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The Engineer's Guide To EMI In DC-DC Converters (Part 1): Standards Requirements And Measurement Techniques

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There's an inescapable requirement in most power-supply applications to reduce electromagnetic interference (EMI), so system designers must explore all avenues to reduce both conducted and radiated emissions. Regulatory compliance to electromagnetic compatibility (EMC) standards—for example, CISPR 32 for multimedia equipment[1] and CISPR 25 for automotive applications[2] —is vitally important, as the efforts required to achieve compliance affect both product development costs and time to market.

Although the emergence of faster-switching power devices for dc-dc converters provides an opportunity for increased switching frequency and smaller size, the higher switch voltage and current slew rates (dv/dt and di/dt) that occur during switching transitions often exacerbate EMI, causing problems in the overall system.

For example, the high-switching speed of gallium nitride (GaN) power devices can result in a 10-dB increase in EMI at high frequencies.[3] EMI filters are inevitably part of a power electronic system and make up a relatively large portion of the total volume and weight. Thus, you must place a significant focus on system EMI noise reduction and mitigation, not only to meet EMC regulatory specifications but also to reduce solution cost and increase system power density.

This article, the first in a multipart series on EMI, reviews relevant standards for both industrial and automotive end equipment. This part also explains the associated measurement techniques. A measurement system setup, which includes a line impedance stabilization network (LISN) and an EMI receiver, is described and a practical measurement system from a pre-compliance lab testing environment is presented.

The focus here and throughout the series is mainly on conducted emissions as mitigation of conducted EMI generally supports better radiated EMI performance.

Subsequent parts in this series will explain:

- EMI propagation modes
- effects of circuit parasitics on transient voltage (dv/dt) and transient current (di/dt) waveforms generated during power MOSFET hard switching and the associated EMI behaviors
- EMI mitigation techniques, with a particular focus on the power-stage controller IC and PC board layout.

Practical circuit examples will be provided to illustrate the concepts.

The table below lists commonly used abbreviations and nomenclature pertaining to EMI. These terms will be used throughout the series.

Table. Common acronyms, abbreviations and units related to EMI and EMC.

IEC	International Electrotechnical Commission
CISPR 25	Comité International Spécial des Perturbations Radioélectriques, an IEC technical committee
EN 55022	European standard, a modified derivative of CISPR 22 prepared by CENELEC and ratified by the European Union (EU)
FCC Part 15	Federal Communications Commission; Part 15 subpart B applies to unintentional radiators
ANSI C63.4	American National Standards Institute
CENELEC	Comité Européene de Normalisation Électrotechnique
CE Mark	Conformité Européene
ITE	Information technology equipment
EUT	Equipment under test
OATS	Open area test site
ALSE	Absorber-lined shielded enclosure
SAC, FAR	Semi-anechoic chamber, fully anechoic room
LISN	Line impedance stabilization network
AMN, AN	Artificial mains network, artificial network
AE	Auxiliary/associated equipment
CE, RE	Conducted emissions, radiated emissions
CS, RS	Conducted susceptibility, radiated susceptibility
DM, CM	Differential mode, common mode
RBW	Resolution bandwidth (of EMI receiver/spectrum analyzer)
FFT	Fast Fourier Transform
PE, GW	Protective earth, green wire (both refer to earth or chassis ground)
dBμV, dBμA	0 dBμV = 1 μV, 20 dBμA = 10 μA

EMC Regulatory Specifications

EMC refers to the ability of a system or its constituent components to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. As the effects of interference can pose severe consequences, EMC is a frequent subject of national and international regulation.[4]

Within the EU, power supply products intended for the communications infrastructure markets have typically used the EN 55022/CISPR 22 product standard[5] over many years to show conformance for both conducted and radiated emissions, with the CE declaration of conformity (DoC) for external power supplies referencing this standard to show conformance with the EU's EMC directive 2014/30/EU.[6,7]

Products designed for North American markets have complied with limits established by FCC Part 15. Meanwhile, IEC 61000-6-3 and IEC 61000-6-4 generic EMC standards apply to light industrial and industrial environments, respectively.[8,9]

For emissions, however, the EN 55032 product standard replaces and becomes an amalgamation of EN 55022 (ITE), EN 55013 (broadcast receivers and associated equipment) and EN 55103-1 (audio and studio equipment). This new standard becomes effective as a harmonized emission standard in compliance with the EMC directive.[10] More specifically, any product previously tested under EN 55022 that ships into the EU after March 2, 2017 must now meet the requirements of EN 55032.

As EN 55022 is withdrawn and replaced by EN 55032, power supply manufacturers and vendors need to update their DoC to the new standard in order to affix a valid CE marking logo. Fig. 1 shows the EN 55022/32 class A and class B limits for conducted emissions with quasi-peak (QP) and average (AVG) signal detectors over the applicable frequency range of 150 kHz to 30 MHz.

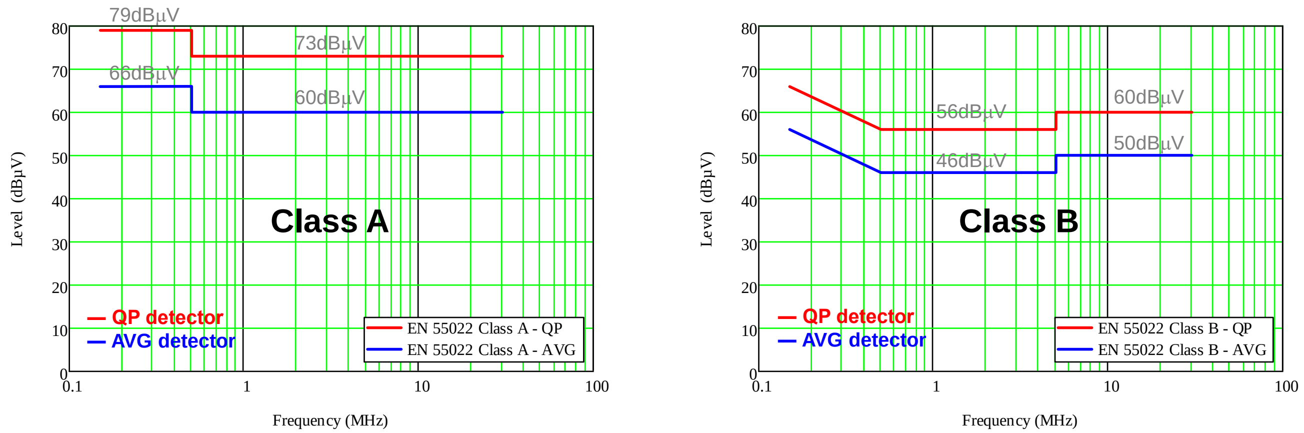
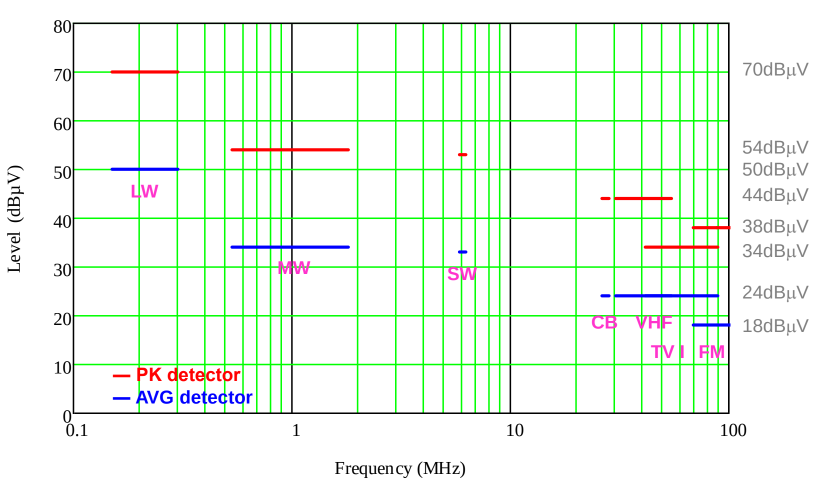


Fig. 1. EN 55022 class A and class B conducted emission limits with quasi-peak and average detectors.

In terms of automotive end equipment, the main impetus for EMC compliance in the future will surely be autonomous vehicles supported by intervehicle communications. The CISPR 25 specification for the "protection of onboard receivers" already has challenging limits for conducted emissions, particularly in the FM band (76 MHz to 108 MHz).

From a regulatory standpoint, UNECE Regulation No. 10,[7, 10] having replaced the EU's Automotive EMC Directive 2004/104/EC in November 2014, requires manufacturers to gain type approval for all vehicles, electronic subassemblies (ESAs), components and separate technical units.

Conducted emissions for CISPR 25 testing are measured over a frequency range of 150 kHz to 108 MHz in specific frequency bands. More specifically, the regulated frequency ranges are dispersed across AM broadcast, FM broadcast and mobile service bands, as displayed in the graphic and tabular formats in Fig. 2. This figure also plots the relevant limit lines for class 5, the most stringent requirements in CISPR 25.



	Band	Frequency (MHz)	PK (dBµV)	QP (dBµV)	AVG (dBµV)
Broadcast	LW	0.15–0.3	70	57	50
Broadcast	MW	0.53–1.8	54	41	34
Broadcast	SW	5.9–6.2	53	40	33
Broadcast	FM	76–108	38	25	18
Broadcast	TV Band I	41–88	34	–	24
Mobile Services	CB	26–28	44	31	24
Mobile Services	VHF	30–54 68–87	44 38	31 25	24 18

Fig. 2. CISPR 25 class 5 conducted emission limits.

Even though higher noise spikes may be allowed in the gaps between the frequency bands, automotive manufacturers may choose to extend these frequency ranges according to their particular in-house EMC requirements.[11] Often based on international IEC standards, these requirements change only a few parameters of different tests or limits, with the essence of the requirements remaining the same.

To appreciate the challenge in complying with CISPR 25 limits, particularly in the FM band, note that 18 dBµV across a measurement resistance of 50 Ω corresponds to a noise current of only 159 nA.

Measuring Conducted EMI

A LISN measures conducted emissions from the equipment under test (EUT). It is an interface inserted at the measurement point between the EMI source and the power source to ensure the repeatability and comparability of EMI measurements.[12, 13] Fig. 3 shows a functional equivalent circuit (not a complete schematic) of a standard 50-µH LISN defined by CISPR 16-1-2[14] or ANSI C63.4[15] standards.

The LISN provides:

- A stable and calibrated source impedance in a given frequency range
- Isolation of the EUT and measuring equipment from the input power source in that frequency range
- A safe and suitable connection to the measuring equipment
- Separate measurement of total noise levels in both lines, designated as L and N in Fig. 3.

In short, it's possible to achieve reproducible results using a defined test setup with a known source impedance. Note that a LISN may contain one or more individual LISN circuits.

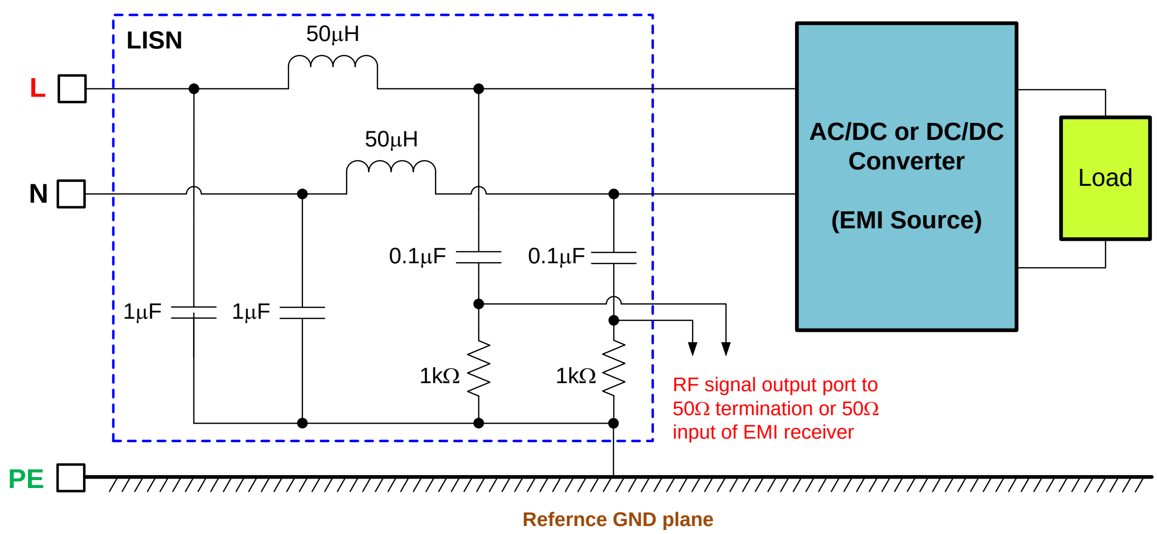


Fig. 3. Conducted emissions measurement with a V-type LISN.

The LISN in principle is a pi-filter network. Through a low-pass LC filter, the EUT connects to the input power lines L and N, as shown in Fig. 3. The value of the LISN inductor is based on the anticipated inductance of the power line for the intended installation of the product.

CISPR 16 and ANSI C63.4 specify a 50-µH inductor for the LISN, a value that tallies with the inductance of a power-distribution wiring system running for approximately 50 m in a telecom installation. In contrast, CISPR 25 specifies a 5-µH LISN to correspond with the approximate inductance of an automotive wiring harness.

The LISN presents a well-defined impedance to the noise emission signal. The LISN manufacturer normally provides a calibration plot indicating the nominal impedance over the designated measurement frequency range. The allowable tolerance according to CISPR 16-1-2 is ±20% amplitude and a ±11.5° phase.

For measurements with an EMI receiver or spectrum analyzer, the noise signal is available from a high-pass filter network (as shown in Fig. 3) with a 0.1-µF coupling capacitor and 1-kΩ discharge resistor that parallels with a 50-Ω termination at the measurement port. Fig. 4 shows a simulated impedance plot of a (50 µH + 5 Ω) || 50 Ω LISN over a frequency range from 150 kHz to 30 MHz.

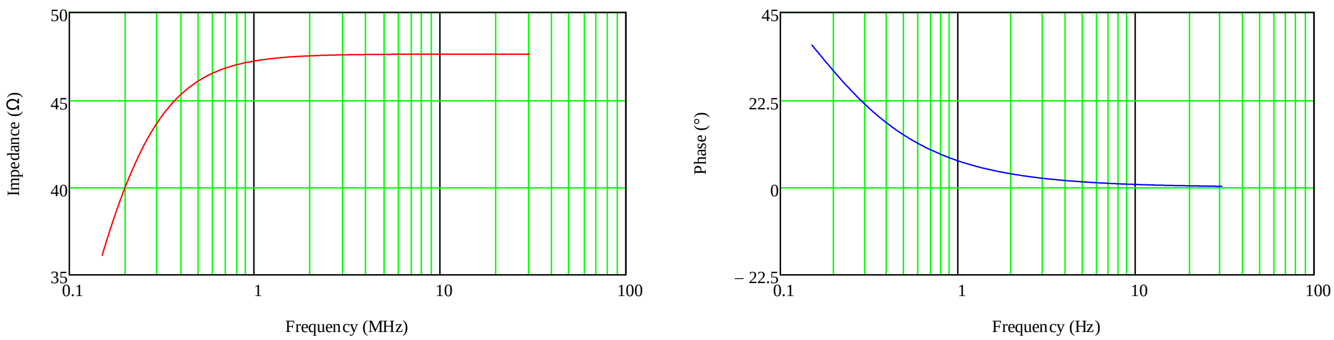


Fig. 4. Nominal impedance characteristic of a 50-Ω, 50-µH LISN at the measurement port over the regulated frequency range from 150 kHz to 30 MHz.

CISPR 25 Test Setup For Automotive Applications

Fig. 5 shows the conducted emissions test setup recommended by CISPR 25. This standard defines the disposition of the system under test and the measurement protocols and equipment. The LISN is designated here as an AN by the CISPR 25 specification. The EUT is remotely grounded when the vehicle power return line is longer than 200 mm, and two ANs are required: one for the positive supply line and one for the power return line. Conversely, if the vehicle power return line is 200 mm or shorter, the EUT is locally grounded and only one AN is required for the positive supply.

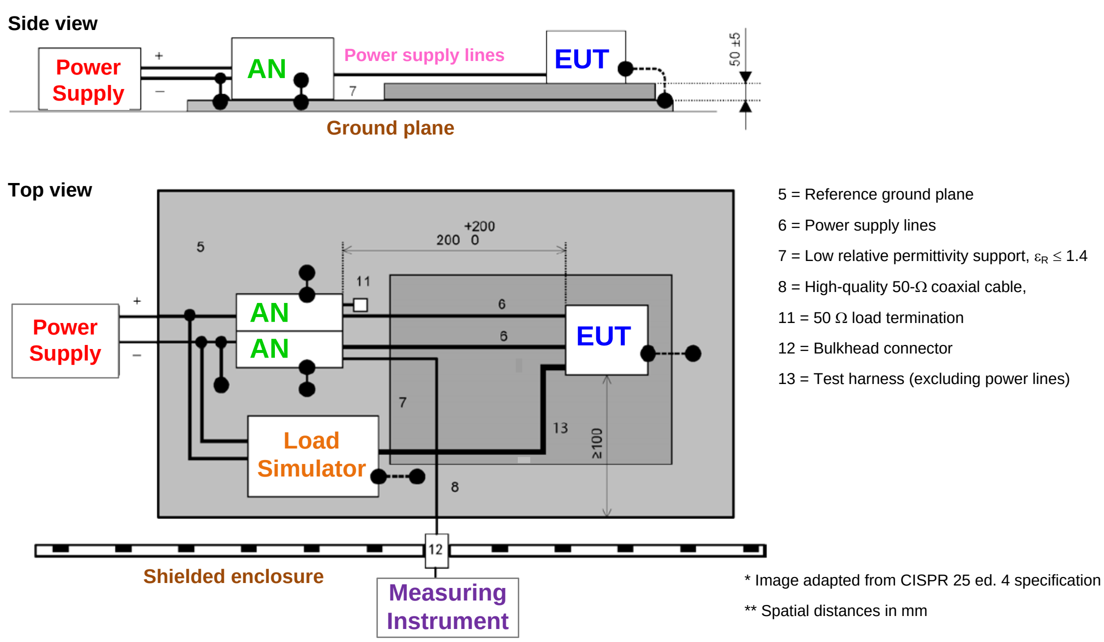


Fig. 5. General overview of CISPR 25 conducted EMI test setup (voltage method).

The AN(s) are mounted directly on the reference ground plane, with the AN case(s) bonded to the ground plane. The power-supply return also connects to the ground plane between the power supply and the AN(s). Connecting the EMI receiver on the measuring port of the corresponding AN ensures the successful measurement of the conducted emissions on each power line. Meanwhile, a 50-Ω load terminates the measuring port of the AN inserted in the other power line.

Fig. 6 shows a CISPR 25 conducted emissions test chamber for pre-compliance testing.[13] The LISNs are the blue boxes on the right side, a lithium-ion car battery is located behind them and the dc-dc converter EUT is located on the insulating material to the left. To test at a specific source voltage, for example 13.5 V, a variable voltage supply is fed through the bulkhead from outside the test chamber. The results are taken on both the line (hot) and return (ground) sides through their respective LISNs.

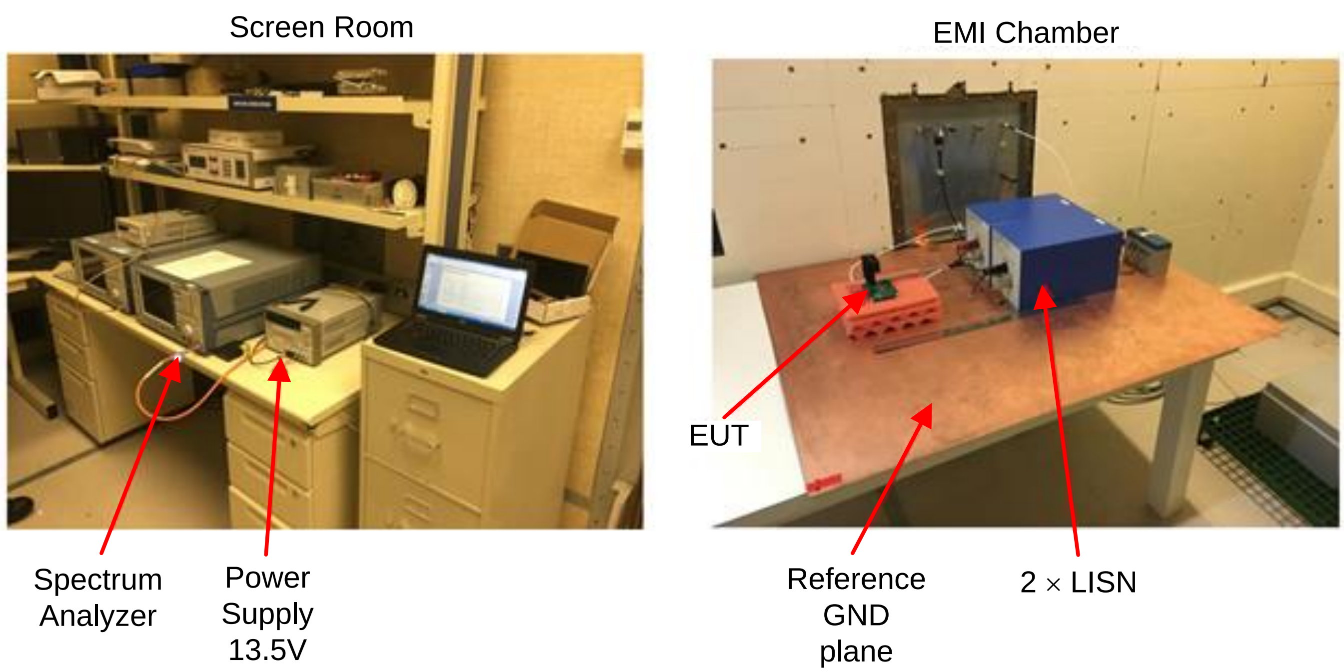


Fig. 6. CISPR 25 conducted EMI test setup using two single-pole LISNs and a copper ground plane.

Fig. 7 shows a typical CISPR 25 conducted EMI scan with yellow and blue denoting the peak and average measurements, respectively. You can see that the dc-dc converter operates quietly and the conducted emissions are much below stringent class 5 limits. This measurement technique changes above 30 MHz, as the EMI receiver's RBW adjusts from 9 kHz to 120 kHz and can result in a change in the measurement noise floor.

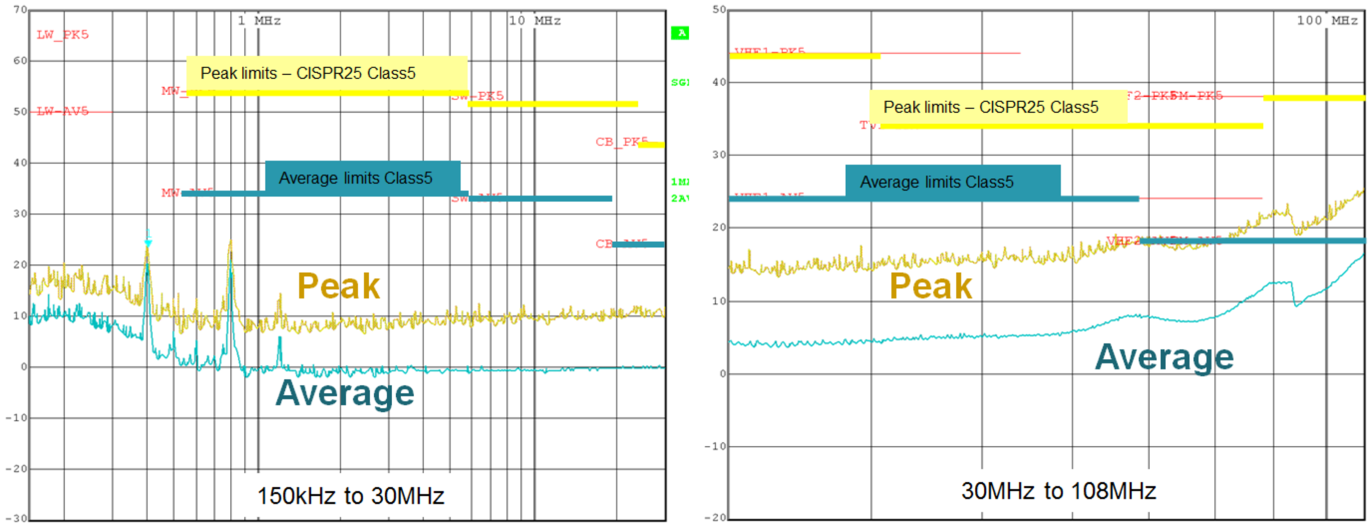


Fig. 7. Typical CISPR 25 conducted EMI measurements.

Summary

Electromagnetic energy, whether intentionally or unintentionally generated, results in EMI with other equipment. Commercial products are designed to minimize the amount of electromagnetic energy produced during normal operation.

Numerous governing bodies throughout the world regulate the permissible level of conducted and radiated EMI generated by an end product. Applicable measurement techniques quantify such emissions so that you can take appropriate steps to achieve regulatory compliance.

While EMC requirements generally pertain to complete systems measured on ac power lines (and signal lines), a dc-dc converter is a subcomponent for which no specified EMC limits exist. However, you can perform pre-compliance testing to determine whether EMI will be an issue.

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About The Author

Timothy Hegarty is an applications engineer for Power Products Solutions at Texas Instruments. With 20 years of power management engineering experience, he has written numerous conference papers, articles, seminars, white papers, application notes and blogs.

Tim's current focus is on enabling technologies for high-frequency, low-EMI, isolated and nonisolated regulators with wide input voltage range, targeting industrial, communications and automotive applications in particular. He is a senior member of the IEEE and a member of the IEEE Power Electronics, Industrial Applications and EMC Societies.

For more information on EMI, see How2Power's Power Supply EMI Anthology. Also see the How2Power's Design Guide, locate the Design Area category and select "EMI and EMC".