ADAS Camera Modules

Matthew Saucedo
Abstract

Optimized Power Solutions for Automotive Camera Modules: One size does not fit all

This training will provide an overview of Automotive Camera Modules and the different challenges associated with these systems, whether it be efficiency, size, flexibility, scalability, or cost. The challenges presented can be system independent or interconnected, which would require appropriate device selection for power, diagnostics, and communication. Various power solutions, ranging from fully-discrete to fully-integrated, will be discussed in realizing your design goals and will help to provide you with a foundation for future camera module designs.
Simplified Agenda

• Where Cameras Live
  • Different Subsystems of Camera Modules w/o Processing

• FPD-Link Device and Features
  • Brief History
  • FPD-Link Communication Channel and Control
  • Remote camera: Power-over-coax (PoC)

• Power-over-coax Overview
  • Component Selection
  • Limitations and Advantages

• Power Selection
  • Fully Discrete Example
  • Fully Integrated Example
  • Partial Integration
Where Cameras Live
Different Subsystems of Camera Modules w/o Processing

Camera Module w/o processing – Analog Output

Camera Module w/o processing – Ethernet Output

Camera Module w/o processing – Serial Digital Output
PCB Design, Where to start?

• What is usually the most expensive component on a PCB?
PCB Design, Where to start? (contd)

• The Connector and Cabling

Source: Courtesy of Rosenberger
Camera Module w/o processing – FPD-Link

FPD-Link Devices for Cameras

• Power and Video transmission/control over single Coax Connector

• High Speed forward channel for Video transmission

• Bidirectional Control over same Coax

• When paired with a companion deserializer, can deliver precise multi-camera sensor clock and sensor synchronization
Brief History of FPD-Link

- **FPD-Link II** was introduced in 2006, designed specifically for automotive infotainment and camera applications. This second generation embedded the clock in the data signal, therefore only needing one diff pair to transmit clock and video data. This aided in reducing the amount of cables and connectors for camera applications.

- The embedding of the clock eliminated any potential for clock skew that commonly occurred due to cable length mismatch when the clock signal and data were transmitted on separate conductors.

- Data throughput at this time was pushing the limit of 1 Gbit/s with LVDS. FPD-Link chipsets changed from an LVDS to current mode logic (CML) approach.

- **FPD-Link III** was introduced in 2010. This time the bidirectional control channel was also embedded. This bidirectional channel enables control signals between source and destination in addition to the video transmission and the clock. The control channels can be interface with I2C, CAN, GPIO.

- FPD-Link III focused on current mode logic (CML) for the serialized high-speed signals. This allowed data rates greater than 3 Gbit/s on cables exceeding 10m.

- FPD-Link III also incorporated adaptive equalization. Usually there is some considerable loss due to cable length, the adaptive equalizer can restore this signal to the original integrity.


FPD-Link

 Serializer / Deserializer

• Benefits:
  – Reduce cable harness cost and weight
  – Low EMI with differential LVDS
  – Diagnostics features

Replaces multiple interfaces (wires) with one pair

Video Data → Serializer (SER) → Deserializer (DES) → Video Data

Clock → I2C

Forward Channel (Video Data)

Bidirectional Control Channel (BCC)
FPD-Link Application Example

**IVI:** In-Vehicle Infotainment

**ADAS:** Advanced Driver Assistance Systems

- **High-Speed:** 4Gbps+
- **High-Resolution:** 2K
- **Low-Latency:** nano sec

Connections

- Infotainment Displays
- ADAS Surround View Cameras

**ECU**
The DS90UB953-Q1 and DS90UB960-Q1 SerDes devices used in this system communicate over two carrier frequencies.

- 2 GHz at full speed ("forward channel")
- Lower frequency of 25 MHz ("backchannel") determined by the deserializer device
Adaptive Equalization

Automatic adaptation (no need to program EQ)
No EMI impact (because it is at the receiver)
Diagnostic function (can read EQ registers)
• Remote camera module powered through PoC over the same coax shared by the high speed data
• PoC network can be designed to avoid any impact on the high speed serial link
PoC Network: Bandwidth consideration

<table>
<thead>
<tr>
<th>FPD-Link III SER</th>
<th>FPD-Link III DES</th>
<th>Clock Mode</th>
<th>Back-Channel Mbps (Nominal)</th>
<th>Forward-Channel Gbps (Highest)</th>
<th>$f_{BCMIN} - f_{FC-NYQUIST}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS90UB913A</td>
<td>DS90UB914A</td>
<td>External Oscillator</td>
<td>2.5</td>
<td>1.4</td>
<td>1.25 – 700 MHz</td>
</tr>
<tr>
<td>DS90UB933</td>
<td>DS90UB934</td>
<td>External Oscillator</td>
<td>2.5</td>
<td>1.8</td>
<td>1.25 – 900 MHz</td>
</tr>
<tr>
<td>DS90UB953</td>
<td>DS90UB954/960</td>
<td>External Oscillator</td>
<td>10</td>
<td>4.2</td>
<td>5 – 2100 MHz</td>
</tr>
<tr>
<td>DS90UB953</td>
<td>DS90UB954/960</td>
<td>Synchronous Mode</td>
<td>50</td>
<td>4.2</td>
<td>25 – 2100 MHz</td>
</tr>
</tbody>
</table>

**FPD-LINK III SERIALIZER**

- FC DRIVER
- BC RX
- V.patient
- 50 Ω

**Forward Channel**: Video + Control

**Back Channel**: Control

**POWER**

**FPD-LINK III DESERIALIZER**

- FC RECEIVER
- BC DR
- 50 Ω

**Bandwidth (Nominal)**

- $f_{BCMIN}$
- $f_{FC-NYQUIST}$

**External Oscillator**

- $2.5$ Mbps
- $1.4$ Gbps (Nominal)
- $2.5$ Mbps
- $1.8$ Gbps (Highest)
- $10$ Mbps
- $4.2$ Gbps (Nominal)
- $50$ Mbps
- $4.2$ Gbps (Highest)

**Synchronous Mode**

- $25$ – 2100 MHz

**Texas Instruments**
High speed automotive connector: FAKRA

**FAKRA** connector series characteristics:

- 50 Ω coaxial connector
- Use shielded coax cable
- Color Coded
- 18dB return loss
- 0.1(√f) dB insertion loss
- -40° to 105°C

Suppliers: Rosenberger, Amphenol, TE

Signal topology: Single-end transmission, 1 data link

Supplier links:

- [www.amphenolrf.com/connectors/fakra.html](http://www.amphenolrf.com/connectors/fakra.html)

Source: Courtesy of Rosenberger
High-speed automotive connector : Mini FAKRA

NEW!
Support higher data rate to 20Gbps
Compact single to quad designs

Supplier: Rosenberger
Signal Topology: Single-end, 1-4 data links
Cable Type: Coaxial

Supplier link:

Source: Courtesy of Rosenberger
High-speed automotive connector: H-MTD

NEW!
Support higher data rate to 20 Gbps
Compact single to quad lane designs

Supplier: Rosenberger
Signal Topology: Differential, 1-4 data links
Cable type:   STP (shielded twisted pair)
             SPP (shielded parallel pair)

Source: Courtesy of Rosenberger
Power-over-Coax Primer

One of the most critical portions of a design that uses POC is the filter circuitry. The goal is twofold:

1. Deliver a clean DC supply to the input of the switching regulators.
2. Protect the FPD-Link communication channels from noise-coupled backwards from the rest of the system.
Power-over-Coax Primer - Filter

**AC Path:** $Z_L$ must be large to avoid degrading signal

**DC Path:** Reduce IR drop to provide effective power distribution
# Power-over-Coax Primer - Inductors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Inductance in nH or mH</td>
</tr>
<tr>
<td>$I_{SAT}$</td>
<td>Saturation current – when L drops to about 30% of nominal value due to magnetic saturation. $I_{DC} \ll I_{SAT}$</td>
</tr>
<tr>
<td>$r_L$</td>
<td>DC Coil resistance, contributes to IR-drop</td>
</tr>
<tr>
<td>SRF</td>
<td>Series Resonant Frequency, beyond which, impedance of $C_S$ starts to dominate, inductor starts to behave as a capacitor</td>
</tr>
<tr>
<td><strong>Frequency Range</strong></td>
<td>When inductor’s impedance is high such that it appears to be transparent to the high frequency signal</td>
</tr>
</tbody>
</table>

---

![Graph of inductance vs. current](image1.png)  
![Graph of impedance vs. frequency](image2.png)
Power-over-Coax Primer – Choosing the right Inductors

- > 2 kΩ across the 10-MHz to 2.2-GHz bandwidth is required.
- To accomplish this, an inductor is typically chosen for filtering the 10-MHz to 1-GHz range, while a ferrite bead is chosen for filtering the 1- to 2.2-GHz frequency band.
- For the high-frequency forward-channel filtering, inductors usually are not sufficient to filter above 1 GHz. In these instances ferrite beads are chosen.
- Using a 4-kΩ resistor in parallel with the 10-µH inductor provides a constant impedance across the complete frequency band for impedance smoothing.
- Use Inductors with apt saturation current ratings based on expected PoC voltage and current.
- These inductors along with ferrites should be chosen well with low ESR (resistance) to minimize any potential drop that may affect power budget.
The VPOC fluctuations on the serializer side, caused by the transient current draw of the sensor, the DC resistance of cables, and PoC components, must be kept to a minimum as well.

Increasing the VPOC voltage and adding extra decoupling capacitance (> 10 µF) help reduce the amplitude and slew rate of the VPOC fluctuations.

A small body size X7R chip capacitor, such as 0603 or 0402, is recommended for external bypass. The small body size reduces the parasitic inductance of the capacitor. The user must pay attention to the resonance frequency of these external bypass capacitors, usually in the range of 20 to 30 MHz.

To provide effective bypassing, multiple capacitors are often used to achieve low impedance between the supply rails over different frequencies of interest.
Power-over-Coax Primer – Equivalent network
Power-over-Coax Primer – BODE (VOUT/VIN)

FREQUENCY (F)

10^15 of noise suppression

VOUT/VIN (DB)
Power-over-Coax Primer – AC coupling Caps

- DC Blocking capacitor included to only pass backchannel and forward channel communication.

- Selected capacitor has very low impedance from the start of the 20 MHz backchannel band through the 2GHz upper limit of the forward channel band.

- AC coupling caps, 0.033 μF and 0.015 μF, are chosen to ensure the high-speed AC data signals are passed through but that the DC is blocked from getting on the data lines. Capacitive values for the DS90UB953/DS90UB954 pair are smaller than previous generations due to them needing to pass 4Gbps of data versus the previous 2Gbps of data seen on 1-MP cameras.
Power-over-Coax Primer – Returning to Cable
50 Ω Single-ended Coaxial (FAKRA/RTK 031)

- Increased cable length results in further attenuation of signal/power
- Increased cable length adds more resistance that will create more (I*R) drop across span of cable that will reduce voltage headroom of PoC voltage
POWER SELECTION
POWER – Where to Start?

- The first step when designing the power portion of a camera module is a brief calculation of the power budget for each rail. This, along with the voltage provided over POC is important in selecting the power strategy.

- Camera sensor and external circuitry require current draw that may vary widely across different sensors and any additional external devices.

- Usually the lower imager rails, 1.2V and 1.8V in image above, requires the most current, while the largest supply voltage, 2.9V, which pertains to the imager analog supply requires the least. The included FPD-Link device, along with any form of supervisors or sequencers will also eat into this power budget.

- Ideally would want to use an LDO for every rail due to excellent noise performance, however not feasible due to limited current savings. Increasing current will stress connectors and cables and increase self-heating of camera that may worsen performance. Will also lead to increased potential drop across coax cable and connectors.
Example Calculation. The Current (A) requirements are generally fixed and tied to the Sensor and FPD-Link device included in the system. In this example, the imager rails are 1.2V, 1.8V, and 2.9V. The FPD-Link device shares the same 1.8V rail. The required currents are highlighted in yellow.

<table>
<thead>
<tr>
<th>Power Sections</th>
<th>Configuration</th>
<th>Input Voltage Range</th>
<th>Output Voltage Range</th>
<th>Current Requirement (A)</th>
<th>Voltage (V)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank 1</td>
<td>cascade</td>
<td>4 to 18.3V</td>
<td>3 to 4V</td>
<td>0.326818182</td>
<td>3.3</td>
<td>1.0785</td>
</tr>
<tr>
<td>Bank 2</td>
<td>1 &gt; 2</td>
<td>3 to 5.5V</td>
<td>0.9 to 1.9V</td>
<td>0.225</td>
<td>1.8</td>
<td>0.405</td>
</tr>
<tr>
<td>Bank 3</td>
<td>1 &gt; 3</td>
<td>3 to 5.5V</td>
<td>0.9 to 1.9V</td>
<td>0.388</td>
<td>1.2</td>
<td>0.4656</td>
</tr>
<tr>
<td>LDO</td>
<td>1 &gt; LDO</td>
<td>3 to 5.5V</td>
<td>2.7 to 3.3V</td>
<td>0.063</td>
<td>2.9</td>
<td>0.1827</td>
</tr>
</tbody>
</table>

12V Current Requirement (A) 0.089875

In this example, the Sensor analog rail 2.9V is tied directly to an LDO output, while the other supplies are tied to a Step-down (BUCK).

The calculations are based on 100% efficiency to get a quick understanding of current savings.

In this example 12V POC is provided, however 5V PoC would be more limited in choosing Imager and Serializer.

FAKRA – current limitation, dependent on gauge of wire
**POWER – Choosing the right Architecture**

- The three different power trees:

  **Fully discrete:** A fully discrete solution has a unique IC that generates each supply. This gives you maximum flexibility but can require more design time to choose all of the different ICs and is not easily scalable towards future designs.

  **Fully integrated:** A dedicated power-management integrated circuit (PMIC) that generates all supply rails for imager and external circuitry. PMICs are usually programmable and can be easily scaled to future designs.

  **Partial integration:** Using a mix of single- and multichannel power supplies to simplify the design. This allows the best of both worlds, and may be the best choice in minimizing solution ‘footprint’, and enabling flexibility.
POWER – Fully discrete

**Fully discrete:** A fully discrete solution has a unique IC that generates each supply. This gives you maximum flexibility but can require more design time to choose all of the different ICs and is not easily scalable towards future designs.

**Advantages:**

- Layout Flexibility enabling compact design resulting in smaller solution footprint

**Disadvantages:**

- More time to choose and select all IC components.
- Supply values are fixed, not really a modular power design that can be easily modified to another imager that may require different rail values + current consumption.
POWER – Fully integrated

**Fully integrated**: A dedicated power-management integrated circuit (PMIC) that generates all supply rails for imager and external circuitry. PMICs are usually programmable and can be easily scaled to future designs.

**Advantages:**

- Simplest solution in terms of project timeline.
- “Highly Reusable” – programmable - can be easily leveraged to future camera module solutions without any significant effort.

**Disadvantages:**

- Reduces layout flexibility as all pins have a fixed pinout.
- May result in increased solution area in order to minimize any switching interaction with imager transmission signals.
Partial integration: Mix of single and multichannel power supplies to simplify design and bring best of both worlds. Included layout flexibility through its partially discrete approach, which aids in simplifying the design and allows an easier means to scale.

Advantages:

• Partial integration simplifies BOM, and offers more layout flexibility than a fully integrated PMIC.

Disadvantages:

• Increased design cycle time
• Not as scalable as PMIC power tree, however most ICs have different voltage variants with compatible device footprints
When designing for automotive applications, there are a few considerations that will limit power design choices. Important system-level specifications include:

- Total solution size needs to be minimized to meet small form factor design of automotive camera module enclosures. Typically around 20mm x 20mm in area. Usually fits within plastic enclosure M12 barrel.

- Avoid interference with the AM radio band. All switching power supplies need to be outside of AM radio band of 540 kHz to 1700 kHz.

- Lower switching frequencies are less desirable because they require large inductors.
  - High frequency switchers >2MHz are generally chosen for power supply architectures

- All devices need to be AEC Q100-Q1 rated.
POWER – PCB constraints

- MOCK board layout with DS90UB953-Q1 and Sony IMX390 imager
- Impedance controlled four-lane MIPI CSI-2
- Via location of MIPI CSI-2 interface restricts movement of power and serializer.
- Vias need to have proper shielding away from any switching supplies
Fully Discrete Example

• Block Diagram and Schematics

• TPS62172-Q1 (2 × 2 mm WSON-8)
  • 3-17V 0.5A Automotive Step-Down Converter in 2x2 QFN

• TLV70218-Q1 and TLV70213-Q1 (1.5 x 1.5mm WSON-6)
  • Automotive 300mA Low-Iq, High PSRR Low-Dropout (LDO) Regulator
Fully Discrete Example

- PCB
Fully Integrated Example

• Block Diagram and Schematics

  - TPS650330-Q1 (4 x 4mm VQFN-24)
    - Three step-down converters with one high PSRR LDO integrated Power Management IC (PMIC)
      - Three step-down converters: BUCK1 $V_{IN}$ range from 4 V to 18.3 V
      - BUCK1 output current up to 1500-mA
      - BUCK2 and BUCK3 $V_{IN}$ range from 3.0 V to 5.5 V
      - One low dropout (LDO) regulator: $V_{IN}$ range from 3.0 V to 5.5 V
Fully Integrated Example

- PCB
Partially Integrated Example (part 1)

- Block Diagram and Schematics

- TPS62162-Q1 (2 × 2 mm WSON-8)
  - 3V-17V 1A Automotive Step-Down Converters in 2x2SON
- TPS62423-Q1 (3 x 3 mm VSON-10)
  - 2.5 V to 6 V Automotive 2.25-MHz Fixed VOUT Dual 800mA Step-Down Converter
- LP5907-Q1 (1 x 1 mm X2SON-4)
  - Automotive 250-mA ultra-low-noise low-IQ low-dropout (LDO) linear regulator
Partially Integrated Example (part 1)

- PCB
Partially Integrated Example (part 2)

- Block Diagram and Schematics

- TPS62162-Q1 (2 × 2 mm WSON-8)
  - 3V-17V 1A Automotive Step-Down Converters in 2x2SON
- TPS650002-Q1 (3-mm × 3-mm WQFN)
  - Step-down converter:
    - $V_{IN}$ range from 2.3 V to 6 V
    - 600-mA Output current
  - 2 LDOs:
    - $V_{IN}$ Range From 1.6 V to 6 V
    - Up to 300-mA output current

![Diagram of partially integrated example](image)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VOLTAGE (V)</th>
<th>CURRENT (A)</th>
<th>POWER (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS90UB953</td>
<td>1.8</td>
<td>0.225</td>
<td>0.405</td>
</tr>
<tr>
<td>AR0233</td>
<td>1.2</td>
<td>0.192</td>
<td>0.2304</td>
</tr>
<tr>
<td>VDD_1.8</td>
<td>1.8</td>
<td>0.001</td>
<td>0.0018</td>
</tr>
<tr>
<td>VDD_IO_1.8</td>
<td>2.8</td>
<td>0.025</td>
<td>0.07</td>
</tr>
<tr>
<td>Rail Total</td>
<td>1.2-V</td>
<td>1.2</td>
<td>0.2304</td>
</tr>
<tr>
<td></td>
<td>1.8-V</td>
<td>1.8</td>
<td>0.4068</td>
</tr>
<tr>
<td></td>
<td>2.8-V</td>
<td>2.8</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>3.3-V</td>
<td>3.3</td>
<td>1.1229</td>
</tr>
</tbody>
</table>
Partially Integrated Example (part 2)

- PCB
Wide Vin Primary Regulators

- Automotive electronics operate from car battery and experience transient loads that range from 5V to 40V
- Wide VIN portfolio withstands the wide range of voltage transients
  - Provide highly reliable and affordable solutions
- Some devices designed for low EMI. May include random spread spectrum option
  - Exhibit low input inductance
  - Switching frequency above AM band (1700 Hz)
  - Added EMI robustness may help in reducing shielding and other expensive EMI mitigation measures.
• **TPS3703-Q1** – integrated overvoltage and under voltage monitor in 1.5 x 1.5mm WSON-6.

• Improves reliability and safety of system and enables advanced diagnostics to camera module when interrupt is connected to serializer.

• Small device footprint allows easy integration into existing designs.
REFERENCES

FPD-Link Learning Center
https://training.ti.com/fpd-link-learning-center

- Introduction to FPD-Link SerDes
- Diagnostic & Data Protection
- FPD-Link Parameters & Transmission Channel
- Power over Coax (PoC)
- Interfaces
- Tools

TI- Designs:

TIDA-01130
TIDA-020002
QUESTIONS?
Thank You