Using the CC1190 Front End with CC1101 under EN 300 220

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Keywords

- *Range Extender*
- *EN 300 220*
- *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 EN 300 220-1 V2.3.1 [4] in the 869.4-869.65 MHz frequency sub-band (g3). The maximum allowed output power in the 869.4-869.65 MHz sub-band is +27 dBm (500 mW), but due to the CC1101 phase noise the maximum output power using the CC1101-CC1190EM 869 MHz reference design [3] is approximately +18 dBm in order to meet modulation bandwidth requirements. The final output power level will depend on the antenna being used.

For details on the regulatory limits in the 863-870 MHz SRD frequency bands, please refer to the ETSI EN 300 220-1 V2.3.1 [4] and ERC Recommendation 70-03 [5]. These can be downloaded from www.etsi.org and www.ero.dk.

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.

This application note assumes the reader is familiar with CC1101 and EN 300 220. The reader is referred to [2] and [4] for details.

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2 Abbreviations

AFA	Adaptive Frequency Agility
EB	Evaluation Board
EIRP	Equivalent Isotropically Radiated Power
EM	Evaluation Module
HGM	High Gain Mode
LBT	Listen-before-Talk
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
SoC	System-on-Chip
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 recommended register settings presented in Chapter 7 and the CC1101-CC1190EM 869 MHz reference design [3].

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 = 869.525 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 869 MHz reference design [3] with a 50 Ω load.

Parameter	Condition	Typical	Unit
Receive Current, HGM	1.2 kbps	20	mA
	4.8 kbps	20	mA
	38.4 kbps	20	mA
Receive Current, LGM	1.2 kbps	17	mA
	4.8 kbps	17	mA
	38.4 kbps	17	mA
Transmit Current[1]	PATABLE = 0x54 (+20 dBm) PATABLE = 0x55 (+19 dBm) PATABLE = 0x57 (+18 dBm) PATABLE = 0x36 (+17 dBm) PATABLE = 0x28 (+16 dBm) PATABLE = 0x27 (+15 dBm)	138 132 120 112 104 99	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 = 869.525 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 869 MHz reference design [3] with a 50 Ω load.

Parameter	Condition	Typical	Unit
Sensitivity[2], HGM	1.2 kbps, GFSK, ±14.8 kHz deviation, 60 kHz RX filter bandwidth. See Figure 4.1.	-118	dBm
	1.2 kbps, GFSK, ±4.9 kHz deviation, 60 kHz RX filter bandwidth. See Figure 4.1.	-115	dBm
	4.8 kbps, GFSK, ±24.7 kHz deviation, 105 kHz RX filter bandwidth. See Figure 4.2.	-113	dBm
	38.4 kbps, GFSK, ±19.8 kHz deviation, 105 kHz RX filter bandwidth. See Figure 4.3.	-108	dBm
Sensitivity, LGM	1.2 kbps, GFSK, ±14.8 kHz deviation, 60 kHz RX filter bandwidth. See Figure 4.4.	-104	dBm
	1.2 kbps, GFSK, ±4.9 kHz deviation, 60 kHz RX filter bandwidth. See Figure 4.4.	-101	dBm
	4.8 kbps, GFSK, ±24.7 kHz deviation, 105 kHz RX filter bandwidth. See Figure 4.5.	-99	dBm
	38.4 kbps, GFSK, ±19.8 kHz deviation, 105 kHz RX filter bandwidth. See Figure 4.6.	-94	dBm
Saturation, HGM	Maximum input power level for 1% PER	-23	dBm
Saturation, LGM	Maximum input power level for 1% PER	-6	dBm
Selectivity and Blocking, HGM and LGM	1.2 kbps. 60 kHz RX filter bandwidth Wanted signal 3 dB and 16 dB above the sensitivity level. Unmodulated interferer. See Figure 4.7. ±2 MHz from wanted signal[3] ±10 MHz from wanted signal[4]	 60 83	dB
	4.8 kbps. 105 kHz RX filter bandwidth. Wanted signal 3 dB and 16 dB above the sensitivity level. Unmodulated interferer. See Figure 4.8. ±2 MHz from wanted signal ±10 MHz from wanted signal	 55 80	dB
	38.4 kbps. 105 kHz RX filter bandwidth. Wanted signal 3 dB and 16 dB above the sensitivity level. Unmodulated interferer. See Figure 4.9. ±2 MHz from wanted signal ±10 MHz from wanted signal	 55 80	dB
Spurious emission[5], HGM	Conducted measurement below 1 GHz Conducted measurement above 1 GHz Radiated VCO leakage (See Figure 4.10)	< -70 < -70 < -54	dBm

Table 4.3. Receive Parameters

[2] Sensitivity limit is defined as 1% packet error rate (PER). Packet length is 20 bytes.
[3] Receiver class 2. Limit at ±2 MHz offset: ≥35 dB – 10log(RX_BW/16). RX_BW in kHz.
[4] Receiver class 2. Limit at ±10 MHz offset: ≥60 dB – 10log(RX_BW/16). RX_BW in kHz.
[5] ETSI EN 300 220 limit: -57 dBm below 1 GHz, -47 dBm above 1 GHz

4.3.1 Typical RX Performance Curves

T_C = 25°C, VDD = 3.0 V, f = 869.525 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 869 MHz reference design [3] with a 50 Ω load.

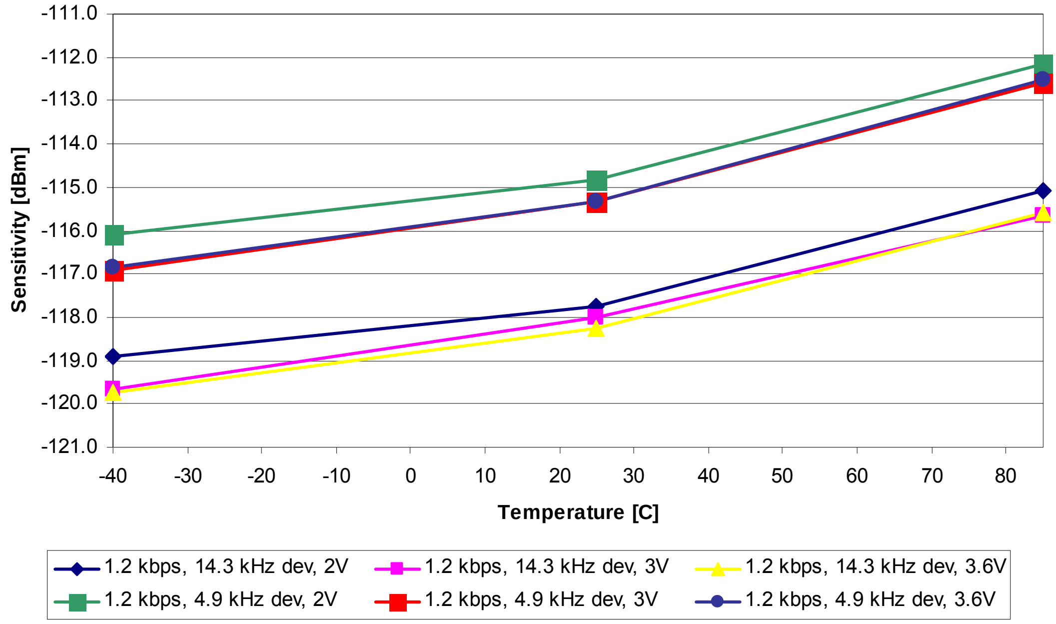

Figure 4.1. Typical Sensitivity vs. Temperature and Power Supply Voltage, HGM, 1.2 kbps

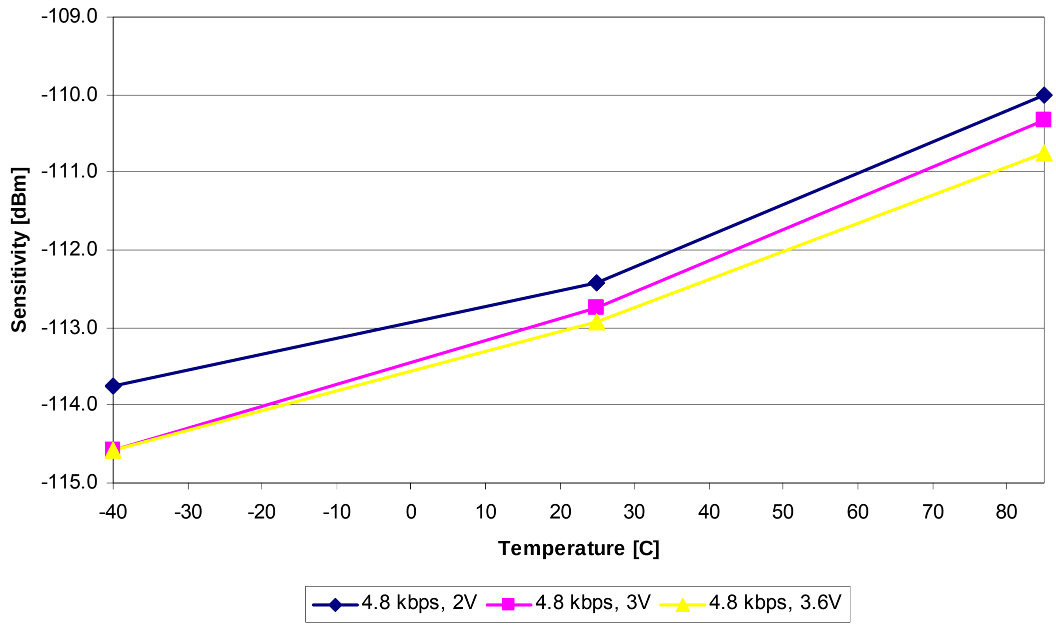

Figure 4.2. Typical Sensitivity[2] vs. Temperature and Power Supply Voltage, HGM, 4.8 kbps

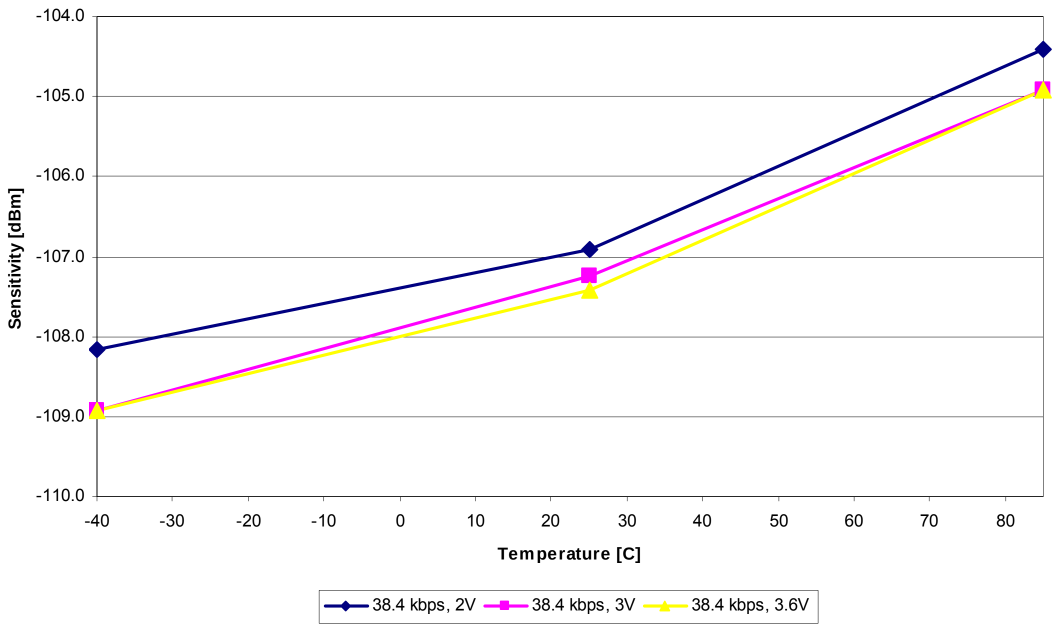

Figure 4.3. Typical Sensitivity[2] vs. Temperature and Power Supply Voltage, HGM, 38.4 kbps

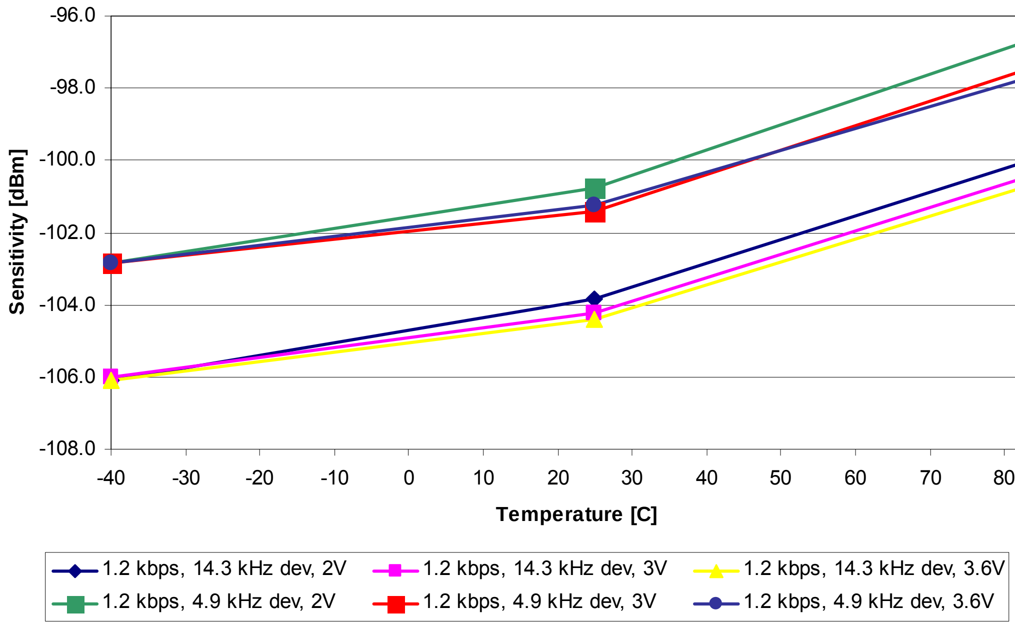

Figure 4.4. Typical Sensitivity[2] vs. Temperature and Power Supply Voltage, LGM, 1.2 kbps

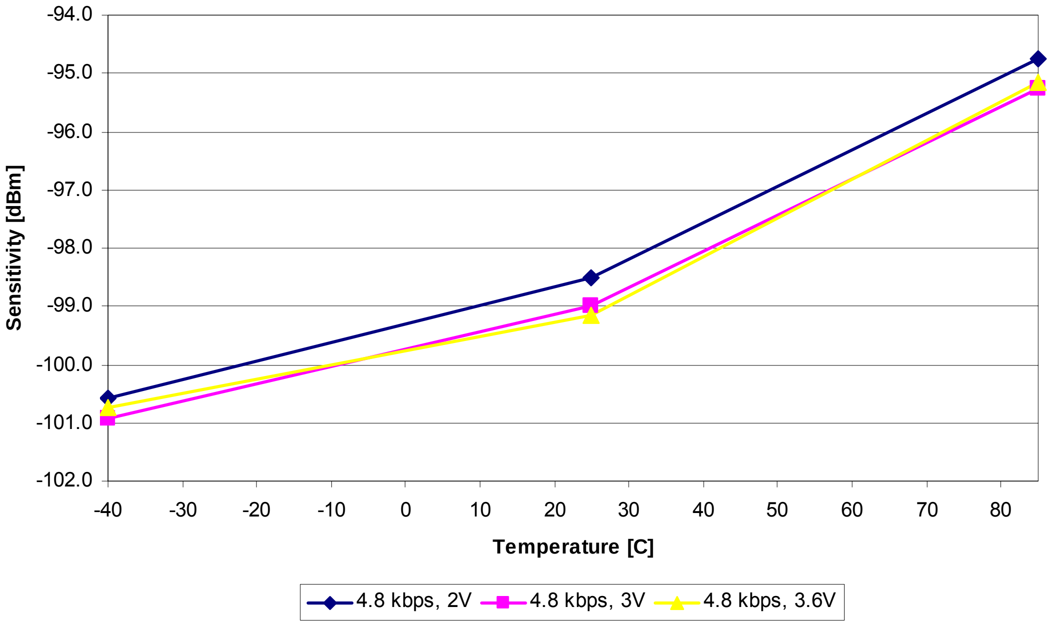

Figure 4.5. Typical Sensitivity[2] vs. Temperature and Power Supply Voltage, LGM, 4.8 kbps

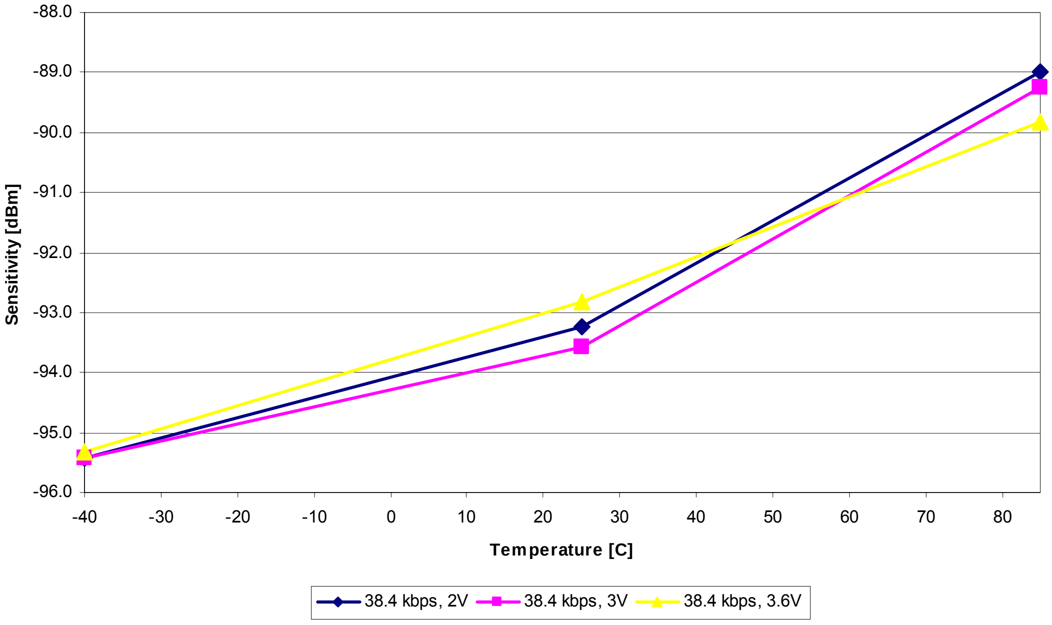

Figure 4.6. Typical Sensitivity[2] vs. Temperature and Power Supply Voltage, LGM, 38.4 kbps

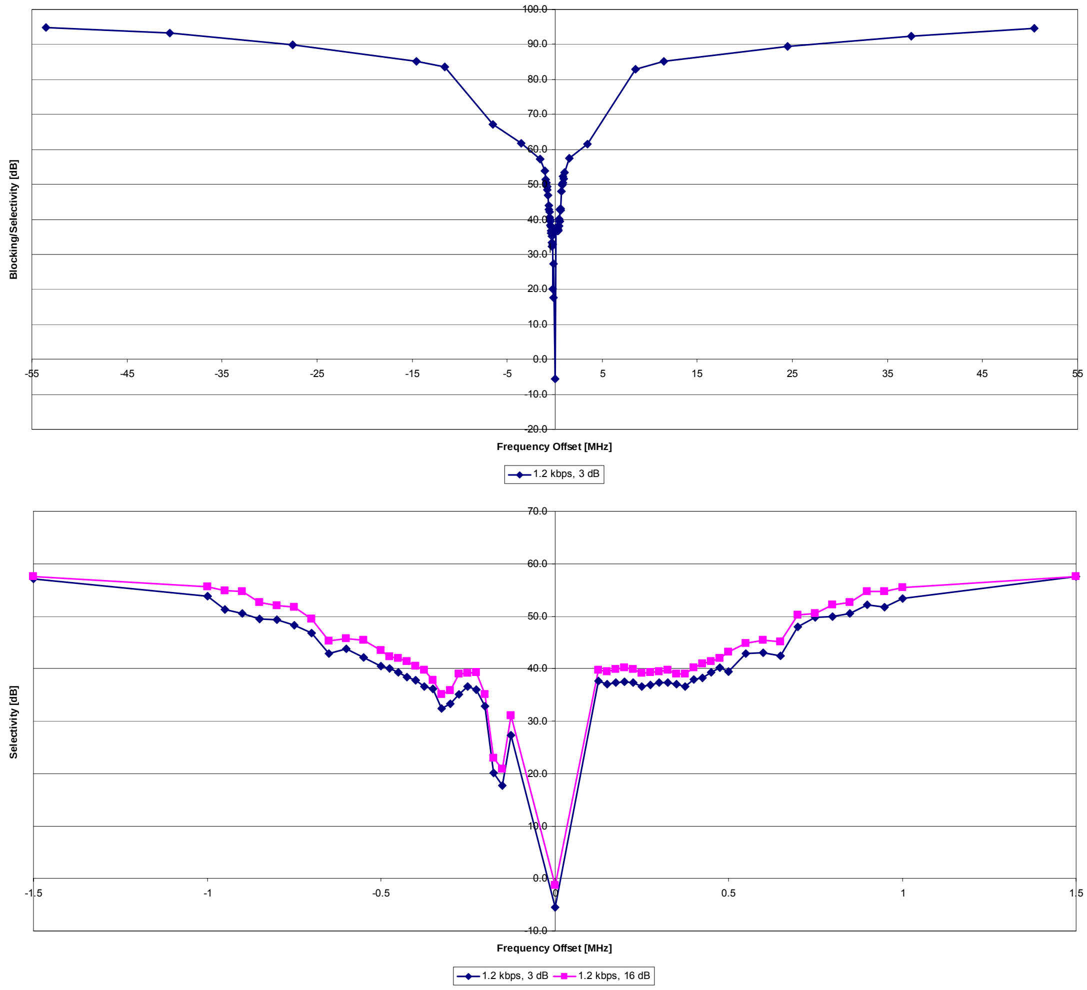

Figure 4.7. Typical Blocking / Selectivity, 1.2 kbps

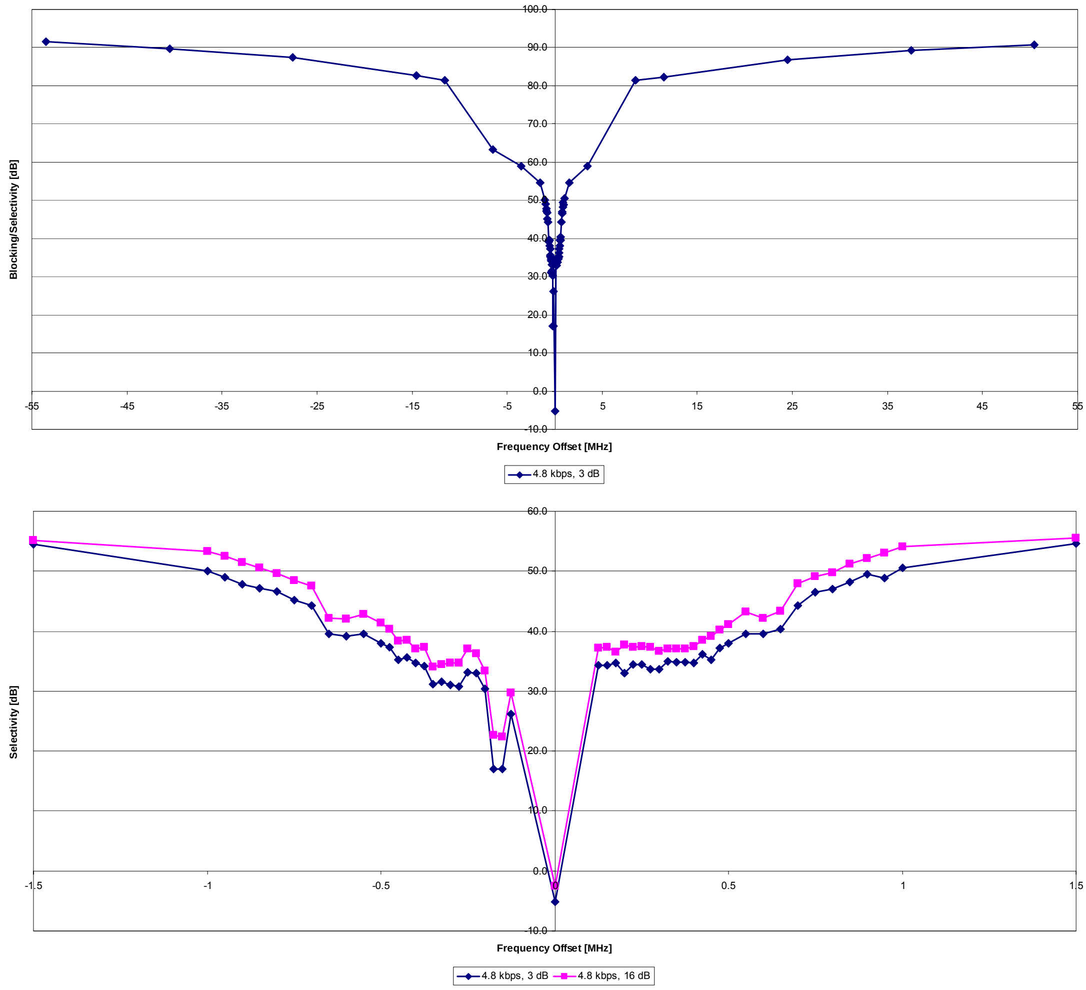

Figure 4.8. Typical Blocking / Selectivity, 4.8 kbps

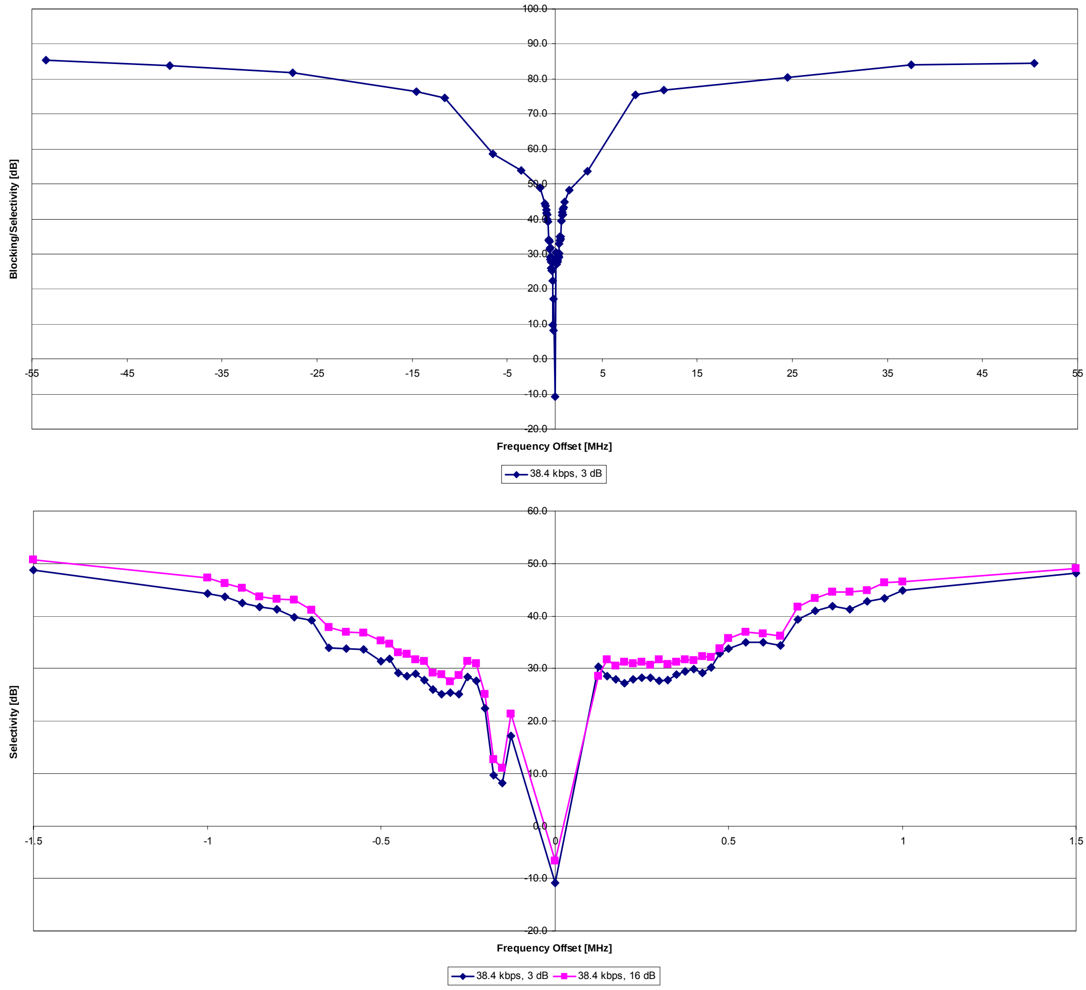

Figure 4.9. Typical Blocking / Selectivity, 38.4 kbps

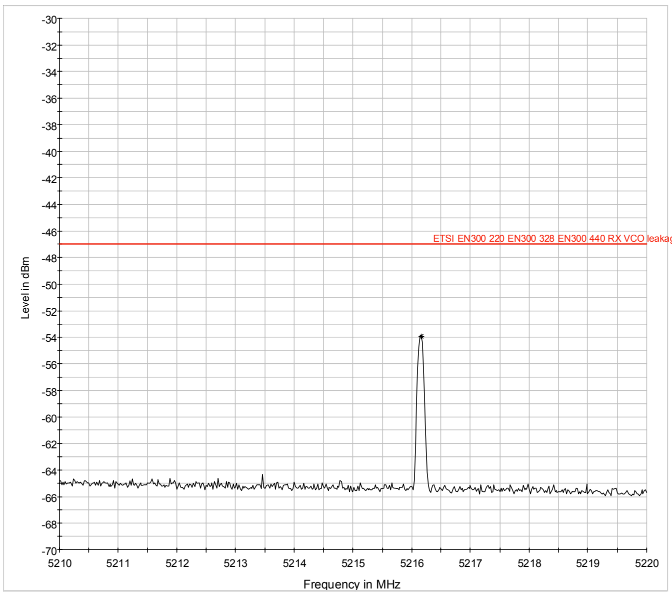

Figure 4.10. Typical RX Radiated Spurious Emission, HGM (VCO leakage worst angle)

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

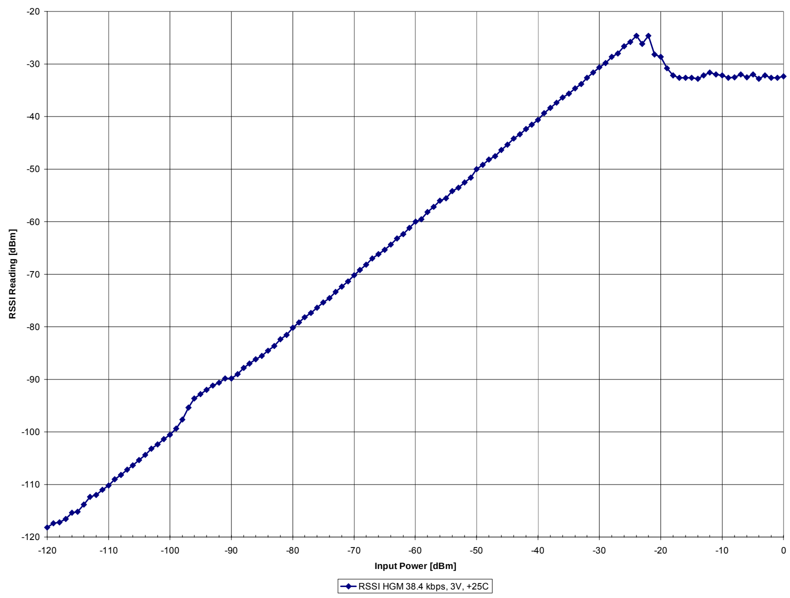

Figure 4.11. Typical RSSI vs. Input Power Level, HGM, 38.4 kbps

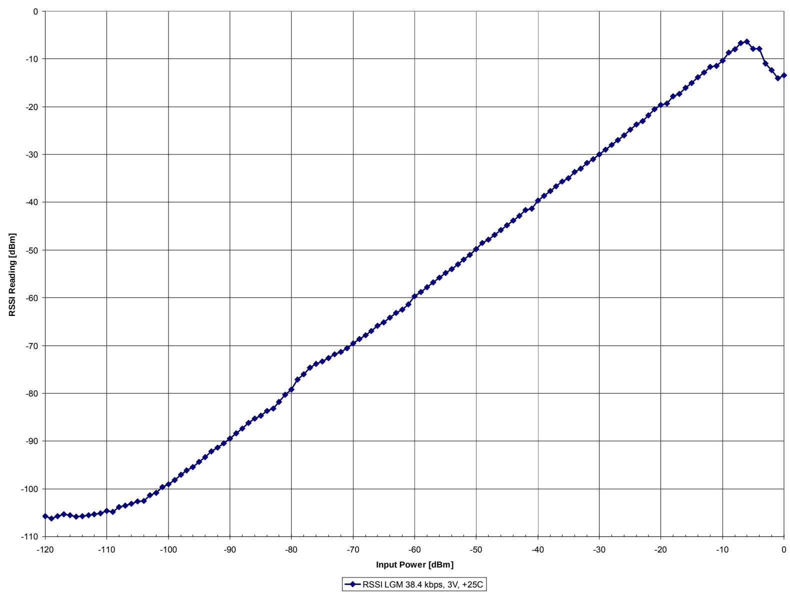

Figure 4.12. Typical RSSI vs. Input Power Level, LGM, 38.4 kbps

4.3.3 Listen Before Talk (LBT) Threshold

If LBT is implemented in the protocol the channel is not considered available for use if the received signal is above the LBT threshold. Conversely, if the received signal is below the LBT threshold, the channel is considered available for use. Note that if the protocol implements LBT without Adaptive Frequency Agility (AFA), the duty cycle limit applies. Refer to EN 300 220-1 V2.3.1 for more details [4].

For a given AGCCTRL2.MAX_LNA_GAIN and AGCCTRL2.MAX_DVGA_GAIN register setting the absolute threshold can be adjusted ±7 dB in steps of 1 dB using AGCCTRL1.CARRIER_SENSE_ABS_THR. See CC1101 data sheet [1] for more details. Table 4.5 shows the LBT threshold for HGM and LGM mode with CARRIER_SENSE_ABS_THR = 7 (+7 dB) and 9 (-7 dB) respectively. Table 4.5 shows that CC1101-CC1190EM 869 MHz reference design comply with the EN 300 220-1 V2.3.1 LBT threshold limit for both HGM and LGM.

If the protocol implements LBT it is better to have the threshold closer to the LBT threshold limit. It is recommended, but not required to have the CC1190 in LGM when doing LBT.

Data Rate [kbps]	RX BW [kHz]	HGM [dBm]	LGM [dBm]	Limit[6] [dBm]
1.2	60	-98 (+7 dB)	-93 (-7 dB)	-92.3 / -96.3
4.8	105	-96 (+7 dB)	-90 (-7 dB)	-89.8 / -93.8
38.4	105	-97 (+7 dB)	-90 (-7 dB)	-89.8 / -93.8

Table 4.5. Typical LBT Threshold (the number in brackets refer to CARRIER_SENSE_ABS_THR setting used)

[6] Limits are for output power <100 mW / 500 mW

4.4 Transmit Parameters

T_C = 25°C, VDD = 3.0 V, f = 869.525 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 869 MHz reference design [3] with a 50 Ω load. Radiated measurements are done with the kit antenna.

Parameter	Condition	Typical	Unit
Output power, HGM	PATABLE = 0x54 PATABLE = 0x55 PATABLE = 0x57 PATABLE = 0x36 PATABLE = 0x28 PATABLE = 0x27	20 19 18 17 16 15	dBm
Efficiency, HGM	PATABLE = 0x54 PATABLE = 0x55 PATABLE = 0x57 PATABLE = 0x36 PATABLE = 0x28 PATABLE = 0x27	22 20 17 14 12 11	%
Spurious emission with PATABLE = 0x54, HGM	Conducted below 1 GHz Conducted above 1 GHz Radiated below 1 GHz Radiated above 1 GHz See Figure 4.17 for radiated measurements above 1 GHz	< -60 < -55 < -60 < -36	dBm
Modulation bandwidth, HGM	See Figure 4.18		
Stability, HGM Maximum VSWR with PATABLE = 0x54	+25˚C - +85˚C: VDD: 2.0 – 3.6 V -20˚C: VDD: 2.0 – 3.6 V -40˚C: VDD: 2.0 – 3.6 V VDD: 2.0 – 3.4 V	 < 15 < 11.5 < 4 < 5.5	

Table 4.6. Transmit Parameters

4.4.1 Typical TX Performance Curves

T_C = 25°C, VDD = 3.0 V, f = 869.525 MHz if nothing else is stated. All parameters are measured on the CC1101-CC1190EM 869 MHz reference design [3] with a 50 Ω load.

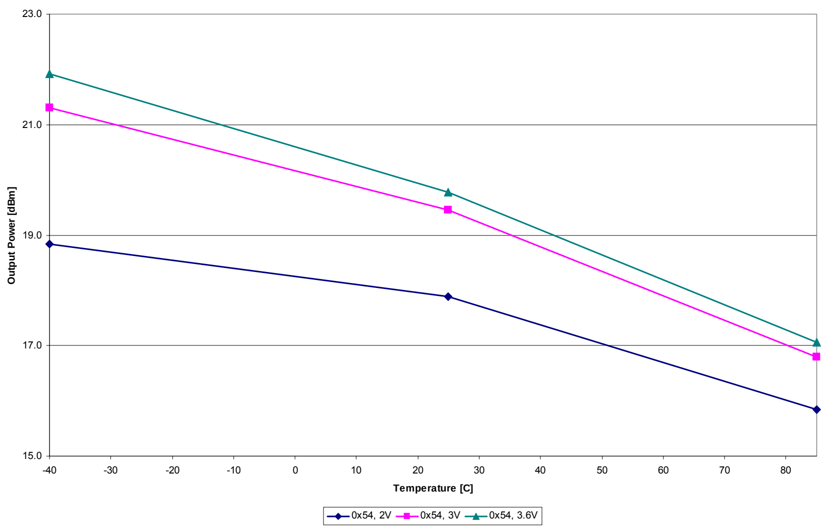

Figure 4.13. Typical Output Power vs. Temperature and Power Supply Voltage. PATABLE = 0x54

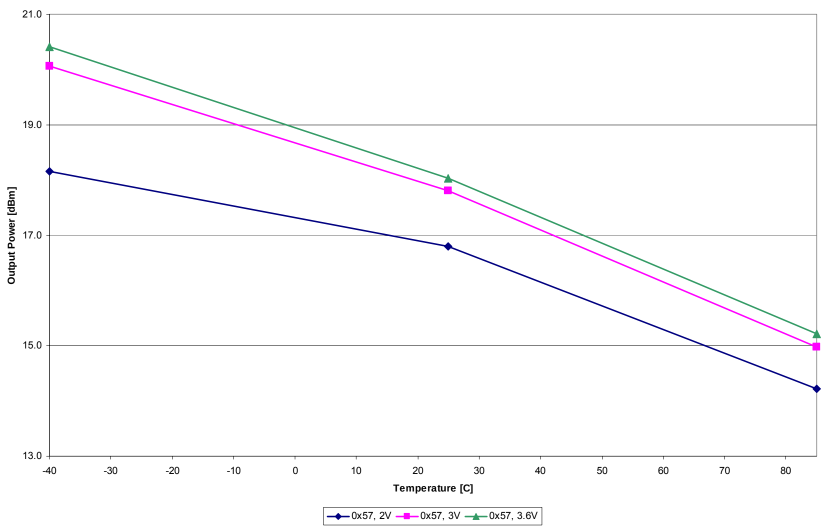

Figure 4.14. Typical Output Power vs. Temperature and Power Supply Voltage. PATABLE = 0x57

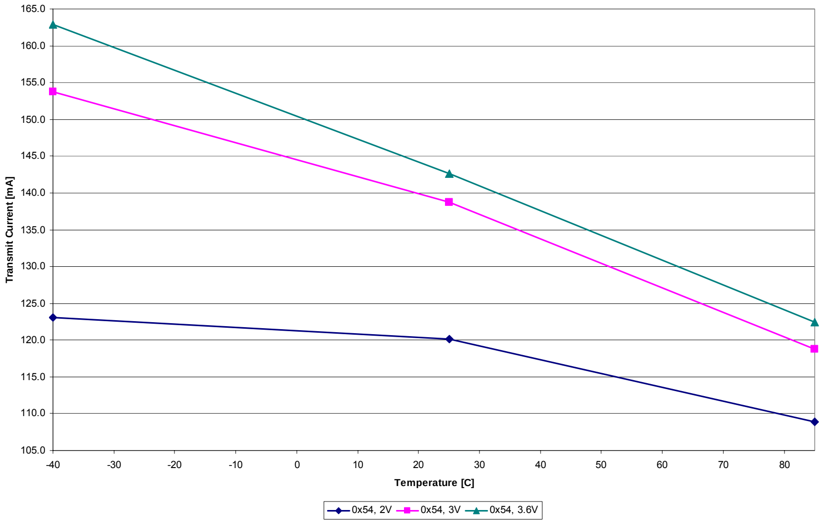

Figure 4.15. Typical TX Current Consumption vs. Temperature and Power Supply Voltage. PATABLE = 0x54

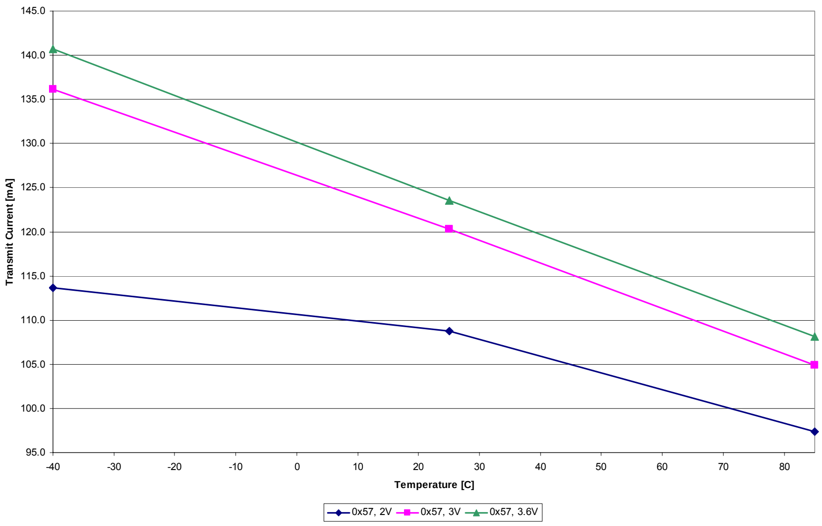

Figure 4.16. Typical TX Current Consumption vs. Temperature and Power Supply Voltage. PATABLE = 0x57

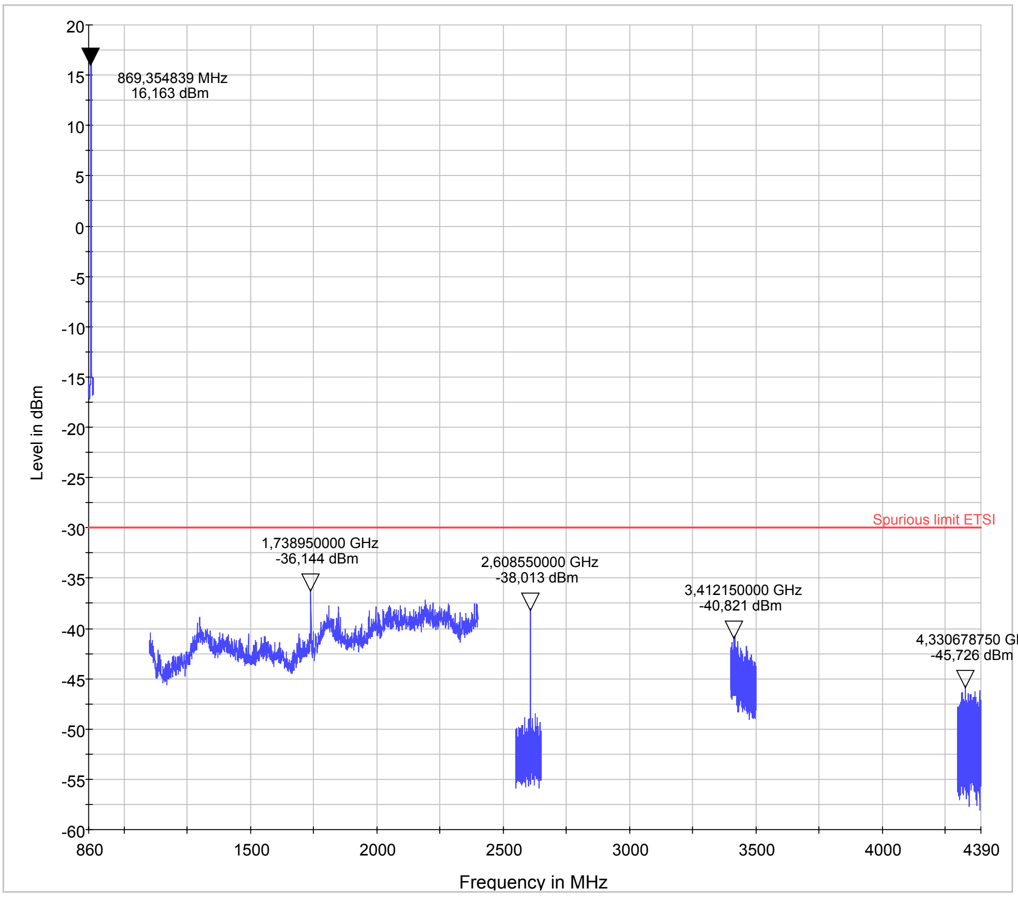

Figure 4.17. Typical Radiated Fundamental and Spurious Emission Measured at Angle with Highest Spurious Emissions. PATABLE = 0x54

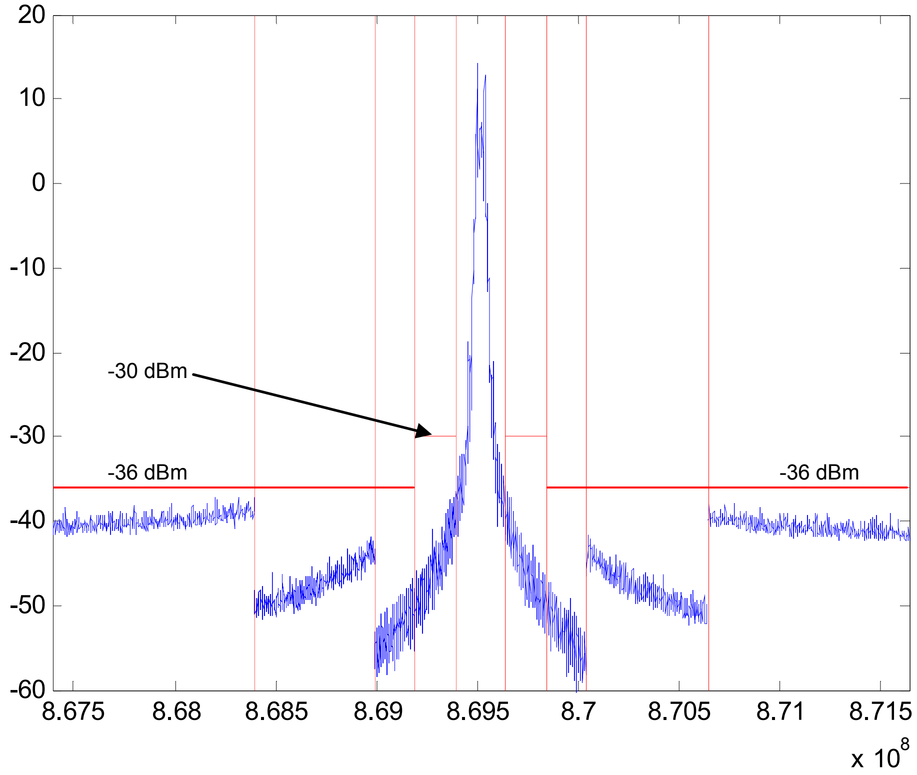

Figure 4.18. Typical Modulation Bandwidth, 38.4 kbps, PATABLE = 0x57. Measured with Resolution Bandwidth According to ETSI EN 300 220-1 [4]

5 Measurement Equipment

The following equipment was used for the measurements.

Measurement	Instrument Type	Instrument Model
RX	Signal Generator	Rohde & Schwarz SMT-03 Rohde & Schwarz SMIQ 06B
TX	Signal Analyzer	Rohde & Schwarz FSQ 26
RX/TX	Power Supply	Agilent E3631A
	Multimeter	Keithley 2000
Stability	Automatic Tuner	Maury MT986EU32
Radiated spurious Emissions	EMC chamber	

Table 5.1. Measurement Equipment

6 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 6.1. CC1190 Control Logic

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

- Using CC1101 GDO0 and GDO2[7] 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 6.1 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.

[7] 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.

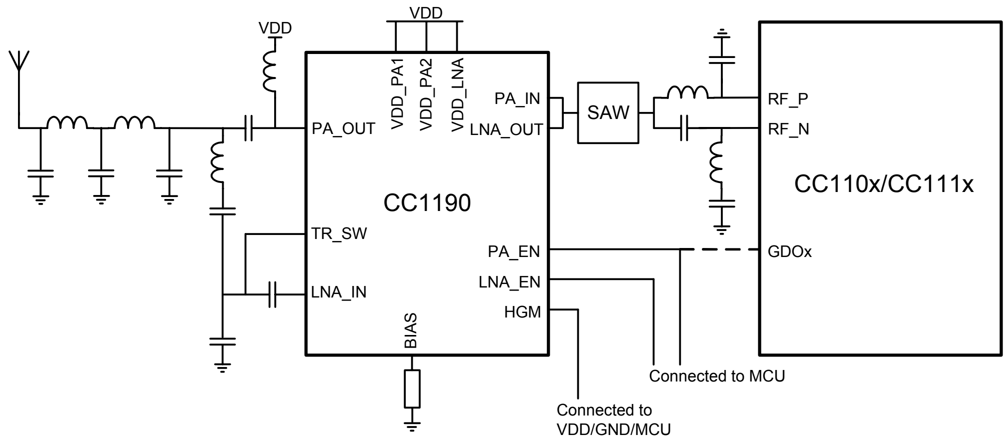

Figure 6.1. Simplified CC11xx-CC1190 Application Circuit

7 CC1101 Register Settings

It is possible to improve the CC1101 phase noise above approximately 200 kHz offset at the cost of increased spurs at RF ± crystal frequency/2 by changing the FIFOTHR and TEST1 register settings. These settings are not used for the CC1101 standalone design due to the increased spur level, but since a SAW filter is used in the CC1101-CC1190 design, the spurs will be attenuated sufficiently to meet EN 300 220 spurious emission requirements. Improving the CC1101 phase noise reduces the modulation bandwidth for a given output power and allows operation up to +18 dBm output power.

For a given data rate a CC1101 design and a CC1101-CC1190 design can use the same register settings except for registers FIFOTHR and TEST1. The register values listed in Table 7.1 need to be used for optimum performance. The same register settings cannot be used in both TX and RX.

CC1101 Register	Setting TX	Setting RX
FIFOTHR	0xC7	0x47
TEST1	0x2D	0x35

Table 7.1. Recommended Register Settings for the CC1101-CC1190 Design

8 SmartRF Studio and SmartRF04EB / TrxEB

The CC1101-CC1190EM 869 MHz together with SmartRF™ Studio 7 software [6] and SmartRF04B or TrxEB can be used to evaluate performance and functionality.

8.1 SmartRF Studio

The CC1101-CC1190 can be configured using the SmartRF Studio 7 software [6]. The SmartRF Studio software is highly recommended for obtaining optimum register settings. The recommended register settings for RX and TX in Table 4.1 are implemented in SmartRF Studio 7. 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 8.1.

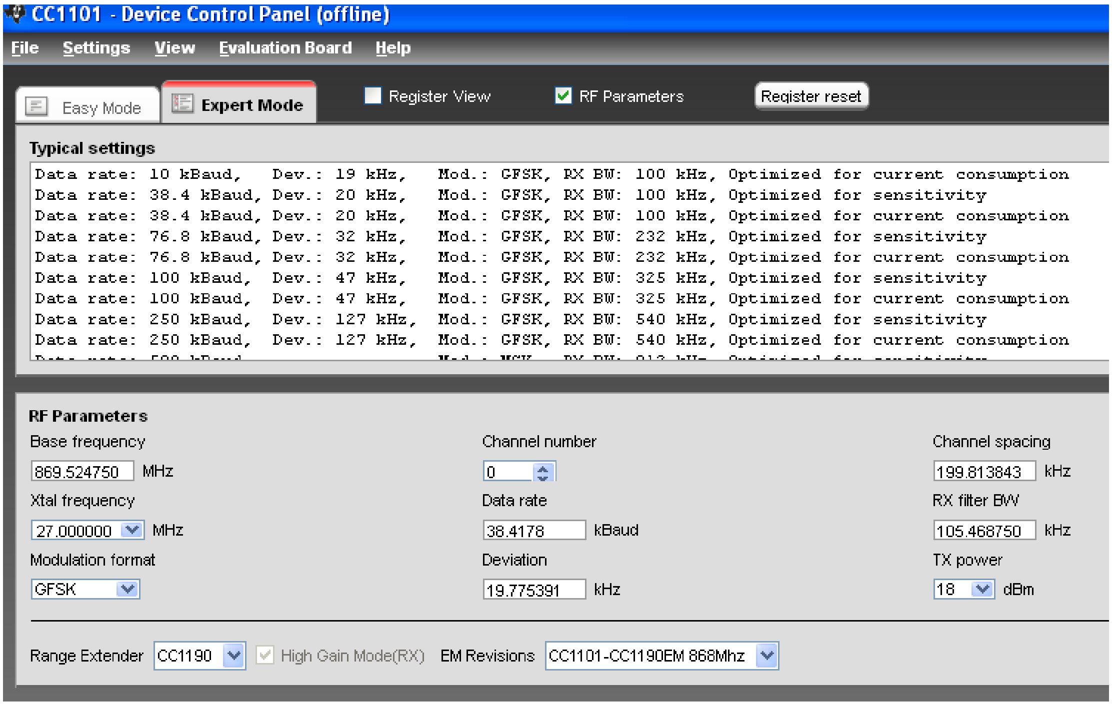

Figure 8.1. SmartRF Studio 7 [6] User Interface

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 8.1.

8.2 SmartRF04EB / TRxEB

If the SmartRF04B 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 8.2. 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 8.2, where the red wire is the positive supply and the black wire is GND. With the test setup in Figure 8.2 the SmartRF04B 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 SmartRF04B is connected to a regulated 3.3 V supply the signals going from CC1101-CC1190 to SmartRF04B (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 8.2 is therefore limited to 3.0 V to 3.6 V.

Figure 8.2. 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.

9 Reference Design

The CC1101-CC1190EM 869 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.

9.1 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.

9.2 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. C30 works as a DC-block.

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

9.3 Bias Resistor

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

9.4 Crystal

There are spurs appearing at N times the reference frequency (= N x crystal frequency/2). These spurs are also folded around the carrier. The further away in Hz the spurs are from the carrier the lower they will be in amplitude. For operation at 869.525 MHz the spur closest to the carrier will be at 864 MHz when using a 27 MHz crystal and at 871 MHz when using a 26 MHz crystal. A 27 MHz crystal frequency is recommended for the CC1101-CC1190 design.

9.5 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 EN 300 220. The SAW filter is matched to the CC1190 PA input/LNA output impedance using a series inductor and a shunt capacitor.

9.6 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 869 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.

10 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 EN 300 220 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.

11 References

[1] CC1101 Datasheet (SWRS061.pdf)

[2] CC1190 Datasheet (SWRS089.pdf)

[3] CC1101–CC1190EM 869 MHz Reference Design (SWRR075.zip)

[4] ETSI EN 300 220 V2.3.1: Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1000 MHz frequency range with power levels ranging up to 500 mW"

[5] CEPT/ERC/Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)"

[6] SmartRF™ Studio 7 (SWRC176.zip)

12 General Information

12.1 Document History

Revision	Date	Description/Changes
SWRA356	2011.01.10	Initial release.