# Designing common mode chokes – is there a better core material to use?

Common mode chokes (CMCs) reduce undesirable common mode currents from multiple phase cables. They are designed so that common mode currents create a magnetisation in the core, and hence experience the impedance of the choke. Magnetisations of differential mode currents, ie the 'normal' current which flows back and forth, compensate for each other, and the total magnetisation is zero (if stray inductance is neglected).

The usual rule of thumb is the higher the impedance, the better the noise reduction, and therefore high permeability cores are preferred.

Ferrites (MnZn) are more cost effective and often have better high-frequency properties in most mainstream applications; however, some emergent applications require performance characteristics including a higher saturation flux density. Nanocrystalline cores have higher saturation induction ($B_S$), usually have higher initial permeability, and they cover a broader frequency range. So a CMC can be much smaller, which also reduces copper losses.

Obviously each manufacturer will prefer their material and will find a good argument in favour of it. Some designers and users have had a better experience with one material class and don't intend to change it. So we have ended up with two worlds – ferrite and nanocrystalline cores.

## What is important if we compare these materials?

**Damping behaviour**

In the significant frequency range, the impedance curves of CMCs with ferrite and nanocrystalline cores are quite similar, if the inductance (L) as the main contribution to impedance is adjusted (by size and number of turns) to be similar at about 100 kHz. Thanks to the high initial permeability of high-permeable nanocrystalline cores, they are a highly effective solution for noise reduction / damping over a broader range of frequencies.

$$L \sim N^2 \mu \frac{A}{l} \qquad (1)$$

(N = number of wire turns, μ = permeability, A = core cross section, l = mean magnetic path length which is proportional to mean core diameter).

**Tolerable common mode currents**

Damping requires that a current does not saturate the core, which is valid especially for non-avoidable DC or low-frequency common mode currents. The maximum common mode current depends on above mentioned parameters as

$$I_{CM,max} \sim \frac{B_S}{N\mu} l \qquad (2)$$

### Impact of permeability

If there is no common mode current to consider, ie equation (2) is not applicable, permeability can be as high as possible to achieve high inductance. As a result, N and core size can be adjusted according to nominal current and available space on the PCB. If there is a common mode current, permeability is limited by space. The more space for core diameter, the higher $\mu$ can be for two reasons – directly from equation (2) and, if there is more space, the cross section can also be higher, and according to equation (1) the number of turns can be reduced to achieve a certain inductance and so $\mu$ can also be higher according to equation (2).

### Impact of saturation induction

If equation (2) has to be applied, ie there are common mode currents, high $B_S$ helps to reduce core size or allow higher $\mu$ and/or N. High $B_S$ can also help to use stray inductance to reduce differential mode disturbances.

### Impact of number of turns

Due to the linear influence of N on $I_{CM,max}$, and the quadratic influence on L, L is reduced dramatically if N must be reduced to allow higher $\mu$. Or from another view, to allow higher $I_{CM,max}$, it is better to reduce permeability (with the same linear influence on both L and $I_{CM,max}$) than to decrease N.

### Impact of core geometry

Detailed analysis of equation (1) shows that L remains uniform for constant ratio outer / inner diameter for toroidal cores. So L remains constant when shrinking the core, maintaining the same core height, but $I_{CM,max}$ decreases. However, although classic CMCs are basing on toroidal cores, there are different shapes, which may have advantages in the application or for choke production. Especially for applications where N = 1 (wires or bars are pulled through the core) or in flat devices, oval cores have advantages. For ferrites, new shapes have been developed, allowing highly effective winding for small wire cross section.

## Conclusion – which material to use?

If there is no or very small common mode current, the rule of thumb is the higher the permeability, the smaller the core and/or the lower the number of turns. The diameter of the core is controlled more or less by the nominal current via the wire diameter and the number of turns, therefore a lower number of turns allows even smaller cores. The highest permeability can be achieved with nanocrystalline material of FT-1 or FT-3 class, although it is significantly more expensive than usual ferrite cores. If there is a limit on space, or to decrease copper losses, then nanocrystalline should be the engineer's first choice. Since the core is smaller and less copper is used in any case, the costs for the CMC are not higher than for ferrite cores. And thanks to higher $B_S$ and lower N it can withstand higher common mode currents. Smaller N provides smaller capacitance, which provides better performance at high frequencies (>>1 MHz). Finally the temperature dependence of inductance may be better.

The higher the common mode currents, the bigger the core needs to be or the lower the permeability. Permeability can be tailored (reduced) for the above-mentioned nanocrystalline materials, but it ends at a certain point. Both effects favour ferrites for cost and space reasons, even with much lower $B_S$. To achieve high enough impedance, N increases dramatically. Another limit for ferrites is that larger size can become critical due to mechanical reasons – ferrites are susceptible to mechanical failure being ceramic-based products.

To provide a compromise and increase the applicable range of nanocrystalline material, alloys with lower permeability comparable with rather high permeable ferrites and increased $B_S$ have been developed, which are more expensive than common alloys. So again the amount of space plays an important role, as you have to pay for size reduction.

| | Ferrite (MnZn) | Nanocrystalline |
|---|---|---|
| **Permeability (μ)** | Low to medium | High<br>New materials – medium |
| **Saturation induction ($B_S$)** | Low | High |
| **Frequency range** | Focus on medium | Broadband |
| **Core shape** | Toroidal, more complex | Toroidal, oval |
| **Costs** | Low | Material – medium<br>CMC – comparable due to size |

Each material has its benefits, and making sure you use the right core material for your common mode choke is key, providing superior noise reduction, loss factor, temperature performance and product consistency, while improving on its overall performance.