Application Note

Reducing Cabling Effort in Camera-Based Driver Monitoring Systems (DMS)

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ABSTRACT

With the growing number of cars with automated driving features and due to new legislation, the demand for Driver Monitoring Systems (DMS) is increasing significantly. Adding a new system in a vehicle introduces the challenge of increased space, cost and weight. As the wiring harness in the vehicle is already one of the heaviest and more expensive components, adding a new system is further increasing the cost and weight impact due to additional cabling needs. This application note presents a design approach to reduce the amount of cabling needed for a driver monitoring system by using Power-over-Coax (PoC).

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1 Introduction

90% of fatalities in car crashes in the United States are caused by human error and 10% of the total were due to driver drowsiness or distraction. Driver monitoring systems (DMS) as well as occupant status monitoring (OSM) are systems that track the condition and the position of the driver or the passengers. Today's implementations predominantly use camera-based systems where the driver is illuminated via an Infrared LED (IR LED) to avoid blinding and glaring the driver. The reflection is than captured by an image sensor and the picture processed. During processing the system identifies facial position, eye movements, eye blinking repetition, dilation of the eyes and position of the driver in the seat like slumping down. Taking this data, and often applying AI mechanisms, a level of alertness of the driver can be defined and used to determine if the driver is attentive enough or is not paying, or possibly cannot pay enough attention to the road and traffic, due to his or her health condition. Depending on the alertness level the system can then create a visual or acoustic warning sign or vibration in the steering wheel or eventually slow down the car to increase driver engagement again.

As car safety institutions worldwide are defining and deploying guidance and mandatory requirements for driver monitoring systems, the market for camera based DMS and OMS systems is expected to grow to more than 50 million systems per year over the next five years.

2 System Description

Figure 2-1 shows the basic architecture in the car with the DMS Electronic Control Unit (ECU) and the remote camera module which includes the near-infrared (NIR) illumination.

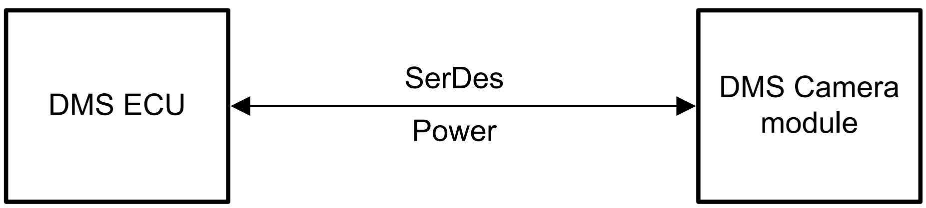

Figure 2-1. DMS Architecture with Remote Camera Module

The ECU module provides power to the camera module and receives the image data from the camera module via a high-speed Serializer/Deserializer (SerDes) link. The NIR illumination is commonly implemented by using cost-effective IR LEDs to maintain robust operation in different driving situations with changing light conditions. Another benefit of using light in the IR spectrum is that the light is invisible to the human eye and cannot distract the driver, but can cause damage to the retina of the eye at higher power and exposure times. The camera module can be positioned in various locations within the car, e.g. in the instrument cluster, dashboard, interior mirror or the a-pillar.

The following two figures illustrate two different concepts how the camera module can be connected to the ECU.

2.1 Dual Cable Concept

The first implementation, shown in Figure 2-2, is one of the common implementation for DMS systems with remote camera modules in the vehicle. The ECU is connected with two cables to the camera module. One cable is used to power the imaging subsystem and transmit the image data to the ECU. This is usually realized by using Power-over-Coax (PoC). The second cable is powering the IR illumination on the camera board with the LED driver either placed on the ECU or on the camera module.

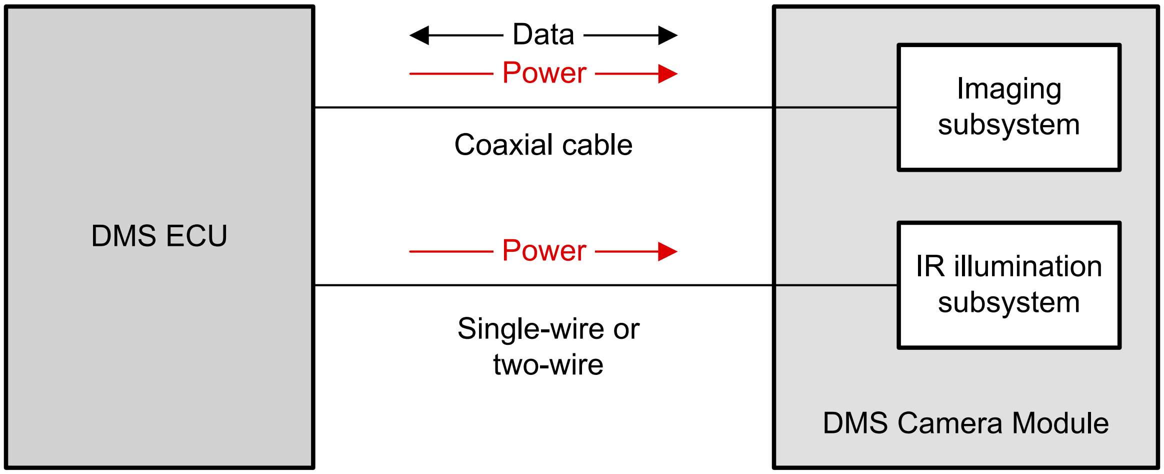

Figure 2-2. DMS ECU and Camera Dual Cable Implementation

2.2 Single Cable Concept

Figure 2-3 shows a different implementation concept how to connect the camera module to the ECU. In this concept, the power for the IR illumination and imaging subsystem is provided by a single coaxial cable which is also used to transmit the image data to the ECU. This concept helps to reduce cabling cost and weight. Separation of data and power is achieved by using PoC.

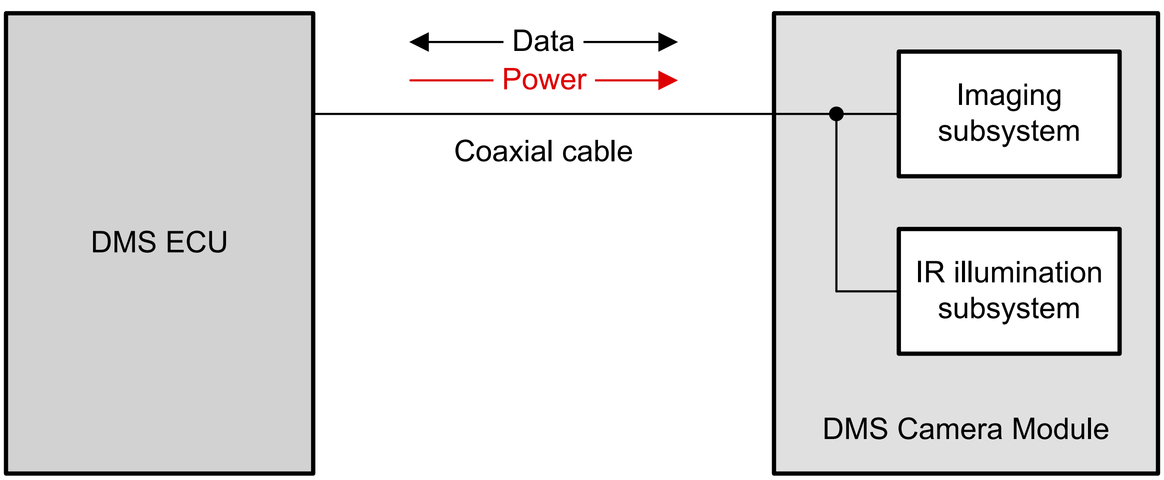

Figure 2-3. DMS ECU and Camera Single Cable Implementation

The next section describes a design implemenation for the single cable concept of a DMS camera module with IR illumination.

3 Camera Module Design with Single Coaxial Cable Connection

Figure 3-1 shows a reference test design of a remote camera module with IR illumination and single coaxial cable connection. The module can be divided into two subsystems: An imager subsystem and the IR illumination subsystem. The imager subsystem includes the serializer and the 1.8V power supply for the serializer. Both subsystems are powered over the coaxial cable through the PoC filter. As the IR LEDs are driven with large current pulses the illumination subsystem includes additional components beside the LED driver to reduce the impact from the pulsing LEDs on other parts of the system, especially the high-speed FPD-Link communication.

The high peak current pulse driving the IR LEDs is transformed to a lower peak current on the input side. This allows to control the peak current on the coaxial cable.

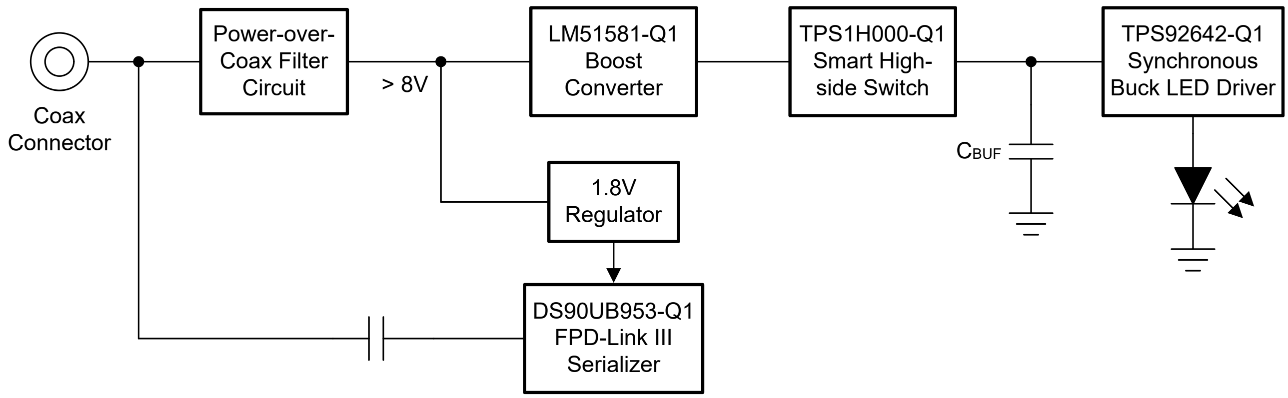

Figure 3-1. Block Diagram of DMS Camera Module With Single Coax Connection

The individual functional blocks and design considerations are discussed in the following sections.

3.1 Power-Over-Coax Filter

A Power-over-Coax (PoC) network separates the high-speed data signal from the DC power on a coaxial cable. The high-speed data consists of a high-speed forward channel carrying video and control data to the Deserializer and a lower speed back channel carrying control data to the serializer. The Serializer and Deserializer network is implemented with the FPD-Link technology from TI.

For more information on PoC see *Power-over-Coax Design Guidelines for DS90UB953-Q1*.

With the usage of PoC, the maximum current delivered to the camera module is limited due to the current rating of different components in the power path, like the connectors, coaxial cable and PoC inductors. The maximum current rating of these components is typically in the 1 A range and shall not be exceeded to minimize cables losses and prevent saturation effects on the PoC inductors.

The procedure to determine the required current rating for a given LED configuration is described in the Design Steps section.

3.2 Boost Converter

As shown in Figure 3-1, the boost converter is directly placed after the PoC filter. The purpose of the boost converter is to charge the buffer capacitor to a constant voltage level, typically in the range of 18 – 35 V. The boost converter allows the illumination to operate with a PoC voltage in the typical range from 8 – 16 V or higher.

The design uses the LM51581-Q1 boost converter with it's large input and output voltage range and small overall solution size.

3.3 High-Side Switch

The high-side switch is placed between the boost converter and the LED driver and buffer capacitor. The high-side switch limits the output current of the boost converter and thus also the PoC current on the input side. This makes sure that the current rating of the components on the PoC side is not exceeded.

The procedure to determine the minimum current limit for a given LED configuration is described in the Design Steps section.

The design uses the TPS1H000-Q1 high-side switch due to the adjustable current limit and small size.

3.4 Buffer Capacitor

The buffer capacitor stores the required energy for the high current LED pulses and is placed at the input of the LED driver. The capacitor is discharged during the on-state of the IR LEDs and recharged during the off-state of the IR LEDs. The buffer capacitor is required to store enough energy to drive the LEDs for the specified pulse duration and power.

To calculate the minimum required capacitor size, follow the steps in the Design Steps section.

Once the minimum capacitor size has been calculated, a fitting capacitor can be selected and checked if the required PCB dimensions can be fulfilled as the capacitor size has a significant impact on the overall solution size.

3.5 LED Driver

The LED driver uses a buck converter topology and provides a constant current to the connected IR LED string during the on-time period. The majority of the energy for the LED current pulse is drawn from the buffer capacitor.

The design uses the TPS92642-Q1 synchronous buck IR LED driver with it's diagnostic features including eye safety protection, high output current capability of 5 A and high efficiency.

3.6 Serializer

The design uses a DS90UB953-Q1 FPD-Link III serializer to establish a high-speed connection to a deserializer link partner board, like the DS90UB954-Q1EVM. The diagnostic features of the FPD-Link III devices are used to determine the impact from the pulsing LEDs on the high-speed FPD-Link channel performance.

3.7 Design Steps

The following equations provide a guideline to calculate the required parameters for the design configuration.

The first step is to calculate the required energy which needs to be stored in the buffer capacitor for a single LED pulse with Equation 1.

$$E_{LED} = \frac{V_{F(MAX)} \times I_{LED} \times N \times t_{ON}}{\eta} \tag{1}$$

where

- $V_{F(MAX)}$ is the maximum forward voltage of one IR LED
- I_{LED} is the desired peak LED current
- N is the number of LEDs connected in series
- t_{ON} is the desired LED current pulse on-time
- η is the estimated efficiency of the LED driver

In the next step, the required high-side switch current limit can be calculated with Equation 2.

$$I_{LIM(MIN)} = \frac{E_{LED}}{V_{Boost} \times t_{OFF}} \tag{2}$$

where

- V_{Boost} is the configured output voltage of the boost converter stage
- t_{off} specificies the time for recharging the buffer capacitor and can be selected depending on the LED pulse frequency and on-time

The calculated value represents the minimum recharge current which is required to fully recharge the buffer capacitor before the next LED pulse occurs.

Once an appropiate recharge current has been selected, the resulting input current which flows over the coaxial cable and PoC filter inductors can be determined with Equation 3.

$$I_{PoC} = I_{LIM} \times \frac{V_{Boost}}{V_{PoC}} \times \frac{1}{\eta} + \frac{\Delta I}{2} \quad (3)$$

where

- I_{LIM} is the selected recharge current limit
- V_{PoC} is the voltage on the coaxial cable
- η is the estimated efficiency of the boost converter
- ΔI is the peak-to-peak inductor ripple current, which is typically 20 - 40 % of the output current

In the last step, the required buffer capacitor size can be calculated with Equation 4.

$$C_{BUF(MIN)} = \frac{2 \times E_{LED} - I_{LIM(MIN)} \times V_{Boost}}{V_{Boost}^2 - V_{BUF(MIN)}^2} \quad (4)$$

$V_{BUF(MIN)}$ represents the minimum voltage level in the buffer capacitor at the end of the discharge cycle. The minimum voltage level must be greater than the maximum expected output voltage of the LED driver.

4 Test Results

This section shows the test results for the system described in the previous section. The system configuration has been set according to the description in the Section 4.4 section and with a PoC voltage of 12 V, high-side switch current limit of 250 mA and a buffer capacitor size of 330 µF.

4.1 LED and PoC Voltage Waveforms

Figure 4-1 shows the voltage waveform of the LED driver output in yellow and the corresponding voltage on the coaxial cable in green. The figure shows that the LEDs are pulsed correctly and the voltage waveform on the coaxial cable is as expected. The figure shows the waveforms for a LED current of 2.5 A , a pulse width of 4 ms and a high-side switch current limit of 250 mA.

Figure 4-1. LED and PoC Voltage Waveform

4.2 Margin Analysis Program Result

Margin Analysis Program (MAP) is used to evaluate the FPD-Link high-speed channel performance during the pulsing LED current. In MAP, the adaptive equalization process is disabled. The strobe position and equalization (EQ) level are set manually to create representations of the signal eye which can be used for system evaluation. The following two figures show the MAP result with and without pulsed LEDs.

Green areas indicate that for the given combination of EQ level and strobe position no bit errors have been detected. Red areas indicate where bit errors have been detected.

Figure 4-2 shows the MAP result without pulsing LEDs and Figure 4-2 shows the MAP result with pulsing LEDs. A comparison between both diagrams is showing insignificant differences in the results and therefore negligible impact on the FPD-Link communication from the pulsing LEDs.

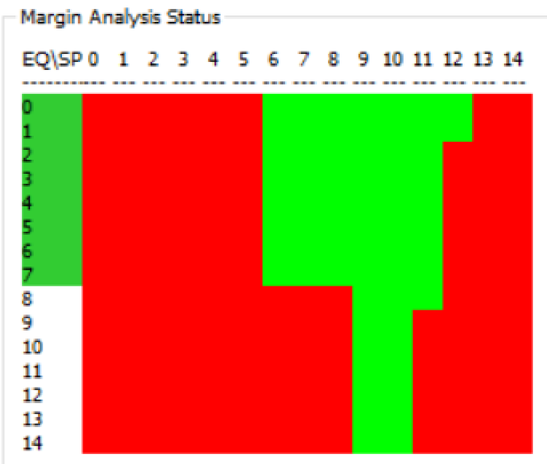

Figure 4-2. MAP result without pulsing LEDs

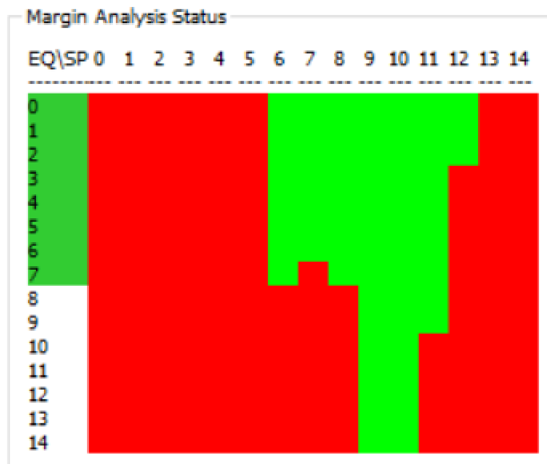

Figure 4-3. MAP result with pulsing LEDs

For more information on MAP, see *Margin Analysis Program (MAP) and strobe positions for DS90UB954-Q1 and DS90UB960-Q1*.

4.3 Differential Supply Noise Level

The differential supply noise level is measured directly between the Dout**+** and Dout**-** pins of the serializer and has direct impact on the FPD-Link back channel performance. The noise limit for FPD-Link **III** is 25 mVpp in the frequency range of 0 – 50 MHz. To correctly measure the differential supply noise, both the serializer and deserializer need to be powered down by pulling the PDB pins low on both devices. Figure 4-4 shows the noise level with pulsing LEDs.

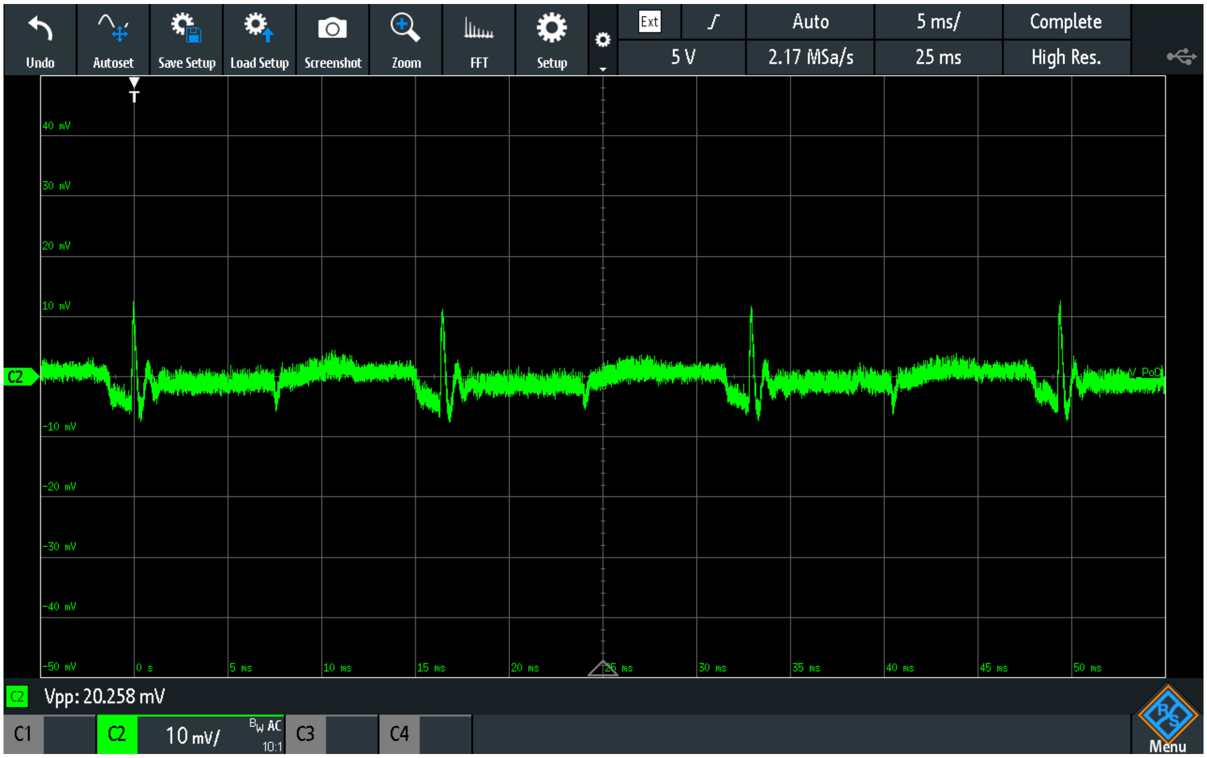

Figure 4-4. Differential Supply Noise

The measured noise level is 20 mVpp, which is below the mentioned limit of 25 mVpp specified for FPD-Link **III**.

4.4 Test Cases

Table 4-1 shows the test cases with different test parameters such as LED pulse duration and frequency, LED peak power, PoC voltage and high-side switch current limit. All shown test cases have passed the MAP test with negligible impact. The boost converter output voltage for all tests was set to 24 V.

Table 4-1. List of Test Cases

Test case	PoC Voltage(1) (V)	HSS Current Limit (mA)	Capacitor Size (µF)	LED Peak Current (A)	LED Peak Power(2) (W)	LED Pulse Width (ms)	LED Pulse Frequency (Hz)
1	12	400	560	3	18	4	30
2	12	200	330	3	18	3	30
3	12	200	330	3	18	2	60
4	12	100	220	3	18	3	30
5	9	200	330	3	18	2	60
6	12	250	330	2.5	15	4	60
7	8	250	330	2.5	15	4	60

(1) PoC voltage value indicates the voltage level on the ECU side and does not consider the voltage drop across the coaxial cable.
(2) All tests have been performed with a LED string configuration of two OSRAM SFH 4728AS A01 IR LEDs connected in series.

5 Summary

The presented single cable implementation using Power-over-Coax helps reducing the amount of cabling needed for a DMS system with a remote camera module. The approach to combine the power connection for IR illumination with the PoC connection for the camera subsystem enables lowering cost and weight of the camera module cabling. The app note also discussed how the basic parameters can be calculated for a chosen LED string configuration. The presented test results proving that with the correct configuration the noise impact from the pulsing IR LEDs on the high-speed FPD-Link forward and back channel is within the specified limits.

6 References

1. Texas Instruments, *Power-over-Coax Design Guidelines for DS90UB953-Q1* Application Report.
2. Texas Instruments, *Margin Analysis Program (MAP) and strobe positions for DS90UB954-Q1 and DS90UB960-Q1* Application Report.

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