

The Common-core Filter as an Electromagnetic Interference-suppression Device

Though everyone is daily made aware of the existence of electromagnetic interference (as when one drives an automobile near a faulty neon sign and hears a loud "buzz" on the car radio, or when one uses a television receiver while an electric mixer is running nearby and the interference from that appliance obliterates the picture) it is not the most frequently cited form of pollution. However, radio communication services are expanding at a rapid rate, receivers are becoming more sensitive, and we are moving toward more complex types of communication. Because of these factors and the accelerated growth in the use of electrical appliances both at home and in industry, there is an ever-increasing effort to control electromagnetic interference caused by electrical equipment. Some nations, in fact, have promulgated laws to control electromagnetic interference. As industry responds to the need, undoubtedly more and more electrical equipment will have built-in powerline filters and other noise-suppression devices to prevent interference. The problem, however, is not merely one of the cost of adding a powerline filter, but that the addition of a filter may also affect the safety and performance of a machine.

A normal powerline filter is built as a classical low-pass filter, i.e., series inductors and shunt capacitors for each powerline to the machine with the shunt capacitors connected from each powerline to the machine-frame ground. For adequate insertion loss, this type of filter must have shunt capacitors of a value that can cause

Nomenclature

A	cross-sectional area of core
I	current in winding
ℓ	length of core
N	number of turns on core
μ	permeability of core
ϕ	magnetic flux
F	magnetomotive force
L	inductance
ω	angular frequency

excessive safety ground (green wire) current in convenience-outlet ac-powered machines. (For approval in the United States by the Underwriters' Laboratory, it is required that the green wire current be no higher than 5 mA. This criterion is established to protect a machine user when the safety ground is not properly connected.)

When the shunt capacitor's value is limited, the series inductance in a filter can be increased to give a higher insertion loss. However, the inductor will cause a voltage drop in the filter approximately equal to $I\omega L$. When L is large for insertion loss, and I is large due to machine power requirements, this voltage drop may be large enough to impair the function of the machine. This is especially true for low power-factor (<0.7 inductive) machines, where the phase difference between the inductor

voltage drop and the machine voltage is small. Thus, the problem is to determine not only what is needed but also what is practicable and safe.

The common-core powerline filter discussed here is intended to reliably suppress the noise conducted along and radiated from the powerline of a machine, yet not affect machine safety and performance. While this type of filter is not new [1, 2], neither is it well known. The common-core inductor works to attenuate common-mode powerline interference. (The term "common-mode" denotes interference, or a signal, of identical form on all lines with respect to the safety ground. Interference is usually common-mode or "quasi-common-mode," the latter being interference on one or more, but not all powerlines with respect to ground.) The common-core inductor is particularly useful in that it causes no voltage drop when properly connected in a powerline filter, yet very large inductances may be fabricated to give high insertion loss. Since large inductances are possible, it is acceptable to include a very low capacitance, or even none at all, to ground. The green-wire current will thus be small, resulting in a safer machine.

It can be seen from Fig. 1 that the schematic representation of a common-core inductor is similar to that of a transformer. This inductor is unique because high powerline currents cause no core saturation and no voltage drop across the core is realized. Core saturation does not occur since, for saturation, the magnetomotive force F in the core must exceed the point where F and the magnetic flux ϕ have a linear relationship.

Since the equation for flux is $\phi = \mu NIA/\ell$, and all terms are constant except I , if the current I , or the effect of this current, can be held equal to zero, the core will not saturate and the inductance will therefore not be affected by high currents. The effect of I may be nullified by letting $\sum_{i=1}^n I_i = 0$, where $n (> 1)$ is the number of windings. For a three-winding inductor, $I_A + I_B + I_C = 0$ (see Fig. 1). This condition also nullifies the inductance in each powerline, thus causing no voltage drop and therefore not affecting the machine power.

In the common mode, however, the inductor appears as a classical inductor, thus attenuating common-mode signals. Close examination of the manner of winding this inductor reveals that it is essentially a trifilar-wound transformer with the dotted leads connected to the load or machine and the other leads connected to the powerline. Because the interference signal is common-mode, the voltage at the inductor leads is the same on all and, according to one of Kirchhoff's Laws, these points may be theoretically connected together. The common-core inductor thus appears as a single element, having an inductance equal to that of any one of the windings. An equivalent circuit of this configuration with the connection for interference measurement is shown in

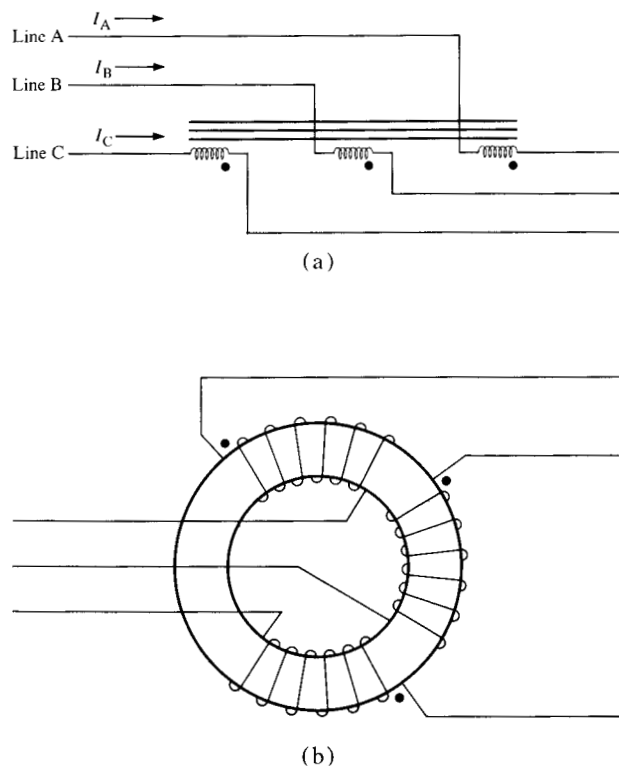


Figure 1(a) Schematic and (b) pictorial illustrations of a common-core inductor.

Figure 2 Equivalent circuit and method of noise measurement of a common-core inductor used as a powerline filter.

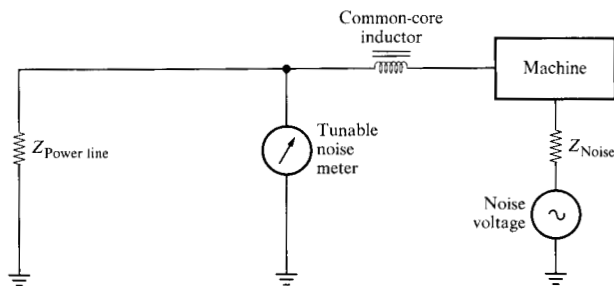


Fig. 2. Note that the noise meter is shown connected only to one powerline. In practice each powerline is measured, since the interference is not always pure common-mode.

To insure that the noise voltage is truly common-mode, or equally distributed on all powerlines, large capacitors ($2 \mu\text{F}$ or more) may be connected from each individual line to each of the other two on the noise-generator side of the inductor.

The proof of performance of any device is how well it works in a particular application. The performances of both a two-line and a three-line common-core inductor

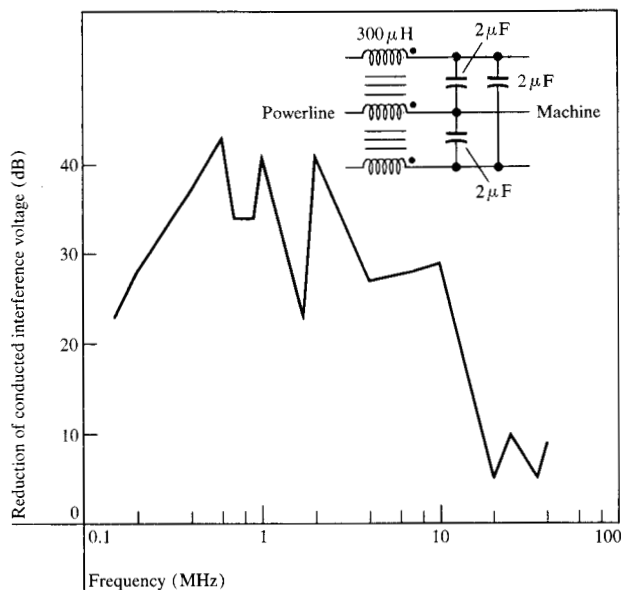


Figure 3 Conducted-interference reduction produced by a common-core filter with 300- μ H inductor and 2- μ F capacitors.

Table 1 Performance data for common-core filters.

300 μ H, 2 μ F (Fig. 3)		800 μ H, 4 μ F (Fig. 4)	
Frequency (MHz)	Reduction (dB)	Frequency (MHz)	Reduction (dB)
0.15	23	0.15	39
0.2	28	0.2	35
0.4	37	0.3	48
0.6	43	0.4	57
0.7	34	0.6	61
0.9	34	0.8	47
1.0	41	1.0	51
1.7	23	1.5	50
2.0	41	2.0	64
4.0	27	3.0	72
7.0	28	4.0	61
10.0	29	6.0	49
20.0	5	8.0	33
25.0	10	10.0	41
35.0	5	15.0	30
40.0	9	20.0	22
		30.0	30

have been verified. Data from two different three-line filters are reproduced in Figs. 3 and 4, where a schematic of the filter used is also shown for each case.

In practice this filter has been constructed by using a toroidal core, as illustrated in Fig. 1(b). A high-permeability ferrite is used as a core material, since saturation is no problem. To obtain the data shown in Fig. 3, a 300- μ H inductor with 2- μ F capacitors between powerlines on the machine side was used as a powerline filter. Current requirements of the machine were approximately 20A

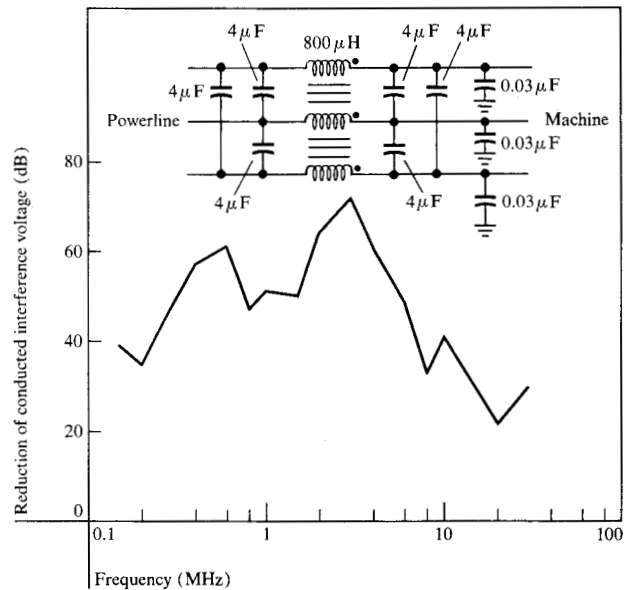


Figure 4 Conducted-interference reduction produced by a common-core filter with 800- μ H inductor and 4- μ F capacitors.

per line; however, the filter case occupied less than 80 cu in. and could have been smaller.

The filter for the data illustrated in Fig. 4 contained a three-line common-core inductor with 800 μ H per line; 4- μ F capacitors connected each pair of lines on each side of the inductor. Also, 0.03- μ F capacitors were connected between each line and ground on the machine side. These capacitors are small enough to limit the green-wire current, but their inclusion increases considerably the insertion loss at higher frequencies.

The data shown graphically in Figs. 3 and 4 and tabulated in Table 1 represent the differences in the conducted interference levels of a machine with and without a powerline filter installed. As may be seen from these Figures, a reduction of powerline interference voltages in the frequency range of 0.15 to 30 MHz may be obtained. Above 30 MHz the effectiveness of these particular filters deteriorates; on commercial machines, however, the powerline-conducted interference normally decreases with increasing frequency and the need for filtering is minimal at frequencies above 30 MHz.

References

1. T. H. Herring, "The Common Mode Choke," *IEEE EMC Symposium Record* (1970).
2. F. E. King, "Baluns as EMC Control Devices," *IEEE EMC Symposium Record* (1970).

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