Silicon Oscillators Offer EMI Improvements

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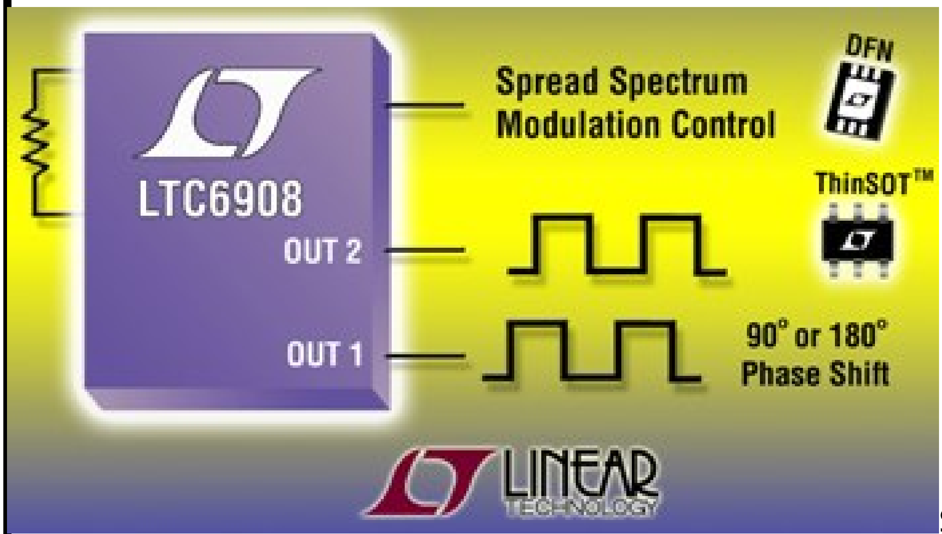
One of the most difficult electronics design challenge is to track down and eliminate electromagnetic interference (EMI). Switching regulators, a common source of EMI, continue growing in usage due to their space and efficiency advantages over linear regulators. For the designer, however, the EMI and associated regulatory requirements can present a significant challenge. To specifically address EMI in switching regulators, a multi-phase, spread-spectrum silicon oscillator is an appropriate solution.



Since their introduction, silicon oscillators have proven their versatility in a wide range of clock applications. These tiny devices generate precise square-wave signals without the use of a crystal or ceramic resonator and without an external resistor-capacitor time constant. Silicon oscillators have outstanding environmental characteristics such as inherent immunity to shock, vibration and acceleration. Linear Technology’s LTC6908 will be used as an example in this article. It has operating temperature range from -40°C to 125°C, an output frequency range spanning 1 kHz to 170 MHz, consistently fast start up, low power consumption and a footprint as low as 2 mm x 3 mm. Their programmability enables these parts to intelligently control clock phase and frequency.

The reduction of switcher EMI, typically using grounding, shielding and filtering, is focused on the control and containment of emissions generated from the internal switching currents. EMI can also be improved by reducing the switching current with phase-synchronization. With phase-synchronization, two or more switching regulators are driven with a clock that has a phase between each regulator. By using phase-synchronization, each switcher’s turn-on is staggered to reduce peak currents and therefore, peak EMI. The resulting higher frequency EMI is further reduced since filtering and grounding is more effective at higher frequencies. One version of the multi-spread-spectrum silicon oscillators has two outputs with a 180°

phase-shift between them, and another version has two outputs with a 90° phase shift between them. The former is appropriate for synchronizing two single switching regulators, and the latter is suitable for synchronizing two dual, 2-phase switching regulators.

LTC6908 spread spectrum silicon oscillators from Linear Technology.

In addition to reducing the switching current, constantly varying the switcher's clock frequency can also improve EMI. This technique, referred to as spread spectrum frequency modulation (SSFM), improves EMI by not allowing emissions to stay in a receiver's band for any significant length of time. The key determinants for effective SSFM are the amount of frequency spreading and the modulation rate. This oscillator fixes the amount of frequency spreading to ±10 percent of the nominal frequency and allows the user to select a modulation rate.

Because output ripple from most switching regulators is frequency dependent, using a periodic waveform for SSFM results in amplitude modulated ripple and may result in poor PSRR performance or possible beat notes. To avoid these issues, look for a spread-spectrum silicon oscillator that uses a pseudorandom frequency modulation. The higher the rate of frequency modulation, the less time a switcher is operating at any given frequency and the less time emissions will be “in-band” for a given receiver.

To avoid exceeding a switcher's bandwidth, which can lead to output spikes, the LTC6908's spread spectrum modulation rate can be reduced from the highest rate of 1/16th of the nominal frequency, to 1/32nd or 1/64th. In addition, a proprietary internal filter provides a smooth transition between each frequency change, for all frequencies and modulation rates.

At any instant of time, peak emissions may appear to be the same, whether or not SSFM is enabled. The effectiveness of SSFM depends upon the bandwidth of the receiver. To receive an “instantaneous snapshot” of emissions requires an infinite bandwidth, and every practical system has a limited bandwidth. For example, the bandwidth of AM radio is 9 kHz and FM radio is 75 kHz. If the frequency of the emissions change faster than the bandwidth of the receiver, the reduction in EMI will be significant.

Multiphase synchronization offers clear benefits when using multiple switching regulators. The amount of benefit provided by SSFM depends on the bandwidths of interest and is certainly not a substitute for good design. However, in many situations, SSFM significantly reduces electromagnetic interference and makes designers' lives a little less stressful. With their attractive price tag, small size, simplicity and their potential benefits, multi-phase spread spectrum silicon oscillators present cost-effective insurance against EMI in switching regulators.

For more information, contact Linear Technology, 1630 McCarthy Blvd., Milpitas, CA 95035; (800) 454-6327; www.linear.com [1].

Understanding EMI Reduction Techniques

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EMI (Electro-Magnetic Interference) comes in different forms, frequencies, and levels. Electronic equipment has different categories for both emissions and susceptibility. Under normal circumstances elimination is not possible so reduction to acceptable levels is what can be reasonably achieved. Coupling factors, rise time, emissions and susceptibility are phrases that must be understood with confidence. It is less “Black Art” than the urban legends lead you to believe. It’s well founded in principal and practice.

Understanding of the coupling methods of EMI is necessary in order to reduce emissions and susceptibility. Some of the techniques for shielding are effective for both but there are issues that must be handled differently. On the susceptibility side, to make a system more immune, the reception path of the EMI or noise needs understanding.

Most of the power devices today are switch mode. PWM (Pulse Width Modulation) techniques are used in more and more devices at lower power levels to achieve greater efficiency. Concerns of radiated and received noise are falling into lower and lower categories. Techniques once thought only necessary for high power electronics are now migrating into low level power supplies and regulators. Linear devices for all their inherent good traits of EMI are just too inefficient.

Coupling Factors:

•**Conducted Noise** is usually through the AC line and requires a RLC type filter. Various companies like Schaffner, ONEAC, and ABB just to name a few manufacture these.

•**Magnetically Coupled Noise** is a phenomenon that has sufficient power to turn data lines (Optocouplers) on. The process requires an emitter and receiver so you must shield both the source and reception devices. You should also attenuate the source whenever possible. Attenuation can be achieved by inductance or PWM conditioning (slowing the rise-time) in most applications. This can occur on two planes or reference, common mode or differential mode. Magnetic inducted noise follows the path of least inductance! This noise will be limited by reducing the inductance of the intended path to less than the inductance of the unintended path. You must maintain that the area that a conductor encircles is proportional to the inductance. If there is an opportunity for a signal to couple into a circuit that is closer in proximity (less inductance through less area) than you may induce a voltage onto that circuit.

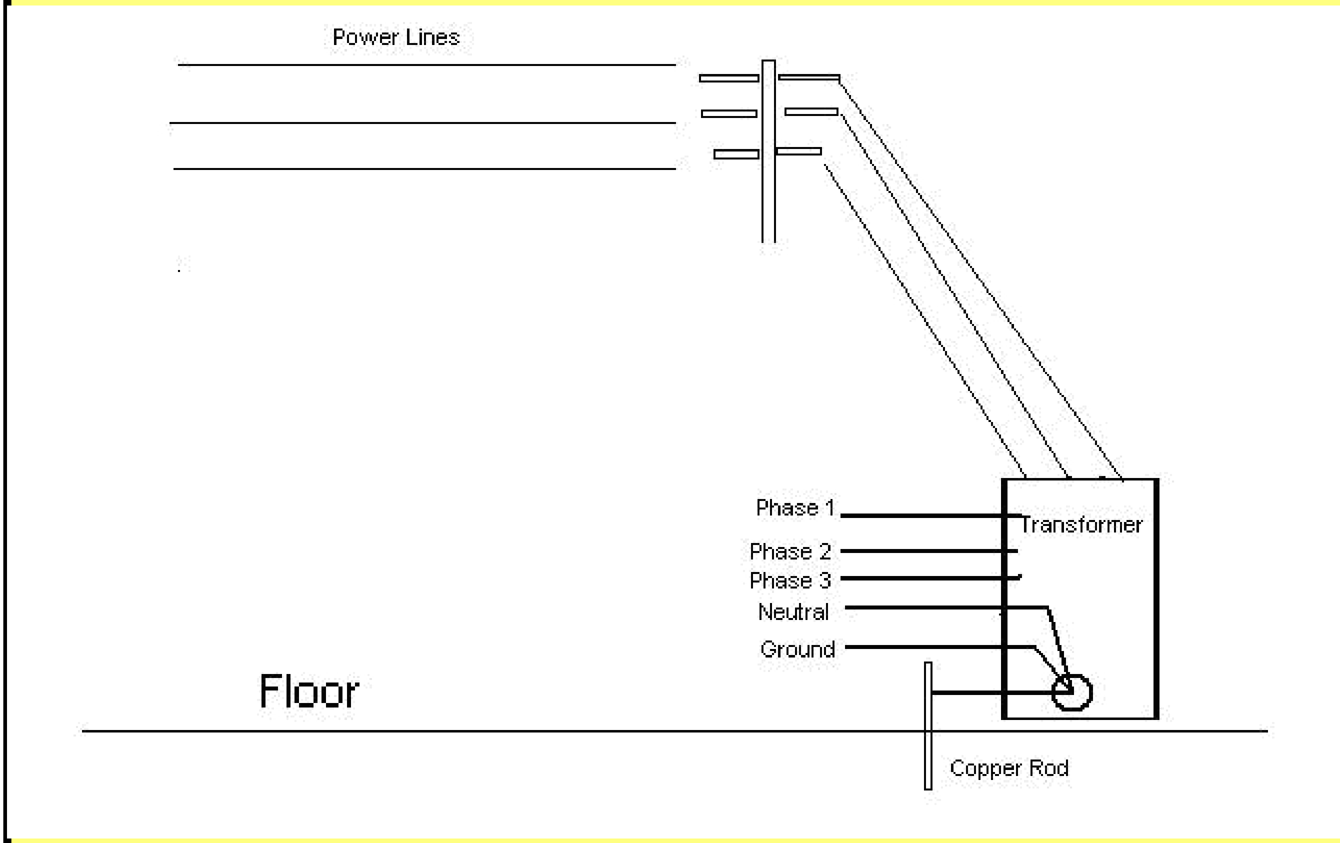
•**Capacitive Induced noise** is a noise that does not have power, but can wreak havoc with high-speed data lines, analog or high impedance inputs. Typically this is one of the easier noise coupling mechanisms to resolve. Issues begin when a capacitive induced signal gets into an amplifier. Now it can have the power to radiate very high frequencies that the system is not prepared for. The identification of this is that it is usually high frequency (100 MHz or higher) and has a net zero DC voltage value when observing the signal through an oscilloscope.

•**Radiated or RFI noise** requires a transmission source and reception antenna that is at least ?/20 long (wavelength/20). You must also be ½ ? away from the source minimum. It is the least likely source of trouble in most systems. At 100 MHz, ?/20 is 1.54 meters since ? is 30 meters.

With an understanding of the coupling factors, you can assess what your problem is, make a qualified judgment as to its cause, and decide what the mechanism of coupling is. Armed with this knowledge, you can use proven methods to reduce the cause and affect, whether it is to meet an EMC (Electro-Magnetic Compliance) standard or if you simply want to reduce spurious failures of an electronic circuit. Servo amplifiers, power supplies, and electronics with clock frequencies all must work uninterrupted from outside interference as well as not interfere with themselves. Sensitive analog circuitry must be immune from the interference of outside radiated signals and still be able to conduct their function.

With all noise immunity measures, things start with a good grounding and shielding scheme. The first rule in grounding is safety first. No safety ground can be compromised in the interest of noise immunity. There are times when it appears to contradict a good grounding scheme to have multiple earth grounds in a system, but if the safety code requires it, learn to work with it. The ground should be a non-current carrying conductor. Only in failure would there be current. It is a reference. Phases, Neutral and shields can all be current carrying at times, but the ground should be at reference.

Grounding and Shielding Techniques



* A ground is not a current carrying conductor in normal operation.
* A shield is always connected to ground and is also not normally a current carrying conductor.
* A shield may have stray currents that are given a path to ground.

Now here is where some definitions and discrepancies sometimes exist. Anyone that has used single ended analog circuitry in the past will know of certain rules pertaining to the grounds and shields that are somewhat in conflict with operation in today’s environments. These rules indicate that the best grounding practice is to ground at “one end” at the “source” and definitely worked for the purpose of analog signals prone to 50 or 60 Hz noise induced by the power. I am not going to say that these are obsolete, but they are not likely to be effective with EMC currently.

The approach currently is to use differential mode products that are grounded at both ends. The grounds should be braided shields for use near power electronics and their subsequent magnetically induced noise. The coverage of this cable should be at least 85% or greater and have a 360 degree clamp to earth ground. Any cable required for bringing earth ground to a chassis or mounting surface should be a braided style like a 0000 AWG that is as short as possible with a direct path to the incoming earth ground reference. Having any sort of loop in this will defeat the purpose.

Braided Shields and Braided Cables
Braided shields offer the most protection against stray magnetically induced noise in the 30 – 100 MHz band, and with 85% or greater coverage it will reduce RFI interference significantly below 500 MHz. The braided wire for grounds is done because the surface area of a braid is significantly greater than solid wire or stranded wire. Given the skin effect of high frequency interference, the greater surface area is imperative. It is effective for both immunity and emissions. When a noise of less than 100 MHz is within the shield, it will have a large inductive path in order to couple onto an unintended circuit that could cause harm. Should frequencies of much higher than 100 MHz have to be guarded against, then greater than 85% coverage will be necessary.

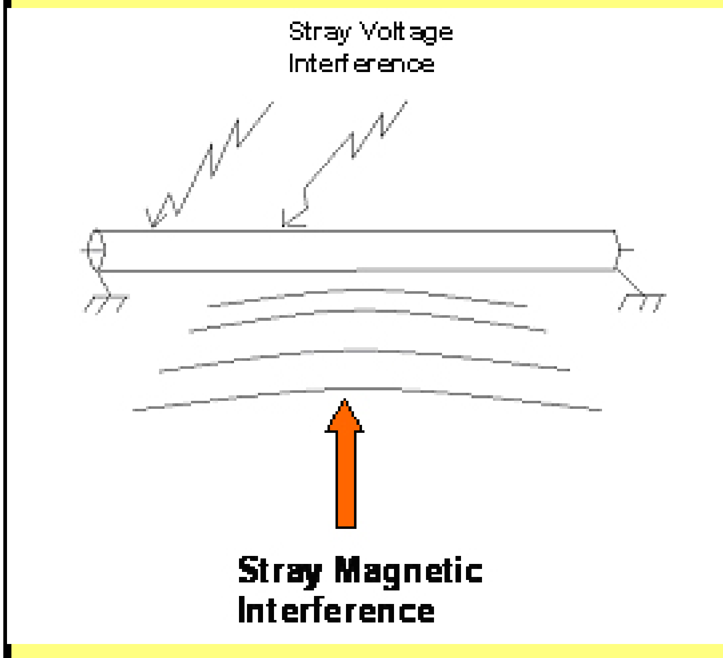
Foil Shields
Foil shields are typically used for high frequency capacitive coupled noise. Clock frequencies leaking out of an enclosure many times fall into this category. A foil shield is not an effective shield for magnetic noise. The reason for this is that the power of a magnetically induced spike will quickly saturate the relatively thin foil and couple onto the cable. Foil provides 100% coverage and thus a very good shield against high frequency. In some cases, the use of both foil and braided shields is used. Many RG-59 cables have this. This is the cable used to bring your television signal from your cable company or satellite once it is converted. There is a reason that they are used in RF signals on your television. Interference will cause signal integrity loss or crosstalk of other signals. Usually the signals from cable or satellite are converted to VHF (Very High Frequency Band) and that may contain local TV stations (Soon to be obsolete!) that can interfere if the shielding were less than adequate. The upper band of the VHF spectrum is 300 MHz so using a little math; the wavelength or lambda is 1 meter. Any exposed area of 1/20th of a meter or 5

cm can have this induced upon the signal. Less than 2 inches of exposed cable is an invitation for this.

Why Do You Need Twisted Pairs?
Twisted pairs offer the least amount of area between conductors of a given circuit and hence, the inductive area. Since a major contributor to induced noise is the inductance, then reducing the area between the conductors will encourage high frequency stray magnetic currents to stay within the circuit. So s good reason to twist the pairs is for reducing the emissions by reducing the inductance of the intended path! The reason for the twisting the pairs also has an immunity value. Since the twisted pair cannot encircle something within its signal and return, inducing a noise on a twisted pair even without a shield would require a significant signal and high frequency.

Power Supplies and Servo Amplifiers
Switch-mode power supplies and servo amplifiers are prone to noise emission and immunity to noise. Due to the higher power, there are two major areas of concern related to coupling, direct coupling and inductive coupling. There are two modes of concern as well. Common mode noise and differential mode noise are handled differently and need understanding.

Direct Coupled noise can have a non-zero voltage average (DC offset!). Inductive coupled noise cannot. The most common way in which to eliminate direct-coupled noise is through filtering. Emissions and immunity are concerns. There are times that a servo drive can be its own noise source and receiver when it comes to direct coupled noise. I have seen issues where direct-coupled noise has come from the drive itself, reflected to the line and come back due to a stiff coupling of the line.



Common Mode Inductive Noise

This noise occurs with the complex model of a motor or load of a servo amplifier of power supply. The inductance and capacitance not being equal in a three-phase motor can create stray currents that are common to all three phases and the ground. When this occurs, the current spikes can go unnoticed by standard measurement techniques. On the right is a plot from an oscilloscope and current probe across three leads of the motor. The spikes are occurring at the edge of each commutation of a 16 KHz PWM frequency. Because of the way this propagates, you can have paths that you didn't account for or possibly cannot eliminate entirely. A method that is often successful is to create a higher inductive path in common with all three leads. If the currents were subjected to an inductance in common with all three leads, then you would have the noise attenuated. Ferrite "doughnuts" are commonly used for this or a Common-Mode Choke. You can have clamp style or wind the cables through a ferrite ring. The net series inductance of a common mode choke is near zero, so your performance is not affected in the intended direction of the current.

When clamped across the three phases of a drive with a current probe, you can have significantly ringing signals. In cases where equipment is completely laid out, you may be required to accept the limitations that you cannot be perfect, but improve within an acceptable level. The signal on the right is an unacceptable signal for this application. It is a common mode signal measured in an application where an 18-ampere drive had common mode issues. This was intermittently affecting digital signals in the system. The equipment was already completely designed and a total layout change was not possible. The noise was measured at 13.6 amperes peak. Improvements can be made and the following improvement gave a large margin of immunity for the digital errors that were seen previously. Using a combination of proper shielding and a common mode choke, the signal ringing was eliminated. The signal at the right shows the affect of a common mode Ferrite inductor on the signal. The amplitude was reduced to a level that it did not couple within the digital signals and integrity of the system was improved. A re-designed cabinet would result in improved performance from this. Good layout, good grounding and proper shielding are more easily employed with upfront design.

Links:
[1] http://www.linear.com/
[2] http://www.kollmorgen.com/