Application Report

SWRA629A – October 2018 – Revised June 2019

Integrated Filter Balun for CC1352

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ABSTRACT

This application report describes the matched-balun filter components that have been specifically designed for the CC1352R [1] and CC1352P [2] operating in the 868 MHz, 915 MHz, 920 MHz and 2.4 GHz ISM bands.

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Trademarks

1 Introduction

With the matched-balun filter component; the component count is significantly reduced whilst still obtaining the high radio performance.

The matched-filter balun component is commonly designated as an Integrated Passive Component (IPC). 23 passives are required at the CC1352R RF ports. With the IPC, the component count is reduced from 23 to 3 components which saves space and reduces pick-and-place assembly costs.

CC1352R IPC can also be used in the same manner with the CC1352P which has an additional RF port with a high power PA.

The IPC is available for CC1352R and CC1352P and is available from two different vendors, Johanson Technology (part number: 0900PC15A0036) [4] and Murata (part number: LFB21868MDZ5E757) [5]. These parts share a common footprint and pinout.

The size for the matched balun filter component is only 2.0 mm x 1.25 mm (EIA 0805, Metric 2012) therefore it is recommended for compact designs.

All measurement results presented in this document are based on measurements performed on the CC1352R EM Rev 1.1 Reference Design [6], unless otherwise specified.

The comparison performance and benefits of the JTI IPC and the Murata IPC are explained in this document.

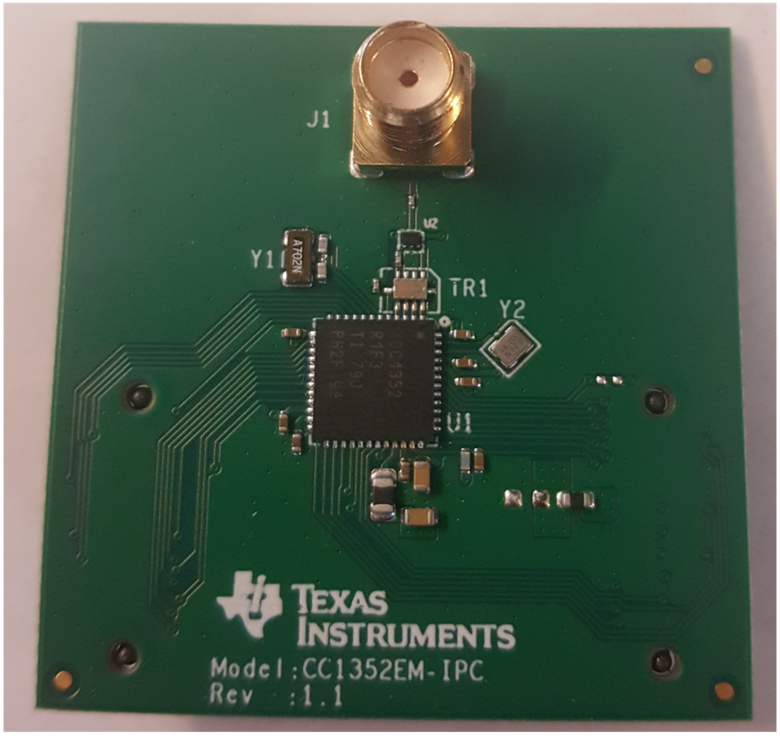


Figure 1. CC1352EM-IPC Rev1.1 EM

1.1 Acronyms Used in This Document

Table 1. Acronyms Used in This Document

Acronym	Description
DC	Direct Current
EM	Evaluation Module
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

2 Reference Designs Available

The existing reference designs for CC1352R [3] and CC1352P are based upon passive discrete components, see Figure 2. Each RF port is terminated with 50 Ω impedance that can be connected to SMA connector, switch or diplexer. The main advantage with using a switch or diplexer is a common RF port instead of several RF ports.

2.1 CC1352x Discrete Reference Design

CC1352R has two RF ports and CC1352P has three RF ports. The additional RF port in CC1352P is a high power PA that can only be configured as a Tx port. The CC1352 IPC can be used for both CC1352R and CC1352P.

The decoupling capacitors C41 and C51 are relatively large values to integrate into a small compact ceramic package so these components will still be required with the IPC.

A SP3T switch is used on the high power PA LaunchPads to enable a common RF port which is then connected to an integrated PCB dual-band antenna.

The components values are not shown in Figure 2 since these are dependent on the choice of frequency of each RF port. Each RF port can be configured to operate in a specific ISM band (315 MHz, 430-510 MHz, 863-930 MHz or 2.4 GHz).

Configuration of the Rx_Tx pin allows for external biasing or internal biasing of the LNA when operating in Rx mode. Theoretically, with external biasing of the LNA, the sensitivity can be improved providing that the external biasing inductance has lower losses than the internal biasing inductance.

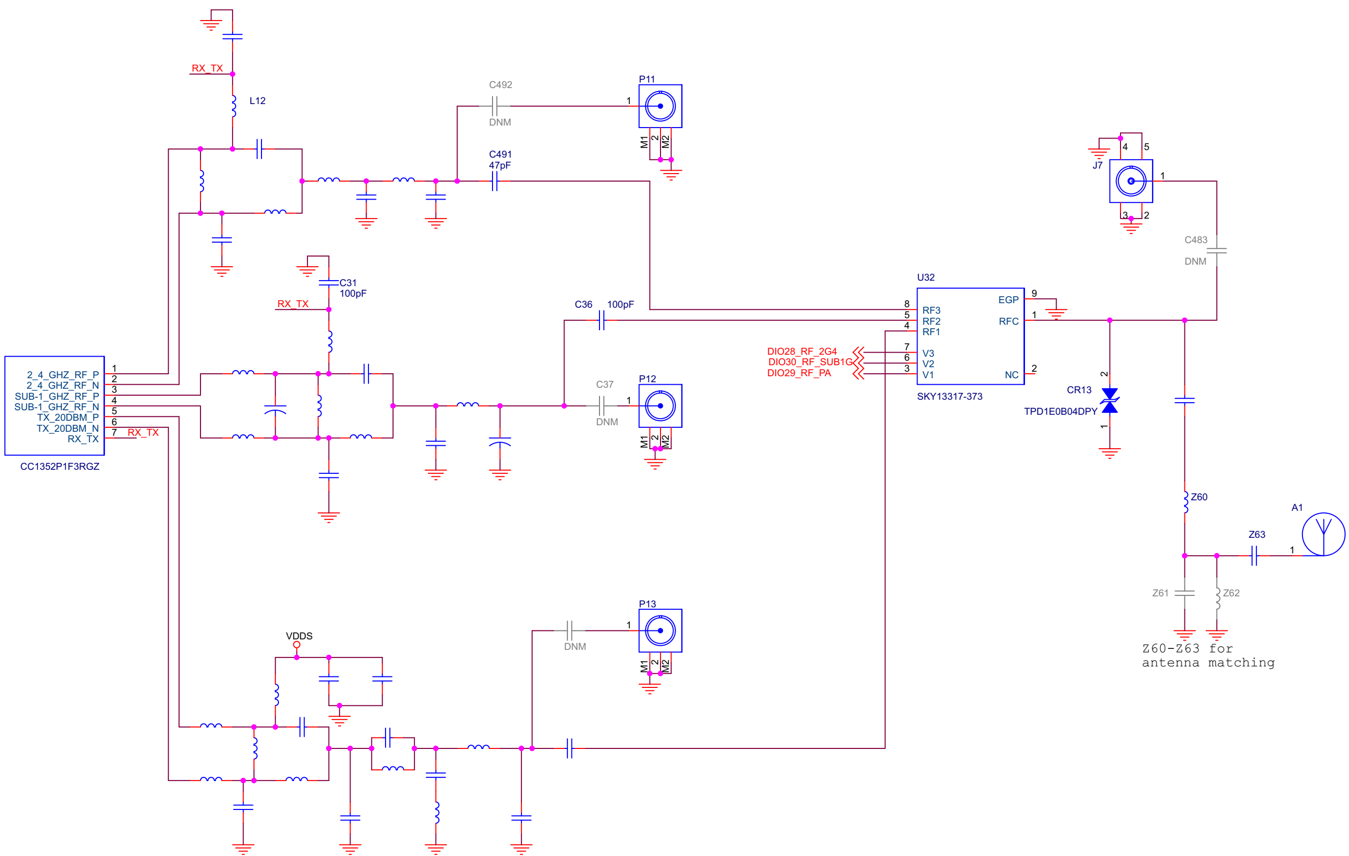


Figure 2. CC1352P LaunchPad RF Frontend Discrete Component Concept

2.2 CC1352 IPC

The objectives with the IPC compared to the discrete design:

- Reduce the amount of external components required
- Reduce the overall size, more compact
- Reduced component count so the layout process is easier and less prone to RF cross-talk due to poor RF layouts
- Flexibility to change IPC to different versions to enable different frequencies
- Common footprint and pinout for all IPCs
- Maintain RF performance of discrete design

2.2.1 JTI CC1352 IPC Equivalent Circuit

The equivalent circuit of the IPC from Johanson Technology (JTI) is shown in Figure 3. The complete specification of their IPC is available from the Johanson Technology web site [1].

JTI's matched balun filter solution implementation just requires two external DC blocking components (C41 and C51). The JTI CC1352 IPC should be configured as external biasing for both sub-1 GHz and 2.4 GHz Rx operation.

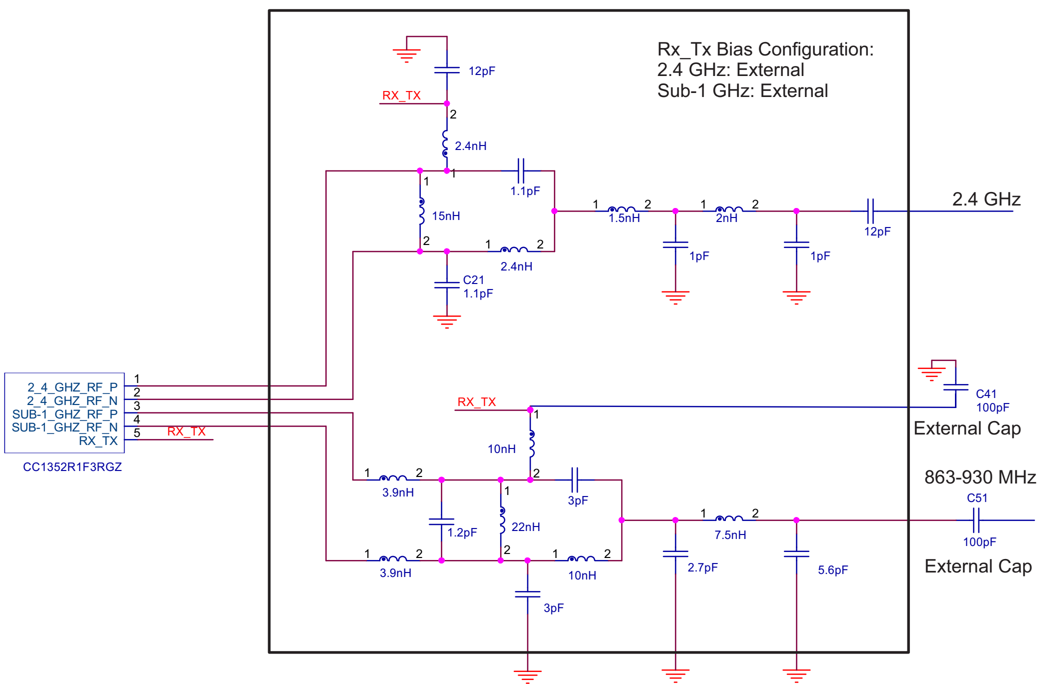


Figure 3. JTI CC1352 IPC Equivalent Circuit for 863-930 MHz and 2.4 GHz

2.2.2 Murata CC1352 IPC Equivalent Circuit

The equivalent circuit of the IPC from Murata is shown in Figure 4. The complete specification of their IPC is available from Murata [5].

Murata's matched balun filter solution implementation just requires two external DC blocking components (C41 and C51). The Murata CC1352 IPC should be configured as external biasing for sub-1 GHz and as internal biasing for 2.4 GHz Rx operation.

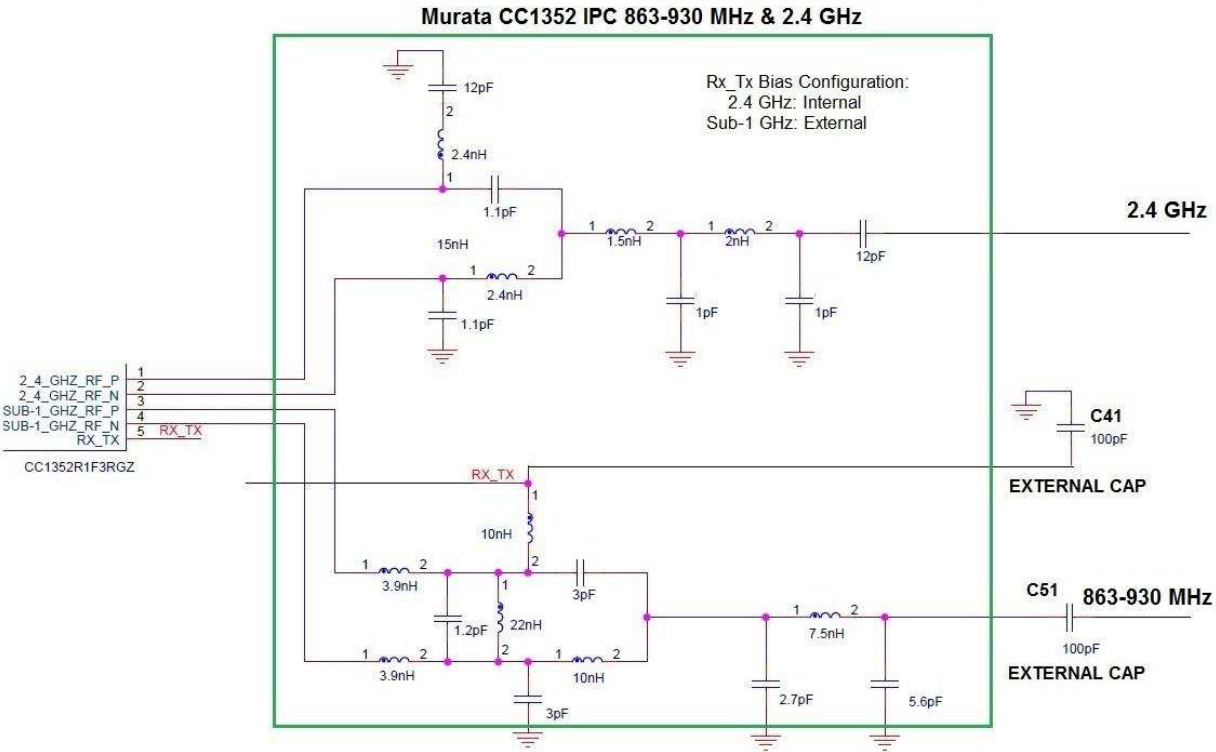


Figure 4. Murata CC1352 IPC Equivalent Circuit for 863-930 MHz & 2.4 GHz

Figure 5 shows the CC1352R IPC schematic with a common RF port. The sub-1 GHz RF port and 2.4 GHz RF port from the IPC are connected to the dual-through section of the SPDT switch. The single-pole port of the switch can be connected to a single-feed dual-band antenna. The SPDT switch can be controlled by any DIO. DIO30 is used in the CC1352R EM IPC EM design.

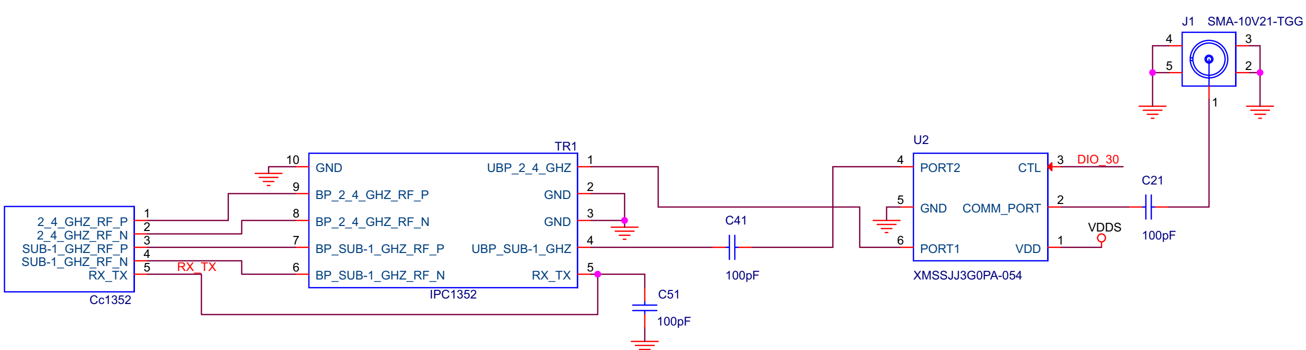
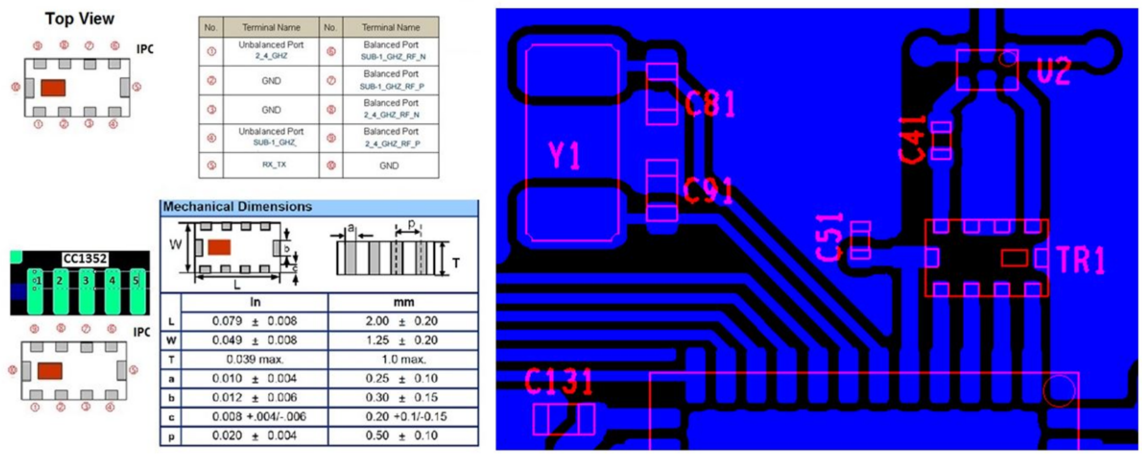


Figure 5. CC1352 IPC RF Frontend With SPDT Switch for 863-930 MHz and 2.4 GHz

2.2.3 CC1352 IPC Size and Dimensions

The physical size of the IPC and dimensions are shown in Figure 6. The dimension are only 2.00 mm x 1.25 mm which is similar in size as a 0805 (EIA size) or 2012 (metric size) footprint. This makes the IPC ideal for compact designs and makes the layout much easier and less risk for RF layout issues. The layout size comparison between the IPC and the discrete design is shown in Figure 7.



No.	Terminal Name	No.	Terminal Name
①	Unbalanced Port 2_4_GHZ	⑥	Balanced Port SUB-1_GHZ_RF_N
②	GND	⑦	Balanced Port SUB-1_GHZ_RF_P
③	GND	⑧	Balanced Port 2_4_GHZ_RF_N
④	Unbalanced Port SUB-1_GHZ_	⑨	Balanced Port 2_4_GHZ_RF_P
⑤	RX_TX	⑩	GND

Mechanical Dimensions

	In	mm
L	0.079 ± 0.008	2.00 ± 0.20
W	0.049 ± 0.008	1.25 ± 0.20
T	0.039 max.	1.0 max.
a	0.010 ± 0.004	0.25 ± 0.10
b	0.012 ± 0.006	0.30 ± 0.15
c	0.008 +.004/-.006	0.20 +0.1/-0.15
p	0.020 ± 0.004	0.50 ± 0.10

Figure 6. Component Size and Dimensions

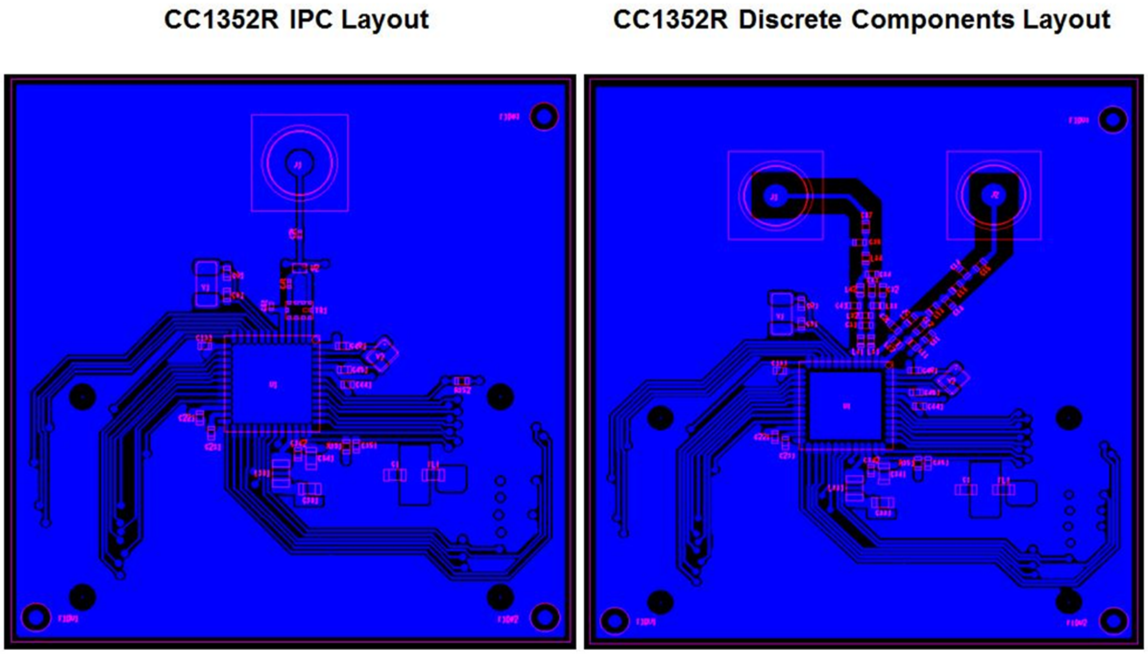


Figure 7. Size Comparison Between the IPC and Discrete Design

2.2.4 CC1352 IPC Reference Design

2.2.4.1 Component Placement and Layout

The IPC component placement influences the RF performance and the reference design should be followed as close as possible [6]. For more information, see Figure 8 and Figure 9. The distance between the IPC and the CC1352 is important and this should be 1.26 mm, see Figure 9.

In the event that the reference design [6] cannot be copied then the routing from the RF pins must be symmetrical to the IPC. The length of the tracks should be kept to a minimum and preferably the same recommended length that is used in the reference design of 1.26 mm. The width of the tracks between CC1352 and the IPC should also be kept as 0.25 mm.

If the recommended distance of 1.26 mm, 0.25 mm track width or GND via placements are too far away from the IPC, this will introduce phase shifts and additional parasitic inductance. Not following the reference design will affect the Tx output power, Tx harmonic attenuation and Rx sensitivity. For recommended GND via placements for the IPC, see Figure 9.

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.

DC blocking components C41 and C51 are 0201 passives. U2 is a compact SPDT switch that combines the two RF ports into one common RF port. With one common RF port then a dual-band antenna can then be added.

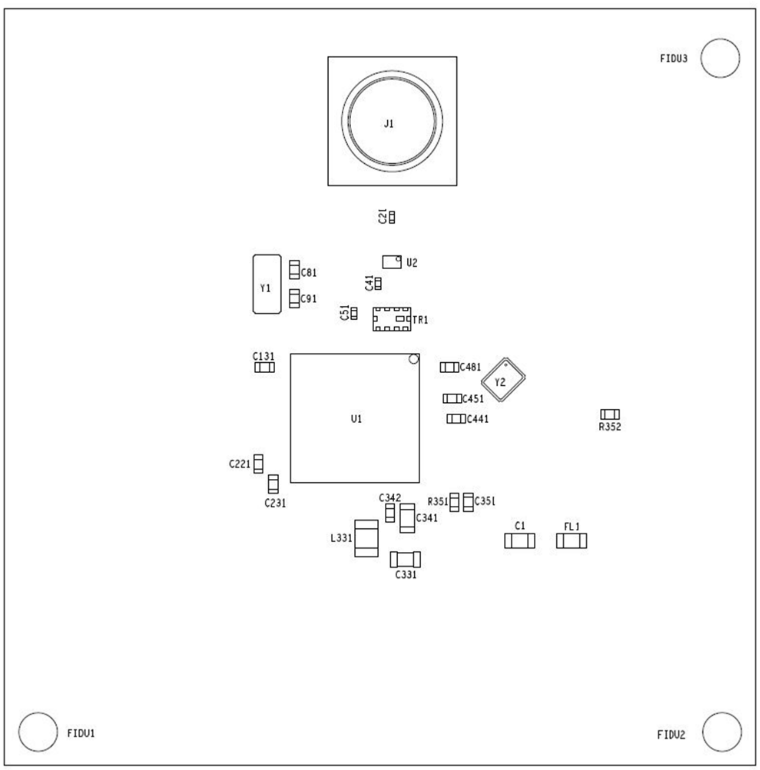


Figure 8. Component Placement

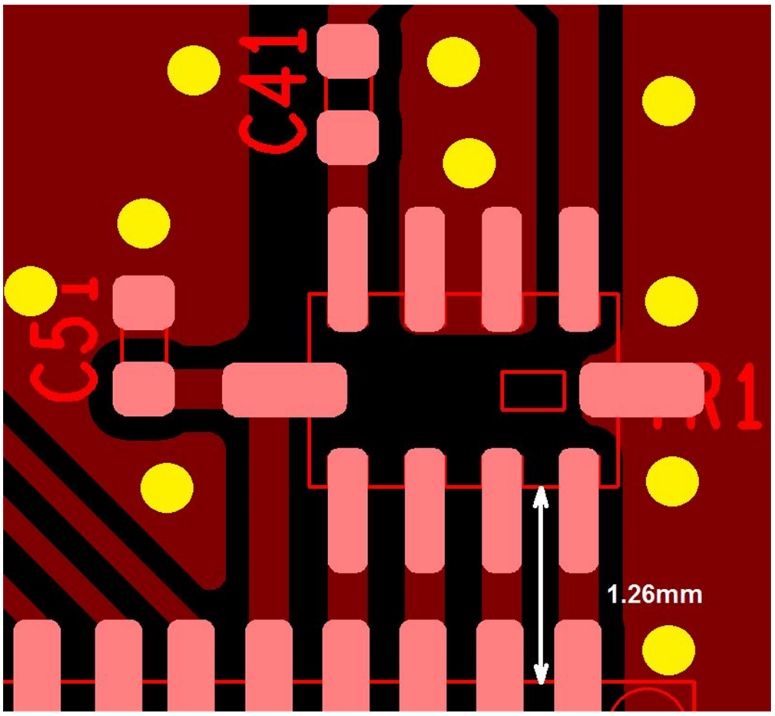


Figure 9. Distance Between CC1352 and IPC and Via Placement

2.2.4.2 Layout, Layer 1

Figure 10 shows the top layer of the 4-layer reference design. Remaining area is filled with GND for shielding purposes.

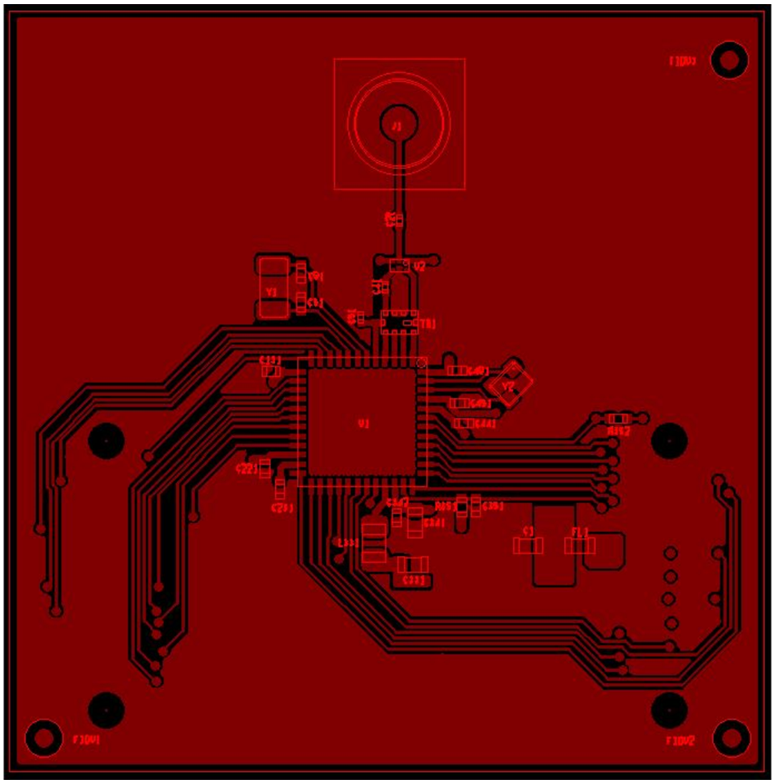


Figure 10. Layer 1

2.2.4.3 Layout, Layer 2

Figure 11 shows the second layer of the 4-layer reference design. This layer is mainly a GND layer. It is important to have a solid ground plane underneath the complete RF section and to avoid any routing directly underneath the RF section. The reference design [6] has a thickness of 175 um between layer 1 and layer 2. This is the main parameter in the FR4 PCB stack-up that should be kept similar when copying the reference design.

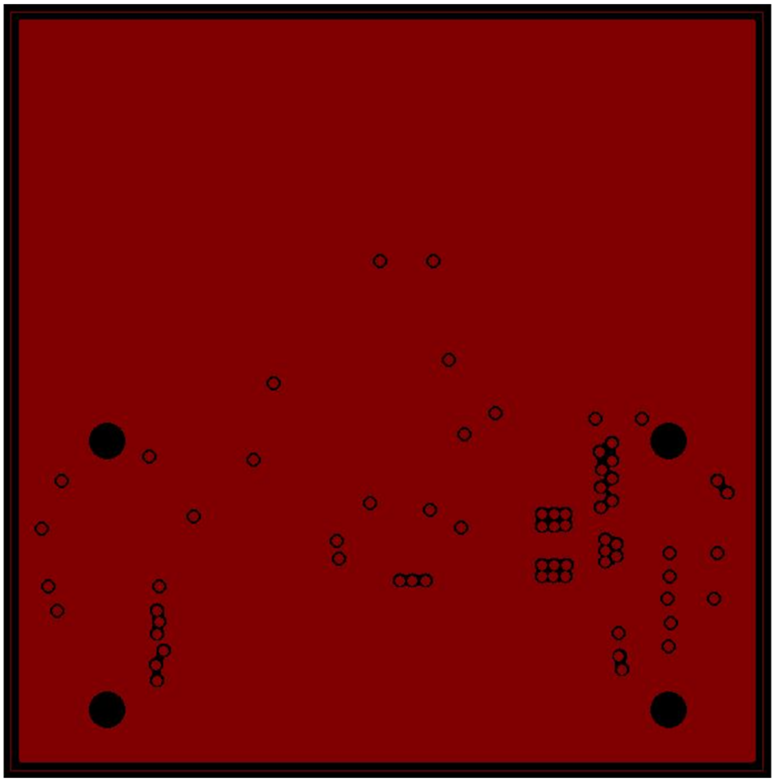


Figure 11. Layer 2

2.2.4.4 Layout, Layer 3

Figure 12 shows the third layer of the 4-layer reference design. This layer is mainly for VDDS and VDDR power. Remaining area is filled with GND for shielding purposes. The power routing should always be routed to the decoupling capacitor first; then from the decoupling capacitor to the pad of the CC1352.

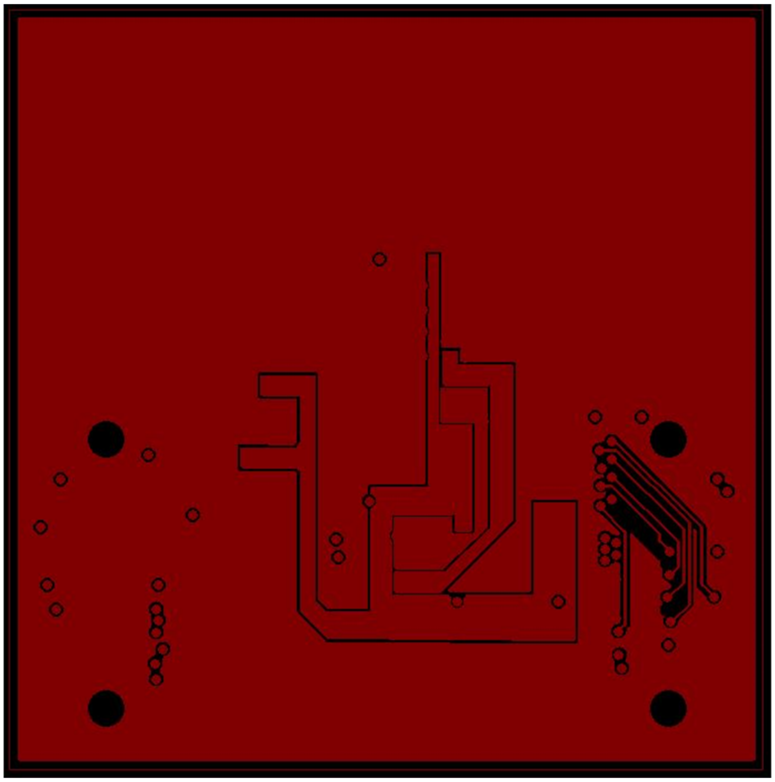


Figure 12. Layer 3

2.2.4.5 Layout, Layer 4

Figure 13 shows the fourth layer of the 4-layer reference design. This layer is mainly for the connector / DIO distribution. Remaining area is filled with GND for shielding purposes.

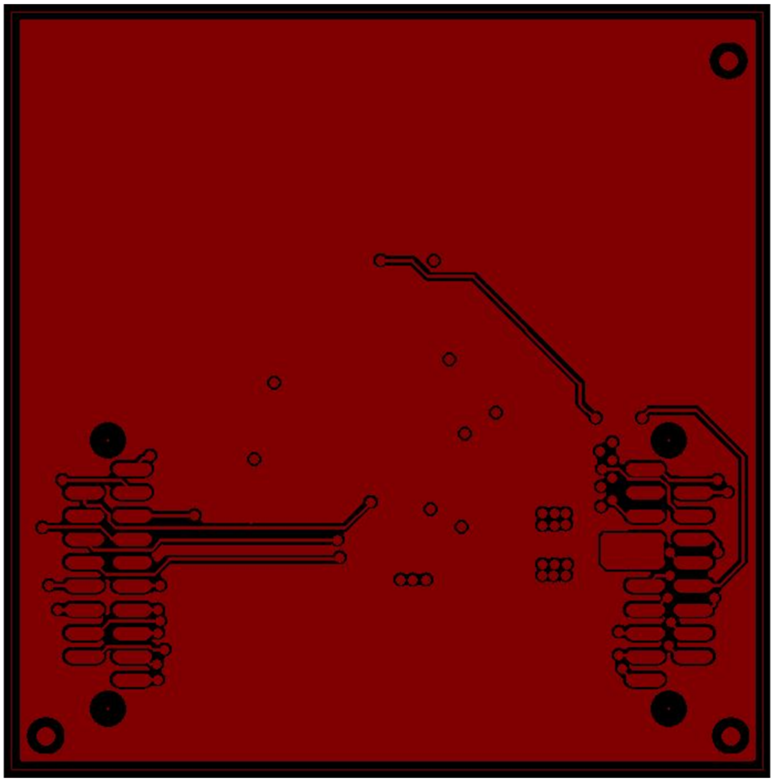


Figure 13. Layer 4

3 IPC Measurement Results

All results presented in this chapter are based on measurements performed on CC1352 EM Rev 1.1 [6], unless otherwise noted. A minimum of four 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 in room temperature from typical devices.

NOTE: All values are in dBm if not otherwise stated. All the measurements are measured at the SMA connector after the switch. The switch has a typical insertion loss of 0.7 dB on the reference design [6].

3.1 Sub-1 GHz

3.1.1 CC1352R Output Power, Sensitivity and Link Budget

Figure 14 shows the output power measurements across a frequency span from 863-950 MHz.

Summary: Murata has a higher output power than Johanson with maximum power settings (boost setting). High output power across the entire 863-950 MHz frequency span.

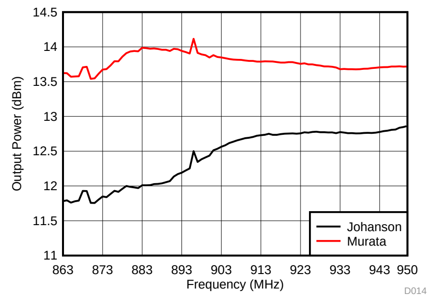


Figure 14. Sub-1 GHz Output Power vs Frequency

Figure 15 shows the sensitivity measurements (50 kbps datarate) across a frequency span from 863-950 MHz.

Summary: Johanson has better sensitivity than Murata especially in the band from 900-950 MHz.

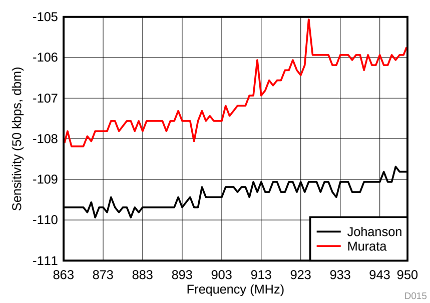


Figure 15. Sub-1 GHz Sensitivity vs Frequency

Figure 16 shows the link budget that is the sum of the output power and the sensitivity measurements. This is a main parameter for greater range

Summary: 863-899 MHz, both Johanson and Murata have a similar link budget. For 900-950 MHz, then Johanson has a stronger link budget.

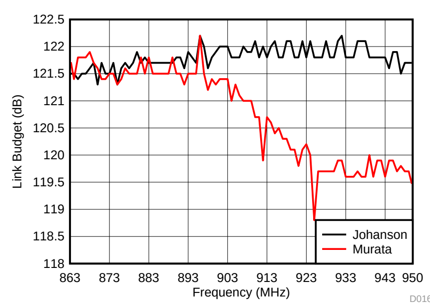


Figure 16. Sub-1 GHz Link Budget vs Frequency

3.1.2 CC1352R Tx Efficiency, Tx Harmonics at Maximum Output Power (Boost)

3 V, Maximum output power setting; average results from 863-870 MHz:

- JTI Tx Efficiency: 17.2 %
- Murata Tx Efficiency: 21.0 %
- JTI Tx Current: 29.6 mA
- Murata Tx Current: 42.8 mA
- JTI Tx Output Power: 11.8 dBm
- Murata Output Power: 13.9 dBm
- JTI 2nd Harmonic Level: -38.2 dBm
- Murata 2nd Harmonic Level: -36.3 dBm
- JTI 3rd Harmonic Level: -40.2 dBm
- Murata 3rd Harmonic Level: -40.4 dBm
- JTI 4th Harmonic Level: -60.9 dBm
- Murata 4th Harmonic Level: -48.9 dBm
- JTI 5th Harmonic Level: -37.5 dBm
- Murata 5th Harmonic Level: -36.2 dBm

3.1.3 CC1352 Rx Current

3.6 V, -100 dBm signal generator RF:

- JTI Rx Current: 6.9 mA
- Murata Rx Current: 6.8 mA

3.1.4 CC1352R Tx Efficiency, Tx Harmonics and Tx Output at Various PA Settings

Figure 17 shows the output power against PA settings at 868 MHz.

Summary: Murata has optimized the output power level for the first three powers steps. The remaining power steps, Johanson has higher output power than Murata.

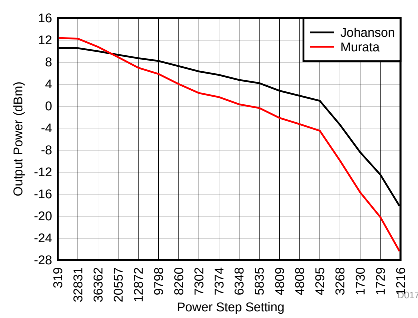


Figure 17. 868 MHz Output Power vs PA Setting

Figure 18 shows the Tx current against PA settings at 868 MHz

Summary: Murata has optimized their output power level for the maximum output level with boost mode and Johanson has optimized their output power level for the normal mode. Johanson has a lower current Tx current consumption in the normal Tx mode than Murata.

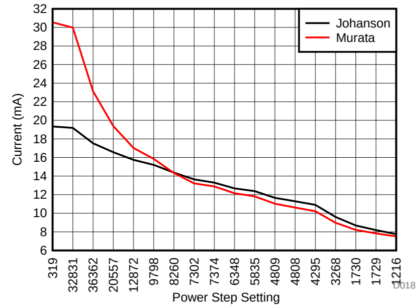


Figure 18. 868 MHz Tx Current vs PA Setting

Figure 19 shows the Tx efficiency against PA settings at 868 MHz.

Summary: Murata has optimized their Tx efficiency for the maximum output level with boost (max) mode and Johanson has optimized their Tx efficiency for the normal mode. Figure 18 shows a significant increase of current for Murata in the first steps but the efficiency is similar although Johanson has a greater Tx efficiency for all power steps in the normal mode than Murata.

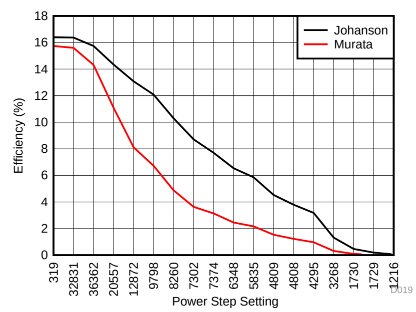


Figure 19. 868 MHz Tx Efficiency vs PA Setting

Figure 20 shows the 868 MHz 2nd harmonic against PA settings.

Summary: Similar performance.

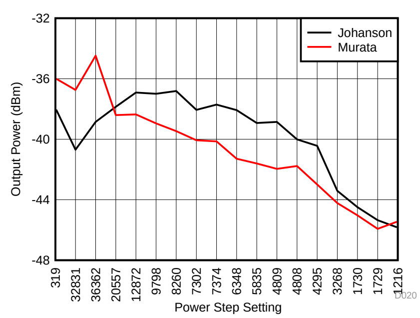


Figure 20. 868 MHz 2nd Harmonic vs PA Setting

[Figure 21](#) shows the 868 MHz 3rd harmonic against PA settings

Summary: Similar performance.

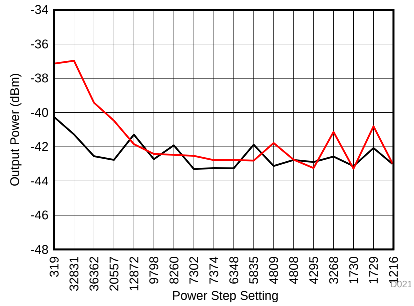


Figure 21. 868 MHz Tx 3rd Harmonic vs PA Setting

[Figure 22](#) shows the 868 MHz 4th harmonic against PA settings.

Summary: Similar performance.

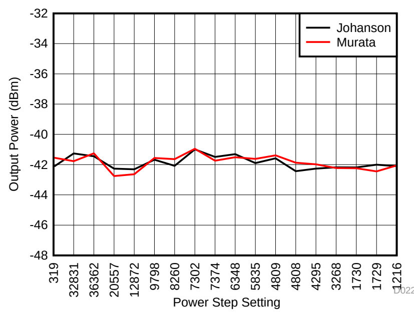


Figure 22. 868 MHz 4th Harmonic vs PA Setting

[Figure 23](#) shows the 868 MHz 5th harmonic against PA settings

Summary: Similar performance.

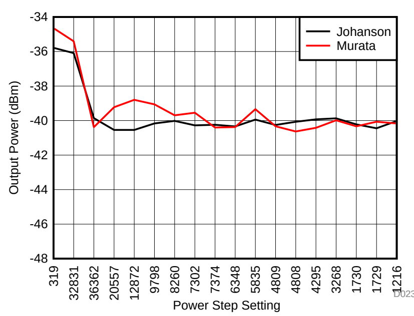


Figure 23. 868 MHz Tx 5th Harmonic vs PA Setting

3.1.5 Overview of Harmonic Emission Regulatory Requirements

Table 2. ETSI and FCC Limits for Harmonic Radiation

Limit	fc	2nd Harmonic	3rd Harmonic	4th Harmonic	5th Harmonic
FCC 15.249	0 dBm	54 dBmV/m	54 dBmV/m	54 dBmV/m	54 dBmV/m
FCC 15.247	30 dBm	20 dBc	54 dBmV/m	54 dBmV/m	54 dBmV/m
ETSI EN 300 220	14 dBm	−30 dBm	−30 dBm	−30 dBm	−30 dBm

The maximum harmonic level for ETSI EN 300 220 regulations for 868 MHz is -30 dBm and all tests measurements are within this limit.

The programmed output power and the quality of the ground plane will affect the level of the harmonics and thus determine the necessary duty cycling for FCC. Harmonic emission will also depend on the RF layout and if there are any PCB traces / stubs acting as unwanted antennas emitting emissions.

Table 2 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 2, if duty cycling is being used. 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. For more comparisons, see Table 3.

$$CF = -20 \bullet \log\left(\frac{t}{100\ ms}\right) \tag{1}$$

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.

Table 3. FCC Correction Factor and Maximum Duty Cycling

Measured violating harmonic (using maximum output power)	-21.23	-25	-30	-35	-40	-41.23	dBm
Regulatory requirement (2nd/3rd harmonics)	-41.23	-41.23	-41.23	-41.23	-41.23	-41.23	dBm
TX ON TIME (ms)	10.00	15.43	27.45	48.81	86.80	100.00	ms
Duty cycle	10.00	15.43	27.45	48.81	86.80	100.00	%

3.1.6 Radiated Emissions

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 reference design board is 4-layer, 1.6 mm thick, FR4 PCB. The radiated emission level will be dependent on the ground plane, decoupling capacitors and power routing. The choice of antenna will also affect the radiated emissions.

A dual-band antenna from the CC-Antenna-DK2 was used for the tests. The antenna from the CC-Antenna-DK2 was nr 9 and this is widely used on the LaunchPad designs as well; results from the emission tests are shown in Figure 24 and Figure 25.

It is important that the antenna is matched (VSWR < 3:1) for both sub-1 GHz and 2.4 GHz frequencies. Otherwise, if the antenna mismatch is large then there will be unwanted emissions and the wanted output power will be reduced.

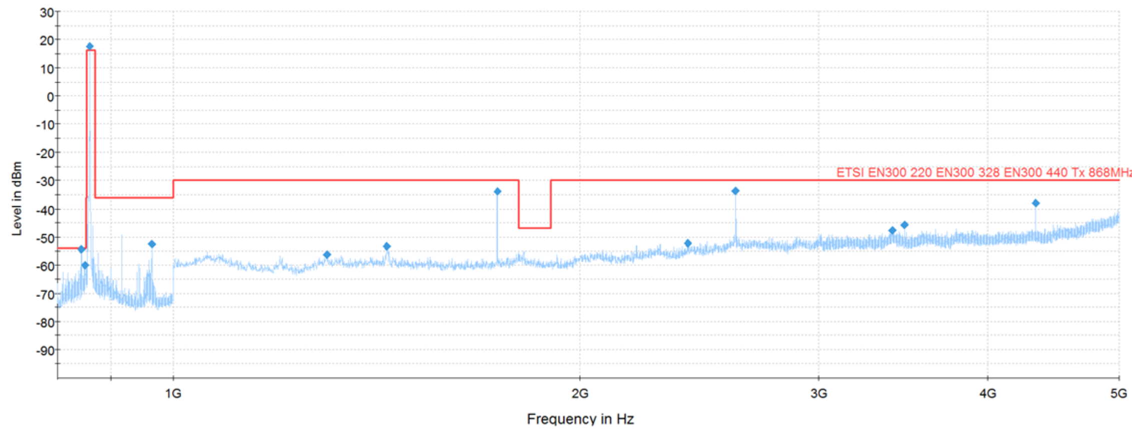


Figure 24. Murata - 868 MHz ETSI EN300 220 Radiated Emissions at Max Output Power

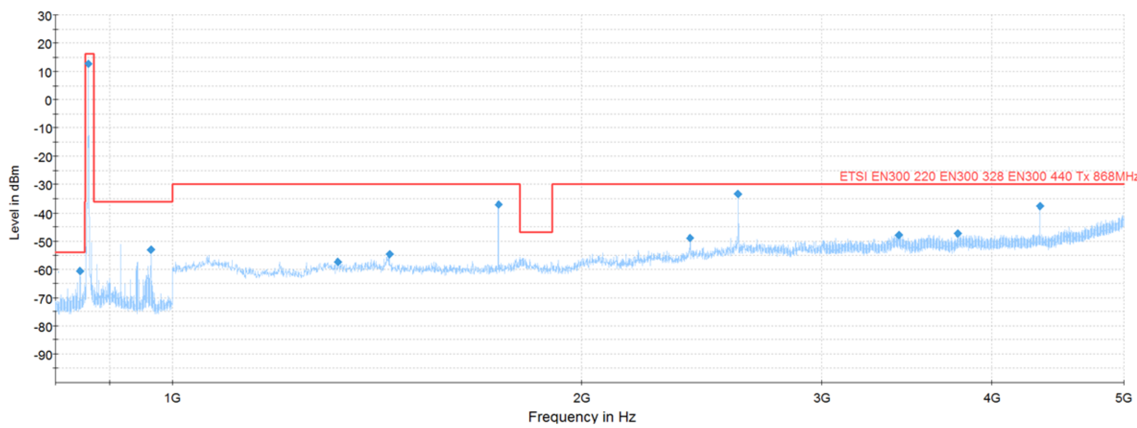


Figure 25. JTI - 868 MHz ETSI EN300 220 Radiated Emissions at Max Output Power

3.2 2.4 GHz

3.2.1 CC1352R Output Power, 1 Mbps BLE Sensitivity and Link Budget

Figure 26 shows the output power measurements across a frequency span from 2402-2480 MHz.

Summary: Murata has a higher output power than Johanson with maximum power settings (boost setting).

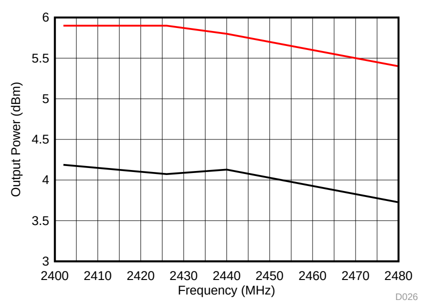


Figure 26. 2.4 GHz Output Power v Frequency

Figure 27 shows the sensitivity measurements (1 Mbps BLE data rate) across a frequency span from 2402-2480 MHz.

Summary: Murata has better sensitivity than Johanson.

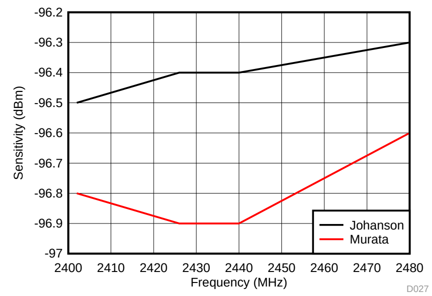


Figure 27. 2.4 GHz 1 Mbps BLE Sensitivity v Frequency

Figure 28 shows the 1 Mbps BLE link budget which is the sum of the output power and the sensitivity measurements. This is a main parameter for greater range.

Summary: Murata has a greater link budget with maximum output power setting.

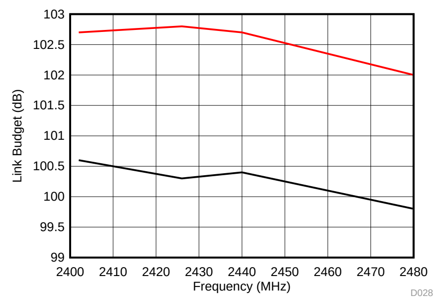


Figure 28. 2.4 GHz 1 Mbps BLE Link Budget v Frequency

3.2.2 CC1352R Tx Efficiency, Tx Harmonics at Maximum Output Power (Boost)

3 V, Maximum output power setting; average results from 2402-2480 MHz:

- JTI Tx Efficiency: 4.0 %
- Murata Tx Efficiency: 6.0 %
- JTI Tx Current: 20.3 mA
- Murata Tx Current: 21.1 mA
- JTI Tx Output Power: 11.8 dBm
- Murata Output Power: 13.9 dBm
- JTI 2nd Harmonic Level: -53 dBm
- Murata 2nd Harmonic Level: -62 dBm
- JTI 3rd Harmonic Level: -60 dBm
- Murata 3rd Harmonic Level: -60 dBm

3.3 Isolation Between Sub-1 GHz Port and 2.4 GHz Port

These tests were performed to determine if a diplexer or a switch could be used to combine the RF ports to a common RF port. The tests were conducted on CC1352R EM Rev 1.0 that had a SMA on each RF port after the IPC.

It is important to note the level of the third harmonic of the 868 MHz on the 2.4 GHz port. The 3rd harmonic of 868 MHz is 2604 MHz, which is close in frequency to the 2.4 GHz pass band, 2402-2480 MHz.

Maximum output power was transmitted at 868 MHz on the sub-1 GHz port and the level of the third harmonic was measured on the 2.4 GHz port.

- Discrete reference design: -45 dBm
- Murata IPC: -33 dBm
- Johanson IPC: -33 dBm

It is possible to use a diplexer or switch on the discrete reference design since the isolation between the two RF ports is sufficient. However, for the IPC solution the isolation is not sufficient to use a diplexer at 868 MHz and 2.4 GHz.

Therefore, a switch is recommended to be used in combination with the IPC to avoid a spurious emission at 2604 MHz. With an efficient 2.4 GHz antenna directly connected to the IPC 2.4 GHz port or connected through a diplexer will fail the regulatory limits of ETSI. An additional advantage with the switch is there is a natural switch isolation which will help to reduce any unwanted harmonics caused through the lower isolation between the two RF ports.

4 Summary

As an alternative to the discrete reference designs shown in Figure 2, the IPC component reference design has similar performance of the discrete multi-layer inductor reference design with a lower component count. 23 passives are required at the CC1352R RF ports. With the IPC, the component count is reduced from 23 to 3 components, which saves space and reduces pick-and-place assembly costs.

It is recommended to combine the two RF ports into one with a SPDT switch. It is possible to use a diplexer or switch on the discrete reference design since the isolation between the two RF ports is sufficient. However, for the IPC solution, the isolation is not sufficient to use a diplexer at 868 MHz and 2.4 GHz.

Table 4 summarizes the link budget for the various reference designs with CC1352R and CC1352P (PA Tx + Rx configuration) with maximum output power. The values shown in Table 4 will naturally vary with approximately ± 1 dB at room temperature.

Table 4. Summary of Link Budget at Maximum Output Power

		Johanson	Murata	Discrete
CC1352R IPC Tx + Rx	868 MHz, 50 kbps	121.6	121.9	123.0
	915 MHz, 50 kbps	122.1	120.4	123.0
	2402-2480 MHz, 1 Mbps	100.3	102.6	101.8
CC1352P IPC sep Tx PA + Rx	868 MHz	129.2	127.7	129.0
	915 MHz	128.8	126.1	129.0
	2402-2480 MHz, 1 Mbps	115.9	116.4	116.5

Murata IPC is optimized for maximum output power (boost mode) and Johanson is optimized at the lower output power steps (normal mode). Tx current is higher for Murata IPC but also has a higher Tx efficiency at the maximum output power. Johanson IPC has a higher Tx efficiency at the lower output power steps. Rx current, Isolation and Tx harmonics are similar for both devices.

Johanson IPC is optimized for sub-1 GHz sensitivity, which makes it ideal when using the CC1352P PA as a pure Tx port and the standard sub-1 GHz port as a pure Rx. For low power sub-1 GHz operations, then Johanson IPC is ideal. Murata IPC has better link budget performance at 2.4 GHz than Johanson.

Pending on the choice of chip between CC1352R and CC1352P, ISM frequency and output power setting; both Murata and Johanson have their own particular advantages. It is recommended to evaluate both vendors since they are drop-in replacements of each other and can be fully evaluated for each application case.

5 References

1. *CC1352R SimpleLink™ High-Performance Dual-Band Wireless MCU Data Sheet*
2. *CC1352P SimpleLink™ High-Performance Dual-Band Wireless MCU With Integrated Power Amplifier Data Sheet*
3. *CC1352R LaunchPad Design Files*
4. Johanson Technology Datasheets and Contact Information
5. Murata Contact Information
6. *CC1352 IPC Reference Design Files*

Revision History

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

Changes from Original (October 2018) to A Revision	Page
• Figure 4 was updated in Section 2.2.2.	6