CMOSTEK AN212

CMT2300A Tx Matching Guide

Introduction

CMT2300 integrates a highly efficient 20dBm Class-E PA structure. This application document describes how to match the Class-E PA structure.

Usually, a high quality match requires the following points：

（1） Achieve the output power as design
（2） Consume the minimum current, i.e. the maximum efficiency.
（3） Satisfy the local safety requirements of users, such as ETSI, FCC, ARIB, etc
（4） The output power is insensitive to the change of antenna impedance
（5） Use the least components to optimize the cost

The part number covered in this document is shown in the following list.

Table 1. Part Number Covered in this Document

Part number	Working frequency	Modulation	Main Function	Configuration	Package
CMT2300A	140 - 1020 MHz	(G)FSK/OOK	Transceiver	Register	QFN16

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1. Class-E PA Switch Description

For conventional power amplifiers, matching is relatively simple and accomplished by making the load impedance and PA output impedance matching together whether it belongs to class A, class B or class C.

The Class-E power amplifier is completely different from the traditional type. It is a switching power amplifier with design of changing the voltage and current waveform of the drain of the switch, so that there is no V-I overlap when the switch is closed and finally achieve high efficiency power amplifier.

The basic structure of Class-E PA is shown in firgure 1. L0-C0 resonates in series at the working carrier frequency, and Cshunt stores energy during switch off, all of which forms an attenuated load network with inductors Lx and load resistors Rload. In the switching transient process, the energy stored in Cshunt while C0, L0 supplies energy for the load resistance Rload, which is the damping resistance in load network. Its value has a great influence on the drain voltage waveform of the switch.

The high efficiency of Class-E PA is achieved by no overlapping of the leakage waveform V-I of the switch, so it is important to select the appropriate load resistance Rload. When the load resistance Rload is too high, the current of the resonant loop and the voltage to charge the capacitor $_{\text{Cshunt}}$ is low. When it is superimposed with the charging voltage of the power supply VDD to the capacitor $_{\text{Cshunt}}$, the voltage on the capacitor $_{\text{Cshunt}}$ is not zero at the moment when the switch is from cutoff to on-off, and must be discharged through the switch during the on-off period. This situation not only wastes energy, but also causes spike current. When the load resistance Rload is too low, not only the current in the resonant loop but also the voltage to charge the capacitor $_{\text{Cshunt}}$ is high. When it is superimposed with the voltage of the power supply VDD to charge the capacitor $_{\text{Cshunt}}$, the voltage on the capacitor $_{\text{Cshunt}}$ will swing to a negative value below zero at the moment when the switch is from cutoff to on-off. This reverse voltage will generate reverse current, which will increase the power consumption of the switching tube due to the existance of both voltage and current.

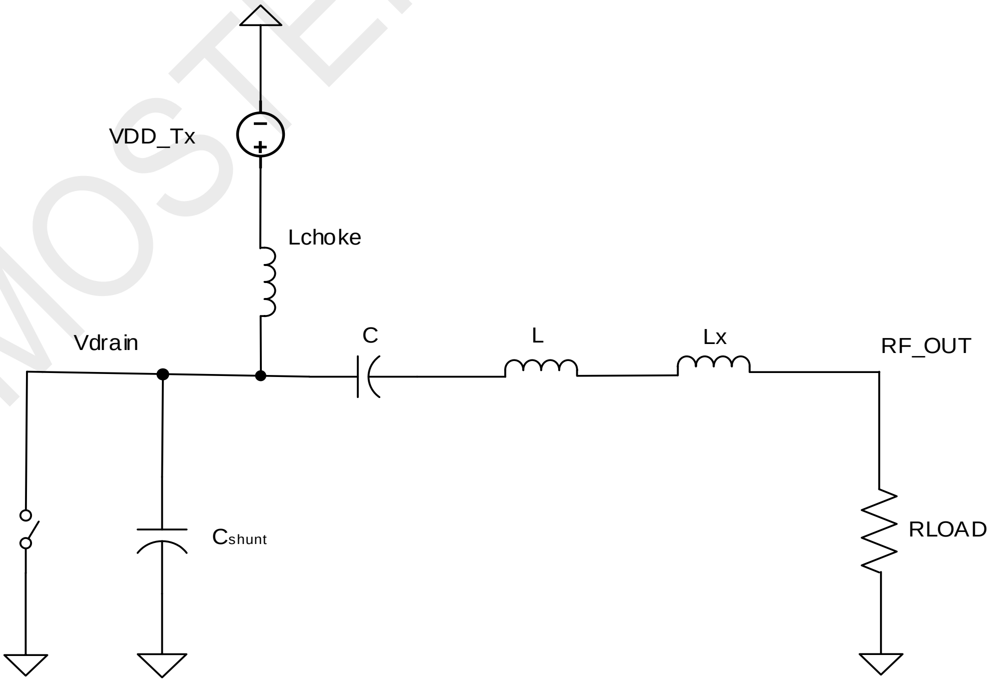

Figure 1. Basic Structure PA Circuit Topology

2. Class-E PA Matching Process

The last section briefly introduces the core idea and working principle of class-E PA. The detailed process is omitted here(readers can search the detailed working principles of Class E on the Internet)， while steps of how to match PA are summarized as follows:

（1） Select a suitable Choke inductor

（2） Calculate the optimal load impedance Z-Load according to the output power

（3） Select the appropriate series resonant capacitor C0 (as shown in figure1).

（4） Calculate L0 according to the selected C0

（5） Calculate the L-shaped matching component values Lx and Cx according to the optimal load resistance Z-Load;

（6） Design a T-type low-pass filter

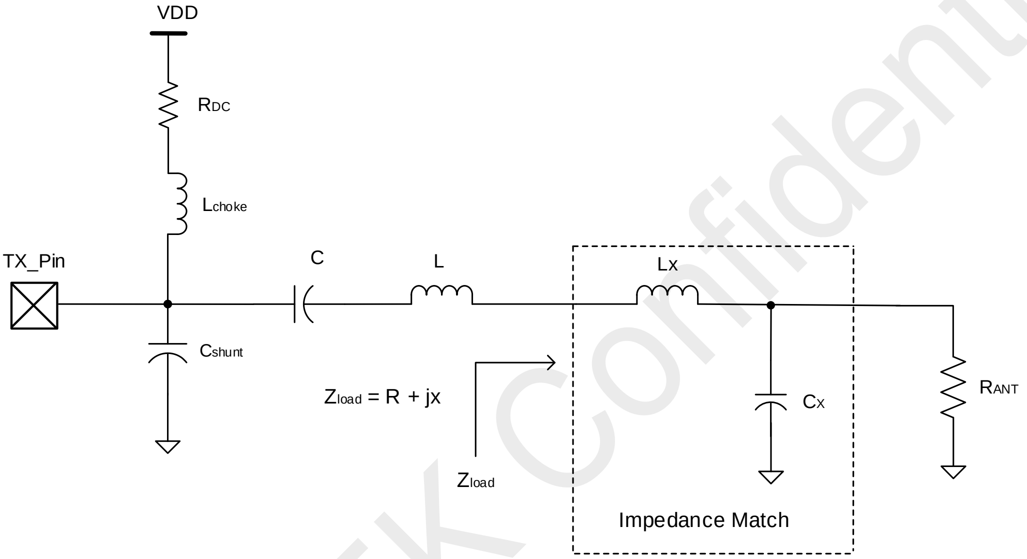

Figure 2. Impedance Match to Transform Rant to Zload

Now let's go through all the steps in detail.

2.1 Select a suitable Choke inductor

This inductor is also called energy inductor, the higher the frequency, the better the resistance. However, both of the value of inductor Q and self-resonant frequency are low in application, so the inductor can not be the highest. According to experience, this inductor value can be selected at different frequencies as follows:

Frequency	Inductance value
315 MHz	270 or 330 nH
433.92 MHz	180 or 220 nH
868 MHz	100 nH
915 MHz	100 nH

2.2 Calculate the optimal load impedance Z-Load according to the output power

Below shows the formulas derived from Class-E theory:

$$P_{AC\_out} = \frac{2V_{DD}^{2}}{(1+\frac{\pi^{2}}{4})\cdot R} = \pi\cdot\omega c\cdot V_{DD}^{2} \qquad \omega c = \frac{2}{\pi\cdot(1+\frac{\pi^{2}}{4})\cdot R} = \frac{1}{5.4466\cdot R} \qquad X = R\cdot\tan(\psi) = 1.1525\cdot R$$

According to the formula, the output power of PA is related to three parameters: 1) supply voltage; 2) PA output capacitance Cshunt; 3) Operating frequency. As shown in figure 2, the optimal load impedance Z-Load = R+jX, where R is the optimal load resistance mentioned above. It is closely related to the output power and output capacitance of PA. In the design of the CMT2300, the output capacitance of the PA is approximately 3pF. Below we list the optimal load impedance Z-Load at 20dBm output at different frequencies.

Frequency	Optimum load impedance（Z-Load）
315 MHz	30.9+ j35.6 Ω
433.92 MHz	22.4 + j25.9 Ω
868 MHz	11.2 + j12.9 Ω
915 MHz	10.6 + j12.2 Ω

2.3 Select the appropriate series resonant capacitor C0 and calculate L0

Combined with step 3 and step 4, it is required that C0 and L0 work on the series resonance. Therefore, there will be countless combinations of values. How to choose? Large component values are with low self-resonant frequency while low component values are more sensitive to parasitic parameters. Thus, do not choose particularly high or low component values. If you want low harmonics, choose high inductance, low capacitance; If you want low current and high efficiency, choose low inductance and high capacitance.

2.4 Calculate the L-shaped matching component values Lx and Cx according to the optimal load resistance Z-Load

If the load impedance of the antenna is already known, and the impedance is higher than Z-Load, it can be matched by an L-shape matching; However, L-shaped matching is limited by conversion impedance ratio and the value of components cannot be flexibly selected. Also, harmonic suppression is not enough. Therefore, it is not recommended to match the optimal load resistance directly to the antenna. An intermediate transition impedance Rmid can be introduced (which can be any value larger than the optimal load impedance) to attach a T-shape filter to match the Rmid to the antenna load.

Below takes the 50Ω antenna as an example, as shown in figure 3.

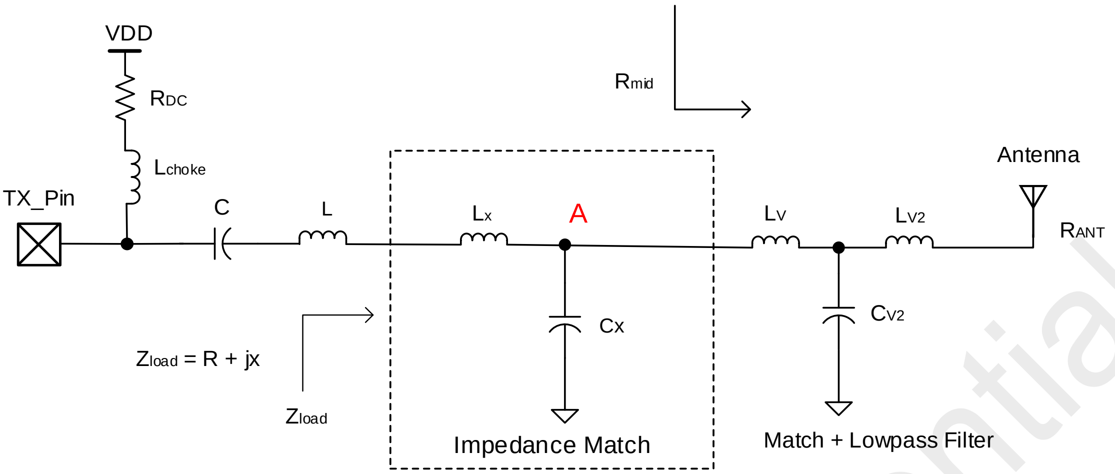

Figure 3. Resistance Impedance Matching Conversion between Rant and Rmid

As shown in Figure 3, point A (marked in red) in the figure is defined as the impedance Rmid of an intermediate transition. Obviously, the impedance of point A needs to be higher than the optimal load resistance Z-Load. Considering that the post level T filter can use appropriate values of the components, it needs to convert the impedance of point A to the following values according to the calculation. The example is as follows:

Frequency	Optimum Load Impedance	Rmid Resistance Value
315 MHz	30.9+ j35.6 Ω	70
433.92 MHz	22.4 + j25.9 Ω	50
868 MHz	11.2 + j12.9 Ω	50
915 MHz	10.6 + j12.2 Ω	50

Matching the best load impedance in the above table to Rmid resistance can obtain the value of Lx and Cx, as shown in figure 2. It is obviously that L0 and Lx can be combined into one inductance. If we convert the best load resistance Z-Load to the impedance at point A as cited above, the corresponding values can be obtained as follows:

Frequency	C0	L0 + Lx	Cx
315 MHz	12 pF	47 nH	12 pF
433.92 MHz	15 pF	27 nH	9.1 pF
868 MHz	9.1 pF	10 nH	6.8 pF
915 MHz	8.2 pF	10nH	6.2 pF

Impedance at point A can also be converted to other impedance values with the corresponding component values changed. Either Rmid and C0, L0 can be selected on the basic that the calculated component value is closest to a suitable nominal value. Note that the parasitic capacitance of PA end to GND has to be updated according to the application of different circuit boards. This parasitic capacitance can be summed up in Cshunt and it is about 3pF in our application sample board. While in other circuit boards, this value may be changed and the PA optimal load will change accordingl with the same calculation and matching way.

2.5 Design a T - shape low - pass filter

T-shape low-pass filter not only plays the role of suppressing higher harmonics, but also match the impedance conversion of point A to the antenna impedance. Be careful not to set the Q value of T-shape low-pass filter too high. The higher the Q value, the better the harmonic suppression. While it will be sensitive to the change of antenna impedance and leads to efficiency decline.

3. Revise History

Table 3-1. Revise History

Version	Chapter	Description	Date
0.1	All	Initial	2023/01/03

4. Contacts

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