Reducing Switcher EMI with Spread Spectrum Technology

High Performance Analog Solutions from Linear Technology

Offering a significant space and efficiency advantage over linear regulators, switching regulators continue to expand into an increasing number of applications. One trade-off, however, is the potential for electromagnetic interference (EMI). Switching regulator EMI, a result of the internal switching current, is traditionally controlled and contained with a combination of grounding, shielding and filtering. In addition to these techniques, decreasing the peak switching current and altering the switching frequency can also reduce EMI. With this in mind, Linear Technology developed the LTC6902 and LTC6908 silicon oscillators specifically for the reduction of EMI by intelligently controlling the switching regulator clock.

Since their introduction, Linear Technology's silicon oscillators have proven their versatility across a wide range of clock applications. These solid-state devices generate precise square-wave signals without a crystal or ceramic resonator and without an external resistor-capacitor time constant. They have outstanding environmental characteristics such as inherent immunity to shock, vibration and acceleration, in addition to an operating temperature range from -40°C to 125°C. Output frequency range spans from 1kHz to 170MHz, start-up is consistently fast, power consumption is low and the footprint is as small as 2mm x 3mm. Since silicon oscillators are programmable, they can intelligently control a clock frequency with multiple phases. Specifically, they are ideal for multiphase synchronization and spread-spectrum frequency modulation (SSFM).

Why is EMI Important?

Tremendous growth in the use of portable electronics has increased the potential for EMI between devices. EMI can be a nuisance, as in the case of noise in a television or radio receiver. EMI can impair electronic device operation, such as avionic equipment, which is why airlines ban the use of portable electronics during take-off and landing periods. Underscoring the importance of this issue, government regulations have established EMI limits and test methods to ensure that products operate without experiencing interruptions and without interrupting other devices. Testing and tracking down EMI requires a lot of time and effort, so taking a proactive design approach to avoid last minute modifications and time-consuming retests is always a good idea.

Multiphase Synchronization

The current waveform in a switching regulator is irregular, producing EMI concentrated at the switching frequency. Instead of using a single switcher, multiple switchers synchronized out of phase will have a lower peak current and therefore lower EMI. This phase-synchronization is achieved by using a single clock with a phase shift placed between each regulator. This technique staggers the turn-on time of each switcher such that there is input current where previously there was a dead band. Figure 1 illustrates two switching regulators operated with a single 200kHz clock with the resulting peak input currents. Placing a 180° phase-shift on the 2nd regulator clock results in smaller current peaks at twice the

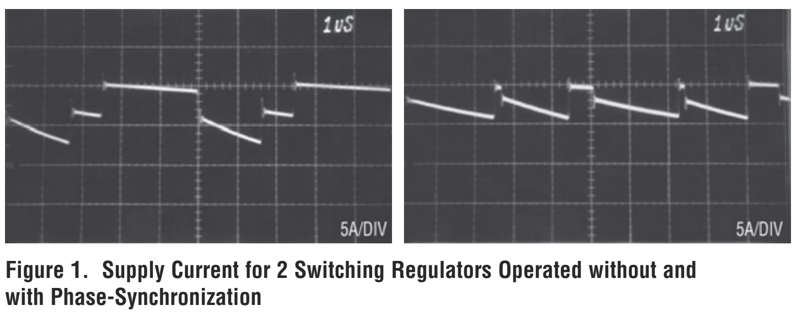


Figure 1. Supply Current for 2 Switching Regulators Operated without and with Phase-Synchronization

frequency (400kHz), and therefore smaller peak EMI. Since EMI is now at twice the frequency, it is further reduced since filtering is more effective at higher frequencies. Many dual and multiphase regulators take advantage of this technique by including built-in clock phase shifting. For example, Linear Technology's LTC3728, a dual 2-phase regulator, internally generates a 180° phase shift between the two regulator clocks.

A separate external clock with multiple phases is useful for synchronizing multiple dual or multiphase regulators, or when power requirements dictate the use of separate regulators. For these applications, Linear Technology's LTC6902 silicon oscillator provides 4 outputs, programmable for 2, 3 or 4 clock phases. Linear Technology's LTC6908 takes a simpler approach by providing 2 outputs available in 2 versions; the LTC6908-1 has two outputs with 180° phase-shift between them and the LTC6908-2 has two outputs with a 90° phase shift between them. The former is ideal for synchronizing 2 single switching regulators and the latter is ideal for synchronizing 2 dual, 2-phase switching regulators. For EMI improvement, however, phase-synchronization is only part of the story.

Additional Benefits of Multiphase Synchronization

In addition to improved EMI, using multiphase synchronization with parallel regulators has a net effect of canceling ripple currents on the input and output. This allows for a significant reduction in input and output capacitors. A multiphase solution has a smaller equivalent inductance and therefore, can provide a higher current slew rate. A multiphase solution also has less switching time delay for a load transient. As a result of the improved load transient response, the needed output capacitance is further reduced.

Spread Spectrum Frequency Modulation (SSFM)

The most dramatic improvement to EMI may be achieved by continuously varying the switcher's clock frequency. The technique, referred to as SSFM, improves EMI by not allowing emitted energy to stay in any receiver's band for a significant length of time. The effectiveness of SSFM with switching regulators depends upon the amount of frequency spreading, typically ±10%, and the modulation profile.

Various methods of frequency spreading are used for SSFM, such as modulating the clock frequency with a sine wave or a triangular wave. Most switchers exhibit ripple that varies with frequency; more ripple at lower switching frequencies and less at higher switching frequencies. As a result, a switcher's ripple will exhibit an amplitude modulation that follows the clock's modulating signal. If the clock's modulating signal is periodic, there will be a periodic ripple modulation and a distinct spectral component at the modulating frequency. Since the modulating frequency is much lower than the switcher's clock, it may be difficult to filter out. This could lead to system problems such as audible tones or visible display artifacts due to supply noise coupling or limited power supply rejection of the downstream circuitry.

To avoid this periodic ripple, Linear Technology's LTC6902 and LTC6908 silicon oscillators use a pseudorandom frequency modulating waveform that approximates band-limited noise. In this technique, the switching regulator clock shifts from one frequency to another in a pseudorandom fashion. Since the switcher's output ripple is amplitude modulated by a noise-like signal, the output looks essentially as if there were no modulation and the downstream system implications are negligible. The higher the rate of frequency shifting, or the hop-rate, the less time the switcher is operating at a given frequency and the less time EMI will be "in-band" for a given receiver.

There is a limit, however, to the rate of frequency change (dF/dt) that the switcher can track. If the frequency abruptly hops from one frequency to another, output spikes will occur at the clock frequency transition edge (much like a load step response). Lower bandwidth switchers have more pronounced spikes. For this reason, Linear Technology's newest SSFM oscillator, the LTC6908, includes a proprietary tracking filter to smooth the transition from one frequency to the next. Most switchers have a bandwidth of 1/10th to 1/20th of the nominal switching frequency and will operate fine using the LTC6908's default modulation rate of 1/16th of the nominal clock frequency. For limited bandwidth switchers, the LTC6908's modulation rate can be decreased to 1/32nd or even 1/64th of the nominal clock rate to ensure proper regulation. The internal filter tracks the hop rate to provide optimal smoothing for all frequencies and modulation rates.

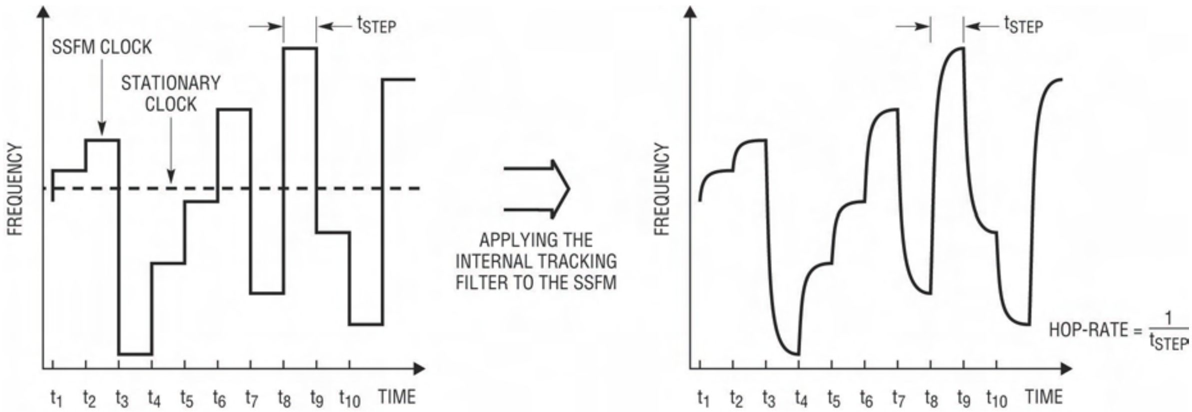


Figure 2. Pseudorandom Modulation and the LTC6908 Internal Tracking Filter

Does It Really Work?

In the world of EMC (Electromagnetic Compatibility), switchers are almost always emitters and everything else is a potential receiver. At any instant in time, peak emissions from a switching regulator ***appear*** to be the same, whether or not SSFM is enabled. The amplitude of the instantaneous emission is unchanged but it does move around in frequency. So, how does this work? The effectiveness of SSFM depends on the amount of spreading and the frequency modulation rate relative to the bandwidth of the receiver. To receive an "instantaneous snapshot" of emissions requires a receiver that has infinite bandwidth and, fortunately, every practical system has a limited bandwidth. A system's bandwidth determines two important characteristics: the range of frequencies for which the receiver will respond and how quickly the receiver will respond (its response time) when subjected to EMI. If the emitting signal stays in-band for a short time, relative to the system's response time, interference is significantly reduced. Any performance enhancement must be determined on a system to system basis and while SSFM may yield improvements, it is

Linear Technology's Spread Spectrum Silicon Oscillators

Device	LTC6902	LTC6908-1	LTC6908-2
Frequency Output	5kHz to 20MHz	10kHz to 10MHz	10kHz to 10MHz
Frequency Set	Resistor	Resistor	Resistor
Outputs	4	2	2
Output Phases	0°/180°/0°/180° 0°/120°/240°/NA 0°/90°/180°/270° (Programmable)	0°/180° (Fixed)	0°/90° (Fixed)
Spread Spectrum Amount	0% to 100% (Programmable)	0% or ±10% (Programmable)	0% or ±10% (Programmable)
Modulation Tracking Filter		✔	✔
Operating Temperature	-40°C to +85°C	-40°C to +125°C	-40°C to +125°C
Package	MSOP-10	SOT23, 2mm x 3mm DFN	SOT23, 2mm x 3mm DFN
Price	$2.20	$1.65	$1.65

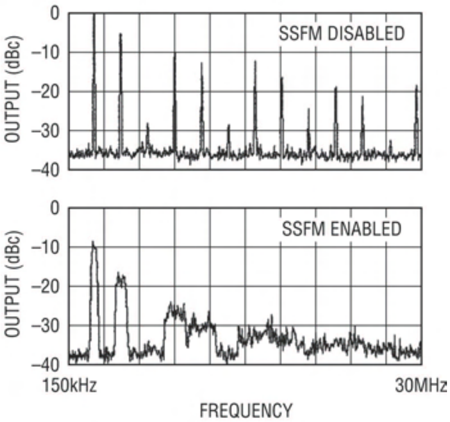


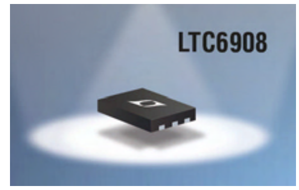
Figure 3. Switching Regulator Output Emissions using an LTC6908 (9kHz Resolution Bandwidth, Peak Detector Test)

not a substitute for standard layout, filtering and shielding practices.

In addition to in-system Electromagnetic compatibility (EMC) concerns, all systems are required to pass regulatory agency EMC tests before they are allowed for sale in the market. During regulatory agency EMC testing, the bandwidth of the test equipment is set to strictly defined standards (per CISPR 16-1) chosen to reflect the real world bandwidths of interest. The regulatory agency measurement bandwidths are well defined and consistent for all systems. Just as discussed in the previous paragraph, if the emitting signal enters the measurement system's band infrequently and for a short duration, relative to the system's response time, measured EMI is reduced.

Summary

In applications using multiple switching regulators, multiphase synchronization offers clear benefits, including reduced EMI. As for the EMI benefits of SSFM, it depends on the bandwidths of interest. SSFM is not a substitute for proper design, but when faced with unacceptable EMI at the end of a design, few options are as straightforward as enabling SSFM on the switching regulator clock. Using Linear Technology's LTC6908, both multi-phase synchronization and SSFM could hardly be simpler. The amount of frequency spreading and the phase relationship between outputs is fixed and the user only needs to program the center frequency and select one of three modulation rates. With a price of $1.65, the small size, simplicity and potential benefits make the LTC6908 very affordable insurance.



LTC6908 SSFM Clock (2mm x 3mm DFN Package)

Regulatory Testing

Regulatory agency EMC tests first scan each band using an envelope detector called a peak detector. Measurements of the peak detector that are above the pass/fail limit are further analyzed with a quasi-peak detector. The quasi-peak detector processes the peak detector's output to weigh the signal measurement according to its repetition rate. Additionally, many agencies require that a system pass a test using an average detector. The average detector is simply the peak detected output processed through a very low frequency, low pass filter. Note that a continuous, steady state, stationary emission will yield the same measurement regardless of which detector is used.

Using SSFM, if the finite response time of the measurement system is longer than the time for which emissions are in band, the peak detector measurement will be reduced. The typical bandwidth setting of the detector results in a modest amount of attenuation. With SSFM, the quasi-peak and average detector measurements can be even lower and never results in a higher value. Typically, SSFM provides a modest reduction of the quasi-peak detector measurement and a considerable reduction of the average detector measurement. In summary, SSFM potentially lowers the peak detected measurement by staying in the measurement band for short periods of time, gives an additional quasi-peak detector improvement by entering the measurement band infrequently and yields even more substantial improvement with the average detector.

Regulatory Agency EMI Test Bandwidths (per CISPR 16-1)

Band A (9KHz to 150kHz):	BW = 220Hz
Band B (150kHz to 30MHz):	BW = 9kHz
Band C (30MHz to 1000MHz):	BW = 120kHz

Real World System Bandwidths

Voice:	BW = 3kHz
GSM:	BW = 8kHz
AM Radio:	BW = 9kHz
Audio:	BW = 20kHz
FM Radio:	BW = 75kHz
TV:	BW = 6-8 MHz