Lumped LC Balun Design

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Part I: Introduction

The RF SOCs have either Single Ended or Differential Ended RF Input/Output. For example, TI CC2538 is Differential Ended. NXP JN5169 is Single Ended. For the Differential Ended SOC, the Balun may be required to turn the Differential Ended signal into the Single Ended signal due to the requirements of PA, Antenna, etc. On the other hand, The Balun can also perform impedance matching.

We will focus on the theoretical part of LC Balun design. Thus, to simplify analysis, lumped parameter models, rather than distributed parameter models are used in this paper. Therefore, all theoretical calculations in this paper can not be used in the real-world design directly.

Part II: Understanding the Differential Signal

According to the CC2538 datasheet, the differential impedance on the RF pins is 66 + j64 Ohm. This value is adopted to illustrate the concept of the differential signal.

<u>The Impedance is Defined as</u>

$$Z = R + jX$$

Where the real part of impedance is the resistance R and the imaginary part is the reactance X.

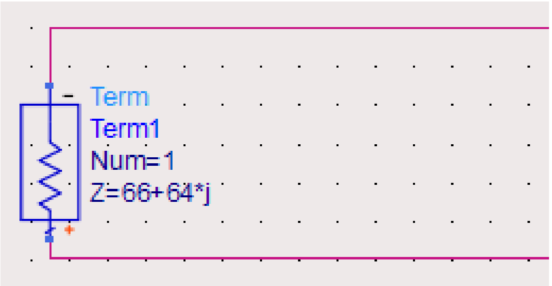
$$X > 0 \ \rightarrow Inductance$$

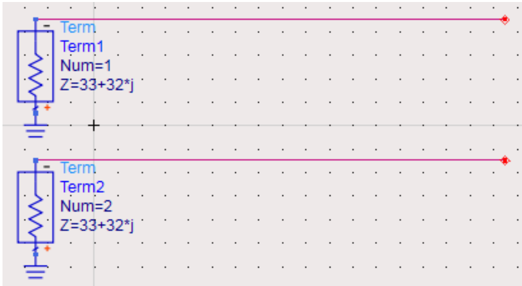
$$X = 0 \ \rightarrow Resistance$$

$$X < 0 \ \rightarrow Capacitance$$

The CC2538 differential impedance is 66 + j64 Ohm which means the imaginary part is positive. Therefore, the reactance is inductance.

Differential Pair Trace

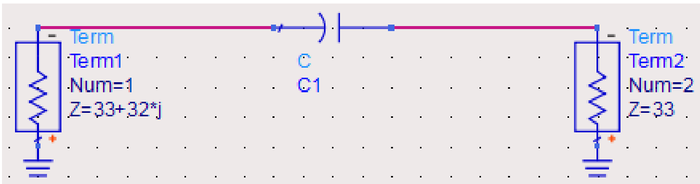




The CC2538 differential impedance is shown in the left-hand side of above diagrams. This impedance can also be described as the right-hand side diagram if the reference plane changes to ground and the coupling is omitted.

Matching the impedance from 66 + j64 Ohm to 66 Ohm

If we focus on one trace of the differential pair and the ground plane is used as reference. The Term1 and Term2 are matched if we can find a C1 which has impedance -j32 @ 2.45Ghz. The CC2538 RF center operation frequency is 2.45Ghz.



We know that

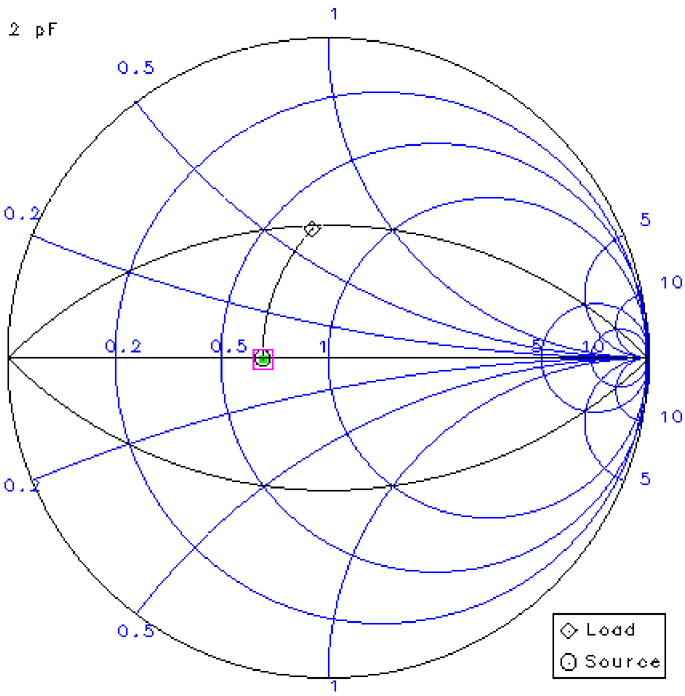
$$L = \frac{X_L}{\omega} = \frac{X_L}{2\pi f}$$

$$C = \frac{1}{\omega X_C} = \frac{1}{2\pi f X_C}$$

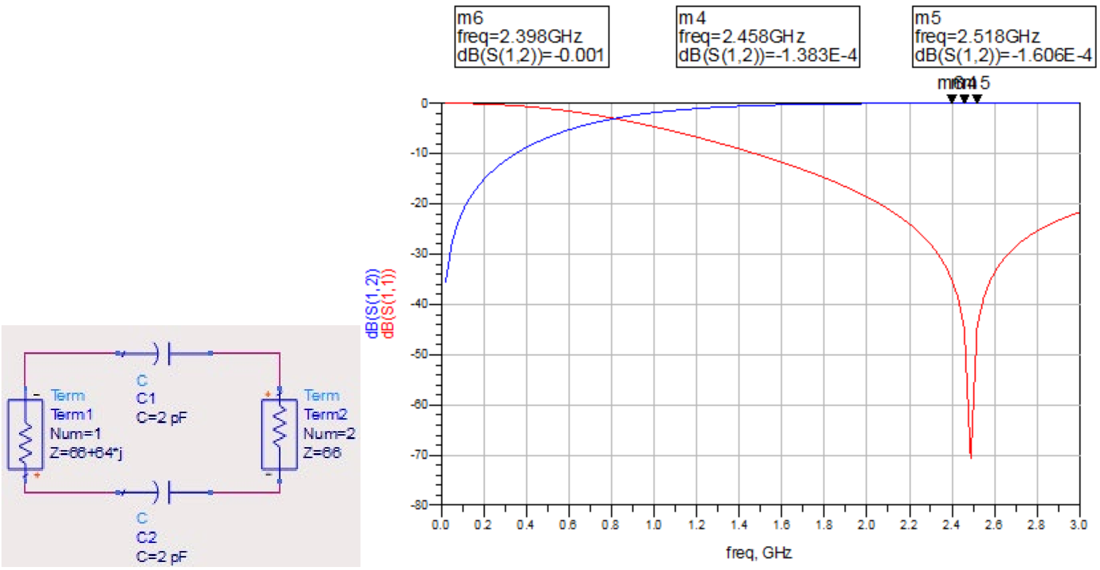
So

$$C1 = \frac{1}{2 * \pi * (2.45 * 10^9) * 32} = 2.030037539 * 10^{-12}\ F \approx 2\ pF$$

The matching result is ploted on the smith chart:



Place the 2pF capacitors on the each trace of the differential pair:



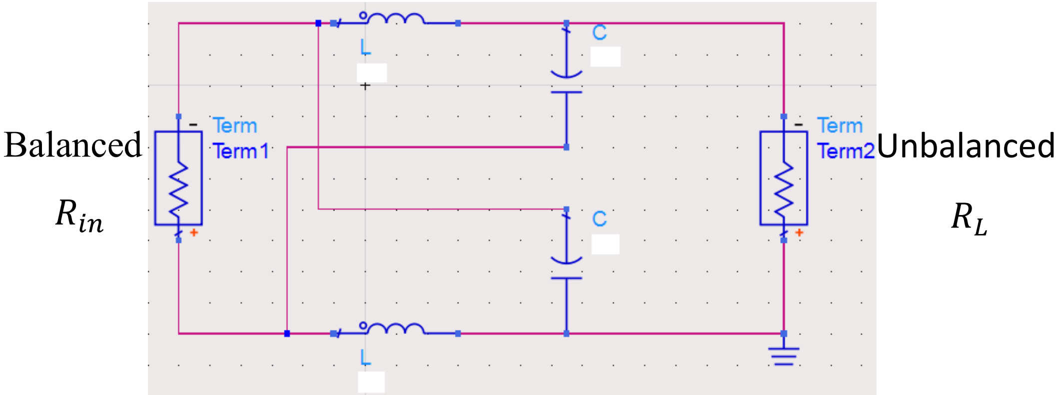
Finally, according to the S (1,1) and S (1,2), the Term1 66 + j64 Ohm is well matched to the Term2 66 Ohm. C1 and C2 also works as the DC blocking capacitors which prevent the flow of DC signals into the following RF circuits.

Part III: LC Balun

The CC2538 differential impedance 66 + j64 Ohm had been matched to 66 Ohm in the Part II. In the Part III, we are going to match the impedance from the differential ended 66 Ohm to the single ended 50 Ohm using a lumped LC Balun.

The Theory behind the Lumped LC Balun

A lumped LC Balun is realized using lumped components, two inductors and two capacitors which are shown in the following diagram.



The characteristic impedance (Z_0) of the lumped LC Balun is given by

$$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{R_{in}R_L}$$

Design Steps:

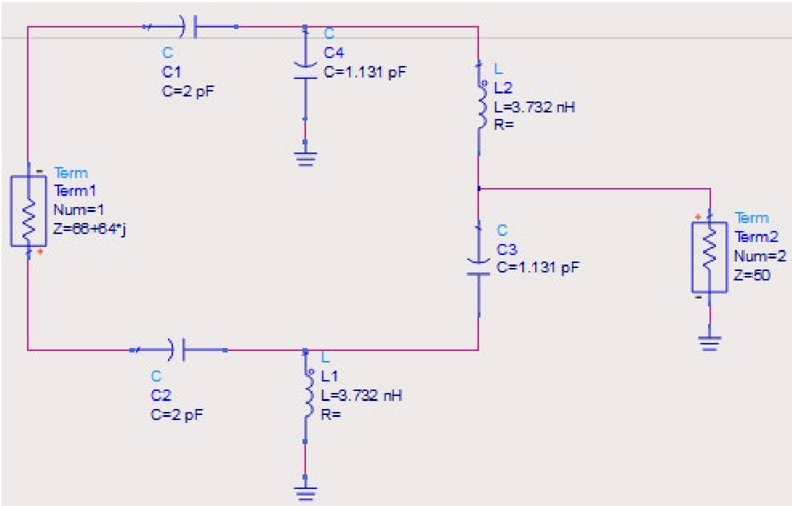
1. Know your operation frequency f_0
2. Find the impedance of reactive elements using the equation $X = \sqrt{R_{in}R_L}$
3. Compute the values of inductor and capacitor. $L = \frac{X}{2\pi f_0}$ and $C = \frac{1}{X2\pi f_0}$

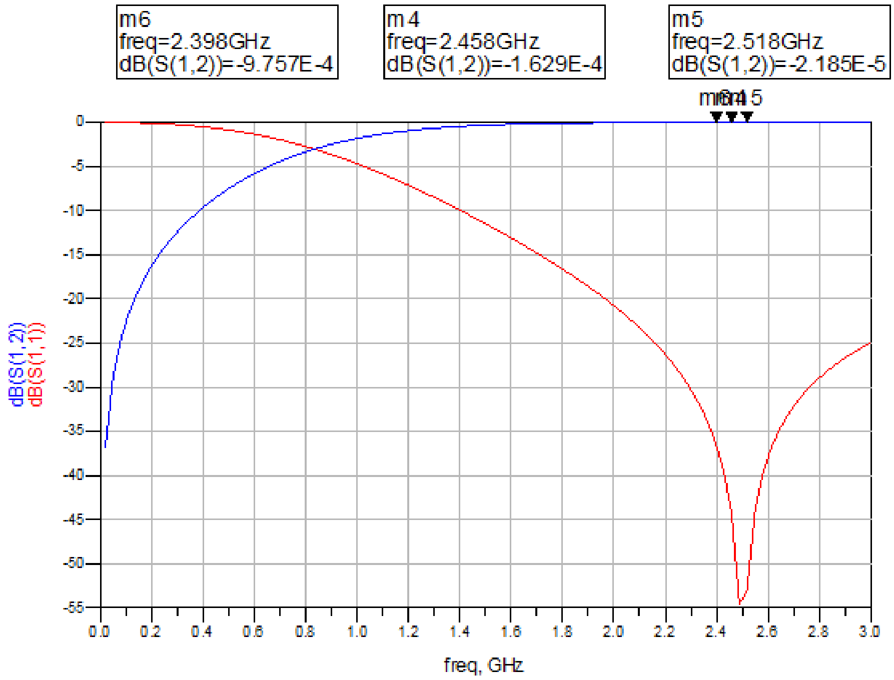
Matching from the Differential Ended 66 Ohm to the Single Ended 50 Ohm

1. The CC2538 RF center operating frequency is 2.45Ghz.
2. $X = \sqrt{R_{in}R_L} = \sqrt{66 * 50} = 57.44562647\ Ohm$
3. $L = \frac{X}{2\pi f_0} = \frac{57.44562647}{2*\pi*(2.45*10^9)} = 3.731736902 * 10^{-9}\ H \approx 3.732\ nH$

$$C = \frac{1}{X 2\pi f_0} = \frac{1}{57.44562647 * 2 * \pi * (2.45 * 10^9)} = 1.130829365 * 10^{-12}\ F \approx 1.131\ pF$$

Finally, the design is shown in the following diagram:

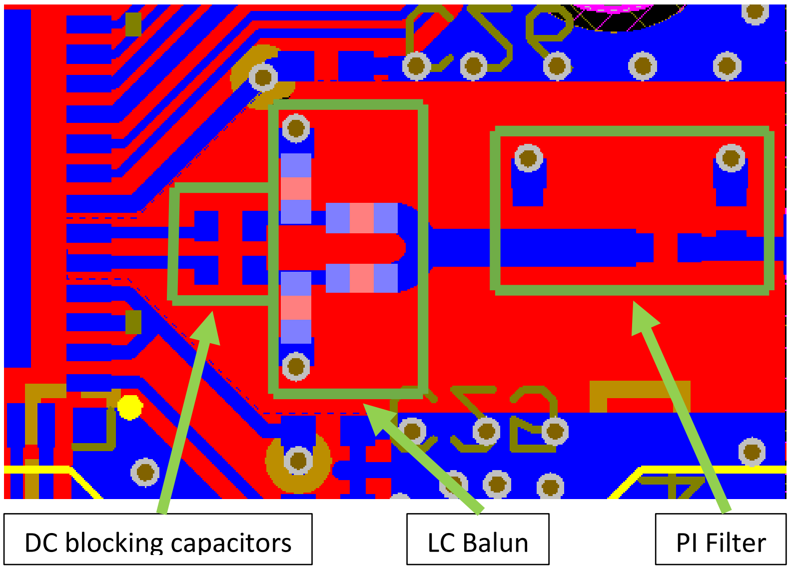




According to the S (1,1) and S (1,2), the Differential Ended 66 Ohm is well matched to the Single Ended 50 Ohm. The two inductors and two capacitors of the lumped LC Balun are L1, L2 and C3, C4

Part IV: A Glance of the Real-World Design

We disscussed the theory behind the lumped LC Balun in the previous Parts. Let us take a look at the real-world CC2538 RF design. I designed this RF circuit for our IEEE 802.15.4 based RF Remote Control Remoter.



The DC blocking capacitors and LC Balun can be easily identified. The PI Filter is employed for harmonic reduction. However, you may already notice the layout is a little bit strange. We have this kind of strange layout, because we must use the distributed parameter models for the real-world microwave design. The layout, PCB stackup, stripline and microstrip impedance control, dielectric constant control become crucial [3].

Part V: Conclusion

The lumped LC Balun has been designed step by step in this paper. During the design process, the theory behind the lumped LC Balun has been illustrated.

Part VI: References

[1] CC2538 Powerful Wireless Microcontroller System-On-Chip for 2.4-GHz IEEE 802.15.4 ,6 LoWPAN ,and ZigBee Applications. Retrieved Nov 29, 2019, from http://www.ti.com/lit/ds/symlink/cc2538.pdf

[2] Differential Pair Transmission Lines. Retrieved Nov 29, 2019, from http://www.westmichigan-emc.org/archive/2014%20IEEE%20Bill%20Spence%20Diff%20Pairs.pdf

[3] Neil (Bing) Hao. The Considerations of Antenna Design for IOT and Wearable Devices. Retrieved Nov 29, 2019, from

http://uniteng.com/index.php/2019/11/20/the-considerations-of-antenna-design-for-iot-and-wearable-devices/