Technical Bulletin

EMI/RFI FILTER • COMMON MODE FILTER

EMI Filter

Switch Mode Power Supplies 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 same 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, as shown in Figure 1, can eliminate this type of interference. This diagram shows a differential noise filter and a common-mode noise 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 Filter

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 other winding. The insertion impedance of the inductor to the input power line is thus zero, except for small losses in the leakage reactance and the dc resistance of the windings.

In Figure 2a, the instantaneous current is shown as proceeding in one direction in one input line and returning through the remaining 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 there are opposing fluxes

FIGURE 1: SCHEMATIC OF AN EMI FILTER

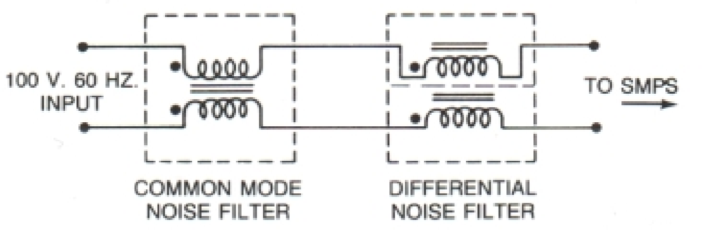
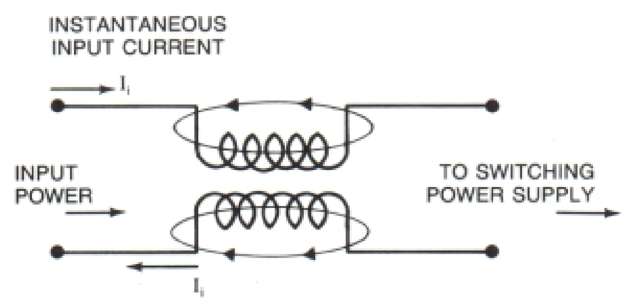
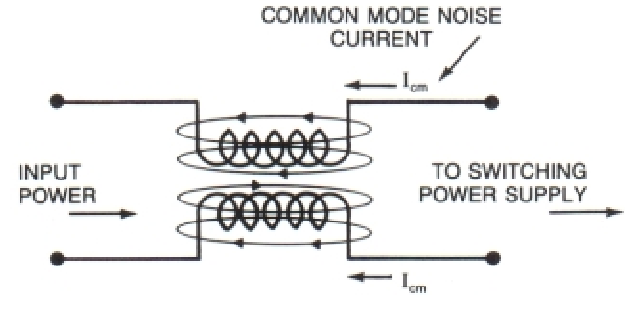


FIGURE 2: COMMON MODE NOISE (CMN) FILTER

2a: REACTION TO INSTANTANEOUS INPUT CURRENT



2b: REACTION TO CMN CURRENT



generated in the core which cancel each other and thus almost no voltage is induced in either winding. The input current needed to power the SMPS therefore will pass through the filter without any appreciable power loss.

Common mode noise (CMN), 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 common mode noise voltages are thus attenuated in the windings of the common mode inductor, keeping the input power lines free from the unwanted noise.

Choosing the Inductor Material

A SMPS normally operates at 20 KHz and above. The unwanted noise generated in these supplies are at frequencies higher than 20 KHz, often between 100 KHz and 50MHz. 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 from its more common parameters such as permeability and loss factor. Figure 3 shows a graph of impedance Z_t vs. frequency for a ferrite toroid, J-42206-TC, wound with 10 turns. The wound unit reaches its highest impedance between 1 and 10 MHz. The series inductive reactance (X_s) and series resistance (R_s) of the wound unit, which are functions of the permeability and loss factor of the material which together generate the total impedance (Z_t), are also plotted.

This graph shows that at low frequencies the series inductive reactance, X_s, equals the total impedance while at high frequencies it is the series resistance, R_s, which 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 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. The permeability falling off above 750 KHz causes the inductive reactance to fall in figure 3. The

FIGURE 3: J MATERIAL

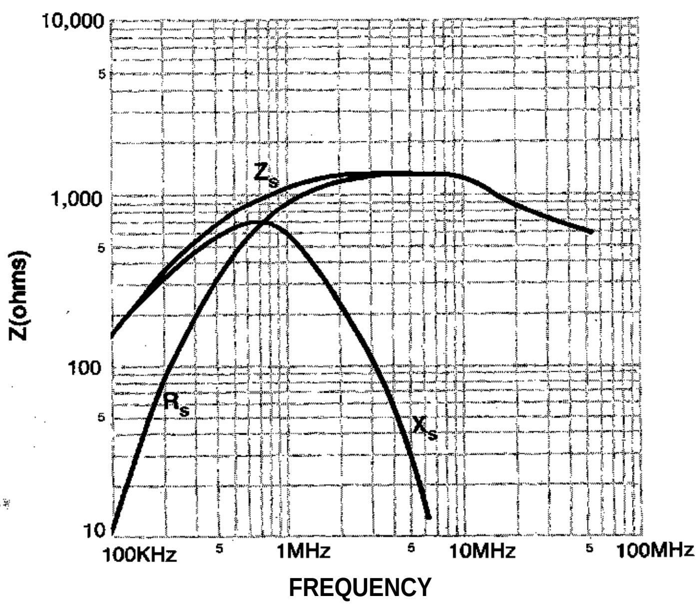
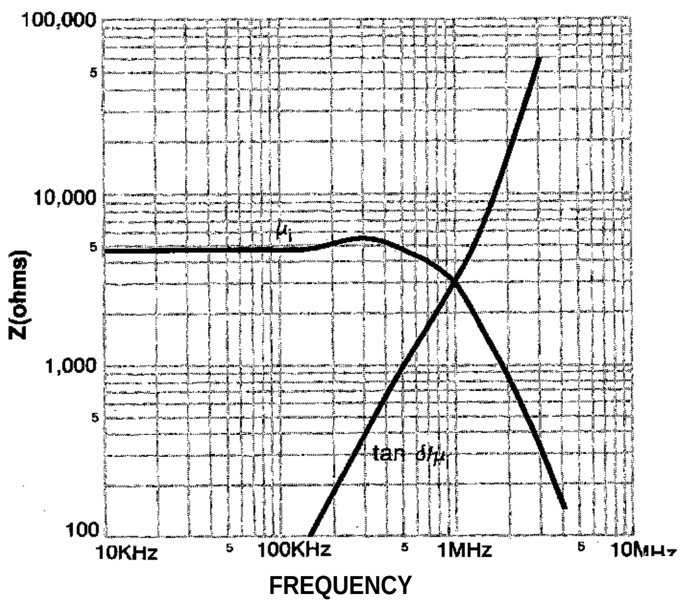


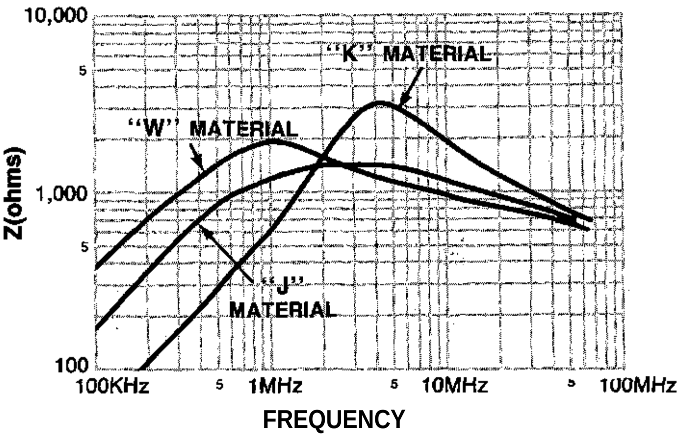
FIGURE 4: J MATERIAL



loss factor increasing with frequency causes the resistance to ultimately become the dominant source of impedance at high frequencies.

In figure 3 the total impedance has its highest value, and thus is most useful as a filter material, 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 best material is to use comparative impedance vs. frequency curves, as shown in figure 5.

FIGURE 5: IMPEDANCE VS FREQUENCY OF FERRITE TOROIDS IN THREE DIFFERENT MATERIALS



The total impedance vs. frequency for three different ferrite materials is shown in figure 5. J material 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 has from 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 major noise problem. K material 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 non-metallic divider between its two windings, it is normally epoxied to a printed circuit header for attaching to a pc board and must be wound by hand or 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 also relatively inexpensive.

E core sets have more leakage inductance than toroids that can be used to provide some differential filtering in a common mode filter. 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

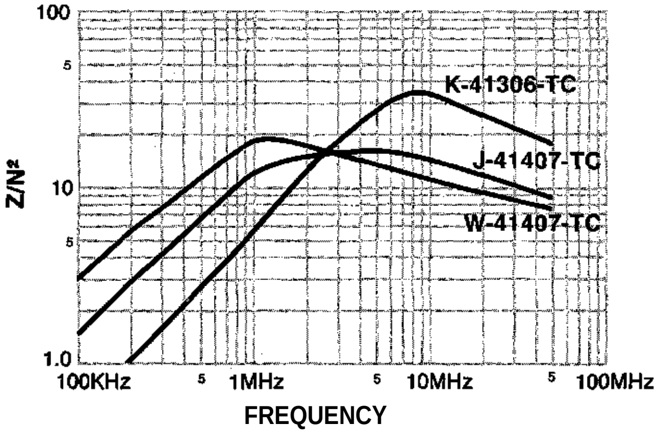
The core size for a particular filter can be determined from the impedance required and the impedance versus frequency curves in Figure 6. Considering the space available for the filter, select a core from the graph in Figure 6. To obtain a specific impedance, divide the desired impedance by the impedance per turn squared (Z/N^2) read from the graph at the frequency of interest. 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.

Concern over possible saturation of the core is not necessary as most common mode noises are at relatively low voltages.

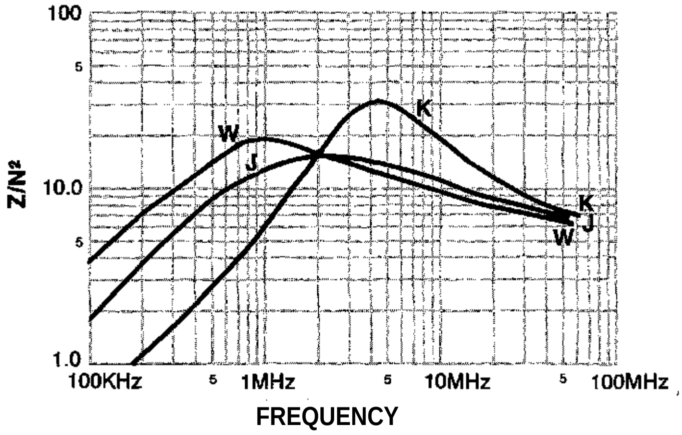
These are typical value curves and, as such, have tolerances of ± 30%. Readings on these cores are affected by the number of turns and wire size used and the placement of wires on the core.

FIGURE 6: IMPEDANCE PER TURN SQUARED VS FREQUENCY

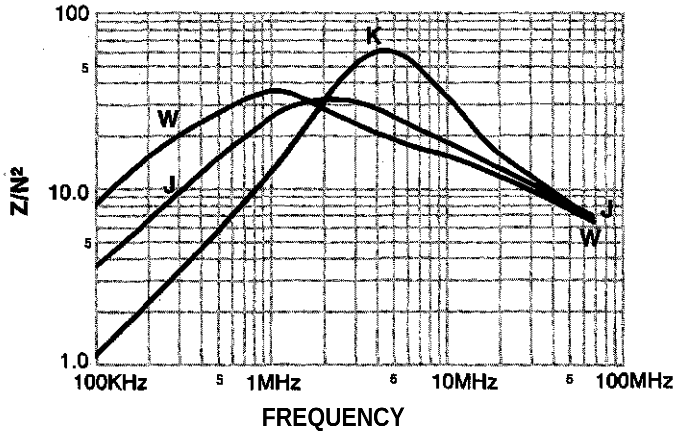
SMALL TOROIDS



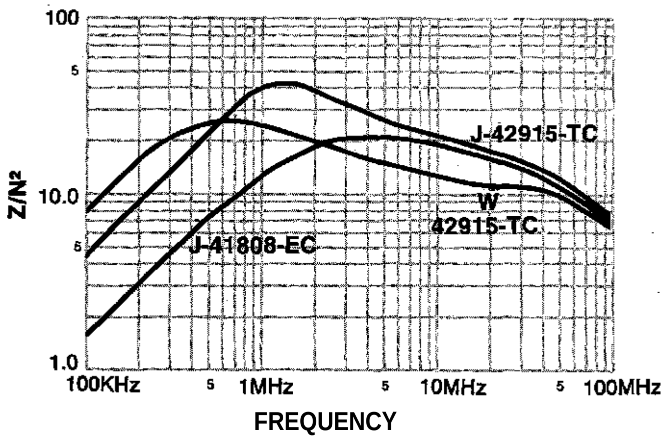
42206-TC SIZE TOROID



42212-TC SIZE TOROID



LARGE TOROIDS



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