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Application Note 107

Donald E. Fulton

Reducing Motor Drive Radiated Emissions

Introduction

This application note discusses radiated emissions (30 Mhz+) of motor drives and techniques to reduce radiated emissions. This application note covers:

- Emission Specs and Radiation Monitoring Equipment
- RF Basics
- Specific Techniques to Reduce Radiated Emissions

FCC and CE Emission Requirements

The FCC has a general requirement that equipment not cause electromagnetic spectrum or broadcast interference. The FCC has an active enforcement policy for electronics used in home and office, but the FCC specifically exempts industrial equipment from emission testing. The CE EMC requirements did not become mandatory until 1996. The result of these policies has been that much U.S. and European industrial electronic equipment designed prior to 1996 will not meet the CE EMC requirements without some add-ons and carefully installed shielded cabling.

The 1996 mandatory EMC requirements of the European Union have provided impetus to U.S. manufacturers of industrial electronics to buy equipment to monitor radiated emissions and to reduce these emissions in new designs.

The CE EMC standard that applies to most industrial equipment incorporating drives is the generic EMC emission standard for heavy industrial equipment: 50081-2. 50081-2 requires, per EN55011, that emissions, from 30 Mhz to 230 Mhz be below 30 dbuV/m @ 30 meters. Emissions from 230 Mhz to 1 Ghz are also regulated, but are of less concern with drives.

Antenna and Spectrum Analyzer

Radiated emissions can be observed for engineering purposes and pre-regulatory testing with relatively inexpensive equipment. All that is needed is a single antenna (covering 30 Mhz to 300 Mhz), an inexpensive spectrum analyzer (500 Khz to 500 Mhz, $1,500) and a stand for the antenna (optional). The antenna couples directly to the spectrum analyzer.

A good distance for the antenna is about 3 meters. This puts the antenna in the far field and increases the voltage output from the antenna by a factor of 10 (20 db), compared to the spec distance of 30 meters. The quieter the environment the better, but useful data can be obtained in most industrial environments. Turn the equipment on and off and note the change. Local FM stations show up as narrow spikes and are easily ignored. The spectrum analyzer can help identify the source of the radiation. Power supplies display as broad band lobes 5 Mhz or more wide; crystal clocks usually display as narrow spikes at harmonics of the clock frequency.

The main difficulty in testing in-house is background RF noise. The author successfully used this equipment in a busy engineering lab. On/off tests help separate the drive under test from the background. Some work was done in the evening when the background could be quieted by turning off other equipment. The author found computers and scopes in the lab to be no problem, and a burn-in room about 60 feet away to be an acceptable neighbor. RF equipment manufacturers recommend using the plant parking lot as a convenient open field test site.

Pacific Scientific found the following equipment useful for monitoring radiated emissions:

Antenna

Biconical type, 30 Mhz to 300 Mhz
ComPower Corp, model AB-100 + stand

Spectrum Analyzer

500 Khz to 500 Mhz
ComPower Corp, model SA-505
(same as Hameg model HM5005, Germany)

This equipment was purchased from ComPower Corp (see Appendix) and cost less than four thousand dollars. Newer model spectrum analyzers extend down to 150 Khz which allows them to also be used in evaluating line conducted emissions.

RF Basics

Cable Radiation

In the frequency range of interest (30 Mhz to 300 Mhz) what radiates is cables. The key to quieting radiation from equipment is to prevent the cables from radiating. Cables longer than 7.5 ft to 0.75 ft act as 1/4 wave radiating antennas for 30 Mhz to 300 Mhz. Cables can be quieted by a combination of shielding, adding bypass caps, or absorbing RF energy by enclosing a cable in ferrite.

The only non-cable antenna the author has seen is a gap ‘antenna’ about a foot long between the cover and chassis in one product that radiated some logic clock spikes in the 200 Mhz to 250 Mhz region when the product was flexed. During EMC testing, radiation from a seam antenna can be killed with RF tape along the offending seam. A permanent fix is to add a screw or two to the offending seam to shorten it, or add an RF gasket to the product along the seam.

Frame, Mounting Plate

The metal frame of most machines, or a cabinet mounting plate, provides a large reservoir of charge. A continuous metal (or conductive) structure, can absorb excess charge without much change in potential with respect to the earth. For this reason it is inherently a ‘local RF earth ground’ or ground plane and does not radiate. The local ground (frame, product chassis, or mounting plate) is where cable shields and bypass caps **MUST** be connected.

Shield pins on drive connectors should AC couple the shield to the drive chassis within the product with as short a path as possible.

Note: *A shield connection that goes to the chassis via a connector pin into a PC board will not ground the shield as effectively as clamping the shield directly to the local ground, especially above 100 Mhz.*

Paint

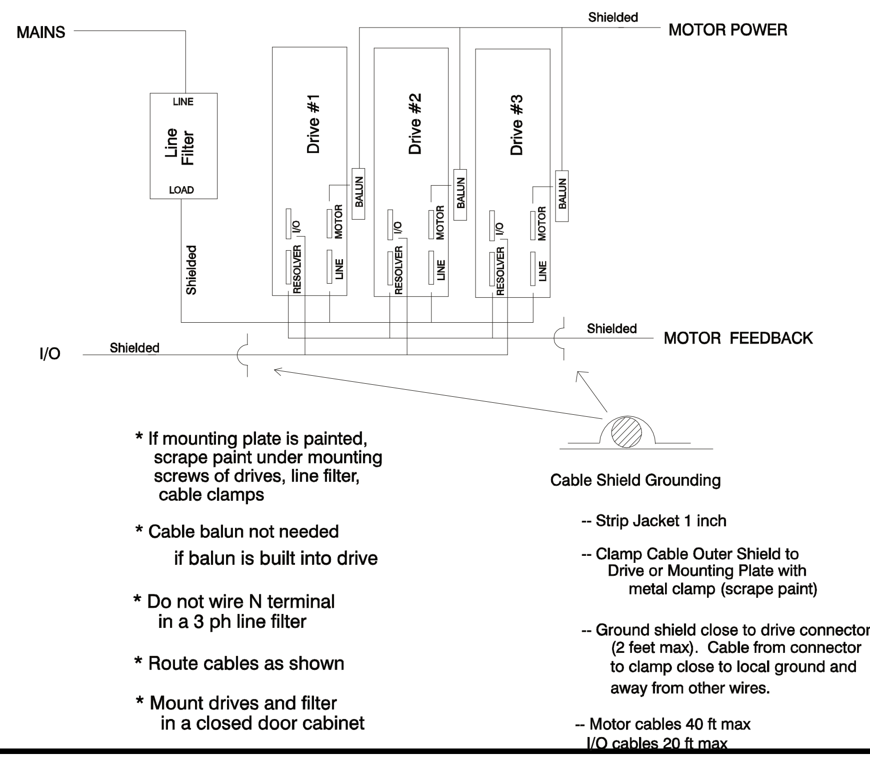
Paint reduces the effectiveness of the local ground plane. If a mounting plate is painted, scrape a few square inches under the mounting screws of drives, line filter, and cable clamps.

Grounding The impedance to the frame at 30 Mhz+ must be less than a few ohms because the cable antennas have a radiation impedance of about 50 ohms. In order to achieve 20 db of attenuation, capacitive bypass paths need an impedance of less than 5 ohms, and ferrite series impedance need an impedance of greater than 500 ohms.

The key to reducing radiation is to keep the length of the cable shield connection to frame SHORT. Position bypass caps so the the lead and wire length from the cap to frame is SHORT (**less than 1/2 inch**). Consider impedance at 60 Mhz: a 1 nf cap has an impedance of about 3 ohms (10 nf has 0.3 ohms); one inch of wire has an impedance of about 10 ohms; and the radiation resistance of cables is about 50 ohms.

The shortest and hence the most effective way to ground cable shields is to clamp them directly to the local ground (see “Optimum Shield Grounding” below).

Typical CE EMC Installation Instructions



Specific Techniques to Reduce Radiated Emissions

Shielded Cables Shielded cables, correctly installed, are very effective at preventing cables from radiating. Using shielded cables and correctly grounding the shields is the key to passing the radiated emission test. Pacific Scientific recommends that all resolver and motor cables be shielded. Line wiring between the drives and line filter should be shielded, and I/O cables should be shielded.

How cable shields are grounded is VERY important. Just connecting the shield to a pin on a drive connector marked ‘shield’ may not be sufficient. In equipment that was not specifically designed to meet CE, the length of the internal path in the drive from the shield pin to the equipment chassis may be too long.

Testing the Shield pin

If you have an antenna and spectrum analyzer, it is possible to test the 'shield' pin of unknown equipment to see if it provides a low impedance RF ground to the equipment chassis. Place a square foot or so of aluminum foil along the side the equipment chassis and then bend up (or tear) the aluminum foil so that it touches the shield pin. If radiated noise from that cable goes down, then the shield pin is not properly RF grounding the shield to the chassis and a shorter external shield to frame connection is needed.

Quieted Drives

The effectiveness of shield pins on pin type connectors can sometimes be substantially improved, especially in the lower range (30 Mhz to 70 Mhz) where power supply radiation is strong. This can be done by the manufacturer adding a few internal capacitors to shorten the path from the shield pins to the chassis. Bypass caps added to line wiring are also useful.

Optimum Shield Grounding

The most effective shield grounding technique is to ground the cable shields directly to the drive sheet metal or mounting plate that forms the local ground. Clamping the shield to the drive sheet metal is preferred because tests at Danaher Motion show that the portion of the cable that is between the drive connector and clamp is 'RF Live', meaning that it can radiate and/or couple RF energy to adjacent wires. Best is to attach a cable clamp under a nearby drive screw within a few inches of the connector. If the shield clamp is to the mounting plate, position it no more than two feet from the drive connector and, this is important, route the portion of the cable from the clamp to the drive close to the local ground and away from other wires.

The cable to use should be one with an outer braid or foil/braid shield. The cable clamp should press the cable braid firmly to the grounded mounting surface. Expose the cable outer braid shield by stripping off an inch or so of the outer jacket, taking care not to cut through the braid. Use a metal clamp to squeeze the cable shield directly to the local ground. There should be no paint under the cable clamp or the drive mounting areas. Do not pull out the braid and run it separately to the ground. A separately grounded braid is not as effective at high frequencies as squeezing the exposed cable braid to the local ground with a metal clamp.

During recent CE testing of Danaher Motion Pacific Scientific's quieted drives clamping the resolver feedback cable shield to the mounting plate about two feet down the cable made a 20 db reduction in a 140 Mhz clock spike, pulling it below spec. However, as noted above, tests at Danaher Motion have shown that the a more robust and reliable approach is to clamp the cable shield to the drive sheet metal within a few inches of the connector.

Motor Cable Baluns

Motor cable baluns are very effective noise suppressers. Experience has shown that a very wide range of noise problems can be solved by adding a balun to a drive motor cable. Consult the factory to find out which Danaher Motion drives have built-in baluns.

Baluns absorb the common mode volt-time on every PWM switching edge, slowing and reducing the amplitude of the current charging and discharging the motor cable shield capacitance and motor capacitance. Baluns help in the several ways:

- Act as a filter to attenuate line conducted noise from the drive;
- Reduce noise coupling directly from the motor cable;
- Attenuate radiated emissions of the motor cable because its ferrite absorbs RF energy

Motor cable baluns are strongly recommended because they are very effective at reducing a wide range of drive noise problems. In the author's experience radiated emission from a shielded motor cable where the drive or the cable has a balun is low.

Additional Techniques to Reduce Radiated Emissions

While cable shields are the primary means to reduce radiation, other techniques are also available to attenuate RF emissions:

- Commercial line filters
- Bypass caps on line wiring or individual cable wires can be used to bleed away RF currents to the chassis.
- Ferrite over the cable will absorb RF energy (3 to 8 db)

Commercial Line Filters

If a drive was not designed to meet CE, it is nearly certain that the cabinet will need a commercial line filter to reduce ‘conducted’ line emissions to the low levels specified by CE. One line filter can filter all the drives in a cabinet. That same commercial line filter, if properly mounted, can be very effective at reducing ‘radiated’ emissions from line wiring.

For the line filter to prevent RF noise from getting onto the line wiring it is important that line filter case be RF grounded to the drive chassis. This can be accomplished by mounting the filter near to the drives on the same mounting plate or metal surface. Scrape a few square inches of paint from under the mounting screws of both. While it is possible to used unshielded wiring between the filter and the drives, you must be careful to route the wiring close to the local ground plane to prevent it from radiating. In the author’s experience this is troublesome and not worth the risk, so shielded wiring between the drives and the line filter is recommended.

A preferred mounting position for the filter is near the outside wall of the cabinet and adjacent to the drives. The line cord should enter the cabinet wall near the filter and be routed directly to it. Keep the wiring from the line side of the filter away from other cables.

Line ByPass Caps

Line wiring, if not shielded, can be quieted by adding 1 nf to 10 nf caps from the line to frame. Commercial line filters suppress radiated emission because they include a few nf of bypass cap from each line to the case of the filter. Mount discrete line bypass caps at the line connector of the drives. This location prevents RF noise generated within the drive from getting out onto the system line wiring. The control supply of drives, especially those with switching supplies, should also have bypass caps.

If a good RF ground to the chassis is not available at the drive connector, then one option is to route the line wiring through a terminal block on the ground plane. Mount the bypass caps on the terminal block, and route the wiring between the drive and the terminal block along the ground plane. The line power needs to go the equipment by way of cap bypassed terminal block.

An important consideration for caps used on the line is that they be rated for line operation. Caps used on the line should be a special type, called ‘Safety’ or ‘Interference Suppresser,’ which are highly ruggedized to withstand line spikes. Capacitors to be used from the line to earth ground should be of the Y class. Capacitors from the line to earth ground add to machine ‘leakage current’. A generally accepted international threshold for leakage current is 3.5 ma. To stay below this threshold the capacitance on each phase of a 240 VAC line generally should be no more than 10 nf. Tests show that the RF bypassing is about the same for caps from 1 to 10 nf.

Y Type Capacitors

Sprague: AC Rated, Y type, 440 L series
440LD10 1 nf
440LS10 10 nf

Panasonic Interference

Suppresser:	ECQ-UF series, Class Y
	ECQ-U2A102MF 1 nf
	ECQ-U2A103MF 10 nf

I/O Bypass Caps

Only I/O signals that switch rapidly are capable of generating significant RF energy. For example, an encoder emulator signal at top motor speeds and high line counts can be a logic signal switching near 1 Mhz.

Adding about 470 pf to frame will reduce radiation from such a signal. Check that the cap does not significantly round off the waveform. An encoder emulator cable driver can typically supply substantial current so will not be much affected by a 470 pf shunt load.

Ferrite Cable Clamp-Ons

Ferrite can also be used to reduce emissions in two ways. An entire cable can be quieted by putting ferrite around the cable (3 to 8 db reduction) or individual wires can be quieted by slipping ferrite beads over the wires.

Magnetic manufacturers make ferrite pieces in plastic shells that may be clamped around entire cables. Clamp them on the cable as the cable emerges from a drive. A typical computer video cable is an example of this type of ferrite quieting. Ferrite cable clamps work because their RF resistance is higher than the cable radiation resistance, so the RF energy is absorbed by the ferrite instead of being radiated.

Ferrite beads can be inserted over individual wires. The goal is 500 ohm impedance at 30 Mhz+. Higher impedance is achieved by using longer ferrite beads, two or more beads in series, or a two and one half turn ferrite bead. Ferrite beads generally have no significant effect on drive I/O signals. Ferrite beads over single wires that carry amps of current are not effective because the ferrite saturates.

In its motor drive tests, Danaher Motion found that bypass capacitors are more effective than ferrite at reducing radiated emissions. Since clamp-on ferrite can be added at later stages of machine design and experimented with during radiation testing, a good approach is to start with bypass caps and later add clamp-on ferrite as required.

Appendix

Manufacturers of inexpensive radiated emission monitoring equipment:

ComPower Corp	Hameg Instruments
114 Olinda Drive	266 East Meadow Ave.

Brea, CA 92621
714-528-8800

East Meadow, NY 11554
516-794-4080
1-800-247-1241

Magnetic Vendors

Cable, Connector EMI Suppresser Kits and Bead & Balun Kits

Fair-Rite Products Corp.
P.O. Box J
One Commercial Row
Wallkill, New York 12589
914-895-2055; 914-895-2629 (fax)

Phillips Ferrite Components
1-800-447-3762 Ext 105

References

“Shielding, Filtering, and Bypassing I/O Cables”, by Dash and Straus.
Compliance Engineering 1995 Reference Guide
629 Mass Ave.
Boxborough, MA 01719
508-264-4208

(815) 226-2222
Email: customer.support@danahermotion.com
Website: www.DanaherMotion.com