Application Report

SWRA437–September 2013

AN125 - CC2538 + CC1200 Evaluation Module

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ABSTRACT

This application report describes how to combine the CC2538 and the CC1200 devices in the same design. It further describes the expected performance from this combination as well as important factors to consider with respect to the layout. It describes how to interface the CC2538+CC1200 combo evaluation module (EM) with the SmartRF06 EB and the CC Debugger to individually test and analyze the performance of the CC2538 and CC1200 devices. The combined CC2538 and CC1200 solution is suitable for systems targeting IEEE 802.15.4 standard.

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1 Introduction

The CC2538+CC1200 EM is a combo board, which is targeted to use in Zigbee application in both 2.45 GHz and 900 MHz ISM frequency bands. The CC2538 is used as the Zigbee application processor and 2.45 GHz Radio and the CC1200 is used as the 900 MHz radio in this design. The CC2538/CC1200 EM is shown in Figure 1 and Figure 2.

The CC2538xFnn is the ideal system-on-chip (SoC) for high-performance Zigbee applications. It combines a powerful ARM® Cortex™-M3-based MCU system with up to 32K on-chip RAM and up to 512K on-chip Flash with robust IEEE 802.15.4 radio. This enables it to handle complex network stacks with security, demanding applications, and over-the-air download. Thirty-two GPIOs and serial peripherals enable simple connections to the rest of the board. The powerful security accelerators enable quick and efficient authentication and encryption while leaving the CPU free to handle application tasks. The low-power modes with retention enable quick startup from sleep and minimum energy spent to perform periodic tasks. For a smooth development, the CC2538xFnn includes a powerful debugging system and a comprehensive driver library. To reduce the application Flash footprint, CC2538xFnn ROM includes a utility function library and a serial bootloader. Combined with the free-to-use Z-Stack™ PRO software or ZigBee IP stacks from Texas Instruments, the CC2538 provides the most capable and robust ZigBee solution in the market. The CC2538 radio operates in the frequency band of 2394-2507 MHz for compliance with IEEE 802.15.4 standard. For more details about the specifications and operating conditions, see the CC2538 data sheet [1].

The CC1200 is a fully integrated single-chip radio transceiver designed for high performance at very low power and low voltage operation in cost effective wireless systems. The device is mainly intended for the Industrial, Scientific and Medical (ISM) and short range device (SRD) frequency bands at 164-192 MHz, 410-480 MHz and 820-950 MHz. The CC1200 is optimized towards wideband applications for compliance with IEEE 802.15.4g standard but can also cover narrowband down to 12.5 KHz channels as well. The CC1200 provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication and wake-on-radio. The CC1200 main operating parameters can be controlled via serial peripheral interface (SPI) interface. In a typical system, the CC1200 will be used together with a microcontroller. For more details about the specifications and operating conditions, see the CC1200 data sheet [2].

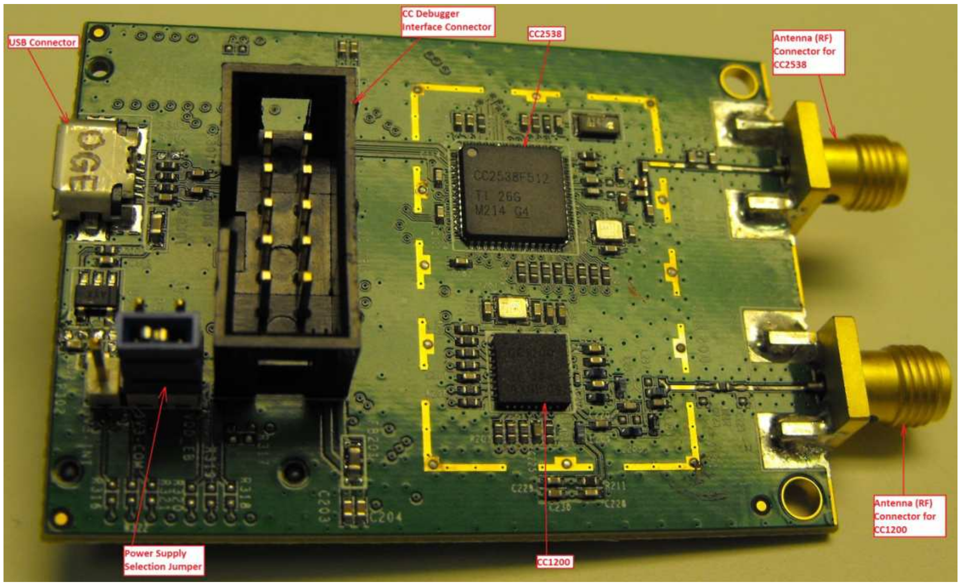

Figure 1. CC2538+CC1200 EM – Top Side

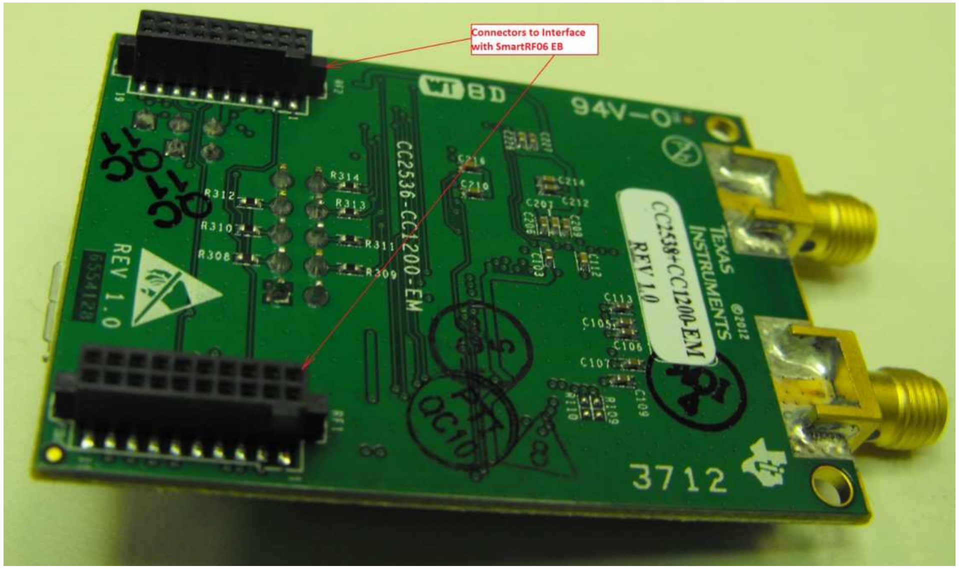

Figure 2. CC2538+CC1200 EM – Bottom Side

Table 1. Abbreviations

Acronym	Description
SoC	System-on-Chip
DSSS	Direct Sequence Spread Spectrum
EIRP	Equivalent Isotropically Radiated Power
EM	Evaluation Module
EVM	Error Vector Magnitude
ISM	Industrial, Scientific, Medical
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
LNA	Low Noise Amplifier
PA	Power Amplifier
PCB	Printed Circuit Board
PSD	Power Spectral Density
RF	Radio Frequency
RSSI	Receive Signal Strength Indicator
RX	Receive, Receive Mode
TX	Transmit, Transmit Mode
SRD	Short Range Device

2 Absolute Maximum Ratings

The absolute maximum ratings and operating conditions listed in the CC2538 data sheet [1] and the CC1200 data sheet [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.

3 CC2538 - Electrical Specifications

These characteristics are only valid when using the CC2538+CC1200 Evaluation Module reference design [3] and the register settings recommended by SmartRF™ Studio software.

3.1 CC2538 - Operating Conditions

Table 2. CC2538 - Operating Conditions

Device	Parameter	Min	Max	Unit
CC2538	Operating Frequency	2394	2507	MHz
	Operating Supply Voltage	2.0	3.6	V
	Operating Temperature	-40	125	°C

3.2 CC2538 - Current Consumption

T_C = 25°C, V_{DD} = 3.3 V, f = 2450 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] with a 50 Ω load.

Table 3. CC2538 - Current Consumption

Parameter	Condition	Typical	Unit
Receive Current	-50 dBm input power, no peripheral active, CPU idle	20	mA
	-100 dBm input power, no peripheral active, CPU idle	24	
Transmit Current	0 dBm output power, no peripheral active, CPU idle	24	mA
	7 dBm output power, no peripheral active, CPU idle	34	
Power Down Current	Power Mode 3 (for details, see the device-specific data sheet)	0.4	µA

3.3 CC2538 - Receive Parameters

T_C = 25°C, V_{DD} = 3.3 V, f = 2450 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] with a 50 Ω load.

Table 4. CC2538 - Receive Parameters

Parameter	Condition	Typical	Unit
Rx Sensitivity	PER = 1%, IEEE 802.15.4 [6] requires -85 dBm	-97	dBm
Saturation	IEEE 802.15.4 [6] requires -20dBm	10	dBm
Adjacent channel Rejection	5 MHz channel spacing		
	Wanted signal level = -82 dBm, adjacent channel = modulated at 5 MHz away from the wanted signal, PER = 1%		
	IEEE 802.15.4 [6] requires 0 dB		
	Lower adjacent channel rejection	44	dBc
	Upper adjacent channel rejection	44	
Alternate channel Rejection	10 MHz channel spacing		
	Wanted signal level = -82 dBm, alternate channel = Modulated at 10 MHz away from the wanted signal, PER = 1%		
	IEEE 802.15.4 [6] requires 30 dB		
	Lower alternate channel rejection	52	dBc
	Upper alternate channel rejection	52	
Blocking	Wanted signal 3 dB above the sensitivity level, CW interferer PER = 1%		
	±5 MHz from wanted signal, IEEE 802.15.4 [6] requires 0 dB	-37	dBm
	±10 MHz from wanted signal, IEEE 802.15.4 [6] requires 30 dB	-38	
	±20 MHz from wanted signal. Wanted signal at -82 dBm	-37	
	±50 MHz from wanted signal. Wanted signal at -82 dBm	-34	
Spurious emissions	Conducted measurement in receive mode.		
	30 MHz through 1000 MHz	-80	dBm
	1 GHz through 12.75 GHz	-80	

3.3.1 CC2538 - Typical Rx Performance Plots

T_C = 25°C, V_{DD} = 3.3 V, f = 2450 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] with a 50 Ω load.

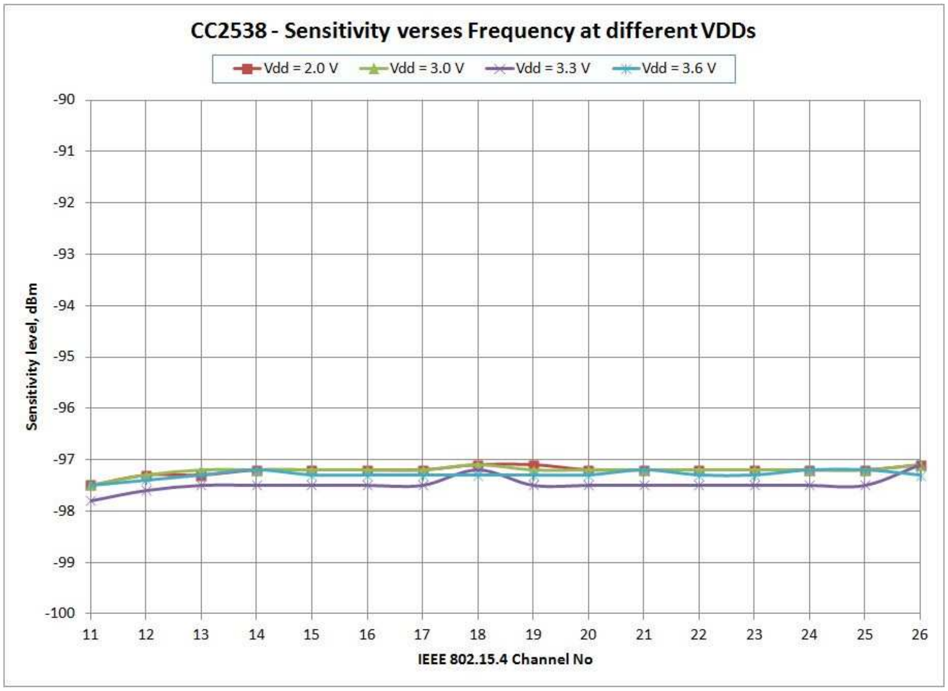

Figure 3. Sensitivity vs. Frequency at Different VDDs

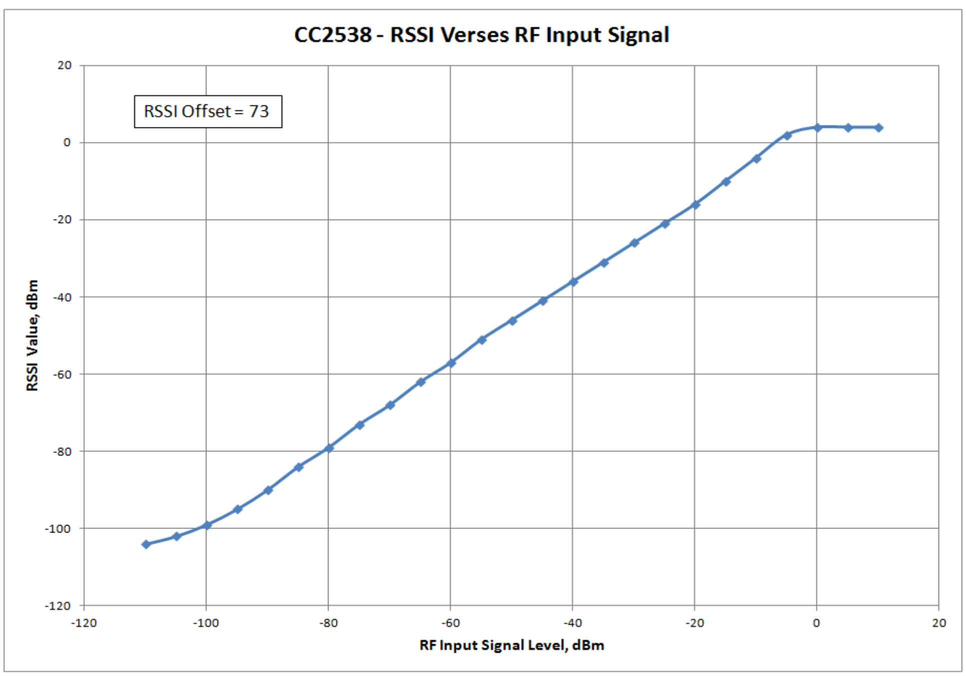

Figure 4. RSSI Readout vs. Input Power

3.4 CC2538 - Transmit Parameters

T_C = 25°C, V_{DD} = 3.3 V, f = 2450 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] with a 50 Ω load.

Table 5. CC2538 - Receive Parameters

Parameter	Condition	Typical	Unit
Output power	Maximum setting	7	dBm
	Minimum setting	-24	
Spurious emissions	At maximum power level setting		
	25 MHz – 1000 MHz (Outside restricted band)	-56	dBm
	25 MHz – 1000 MHz (Within FCC restricted band)	-58	
	25 MHz – 1000 MHz (Within ETSI restricted band)	-58	
	1800 MHz – 1900 MHz (ETSI restricted band)	-60	
	5150 MHz – 5300 MHz (ETSI restricted band)	-54	
	1 GHz – 12.75 GHz (Except restricted bands)	-51	
	At 2483.5 MHz and above (FCC restricted band), Fc=2480 MHz (1)	-42	
Error Vector Magnitude (EVM)	Error Vector Magnitude (EVM)	3	%
	Measured as defined by IEEE 802.15.4 [6]		
Optimum load impedance	Differential impedance	66+j64	Ω

(1) To improve margins for passing FCC requirements at 2483.5 MHz and above when transmitting at 2480 MHz, use a lower output power setting or less than 100% duty cycle.

3.4.1 CC2538 - Typical Tx Performance Plots

T_C = 25°C, V_{DD} = 3.3 V, f = 2450 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] with a 50 Ω load.

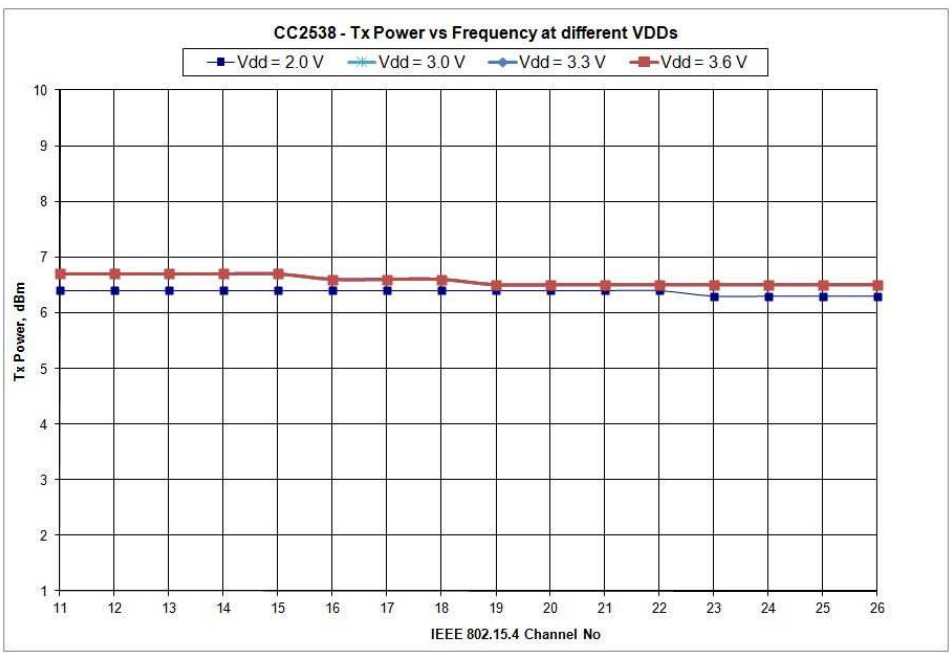

Figure 5. Tx Power vs. Frequency at Different VDDs at Max Power Level Setting

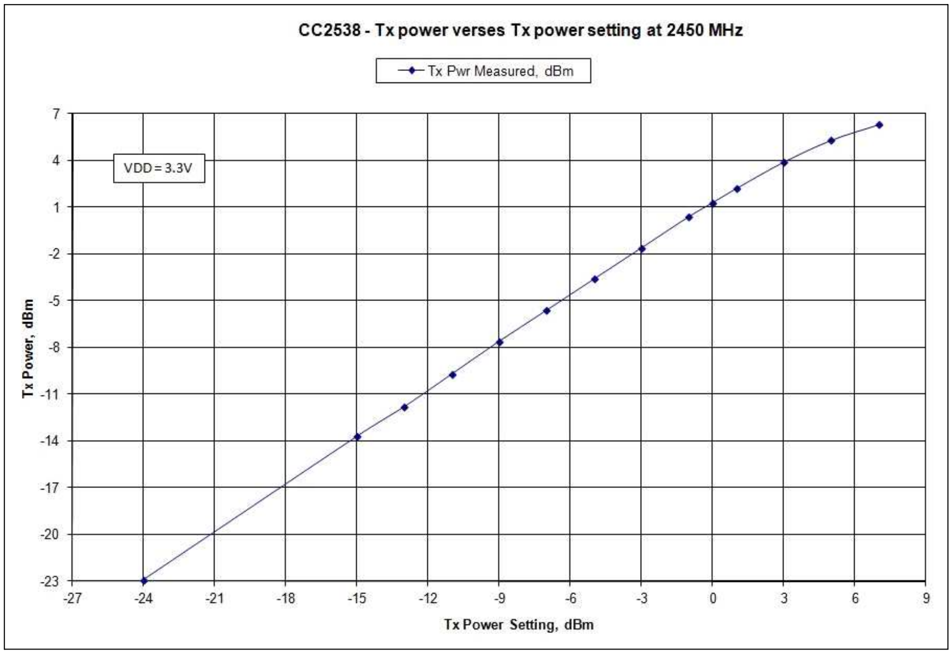

Figure 6. Tx Power vs. Tx Power Setting at 2450 MHz

4 CC1200 - Electrical Specifications

These characteristics are only valid when using the CC2538+CC1200 EM reference design [3] with the register settings recommended by SmartRF Studio software.

4.1 Operating Conditions

Table 6. CC2538 - Operating Conditions

Device	Parameter	Min	Max	Unit
CC1200	Operating Frequency	820	950	MHz
	Operating Supply Voltage	2.0	3.6	V
	Operating Temperature	-40	85	°C

4.2 CC1200 - Current Consumption

T_C = 25°C, V_{DD} = 3.3 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] with a 50 Ω load.

Table 7. CC1200 - Current Consumption

Parameter	Condition	Typical	Unit
Receive Current	Wait for sync – in Sniff Mode		mA
	1.2 kbps, 3 byte preamble	3.4	
	50 kbps, 24 byte preamble	2.1	
RX Peak current	Peak current consumption during packet reception	23.5	mA
Transmit Current	TXPOWER = +14 dBm	46	mA
	TXPOWER = +10 dBm	36	
Power Down with Retention Current	Low-power RC oscillator running	0.3	µA
		0.5	
XOFF Mode	Crystal oscillator / TCXO disabled	180	µA
IDLE Mode	Clock running, system waiting with no radio activity	1.5	mA

4.3 CC1200 - Receive Parameters

T_C = 25°C, V_{DD} = 3.3 V, f = 915 MHz, BER=1% if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] at an Antenna connector.

Table 8. Receive Parameters

Parameter	Condition	Typical	Unit
Rx Sensitivity	38.4 kbps, 2-GFSK, Dev = 20 KHz, CHF = 104 KHz	-110	dBm
	50 kbps, 2-GFSK, Dev = 25 KHz, CHF = 104 KHz	-109	
	500 kbps, 2-GMSK, CHF = 833 KHz	-97	
	1 Mbps, 4-GFSK, Dev = 400 KHz, CHF = 1.66 MHz	-97	
Saturation	Maximum input power level	+10	dBm
Selectivity and Blocking	38.4 kbps, 2-GFSK, Dev = 20 KHz,		
	100 KHz Channel Separation, CHF = 104 KHz		
	±100 KHz (Adjacent channel)	44	dB
	±200 KHz (Alternate channel)	44	
	±2 MHz from wanted signal	64	
	±10 MHz from wanted signal	72	
	50 kbps, 2-GFSK, Dev = 25 KHz,		
	200 KHz Channel Separation, CHF = 104 KHz		
	±200 KHz (Adjacent channel)	41	dB
	±400 KHz (Alternate channel)	46	
	±2 MHz from wanted signal	65	
	±10 MHz from wanted signal	71	
	1 Mbps, 4-GFSK, Dev = 400 KHz,		
	2 MHz Channel Separation, CHF = 1.6 MHz		
	±2 MHz (Adjacent channel)	46	dB
	±4 MHz (Alternate channel)	52	
	±10 MHz from wanted signal	59	
Spurious Emissions	Conducted in receive mode		
	30 MHz thru 1 GHz	<-56	dBm
	1 GHz thru 13 GHz	<-57	

Table 8. Receive Parameters (continued)

Parameter	Condition	Typical	Unit
Optimum Source Impedance	Differential	60+j60	Ω
	Single Ended	30+j30	

4.3.1 CC1200 -Typical Rx Performance Plots

T_C = 25°C, V_{DD} = 3.3 V, f = 915 MHz, BER = 1% if nothing else is stated. All parameters are measured on the CC2538+CC1200 EM reference design [3] at an Antenna connector.

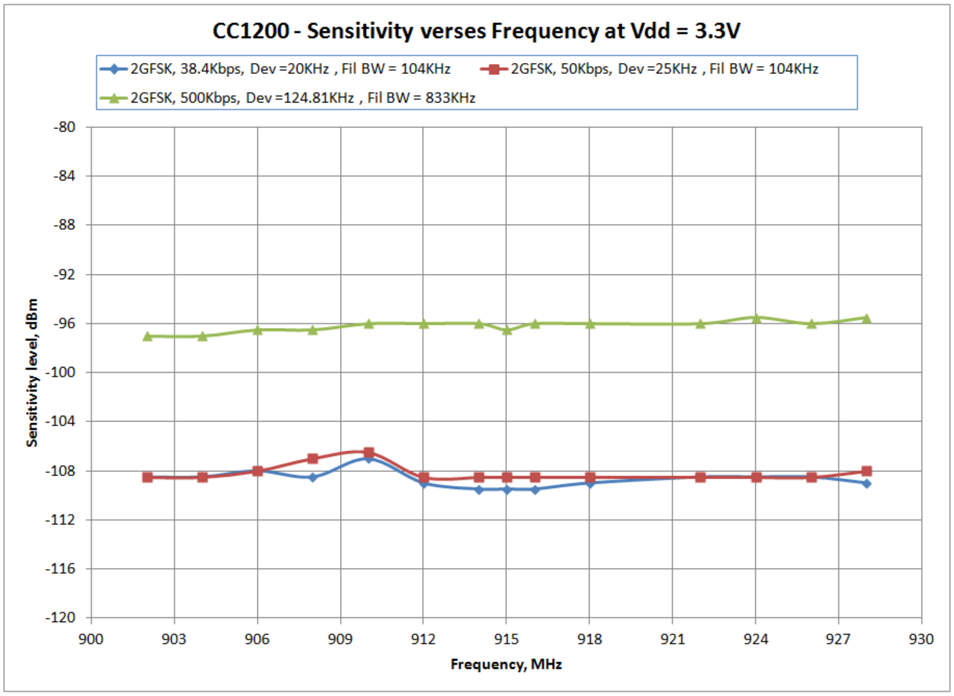

Figure 7. CC1200 – Sensitivity vs Frequency at VDD = 3.3 V

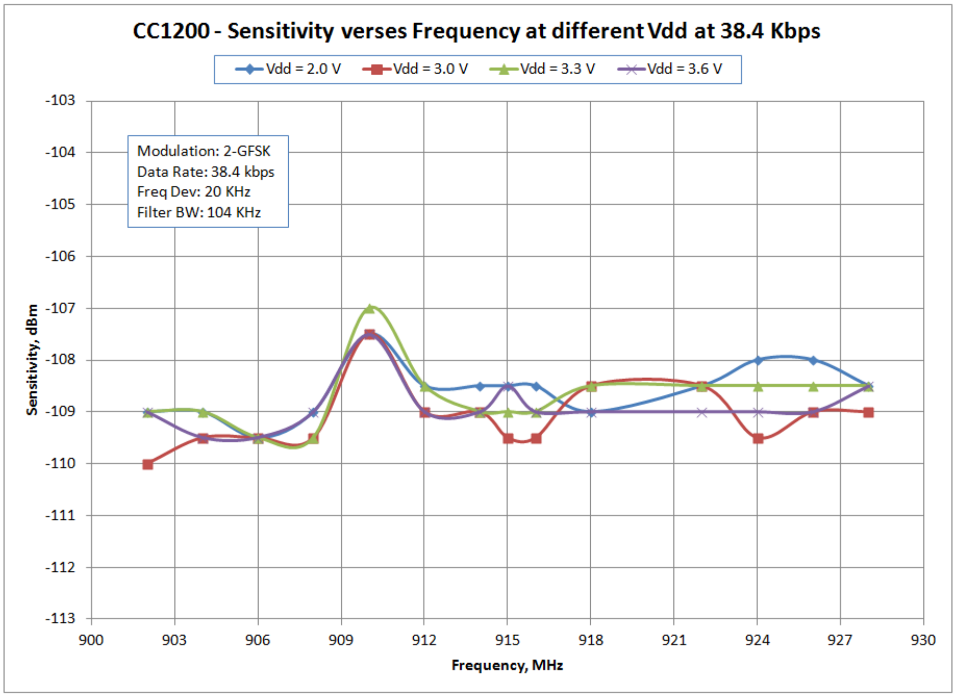

Figure 8. CC1200 - Sensitivity vs Frequency at Different VDDs at 38.4 kbps

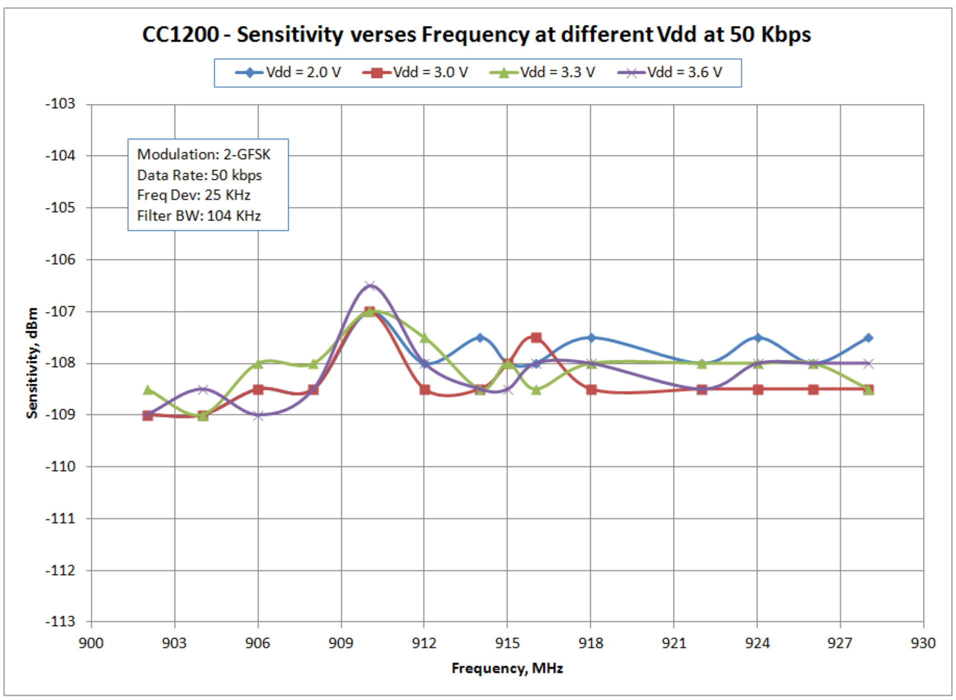

Figure 9. CC1200 - Sensitivity vs Frequency at Different VDDs at 50 kbps

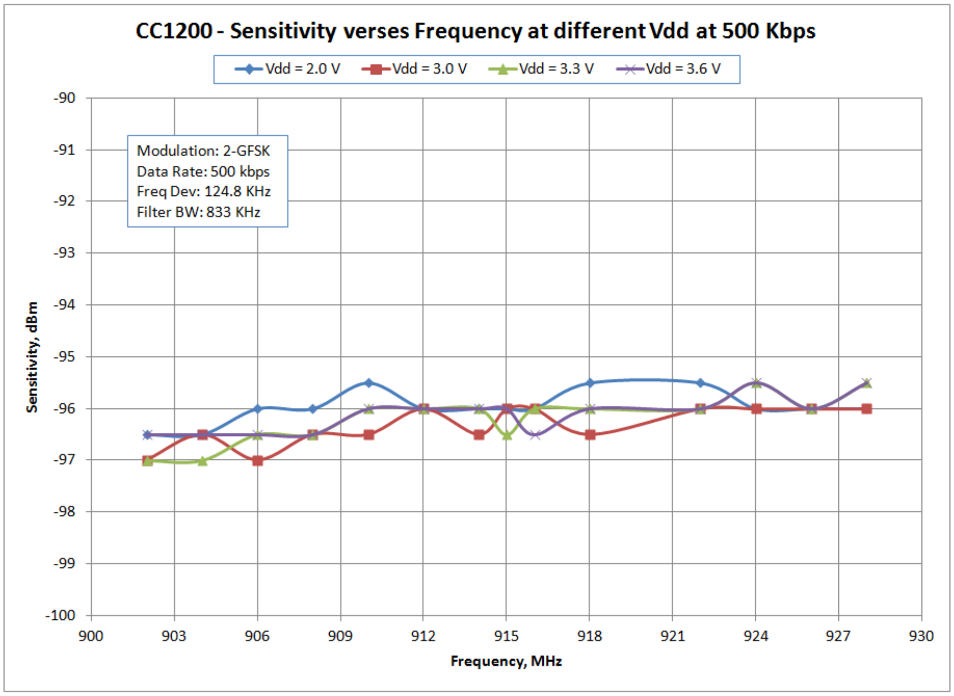

Figure 10. CC1200 - Sensitivity vs Frequency at Different VDDs at 500 kbps

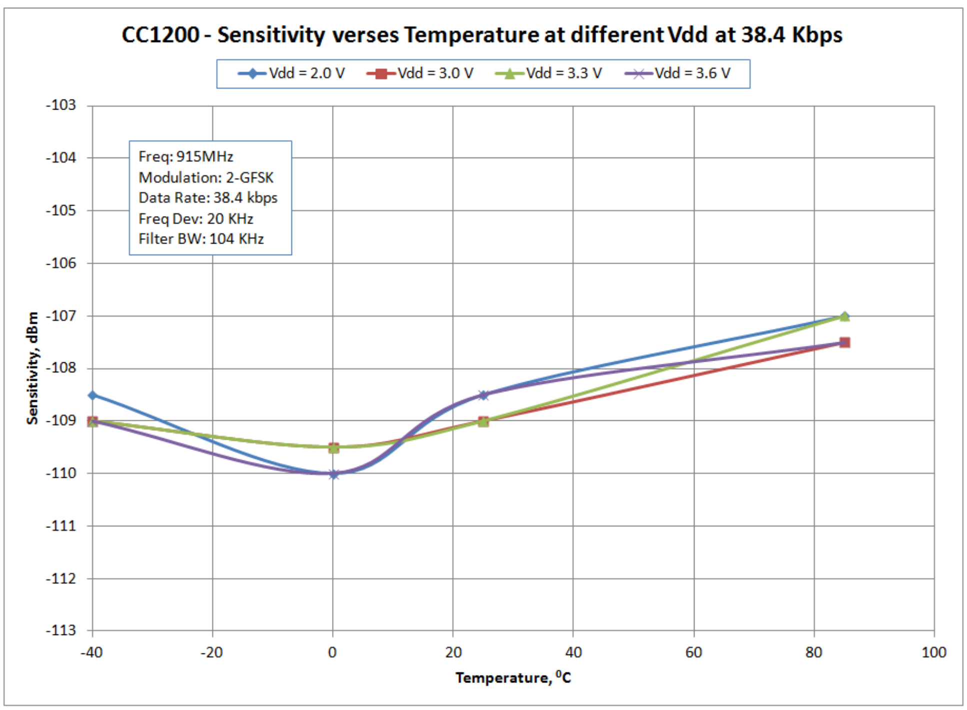

Figure 11. CC1200 - Sensitivity vs Temperature at Different VDDs at 38.4 kbps

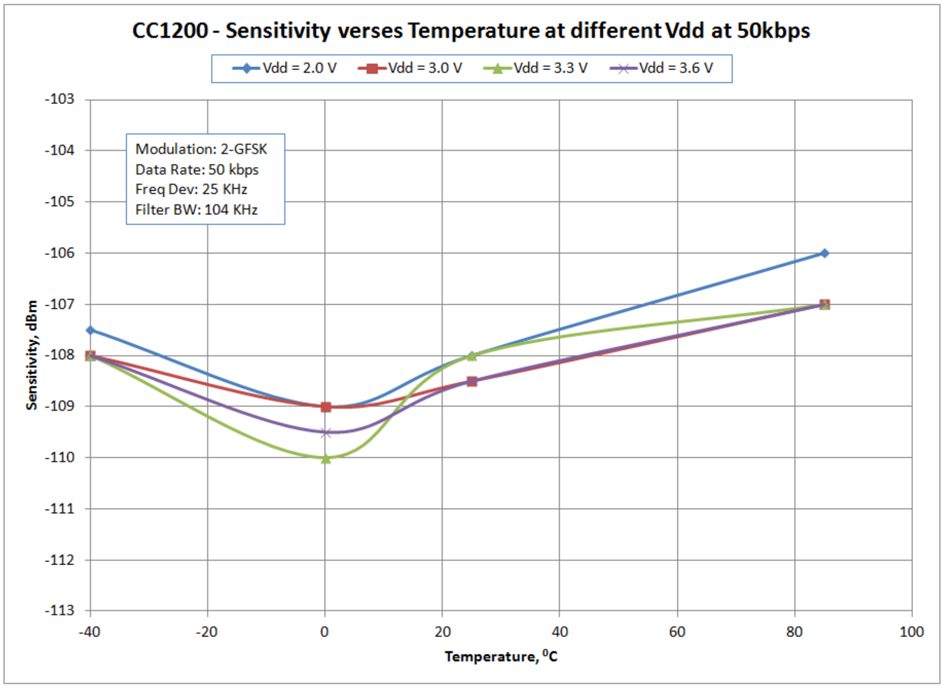

Figure 12. CC1200 - Sensitivity vs Temperature at Different VDDs at 50 kbps

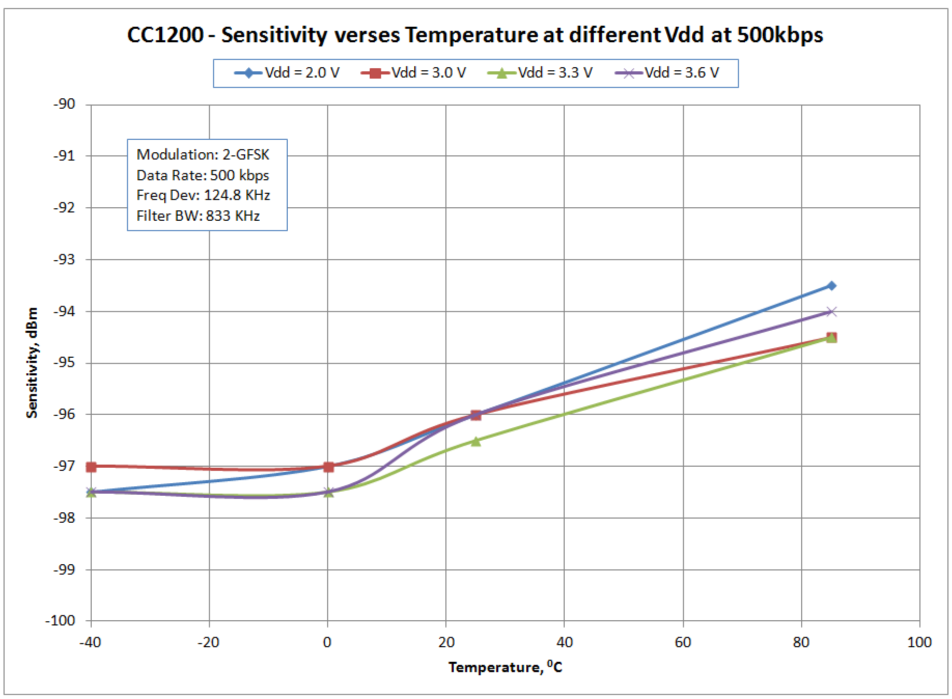

Figure 13. CC1200 - Sensitivity vs Temperature at Different VDDs at 500 kbps

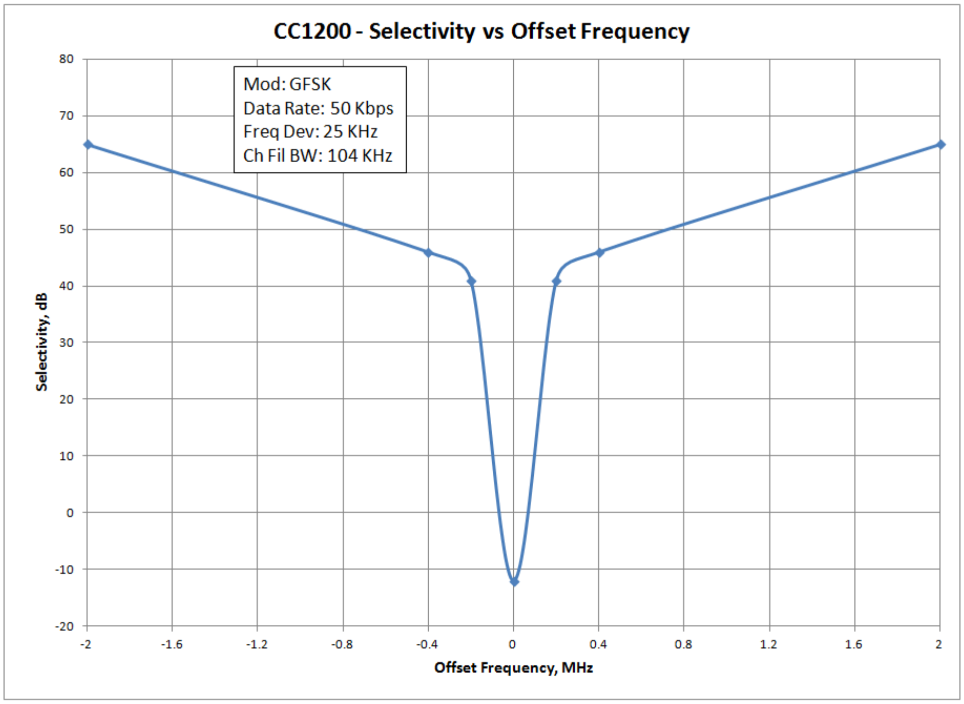

Figure 14. CC1200 - Selectivity / Blocking at 100 KHz Channel Spacing

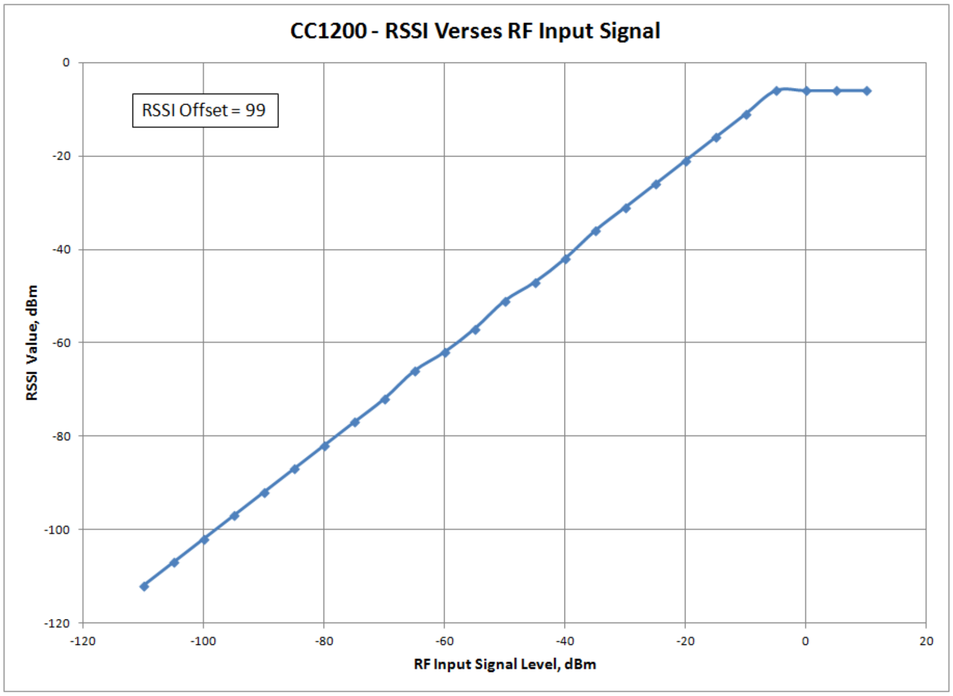

Figure 15. RSSI Readout vs. Input Power

4.4 CC1200 - Transmit Parameters

T_C = 25°C, V_{DD} = 3.3 V, f = 915 MHz, BER = 1% if nothing else is stated. All parameters are measured on the CC2538+CC1200 Combo EM reference design [3] at an Antenna connector.

Table 9. CC1200 - Transmit Parameters

Parameter	Condition	Typical	Unit
Rx Sensitivity	Maximum in CW mode	14	dBm
	Minimum in CW mode	-38	
Harmonic suppression	Transmit power at +14 dBm typical		
	Second harmonic level	-57	dB
	Third harmonic level	-46	
	Fourth harmonic level	-58	
	Fifth harmonic level	-73	
Tx Spurious Emission	Transmit power at +14 dBm typical		
	Conducted from 30 MHz thru 1 GHz	<-57	dBm
	Conducted from 1 GHz thru 12.75 GHz	<-50	
Optimum Source Impedance	868/915/920 MHz bands	35+j35	Ω

4.4.1 CC1200 - Typical Tx Performance Plots

T_C = 25°C, V_{DD} = 3.3 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC2538+CC1200 Combo EM reference design [3] at an Antenna connector.

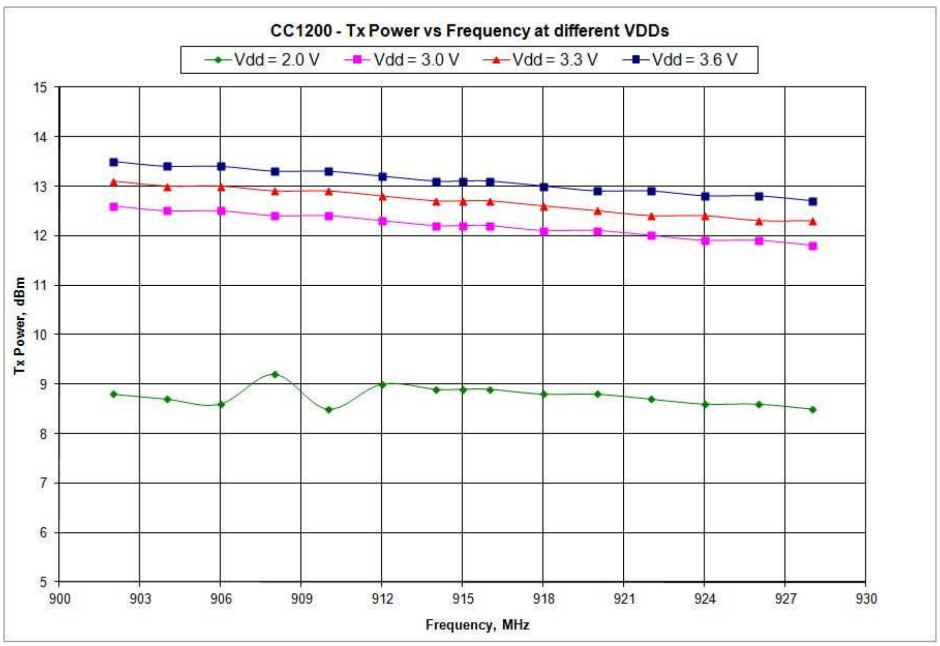

Figure 16. CC1200 - Output Power vs Frequency at Different VDDs, TXPOWER = 0x3F

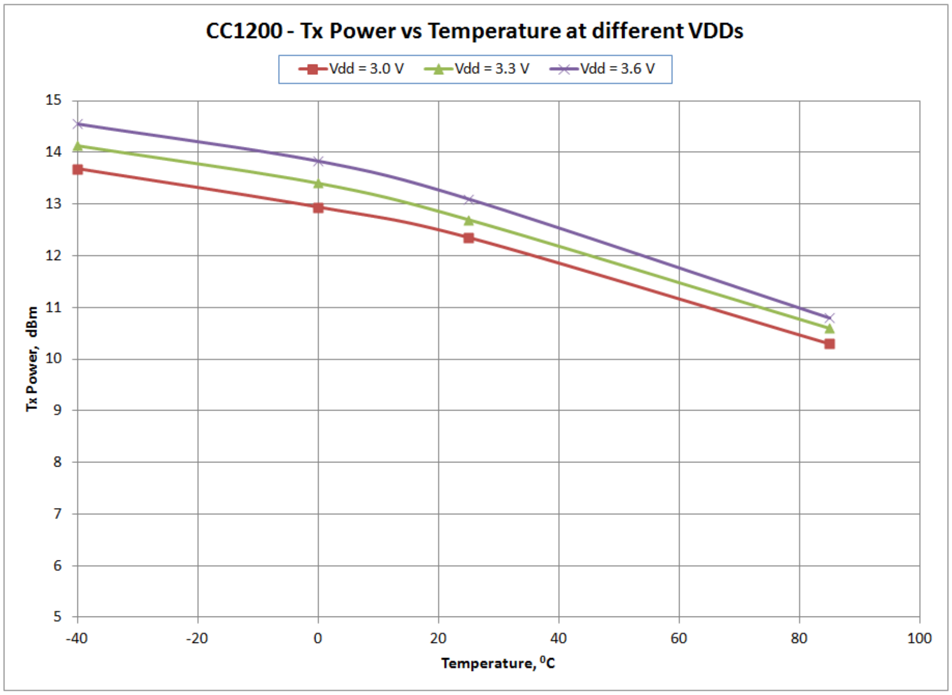

Figure 17. CC1200 - Output Power vs Temperature

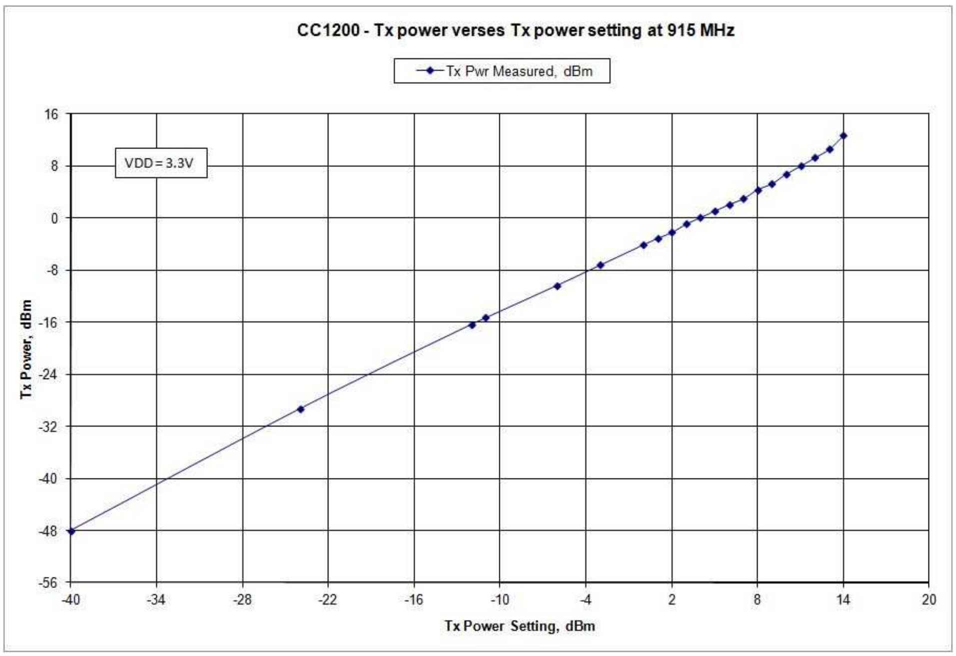

Figure 18. CC1200 – TX power vs PA Power Setting at Different VDDs

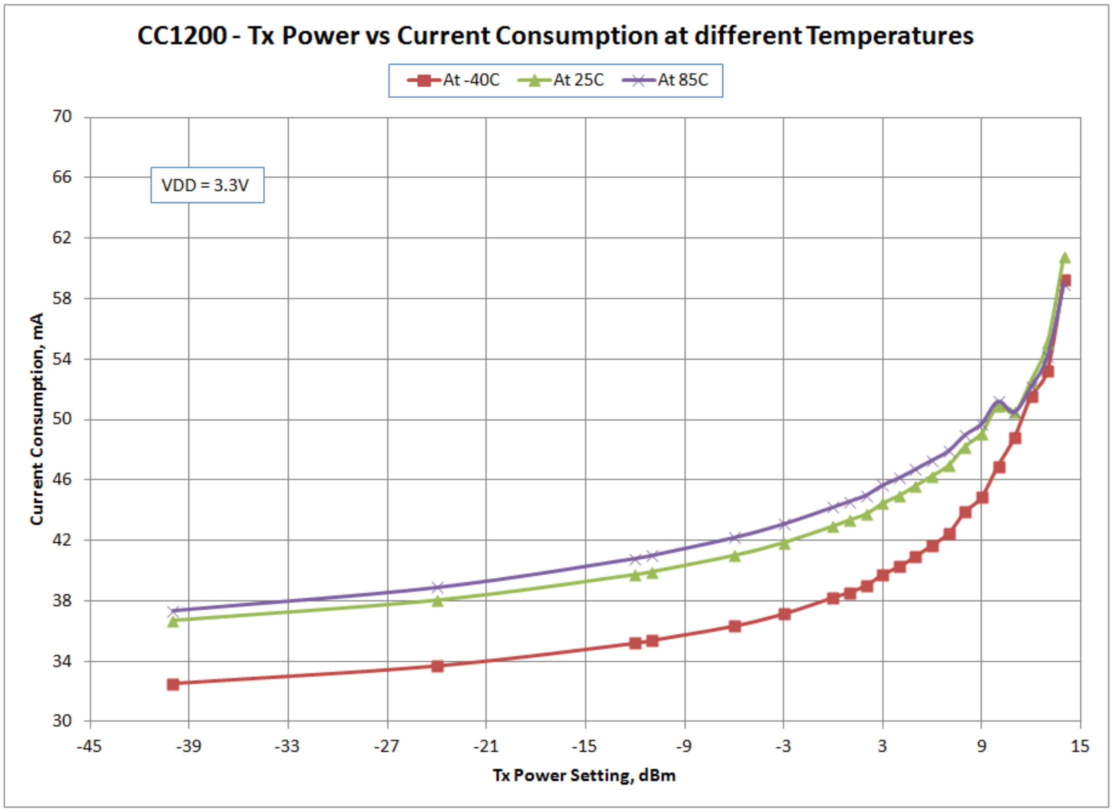

Figure 19. CC1200 – TX Current Consumption vs TX Power at Different Temperatures

5 CC2358 - Test Tools

The CC2538+CC1200 EM together with SmartRF06 EB and Smart RF Studio 7 software can be used to evaluate the CC2538 performance and functionality

5.1 SmartRF06 EB

The SmartRF06 EB [6] is the mother board in the development kits for low power RF ARM Cortex-M-based SoC from Texas Instruments. The CC2538+CC1200 EM interfaced with SmartRF06 EB is shown in Figure 20. The CC2538+CC1200 EM can be powered-up from different power supply sources by placing the Power supply jumper in the appropriate position. For details about the placement of the Power supply jumper, see Section 7.4.

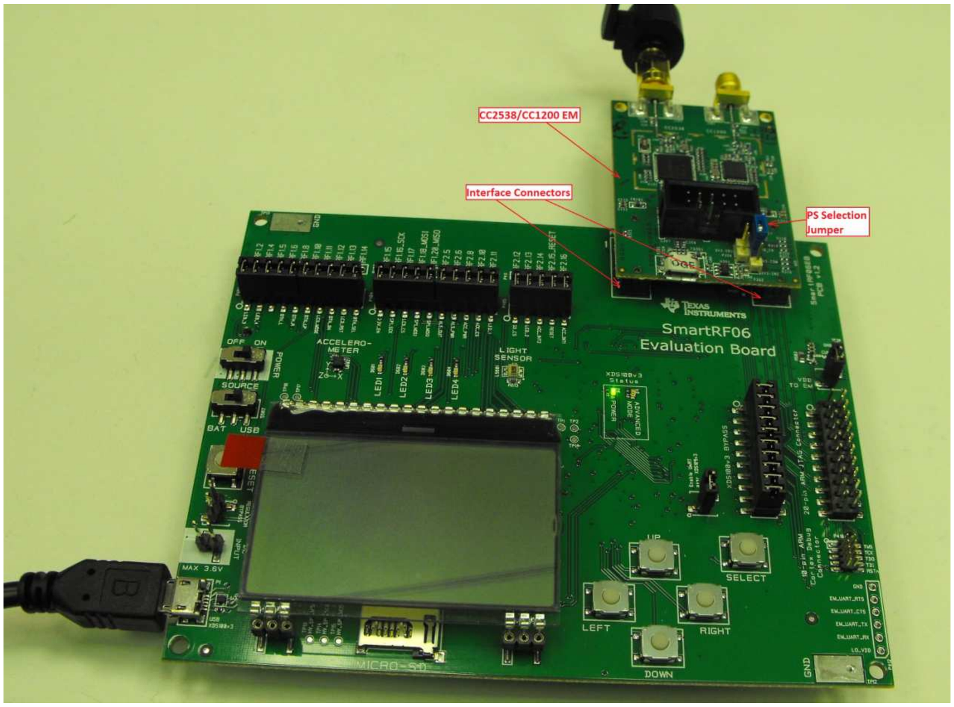

Figure 20. CC2538 - SmartRF06 EB With CC2358+CC1200 EM

5.2 SmartRF Studio

The CC2538+CC1200 EM can be configured using the SmartRF Studio 7 software [6]. The SmartRF Studio software is highly recommended for obtaining optimum register settings. A screen shot of the SmartRF Studio interface for CC2538+CC1200 EM is shown in Figure 21.

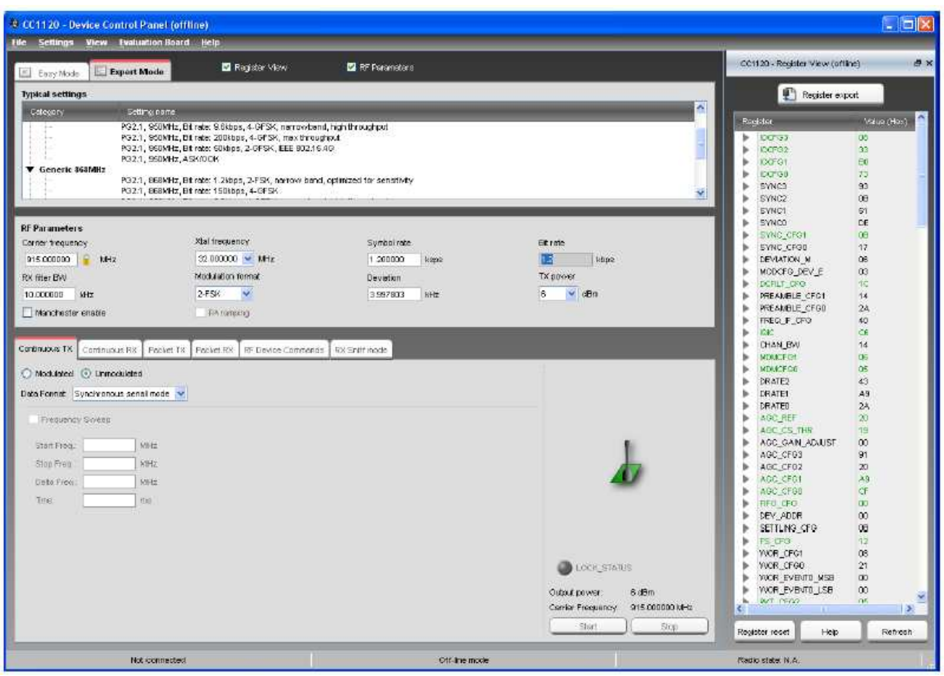

Figure 21. CC2538 - SmartRF Studio 7 User Interface

6 CC1200 - Test tools

The CC2538+CC1200 EM together with CC Debugger and SmartRF Studio 7 software can be used to evaluate the CC1200 performance and functionality.

6.1 CC Debugger

The CC Debugger is primarily used for debugging and programming the Flash on CCxxxx 8051-based SoC devices from Texas Instruments. It can also be used to control some of the supported CCxxxx RF transceivers from SmarRF Studio software. The CC2538+CC1200 EM interfaced with the CC Debugger is shown in Figure 22. The CC2538+CC1200 EM can be powered-up from different power supply sources by placing the Power supply jumper in the appropriate position. For details about the placement of Power supply jumper, see Section 7.4.

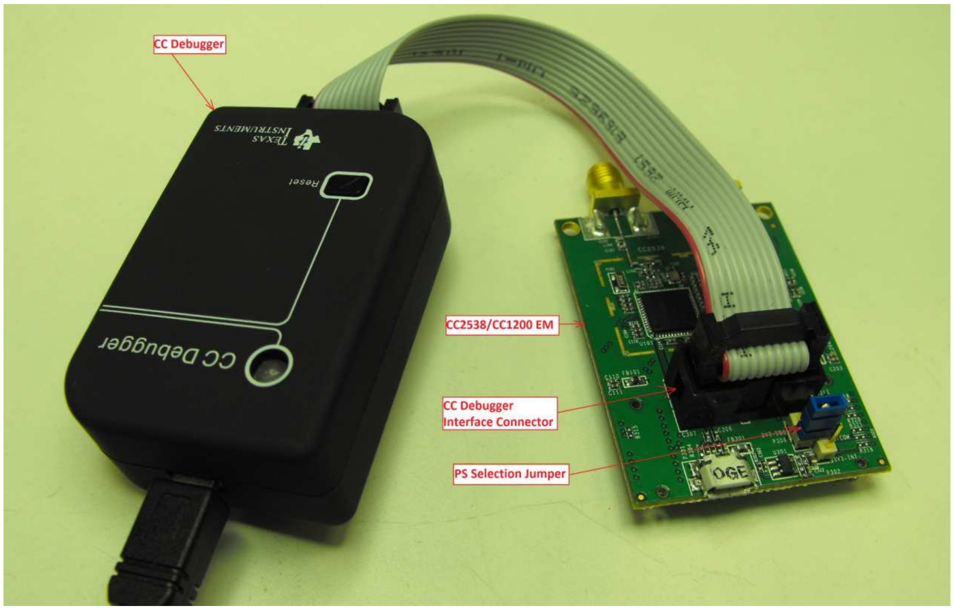

Figure 22. CC1200 - CC Debugger With CC2358+CC1200 EM

6.2 SmartRF Studio

The CC2538+CC1200 Combo EM can be configured using the SmartRF Studio 7 software [6]. The SmartRF Studio software is highly recommended for obtaining optimum register settings. A screen shot of the SmartRF Studio interface for CC2538+CC1200 Combo EM is shown in Figure 23.

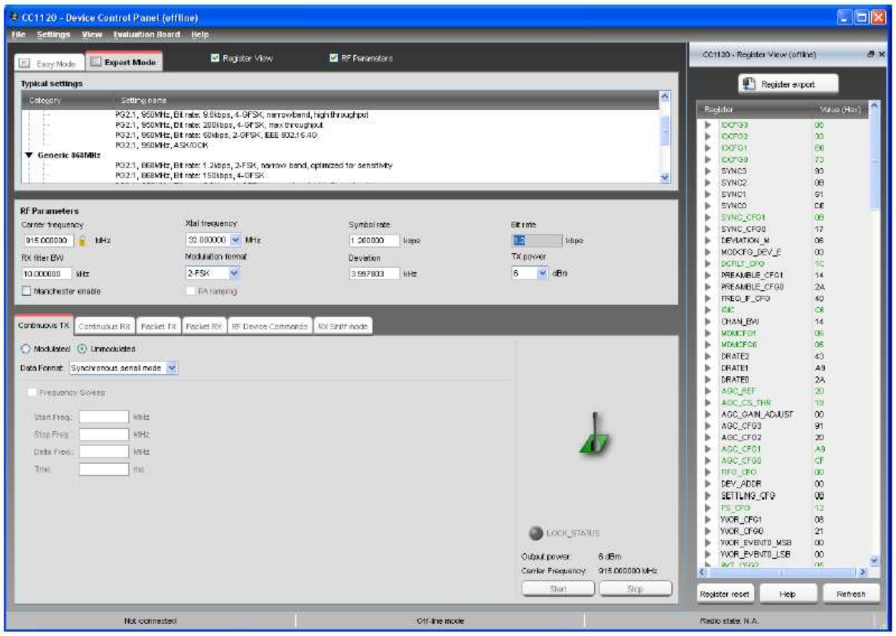

Figure 23. CC1200 - SmartRF Studio 7 User Interface

7 Reference Design

The CC2358+CC1200 EM reference design includes schematic, bill of materials and Gerber files [3]. It is highly recommended to follow the reference design for optimum performance.

7.1 Power Decoupling

Proper power supply decoupling must be used for optimum performance. The placement and value of the decoupling components and the power supply filtering are very important to achieve the best performance.

7.2 Input/ Output Matching and Filtering

The RF input/output of CC2538 is differential ended. A balun is required to transform the differential input/output to a single ended input/output. The circuit that consists of components C115, C119, L101, L102, C123, C116 and L103 forms as a balun and it matches the CC2538 to a 50 Ω impedance. The circuit that follows the balun is a harmonic filter and provides filtering to the harmonics to pass regulatory demands.

The LNA input of CC1200 is differential ended. A balun is required to transform the differential input to a single ended input. The circuit that consists of components L202, L201, C215, C213 and L204 forms as a balun and it matches a 50 Ω impedance. The circuit that follows the balun is a harmonic filter and provides filtering to the harmonics to pass regulatory demands.

7.3 Bias Resistor

R102 is a bias resistor for CC2538. The bias resistor is used to set an accurate bias current for internal use in the CC2538.

R210 is a bias resistor for CC1200. The bias resistor is used to set an accurate bias current for internal use in the CC1200.

7.4 Power Supply Selection

The CC2538+CC1200 EM can be powered up from different power supply sources such as SmarRF06 EB, CC Debugger, on-board power supply and an eternal power supply. The source of the power supply can be selected by placing a power supply jumper to the appropriate position on connectors P302 and P306. The Jumper position options are shown in Figure 24 and Figure 25. For further details, see the schematic shown in the reference design [3].

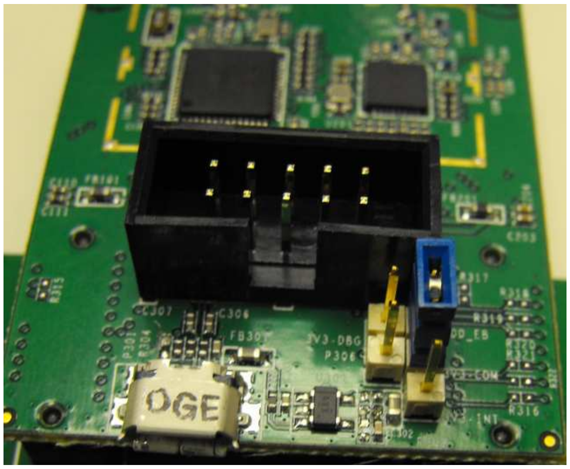

Figure 24. PS Jumper Position for PS From SmartRF06 EB

Figure 25. PS Jumper Position for PS From CC Debugger

8 PCB Layout Considerations

The Texas Instruments reference design uses a 1.6 mm (0.062”) 4-layer PCB solution. Note that the different layers have different thickness; it is important to follow the recommendation given in the CC2538+CC1200 EM reference design [3] to ensure optimum performance.

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. For footprint recommendations, see the device-specific data sheets.

Layer two is a complete ground plane and is not used for any routing. This is done to ensure short return current paths. 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 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 as for layer one, open areas are filled with metallization connected to ground using several vias.

9 References

1. *CC2538 A Powerful System-On-Chip for 2.4-GHz IEEE 802.15.4, 6LoWPAN and ZigBee Applications Data Sheet* (SWRS096)
2. *CC1200 Low Power, High Performance RF Transceiver Data Sheet* (SWRS123)
3. *CC2538 + CC1200 Reference Design* (SWRR132)
4. *SmartRF06 Evaluation Board User's Guide* (SWRU321)
5. *CC Debugger User's Guide* (SWRU197)
6. *AN058 - Antenna Selection Guide* (SWRA161)
7. *DN0007 - 2.4 GHz Inverted F Antenna* (SWRU120)
8. 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) (http://standards.ieee.org/getieee802/download/802.15.4-2006)
9. *AN032 - SRD Regulations for License-Free Transceiver Operation in the 2.4 GHz Band* (SWRA060)
10. *AN066 - TI-MAC SW Modifications for Using CC2591 RF Front End with MSP430F2618+CC2520* (SWRA230)
11. DA 00-705 (http://www.fcc.gov/Bureaus/Engineering_Technology/Public_Notices/2000/da000705.doc)

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