Power-over-Coax Filter Design Challenges for Automotive Vision Applications

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Introduction

Automotive industry has been facing exciting and important challenges in recent years. It is not only the move from classic combustion engine cars to hybrid or fully electrical vehicles. Much more is going on in the field of Advanced Driver Assistance Systems (ADAS) helping to make roads and surrounding areas a safer place for everyone.

The irreplaceable part of every ADAS system is a sensor, or more often, a group of sensors providing data to the Electronic Control Unit (ECU) which processes the data in a real time. The role of the sensors in the system is critical as the data provided has a huge impact on the system performance. While there are many various types of sensors used in the automotive industry (Figure 1), such as Radar, Ultrasonic and Lidar, this paper focuses on Camera – the key sensor used in Vision Active Safety Systems.

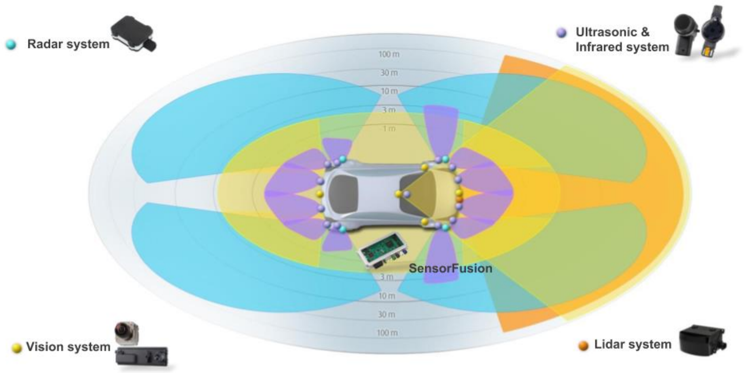

Figure 1 Active Safety Sensors

Challenges of Power-over-Coax (PoC) Design for Automotive Vision Applications

Given by the nature of the target scenario and the type of the vision system (Rear View Camera, Surround View System, Driver Monitoring System), the automotive cameras are often installed in remote locations such as trunk lids, bumpers or rear view mirrors (Figure 2). This can make the connection between the sensors and controlling unit at least several meters long in case of passenger cars and easily more than 10m in case of large pick-ups or trucks. There are normally three different types of signals which are needed to be transferred between the camera and ECU – serialized video data, both-direction communications and DC power. Depending on the system type and required functionality, two or three pairs of wiring are needed for the sensor connection. This brings weight and cost to the system design and it is therefore advisable to limit the number of wires used for such a connection.

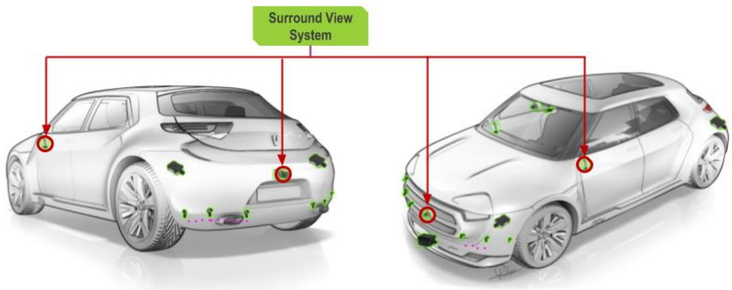

Figure 2 Surround View System Sensors

The Power-over-Coax (PoC) technology [1] where data, communications and DC power share a single coaxial harness seems to be an ideal solution to the abovementioned problems. It brings benefits in terms of reduced weight and cost of the wiring, but on the other side there are also some new challenges which the hardware designer needs to face. For example, as the physical medium (coaxial cable) is shared by three signals with completely different characteristics – over 500Mbps for forward video data channel, about 3 MHz for reverse/back communication channel and finally, the DC power, a high-performance filter formed by passive components has to be used on both sides of the communication link. Figure 3 shows an example of the filter characteristics which will be used to demonstrate the challenges related to the design. The shown impedance of the filter (blue curve) allows DC power to pass through the filter with little loss while stopping the Back and Forward Channel frequencies defined in red areas.

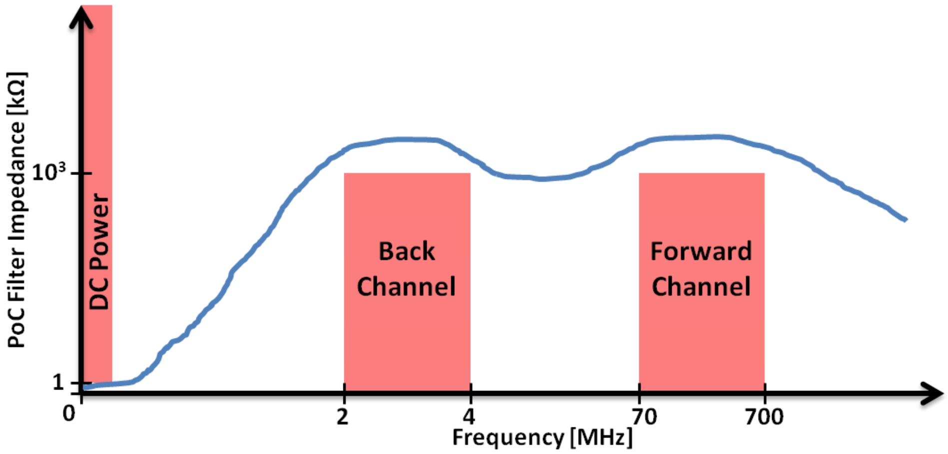

Figure 3 Filter Impedance for PoC technology

Normally, a camera is powered from the ECU side and therefore both the ECU and the Camera is equipped with the PoC filter. The filter on the ECU side is used to merge DC power with the video and communication data, while the task of the filter on the camera side is to separate the DC power from the video and communication data, to provide stable DC power to the camera circuitry. A typical PoC topology is shown in Figure 4.

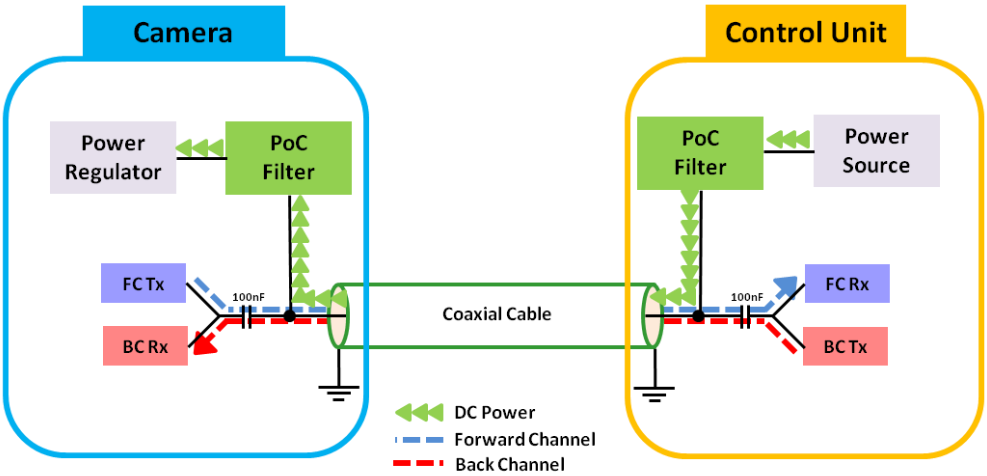

Figure 4 Typical PoC topology

The design of the filter is not a trivial task as there are many aspects to be taken into account. For example, electrical properties of the real-world passive components forming the filter, influence of the filter on power and signal integrity of the high-speed serial link, voltage drops caused by the DC resistance of the components, and also other automotive-specific aspects of the design, such as ISO test pulse mitigation and EMC compliance.

Power-over-Coax Filter Design

As mentioned above, an ideal frequency response of the filter would be 0Ω impedance at DC and high impedance in bands with communication. In real designs impedance lower than 1Ω at DC and higher than 1kΩ at communication bands is normally acceptable (see Figure 3).

If there was an ideal inductor, just a single component would be enough to fulfill the above mentioned criteria. The value of the inductor can be determined based on the following relation:

$$L = \frac{|X_L|}{\omega}, \tag{1}$$

Where L is the inductance, X_L impedance and ω angular frequency.

If the 1kΩ criterion mentioned above and the minimum backchannel frequency as defined in Figure 3 (2 MHz) is used, the minimum inductance to comply with the parameter is 79.6 uH. An 82uH inductor is therefore a good choice. Figure 5 shows the impedance characteristic for an ideal 82uH inductor (red curve) as well as an example of a real inductor with parasitic parameters considered. In both cases, a parallel 2.5kΩ damping resistor is connected.

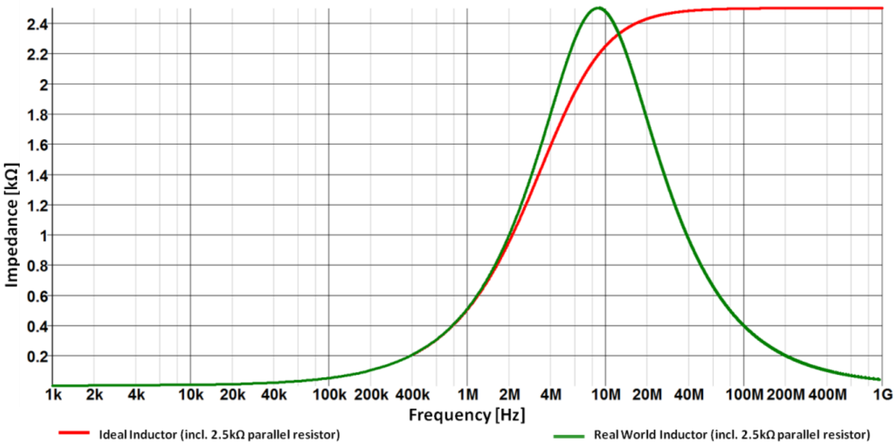

Figure 5 Frequency characteristics of ideal and real inductor

As can be seen in the figure, the inductor Self Resonance Frequency (SRF) is 9MHz. Beyond this point, the impedance drops due to the parasitics (Figure 5 – green curve) and reaches 1kΩ at 40 MHz. Despite having a good impedance characteristic for the Back Channel band, a single inductor solution is not able to provide sufficient impedance in the whole required frequency range as defined in Figure 3 and another series inductor needs to be connected to cover the required forward channel band.

When using the equation (1), the required inductance of the additional inductor can be calculated to cover the Forward channel frequency range starting at 70MHz. Based on the real properties of the inductor and the required band, the second inductor can be sufficient, however in this particular case, another inductor to cover the highest frequencies is needed. Figure 6 shows a three inductor solution considering real parameters of the inductors based on the information provided by the passive components manufacturer.

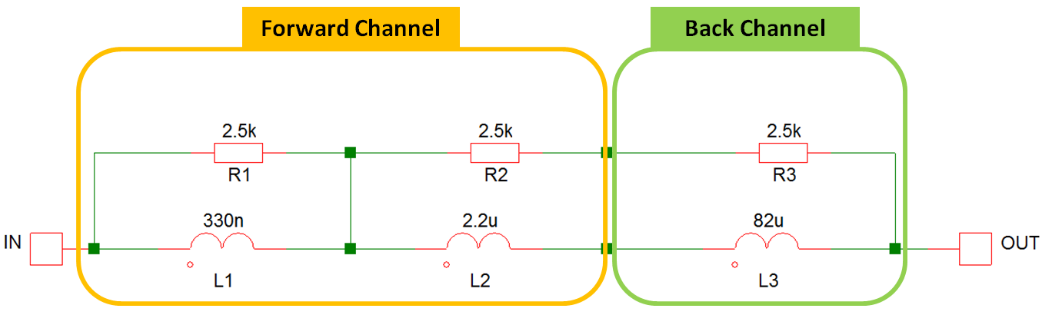

Figure 6 PoC Filter

The frequency response of the above mentioned solution can be estimated by using models provided by the manufacturers. Figure 7 shows the impedance characteristic vs. frequency together with the requirements defined in Figure 3. As can be seen, the filter impedance is very low at low frequencies allowing DC current to pass through the filter and provide power to the camera (Figure 4). The filter impedance reaches 1kΩ at 2MHz and has the first maximum at 9MHz which is the SRF of the 82uH inductor. The impedance then drops below 1kΩ at 30MHz however reaches the required value at 70MHz again. The SFR of the 2.2uH inductor is 137MHz and after that the impedance lowers again however does not drop under 1kΩ in the next minimum. Finally, the third inductor (330nH) with SRF of 400 MHz ensures that the impedance does not drop under the limit before 700 MHz is reached. The filter is therefore compliant with the input requirements.

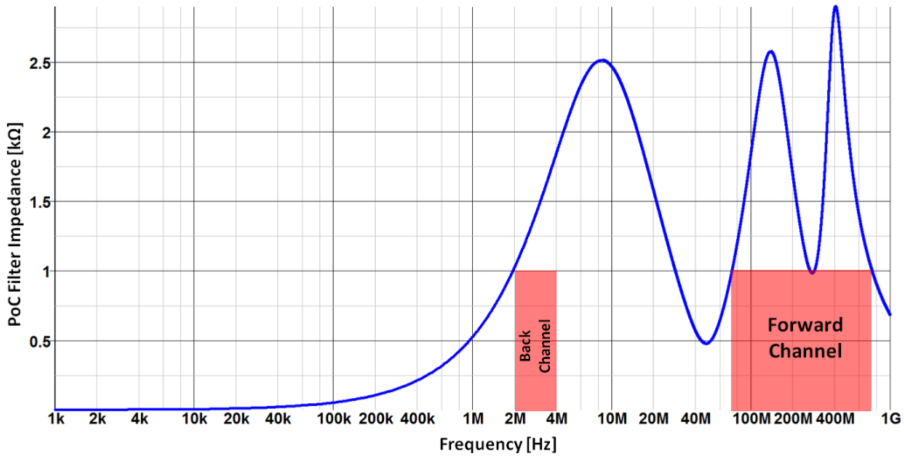

Figure 7 PoC Filter Frequency Characteristics and requirements

Other Design Considerations and Limitations

Choosing appropriate inductor for the PoC filters is a complex task. It is not only a real component frequency characteristics that have to be taken into account. Many models do not consider some additional parameters having a negative effect on the inductance such as current, temperature and component tolerance [2].

Also, an excessive DC resistance of the inductor in the filter can cause an unacceptable voltage drop which reduces a useable voltage and generates heat. Higher current inductors are physically larger having a negative impact on the PCB size and also on the performance towards higher frequencies. An obvious solution would be to increase the camera input voltage and therefore decrease the current level needed for the camera. Such a solution, however, has a negative impact on the power efficiency of the camera main power supply which causes inefficiency and additional heat generated on the PCB. Another disadvantage of the higher input voltage is increased voltage stress of other components connected before the main power supply. For example, capacitors connected to this rail have to withstand a higher voltage which means larger package. The selection of the system voltage and current is always a trade-off and a suitable compromise between both needs to be found.

Conclusion

Main challenges and potential issues of the power-over-coax filters for automotive applications were described in the paper. The design starts with the requirements defined based on the frequency spectrum of both the Back and Forward Channel. It was shown why multiple inductors need to be used to fulfill the requirements. Simulated characteristic considering real parameters of the components have been shown and some other consideration in relation to the current and voltage used for powering the cameras was discussed. The accurate data from components manufacturers are critical for a successful PoC filter design.

Although the paper deals with a Camera-to-ECU chain and its circuitry, the challenges, design notes and results are generally applicable to any sensor or device powered using Power-over-Coax (PoC) technology.

References

[1] Sending Power Over Coax in DS90UB913A Designs, Application Report, Texas Instruments, Dallas, Texas, June 2014.

[2] Chip Inductors, Catalogue, Murata Manufacturing Company, Kyoto, Japan. November 2013,