EM430F6137RF900 Reference Design Guide

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ABSTRACT

This document explains the theory behind and recommended practices to layout the EM430F6137RF900 RF filter-balun. It also describes tips and tricks for the EM430F6137RF900, including steps to modify the RF-front end to operate at 315 MHz or 433 MHz, necessary additions for bootloader (BSL) communication, recommendations for achieving ETSI compliance, and how to debug the EM430F6137RF900 board using Spy-Bi-Wire mode.

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1 Impedance Matching and Filter Design Principles

The CC430 MCUs have differential RF ports, RF_P and RF_N, that have an optimal impedance from the chip toward the antenna of Z = 86.5 + j43 Ω at 868 or 915 MHz and 116 + j41 Ω at 433 MHz.[6] The impedance of the selected antenna port is 50 Ω. Therefore, it is important to ensure proper impedance matching between the radio and the antenna through the use of a circuit network that translates a balanced signal from the CC430 to a 50-Ω unbalanced antenna load. This circuit is called a balun.

Figure 1 shows a typical application circuit for 868 or 915 MHz including the balun.

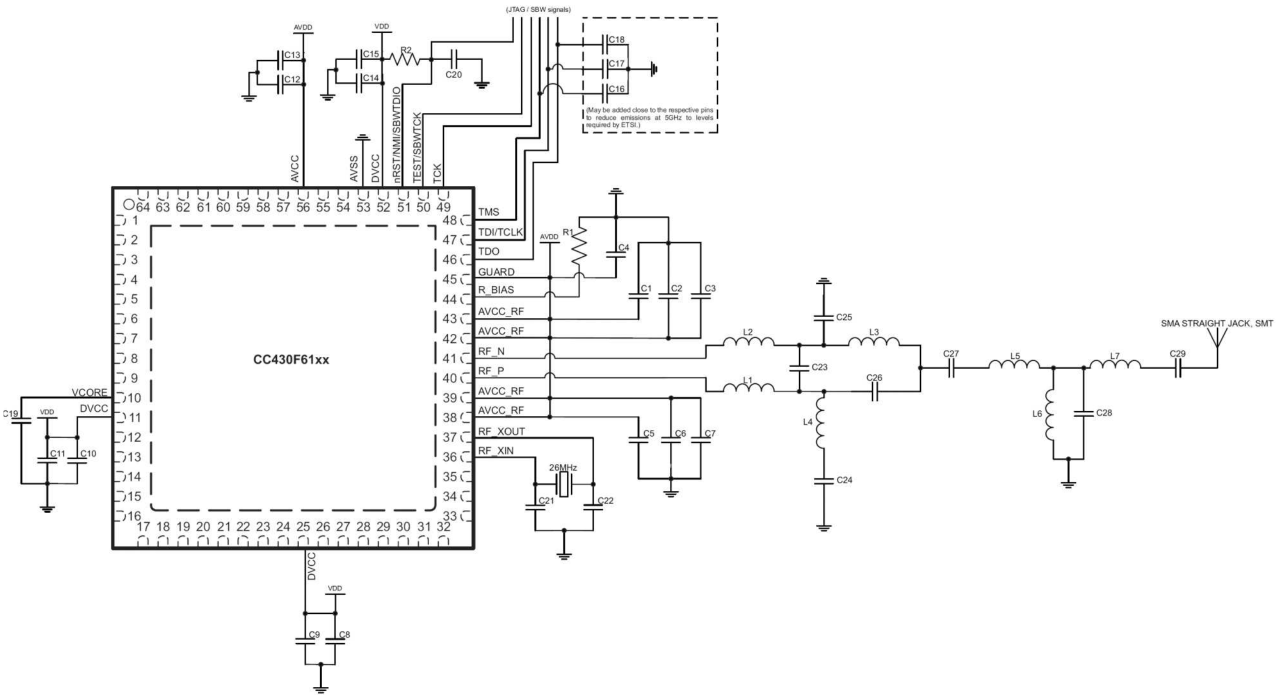

Figure 1. Typical Balun Circuit for 868 or 915 MHz

In transmit (TX) mode, the balun has two purposes:

- Provide optimum matching for the lowest possible current consumption and highest possible output power
- Fulfill regulatory harmonic and spurious emissions regulations

In receive (RX) mode, the balun has a single purpose:

- Provide optimum matching for the best possible sensitivity

The balun can be functionally divided into its different parts:

- Differential low-pass filter: L1, L2, C23
- Balun: C25, C26, L3, L4
- T-section band-pass filter: C27, C28, C29, L5, L6, L7
- DC block: C24

The recommended values of the balun components for different frequencies are in the EM430F6137RF900 target board files.

An ideal output signal from the CC430 in TX mode is a square wave signal at the RF_P and RF_N pins and a sine wave at the antenna port. To achieve this, the balun must successfully suppress the most prominent odd harmonics – the third and fifth – of the square wave. The lowest possible current consumption is achieved by having these odd harmonics reflected back towards the RF front-end with a high real part of the impedance. The easiest way to do this is through the use of the differential low-pass filter.

Following the low-pass filter is the balun that matches the impedance of the output to the 50-Ω node. The filter is designed to shift the output signal in phase by ±90° through the use of a low-pass and a high-pass filter. To achieve the best amplitude and phase balance in the balun, the layout trace from the single-ended port to each of the RF pins should be as equal in length and as symmetrical as possible. Any unbalance in the balun design causes high second and fourth harmonic levels, reduced output power at the single-ended side of the balun, higher transmit current consumption, and reduced sensitivity.

The filter that follows the balun is recommended to be T-type filter rather than a Pi-type to reduce the radiated emissions through shunt capacitors.

In the case of the EM430F6137RF900 target board, the filter is a band-pass filter and is dimensioned to have a 50-Ω impedance at both sides so it can easily be removed or redesigned to fulfill any special requirements (see Figure 2).

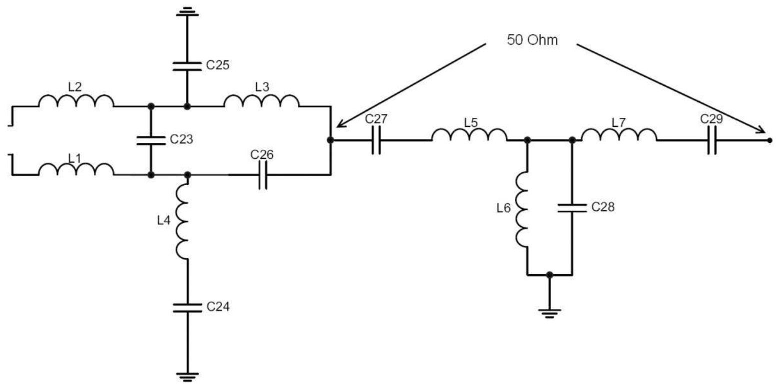

Figure 2. 50-Ω Points in the Balun

1.1 *Filter and Balun Layout Best Practices*

The following key considerations should be taken into account during layout:

- The traces for the RF layout should be symmetrical.
- A solid ground-plane should be implemented beneath the RF circuitry.
- It is recommended that the distance between layer 1, with the RF circuitry, and ground is 410 µm. Changing the thickness of the board changes the inductance of the vias which, in series with the decoupling capacitors, could negatively affect the performance. The EM430F6137RF900 PCB uses 4-layer technique with the distance between the TOP (RF circuitry) and GND layers being 410 µm.
- Shorter or longer trace lengths may degrade the performance, because they will influence the impedance of the traces in the balun.
- The design should be implemented on an FR4 substrate. Changing the substrate changes the impedance of the PCB traces.
- Decoupling capacitors C1 to C15 should be used and should be placed as close to the pins as possible.[1] Vias should be placed close to all decoupling capacitors to ensure a good connection to the solid ground plane below.
- 0402 components are used for the EM430F6137RF900 target board. Changing to 0603 will change the parasitic values of the components and may require a different solution.
- Components from different vendors have slightly different performance. Inductors and capacitors from Murata (the LQW15 and GRM15 series) are used in the CC430F613x and CC430F513x evaluation kits.
- Multilayer type inductors are used in the CC430F613x and CC430F513x evaluation kits. A slightly higher output power and reduction of harmonic emissions can be achieved by replacing the multilayer type of inductors with wire-wound inductors. Multilayer inductors were chosen for the target board due to tradeoffs in cost.

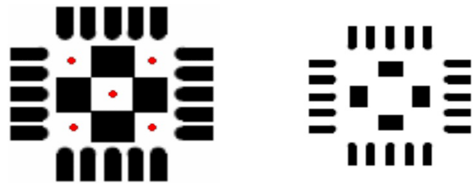

Figure 3. Example Solder Paste, With and Without Vias (CC11xx)

2 EM430F6137RF900 RF Front End

The RF front-end is a balun circuit required to match the impedance of the differential CC430 outputs to a 50-Ω load, such as the monopole SMA antenna provided with the EM430F6137RF900 kit, an RF signal generator, or a spectrum analyzer. The EM430F6137RF900 comes populated with the RF front end intended to operate within the 868- or 915-MHz frequency bands (see Figure 4 and Table 1).

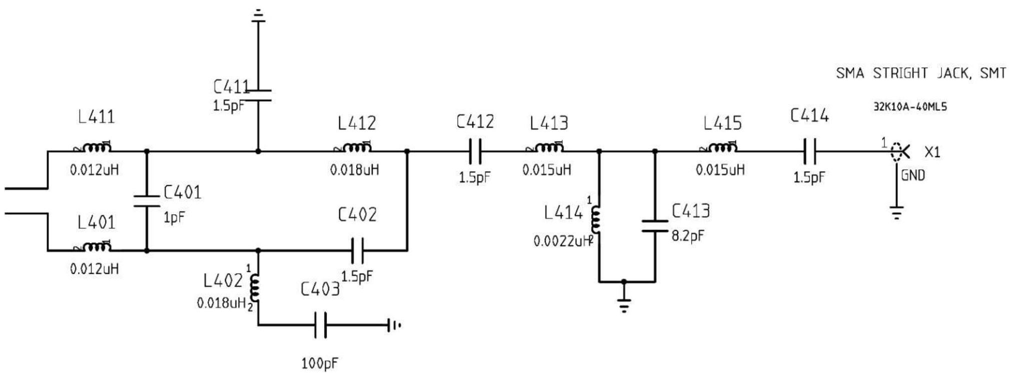

Figure 4. RF Front End for 868 or 915 MHz

Table 1. Components for 868 or 915 MHz

Qty	Mfg	Part No	Value	Description	Schematic Reference
2	Murata	LQW15AN12NJ00	12nH	INDUCTOR,SMT, 0402,±5%,500mA,250MHz	L411, L401
1	Murata	GJM1555C1H1R0CB01D	1pF	CAPACITOR, SMT, CERAMIC, 0402, 50V, ±0.25pF, NP0	C401
4	Murata	GRM1555C1H1R5CZ01	1.5pF	CAPACITOR,S MT, CERAMIC, 0402, 50V, ±0.25pF, C0G(NP0)	C402,C411-C412,C414
1	Murata	GRM1555C1H101JZ01	100pF	CAPACITOR, SMT, CERAMIC, 0402, 50V, ±0.25pF, C0G(NP0)	C403
2	Murata	LQW15AN18NJ00	18nH	INDUCTOR, SMT, 0402, ±5%, 370mA, 250MHz	L402,L412
2	Murata	LQW15AN15NJ00	15nH	INDUCTOR, SMT, 0402, ±5%, 460mA, 250MHz	L413,L415
	Murata	LQW15AN2N2C10	2.2nH	INDUCTOR, SMT, 0402, ±0.2nH, 1000mA, 250MHz	L414
1	Murata	GRM1555C1H8R2CZ01	8.2pF	CAPACITOR, SMT, CERAMIC, 0402, 50V, ±0.25pF, C0G(NP0)	C413
1	Nearson	S463 AM 915	50Ω	915 MHz antenna	

To successfully operate the EM board at the frequencies of 315 MHz and 433 MHz, the components of the balun circuit must be replaced. Section 2.1 and Section 2.2 describe the necessary component changes, and care should be taken to use either the exact components recommended in the bill-of-materials documents or components that have the same accuracy. Conveniently, the same board and RF layout may be re-used.

2.1 Changing the RF Front End For 315 MHz

The following excerpts from the respective schematics and BOM (see Figure 5 and Table 2) summarize the appropriate components and board modifications to change the CC430 EM into a 315-MHz board.

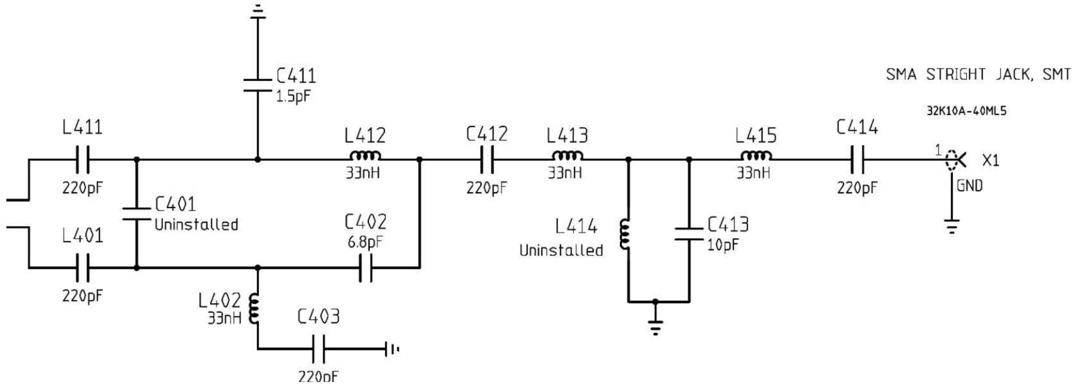

Figure 5. RF Front End for 315 MHz

Table 2. Components for 315 MHz

Qty	Mfg	Part No	Value	Description	Schematic Reference
1	Murata	LQP15MN2N2B02	Uninstalled	INDUCTOR, SMT, 0402, 2.2nH, ±0.1nH, 220mA, 500MHz	L414
1	Murata	GRM1555C1H2R7BZ01	Uninstalled	CAPACITOR, SMT, CERAMIC, 0402, 2.7pF, 50V, ±0.1pF, C0G	C401
5	Murata	GRM1555C1H221JA01	220pF	CAPACITOR, SMT, CERAMIC, 0402, 220pF, 50V, ± 5%, C0G	C403, C412,
1	Murata	GRM1555C1H6R8CZ01	6.8pF	CAPACITOR, SMT, CERAMIC, 0402, 6.8pF, 50V, ±0.25pF, C0G	C402
1	Murata	GRM1555C1H1R5CZ01	1.5pF	CAPACITOR, SMT, CERAMIC, 0402, 50V, ±0.25pF, C0G(NP0)	C411
4	Murata	LQW15AN33NJ00	33nH	INDUCTOR, SMT, 0402, 33nH, ±5%, 280mA, 500MHz	L402, L412-L413, L415
1	Murata	GRM1555C1H100JZ01	10pF	CAPACITOR, SMT, CERAMIC, 0402, 10pF, 50V, ± 5%, C0G	C413
1	Nearson	L362AM-315R	50?	315 MHz antenna	

2.2 Changing the RF Front End For 434 MHz

The following excerpts from the respective schematics and BOM (see Figure 6 and Table 3) summarize the appropriate components and board modifications to change the CC430 EM into a 434-MHz board.

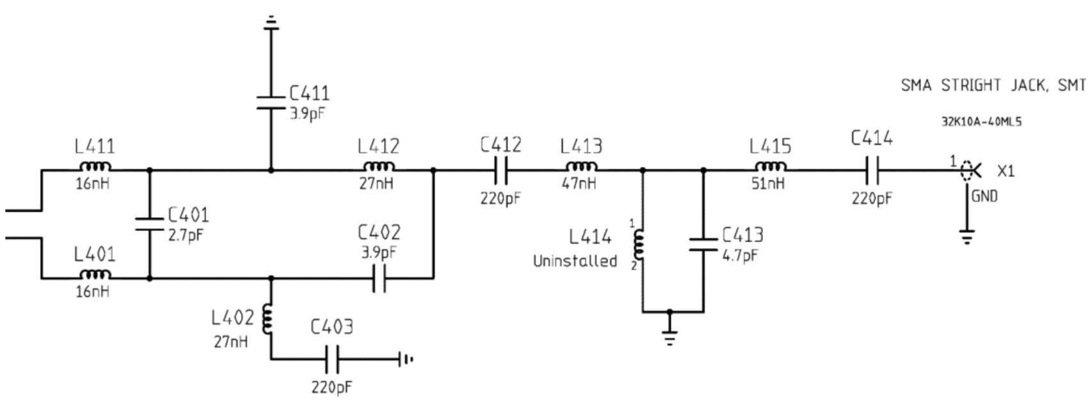

Figure 6. RF Front End for 434 MHz

Table 3. Components for 434 MHz

Qty	Mfg	Part No	Value	Description	Schematic Reference
1	Murata	LQP15MN2N2B02	Uninstalled	INDUCTOR, SMT, 0402, 2.2nH, ±0.1nH, 220mA, 500MHz	L414
2	Murata	LQW15AN16NJ00	16nH	INDUCTOR, SMT, 0402, 16nH, ±0.1nH, 130mA, 500MHz	L401, L411
2	Murata	LQW15AN27NJ00	27nH	INDUCTOR, SMT, 0402, 27nH, ±5%, 280mA, 500MHz	L402, L412
2	Murata	GRM1555C1H3R9BZ01	3.9pF	CAPACITOR, SMT, CERAMIC, 0402, 3.9pF, 50V, ±0.1pF, C0G	C402, C411
1	Murata	GRM1555C1H2R7BZ01	2.7pF	CAPACITOR, SMT, CERAMIC, 0402, 2.7pF, 50V, ±0.1pF, C0G	C401
3	Murata	GRM1555C1H221JA01	220pF	CAPACITOR, SMT, CERAMIC, 0402, 220pF, 50V, ± 5%, C0G	C403, C412, C414
1	Murata	LQW15AN51NJ00	51nH	INDUCTOR, SMT, 0402, 51nH, ± 5%, 210mA, 100MHz	L415
1	Murata	LQW15AN47NJ00	4.7nH	INDUCTOR, SMT, 0402, 47nH, ± 5%, 210mA, 100MHz	L413
1	Murata	GRM1555C1H4R7BZ01	4.7pF	CAPACITOR, SMT, CERAMIC, 0402, 4.7pF, 50V, ±0.1pF, C0G	C413
1	Nearson	L362AM-434R	50?	434 MHz antenna	

3 EM430F6137RF900 Schematic Tips and Tricks

3.1 Achieving Successful BSL Communication

To communicate in BSL mode, additional 0-Ω resistors must be populated on the EM430F6137RF900. When the EM430F6137RF900 is flipped over and the JTAG connector is pointed away at the top right of the board, two pairs of 0402 component pads are visible—one at the top left next to the back of CON10 and the other in the center of the board directly above CON1.

The pair of pads above CON1 is for R231 and R221 on the EM430F6137RF900 schematic. Both pads must be populated with 0-Ω resistors to communicate over BSL. The pair of pads next to COM10 at the top of the board is for R4 and R5 on the EM schematic. When supplying a voltage through the BSL connector populate R4 with a 0-Ω resistor. If supplying an external voltage, remove R4 and populate R5 with a 0-Ω resistor.

The resistors are marked on the silk screen.

3.2 Communicating in Spy-Bi-Wire (SBW) Mode

There is a row of six consecutive 0.1-in spacing jumpers populated at the top-center of the board. The two left-most jumpers in this set of six should be moved to connect to pins one and two on the header instead of pins five and six to successfully debug in Spy-Bi-Wire mode (see Figure 7).

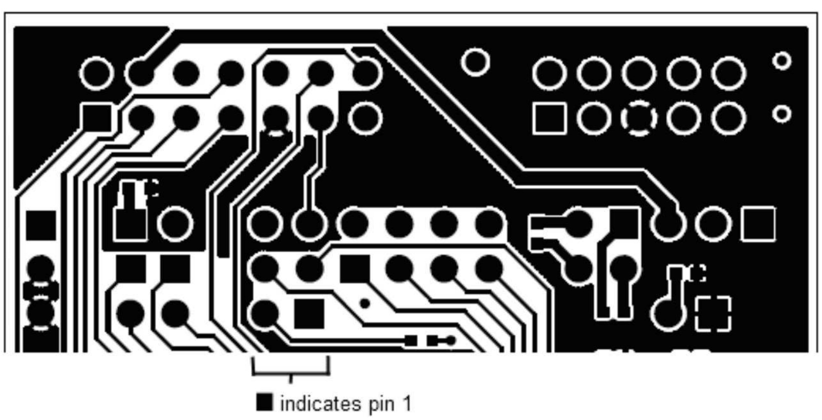

Figure 7. EM430F6137RF900 Front - SBW Communication

4 ETSI Compliance

Wire wound inductors perform better than multilayer inductors at high frequencies because the self-resonant frequency is higher. By using wire-wound instead of multilayer in the balun, it is possible to achieve better suppression of harmonic emission. Multilayer inductors are less expensive that wire-wound inductors. For an example of measurements based on the two different types of inductors, see DN017 - CC11xx 868/915 MHz RF Matching.

ETSI

ETSI EN 300 220 requires spurious emission above 1 GHz to be below –30 dBm. When using multilayer inductors, the highest PA setting that ensures compliance with ETSI is 0xC2. Using 0xC0, which is the CC430 PA setting resulting in maximum output power, results in a level of second harmonic which is at the ETSI limit. It is therefore recommended to use wire-wound inductors in the balun to achieve highest possible output power when seeking compliance with ETSI EN 300 220.

4.1 Capacitors on TMS, TDI, and TDO Pins

For systems targeting compliance with the ETSI EN 300 220 in Europe, the receiver spurious radiations should not exceed –47 dBm for frequencies >1000 MHz. To meet these requirements it is generally recommended to include 2-pF capacitors on the three JTAG pins TMS, TDI, and TDO. To check if the number of external components can be minimized, measurements should be performed with and without the capacitors mounted as the level of spurious emission is to some extent dependent on the PCB layout.

5 References

1. EM430F6137RF900_Rev3_2EB1_schematic
2. EM430F6137RF900_Rev3_2EB1_315_schematic
3. EM430F6137RF900_Rev3_2EB1_315_BOM
4. EM430F6137RF900_Rev3_2EB1_434_schematic
5. EM430F6137RF900_Rev3_2EB1_434_BOM
6. CC430F613x, CC430F612x, CC430F513x MSP430 SoC With RF Core
7. CC11xx 868/915 MHz RF Matching

Revision History

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

Changes from May 28, 2010 to April 1, 2019	Page
• Editorial and format changes throughout document	1

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