WHITE PAPER

Practical EMI Control in a Power Component Design Space

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Abstract

The control of electromagnetic interference (EMI) within switched-mode power systems is a perennial topic. This article attempts to address the notion of control of conducted emissions in the context of applying Vicor Power Components in a customer application. Vicor has developed quasi-resonant topologies that mitigate noise to a great extent by design. Although there are significant noise reductions to be had using resonant topologies in SMPS, no converter is ever noise-free. Applying power modules in a way to assure compliance with CE engineering standards can often prevent unforeseen, costly delays in bringing products to market.

Managing conducted emissions from concept through implementation

Introduction

Conducted emissions control must be a consideration at the outset of a power system design, made well before final integration with other parts of a complete application. The noise mitigation schemes used must be developed alongside the power and signal processing pathways. The implementation of the system should be routinely subject to a series of pre-qualification tests, which although subjective, quickly bear results which indicate whether or not the final product will be adequately arranged for successful qualification outcomes. We look for minimal emissions that are below those levels that represent adequate performance.

Model of an embedded power component

The block diagram shown in Figure 1 is the author's attempt to show all the features of a power system that address aspects that go beyond a simple DC input / output power specification. Identifying power support functions in this way allows us to be able to look at tradeoffs and interactions between these various functions. Knowledge of interactions between required functions allows the designer to adopt a design sequence that effectively addresses all aspects of performance of the finalized design.

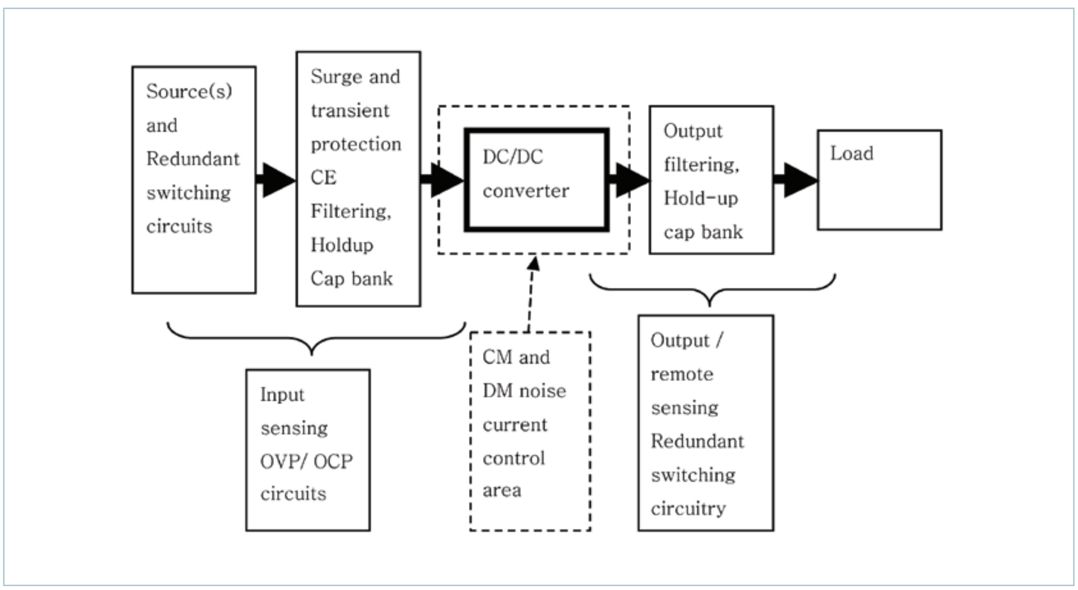

Figure 1
Generic system block diagram for a switching power system. DC power flow on the busses are represented with bold arrows. The DC-DC converter is generally arranged with galvanically-isolated input and output power ports

Comments on the Model

In the context of noise, analog and digital systems are thought of respectively as receivers and transmitters of electrical noise. Switched-mode power converters present a mixed-mode environment. Controllers, be they digital or analog in nature, are set alongside switched power devices. Power components are modular: to a great extent the OEM (original engineering manufacturer) will have taken great pains to mitigate the effect of noise sources internal to the module, sometimes with mixed results. If not countered, self-noise of a power module is often sufficient to affect signaling affecting control of power within the component.

Implementing a system with such products involves introducing measures that the OEM should provide in applications literature. Module self-noise can be reduced with the introduction of suitable external components that are selected and arranged in a board layout designed to introduce minimal parasitics. The components will interact with the printed circuit layout, which means that noise performance is not something that can be automatically guaranteed. In almost every case that such provisions are offered, there will be reference made to engineering standards for CE (conducted emissions) such as CISPR22 or EN61000-4-6. These two standards contain clear definitions and detailed test arrangements that can be used to authenticate a power system's emission and susceptibility characteristics.

CE standards focus on conducted electrical noise that propagates to the input power source. Noise appearing at the output side of the system can also be attenuated, with either CM (common-mode) or DM (differential-mode) filtering or a combination of the two, just as for input-source-terminated CE. It can be argued that using power components facilitates noise control design in the integrated application. Although it is generally not possible to integrate all the suppression elements in a power component, the manufacturer will recommend the minimum effective external measures required in an optimal board layout. Given the nature of the varied types of applications being worked on by customers, applications engineers at the OEM can often be called upon to determine adequacy of current noise control strategies and suggest ways to suppress noise. This paper illustrates such an example.

Applying the Model

To illustrate an important interaction example using Figure 1, the inductance of the input power bus and the capacitors situated at the input port of the DC-DC converter (be they part of the hold-up or the filtering function) interact with the dynamic (negative) input impedance the converter presents. This introduces the prospect of input power bus instability. [b] Clearly, the choice of the hold-up capacitors with their attendant ESR is critical. These components, along with necessary surge and transient protection elements, impact the differential filtering of conducted noise travelling from the DC-DC converter's input port to the source.

Besides DM noise, there are CM noise currents emanating from each of the converter's input and output ports. Controlling such noise mandates the use of highly localized common-mode filtering components. These components will offer HF currents very small loops which are formed going from the power terminal, back through the coupling capacitance, afforded by a specially devised shield plane, back into the converter. Figure 2 shows the equivalent circuit of the DC-DC converter expressed in noise terms, as input-referenced noise current sources with X and Y capacitors set in place.

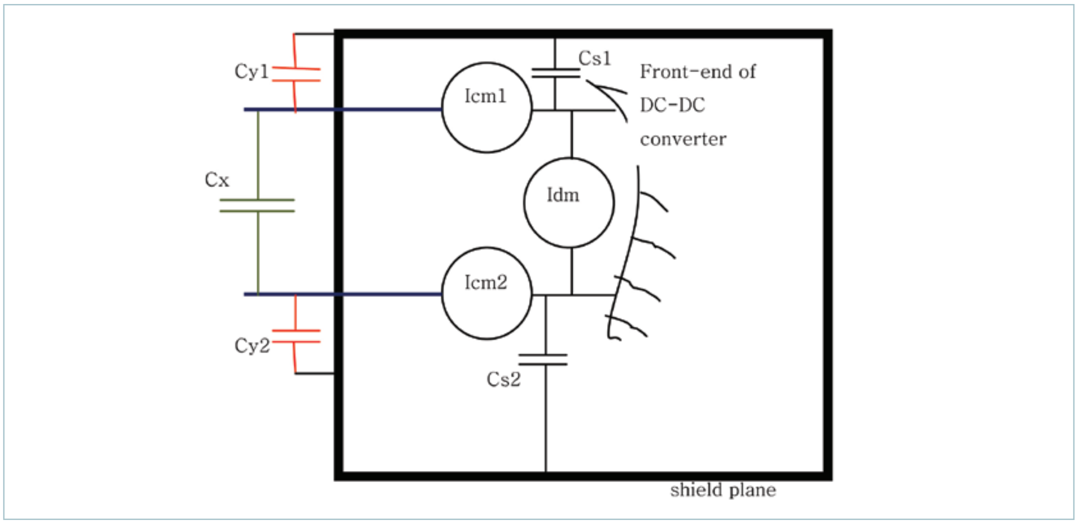

Figure 2
Input-power-port noise equivalent circuit of a DC-DC converter expressed with differential and CM noise current sources, along with noise-suppression X and Y capacitors, installed and connected to an underlying shield plane which offers HF capacitive coupling (Cs1, Cs2 shown as lumped equivalents) back to the source at low impedance.

Noise-control development strategy

A full qualification test is expensive and time-consuming. This process should only be carried out once, at the pre-production stage of development, before freezing the design for production.

In the meantime, many simpler tests can be performed using equipment that is accessible to most designers and technicians working on hardware in a laboratory setting. It will be possible to set up and tailor noise control networks so as to minimize noise. This is often an iterative process, based on engineering intuition and a detailed understanding of parasitics in the layout, possibly exploiting them to aid in noise control. [h]

Test references should be established at the outset. It is important to run some "zerosignal" tests to establish the instrumentation's noise floor and to establish whether there are other noise sources that unexpectedly contribute energy to the system. These sources, if present, need to be noted; if it is possible to eliminate them with modest measures, then a small investment in shielding and grounding of the lab bench may be in order.

Once a zero-energy input profile has been secured and collected, data should be developed for a signal with known characteristics. This test data set will be used as a background template which can be used to assess noise sources associated with the application's CE noise profile. With the veracity of the oscilloscope instrument and its coaxial probe established, it is now possible to exploit featured FFT processing running on the wideband oscilloscope as a rapid indicator of the conducted noise signal spectrum. It is easy to quickly establish read-back of the effectiveness of differing arrangements of CM and DM filtering and to iterate on topologies and discrete component selections for CE control.

Example of noise-control assessment

The block diagram in Figure 3 shows a system that was set up and augmented using networks of CE control elements. Some experimentation on component technology options and optimal placement of component networks (such as for the set ups shown in Figures 4 and 5) carried out to maximize noise control. At the completion of the iterative phase of establishing and testing noise control arrangements highlighted with Figures 6 through 9 inclusive, the customer had a full qualification test done on their previously non-compliant target system, modified in accordance with the measures outlined. It was established that the CE noise profile of the system was robustly attained with a good margin to spare. [h]

Figure 3
Block diagram showing basic source / power converter and load arrangement for the unsuppressed system

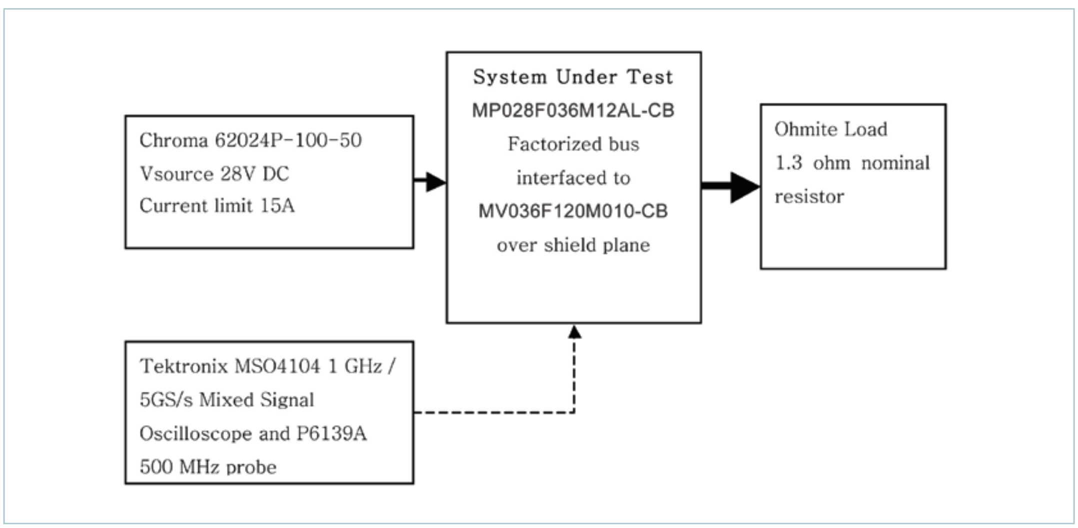

Figure 4
Intermediate bench set up shows coaxially-grounded scope probe, inboard-shield ground contacts made at measurement stations out of adapted pieces of shielding cages of Johnson jacks. Shield ground plane is a solid copper layer. Y-cap provisional placement was changed to gain better oscilloscope acquired noise spectra

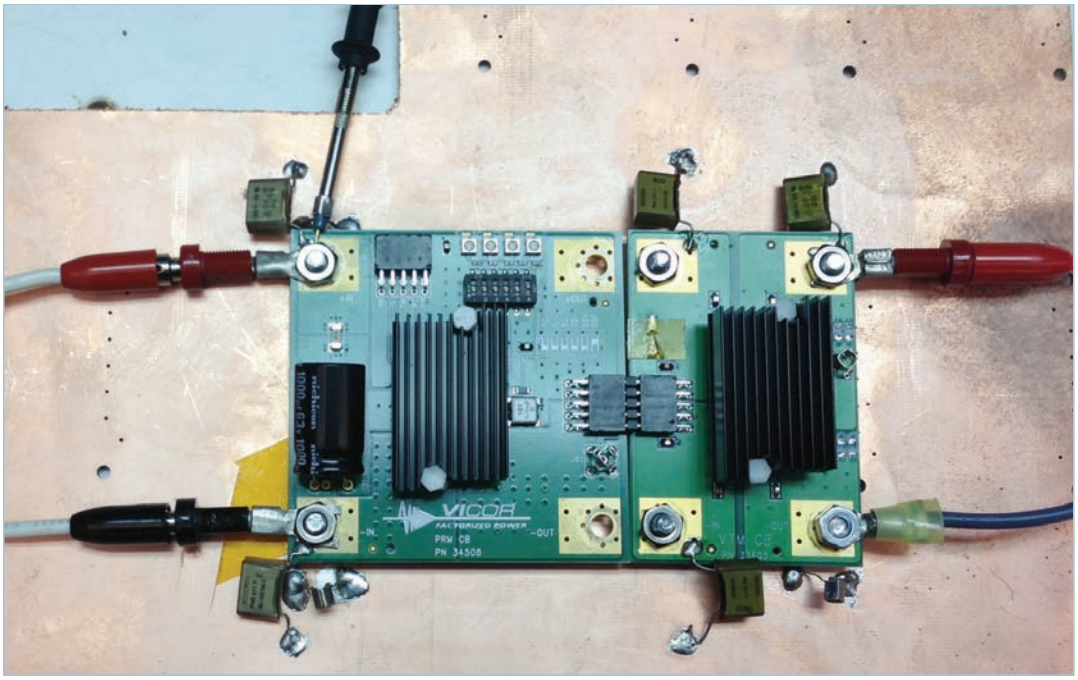

Figure 5
View on the VTM™ evaluation test fixture board's edge. Shows the noise reference voltage point for the system which is located at VTM's (–OUT) terminal

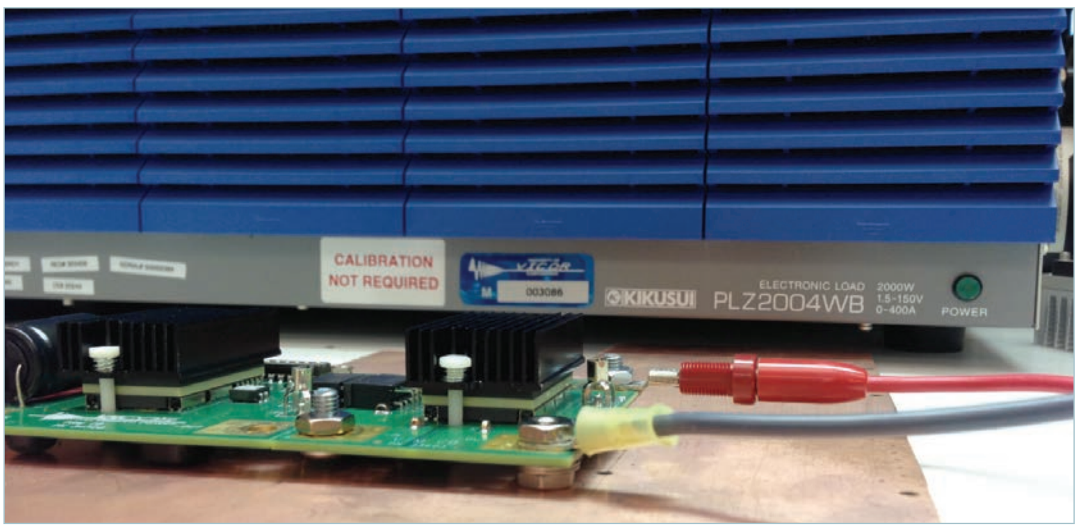

Figure 6
Unsuppressed CE noise characteristic for the PRM™ (+IN) power terminal

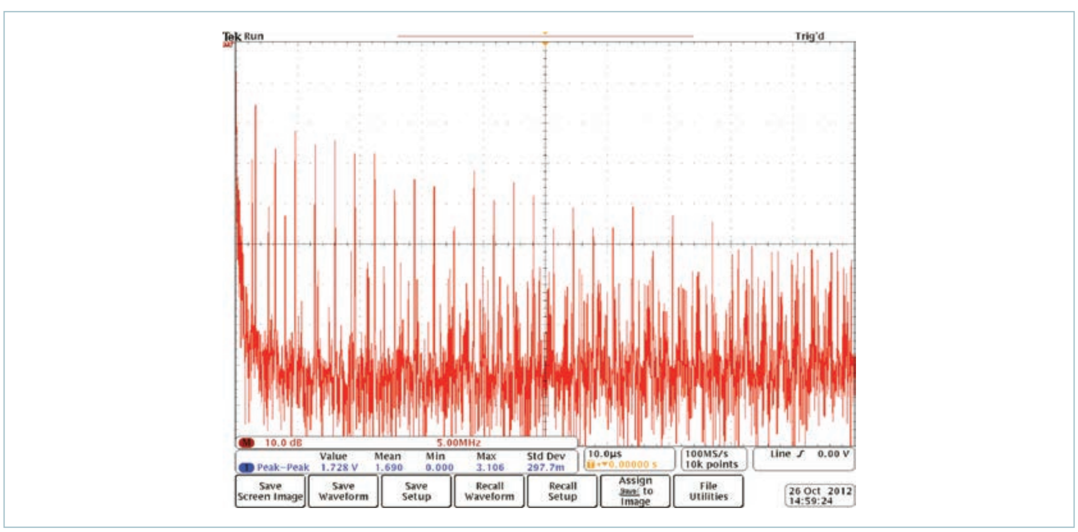

Figure 7
Outline of CE noise suppression arrangement. The M-FIAM™ is a filter and input attenuator module offering CE compliance in conformance with MIL-STD 461E

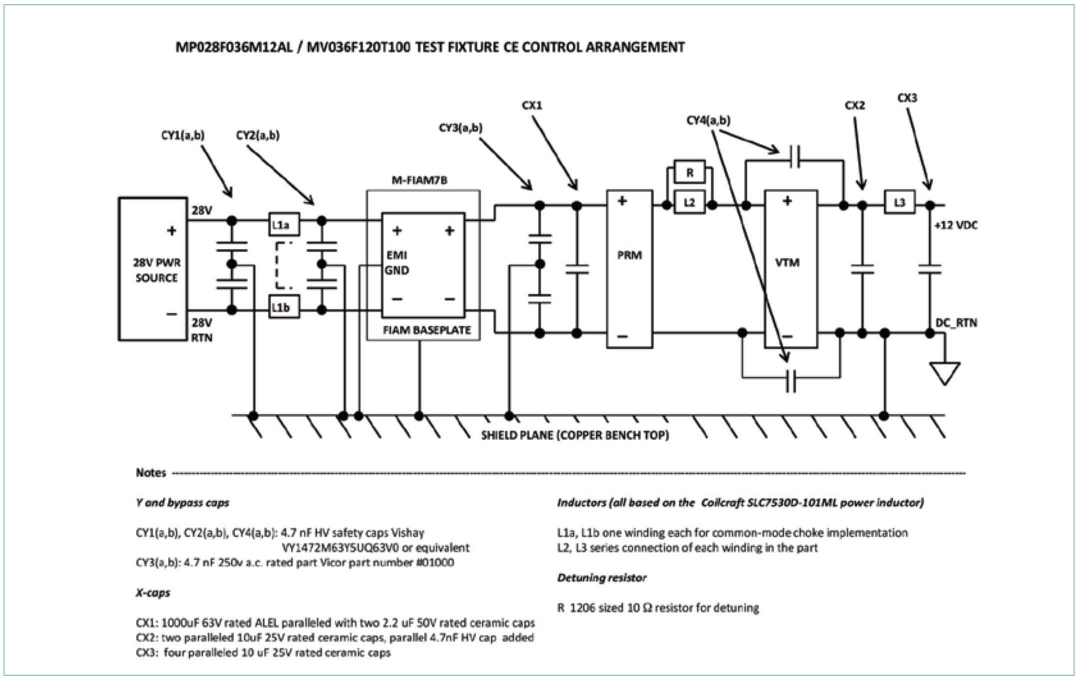

Figure 8
Partial view of adapted noise-control prototype: see the probe attached for the measurement of CE at the M-FIAM's (–IN) terminal. Note that the "bypass style" Y caps (C4a, C4b) across the top and bottom of the VTM™ isolation barrier are mounted underneath the VTM evaluation board

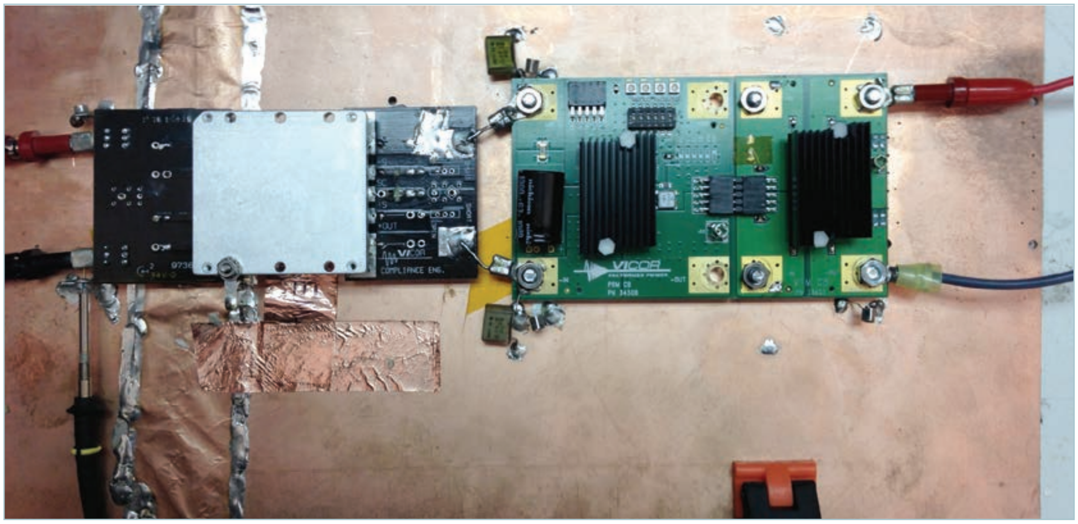

Figure 9
Outcome of the CE noise-suppression arrangements measured at the 28V_{DC} source (+) terminal, location of which is shown in Figure 8

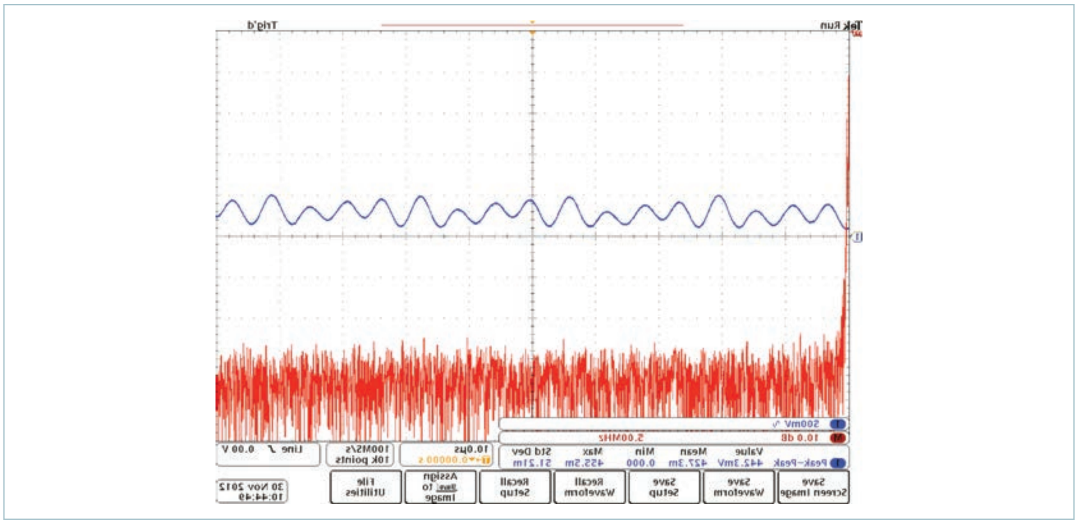

Table 1
Summary of DC power figures or system under test

DC Voltages, Currents and Output Power Bus Inductance for Conducted Emissions for PRM™, VTM™ powertrain-based test rig		
V_SOURCE	27.993V	Voltage measured at Chroma's output power terminals
V_IN_PRM	27.093V	Voltage measured accross the PRM's input power terminals (+IN, –IN)
R_LOAD	1.37Ω	Load set across VTM's output power bus terminals (+OUT, –OUT)
I_SOURCE	4.507A	Current delivered by the Chroma supply
I_LOAD	9.72A	Current in the load
L_OUTPUT	24µH	Inductance presented by Ohmite load (1khz test frequency)

Summary

A suggested method for resolving a functional design whilst testing and providing for control of CE noise early on in the design and development of a power system has been outlined. This forms a paradigm that is easily followed. The noise reductions arising from exercising this approach have been successfully demonstrated, using equipment commonly available in most electronic development lab settings.

References

[a] Vicor Application Note AN: 005 “FPA Printed Cicuit Board Layout Guidelines” P. Yeaman Rev 1.2, Nov 2013

[b] Vicor Application Note AN:023 “Filter Network Design for VI Chip DC to DC Converter Modules” Xiaoyan Yu, Vicor Applications Engineering, Aug 2012

[c] “Power System – CE EMI Topology Review”, Vicor Internal document

[d] “Introduction to Electromagnetic Compatibility” P Clayton, (Wiley Interscience ISBN-13 978-0471755005)

[e] “The Circuit Designer’s Companion” T Williams, 2nd Edition, (EDN Series for Design Engineers, Newnes ISBN-13: 978-0750663700)

[f] “Back to Basics -- What are Y-Capacitors?” Vicor PowerBlog, June 5, 2013

[g] “Capacitor Characteristics Impact Power Supply Decoupling” D Bourner, *PCIM*, May 2001

[h] “CE EMI Topology Review” D Bourner, Vicor Internal Report

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