Measuring Common-Mode And Differential-Mode EMI Currents

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Electromagnetic interference (EMI) filters, whether built into a power supply or added externally between the ac line and power supply input, are used to limit line-conducted EMI to the limits established by FCC, CISPR or other requirements. When designing or specifying these filters, many engineers tend to rely on the solutions that have worked for them in the past. If those solutions don't bring them within compliance, they'll change filter components until the unit passes.

Often this process is done without regard to the true source of the problem. They key is that line-conducted EMI current is composed of two elements: common mode (CM) current and differential mode (DM) current. Either one of these contributors to line-conducted EMI may be responsible for a unit failing EMC testing. And without knowing why a unit is failing, coming up with a solution can become a time-confusing exercise in trial and error.

On the other hand, by measuring CM and DM EMI currents separately, engineers can identify why their products are exceeding the specified EMI limits and quickly tailor an EMI filter solution to pass EMC testing. Although the techniques for measuring CM and DM currents are well documented in the literature, many power supply engineers are still unfamiliar with them and therefore do not make these measurements.

Also contributing to the problem is a lack of relevant data from filter component manufacturers. For example, the makers of common-mode chokes provide little data on the parasitic leakage inductance and capacitance between windings in their chokes. The parasitic leakage inductance is relevant because it represents a differential mode parasitic, and using a choke with higher common-mode inductance tends to increase the differential mode inductance too, which can lead to higher DM currents.

In this article, we review the literature regarding measurement of CM and DM EMI currents, particularly the work of EMI consultants, authors and instructors in this field as well as application notes published by power semiconductor manufacturers. We offer an overview of the different measurement techniques and point to the references where readers can delve more into the details of making the measurements. We also review the FCC and CISPR limits that power supply designers and users must commonly meet. Once designers have obtained their measurements of CM and DM currents, EMI filter design becomes straightforward. Although filter design is beyond the scope of this article, several of the sources cited provide detailed information on this topic.

EMI Authorities And Sources

Michael Schutten PhD,[1] is an EMI expert employed by General Electric Corporate Research. Schutten speaks at many IEEE EMC conferences. At the 2017 APEC Educational Seminar, Michael talked about CM currents and DM currents and how measuring them helps in the design of an EMI filter. A test equipment setup for measuring CM and DM currents, which was presented in his seminar, is shown later in the article.

A power supply company, CUI, published a marketing flier in 2013 titled "Electromagnetic Compatibility Considerations for Switching Power Supplies" where it was stated on page 6[2] that "(EMI Line conducted) currents at frequencies below 5 MHz are mostly differential mode currents, while those above 5 MHz are usually common mode currents."

Henry Ott[3] is a renowned EMI consultant in the electronics industry. In chapter 18 of his book "Electromagnetic Compatibility Engineering," he discusses measuring these CM and DM currents during precompliance testing in order to design an EMI filter. Once the values are known of the CM and DM currents, the design of the EMI input filter can begin.

There are many publications—books, seminars, and application notes—that go into great detail on designing an EMI input filter. These include the work of R.L. Ozenbaugh and T. Pullen,[4] who wrote the book "EMI Filter Design." Another EMI consultant expert, M.J. Nave,[5] wrote one of the first EMI filter design books, "Power Line Filter Design for Switch-Mode Power Supplies, 2nd Edition.[6] Michael Schutten[1] who presented an EMC workshop at APEC 2017 used both Henry Ott and Mark J Nave as references for his material.

Making The Measurements

Mark J. Nave, has two noted references. The first is his book [5], and second is his APEC 1991 Professional Educational Seminar "EMI Control and Filter Design".[6] He presented examples of how to separate the line-conducted currents into CM currents and DM currents using a toroid current-sense transformer (Pearson Model 8585C,[7] which has a 200-MHz bandwidth.)

In his 1991 APEC presentation, Nave presented the circuit shown in Fig. 2, which is called a LISN MATE.[8] Henry Ott also talks about this circuit in his book and TekBox[9] offers this circuit as for sale as a product that provides DM and CM signal levels.

A passive circuit used by EMI engineers to measure the line-conducted current is called a line impedance stabilization network (LISN). This network is used to detect and measure the amplitude currents from 0.15 MHz to 30 MHz emanating from a product. In the United States, the Federal Communication Commission (FCC) sets the magnitude limits of these currents and frequencies.

A dual LISN is needed to make these measurements. One LISN is connected to the ac hot while the other LISN is connected to the ac neutral. Fig. 3 is a schematic of a dual LISN network. The outputs from the LISNs, are two coaxial cables. The top coaxial cable in Fig. 3 is called the ac hot sense, while the lower coaxial is called the ac neutral sense.

When both coaxial cables are fed through a wide-bandwidth current-sense transducer in the same direction, the CM currents produced by the power supply flow in the opposite direction, and these currents can be seen on a spectrum analyzer. When one of the LISN output coaxial cables is fed through the current-sense transducer in the opposite direction, the results measured on the spectrum analyzer are DM currents. Kenneth Wyatt[10] describes this technique in "Measuring Common Mode Versus Differential Mode Conducted Emissions," where the CM and DM currents are highlighted when he measured a power supply.

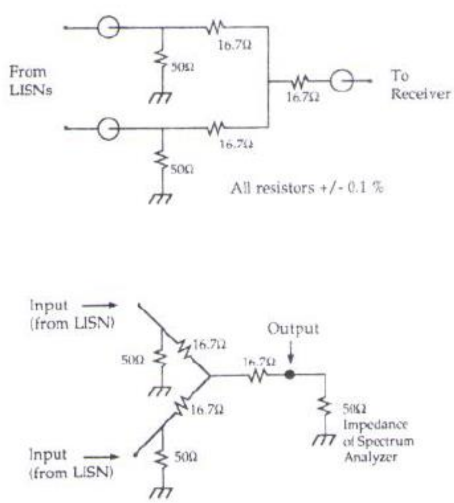

Fig. 1. Technique to measure CM and DM currents coming from a LISN. This circuit is called a LISN MATE (see reference [7]) and is described by Mark Nave in 1991 and Henry Ott in 2011, and in their respective literature.

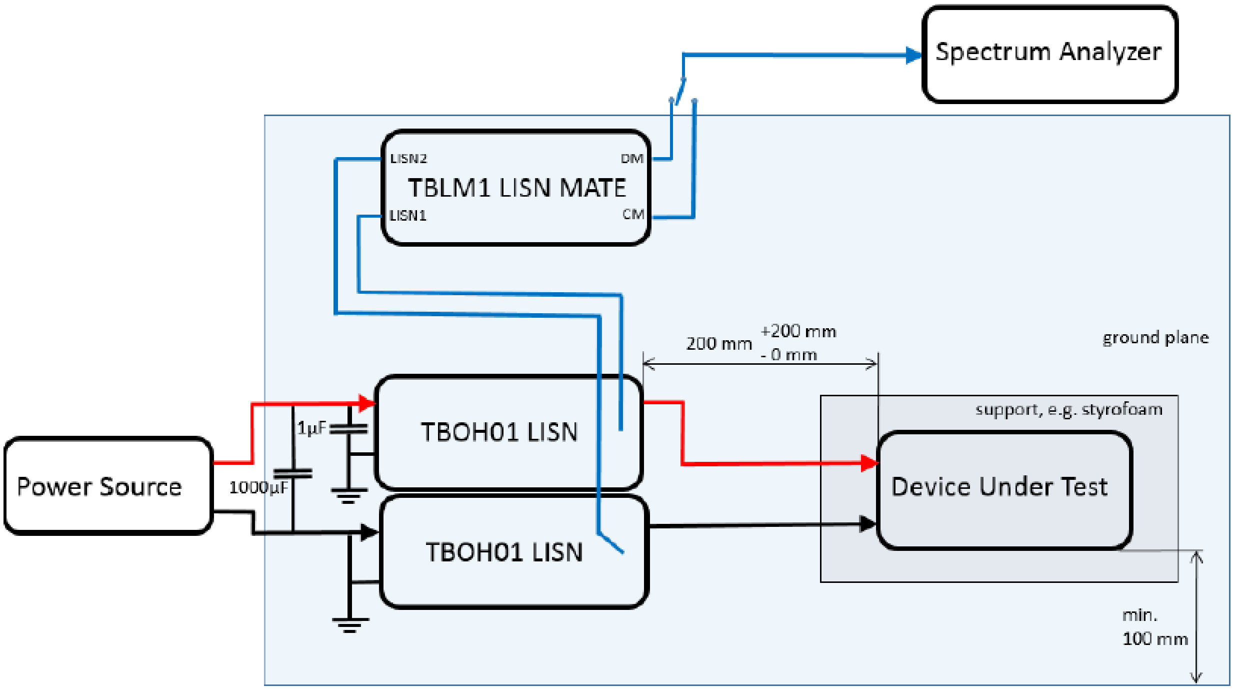

Fig. 2. A test equipment setup for a commercially available LISN Mate to measure DC and CM currents.

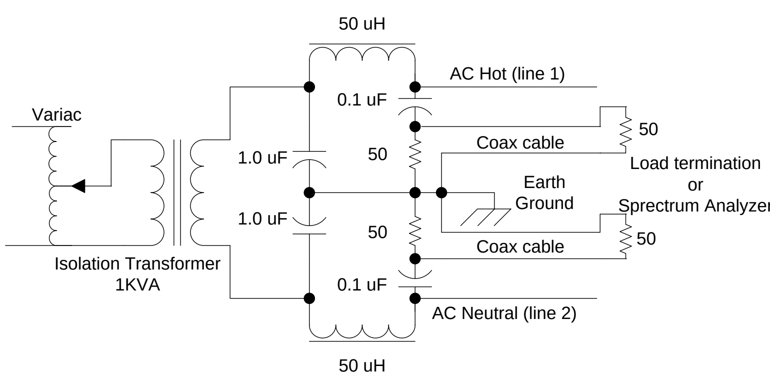

Fig. 3. Schematic of a dual, 50-µH LISN using 0.1-µF coupling capacitors to the 50-Ω loads.

An alternative approach for measuring CM and DM currents is shown in Fig. 4. This approach utilizes Mini-Circuits components.[11,12]

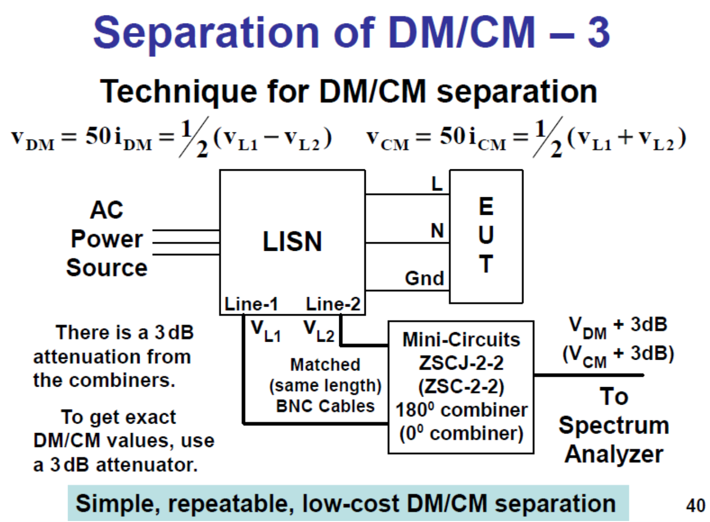

Fig. 4. The use of a Mini-Circuits combiner to measure common mode and differential mode currents per Michael Schutten's presentation (see reference [1], page 40). This technique requires a 3-dB attenuator pad (not shown) prior to the spectrum analyzer input.

CISPR 22 And FCC

The line-conducted emissions for both CISPR and FCC Part 15 are shown in Fig. 5. Both the Class A and Class B limits are presented on the same graph. The FCC Part 15, and CISPR specification limits have been harmonized with a few exceptions. The exact data is shown in the table.

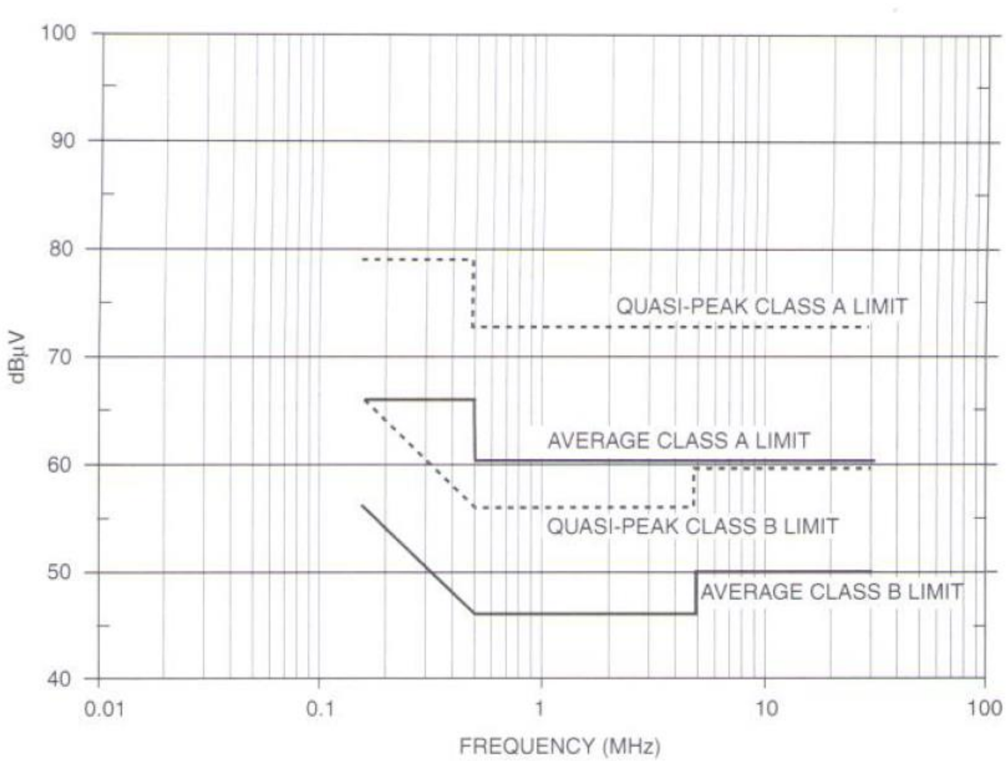

Fig. 5. Line-conducted emissions limits as shown in Henry Ott's book[3] in Figs. 1-4 page 15 and Figs. 18-12, page 702.

Table. FCC Part 15, line conducted and CISPR, line conducted limits on EMI.[2] This data is presented in Henry Ott's book[3] on page 13 in Tables 1-5 and 1-6.

FCC Class A Conducted EMI Limit	
Frequency of Emission (MHz)	Conducted Limit (µV)
0.45 ~ 1.6	1000
1.6 ~ 30.0	3000
FCC Class B Conducted EMI Limit	
Frequency of Emission (MHz)	Conducted Limit (µV)
0.455 ~ 1.6	250
1.6 ~ 30.0	250

CISPR Class A Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (dBµV)	
	Quasi-peak	Average
0.15 ~ 0.50	79	66
0.50 ~ 30.0	73	60
CISPR Class B Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (dBµV)	
	Quasi-peak	Average
0.15 ~ 0.50	66 ~ 56*	56 ~ 46*
0.50 ~ 5.00	56	46
5.00 ~ 30.0	60	50

Industry Application Notes

Texas Instruments (TI) and Power Integrations have application notes and examples on their websites. For example, Timothy Hegarty from Texas Instruments, published two articles in this newsletter dealing with the subject of common-mode EMI and how to mitigate it in dc-dc converters. In addition to being available on the TI website, these articles can be accessed directly from How2Power.com as noted below in the references.

In particular see "The Engineer's Guide to EMI in DC-DC Converters (Part 8): Common-Mode Mitigation in Isolated Designs"[13] and "The Engineer's Guide to EMI in DC-DC Converters (Part 7): Common-Mode Noise Of A Flyback"[14]. Also, Power Integrations has a number of detailed application examples that are relevant including DER-648,[15] DER-740,[16] DER-535,[17] and DER 197.[18]

Timothy Hegarty's articles will get you started in designing an EMI filter for a power supply design, but the power supply designer must verify CM and DM currents in order to design an EMI filter that meets the FCC and CISPR limits. The Power Integrations application notes provide FCC and CISPR line conducted emissions results.

Note that whenever a printed circuit board is redesigned or a new housing is used, the CM and DM tests need to be repeated. These application notes are a good starting point for the design of a power supply to be placed in a product.

Keep in mind that application notes from the industry should be considered more as a suggestion than as a final design. These application notes provide guidance to the design engineer. They cannot address all aspects of the design that effect EMI. There are hidden CM current radiation paths on a pc board and cables that are very difficult to show. This noise is picked up by both pc board traces and ac power line cables. Cables and ac power line routing must be checked during precompliance testing before the final design is placed into production to ensure the design meets the FCC and CISPR limits.

Summary

This article presents methods of separating and measuring CM and DM EMI currents. After studying the data taken during precompliance testing, an EMI filter can be designed to minimize the line-conducted noise in order to pass FCC and CISPR line-conducted limits. Several EMI filter design books and EMI seminars with design examples have been cited here to help you learn the measurement techniques.

References

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12. Mini-Circuit's, ZSCJ-2-2(+) 2-Way-180^{O} Coaxial Power Splitter/Combiner model.
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15. "DER-648 - 150 W Power Factor Corrected LLC Power Supply Using HiperPFS-4 and HiperLCS," Power Integrations Design Example, page 100.
16. "DER-740 - 29 W High Power Factor, Isolated Flyback LED Driver with 3-in-1 and DALI Dimming," Power Integrations Design Example, pages 66 and 67.
17. "DER-535 - 65 W Power Supply," Power Integrations Design Example, pages 47 and 48.
18. "DER-197 - 65 W Adapter," Power Integrations Design Example, page 31.

About The Authors

Kevin Parmenter is an IEEE Senior Member and has over 20 years of experience in the electronics and semiconductor industry. Kevin is currently director of Field Applications Engineering North America for Taiwan Semiconductor. Previously he was vice president of applications engineering in the U.S.A. for Excelsys, an Advanced Energy company; director of Advanced Technical Marketing for Digital Power Products at Exar; and led global product applications engineering and new product definition for Freescale Semiconductors AMPD - Analog, Mixed Signal and Power Division.

Prior to that, Kevin worked for Fairchild Semiconductor in the Americas as senior director of field applications engineering and held various technical and management positions with increasing responsibility at ON Semiconductor and in the Motorola Semiconductor Products Sector. Kevin also led an applications engineering team for the start-up Primarion.

Kevin serves on he board of directors of the PSMA (Power Sources Manufacturers Association) and was the general chair of APEC 2009 (the IEEE Applied Power Electronics Conference.) Kevin has also had design engineering experience in the medical electronics and military electronics fields. He holds a BSEE and BS in Business Administration, is a member of the IEEE, and holds an Amateur Extra class FCC license (call sign KG5Q) as well as an FCC Commercial Radiotelephone License.

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For further reading on power supply-related safety and compliance issues, see How2Power's special section on [Power Supply Safety and Compliance].