Application Report
SNVA810–February 2018

Low Conducted EMI Power Solution for Automotive Digital Cockpit With LMR14050 and TPS65263

Vental Mao, Daniel Li

ABSTRACT

For automotive electronics, a challenge is electromagnetic interference (EMI). The circuit schematic and printed circuit board (PCB) are critical to achieving excellent EMI performance for the power rail in the automotive digital cockpit. Therefore, knowing how to choose the IC and design the circuit has the most significant impact, while knowing how to optimize the board layout is also pivotal for EMI performance. This application report provides a way to design the low conducted EMI power solution for the automotive digital cockpit.

Contents

List of Figures

List of Tables

1 Introduction

As the central controller of the automotive digital cockpit, the processor needs multi-channel power rails. For example, the i.MX 6ULL processor is an integrated multimedia-focused product whose main parts are powered by 3.3 V at 2 A (Telecom and LCD module), 1.8 V at 2 A (DRAM module), and 1.5 V at 3 A (Core). The TPS6526x-Q1 family is easy-to-use, triple synchronous, buck converters, with I^{2}C-controlled dynamic voltage scaling, capable of delivering 3 A, 2 A, and 2 A of 3-channel load current, with 4-V to 18-V input voltage. Additionally, the switching frequency of this part is adjustable from 300 KHz to 2.3 MHz, which is also suitable for an automotive application.

Normally, an automotive application needs a wide input voltage as its first power stage to be used in different conditions. The LMR140x0-Q1 family of devices, with 4-V to 40-V wide input voltage and 2 A, 3.5 A, and 5-A load, is frequently applied in the automotive field. The devices also feature an adjustable frequency from 200 KHz to 2.5 MHz, selectable PFM at light load, optional spread spectrum, precision enable, and so on. The devices in this family are available in an HSOIC-8 and WSON-10 package. The pinout is designed to enable an optimized PCB layout, with the best EMI and thermal performance.

Choose the LMR14050-Q1 device as the first stage, with 5-V, 5-A output to power on the TPS65263-Q1 device, and 3.3-V, 1.5-V, and 1.8-V output. Both devices work with 2.2 MHz, set this frequency to avoid AM and FM disturbance. Meanwhile, the 5-V voltage can also supply the USB bus and some other devices. Figure 1 shows the power tree block diagram.

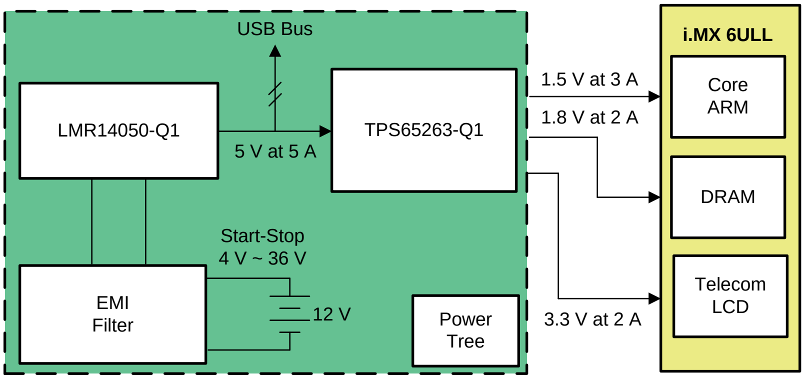


Figure 1. Block Diagram

2 Buck Converter Layout Considerations for EMI Performance

In general, the EMI can be classified in the switching-converter as conducted EMI and radiated EMI. The difference between them is the manner in which the EMI field propagates. If the noise is coupled through physical contact of the conductors in the PCB, such as the parasitic impedance or connections, then the noise is called conducted EMI. For the radiated EMI, the noise can propagate through radio transmission.

For good EMI performance, the board layout is a critical aspect. A poorly designed PCB will deteriorate the EMI. Due to the switching action of the converter, voltage transients and current transients with fast rates exist in the circuit and can be symboled as dv/dt and di/dt. These transients generate a voltage shift with the switching frequency and voltage spikes with high frequency by using the equation V = L × (di/dt), where L is the parasitic inductance of the current loop. These voltage shifts and voltage spikes are the root cause of the undesirable EMI, so reducing the parasitic inductance and the slew rate of the voltage transient and current transient in the PCB are the main considerations in the layout.

2.1 Minimize Loop Area and High di/dt

Figure 2 shows a simplified buck converter schematic. There are two, large current, high di/dt loops in the buck circuit. One loop is formed by the input capacitor, high-side FET, and low-side FET (power loop); the other loop is formed by the boot capacitor, and boot resistor and high-side FET (charge loop). For the power loop, minimizing the loop area is more critical because the parasitic inductance is proportional to the loop area. In the charge loop, the boot resistor (Rboot) is used to control the speed of the switch, which changes the drive-current transient rate. With the drive-current transient rate decreasing, the switching action is also slowed down, which decreases the rate of the voltage transient and current transient in the power loop. So, minimizing the loop area and slowing the drive-current transient rate are all effective for the EMI in the charge loop.

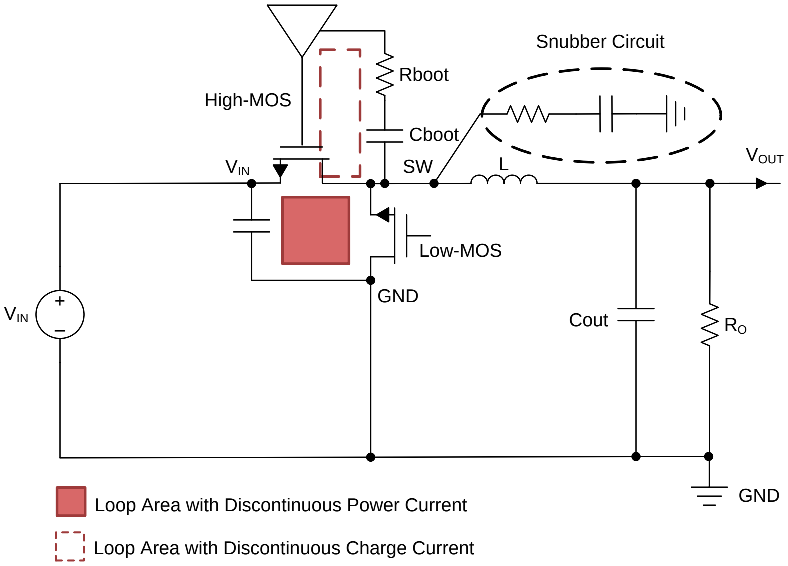


Figure 2. Simplified Buck Converter Schematic

From the previous analysis, the outside Schottky diode must be placed close to the LMR14050-Q1 device. Then, the boot capacitor and boot resistor must also be placed closed to the IC. The boot resistor can control the switch rate, which is helpful for EMI, by reducing the SW voltage spike, but it also increases the switching loss. Besides, a snubber circuit can be added to absorb the excess energy, which will also increase power consumption. So the trade-off between the EMI and efficiency should be considered.

Figure 3 shows the pin configuration compact with the layout of the LMR14050-Q1 and TPS65263-Q1. The layout is based on the principle which was previously mentioned, and the red circuit in the layout is the power loop of the buck converter. All the input caps and the diode must be located following the loop.

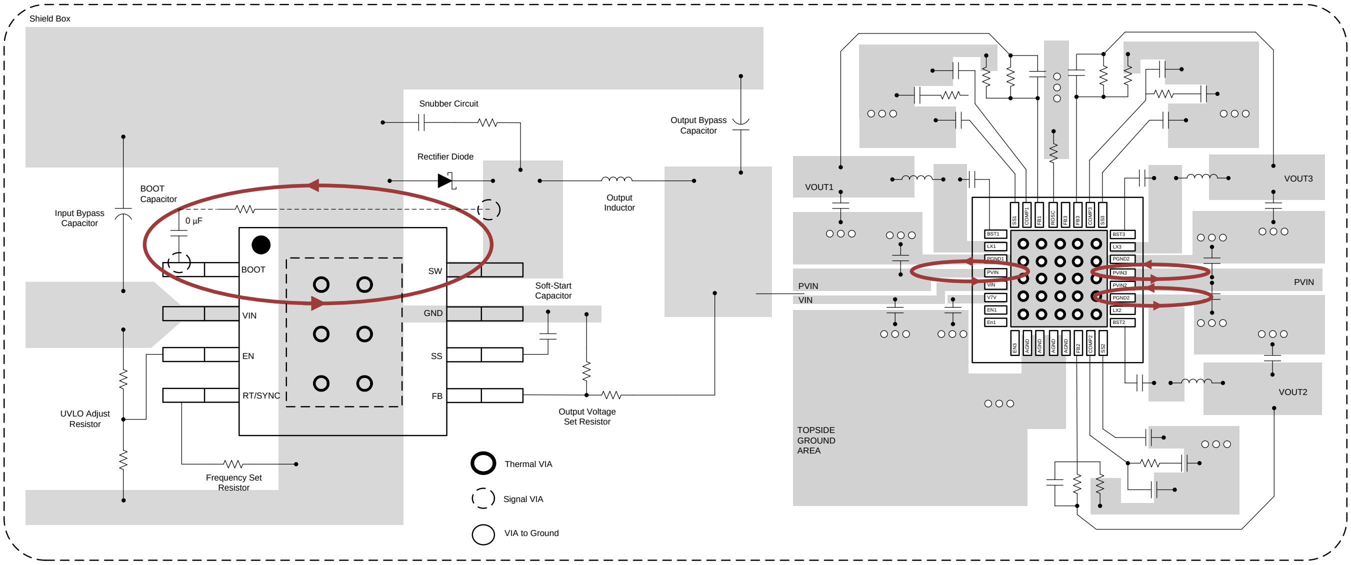


Figure 3. Pin Configuration Compact With the Layout

2.2 *Spread Spectrum*

Dithering the switching frequency, which is called a spread spectrum, is also an effective technique to reduce the EMI. In general, the fundamental switch node frequency is shown at the spectrum analysis as a sharp spectral line with a high peak. One way to reduce this is to use spread spectrum technology, which periodically changes the switching frequency slightly and spreads the energy wider. This is useful not only for the fundamental, but especially for the higher frequency harmonic as well. In this solution, the LMR14050SSQDDARQ1 device has the spread spectrum function, which can be seen in the spectrum of Figure 7.

2.3 *EMI Filter*

In addition to the layout, another critical role for good EMI is the input filter. With switch ON and OFF actions, the discontinuous currents bring voltage ripples. These ripples have a wide frequency range, including the switching frequency and high-order harmonic frequency. These noises are coupled to other systems by the connection, which interferes with their operation and even break them down. Therefore, adding an input filter to smooth the voltage perturbations is considerable.

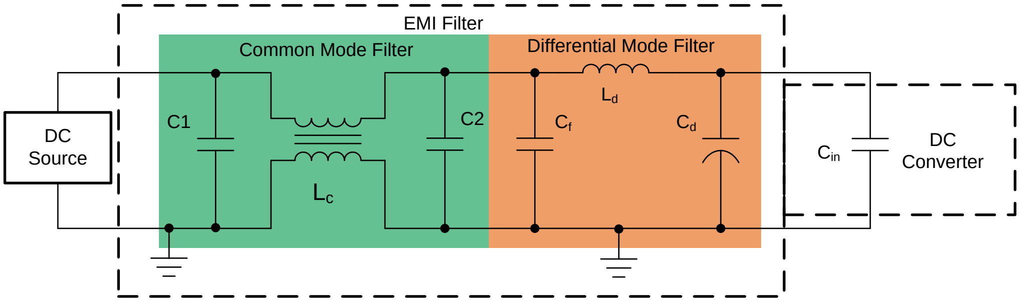


Figure 4. Simplified EMI Filter

Figure 4 shows a simplified EMI filter, which includes the common mode filter (CM) filter and the differential mode (DM) filter. The main purpose of this filter is to filter the noise coming from the input of the converter. For the low or medium power converter, the suggested value of L_d of the DM filter is in the range of 1 µH to 10 µH. C_f can be picked using Equation 1 or Equation 2.

$$C_{fa} = \frac{C_{in}}{C_{in} L_d \left(\frac{2\pi f_s}{10} \right)^2 - 1} \tag{1}$$

$$C_{fb} = \frac{1}{L_d} \left(\frac{10^{|ATT|_{dB}/40}}{2\pi f_s} \right)^2 \tag{2}$$

where

- f_s is the switching frequency.
- $|Att|_{dB}$ is the attenuation of the filter design in dB.

Equation 3 is the analytical formula to obtain the required attenuation.

$$|ATT|_{dB} = 20\log\left(\frac{\frac{1}{\pi^2 f_S C_{in}} \sin(\pi D)}{1\mu V} \right) - V_{max} \tag{3}$$

where

- V_{max} is the maximum noise level in dBµV.
- D is the duty cycle.

Now, select the bigger value between Equation 1 and Equation 2 as the value of C_f. For the damping capacitor, C_d, an electrolytic capacitor can be used, see Equation 4.

$$C_d > 4 \times C_{in} \tag{4}$$

Equation 5 gives the ESR value.

$$ESR = \sqrt{L_d / C_{in}} \tag{5}$$

For the CM filter, there is an easy way to choose the CM inductor. Figure 5 shows the frequency versus impedance characteristic diagram of the CM inductor (PLT5BPH5013R1SNL). Z_c is the common mode impedance and Z_d is the differential mode impedance. Normally, the higher impedance can pass less AC signal, which is the key to filtering the noise. So, choosing a CM inductor with high impedance at the noise frequency is an effective method. Also, the high-frequency capacitor should be added, to deliver the noise to the GND.

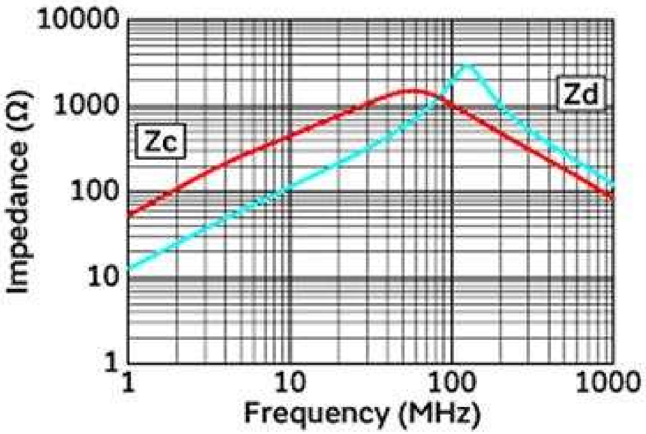


Figure 5. Frequency Versus Impedance Characteristic Diagram

2.4 Shielding

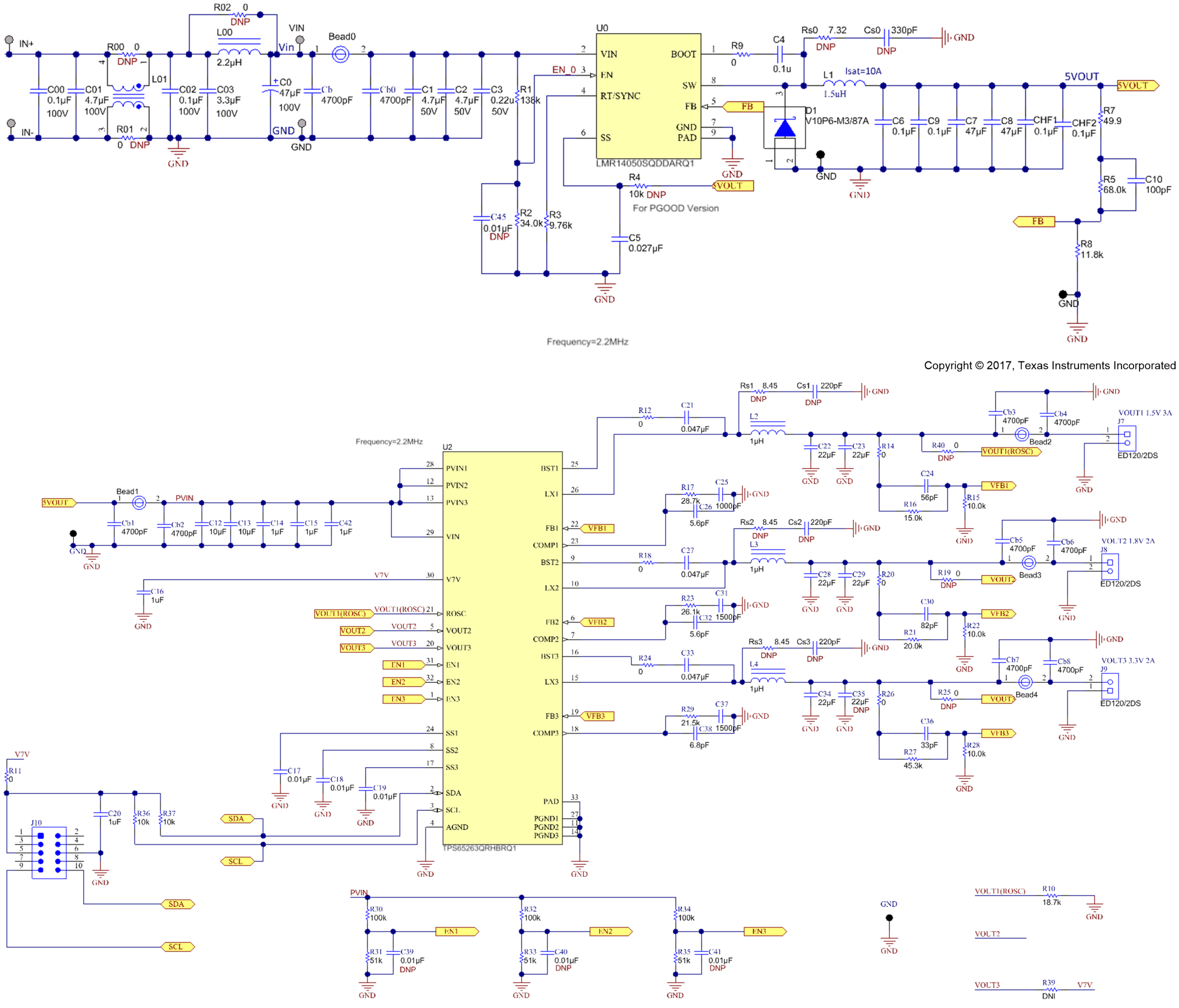
For a better radiated EMI, shielding, such as ground shielding and mask shielding, can be added to the board.

Ground shielding is an unbroken ground plane added in the middle layer of the PCB. When the ground plane is added, the high di/dt current path goes through the top layer and induces an opposing current on the ground plane at the same time. This opposing current, called mirror current, generates an opposing magnetic to cancel the magnetic in the top layer. Additionally, the ground plane also minimizes the current loop area to reduce the radiated energy.

Mask shielding means using a mental mask to connect with the power ground, which can block the radiated noise from the outside. Shielding is an effective way to decrease the radiated EMI approximately 14 dBμV/m in this design.

3 Design With LMR14050-Q1 and TPS65263-Q1

Figure 6 shows the design example for the processor of the automotive digital cockpit, using the nonsynchronous buck regulator LMR14050-Q1, and the synchronous buck regulator TPS65263-Q1, from TI.



Copyright © 2017, Texas Instruments Incorporated

Copyright © 2018, Texas Instruments Incorporated

Figure 6. Solution for Processor of Automotive Digital Cockpit

Table 1 lists the design specifications.

Table 1. Power Solution Specification Summary

Part Number	Design Parameter	Example Value
LMR14050SSQDDARQ1	Input voltage range (V_{IN})	4 V to 36 V (typical 12 V)
	Output voltage (V_{OUT1})	5 V
	Load current (I_{OUT1})	5 A
	Switching frequency (F_{SW1})	2.2 MHz

Table 1. Power Solution Specification Summary (continued)

Part Number	Design Parameter	Example Value
TPS65263QRHBRQ1	Input voltage range (V_{OUT1})	5 V
	Output voltage (V_{OUT2}, V_{OUT3}, and V_{OUT4})	1.5 V,1.8 V, and 3.3 V
	Load current (I_{OUT2}, I_{OUT3}, and I_{OUT4})	3 A, 2 A, and 2 A
	Switching Frequency (F_{SW2})	2.2 MHz

For the schematic of the LMR14050-Q1 device, WEBENCH® software can be used to generate a complete design. The data sheet of the two devices is also an effective tool to design the circuit.

4 Experiment Results

Use the 12-V battery as the power source and the power resistor as the load to make the circuit work with full load, and then measure the EMI performance. Figure 7 and Figure 8 show the positive and negative noise from the input wire without the filter and shielding mask, and the EMI standard in the diagram is the CISPR25 Class 5 (C5). In Figure 7 and Figure 8, the noise from 5-MHz to approximately 40-MHz frequency exceeds the average limit, and for the high frequency (30 MHz to approximately 100 MHz), not only does the average, but also the peak both exceed the limit.

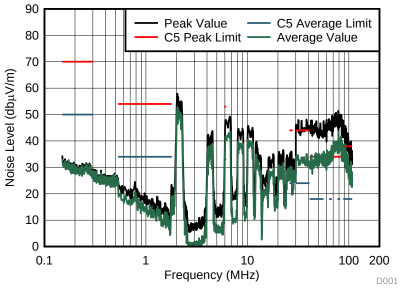


Figure 7. Noise Without Filter and Shielding Mask for C5 Standard (Positive)

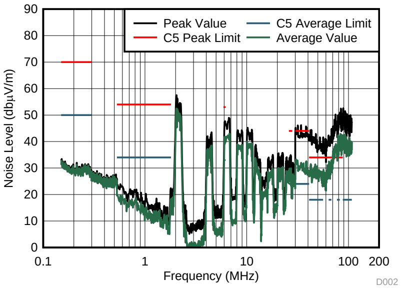


Figure 8. Noise Without Filter and Shielding Mask for C5 Standard (Negative)

To optimize the EMI performance, analyzing the noise type is significant. Figure 9 and Figure 10 show the noise type of this application without the filter and shielding mask. In Figure 9, the CM noise is located at the high frequency band (30 MHz to approximately 100 MHz), and the DM noise (see Figure 10) focuses on the middle frequency band (2 MHz to approximately 30 MHz). The side-band harmonic windows are the results with spread spectrum technology.

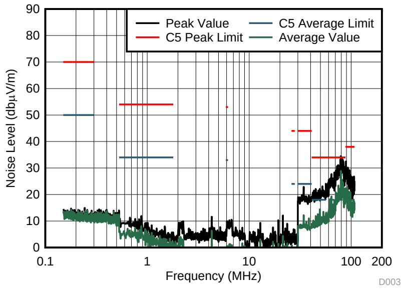


Figure 9. Noise Type Analysis (CM Noise)

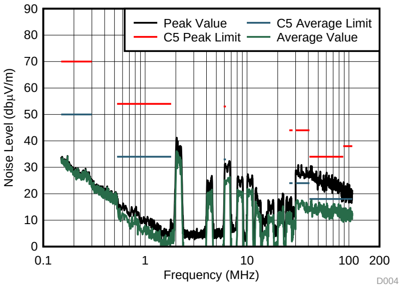


Figure 10. Noise Type Analysis (DM Noise)

After measuring the maximum DM noise level, the attenuation coefficient of $|Att|_{dB}$ can be set. Then, the value of the DM inductor and capacitors can easily be selected. In this design, L_d = 2.2 µH, C_d = 47 µF (with ESR = 0.42 Ω), and C_f = 3.3 µF. Figure 11 and Figure 12 show the EMI result with the DM filter. The DM noise is attenuated nearly 35 dBµV/m by the filter during the middle frequency band.

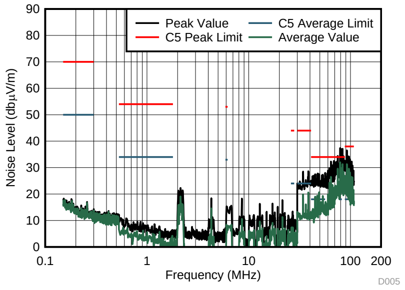


Figure 11. Noise With DM Filter for C5 Standard (Positive)

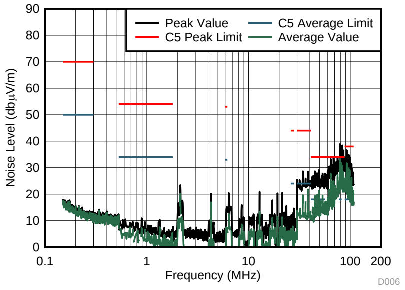


Figure 12. Noise With DM Filter for C5 Standard (Negative)

The high-frequency noise (30 MHz to 100 MHz) is also reduced, but still exceeds the limit level. This is because the DM filter does not effectively filter CM noise, so the CM filter is necessary. Figure 13 and Figure 14 show the noise with the CM and DM filter. Compared with Figure 11 and Figure 12, the CM noise (40 MHz to 100 MHz) is decreased nearly 20 dBµV/m. The EMI performance passes CISPR25 Class 5.

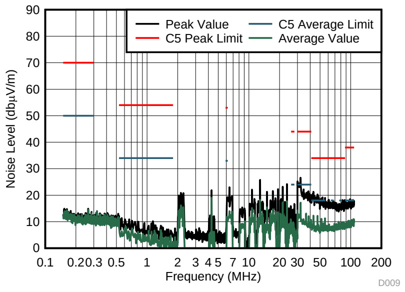


Figure 13. Noise With DM and CM Filter for C5 Standard (Positive)

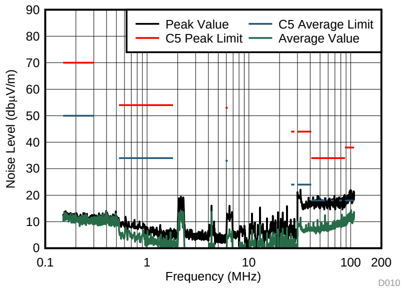


Figure 14. Noise With DM and CM Filter for C5 Standard (Negative)

According to the analysis from Section 2.4, adding a shielding mask is another effective way to optimize the EMI performance. Figure 15 and Figure 16 show the noise, only with the CM filter and shielding mask. The CM noise is filtered out and decreased to a low noise level. The DM noise is also mostly filtered, because the leakage inductance of the CM inductor can form the DM filter with parasitic capacitance. Figure 17 and Figure 18 show the noise with all the filters and a shielding mask. The noise is attenuated nearly 14 dBµV/m, compared with the data in Figure 13 and Figure 14, and close to the floor noise of the EMI equipment. The main reason for the EMI results in Figure 15 through Figure 18 is that the shield reduces radiated noise coupling with the long input wire, which acts an antenna, especially the middle-frequency band noise in this design.

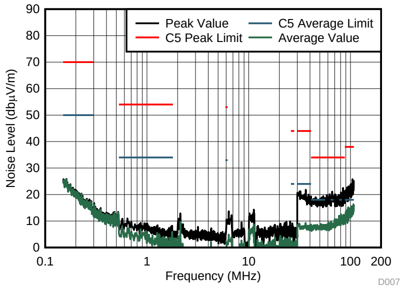


Figure 15. Noise With CM Filter and Shielding Mask for C5 Standard (Positive)

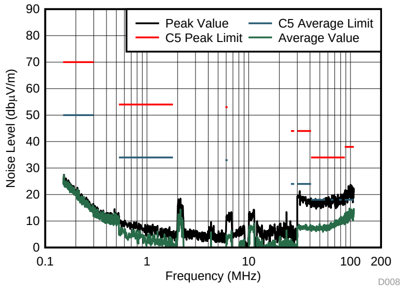


Figure 16. Noise With CM Filter and Shielding Mask for C5 Standard (Negative)

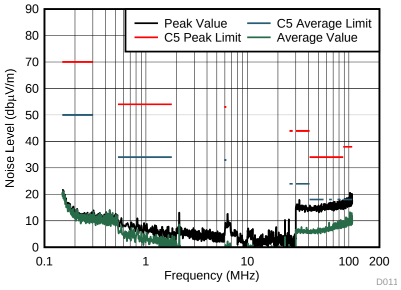


Figure 17. Noise With All Filters and Shielding Mask for C5 Standard (Positive)

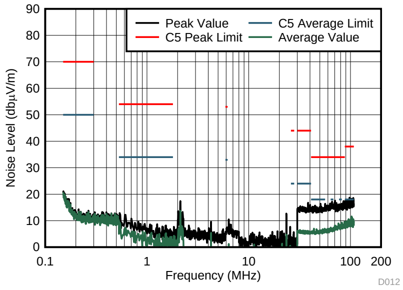


Figure 18. Noise With All Filters and Shielding Mask for C5 Standard (Negative)

5 Conclusion

This application report presents a power solution for the processor in the automotive digital cockpit, such as the i.MX 6ULL. The power tree has two stages that provide four power rails:

- First stage – LMR14050: 5 V at 5 A (USB bus or other device)
- Second stage – TPS65263: 3.3 V at 2 A (Telecom and LCD module), 1.8 V at 2 A (DRAM module), and 1.5 V at 3 A (Core).

Data tested, based on the example design, shows that the conducted EMI performance of this solution can pass the CISPR25 Class 5 standard with the CM and DM filters, and even have the lowest noise level with all the filters and shielding, making it suitable as a power solution for an automotive digital cockpit.

6 References

- NXP Semiconductors, i.MX 6ULL Application Processors for Consumer Products, data sheet
- Texas Instruments, *TPS65263, 4.5- to 18-V Input Voltage, 3-A/2-A/2-A Output Current Triple Synchronous Step-Down Converter With I2C Controlled Dynamic Voltage Scaling*, data sheet
- Texas Instruments, *LMR14050 SIMPLE SWITCHER® 40 V 5 A, 2.2 MHz Step-Down Converter with 40 µA IQ*, data sheet
- Texas Instruments, *Low Radiated EMI Layout Made SIMPLE With LM4360x and LM4600x*, application report
- Texas Instruments, *AN-2155 Layout Tips for EMI Reduction in DC / DC Converters*, application report
- Texas Instruments, *AN-2162 Simple Success With Conducted EMI From DC-DC Converters*, application report
- M. Sclocchi, *Input Filter Design for Switching Power Supplies*

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated (‘TI”) technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, “TI Resources”) are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI’s provision of TI Resources does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI’s standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2018, Texas Instruments Incorporated