Application Note

CC13xx/CC26xx Hardware Configuration and PCB Design Considerations

TEXAS INSTRUMENTS

ABSTRACT

This application report provides design guidelines for the CC13xx/CC26xx SimpleLink™ ultra-low-power wireless MCU platform. There is an overview of the different reference designs followed by RF front-end, schematic, PCB, and antenna design considerations. The document also covers crystal oscillator tuning, optimum load impedance as well as a brief explanation of the different power supply configurations. The last section of the document provides a summary of steps to carry out at board bring-up.

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1 Reference Design

A TI LaunchPad™ is the main development platform for CC13xx and CC26xx devices. A LaunchPad includes optimized external RF components on-board, PCB antenna and built-in debugger providing an easy-to-use development environment with a single core software development kit (SDK) and rich tool set. Each CC13xx/CC26xx family member is featured on a dedicated LaunchPad with RF matching network and an antenna optimized for operation at one or more of the supported ISM bands. All TI LaunchPad design files, including Gerber-files and CAD source, are available for download at ti.com and can be used as a reference design when integrating CC13xx/CC26xx into custom hardware.

1.1 Sub-1GHz LaunchPads

This section provides the different LaunchPad designs and which design to follow for a specific CC13xx/CC26xx device and ISM band.

1.1.1 LAUNCHXL-CC1310

Featured device:	CC1310
ISM band:	868MHz and 915MHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*LAUNCHXL-CC1310 Design Files*

1.1.2 LAUNCHXL-CC1312R

Featured device:	CC1312R
ISM band:	868MHz and 915MHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*SimpleLink Sub-1GHz CC1312R Wireless (MCU) LaunchPad Dev Kit 868MHz/915MHz App*

1.2 2.4GHz LaunchPads

1.2.1 LAUNCHXL-CC2640R2

The LAUNCHXL-CC2640R2 is a single-protocol LaunchPad that operates in 2.4GHz supporting BLE 5.1 and earlier LE specifications. The RF front end enables up to +5dBm of output power.

Featured device:	CC2640R2F
ISM band:	2.4GHz
Antenna:	*2.4GHz Inverted F Antenna*
RF front-end:	Differential, internal bias
Design files:	*LAUNCHXL-CC2640R2 Design Files*

1.2.2 LAUNCHXL-CC26x2R

The LAUNCHXL-CC26x2R is a multi-protocol LaunchPad that operates at 2.4GHz. The RF front end enables up to +5dBm of output power. LAUNCHXL-CC26x2R can also be used for development with CC2642R.

Featured device:	CC2652R
ISM band:	2.4GHz
Antenna:	*2.4GHz Inverted F Antenna*
RF front end:	Differential, internal bias
Design files:	*CC26x2R LaunchPad Design Files*

1.2.3 LP-CC26x1

The LP-CC26x1 is a multi-protocol LaunchPad that operates at 2.4GHz. The LaunchPad comes in two versions: LP-CC2651R3 which enables up to +5dBm of output power and LP-CC2651P3 which enables up to +20dBm of output power.

Featured device	CC2651R3 and CC2651P3
ISM band	2.4GHz
Antenna	*2.4GHz Inverted F Antenna*
RF Front End	Differential, external bias
Design Files	*LP-CC26x1 LaunchPad Design Files*

1.3 Dual-Band LaunchPads

1.3.1 LAUNCHXL-CC1350EU/US

The LAUNCHXL-CC1350EU/US is a dual-band LaunchPad that operates between 868MHz/915MHz or 2.4GHz. The sub-1 GHz path enables up to +15dBm of output power, and the 2.4GHz path enables up to +9dBm of output power. The LaunchPad comes in two different versions: EU (868MHz) and US (915MHz). Both paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1350
ISM band:	868MHz, 915MHz, and 2.4GHz
Antenna:	• *Miniature Helical PCB Antenna for 868MHz or 915/920MHz*
	• *2.4GHz Inverted F Antenna*
RF front-end:	Differential, external bias
Design files:	*LAUNCHXL-CC1350 Design Files*

1.3.2 LAUNCHXL-CC1350-4

The LAUNCHXL-CC1350-4 is a dual-band LaunchPad that operates between 433MHz or 2.4GHz. The sub-1GHz path enables up to +15dBm of output power, and the 2.4GHz path enables up to +9dBm of output power. Both paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1350
ISM band:	433MHz and 2.4GHz
Antenna:	• *Miniature Helical PCB Antenna for 868MHz or 915/920MHz*
	• *2.4GHz Inverted F Antenna*
RF front-end:	Differential, external bias
Design files:	*CC1350 Dual Band Launchpad for 433 MHz/ 2.4GHz Band Rev A*

1.3.3 LAUNCHXL-CC1352R

The LAUNCHXL-CC1352R is a dual-band LaunchPad that operates between 868MHz/915MHz or 2.4GHz. The sub-1GHz path enables up to +14dBm of output power, and the 2.4GHz path enables up to +5dBm of output power. The current revision uses a diplexer instead of a switch to allow both frequency bands to share an RF path, which frees up one DIO pin. Both paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1352R
ISM band:	868MHz, 915MHz, and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*CC1352R LaunchPad Design Files*

1.3.4 LAUNCHXL-CC1352P1

The LAUNCHXL-CC1352P1 is a dual-band LaunchPad that operates between 868MHz/915MHz or the 2.4GHz. The sub-1GHz has a high-power PA path enabling up to +20dBm output power, and a regular path with up to +14dBm output power. The 2.4GHz path enables up to +10dBm output power. All three paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1352P
ISM band:	868MHz, 915MHz, and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*CC1352R LaunchPad Design Files*

1.3.5 LAUNCHXL-CC1352P-2

The LAUNCHXL-CC1352P-2 is a dual-band LaunchPad that operates between 868MHz/915MHz or 2.4GHz. The sub-1GHz path enables up to +14dBm output power. The 2.4GHz output has a high-power PA path enabling up to +20dBm output power, and a regular path with up to +5dBm output power. All three paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1352P
ISM band:	868MHz, 915MHz and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*LAUNCHXL-CC1352P-2 Design Files*

1.3.6 LAUNCHXL-CC1352P-4

The LAUNCHXL-CC1352P-4 is a dual-band LaunchPad that operates between 433MHz or 2.4GHz. The sub-1GHz path enables up to +13dBm output power. The 2.4GHz path biases the high-power PA to provide up to +10dBm output power, and a regular that enables up to +5dBm of output power. All three paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1352P
ISM band:	433MHz and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*LAUNCHXL-CC1352P-4 Design Files*

1.3.7 LP-CC1352P7-1

The LP-CC1352P7-1 is a dual-band LaunchPad that operates between 868MHz/915MHz or 2.4GHz. The sub-1 GHz output has a high-power PA path enabling up to +20dBm output power or a regular path with up to +14dBm output power. The 2.4GHz path enables up to +5dBm output power. All three paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1352P7-1
ISM band:	868MHz, 915MHz and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*LAUNCHXL-CC1352P7-1 Design Files*

1.3.8 LP-CC1352P7-4

The LP-CC1352P7-4 is a dual-band LaunchPad that operates between 433MHz or 2.4GHz. The sub-1 GHz output has a high-power PA path enabling up to +20dBm output power, and a regular path with up to +14dBm output power. The 2.4GHz path enables up to +5dBm output power. All three paths share a dual-band antenna optimized for both frequency bands.

Featured device:	CC1352P7-4
ISM band:	433MHz and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front-end:	Differential, external bias
Design files:	*LAUNCHXL-CC1352P7-4 Design Files*

1.3.9 LP-EM-CC1354P10-6

The LP-EM-CC1354P10-6 is a dual-band LaunchPad that operates between 868MHz/915MHz or 2.4GH. The sub-1 GHz path enables up to +14dBm output power. The 2.4GHz high-power PA path can be configured up to +10dBm or +20dBm, and the regular path enables +5dBm of output power. All three paths share a dual-band antenna optimized for both frequency bands.

Please note that this LaunchPad requires an LP-XDS110 debugger.

Featured device:	CC1354P
ISM band:	868MHz, 915MHz, and 2.4GHz
Antenna:	*Monopole PCB Antenna with Single or Dual Band Option*
RF front end:	Differential, external bias
Design files:	*LP-EM-CC1354P10-6 Design Files*

1.4 Reference Design Overview

When designing a custom board the reference design should be closely followed. Not all combinations of CC13xx/CC26xx devices and ISM bands are covered by any one reference design, but it is possible to use an RF front-end from one reference design and combine it with a compatible CC13xx/CC26xx device. Table 1-1 shows which CC13xx/CC26xx reference design to use for a given ISM band.

If the application requires operation in the 433MHz band, but does not need 2.4GHz operation or +20dBm transmit power, the CC1312R device can be used instead of CC1352P. Then, the LAUNCHXL-CC1352P-4 reference design should be followed, but only the RF front-end on the SUB-1_GHZ_RF_P/N pins is required.

Table 1-1. CC13xx/CC26xx Reference Design Overview

Frequency Band	Supported Device	Reference Design	Comment
433MHz 470MHz 510MHz	CC1310	CC13xxEM-7XD-4251	
	CC1312R	LAUNCHXL-CC1352P-4	Use the 433MHz front-end from the CC1352P reference design
779MHz 868MHz 915MHz	CC1310	LAUNCHXL-CC1310	For other reference designs, see the following link
	CC1311R3	LP-CC1311R3	
	CC1311P3	LP-CC1311P3	
	CC1312R	LAUNCHXL-CC1312R1	
2.4GHz	CC26x0	CC2650EM-7ID	Characterization board for CC26x0. Using the 7x7 QFN in combination with differential RF, internal bias.
		CC2650EM-5XD	Characterization board for CC26x0. Using the 5x5 QFN in combination with differential RF, external bias.
		CC2650EM-4XS	Characterization board for CC26x0. Using the 4x4 QFN in combination with single ended RF, internal bias.
		CC2650EM-4XS_Ext_Reg	Characterization board for CC26x0. Using the 4x4 QFN in External Regulator mode configuration.
	CC2640R2	LAUNCHXL-CC2640R2	Evaluation and development platform.
		CC2640EM-CXS	Characterization board for the CC2640R2F WCSP.
	CC2642R CC2652R	LAUNCHXL-CC26x2R1	Evaluation and development platform.
		CC26x2REM-7ID	Characterization board.
Multi-band	CC1350	LAUNCHXL-CC1350-4	• 433MHz • 2.4GHz
	CC1352P	LAUNCHXL-CC1352P-4	
	CC1350	LAUNCHXL-CC1350	• 868/915MHz • 2.4GHz
	CC1352R	LAUNCHXL-CC1352R1	
		CC1352REM-XD7793-XD24	
	CC1352P	LAUNCHXL-CC1352P1	• 868/915MHz at 20dBm • 2.4GHz at 5dBm
		CC1352PEM-XD7793-XD24-PA9093	
		LAUNCHXL-CC1352P-2	• 868/915MHz at 14dBm • 2.4GHz at 20dBm
		CC1352PEM-XD7793-XD24-PA24	
	CC1354P10	LP-EM-CC1354P10-6	• 868/915MHz at 14dBm • 2.4GHz at 10/20dBm

2 Front-End Configurations

2.1 Overview of Front-end Configurations

CC13xx and CC26xx have the following front-end configuration:

- Single ended: Either the RF_P pin or the RF_N pin is used as the RF path.
- Differential: Both RF_P and RF_N are used as a differential RF interface.
- Internal or external bias of the LNA: The LNA can be biased by an internal or external inductor. Both types of biasing can be selected for single-ended and differential configuration.

Figure 2-1 shows the front-end configuration. Components and connections highlighted in red color are not required if an internal bias is used. The component values depend on the frequency band of operation.
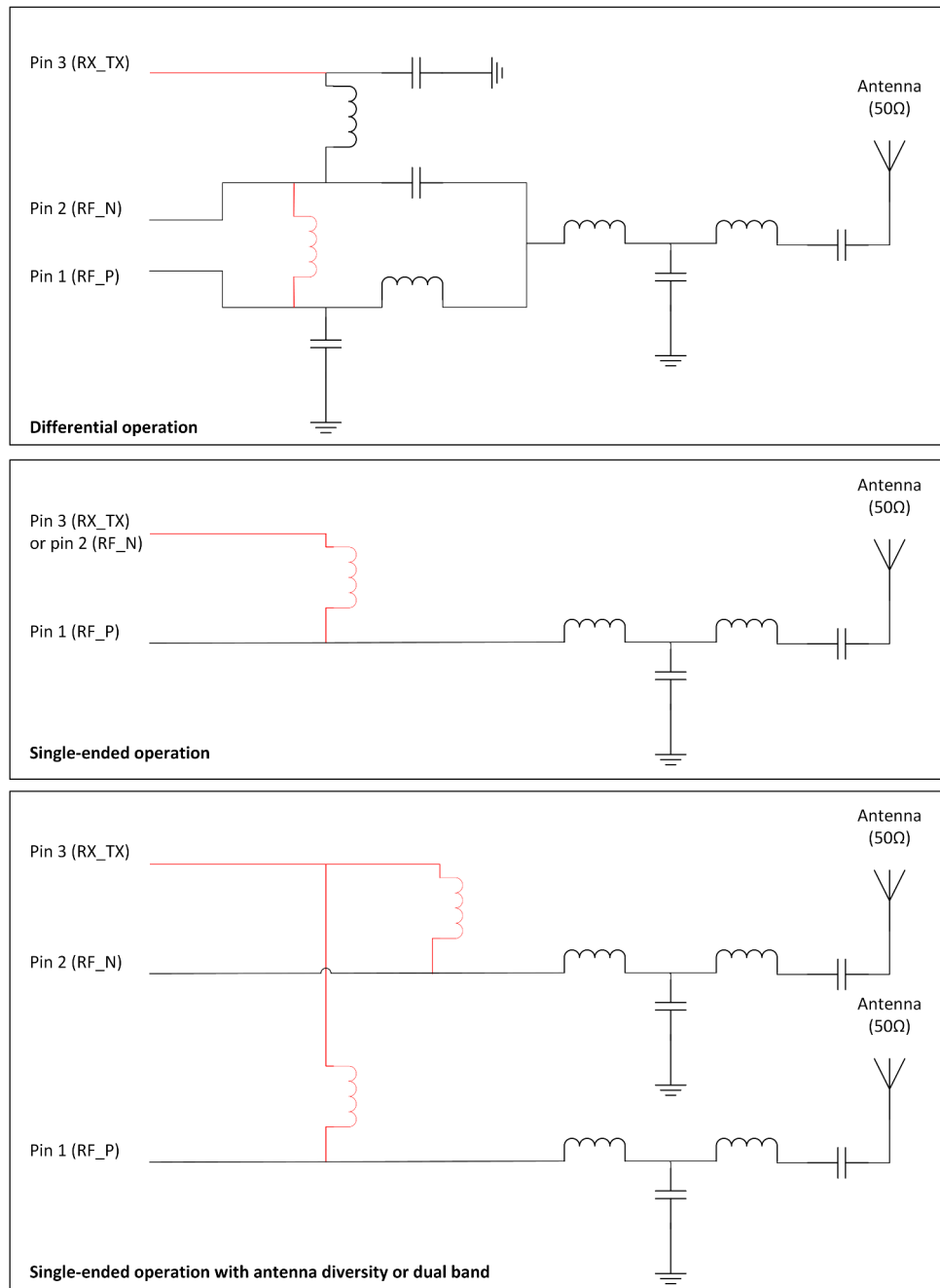
Figure 2-1. CC13xx/CC26xx Front-End Configuration (red = Required if an External Bias is Used)

Figure 2-2 summarizes the pros and cons of the different solutions. All numbers in the figure are compared to a differential front-end and external biasing.

Figure 2-2. Comparison of CC13xx/CC26xx Front-End Configuration

2.2 Configuring the Front-End Mode

The front-end mode is set in the CMD_RADIO_SETUP command:

- Config.frontEndMode = 0x00: Differential mode
- Config.frontEndMode = 0x01: Single-ended mode RFP
- Config.frontEndMode = 0x02: Single-ended mode RFN

For single-ended operation that uses one RF pin in RX and the other RF pin in TX, an additional override has to be set:

$$ADI\_HALFREG\_OVERRIDES(0, 16, 0x7, x) \tag{1}$$

where, x = 1 configures the PA output on RFP and x = 2 configures the PA output on RFN.

For single-ended operation, the pin set by CMD_RADIO_SETUP Config.frontEndMode will be used in RX and the pin set by the ADI_HALFREG_OVERRIDE override will be used in TX.

The LNA biasing is set in the CMD_RADIO_SETUP command:

- config.biasMode = 0: Internal bias
- config.biasMode = 1: External bias

2.3 CC13xx Single-Ended Mode

2.3.1 Single-Ended Modes

A typical sub-1GHz design usually requires long range and a differential design is typically used. For lower cost and a smaller footprint, a single-ended design can be used at the expense of shorter range shown in Figure 2-3.

If a CC13xx device is interfaced to a front-end module (FEM) with dedicated 50Ω ports for RX and TX, fewer components than in the combined single-ended RX/TX design are needed. This is covered in Section 2.3.2 and Section 2.3.3 for TX- and RX-only.
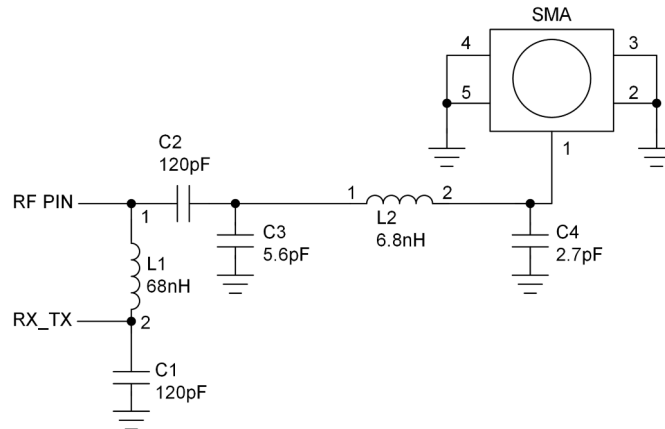

Figure 2-3. Single-Ended TX and RX With an External Bias (868/915MHz)

2.3.2 Single-Ended TX-Only

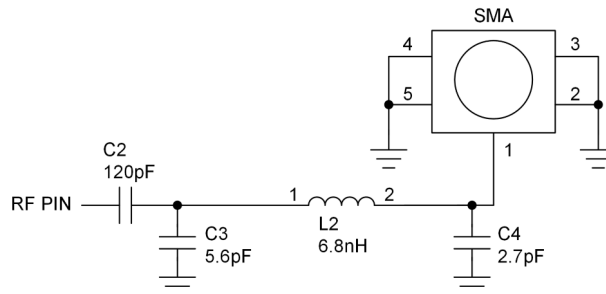A suggested matching network is shown in Figure 2-4.

Figure 2-4. Single-Ended TX-Only (868/915MHz)

2.3.3 Single-Ended RX-Only

A suggested matching network is shown in Figure 2-5. This match gives sensitivity of -110dBm (measured on 3 units at 25°C, 3.0V, 868MHz).
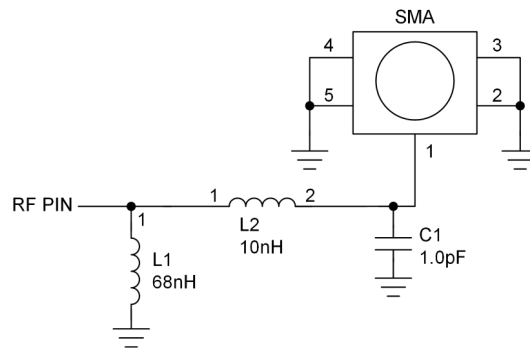

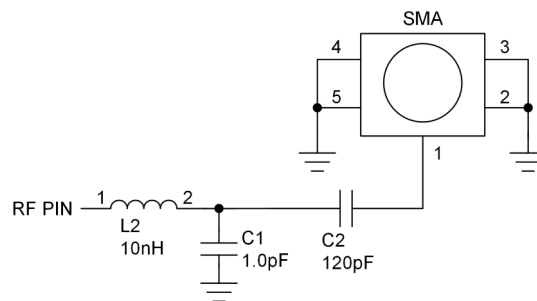**Figure 2-5. Single-Ended Rx-Only with External Bias (868/915MHz)**

Figure 2-6. Single-Ended Rx-Only with Internal Bias (868/915MHz)

2.3.4 Single-Ended Modes - 2.4GHz

For CC13x2, the single-ended configuration shown in Figure 2-7 can be used for the 2.4GHz path.
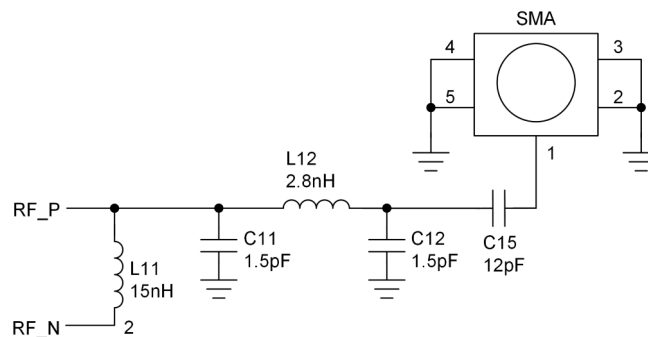

Figure 2-7. Single-Ended RX/TX with External Bias (2.4GHz)

2.4 CC26xx Single-End Mode

For CC26xx, a single-ended configuration is recommended when maximum output power is not needed. For 0dBm output power using single-ended mode, the current consumption and component count can be lower than for the corresponding differential mode.

Reference designs for both single-ended and differential configurations are available.

1. Go to: https://www.ti.com/product/CC2640R2F/technicaldocuments.
2. Scroll down to *Design Files*.
3. The designs are named 4XS, 5XD, and 7ID. The first number indicate the packet size, X - External bias, I - Internal bias, S – Single-ended, D – Differential.

3 Schematic

3.1 Schematic Overview

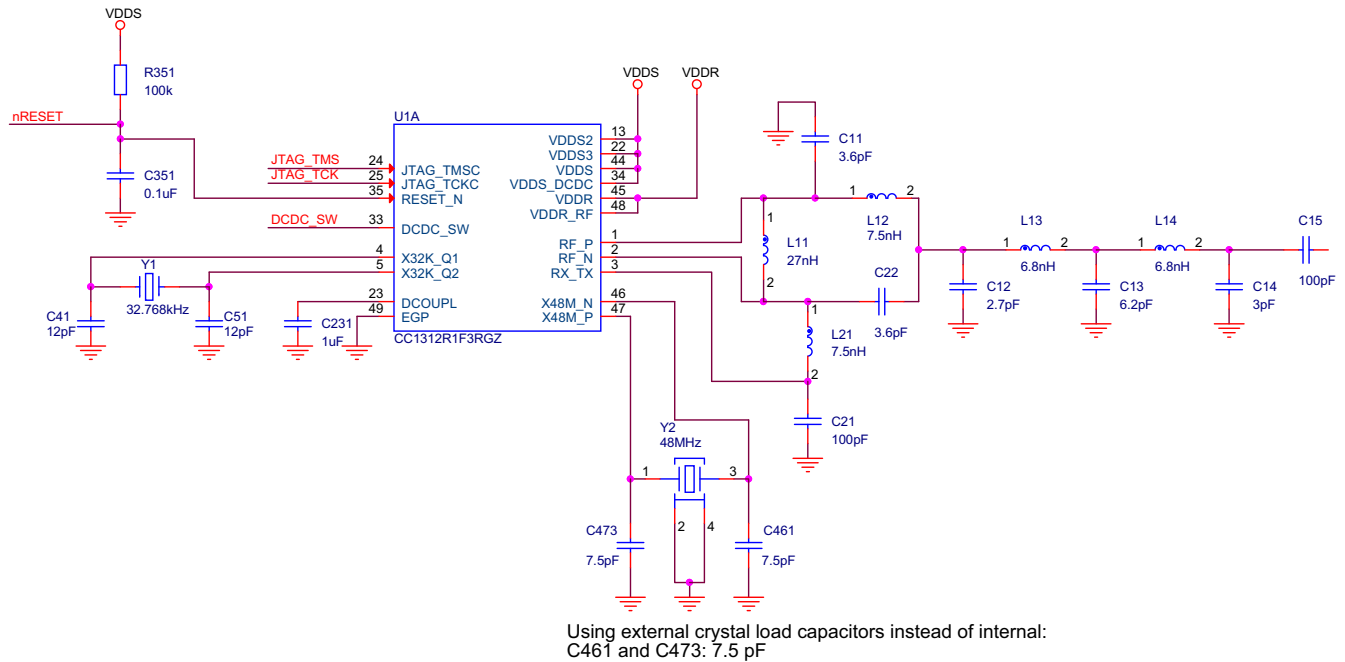Figure 3-1 shows the RF section and components discussed.

Figure 3-1. RF Section and Components of the CC1312R Schematic

3.1.1 24/48MHz Crystal

A 24/48MHz crystal is required as the frequency reference for the radio.

For CC26x2/CC13x2, there will be spurs at N x 48MHz offset from the carrier. These spurs are caused by the current going back and forth between the crystal and the XOSC tuning capacitors (which form the oscillator tank together with off-chip capacitances). This current is quite large due to the high Q of the crystal tank and can create an IR drop on the power rails that are shared with the PA and VCO. Setting the XOSC tuning capacitors to zero reduces the spurs by approximately 5dB for the largest spur compared to the default setting.

The internal capacitor array can be used in most use cases, but it is recommended to use external crystal loading capacitors and setting the internal XOSC tuning capacitors to zero for systems targeting compliance with ARIB STD T-108 and Chinese regulations in 470 – 510MHz frequency band as well as when using the +20dBm PA. For information on how to set the internal XOSC tuning capacitors, see Section 6.4.

3.1.2 32.768kHz Crystal

The 32.768kHz crystal is optional. The internal low-speed RC oscillator (32kHz) can be used as a reference if the low-power crystal oscillator is not used. The RC oscillator can be calibrated automatically to provide a sleep timer accurate enough for *Bluetooth*® Low Energy. Using an external crystal has the advantage that it increases sleep clock accuracy and reduces the power consumption for Bluetooth Low Energy (shorter RX windows around connection events). An external crystal is required for time synchronous protocols such as TI 15.4-Stack and wM-Bus.

3.1.3 Balun

A balun is a network that transforms from a balanced (differential) to an unbalanced (single-ended) signal. The design is a lumped, lattice-type LC that has a ±90° phase shift implemented by using a low-pass filter and a high-pass filter. It is important to keep the balun as symmetrical as possible. If only one of the RF pins is used for RF output/input, no balun is required. In this case a filter is required between the chip and the antenna. For more details, see Section 2.3.

3.1.4 Filter

An LC filter is placed between the balun and the antenna. The filter has two functions: attenuate harmonics and perform an impedance transformation to 50Ω. The latter is important since measuring equipment, such as spectrum analyzers and RF signal generators, have a port impedance of 50Ω. The word "filter balun" is sometimes used to describe all the components necessary to implement a balun, filter and to ensure proper impedance matching between the radio and the antenna.

3.1.5 RX_TX Pin

This pin is not present on all CC26x0/CC13x0 and CC26x2/CC13x2 devices. This pin provides a ground connection in RX mode. This is referred to an external bias and improves sensitivity by approximately 1dB compared to internally biasing of the LNA.

3.1.6 Decoupling Capacitors

In the reference design there are several decoupling capacitors. The schematic indicates which supply pin the decoupling capacitor needs to be placed close to.
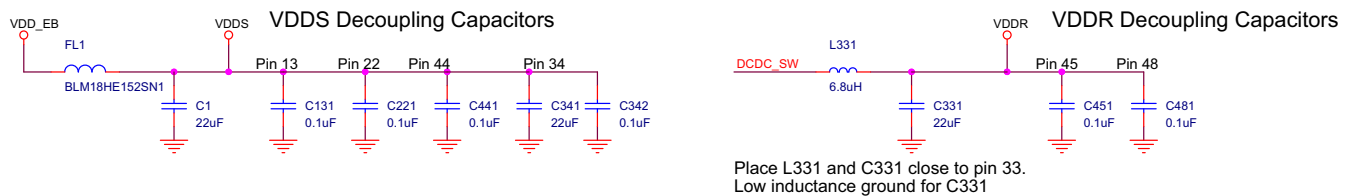

Figure 3-2. LAUNCHXL-CC1312R1 Decoupling Capacitors

3.1.7 Antenna Components

A pi-match network is recommended between the LC filter and the antenna for antenna impedance matching. For more information, see Section 5.1.

3.1.8 RF Shield

An RF shield is used on some of the TI reference designs to reduce the radiation of spurious signals, in particular the 3rd harmonic radiated power levels.

3.1.9 I/O Pins Drive Strength

The I/O pins have configurable drive strength and maximum current. All I/O pins support 2mA and 4mA, while five pins support up to 8mA.

Table 3-1. CC26x0/CC13x0, CC26x2/CC13x2 and CC26x4/CC13x4 Pins With up to 8mA Drive Strength

8 x 8 QFN (RSK)	7 × 7 QFN (RGZ)	5 × 5 QFN (RHB)	WCSP (YFV)	4 × 4 QFN (RSM)
DIO5	DIO5	DIO2	DIO2	DIO0
DIO6	DIO6	DIO3	DIO3	DIO1
DIO7	DIO7	DIO4	DIO4	DIO2
DIO16	DIO16	DIO5	DIO5	DIO3
DIO17	DIO17	DIO6	DIO6	DIO4

3.2 Bootloader Pins

The bootloader communicates with an external device over a 2-pin universal asynchronous receiver/transmitter (UART) or a 4-pin SSI interface. The SSI0 port has the advantage of supporting higher and more flexible data rates, but it also requires more connections to the CC13xx/CC26xx devices. The UART0 has the disadvantage of having slightly lower and possibly less flexible rates. However, the UART0 requires fewer pins and can be easily implemented with any standard UART connection. The serial interface signals are configured to specific DIOs. These pins are fixed and cannot be reconfigured.

Table 3-2. CC13x0/CC26x0: Configuration of Signal Interfaces

Signal	Pin Configuration	7 × 7 QFN (RGZ)	5 × 5 QFN (RHB)	4 × 4 QFN (RSM)	2.7 × 2.7 WCSP (YFV)
UART0 RX	Input with pull-up	DIO2	DIO1	DIO1	DIO1
UART0 TX	No pull (output when selected)	DIO3	DIO0	DIO2	DIO0
SSI0 CLK	Input with pull-up	DIO10	DIO10	DIO8	DIO10
SSI0 FSS	Input with pull-up	DIO11	DIO9	DIO7	DIO9
SSI0 RX	Input with pull-up	DIO9	DIO11	DIO9	DIO11
SSI0 TX	No pull (output when selected)	DIO8	DIO12	DIO0	DIO12

Table 3-3. CC1311Rx, CC1312Rx, CC2651Rx, CC2652Rx: Configuration of Signal Interfaces

Signal	Pin Configuration	
UART0 RX	Input with pull-up	DIO2
UART0 TX	No pull (output when selected)	DIO3
SSI0 CLK	Input with pull-up	DIO10
SSI0 FSS	Input with pull-up	DIO11
SSI0 RX	Input with pull-up	DIO9
SSI0 TX	No pull (output when selected)	DIO8

Table 3-4. CC13x4x10, CC26x4x10: Configuration of Signal Interfaces

Signal	Pin Configuration	CC26x4x10	CC1314R10	CC1354x10
UART0 RX	Input with pull-up	DIO12	DIO2	DIO12
UART0 TX	No pull (output when selected)	DIO13	DIO3	DIO13
SPI0 MISO	No pull (output when selected)	DIO8	DIO8	DIO8
SPI0 MOSI	Input with pull-up	DIO9	DIO9	DIO9
SPI0 CLK	Input with pull-up	DIO10	DIO10	DIO10
SPI0 CS	Input with pull-up	DIO11	DIO11	DIO11

3.3 AUX Pins

3.3.1 Reference

There are up to 31 signals (AUXIO0 to AUXIO30) in the sensor controller domain (AUX Domain). These signals can be routed to specific DIO pins given in Table 3-5. The signals AUXIO19 to AUXIO26 have analog capability, but can also be used as digital I/Os. All the other AUXIOn signals are digital only.

Table 3-5. CC13x4/CC26x4 Pin Mapping

DIO	AUX Domain I/O	DIO	AUX Domain I/O	DIO	AUX Domain I/O
DIO30	19	DIO19	30	DIO8	10
DIO29	20	DIO18	31	DIO7	11
DIO28	21	DIO17	1	DIO6	12
DIO27	22	DIO16	2	DIO5	13
DIO26	23	DIO15	3	DIO4	14
DIO25	24	DIO14	4	DIO3	15
DIO24	25	DIO13	5	DIO2	16
DIO23	26	DIO12	6	DIO1	17
DIO22	27	DIO11	7	DIO0	18
DIO21	28	DIO10	8		
DIO20	29	DIO9	9		

3.3.2 CC26x2/CC13x2 AUX Pins

There are up to 32 signals (AUXIO0 to AUXIO31) in the sensor controller domain (AUX Domain). These signals can be routed to specific DIO pins given in Table 3-6. The signals AUXIO19 to AUXIO26 have analog capability, but can also be used as digital I/Os. All the other AUXIOn signals are digital only.

Table 3-6. CC13x2/CC26x2 Pin Mapping

DIO	AUX Domain I/O	DIO	AUX Domain I/O	DIO	AUX Domain I/O
DIO30	19	DIO19	30	DIO8	10
DIO29	20	DIO18	31	DIO7	11
DIO28	21	DIO17	1	DIO6	12
DIO27	22	DIO16	2	DIO5	13
DIO26	23	DIO15	3	DIO4	14
DIO25	24	DIO14	4	DIO3	15
DIO24	25	DIO13	5	DIO2	16
DIO23	26	DIO12	6	DIO1	17
DIO22	27	DIO11	7	DIO0	18
DIO21	28	DIO10	8		
DIO20	29	DIO9	9		

3.3.3 CC26x0/CC13x0 AUX Pins

There are up to 16 signals (AUXIO0 to AUXIO15) in the sensor controller domain (AUX). These signals can be routed to specific pins given in Table 3-7. AUXIO0 to AUXIO7 have analog capability, but can also be used as digital I/Os, while AUXIO8 to AUXIO15 are digital only.

Table 3-7. CC13x0/CC26x0 Pin Mapping

7 × 7 QFN (RGZ)	5 × 5 QFN (RHB)	WCSP (YFV)	4 × 4 QFN (RSM)	AUX Domain I/O
DIO30	DIO14			0
DIO29	DIO13	DIO13		1
DIO28	DIO12	DIO12		2
DIO27	DIO11	DIO11	DIO9	3
DIO26	DIO9	DIO9	DIO8	4
DIO25	DIO10	DIO10	DIO7	5
DIO24	DIO8	DIO8	DIO6	6
DIO23	DIO7	DIO7	DIO5	7
DIO7	DIO4	DIO4	DIO2	8
DIO6	DIO3	DIO3	DIO1	9
DIO5	DIO2	DIO2	DIO0	10
DIO4	DIO1	DIO1		11
DIO3	DIO0	DIO0		12
DIO2				13
DIO1				14
DIO0				15

3.4 JTAG Pins

The on-chip debug support is done through a dedicated cJTAG (IEEE 1149.7) or JTAG (IEEE 1149.1) interface. The 2-pin cJTAG mode using only TCK and TMS I/O pads is the default configuration after power up. The 4-pin JTAG uses TCK, TMS, TDI, and TDO.

Table 3-8. CC26x0/CC13x0, CC26x2/CC13x2, and CC26x4x10/CC13x4x10 JTAG Pins

Signal	8 x 8 QFN (RSK)	7 × 7 QFN (RGZ)	5 × 5 QFN (RHB)	WCSP (YFV)	4 × 4 QFN (RSM)
TCK	Pin 25	Pin 25	Pin 14	Pin F2	Pin 14
TMS	Pin 24	Pin 24	Pin 13	Pin E4	Pin 13
TDI	DIO17	DIO17	DIO6	DIO6	DIO4
TDO	DIO16	DIO16	DIO5	DIO5	DIO3

4 PCB Layout

4.1 Board Stack-Up

It is important that the distance from the top layer to the ground layer matches the reference design. Deviating from the recommended board stack-up can change the parasitics and can in some cases lead to a re-design of the filter balun.

DESIGN CROSS SECTION CHART
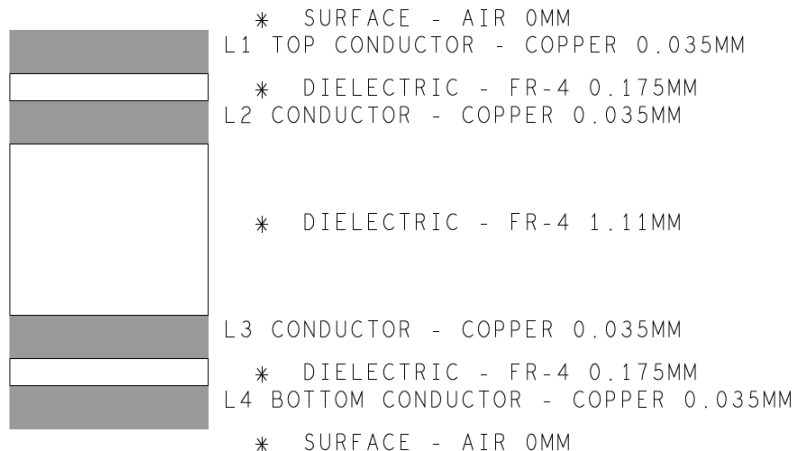TOTAL THICKNESS 1.6MM

```
                                    *  SURFACE - AIR 0MM
                                 L1 TOP CONDUCTOR - COPPER 0.035MM
                                    *  DIELECTRIC - FR-4 0.175MM
                                 L2 CONDUCTOR - COPPER 0.035MM


                                    *  DIELECTRIC - FR-4 1.11MM


                                 L3 CONDUCTOR - COPPER 0.035MM
                                    *  DIELECTRIC - FR-4 0.175MM
                                 L4 BOTTOM CONDUCTOR - COPPER 0.035MM
                                    *  SURFACE - AIR 0MM
```

Figure 4-1. LAUNCHXL-CC2640R2 Board Stack Up

4.2 Balun - Sub-1GHz

It is important to keep the balun as close and symmetrical as possible with regard to the RF ports. Therefore, the trace length from the single ended port to each of the RF pins should be equal to achieve best amplitude and phase balance. For a good balun PCB layout, see Figure 4-2. An unbalance in the balun causes higher harmonic levels, especially at the 2nd and 4th harmonics. Another effect of having an unsymmetrical balun is reduced output power at the single ended side of the balun. Both component values and component placement is important to achieve best possible symmetry in the balun. Amplitude imbalance should be a maximum of 1.5dB and the phase imbalance a maximum of 10°.

To ensure optimal performance it is important to implement the same layout of the balun, match, and filter as in the reference design. Changing the placement of these parts might require tuning on the component values to obtain the desired performance. Tuning requires advanced RF skills and the proper equipment.

There must be an uninterrupted and solid ground plane under all the RF components, stretching from the antenna and all the way back to the ground vias in the chip exposed ground pad (EGP). There must not be any traces under the RF path.
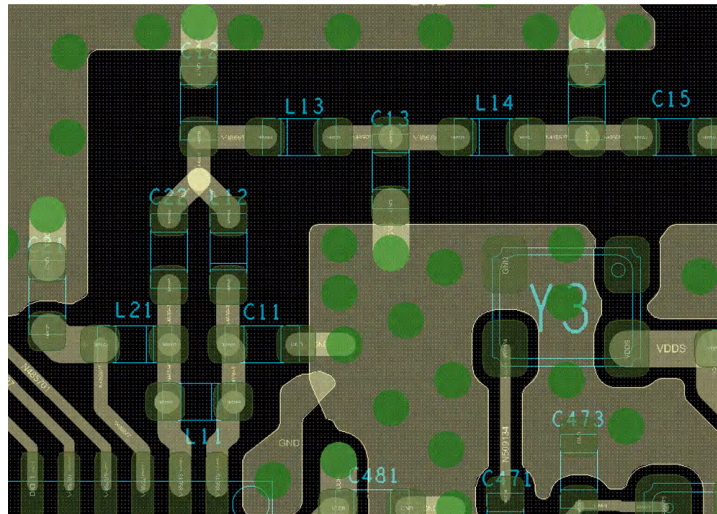
Figure 4-2. CC1312R Balun and LC Filter PCB Layout

4.3 Balun - 2.4GHz

We recommend following the reference design closely as some designs require the use of a longer path length from the RF port and the balun is optimized based on this extended length. Any attempts to shorten the extended length requires the balun and matching circuit to be re-tuned. For example, the figure below shows LP-EM-CC1354P10-6 2.4GHz path has an extended length due to space restrictions that prevent parts from being placed closer to the RF port.
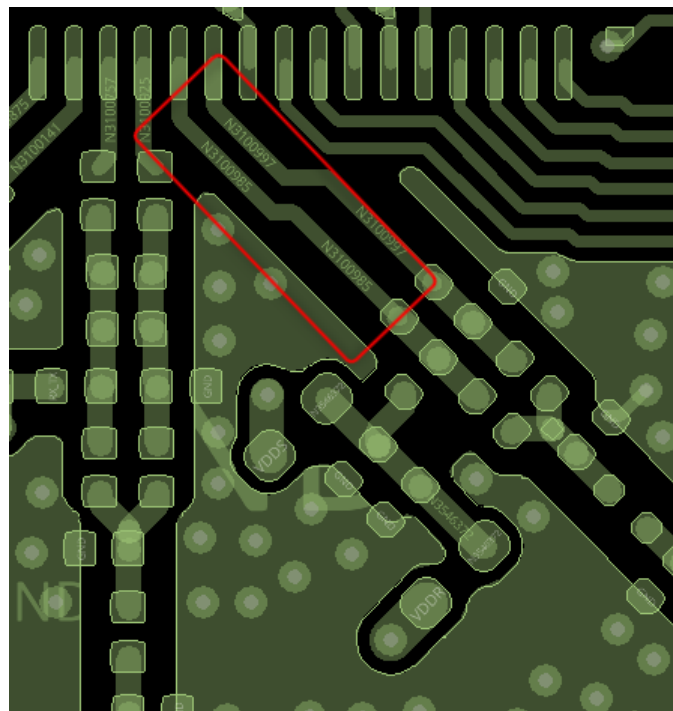
Figure 4-3. LP-EM-CC1354P10-6 Balun Layout

4.3.1 Recommended Layout and Considerations for 20dBm

When designing for a high-powered, 20dBm path, we recommend removing all header pins to help reduce 2nd harmonic emissions, using high-Q, tight tolerance inductors and capacitors to help achieve maximum output power, and a fully enclosed shield to help reduce 2nd and 3rd harmonics.

Regarding the shield, we present the following two options:

Option A

A fully enclosed shield is generally the lower cost option to help used to reduce harmonics, but all traces must either be contained with the shield or routed out to different layer using vias. Consequentially, the RF path has to be routed on a different layer using transition vias which must follow the reference design closely to maintain maximum output power and minimum harmonics.

Option B

A custom, fully-enclosed shield with a single opening for the RF trace can also be used to achieve the same performance. This option allows the RF trace to be routed on the same layer without the need for transition vias.

Note

We highly recommend EM simulations to characterize your shield cavity as variations in performance can occur depending component density and placements.

4.4 LC Filter

The LC filter should be laid out so that crosstalk between the shunt components is minimized. Figure 4-4 shows three different layouts from worse to best. The advantage with the layout to the right is that the parasitic inductance in the PCB track (in black) between the shunt capacitor and the series inductor is in series with the inductor. In the middle figure, the parasitic inductance is in series with the shunt capacitor forming a series LC circuit. The placement of C12, L13, C13, L14, and C14 in Figure 4-2 shows good design practice.

If the design cannot use the reference design as-is (for example, use of a different component size) the filter balun will most likely have to be re-tuned. Simulate both the TI reference design and the custom design using an electromagnetic simulator. The two designs should have the same S21/S22.
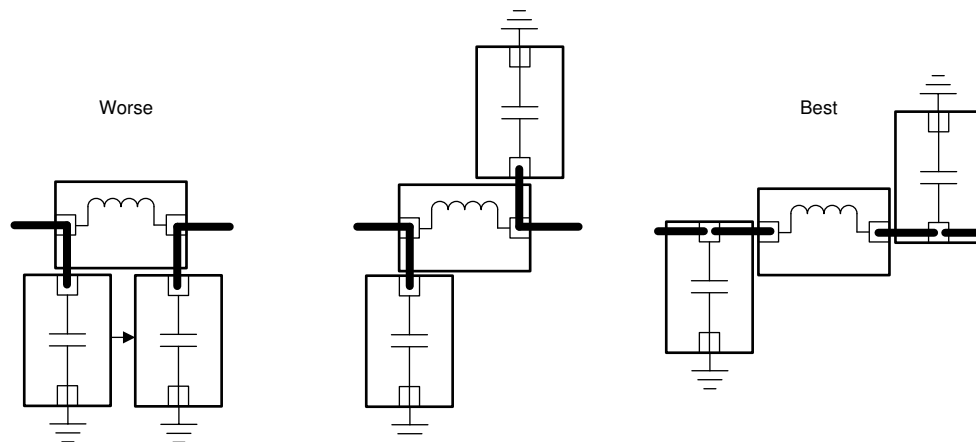

Figure 4-4. LC Filter PCB Layout Design Guideline

4.5 Decoupling Capacitors

General rules for decoupling capacitors:

- Ensure decoupling capacitors are on same layer as the active component for best results.
- Route power into the decoupling capacitor and then into the active component.
- Each decoupling capacitor should have a separate via to ground to minimize noise coupling (see Figure 4-5).
- The decoupling capacitor should be placed close to the pin it is supposed decouple (see Figure 3-2).
- The ground current return path between decoupling capacitor and chip should be short and direct (low impedance). For details, see Section 4.7.
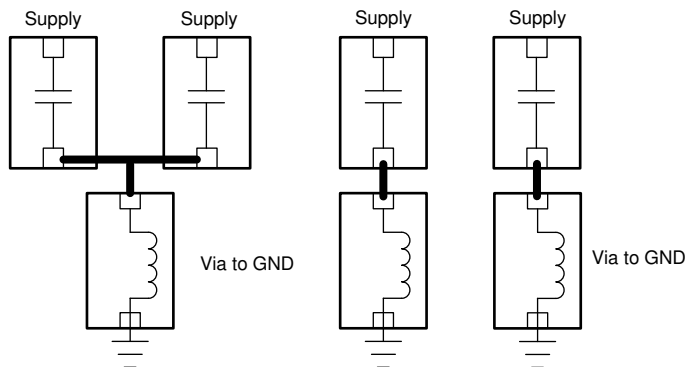
Figure 4-5. Decoupling Capacitors and VIA to Ground

The right side of Figure 4-5 that uses separate vias to ground has less noise coupling.

4.6 Placement of Crystal Load Capacitors

The main oscillation loop current is flowing between the crystal and the load capacitors. Keep this signal path (crystal to C_{L1} to C_{L2} to crystal) as short as possible and use a symmetrical layout. Hence, both the capacitors' ground connections should always be as close as possible. Never route the ground connection between the capacitors or all around the crystal, because this long ground trace is sensitive to crosstalk and EMI.

4.7 Current Return Path

There needs to be a solid ground plane from the capacitor ground pad back to the chip. Figure 4-6 illustrates this. In the bad example, notice the break in ground plane on layer 2 causing a longer return path while the good example has no breaks. Failure to follow this can lead to reduced RF performance and higher spurious emissions.
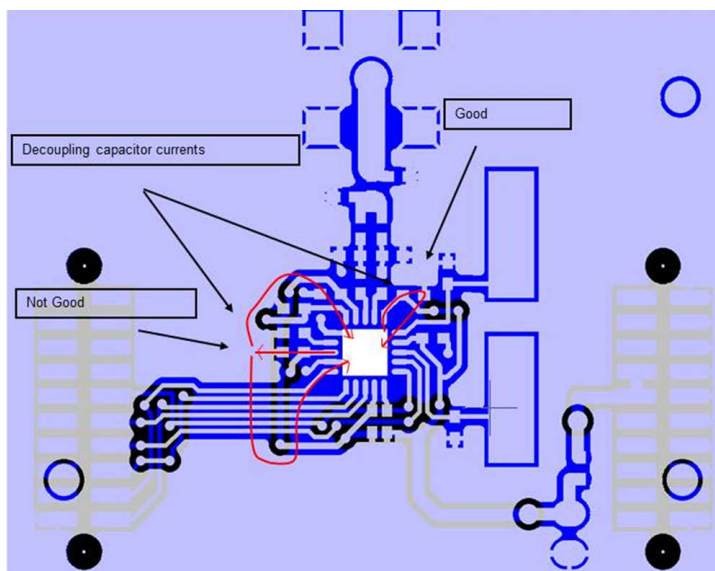

Figure 4-6. Current Return Path

4.8 DC/DC Regulator

The DCDC components must be placed close to the DCDC_SW pin. The capacitor at the DC/DC regulator output (DCDC_SW pin) must have a short and direct ground connection to the chip (low impedance). Keep a solid ground plane from the capacitor ground pad back to the chip as shown for C331 in Figure 4-7.
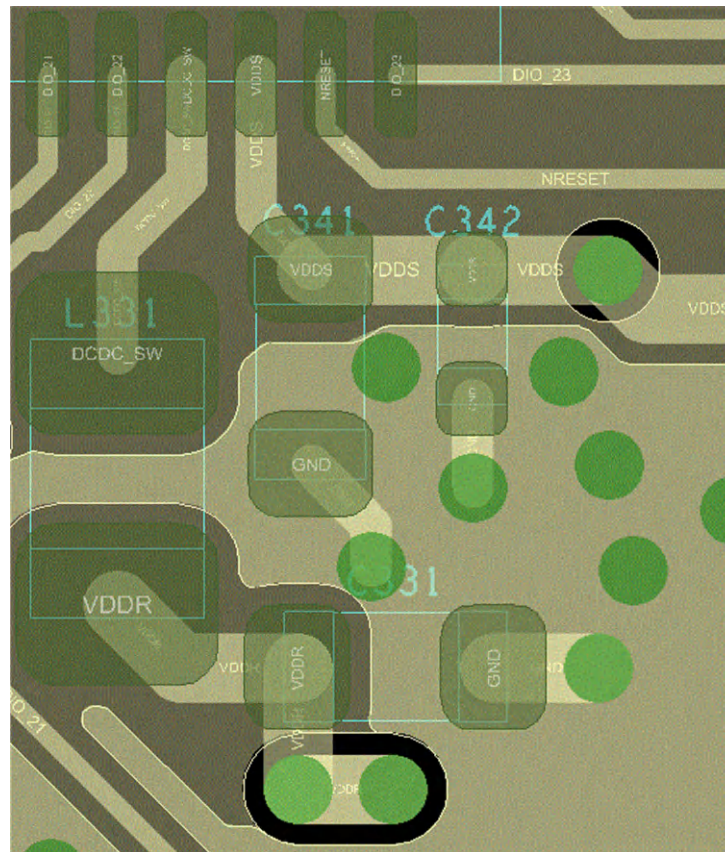

Figure 4-7. CC1312R DC/DC Regulator PCB Layout

4.9 Antenna Matching Components

A pi-network is recommended for antenna impedance matching. The antenna matching components should be placed as close to the antenna as possible.

4.10 Transmission Lines

Traces in the balun and LC filter are too short to be considered transmission lines, but longer traces, such as from the LC filter, towards the antenna should have a 50Ω impedance. TXLine is a free tool for PCB trace impedance calculations: TXLine Transmission Line Calculator.

4.11 Electromagnetic Simulation

If the design does not follow the reference design (for example, different filter balun component placement or component size), it is recommended to use Advanced Design System (ADS) or similar to simulate and then compare the impedances and S-parameters of the custom design with the reference design. Changes to the filter balun component values might be required if the custom design deviates too much from the reference design.

5 Antenna

5.1 Single-Band Antenna

The existing antenna documentation available at TI is mainly orientated towards antennas that operate at a single frequency. Two antenna selection guides are available: the *Antenna Selection Quick Guide* and a comprehensive *Antenna Selection Guide*. In addition to the documentation, there is a *CC-Antenna-DK2 and Antenna Measurements Summary* available on ti.com, as well, with complete documentation. All antenna documentation that is available from TI can be accessed from the *Antenna Selection Quick Guide* since it contains hyperlinks to all antenna documentation, antenna measurement reports, and all antenna reference designs.

It is always advised to include an antenna matching network to tune and to reduce the mismatch losses of the antenna. For a single-band antenna, the recommendation is to always include a pi-match network prior to the antenna, see Figure 5-1. Only two of the three footprints/components are required. The impedance of the antenna will determine if footprint/component ANT1 or ANT3 is used. ANT2 will always be used and even if the antenna is perfectly matched, then this can just be set as a 0Ω resistor.
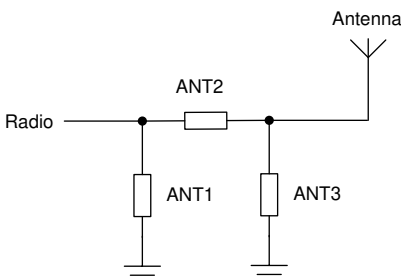

Figure 5-1. Recommended Antenna PI-Match Network for Single-Band Antennas

5.2 Dual-Band Antenna

The introduction of dual-band operation with advantages of Bluetooth Low Energy combined with long-range advantages of sub-1GHz sets the need of dual-band antennas. Separate antennas can be used for each of the bands, but physical space is normally limited on most handheld devices that promote usage of dual-band antennas. The most popular dual-band configurations are shown below:

- 863/928MHz and 2.4GHz
- 433-450MHz and 2.4GHz
- 470-510MHz and 2.4GHz

For dual-band operation that contains a low-band and a high-band, the antenna pi-match shown in Figure 5-1 is not recommended. It is recommended to use an LC, CL match network instead as shown in Figure 5-2. The LC part is used to match the high-band and the CL part is used for the low-band. Therefore, the LC section will be denoted as $L_{HIGH} C_{HIGH}$ and the CL section as $C_{LOW} L_{LOW}$ in order to identify the components.
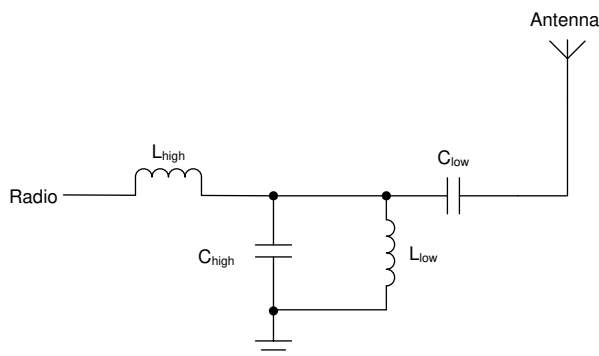

Figure 5-2. Recommended Antenna Match Network for Dual-Band Antennas

5.2.1 Dual-Band Antenna Match Example: 863-928 MHz and 2.4 GHz

This example is based on LaunchPad-CC1352P1.

- Assemble L_{HIGH}: 0Ω and C_{LOW} : 0Ω; C_{HIGH}: NC and L_{LOW} : NC
- Measure initial impedance with a network analyzer (VNA) at the low-band (868MHz) and high-band (2440MHz)
  - 868MHz: 54 + j30, VSWR: 1.78:1
  - 2.44GHz: 14 - j32, VSWR: 5.05:1 (This is not required at this stage but included for documentation purposes to note the delta).
- Match the low-band with only the C_{LOW} and L_{LOW} components
  - C_{LOW}: 5.6pF and L_{LOW}: NC; see Figure 5-3
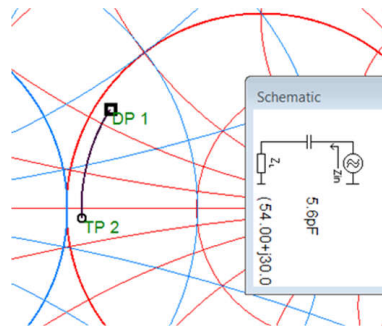
Figure 5-3. Matching the Low-Band With C_{LOW}: 5.6pF and L_{LOW}: NC

- Confirm the low-band is matched by measuring the impedance again:
  - 868MHz: 42 + j2, VSWR: 1.18:1. Good match at the low-band
  - 2.44GHz: 16+j34, VSWR: 5.38:1
- Match the high-band with only the C_{HIGH} and L_{HIGH} components
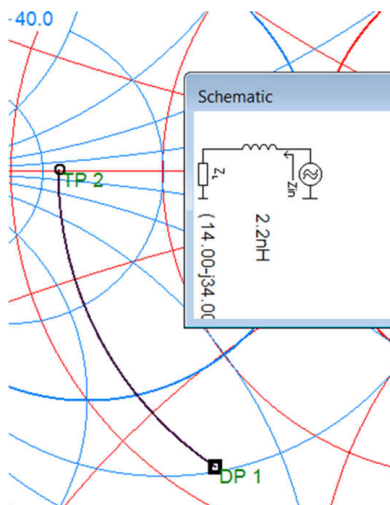 - L_{HIGH} : 2.2nH and C_{HIGH}: NC; see Figure 5-4

Figure 5-4. Matching the High-Band With an Ideal Value of L_{HIGH}: 2.2nH and C_{HIGH}: NC

- L$_{HIGH}$: 2.2nH was not sufficient when measured and a value of 3.3nH was used instead. The antenna match components are based on ideal components with no parasitics. The match is not ideal but the C$_{HIGH}$ component could not be used due to the impedance position in the Smith chart.
- Measure final impedance with a network analyzer (VNA) at the low-band (868MHz) and high-band (2440MHz),
  – 868MHz: 37 + j8, VSWR: 1.36:1 Good match at the low-band
  – 2.44GHz: 16+j8, VSWR: 3.18:1 Reasonable match at the high-band but would prefer VSWR < 2.00:1; see Figure 5-5 and Figure 5-6.
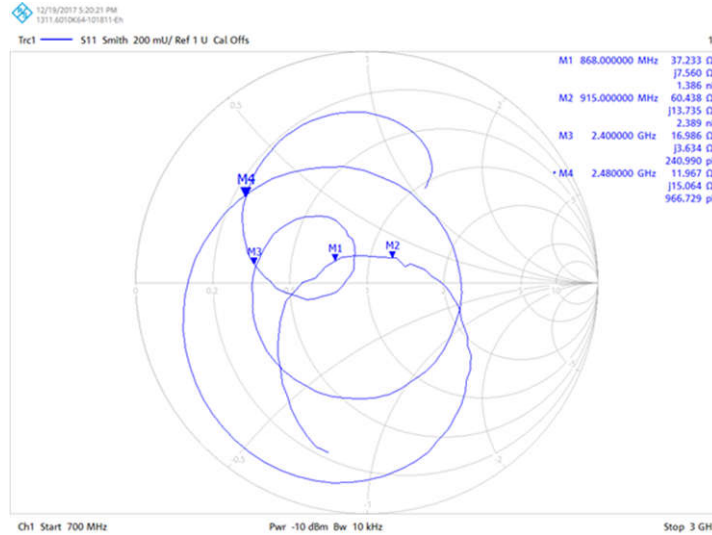

Figure 5-5. Smith Chart With Final Match Values of L$_{HIGH}$: 3.3nH and C$_{LOW}$: 5.6pF
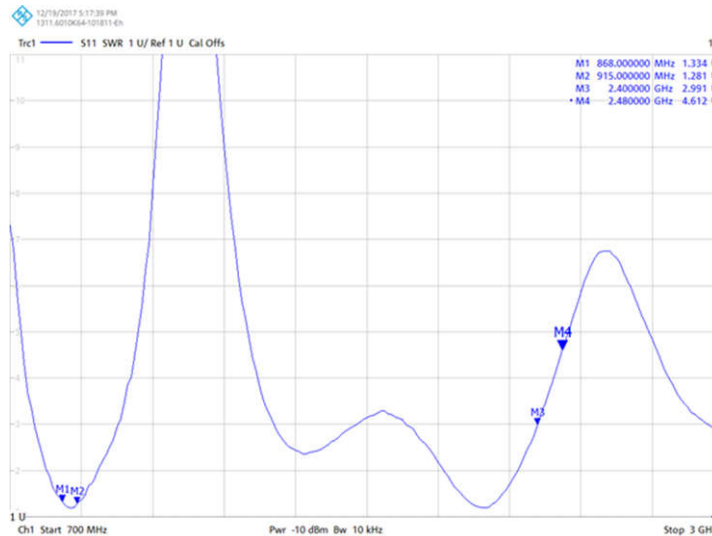

Figure 5-6. VSWR Chart With Final Match Values of L$_{HIGH}$: 3.3nH and C$_{LOW}$: 5.6pF

- With the matching components, the antenna match was improved by:
  – 868MHz: VSWR: 1.78:1 –> 1.36:1
  – 2.44GHz: VSWR: 5.05:1 –> 3.18:1

The example shown above used a low-band of 868MHz but a main requirement of the LaunchPad-CC1352P-1 was for good operation for the complete 863 – 928MHz band since it was important to cover both ETSI (863-870MHz) and FCC bands (902-928MHz). The antenna length on CC1352P1 has a natural resonance of approximately 900MHz with no matching components.

If the performance at 2.44GHz is more important than supporting both 868MHz and 915MHz ISM bands, then the length of the antenna can be increased so the natural resonance will be around 813MHz (2440MHz/3). This would give very good performance at 868 MHz and 2.4GHz but the 915MHz band would suffer. A common antenna match for dual-bands is a compromise of performance between the high-band and low-band.

5.2.2 Dual-Band Antenna Match: 433-510MHz and 2.4GHz

This antenna design is based on LaunchPad-CC1352P-4 that uses the *433MHz to 930MHz and 2.4GHz BOM Tunable PCB Antenna*. This BOM Tunable Antenna is fully documented *433 to 930-MHz and 2.4-GHz BOM Tunable PCB Antenna*, application note.

In order to cover the frequency band 433 – 510MHz, an external component (LANT) is added to the antenna structure normally used for 863-928MHz and 2.4GHz. This is required to keep the antenna relatively small and to maintain a high efficiency. The LANT component extends the length of the antenna structure with the extra inductance added. It is difficult to cover the entire frequency band of 433 – 510MHz with just one BOM due to the wide bandwidth so the frequency range is divided up into the several regions. An additional antenna structure has also been added that also extends the length of the standard antenna, see Figure 5-7.

Value of L_{ANT} component for 433-510MHz operation:

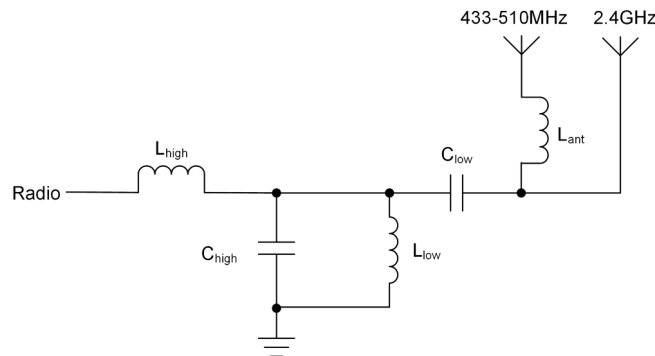- 51nH: 433MHz
- 39nH: 470MHz
- 33nH: 490MHz

Figure 5-7. Recommended Antenna Match Network for Dual-Band Antennas (433-510MHz and 2.4GHz)

Once the LANT component has been chosen then the matching procedure is similar as shown in the previous example. After the antenna matching process, the final values of the antenna match components can be fixed. As can be seen in Figure 5-8, the matching of 490MHz and 2.4GHz are both below VSWR 1.90 :1, which are good results.
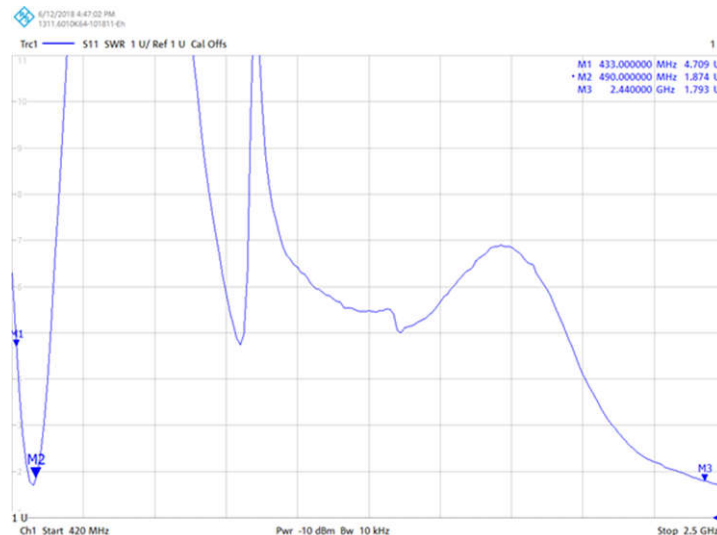
Figure 5-8. VSWR Chart with Final Match Values of L$_{ANT}$: 33nH L$_{HIGH}$: 3.9nH and C$_{LOW}$: 0 Ω

Matching the antenna should be performed in the final casing of the product including all surrounding components such as batteries, displays, and so forth. Casing can affect the antenna's resonance even if the material choice is plastic. The positioning of the antenna or body effects will also affect the antenna's resonance. The antenna is always detuned by a shift downwards in frequency. Therefore, if there are two different environments for the antenna such as handheld and stand-alone on a wooden desk, then it is preferable to have the stand-alone resonance slightly higher so the antenna's bandwidth can be utilized when detuned by body effects/metal objects, and so forth.

6 Crystal Tuning

6.1 CC13xx/CC26xx Crystal Oscillators

The CC13xx/CC26xx devices have two crystal oscillators as shown in Figure 6-1. The high frequency crystal oscillator (HFXOSC), running at 24MHz for CC13x0/CC26x0 and 48MHz for CC13x2/CC26x2, is mandatory to operate the radio. The low frequency crystal oscillator (LFXOSC) is used for RTC timing and only required when accurate RTC timing is necessary, for example for synchronous protocols such as Bluetooth Low Energy. For more details, please see *The Crystal Selection Guide*.

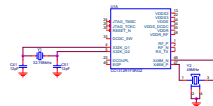**Figure 6-1. CC1312R With 32kHz and 48MHz Crystals**

Both crystal oscillators are pierce type oscillators are shown in Figure 6-2. In this type of oscillator, the crystal and the load capacitors form a pi-filter providing a 180° phase shift to the internal amplifier keeping the oscillator locked at the specified frequency. For this frequency to be correct, the load capacitance must be dimensioned properly based on the crystal´s capacitive load (CL) parameter.
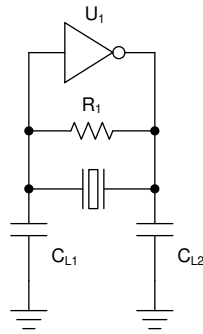
Figure 6-2. Pierce-Type Oscillator

A key difference between the oscillators is that the high frequency oscillator has internal variable load capacitance inside the IC and does in most cases not require external load capacitors. For details on when it is required to use external capacitors instead of the internal variable load capacitance, see Section 3.1.1. The low frequency oscillator on the other hand needs to have external capacitors to operate properly.

6.2 Crystal Selection

When selecting a crystal part, it is important to look at the device-specific CC13xx/CC26xx data sheets that lists requirements for the crystal parameters. All of these requirements must be fulfilled to ensure proper operation of the oscillator(s) and proper operation of the device.

6.3 Tuning the LF Crystal Oscillator

The frequency of the 32kHz crystal oscillator is set by properly dimensioning the load capacitors relative to the crystal´s wanted load capacitance, CL. From the crystal´s point of view, the two capacitors are placed in series, which means that the "resistor parallel" equation to calculate the resulting total capacitance must be used. Also keep in mind that the PCB traces and the pads add some parasitic capacitance. Equation 2 shows how to calculate the right load capacitance value.

$$CL = \frac{C1 \times C2}{C1 + C2} + C_{parasitic} \approx \frac{\text{load capacitor value}}{2} + C_{parasitic}$$

(2)

The last simplification requires that C1 and C2 are equal.

The best way to measure the frequency accuracy of the oscillator is to output the clock signal on an I/O pin. This way the frequency can be measured using a frequency counter without affecting the oscillator. The following Driverlib calls can output the selected 32kHz clock source in all power states except Shutdown:

```
#include <driverlib/aon_ioc.h>
IOCPortConfigureSet(IOIDn, IOC_PORT_AON_CLK32K, IOC_STD_OUTPUT);
AONIOC32kHzOutputEnable();
```

6.4 Tuning the HF Oscillator

The HF oscillator has internal variable load capacitors (cap-array) in the IC and does not require external capacitors to be mounted. There are some exceptions. For details on when it is required to use external capacitors instead of the internal cap-array, see Section 3.1.1.

The load capacitance is set in CCFG.c through the following defines:

```
#ifndef SET_CCFG_MODE_CONF_XOSC_CAP_MOD
// #define SET_CCFG_MODE_CONF_XOSC_CAP_MOD          0x0        // Apply cap-array delta
#define SET_CCFG_MODE_CONF_XOSC_CAP_MOD             0x1        // Don't apply cap-array delta
#endif
#ifndef SET_CCFG_MODE_CONF_XOSC_CAPARRAY_DELTA
#define SET_CCFG_MODE_CONF_XOSC_CAPARRAY_DELTA      0xFF       // Signed 8-bit value, directly
modifying trimmed XOSC cap-array value
#endif
```

The SET_CCFG_MODE_CONF_XOSC_CAP_MOD defines tells the system whether it should use the default value or use an offset from the default value set by SET_CCFG_MODE_CONF_XOSC_CAPARRAY_DELTA. The default cap-array values are 9pF for CC13x0/CC26x0 QFN, 5pF for CC2640R2F WCSP, and 6.7pF for CC13x2/CC26x2.

The cap-array delta value is an offset from the default value that can be either negative or positive. Table 6-1 shows the resulting total capacitance measured on an evaluation board versus cap-array delta values. Note that the resulting capacitance value includes parasitic capacitances, which is why the lowest setting is not 0pF. Using a delta value equal to or lower than the most negative value in the table completely disables the internal load capacitor array.

The best way to measure the accuracy of the HF crystal oscillator is to output an unmodulated carrier wave from the radio and measuring the frequency offset from the wanted frequency using a spectrum analyzer. The relative offset of crystal frequency, typically stated in Parts per Million (ppm), is the same as the relative offset of the RF carrier.

For testing purposes cap-array delta values can be adjusted in SmartRF™ Studio. This simplifies tuning greatly by allowing on-the-fly updates of the load capacitance. The optimum value found in SmartRF Studio can then be entered into CCFG in the applicable software project.

Table 6-1. Cap-Array Delta

Measured Capacitance on Reference Board (pF)	CCFG Delta Value for CC13x0/CC26x0 QFN	CCFG Delta Value for CC2640R2F WCSP	CCFG Delta Value for CC13x1/CC26x1 QFN	CCFG Delta Value for CC13x2/CC26x2 QFN	CCFG Delta Value for CC13x4/CC26x4 QFN
2.1	< -55	< -28	< -40	< -40	< -40
2.1	-55	-28	-40	-40	-40
2.2	-54	-27	-39	-39	-39
2.3	-53	-26	-38	-38	-38
2.4	-52	-25	-37	-37	-37
2.5	-51	-24	-36	-36	-36
2.6	-50	-23	-35	-35	-35
2.7	-49	-22	-34	-34	-34
2.7	-48	-21	-33	-33	-33
2.8	-47	-20	-32	-32	-32
2.9	-46	-19	-31	-31	-31
3.0	-45	-18	-30	-30	-30
3.1	-44	-17	-29	-29	-29
3.2	-43	-16	-28	-28	-28
3.3	-42	-15	-27	-27	-27
3.4	-41	-14	-26	-26	-26
3.4	-40	-13	-25	-25	-25
3.6	-38	-12	-24	-24	-24
3.7	-37	-11	-23	-23	-23
3.8	-36	-10	-22	-22	-22
3.9	-35	-9	-21	-21	-21
4.0	-34	-8	-20	-20	-20
4.1	-33	-7	-19	-19	-19
4.3	-32	-6	-18	-18	-18
4.4	-31	-5	-17	-17	-17
4.5	-30	-4	-16	-16	-16
4.6	-29	-3	-15	-15	-15
4.7	-28	-2	-14	-14	-14
4.8	-27	-1	-13	-13	-13

Table 6-1. Cap-Array Delta (continued)

Measured Capacitance on Reference Board (pF)	CCFG Delta Value for CC13x0/CC26x0 QFN	CCFG Delta Value for CC2640R2F WCSP	CCFG Delta Value for CC13x1/CC26x1 QFN	CCFG Delta Value for CC13x2/CC26x2 QFN	CCFG Delta Value for CC13x4/CC26x4 QFN
5.0	-26	0	-12	-12	-12
5.1	-25	1	-11	-11	-11
5.2	-24	2	-10	-10	-10
5.3	-23	3	-9	-9	-9
5.5	-21	4	-8	-8	-8
5.6	-20	5	-7	-7	-7
5.8	-19	6	-6	-6	-6
5.9	-18	7	-5	-5	-5
6.1	-17	8	-4	-4	-4
6.2	-16	9	-3	-3	-3
6.4	-15	10	-2	-2	-2
6.5	-14	11	-1	-1	-1
6.7	-13	12	0	0	0
6.8	-12	13	1	1	1
7.0	-11	14	2	2	2
7.1	-10	15	3	3	3
7.3	-9	16	4	4	4
7.4	-8	17	5	5	5
7.6	-7	18	6	6	6
7.7	-6	19	7	7	7
7.9	-5	21	8	8	8
8.2	-4	22	9	9	9
8.4	-3	23	10	10	10
8.6	-2	24	11	11	11
8.8	-1	25	12	12	12
9.0	0	26	13	13	13
9.2	1	27	14	14	14
9.4	2	28	15	15	15
9.6	3	29	16	16	16
9.8	4	30	17	17	17
10.1	5	31	18	18	18
10.3	6	32	19	19	19
10.5	7	33	20	20	20
10.7	8	34	21	21	21
10.9	9	35	22	22	22
11.1	10	36	23	23	23
11.1	> 10	> 36	> 23	> 23	> 23

7 TCXO Support

CC13x0 and CC26x0 do not support a TCXO as clock source. The CC13x2 family of devices has support for TCXO. Two types of TCXO are supported: clipped sine wave and CMOS output. The TCXO output should be connected to the X48M_P input. If a clipped sine wave type is used, a series cap is required since internal common mode bias is used in this case. The data sheet for the selected TCXO should be checked for the recommended value for the series cap.

7.1 Hardware

For reference design, see the design files for the CC1312R Launchpad. It is important that the TCXO comply with the requirements in the data sheet. Note the maximum output voltage.

7.2 Software

SDK version 4.10 or newer has to be used. TCXO usage is enabled in syscfg. Under TI Devices → Device Configuration, select *External 48MHz TCXO* as HF Clock source. When TCXO is selected as source, select the TCXO type and the TCXO Max Startup Time. It is important that this time is set correctly. If a too short time is set, the chip could attempt to switch to the TCXO before this is stable, which again could cause the chip to malfunction.

When a TCXO is used, the internal load capacitors have to be reduced to avoid loading the TCXO. The required setting will be dependent on the selected TCXO. Turning off the capacitor array could cause the output swing to be too large from some TCXOs. In these cases, the capacitor in the capacitor array will help reducing the voltage swing. The capacitor array should be set to a value where the swing on the X48M_P is within the value set in the CC13x2 data sheet, both for minimum and maximum swing. Care has to be taken when doing the measurement to avoid that the measurement does not increase the load on this node, which will impact the measurement result.

In syscfg go to TI Devices → Device Configuration and tick the box next to "Enable XOSC Cap array modification" and set the wanted value.

The power driver contains a function hook PowerCC26X2_Config.enableTCXOFxn that has to be added to the code. If this function is not defined, the code will compile but it will hang when the system requests the radio to turn on. The function hook makes it possible to power the TCXO from a DIO and turn off the TCXO when the CC13x2 is in standby and turn it on again in time for a RF operation.

The following code snippet show how this function can look when the TCXO is powered by a DIO:

```
void Power_enableTCXO(bool turnOn)
{
    if ( turnOn ) {
        // Set corresponding DIO high to enable the TCXO
        GPIO_write(GPIO_TCXO_PIN, 1);
    }
    else {
        // Set the corresponding DIO low to disable the TCXO
        GPIO_write(GPIO_TCXO_PIN, 0);
    }
}
```

SmartRF Studio 2.17 or earlier does not support TCXO.

7.3 Example: Usage of TCXO on CC1312R Launchpad

The CC1312R Launchpad has a TCXO mounted but the crystal is used by default. To select the TCXO the following changes have to be done on the board:

- Remove R5 and R6
- Mount 0Ω resistors for R7 and R8.

In syscfg:

1. Go to TI Devices → Device configuration.
2. Set the following:
   a. Enable XOSC Cap array modification: Tick to enable
   b. XOSC Cap Array Delta: 0xE7
   c. HF Clock Source: External 48 MHz TCXO
   d. TCXO Type: Clipped Sine Type
   e. TCXO Max Start-up Time: 0x14

8 Integrated Passive Component (IPC)

An Integrated Passive Component (IPC) is a matched-filter balun component specially designed or matched to the RF section. The IPC reduces the component count that saves space and reduces pick-and-place assembly costs. In addition, there is less risk of a poor RF layout with an IPC since the RF crosstalk is minimized. Table 8-1 lists the available IPC's.

Table 8-1. Available IPC's

Chip Family	Frequency (MHz)	Vendor	Part Number	Application Note
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	430 - 435	Johanson Technology	0433BM15A0001	SWRA250
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	430 - 435	Johanson Technology	0433BM15A0001E-AEC*1	SWRA250
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	863 - 873	Johanson Technology	0868BM15C0001	SWRA250
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	863 - 873	Johanson Technology	0868BM15C0001E-AEC*1	SWRA250
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	863 - 928	Johanson Technology	0896BM15A0001	SWRA250
CC1120, CC1121, CC1175, CC1200, CC1201	863 - 928	Johanson Technology	0900PC15J0013	SWRA407
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	902 - 928	Johanson Technology	0915BM15A0001	SWRA297
CC1101, CC1111, CC1110, CC110L, CC113L, CC115L, CC430	902 - 928	Johanson Technology	0915BM15A0001E-AEC*1	SWRA297
CC13xx	430-510	Walsin	RFBLN2520090YC3T10	SWRA524
CC13xx	770-928	Murata	LFB18868MBG9E212	SWRA524
CC13xx	770-928	Johanson Technology	0850BM14E0016	SWRA524
CC1352R, CC1352P	863 – 928 2400 - 2480	Murata	LFB21868MDZ5E757	SWRA629
CC1352R, CC1352P	430 - 435, 2400 - 2480	Murata	LFB21433MDZ6F112	SWRA629
CC1352R, CC1352P	863 – 928 2400 - 2480	Johanson Technology	0900PC15A0036	SWRA629
CC2420	2400 - 2480	Anaren	BD2425N50200A00	SWRA155
CC2430	2400 - 2480	Anaren	BD2425N50200A00	SWRA156
CC2430, CC2480	2400 - 2480	Johanson Technology	2450BM15A0001	
CC2520	2400 - 2480	Johanson Technology	2450BM15B0002	
CC2500, CC2510	2400 - 2480	Johanson Technology	2450BM15B0003	
CC1352R, CC1352P, CC2620, CC2630, CC2640, CC2650	2400 - 2480	Murata	LFB182G45BG5D920	
CC1352R, CC1352P, CC2620, CC2630, CC2640, CC2650	2400 - 2480	Johanson Technology	2450BM14G0011	SWRA572
CC1352R, CC1352P, CC2620, CC2630, CC2640, CC2650	2400 - 2480	Johanson Technology		
CC13xP, CC26xP For HPA port, TX only.	2400 - 2480	Murata	LFB182G45BGEF296	SWRA729

9 Optimum Load Impedance

The matching environment for optimum performance is determined through a combination of load- and source-pull measurements, given as a terminating load/source impedance. This requires comprehensive measurements to characterize the nonlinear response of the RF front-end.

The parameters considered include:
- TX Output Power
- TX Efficiency
- TX Harmonic Power Levels
- TX Output Spectrum
- RX Sensitivity

The operating conditions considered include:
- Frequency
- Voltage Range
- TX Power Settings
- Package Parasitics

Additionally, the effect of temperature variation on TX/RX performance must also be considered.

These impedance locations are typically located in different regions of the Smith chart and a design space giving the best tradeoff between TX and RX performance is identified for a given set of operating conditions.

The identified target impedance(s) can also be highly dependent on the power and ground planes of the application circuit as well as accurate measurement system calibration, along with the effects of differential and common current components due to the PCB layout. Whilst detailed simulations of the PCB using EDA tools can add confidence to a design, simulation inaccuracies (such as component models) add additional errors that can be difficult to account for.

Due to the number of parameters that must be considered and amount of testing required for a robust design, it is strongly recommended to follow the reference design.

10 PA Table

The PA table for the various devices is provided in SmartRF Studio. The txpower values used in the table are selected to provide as low as possible device to device variation. In addition, the txpower setting has a built-in temperature compensation giving a very low output variation as a function of temperature.

The PA used is designed to be highly effective on maximum power. With maximum power the PA is in saturation and due to this the device to device variation is low. For lower power settings, the PA is in the linear region and the output power will therefore be dependent on the transistor gain, which will have a higher device to device variation. For the output powers not covered by the PA table provided by SmartRF Studio, it has not been possible to find a txpower setting that gives a low device to device variation or a stable output power over temperature.

It is possible for customers to generate a custom PA table if that is needed. The output power of a FEM will typically not be constant as a function of temperature and it could be possible to find a txpower value that gives a more constant output power over temperature when using a FEM.

The parameter txPower contains temp. coefficient setting, gain setting, IB setting and the TX BOOST bit:
- txPower[15:9]: temp coefficient
- txPower[8]: TX BOOST bit
- txPower[7:6]: Gain
- txPower[5:0]: IB

The temperature coefficient is applied to automatically compensate the IB setting based on the temperature readout of AON_BATMON_TEMP.

There are three different gain settings and for each gain setting the IB can be adjusted from 0x0 to 0x3F resulting in 64*3 192 available settings for TX output power. The temperature coefficient is given as an input

in addition to the requested gain and IB setting.Based on the readout from the temperature sensor and the temperature coefficient setting the IB is adjusted. IB is adjusted based on Equation 3.

$$Ib = Ib_{requested} + \frac{(Temperature - 25°) \cdot temcoeff}{256}$$

(3)

A custom TX power table should be generated by the following method (to obtain constant Tx power over temperature for a certain Tx parameter value):

1. Room temp setting: Adjust the gain and IB setting to get the requested output power level at room temperature with temperature compensation disabled. This setting will be the Ib_requested.
2. Low temp setting: Use the same gain setting and adjust the IB setting to get the closest output power level from step 1 at low temperature. This setting will be the Ib_low_temp.
3. High temp setting: Use the same gain setting and adjust the IB setting to get the closest output power level from step 1 at high temperature. This setting will be the Ib_high_temp.
4. Calculate temp coefficient. Use the IB settings from the low and high temperature measurements to calculate the temperature coefficients. The temp coefficient is based on a linear approximation between the two temperature extremes and calculated as shown in Equation 4.

$$temp\_coeff = 256 \cdot \frac{(Ib\_high\_temp - Ib\_low\_temp)}{high\_temp - low\_temp}$$

(4)

$$Ib = Ib_{requested} + \frac{(Temperature - 25\ deg) \cdot temcoeff}{256}$$

(5)

$$temp\_coeff = 256 \cdot \frac{(Ib\_high\_temp - Ib\_low\_temp)}{high\_temp - low\_temp}$$

(6)

5. Repeat step 1-3 for all the desired power levels.

11 Power Supply Configuration

11.1 Introduction

The CC13xx/CC26xx devices have three power rails that are exposed on external pins: VDDS, VDDR and DCOUPL. VDDS is the main power source for the wireless microcontroller and must be supplied externally with 1.8V to 3.8V. VDDR is an internal power rail that is supplied from the internal DC/DC converter, or the internal Global LDO, but can be powered from an external supply. VDDR is regulated to approximately 1.68V, or 1.95V when running in boost mode for maximum output power in sub-1GHz bands. In boost mode, a minimum VDDS voltage of 2.1V is required. DCOUPL is supplied internally by either Digital LDO or Micro LDO depending on the power state. This power rail is trimmed to approximately 1.28V and requires an external decoupling capacitor of 1µF.

11.2 DC/DC Converter Mode
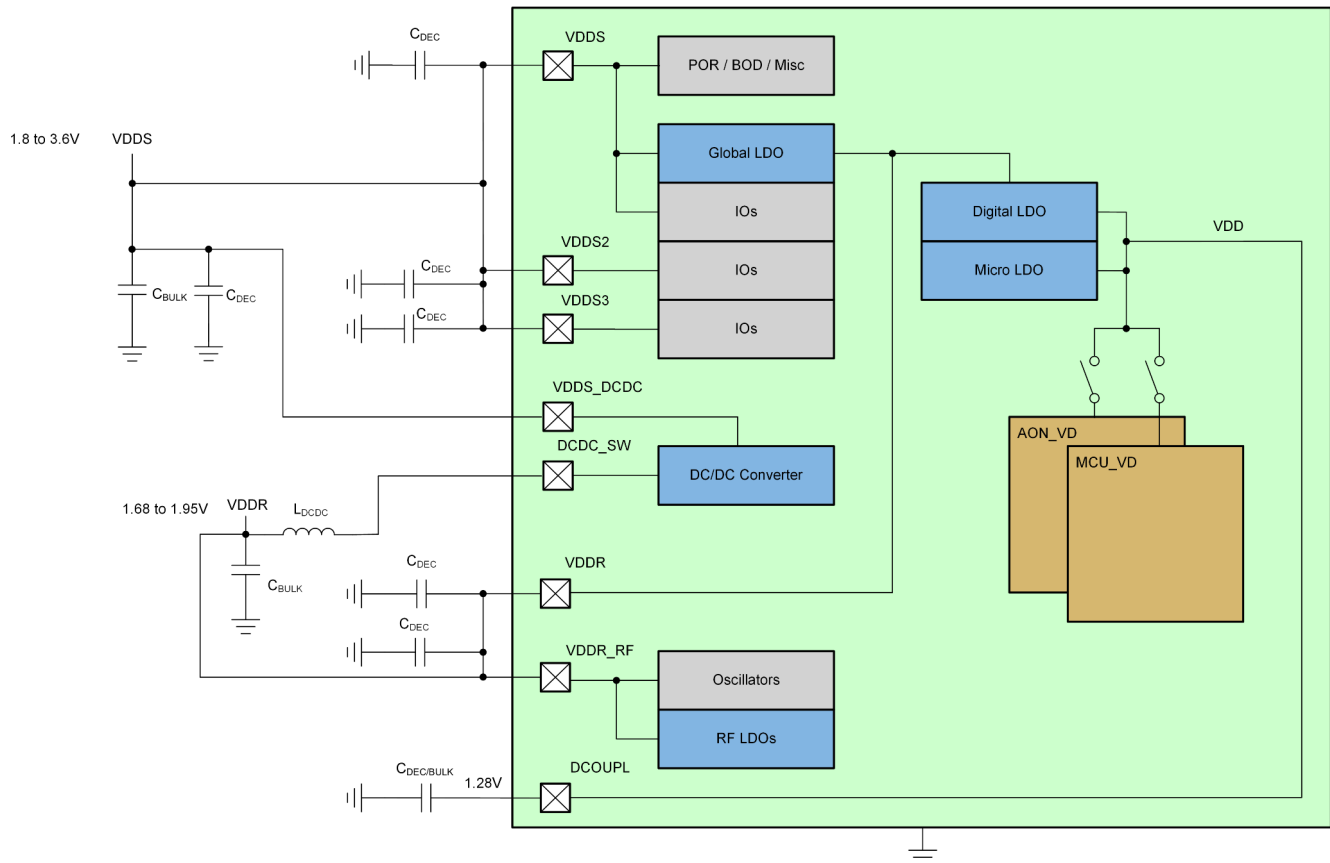
Figure 11-1. DC/DC Mode

Note

The VDDS_DCDC pin is not present on all devices.

Maximum efficiency is obtained by using the internal DC/DC converter, and it requires an external inductor (LDCDC) and capacitor (CDCDC). The components should be placed as close as possible to the CC13xx/CC26xx device and it is important to have a short current return path for from the CDCDC ground to the pad on the chip (see Section 4.8). In addition, the bulk capacitor on VDDS should be placed close to the VDDS_DCDC-pin. The actual value of LDCDC, CDCDC and CBULK vary from device to device. For the actual values, see the device-specific reference design.

When operating in DC/DC mode, the power system dynamically switches between the Global LDO and DC/DC converter depending on the required load to achieve maximum efficiency. If VDDS drops below 2.0V, the DC/DC converter will be less efficient than the LDO and the device will run in global LDO mode. For systems operating

with VDDS less than 2.0V, consider either global LDO or external regulator mode to save component cost and board area.

The software setup required to use the DCDC converter or the GLDO operation is done in the Customer Configuration (CCFG) register bank.

For devices that use SDK up to version 5.x (CC2640R2), the settings below must be made to the file ccfg.c.

```
#ifndef SET_CCFG_MODE_CONF_DCDC_RECHARGE
#define SET_CCFG_MODE_CONF_DCDC_RECHARGE        0x0   // Use the DC/DC during recharge in powerdown
// #define SET_CCFG_MODE_CONF_DCDC_RECHARGE     0x1   // Do not use the DC/DC during recharge in
powerdown
#endif
#ifndef SET_CCFG_MODE_CONF_DCDC_ACTIVE
#define SET_CCFG_MODE_CONF_DCDC_ACTIVE          0x0   // Use the DC/DC during active mode
// #define SET_CCFG_MODE_CONF_DCDC_ACTIVE       0x1   // Do not use the DC/DC during active mode
#endif
```

For devices that use SDK version 6.x and above, this is set up in the section TI DEVICES followed by Device Configuration of the Sysconfig file as indicated in the following image.

11.3 Global LDO Mode
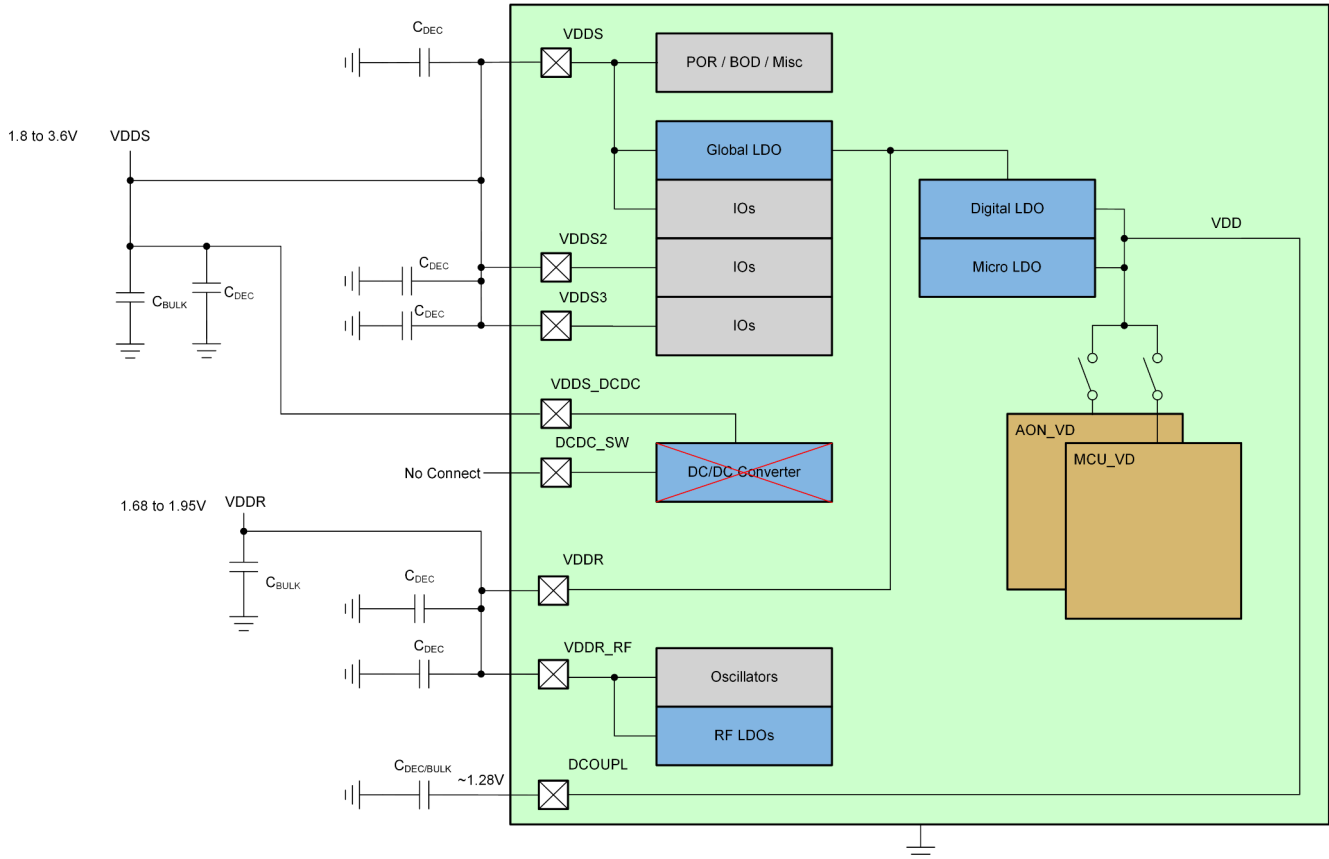
Figure 11-2. Global LDO Mode

Note

The VDDS_DCDC pin is not present on all devices.
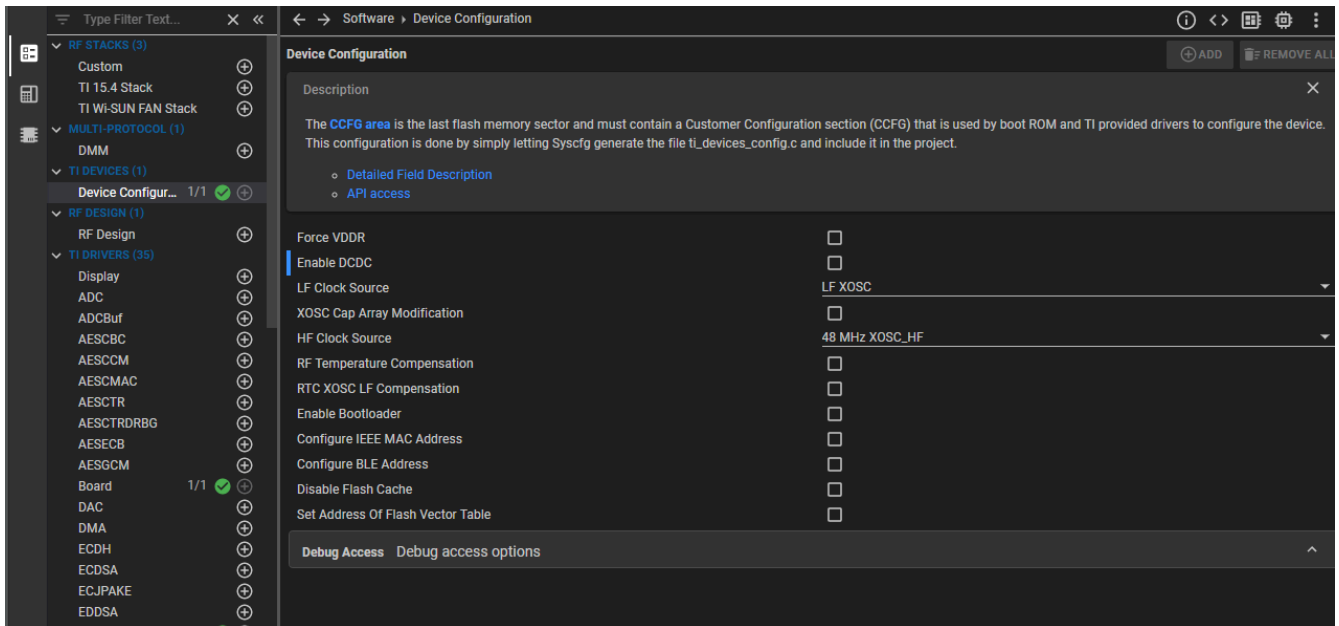
To save cost and PCB area the DC/DC inductor can be removed and VDDR can be supplied from the Global LDO at the cost of higher power consumption. In this mode a bulk capacitor on VDDR is still required and should be placed close to the VDDR pin. The VDDS_DCDC-pin must be connected to VDDS and the DCDC_SW should be left floating to avoid short circuiting VDDS if the DC/DC converter is mistakenly enabled from software. The VDDS bulk capacitor does not need to be close to the VDDS_DCDC pin and should rather be placed close to the VDDS pin.

The software setup required to use the DCDC converter or the GLDO operation is done in the Customer Configuration (CCFG) register bank.

For devices that use SDK up to version 5.x (CC2640R2), the settings below must be made to the file ccfg.c.

```
#ifndef SET_CCFG_MODE_CONF_DCDC_RECHARGE
// #define SET_CCFG_MODE_CONF_DCDC_RECHARGE    0x0   // Use the DC/DC during recharge in powerdown
#define SET_CCFG_MODE_CONF_DCDC_RECHARGE       0x1   // Do not use the DC/DC during recharge in
powerdown
#endif
#ifndef SET_CCFG_MODE_CONF_DCDC_ACTIVE
// #define SET_CCFG_MODE_CONF_DCDC_ACTIVE      0x0   // Use the DC/DC during active mode
#define SET_CCFG_MODE_CONF_DCDC_ACTIVE         0x1   // Do not use the DC/DC during active mode
#endif
```

For devices that use SDK version 6.x and above, this is set up in the section TI DEVICES followed by Device Configuration of the Sysconfig file as indicated in the following image.

CC13xx/CC26xx Hardware Configuration and PCB Design Considerations

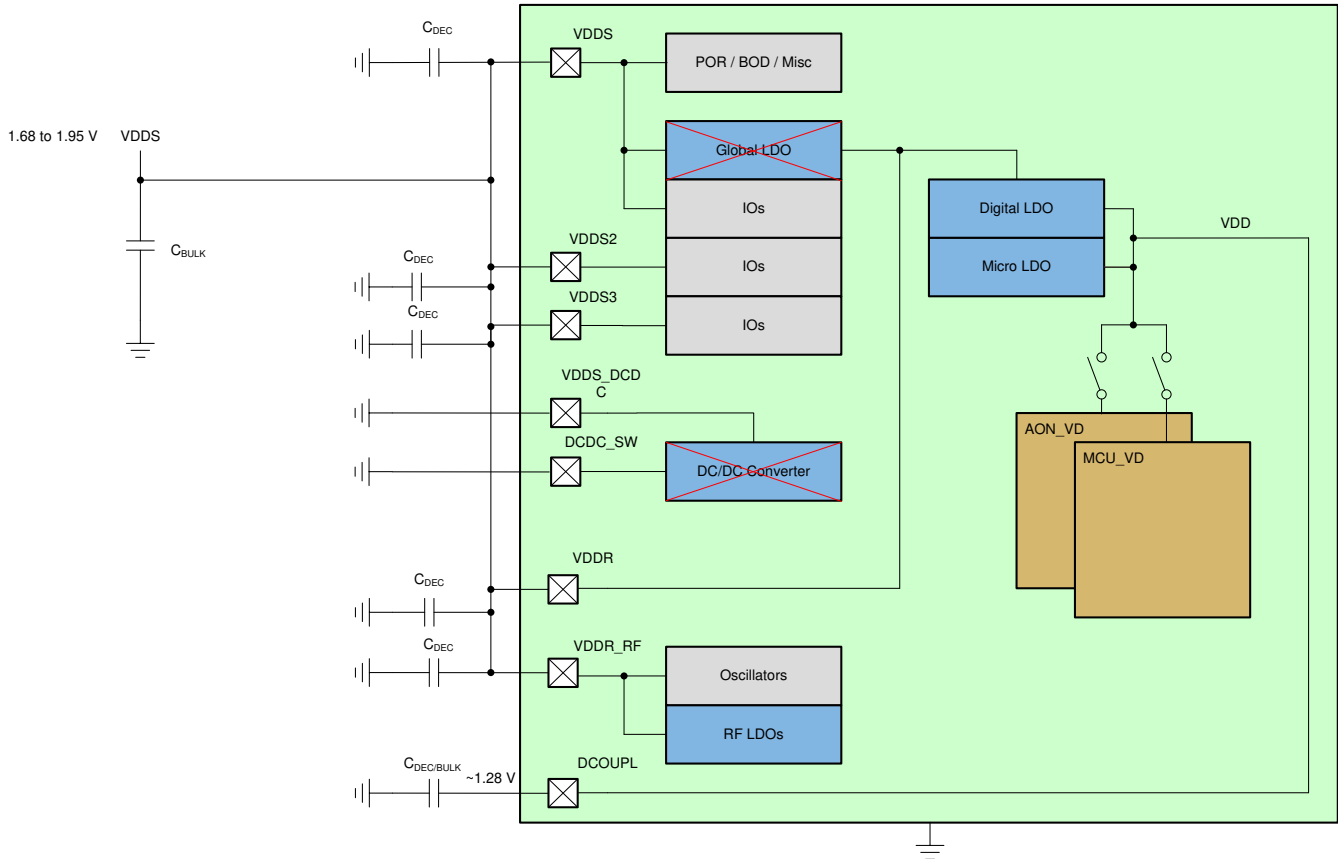## 11.4 External Regulator Mode

Figure 11-3. External Regulator Mode

In external regulator mode, neither the Global LDO nor the DC/DC is active and both VDDS and VDDR must be powered from the same rail. The regulators are disabled by connecting VDDS_DCDC to ground. Note that the maximum voltage level on the external regulator is limited by VDDR and should not exceed the absolute maximum rating defined in the device-specific data sheet. To achieve maximum output power for the sub-1GHz PA, the supply voltage should be set to 1.95V.

Note
External Regulator Mode is only supported on CC26x0 devices.

12 Board Bring-Up

Before starting to develop software or doing range testing, It is recommended to do conducted measurements to verify that the board has the expected performance. Typically, the sensitivity, output power, harmonics, and current consumption should be measured to verify the hardware design.

The required measurements depend on the type of board and application. If it is a design with 10m range requirement the checkout does not need to be as detailed as for a design with a range extender. For the latter, and other designs that require high performance, having access to a spectrum analyzer and a signal generator with the option to send RF packets is highly recommended.

Different measurement methods are discussed in the following sections. It is up to the reader to select the methods applicable for their board.

12.1 Power On

When powering on the board for the first time, check that the voltages on the following pins are as expected.

CC13xx and CC26xx

- VDDR = 1.68 V for CCFG_FORCE_VDDR_HH = 0
- VDDR = 1.95 V for CCFG_FORCE_VDDR_HH = 1
- DCOUPL = 1.27 V

Do NOT measure directly on the X24M_P and X24M_N nor X48M_P and X48M_N pins since this could brick the device.

12.2 RF Test: SmartRF Studio

In order to use SmartRF Studio for testing, the board needs a connector that enables a debugger to be connected directly to the RF chip:

- For the CC13xx and CC26xx, an XDS100v3, XDS110 or XDS200 should be used.

The required pins in cJTAG-mode are VDDS, GND, RESET, TCK and TMS.

1. Connect a debugger to the board. Open SmartRF Studio and verify that the device is visible in the list of connected devices.
2. Place two good known boards with 2m distance. In this context "good known boards" are EM's or LaunchPads from TI. Use a predefined PHY setting in SmartRF Studio that is a closest match to the PHY that will be used in the final product
3. Set one board to PacketRX and the other to PacketTX and transmit 100 packets. Confirm that the packets are received and note the RSSI for the received packets.
4. Replace the board used in TX with the device under test (DUT). Repeat the test described in 3.
5. Replace the board used in RX with the DUT. Replace the board used in TX with a good known board. Repeat the test described in 3.
6. If possible, the measurements should be done with a good known antenna first and then repeated with the antenna that is going to be used in the final design later. A poorly tuned antenna could cause a significant loss in sensitivity/output power.
7. If the results are satisfactory, change the settings from the predefined setting to the RF settings planned to be used in the final product. Repeat the tests described in 3 to 5 with the wanted RF settings.

If the RSSI deviates from the reference, the schematic and layout should be reviewed. Note that if the network between the RF ports and the antenna on the customer board is different from the TI evaluation board, the losses due to SAW filters and switches must be to be taken into consideration.

12.3 RF Test: Conducted Measurements

For high performance designs it is highly recommended to perform conducted measurements to verify the performance before setting up an RF link.

12.3.1 Sensitivity

1. Disconnect the antenna and perform conducted measurements at the SMA connector or solder a semi rigid coax cable at the 50Ω point.
2. Configure the board under test and use the PacketRX option in SmartRF Studio similar to the test described in Section 12.2. In PacketRX mode, you can set an expected packet count.
3. Preferred: Use a signal generator that is capable of transmitting data packets. Remember to set up the sync word and CRC correctly.
4. If a signal generator is not available, use an EM/LaunchPad as a transmitter. Use coax cables and attenuation between the EM/LauncPad SMA connector and the 50Ω point on the custom board. It is difficult to get an accurate number using this method since the exact values of output power and attenuation are normally not known. Some energy will also travel over the air from the EM to the DUT. In addition, background noise could impact the results. To get more accurate results, the receiver should be placed in a shielded box.
5. SmartRF Studio will calculate the packet error rate (PER) and bit error rate (BER).

If the wanted RF settings are different from the predefined setting, PER vs level should be run in addition. The input power level should be increased in 1- 2dB steps from the sensitivity limit to around 0 dBm. For each power level, transmit at least 100 packets and record the PER. If the AGC settings are not optimal it is common that the PER for some of the steps will be above 0 (residual PER) and if that is the case the AGC settings have to be reviewed.

If the conducted sensitivity is poor:

• Are the settings the same as the recommended values from SmartRF Studio? If the sensitivity is good when using SmartRF Studio and not with the settings used for the project the settings have to be reviewed.
• What is the frequency difference between the DUT and the signal source? Frequency offset can be measured by transmitting an un-modulated continuous wave
• Is the schematic, including all component values, in accordance with the reference design?
• Is the layout in accordance with the reference design?

12.3.2 Output Power

1. Disconnect the antenna and perform conducted measurements at the SMA connector or solder a semi-rigid coax cable at the 50Ω point.
2. Preferred: Use a spectrum analyzer (SA). Use 1MHz RBW for measuring output power.
3. If an SA is not available use an EM or Launchpad with a SMA connection point. Use coax cables and attenuation between the EM/LaunchPad SMA connector and the 50Ω point on the custom board. Use SmartRF Studio and set the EM/Launchpad in continuous RX and read the RSSI. Note that the RSSI has a given tolerance so the measurement will not be as accurate as the preferred method.

12.4 Software Bring-Up

For CC13xx:

Basic examples for RF and other drivers can be found under TI Drivers under software -> Examples -> Development Tools -> <Development board in question> at http://dev.ti.com/tirex/#/. Before starting to write own software it is recommended to run the RF examples that are closest to the wanted application unmodified and verify that they work. Then, if required, change the RF settings to the wanted data rate, and so forth.

For CC26xx and Bluetooth Low Energy:

For more information, see Initial Board Bring Up on recommended software images to run initially.

Basic examples for RF and other drivers can be found under TI Drivers under software -> Examples -> Development Tools -> <Development board in question> at https://dev.ti.com/tirex/#/.

12.5 Hardware Troubleshooting

This section covers some of the common causes for poor performance.

12.5.1 No Link: RF Settings

To get a link between two RF chips the two RF chips have to operate on the same frequency and with the same RF settings. This means that the two have to use the same data rate, deviation and modulation format. A common mistake is that the sync word has been set differently on the two devices, they have to be equal.

12.5.2 No Link: Frequency Offset

For narrow band systems a too large frequency offset between the TX and RX devices could result in no link or a very poor link.

The minimum required RX bandwidth to ensure reception is given by:

RX BW = Signal Bandwidth + 4*ppm Crystal * RF Frequency of Operation   (7)

For FSK the signal bandwidth can be approximated as data rate + 2*frequency deviation (Carson's rule).

For CC13x0: For low data rates, the bit repetition patch *CC13x0 Low Data Rate Operation* should be used. If this patch is not used, the frequency offset tolerance could be under 10 ppm, which could cause loss of link with a normal crystal tolerance.

12.5.3 Poor Link: Antenna

An antenna needs a matching network in order to tune and reduce the mismatch losses of the antenna. If the antenna is not tuned, energy will be lost both in TX and RX and the link budget will be lower. For more details, see Section 5.

12.5.4 Bluetooth Low Energy: Device Does Advertising But Cannot Connect

If using the 32kHz crystal oscillator as RTC source:

- Incorrect load capacitors for the 32.768kHz crystal – causes frequency offset
- 32kHz crystal does not start up (incorrect load capacitors, crystal missing, soldering issues) – the device defaults to run the RTC from the 48MHz RC oscillator at 31.25kHz. For more information, see the *PRCM* chapter in the *CC13x0, CC26x0 SimpleLink™ Wireless MCU* and *C13x2, CC26x2 SimpleLink™ Wireless MCU* technical reference manuals.

If using the 32kHz RC oscillator as RTC source:

- Calibration is not configured correctly. For more information, see the Bluetooth Low Energy Stack User's Guide that is provided with the SDK.

Incorrect RTC frequency will lead to the device missing the connection events and thus breaking the link with the central device.

To debug this problem, the 32kHz clock can be output on an I/O pin and measured with a frequency counter. For more information on how to do this, see the *I/O* chapter in the *CC13x0, CC26x0 SimpleLink™ Wireless MCU* and *C13x2, CC26x2 SimpleLink™ Wireless MCU* technical reference manuals. By outputting the clock on a pin, you will always measure the _selected_ RTC clock source, as well as be able to measure without affecting the clock source (which probing the crystal for example will do).

If using a 32.768kHz crystal make sure the crystal part is within the requirements outlined in the device-specific CC13xx/CC26xx data sheets. Also make sure that the load capacitors are dimensioned properly as shown in Section 6.3.

Verify that the BLE-Stack has been configured with the correct Sleep Clock Accuracy. The default setting is 40ppm and can be adjusted with the HCI_EXT_SetSCACmd API, see hci.h or the TI Vendor Specific API Guide included in the SDK.

12.5.5 Poor Sensitivity: DCDC Layout

It is highly recommended to follow the reference design when it comes to the components connected to the DCDC_SW pin. The shunt capacitor following the series inductor from the DCDC_SW pin has to have a short return path to chip ground from the ground pad (see Section 4.8). A poor DCDC layout could cause more than 5dB loss in sensitivity. To check if the sensitivity is limited by the DCDC, turn off the DCDC in the CCFG.c file.

12.5.6 Poor Sensitivity: Background noise

A RF channel will receive all radio traffic in the selected frequency span. In addition to the wanted signal the channel will also receive background noise. Part of the background noise is other RF traffic on the selected band. To receive a RF packet the received signal has to have a given SNR. If the background noise increases, the practical sensitivity will be poorer.

Example: If the conducted sensitivity is -110dBm, the required SNR is 7dB and the background noise is -100dBm, the practical radiated sensitivity will be -93dBm.

Before doing a range test the background noise should be measured. One method is to turn off all known TX sources, attach a Launchpad or a known good board to SmartRF Studio, select the *Continuous RX* tab and press play. The average of the resulting graph could be used as an input to find the practical sensitivity.

12.5.7 High Sleep Power Consumption

- Note that the chip is not going into the lowest power modes when a debugger is connected.
- Software: Use the pinStandby or pinShutdown examples in the relevant SDK.
- When measuring current draw on a Launchpad, remove all jumpers.
- Ensure that every IC on the board is powered down.
- If the application is configured to use the 32kHz crystal (set in CCFG.c), check that this is connected and that the oscillator is running.

13 References

- TXLine Transmission Line Calculator
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14 Revision History

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