The pros and cons of spread-spectrum implementation methods in buck regulators

By Sam Jaffe
Applications Engineer, >30-V Buck Converters/Controllers/Modules

Introduction

In power converters and other devices, the spread-spectrum feature converts a narrowband signal into a wideband signal while maintaining device functionality. The conversion of harmonic peaks into a flat smoothed response and the blending of harmonic energies into one another improves operating conditions by reducing electromagnetic interference (EMI) results for both the device and associated system.

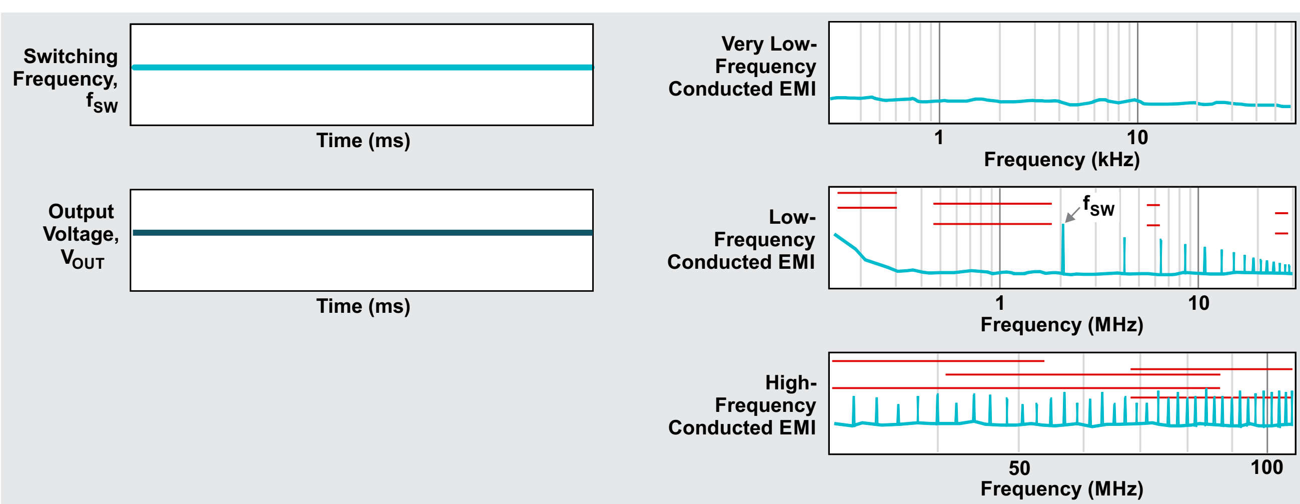
Spread spectrum can reduce the peak envelope on a peak and average EMI sweep by as much as 10 dBµV, which enables designers to choose a smaller-size and less-expensive input EMI filter. This article describes the process adopted by chip designers to achieve spread spectrum in a buck converter and how it can be extended to other systems. Also covered are the most common modern spread-spectrum implementation methods and their pros and cons.

The first question is, where does the EMI come from in a buck converter? A buck converter converts power when its switch node switches between connecting to the input voltage (V_{IN}) and connecting to ground (GND) at a high frequency. The duty cycle sets the average voltage on the switch node to be equal to the chosen output voltage. This switch node is fed through a low-pass inductor-capacitor filter that provides the DC output. Most buck converters switch at a fixed frequency (f_{SW}), which generates EMI at that frequency and its harmonics ($n \times f_{SW}$). The distinct peaks from the fundamental frequency and its harmonics are at risk of violating the maximum allowable EMI emission at those frequencies.

In Figure 1, the switching frequency (f_{SW} = 2.1 MHz) is constant over time. The output ripple is flat; the very low-frequency EMI sweep shows the noise floor, the low-frequency EMI sweep shows the sharp peak fundamental frequency and the following harmonics, and the high-frequency EMI sweep shows the higher harmonics. The red lines in Figure 1 represent the limit lines for a typical EMI test.

In a spread-spectrum buck converter, f_{SW} is dithered so that the device switches at a range of frequencies. For example, if a device switches at 1 MHz with ±5% dithering, the fundamental frequency emission will spread the energy between 0.95 MHz and 1.05 MHz, or 50 kHz above and below the center frequency. The second harmonic spreads between 1.90 MHz and 2.10 MHz, or 100 kHz above and below the center frequency. For this example, at the 10th and higher harmonics, the spreads begin to blend into one another and the peaks have turned into a flat energy-averaged waveform, which is often as much as 10 dBµV lower than the tops of the sharp peaks without spread spectrum.

Figure 1. Fixed-frequency performance without spread-spectrum



The following description covers two of the most common spread-spectrum implementation methods, followed by two additional improved methods.

1. Triangular modulation method

The triangular modulation method adjusts f_{SW} up and down in a triangular shape. The typical spread is ±4% to ±10% (Δf_{SW}) with a modulation frequency of 4 kHz to 15 kHz (f_m). See Figure 2.

Pros

This method is simple and easy to understand and implement. The continuous ramp-up and ramp-down ensure that there are no consecutive switch cycles of the same frequency, which will cause a spike at that frequency and its associated harmonics. Triangular modulation also does a great job of spreading the energy evenly away from the center frequency, creating a mostly flat band of energy with only some peaking at the end of the band (peaking not shown in Figure 2). Spread spectrum spreads the fundamental frequency as well as the higher harmonics.

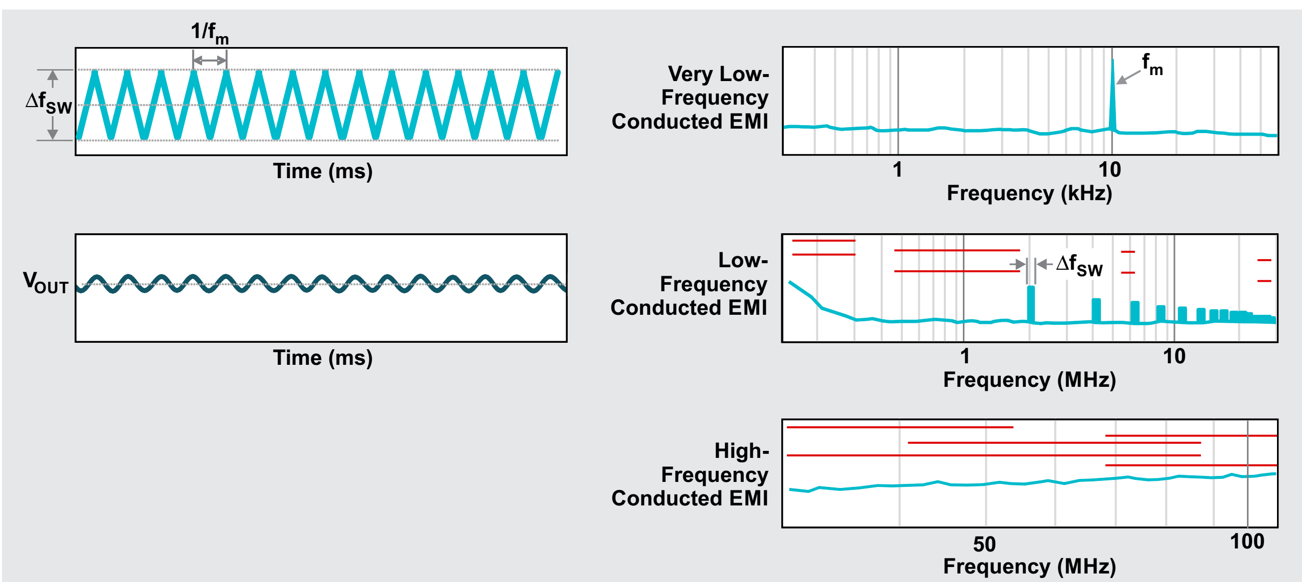
Spreading the fundamental frequency will reduce its amplitude, enabling designers to choose a lower-cost input EMI filter. The lower fundamental requires less inductance and capacitance in the input LC filter to stay below the EMI test limit lines. Using triangular modulation ensures that this fundamental frequency spread is reasonably flat and evenly distributed. Other methods may more heavily weight the center frequencies or end frequencies, which can result in less attenuation at the fundamental frequency and early harmonics.

Cons

To avoid excessive overlaps from beat frequencies, the triangular modulation frequency (f_m) must be slow enough to ensure multiple switching cycles per ramp-up and ramp-down. But the higher-frequency EMI sweeps spend very little time measuring the EMI per data point. A slow ramp-up or ramp-down can result in the EMI sweep measuring only a small fraction of this ramp-up/-down, which would show up as a less-spread emission, effectively reducing Δf_{SW}. Slow ramping is a bigger issue for discrete triangular modulation, where the ramp-up and ramp-down are actually stair steps, switching more than once per step.

Another drawback is that the output voltage and input voltage acquire a ripple at the triangular modulation frequency. This is caused by two factors. The first factor comes from the amplitude modulation of the inductor current ripple. A lower switching frequency results in a larger inductor current ripple and vice versa, creating a voltage ripple on the input at the triangular modulation frequency, f_m. The second factor is the interaction between this amplitude-modulated inductor current with the control scheme—usually peak or valley current-mode control. The change in inductor current amplitude will shift the average inductor current up and down, causing a voltage ripple on the output voltage as well as the input voltage. This frequency is also f_m and is often in the audible range, which can create an audible tone if very-low frequency noise interacts with any sound-generating circuitry, such as an audio amplifier, or even a ceramic capacitor on a poorly mounted printed circuit board.

Figure 2. Triangular modulation spread-spectrum performance



2. Pseudo-random modulation method

The pseudo-random modulation method adjusts f_{SW} up and down pseudo-randomly (programmatically generated but essentially random). Some implementations limit the maximum step size to prevent the frequency from jumping too far and causing too much disruption in normal operation. The typical spread is ±3% to ±6%, and the frequency usually changes every switch cycle. In Figure 3, notice that the time scale of the waveforms are in microseconds (as opposed to milliseconds for the other schemes) since the switching frequency changes every switch cycle.

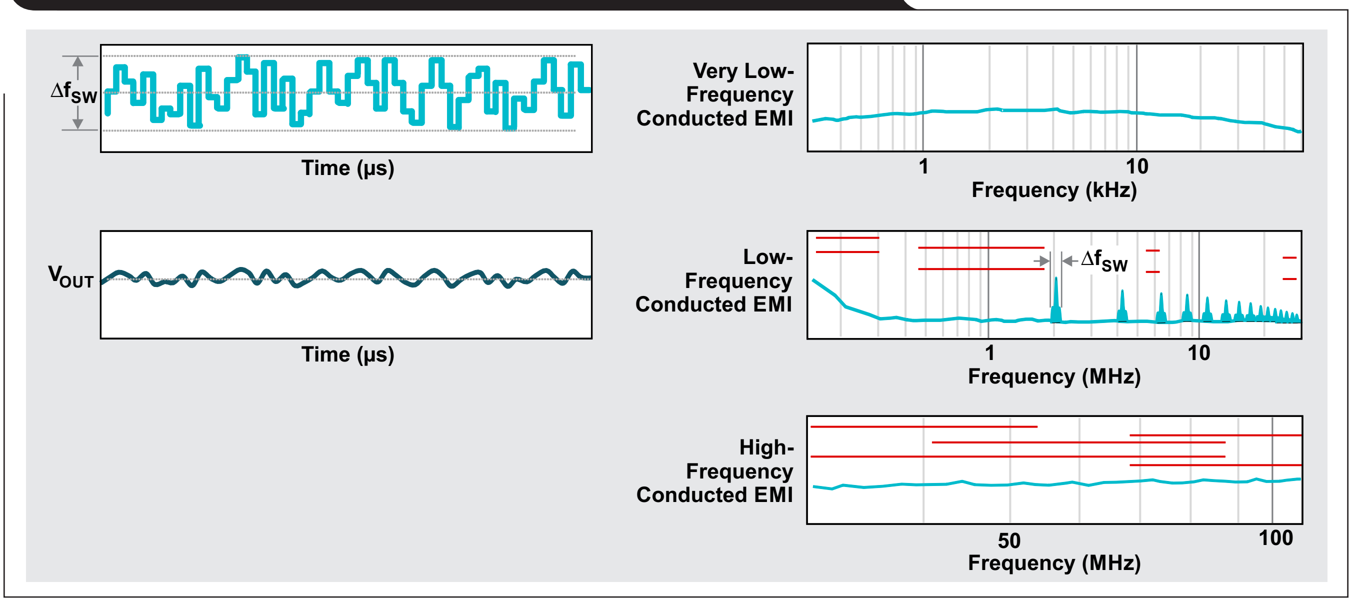
Pros

Note that f_{SW} can change widely in a short period of time, which can help avoid the issue of the EMI sweep scanning only a small portion of the spread. This wide jump results in great high-frequency performance. The very low-frequency EMI is distributed randomly, which means that the EMI on the output and input will not generate a tone if coupled into sound-generating circuitry. The EMI is still there but it is spread, yielding more of a white-noise sound versus a single tone like the triangular modulation method.

Cons

Depending on the frequency distribution and implementation, the fundamental (and early harmonics) energy may not be well distributed. This scattered energy can result in sharper and taller emissions at these frequencies and the inability to notably reduce the size and cost of the input EMI filter versus using the triangular modulation method. Another drawback is the possibility of repeating codes caused by the digital nature of the pseudo-random pattern. If the random generator ends up switching at the same frequency for multiple cycles, it will appear as if spread spectrum is off for that time. Ensuring that there are no repeating codes in the implementation, using a large number of distinct steps, or implementing truly random analog steps can help avoid the perception that spread spectrum is off.

Figure 3. Pseudo-random modulation spread-spectrum performance



3. Adding spread spectrum to spread spectrum

Triangular and pseudo-random techniques work to eliminate inherent switching peaks, but have non-idealities which let some peaks through or cause additional noise and peaks due to the modulation discussed earlier. Adding spread spectrum to spread spectrum will help reduce or eliminate these unwanted peaks and noise. To begin, start with the triangular modulation method, but add modulation to the triangular modulation. This addition will cause the triangle frequency (f_m) to change over time, which will spread the audible noise spike from a tone to noise. On top of that waveform, a bit of pseudo-random modulation is added as shown in Figure 4.

Pros

Low-frequency audible noise will spread from a tone to noise from the modulated triangle and pseudo-random modulation. The fundamental and early harmonics spread evenly with the triangular modulation method, which can reduce the size and cost of the input EMI filter. High-frequency harmonics spread because of the additional pseudo-random modulation.

Cons

This method is more complicated and harder to implement. Even though the low-frequency noise spreads, it is still present and can induce noise (such as white noise) in sound-generating circuits.

Figure 4. Adding spread-spectrum to spread-spectrum performance

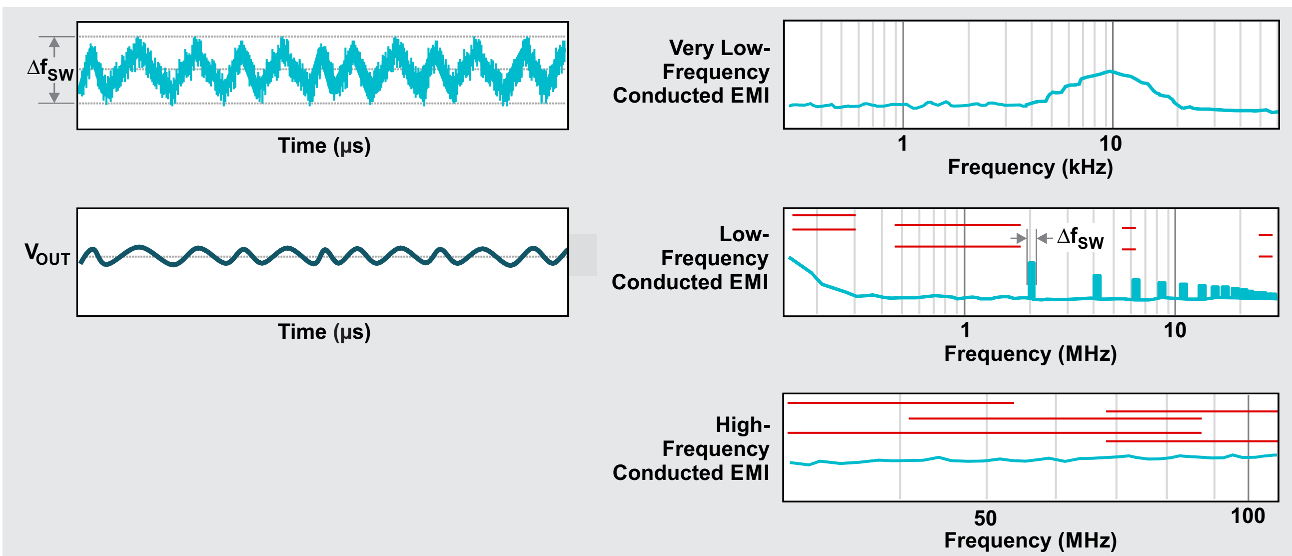
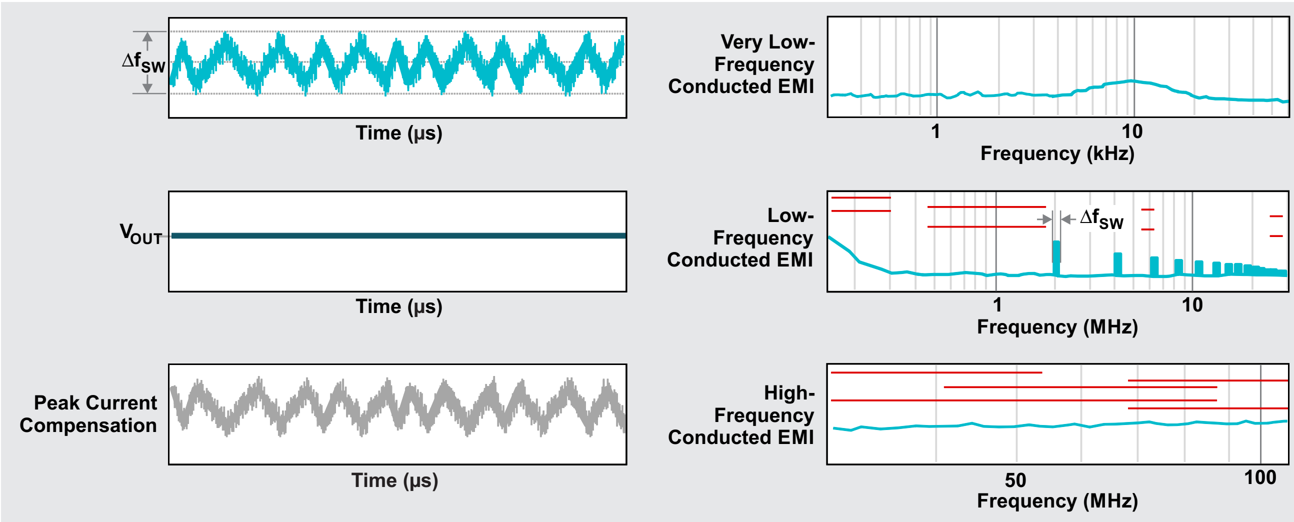


Figure 5. Dual-random spread-spectrum performance



4. Dual-random spread spectrum

Dual-random spread spectrum is exactly the same as adding spread spectrum to spread spectrum but with one addition—low-frequency ripple cancellation. This method adds some communication between the spread-spectrum modulator and the peak or valley current-control circuitry to preemptively adjust the peak or valley current command values to cancel the noise associated with spread spectrum, as shown in Figure 5.

Pros

This method eliminates the very low-frequency output voltage ripple and the associated input voltage ripple. Audible noise is eliminated from the output and greatly reduced on the input.

Cons

It may require a resistor to tune the cancellation based on operating conditions, depending on the device.

Conclusion

Spread spectrum is an excellent feature that can greatly improve EMI results with little to no effect on other system operations. The four methods described in this article each have their own benefits and drawbacks, but techniques continue to improve as designers learn more about spread-spectrum optimization. With this knowledge, specific design requirement can be matched to particular methods that take full advantage of all that spread spectrum has to offer.

Related Web sites

Product information:
LM62460-Q1
LM61480-Q1
LM61495-Q1
LM25149-Q1
LM5156
LM51571-Q1

TI Worldwide Technical Support

TI Support

Thank you for your business. Find the answer to your support need or get in touch with our support center at

www.ti.com/support

China: http://www.ti.com.cn/guidedsupport/cn/docs/supporthome.tsp

Japan: http://www.tij.co.jp/guidedsupport/jp/docs/supporthome.tsp

Technical support forums

Search through millions of technical questions and answers at TI's E2E™ Community (engineer-to-engineer) at

e2e.ti.com

China: http://www.deyisupport.com/

Japan: http://e2e.ti.com/group/jp/

TI Training

From technology fundamentals to advanced implementation, we offer on-demand and live training to help bring your next-generation designs to life. Get started now at

training.ti.com

China: http://www.ti.com.cn/general/cn/docs/gencontent.tsp?contentId=71968

Japan: https://training.ti.com/jp

A011617

Texas Instruments

SLYT809