Using the CC1190 Front End with CC1101 under FCC 15.247

By Marius Ubostad and Sverre Hellan

Keywords

- *Range Extender*
- *FCC Section 15.247*
- *External PA*
- *External LNA*
- *CC1101*
- *CC430*
- *CC1100*
- *CC1110*
- *CC1111*
- *CC1190*

1 Introduction

The CC1101 is a truly low-cost, highly integrated and very flexible RF transceiver. The CC1101 is primarily designed for use in low-power applications in the 315, 433, 868 and 915 MHz SRD/ISM bands.

The CC1190 is a range extender for 850-950 MHz RF transceivers, transmitters, and System-on-Chip devices from Texas Instruments. It increases the link budget by providing a power amplifier (PA) for increased output power, and a low-noise amplifier (LNA) with low noise figure for improved receiver sensitivity in addition to switches and RF matching for simple design of high performance wireless systems.

This application note outlines the expected performance when using a CC1101-CC1190 design under FCC Section 15.247 in the 902-928 MHz frequency band. This application note assumes the reader is familiar with CC1101 and FCC 15.247 regulatory limits. The reader is referred to [1] and [4] for details.

The application note is also applicable for CC1100, CC1110, CC1111, and CC430 when used with the CC1190 as they use the same radio as the CC1101.

Table of Contents

2 Abbreviations

EB	Evaluation Board
EM	Evaluation Module
FCC	Federal Communications Commission
HGM	High Gain Mode
LNA	Low Noise Amplifier
LGM	Low Gain Mode
PA	Power Amplifier
PCB	Printed Circuit Board
PER	Packet Error Rate
RF	Radio Frequency
RSSI	Receive Signal Strength Indicator
RX	Receive, Receive Mode
TrxEB	SmartRF Transceiver EB
TX	Transmit, Transmit Mode

3 Absolute Maximum Ratings

The absolute maximum ratings and operating conditions listed in the CC1101 datasheet [1] and the CC1190 datasheet [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

Note that the characteristics in Chapter 4 are only valid when using the CC1101-CC1190EM 915 MHz reference design [3] and register settings recommended by the SmartRF Studio software [5].

4.1 Operating Conditions

Parameter	Min	Max	Unit
Operating Frequency	850	950	MHz
Operating Supply Voltage	2.0	3.6	V
Operating Temperature	-40	+85	°C

Table 4.1. Operating Conditions

4.2 Current Consumption

T_C = 25°C, VDD = 3.0 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 915 MHz reference design [3] with a 50 Ω load.

Parameter	Condition	Typical	Unit
Receive Current, HGM	1.2 kbps	20	mA
	50 kbps	21	mA
	250 kbps	22	mA
Receive Current, LGM	1.2 kbps	18	mA
	50 kbps	19	mA
	250 kbps	20	mA
Transmit Current[1]	PATABLE = 0x80 (+26 dBm) PATABLE = 0x8B (+25 dBm) PATABLE = 0x8E (+24 dBm) PATABLE = 0x51 (+23 dBm) PATABLE = 0x3F (+22 dBm) PATABLE = 0x55 (+21 dBm) PATABLE = 0x39 (+20 dBm) PATABLE = 0x2B (+19 dBm) PATABLE = 0x2A (+18 dBm) PATABLE = 0x28 (+17 dBm) PATABLE = 0x35 (+16 dBm) PATABLE = 0x26 (+15 dBm)	348 305 273 243 228 198 187 166 156 135 131 115	mA
Power Down Current		250	nA

Table 4.2. Current Consumption

[1] The RF output power of the CC1101–CC1190 is controlled by the 8 bit value in the CC1101 PATABLE register. The power settings are a small subset of all the possible PATABLE register settings.

4.3 Receive Parameters

T_C = 25°C, VDD = 3.0 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 915 MHz reference design [3] with a 50 Ω load.

Parameter	Condition	Typical	Unit
Sensitivity[2], HGM	1.2 kbps, GFSK, ±14.3 kHz deviation, 58 kHz RX filter bandwidth. See Figure 4.1.	-119.5	dBm
	4.8 kbps, GFSK, ±25.4 kHz deviation, 58 kHz RX filter bandwidth.	-114.5	dBm
	9.6 kbps, *2*FSK, ±4.8 kHz deviation, 58 kHz RX filter bandwidth.	-112.0	dBm
	38.4 kbps, GFSK, ±19.8 kHz deviation, 102 kHz RX filter bandwidth.	-109.0	dBm
	50 kbps, 2FSK, ±25.4 kHz deviation, 135 kHz RX filter bandwidth. See Figure 4.2	-108.0	dBm
	115.2 kbps, GFSK, ±76.2 kHz deviation, 270 kHz RX filter bandwidth.	-103.0	dBm
	250 kbps, GFSK, ±127 kHz deviation, 540 kHz RX filter bandwidth. See Figure 4.3.	-101.0	dBm
	300 kbps, 2FSK, ±76.2 kHz deviation, 464 kHz RX filter bandwidth.	-95.0	dBm
Sensitivity[2], LGM	1.2 kbps, GFSK, ±14.282 kHz deviation, 58 kHz RX filter bandwidth. See Figure 4.4	-108.0	dBm
	50 kbps, 2FSK, ±25.39 kHz deviation, 135 kHz RX filter bandwidth. See Figure 4.5	-95.0	dBm
	250 kbps, GFSK, ±127 kHz deviation, 540 kHz RX filter bandwidth. See Figure 4.6	-88.0	dBm
Saturation, HGM	Maximum input power level for 1% PER	-28	dBm
Saturation, LGM	Maximum input power level for 1% PER	-11	dBm
Selectivity and Blocking, HGM	1.2 kbps. 58 kHz RX filter bandwidth Wanted signal 3 dB above the sensitivity level. Unmodulated interferer. See Figure 4.7. ±2 MHz from wanted signal ±10 MHz from wanted signal	62 72	dB
	50 kbps. 102 kHz RX filter bandwidth. Wanted signal 3 dB above the sensitivity level. Unmodulated interferer. See Figure 4.8. ±2 MHz from wanted signal ±10 MHz from wanted signal	49 59	dB
	250 kbps. 540 kHz RX filter bandwidth. Wanted signal 3 dB above the sensitivity level. Unmodulated interferer. See Figure 4.9. ±2 MHz from wanted signal ±10 MHz from wanted signal	40 51	dB
Spurious emission, HGM	Conducted measurement below 1 GHz Conducted measurement above 1 GHz	< -60 < -50	dBm

Table 4.3. Receive Parameters

[2] Sensitivity limit is defined as 1% packet error rate (PER). Packet length is 20 bytes.

4.3.1 Typical RX Performance vs. Temperature and VDD

T_C = 25°C, VDD = 3.0 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 915 MHz reference design [3] with a 50 Ω load.

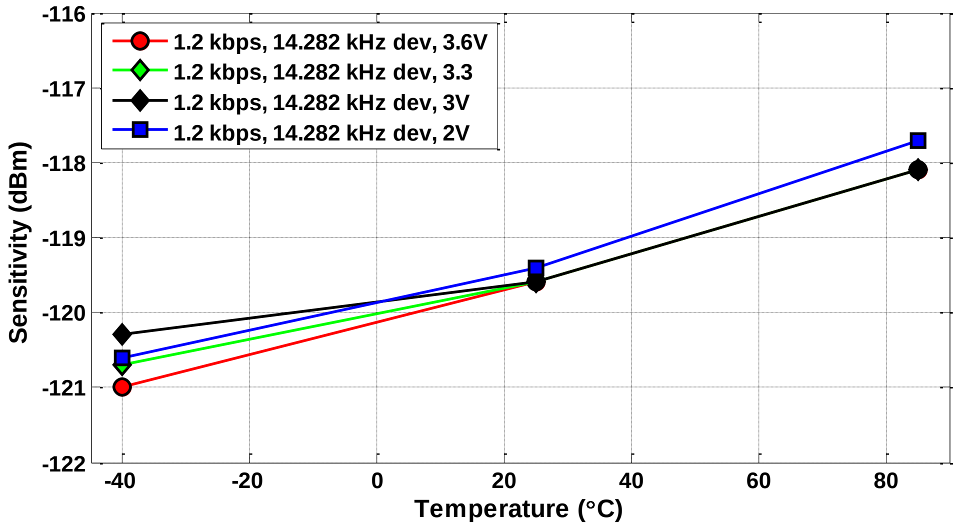

Figure 4.1. Typical Sensitivity vs. Temperature and Power Supply Voltage, HGM, 1.2 kbps

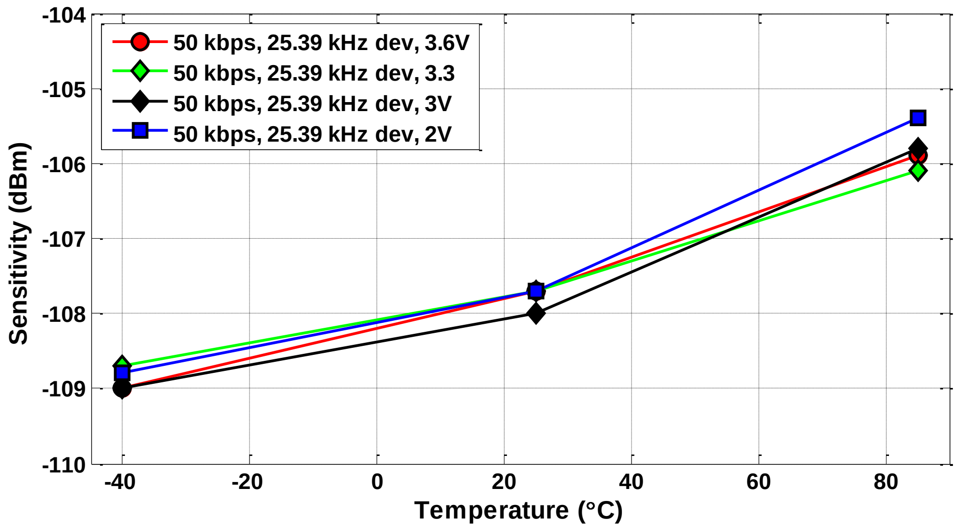

Figure 4.2. Typical Sensitivity vs. Temperature and Power Supply Voltage, HGM, 50 kbps

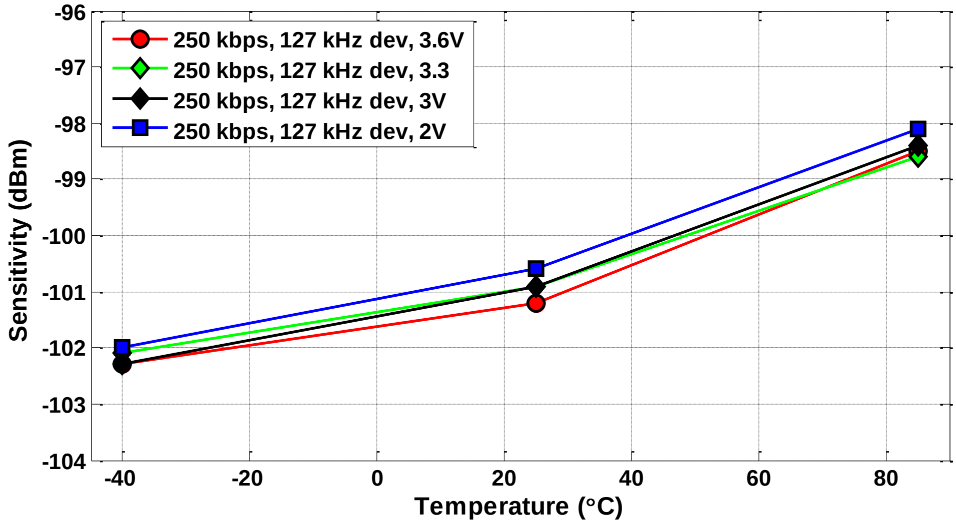

Figure 4.3. Typical Sensitivity vs. Temperature and Power Supply Voltage, HGM, 250 kbps

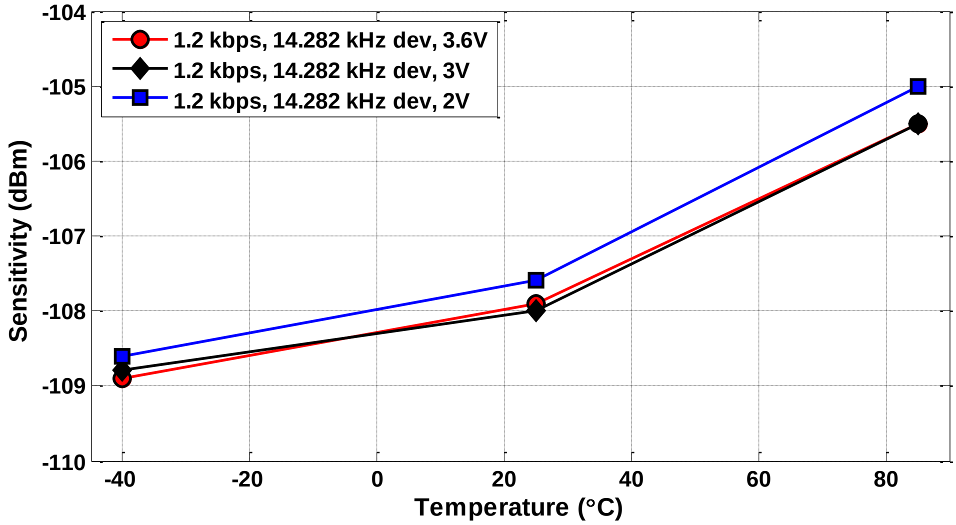

Figure 4.4. Typical Sensitivity vs. Temperature and Power Supply Voltage, LGM, 1.2 kbps

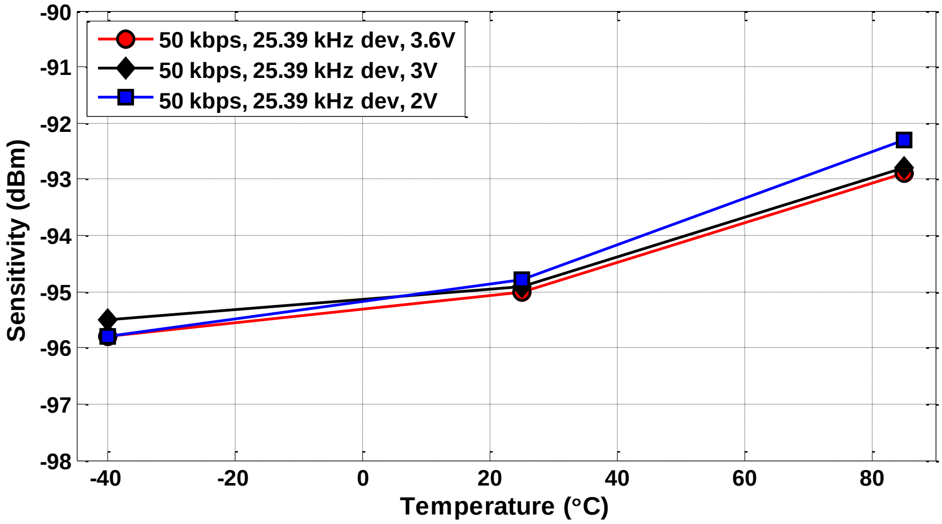

Figure 4.5. Typical Sensitivity vs. Temperature and Power Supply Voltage, LGM, 50 kbps

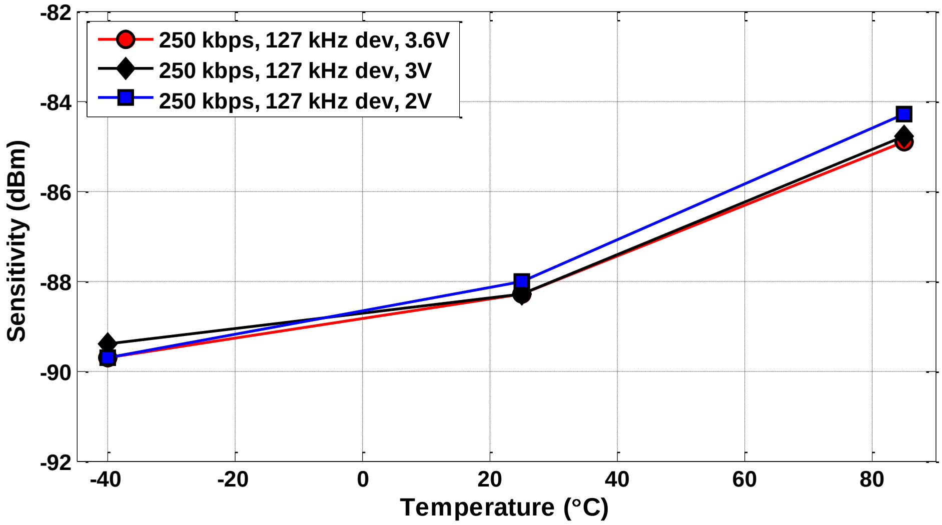

Figure 4.6. Typical Sensitivity vs. Temperature and Power Supply Voltage, LGM, 250 kbps

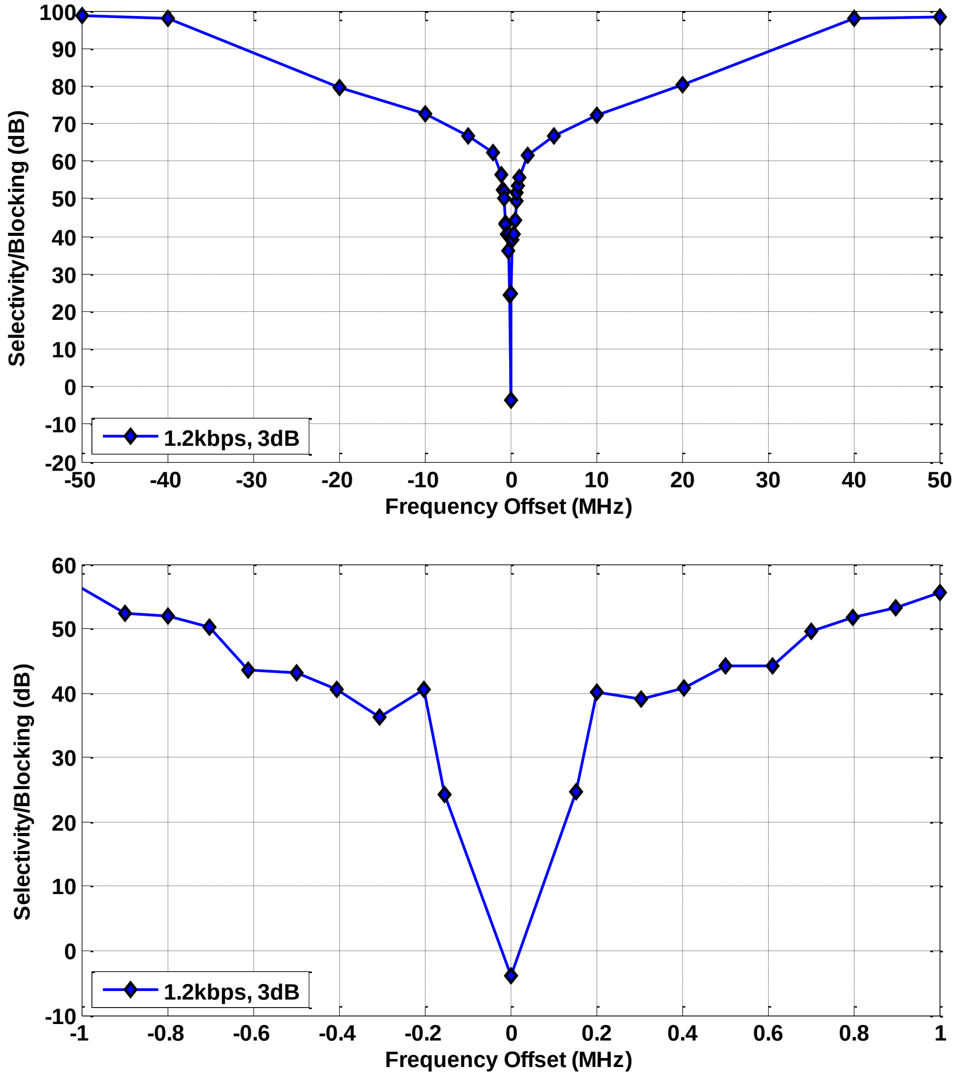

Figure 4.7. Typical Blocking / Selectivity, 1.2 kbps

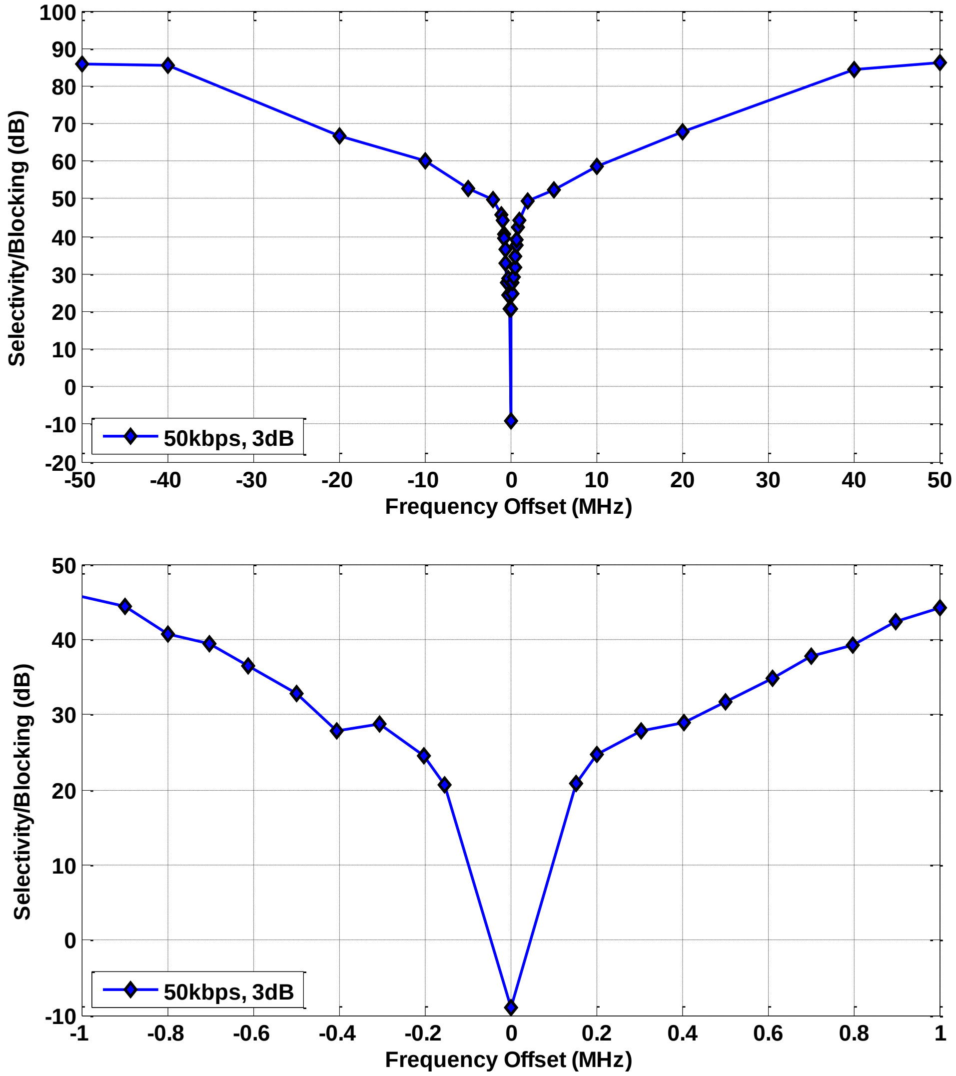

Figure 4.8. Typical Blocking / Selectivity, 50 kbps

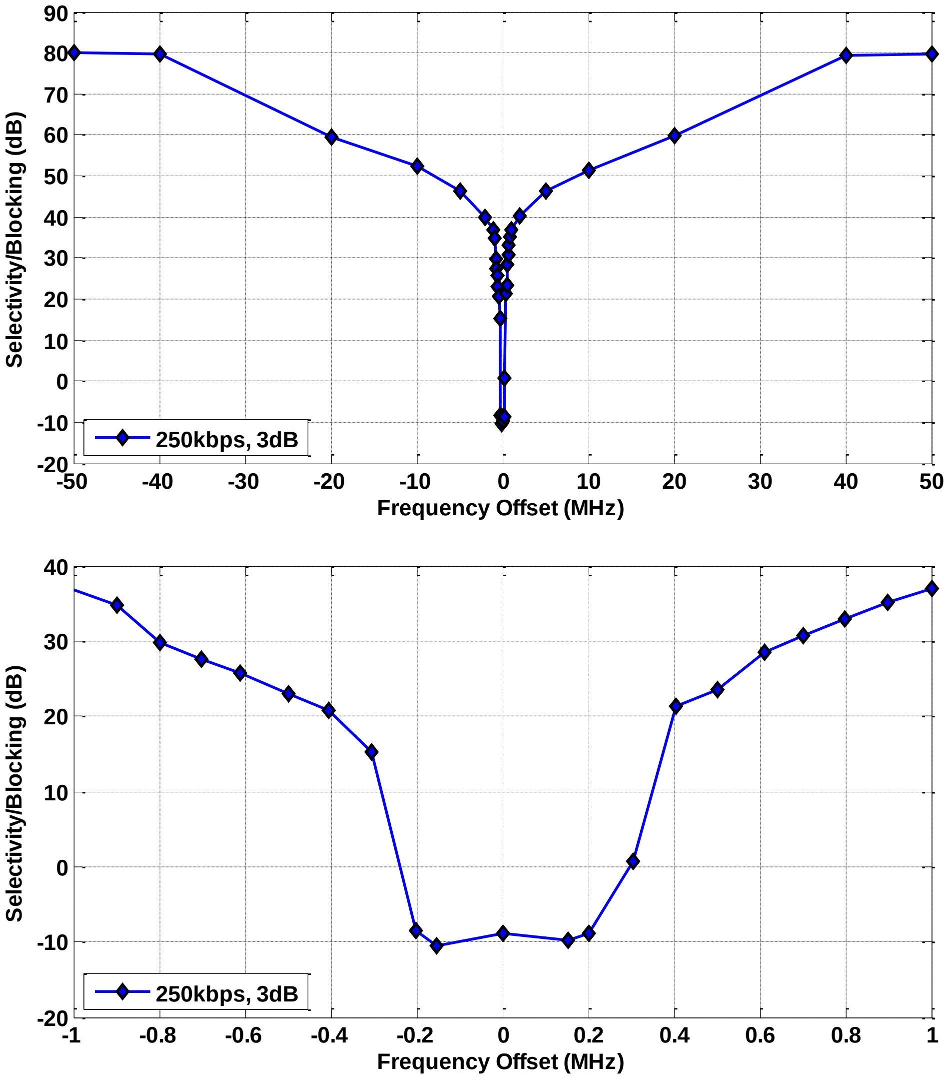

Figure 4.9: Typical Blocking / Selectivity, 250 kbps

4.3.2 Received Signal Strength Indicator (RSSI)

The CC1101-CC1190 RSSI readouts can be converted to an absolute level in dBm by subtracting an offset. A CC1101-CC1190 design has a different offset value compared to a standalone CC1101 design due to the CC1190 external LNA gain and the SAW filter insertion loss. Table 4.4 gives the typical offset value for HGM and LGM. Refer to the CC1101 data sheet [1] for more details on how to convert the RSSI readout to an absolute power level in dBm.

HGM	LGM
81	63

Table 4.4. Typical RSSI Offset Values

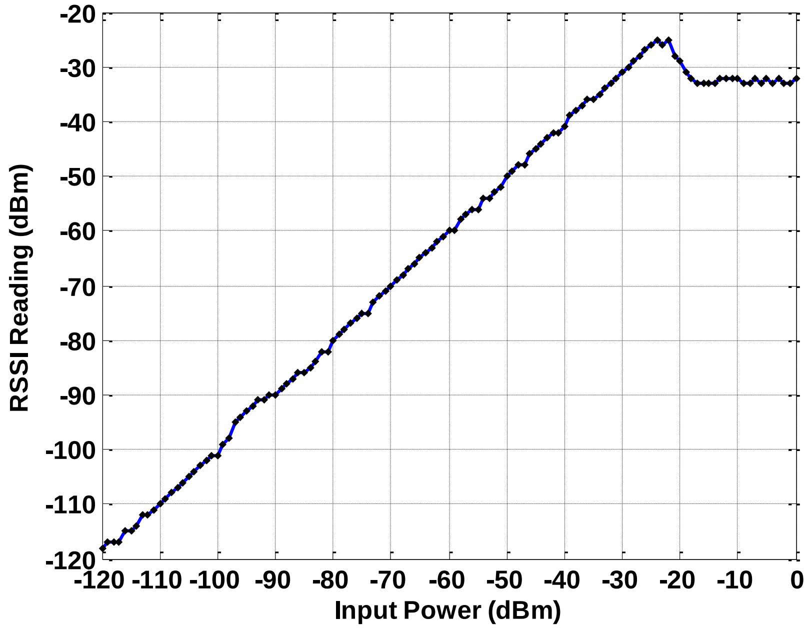

Figure 4.10. Typical RSSI vs. Input Power Level, HGM, 50 kbps

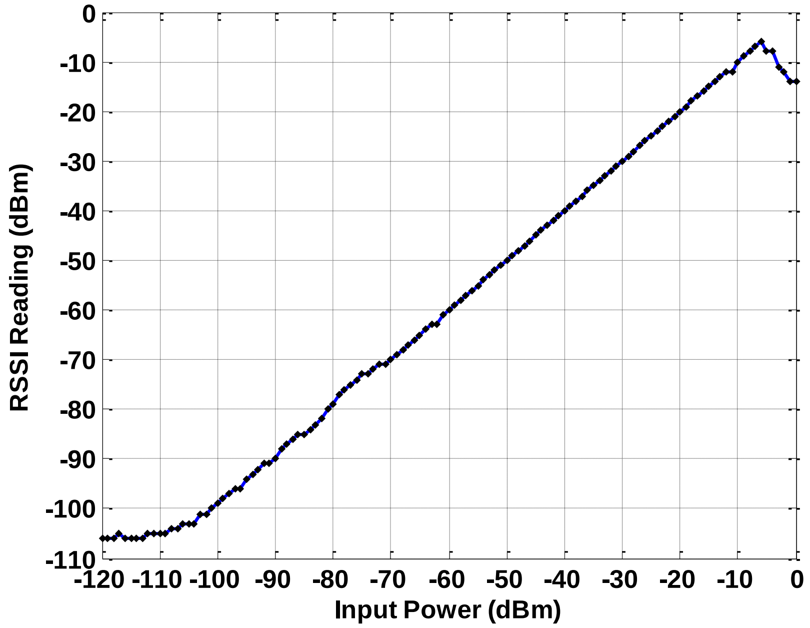

Figure 4.11. Typical RSSI vs. Input Power Level, LGM, 50 kbps

4.4 Transmit Parameters

T_C = 25°C, VDD = 3.0 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 915 MHz reference design [3] with a 50 Ω load, except for the load-pull measurements. Radiated measurements are done with the kit antenna.

Parameter	Condition	Typical	Unit
Output power[1], HGM	PATABLE = 0x80 PATABLE = 0x8B PATABLE = 0x8E PATABLE = 0x51 PATABLE = 0x3F PATABLE = 0x55 PATABLE = 0x39 PATABLE = 0x2B PATABLE = 0x2A PATABLE = 0x28 PATABLE = 0x35 PATABLE = 0x26	26 25 24 23 22 21 20 19 18 17 16 15	dBm
Efficiency, HGM	PATABLE = 0x80 PATABLE = 0x8B PATABLE = 0x8E PATABLE = 0x51 PATABLE = 0x3F PATABLE = 0x55	37 34 31 27 24 21	%
Spurious emission with PATABLE = 0x80, HGM	Conducted below 1 GHz Conducted 2nd harmonic Conducted except 2nd harmonic Radiated above 2nd harmonic	< -60 < -9 < -49 < -38	dBm
Spurious emission with PATABLE = 0x8E, HGM	Radiated above 2nd harmonic	< -41.2	dBm
20 dB bandwidth, HGM	1.2 kbps, GFSK, ±14.3 kHz deviation 4.8 kbps, GFSK, ±25.4 kHz deviation 9.6 kbps, *2*FSK, ±4.8 kHz deviation 38.4 kbps, GFSK, ±19.8 kHz deviation 50 kbps, 2FSK, ±25.4 kHz deviation 115.2 kbps, GFSK, ±76.2 kHz deviation 250 kbps, GFSK, ±127 kHz deviation	26.3 67.0 28.6 79.7 116.4 201.2 430.3	kHz
Stability, HGM Maximum VSWR with PATABLE = 0x80	**+25˚C - +85˚C:** VDD: 2.0 – 3.6 V **-20˚C:** VDD: 2.0 – 3.6 V VDD: 2.0 – 3.0 V **-40˚C:** VDD: 2.0 – 3.6 V VDD: 2.0 – 3.0 V	 < 6 < 3 < 4.5 < 3 < 4.5	

Table 4.5. Transmit Parameters

4.4.1 Typical TX Performance vs. Temperature and VDD

T_C = 25°C, VDD = 3.0 V, f = 915 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 915 MHz reference design [3] with a 50 Ω load.

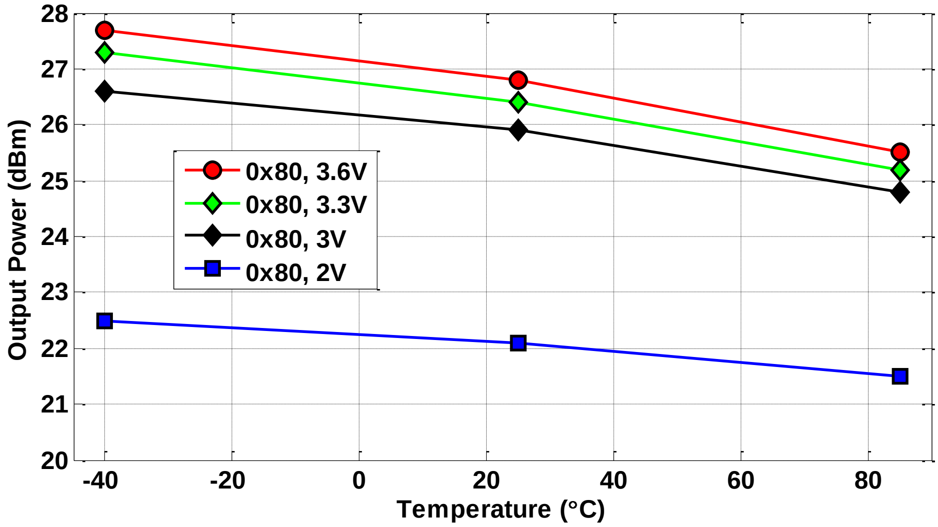

Figure 4.12. Typical Output Power vs. Temperature and Power Supply Voltage. PATABLE = 0x80

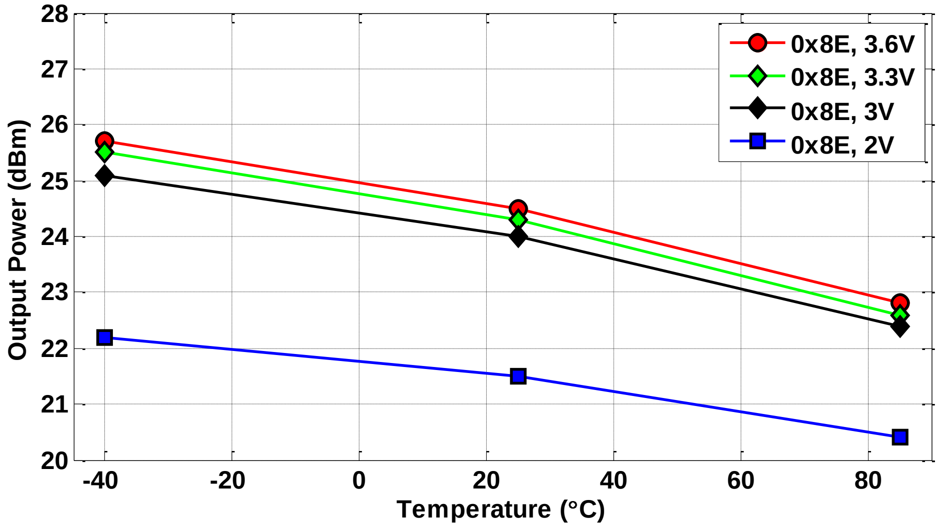

Figure 4.13. Typical Output Power vs. Temperature and Power Supply Voltage. PATABLE = 0x8E

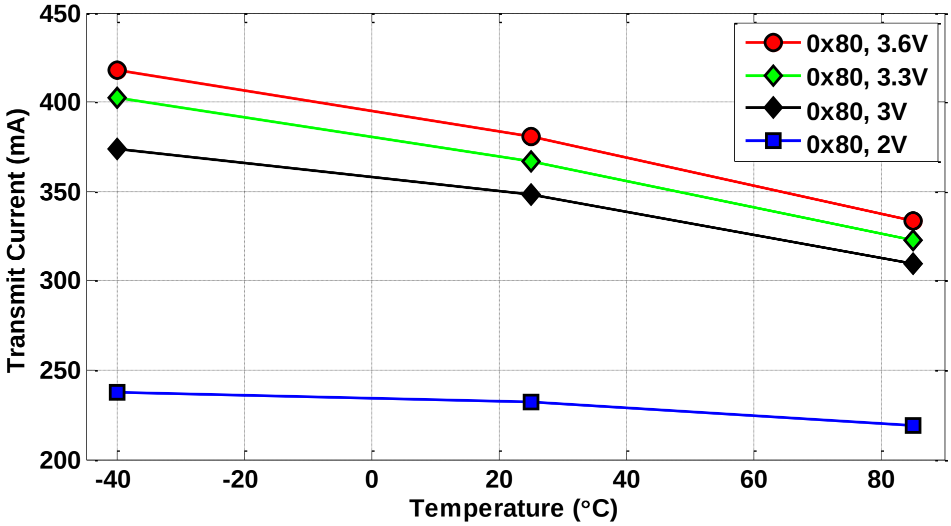

Figure 4.14. Typical TX Current Consumption vs. Temperature and Power Supply Voltage. PATABLE = 0x80

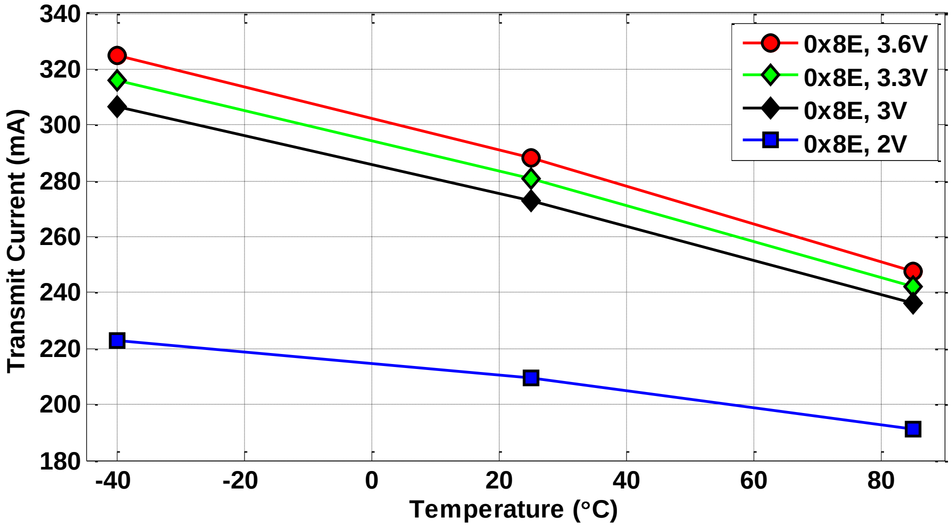

Figure 4.15. Typical TX Current Consumption vs. Temperature and Power Supply Voltage. PATABLE = 0x8E

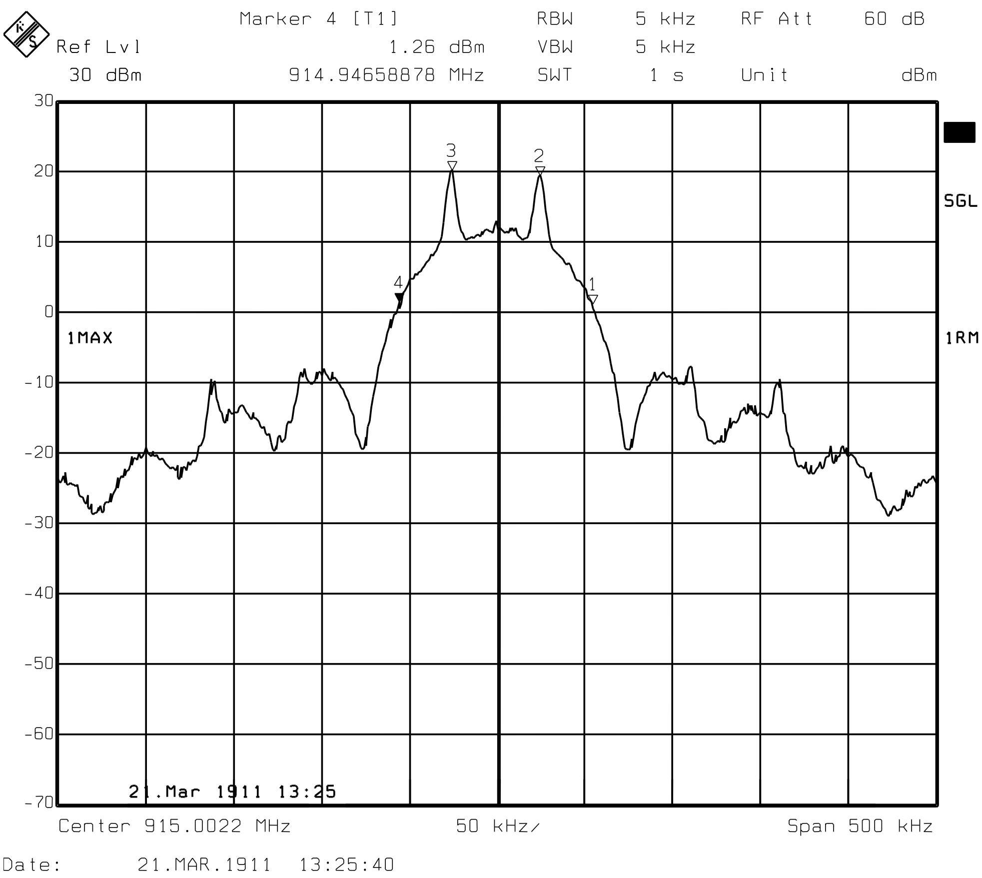

Figure 4.16. Typical Modulation Bandwidth, 50 kbps, PATABLE = 0x80. Measured according to FCC 15.247

4.4.2 Duty Cycling

Section 15.209 gives the general limits for the emission of intentional or unintentional radiators. Above 960 MHz the limit is -41.2 dBm (500 uV/m at 3 m distance). When operating under Section 15.247 the spurious emission must be 20 dB below the carrier unless it falls within one of the restricted bands defined in Section 15.205. When operating in the in the 902-928 MHz frequency range the 3^{rd}, 4^{th}, 5^{th}, and 6^{th} harmonics fall within restricted bands. In the restricted bands the general limits of -41.2 dBm apply.

Pulsed transmissions allow higher peak harmonic and spurious emissions above 1 GHz because an averaging detector is called for in the measurements. The average limit must be below -41.2 dBm, but maximum peak spurious level for pulsed transmission is 20 dB above the average limit. If the duty cycle factor of the periodic signal is known, measuring the peak value and adding a duty cycle relaxation factor determines the average value. The relaxation factor applies to the TX on-time as measured over a 100 ms period. The relaxation factor is 20 log (TX on-time/100 ms) [dB].

As an example, a 50 % duty cycle allows for 6 dB higher peak emission than without duty cycling. Figure 4.17 gives the relaxation factor for different transmission on-times over a 100 ms period.

If the TX on-time is above 100 ms duty cycle relaxation cannot be applied and the maximum output power, when using the CC1101+CC1190 915 MHz reference design, is limited to +24 dBm (see Table 4.5).

The CC1101+CC1190 915 MHz reference design has a maximum output power of +26 dBm. The radiated 3^{rd} harmonic is then typically <-38 dBm and a minimum 3.2 dB duty cycle relaxation factor must be applied to get the average value below -41.2 dBm. The maximum TX on-time in any 100 ms period is thus limited to 69 ms as seen in Figure 4.17.

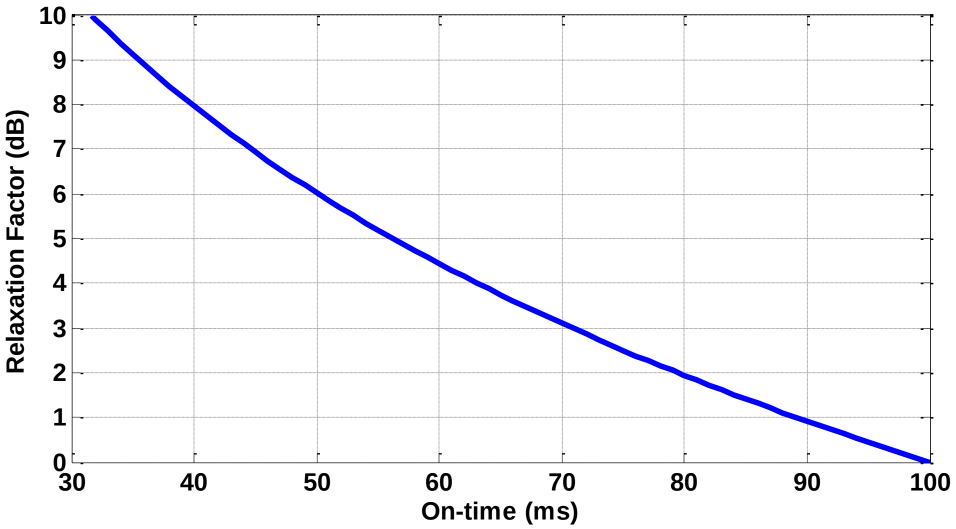

Figure 4.17. Relaxation Factor vs. Duty Cycling

4.4.3 Typical TX Parameters vs. Load Impedance

The load impedance presented to the CC1190 PA output is critical to the TX performance of the reference design. The load impedance is selected as a compromise between several criteria, such as output power, efficiency and the level of the harmonics. The matching components between the PA output and the antenna should transform 50 ohm antenna impedance to the selected impedance which the CC1190 PA should see. This is taken care of by the reference design and the user should provide a well matched antenna to get the required performance.

In order to measure the performance under different mismatch conditions the CC1101-CC1190EM 915 MHz reference design is loaded with different impedances at the SMA connector reference plane. A well matched antenna will have impedance inside the black circle in the Smith chart, which illustrates the limit for 10 dB return loss. At each load the output power, current and spurious frequency components are measured. These measurements are known as load-pull measurements.

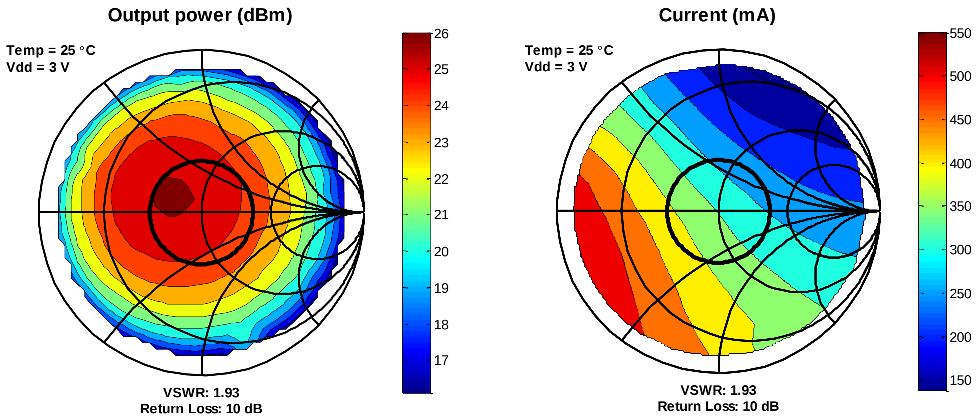

Figure 4.18. Output Power (left) and Current (right) vs. Load Impedance at SMA Connector at 25°C. PATABLE = 0x80.

Most PAs have the ability to oscillate at unwanted frequencies under certain conditions. The worst conditions are usually high output power, low temperatures, and high VDD. This is also the case for CC1190. The spurious frequency components are measured under different mismatch conditions as illustrated in Figure 4.19 and Figure 4.20. The blue colors indicate that the spurious levels are at the noise floor. The CC1101-CC1190EM 915 MHz reference design is a very robust design which tolerates high mismatch ratios at high output power, low temperatures and high VDD.

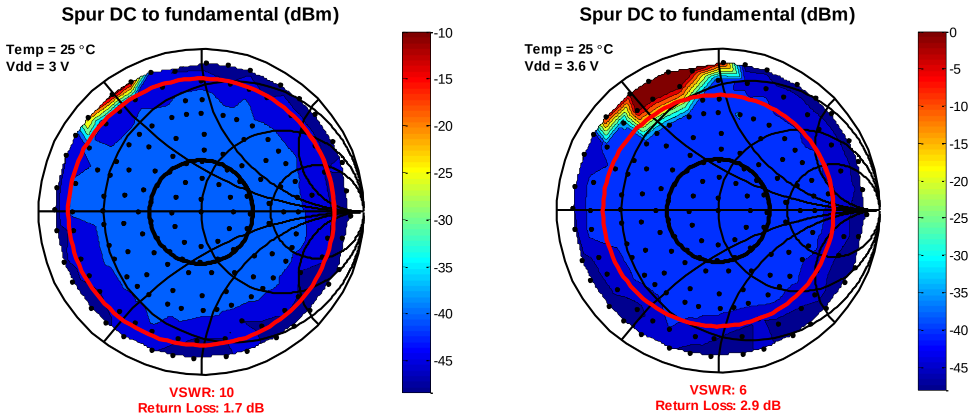

Figure 4.19. Spurious Frequency Components vs. Load Impedance at SMA Connector at 25°C. PATABLE = 0x80.

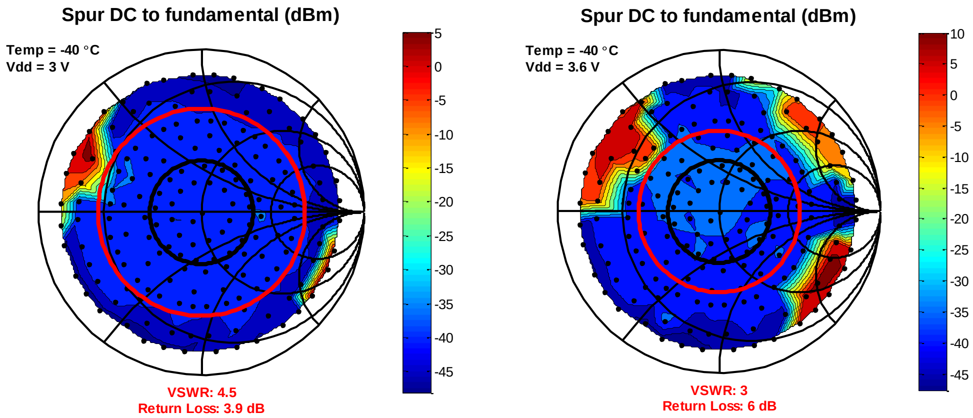

Figure 4.20. Spurious Frequency Components vs. Load Impedance at SMA Connector at -40°C. PATABLE = 0x80.

4.5 Measurement Equipment

The following equipment was used for the measurements.

Measurement	Instrument Type	Instrument Model
RX	Signal Generator	Rohde & Schwarz SMF Rohde & Schwarz SMIQ 06B
TX	Signal Analyzer	Rohde & Schwarz FSG
RX/TX	Power Supply	Agilent E3631A
	Multimeter	Keithley 2000
Stability	Automatic Tuner	Maury MT986EU32
Radiated spurious Emissions	EMC chamber	

Table 4.6. Measurement Equipment

5 Controlling the CC1190

There are three digital control pins (PA_EN, LNA_EN, and HGM) that sets the CC1190 mode of operation.

PA_EN	LNA_EN	HGM	Mode of Operation
0	0	X	Power Down
0	1	0	RX LGM
0	1	1	RX HGM
1	0	0	TX LGM
1	0	1	TX HGM

Table 5.1. CC1190 Control Logic

There are different ways of controlling the CC1190 mode of operation in a CC1101-CC1190 design.

- Using CC1101 GDO0 and GDO2[3] pins to set two of the CC1190 control signals (e.g. PA_EN and LNA_EN). The third control signal (e.g. HGM) can be hardwired to GND/VDD or connected to an external MCU.
- Using an external MCU to control PA_EN, LNA_EN, and HGM.

Using an external MCU to set two (or all three) digital control signals is the recommended solution for a CC1101-CC1190 design since GDO0 or GDO2 is typically programmed to provide a signal related to the CC1101 packet handler engine to the interfacing MCU and GDO1 is the same pin as the SO pin on the SPI interface. The GDO pin not used to provide information to the interfacing MCU can be used to control the CC1190.

Figure 5.1 shows a simplified application circuit where an external MCU controls HGM and LNA_EN. PA_EN is controlled either by external MCU or one of the CC1101 GDO pins.

[3] GDO1 is not used since this is the same pin as the SO pin on the SPI interface. The output programmed on this pin will only be valid when CSn is high.

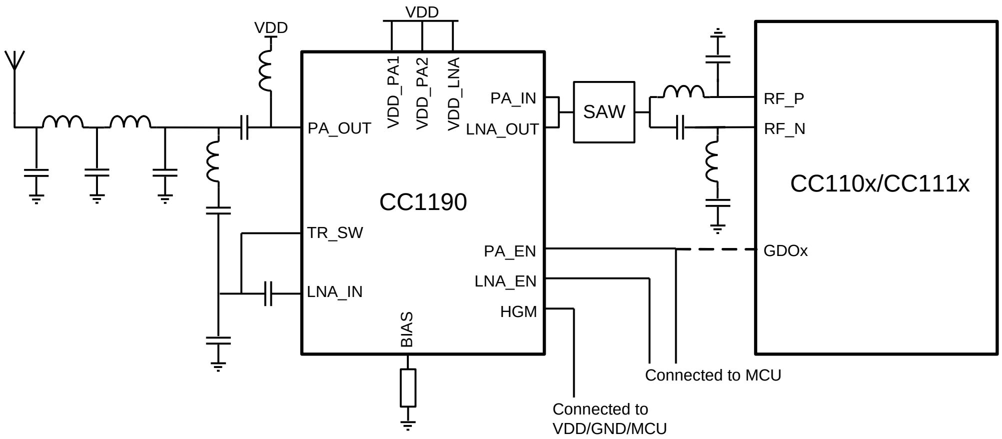

Figure 5.1. Simplified CC11xx-CC1190 Application Circuit

6 SmartRF Studio and SmartRF04EB / TrxEB

The CC1101-CC1190EM 915 MHz together with SmartRF™ Studio 7 software [5] and SmartRF04EB or TrxEB can be used to evaluate performance and functionality.

6.1 SmartRF Studio

The CC1101-CC1190 can be configured using the SmartRF Studio 7 software [5]. The SmartRF Studio software is highly recommended for obtaining optimum register settings. SmartRF Studio 7 uses an external MCU (the USB controller on the Evaluation Boards) to control the three digital control pins (PA_EN, LNA_EN, and HGM). A screenshot of the SmartRF Studio user interface for CC1101-CC1190 is shown in Figure 6.1.

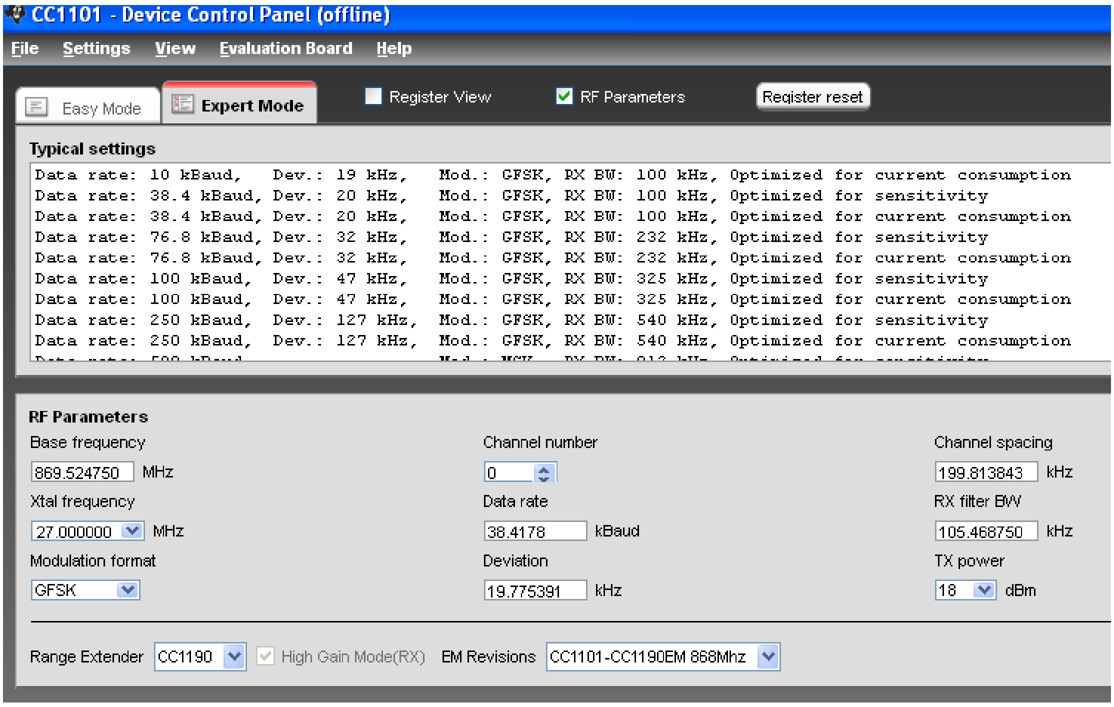

Figure 6.1. SmartRF Studio 7 [5] User Interface (868 MHz version shown)

In order to control the CC1190 the user needs to select CC1190 as "Range Extender" and select the appropriate "EM Revisions" as shown in Figure 6.1.

6.2 SmartRF04EB / TRxEB

If the SmartRF04EB is connected to a USB socket on a PC, it will draw power from the USB bus when the switch is in the position shown in Figure 6.2. The onboard voltage regulator supplies 3.3 V to the board, but has limited current source capability and cannot supply the CC1101-CC1190EM. An external supply is therefore needed and shall be connected as shown in Figure 6.2, where the red wire is the positive supply and the black wire is GND. With the test setup in Figure 6.2 the SmartRF04EB is connected to a 3.3 V supply through the USB and voltage regulator and CC1101-CC1190 is powered by the external supply. Since the SmartRF04EB is connected to a regulated 3.3 V supply the signals going from CC1101-CC1190 to SmartRF04EB (and vice versa) need to be within 3.0 V to 3.6 V. The external supply connected to CC1101-CC1190 when using the test setup in Figure 6.2 is therefore limited to 3.0 V to 3.6 V.

Figure 6.2. SmartRF04EB Connection

If CC1101-CC1190 is used with the TrxEB and the USB controller the supply range is 3.0 V to 3.6 V.

7 Reference Design

The CC1101-CC1190EM 915 MHz reference design includes schematic and gerber files [3]. It is highly recommended to follow the reference design for optimum performance. The reference design also includes bill of materials with manufacturers and part numbers.

7.1 Power Decoupling

Proper power supply decoupling must be used for optimum performance. The capacitors C27-C29 ensure good RF ground after L21 and thus prevent RF leakage into the power supply lines causing oscillations. The power supply filtering consisting of C2, C3 and L2 ensure well defined impedance looking towards the power supply.

7.2 Input/ Output Matching and Filtering

The PA and the LNA of the CC1190 are single ended input/output. A balun is required to transform the differential output of the CC1101 to single ended input of the CC1190 PA and the single ended output of the LNA to the differential input of CC1101. The values of the matching components between the SAW filter and the CC1190 PA input are chosen to present optimum source impedance to the CC1190 PA input with respect to stability.

The CC1190 PA performance is highly dependent on the impedance presented at the output, and the LNA performance is highly dependent on the impedance presented at the input. The impedance is defined by L21 and all components towards the antenna. These components also ensure the required filtering of harmonics to pass regulatory requirements.

The layout and component values need to be copied exactly to obtain the same performance as presented in this application note.

7.3 Bias Resistor

R141 is a bias resistor. The bias resistor is used to set an accurate bias current for internal use in the CC1190.

7.4 SAW Filter

A SAW is recommended for the CC1101-CC1190 design to attenuate spurs below the carrier frequency that will otherwise violate spurious emission limits under Section 15.209 and 15.205 The SAW filter is matched to the CC1190 PA input/LNA output impedance using a series inductor and a shunt capacitor.

7.5 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 recommended to follow the recommendation given in the CC1101–CC1190EM 915 MHz 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. Footprint recommendation for the CC1190 is given in the CC1190 datasheet [2].

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.

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.

7.6 Shielding

RF shielding is necessary to keep the radiated harmonics below the regulatory limits.

8 Disclaimer

The CC1101-CC1190EM evaluation board is intended for use for ENGINEERING DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY and is not considered by TI to be a finished end-product fit for general consumer use. Persons handling the product(s) must have electronics training and observe good engineering practice standards. As such, the goods being provided are not intended to be complete in terms of required design-, marketing-, and/or manufacturing-related protective considerations, including product safety and environmental measures typically found in end products that incorporate such semiconductor components or circuit boards. This evaluation board has been tested against FCC Section 15.247, 15.209, and 15.205 regulations, but there has been no formal compliance testing at an external test house. It is the end user's responsibility to ensure that his system complies with applicable regulations.

9 References

[1] CC1101 Datasheet (SWRS061.pdf)

[2] CC1190 Datasheet (SWRS089.pdf)

[3] CC1101–CC1190EM 915 MHz Reference Design (SWRR077.zip)

[4] FCC rules (www.fcc.gov)

[5] SmartRF™ Studio 7 (SWRC176.zip)

10 General Information

10.1 Document History

Revision	Date	Description/Changes
SWRA361	2011.03.28	Initial release.
SWRA361A	2011.05.02	Corrected figure text in Figure 4.20 from 25C to -40C