EMC challenges in power electronics

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State-of-the-art power electronics pose new challenges for science and industry. The introduction of wide bandgap semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN) has enabled higher switching frequencies as well as considerably greater edge steepness. While increasing the efficiency of switched mode power supply (SMPS) units, these higher switching frequencies can increase unwanted high-frequency interference propagated along connecting cables or emitted as electromagnetic fields. With suitable equipment, such as high-performance oscilloscopes, important analyses and electromagnetic compatibility (EMC) optimisation can be performed on the lab bench during the early stages of device development.

The Institute of Electronics (IFE) at the Graz University of Technology is conducting research into power electronics circuit design with respect to spurious emissions, including the optimisation of gate-drive signals, identification of weak points in the layout and the influence of active and passive components. The objective is to develop a simulation software that automatically proposes changes to the circuit design with a view to reducing the spurious emissions.

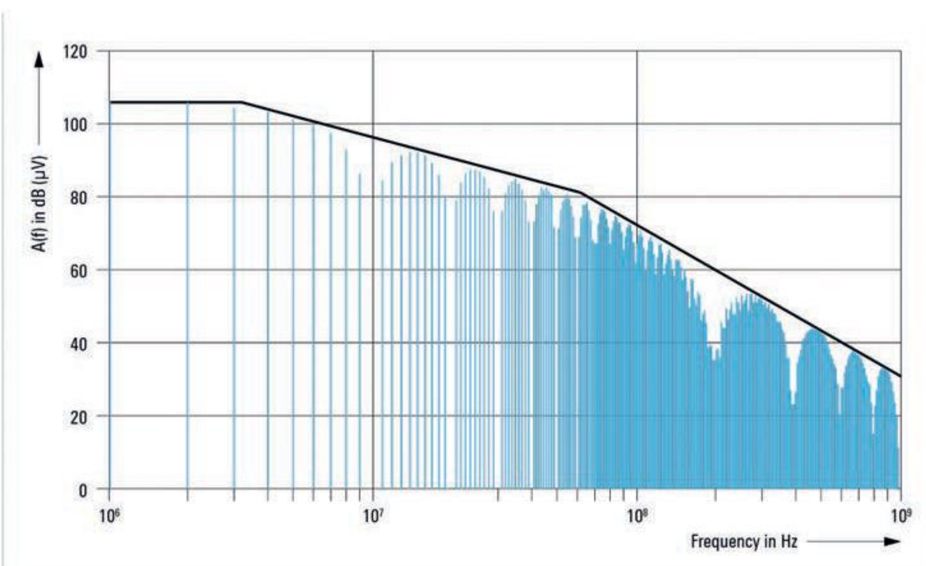
Effect on harmonics

Generally speaking, the steeper the switching edges, the wider the disturbance spectrum, and the stronger the resulting harmonics. 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. For example, a typical trapezoidal periodic drive signal consists of the sum of the fundamental, corresponding to the switching frequency, and its harmonics, representing multiples of the fundamental.

Figure 1 shows the frequency spectrum of a periodic trapezoidal 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 and, therefore, often higher conducted and radiated emissions of power electronic systems.

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; see Figure 2.

Figure 1: Switching frequency and edge steepness determine the harmonics spectrum of a periodic trapezoidal-wave signal



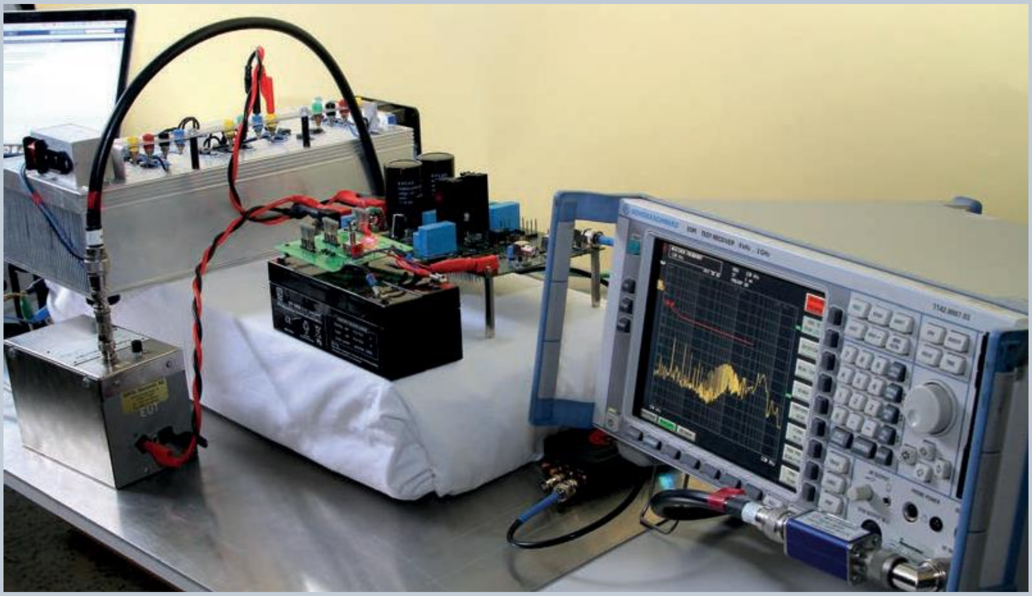


Figure 2: Test setup for measuring conducted spurious emissions

Figure 3: Comparison of standard square wave gate drive signal (left) with optimised gate drive signal (right). The lower red amplitude inside the white circle shows the significantly reduced emissions

An EMI test receiver is used to, for example, measure the spectrum of conducted interference in compliance with the relevant standards. Filter circuits may be required to ensure that the limits defined in the standards are observed. Because these can significantly increase the price and weight of the finished product, manufacturers often seek other ways to reduce unwanted electromagnetic interference.

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

Targeted driving of the power electronics in the SMPS, such as gate driving of the power MOSFETs, can eliminate costly filter circuits with no significant reduction in efficiency. Figure 3 compares the gate drive by the square wave signal with the drive by a specially-formed voltage 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.

The development phase

High-sensitivity oscilloscopes with fast FFT functionality help developers minimise unwanted spurious emissions. As a result, the influence of a modified gate drive on spurious emissions can be qualitatively assessed immediately. Moreover, some oscilloscopes have a gating function that allows the spectrum and the time

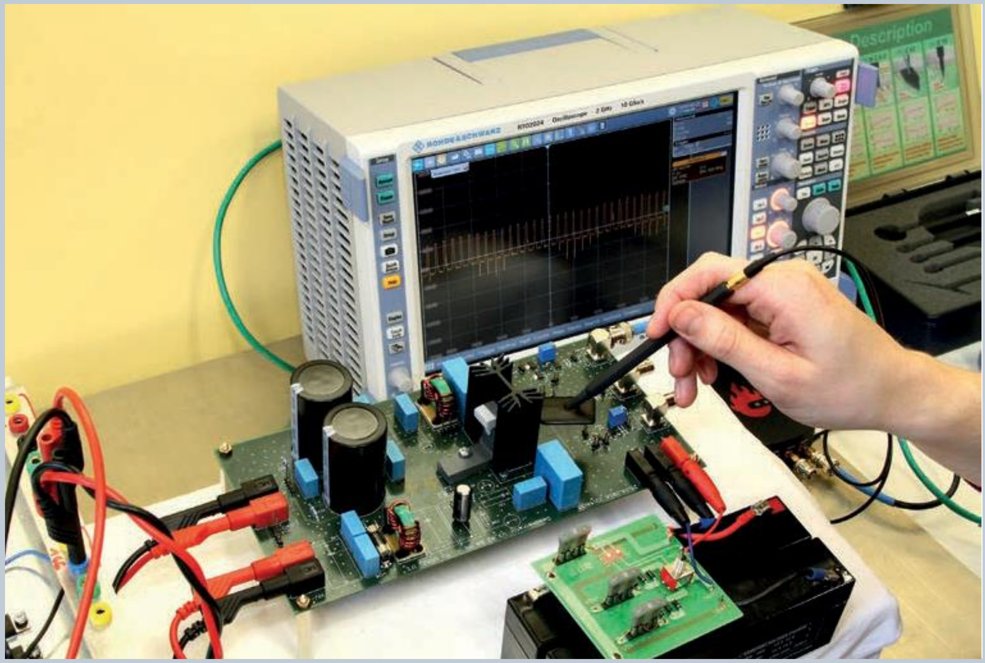


Figure 4: Detection of interference sources using an E field probe

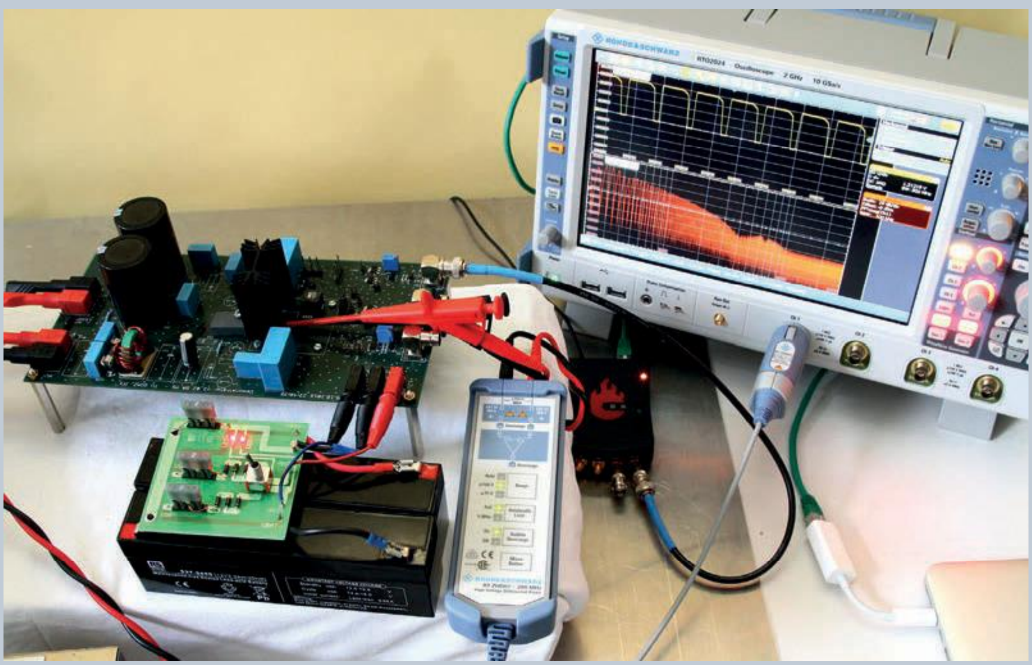


Figure 5: Measurement using a differential probe

domain signal to be clearly correlated, to precisely analyse which section of the time domain corresponds to which spectrum. This enables an easy optimisation early in device 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 the SMPS. Frequency modulation of the control signal, known as spread-spectrum clocking, can be used to suppress specific individual harmonics in the disturbance spectrum. 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.

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 and maximum efficiency.

Localising interference sources

In complicated electronic circuits, it is not always possible to clearly identify the source of spurious emissions or the effect of filter circuits. In practice, near-field probe sets have proven valuable, provided the oscilloscope front-end has adequate sensitivity. Some are sensitive enough for use without a preamplifier; see Figure 4. As a result, complicated circuits can be checked for sources of interference without the exact voltage and current value needing to be known. Unexpected effects such as the electrical or magnetic coupling of electrolytic capacitors, coils, driver circuits or heat sinks are often revealed in this way, an invaluable advantage for further development.

To determine the radiated E and H fields with micrometer precision, IFE uses two surface scan systems to check the surfaces of printed boards and microchips for interference fields. These useful tools for analysing the source of electromagnetic interference fields enable developers designing the first prototypes of a device to recognise and resolve potential EMC problems.

Understanding which component of an electronic system is responsible for unwanted high emissions is crucial for circuit layout optimisation

Power loss measurement

Differential voltage measurements are very useful in determining power loss. Figure 5 shows a test setup with a SiC diode in a SMPS buck converter circuit. Using wideband differential high-voltage probes such as those shown in the example allows floating measurement of the voltage at the diode. A good estimate of the current can be made by measuring with a current probe.

Using an oscilloscope with suitable mathematical functions built in, the power loss at the diode can be determined by multiplying current and voltage; Figure 6. This makes it possible to optimise the switching signal shape and the switching frequency, taking efficiency into account.

Verification measurements

Simulation tools help recognise and resolve problems concerning conducted and radiated spurious emissions at an early stage. 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 must be considered to achieve a realistic simulation. The extremely fast switching edges of state-of-the-art power semiconductors make this increasingly important. Understanding which component of an electronic system is responsible for unwanted high emissions (and needs improvement) is crucial for optimisation of a specific circuit layout.

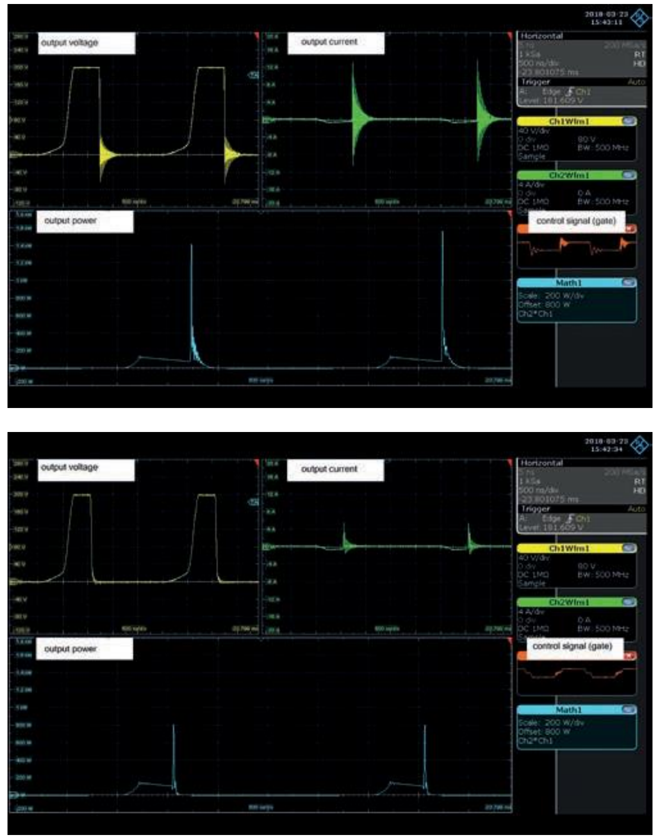


Figure 6: Power loss measurement comparing standard square wave signal (top) against drive with special characteristic (bottom). The optimised gate drive signal reduces the disturbance power considerably

The IFE is conducting research into simulation tools to provide manufacturers with new possibilities for predicting the EMC behavior of their devices. Current research includes, among other things, the high-frequency behaviour of active components such as power transistors, because most current models are not suitable for precise EMC simulations. 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 spurious emission in the particular frequency range. This will help to identify problems relating to the circuit design or layout. The results can be confirmed by means of subsequent verification measurements, and improvements can then be made. EW