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A Practical Method for Separating Common-Mode and Differential-Mode Emissions in Conducted Emissions Testing

Ling Jiang, Applications Engineer, **Frank Wang**, EMI Engineer,
Keith Szolusha, Applications Director, and **Kurk Mathews**, Senior Applications Manager

EMI from switching regulators is broken down into radiated and conducted emissions (CE). This article focuses on conducted emissions, which can be further classified into two categories: common-mode (CM) noise and differential-mode (DM) noise. Why the CM-DM distinction? EMI mitigation techniques that are effective for CM noise are not necessarily effective for DM noise, and vice versa, so identifying the source of conducted emissions can save time and money in suppressing it. This article presents a practical method of separating CM emissions and DM emissions from the total conducted emissions for an LTC7818 controlled switching regulator. Knowing where the CM noise and DM noise appear in the CE spectrum enables power supply designers to effectively apply EMI suppression techniques, which saves design time and BOM costs in the long run.

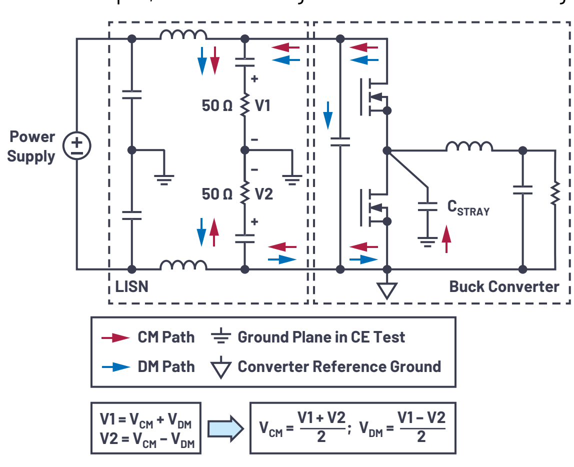


Figure 1. The CM noise path and DM noise path in a buck converter.

Figure 1 shows the CM noise and DM noise paths for a typical buck converter. DM noise is produced between the supply line and the return line, while CM noise is produced between the supply lines and the ground plane (such as a copper test table) via stray capacitance, C_{STRAY}. The LISN for CE measurement is placed between the power supply and buck converter. The LISN itself cannot be used for direct measurement of CM and DM noise, but it does measure supply and return supply line noise—V1 and V2 in Figure 1, respectively. These voltages are measured across 50 Ω resistors. From the definition of CM and DM noise, shown in Figure 1, V1 and V2 can be expressed by the sum and difference of the CM voltage (V_{CM}) and DM voltage (V_{DM}), respectively. This allows us to calculate V_{CM} from the average of V1 and V2, and V_{DM} as half of the difference between V1 and V2.

Measuring CM Noise and DM Noise

A T type power combiner is a passive device that combines two input signals to a single port output. A 0° combiner produces a vector sum of the input signals at the output port and a 180° combiner produces a vector difference of input signals.[1] Therefore, a 0° combiner can be used to produce V_{CM} and a 180° combiner to produce V_{DM}.

The two combiners shown in Figure 2, ZFSC-2-1W+ (0°) and ZFSCJ-2-1+ (180°) from Mini-Circuits, were used to measure V_{CM} and V_{DM} from 1 MHz to 108 MHz. For these devices, measurement error increases for frequencies below 1 MHz. For lower frequency measurements, use different combiners, such as ZMSC-2-1+ (0°) and ZMSCJ-2-2 (180°).

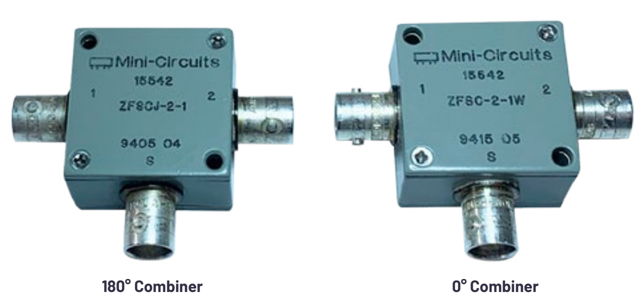


Figure 2. 0°and 180° combiners.

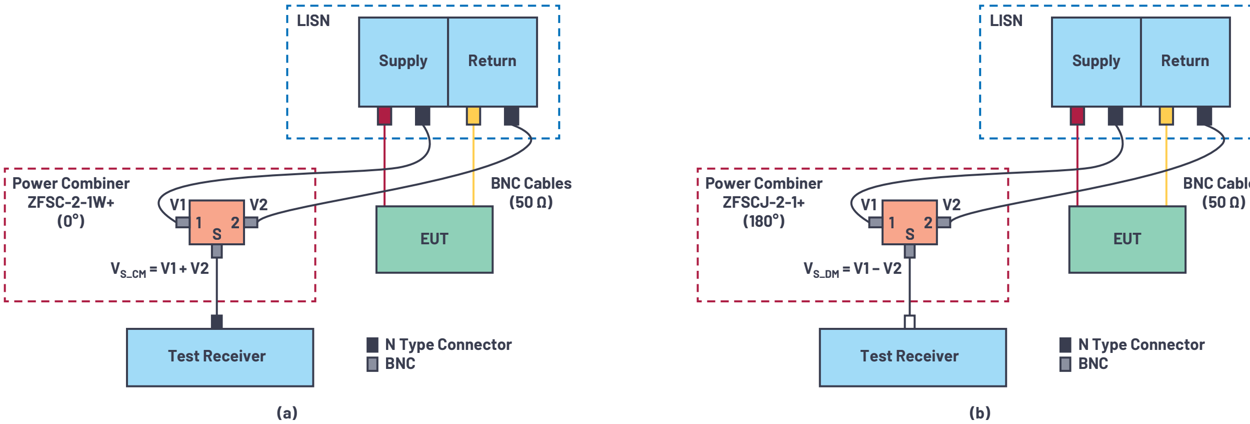


Figure 3. Experimental setup for measuring (a) V_{CM} and (b) V_{DM}.

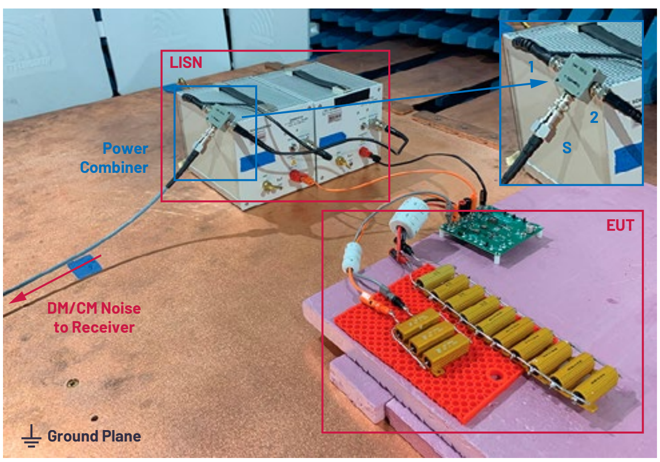


Figure 4. Test setup for measuring CM noise and DM noise.

The diagram of the test setup is shown in Figure 3. The power combiner is added to the standard CE test setup. The outputs of the LISN for the supply line and return line are connected to Input Port 1 and Input Port 2 of the combiner, respectively. For the 0° combiner, the output voltage is V_{S_CM} = V1 + V2; for the 180° combiner, the output voltage is V_{S_DM} = V1 – V2.

The output signals of combiners V_{S_CM} and V_{S_DM} must be processed in the test receiver to produce V_{CM} and V_{DM}. First, the power combiners have specified insertion losses compensated in the receiver. Second, since $V_{CM} = 0.5\ V_{S\_CM}$ and $V_{DM} = 0.5\ V_{S\_DM}$, the test receiver subtracts an additional 6 dBμV from the received signal. After compensating for these two factors, the measured CM noise and DM noise are read in the test receiver.

Experimental Verification of CM Noise and DM Noise Measuring

A standard demo board with dual buck converters is used to verify this method. The switching frequency of the demo board is 2.2 MHz, while V_{IN} = 12 V, V_{OUT1} = 3.3 V, I_{OUT1} = 10 A, V_{OUT2} = 5 V, and I_{OUT2} = 10 A. Figure 4 shows the test setup in the EMI chamber.

Figure 5 and Figure 6 illustrate the test results. In Figure 5, the higher EMI curve shows the total voltage method CE measured with the standard CISPR 25 setup, while the lower emissions curve shows the separated CM noise measured by adding the 0° combiner. In Figure 6, the higher emissions curve shows the total CE, while the lower EMI curve shows the separated DM noise measured by adding the 180° combiner. These test results comply with theoretical analysis, suggesting that DM noise dominates the noise at a lower frequency range, while CM noise dominates at the higher frequency range.

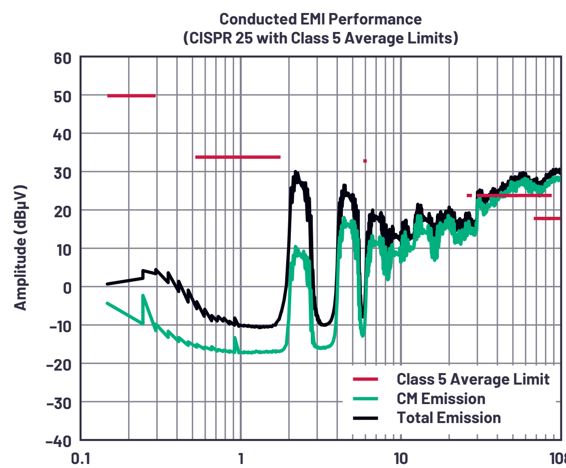


Figure 5. Measured CM noise vs. total noise.

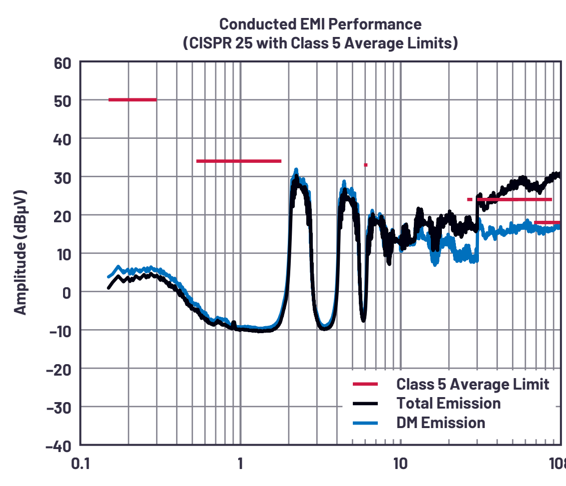


Figure 6. Measured DM noise vs. total noise.

Adjusted Demo Board Passes CISPR 25 Class 5

According to the measured results, the total noise emission exceeds the limit of CISPR 25 Class 5 at the range of 30 MHz to 108 MHz. By separating the CM and DM noise measurements, it appears that the high conducted emissions at this range are caused by CM noise. It makes little sense to add or enhance the DM EMI filter or otherwise reduce the input ripple, as these mitigation techniques would not reduce the problematic CM noise at this range.

Therefore, methods specifically addressing CM noise are implemented on this demo board. One source of CM noise is high dV/dt signals in the switching circuit. Reducing dV/dt by increasing the gate resistance can decrease the noise level. As previously mentioned, CM noise passes through the LISN via the stray capacitance C_{STRAY}. The smaller the C_{STRAY}, the lower the CM noise detected in LISN. To reduce C_{STRAY}, the copper area of the switch node cuts down on this demo board. Furthermore, a CM EMI filter is added at the input of the converter to obtain high CM impedance, therefore reducing the CM noise into the LISN. By implementing these methods, the noise at 30 MHz to 108 MHz is reduced enough for compliance with CISPR 25 Class 5, as shown in Figure 7.

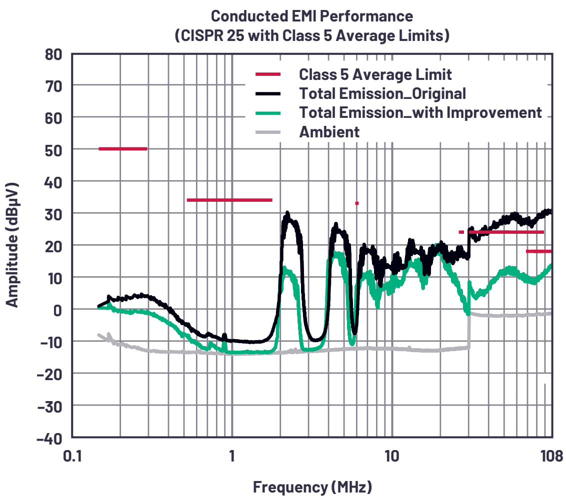


Figure 7. Total noise with improvement.

Conclusion

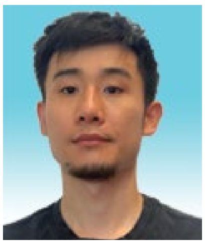
A practical method for measuring and separating CM noise and DM noise from total conducted emissions is presented in this article and verified with test results. If a designer can separate CM and DM noise, specific CM- or DM-targeted mitigation solutions can be implemented to suppress the noises effectively. Overall, this method helps quickly find the root cause of EMI failure, saving time in EMI design.

References

"AN-10-006: Understanding Power Splitters." Mini-Circuits, April 2015.

About the Author

Ling Jiang received a Ph.D. degree in electrical engineering from the University of Tennessee at Knoxville in 2018. After graduating, she joined the Power Products Group at Analog Devices in Santa Clara, California. Ling is an applications engineer supporting controllers and μModule devices for automotive, data center, industrial, and other applications. She can be reached at ling.jiang@analog.com.



About the Author

Frank Wang received an electrical engineering master's degree from the University of Texas at Dallas and worked in an independent, accredited compliance lab before joining Analog Devices. He has four years of relevant work experience as an EMC/EMI test engineer and project lead. Frank has experience in standard testing, arranging schedules, debugging with engineers, calibrating testing instruments, and chamber maintenance. He can be reached at frank.wang@analog.com.

About the Author

Keith Szolusha is an applications director with Analog Devices in Santa Clara, California. Keith works in the BBI Power Products Group, which focuses on boost, buck-boost, and LED driver products, while also managing the power products EMI chamber line. He received his B.S.E.E. in 1997 and M.S.E.E. in 1998 from MIT in Cambridge, Massachusetts, with a concentration in technical writing. He can be reached at keith.szolusha@analog.com.

About the Author

Kurk Mathews is a senior applications manager for the Power Products Group at Analog Devices in California. Kurk joined Linear Technology, now part of Analog Devices, as an applications engineer in 1994, supporting isolated converters and high power products. His group supports power applications and the development of new controllers, monolithic converters, and gate drivers. He enjoys analog circuit design and troubleshooting using a variety of new and old test equipment. Kurk graduated from the University of Arizona with a B.S. in electrical engineering. He can be reached at kurk.mathews@analog.com.