Motion Control™
TECHNOLOGY

Reducing Electromagnetic Interference in Motion Systems

EMI (Electromagnetic 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.

Understanding 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.

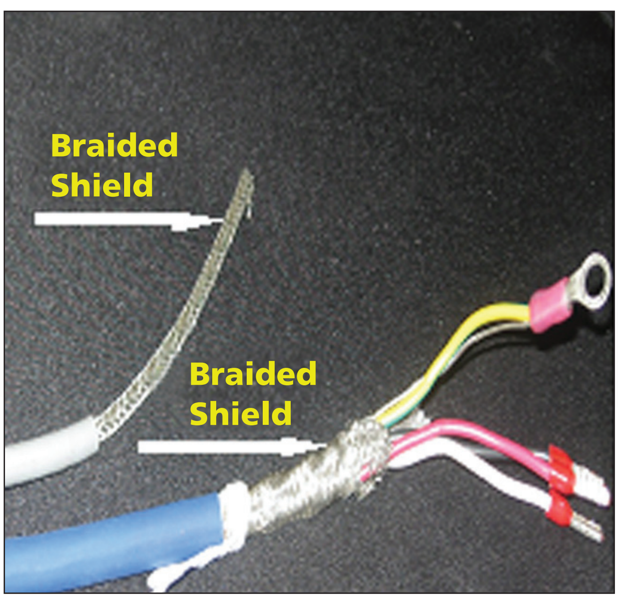

Figure 1. Braided shields offer the most protection against stray magnetically induced noise in the 30–100 MHz band.

Coupling Factors

Conducted noise is usually through the AC line and requires an RLC-type filter. Various companies like Schaffner, ONEAC, and ABB 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 of 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), you may induce a voltage onto that circuit.

Capacitive induced noise is 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, where 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 $\lambda/20$ long (wavelength/20). You must also be ½λ away from the source minimum. It is the least likely source of trouble in most systems. At 100 MHz, $\lambda/20$ is 1.54 meters since λ 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 perform 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.

Here is where some definitions and discrepancies sometimes exist. Anyone who has used single-ended analog circuitry 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 this practice definitely worked for analog signals prone to 50- or 60-Hz noise induced by the power. This practice is 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.

Why Braided Shields and 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.

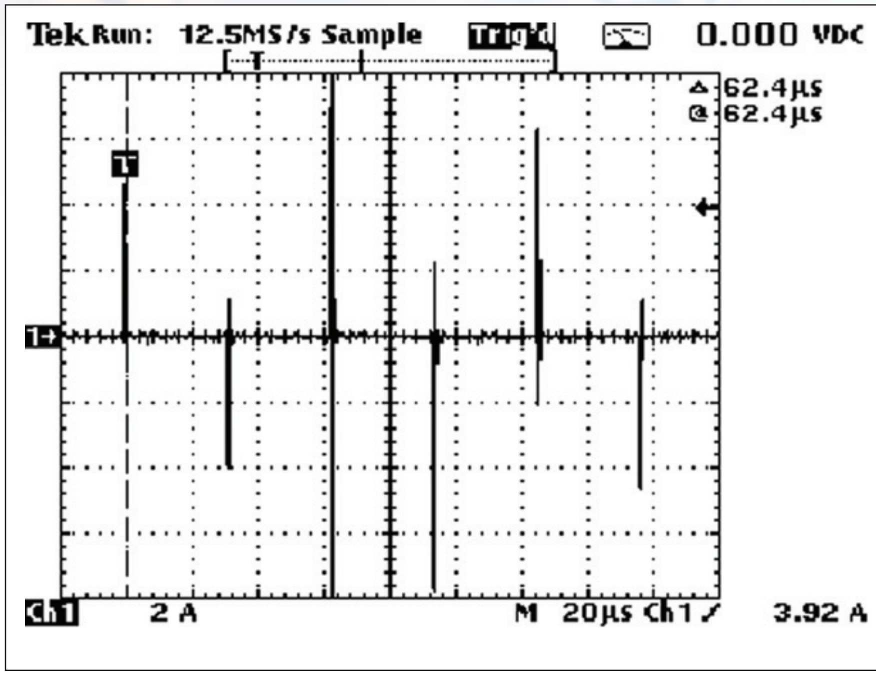

Figure 2. Common mode of PWM measured with a current probe.

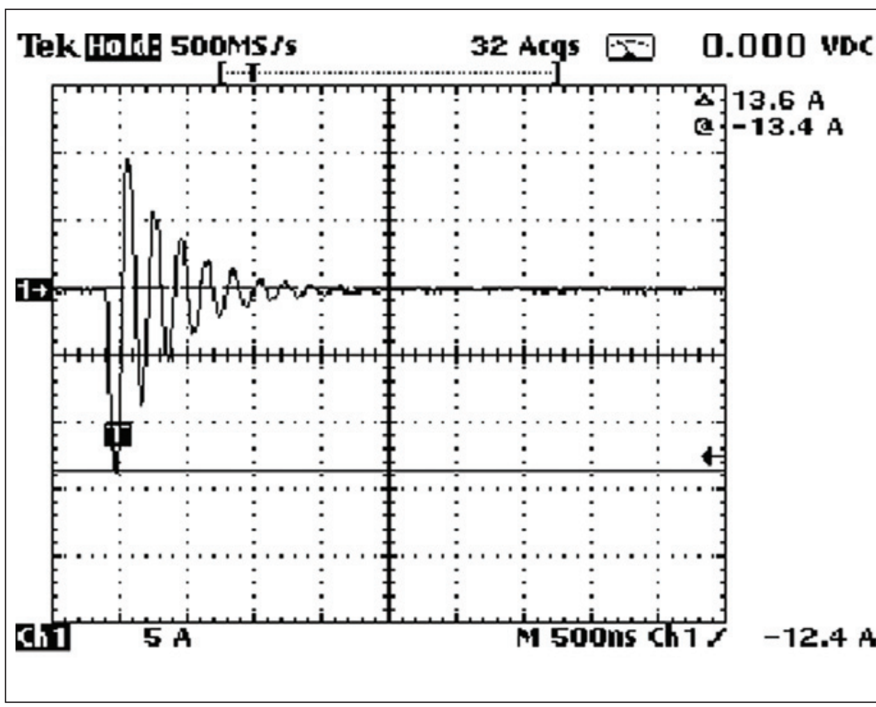

Figure 3. A 13.6-ampere peak signal in common mode.

What About 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 is a very good shield against high frequency. In some cases, both foil and braided shields are 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 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 that can interfere if the shielding were less than adequate. The upper band of the VHF spectrum is 300 MHz, so the wavelength or lambda is 1 meter. Any exposed area of $1/20^{th}$ of a meter, or 5 cm, can have this induced upon the signal. Less than 2" 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, reducing the area between the conductors will encourage high-frequency stray magnetic currents to stay within the circuit. So a good reason to twist the pairs is to reduce the emissions by reducing the inductance of the intended path. The reason for 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.

Direct-coupled noise can have a non-zero voltage average (DC offset); inductive coupled noise cannot. The most common way 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. There have been cases where direct-coupled noise has come from the drive itself, reflected to the line, and sent 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 or 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. Figure 3 shows 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.

What Does Common Mode Noise Look Like?

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 in Figure 3 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 were 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. Good layout, good grounding, and proper shielding are more easily employed with upfront design.

What Does EMI Look Like?

A lot of important information is available by looking at the EMI signals. With some knowledge of coupling and noise, it can be determined that the noise is common mode or differential mode. Observation of the signal can also identify its coupling mechanism. Is this a radiated noise, inductively coupled, direct-coupled, or is it capacitive noise? AC-coupled noise differs from noise that is direct-coupled. The induced signal is symmetric about zero. In other words, it is AC-coupled. It has a characteristic high-frequency component, but has significant power. This is the real issue with magnetically coupled noise; it can turn on or even destroy devices. Capacitively coupled noise would have nowhere near those power levels, and usually can couple a significantly higher-frequency component. Generally, when speaking of less than 10 MHz, one is more likely in the magnetically coupled arena.

To eliminate direct-coupled noise with a residual DC offset, the signal must be de-coupled from the signal. Should you try to use inductance to resolve this, it's possible to make the signal into a more problematic issue. Identifying the mode and coupling factors is the first strategic move at resolution. The tools used to measure this are usually oscilloscopes, spectrum analyzers, and current probes. It is important to identify the noise because the solutions for each type of noise are unique and specific. Capacitive coupling will not be resolved with inductive solutions, and vice versa.

This article was written by Lee Stephens, Systems Engineer, at Kollmorgen, Radford, VA.

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