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# Comparing dc/dc converters' noise-related performance

[illegible]

Today, dc/dc-converter components employing high-frequency switching are the devices that designers most often use to accomplish power conversion. Designers have long recognized efficient high-frequency operation as the key to achieving high power density and improved performance in switch-mode converters. High-frequency operation translates into smaller magnetics and capacitors, shorter response times, smaller filters, and lower noise levels. Notwithstanding noise-performance improvements, all dc/dc converters generate EMI (electromagnetic interference), or noise. This noise—common mode, differential mode, and radiated—can vary widely among dc/dc converters from supplier to supplier and topology to topology. Although the many designs, or topologies, of dc/dc-converter components number in the hundreds, two are dominant: so-called fixed-frequency PWM (pulse-width-modulation) and variable-frequency, quasiresonant ZCS/ZVS (zero-current switching/zero-voltage switching). Design engineers working with dc/dc converters must understand the noise performance differences of these two main topological classes.

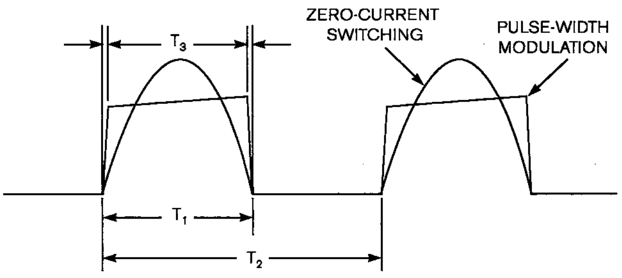
Fixed-frequency PWM converters inherently trade off efficiency against operating frequency because of switching losses. These converters dissipate power and noise in the switching element each time they discontinuously make and break inductive-current flow during their brief turn-on and turn-off transitions. Power dissipation due to switching losses increases directly with operating frequency in PWM converters until it becomes a dominant loss factor. At that point, efficiency declines rapidly, and the thermal and electrical stresses on the switch element become unmanageable. The losses result in a "frequency barrier" that limits achievable power density in conventional converters.

Variable-frequency, quasiresonant ZCS/ZVS converters overcome the frequency barrier by implementing forward-converter switching at zero current and zero voltage. Each switch cycle delivers a quantized "packet" of energy to the converter output, and switch turn-on and turn-off occurs at zero current and voltage, resulting in an essentially lossless switch. ZCS converters can operate at frequencies in excess of 1 MHz. By eliminating the fast current discontinuities characteristic of conventional topologies, ZCS/ZVS results in a virtually lossless transfer of energy from input to output with dramatically reduced levels of conducted and radiated noise.

The noise that the switch generates is a major difference between PWM and ZCS/ZVS converters. Among other differences, ZCS/ZVS converters have sinusoidal waveforms rather than the square waveforms of PWM converters. The lower harmonic content and lack of sharp edges of ZCS/ZVS result in much less excitation of parasitic capacitance and inductance, resulting in less noise. With PWM, the input voltage switches at a constant frequency—usually, several hundred kilohertz—to create a pulse train. The converter adjusts the width of the pulses to provide the necessary power to the load at the correct voltage. At full load, the current waveform looks much like a square wave (**Figure 1**).

Many designers intuitively assume that it's easier to design a filter for a fixed-frequency converter than for a variable-frequency converter. In fact, the opposite is true (**Reference 1**). The perception is, in all likelihood, attributable to the term "fixed frequency," which is a misnomer. Both topologies have frequency elements that are more or less fixed and frequency elements that vary as a function of operating conditions.

**Figure** 1 compares the waveforms of the current flowing through the main switch. In a module using a quasiresonant



**NOTES:** PULSE-WIDTH-MODULATION CONVERTERS OPERATE AT A LOWER FREQUENCY THAN ZERO-CURRENT-SWITCHING CONVERTERS.
$T_1$: ON-TIME OF THE SWITCHING DEVICE.
$T_2$: PULSE-REPETITION RATE OR OPERATING FREQUENCY.
$T_3$: RISE AND FALL TIME OF THE CURRENT ON THE SWITCHING DEVICE.

Figure 1 ZCS/ZVS converters have sinusoidal waveforms rather than the square waveforms of PWM converters. The lower harmonic content and lack of sharp edges of ZCS/ZVS result in much less excitation of parasitic capacitance and inductance, resulting in less noise. Not drawn to scale.

topology, the pulse width or on-time, $T_1$, is fixed, and the repetition rate or period, $T_2$, is variable. Conversely, in a module using PWM, the opposite is true; the repetition rate is fixed, and the pulse width is variable. The rise/fall time, $T_3$, is a fixed frequency in both topologies. In the variable-frequency design, however, there are no high-frequency components associated with the leading and falling edges of the current waveform, $T_3$, because it is essentially a half-wave-rectified sine wave. The spectral content of the variable-frequency waveform is lower in amplitude and contained in a narrower band. **Figure 2** shows the characteristic harmonic spectra for each of the topologies. In the fixed-frequency waveform, the spectral content is higher in amplitude and spread over a broader range of harmonics.

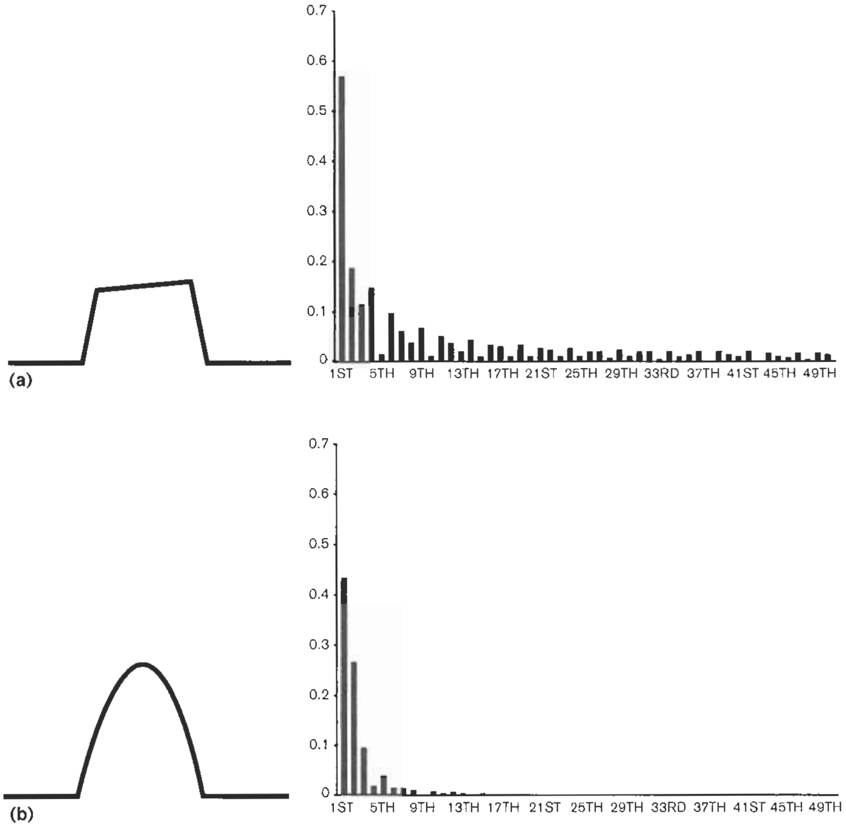
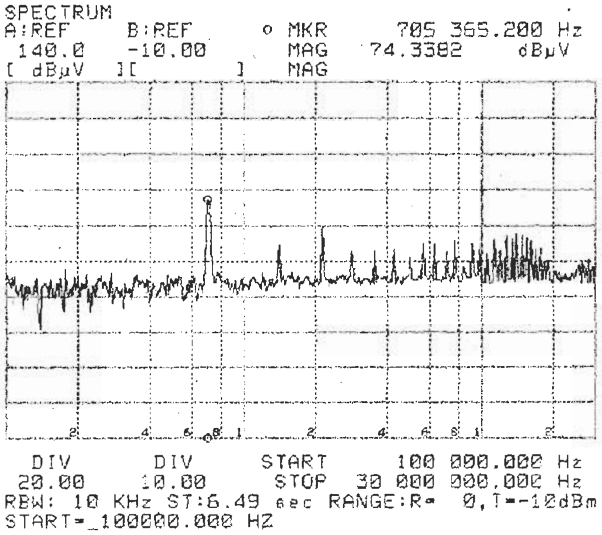


Figure 2 The spectral content of the fixed-frequency waveform (a) is higher in amplitude and spread over a broader range of harmonics, whereas the spectral content of the variable-frequency waveform (b) is lower in amplitude and contained in a narrower band. Note: The waveforms are not drawn to scale.

A more difficult aspect of converter EMI to control is that of parasitic excitation by high di/dt in PWM converters. This excitation results in noise of 10 to 30 MHz, which can be difficult to suppress because it often couples to the secondary of the converter through the transformer as common-mode noise. ZCS/ZVS converters generate less parasitic noise due to the "soft" edges of the current waveform. **Figure 3** shows a typical comparison.

Clearly, for applications that require low noise, an effective first step to minimizing noise that the dc/dc converter generates is to select a topology, such as ZCS, that is inherently lower in common-mode noise. Also, designers should avoid using some products in noise-sensitive applications. Control devices mounted on copper plates, for example, create parasitic capacitance from primary-referenced control devices to secondary-referenced control devices through the copper base, resulting in high common-mode noise. Incidentally, even for applications that need not meet EMI requirements, designers typically use bypass capacitors at the input and the output pins of dc/dc converters because they are the most effective way to reduce common-mode noise. **Figure 3** shows an example of conducted input noise of a dc/dc converter—in this case, a variable-frequency, quasiresonant ZCS dc/dc converter using bypass capacitors but with no additional filtering.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SPECTRUM
A:REF      B:REF          o MKR        705 365.200 Hz
 140.0     -10.00           MAG      74.3382      dBµV
[ dBµV   ][           ]     MAG
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  DIV        DIV       START       100 000.000 Hz
 20.00      10.00       STOP   30 000 000.000 Hz
RBW: 10 KHz ST:6.49 sec RANGE:R=  0,T=-10dBm
START=_100000.000 HZ
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Figure 3 The spectral density of the conducted noise versus load appears for a 48V-input, 5V-output, 30A-load ZCS dc/dc converter using bypass capacitors but no additional filtering.

Although component power modules usually incorporate some internal input and output filtering, designs often need additional external filtering to meet either system requirements or agency specifications. For example, FCC (Federal Communications Commission) and European agencies specify the allowable levels of power-supply noise that may conduct back into the ac line. Many designers tackle these issues on their own, but most dc/dc-converter manufacturers provide detailed application notes and offer the assistance of a knowledgeable, experienced, and accessible application-engineering staff. Some dc/dc-converter suppliers also offer ac front ends and EMI filters as modular accessories. These filters not only save time, but also provide a means of risk prevention. The EMI filter works with the supplier's converter modules, and, assuming proper layout, the combination meets the specified EMC (electromagnetic-compatibility) directives.

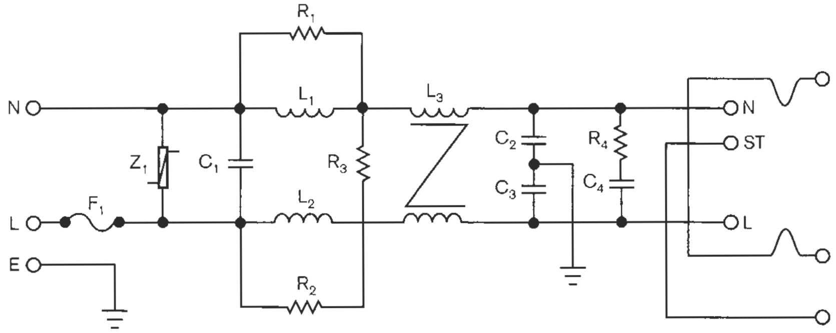

Figure 4 This filter configuration provides sufficient attenuation to comply with the Level B conducted-emissions limit for emission noise standard EN55022. The single-package EMI filter comprises a through-hole filter with a common-mode choke and Y capacitors between line and ground, plus two additional inductors and an X capacitor between the two lines. $Z_1$ provides transient protection.

In the United States and Europe, the Class A and Class B limits of both FCC and VDE (Verband der Elektrotechnik, www.vde.com/vde_en) standards govern conducted-noise emissions. In the United States, the FCC requires compliance with Class A for equipment operating in factory settings and Class B, the stricter standard, for equipment for home use. In Europe, all countries require that equipment for both home and factory use meets the VDE Class B standard.

Most switching power supplies today operate at 100 kHz to 1 MHz. Usually, the dominant peaks in the conducted-noise spectrum reflect back to the power line and correspond to the fundamental switching frequency and its harmonic components. Conducted-emissions standards, such as EN55011 and EN55022, set quasipeak and average limits on conducted noise from the input of converters or power-supply systems back to the source over the frequency range of 150 kHz to 30 MHz. To comply, all of the conducted noise—the peaks in the spectrum—must fall below the specified limits.

Designers most often construct EMI filters in a single package with configurations similar to that of **Figure 4**. The through-hole EMI filter has a common-mode choke and line-to-ground Y capacitors plus two additional inductors and a line-to-line X capacitor. $Z_1$ provides transient protection. This filter configuration provides sufficient attenuation to comply with the Level B conducted-emissions limit. **Figure 5** shows a comparison of ZCS-converter-generated and PWM-converter-generated conducted-input noise. Notice that the unfiltered noise performance of the ZCS converter in **Figure 3** is superior to the filtered noise performance of the PWM converter. EDN

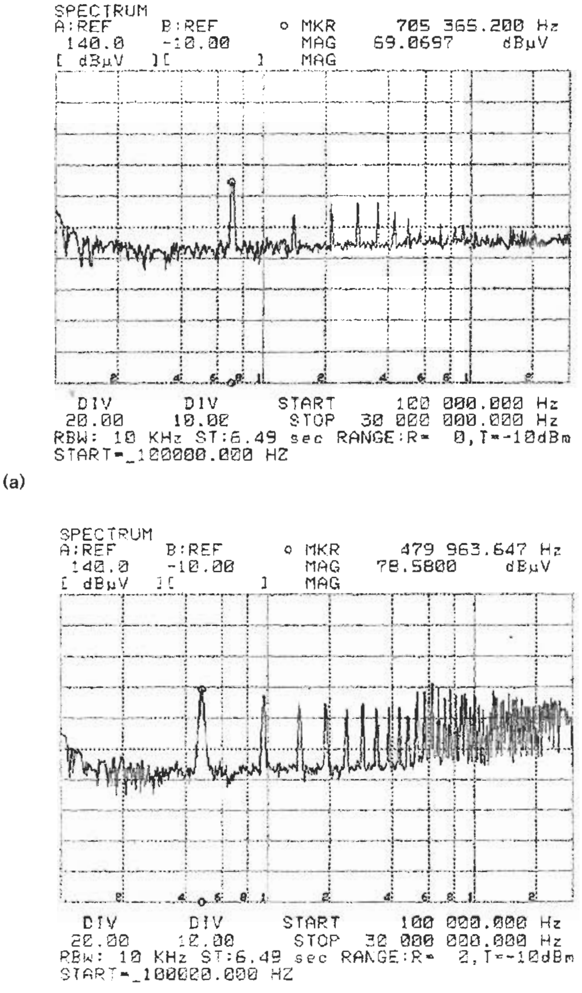

Figure 5 The conducted input noise for a ZCS converter with a common-mode choke (a) and for a PWM converter with a filter (b) are both for a 48V-input, 5V-output, 30A converter.

## REFERENCE

Hsiu, L, M Goldman, R Carlsten, A Witulski, and W Kerwin, "Characterization and Comparison of Noise Generation for Quasi-Resonant and Pulsewidth-Modulated Converters," *IEEE Transactions on Power Electronics*, Volume 9, No. 4, July 1994.

## AUTHOR'S BIOGRAPHY

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