MHz switching frequency-based devices enable miniaturization of the DC-DC converter and EMI filters

Achieving EMI conducted emission compliance for automobiles with a single stage filter.

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When it comes to electric vehicles (EVs), all OEMs want to design lighter, smaller and more affordable solutions. Additionally, utilities, regulatory agencies and OEM's are seeking to leverage a vehicle to grid (V2G) connection to enable energy, period exchange with the distribution network From a power electronics perspective, this pursuit entails power conversion circuitry with greater power densities and the ability to meet the requirements for connecting the vehicle to the grid.

With respect to DC-DC power converters, one notable way to miniaturize the system and increase overall power density is through higher-frequency switching. Yet, despite the potential benefits of systems with switching frequencies over 1.3MHz, technical challenges have kept many designers to working at lower frequencies, such as 100kHz or below.

Imagine having a DC-DC power conversion solutions that harness the benefits of high-frequency switching without incurring conventional shortcomings. That could go a long way toward achieving smaller and lightweight EV power design goals of the OEM while adding V2G capability.

The benefits of high-frequency DC-DC power conversion

In the pursuit of lighter, smaller and more affordable automotive systems, high-frequency power conversion offers a promising solution.

The primary benefit of moving to higher-frequency power conversion systems is a reduction in component size in both the physical device and the supporting input and output EMI filters. Some of the most space-consuming components in the converter itself are the passives, such as inductors and capacitors. Inductors and capacitors store and release energy in each switching cycle to smooth out current and voltage waveforms, respectively. When the converter's switching frequency is higher, these components store less energy per cycle, allowing for smaller-value components allowing a decrease in the overall system size and enabling more power-dense systems for the same power level target.

Beyond the converter, the associated input EMI filters are a major space consumer related to DC-DC conversion. DC-DC converters generate EMI due to the rapid switching of currents and voltages, which can create noise at the switching frequency and its harmonics. To mitigate this noise, EMI filters are employed at the input with cutoff frequencies typically dependent by the power stage requirements. (Figure 1)

These filters also rely on passive components where size is directly correlated to switching frequency. By shifting the converter's switching frequency to the MHz order, the desired EMI filter cutoff frequency can be increased. At higher cutoff frequencies, designers can make the passive components in the EMI filter much smaller, decreasing overall system size and weight while increasing system power density.

Not only does switching to higher-frequency DC-DC conversion reduce component size and weight, but it also enables systems with improved transient responses. In DC-DC converters, the control loop bandwidth is typically a fraction of the switching frequency. Higher switching frequencies enable higher control loop bandwidth, allowing the feedback loop to react more rapidly to disturbances. A higher bandwidth allows the converter to correct output deviations quicker, ensuring that the output voltage remains stable even with sudden load or input voltage changes.

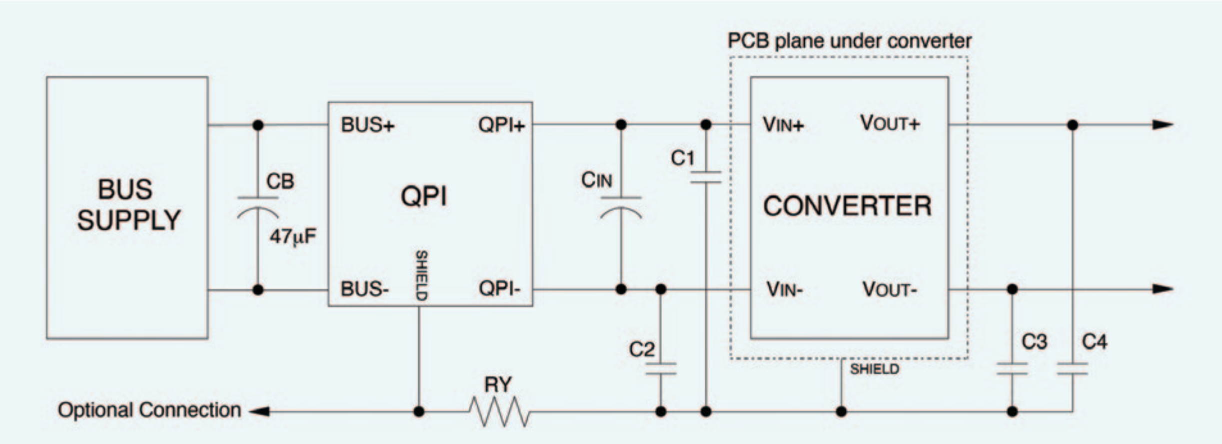

Figure 1: An active EMI filter (labeled QPI) is often employed at the input of a DC-DC converter, with its cutoff frequency determined by the switching frequency of the converter.

Conventional challenges facing high-frequency DC-DC power conversion

Although moving to higher-frequency DC-DC conversion can yield many tangible benefits, a number of technical challenges have historically prevented this pursuit.

First, moving to higher frequency operation may present a barrier to achieving EMC compliance. For conducted emissions standards such as CISPR32 (required for V2G applications), the frequency range evaluated by the standard is from 150kHz to 30MHz. Operating at a higher fundamental frequency, such as above 1MHz, creates the largest harmonics within the frequency range of interest, running the risk of compliance failure. For this reason, many power converter designers choose to operate at lower frequencies, such as 100kHz, ensuring that their first harmonic falls below the frequency range of interest. Same issues can found if the power stage is called to be compliant with the CISPR25 reference standard.

Also, fear of increased losses is another potential drawback when using higher-frequency switching converters. Switching losses occur when a switch, such as a MOSFET, transitions from its on-state to its off-state and vice versa. These losses are significant because both the voltage across the switch and the current through the switch are non-zero during the transition period. (Figure 2)

All else being equal, higher switching frequencies result in more frequent transitions per unit of time, leading to increased switching losses. Since the energy dissipated per switching event is proportional to the crossover time and the product of the voltage and current, increasing the frequency means that these energy losses accumulate more quickly. Therefore, the total power loss due to switching is directly proportional to the switching frequency, making higher-frequency operation associated with higher switching losses.

Finally, issues concerning the self-resonance of passive components occur during high-frequency operations. Self-resonance is a phenomenon in which electrical components exhibit resonant behavior due to their parasitic properties. This leads to unpredictable behavior, impedance peaks, efficiency losses and signal integrity issues. Self-resonance becomes a significant problem at higher switching frequencies as these frequencies approach the self-resonant frequencies of components, amplifying noise and EMI and complicating circuit design. Also working beyond the self resonant frequency an inductor exhibits a capacitor behavior and vice-versa a capacitor

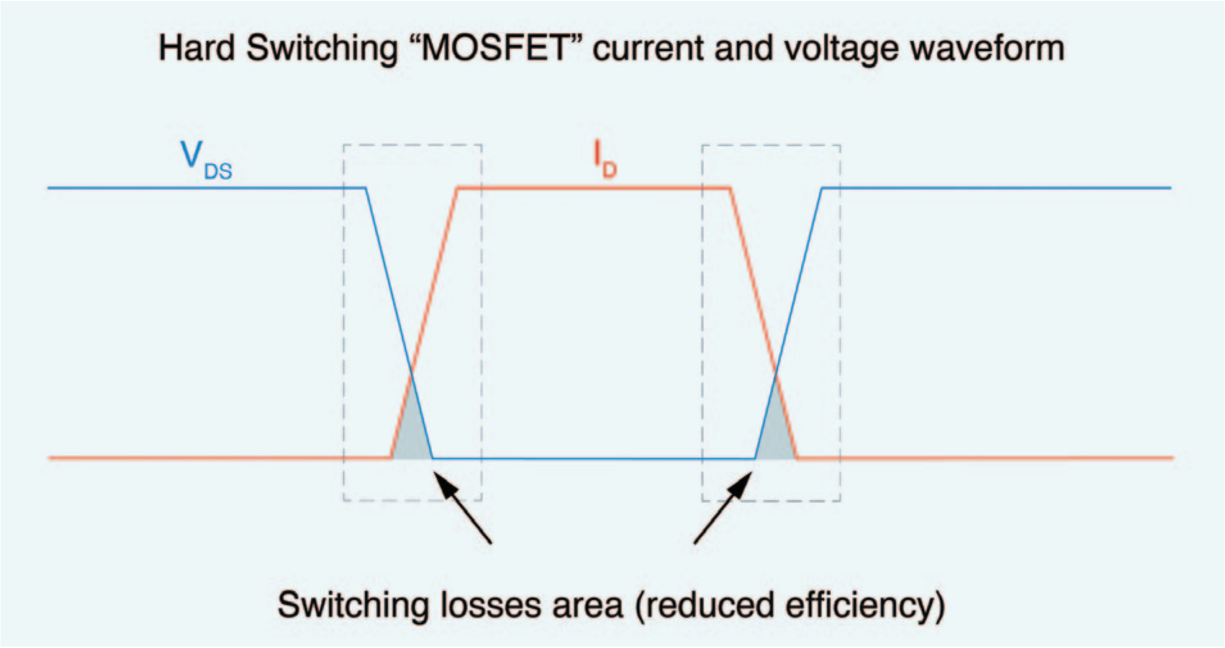

Figure 2: **Switching losses occur during "hard switching", where the MOSFET transitions while voltage and current waveforms are both non-zero.**

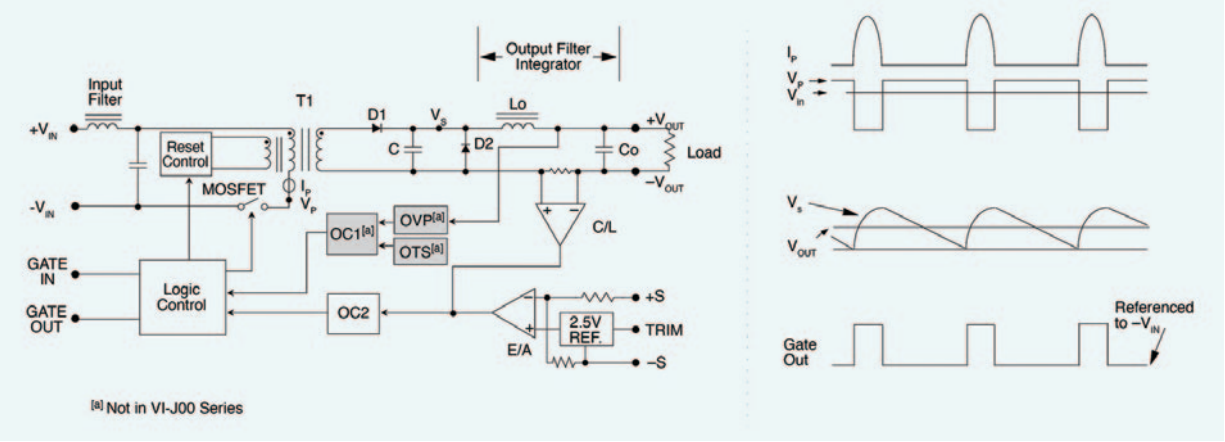

Figure 3: **Zero-current switching is achieved through a set of dedicated circuitry, which avoids high-frequency switching losses through specially timed MOSFET transitions.**

behaves like an inductor.

Solving high-frequency power conversion

With decades of industry-leading experience in power electronics design, Vicor has developed DC-DC conversion solutions that harness all the benefits of high-frequency conversion without the negative side effects. Specifically, the Vicor NBM™ family of non-isolated bus converter modules successfully switch at frequencies above 1.3MHz.

With respect to efficiency, the NBM™ line of products can realize minimal power losses at high frequency by using zero voltage switching (ZVS) and zero current switching (ZCS) technology. Zero-voltage switching works by carefully timing the switch's operation so that the switching aligns with the moments when the voltage across the switch is zero. Similarly, zero-current switching works by timing the switch's operation so that it coincides with the moments when the current through the switch is zero. (Figure 3)

Vicor ZVS and ZCS are achieved by introducing a separate phase to the pulse-width modulation (PWM) timing. Utilizing the added phase, the solutions use a clamp switch and circuit resonance to efficiently operate the high side and synchronous MOSFETs with soft switching, avoiding losses incurred during conventional PWM hard switching operation and timing. Thanks to ZVS and ZCS, products like the NBM line of DC-DC converters can operate at 1.5 to 1.7 MHz while still achieving peak efficiencies of up to 99%. The combination of high switching frequencies and efficiency enables solutions with unparalleled power density, up to 550 kW / liter.

In terms of EMC, the NBM™ products can achieve compliance, even at unusually high frequencies. In a recent set of tests, conducted emission compliance of the NBM9280 power module was evaluated. This Vicor module is capable of converting 37.5kW, with a power density of 550 kW/liter, for electrified vehicle applications. The testing found that, even at a switching frequency of 1.3MHz, the NBM9280 could satisfy CISPR32 limits with a combination of Pi filtering and introducing a ferrite core around the input power cables. (Figure 4) The resulting filtering components were significantly smaller than what is necessary for a lower-frequency (i.e., 100kHz) solution, yet the same compliance was achieved.

All things considered, automotive designers can simply replace their existing DC-DC conversion systems with the NBM™ line of products and immediately realize the benefits of smaller size and greater power density without risk of compliance failure or efficiency losses.

Higher frequency supports today's EV demand period.

With a shift to EVs the automotive industry is demanding smaller, lighter and more power-dense solutions which can support vehicle to grid interfaces. For power electronics designers, a switch to higher-frequency DC-DC conversion solutions is an ideal way to meet these demands.

Vicor has been able to develop DC-DC conversion solutions that operate with switching frequencies as high as 1.74MHz without incurring the conventional shortcomings of high switching frequencies. With products like the NBM™ family of DC-DC converters, automotive designers can realize a future where vehicles are efficient, lightweight and high performing, without the design complexity or expertise that often accompany these results.

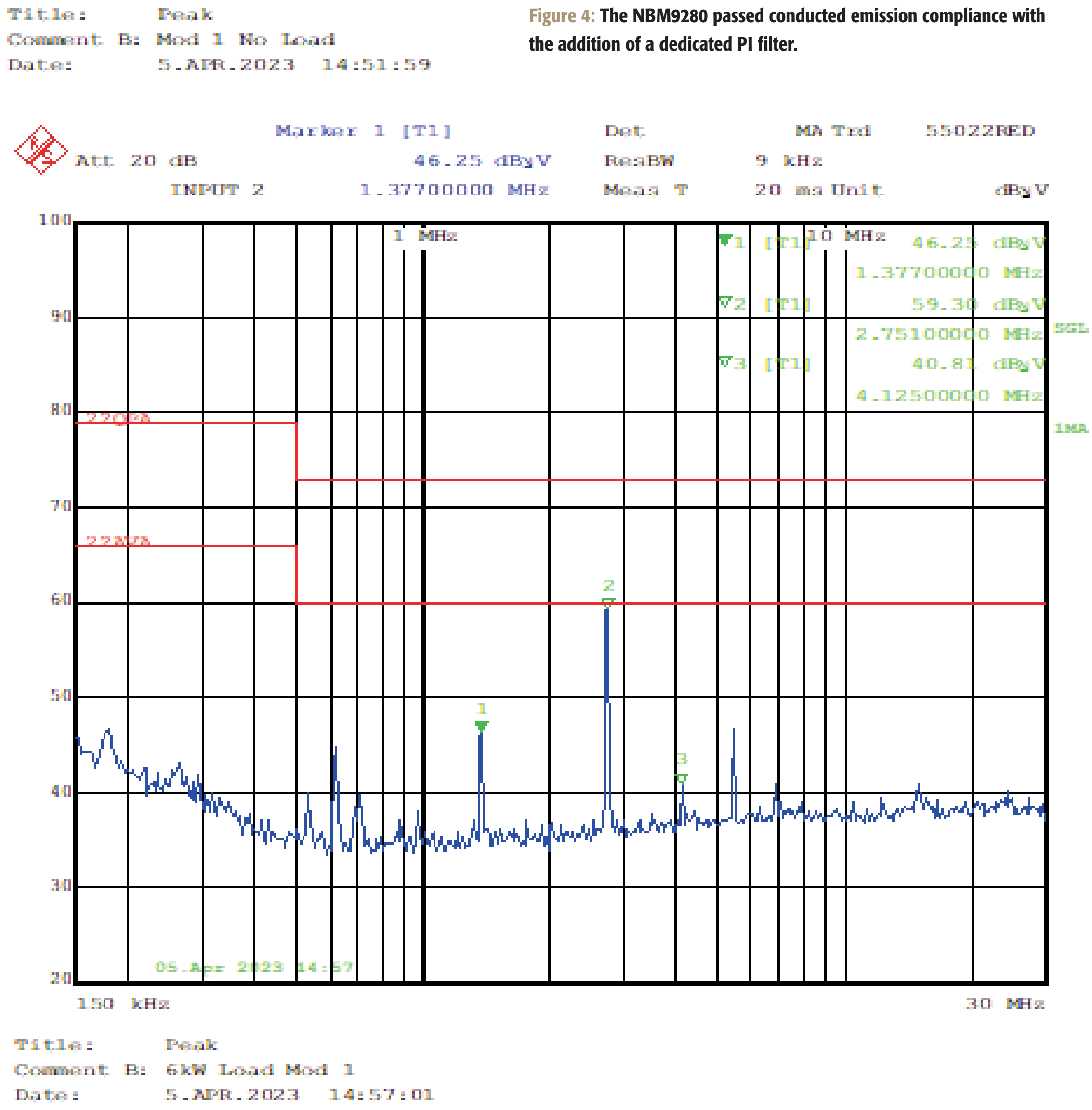

Figure 4: The NBM9280 passed conducted emission compliance with the addition of a dedicated PI filter.