How to design remotely-powered cameras for automotive applications

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Introduction

Real-time surround view has become a necessity in modern day automobiles with advanced driver-assistance systems (ADAS), especially when it comes to safety and advanced driver-assist features, as well as autonomous vehicles. Camera modules placed in strategic locations provide the best view around the outside of the vehicle (Figure 1). Typically, these placements do not have direct access to power. Therefore, the ability to remotely-power automotive cameras has become a sought-after feature. This article outlines the design challenges and considerations when designing a remotely-powered device being implemented with a high-performance FPD-Link III, serializer/deserializer (SerDes) chipset.

Figure 2 shows a simplified diagram of a car with several camera modules and video processing sub-systems that implement FPD-Link III, megapixel-serializer and deserializer chipsets. The SerDes modules are connected with a cable that carries the serialized high-speed video signal, the low-speed bidirectional control signal, and direct-current (DC) power for the camera module. A shielded coaxial cable with less copper and lighter weight is commonly used because of it can help to improve the vehicle's fuel economy.

Figure 1. Example of surround view using FPD-Link III megapixel SerDes chipsets

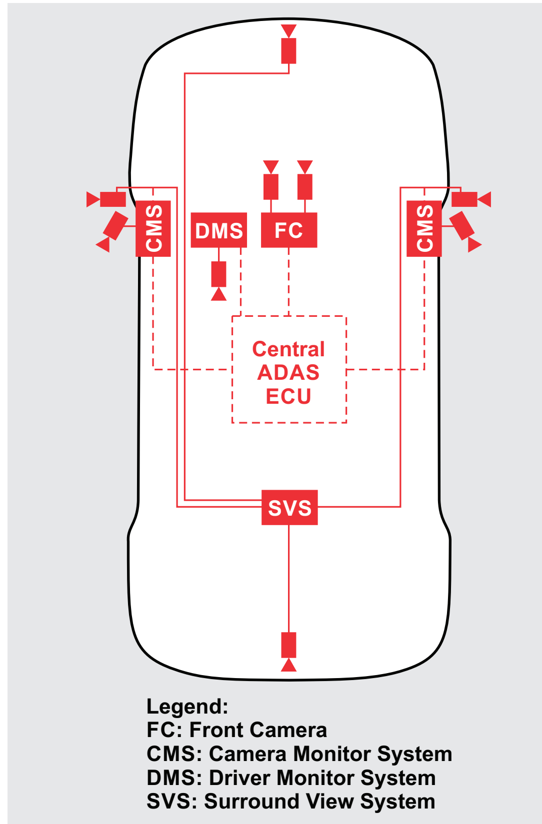


Figure 2. Remote camera sub-system with FPD-Link III, megapixel SerDes modules

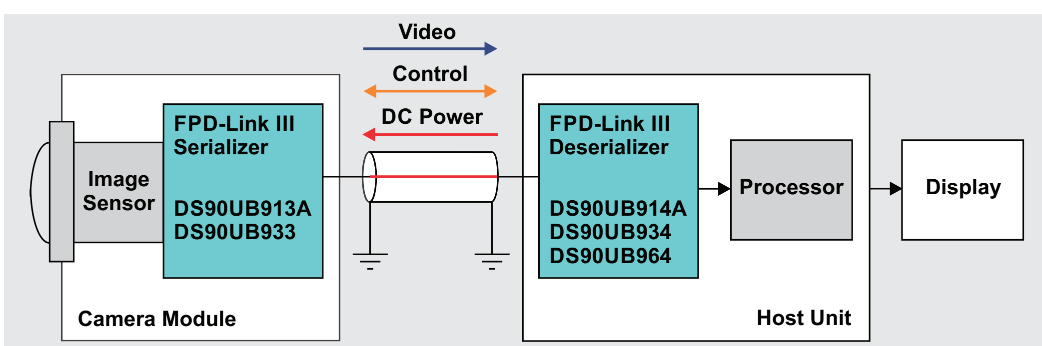


Figure 3. A method to share signal and DC power on one cable

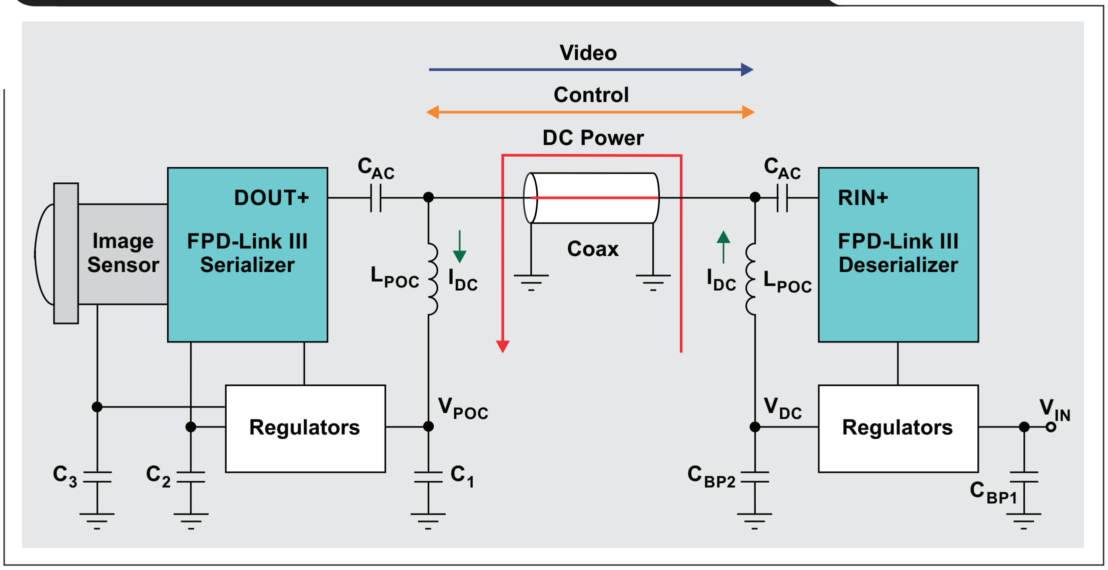


Figure 3 shows a detailed implementation of the remote camera module. An inductor, L_{POC}, is used on each side of the cable to deliver DC power. At high frequencies, the inductor presents a high impedance that blocks the AC high-speed video and low-speed control signals. The coupling capacitors, C_{AC}, block the DC power voltage so that only the AC signals are allowed to communicate between the serializer and the deserializer.

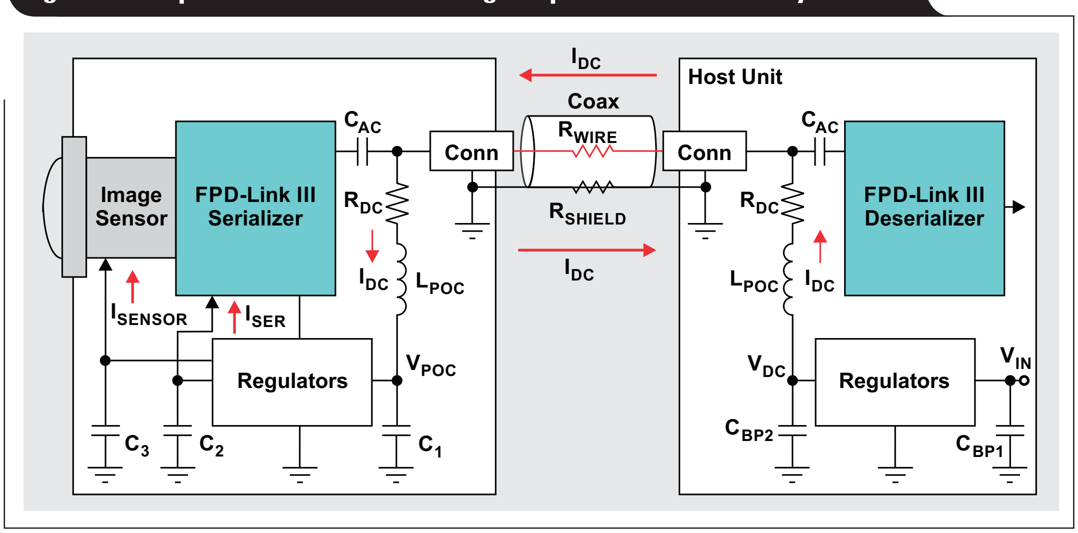
Current and load considerations

In the host processing unit, the supply voltage, V_{DC}, is connected to the wire through an inductor, L_{POC}. At the camera module, the power supply is extracted through another L_{POC}, and regulated into the necessary supply rails for the serializer and image sensor. The return current is carried by the cable's external shield. The power delivered from the host to the camera module is $I_{DC} \times V_{DC}$.

A power inductor is usually built with a magnetic core. When the current approaches the saturation current, its inductance starts to decrease and eventually collapses. The feed inductor, L_{POC}, is chosen to have a current capability well above the current drawn by the serializer and image sensor.

Figure 4 shows the simplified DC power circuit. As in any power distribution system, it is important to consider the voltage drop caused by the DC resistances from the wire and the feed inductors, L_{POC}. For a 10-meter automotive coaxial cable such as the DACAR-462, its DC wire resistance can be 2.5 to 3.5 Ω, and its braided shield can be 0.3 to 0.4 Ω. The miniature inductor, L_{POC}, also has a DC resistance of about 1.5 to 2.5 Ω. Choose a supply voltage, V_{DC}, that allows for the voltage drop across the internal resistance (IR-drop) before it reaches the load in the remote camera module.

Figure 4. Simplified DC circuit showing the power distribution system



Another design challenge arises from the image sensor's current fluctuation. During blanking periods between video frames, the image sensor is inactive and its current consumption drops from its full load, I_{SENSOR}, to its quiescent state, I_{SQ}. As a result, the IR-drop fluctuates and creates a pulse with amplitude, V_{PULSE}, at a frequency equal to the video frame rate. The IR-drop and pulse waveforms are illustrated in Figure 5.

The V_{PULSE} fluctuation appears at the V_{POC} node. Although it is attenuated by the high-pass LC filter, L_{POC} and C_{AC}, its presence at the serializer's DOUT+ pin is detrimental to the AC signal performance. V_{PULSE} can be reduced by lowering the DC resistance or reducing I_{DC}. Bypass capacitors C_3 and C_1 slow down the pulse's transition edge and reduce its harmonic components that may interfere with the high-speed communication.

From the above considerations, it is advantageous to use a step-up voltage for V_{DC} in the host unit and then a step-down to the necessary supply rails at the camera module. The current through the inductor, I_{DC}, is correspondingly reduced by the ratio of N, where $N = V_{POC}/V_{DD}$. The reduced I_{DC} keeps the inductors' saturation current low, which supports a higher bandwidth. Lowering I_{DC} also reduces the IR-drop in the power distribution and reduces the interference pulse, V_{PULSE}.

Assuming the image sensor and the serializer are powered by a 1.8-V supply rail, Tables 1 and 2 illustrate examples with a V_{POC} of 4 V, 6 V and 10 V with ten meters and three meters of coaxial cables. Using the calculations provided, it is clear that a V_{DC} of 10 V is better than 6 V, and a V_{DC} of 4 V with a linear regulator creates an excessive interference-pulse amplitude.

Figure 5. An interference pulse is created by the changing current load in the image sensor

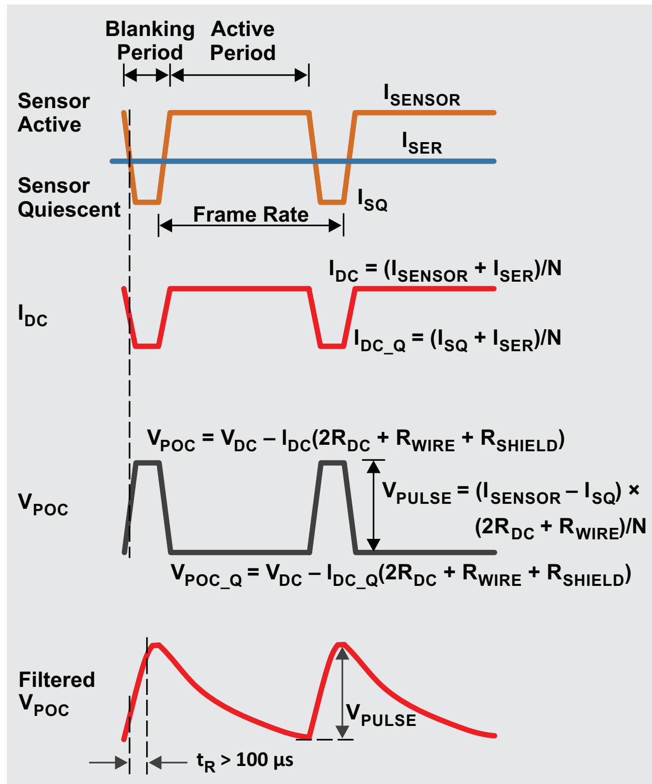


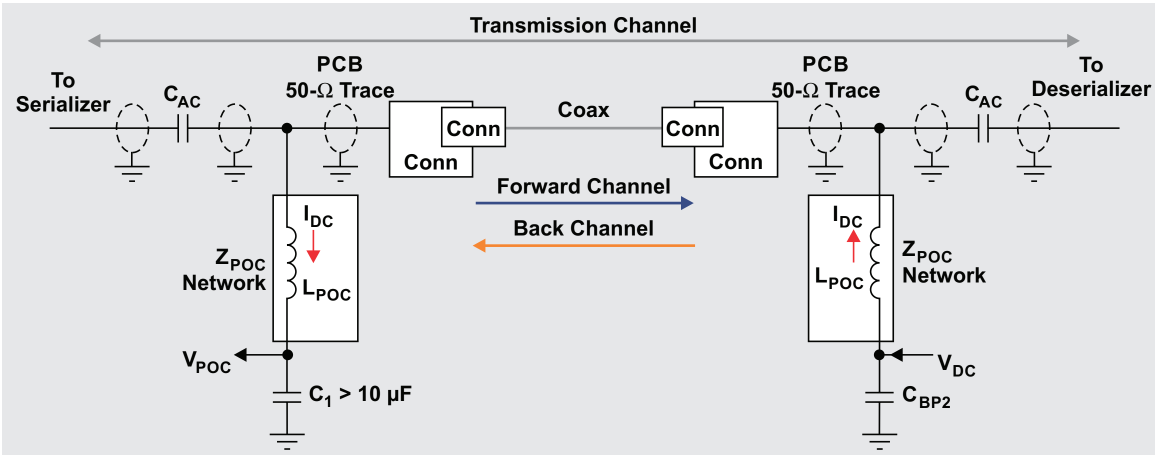
Table 1. Different V_{DC} voltages and the estimated V_{PULSE} with 10 meters of cable

V_{POC} (V)	Image sensor (mA/V_{DD})	Serializer (mA/V_{DD})	$N = V_{POC}/V_{DD}$	$I_{DC} = (I_{SER} + I_{SENSOR}) / 0.9 \times N$ (mA)	R_{WIRE} (Ω)	$2R_{DC}$ (Ω)	V_{DC} Source (V)	V_{PULSE} (mV_{PP})
4	150/1.8	100/1.8	1	250	3	4.2	5.8	1080
4	150/1.8	100/1.8	2.22	125	3	4.2	4.9	542
6	150/1.8	100/1.8	3.3	83.3	3	4.2	6.6	361
10	150/1.8	100/1.8	5.6	50	3	4.2	10.36	217

Table 2: Different V_{DC} voltages and the estimated V_{PULSE} with 3 meters of cable

V_{POC} (V)	Image sensor (mA/V_{DD})	Serializer (mA/V_{DD})	$N = V_{POC}/V_{DD}$	$I_{DC} = (I_{SER} + I_{SENSOR}) / 0.9 \times N$ (mA)	R_{WIRE} (Ω)	$2R_{DC}$ (Ω)	V_{DC} Source (V)	V_{PULSE} (mV_{PP})
4	150/1.8	100/1.8	1	250	0.9	4.2	5.28	770
4	150/1.8	100/1.8	2.22	125	0.9	4.2	4.65	391
6	150/1.8	100/1.8	3.3	83.3	0.9	4.2	6.44	261
10	150/1.8	100/1.8	5.6	50	0.9	4.2	10.26	157

Figure 6. Simplified diagram for the transmission channel between the SerDes modules



Bandwidth considerations

Figure 6 illustrates the simplified diagram of the transmission channel between the SerDes modules. It includes the printed-circuit board (PCB) 50-Ω traces, AC-coupling capacitors, feed inductors, L_{POC}, and the interconnecting cable. The transmission channel has a characteristic impedance of 50 Ω, while the two inductors, L_{POC}, act as shunting networks to ground. To avoid shunting and degrading the channel's impedance, L_{POC} is designed to provide a high impedance (≥ 2 kΩ) within the frequency range for the high-speed video signal (GHz) and the lower speed control signals (MHz). L_{POC} maintains high impedance over the operating temperature range and under current load I_{DC} without saturation.

Constructing a wide-bandwidth inductor network

A wide-bandwidth inductor network can be constructed by cascading inductors of different sizes and bandwidths, which will cover the low-band, mid-band and high-band of the frequency range. A resistor across the inductor will lower its Q-factor and widen its frequency range. Figure 7 illustrates the impedance and frequency range for individual inductors.

Figure 8 illustrates the composite impedance of the cascaded inductor network to cover the desired frequency range.

Figure 7. Impedance plot of individual inductors

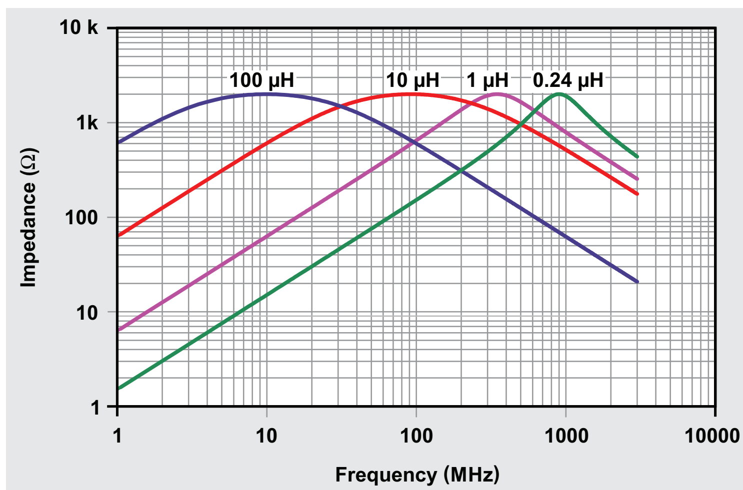
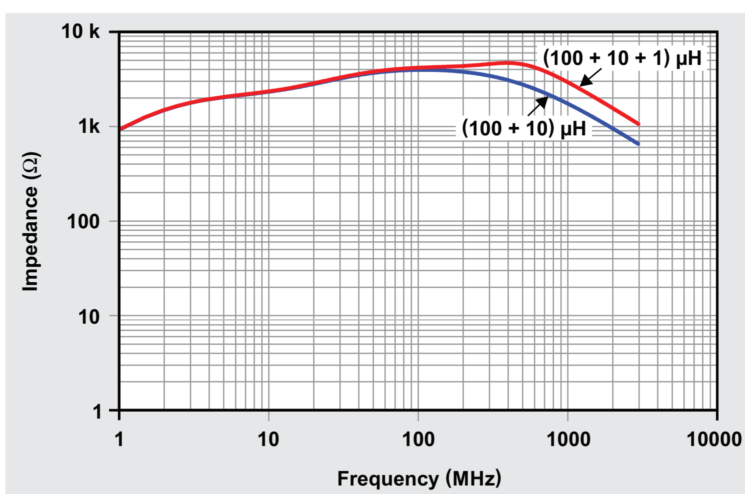


Figure 8. Impedance plot of a wide-bandwidth, composite inductor network



PCB considerations

When implementing a composite inductor network on a PCB, avoid introducing excessive parasitic capacitances, $C_{PARASITIC}$, with the components' landing pads. $C_{PARASITIC}$ limits the network's bandwidth. Figure 9 illustrates the simplified diagram of the wide-bandwidth composite inductor network and the possible $C_{PARASITIC}$ introduced by the components' landing pads. Figure 10 shows three PCB recommendations for routing the power feed network and the high-speed traces.

Figure 9. Simplified wide-bandwidth, composite inductor network

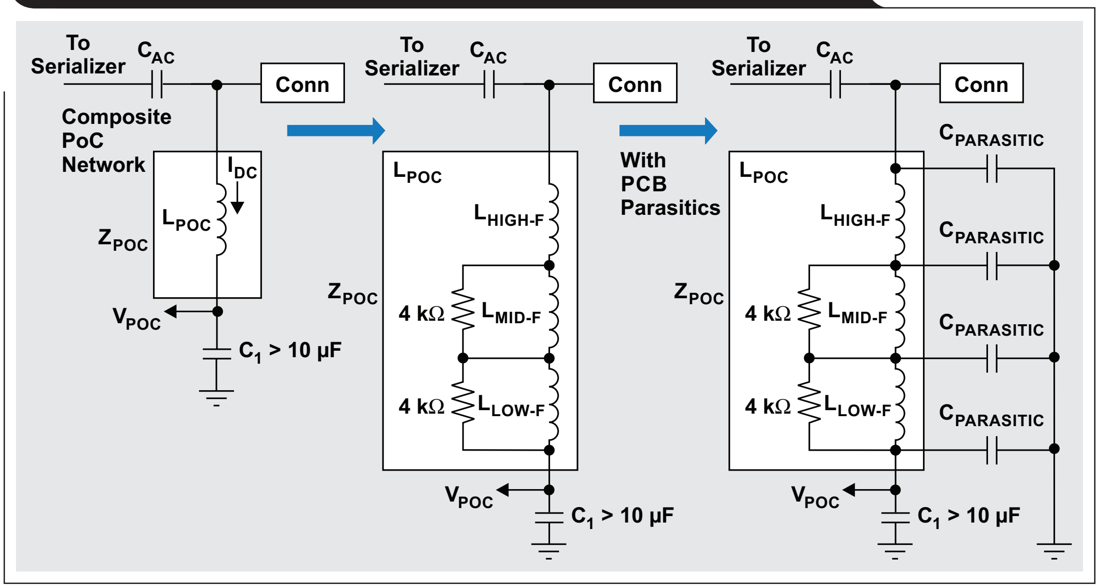
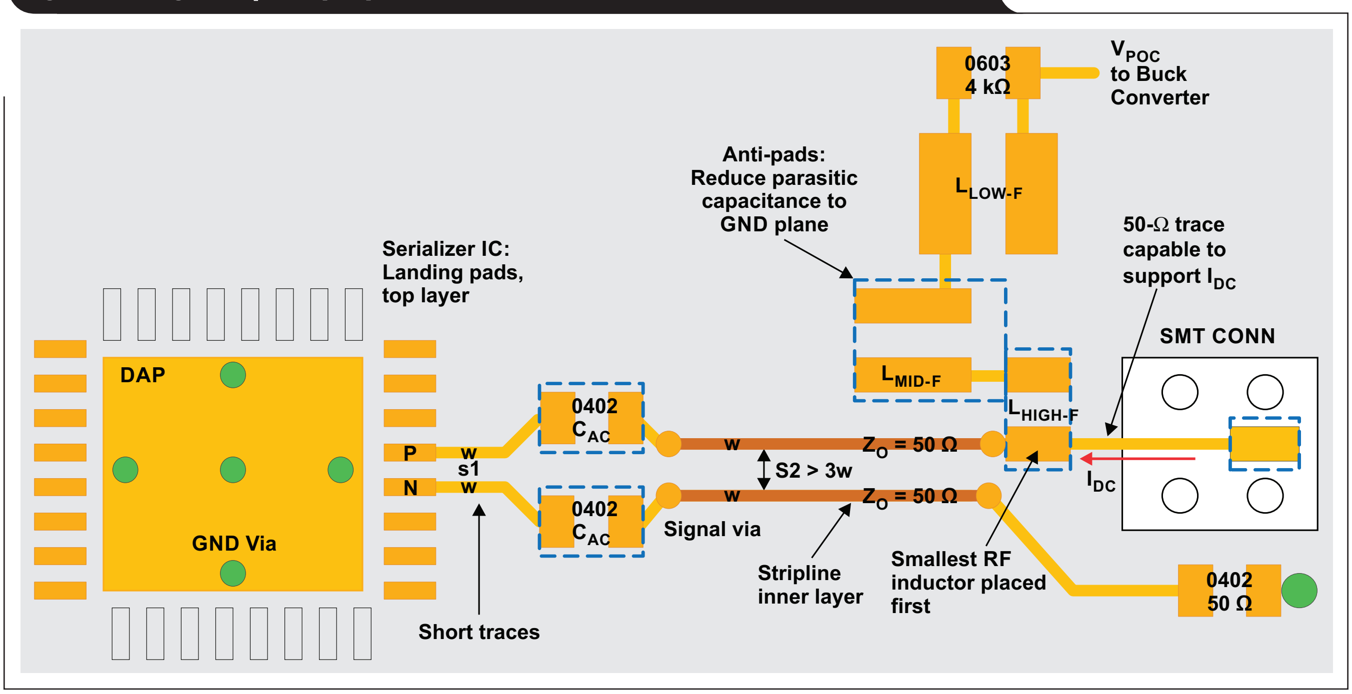


Figure 10. High-frequency layout recommendation for remote camera module



Design procedure and requirements

Table 3 outlines a step-by-step procedure that includes requirements for powering a remote camera.

Table 3. Design procedure and requirements

Parameters	Design Procedure and Requirements
P_{LOAD}, I_{SENSOR}, V_{POC}, and N	• Look up the maximum I_{SER} and I_{SENSOR} from the serializer's and image sensor's data sheets. • Calculate the power $P_{LOAD} = (I_{SER} + I_{SENSOR}) \times V_{DD}$. • Select the input voltage to the buck converter V_{POC}, including the switcher's power efficiency, E (E = 0.9 for 90% efficiency). • Derive $I_{DC} = (P_{LOAD}/E)/V_{POC}$; keep I_{DC} < 200 mA. • $N = V_{POC}/V_{DD}$.
L_{POC}, and I_{SAT}	• Look up the line rate for the forward channel video data (DR_{FC}) in GBPS. • Derive the maximum frequency, f_{MAX} = Nyquist frequency = $(0.5 \times DR_{FC})$ in GHz. • Look up the back-channel data rate, DR_{BC}, for the bi-direction control data in MBPS. • Derive the minimum frequency, $f_{MIN} = DR_{BC}$ in MHz. • Calculate the inductance of the low-frequency band, L_{LOW-F}, that achieves 2 kΩ of impedance at f_{MIN}. Factor in component tolerance. • Set $L_{MID-F} = 0.1 \times L_{LOW-F}$ and $L_{HIGH-F} = 0.1 \times L_{MID-F}$. • Add a shunt resistor of 2 to 4 kΩ across the inductor to lower its Q-factor and widen its frequency range. • Build a composite feed inductor network, $L_{POC} = L_{LOW-F} + L_{MID-F} + L_{HIGH-F}$. Continue adding small RF inductors to L_{POC} until achieving an impedance of 2 kΩ at maximum frequency, f_{MAX}. • Obtain inductor's model from vendor. Use simulator to estimate impedance Z_{POC}, including effect of PCB parasitic from landing pads. • Consult the inductor's specification to ensure the current rating and saturation current, I_{SAT}, of each inductor is at least $1.5 \times I_{DC}$.
R_{WIRE}, R_{DC}, V_{DC}, V_{PULSE}, and t_R	• Determine the maximum cable length in meters. • Consult vendor to determine cable's wire and shield resistance, R_{WIRE} and R_{SHIELD}. Also check if cable's current rating is able to support I_{DC}. • Consult inductor's data sheet to determine total DC resistance, R_{DC}, of the composite feed-inductor network. • Estimate the source voltage, $V_{DC} = V_{POC} + I_{DC} \times (R_{WIRE} + 2R_{DC})$ • Consult vendor to derive the current change of the image sensor between active and blanking, ΔI_{SENSOR}. Explore the possibility of minimizing the current change. • Estimate the interference pulse amplitude, $V_{PULSE} = [\Delta I_{SENSOR}/(N \times E)] \times (R_{WIRE} + 2R_{DC})$. • Add bypass capacitors C_1 and C_3 to achieve pulse transition time, t_R > 100 µs. • Consult serializer's data sheet to ensure V_{PULSE}, t_R, and switching noise are within an acceptable level of interference immunity. • If V_{PULSE} is too high, raise V_{POC} to increase N.
PCB Layout	• Place the smallest inductor L_{HIGH-F} close to and after the connector footprint. Do not place inductor before the connector's landing pad, which will create a stub and degrade signal integrity. • Consult PCB material property to ensure the short 50-Ω trace from the connector's landing pad to the first inductor, L_{HIGH-F}, is capable of supporting the current loading, I_{DC}. • Use anti-pads (ground relief) in the ground/power planes under the inductors' landing pads. Anti-pads are used to reduce the parasitic capacitances that will limit the frequency range of L_{POC}. • See Figure 10 for layout recommendations.

Conclusion

Using remotely powered cameras in automobiles is becoming ever more popular with both designers and consumers. By following the design procedure and design requirements outlined in this article, a designer can now use a single coaxial cable to carry the video signal, the control signal and DC power between the camera module and its host processor unit. This scheme offers excellent video quality with the advantages of easy wiring along with weight reduction, which can contribute to a vehicle's improved fuel efficiency.

Texas Instruments offers high-performance FPD-Link III, SerDes chipsets that are designed to support megapixel camera modules with high immunity to interference. See product information below.

The information presented in this article is equally applicable to automotive camera modules, or other remotely-powered applications.

Related Web sites

Product information:

FPD-Link III Serializers/Deserializers
DS90UB913A-Q1
DS90UB914A-Q1
DS90UB933-Q1
DS90UB934-Q1
DS90UB964-Q1

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