Design Note DN025

Johanson Technology Matched Balun Filter optimized for CC1101 868/915 MHz

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Keywords

- *Matched Balun Filter*
- *860 - 868 MHz*
- *900 - 928 MHz*
- *ISM bands*
- *Johanson Technology*
- *CC1100*
- *CC1101*
- *CC1110*
- *CC1111*
- *CC1150*

1 Introduction

This document describes a matched chip balun filter that has been specifically designed for the CC11xx family of ICs operating in the 868 and 915 MHz ISM bands.

With the Johanson Technology (JTI) Matched Balun Filter component; the component count is significantly reduced whilst still obtaining the high radio performance.

The size for the Matched Balun Filter component is only 2.0 mm x 1.25 mm and the JTI part number is 0896BM15A0001 [4].

All measurement results presented in this document are based on measurements performed on the CC1101 JTI EM Rev 1.0 Reference Design board [6], shown in Figure 1.

The Matched Filter Balun can also be used for CC1100, CC1110, CC1111 and CC1150.

The comparison performance of the JTI Reference Design and the Discrete Reference Design will be discussed in this document.

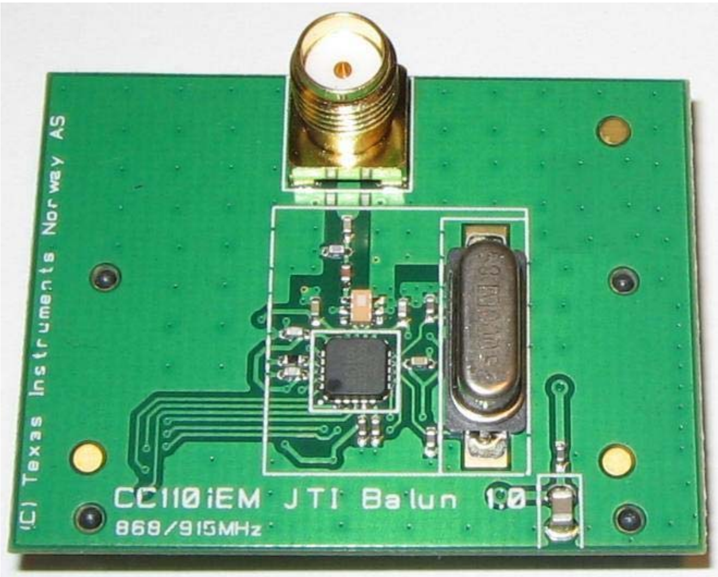

Figure 1. CC1101 868 / 915 JTI Balun EM Board

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2 Abbreviations

ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FR4	Material type used for producing PCB
ISM	Industrial, Scientific, Medical
JTI	Johanson Technology
LC	Inductor (L) Capacitor (C) configuration
ML	Multi-Layer Inductor
NM	Not Mounted
PCB	Printed Circuit Board
SoC	System on Chip
SRD	Short Range Devices
WW	Wire-Wound Inductor

3 Description of the Reference Design

The traditional reference design for the CC1101 has been the discrete solution [8] shown in Figure 2. Johanson Technology has developed a solution with a chip balun that is especially matched for the CC11xx chips. Please refer to Appendix A for data sheet of the matched balun filter component (the full specification is available from the Johanson Technology web site [4]).

The JTI matched balun filter solution [6] implemented on the CC1101 868/915 MHz JTI Balun reference design consists of the Matched Balun Filter and an external LC filter which is valid for all CC11xx. The need of the LC filter is discussed in more detail in Section 4 in this document.

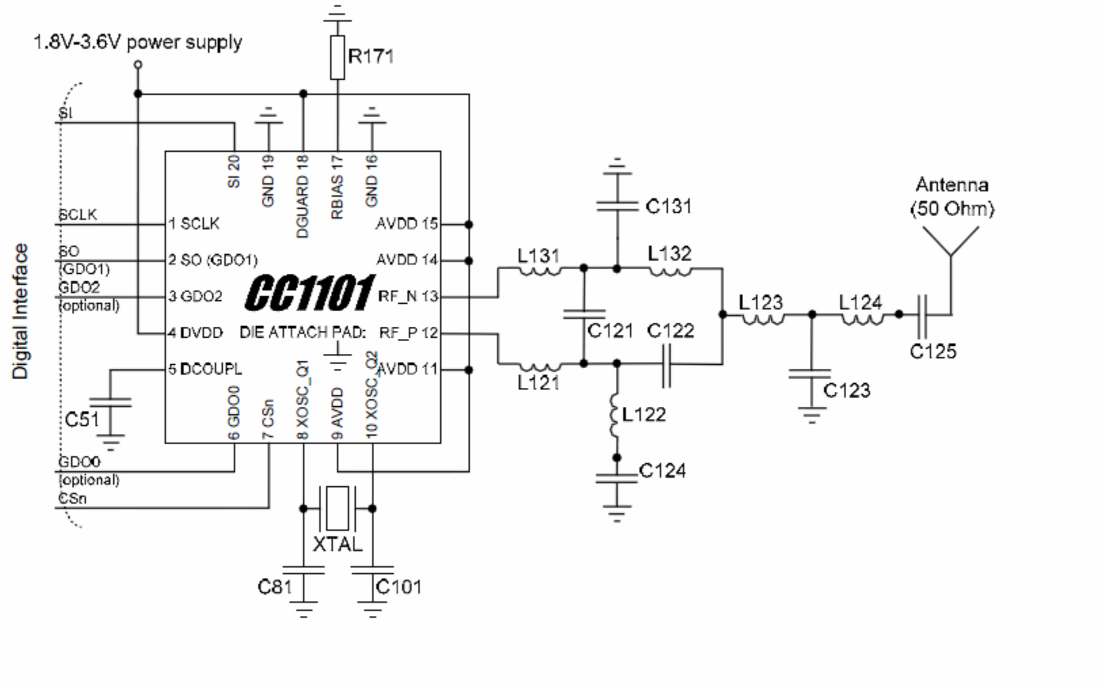


Figure 2. Discrete Reference Design for the CC11xx 868/915 MHz (no decoupling capacitors shown)

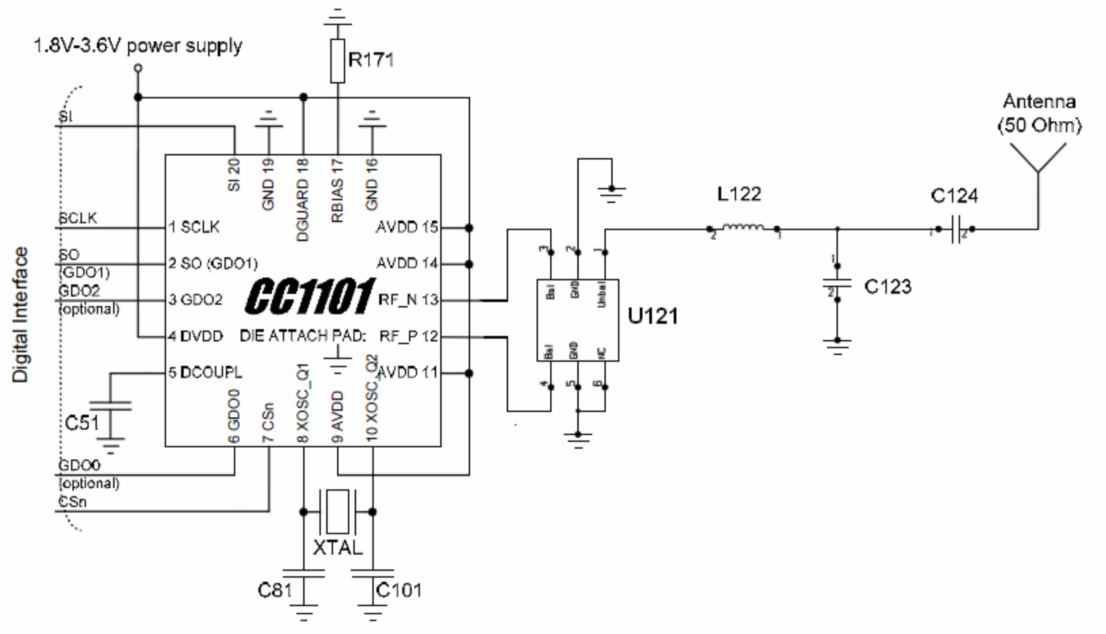


Figure 3. JTI Reference Design for the CC11xx 868/915 MHz (no decoupling capacitors shown)

Referring to Figure 3, U121 is the JTI Matched Balun Filter 0896BM15A0001. Inductor L122 is 5.6nH and capacitor C123 is 1.8pF; these two components from the LC filter. C124 is a DC blocking capacitor required to protect the CC11xx RF block and should be NPO type to minimize losses; recommended value of 100pF. The DC block is only needed when there is a DC path in the antenna. Recommended part numbers from Johanson Technology for the inductor (L122) is L-07C5N6SV4 and the capacitor (CC123) is 500R07S1R8BV4.

3.1 Component Placement

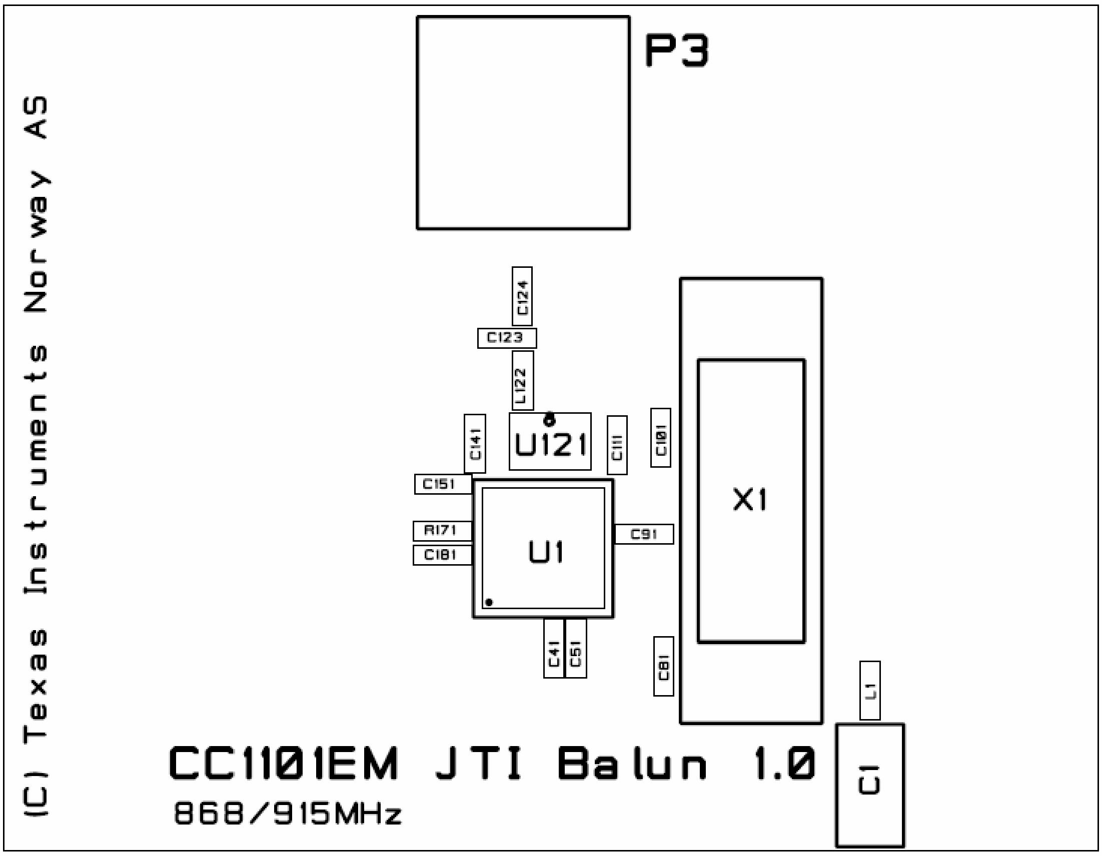


Figure 4. Component Placement

The component placement influences the RF performance. In the event that the reference design [6] can not be copied then it is important to position the inductor L122 so that the coupling effects to the Matched Balun Filter U121 are minimized as much as possible. Experiments with placing L122 in parallel to U121 showed that coupling was evident and the Matched Balun Filter performance was not optimum. Keep the inductor L122 at 90 degrees to the balun as shown in Figure 4 or position it on the left side of U121 to avoid coupling to pin 6 of U121.

3.2 Schematic

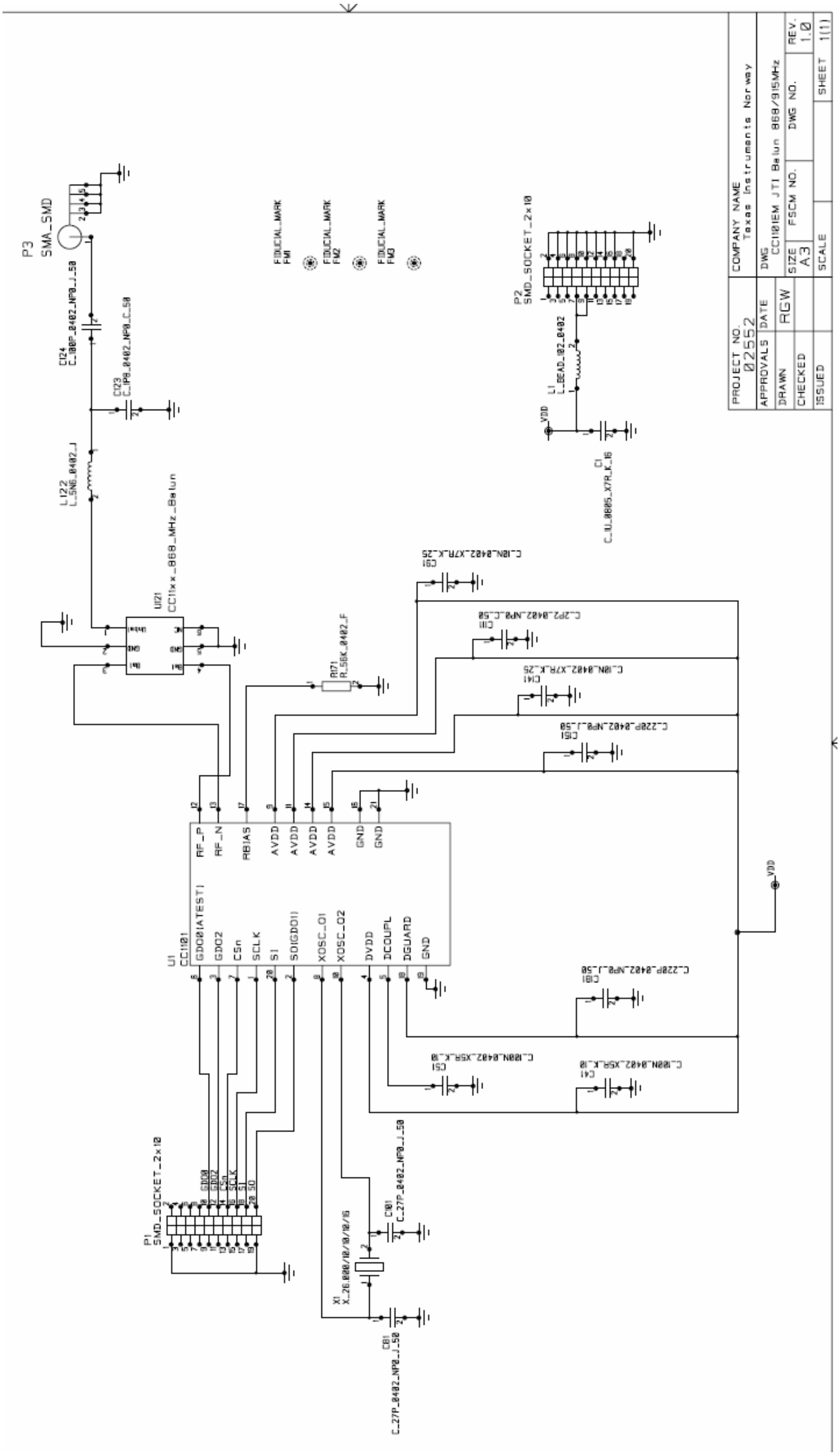


Figure 5. CC1101 JTI 868/915MHz Reference Design Schematic Rev1.0

3.3 Layout

The layout greatly influences the RF performance. TI recommends to always copy our reference design [6] as closely as possible.

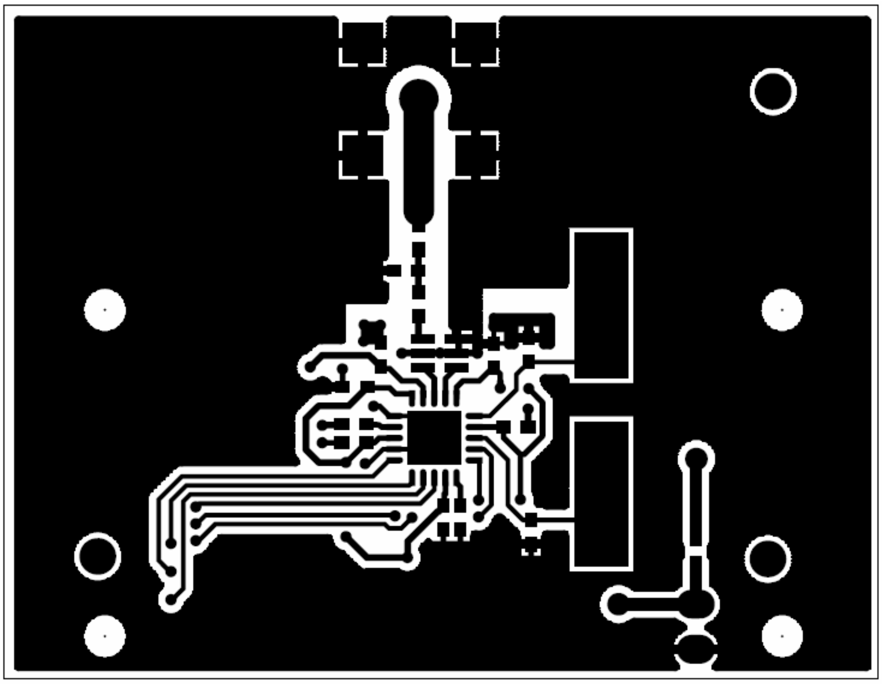


Figure 6. Layer 1 of CC1101 JTI 868/915 MHz Reference Design Layout

The ground from the decoupling capacitors has been divided from the remaining ground on layer1. Tests from the lab have proven that this is not necessary and the ground can be solid as shown in Figure 7. As previously mentioned, the most important critical part of the layout is the positioning of the inductor L122 in order to minimize the coupling effect to the Matched Balun Filter.

In the event that the reference design [6] can not be copied then the routing from the RF pins RF_P & RF_N must be symmetrical to the Matched Balun Filter component, U121. The length of the tracks should be kept to a minimum and preferably the same length that is used in the reference design [6]. If this routing is not symmetrical; then the output power will be reduced and the harmonics will increase.

All component ground pads should have the own ground via which should be positioned as close as possible to the ground pad. When positioning the ground vias for the component pad grounds it is important to try to keep the return path loop to ground as little as possible in order to prevent unnecessary radiated emissions.

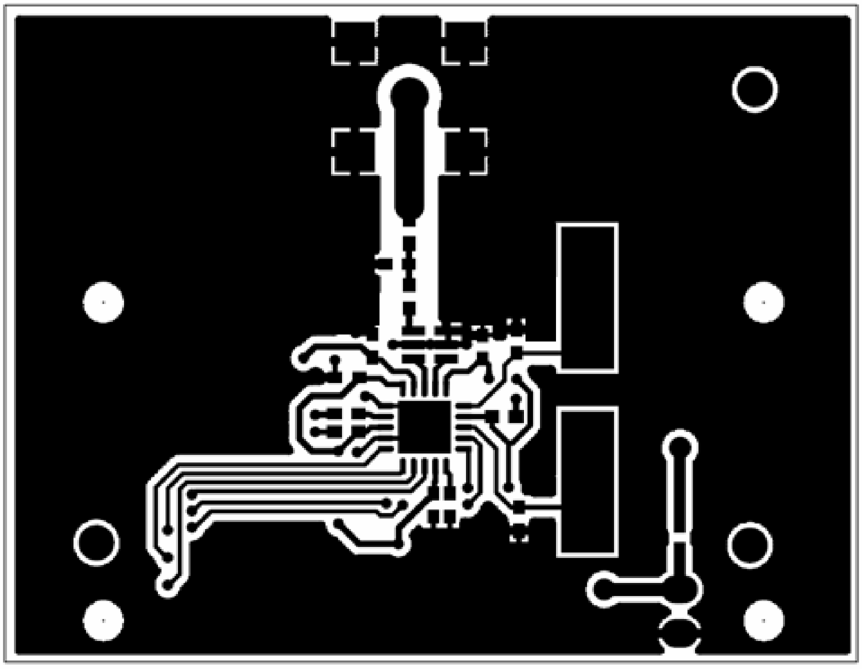


Figure 7. Alternative grounding on layer 1

The routing in Figure 7 is the same as Figure 6 apart from the ground fill around the balun.

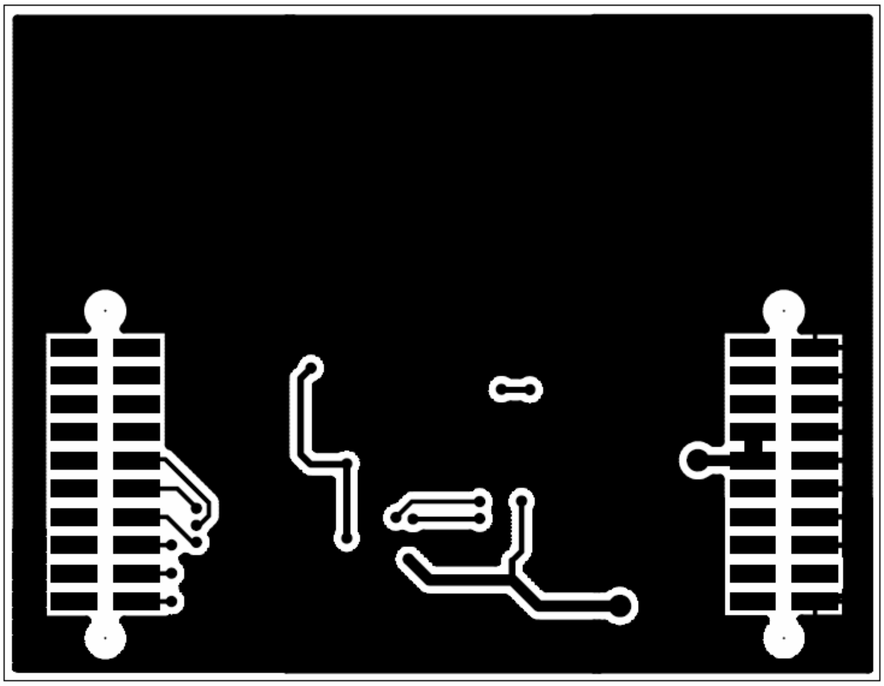


Figure 8. Layer 2 of CC1101 JTI 868/915 MHz Reference Design Layout

On the second layer; it is important to have a solid ground plane underneath the RF structure and to avoid any routing directly underneath the RF. The power routing has been routed in a star formation and the power tracks must always be routed to the decoupling capacitor first; then from the decoupling capacitor to the pad of the CC1101.

4 Measurement Results

All results presented in this chapter are based on measurements performed with CC1101 JTI EM Rev 1.0 Reference Design board [6]. A minimum of six units have been measured in order to obtain an average result which is presented in this report. All measurement results presented are the average of each batch tested from typical devices.

The output power and harmonics measurements were performed with four different power PATABLE settings: 0xC0 & 0xC2 for 10 dBm applications and 0x8E & 0x50 for 0 dBm applications.

Note: all values are in dBm if not otherwise stated.

SmartRF04® RF studio was used to configure the devices. The settings for the registers are the default settings used.

4.1 Sensitivity

	868 MHz			
	1.2kBaud	**38.4kBaud**	**250kBaud**	**500kBaud**
JTI with LC	-111.6	-103.6	-94.8	-87.2
Discete ML	-111.0	-103.0	-94.0	-87.0
	915 MHz			
	1.2kBaud	**38.4kBaud**	**250kBaud**	**500kBaud**
JTI with LC	-111.4	-103.2	-94.4	-87.3
Discete ML	-111.0	-103.0	-94.0	-87.0

Table 1. Average Sensitivity values obtained.

As can be seen from Table 1; the JTI reference design with LC has the same or better sensitivity than the discrete solution with Multi-Layer (ML) inductors.

	868 MHz			
	1.2kBaud	**38.4kBaud**	**250kBaud**	**500kBaud**
JTI no LC	-111.4	-103.1	-94.4	-86.5
JTI with LC	-111.6	-103.6	-94.8	-87.2
difference	-0.2	-0.5	-0.4	-0.7
	915 MHz			
	1.2kBaud	**38.4kBaud**	**250kBaud**	**500kBaud**
JTI no LC	-111.3	-102.2	-93.8	-86.2
JTI with LC	-111.4	-103.2	-94.4	-87.3
difference	-0.1	-0.9	-0.6	-1.1

Table 2. Difference in Sensitivity values with and without LC filter.

As can be seen from Table 1 and Table 2; the sensitivity is same or better with the LC filter.

4.2 Output Power and Harmonics

	868 MHz			915 MHz		
	JTI with LC	JTI no LC	Limit	JTI with LC	JTI no LC	Limit
Fundamental						
C0	10.8	11.4		11.2	11.4	
C2	10.0	10.7		10.4	10.7	
8E	1.5	1.4		0.8	0.8	
50	0.3	0.3		0.0	-0.1	
2 harmonic						
C0	**-28.9**	**-25.2**	-30	-28.1	-25.7	-20
C2	-34.0	**-29.7**	-30	-32.9	-30.1	-20
8E	-40.8	-42.0	-30	-43.1	-45.8	-41.2
50	-35.9	-33.8	-30	**-37.2**	**-35.7**	-41.2
3 harmonic						
C0	-48.3	-42.3	-30	-49.4	**-40.4**	-41.2
C2	-48.6	-42.7	-30	-49.9	**-41.2**	-41.2
8E	-55.4	-53.4	-30	-56.3	-52.8	-41.2
50	-55.1	-53.2	-30	-56.1	-53.1	-41.2
4 harmonic						
C0	-48.5	**-29.6**	-30	-49.9	**-30.2**	-41.2
C2	-51.5	-33.4	-30	-52.2	**-33.7**	-41.2
8E	-54.6	-40.2	-30	-53.7	**-37.8**	-41.2
50	-55.5	-42.5	-30	-54.8	**-41.0**	-41.2
5 harmonic						
C0	-52.2	-44.5	-30	-52.4	-44.4	-41.2
C2	-52.6	-44.8	-30	-52.6	-45.0	-41.2
8E	-55.1	-53.4	-30	-54.5	-53.5	-41.2
50	-55.0	-53.4	-30	-54.5	-53.7	-41.2
6 harmonic						
C0	-53.4	-43.3	-30	-52.0	-43.7	-41.2
C2	-53.5	-46.4	-30	-52.1	-46.7	-41.2
8E	-53.6	-48.3	-30	-52.2	-47.3	-41.2
50	-53.6	-51.2	-30	-52.1	-49.5	-41.2
7 harmonic						
C0	-51.9	-50.8	-30	-50.9	-50.7	-20
C2	-51.9	-50.7	-30	-50.9	-50.6	-20
8E	-51.9	-52.0	-30	-50.8	-50.9	-41.2
50	-51.9	-52.0	-30	-50.9	-51.0	-41.2
8 harmonic						
C0	-49.4	-47.6	-30	-52.6	-48.5	-41.2
C2	-49.4	-49.1	-30	-53.8	-51.5	-41.2
8E	-49.4	-48.9	-30	-54.0	-51.7	-41.2
50	-49.3	-49.5	-30	-54.6	-54.0	-41.2
9 harmonic						
C0	-52.4	-52.4	-30	-52.6	-53.3	-41.2
C2	-52.4	-52.2	-30	-52.3	-53.2	-41.2
8E	-52.6	-52.5	-30	-53.5	-53.6	-41.2
50	-52.6	-52.7	-30	-53.5	-53.6	-41.2

Table 3. Output Power and Conducted Harmonic values obtained.

The values shown in red exceed the regulatory requirements. If the recommended values and configuration are followed as specified in Table 5 then the regulatory requirements will be fulfilled.

Limit values shown in Table 3 are taken from the ETSI EN 300 220 regulations for 868 MHz and FCC 15.247 for 915 MHz.

4.2.1 Overview of Harmonic Emission Regulatory Requirements

Harmonic emission will depend on ground plane geometry, encapsulation etc. Table 4 shows the FCC- and ETSI limits. Above 1 GHz, FCC allows the radiation to be up to 20 dB above the limits given in Table 4, if duty cycling is being used. The second harmonic would only be an issue when qualifying under FCC part 15.249 since 15.247 only requires 20 dBc.

Limit	2 harmonic	3 harmonic	4 harmonic	5 harmonic	6 harmonic	7 harmonic	8 harmonic	9 harmonic
FCC 15.249	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m	54 dBµV/m
FCC 15.247	20 dBc	54 dBµV/m	54 dBµV/m	54 dBµV/m	20 dBc	20 dBc	54 dBµV/m	54 dBµV/m
ETSI EN 300 220	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm	-30 dBm

Table 4. ETSI and FCC Limits for Harmonic Radiation.

The programmed output power and size of the ground plane will affect the level of the harmonics and thus determine the necessary duty cycling.

The allowed additional emission, or correction factor, is calculated based on maximum transmission time during 100 ms. Equation 1 can be used to calculate the correction factor, where t is equal to maximum transmission time during 100 ms. From Equation 1, it can be calculated that a maximum transmission time of 50 ms, during 100 ms, will permit all radiation above 1 GHz to be 6 dB above the given limits.

$$CF = -20 \bullet \log\left(\frac{t}{100ms}\right)$$

Equation 1. FCC Correction Factor.

Even when an averaging detector is utilised, there is still a limit on emissions measured using a peak detector function with a limit 20 dB above the average limit.

For more information and recommendations on how to comply with the different ETSI sub bands please see Application Note 050 [3]. Application note AN001 [9] covers the regulations in more detail for Short Range Devices (SRD) for license free transceiver operation.

4.2.2 Radiated Emissions

Figure 9, Figure 10 and Figure 11 are from an anechoic chamber performed with the specified settings stated in the figure text. The tests were not performed according to the ETSI or FCC regulations since this was not possible in the lab that was used. In these tests, the detector on the spectrum analyzer was set to max hold in order to find the worst case limits. These measurements have to be performed on the final application board to be compliant to the ETSI and FCC regulations so these measurements are just for pre-qualification purposes. The charts are only showing a maximum of -10 dBm; this is due to the software used to record the graphs; 10 dBm and 0 dBm was transmitted for the tests.

The reference design boards are 2-layer, 0.8 mm thick, FR4 PCB. The radiated emission level will be dependant on the ground plane, decoupling capacitors, power routing and thickness of the PCB. The choice of antenna will also effect the radiated emissions.

In theory, performing the test with a 4-layer FR4 PCB with a ground plane on layer 2, will give a better performance since the pre-preg is typically 80-100 um thick and this will give a better grounding and amount of radiated energy will be less compared to a similar design on a 2-layer. Even when several pre-preg layers will be used between layer 1 and layer 2 on a 4-layer FR4 PCB; the thickness will generally be less than 0.8 mm, so the radiated performance will be better.

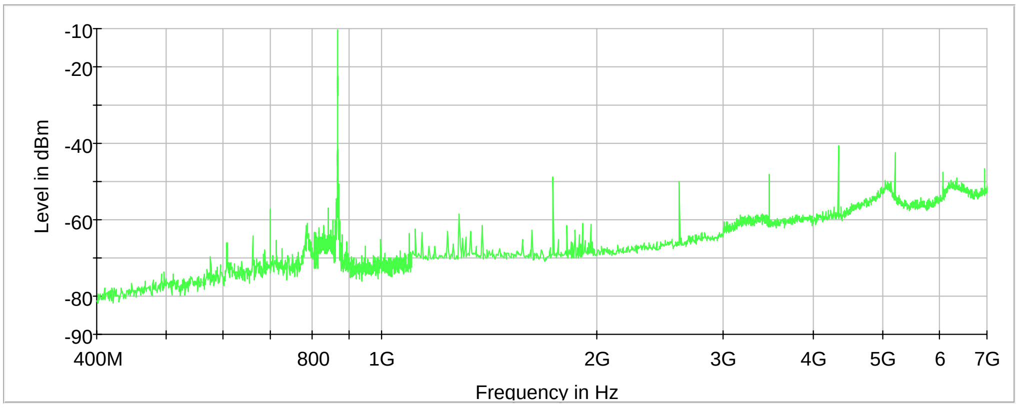


Figure 9. 10 dBm output power (0xC2); 868 MHz un-modulated static TX carrier.

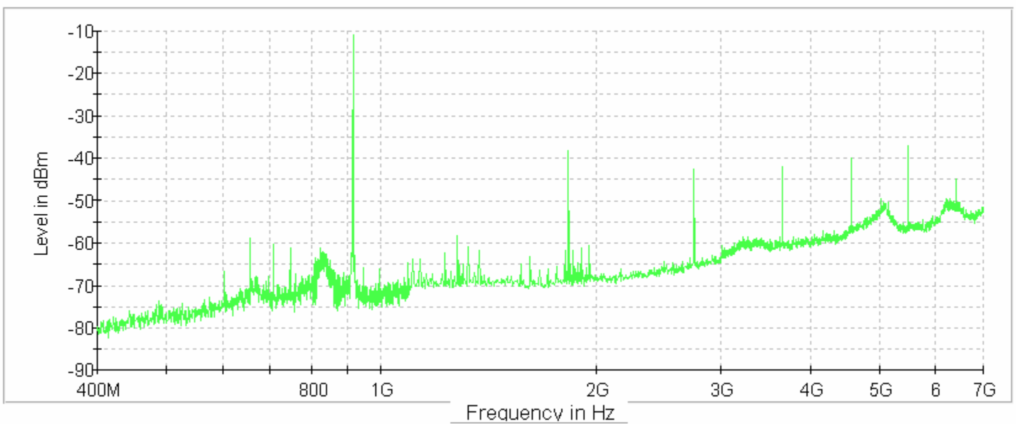


Figure 10. 10 dBm output power (0xC0); 915 MHz un-modulated static TX carrier

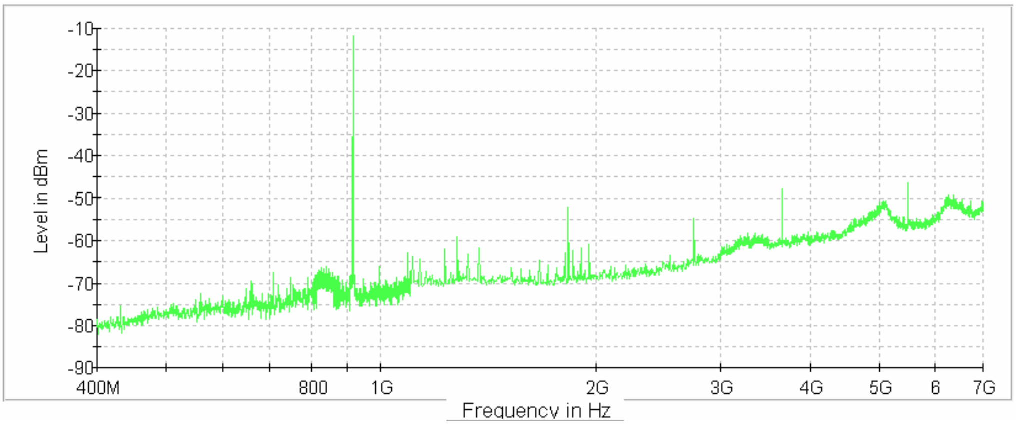


Figure 11. 0 dBm output power (0xC0); 915 MHz un-modulated static TX carrier

As can be seen in Figure 10; there are some higher order harmonics that exceed the FCC limit of -41.2 dBm. If this was the case in the application; then equation 1 could be used to correlate the level by not continuously transmitting.

4.2.3 Summary of measurements

Use of an LC filter does not affect the sensitivity or the output power measurements significantly. For the total link budget, there is an advantage using the LC filter for the sensitivity and a slight power loss for the output power. Therefore, the total effect of the LC filter on the system performance will be the same. However, the main benefits of the LC filter are the suppression of the harmonics.

When deciding which configuration should be used, the following should be considered:

There are mainly two power applications categories with 10 dBm and 0 dBm; there are FCC and ETSI regulatory requirements; and also if conducted emissions will also be tested in the final application (i.e. no internal antenna available, only RF connector). The level of the output power setting will also affect the levels of the harmonics as can be seen in Table 3.

Refer to Table 5, to summarize all the previous mentioned application variables to obtain the recommended application settings. The recommended power setting is also included in Table 5.

	ETSI int antenna		**ETSI (RF Connector)**	
10 dBm	JTI with LC	0xC0: 10.8 dBm	JTI with LC	0xC2:10 dBm
0 dBm	JTI no LC	0x50: 0.3 dBm	JTI no LC	0x50: 0.3 dBm

	FCC int antenna		**FCC (RF Connector)**	
10 dBm	JTI with LC	0xC0: 11.2 dBm (1)	JTI with LC	0xC0: 11.2 dBm (1)
0 dBm	JTI with LC	0x8E: 0.8 dBm	JTI with LC	0x8E: 0.8 dBm

Table 5. Recommended output power settings and application configuration

(1) Risk for radiated emissions. The boards that were tested in the EMC chamber

For example; a customer with PCB size restrictions has an integrated antenna [7], 0 dBm output power; targeting only the ETSI market. With reference to Table 5; the LC filter will not be required for regulatory issues and with a power setting of 0x50, the expected power should be around 0.3 dBm.

5 Conclusion

As an alternative to the traditional reference design as shown in Figure 2; the JTI reference design can match the performance of the discrete ML inductor reference design with a lower component count. The 868 / 915 MHz discrete solution has a total of 12 components in the RF section compared to the JTI solution of 2 to 4 components depending on the usage of the LC filter.

The best performance is still obtained by using the discrete WW inductor solution [10] but the JTI reference design with its lower component count matches the performance of the discrete ML inductor reference design.

Depending on application, Table 5 recommends the power setting and configuration that should be used for a constant transmission. If the final application does not transmit for the whole of the time; then there will be additional margin for the harmonic emissions which is explained in section 4.2.1. If this is valid then; the LC filter can be removed if the regulatory requirements are fulfilled with good margin.

Good practice would be to incorporate the LC filter into the first prototype. The filter can always be removed by using a 100pF capacitor or 0 ohm resistor instead of using the 5.6nH inductor and leaving the 1.8pF capacitor un-mounted.

6 References

[1] CC1101 Data Sheet (cc1101.pdf)

[2] DN001 Antenna Measurement with Network Analyzer (swra096.pdf)

[3] AN050 Using the CC1101 in the European 868MHz SRD band (swra146.pdf)

[4] Full Data Sheet of 0896BM15A0001

[5] Contact information: http://www.johansontechnology.com/en/contact.html

[6] CC1101 JTI Balun 868/915 MHz Ref. Design Rev1.0 (swrc112.zip)

[7] DN016 Compact 868/915 MHz Antenna Design (swra160a.pdf)

[8] CC1101EM 868 and 915MHz Reference Design (swrr045.zip)

[9] AN001 SRD Regulations for License Free Transceiver Operation (swra090.pdf)

[10] DN017 CC11xx 868/915 MHz RF Matching (Rev. A) (swra168a.pdf)

Appendix A

High Frequency Ceramic Solutions

Preliminary

896 MHz Balun/Matching Network for T.I. Chipset CC11XX — **P/N 0896BM15A0001**

Detail Specification: 10/24/08 — Page 1 of 2

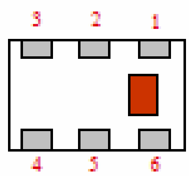
General Specifications

Part Number	0896BM15A0001
Frequency (MHz)	863 - 928 MHz
Unbalanced Impedence	50 Ω
Differential Balanced Impedence	Conj. match to T.I. CC11XX Chipset
Insertion Loss	1.5 dB max.
Return Loss	9.5 dB min.
Attenuation (min.)	25 @ 1726 - 1856MHz
	35 min.@ 2589 - 2784MHz
	35 min.@ 3452 - 3712MHz
	35 min.@ 4315 - 4640MHz

Phase Difference	180° ± 10
Amplitude Difference	1.5 dB max.
Operating Temperature	-40 to +85°C
Power Rating	1W max.
Storage Conditions	+5 to +35°C, Humidity 45 - 75%RH
Storage Period	12 mos. Max
Reel quantity	4000 pcs

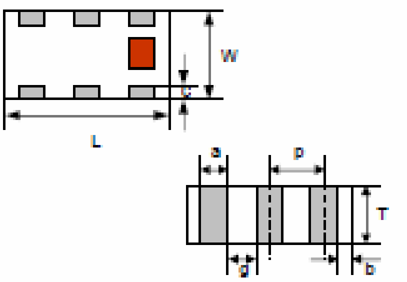
Terminal Configuration

No.	Function
1	Unbalanced Port
2	GND
3	Balanced Port
4	Balanced Port
5	GND
6	GND



Mechanical Dimensions

	In	mm
L	0.079 ± 0.004	2.00 ± 0.10
W	0.049 ± 0.004	1.25 ± 0.10
T	0.028 ± 0.004	0.70 ± 0.10
a	0.012 ± 0.004	0.30 ± 0.10
b	0.008 ± 0.004	0.20 ± 0.10
c	0.012 +.004/-.008	0.30 +0.1/-0.20
g	0.014 ± 0.004	0.35 ± 0.10
p	0.026 ± 0.002	0.65 ± 0.05



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7 General Information

7.1 Document History

Revision	Date	Description/Changes
SWRA250	2009.01.14	Initial release.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
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