# Ferrite Material and Core Size Selection For EMI Filters

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## EMI FILTERS

Switch-mode power supplies (SMPS) normally generate excessive high frequency noise. These unwanted electrical signals can pass from the power supply through the input power connections into the power lines. Other electronic equipment such as computers, instruments and motor controls connected to these power lines may pick up this noise, which can cause program errors and even total breakdown of connected equipment.

An EMI noise filter inserted between the power line and the SMPS can eliminate this type of interference. Figure 1 shows a differential noise filter and common-mode noise (CMN) filter in series. In many cases the common-mode filter is used alone, as it can often eliminate as much as 90% of the unwanted noise.

## COMMON-MODE FILTERS

In a CMN filter, each winding of the inductor is connected in series with one of the input power lines. The connections and phasing of the inductor windings are such that the flux created by each winding appears to cancel the flux of the next winding. The insertion impedance of the inductor to the input power lines is thus zero, except for small losses in the leakage reactance and the dc resistance of the windings.

**Optimum ferrite materials are not easily identifiable according to the usual parameters.**

In Figure 2a, the instantaneous current proceeds through one input line and returns through the other input line. In the top winding, the current going into the supply tends to produce a voltage as noted. In the bottom winding, the current leaving the supply tends to produce an opposing voltage. In reality, opposing fluxes which cancel each other are generated in the core; thus, almost no voltage is induced in either winding. The input current needed to power the SMPS will therefore pass through the filter without any appreciable power loss.

Common-mode noise, shown in Figure 2b, is defined as unwanted high frequency current that appears in one or both input power lines and returns to the noise source through the ground of the transformer. This current sees the full impedance of either one or both windings of the CMN inductor because it is not canceled by a return current. The CMN voltages are thus attenuated in the windings of the common-mode inductor, keeping the input power lines free from the unwanted noise.

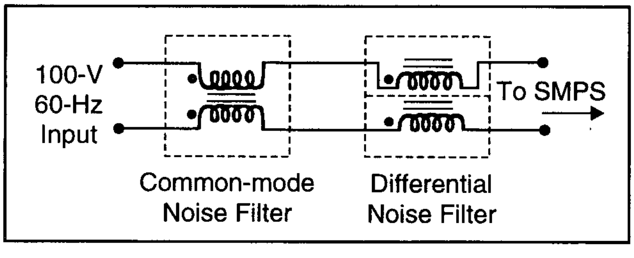


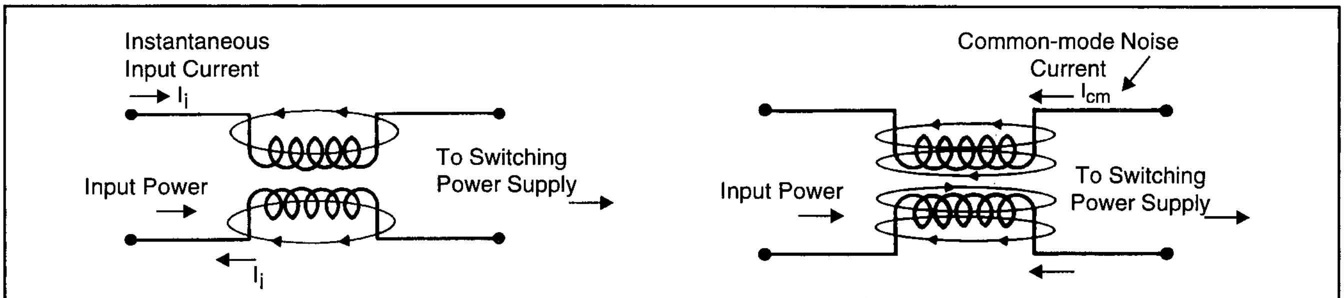

***Figure 1**. Schematic of an EMI Filter.*

## CHOOSING THE INDUCTOR MATERIAL

A SMPS normally operates at 20 kHz and above. Unwanted noises generated in these supplies are at frequencies higher than 20 kHz, often between 100 kHz and 50 MHz. The most appropriate and cost-effective material for the transformer is a ferrite that offers the highest impedance in the frequency band of the unwanted noise signals.

A ferrite material having the highest impedance at selected frequencies cannot be easily identified based on its more commonly defined parameters such as permeability and loss factor. Figure 3 is a graph of impedance, $Z_t$, versus frequency for a ferrite toroid wound with 10 turns. The wound unit reaches its highest impedance between 1 and 10 MHz. Also plotted for the wound unit are the series inductive reactance, $X_s$, and series resistance, $R_s$; these are functions of the permeability and loss factor of the material.

Figure 3 shows that, at low frequencies, the series inductive reactance, $X_s$, equals the total impedance, while at high frequencies, the series resistance, $R_s$, makes up the total impedance. As the frequency increases from a low value, the series resistance increases and starts to add to the series reactance to create $Z_t$, the total impedance. At approximately 750 kHz the decreasing reactance equals the increasing resistance. Above this frequency, the series resistance




*a. Reaction to Instantaneous Input Current.* *b. Reaction to CMN Current.*

***Figure 2.*** *Common-mode Noise (CMN) Filter.*

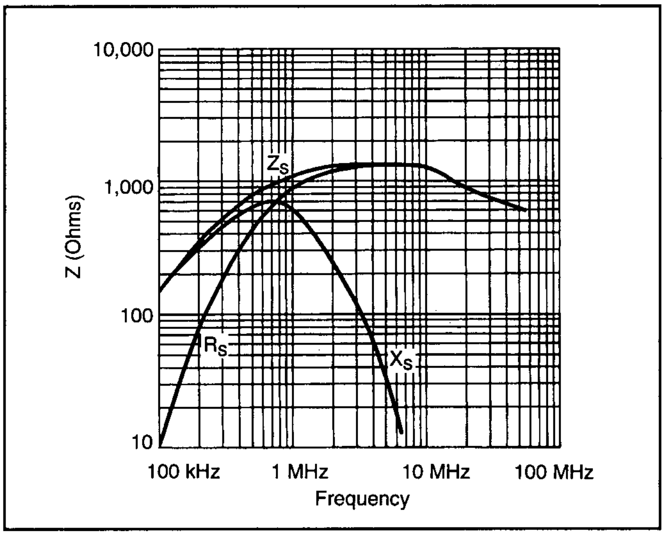



***Figure 3.*** *Impedance, Reactance and Resistance of J Ferrite Material.*

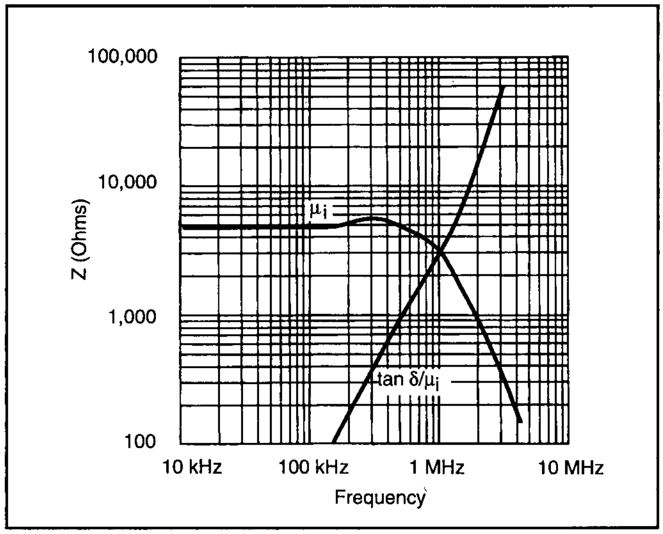



***Figure 4.*** *Permeability and Loss Factor of J Ferrite Material.*

is the major, and eventually, the only contributor to the total impedance.

Figure 4 shows the permeability and loss factor of the ferrite material used in the core in Figure 3 as a function of frequency. Permeability, falling off above 750 kHz, causes the inductive reactance to fall (Figure 3). The loss factor, increasing with frequency, causes the resistance to ultimately become the dominant source of impedance at high frequencies.

Figure 3 shows that the total impedance has its highest value, and thus is most useful, in a filter between the frequencies of 1 and 20 MHz. This is due to the material losses, with only slight contributions from the material permeability. It is obvious that the useful frequency range of a ferrite material for a common-mode filter is impossible to identify from the permeability and loss factor at a low frequency. The best way to identify the most desirable material is to use comparative impedance versus frequency curves.

Total impedance versus frequency for three differential ferrite materials is shown in Figure 5. J material (5000μ) has a high total impedance over the frequency range of 1 to 20 MHz. It is the most widely used ferrite material for winding common-mode filter chokes. W material (10,000μ) has 20% to 50% more impedance than J material at frequencies less than 1 MHz. W material is often used in place of J material when low frequency noise is the predominant problem. K material (1500 μ) can be used at frequencies above 2 MHz because it produces up to 100% more impedance than J material over this frequency range. For filter requirements specified at frequencies both above and below 2 MHz, the J or W material cores are preferred.

## CORE SHAPE

The toroid is the most popular core geometry for a CMN filter as it is inexpensive and has low leakage flux. The wound toroid, however, normally uses a nonmetallic divider between its two windings, usually epoxied to a printed circuit header for attaching to a pc board, and it must be wound by hand or wound individually on a toroid winder.

An E-core assembly is more expensive than a toroid but has advantages that may make the finished transformer less costly to manufacture. E-core bobbins are available for printed circuit board mounting, and they contain dividers for separating the two windings. Bobbin winding is relatively inexpensive.

Compared to toroids, E-core sets have more leakage inductance that can be used to provide some differential filtering in common-mode filters. It is possible to introduce an air gap in the E-core assembly to increase the leakage inductance and have a unit that will absorb both the common-mode and differential unwanted noise.

## IMPEDANCE CURVES

The core size for a particular filter can be determined from the impedance required and from the impedance versus frequency curves in Figure 6. Considering the space available for the filter, a core can be selected from the graphs in Figure 6. To obtain a specific impedance, the impedance per turn squared ($Z/N^2$) read from the graph at the frequency of interest is divided by the desired impedance. The square root of this number is the number of turns needed on the core selected. If the core cannot contain the number of turns of the wire size selected, a larger core must be selected.

The curves in Figure 6 are typical and have tolerances of ±30%. Readings on these cores are affected by the number of turns, wire size used, and the placement of wires on the core. Concern over possible saturation of the core is not necessary, as most common-mode noises are at relatively low voltages.

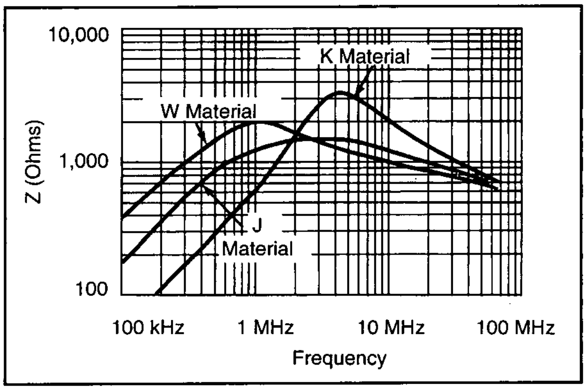



***Figure 5**. Impedance vs. Frequency of Ferrite Toroids in Three Different Materials.*

## CONCLUSION

Ferrite toroids are the most popular shapes used in CMN filters. Optimum materials are not readily identified according to the usual defining parameters such as permeability and loss factors. Selection is best made by winding cores of different materials, plotting impedance and permeability versus frequency, then selecting the material which provides the broadest range attenuation.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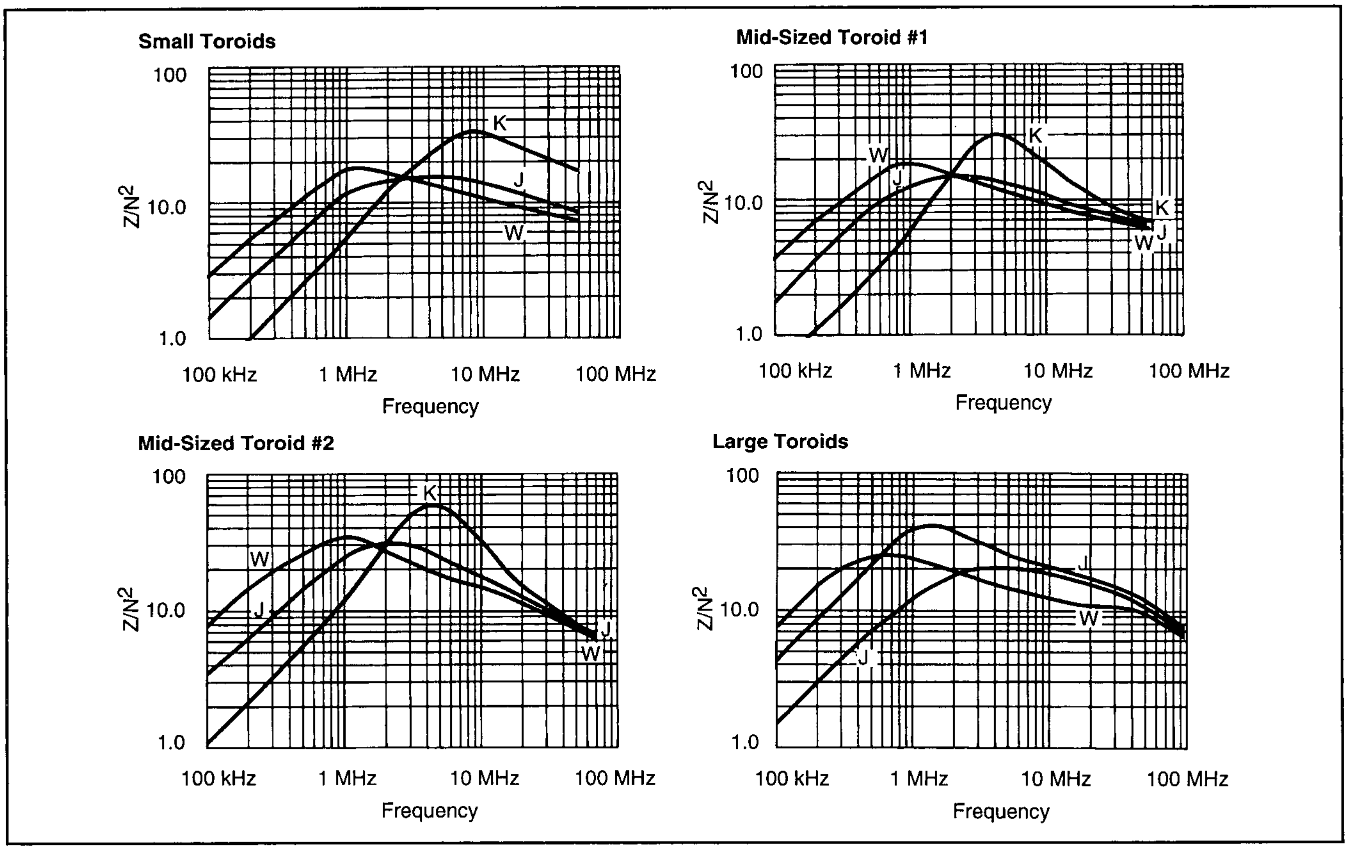


***Figure 6**. Impedance per Turn Squared vs. Frequency.*