. Conducted Spurious Emission, Upper Band Edge (TXPOWER = 0xE5, RBW = 1 MHz, VBW = 10 KHz)

8 Controlling the CC2592

There are three digital control pins (PA_EN, LNA_EN and HGM) on the CC2592 that control the state of the chip. [Table 10](#) shows the control logic when connecting the CC2592 to a CC2530 device.

Table 10. Control Logic for Connecting the CC2592 to a CC2530 Device

PA_EN	LNA_EN	HGM	Mode of Operation
0	0	X	Power Down
X	1	0	RX Low Gain Mode
X	1	1	RX High Gain Mode
1	0	X	TX

The *SimpleLink™ ZigBee® Network Range Extender Reference Design* [\[3\]](#) uses three of the CC2530 GPIO pins on the CC2530 to control the CC2592. The I/O pins used are shown in [Figure 12](#). PA_EN and LNA_EN must be controlled by RF observation signals as shown in [Figure 12](#), whereas, the HGM pin can be controlled by any GPIO or alternatively tied to VDD or GND.

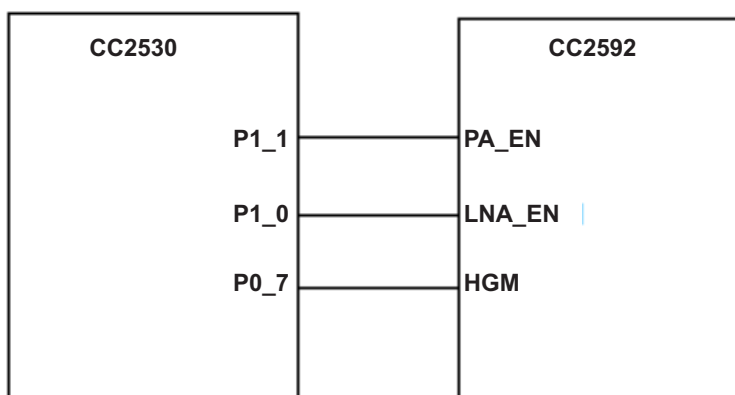


Figure 12. CC2530-CC2592 Interconnect

When using the CC2592 with the CC2530, the RF observation registers must be set according to [Table 11](#). This enables the RF core of CC2530 to control the CC2592 through P1. If required, other P1 pins can be used, see the *CC2538 System-on-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee®/ZigBee IP® Applications User's Guide* ([SWRU319](#)) for details.

Table 11. CC2530 Registers for CC2592 Control

CC2530 REGISTER	RECOMMENDED VALUE
AGCTRL1	0x15
FSCAL1	0x00
RFC_OBS_CTRL0	0x68
RFC_OBS_CTRL1	0x6A
TXPOWER	See Table 6
OBSSEL1	0xFB
OBSSEL0	0xFC
P0DIR	0x80

9 Integrating CC2592 With Z-Stack and TIMAC (spell out this acronym - TIMAC)

Developers are referred to the following wiki pages for information on how to integrate the SimpleLink CC2592 Front End with their [Z-Stack](#) or TIMAC-based product:

- For integrating CC2592 with Z-Stack, see the [Enabling the Support of CC259x PA/LNA with Z-Stack](#) wiki
- For integrating CC2592 with TIMAC, see the [Enabling the Support of CC259x PA/LNA with TIMAC](#) wiki

10 References

1. CC2530: A True System-on-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee Applications Data Manual ([SWRS081](#))
2. CC2592: CC2592 2.4-GHz Range Extender Data Manual ([SWRS159](#))
3. SimpleLink™ ZigBee® Network Range Extender Reference Design product page (www.ti.com/tool/cc2530-cc2592em-rd)
4. Antenna Selection Guide ([SWRA161](#))
5. 2.4 GHz Inverted F Antenna ([SWRU120B](#))
6. CC2538 System-on-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee®/ZigBee IP® Applications User's Guide ([SWRU319](#))
7. [IEEE std. 802.15.4 – 2006: Wireless Medium Access Control \(MAC\) and Physical Layer \(PHY\) specification for Low Rate Wireless Personal Area Networks \(LR-WPANs\)](#)
8. SRD Regulations for License-Free Transceiver Operation in the 2.4 GHz Band ([SWRA060](#))
9. DA 00-705: [Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems](#)

Marker - Delta Method

- Power Setting: 0xE5
- Set the DUT in Modulated TX
- Center Frequency: 2480 MHz
- Span: 10 MHz

RBW	VBW	Detector	Meas. Name	Power	Comments
1 MHz	1 MHz	Max Peak + Max Hold	PEAK	18.9	
1 MHz	10 Hz	Average + Max Hold	AVERAGE	16.6	The power will be lower for AVERAGE than for PEAK

- Choose a spectrum analyzer that encompasses both the peak of the fundamental emission and the band-edge emission under investigation (for example, 2483.5 MHz, edge in [Figure 13](#)).

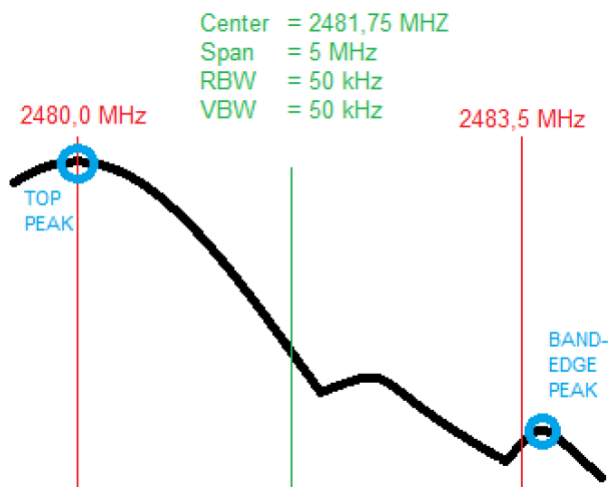


Figure 13. Band-Edge Setup

RBW	VBW	Detector	Meas. Name	Power	Comments
1% of total span	>= RBW (100 KHz)	Max Peak + Max Hold	TOP PEAK	13.0	RBW - never less than 30 kHz. Several sweeps in peak hold mode
1% of total span	>= RBW (100 KHz)	Max Peak + Max Hold	Band-Edge PEAK	-33.0	RBW - never less than 30 kHz. Several sweeps in peak hold mode
TOP PEAK - Band Edge PEAK ->			DELTA	46.0	Delta will normally be > 40dB

- Record the peak levels of the fundamental emission and the relevant band edge emission. The band edge peak is measured at the highest point to the right of the 2483.5 MHz line, which is typically on this line. However in some cases there may be a higher peak nearby. Observe the stored trace and measure the amplitude delta between the top peak of the fundamental and the peak of the band-edge emission.
- Note a lower RBW, even as low as 30 KHz, may be required to see the band-edge peak.
- When the DELTA value is calculated, use it to check how the PEAK and Average values are compared to their respective limits.

Math	Power (dBm)	Limits/Comments
PEAK - DELTA =	-27.1	-21.2 dBm (74 dBuV/m)
AVERAGE - DELTA =	-29.4	-41.2 dBm (54 dBuV/m)
BACK OFF =	$(-29.4) - (-41.2) = 11.8$	Required back off on channel 26

Revision History

Changes from Original (August 2014) to A Revision	Page
• Updates were made in Section 4.2 .	3
• Updates were made in Section 4.3 .	3
• Updates were made in Section 4.5 .	4
• Updates were made in Table 6 .	4
• Updates were made in Section 4.7 .	5
• Updates were made in Section 5 .	9
• Update was made in Section 7.1 .	12
• Updates were made in Section 8 .	15
• Added new section Section 9 .	16
• Updates were made in Appendix A .	17

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

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com