Application Note

2.4-GHz, 10-dBm PA IPC for CC26x2P and CC1352P

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ABSTRACT

This application note describes the Integrated Passive Component (IPC) designed specifically for the high-power PA port available on the CC26x2P [1] and CC1352P [2] devices operating in the 2.4-GHz ISM bands at 10-dBm output power. With the PA IPC the component count is reduced while still obtaining high radio performance.

The matched-filter balun component is commonly designated as an Integrated Passive Component (IPC). The CC26x2P and CC1352P PA Tx port require 11 passive componenets. With the PA IPC, the component count is reduced from 11 to a single component which saves space and reduces pick-and-place assembly costs.

The PA IPC is available from Murata [3] and is only 1.6 mm x 0.80 mm making it ideal for compact designs.

All measurement results presented in this document are based on measurements performed on the CC2652P PA IPC EM Rev 1.0 Reference Design unless otherwise specified; see Figure 1-1.

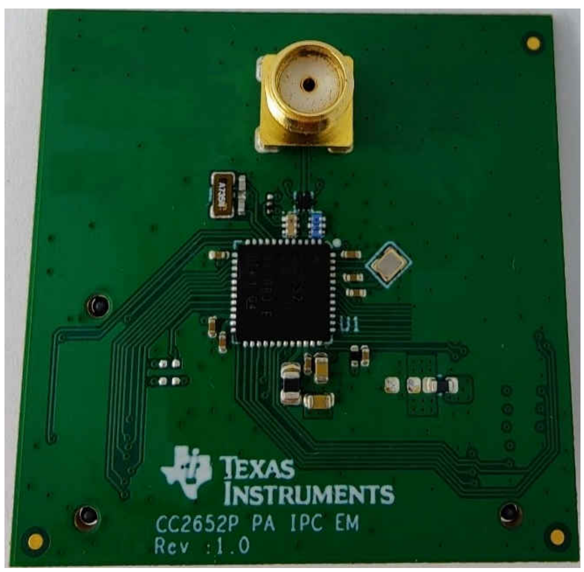

Figure 1-1. CC2652P PA IPC EM Rev 1.0

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Acronyms

Acronym	Definition
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
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
PA	Power Amplifier
IPC	Integrated Passive Component

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1 Reference Designs Available

The existing reference designs for the 10 dBm PA 2.4 GHz are based upon LAUNCHXL-CC2652P [7] and LAUNCHXL-CC1352P-4 [6], these are based upon passive discrete components, refer to Figure 1-1.

Each RF port is terminated with 50-ohm impedance that can be connected to SMA connector, switch or diplexer. The main advantage in using a switch or diplexer is a common RF port instead of several RF ports.

LAUNCHXL-CC2652P [4] has two RF ports and LAUNCHXL-CC1352P-4 [5] has three RF ports. The additional RF port in CC1352P can be configured for both Sub-1 GHz or 2.4 GHz. The PA port of CC2652P [1] and CC1352P [2] can be configured as 20 dBm or 10 dBm. The PA IPC [3] can be used for 10 dBm, 2.4 GHz for both CC26x2P [1] and CC1352P [2]

This application note will document the measurements performed on the PA Tx port for CC2652P [1] and CC1352P [2] for 10 dBm 2.4 GHz with the IPC [3] component. The parts in the reference design not related to the PA port will not be discussed.

A switch (SPDT for CC2652P and SP3T for CC1352P) is used on the LaunchPads [5] to enable a common RF port which is connected to an integrated PCB dual-band antenna.

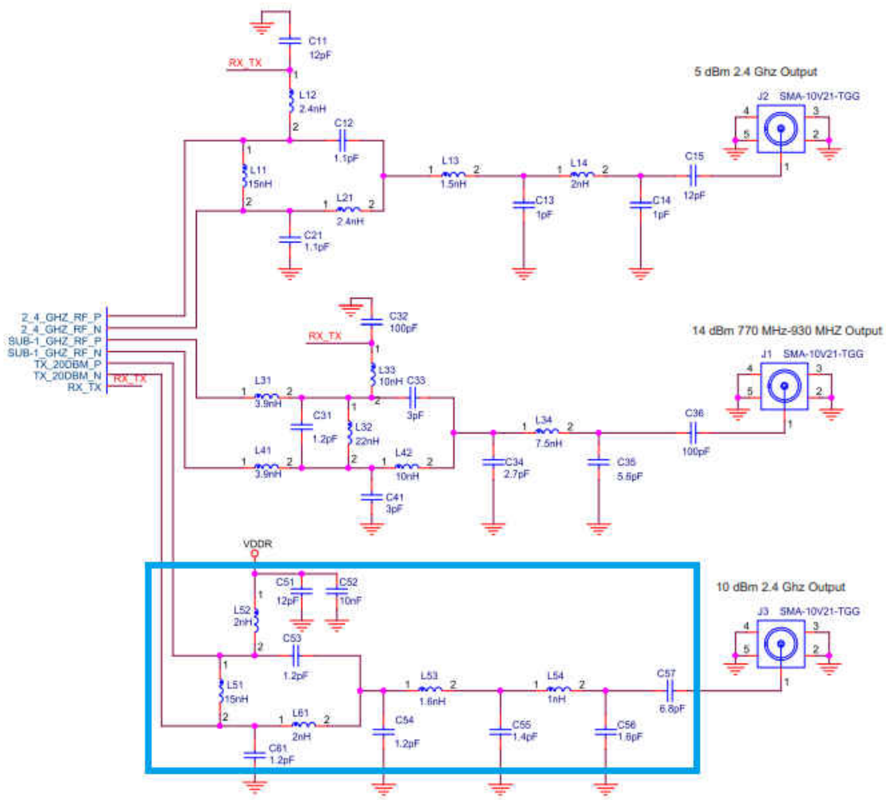

Figure 1-1. CC1352PEM-XD7793-XD24-PA24_10 dBm RF Section Schematic

1.1 Single Component for 10-dBm PA Port

The objectives with the PA IPC compared to the discrete design [4] are to:

- Reduce the number of external components required
- Reduce the overall size for a more compact layout
- Ease the layout process so less risks of RF cross-talk for poor RF layouts
- Maintain similar RF performance of discrete design

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1.1.1 Murata PA IPC Equivalent Circuit

The equivalent circuit of the IPC from Murata is shown in Figure 1-2. The complete specification of their IPC is available from Murata [3]. Murata's matched balun filter solution implementation contains a DC blocking capacitor (C57) and a bypass capacitor (C51).

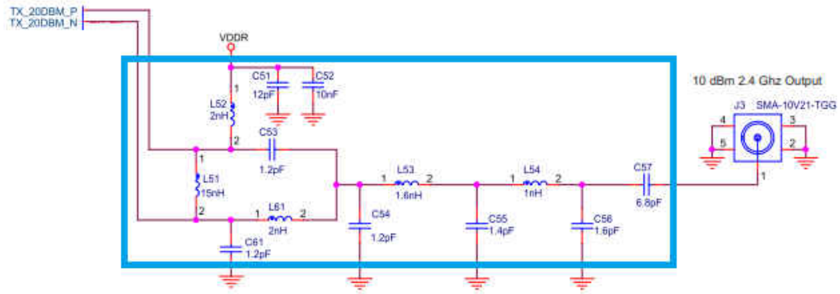

Figure 1-2. Murata CC1352P IPC Equivalent Circuit for 10 dBm PA 2.4 GHz

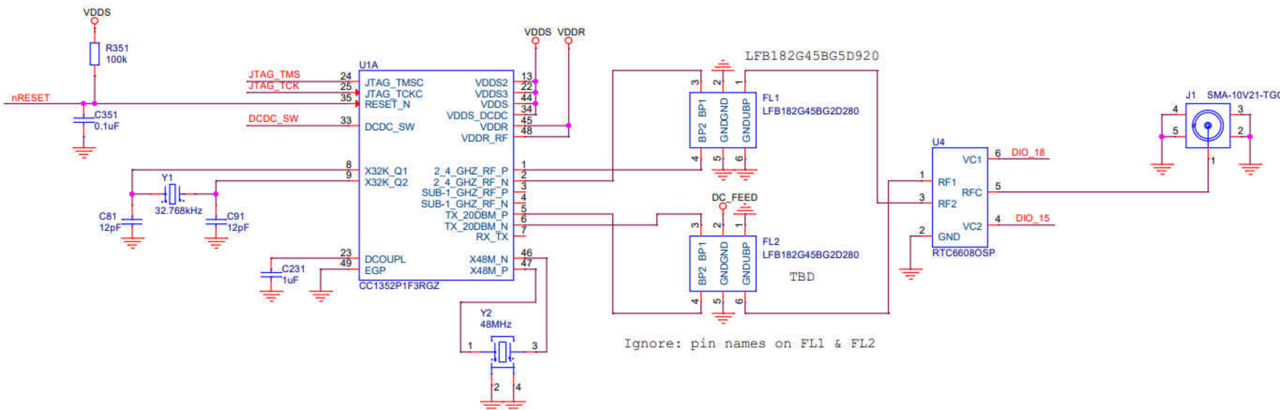

Figure 1-3. CC2652P PA IPC EM Rev 1.0 Schematic

The 10 dBm PA IPC was evaluated on the CC2652P PA IPC EM board shown in Figure 1-1 and the schematic is shown in Figure 1-3. The CC2652P PA IPC EM board utilizes two IPCs, one IPC for the Rx / 5 dBm Tx port [6] and the second IPC [3] for the 10 dBm PA section. Only the 10 dBm PA IPC connected to pins 5 and 6 will be discussed in this application note.

CC2652P PA IPC EM board has a common RF port. The Rx / 5 dBm Tx RF port and the 10 dBm PA port from the unbalanced RF ports of the IPCs are connected to the dual-throw section of the SPDT switch. The single-pole port of the switch is connected to a SMA or can be connected to a single-feed dual-band antenna. The SPDT switch can be controlled by any DIOs. DIO15 and DIO18 are used in the CC2652P PA IPC EM design.

1.1.2 IPC Size and Dimensions

The physical size of the IPC and dimensions are shown in Figure 1-4. The dimensions are only 1.60 mm x 0.80 mm. This makes the IPC ideal for compact designs and makes the layout much easier and less risk for RF layout issues.

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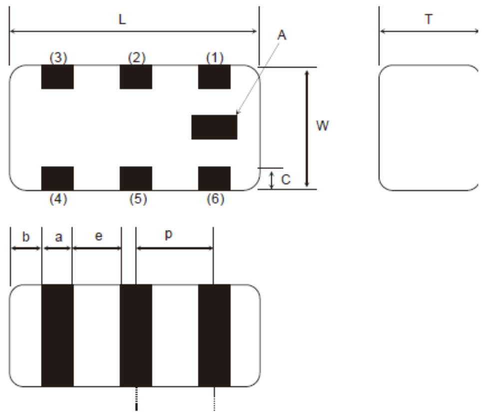

Mark	Meaning
A	Directional Input Mark

(in mm)

Mark	Dimension	Mark	Dimension	Mark	Dimension
L	1.6±0.1	a	0.2±0.1	e	0.3±0.1
W	0.8±0.1	b	0.20+0.10/-0.15	p	0.50±0.05
T	0.65 max.	c	0.15±0.10	-	-

TERMINAL CONFIGURATION

Terminal No.	Terminal Name	Terminal No.	Terminal Name
(1)	GND	(4)	Balance Port
(2)	VDDR	(5)	GND
(3)	Balance Port	(6)	Unbalance Port

Figure 1-4. Component Size and Dimensions

1.2 CC2652P PA IPC EM

1.2.1 Component Placement and Layout

The PA IPC component placement influences the RF performance and the reference design should be followed as close as possible, refer to Figure 1-5 and Figure 1-6. The distance between the PA IPC and the CC1352P/CC2652P is important and this should be 0.66 mm as can be seen in Figure 1-6.

In the event that the reference design 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 0.66 mm. The width of the tracks between CC1352P/CC2652P and the IPC should also be kept as 0.15 mm.

If the recommended distance of 0.66 mm, 0.15 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 harmonics and Rx sensitivity. Refer to Figure 1-6 for recommended GND via placements for the IPC.

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.

The DC blocking capacitor and bypass capacitor is integrated into the PA IPC. U2 is a compact SPDT switch that combines the two RF ports into one common RF port.

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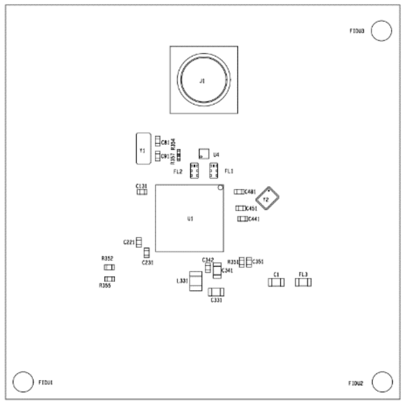

Figure 1-5. CC2652P Component Placement

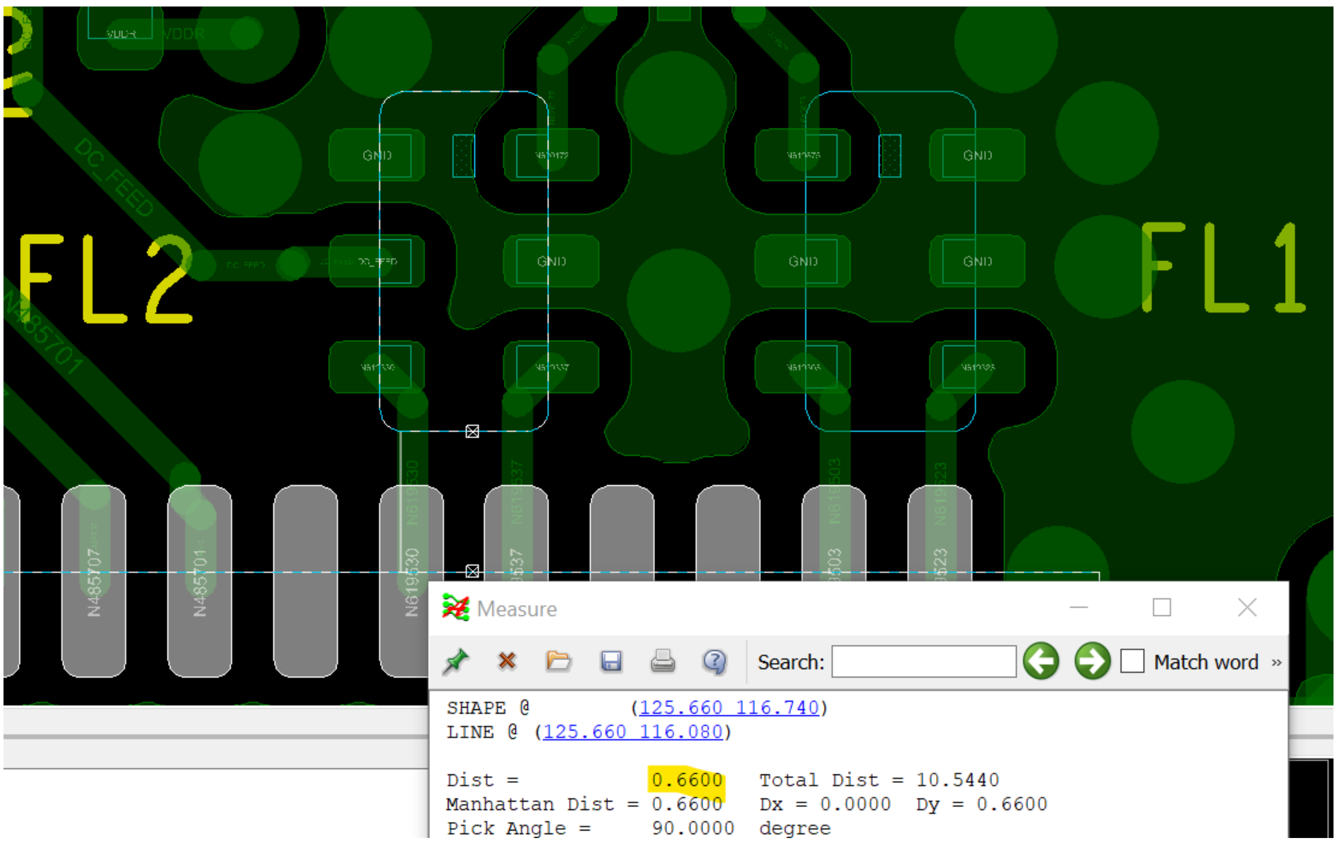

Figure 1-6. Via Placement and Distance between CC1352P / CC2652P and the PA IPC (FL2)

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1.2.2 Layout - Layer 1

Figure 1-7 shows the top layer of the 4-layer reference design. Remaining area is filled with GND for shielding purposes.

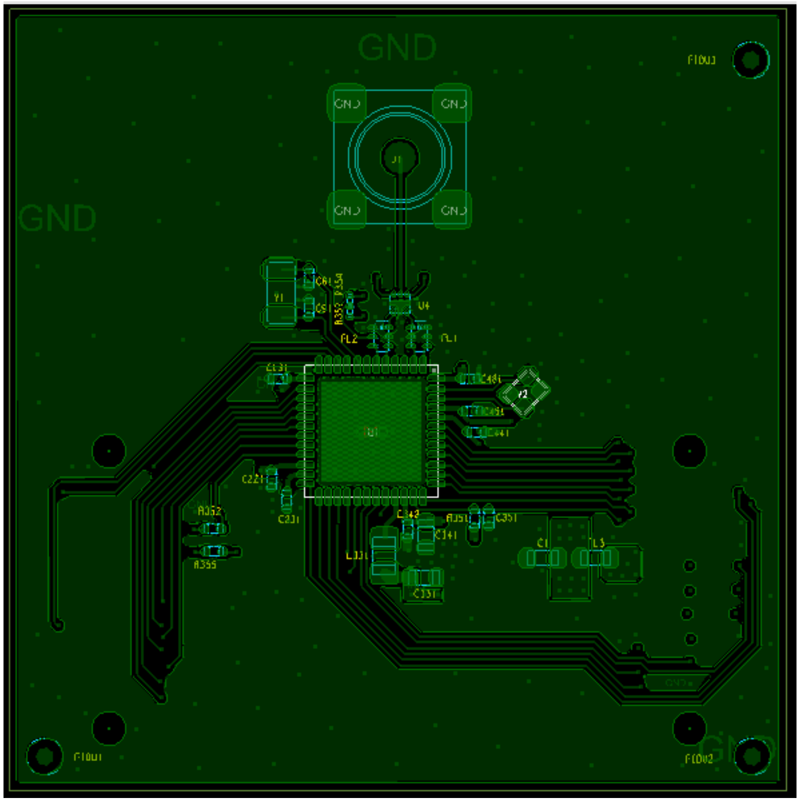

Figure 1-7. Layer 1

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1.2.3 Layout - Layer 2

Figure 1-8 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.

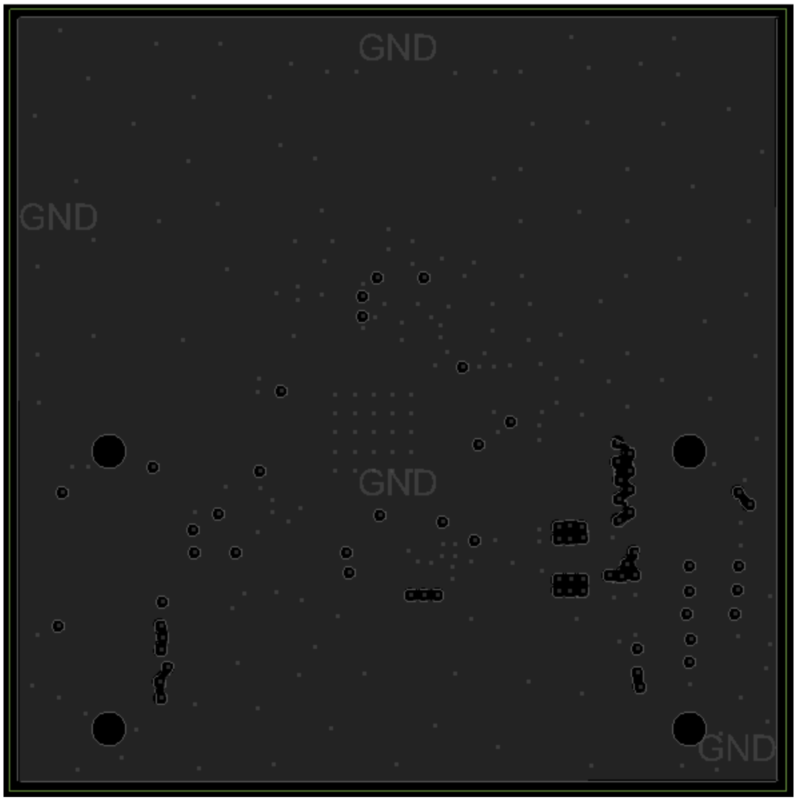

Figure 1-8. Layer 2

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1.2.4 Layout - Layer 3

Figure 1-9 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 CC2652P.

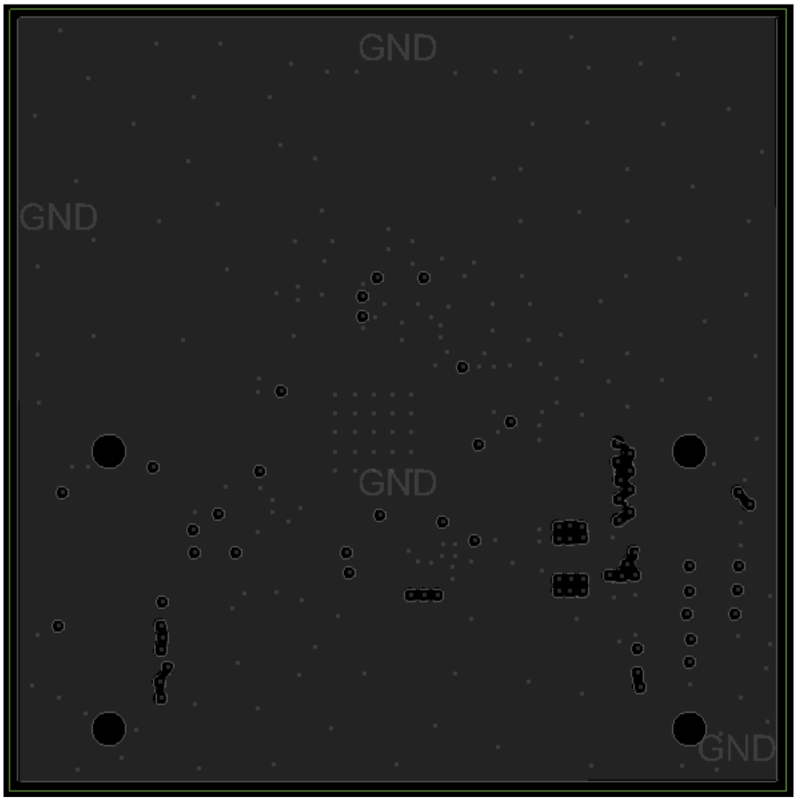

Figure 1-9. Layer 3

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1.2.5 Layout - Layer 4

Figure 1-10 shows the fourth layer of the 4-layer reference design. This layer is mainly for the connector or DIO distribution. Remaining area is filled with GND for shielding purposes.

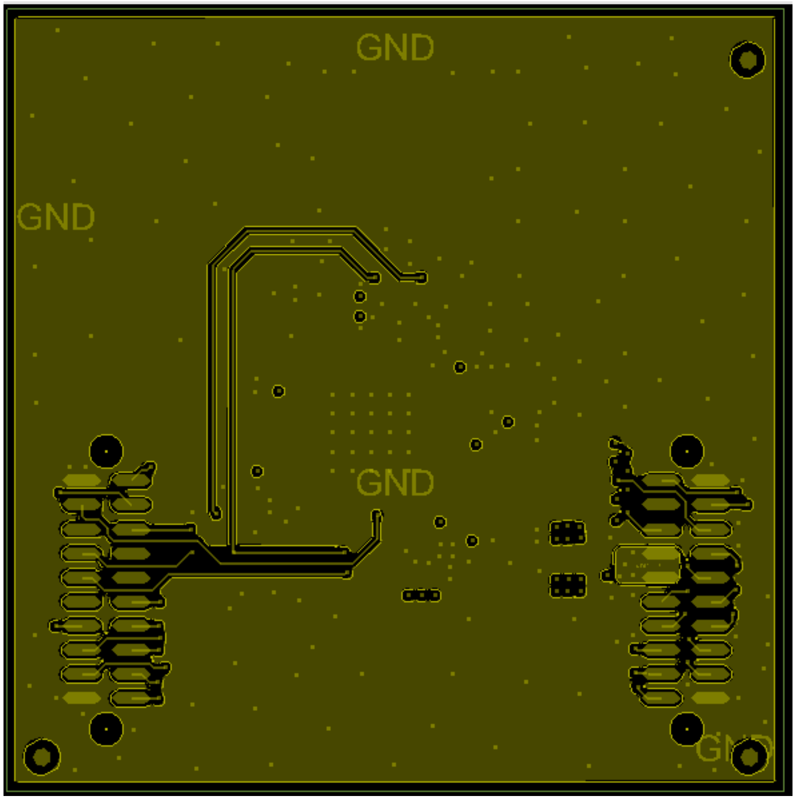

Figure 1-10. Layer 4

For hardware configuration and PCB design considerations refer to the provided application report [7].

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2 PA IPC Measurement Results

All results presented in this chapter are based on measurements performed on CC2652P PA IPC EM Rev 1.0 unless otherwise noted. 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 [1].

2.1 CC2652P Output Power, 1-Mbps Bluetooth Low Energy

Figure 2-1 shows the output power measurements for three discrete frequencies 2402, 2440 and 2480 MHz.

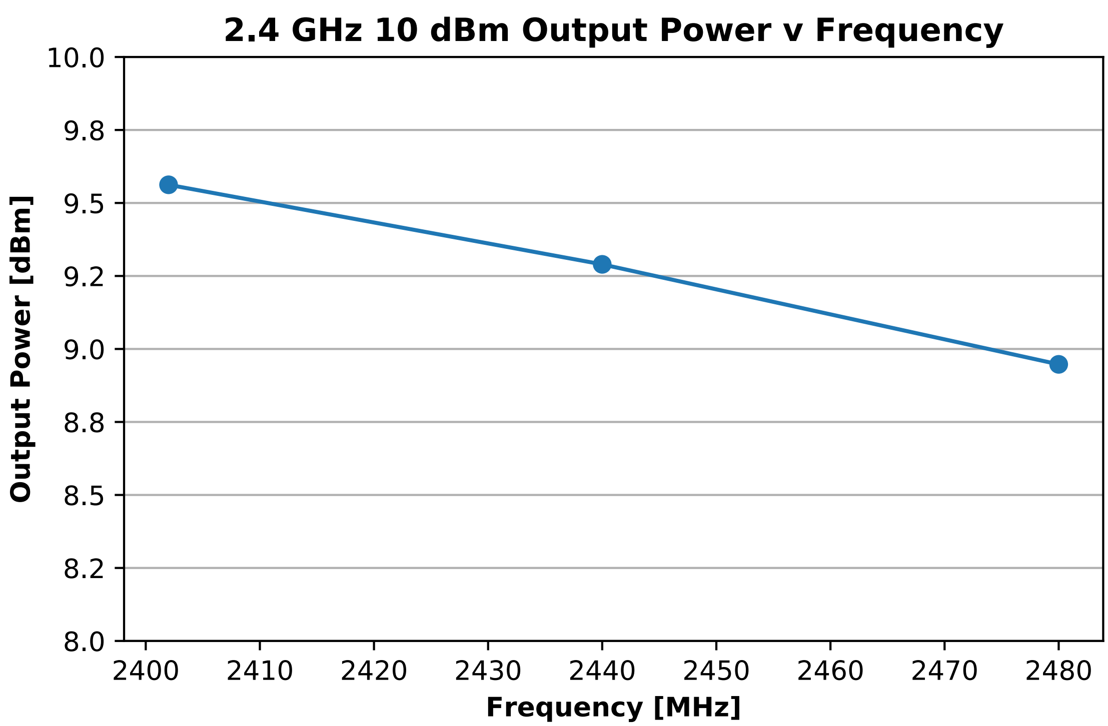

Figure 2-1. CC2652P - Output Power versus Frequency

Figure 2-2 shows the second harmonic at 10 dBm output vs three discrete frequencies, 2402, 2440, and 2480 MHz compared to FCC and ETSI regulations. Compliance with FCC and ETSI regulations will discussed in Section 3.

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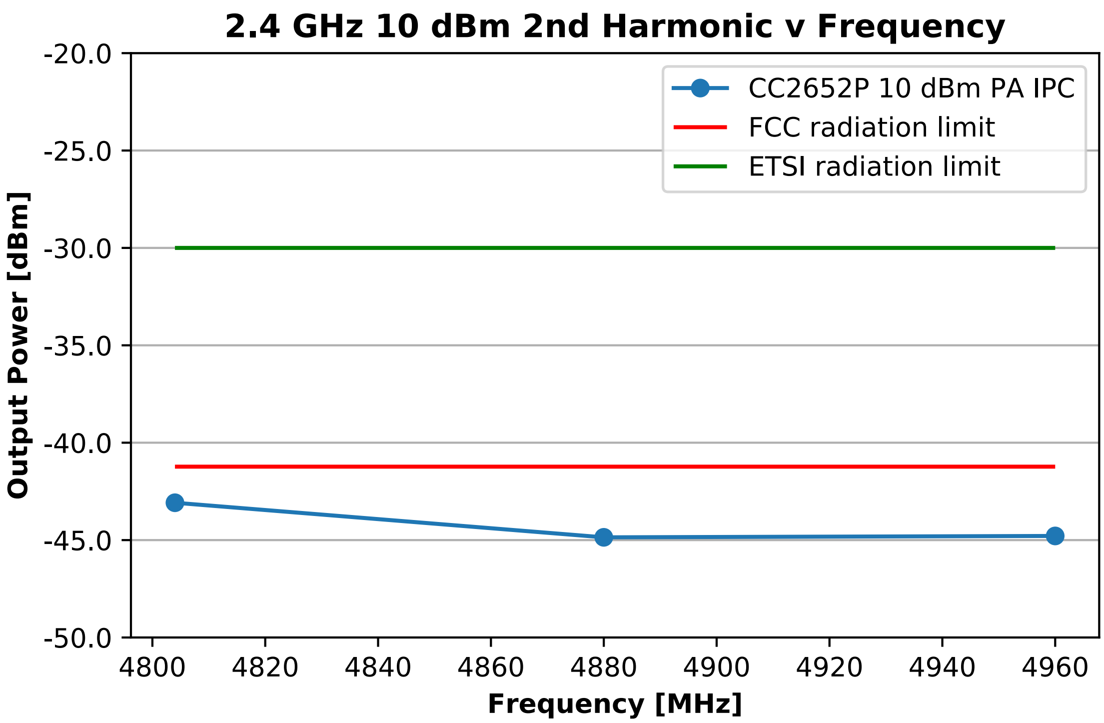

Figure 2-2. CC2652P - 2nd Harmonic versus Frequency

Figure 2-3 shows the third harmonic at 10dBm output vs three discrete frequencies, 2402, 2440 and 2480 MHz.

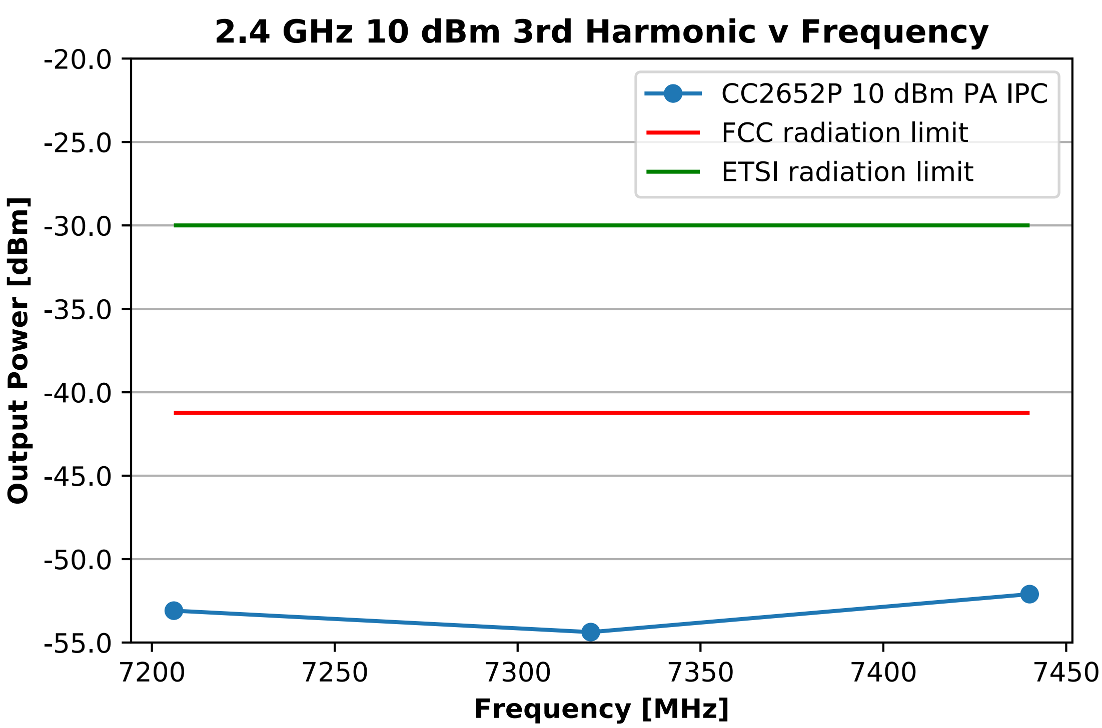

Figure 2-3. CC2652P - 3rd Harmonic versus Frequency

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

- TX Efficiency: 9.6 %
- TX Current: 25.76 mA
- Output Power: 9.3 dBm
- 2nd Harmonic Level: -44.7 dBm
- 3rd Harmonic Level: -54.4 dBm

2.2 CC2652P TX Efficiency, Harmonics, and Output Power at Various PA Settings

Table 2-1. PA Settings for CC2652P

Index [hex]	Output Power [dBm]
0x144F2A	6
0x144F2A	7
0x10335A	8
0x103F5F	9
0x104F66	10

Figure 2-4 shows the current for each of the PA settings given above.

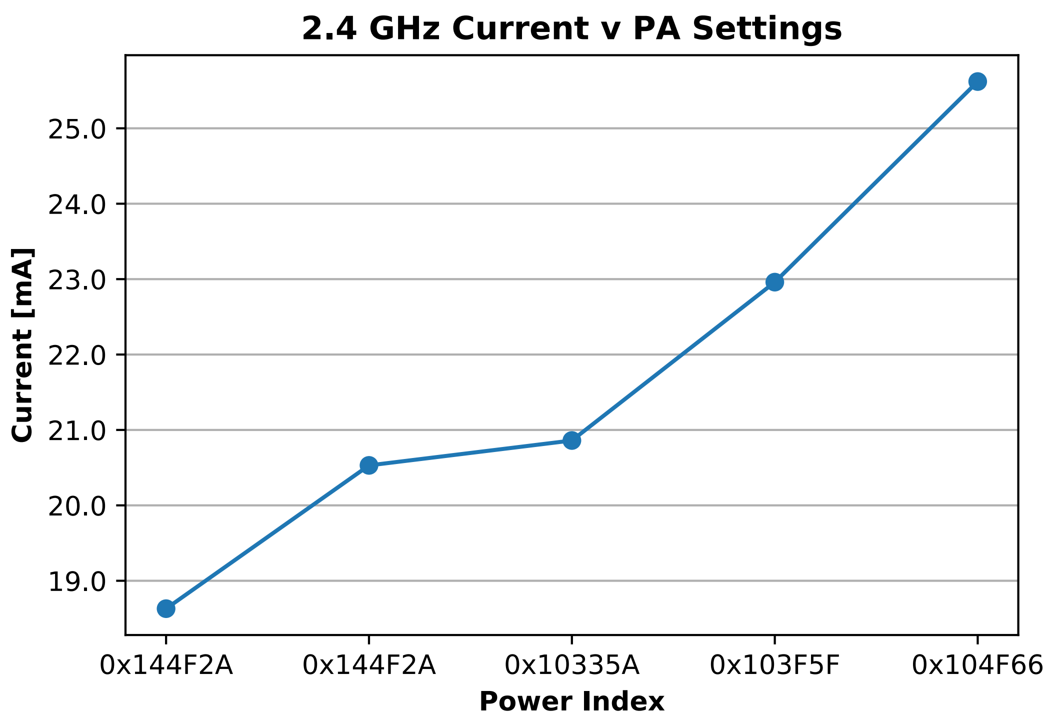

Figure 2-4. CC2652P - Current versus PA Settings

Figure 2-5 shows the output power versus all of the PA setting given in Table 2-1 for the CC2652P.

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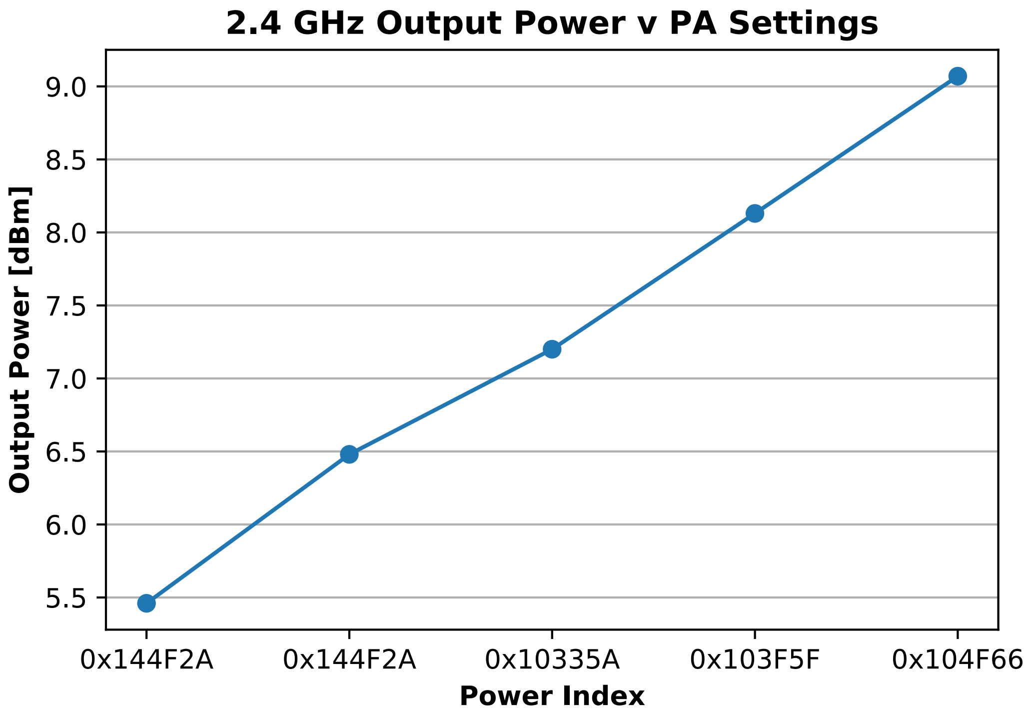

Figure 2-5. CC2652P - Output Power versus PA Settings

Figure 2-6 shows the efficiency versus all of the PA setting given in Table 2-1 for the CC2652P. The efficiency increases almost linearly with an increase in power setting.

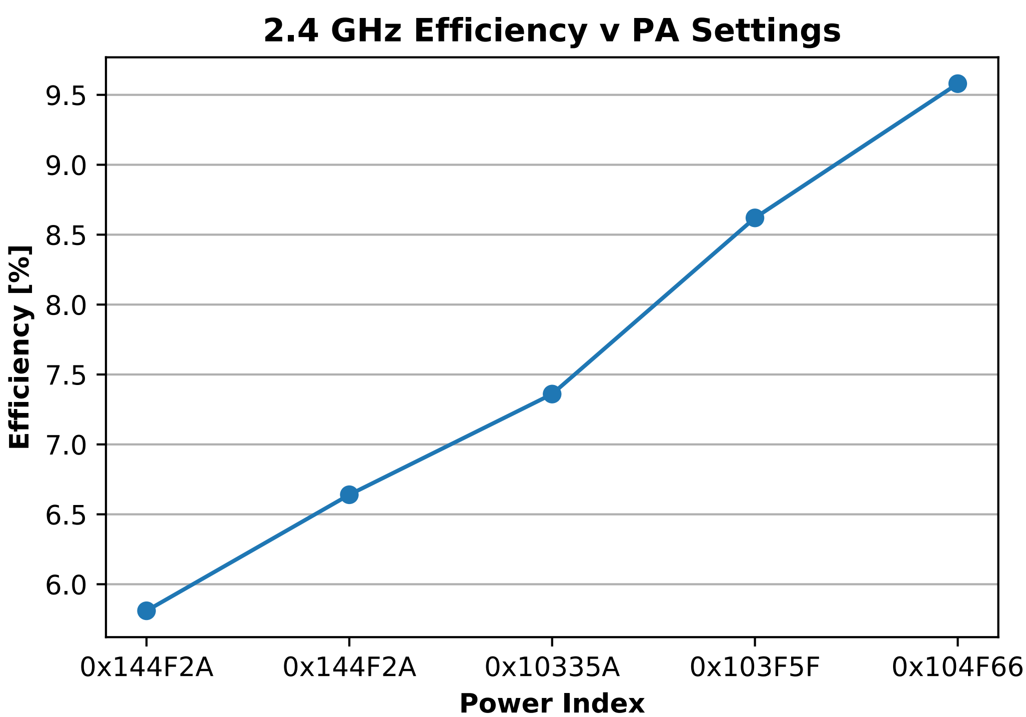

Figure 2-6. CC2652P - Efficiency versus PA Settings

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3 Harmonic Emission Regulatory Requirements

Note

All measurements presented in this chapter have to be performed on the final application board to be compliant to the ETSI and FCC regulations so these measurements are for pre-qualification purposes only.

The emissions regulations given by the FCC and ETSI is given in the Table 3-1 and have to be met by all products intended for the markets governed by these regulations.

Table 3-1. 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

Table 3-1 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 3-1, if duty cycling is being used.

3.1 Compliance with FCC regulations

Table 3-2. Examples of 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 or 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	%

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

If duty cycling is not an option whilst operating at maximum output power, it is recommended to implement a notch filter or band stop filter to meet the FCC requirements for the 2nd harmonic. The notch filter given in Figure 3-1 consists of one inductor in series with a capacitor. The values of the components as shown in Figure 3-1 is derived by Equation 2, and should sufficiently attenuate the 2nd harmonic. Where *L* is an inductor and *Ctot* is the sum of the capacitor C and the parasitic capacitance from the layout. The filter should be connected to the unbalanced port of the PA IPC. However, if a switch is utilized it would be beneficial to place it at the common port of the RF switch so all RF ports will benefit from the additional filtering.

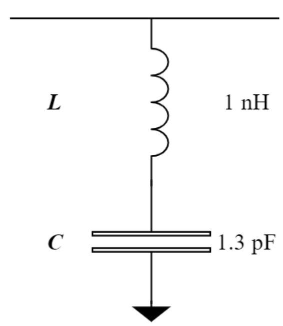

Figure 3-1. Circuit Diagram of the Notch Filter.

$$f\_c = 1/(2\pi\sqrt{(LC\_tot)}) \quad (2)$$

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3.2 Compliance with Regulations

Figure 3-2 shows that the CC1352P/CC2652P complies with ETSI conducted, ETSI radiated regulations, and the FCC conducted regulations. The FCC radiated regulations are compliant if duty cycling is utilised whilst operating at maximum output power. If it is not possible to use duty cycling, then it is recommended to use an external notch filter to pass FCC radiated regulations or to reduce the output power.

Note that 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.

It is important that the antenna is matched (VSWR < 2.1) for 2.4 GHz frequencies. Otherwise, if the antenna mismatch is large then there will be unwanted radiated emissions and the wanted output power will be reduced.

Figure 3-2 shows worst case radiated performance when using the 10 dBm setting. If there is a need to decrease the fundamental and/or the 2nd harmonic a reduction in power setting would also give the desired result.

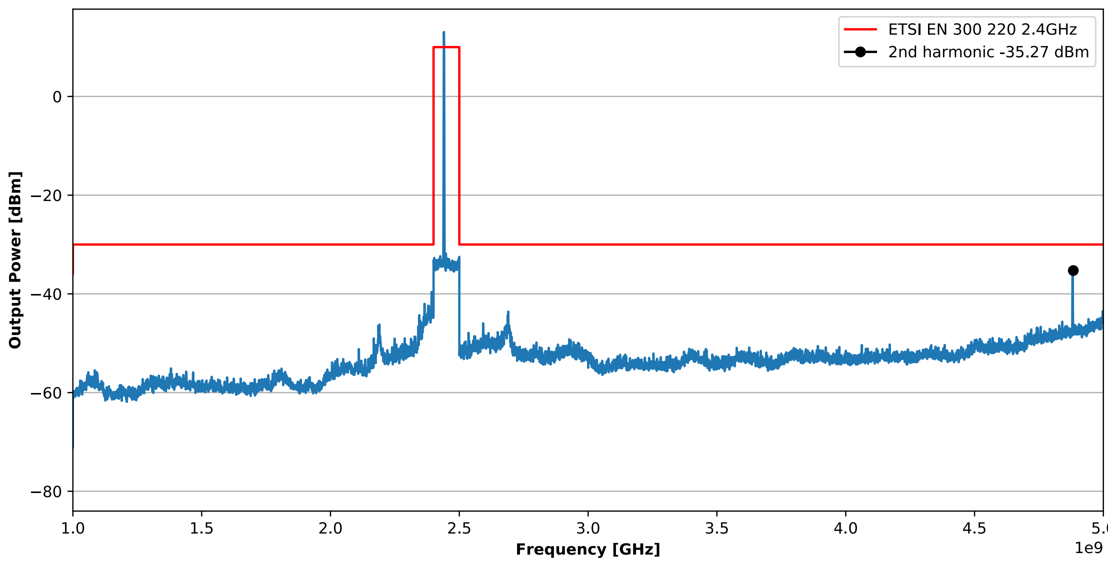

Figure 3-2. 2.4-GHz ETSI EN300 220 Radiated Emissions at 10-dBm Output

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4 Summary

As an alternative to the discrete reference designs as shown in Figure 1-2 the 10 dBm PA IPC component reference design has similar performance to the discrete reference design with a lower component count. 11 passives are required for the CC2652P 10 dBm PA port but by using the IPC, the component count is reduced from 11 to a single component which saves space and reduces pick-and-place assembly costs.

Figure 4-1 shows that the efficiency of the LAUNCHXL-CC1352P-4 10 dBm is 10.9 % and the 10 dBm PA IPC is 9.6 % which shows similar performance for a very compact design. This means that there will be a slight loss in performance when implementing the 10 dBm PA IPC compared to the standard reference design.

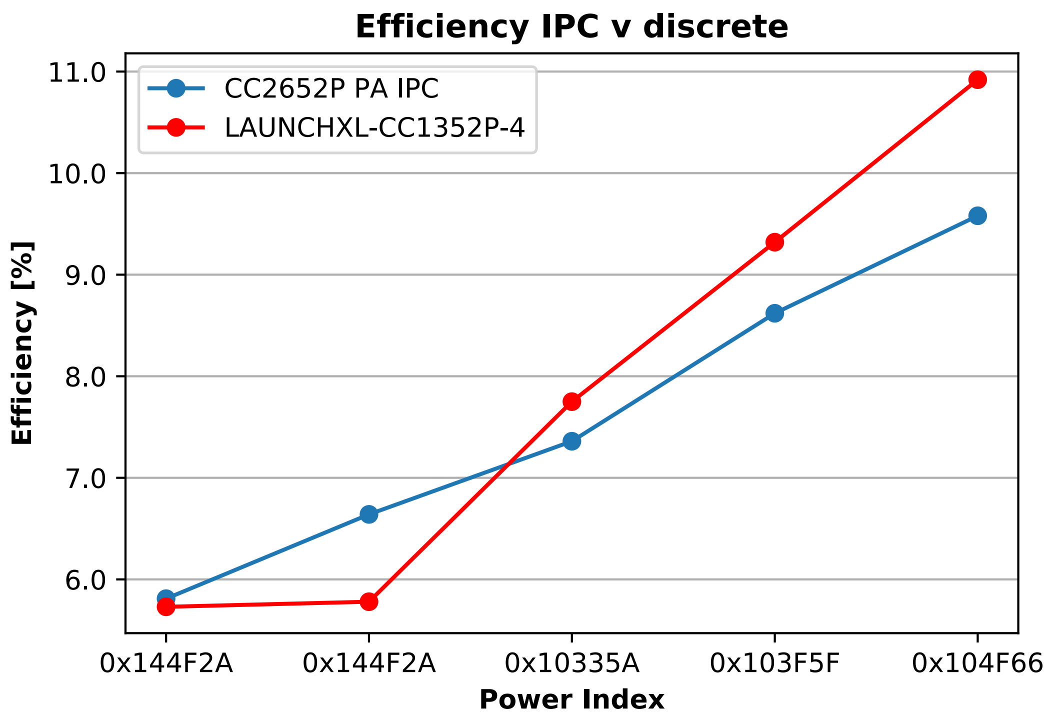

Figure 4-1. Comparison of Efficiency between the IPC and Discrete Solution

There are some clear advantages to the 10 dBm PA IPC compared to the discrete design. If the loss in efficiency is acceptable the 10 dBm PA IPC offers improvements with a more compact layout, reduced "pick-n-place" production costs, and an easy layout.

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5 References

- [1] CC2652P Data Sheet
- [2] CC1352P Data Sheet
- [3] Murata Contact Information
- [4] LAUNCHXL-CC2652P Reference Design
- [5] LAUNCHXL-CC1352P-4 Reference Design
- [6] Rx / 5 dBm Tx IPC for 2.4 GHz App Note
- [7] CC13xx/CC26xx Hardware Configuration and PCB Design

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