Application Note

Reducing Conducted EMI in a Buck Converter for 48 V Automotive Applications

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ABSTRACT

This application note discusses some of the challenges of EMI (electromagnetic interference) in buck converters particularly in automotive systems where the power rail is increasing to 48V DC. The higher rates of change in voltage (dv/dt) and current (di/dt) in the buck converter make it more difficult to meet conducted EMI compliance. This application note discusses the composition and generation of conducted EMI noise in buck converters, using an emission model. To address these EMI related concerns, several methods and techniques were implemented to help designers mitigate conducted EMI issues in a buck regulator. Layout tips, inductor selection, ferrite bead optimization and spread spectrum are discussed in this article.

Table of Contents

List of Figures

List of Tables

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1 Introduction

With the increasing use of 48V DCDC power rails in automotive systems, the higher dv/dt and di/dt of buck converters can make it more challenging for a system to meet EMI specifications. Table 1-1 shows the peak and average limits of conducted EMI for CISPR 25, which covers a specific frequency range from 150 kHz to 108 MHz.

Table 1-1. Conducted Emissions Peak and Average Limits in CISPR 25

		Levels in dB (µV)									
Band	Frequency (MHz)	Class 1		Class 2		Class 3		Class 4		Class 5	
		Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average
Broadcast											
LW	0.15 - 0.3	110	90	100	80	90	70	80	60	70	50
MW	0.53 - 1.8	86	66	78	58	70	50	62	42	54	34
SW	5.9 - 6.2	77	57	71	51	65	45	59	39	53	33
FM	76 - 108	62	42	56	36	50	30	44	24	38	18
TV Band I	41 - 88	58	48	52	42	46	36	40	30	34	24
Mobile Services											
CB	26 - 28	68	48	62	42	56	36	50	30	44	24
VHF	30 - 54	68	48	62	42	56	36	50	30	44	24
VHF	68 - 87	62	42	56	36	50	30	44	24	38	18

Typically, the EMI noise in the frequency range of 150 kHz to 30 MHz is primarily comprised of the switching frequency and its harmonics. This type of noise can be reduced by using EMI filters. However, for the frequency range of 30 MHz to 108 MHz, which includes AM and FM radio, the EMI noise is mainly caused by near-field radiation. EMI filters are less effective in this frequency band due to the influence of parasitic capacitance and inductance. Therefore, more design considerations are necessary to meet the EMI limits, particularly in the FM band. This application focuses on conducted EMI and provides tips and tricks that were implemented on the LMR38020-Q1 EVM.

2 Conducted Emission Model of Buck Converters

The conducted emission model of a buck converter involves understanding the sources and propagation paths of both differential-mode (DM) and common-mode (CM) noise. By understanding these sources, designers can develop mitigation strategies to reduce conducted electromagnetic interference (EMI) noise.

DM noise refers to the noise that flows between the input and output of the converter. It is caused by the switching action of the converter, which results in voltage and current variations. These variations can generate high-frequency noise that can propagate through the input and output circuits. The main sources of DM noise in a buck converter are the switching transistor, the inductor, and the input capacitor.

CM noise, on the other hand, refers to the noise that flows in parallel to the input and output of the converter. It is caused by asymmetries in the converter's layout and parasitic capacitance. CM noise can be induced by the switching action of the converter and can propagate through the ground and power lines. The main sources of CM noise in a buck converter are the parasitic capacitance between the input and output circuits, the ground plane, and the power traces.

2.1 DM Noise Emission Model

A typical buck circuit with an input EMI filter (L_f, C_f) is shown in Figure 2-1. The dashed line highlights the Line Impedance Stabilization Network (LISN) measuring conducted noise. The switcher’s input current i_{Q1} is discontinuous resulting in fundamental and lower-order harmonics as well as high frequency noise current. Differential noise is caused by the opposite propagation paths between the positive and return power lines and is related to the fast di/dt of the input current, so it can be equivalent to current source diven model like

Figure 2-2. The EMI filter can reduce the fundamental and lower order harmonics but it may be less effective in reducing high frequency DM noise due to parasitic parameters of inductors and capacitors. In order to reduce high frequency DM noise, package technology and layout routing techniques become important to mitigate these sources of noise in the system.

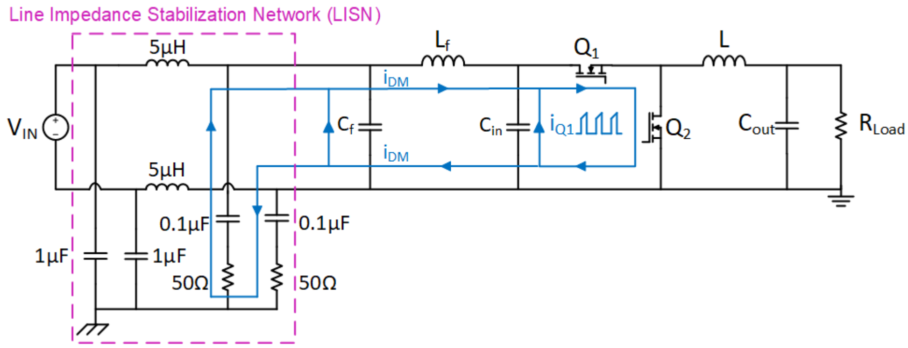


Figure 2-1. Propagation Path of DM Noise Induced by di/dt

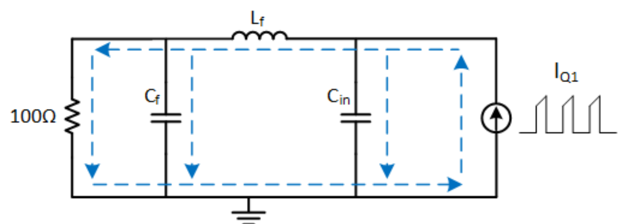


Figure 2-2. Emission Model of DM Noise Induced by di/dt

Besides, the input current loop can induce magnetic field that bypasses the EMI filter and couples to the LISN as shown in the Figure 2-3. This magnetic coupling is modeled as mutual inductance (M_1). The leakage magnetic field of the power inductor also couples to the LISN network with a mutual inductance (M_2). Its emission model can be equivalent to Figure 2-4. Both types of magnetic coupling can generate DM noise current. To address these, it is critical to minimize the input current loop of the buck converter by strategically placing the input capacitor to reduce magnetic coupling (M_1) and it is also beneficial to use a fully sealed inductor to reduce magnetic coupling (M_2).

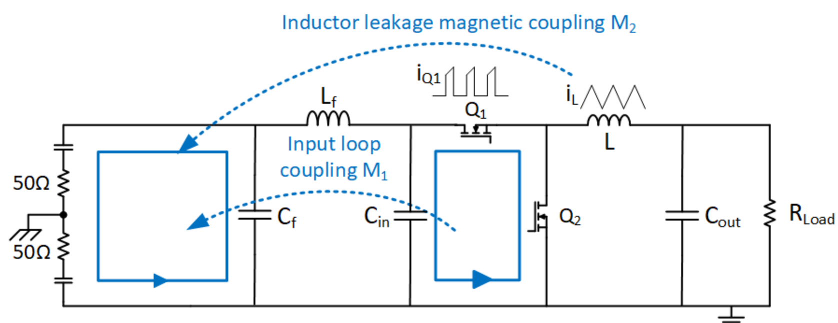


Figure 2-3. Propagation Path of DM Noise Induced by Magnetic Coupling

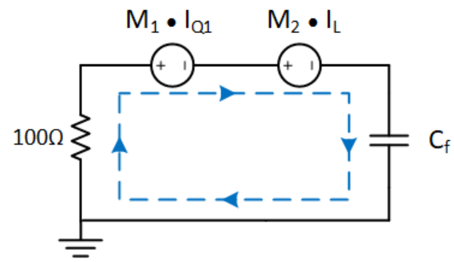


Figure 2-4. Emission Model of DM Noise Induced by Magnetic Coupling

2.2 CM Noise Emission Model

In addition to high di/dt causing DM-noise current, the high dv/dt at the SW node can also couple displacement current to ground through parasitic capacitance Cp. This coupled noise current is then returned by the power line and GND line in the same direction, resulting in CM noise.

Figure 2-5 illustrates the propagation path of CM noise. It can be observed that EMI filters (Lf and Cf) do not effectively hinder the propagation of CM noise, except when a common-mode choke (LCM) is added at the input wire. However, this solution can increase the system cost and solution size, and may not be feasible in some applications.

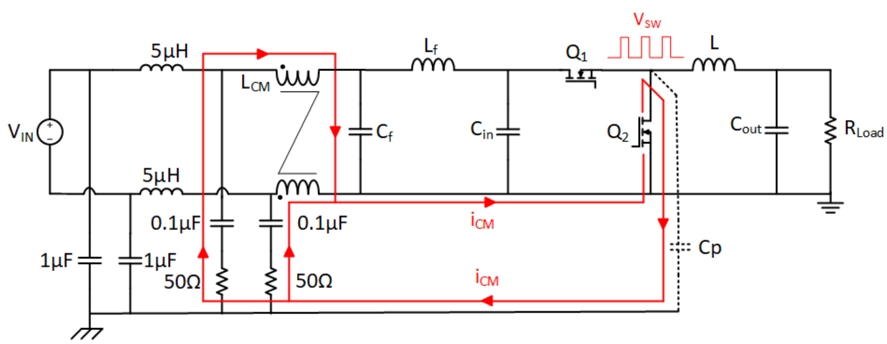


Figure 2-5. Propagation Path of CM Noise

CM noise is influenced by dv/dt and Cp. It can be represented as a voltage source-driven model, as shown in Figure 2-6. The noise source can be reduced by either slowing down the dv/dt slew rate by adding a series Rboot with Cboot, or by reducing Cp by minimizing the SW node area.

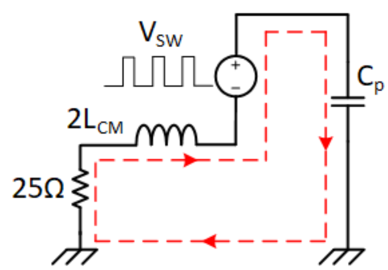


Figure 2-6. Emission Model of CM Noise

3 Reducing Conducted EMI of Buck Converter in 48V DC Power rail

Section 2 presented the propagation path and emission model for both differential mode (DM) noise and common mode (CM) noise of the buck converter. By understanding these factors, EMI issues can be addressed by minimizing noise sources and interfering propagation paths. The EMI tests conducted follow the CISPR 25 Class 5 standard. In this study, the LMR38020-Q1 is used, which is an 80 V, 2 A synchronous buck converter. The schematic of the converter is shown in Figure 3-1. The test conditions include Vin=48 V, Vout=5 V, Iout=2 A, and Fsw=400 kHz, which are typical parameters for a DC-DC power system in an automotive setting.

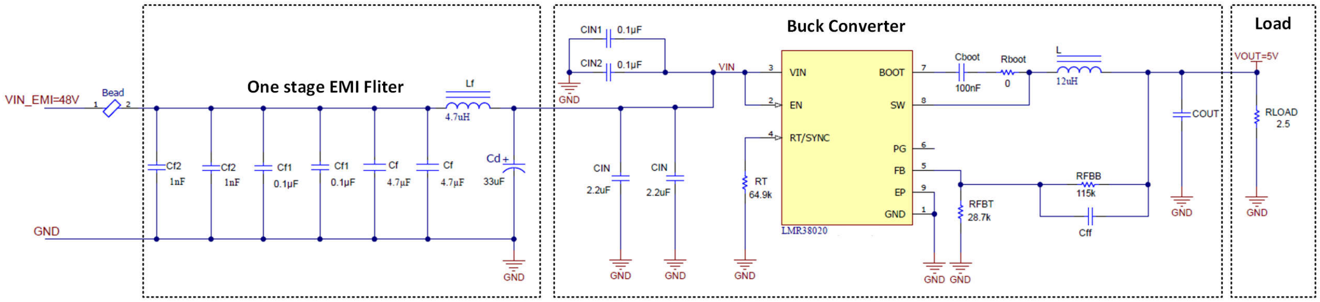


Figure 3-1. Buck Converter Schematic with EMI Filter and Bead

3.1 Bead Consideration

It is evident that the addition of a single-stage EMI filter in front of the converter is effective in reducing DM noise at the switching frequency and its harmonics. However, in some cases, a two-stage filter may be necessary to achieve greater attenuation of DM noise. To maintain a low cost and high-power density solution, an input choke is not utilized in this design.

Furthermore, Figure 3-2 illustrates the inclusion of a bead with a higher self-resonant frequency (SRF) in front of the EMI filter. This serves to increase the input impedance at high frequencies, thus suppressing DM noise caused by input current spikes and magnetic coupling.

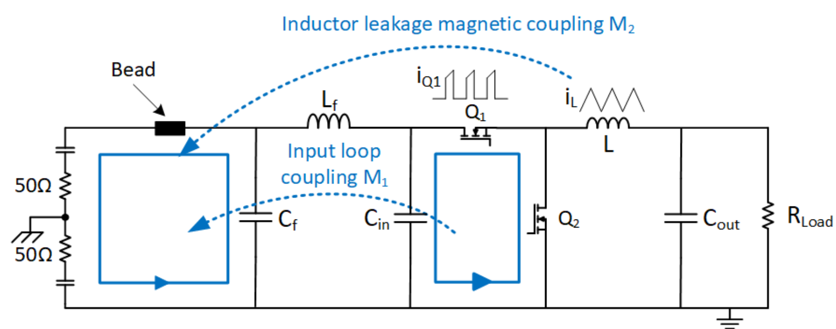


Figure 3-2. Effect of Bead Adding in Front of EMI Filter

Figure 3-3 and Figure 3-4 present the EMI test results with and without the ferrite bead. The data indicates that the inclusion of the bead leads to noticeable reduction in noise levels particularly in the 10 MHz-70 MHz range where the peak noise is approximately 8db lower with the bead and the average noise is reduced by 10db. These results demonstrate the effectiveness of the bead in mitigating noise in the high frequency range.

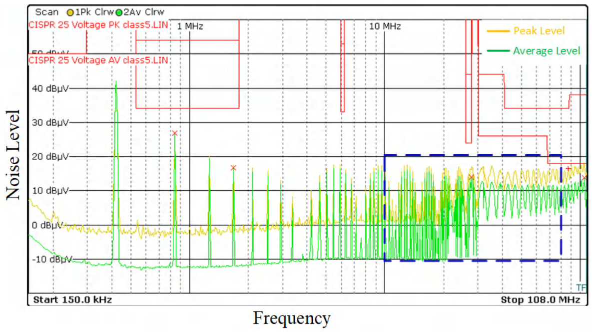


Figure 3-3. Conducted EMI Test Result Without Ferrite Bead

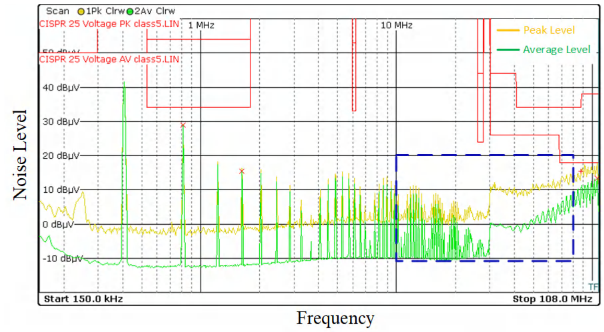


Figure 3-4. Conducted EMI Test Result With Ferrite Bead

3.2 Layout Consideration

Layout plays a crucial role in minimizing EMI noise, and when possible, a four-layer PCB is recommended. The top layer should primarily accommodate the converter, inductor, and SW node, all of which are noise sources. The second layer should be a continuous copper pour acting as a ground plane to provide shielding. The third layer can be utilized for routing input, output, and signal traces. Lastly, the bottom layer should house the EMI filter, positioned far away from the noise sources on the top layer.

The recommended layout for the synchronous buck converter LMR38020-Q1 is outlined below, with important points to consider:

1. Top-layer considerations, as shown in Figure 3-5.

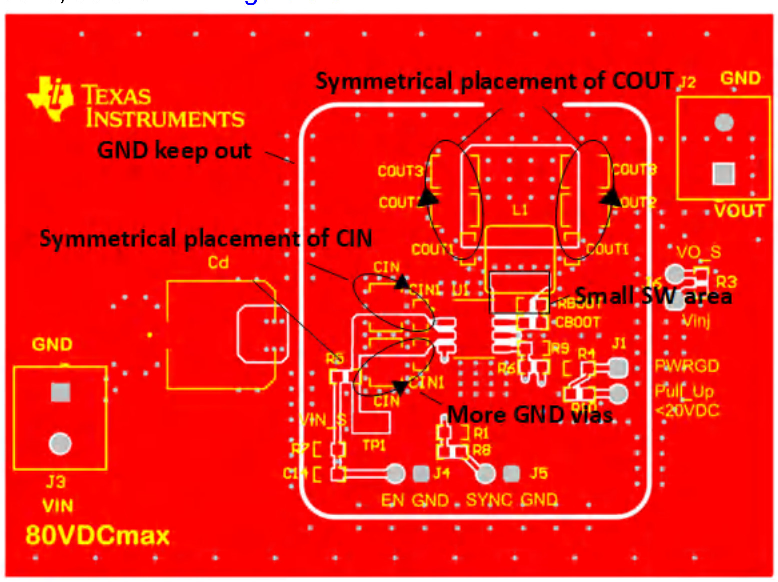
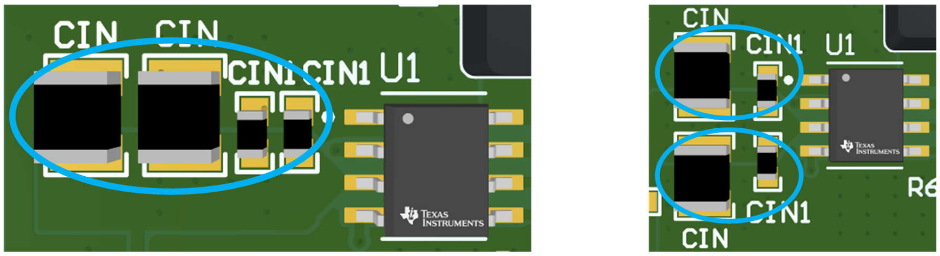


Figure 3-5. Top-layer Layout

- The input capacitor (Cin) should be positioned in close proximity to the VIN and GND pins to minimize the input-critical loop area. Additionally, more vias should be placed around the GND and VIN planes of Cin to reduce the parasitic inductance of the input current loop. Moreover, Cin should be placed symmetrically to create two input loops, which cancels out the magnetic field induced and weakens magnetic coupling to the LISN. Similarly, the output capacitor should also be placed symmetrically to achieve the same effect.
- The SW node, being a major source of noise, should be routed without any vias connected to other layers. Furthermore, the SW node area should be kept small to minimize the parasitic capacitor (Cp).
- It is advisable to include a GND keep out area to isolate the outer GND from the inner GND noise.

Figure 3-6 illustrates the placement of Cin in both asymmetric and symmetrical configurations. Figure 3-7 and Figure 3-8 display the comparison of EMI test results between the two configurations. The data indicates that in the FM band, the peak and average noise levels of the symmetrical capacitor placement are approximately 4dB lower compared to the asymmetric configuration. This finding validates the benefits of magnetic field cancellation achieved through the symmetrical placement of capacitors.



Non-symmetrical placement of Cin   Symmetrical placement of Cin

Figure 3-6. Cin With and Without Symmetrical Placement of Buck Converter

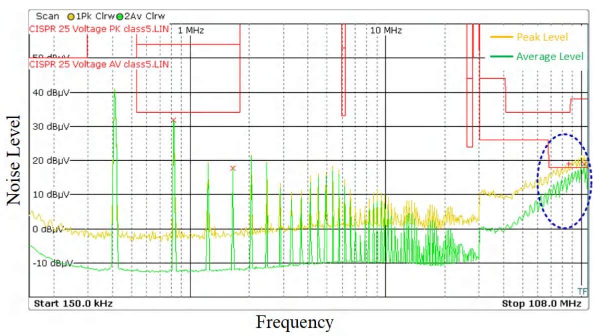


Figure 3-7. Conducted EMI Test Result of Non-symmetrical Cin Placement

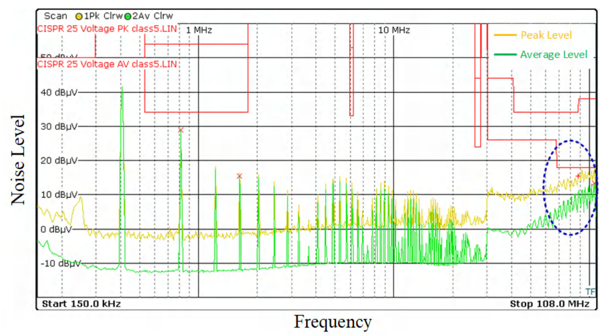


Figure 3-8. Conducted EMI Test Result of Symmetrical Cin Placement

1. Figure 3-9 demonstrates the second layer layout considerations. In this layout the entire second layer is filled with copper as the ground plane. This ground plane is positioned directly underneath the input critical loop and the inductor. By doing so, eddy currents are induced in the copper which help weaken the magnetic coupling between components and reduces the overall EMI noise.

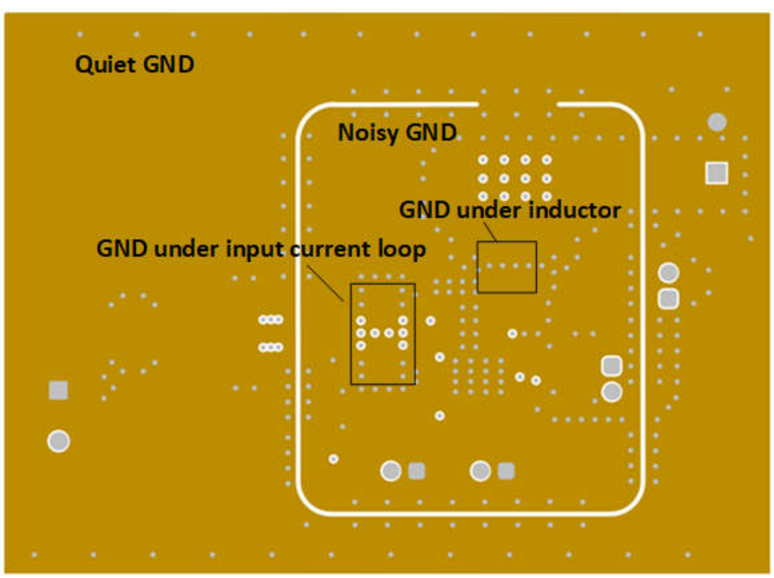


Figure 3-9. Second-layer Layout

2. Third-layer is shown in Figure 3-10, this layer is mainly used for signal traces. Signals such as PowerGood and EN UVLO can be routed on this plane.

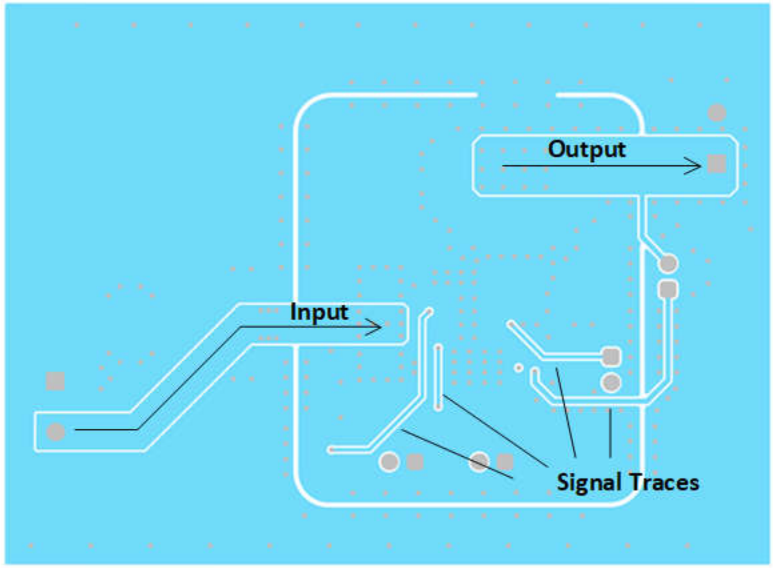


Figure 3-10. Third-layer Layout

3. Bottom-layer is shown in Figure 3-11. The EMI filter is placed on this layer and away from the noise sources previously discussed that are on top layer. Notice the filter capacitors are placed symmetrically as well to further reduce any magnetic coupling.

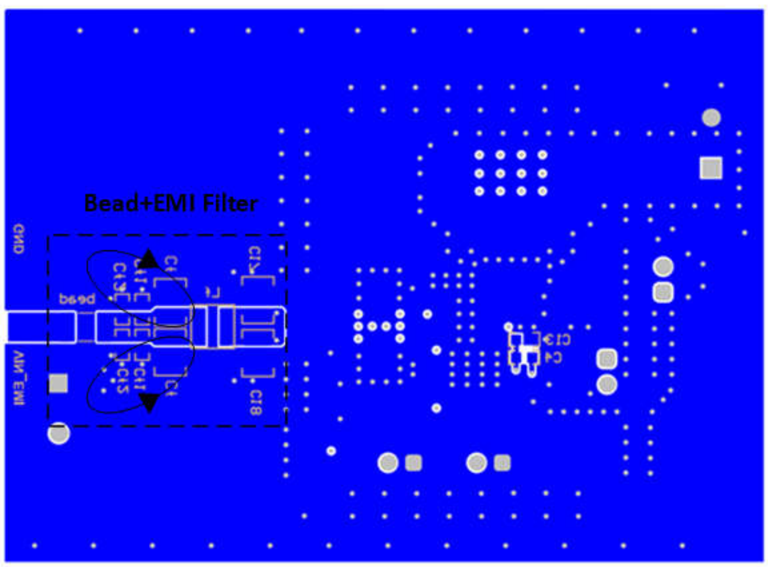


Figure 3-11. Bottom-layer Layout

3.3 Power Inductor Consideration

When selecting a power inductor, it is important to consider the electrical coupling caused by the SW node through parasitic capacitance to ground. These near-field couplings can result in high-frequency EMI noise.

To mitigate this noise, the recommendation is to use an inductor with terminations positioned underneath the package. This configuration helps to minimize magnetic coupling. Additionally, the size of the inductor needs to be kept as small as possible while still meeting the requirements for Isat and Irms. This smaller size helps in minimizing the electrical coupling.

Figure 3-12 depicts two different sizes of inductors on the same board. In Figure 3-13 and Figure 3-14, the EMI test results are compared, showing that the noise level of the small-sized inductors is 5dB lower than that of the normal-sized inductor in the FM band. This demonstrates the effectiveness of using smaller-sized inductors in reducing EMI noise.

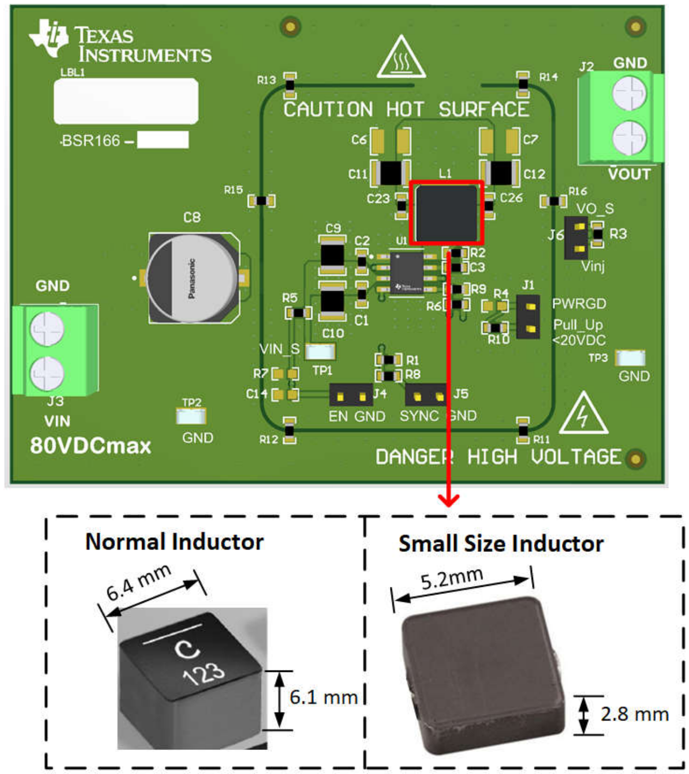


Figure 3-12. Different Size of Inductor Selection in Buck Converter

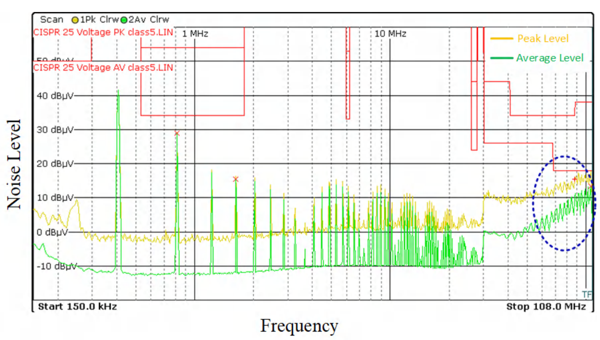


Figure 3-13. Conducted EMI Test Result of Normal Inductor

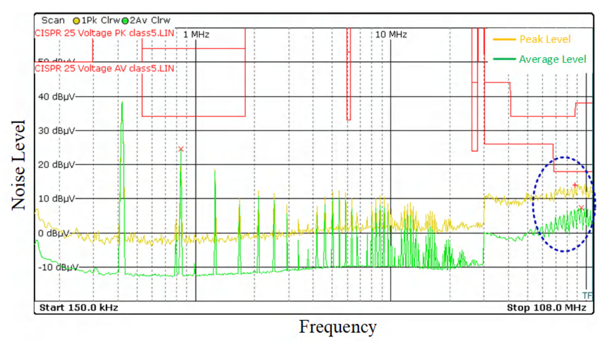


Figure 3-14. Conducted EMI Test Result of Small Size Inductor

Adding a shield is a commonly used method to reduce EMI noise. The shield needs to be connected to the PCB ground to effectively mitigate noise. Figure 3-15 illustrates the impact of adding a shield. The parasitic capacitance Cp between the SW node and ground is replaced by two capacitance: Cp1, which represents the capacitance between the SW node and PCB ground, and Cp2, which represents the capacitance between the PCB ground and the overall ground. The CM noise emission model, as shown in Figure 3-16, also changes when a shield is added. The CM noise now flows between Cp1 and the PCB ground, rather than flowing into chassis (system) ground. This change in noise flow can make the noise less detectable by the LISN.

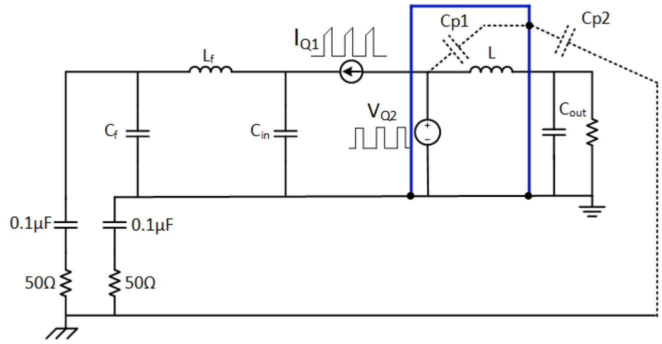


Figure 3-15. The Shield Effect on Parasitic Capacitance

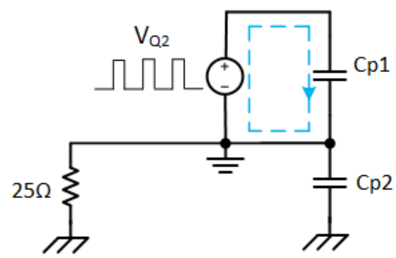


Figure 3-16. CM Noise Emission Model of Shield Added

Traditional shields are often bulky and have poor heat dissipation. To overcome these limitations, selecting an inductor with a metal shield can be a better option. Figure 3-17 presents the test results of using a metal shield inductor. It can be observed that compared to the normal inductor noise shown in Figure 3-13, the EMI noise in the FM band is reduced by approximately 10dB when using the metal shield inductor. This demonstrates the effectiveness of using a metal shield inductor in reducing EMI noise.

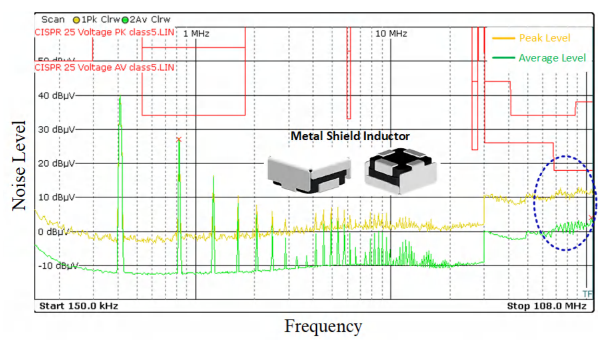


Figure 3-17. Conducted EMI Result of Metal Shield Inductor

3.4 Spread Spectrum

Spread spectrum is a technique that works by converting an EMI source signal into a wide-band signal. This spreading of energy over multiple frequencies helps to reduce the noise amplitude, resulting in an overall improvement in EMI performance.

Figure 3-18 and Figure 3-19 present the EMI results of the LMR38020Q without spread spectrum and with spread spectrum. It can be observed that the noise level of the spread spectrum version is 5dB lower at switching frequency and its harmonics, and 10dB lower in the FM band. This demonstrates that the implementation of spread spectrum can significantly enhance EMI performance in an automotive 48V DC system.

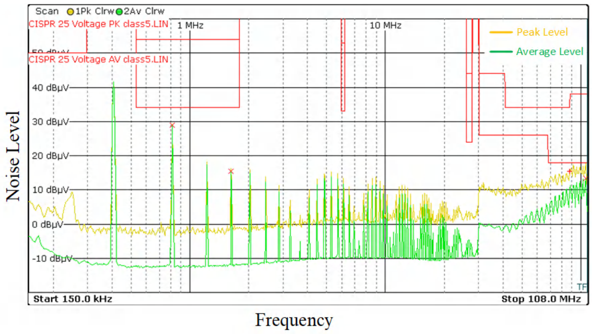


Figure 3-18. Conducted EMI Result Without Spread Spectrum

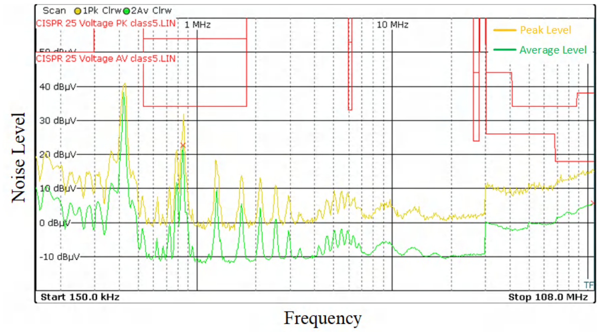


Figure 3-19. Conducted EMI Result With Spread Spectrum

4 Summary

This application note provides guidance on reducing conducted EMI noise in a buck converter operating in a 48 V automotive system. The key methods discussed include EMI filter considerations, layout optimization, inductor selection, and the use of spread spectrum techniques. These approaches are effective in mitigating EMI noise, particularly in the challenging FM band frequency range commonly found in automotive applications. By following these recommendations, designers can achieve improved EMI performance in their buck converter designs.

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