Analysis on PoC inductors in automotive camera applications

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Supporters

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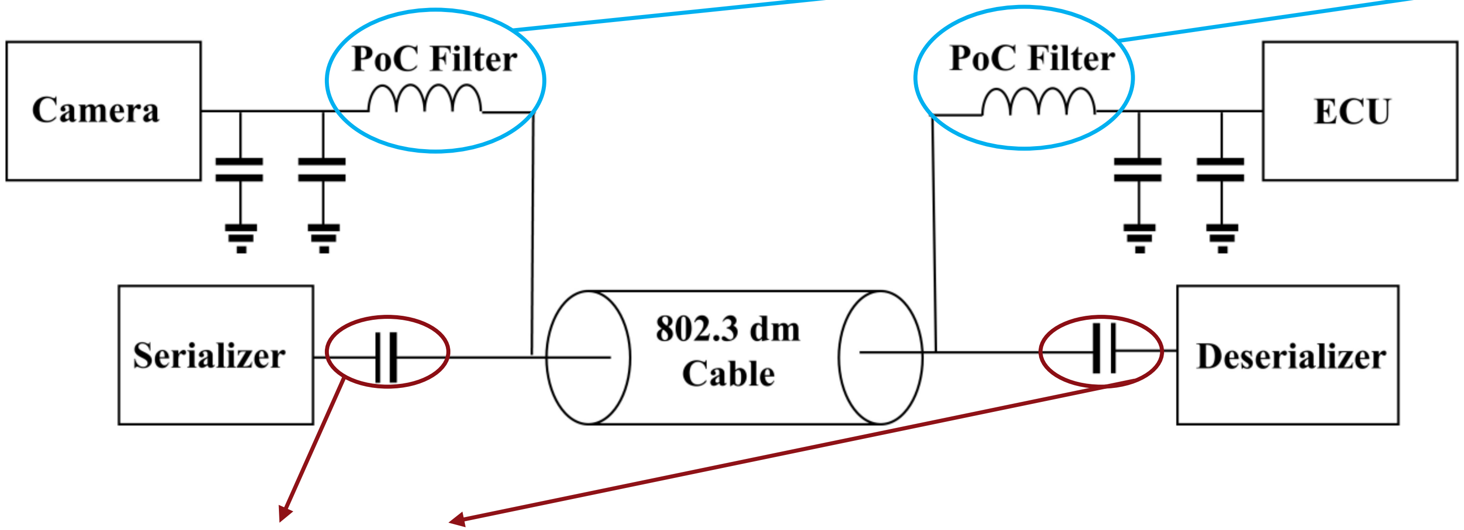
Motivation

- Power over Coax (PoC) is a must-support feature in 802.3 dm, and the use of PoC inductors has a direct impact on many critical factors in automotive camera application, such as the cost, footprint and IL/RL.
- Previous contributions in 802.3 dm gave some relevant opinions/conclusions, but with no technical proof.
- In this contribution, I share the fundamental factors that truly affect the complexity of PoC inductor. I hope this presentation can trigger more relevant research.

Background

- PoC enables transmission of the signal and power supply over a single coaxial cable, thereby reducing the weight of wire harnesses in the car.
- With only one coaxial cable, we need to make sure the DC power will not mix with the AC signaling. PoC filter is the key component here.



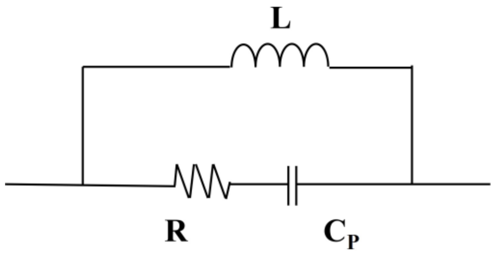
PoC filter (inductor) blocks the AC signals on the channel from entering the power line while allowing DC current to pass

If we fail to do this, AC signal components may leak into the power line, and signal transmitted may be **attenuated**.

AC coupling capacitors allow the high-frequency AC signals to pass, while blocking DC power from entering the device

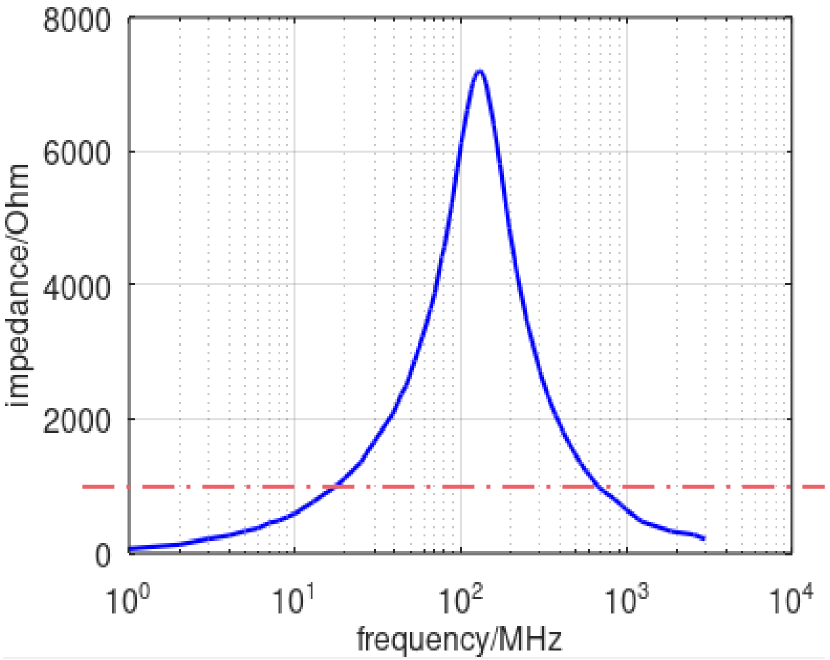
PoC inductor - Basics

- Ideally, Inductor has higher impedance in higher frequencies where $X = 2\pi f L$. This means if we want a high impedance in low frequency, we need an inductor with relatively larger inductance.
- However, real inductors have parasitic resistance and capacitance that will greatly impact the inductor impedance. The realistic model of real inductor looks like



- With the existence of parasitic capacitance, the impedance of inductor will not increase with the increase of frequency forever, but achieves its highest impedance at self-resonant frequency (SRF). Above the SRF, the inductor begins to act like a capacitor

$$f_{SRF} = \frac{1}{2\pi\sqrt{LC_P}}$$



We need at least 1Kohm to achieve good blocking performance

In this specific case, SRF is around 130Mhz, and the inductor takes effect for a frequency range of roughly 20MHz~650MHz

PoC inductor - Requirements

- **Fundamental Requirement**: To ensure good communication quality, we require inductors with high impedance for AC components over the **entire operating bandwidth range** from low to high frequencies
- Additional Requirement: With the satisfaction of fundamental requirement, we pursue compact product dimensions, smaller footprint, lower number of inductors, and lower cost.

With the fact that a single inductor cannot provide big enough impedance over infinite bandwidth, it is challenging to design a PoC filter satisfying all the requirements. The following factors matter：

- The ability of PoC inductor products available in the market.
  - This basically decides everything. The better the product, the easier the life.
- The operating frequency range of the application
  - We not only care about the width of frequency range, but also the upper limit and lower limit of the frequency band.
- The type of inductor – wound ferrite core? Multi-layer type? Or other type?
  - Different type of inductors owns different cost/size/feature.

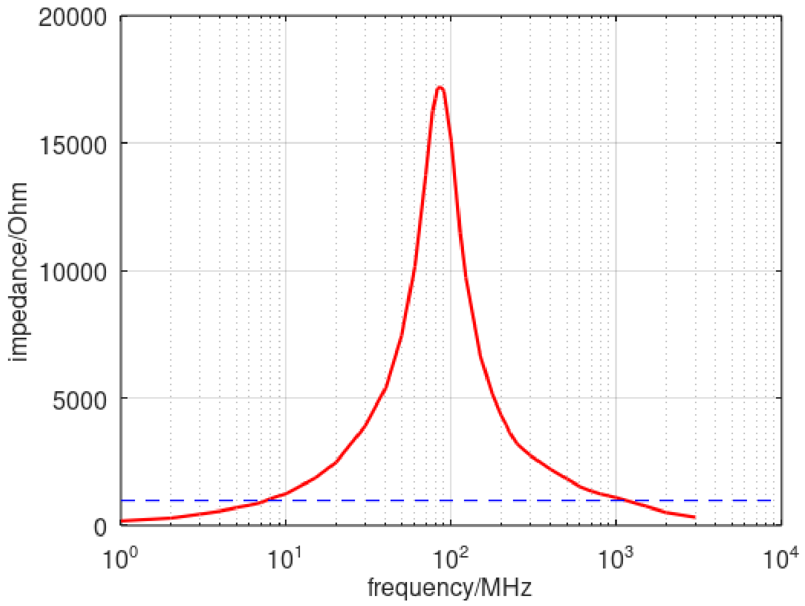
What's in the market? (1)

There are several leading manufacturers of inductor for automotive PoC market worldwide, who design and produce custom PoC inductors. The main characteristics of these custom PoC inductors are:

- They are able to cover a wide frequency range with a single device, thereby reducing the number of inductor components required
- Have relatively smaller size and weight

There are two typical types of state-of-the-art products:

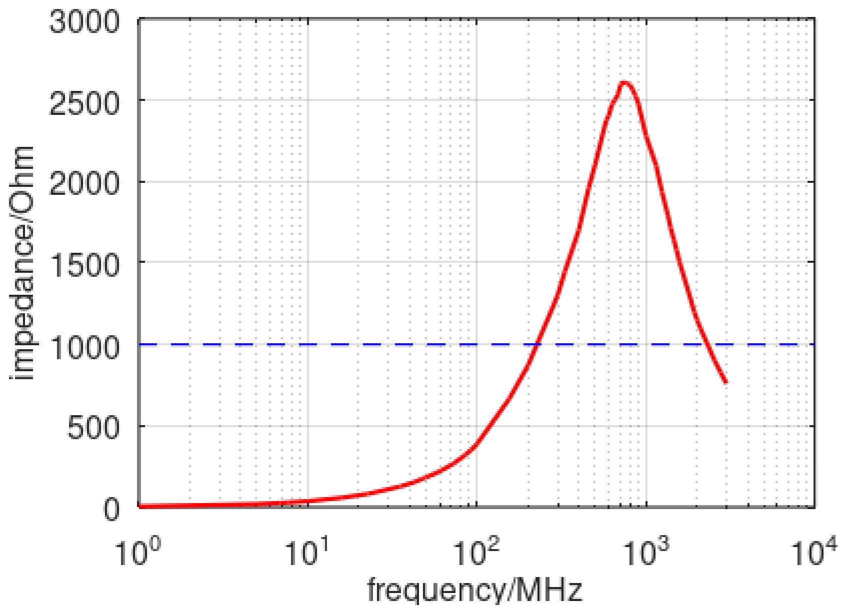
- Type A - Custom PoC inductor which has a frequency range coverage of: **several MHz~1.x GHz**.
  - ✓ This kind of inductor is suitable for proprietary use cases using FDD who has a backward channel operating at low frequency band. However, this type of inductor is not able to provide high impedance for use cases requiring a speed higher than 3Gbps.
  - ✓ The typical size is **8±0.5mm^2 and 2±0.5 mm height**. The typical inductance is **2~50uH**. The typical SRF is **50~500MHz**. Typical inductor type is **Wire wound ferrite inductor**



One example of Type A inductor.

What's in the market? (2)

- Type B - Custom PoC inductor which has a frequency range coverage of: **hundreds of MHz~3.x GHz**.
  - ✓ This kind of inductor is suitable for use cases which does not require an extremely low frequency band. In the meanwhile, it is able to cover a higher frequency range up to 3.x GHz, and correspondingly support a much higher data rate compared to Type A.
  - ✓ The typical size is **1.2±0.5mm^2 and 0.9±0.2mm height**. The typical inductance is **30~700nH**. The typical SRF is **0.5~2GHz**. Typical inductor type is **multi-layer type inductor**

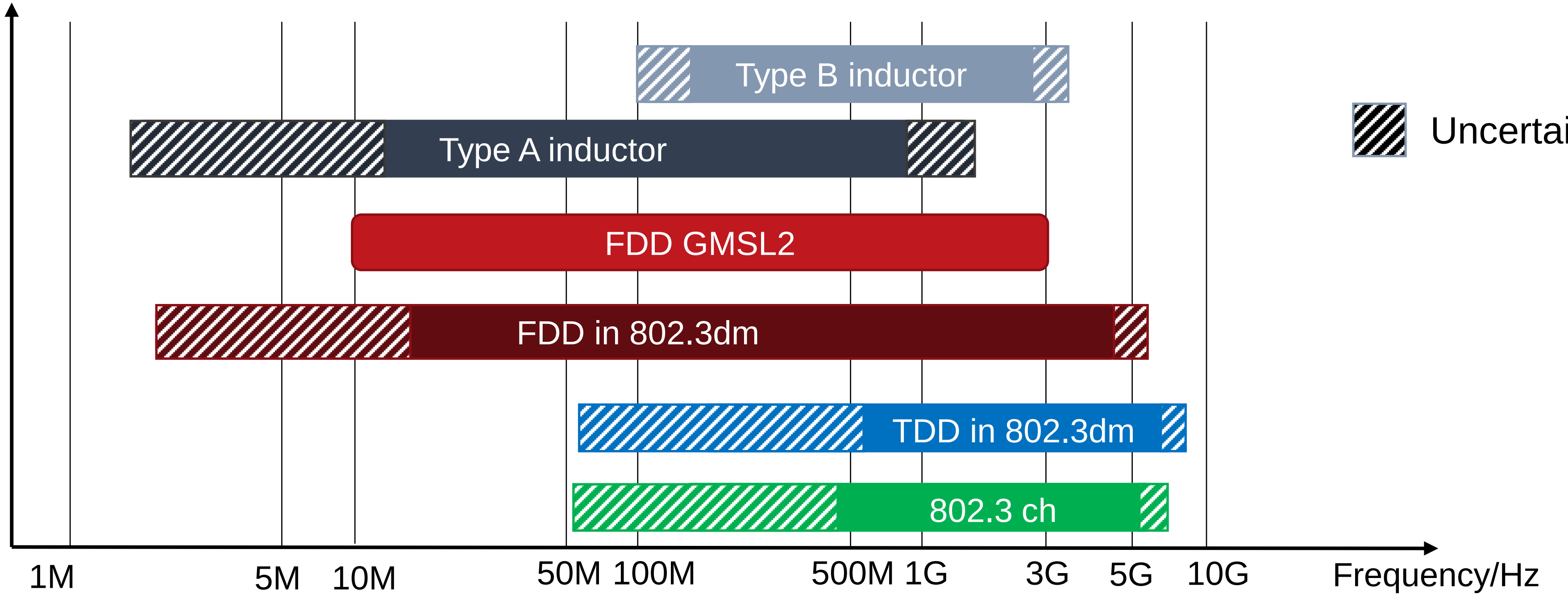


One example of Type B inductor.

- Type A and Type B are two most typical custom PoC inductors for automotive application. There are other types of custom PoC inductors as well, offering performance that lies between the two.
- Note that, there does not exist a single PoC inductor who can offer high impedance for a wide frequency range up to more than 3.x GHz in the market! This is challenging for 802.3dm, where a line rate >10Gbps is definitely the case.

PoC inductors in different duplexing schemes (1)

- There are very mature techniques and products providing extremely high impedance for low frequency range (hundreds of KHz to tens of MHz). It is however challenging to design PoC inductor which offers high impedance in high frequency band, as this intrinsically requires a high inductance for high impedance as well as a low inductance for high SRF, which is somewhat contradicted.
- As mentioned earlier, the operating frequency range matters! The following is a comparison of the required frequency range between different duplexing schemes



PoC inductor in different duplexing schemes (2)

By comparing the operating frequency band of FDD, TDD, 802.3ch, and the custom PoC inductors available in the market, we have the following observations:

- For a medium data rate requirement, e.g., GMSL2 with 6Gbps, FDD scheme may need more than one PoC inductor to achieve high impedance over its operating frequency range.
  - ✓ FDD has a low-speed backward channel occupying low frequency range, and this is the main difference compared to the other two schemes.
  - ✓ This might be realized by using both Type A and Type B inductor, or possibly be realized by using a Type B inductor plus one inductor dedicated for low frequency range. There can be different real implementations, some of the solutions might involve more than two inductors.
  - ✓ For realizing the same speed, TDD and 802.3ch may achieve the aim with a single PoC inductor.
  - ✓ Such disadvantage of FDD might be mitigated soon, with the appearance of new PoC inductor.

PoC inductor in different duplexing schemes (3)

- When it comes to the speed requirement of 10Gbps, no matter which duplexing scheme to use, one single inductor cannot achieve the goal.

  - ✓ We need to cascade probably two or three PoC inductors in series for all the duplexing schemes, and this is a challenge to be noted by the group.
  - ✓ It is hardly to draw a conclusion that FDD face a disadvantage in this scenario. FDD still has disadvantage in low frequency range, but also it has the lowest upper limit of frequency band. By carefully choosing the combination of inductors, it is likely the same number of PoC inductors can be used by FDD.
  - ✓ It could be even more challenging for TDD scheme which requires the largest line rate due to inefficiencies in bandwidth utilization. This is because the higher the line rate, the higher the upper limit of frequency range, and the more attenuation in impedance after SRF. Note that the impedance after SRF decreases quickly.
  - ✓ For instance, the available Type B inductor may have an impedance of 500ohm at 5GHz, but only 300ohm at 5.5GHz. This means if the operating frequency range is up to 5GHz, we can simply combine two Type B inductors to achieve the aim. However, we need more than three inductors if the same type of inductors are used when the upper limit of frequency band further increases.

Other relevant factors

Note that there are some other important factors not considered in this presentation due to lack of knowledge or equipment, but are absolutely important.

- Insertion Loss & Return loss
  - PoC filters can introduce additional IL and RL to the channel. After a set of PoC solution is made, it is expected to have measurements on these.
- Cost
  - The cost is of course related to the number of PoC inductors used, but it may also has a close relationship to other factors, e.g., material used, size, difficulty to make.

In addition, it is worth thinking about the following question.

- High impedance correlates to lower signal loss. But do we really require at least 1kohm impedance for all the frequencies? Is it possible to relax the condition or we actually need a more strict requirement?

Conclusions

- Real-world PoC inductors cannot provide high impedance over infinite bandwidth
- To achieve good AC blocking performance, we require impedance over 1Kohm for the whole operating frequency band
- There are custom PoC inductors designed specifically for automotive applications, which are able to cover wide frequency range with a single device, while maintaining a relatively small size.
- Even talking about custom PoC inductors, there does not exist a single inductor who can offer high impedance for frequency more than 3.x GHz in the market yet.
- FDD scheme requires a low-frequency backward channel, which is the main difference compared to TDD and 802.3ch.
- For 10Gbps, the situation is more complicated. We need more than one inductors for all the duplexing schemes, and it is hard to compare which scheme is better.
- Hope the experts in the group can bring more relevant information, as PoC inductor directly impacts the footprint, cost, and IL/RL.

Thank You