Regulatory issues with motor-driven appliances

Noise from motor-driven appliances requires special attention.

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Much has been written about designing computer equipment which complies with regulatory standards, but very little information is available on appliances. Many appliances are motor-driven, and hence, are plagued by EMI caused by motors. These problems are many times harder to solve than clock frequencies and transmission lines because, unlike many of the defined clock frequencies associated with computer type equipment, they are so irregular and unpredictable. When these problems occur, one wants to ensure that the solution reduces the noise problem well below the allowable limit to accommodate unpredictable variations. Well below, in this instance, means 10-20 dB below the limit. This should keep the product in compliance throughout various production stages. In addition, the production line output should be tested regularly by sampling units to ensure that products remain compliant with regulations.

The European Union has more requirements for appliances than the U.S. In the United States, if a digital device is utilized exclusively in an appliance, it is declared exempt from the Federal Communications Commission (FCC) Regulations, Part 15. However, Part 15 states that if the device is found to cause harmful interference, the operator of the exempted device will be required by the FCC to stop operating the device (Sect 15.103). This section goes on to say that the FCC "strongly recommends" that the manufacturer of an exempted device should endeavor to have the device meet the specific technical standards of this part.

Europe on the other hand, requires compliance to the EMC Directive (89/336/EEC). Applicable sections are EN55022, if the appliance has a microprocessor, and/or EN55014, if it is a motor-driven device. If EN55022 is required, chances are that the immunity part of the EMC Directive will also have to be tested, so EN50082-1 will be required.

The reason the safety regulation (EN60334-XX) is mentioned in this group of regulations is that some of the fixes used to solve the EMC problems may contradict some of the safety requirements. For example, when solving EMC problems, one must be sensitive to adding capacitance across the input mains lines. While this may solve the EMC problem, it can cause too much additional leakage to ground and exceed the allowable requirements of the safety standard.

PROBLEM AREAS IN APPLIANCES

Problem areas in appliances usually involve plastic enclosures; long wire harnesses; multiple motors; and a scarcity of room in which to put EMC components and 2-wire power cords (no ground available).

Plastic enclosures offer a neat ergonomic package and inexpensive housings for high volume products. However, they often create a grounding problem for the electrical system of the product.

Another potential problem is that the working end of some appliances is a relatively long distance from the controlling end (e.g., a vacuum cleaner). This type of design demands long wire lengths between filters and loads. These wires are frequently not harnessed due to cost constraints or lack of thought. Hence, the EMC spectra displayed by these devices can be quite variable as they come off the production line. It is embarrassing to certify a product from an engineering sample only to find out that 5 out of the first 10 production line units fail.

Yet another possible problem area is that some appliances involve multiple motors. This always enhances the electrical noise problems, especially if the motors are brush types. Now the problems are multiplied by the number of motor devices included. The question then becomes: is it better to solve the system problem or to tackle each device singly?

A problem not unique to the appliance industry is the scarcity of physical space in which to install problem-solving components after the design is completed. When the product is finally tested, the product enclosure is designed and tooling is developed, there is not a cubic inch of available space left over in case of an EMC problem.

Finally, there is the problem of a 2-wire power cord with no ground included. Many appliances are double-insulated and rely only on a simple two-wire power cord. This creates a problem with the ability to filter noise. There is no base ground against which to operate the filter. With appliances in this category, attention must be directed at shielding or filtering between line to line.

SOLUTIONS

Now that the regulations that control the appliance industry have been discussed, and the pitfalls that arise in this product category have been explained, it is useful to look at some possible solutions to these problems. In the EMC tool-bag of tricks are capacitors, inductors (chokes), line filters, and grounding. With something this simple, this should be a very short article.

Unfortunately, EMC problems are usually attacked after the product is fully designed and packaged (including the shipping box) and it is ready to ship to the distribution area (usually in a very large quantity). This is probably the worst time in the project to think of EMC. The manufacturer is under a time crunch, the project design budget has been used up, and the responsible engineers may already be off on another project and unavailable to help on the project at hand. If this priority could be reordered in a product development cycle, the process would be easier on all parties. A description of the tricks mentioned above will demonstrate how each one can be effective.

CAPACITORS

Capacitors are used to shunt out voltage spikes by providing a very low impedance path to the common side of the noise-generating source. The voltage spikes are those generated by the brushes. Capacitors can be connected from each side of the motor to ground or simply across the motor. If the spark noise turns out to be common mode, then a capacitor across the motor leads will not do much good, but typically the noise is differential due to the random nature of the brush transients. However, placing the capacitor from brush to ground will have a great effect. Where to put the capacitor and how to connect it is very dependent on what type of noise is at hand. These voltage spikes have been generated by the brushes breaking contact with the commutator bars.

The amplitude of the spikes sometimes can be reduced by changing the composition of the brush material to a softer material or by providing more pressure by the brushes on the commutator bars. This, however, reduces the life span of the brushes and causes other problems.

In order to make a capacitor into a good effective filter, it must be provided with a very short ground path to the common side of the noise generating circuit. A wire in free space has an inductance of approximately 1 nH per inch. If a brush-generated noise spike is in the frequency range of 50 to 100 MHz and it takes 4" to 6" of wire to get to the ground connection or to the capacitor lead, the inductive reactance alone of the wire, even before considering the capacitive reactance, is going to be

$X_l = 2\pi fL$
$X_l = 3.77$ ohms

Now adding a shunt capacitor (.01 uF) for a noise filter,

$X_c = 1/2\pi fC$
$X_c = 0.159$ ohms

The result is 0.159 ohms of capacitive reactance. What was thought to be a real good filter turned out to be less than expected because of the inductance factor of the lead to the component or to ground. If this lead had been reduced to 1", then the inductive reactance would only be 0.628 ohms and the capacitor would be about 20 percent more effective.

When using the motor case for a ground connection, the paint must be removed so the wire can make a good ground connection. Counting on the three or four threads of the connection screw is not always a good idea. Even if the appliance enclosure is metal, grounding the filter components directly to the noise-generating source instead of the closest, most convenient place on the case is always a better choice. This reduces any path length, and minimizes the impedance for the noise to get back to the source and provides a much better filter.

LINE FILTERS

In most products, an input mains line

filter is a necessity. The line filter provides a quick, compact system fix for the whole product if it is installed correctly. The line filter ensures that the input mains conductors are clean from noise generated within the product. Again, however, a critical feature of the line filter, as with any filter component, is a very short low resistance path to the ground of the noise-generating device.

Line filters contain inductors and capacitors to help filter differential and common-mode noise to the system ground. These filters are an easy method to reduce both types of noise in a very small (space-conscious) and cost-effective way. Line filters physically belong directly where the input mains connect to the device. Some line filters are mounted deep within the product only to have radiated noise from somewhere in the system couple into the input wires of the line filter, rendering the filter action null and void. If a designer remembers 1) the line filter, 2) a good system ground, and 3) line filter characteristics down to 150 kHz (for Europe), then the design has a good chance of meeting regulations.

Line filters are not easy components to select from a catalog. The industry standard specifies these components in a 50-ohm system (input and output). In reality, no systems are ever 50-ohm; this is just the way they are compared. When the regulatory conducted emissions test is performed, it is done with a line impedance stabilization network (LISN) placed in the input mains circuit. This provides a constant method throughout all testing agencies to test against the standard. The LISN takes care of the input side of the line filter and stabilizes this circuit to a constant 50 ohms across the measured frequency range. The impedance of the line filter output load is strictly determined by the appliance and it will never have an impedance of 50 ohms. If it did, the data characteristics published by line filter manufacturers could be applied directly to ascertain which filter would be better suited for the application. However, this not being the case, a line filter almost always has to be tried in the system and measurement data recorded to accurately determine which filter is best for the product. A good rule of thumb to use when the actual conditions that the equipment is presenting are not known, is to derate the line filter characteristics by 20 dB for a preliminary assessment of how good it can perform in the application.

With a 2-wire appliance, a line filter does not help nearly as much as it would with a 3-wire system. The line filter has two methods of filtering, namely, series and shunt to earth ground. A 2-wire system will get the benefit of the series filtering (inductors and line-to-line capacitors, or X caps), but it will not take advantage of the shunt to earth ground filtering which the Y capacitors provide.

Discrete Inductors

Another solution is to place small discrete inductors directly at the motor brushes to help reduce noise. The characteristic action of an inductor prevents a sudden change of current to be fed to the brushes when they pass over the gaps between the commutator bars. Small chokes on the order of 10-25 μH are used in this case.

A series choke can also be combined with a small shunt capacitor to ground to form a lowpass filter to increase the filtering impact of a simple inductor or capacitor. This solution helps with the conducted noise. The difference between using a single capacitor or using an LC circuit is significant. Just using a simple capacitor of 4000 pF from a brush to ground results in a frequency roll-off of 79.5 MHz. This is considering the inductance value of the 1" capacitor lead wire. If a discrete inductor (10 μH) is placed in series with the capacitor, the roll-off frequency becomes 0.795 MHz. This is a significant improvement and represents more effective suppression of the broadband noise of the brushes.

This technique helps eliminate conducted noise, but the radiated noise also caused by the sparks must still be handled. Shielding the sparks by screening the vent holes in the motor helps. Another possible solution is the use of shielded wires on the motor leads.

Grounding

Perhaps the single most important tool is grounding. We have mentioned grounding in two of the solution techniques already discussed. A filter cannot give proper designed results if it doesn't have a low resistance path to the system ground. Also, capacitors cannot do a good job of shunting noise to ground if the ground impedance is very large. Large is relative. Here, large means anything greater than milliohms.

Remember that the ground path is half the path of the noise or noise solution. If a very good filtering component is used, but long leads are used to connect to it, the filtering effectiveness of the component is substantially reduced. When using a nonmetallic enclosure, there is no convenient ground plane that contacts all components in a product. This makes it extremely difficult to provide good filtering.

To effect a good ground path, one can confine noisy components into one area with one common ground or use a large tinned copper braid strap to try to enhance the grounding system of an appliance.

SUMMARY

In summary, motors, and particularly brush motors, cause a lot of noise that must be addressed to comply with the required regulations. The best time to investigate these issues is in the design stage, not at the end of the product development cycle. Much of the testing can be performed before the product is in its final package; the designer must be sure that the wire harness is very similar to the one that will be used in the final production version.

Attention to details on grounding

is most important. Filters and EMC components cannot work effectively if there is not a good ground. Also, a good short analysis of the actual circuit, including motor windings, to understand how individual filtering components affect the noise is advisable. This does not have to be a massive CAD-oriented design review. Instead, a simple understanding of impedances based on Ohm's Law and a realization of how filter components function is sufficient.

Appliances can be modified or designed to comply with the necessary regulations. Compliance requires forethought, creative engineering and pretesting, but it is achievable. A large margin below the specified limit should be allowed because of the random nature of the amplitudes and frequencies generated by motors. Also, readers should understand that even if the same components are used, component variation is much larger than would be expected. Finally, the designer should be allowed the time to understand the issue of variations before going to the test lab and facing a surprise.

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