Exclusive Technology Feature

ISSUE: August 2019

Advanced Scopes And Probes Help Optimize SMPS Gate Drives For EMC

by Michael Fuchs, Bernhard Auinger and Lukas Pichler, Institute of Electronics (IFE) at the Graz University of Technology, Styria, Austria; Markus Herdin, Rohde & Schwarz, Munich, Germany; and Bernd Deutschmann, Institute of Electronics (IFE) at the Graz University of Technology, Styria, Austria

State-of-the-art power electronics poses new challenges for science and industry. The introduction of wide-bandgap semiconductor materials, e.g. silicon carbide (SiC) and gallium nitride (GaN), has enabled higher switching frequencies as well as much steeper edges on switching waveforms. This increases the efficiency of switched-mode power supply units, but on the downside results in unwanted, high-frequency interference that propagates along connecting cables or is emitted as electromagnetic waves.

The Institute of Electronics (IFE) at the Graz University of Technology in Austria is conducting electromagnetic compatibility (EMC) research on gate drive methods with a view to minimizing spurious emissions. High-performance oscilloscopes such as the R&S RTO2000 enable these optimization measures to be implemented on the developer's lab bench.

This article describes the measurements necessary for gate drive optimization and offers some measurement examples to illustrate the setups and measurement results that can be obtained. Among the topics discussed are the use of scope features to observe the effects of modified gate-drive waveforms and spread spectrum modulation on the emissions spectrum, the use of near field probes to locate sources of interference, and the use of differential high-voltage probes to assess power loss across a semiconductor component.

The Effect Of Waveform Characteristics On the Disturbance Spectrum

Generally speaking, the steeper the edges are, the wider the disturbance spectrum and the higher the amplitudes of the resulting harmonics will be. This can be explained simply in mathematical terms: according to the Fourier decomposition, each periodic oscillation can be represented as a sum of individual sine and cosine oscillations. A square-wave, periodic drive signal consists of, for example, the sum of the fundamental, which corresponds to the switching frequency, and its harmonics, which represent multiples of the fundamental. Reduction in the amplitude of these harmonics occurs at frequencies that increase as the edges of the square-wave signal become steeper.

Fig. 1 shows the frequency spectrum of a periodic square-wave signal. Here, the switching frequency determines the position of the first break frequency f_{g1}. The second break frequency f_{g2} depends on the edge steepness and shifts to the right for steeper edges, which causes higher harmonic amplitudes in the high frequency range.

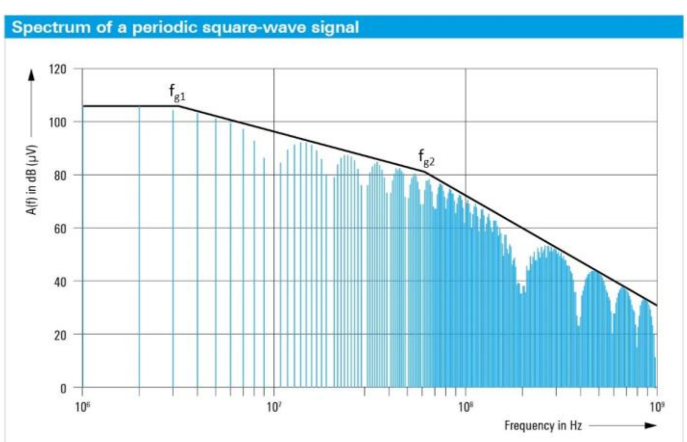


Fig. 1. With a periodic square-wave signal, the harmonics spectrum is determined by the switching frequency and edge steepness. (Source: IFE, Graz University of Technology)

For the CE certification of electronic devices, standards such as those relating to spurious emissions and conducted interference must be observed. These standards give precise details concerning the setup required for EMC measurements. Such a setup is shown in Fig. 2.

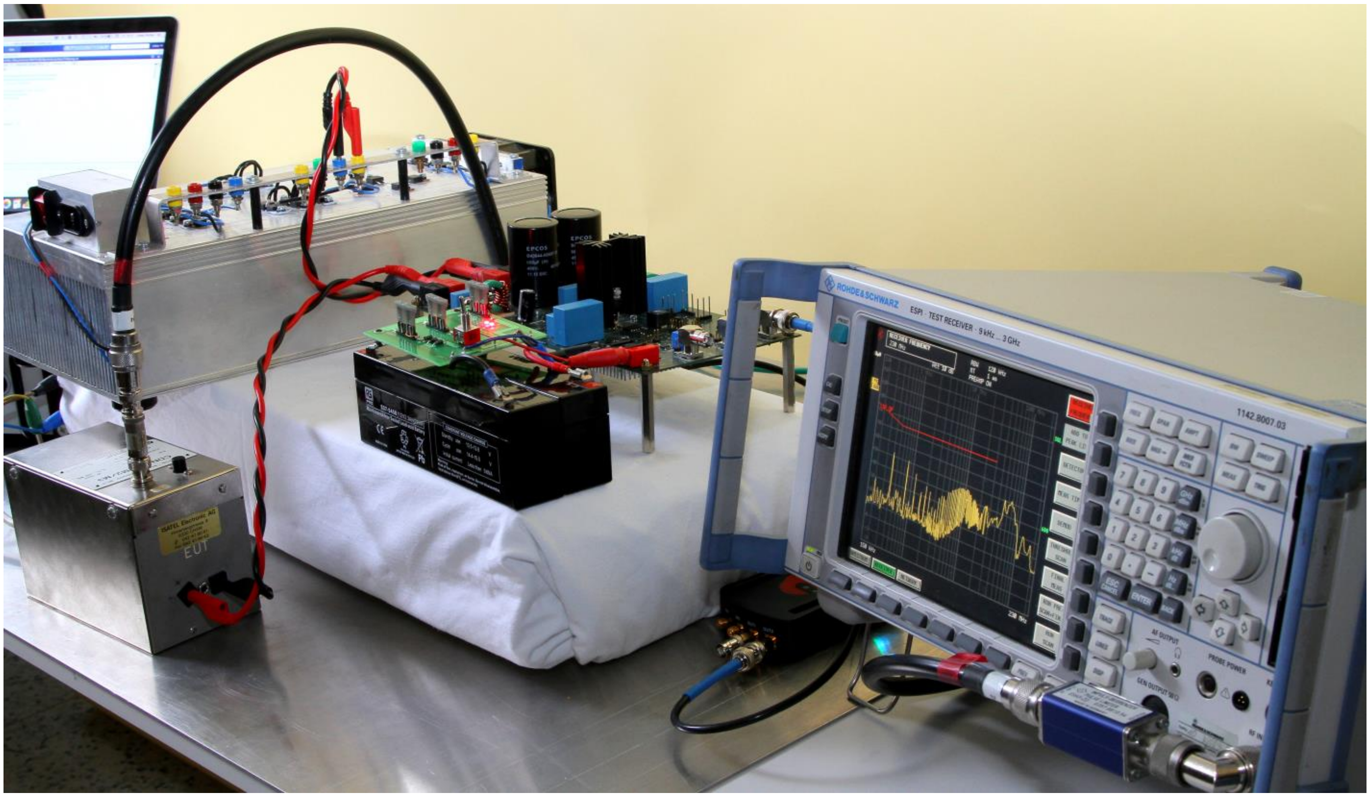


Fig. 2. Test setup for measuring conducted spurious emissions in the lab of the Institute of Electronics at the Graz University of Technology. (Source: IFE, Graz University of Technology)

An EMI test receiver is used to, for example, measure the spectrum of conducted interference in compliance with the relevant standards. Filter circuits, the components of which significantly increase the price and weight of the finished product, are often required to ensure that the limits defined in the standards are observed. Manufacturers therefore try to find other ways to reduce unwanted electromagnetic interference.

For this reason, a compromise must be made when designing devices for switched-mode power supply units. On the one hand, fast edges allow a higher clock rate, which results in significantly smaller storage chokes and capacitors. On the other hand, this shifts the spurious emissions toward higher frequencies. The spurious emissions propagate along, for example, connecting cables, which results in the switched-mode power supply unit frequently being the primary cause of EMC problems.

Targeted driving of the power electronics in the switched-mode power supply units, e.g. gate driving of MOSFET half-bridges, can reduce the need for costly filter circuits without any significant reduction in the efficiency of the switched-mode power supply unit. Fig. 3 compares the output spectrum produced by a conventional, square wave gate-drive signal with the spectrum produced by a specially shaped gate-drive voltage characteristic.

With the optimized gate-drive waveform, the objective is to keep the input voltage constant across what is known as the Miller plateau during the charging time of the parasitic capacitor between the gate and drain of the power MOSFET, until charge reversal has been completed. During this time, a rapid change in the input signal would lead only to higher disturbance amplitudes, but not to a higher switchover speed nor, therefore, to an increase in the circuit's efficiency.

(a)

(b)

Fig. 3. Comparison of different gate drive signals. Fig. 3a shows a standard square-wave signal; Fig. 3b shows a drive with optimized gate-drive signal. The lower red amplitude inside the white circle shows the significantly reduced emissions—approximately 20 dB less than that produced by the square-wave gate drive. (Source: IFE, Graz University of Technology)

Correlating Gate-Drive Signals With The Emitted Noise Spectra

High-sensitivity oscilloscopes with fast FFT functionality help developers to easily analyze unwanted spurious emissions. The influence of a modified gate drive on spurious emissions can be qualitatively assessed immediately. A further advantage of oscilloscopes from Rohde & Schwarz is that the spectrum and the time domain signal can be clearly correlated. Using the gating function, it is possible to precisely analyze which section of the time domain corresponds to which spectrum. This allows for easy optimization early on in power converter development and increases the prospects of successful CE certification.

Aside from the shape of the drive signal, there are other ways to change the disturbance spectrum of switched-mode power supply units. Frequency modulation of the control signal, known as spread spectrum clocking, can be used to suppress specific individual harmonics in the disturbance spectrum.[1] This is achieved by targeted adjustment of the clock frequency by means of frequency modulation of the control signal and can be used to, for example, keep communications channels free from interference.[2]

Ideally, adaptive gate drives can be implemented that are regulated according to the current output load and temperature in such a way that the gate drives always ensure minimal interference with maximum efficiency. Results from the research so far conducted are extremely promising.

Locating Interference Sources Using Near-Field Probes

In complicated electronic circuits, it is not always possible to easily identify the source of spurious emissions or the effect of filter circuits. In practice, near-field probe sets such as the R&S HZ-15 set have proven to be valuable tools to locate the source of unwanted emissions. Unexpected effects such as the electrical or magnetic coupling of electrolytic capacitors, coils, driver circuits or heat sinks are often revealed in this way. This is an invaluable advantage for further development. Due to the sensitive front end of Rohde & Schwarz oscilloscopes, it is not necessary to have an additional spectrum analyzer for near-field probing (Fig. 4).

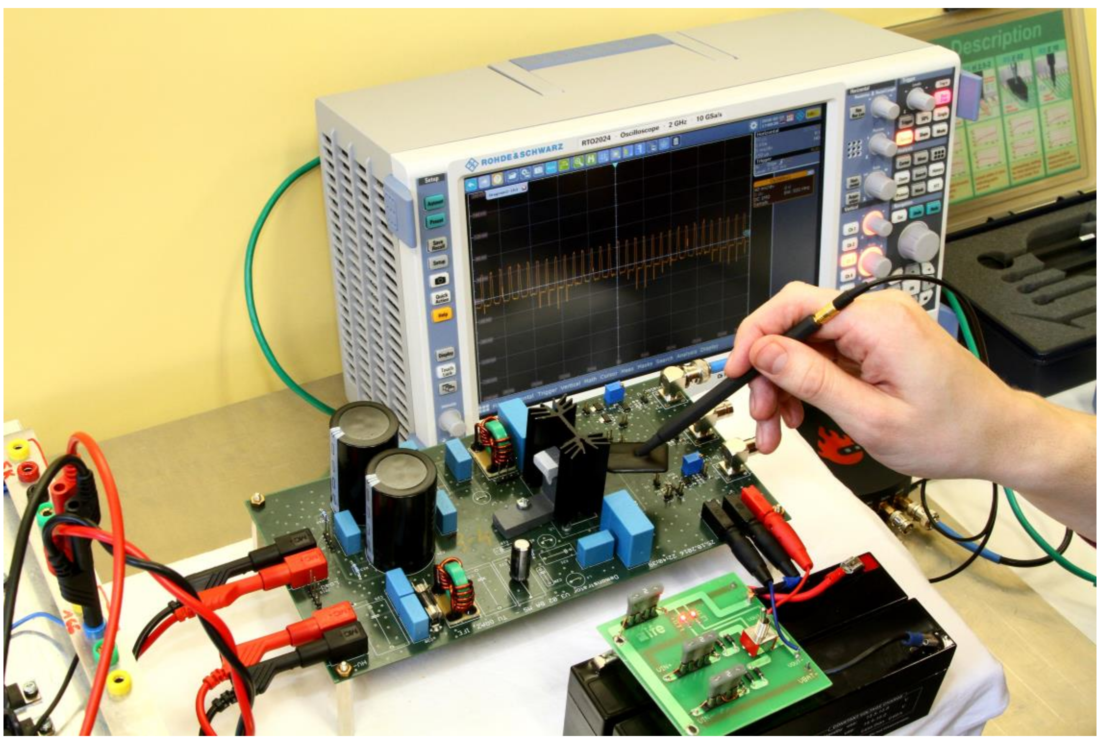


Fig. 4. Detection of interference sources using an E field probe. (Source: IFE, Graz University of Technology)

To determine the radiated E and H fields with micrometer precision, the Institute of Electronics at the Graz University of Technology also uses surface scan systems to check the surfaces of printed boards and microchips for interference fields. These useful tools for analyzing the source of electromagnetic interference fields enable developers to recognize and resolve potential EMC problems when designing the first prototypes of a design.[3]

Loss Measurement Using Differential Probes

Measuring the voltage across a particular component is essential for determining power loss. Typically this has to be done in a differential manner. Fig. 5 shows a test setup with a SiC diode in a switched-mode power supply unit (buck converter circuit). The use of wideband, differential high-voltage probes—the R&S RT-ZHD07 differential probe in the example—allows floating measurement of the voltage at the diode. The developer can obtain a good estimate of the current by measuring the current using a current probe.

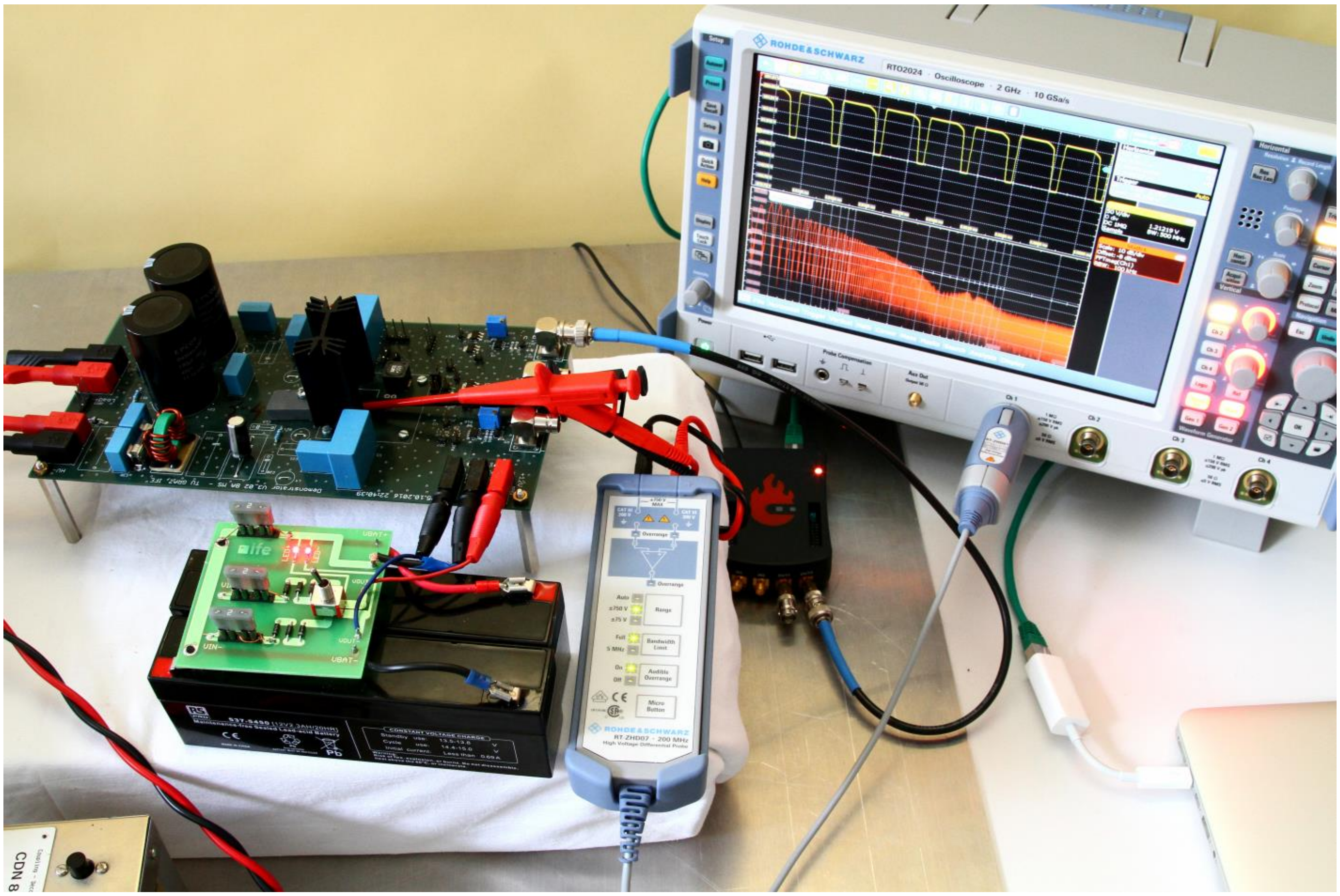
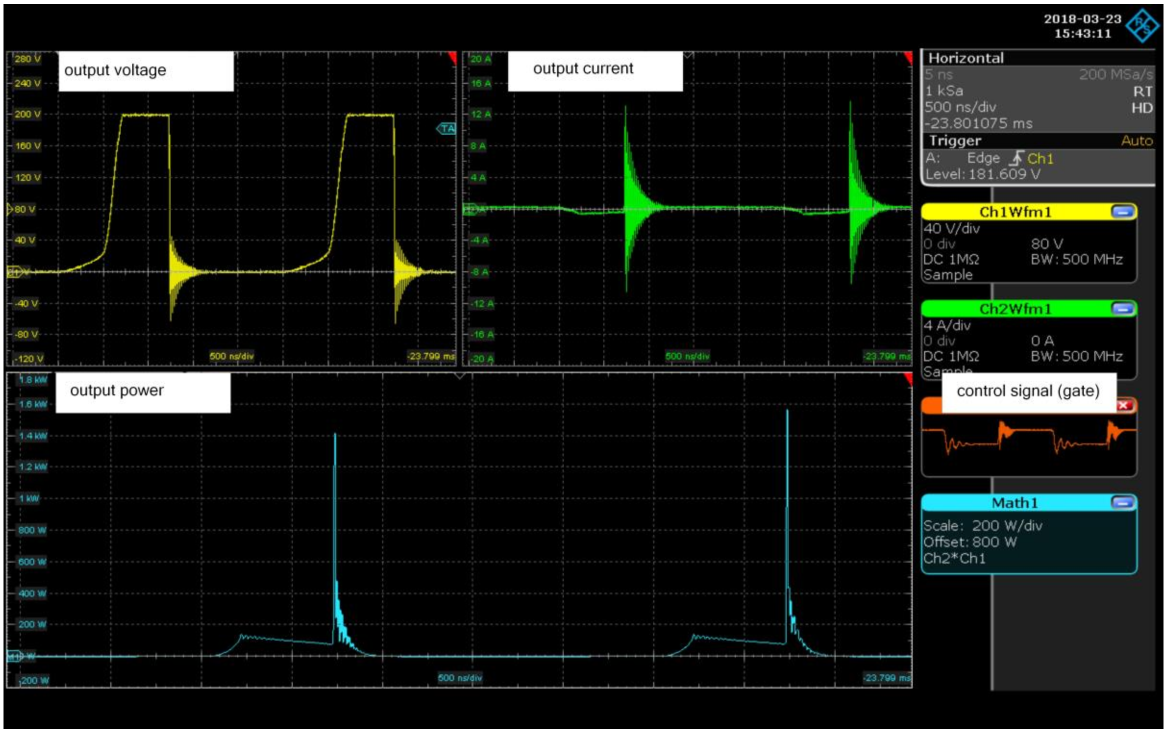
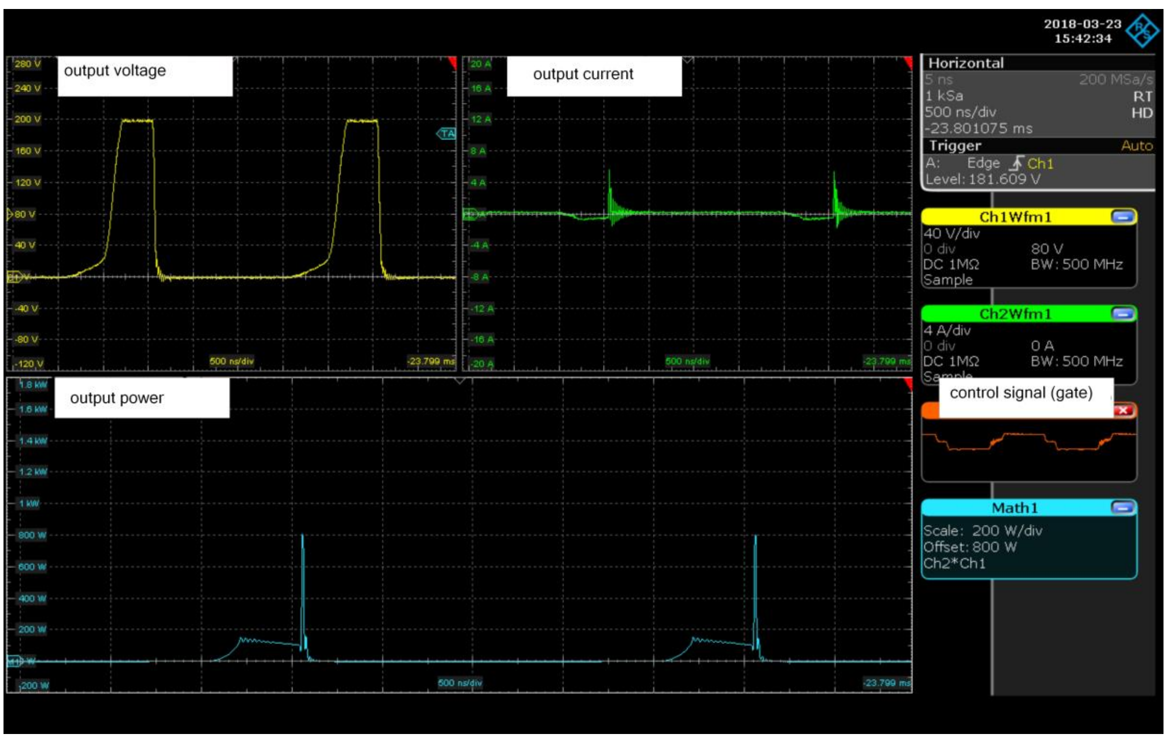


Fig. 5. Measurement using a differential probe. (Source: IFE, Graz University of Technology)

In combination with the mathematical functions of the R&S RTO2000 oscilloscope, the power loss at the diode can be determined by multiplying the current and voltage (Fig. 6). Only then is it possible to optimize the switching signal shape and the switching frequency, taking the efficiency into account.



(a)



(b)

Fig. 6. Power loss measurement. Fig. 6a shows a standard square-wave signal; Fig. 6b shows a drive with special characteristic. The optimized gate-drive signal reduces the disturbance power considerably. (Source: IFE, Graz University of Technology).

Verification Measurements Are Essential

In the context of EMC, device developers increasingly use simulation tools that are intended to recognize and resolve problems concerning conducted and radiated spurious emissions at an early stage.[4] A fundamental problem often encountered when simulating complex circuits is the absence of models of active and passive components. Moreover, parasitic capacitances and inductances of conductor tracks and heat sinks need to be taken into consideration to achieve a realistic simulation. The extremely fast switching edges of state-of-the-art power semiconductors make this increasingly important. Crucial for optimization of a specific circuit layout is the question as to which component of the electronic system is responsible for the unwanted high emissions and therefore needs to be improved.

The IFE is conducting research into simulation tools in order to provide device manufacturers with new possibilities for predicting the EMC behavior of an electronic device. The subject of current research includes, among other things, the high-frequency behavior of active components such as power transistors, because most of the available manufacturer models are not suitable. Furthermore, a simulation program is being developed that marks individual frequency bands in the spectrum and automatically proposes changes to the circuit design with a view to reducing the spurious emission in the corresponding frequency range. Ideally, this will allow problems relating to the layout or circuit to be identified. The problem can be confirmed by means of subsequent verification measurements, and improvements can then be made.

References

1. "Spread spectrum parameter optimization to suppress certain frequency spectral components" by Bernhard Auinger, Bernd Deutschmann and Gunter Winkler, Electromagnetic Compatibility of Integrated Circuits (EMCCompo), 2017 11th International Workshop, ISBN: 978-1-5386-2689-4, July 4-8, 2017.

2. "Elimination of electromagnetic interference in communication channels by using spread spectrum techniques" by Bernhard Auinger, Bernd Deutschmann and Gunter Winkler, Electromagnetic Compatibility - EMC EUROPE, 2017 International Symposium, ISSN 2325-0364, Sept. 4-7, 2017.

3. "Highlighting the distribution path of transient disturbances by near field scanning techniques" by B. Deutschmann, S. Schindlbacher and G. Winkler, e & i Elektrotechnik & Informationstechnik Journal, February 2016, Volume 133, Issue 1, pp. 18–24, DOI 10.1007/s00502-015-0382-6.

4. "Modeling of a Buck Converter With a SiC JFET to Predict EMC Conducted Emissions" by Eliana Rondon-Pinilla, Florent Morel, Christian Vollaire and Jean-Luc Schanen, IEEE Transactions on Power Electronics, vol. 29, Issue: 5, pp. 2246 – 2260, May 2014.

5. For more information on Rohde & Schwarz's power electronics test solutions, see the website.

About The Authors

Since 2016, Michael Fuchs has been working as a university assistant and PhD-student at the Institute of Electronics at Graz University of Technology-Austria. His research focuses on the simulation of electromagnetic emissions (EME) in high-voltage switched power converters and EMC-suitable circuit design. Michael is also currently teaching different subjects relating to the fundamentals of electronics and electromagnetic compatibility. He holds a BSc degree in electrical- and sound-engineering and an MSc degree from the Institute of Electronics at Graz University of Technology-Austria.

Bernhard Auinger is staff scientist and head of the research unit "Electromagnetic Compatibility and Coexistence" in the Austria-based research center Silicon Austria Labs.

He focuses on enabling the paradigm shift in electronics for "design EMC first time right" employing model-based design and leading edge measurement technology.

Lukas Pichler received his bachelor of science in electrical engineering at the Graz University of Technology in 2017 and is continuing his studies there for a master's degree in electrical engineering. He is currently a member of the EMC project team at the IFE.

Markus Herdin is a seasoned market development professional at Rohde & Schwarz with a focus on power electronics test & measurement applications as well as EMC applications for oscilloscopes. His experience at Rohde & Schwarz includes roles in product management, product development and corporate business development. Markus holds a PhD in electrical engineering as well as an MBA from the University of Chicago Booth.

Bernd Deutschmann is a professor and head of the Institute of Electronics at the Graz University of Technology. His research interests include EMC-compliant designs of integrated circuits, power electronics as well as EMC simulation and T&M technology.

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".